BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

MIDWEST GENERATION, LLC	)	
	)	
Petitioner,	)	
	)	
v.	)	**PCB**
	)	**(Adjusted Standard - Land)**
ILLINOIS ENVIRONMENTAL	)	
PROTECTION AGENCY	)	
	)	
Respondents.	)	

NOTICE OF FILING

To:

Division of Legal Counsel
Illinois Environmental Protection Agency
1021 N. Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276
Epa.dlc@illinois.gov

Don Brown, Assistant Clerk
Illinois Pollution Control Board
James R. Thompson Center
100 West Randolph Street, Suite 11-500
Chicago, IL 60601

PLEASE TAKE NOTICE that I have today electronically filed with the Office of the Clerk of the Pollution Control Board Midwest Generation LLC's Petition for an Adjusted Standard and Finding of Inapplicability for the Waukegan Station with supporting documents, and the Appearances of Susan M. Franzetti, Kristen L. Gale, and Molly Snittjer, a copy of which are herewith served upon you.

Dated: May 11, 2021

MIDWEST GENERATION, L.L.C.

By: /s/ Kristen L. Gale
One of Its Attorneys

Kristen L. Gale
Susan M. Franzetti
Molly Snittjer
Nijman Franzetti LLP
10 S. LaSalle St, Suite 3600
Chicago, Illinois 60603
(312) 262-5524
kg@nijmanfranzetti.com
sf@nijmanfranzetti.com
ms@nijmanfranzetti.com

CERTIFICATE OF SERVICE

The undersigned, an attorney, certifies that a true copy of the foregoing Midwest Generation LLC's Petition for an Adjusted Standard and Finding of Inapplicability for the Waukegan Station with supporting exhibits, and the Appearances of Susan M. Franzetti, Kristen L. Gale, and Molly Snittjer, on May, 11, 2021 with the following:

Division of Legal Counsel
Illinois Environmental Protection Agency
1021 N. Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276
Epa.dlc@illinois.gov

Don Brown, Assistant Clerk
Illinois Pollution Control Board
James R. Thompson Center
100 West Randolph Street, Suite 11-500
Chicago, IL 60601

and that true copies were filed to the Agency by FedEx, delivery charge prepaid, and electronic mail, and the Board electronically on May 11, 2021 to the parties listed above.

/s/ Kristen L. Gale

Kristen L. Gale
Susan M. Franzetti
Molly Snittjer
Nijman Franzetti LLP
10 S. LaSalle St, Suite 3600
Chicago, Illinois 60603
(312) 262-5524
kg@nijmanfranzetti.com
sf@nijmanfranzetti.com
ms@nijmanfranzetti.com

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

MIDWEST GENERATION, LLC	)	
Petitioner,	)	
	)	PCB
v.	)	(Adjusted Standard - Land)
	)	
ILLINOIS ENVIRONMENTAL	)	
PROTECTION AGENCY	)	
Respondent.	)	

ENTRY OF APPEARANCE OF SUSAN M. FRANZETTI

NOW COMES Susan M. Franzetti, of Midwest Generation, LLC, and hereby enters her appearance as counsel in this matter on behalf of Midwest Generation, LLC. This appearance shall also serve as consent to service via email.

Respectfully submitted,

__/s/Susan M. Franzetti________________
Susan M. Franzetti
Attorney
Nijman Franzetti LLP
10 S. LaSalle Street, Suite 3600
Chicago, IL 60603
(312) 251-5590
sf@nijmanfranzetti.com

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

MIDWEST GENERATION, LLC	)	
Petitioner,	)	
	)	PCB
v.	)	(Adjusted Standard - Land)
	)	
ILLINOIS ENVIRONMENTAL	)	
PROTECTION AGENCY	)	
Respondent.	)	

ENTRY OF APPEARANCE OF KRISTEN L. GALE

NOW COMES Kristen L. Gale, of Midwest Generation, LLC, and hereby enters her appearance as counsel in this matter on behalf of Midwest Generation, LLC. This appearance shall also serve as consent to service via email.

Respectfully submitted,

__/s/Kristin L. Gale
Kristen L. Gale
Attorney
Nijman Franzetti LLP
10 S. LaSalle Street, Suite 3600
Chicago, IL 60603
(312) 262-5524
kg@nijmanfranzetti.com

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

MIDWEST GENERATION, LLC)
Petitioner,)
) PCB
v.) (Adjusted Standard - Land)
)
ILLINOIS ENVIRONMENTAL)
PROTECTION AGENCY)
Respondent.)

ENTRY OF APPEARANCE OF MOLLY SNITTJER

NOW COMES Molly Snittjer, of Midwest Generation, LLC, and hereby enters her appearance as counsel in this matter on behalf of Midwest Generation, LLC. This appearance shall also serve as consent to service via email.

Respectfully submitted,

_/s/Molly Snittjer________________
Molly Snittjer
Attorney
Nijman Franzetti LLP
10 S. LaSalle Street, Suite 3600
Chicago, IL 60603
(312)868-0081
ms@nijmanfranzetti.com

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:

PETITION OF MIDWEST GENERATION FOR AN ADJUSTED STANDARD FROM 845.740(a) AND FINDING OF INAPPLICABILITY OF PART 845	**AS** **(Adjusted Standard-Land)**

MIDWEST GENERATION, LLC'S PETITION FOR AN ADJUSTED STANDARD AND A FINDING OF INAPPLICABILITY FOR WAUKEGAN STATION

Midwest Generation, LLC ("MWG") petitions the Illinois Pollution Control Board ("Board") for an adjusted standard from the Part 845 Illinois Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments at 35 Ill. Adm. Code 845 ("Illinois CCR Rule"). MWG seeks this regulatory relief for two areas at its Waukegan Station in Waukegan, Lake County, Illinois ("Waukegan" or "Station"), known as the East Pond and the "Grassy Field". An adjusted standard is needed for the East Pond to allow the decontamination and retention of its existing liner rather than the liner's removal as provided in the Illinois CCR Rule. For the Grassy Field, MWG seeks an adjusted standard finding that Part 845 of the Board rules is inapplicable because there is an existing dispute with the Illinois Environmental Protection Agency ("Illinois EPA") concerning its proper regulatory status.

The Illinois CCR Rule regulates the East Pond as a Coal Combustion Residual ("CCR") surface impoundment. MWG plans to close the East Pond by removing the CCR and converting the East Pond to a low-volume waste pond to hold the Station's process water. MWG seeks to reuse the East Pond's high-density polyethylene ("HDPE") liner because it is in good condition and, after decontamination, can continue to serve its intended purpose as a liner for the new process water pond. The CCR surface impoundment closure by removal requirements under the Illinois

CCR Rule instead requires removal of the East Pond liner. By comparison, the federal CCR does not require removal of a liner when a CCR surface impoundment is closed by removal. Because the East Pond liner is in good condition and can be effectively decontaminated, consistent with the federal CCR rule, MWG is requesting an adjusted standard from Section 845.740(a) to allow the continued post-closure use of the East Pond liner.

The Grassy Field is not a CCR surface impoundment, but merely, as its name implies, a grassy field. In December 2019, Illinois EPA determined, without consultation with MWG, that the Grassy Field was a CCR surface impoundment and issued an invoice for the initial fee pursuant to Section 22.59(j) of the Act. 415 ILCS 5/22.59(j). The Grassy Field is not a depression or excavation, it is not designed to hold CCR and liquids, and it was never designed to accumulate CCR and liquid. No CCR or CCR slurry water is directed or has ever been directed at the Grassy Field. Because the Grassy Field is not a depression or excavation and it is not designed to hold CCR and liquids, it does not satisfy the regulatory definition of CCR surface impoundment under Section 3.143 of the Illinois Environmental Protection Act ("Act") and should not be regulated under the CCR Rule. 415 ILCS 5/3.143.

This Petition sets forth the factual and legal bases for MWG's requested relief. In further support of this Petition, MWG submits the affidavit of Christopher Lux and the affidavit and expert opinion of David Nielson, P.E., which are attached as Exhibits 1, 2 and 3, respectively, along with additional supporting documents.

I. Background

On July 30, 2019, Illinois enacted the Coal Ash Pollution Prevention Act ("CAPP Act") to regulate CCR surface impoundments and ordered the Illinois EPA and the Board to draft and implement regulations, including a permit program, to regulate CCR surface impoundments at electric generating stations. Illinois Public Act 101-0171. Pursuant to the CAPP Act, a "CCR surface impoundment" means "a natural topographic depression, man-made excavation, or diked area, which is designed to hold an accumulation of CCR and liquids, and the surface impoundment treats, stores, or disposes of CCR." 415 ILCS 5/3.143. The CAPP also created a new Section 22.59 of the Act for CCR surface impoundments. In relevant part, Section 22.59 requires an owner or operator of a CCR surface impoundment to pay an initial fee to the Agency six months after the effective date of CAPP. 415 ILCS 5/22.59(j)(1).

A. Illinois CCR Rulemaking on Liners

Pursuant to Section 22.59 of the Act, Illinois EPA filed proposed new standards for the operation, maintenance, and closure of CCR surface impoundments as new Part 845 of the Board's Rules. *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845,* PCB 20-19. The proposed Illinois CCR rule closely mirrored the federal CCR rule, and the Illinois EPA stated that the desired purpose was to obtain federal approval of the program. *Id.*, Illinois EPA Statement of Reasons, March 30, 2020, p. 10. To follow that purpose, the original language for closure by removal in the proposed Illinois CCR Rule included the same language as in Section 257.102(c) of the federal CCR Rule:

> "An owner may close by removing and decontaminating all areas affected by releases from the CCR surface impoundment. CCR removal and decontamination of the CCR surface impoundment are complete when the CCR in the surface impoundment and any areas affected by releases from the CCR surface impoundment have been removed. Proposed 35 Ill. Adm. Code 845.740(a).

Throughout the hearing process, including pre-filed questions, pre-filed answers, and two hearings held in August and September 2020, the Agency maintained this proposed language and gave no indication that it was considering revising it.

By comparison, in the proposed Section 845.770 requirements for retrofitting a CCR surface impoundment, Illinois EPA included a requirement to remove the liner even though the federal CCR rule required only that the CCR and any contaminated soils and sediments be removed. 40 CFR 257.102(k). MWG provided expert testimony by David E. Nielson that plastic liners like those in its impoundments could be effectively decontaminated, dispensing with the need for removal. *See* Ex. 4, Pre-filed Expert Testimony of David Nielson, p. 12. Geomembrane liners are flexible membranes manufactured of polyethylene (i.e. plastic) and are defined by the ASTM International as "an essentially impermeable geosynthetic composed of one or more synthetic sheets." Ex. 4, p. 12; ASTM D4439. They "are very low-permeability plastic products that are nonabsorptive," meaning they are unlikely to absorb the CCR constituents. Ex. 5, 9/30/2020 Tr., p. 199:7-8. Based on the conservative assumption that geomembranes could have small holes, the U.S.EPA nevertheless determined that a liner did not have to be removed as part of retro-fitting a CCR surface impoundment. Ex. 6, MWG Pre-Filed Answers, p. 44-45, 40 CFR 257.102(k). Relying upon the ASTM standard and these U.S.EPA conclusions, Mr. Nielson's expert witness testimony demonstrated that a liner may be decontaminated, without requiring the entire liner to be removed. The Board subsequently inquired in its pre-filed questions whether Section 845.770(a)(1) could specify that only "contaminated liners" would need to be removed, which MWG agreed was acceptable and Mr. Nielson supported. Ex. 6, pp. 1, 47.

In the Agency's post-hearing comments, for the first time and without any prior indication or explanation, the Agency presented new requirements for closure by removal. Ex. 7, Agency Final Comment, pp. 86-87. Without any technical support, the Agency submitted that an owner/operator must also remove "containment system components such as the impoundment liner and contaminated subsoils, and CCR impoundment structures and ancillary equipment." Ex. 7, p.

87. The Agency merely offered its belief that the modifications were required to comply with the Part B *proposed* federal CCR rule. Ex. 7, p. 86-87. MWG objected because the federal CCR rule does not require removal of the liner. Ex. 8, MWG's Response, p. 3. The applicable federal CCR rule as well as the proposed federal CCR rule the Agency relied upon, only require that materials which contacted CCR be decontaminated. *Id.* There was no evidence in the rulemaking record to demonstrate that a liner contaminated with CCR cannot be effectively decontaminated. *Id.*, p. 3-5. In fact, Illinois EPA admitted it was simply assuming without any scientific or other support that all liners became contaminated and could not be decontaminated. *Id.* citing 8/25/2020 Hearing Tr., pp. 73:20-23, 76:14-17, attached as Ex. 9. Moreover, the expert testimony during the rulemaking stated precisely the opposite. Ex. 8, p. 4. MWG's expert explained that a synthetic liner ("geomembrane liner" or "geosynthetic liner") does not absorb CCR. Hence, they are not likely to be contaminated merely because of contact with CCR. *Id.* But where a geosynthetic liner has been contaminated by CCR, it can be decontaminated so that it is suitable to reuse as part of a CCR surface impoundment retrofit. *Id.*

B. Illinois CCR Final Rule

On February 4, 2021, the Board issued its Second Notice Order and Opinion for the Illinois CCR Rule. The Board adopted the Illinois EPA's requested changes to the closure by removal requirements that required removal of a liner and all associated equipment regardless of the condition. Feb. 4, 2020 Order, pp. 95-96. The Board reasoned that these changes were required to be consistent with the proposed federal CCR rule. *Id*. The Board did not address or discuss MWG's objections to this modified language. *Id.* But the Board agreed with MWG that when retrofitting a CCR surface impoundment, a competent plastic liner could be reused as long as the owner or operator demonstrated that the liner was decontaminated. The Board stated that "Midwest

Generation has raised a valid concern about removing competent, uncontaminated existing synthetic (geomembrane) liners while retrofitting CCR surface impoundments." Opinion, p. 99.

The Board's Opinion also addressed areas where a regulated party disputed Illinois EPA's position on whether an area qualified as a CCR surface impoundment under Section 3.143 of the Act. The Board stated that a party could seek a regulatory relief mechanism, such as an adjusted standard, to resolve the dispute. *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845,* PCB 20-19, Order (February 4, 2021), p. 14. Of particular relevance here, the Board expressly stated that unconsolidated areas of CCR do not "fit the definition of 'CCR surface impoundment' and would therefore not be regulated by the framework of Part 845, nor were they included in the mandate of Section 22.59(g)." *Id.* at 12. The Board found "that regulation of these unconsolidated coal ash fills, and piles is beyond the scope of Section 22.59(g)…" *Id.*[1]

C. Waukegan Station Background

Built in about 1923, the Waukegan Station has operated as a power plant ever since. Ex. 1, Lux Affidavit, ¶4. MWG began operating the Station in 1999. Since at least the 1930s, the area around Waukegan Station has historically been dominated by industries. *Id.*, ¶5. Waukegan Station has various environmental permits, including an NPDES permit for its wastewater discharges, and a construction permit, No. 2016-EB-61340, which requires MWG to monitor the groundwater at all of its monitoring wells for the constituents in 35 Ill. Adm. Code 620.410(a), including the wells

---

[1] Concluding that it did not have sufficient information regarding the unconsolidated fill areas and piles, the Board ordered the Clerk to open a subdocket to solicit more information and evidence on historic, unconsolidated coal ash fill in Illinois. Id. at 105.

surrounding the Grassy Field.[2] *See* NPDES Permit, attached as Ex. 10, Permit No. 2016-EB-61340, attached as Ex. 11, map of monitoring wells, attached as Ex. 12.

1. Waukegan CCR Surface Impoundments

Waukegan has two CCR surface impoundments - the West Ash Pond and East Ash Pond – located on the southern side of the Station, which operate as part of the Station's NPDES permitted ash management system. Ex. 1, ¶11, Ex. 12. These ponds are each approximately 9 acres and were originally built in 1977 with a plastic liner. Ex. 1, ¶12. The ponds alternate receiving the slurry of bottom ash and liquid, thus only one pond (East Pond or West Pond) is in service at a time. Ex.1, ¶16. When in service, the ponds receive CCR and non-CCR waste streams: the slurry of CCR and liquid (a CCR waste stream), overflow from non-CCR basins (non-CCR waste stream), and effluent from the Station's main collection tank, which is a non-CCR waste stream (non-CCR waste stream). Ex. 13, p. iii. In 2003, MWG relined the East Pond with a high-density polyethylene ("HDPE") liner and relined the West Pond with an HDPE liner in 2004. Ex. 1, ¶¶13-14.

2. Groundwater Monitoring at Waukegan Station

MWG has been monitoring the groundwater surrounding the CCR surface impoundments and upgradient of the CCR surface impoundments for over ten years. It is currently monitoring the groundwater under two different state and federal programs. On the state side, beginning in 2010, MWG began monitoring the groundwater upgradient and downgradient of the West Pond and East Pond. Ex. 1, ¶28. In 2013, MWG entered into a Compliance Commitment Agreement ("CCA") with the Illinois EPA which continued its groundwater monitoring for the constituents in 35 Ill.

---

[2] The Waukegan CCR surface impoundments and the Grassy Field are also the subject of an enforcement action in front of the Board. *Sierra Club v. Midwest Generation, LLC*, PCB 13-15. The enforcement action alleges violations of the Act and Part 620 of the Board Rules and is unrelated to MWG's request for Part 845 regulatory relief here.

Adm. Code 620.410. *See* CCA, attached as Ex. 14. In 2016, Illinois EPA included the CCA groundwater monitoring in a construction permit for reconstructing the slope of the East Pond. Ex. 11. Then, following passage of the federal CCR rule in 2015, MWG also began to monitor the groundwater upgradient and downgradient of the CCR surface impoundments pursuant to the federal CCR rule. Ex. 1, ¶29; 40 C.F.R. 257. As part of the federal CCR rule, MWG conducted an Alternate Source Demonstration for both CCR surface impoundments, which demonstrated that the ponds are not a source of constituents in the groundwater. *See* Alternate Source Demonstration attached as Ex. 15.

3. MWG's Plans for Reused of the East Pond

In compliance with the federal CCR rule and now also the Illinois CCR rule, MWG is closing both Waukegan CCR surface impoundments by removing the CCR. Ex. 16. But the closure deadline under the federal CCR rule would leave the Waukegan Station without the ability to handle the bottom ash generated by the Station while an alternative management approach is implemented. Hence, on November 30, 2020, the Waukegan Station sought an extension of the deadline for closure of the East Pond by submitting a Demonstration for a Site-Specific Alternative Deadline to Initiate Closure of the East Pond ("Demonstration") to the U.S. EPA. The Demonstration Report, without the supporting documents is attached as Ex. 13.[3]

The Demonstration also evaluated options for future management of the CCR and non-CCR waste streams. It proposed separating the CCR and non-CCR waste streams using a multiple technology system. Ex. 13, p. iii. The multiple technology system will be a submerged scraper conveyor ("SSC") for the CCR waste stream, and low volume waste ponds for the non-CCR waste

---

[3] The supporting documents are not included due to their size. The complete report is publicly available at: http://3659839d00eefa48ab17-3929cea8f28e01ec3cb6bbf40cac69f0.r20.cf1.rackcdn.com/WAU_APE_CPCX.pdf, and MWG can provide the complete document upon request.

stream. Ex. 13, p. 1-18. An SSC has a water-filled trough that causes sedimentation of the suspended ash particles in the transport water. *Id*. Chains and flight scrapers in the SSC move the ash along the trough to a ramp with a conveyer belt. *Id*. As the ash is conveyed up the ramp, the water drains out of the ash and returns to the trough. *Id.* Once the ash reaches the top of the ramp, the ash is deposited into a temporary storage bunker, where it is collected and transported off-site for beneficial reuse or disposal. *Id.* The SSC will be built on the northern half of the area where the West Pond is located. *Id.*

For both future operational flexibility and compliance with the Clean Water Act Steam Electric Power Generating Effluent Guidelines and Standards (40 CFR Part 423, the "ELG Rule") for non-CCR wastewater, MWG plans to repurpose the East Pond as a low-volume waste pond for non-CCR waste streams. A low-volume waste pond is a pond that collects "low volume waste sources" as defined in the ELG Rule:

> "wastewater from all sources except those for which specific limitations or standards are otherwise established in this part. Low volume waste sources include, but are not limited to, the following: Wastewaters from ion exchange water treatment systems, water treatment evaporator blowdown, laboratory and sampling streams, boiler blowdown, floor drains, cooling tower basin cleaning wastes, recirculating house service water systems, and wet scrubber air pollution control systems whose primary purpose is particulate removal. Sanitary wastes, air conditioning wastes, and wastewater from carbon capture or sequestration systems are not included in this definition." 40 C.F.R. § 423.11(b).

The East Pond will be used for temporary storage of large volumes of non-CCR waste streams as well as stormwater until the water can be treated and discharged pursuant to the Station's NPDES permit. Ex. 2, ¶4, Ex. 3. For example, to avoid flooding at the Station during significant rainfall events, the East Pond would collect the stormwater until it can be treated and discharged. Ex. 3. Because the East Pond has an HDPE liner that is in good condition, and can be decontaminated, MWG plans to reuse the HDPE liner instead of removing and replacing it.

4. History of the Grassy Field

Well before the Illinois EPA proposed the Illinois CCR Rule, there was a flat area of grass located to the west of the West Pond called the “Grassy Field”. MWG has not used the Grassy Field for its operations. It is simply a flat area of grass that is not used to manage the CCR generated at Waukegan Station. *See* photos, attached as Ex. 17. Historic aerial photos and historic permit applications show that the Grassy Field was never designed to accumulate CCR and liquids and was not operated to do so. The earliest aerial photo from 1939 appears to show that the area south of the power station is covered in sand. Ex. 18. A 1946 aerial photo, attached as Exhibit 19, shows that the entire area south of the Station from the west property line to the lake was CCR, but it does not show any liquid in the area. Similarly, a 1961 aerial photo, attached as Exhibit 20, shows that the area where the West and East Ash Ponds are now located contains CCR but not an accumulation of liquid. As shown in the 1961 photo, there are ditches present that drained the liquid away from this area, then called the “Slag Field.” Where the West and East Ash Ponds are now, there was a ditch on three of the four sides of the area and also a ditch to the west through what is now known at the Grassy Field. The 1961 photo also shows various alluvial fans and rivlets of material towards the edges to the south and east, demonstrating that the water that transported the CCR to the Slag Field area drained to and was carried away by the ditches.

By 1974, aerial photos showed the Slag Field in a configuration very similar to the two ash ponds as they are built now. Because the print-out of the 1974 photo was not large enough, two 1974 photos, with the perspective shifted to the north and south to capture the Slag Field and the Station, are attached as Exhibit 21. The photos show that the area which became the West Ash Pond, contains ash and there is a berm preventing the CCR from flowing into the Grassy Field. The 1974 photo also shows that ash and liquid were not accumulating in the Grassy Field.

Additional historical evidence that the Grassy Field is not a CCR surface impoundment is contained in a Commonwealth Edison Company ("ComEd") permit application December 22, 1972 and submitted to the Illinois EPA, and the NPDES permit issued by Illinois EPA. The 1972 permit application and 1974 Water Pollution Control Permit (1974-EB-0346) are attached as Exhibits 22 and 23 respectively. The 1972 permit application and resulting permit was for a discharge from the Slag Field to Lake Michigan. A 1972 drawing attached to the permit application shows three ditches on three of the four sides of the Slag Field, labeled the "North Ditch," the "South Ditch," and the "East Ditch." Ex. 22, Fig. 3. Arrows drawn in each of the ditches indicate that the water from the Slag Field flowed into the ditches, to the southeast corner of the Slag Field, into a swamp and ultimately to Lake Michigan. *Id*. These same features can be seen in the 1974 aerial photo. Ex. 21. On March 14, 1974, Illinois EPA issued a Water Pollution Control Permit to ComEd to own and operate a slag field and discharge 4,770 gallons per minute to an unnamed ditch tributary to Lake Michigan. See Exhibit 23, p. 1. The Illinois EPA permit reviewer notes state that the proposed discharge was from the slag field consisting of the ash sluice water and the receiving stream was an unnamed ditch tributary to Lake Michigan. Ex. 23, p. 3. Because the Illinois EPA issued a permit for a discharge, it is evident that the slag field was not used to accumulate liquid, which is a requirement to fall within the definition of "CCR surface impoundment." 415 ILCS 5/3/143.

5. Disputed Illinois EPA Grassy Field Classification

On December 16, 2019, without any prior communication with MWG, Illinois EPA sent MWG an invoice for three CCR surface impoundments: the East Pond, the West Pond, and an "Old Pond." See Illinois EPA invoice attached as Ex. 16. Illinois EPA confirmed to MWG that its designation of the "Old Pond" referred to the Grassy Field.

However, the Agency's self-serving designation of the Grassy field as "Old Pond" does not make it a "pond" or, for that matter, a "surface impoundment" under the CCR Rule. It has none of the characteristics of either a pond or an impoundment. The Grassy Field is not a topographic depression, a man-made excavation, or a diked area. As documented by photographs of the Grassy Field (see Exhibit 17), it is simply a flat field of grass. It was never designed to accumulate CCR and liquids, and MWG has never directed CCR or liquid to the field. Ex. 1, ¶31. It was previously used by the Station as a helicopter pad (*Id*, ¶32), which would not have been a feasible use if it had been designed to accumulate "liquid" as a "CCR surface impoundment."[4]

D. The Board has the Authority to Determine that the CCR Rule is Inapplicable to the Grassy Field

The Board has the authority to determine that the Grassy Field is not a CCR Surface Impoundment within the meaning of the CCR Rule. On prior occasions, the Board has granted a petition for an adjusted standard and issued a finding that certain Board Rules are inapplicable. *See In the Matter of: Petition of Apex Material Technologies, LLC for an Adjusted Standard from Portions of 35 Ill. Adm. Code 807.104 and 810.103, or, in the Alternative, a Finding of Inapplicability,* AS15-2, slip op. pp. 51-52 (June 18, 2015); *In the Matter of: Petition of Westwood Lands, Inc. for and Adjusted Standard from Portions of 35 Ill. Adm. Code 807.104 and 35 Ill. Adm. Code 810.103 or, in the Alternative, a Finding of Inapplicability,* AS09-3, slip-op at 16 (Oct. 7, 2010); *In the Matter of: Petition of Jo'Lyn Corporation and Falcon Waste and Recycling for an Adjusted Standard from 35 Ill. Adm. Code Part 807 or, in the Alternative, a Finding of Inapplicability*, AS 04-2, slip op. at 13-14 (Apr. 7, 2005). With one exception, in each of these

---

[4] On July 18, 2020, Illinois EPA issued a violation notice to MWG stating that it had determined the Old Pond was a CCR surface impoundment and MWG's failure to pay the initial fee due under Section 22.59(j) of the Act was a violation of the Act.

petitions, after evaluating the fact-specific petitioner operations and subject material, as well as prior Board and court opinions, the Board determined that the rules at issue were inapplicable to the petitioners. Even in the one instance where the Board denied a petitioner's request for inapplicability, the Board did so not because it lacked the authority to find the rule inapplicable but because the Board's site-specific factual and legal analysis concluded that the petitioner had failed to make the required showing of inapplicability. *See In the Matter of: Petition of Apex Material Technologies* AS15-2, slip op. pp. 51-52.

II. Application of Automatic Stay

Section 28.1(e) of the Act provides that if a petition for an adjusted standard is sought within 20 days of the effective date of a rule or regulation, the operation of the rule or regulations is stayed as to such person pending disposition of the petition. 415 ILCS 5/28.1(e). On April 15, 2021, the Board issued its Opinion and Order adopting the Final Illinois CCR Rule and expressly provided in the Opinion that the CCR Rule's effective date is April 21, 2021. *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845,* PCB 20-19, April 15, 2021, p. 5. Because MWG has filed its petition within 20 days of the effective date of the Illinois CCR Rule, the requirement to remove the liner in the East Pond for closure by removal of the pond is stayed, and the operation of the Illinois CCR Rule is stayed as to the Grassy Field at the Waukegan Station.

III. Analysis and Petition Content Requirements

The Board requires that certain information be included in each petition for an adjusted standard. 35 Ill. Adm. Code §104.406. In this case, MWG is seeking an adjusted standard for two areas on two different issues: (1) an adjusted standard from the requirement to remove the liner in the East Pond when it is closed by removal of the CCR and (2) an order finding that the Part 845

Rules are inapplicable to the Grassy Field. The Section 104.406 petition requirements are set forth under individual headings below. Within each heading, the required information for both the East Pond and Grassy Field are presented.

a) Standard from which Adjusted Standard is Sought.

The East Pond: The rule-of-general applicability for which MWG requests an adjusted standard is at 35 Ill. Adm. Code Part 845.740(a). Because a competent geosynthetic liner may be decontaminated and because the federal CCR rule allows decontamination, MWG is requesting that the Board grant an adjusted standard from the Illinois CCR Rule allowing for decontamination of a liner when a CCR surface impoundment is closed by removal.

The Grassy Field: The rule-of-general applicability for which MWG requests an adjusted standard is at 35 Ill. Adm. Code Part 845.100. Because the Grassy Field is not a CCR surface impoundment, MWG is requesting that the Board grant an adjusted standard from the Illinois CCR Rule stating that the Illinois CCR Rule is inapplicable to the Grassy Field.

b) Whether the regulation was promulgated to implement the CWA, Safe Drinking Water Act, Comprehensive Environmental Response, Compensation and Liability Act, or the State programs concerning RCRA, UIC, or NPDES:

Part 845 implements Sections 12, 22 and 22.59 of the Act. 35 Ill. Adm. Code 845. Section 22 of the Act provides the Board authority to adopt regulations to promote the purpose of Title V, Land Pollution and Refuse Disposal, the Title implementing the requirements of RCRA. Part 845 was not promulgated to implement the state RCRA program, which is Section 22.4 of the Act. *Big River Zinc Corp. v. Illinois EPA.*, 1991 Ill. ENV. LEXIS 350, PCB 91-61 (May 6, 1991), p. *12 (Regulations or rules adopted pursuant to Section 22.4 implement the state's RCRA program).

c) Level of Justification as Specified by the Regulation.

Part 845 does not include a specific justification for an adjusted standard. Because there is not a specific level of justification, the applicable level of justification are the following factors identified in Section 28.1 of the Act:

> (1) factors relating to that petitioner are substantially and significantly different from the factors relied upon by the Board in adopting the general regulation applicable to that petitioner;
>
> (2) the existence of those factors justifies an adjusted standard;
>
> (3) the requested standard will not result in environmental or health effects substantially and significantly more adverse than the effects considered by the Board in adopting the rule of general applicability; and
>
> (4) the adjusted standard is consistent with any applicable federal law.
>
> 415 ILCS 5/28.1.

d) Nature of Petitioner's Activity that is the Subject of the Proposed Adjusted Standard.

Description of Waukegan Station: The Waukegan Station is located at 401 East Greenwood Ave, Waukegan, Lake County, Illinois, employs approximately 67 people and has operated since approximately 1923. Ex. 1, ¶4. As a coal powered electric generating station, Waukegan generates two types of coal ash from the burning of coal to generate electricity: fly ash and bottom ash. Ex. 1, ¶7. Fly ash consists of lightweight particles and is collected via dry system using electrostatic precipitators. Ex. 1, ¶8. Bottom ash consists of heavier particles that fall to the bottom of the furnace and is mixed with water and conveyed out of the plant via a pipe to either the West Pond or East Pond. Ex. 1, ¶9. MWG contracts with a third-party to remove the fly ash and bottom ash for beneficial reuse. Ex. 1, ¶10.

Pursuant to the federal CCR rule and permit no. 2016-EB-61340, MWG is monitoring the groundwater upgradient and downgradient of both the West and East Ponds. Ex. 11. The

Alternate Source Demonstrations for both ponds demonstrate that the ponds are not a source of constituents in the groundwater. Ex. 15.

East Pond: Both the West Pond and the East Pond are "U-shaped", were originally constructed in 1977 with a geosynthetic liner, and are approximately 9 acres. Ex. 1, ¶12. In 2003, MWG relined the East Pond with a high-density polyethylene ("HDPE") liner and relined the West Pond with an HDPE liner in 2004. Ex. 1, ¶¶13-14. As part of the liner system, at the base of both ponds there is a cushion layer of sand and a warning layer of white limestone. Ex. 1, ¶27. The East Pond and West Pond alternate receiving the CCR waste streams and non-CCR waste streams, thus only one pond (East Pond or West Pond) is in service at a time. Ex. 1, ¶16. The CCR settles out of the water into the pond in service, and the water is reused to transport additional bottom ash from the Station to the Pond. Ex. 1, ¶17. The CCR is temporarily stored in the pond in service until the pond is full, at which time the CCR is removed. Ex. 1, ¶18. When ash is removed from the impoundments at Waukegan, MWG takes specific care to prevent the pond liners from being damaged. Ex. 1, ¶19. The East Pond and West Pond have markers to notify the machine operators, and MWG ensures that before each dredging, all operators in the ponds know to avoid the liners. Ex. 1, ¶20. Trained personnel from third-party contractors operate the machinery to remove the ash. Ex. 1, ¶21. All of the operators in the pond are careful and methodical to ensure the liners are not damaged. Ex. 1, ¶22. The machine operators leave ash material on the slopes of the liners and on the bottom above the warning layer to avoid any damage to the liner. Ex. 1, ¶23. Also, because most of the bottom ash collects on one side of the U-shaped ponds, the contractor only dredges half of the pond, and at times even less. Ex. 1, ¶24. Once MWG has completed removing the ash from a basin, MWG inspects the basin to verify that the ash was removed without damaging the liner, and makes any required requires, and only after the inspection is the basin placed back in service. Ex. 1, ¶25.

In compliance with the federal and Illinois CCR rules, MWG is closing the East Pond by removing the CCR. In compliance with these rules as well as the federal ELG Rule, for its future operations, MWG will separate the CCR and non-CCR waste streams. Ex. 13, p. 1-18. The CCR waste stream will be managed by an SSC, which will be located on the northern part of where the West Pond is located. *Id.* The non-CCR waste streams, including stormwater, will be managed in the East Pond, serving as a new low-volume waste pond under the ELG Rule. Because the East Pond has an HDPE liner that is in good condition, and can be decontaminated, MWG plans to reuse the HDPE liner instead of removing and replacing the liner.

<u>The Grassy Field:</u> The Grassy Field is approximately 10 acres in size and is located west of the West Pond at the Station. Ex. 1, ¶30. CCR is not sluiced to the Grassy Field, the Grassy Field is not a part of the ash management system, and is not used to accumulate liquid. Ex. 1, ¶31. MWG does not regularly use the Grassy Area for any purpose, however it has been used in the past as a landing pad for helicopters. Ex. 1, ¶32. Because liquid CCR is not sluiced to the Grassy Field, the Grassy Field is not a federal CCR surface impoundment. Instead, the Grassy Field is an area of historic unconsolidated fill. The Board stated that unconsolidated areas of CCR does not “fit the definition of ‘CCR surface impoundment’ and would therefore not be regulated by the framework of Part 845, nor were they included in the mandate of Section 22.59(g), and that “regulation of these unconsolidated coal ash fills and piles is beyond the scope of Section 22.59(g)…” *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845,* PCB 20-19, Order (February 4, 2021), at 12.

e) Efforts Necessary to Comply with Regulation

East Pond: Compliance with the CCR Rule for closure by removal by removing the liner as opposed to allowing reuse of it, entails significantly higher costs, including the total waste of a completely good, competent geosynthetic liner, with no added environmental benefits. Before East Pond closure activities begin, MWG would remove the CCR for resale and beneficial use as described in Section III.d, which leaves CCR on the slopes and base of the pond. Ex. 1, ¶¶23-26. Then demolition of the East Pond will proceed. Due to the presence of the CCR on the slopes and bottom, when demolition begins, MWG would assume that during the demolition CCR would escape from the East Pond when the liner is removed, thus requiring excavation of the liner and approximately six inches of soil below the liner. Ex. 2. The total volume of liner and underlying soil removed would be approximately 9,000 cubic yards (“CY”), which would be hauled off-site for disposal in a landfill. Ex. 2, ¶5. Hauling a total quantity of 9,000 CY of soils offsite the site would require 600 trucks based on a 15 CY per truck capacity. *Id.*, ¶6. The total cost for transport and disposal of the liner and soil, including the labor and material costs, would be approximately $365,465. *Id*, ¶7. Following removal and disposal, MWG would have to replace the liner with a new HDPE liner essentially the exact same as the liner currently lining the East Pond. The cost to install a virtually identical liner would be approximately $329,041. *Id.*, ¶8 Accordingly, the total cost to remove the liner in the East Pond and install a new liner would be approximately, $694,506.

The Grassy Field: Because the CCR Rule requirements are only applicable to depressions or excavations that receive CCR and liquid, they are not capable of being applied to the Grassy Field. For example, the initial operating permit application must include an analysis of the chemical constituents within the CCR that will be placed in the CCR surface impoundment and an analysis for the chemical constituents of all waste streams, chemical additives and sorbent materials entering into or contained in the CCR surface impoundment. 35 Ill. Adm. Code 845.230(d)(2)(B), (C). Because no CCR is placed in the Grassy Field and waste streams are not directed to the Grassy Field, neither of these requirements can be applied to the Grassy Field. MWG cannot conduct an analysis of the chemical constituents within the CCR that will be placed in the Grassy Field because no such CCR exists. Ex. 1, ¶31. Similarly, the initial operating permit must include a fugitive dust plan and an inflow design flood control system plan. 35 Ill. Adm. Code 845.230(d)(2)(H), (R). Because, as its name implies, the Grassy Field is a field of grass, no "fugitive dust" is emitted from this area. Hence, there is no need or purpose served by preparing a Fugitive Dust Plan for an area that does not receive or otherwise handle CCR at the Waukegan Station. Ex. 1, ¶35, Ex. 17. Also, because no flow is directed to the Grassy Field, the CCR Rule's requirement to have a plan to manage inflow during and following any peak discharge is simply not applicable. Ex. 1, ¶31. The cost of preparation of the required operating permit application for the Grassy Field, with an attempt to satisfy these unsuitable requirements, is estimated to be approximately $57,200. Ex. 1, ¶33.

Similarly, under the CCR Rule, MWG would have to prepare a construction permit application for "closure" of the Grassy Field. The information required for a construction permit application is even more incongruous than the operating permit requirements for this field of grass. For example, the Design and Construction Plan requires a "statement of purpose for which the CCR surface impoundment is being used, how long the CCR surface impoundment has been in operation, and the types of CCR that have been placed in the CCR surface impoundment." 35 Ill. Adm. Code 845.220(a)(1)(B). The Plan must also include a description of the physical and engineering properties of the materials on which the CCR surface impoundment is constructed, the materials used to construct the CCR surface impoundment, the dates of construction, detailed dimensional drawings of the CCR surface impoundment, and a description of the instrumentation. 35 Ill. Adm. Code 845.220(a)(D), (E), (F), and (G). Because the Grassy Field has never been used as a CCR surface impoundment, MWG cannot describe its purpose nor the length of time it was in operation. Ex. 1, ¶31 Also, because the Grassy Field was never "constructed", MWG cannot describe its construction, provide any dimensional drawings, or the dates of construction. The estimated costs for preparing the construction application would be $125,000. Ex. 1, ¶34.

Additionally, if the Grassy Field is a CCR surface impoundment, then MWG would also have to pay the initial and annual fee pursuant to Section 22.59(j) of the Act. The current total due for 2020 and 2021 would be $100,000, and the annual fees of $25,000 would continue. 415 ILCS 5/22.59(j).

f) Proposed Adjusted Standard and Efforts Necessary to Achieve the Proposed Standard

East Pond: MWG's requested proposed adjusted standard includes the same language that the Illinois EPA originally proposed in the CCR rule, which is effectively the same as the federal CCR rule.[5] In consideration of the Board's requirement to conduct visual inspection and analytical testing for reuse of a liner to retrofit a CCR surface impoundment in Section 845.770(a), MWG is also proposing a similar requirement here for the reuse of the liner. The proposed language is:

> "MWG may close by removing and decontaminating all areas affected by releases from the East Pond at the Waukegan Station. CCR removal and decontamination of the East Pond is complete when the CCR in the East Pond and any areas affected by releases from the CCR surface impoundment have been removed.

---

[5] Illinois EPA's proposed CCR language had some minor non-substantive differences to the federal CCR rule. *Compare* Proposed Illinois EPA 35 Ill. Adm. Code 845.740(a) and 40 C.F.R. §845.102(c).

> MWG must conduct visual inspection and analytical testing to demonstrate that the geomembrane liner in the East Pond is not contaminated with CCR constituents. MWG must submit the results to Illinois EPA."

To reuse the HDPE liner, MWG would follow the same pattern and practice of CCR removal described herein that has been used previously to remove CCR for beneficial reuse. Once the CCR in the middle of the pond is removed, MWG will remove the remaining CCR on the sides and base of the pond that was left in place to protect the integrity of the liner. Ex. 1, ¶26. The contractor will use an excavator with a rubber surface on the edge of the bucket to pull down most of the material from the slopes. *Id.* The contractor will then use a vibrating plate to shake the rest of the material loose to the bottom of the slope, for further removal. *Id.* Then the contractor will use an excavator or end loader with a rubber surface on the edge of the bucket to carefully remove the excess material from the base of the pond. *Id.* At the end, the contractor will power-wash the slopes and base of the pond. Once the sides and the base of the liner is cleaned of CCR materials, MWG will collect wipe samples to confirm that the HDPE liner has been decontaminated of CCR. Ex. 3. The cost to clean and decontaminate the East Pond, including conducting confirmatory wipe samples, is estimated to be approximately $111,155. Ex. 2, ¶10.

Mr. Nielson's expert opinion demonstrates that competent geomembrane liners, including HDPE liners, may be cleaned and decontaminated. Ex. 3. Citing an international study, he explains that a geomembrane is "an essentially impermeable geosynthetic composed of one or more synthetic sheets." *Id*. Mr. Nielson did not find "any evidence that geomembrane liners, such as HDPE become contaminated with waste products that are present in CCR," and he was "not aware of a study that shows that polymer liners become saturated with CCR constituents." *Id.* To provide assurance that the HDPE liner was not contaminated, Mr. Nielson recommended that MWG conduct visual inspections and collect wipe samples of the HDPE liner to confirm that the HDPE liner was decontaminated. *Id.* In fact, Mr. Nielson identified a study of an HDPE liner, in which the pond owner repurposed an HDPE lined impoundment from holding landfill leachate to holding clean water. *Id.* Mr. Nielson's expert analysis demonstrates that the East Pond liner may be effectively decontaminated for reuse instead of being removed and disposed.

The Board has already found that a competent, uncontaminated existing geomembrane liner may be reused. In its Opinion and Second Notice Order, the Board stated that MWG had raised a valid concern about removing competent, uncontaminated liners, and that it saw "no reason for requiring removal of these liners if they can be used as a supplement to the liner system required by this Part." *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845,* PCB 20-19, Order, p. 99. The Board found that an existing liner may be left in place if the owner or operator demonstrates that the liner is not contaminated with CCR constituents. *Id.* Consistent with the Board's direction, MWG has included in its proposed adjusted standard language a requirement that MWG conduct visual inspections and conduct analytical testing to confirm that the liner is not contaminated with CCR constituents.

Because the East Pond is subject to the Illinois CCR Rule, MWG will continue to monitor groundwater surrounding the basin for at least three years, if not longer depending on the results of the groundwater monitoring. 35 Ill. Adm. Code 845.740(b).

<u>Grassy Field:</u> MWG's proposed adjusted standard relief is a finding that the Grassy Field is not a CCR surface impoundment and is not subject to the Part 845 Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments. The proposed language is:

> "Part 845 of the Illinois Pollution Control Board Regulations does not apply to the 10-acre area west of the West Pond known as the Grassy Field located at the MWG Waukegan Generating Station, 401 East Greenwood Ave, Waukegan, IL 60087 because it is an unconsolidated fill area. MWG will continue to conduct quarterly groundwater monitoring of each monitoring well at the Waukegan Station for the constituents listed in 35 Ill. Adm. Code 620.410(a), with the exception of perchlorate, in the addition of field pH and static water elevation. MWG will report the analytical results and field measurements to the Agency quarterly. Two copies of the quarterly reports shall be submitted to:
>
> Groundwater Section
> Illinois Environmental Protection Agency
> Division of Public Water Supplies
> MC #13
> 1021 North Grand Avenue East
> Springfield, IL 62794-9276"

The East Pond construction permit, No. 2016-EB-61340, expires on July 31, 2021. Although MWG has no intention of discontinuing groundwater sampling and related reporting requirements once the construction permit expires, MWG has proposed to include in the Adjusted Standard requirements the same permit language requiring quarterly groundwater sampling and reporting. The estimated annual costs of these activities is approximately $30,000. Ex. 1, ¶36. This cost does not include the estimated annual costs to conduct the groundwater monitoring pursuant to the federal CCR rule, which MWG is also conducting as a separate monitoring program.

g) Description of Impact on the Environment of Complying with the Regulation vs. Complying with the Adjusted Standard

East Pond: Allowing decontamination of a competent geomembrane liner has a more favorable environmental impact than removing and disposing the competent plastic liner and the underlying soil. Disposal of approximately 9,000 cubic yards of liner and soil in a landfill regardless of its condition is a waste of landfill space. Ex. 2, ¶5, Ex. 3. Additionally, the underlying soil will also be removed and disposed in a landfill because of the assumption that the soil mixed with the CCR during demolition, also unnecessarily increasing the volume of material disposed in a landfill. Transportation of the liner and the soil mixed with CCR would require approximately 600 trucks, which is in addition to the trucks required to remove the CCR used for beneficial reuse. *Id.*

By comparison, if the liner is reused, then no landfill space would be required, and no additional trucks will be required. Also, because the liner is in good condition, and because the East Pond will only be used for retention of low-volume wastewater (*i.e.* – process water), there is little risk of groundwater contamination.

The Board has already found that reuse of a competent liner is acceptable for retrofitting a CCR surface impoundment. *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845,* PCB 20-19, Order (February 4, 2021), p. 99. Because the Board found that a competent liner like the one in the East Pond may be decontaminated and reused as part of a retrofitted CCR surface impoundment, there is no reason to suggest that a competent liner cannot be reused to repurpose the East Pond to hold non-CCR waste streams.

Grassy Field: Neither the generally applicable rule nor the proposed adjusted standard removing the Grassy Field from the applicability section of Part 845 have a more favorable environmental impact. The Grassy Field is simply an area at an industrial station that, like any other area at any other property, may be subject to the Act and the Board regulations under various circumstances. For such areas, the record in the CCR Rule proceeding did not provide the Board with a sufficient basis on which to determine whether or to what extent specific rules to regulate such areas are necessary. Hence, there is no evidentiary basis on which to conclude that the CCR Rule's application would have a more favorable environmental impact than the proposed adjusted standard. But what is clear is that the CCR Rule is ill-suited to an area like the Grassy Field because it is premised on the existence of a structure that was designed to hold liquids, which the Grassy Field was not. Hence, any intended favorable environmental impact of the CCR Rule when applied to the Grassy Field simply does not exist.

Further, the Board may adopt regulations that are directly related to historic CCR fill areas. As part of the Board's CCR Opinion and Order, the Board ordered the Clerk to open a subdocket to "solicit more information and evidence, as well as proposed rules, on… historic, unconsolidated coal ash fill in the State…" *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845,* PCB 20-19, Order (February 4, 2021), p. 105. Because the Board intends to assess whether historic CCR fill areas like the Grassy Field warrant specific regulation, there is no negative environmental impact by recognizing that the Illinois CCR Rule is inapplicable to the Grassy Field.

h) **Justification of Proposed Adjusted Standard**.

Because Part 845 does not include a specific justification for an adjusted standard, the applicable level of justification are the factors identified in Section 28.1 of the Act, specified in Section III.C. above. Each of the Section 28.1 factors is addressed below for the East Pond and the Grassy Field.

East Pond: In its CCR Rule Opinion, the Board did not identify the factors it considered in requiring removal of the liner, other than referencing the Illinois EPA's statement that the proposed federal CCR rule includes that requirement. In addition to the fact that the federal CCR Rule "proposal" is not binding, it does not require removal but instead proposes to allow either removal or decontamination. MWG is reasonably proposing an adjusted standard that adopts the proposed federal CCR Rule's decontamination alternative.

Allowing decontamination of a competent liner as opposed to its removal and disposal regardless of liner condition will not result in environmental or health effects substantially and significantly more adverse than the effects that may have been considered by the Board. Reuse of a competent liner is more environmentally beneficial than disposal of approximately 9,000 CY of a plastic liner and its underlying soil. Finally, because the federal CCR rule allows decontamination of a liner, allowing MWG to decontaminate and reuse the liner in the East Pond is consistent with federal law.

Grassy Field: The factors relating to the Grassy Field are substantially and significantly different than the factors relied upon by the Board in consideration of Part 845. The Illinois CCR rulemaking focused on the conditions of active CCR surface impoundments, including their operations and construction. The Board stated that unconsolidated areas of CCR, such as the Grassy Field, does not "fit the definition of 'CCR surface impoundment' and would therefore not be regulated by the framework of Part 845, nor were they included in the mandate of Section 22.59(g)." *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845,* PCB 20-19, Order (February 4, 2021), p. 12.

Finding that the Grassy Field is not a CCR surface impoundment will not result in environmental or health effects substantially and significantly more adverse than the effects considered by the Board. Here, the Illinois CCR Rule specifically considered the potential environmental effects of CCR surface impoundments, and not unconsolidated fill areas. Also, because the Grassy Field is subject to the Act and Board regulations, finding that the Illinois CCR Rule is inapplicable will not result in environmental effects substantially more adverse than the effects considered by the Board.

Also, holding that the Grassy Field is not a CCR surface impoundment is consistent with federal law. In the preamble to the federal CCR Rulemaking, the U.S.EPA specifically stated the requirements in the Illinois CCR rule "do not apply to inactive CCR landfills – which are CCR landfills that do not accept waste after the effective date of the regulations. The Agency is not aware of any damage cases associated with inactive CCR landfills, and as noted, the risks of release from such units are significantly lower than CCR surface impoundments or active CCR landfills." 40 F.R. 21342.

i) **Reasons the Board may Grant the Proposed Adjusted Standard Consistent with Federal Law**.

As stated herein, the Board may grant this adjusted standard for both the East Pond and the Grassy Field because both are consistent with federal law. The applicable federal CCR rule and the proposed federal CCR rule on closure by removal allows for decontamination of a liner and does not require removal. 40 C.F.R. §257.102(c) and *proposed* 40 C.F.R. §257.102(c). Similarly, the applicable federal CCR rule does not apply to inactive CCR landfills or other unconsolidated fill areas. 40 F.R. 21342. Also, there are no procedural requirements applicable to the Board's decision on the petition that are imposed by federal law and not required by the Board regulations.

j) **Hearing on the Petition**.

MWG requests a hearing on the Petition.

k) As required by 35 Ill. Adm. Code 104.406(k) and (l), MWG has provided the citations to relevant supporting documents and legal authorities and has provided required information as applicable to its request the Board's finding of inapplicability.

IV. Conclusion

For the reasons stated, MWG requests the Board enter an Order which states that MWG may close the East Pond by removal of the CCR and decontamination the liner. MWG also requests that the Board enter an order which states that the Part 845 regulations do not apply to the Grassy Field at the Waukegan Station.

Respectfully submitted,
Midwest Generation, LLC

By: /s/ Kristen L. Gale
One of its Attorneys

Kristen L. Gale
Susan M. Franzetti
Molly Snittjer
Nijman Franzetti LLP
10 S. LaSalle St, Suite 3600
Chicago, Illinois 60603
(312) 262-5524
kg@nijmanfranzetti.com
sf@nijmanfranzetti.com
ms@nijmanfranzetti.com

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:

PETITION OF MIDWEST GENERATION FOR AN ADJUSTED STANDARD FROM 35 ILL. ADM. CODE PARTS 811 and 814	**AS (Adjusted Standard)**

INDEX OF EXHIBITS FOR MIDWEST GENERATION, LLC'S PETITION FOR ADJUSTED STANDARD FOR THE WAUKEGAN STATION

Exhibit 1	Affidavit of Christopher Lux
Exhibit 2	Affidavit of David Nielson, P.E.
Exhibit 3	Expert Opinion of David Nielson, P.E.
Exhibit 4	Pre-filed Expert Testimony of David Nielson on behalf of Midwest Generation, LLC, *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845*, PCB 20-19
Exhibit 5	Excerpt of September 30, 2020 Hearing Transcript, *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845*, PCB 20-19
Exhibit 6	Excerpt of Midwest Generation, LLC Pre-Filed Answers, *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845*, PCB 20-19
Exhibit 7	Excerpt of Agency Final Comment, *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845*, PCB 20-19
Exhibit 8	Excerpt of Midwest Generation, LLC's Response Comment, *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845*, PCB 20-19
Exhibit 9	Excerpt of August 25, 2020 Hearing Transcript, *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845*, PCB 20-19

Exhibit 10	NPDES Permit for the Waukegan Station
Exhibit 11	Illinois EPA Construction Permit, No. 2016-EB-61340, for Waukegan Station
Exhibit 12	Map of Monitoring Wells at the Waukegan Station
Exhibit 13	Demonstration for a Site-Specific Alternative Deadline to Initiate Closure of the East Pond, Nov. 30, 2020
Exhibit 14	Compliance Commitment Agreement for Waukegan Station
Exhibit 15	Alternate Source Demonstration for the East Pond and West Pond, March 11, 2019
Exhibit 16	Closure Plan East and West Pond, Waukegan Station, Oct. 2016
Exhibit 17	Pictures of the Grassy Field taken by Christopher Lux
Exhibit 18	1939 Aerial Photo
Exhibit 19	1946 Aerial Photo
Exhibit 20	1961 Aerial Photo
Exhibit 21	1974 Aerial Photo
Exhibit 22	1972 Water Pollution Control Permit application for Waukegan Station
Exhibit 23	1974 Water Pollution Control Permit (1974-EB-0346) for Waukegan Station

EXHIBIT 1

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	
PETITION OF MIDWEST GENERATION FOR AN ADJUSTED STANDARD FROM 845.740(a) AND FINDING OF INAPPLICABILITY OF PART 845	**AS 19-** **(Adjusted Standard)**

AFFIDAVIT OF CHRISTOPHER LUX

I, Christopher Lux, being first duly sworn on oath, depose and state as follows:

1. I am over the age of 18 years and am a resident of Illinois.

2. The information in this Affidavit is based on my personal knowledge or belief in my capacity as Health and Safety Specialist and the Waukegan Station ("Waukegan" or "Station") and the Liaison between Waukegan and the contractor that removes the ash from the ash ponds at the Station, and I would testify to such matters if called as a witness.

3. The Waukegan Station is located at 401 East Greenwood Ave, Waukegan in Lake County, Illinois.

4. Waukegan was built in about 1923 and has been a power plant ever since.

5. MWG began operating the Waukegan Station in 1999, and the area around the station has historically been dominated by industries since at least the 1930s.

6. Approximately 67 people work at the Waukegan Station.

7. Waukegan generates two types of coal ash from the burning of the coal to generate electricity, fly ash and bottom ash.

8. Fly ash consists of lightweight particles and is collected via dry system using electrostatic precipitators.

9. Bottom ash consists of heavier particles that fall to the bottom of the furnace and is mixed with water and conveyed out of the plant via a pipe to either the West Pond or East Pond.

10. MWG contracts with a third party to remove the fly ash and bottom ash from Waukegan for beneficial reuse.

11. Waukegan has two CCR surface impoundments - the West Ash Pond and East Ash Pond, both of which are located on the southern side of the Station and operated as part of the Station's NPDES permitted ash management system.

12. The East Pond and West Pond are each approximately 9 acres, are "U-shaped" and were constructed in approximately 1977 with a plastic liner.

13. In 2003, MWG relined the East Pond with a high-density polyethylene ("HDPE") liner.

14. In 2004, MWG relined the West Pond with an HDPE liner.

15. Other than the East and West Ponds, there is no other basin at Waukegan that holds an accumulation of CCR and liquids or is designed to hold an accumulation of CCR and liquids.

16. The East Pond and West Pond alternate receiving the slurry of bottom ash and liquid, thus only one pond (East Pond or West Pond) is in service at a time.

17. The CCR settles out of the water into one of the ponds, and the water is reused to transport additional bottom ash.

18. The CCR is temporarily stored in the pond in service until the pond is full, at which time the CCR is removed.

19. When ash is removed from the impoundments at Waukegan, MWG takes specific care to prevent the pond liners from being damaged.

20. The East Pond and West Pond have markers to notify the machine operators, and as part of my coordination with the contractor, I ensure that before each dredging all operators in the ponds know to avoid the liners.

21. Trained personnel from third-party contractors operate the machinery to remove the ash.

22. All of the operators in the pond are careful and methodical to ensure the liners are not damaged.

23. The machine operators leave ash material on the slopes of the liners and on the bottom above the warning layer to avoid any damage to the liner.

24. Because most of the bottom ash collects on one side of the U-shaped ponds, the contractor only dredges half of the pond, and at times even less.

25. Once MWG has completed removing the ash from a basin, MWG inspects the basin to verify that the ash was removed safely and only after the inspection is the basin placed back in service.

26. To clean and decontaminate the East Pond for reuse, once the CCR in the middle of the pond that can be removed with equipment is removed MWG's contractor will use a multi-step process to carefully remove the remaining CCR from the slopes and base of the pond and decontaminate the liner. The contractor will first use an excavator with a rubber surface on the edge of the bucket to pull down most of the material from the slopes. The contractor will then use a vibrating plate to shake the rest of the material loose on from the slope to the bottom of the slope, for further removal. Then the contractor will use an excavator or end loader with a rubber surface on the edge of the bucket to carefully remove the excess material from the base of the pond. Finally, the contractor will power-wash the slopes and base of the East Pond.

27. As part of the liner system, at the base both ponds there is a cushion layer of sand and a warning layer of white limestone.

28. Beginning in 2010, MWG began monitoring the groundwater upgradient and downgradient of the West Pond and East Pond.

29. MWG conducts groundwater monitoring surrounding the East Pond and the West Pond pursuant to the federal CCR Rule, 40 C.F.R. 257.

30. To the west of the West Pond is a field of grass ("Grassy Field") that is approximately 10 acres in size.

31. MWG does not direct CCR or liquid to the Grassy Field, and MWG has never directed CCR or liquid to the Grassy Field. The Grassy Field is not a part of the ash management system, and is not used to accumulate water and liquid.

32. MWG has previously used the Grassy Field to land helicopters used for Station operations.

33. The cost of conducting the work to prepare an operating permit application required in Section 845.230 of the Illinois Coal Combustion Residual Rule would be approximately $57,200.

34. The estimated cost for preparing the construction application required in Section 845.220 of the Illinois Coal Combustion Residual Rule would be $125,000.

35. Attached as exhibits of the Petition for Adjusted Standards are two photographs of the Grassy Field that were taken by me on April 14, 2021. The first photo (Ex. 17A), is a photo I took facing southwest from the main plant roof, which provides an overall view of the Grassy Field. The second photo (Ex. 17B) is a photo I took from the road on the north side of the Grassy Field facing south.

36. The estimated annual costs to conduct the monitoring of the groundwater monitoring wells at the Waukegan Station is approximately $30,000.

Under penalties as provided by law pursuant to Section 1-109 of the Code of Civil Procedure, the undersigned certifies that the statements set forth in this instrument are true and correct, except as to matters therein stated to be on information and belief and as to such matters the undersigned certifies as aforesaid that he verily believes the same to be true.

FURTHER AFFIANT SAYETH NOT.

Christopher Lux

Subscribed and Sworn to before me
On 05 / 10, 2021.

Notary Public

My Commission Expires: 03/27/2024

ELIZABETH COSTA
Official Seal
Notary Public - State of Illinois
My Commission Expires Mar 27, 2024

EXHIBIT 2

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:

PETITION OF MIDWEST GENERATION FOR AN ADJUSTED STANDARD FROM 845.740(a) AND FINDING OF INAPPLICABILITY OF PART 845	**AS (Adjusted Standard)**

AFFIDAVIT OF DAVID E. NIELSON IN SUPPORT OF MIDWEST GENERATION LLC'S PETITION FOR AN ADJUSTED STANDARD AT THE WAUKEGAN STATION

I, David E. Nielson, being first duly sworn on oath, depose and state as follows:

1. I am over the age of 18 years and am a resident of Indiana.
2. The information in this Affidavit is based on my personal knowledge or belief in my capacity as an Illinois licensed professional engineer, and as Sr. Consultant and Sr. Manager with Sargent & Lundy headquartered in Chicago, Illinois. I would testify to such matters included herein if called as a witness.
3. In my employment with Sargent & Lundy, I have had primary responsibility for providing engineering services to Midwest Generation, LLC ("MWG") relating to the requirements of the federal Coal Combustion Residual ("CCR") rule (40 C.F.R. 257) and the Illinois CCR rule (35 Ill. Adm Code 845) for modifications of the CCR management systems at the MWG Station located in Waukegan, IL ("Waukegan Station" or "Station"). I assisted in preparing the Demonstration for a Site-Specific Alternative Deadline to Initiate Closure of the East Pond submitted to U.S.EPA which describes the alternatives available and unavailable to the Waukegan Station for storage of bottom ash, and the intended CCR management system that will be installed. Based on this work, I have significant experience related to the compliance requirements for the CCR management systems at the Waukegan Station.

4. Exhibit 3 to the Petition for an Adjusted Standard for the Waukegan Station is my expert opinion that a geomembrane liner of a CCR surface impoundment does not need to be removed. Instead, a geomembrane liner can be decontaminated such that it may be used for another purpose, such as for use as a low volume waste pond.

5. If MWG is required to remove the liner in the East Pond, due to the presence of the CCR in the pond when demolition of the liner begins, it would be assumed that during the demolition CCR would escape from the East Pond when the liner is removed, thus requiring excavation of the liner and approximately six inches of soil below the liner. The total volume of liner and underlying soil removed would be approximately 9.000 cubic yards ("CY"), which would be hauled off-site for disposal in a landfill.

6. Hauling a total quantity of 9,000 CY of soils offsite the Station would require 600 trucks based on a 15 CY per truck capacity.

7. The total cost for excavation, transportation, and disposal of the liner and soil, including the labor and material costs, would be approximately $365,465.

8. The new liner that would be installed in the East Pond would be almost the same as the liner currently lining the East Pond.

9. The cost to install a new liner would cost approximately $329,041.

10. In comparison, the approximate cost to clean and conduct confirmatory wipe samples of the East Pond would be $111.155.

FURTHER AFFIANT SAYETH NOT.

____
David E. Nielson

Subscribed and Sworn to before me
On May 10th, 2021.

Brandon Decker
Notary Public

My Commission Expires: 11/15/2022

NOTARY PUBLIC
STATE OF TEXAS
BRANDON DECKER
Notary ID #131798198
My Commission Expires
November 15, 2022

This notarial act was an online notarization via two-way webcam and audiovisual technology.

EXHIBIT 3

Sargent & Lundy

Expert Opinion of David E. Nielson In Support of Midwest Generation, LLC's Petitions for an Adjusted Standard to Reuse the Polyethylene Liners in the Coal Combustion Residual Surface Impoundments

My name is David E. Nielson I am a Sr. Consultant and Sr. Manager with Sargent & Lundy (S&L). S&L is an Illinois-based engineering firm with over 125 years of history focused on the design of electric power generation and transmission systems. I have over 30 years of professional experience as a geotechnical and civil engineer. I have been a licensed professional engineer (civil) in the state of Illinois in good standing since 1993. My professional career has included services associated with coal combustion residuals (CCR), industrial waste surface impoundments, industrial waste landfills, and municipal solid waste (MSW) landfills in numerous states and regulatory environments since 1990. My curriculum vitae is attached (Attachment G).

I have been retained by Midwest Generation, LLC ("MWG") to provide expert testimony on MWG's Petitions for Adjusted Standards from Section 845.740(a) of the Illinois Coal Combustion Residual rule, Part 845 of the Illinois Pollution Control Board's ("Board") rules. Specifically, I am providing testimony supporting the closure of a CCR surface impoundment, by removal of the CCR with decontamination of the geomembrane liner, so it may be reused as a low-volume wastewater pond liner.

In 2020, I was retained by MWG to review and comment on the Illinois Environmental Protection Agency's ("Illinois EPA") proposed Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments as the new Part 845 of the Illinois Pollution Control Board's Rules. *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845*, PCB 20-19 ("Illinois CCR rule"). In that proceeding, I provided written testimony and oral testimony, including my opinion that a competent geomembrane liner may be reused as part of retrofitting a CCR surface impoundment. *Id.* My opinion here is similar to and consistent with my opinion that I provided *In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New 35 Ill. Adm. Code 845*, PCB 20-19.

I. Background

- The Illinois CCR Rule - Section 845.120 states:
  “"Retrofit" means to remove all CCR and contaminated soils and sediments from the CCR surface impoundment, and to ensure the surface impoundment complies with the requirements in Section 845.410.”

  The Illinois CCR Rule - Section 845.410 details and references the requirements of a composite liner for new and laterally expanded CCR surface impoundments.

- Section 845.770(a)(4) of the Illinois CCR Rule states
  “An owner or operator may request the Agency to approve the use of an existing competent geomembrane liner as a supplemental liner by submitting visual inspection, and analytical testing results to demonstrate that the existing liner is not contaminated with CCR constituents.”

  Thus, the Illinois EPA and Board have established that existing liners can be considered supplemental liners provided that adequate visual and analytical test results demonstrate it is not contaminated with CCR constituents.

- Section 257.102 of the Federal Rule presents the requirements for closure of CCR impoundments by removal. 257.102(c) states “An owner or operator may elect to close a CCR unit by removing and decontaminating all areas affected by releases from the CCR unit. CCR removal and decontamination of the CCR unit are complete when constituent concentrations throughout the CCR unit and any areas affected by releases from the CCR unit have been removed and groundwater monitoring concentrations do not exceed the groundwater protection standard established pursuant to §257.95(h) for constituents listed in appendix IV to this part."

This Federal rule does not require the removal of any decontaminated liner systems.

- Section 845.740 of the Illinois Rule requires removal of liner systems for closure by removal as stated:
  "…containment system components such as the impoundment liner and contaminated subsoils, and CCR impoundment structures and ancillary equipment have been removed."

II. Geomembrane Liners in CCR Surface Impoundments Can be Decontaminated and Reused for Low-Volume Waste Ponds

In my opinion the reuse of geomembrane liners from CCR Surface impoundments that are properly decontaminated and undamaged can enhance the protection of health and the environment when they are repurposed for non-CCR impoundments, including low-volume waste ponds. My opinion is made to a reasonable degree of scientific certainty. This opinion is based on the following:

1. A low-volume waste pond is a pond that collects "low volume waste sources." "Low volume waste sources are defined in the Steam Electric Power Generating Effluent Guidelines and Standards as "wastewater from all sources except those for which specific limitations or standards are otherwise established in this part. Low volume waste sources include, but are not limited to, the following: Wastewaters from ion exchange water treatment systems, water treatment evaporator blowdown, laboratory and sampling streams, boiler blowdown, floor drains, cooling tower basin cleaning wastes, recirculating house service water systems, and wet scrubber air pollution control systems whose primary purpose is particulate removal. Sanitary wastes, air conditioning wastes, and wastewater from carbon capture or sequestration systems are not included in this definition." 40 C.F.R. § 423.11(b).

2. A low volume waste pond has an unmeasurable amount of non-CCR material because it holds the water required for the station operations and also stormwater. A power generating station uses the low volume waste ponds for temporary storage of large volumes of non-CCR waste streams until the water can be treated and discharged pursuant to the station's NPDES permit. For example, stormwater at a station would be directed to a low volume waste pond to avoid flooding a station and to also avoid discharge of stormwater from the station before treatment.

3. Geomembrane liners are flexible membranes that are manufactured of resins such as polyethylene (HDPE, LLDPE, LDPE) and polyvinyl chloride (PVC), which are energy intensive to manufacture and very low permeability. ASTM International defines geomembrane as "an essentially impermeable geosynthetic composed of one or more synthetic sheets." (Attachment A, p. 3).

4. Geomembrane liners, including HDPE, are used worldwide, including hazardous waste landfills, municipal solid waste landfills, hazardous waste impoundments, non-hazardous waste impoundments, tailings ponds, dams, and stormwater management ponds.

5. My research has not found any evidence that geomembrane liners, such as HDPE become contaminated with waste products that are present in CCR. In fact, I am not aware of a study that shows that polymer liners become saturated with CCR constituents. Thus, there is no basis to conclude that a geomembrane liner would be saturated with CCR constituents such that it cannot be decontaminated for reuse.

6. To clean a CCR surface impoundment, first the CCR is carefully removed from the surface impoundment. Following removal, the sides and base of the CCR surface impoundment are methodically cleaned with a high pressure power-washer to remove the residual CCR from the geomembrane. Visual inspections for any damage would also occur, and any potential damage found would be repaired.

7. Performing analytical testing on wipe samples to verify suitable decontamination of the exposed surface of undamaged HDPE liner systems is considered a reasonable

path forward to allow existing liners to be repurposed for non-CCR impoundments. The wipe samples would be obtained for the metal and other constituents regulated by the Illinois CCR Rule (845.600(a)(1)).

I suggest the sampling and testing consist of:

- In accordance with ASTM D6966-18 (Attachment B) perform a systematic and repeatable wipe sampling,
- Analytical chemistry testing to quantify the concentrations of the regulated metals and other chemical constituents.

It is my opinion that performing 1 set of wipe samples and tests per acre is an appropriate testing frequency. This opinion is based on the USEPA guidance that one permeability test should be performed per acre per lift of compacted clay liner (Attachment C, Section 2.8.4.3).

8. Geomembrane liners have been successfully cleaned for reuse for an alternative purpose. In 2018, a geomembrane lined landfill leachate pond was cleaned so the pond could store clean water. The geomembrane liner had been in use for approximately 25 years. Because the geomembrane liner would be exposed, the owner conducted an analysis of the condition of geomembrane after over two decades of use. The analysis showed that the geomembrane was in good condition with little signs of degradation, and the owner continued using the impoundment for clean water. Attachment D.

9. When considering a 60 mil HDPE liner that is 10 acres in extent, it contains over 120,000 pounds or about 60,000 kg of HDPE resin. The energy demand for manufacturing of the resin requires over 76 MJ/kg or 72,000 BTU/kg. (Attachment E, p. 11). Therefore, it is estimated that to manufacture the resin for 10 acres of 60 mil HDPE liner requires over 4,300,000,000 BTU of energy. This includes the energy value of the oil and natural gas products used to make the resin. This does not include the energy required to extrude the resin into sheets,

transportation, deployment, or seaming. Thus, I conclude that the energy intensive requirements to replace decontaminated, undamaged HDPE liner are not warranted.

10. Pond 1 at MWG's Joliet 29 station has a HDPE liner that was repurposed for the existing non-CCR impoundment. Ongoing groundwater testing validates that CCR constituents have not adversely impacted the groundwater. Attachment F.

11. When HDPE liner is removed from an impoundment it is not typically rolled to reduce the volume of waste to be transported to a landfill. Instead it is often removed with an excavator and loaded into dump trucks. Because removal of the liner is a demolition project, there would be no need for the excavators to carefully remove the liner. Instead, when the liner is removed, the CCR material that remained in the CCR surface impoundment would likely mix with the underlying soil. To confirm that all sub-soils were removed of CCR, at least 6 inches of subsoil would have to be removed and disposed of as well as the liner.

12. It is recognized that the zero air void volume of a typical liner for a 10 acre pond only occupies about 80 cubic yards of volume. However, when the material is placed in a dump truck with an excavator along with the nominal 6 inches of subsoil, it would likely require approximately 500 dump truck loads of the waste liner and subsoil to be hauled to a landfill. Additionally, about 5 over the road tractor trailer loads would be required to transport the new liner material from the factory to the site. In my opinion it is not prudent to require about 500 truck trips per 10 acres of lined impoundment to remove and replace an undamaged decontaminated existing liner.

13. Additionally, removing the liner and the subsoil, and installing a virtually identical liner to hold low-volume wastewater will take a significant amount of time compared to removing the CCR and decontaminating the liner. In the Demonstrations for a Site-Specific Alternative Deadline to Initiate Closure of the basins at the MWG Stations that MWG submitted to the U.S. EPA pursuant to the federal CCR rule, MWG committed to providing alternative disposal of the CCR as soon as technically

feasible. *See* Demonstration for a Site-Specific Alternative Deadline to Initiate Closure, Powerton Station, p. 3-5; Demonstration for a Site-Specific Alternative Deadline to Initiate Closure, Waukegan Station, p. 3-5. Because it is technically feasible to decontaminate a geomembrane liner, by removing the CCR and decontaminating the liner, MWG would be fulfilling its commitment to provide the alternative capacity for CCR and non-CCR wastestreams as soon as technically feasible.

III. Conclusion

I recommend that MWG be granted an adjusted standard from the Illinois CCR Rule requirement to remove the geomembrane liner of a CCR surface impoundment for closure by removal of CCR. A competent geomembrane liner does not become saturated with CCR constituents, and can be cleaned and decontaminated for another purpose. Additionally, wipe samples will be taken to confirm that the decontamination cleaning was successful. As previously noted the adjusted standard as requested is in accordance with the USEPA CCR Rule.

Digitally signed by David E. Nielson
Date: 2021.05.09 18:40:37 -05'00'

David E. Nielson, P.E.

ATTACHMENTS

A. ASTM International, Standard Terminology for Geosynthetics, ASTM D4439 - 20, January 2020.

B. ASTM International, Standard Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Determination of Metals, ASTM D6966-18, November 2018.

C. https://geosyntheticsmagazine.com/2019/02/01/a-leachate-pond-geomembrane-after-25-years-of-service/

D. Daniel, D. E. and R. M. Koerner. Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities, EPA/600/R-93/182 (NTIS PB94-159100), 1993.

E. PlasticsEurope, Eco-profiles of the European Plastics Industry, High Density Polyethylene (HDPE), March 2005.

F. Midwest Generation, LLC, 2021; Annual and Quarterly Groundwater Monitoring Report, Joliet #29 Generating Station, January 21, 2021.

G. David E. Nielson, Curriculum Vitae

ATTACHMENT A

Standard Terminology for Geosynthetics
ASTM D4439 - 20

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

Standard Terminology for Geosynthetics[1]

This standard is issued under the fixed designation D4439; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Referenced Documents

1.1 *ASTM Standards:*[2]

C125 Terminology Relating to Concrete and Concrete Aggregates

D1987 Test Method for Biological Clogging of Geotextile or Soil/Geotextile Filters

D4354 Practice for Sampling of Geosynthetics and Rolled Erosion Control Products (RECPs) for Testing

D4491/D4491M Test Methods for Water Permeability of Geotextiles by Permittivity

D4533/D4533M Test Method for Trapezoid Tearing Strength of Geotextiles

D4594/D4594M Test Method for Effects of Temperature on Stability of Geotextiles

D4595 Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method

D4632/D4632M Test Method for Grab Breaking Load and Elongation of Geotextiles

D4716/D4716M Test Method for Determining the (In-plane) Flow Rate per Unit Width and Hydraulic Transmissivity of a Geosynthetic Using a Constant Head

D4751 Test Methods for Determining Apparent Opening Size of a Geotextile

D4759 Practice for Determining the Specification Conformance of Geosynthetics

D4833/D4833M Test Method for Index Puncture Resistance of Geomembranes and Related Products

D4873/D4873M Guide for Identification, Storage, and Handling of Geosynthetic Rolls and Samples

D4884/D4884M Test Method for Strength of Sewn or Bonded Seams of Geotextiles

D4885 Test Method for Determining Performance Strength of Geomembranes by the Wide Strip Tensile Method

D5101 Test Method for Measuring the Filtration Compatibility of Soil-Geotextile Systems

D5141 Test Method for Determining Filtering Efficiency and Flow Rate of the Filtration Component of a Sediment Retention Device

D5262 Test Method for Evaluating the Unconfined Tension Creep and Creep Rupture Behavior of Geosynthetics

D5322 Practice for Laboratory Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids

D5323 Practice for Determination of 2 % Secant Modulus for Polyethylene Geomembranes

D5397 Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test

D5494 Test Method for the Determination of Pyramid Puncture Resistance of Unprotected and Protected Geomembranes

D5496 Practice for In Field Immersion Testing of Geosynthetics

D5514/D5514M Test Method for Large-Scale Hydrostatic Puncture Testing of Geosynthetics

D5567 Test Method for Hydraulic Conductivity Ratio (HCR) Testing of Soil/Geotextile Systems

D5594 Test Method for Determination of the Vinyl Acetate Content of Ethylene-Vinyl Acetate (EVA) Copolymers by Fourier Transform Infrared Spectroscopy (FT-IR)

D5617 Test Method for Multi-Axial Tension Test for Geosynthetics

D5641/D5641M Practice for Geomembrane Seam Evaluation by Vacuum Chamber

D5747/D5747M Practice for Tests to Evaluate the Chemical Resistance of Geomembranes to Liquids

D5818 Practice for Exposure and Retrieval of Samples to Evaluate Installation Damage of Geosynthetics

D5820 Practice for Pressurized Air Channel Evaluation of Dual-Seamed Geomembranes

D5994/D5994M Test Method for Measuring Core Thickness of Textured Geomembranes

1.2 *Federal Standard:*[3]

Federal Standard 751a Stitches, Seams, and Stitchings

---

[1] This terminology is under the jurisdiction of D35 on Geosynthetics and is the direct responsibility of D35.93 on Editorial and Terminology.

Current edition approved Jan. 1, 2020. Published January 2020. Originally approved in 1984. Last previous edition approved in 2018 as D4439 – 18. DOI: 10.1520/D4439-20.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, http://quicksearch.dla.mil.

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States

Copyright ASTM International
Provided by IHS Markit under license with ASTM
No reproduction or networking permitted without license from IHS

Licensee=Sargent & Lundy/5915733100, User=Nielson, David
Not for Resale, 04/27/2021 08:51:47 MDT

2. Terminology

absorption, *n*—the process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body, also, the increase in mass of a porous solid body resulting from penetration of a liquid into its permeable pores. **C125**

aerobic, *n*—a condition in which a measurable volume of air is present in the incubation chamber or system. **D1987**

anaerobic, *n*—a condition in which no measurable volume of air is present in the incubation chamber or system. **D1987**

apparent opening size (AOS), O_{95}, *n—for a geotextile,* a property which indicates the approximate largest particle that would effectively pass through the geotextile. **D4751**

atmosphere for testing geosynthetics, *n*—air maintained at a relative humidity between 50 to 70 % and a temperature of 21 ± 2 °C (70 ± 4 °F). **D4439, D4751, D5494**

back flushing, *n*—a process by which liquid is forced in the reverse direction to the flow direction. **D1987**

basis weight—deprecated term (do not use in the sense of mass per unit area). **D4439**

bend, *vt—in mechanics*, to force an object from its natural or manufactured shape into a curve or into increased curvature. **D4439**

biocide, *n*—a chemical used to kill bacteria and other microorganisms. **D1987**

bituminous geosynthetic barrier (GBR-B), *n*—factory-produced structure of geosynthetic materials in the form of a sheet in which the barrier function is fulfilled by bitumen.

blinding, *n—for geotextiles*, the condition where soil particles block the surface openings of the fabric, thereby reducing the hydraulic conductivity of the system. **D4439**

breaking force, *(F), J, n*—the force at failure. **D4885**

breaking load, *n*—the maximum force applied to a specimen in a tensile test carried to rupture. **D4632/D4632M**

breaking toughness, *T,* (FL^{-1}), Jm^{-2}, *n—for geotextiles*, the actual work-to-break per unit surface area of material. **D4595, D4885**

chemical resistance, *n*—the ability to resist chemical attack. **D5322**

clogging, *n—for geotextiles,* the condition where soil particles move into and are retained in the openings of the fabric, thereby reducing the hydraulic conductivity. **D4439**

clogging potential, *n—in geotextiles*, the tendency for a given geotextile to decrease permeability due to soil particles that have either lodged in the geotextile openings or have built up a restrictive layer on the surface of the geotextile. **D5101**

compressed thickness (t, (L), mm), *n*—thickness under a specified stress applied normal to the material. **D4439**

constant-rate-of-load tensile testing machine (CRL), *n*—a testing machine in which the rate of increase of the load being applied to the specimen is uniform with time after the first 3 s. **D4439**

corresponding force, *n*—synonym for force at specified elongation. **D4885**

coupon, *n*—a portion of a material or laboratory sample from which multiple specimens can be taken for testing. **D5747/D5747M**

creep, *n*—the time-dependent increase in accumulative strain in a material resulting from an applied constant force. **D5262**

critical height *(ch)*, *n*—the maximum exposed height of a cone or pyramid that will not cause a puncture failure of a geosynthetic at a specified hydrostatic pressure for a given period of time. **D5514/D5514M**

cross-machine direction, *n*—the direction in the plane of the fabric perpendicular to the direction of manufacture. **D4632/D4632M**

density (ρ, (ML^{-3}), kg/m^3), *n*—mass per unit volume. **D4439**

design load—the load at which the geosynthetic is required to operate in order to perform its intended function. **D5262**

elastic limit, *n—in mechanics*, the stress intensity at which stress and deformation of a material subjected to an increasing force cease to be proportional; the limit of stress within which a material will return to its original size and shape when the force is removed, and hence, not a permanent set. **D4885**

elongation at break, *n*—the elongation corresponding to the breaking load, that is, the maximum load. **D4632/D4632M**

failure, *n*—an arbitrary point beyond which a material ceases to be functionally capable of its intended use. **D4885, D5262**

failure, *n—in testing geosynthetics*, water or air pressure in the test vessel at failure of the geosynthetic. **D5514/D5514M**

field testing, *n*—testing performed in the field under actual conditions of temperature and exposure to the fluids for which the immersion testing is being performed. **D5496**

fill—deprecated term, see **filling**.

filling, *n*—yarn running from selvage to selvage at right angles to the warp in a woven fabric. **D4439**

flexible polypropylene, *n*—a material having a 2 % secant modulus of less than 300 MPa (40 000 psi) as determined by Practice D5323, produced by polymerization of propylene with or without other alpha olefin monomers.

force at specific elongation, FASE, *n*—the force associated with a specific elongation on the force-elongation curve. **D4439**

force-elongation curve, *n—in a tensile test,* a graphical representation of the relationship between the magnitude of an externally applied force and the change in length of the

Copyright ASTM International
Provided by IHS Markit under license with ASTM
No reproduction or networking permitted without license from IHS

Licensee=Sargent & Lundy/5915733100, User=Nielson, David
Not for Resale, 04/27/2021 08:51:47 MDT

specimen in the direction of the applied force. (*Synonym* for stress-strain curve.) **D4885**

geocomposite, *n*—a product composed of two or more materials, at least one of which is a geosynthetic.

geofoam, *n*—block or planar rigid cellular foamed polymeric material used in geotechnical engineering applications.

geogrid, *n*—a geosynthetic formed by a regular network of integrally connected elements with apertures greater than 6.35 mm (¼ in.) to allow interlocking with surrounding soil, rock, earth, and other surrounding materials to function primarily as reinforcement. **D5262**

geomembrane, *n*—an essentially impermeable geosynthetic composed of one or more synthetic sheets. **D4439, D4873/D4873M, D4885, D5994/D5994M, D5820**

geonet, *n*—a geosynthetic consisting of integrally connected parallel sets of ribs overlying similar sets at various angles for planar drainage of liquids or gases. **D4439**

geostrip—polymeric material in the form of a strip of width not more than 200 mm (7.87 in.), used in contact with soil or other materials in geotechnical and civil engineering applications, or both.

geosynthetic, *n*—a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure, or system. **D4354, D4759, D4873/D4873M, D5617, D5818**

geosynthetic barrier—low-permeability geosynthetic material, used in geotechnical and civil engineering applications with the purpose of reducing or preventing the flow of fluid through the construction.

geosynthetic barrier clay (GBR-C), *n*—factory-produced structure of geosynthetic materials in the form of a sheet, in which the barrier function is fulfilled by clay.

geosynthetic barrier polymeric (GBR-P), *n*—factory-produced structure of geosynthetic materials in the form of a sheet, in which the barrier function is fulfilled by polymers.

geosynthetic cementitious composite mat (GCCM), *n*—a factory-assembled geosynthetic composite consisting of a cementitious material contained within layer or layers of geosynthetic materials that becomes hardened when hydrated.

geosynthetic clay liner, *n*—a manufactured hydraulic barrier consisting of clay bonded to a layer or layers of geosynthetic materials.

geotechnical engineering, *n*—the engineering application of geotechnics. **D4439, D4595**

geotechnics, *n*—the application of scientific methods and engineering principles to the acquisition, interpretation, and use of knowledge of materials of the earth's crust to the solution of engineering problems. **D4439, D4491/D4491M, D4595, D4716/D4716M, D4751**

geotextile, *n*—a permeable geosynthetic comprised solely of textiles.

DISCUSSION—Geotextiles perform several functions in geotechnical engineering applications, including: separation, filtration, drainage, reinforcement, and protection. **D1987, D4439, D5594**

grab test, *n*—*in fabric testing*, a tension test in which only a part of the width of the specimen is gripped in the clamps. **D4632/D4632M**

gradient ratio, *n*—*in geotextiles*, the ratio of the hydraulic gradient through a soil-geotextile system to the hydraulic gradient through the soil alone. **D5101**

gravity flow, *n*—flow in a direction parallel to the plane of a geotextile or related product driven predominately by a difference in elevation between the inlet and outflow points of a specimen. **D4716/D4716M**

head, *n*—pressure at a point in a liquid, expressed in terms of the vertical distance of the point below the surface of the liquid. **D4716/D4716M**

hydraulic conductivity *(k)*, *n*—the rate of discharge of water under laminar flow conditions through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions (20 °C). **D5567**

hydraulic conductivity ratio (HCR), *n*—the ratio of the hydraulic conductivty of the soil/geotextile system, k_{sg}, at any time during the test, to the initial hydraulic conductivity, k_{sgo}, measured at the beginning of the test (NEW).

hydraulic gradient, *i, s (D)*—the loss of hydraulic head per unit distance of flow, dH/dL. **D5101**

hydraulic transmissivity, θ (L^2 T^{-1}), *n*—*for a geotextile or related product*, the volumetric flow rate of water per unit width of specimen per unit gradient in a direction parallel to the plane of the specimen. **D4716/D4716M**

hydrostatic pressure, *n*—a state of stress in which all the principal stresses are equal (and there is no shear stress), as in a liquid at rest; induced artificially by means of a gaged pressure system; the product of the unit weight of the liquid and the difference in elevation between the given point and the free water elevation. **D5514/D5514M**

index test, *n*—a test procedure which may contain a known bias but which may be used to establish an order for a set of specimens with respect to the property of interest. **D4833/D4833M, D4885**

inflection point, *n*—the first point of the force-elongation curve at which the second derivative equals zero. **D4885**

initial tensile modulus, J_p (FL^{-1}), Nm^{-1}, *n*—*for geosynthetics*, the ratio of the change in force per unit width to the change in elongation of the initial portion of a force-elongation curve. **D4885**

in-plane flow, *n*—fluid flow confined to a direction parallel to the plane of a geotextile or related product. **D4716/D4716M**

Copyright ASTM International
Provided by IHS Markit under license with ASTM
No reproduction or networking permitted without license from IHS
Licensee=Sargent & Lundy/5915733100, User=Nielson, David
Not for Resale, 04/27/2021 08:51:47 MDT

integral, *adj—in geosynthetics*, forming a necessary part of the whole; constituent. **D4439**

laboratory sample, *n*—a portion of material taken to represent the lot sample, or the original material, and used in the laboratory as a source of test specimens. **D4354**

laminar flow, *n*—flow in which the head loss is proportional to the first power of the velocity. **D4716/D4716M**

linear density, *n*—mass per unit length; the quotient obtained by dividing the mass of a fiber or yarn by its length.

lot, *n*—a unit of production, or a group of other units or packages, taken for sampling or statistical examination, having one or more common properties and being readily separable from other similar units. **D4354**

lot sample, *n*—one or more shipping units taken at random to represent an acceptance sampling lot and used as a source of laboratory samples. **D4354**

machine direction, *n*—the direction in the plane of the fabric parallel to the direction of manufacture. **D4632/D4632M**

minimum average roll value (MARV), *n*—for geosynthetics, a manufacturing quality control tool used to allow manufacturers to establish published values such that the user/purchaser will have a 97.7 % confidence that the property in question will meet published values. For normally distributed data, "MARV" is calculated as the typical value minus two (2) standard deviations from documented quality control test results for a defined population from one specific test method associated with one specific property.

Discussion—MARV is applicable to a geosynthetic's intrinsic physical properties such as weight, thickness, and strength. MARV may not be appropriate for some hydraulic, performance, or durability properties.

minimum test value, *n—for geosynthetics*, the lowest sample value from documented manufacturing quality control test results for a defined population from one test method associated with one specific property.

modulus of elasticity, *MPa* (FL^{-2}), *n*—the ratio of stress (nominal) to corresponding strain below the proportional limit of a material, expressed in force per unit area, such as megapascals (pounds-force per square inch). **D5323**

multi-axial tension, *n*—stress in more than one direction. **D5617**

multi-linear drainage geocomposite, *n*—a manufactured product composed of a series of parallel single drainage conduits regularly spaced across its width sandwiched between two or more geosynthetics.

nominal, *n*—representative value of a measurable property determined under a set of conditions, by which a product may be described.

nominal value, *n*—representative value of a measurable property by which a product may be described **D4439**

normal direction, *n—for geotextiles*, the direction perpendicular to the plane of a geotextile. **D4439**

normal stress, (FL^{-2}), *n*—the component of applied stress that is perpendicular to the surface on which the force acts. **D4439**

offset modulus, J_o, (FL^{-1}), Nm^{-1}, *n—for geosynthetics*, the ratio of the change in force per unit width to the change in elongation below an arbitrary offset point at which there is a proportional relationship between force and elongation, and above the inflection point on the force-elongation curve. **D4885**

performance property, *n*—a result obtained by conducting a performance test. **D5141**

performance test, *n*—a test which simulates in the laboratory as closely as practicable selected conditions experienced in the field and which can be used in design. (Synonym for **design test**.) **D4885**

performance test, *n—in geosynthetics*, a laboratory procedure which simulates selected field conditions which can be used in design. **D5141**

permeability, *n*—the rate of flow of a liquid under a differential pressure through a material. **D1987, D4491/D4491M**

permeability, *n—of geotextiles,* hydraulic conductivity. **D4491/D4491M**

permeation, *n*—the transmissioin of a fluid through a porous medium (NEW).

permittivity, (Ψ), (T^{-1}), *n—of geotextiles*, the volumetric flow rate of water per unit cross-sectional area per unit head under laminar flow conditions, in the normal direction through a geotextile. **D1987, D4491/D4491M**

pore volume of flow (V_{pq}), *n*—the cumulative volume of flow through a test specimen divided by the volume of voids within the specimen. **D5567**

pre-fabricated vertical drain (PVD), *n*—a geocomposite consisting of geotextile cover and drainage core installed vertically into soil to provide drainage for accelerating consolidation of soils.

Discussion—Also known as band or wick drain.

pressure flow, *n*—flow in a direction parallel to the plane of a geotextile or related product driven predominately by a differential fluid pressure. **D4716/D4716M**

primary sampling unit, *n*—the sampling unit containing all the sources of variability which should be considered in acceptance testing; the sampling unit taken in first stage of selection in any procedure for sampling a lot or shipment. **D4354**

production unit—*as referred to in this practice*, is a quantity of geotextile agreed upon by the purchaser and seller for the purpose of sampling. **D4354**

proportional limit, *n*—the greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). **D4595**

Copyright ASTM International
Provided by IHS Markit under license with ASTM
No reproduction or networking permitted without license from IHS

Licensee=Sargent & Lundy/5915733100, User=Nielson, David
Not for Resale, 04/27/2021 08:51:47 MDT

puncture resistance, (F), *n*—the inherent resisting mechanism of the test specimen to the failure by a penetrating or puncturing object. **D4833/D4833M**

quality assurance, *n*—all those planned or systematic actions necessary to provide adequate confidence that a material, product, system, or service will satisfy given needs. **D4354**

quality control, *n*—the operational techniques and the activities which sustain a quality of material, product, system, or service that will satisfy given needs; also the use of such techniques and activities. **D4354**

rate of creep, *n*—the slope of the creep-time curve at a given time. **D5262**

residual shear strength, *n*—value of shear stress at sufficiently large displacement where the stress remains constant with continued shearing

rib, *n*—for geogrids, the continuous elements of a geogrid which are interconnected to a node or junction.

sample, *n*—(*1*) a portion of material which is taken for testing or for record purposes. (*2*) a group of specimens used, or of observations made, which provide information that can be used for making statistical inferences about the population(s) from which the specimens are drawn. (See also **laboratory sample, lot sample,** and **specimen.**) **D4354, D5818**

sample, laboratory—See **laboratory sample.**

sample, lot—See **lot sample.**

sampling unit, *n*—an identifiable, discrete unit or subunit of material that could be taken as part of a sample. (See also **primary sampling unit, laboratory sample,** and **specimen.**) **D4354**

sampling unit, primary—See **primary sampling unit.**

seam, *n*—a permanent joining of two or more materials. **D5820**

seam, *n*—the connection of two or more pieces of material by mechanical, chemical, or fusion methods to provide the integrity of a single piece of the material. **D5641/D5641M**

seam allowance, *n*—the width of fabric used in making a seam assembly, bounded by the edge of the fabric and the furthest stitch line. **D4884/D4884M**

seam assembly, *n*—the unit obtained by joining fabrics with a seam, including details such as fabric direction(s), seam allowance, sewing threads used, and number of stitches per unit length; and sometimes additional details of fabrication such as sewing-machine type and speed, needle type and size, etc. **D4884/D4884M**

seam design engineering, *n*—the procedures used to select a specific thread, a specific stitch type, and a specific seam type to achieve the required seam strength. **D4884/D4884M**

seam efficiency, sewn, *n*—*in sewn fabrics*, the ratio expressed as a percentage of seam strength to fabric strength.

seam interaction, *n*—the result of combining a specific textile, a specific stitch type, and a specific seam type. **D4884/D4884M**

seam type, *n*—*in sewn fabrics,* an alphanumeric designation relating to the essential characteristics of fabric positioning and rows of stitching in a specific sewn fabric seam (see Federal Standard 751). **D4884/D4884M**

secant modulus, *n*—the ratio of stress (nominal) to corresponding strain at any specified point on the stress-strain curve. **D5323**

secant modulus, J_{sec}, (FL^{-1}), Nm^{-1}, *n*—*for geosynthetics*, the ratio of change in force per unit width to the change in elongation between two points on a force-elongation curve. **D4885**

selvage, *n*—the woven edge portion of a fabric parallel to the warp. **D4884/D4884M**

sewing thread, *n*—a flexible, small-diameter yarn or strand, usually treated with a surface coating, lubricant, or both, intended to be used to stitch one or more pieces of material or an object to a material. **D4884/D4884M**

sewn seam, *n*—*in sewn fabrics*, a series of stitches joining two or more separate plies of a material or materials of planar structure such as textile fabric. **D4884/D4884M**

sewn seam strength, *n*—*for geotextiles*, the maximum resistance, measured in kilonewtons per metre, of the junction formed by stitching together two or more planar structures. **D4884/D4884M**

specification, *n*—a precise statement of a set of requirements to be satisfied by a material, product, system or service that indicates the procedures for determining whether each of the requirements is satisfied. **D4759**

specific gravity, *n*—the ratio of the density of the substance in question to the density of a reference substance at specified conditions of temperature and pressure. **D4439**

specimen, *n*—a specific portion of a material or laboratory sample upon which a test is performed or which is taken for that purpose. (*Syn.* test specimen) **D4354**

standard geosynthetic laboratory environment—a general purposes geosynthetic laboratory should control, monitor, and record the temperature range to 22 ± 3 °C and the relative humidity to 45 to 75 %. In cases of dispute, one should use the "atmosphere for testing" suggested in the appropriate standard test method.

stiffness, *n*—resistance to bending. **D4439**

stitch, *n*—the repeated unit formed by the sewing thread in the production of seams in a sewn fabric (see Federal Standard 751a). **D4884/D4884M**

strain, *n*—the change in length per unit of length in a given direction. **D4439**

stress crack, *n*—an external or internal crack in a plastic caused by tensile stresses less than its short-time mechanical strength. **D5397**

tangent point, *n*—*for geotextiles*, the first point of the force-elongation curve at which a major decrease in slope occurs. **D4595**

Copyright ASTM International
Provided by IHS Markit under license with ASTM
No reproduction or networking permitted without license from IHS
Licensee=Sargent & Lundy/5915733100, User=Nielson, David
Not for Resale, 04/27/2021 08:51:47 MDT

tearing strength, (F, (F), kN), *n*—the force required either (*1*) to start or (*2*) to continue or propagate a tear in a fabric under specified conditions. **D4439, D4533/D4533M**

temperature stability, *n—for a geotextile*, the percent change in tensile strength or in percent elongation as measured at a specified temperature and compared to values obtained at the standard conditions for testing geotextiles. **D4594/D4594M**

tensile creep rupture strength, [FL^{-1}], *n—for geosynthetics*, the force per unit width that will produce failure by rupture in a creep test in a given time, at a specified constant environment **D5262**

tensile creep strain, *n*—the total strain at any given time. **D5262**

tensile modulus, J, (FL^{-1}), Nm^{-1}, *n—for geotextiles*, the ratio of the change in tensile force per unit width to a corresponding change in strain (slope). **D4595**

tensile strength, *n—for geotextiles*, the maximum resistance to deformation developed for a specific material when subjected to tension by an external force. **D4595**

tensile test, *n—in textiles*, a test in which a textile material is stretched in one direction to determine the force-elongation characteristics, the breaking force, or the breaking elongation. **D4595**

test result, *n*—a value obtained by applying a given test method, expressed either as a single observation or a specified combination of a number of observations. **D4354**

test section, *n*—a distinct area of construction. **D5818**

thickness, compressed—See **compressed thickness**.

turbulent flow, *n*—that type of flow in which any water particle may move in any direction with respect to any other particle, and in which the head loss is approximately proportional to the second power of the velocity. **D4716/D4716M**

turf reinforcement mat (TRM), *n—in erosion control*, a non-degradable geosynthetic or geocomposite processed into a matrix sufficient to increase the stability threshold of otherwise unreinforced established vegetation.

Discussion—Products in this category may incorporate ancillary degradable components to enhance the germination and establishment of vegetation.

typical value, *n—for geosynthetics*, the mean value calculated from documented manufacturing quality control test results for a defined population obtained from one test method associated with on specific property. **D4439**

vacuum chamber, *n*—a device that allows a vacuum to be applied to a surface. **D5641/D5641M**

vertical strip drain, *n*—a geocomposite consisting of a geotextile cover and drainage core installed vertically into soil to provide drainage for accelerating consolidation of soils.

Discussion—Also known as band drain, wick drain, or prefabricated vertical drain (PVD).

void ratio (e, (D)), *n*—the ratio of the volume of void space to the volume of solids. **D4439**

warp, *n*—the yarn running lengthwise in a woven fabric. **D4884/D4884M**

weft, *n*—see **filling**.

wide strip tensile test, *n—for geosynthetics*, a tensile test in which the entire width of a 200 mm (8.0 in.) wide specimen is gripped in the clamps and the gage length is 100 mm (4.0 in.). **D4885**

wide-width strip tensile test, *n—for geotextiles*, a uniaxial tensile test in which the entire width of a 200-mm (8.0-in.) wide specimen is gripped in the clamps and the gage length is 100 mm (4.0 in.). **D4595**

work-to-break (W, (LF)), *n—in tensile testing*, the total energy required to rupture a specimen. **D4439, D4595, D4885**

yield point, *n—in geosynthetics*, the point on the force-elongation curve at which the first derivative equals zero (the first maximum). **D4885**

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; http://www.copyright.com/

Copyright ASTM International
Provided by IHS Markit under license with ASTM
No reproduction or networking permitted without license from IHS

Licensee=Sargent & Lundy/5915733100, User=Nielson, David
Not for Resale, 04/27/2021 08:51:47 MDT

ATTACHMENT B

Standard Practice for Collection of Settled Dust Samples
Using Wipe Sampling Methods for Subsequent Determination of Metals
ASTM D6966-18

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: D6966 – 18

Standard Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Determination of Metals[1]

This standard is issued under the fixed designation D6966; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the collection of settled dust on surfaces using the wipe sampling method. These samples are collected in a manner that will permit subsequent extraction and determination of target metals in the wipes using laboratory analysis techniques such as atomic spectrometry.

1.2 This practice does not address the sampling design criteria (that is, sampling plan which includes the number and location of samples) that are used for clearance, hazard evaluation, risk assessment, and other purposes. To provide for valid conclusions, sufficient numbers of samples should be obtained as directed by a sampling plan, for example, in accordance with Guide D7659.

1.3 This practice contains notes that are explanatory and are not part of the mandatory requirements of this practice.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1356 Terminology Relating to Sampling and Analysis of Atmospheres
D4840 Guide for Sample Chain-of-Custody Procedures
D7144 Practice for Collection of Surface Dust by Micro-vacuum Sampling for Subsequent Metals Determination
D7659 Guide for Strategies for Surface Sampling of Metals and Metalloids for Worker Protection
D7707 Specification for Wipe Sampling Materials for Beryllium in Surface Dust
E1792 Specification for Wipe Sampling Materials for Lead in Surface Dust

3. Terminology

3.1 For definitions of terms not listed here, see Terminology D1356.

3.2 *Definitions:*

3.2.1 *batch, n*—a group of field or quality control (QC) samples that are collected or processed together at the same time using the same reagents and equipment.

3.2.2 *wipe, n*—a disposable towellette that is moistened with a wetting agent. **E1792**

3.2.2.1 *Discussion*—These towellettes are used to collect samples of settled dust on surfaces for subsequent determination of metals content in the collected dust.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *field blank, n*—a wipe (see 3.2.2) that is exposed to the same handling as field samples except that no sample is collected (no surface is actually wiped).

3.3.1.1 *Discussion*—Analysis results from field blanks provide information on the analyte background level in the wipe, combined with the potential contamination experienced by samples collected within the batch (see 3.2.1) resulting from handling.

4. Summary of Practice

4.1 Wipe samples of settled dust are collected on surfaces from areas of known dimensions with wipes satisfying certain requirements, using a specified pattern of wiping.

4.2 The collected wipes are then ready for subsequent sample preparation and analysis for the measurement of metals of interest.

---

[1] This practice is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.04 on Workplace Air Quality.

Current edition approved Nov. 1, 2018. Published November 2018. Originally approved in 2003. Last previous edition approved in 2013 as D6966 – 13. DOI: 10.1520/D6966-18.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States

Copyright ASTM International
Provided by IHS Markit under license with ASTM
No reproduction or networking permitted without license from IHS

Licensee=Sargent & Lundy/5915733100, User=Nielson, David
Not for Resale, 04/28/2021 18:09:41 MDT

5. Significance and Use

5.1 This practice is intended for the collection of settled dust samples for the subsequent measurement of target metals. The practice is meant for use in the collection of settled dust samples that are of interest in clearance, hazard evaluation, risk assessment, and other purposes.

5.2 This practice is recommended for the collection of settled dust samples from hard, relatively smooth nonporous surfaces. This practice is less effective for collecting settled dust samples from surfaces with substantial texture such as rough concrete, brickwork, textured ceilings, and soft fibrous surfaces such as upholstery and carpeting. Micro-vacuum sampling using Practice D7144 may be more suitable for these surfaces. Collection efficiency for metals such as lead from smooth, hard surfaces has been found to exceed 75 % (Specification E1792).

6. Apparatus and Materials

6.1 *Sampling Templates*—One or more of the following: 10 cm by 10 cm (minimum dimensions) reusable or disposable aluminum or plastic template(s), or disposable cardboard templates, (full-square, rectangular, square "U-shaped," rectangular "U-shaped," or "L-shaped," or both); or templates of alternative areas having accurately known dimensions (see Note 1). Templates shall be capable of lying flat on a surface.

NOTE 1—For most surfaces, it is recommended to collect settled dust from a minimum surface area of 100 cm^2 to provide sufficient material for subsequent laboratory analysis. However, larger areas (for example, 30 cm by 30 cm) may be appropriate for surfaces having little or no visible settled dust, while a smaller sampling area (for example, 10 cm by 10 cm) may be appropriate for surfaces with high levels of visible settled dust. It is recommended to have a suite of templates with various sampling dimensions.

6.2 *Wipes,* for collection of settled dust samples from surfaces. Wipes shall be individually wrapped and fully wetted. The background metal(s) content of the wipes should be as low as possible. At a maximum, the background level of target metal(s) shall be no more than one-tenth the target concentration the metal(s) to be measured.

NOTE 2—Wipes meeting the requirements of Specifications E1792 or D7707, or both, may be suitable.

NOTE 3—Wipes made of cellulosic materials may produce fewer analysis problems than wipes made of synthetic polymeric materials.

6.3 *Sample containers,* sealable, rigid-walled, 30-mL minimum volume.

NOTE 4—Screw-top plastic centrifuge tubes are an example of a suitable rigid-walled sample container.

NOTE 5—Use of a sealable plastic bag for holding and transporting the settled dust wipe sample is not recommended due to the potential loss of collected dust within the plastic bag during transportation and laboratory handling. Quantitative removal and processing of the settled dust wipe sample by the laboratory is significantly improved through the use of sealable rigid-walled containers.

6.4 *Measuring tool,* tape or ruler, capable of measuring to the nearest ±0.1 cm.

6.5 *Plastic gloves,* powderless.

6.6 *Cleaning cloths,* for cleaning of templates and other equipment.

NOTE 6—Wipes used for dust sampling (6.2) can be used for cleaning templates and other sampling equipment, but other cleaning cloths or wipes not meeting the requirements described in (6.2) may be suitable for this purpose.

6.7 *Adhesive tape,* suitable for securing the template(s) to the surface(s) to be sampled, and for demarcating sampling areas if templates are not used.

NOTE 7—Masking tape, for example, functions well for these purposes.

6.8 *Disposable shoe covers,* optional.

7. Procedure

7.1 Use one of the following two options when collecting settled dust samples from each sampling location. For wide, flat locations, it is recommended to use the template-assisted sampling procedure (see 7.1.1.2 (*1*)). For small locations (for example, window sill, section of a piece of equipment, or portion of a vehicle interior), it will ordinarily be necessary to use the confined-area sampling procedure (see 7.1.1.2 (*2*)).

NOTE 8—Metal contamination problems during field sampling can be severe and may affect subsequent wipe sample analysis results. Contamination can be minimized through frequent changing of gloves, use of shoe covers (see 6.8), and regular cleaning of sampling equipment with cleaning cloths (see 6.6). Use of disposable shoe covers between different locations, and removal of them prior to leaving the sampling site or entering vehicles, can be helpful in minimizing inadvertent transfer of contaminated dust from one location to another.

7.1.1 *Sampling Procedure:*

7.1.1.1 Don a pair of clean, powderless, plastic gloves (see 6.5 and Note 8).

7.1.1.2 Use either a template-assisted sampling procedure (*1*) or tape-defined sampling procedure (*2*):

(*1*) Carefully place a clean template on the surface to be sampled in a manner that minimizes disturbance of settled dust at the sampling location. Tape the outside edge of the template to prevent the template from moving during sample collection.

(*2*) Alternatively, mark the defined area to be sampled with adhesive tape (6.7) being careful not to disturb the settled dust, and measure the area to be sampled using the measuring tool (6.4).

7.1.1.3 Obtain a wipe (6.2) and, if there is a possibility for the package containing the wipe to be contaminated with dust, clean the outside of the package with a cleaning cloth (6.6).

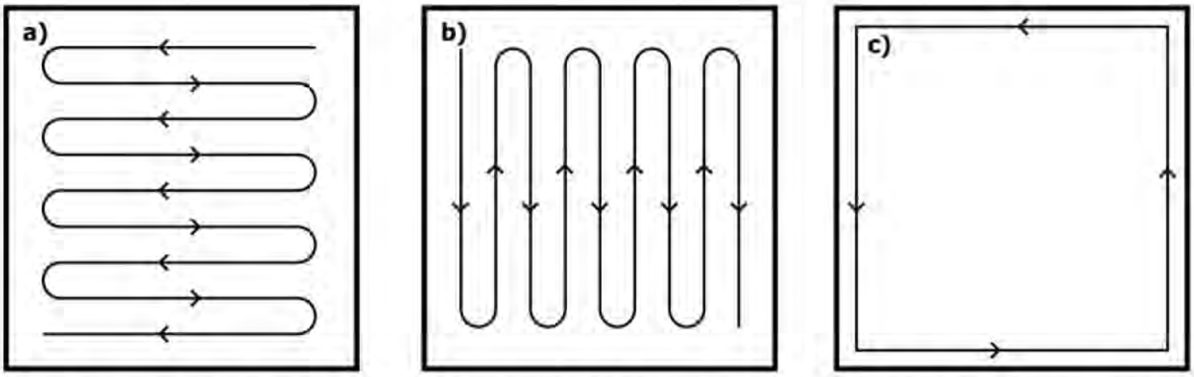
7.1.1.4 Remove the wipe from its package, and inspect the wipe to ensure that it is fully wetted and not contaminated with dust or other material. Discard the wipe if it is found to be too dry or contaminated, or both.

7.1.1.5 Using an open flat hand with the fingers together, place the wipe on the surface to be sampled. Wipe the selected surface area, side to side, in an overlapping "S" or "Z" pattern while applying pressure to the fingertips (refer to Figs. 1 and 2). Wipe the surface so that the entire selected surface area is covered. Perform the wiping procedure using the fingers and not the palm of the hand.

7.1.1.6 Repeat 7.1.1.5 using a different brand of wipe (after selecting a different sampling location) if the wipe originally used significantly changes shape (for example, rolls up by curling) or tears during the wiping process.

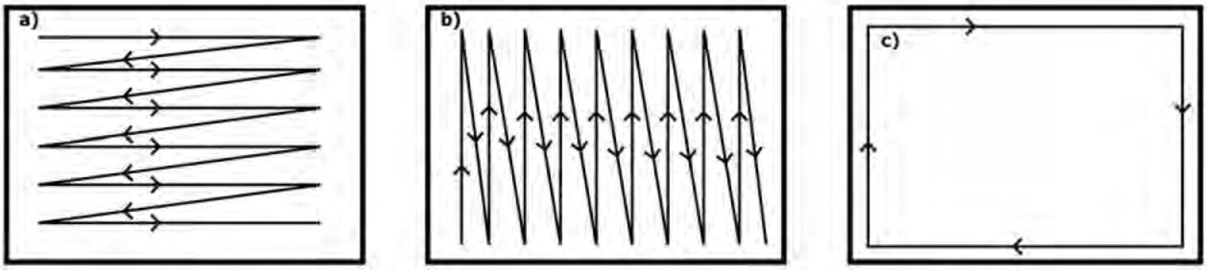
NOTE 9—Some surfaces (for example, rough surfaces) may cause certain wipes to curl up or otherwise significantly change shape during the wiping process. A type of wipe that maintains its integrity should be selected for each surface sampled.

Copyright ASTM International
Provided by IHS Markit under license with ASTM
No reproduction or networking permitted without license from IHS
Licensee=Sargent & Lundy/5915733100, User=Nielson, David
Not for Resale, 04/28/2021 18:09:41 MDT



NOTE 1—Only the center of the wiping path is shown, not the entire wiping width. Fig. 1a) shows the first "S" wiping pattern over the surface area to be sampled; Fig. 1b) demonstrates the second "S" wiping course over the surface; and Fig. 1c) shows the final wiping which is targeted toward edges and corners.

FIG. 1 Schematic of a Side-to-Side Overlapping "S" Wiping Pattern



NOTE 1—Only the center of the wiping path is shown, not the entire wiping width. Fig. 2a) shows the first "Z" wiping pattern over the surface area to be sampled; Fig. 2b) demonstrates the second "Z" wiping course over the surface; and Fig. 2c) shows the final wiping which is targeted toward edges and corners.

FIG. 2 Schematic of a Side-to-Side Overlapping "Z" Wiping Pattern

7.1.1.7 Fold the wipe in half with the collected dust side folded inward and repeat the preceding wiping procedure (7.1.1.5) within the selected sampling area using an up and down overlapping "S" or "Z" pattern at right angles to the first wiping (see Fig. 1, Fig. 2, and Note 10).

NOTE 10—Wipes are folded to envelop the collected dust within the wipe, to avoid loss of the collected dust, and to expose a clean wipe surface for further dust collection from the sampling location. For sample areas containing large amounts of settled dust, carefully wipe the area to ensure as much dust as possible within the wipe is captured.

7.1.1.8 Fold the wipe in half again with the collected dust side folded inward and repeat the wiping procedure one more time, concentrating on collecting settled dust from edges and corners within the selected surface area (see Fig. 1, Fig. 2, and Note 10).

7.1.1.9 Fold the wipe again with the collected dust side folded inward and insert the wipe into a sample container (6.3).

7.1.1.10 Label the sample container with sufficient information to uniquely and indelibly identify the sample.

7.1.1.11 Record the dimensions (in square centimetres) of the selected sampling area (that is, the internal dimensions defined by the template or the taped area) or that the sample is a blank.

7.1.1.12 Discard the gloves.

7.2 Collect field blanks at a minimum frequency of 5 % (at least one field blank for every 20 wipe samples collected). The minimum number of field blanks to collect for each batch of wipe samples used should be three. Place field blanks in sample containers and label these samples in the same fashion as the collected surface dust samples (see 7.1.1.10).

7.3 Follow sampling chain of custody procedures to ensure sample traceability. Ensure that the documentation which accompanies the samples is suitable for a chain of custody to be established in accordance with Guide D4840.

8. Records

8.1 Field data related to sample collection shall be documented in a sample log form or field notebook (see Note 11). If field notebooks are used, then they shall be bound with pre-numbered pages. All entries on sample data forms and field notebooks shall be made using ink, with the signature and date of entry. Any entry errors shall be corrected by using only a single line through the incorrect entry (no scratch outs), accompanied by the initials of the person making the correction, and the date of the correction (see Note 12).

8.1.1 *Electronic Laboratory Notebooks*—If electronic laboratory notebooks, or ELNs, are used in lieu of a field notebook or sample log, procedures shall be implemented to assure the integrity of the data recorded, including prevention of falsification or other unauthorized changes, and regular backup of data.

NOTE 11—Field notebooks are useful for recording field data even when preprinted sample data forms are used.

NOTE 12—These procedures are important to properly document and trace field data.

8.2 At a minimum, the following information shall be documented:

8.2.1 Project or client name, address, and city/state/country location.

8.2.2 General sampling site description.

8.2.3 Information as to the specific collection protocol used (for example, template-assisted; "Z"-wiping pattern, etc.).

8.2.4 Information as to the specific type or brand of wipes used, including manufacturer and lot number.

8.2.5 Information on quality control (QC) samples: which samples are associated with what group of field blanks.

8.2.6 For each sample collected (including field blanks): an individual and unique sample identifier and date of collection. This information shall be recorded on the sample container in addition to the field documentation.

8.2.7 For field samples (not including field blanks), record in field documentation (field notebook or sample log form) the dimensions of each area sampled (in square centimetres).

8.2.8 For each sample collected: name of person collecting the sample, and specific sampling location information from which the sample was removed.

9. Keywords

9.1 metals measurement; sample collection; settled dust; surfaces; wipe

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; http://www.copyright.com/

Copyright ASTM International
Provided by IHS Markit under license with ASTM
No reproduction or networking permitted without license from IHS
Licensee=Sargent & Lundy/5915733100, User=Nielson, David
Not for Resale, 04/28/2021 18:09:41 MDT

ATTACHMENT C

A Leachate Pond Geomembrane After 25 years of Service

Industrial Fabrics Association International

Categories

- Awards
- IAA
- IFF
- Showstoppers
- Business
- Safety
- Conference
- Division News
- Editorial
- Expo News
- Feature
- Case Study
- Containment
- Environmental
- Erosion Control
- Reinforcement
- Separation
- Transportation
- GMA Techline
- Perspective
- Final Inspection
- From Our Readers
- GeoDallas
- Watch
- GeoWatch
- In the Classroom
- In the Industry
- Markets
- Geosynthetics Materials
- Drainage Materials
- Erosion Control

A leachate pond geomembrane after 25 years of service

February 1st, 2019 / By: Richard Thiel / Feature

FIGURE 1 Aerial view of operational leachate and rainwater ponds built 25 years ago

This article reports on the evaluation of an exposed geomembrane liner in a landfill leachate pond after being in service for 25 years. The evaluation was performed in two campaigns: in August 2014 and in May 2018. The purpose of the evaluation was to determine the condition of the geomembrane and to provide a recommendation to the owner on whether or not it was in need of imminent replacement. The results of the evaluation indicate that the geomembrane appears to be in decent condition and is expected to last some number of additional years, but the definitive number is not possible to estimate. Based on the work performed in 2014, it seems that the material is still readily repairable, if need be. Recommendations for future periodic inspection and testing are provided herein.

The leachate pond is a 5-million-gallon (19-million-L) double-lined leachate storage pond that was constructed

Materials
Geocells
Geogrids
Geomembranes
Geosynthetic Clay Liners
Geotextiles
Member News
News
Company News
COVID-19
Events
GMA News
GSI News
IGS-NA (NAGS)
Industry News
Industry News
Panorama
People
Updates
Premier Product Preview
Press Release
Press Release
Products
ShowStoppers
Projects
Resources
Designer's Forum
Technical
Specifications
Testing & Codes
White Papers

for the Headquarters Landfill in Cowlitz County, Wash., in 1993. The pond is designed with a dividing berm that partitions the pond into two equal, symmetric halves. The dividing berm is lined over its top so that the liner system is continuous between the two pond halves. The southern half of the pond has historically contained various levels of clean rainwater, with only occasional containment of leachate toward the end of a few wet winters. The northern half of the pond has historically been the primary management basin for leachate storage, and its sump is used for leachate transfer via an outlet pipe. **Figure 1** shows an aerial view of the ponds.

The pond was operated for 21 years by Weyerhaeuser for its forest products landfill, the leachate of which derived from pulp and paper industrial waste, ash, and related industrial and construction waste. In 2014 the county purchased the landfill, and since that time the landfill has been operated as a mixed municipal solid waste (MSW)/industrial waste landfill.

TABLE 1 Summary of test results for headquarters landfill facility leachate pond primary geomembrane

The 80-mil (2-mm) primary exposed geomembrane that was installed in 1993 was manufactured by GSE Environmental (then Gundle) as a custom order with three co-extruded layers. The top layer is textured high-density polyethylene (HDPE) with a white pigment. The middle layer is very low density polyethylene (VLDPE). The bottom layer is smooth HDPE containing extra carbon black to make it electrically conductive for spark testing. The original project specifications and conformance testing results for the primary pond geomembrane are included in **Table 1**.

Sampling strategy and field observations

In 2014 two above-water samples were taken and tested. Sample #1 was taken from the anchor trench. Sample #2 was taken from the middle of the berm slope on the southern pond (which is south facing) near the crest of the slope. The sample was 12-inches wide × 48-inches long (30-cm × 122-cm) (parallel to the slope crest). The hole was easily repaired with HDPE geomembrane that was on-site for construction of a new landfill cell.

In May 2018 two “below-water” samples were taken from rub sheets in the bottoms of both the southern and northern halves of the pond that had been largely submerged for the past 25 years. Sample #3 was taken from the southern pond that typically contained clean rainwater, and Sample #4 was taken from the northern pond that had continuously contained landfill leachate. Due to sediment and sludge buildup around the outlet in the sump of the northern pond, that pond was cleaned in April 2018. The southern pond also had to be completely emptied and cleaned at this time, because it had been used temporarily for leachate management in the past winter and needed to be prepared to store clean water again. The cleaning activities in both ponds at this time allowed access to the pond bottoms where samples could be cut from existing loose rub sheets. It should be noted that the conditions of the rub sheets would be conservative in the sense that both sides of the rub sheets had been exposed to the contained fluids, whereas for the primary geomembrane, only the upper side would have been exposed to the contained fluids.

FIGURE 2 Patching a hole in pond liner where a sample was taken for testing in May 2014. The photograph shows trial weld being performed

Visual inspection of the exposed and cleaned geomembrane in both halves of the pond indicated the geomembrane to be in good condition with no signs of degradation or cracks. While *where new HDPE is being welded to old pond liner.*

no repair welds were required in 2018, the repair welds performed in 2014 appeared to be successful with excellent trial-weld field test observations. **Figure 2** shows a patch being installed on the sampling location, **Figure 3** shows the beginning of removing sludge from the northern half of the pond in 2018, and **Figure 4** shows the empty northern pond after cleaning.

Results

The samples that were taken in 2014 and 2018 were tested for a suite of index and performance parameters. A summary of the results for both the 2014 and 2018 testing campaigns is presented in **Table 1**. The anchor trench sample appears to meet or exceed the original project specifications. Where there are actual test results from 1993 (thickness, density, carbon black content, carbon black dispersion, tensile break strength and tensile break elongation), there appear to be no degradation in the anchor trench sample. We note there are still substantial oxidative induction time (OIT) and high-pressure oxidative induction time (HP-OIT) values in the anchor trench sample that would exceed current GRI-GM13 standards for new geomembranes. The stress crack results from the single point-notched constant tensile load test (SP-NCTL) are exceptional, which is undoubtedly due to the VLDPE core. Having this stress crack-resistant core was the original purpose of coextruding with VLDPE.

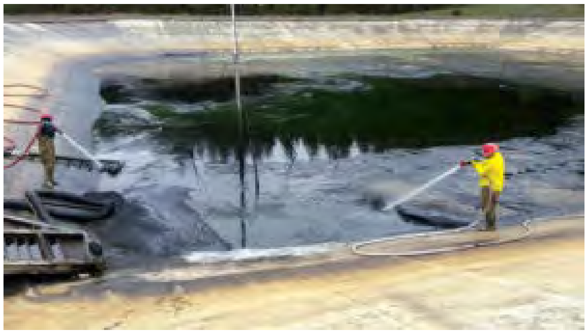


FIGURE 3 April 2018 cleaning sludge from northern half of pond

Comparing the test results between the 2014 above-water exposed sample, the 2018 below-water sample from the northern (leachate) side of the pond, and the 2018 below-water sample from the southern (rainwater) side of the pond indicates very interesting patterns of degradation. With the exception of HP-OIT, the least amount of degradation (as indicated by the test results) occurred in the below-water sample from the leachate (northern) side of the pond. This result was the opposite of what was expected. For HP-OIT, the least amount of degradation occurred in the above-water sample.

The greatest amount of degradation, across the board, occurred in the below-water sample from the rainwater (southern) side of the pond.

Degradation in the exposed above-water sample from 2014 was generally midway between the other two samples, with the exceptions of melt flow index (MFI) and HP-OIT, where it had the least amount of degradation. The small amounts of apparent degradation in tensile yield strength, puncture and tear (all < 10%) in the below-water samples is probably not substantial.

The increase in MFI of 14% in both of the below-water samples is not excessive but is relatively substantial evidence that some level of polymer-chain breakdown is occurring in the primary geomembrane as a result of submergence. However, it is not known in which of the three coextruded layers of the primary geomembrane this might be occurring. That could be determined through more sophisticated testing.

FIGURE 4 April 2018 northern half of pond after cleaning

The most significant test parameters of concern that indicate substantive degradation are the OIT test results that reveal a substantial amount of depletion of the antioxidant package. These results indicate that even though there was some significant degradation, especially in the rainwater side of the pond, there are still ample stabilizers present in the material to protect it for some time, but exactly how much time is not predictable.

The key performance test result is the SP-NCTL stress crack test data, in which all samples continue to perform well.

Discussion

Why was the below-water leachate sample the least degraded? Perhaps the leachate contains a soup of dissolved solids and compounds that was not aggressive in using up or dissolving the antioxidant package and also provided a low diffusion gradient potential for leaching and blooming of antioxidants from the interior of the geomembrane to its surface, and thus preserved the antioxidants within the geomembrane.

Conversely, the clean rainwater may create a high diffusion-gradient differential to pull antioxidants to the surface of the geomembrane. The "very clean" and aggressive pure rainwater may also react with the antioxidants or cause them to move out of the geomembrane and go into solution with the water. In the same manner, the aggressive and very clean water may have also attacked the polyethylene resin at a higher rate than either the leachate or the atmosphere, resulting in apparent degradation in tensile properties.

One interesting conclusion that could be derived from the testing is that if the geomembrane is going to experience failure, it will likely occur on the clean rainwater side of the pond before the leachate side of the pond. This is good news for the pond operator who is wondering when the liner should be replaced. If a failure would occur significantly in advance in the rainwater side of the pond compared to the leachate side, then that may allow adequate response time and not be of great consequence because the water is clean. The clean (southern) side of the pond could be immediately emptied and relined, followed by a transfer of leachate to the relined southern side, and a subsequent relining of the northern side, hopefully before the northern side fails.

While this study was very fortunate in being able to evaluate four samples from a range of exposure conditions (anchor trench, above-water exposed, below-water leachate and below-water rainwater), there could exist elevation zones in both halves of the pond, such as at the waterline, or various UV exposure locations that created a higher level of degradation than any of the samples that were retrieved.

FIGURE 5 Photograph from 2014 of original razor-blade slit that extended through the white surface into the VLDPE core. During the NCTL stress-crack test, the sharp notch eventually blunted and did not propagate, which is a testimony to the functionality of the VLDPE core to resist stress cracking. No photographs were taken in 2018, but the NCTL results indicated continued very strong performance for this test.

In 2014 the testing laboratory took some close-up photographs (e.g., **Figure 5**) of the razor-blade slit in the test specimen during the SP-NCTL test. It was clear, even in such photographs, that blunting of the sharp razor cut had occurred during the test due to the performance of the VLDPE core and that cracks will not easily expand through the VLDPE layer. This provides further confidence that a sudden failure may not be catastrophic, especially considering the presence of a complete secondary geomembrane and leakage collection layer between the primary and secondary geomembranes.

Conclusions, recommendations, qualifiers and other considerations

Field observations indicated that the exposed geomembrane is in decent shape after 25 years of service and shows no visible signs of degradation. There does not appear to be any leakage of leachate into the leakage detection layer in these double-lined ponds, which is again indicative of positive primary liner performance.

Laboratory test results of geomembrane samples taken from the northern and southern halves of the pond support the field observations and indicate that there are still ample stabilizers present to protect this material for some years to come, perhaps even on the order of five to ten years. We must add a caveat that these conclusions with the fact that a limited number of samples were taken, and there could be more critical areas that were not detected.

Based on these results, the team concluded that the leachate pond can continue in operation in the same manner it has been since put into service 26 years ago. The owner was advised to obtain additional samples from the southern pond in three years' time and that it be tested for the same parameters that were tested in this study. This will allow for a better estimate to be made of remaining lifetime. The sample would be of highest value if it could be taken in the summer when the water level is low and a trial weld be performed to continue to assess liner repairability. In addition, the leakage detection sumps should continue to be monitored. Some leakage can be allowed to the extent that it would not exceed 12 inches (30 cm) of head on the secondary liner system outside the sumps. Since there is a dual-basin system in the pond, one side of the pond could be taken out of service, if need be, while the pond was operated from the other side.

Richard Thiel, P.E., is the president of Thiel Engineering in Oregon House, Calif.

More News:

Amsterdam Schiphol Airport: Effective stormwater management

Fabtech Australia replaces huge anaerobic lagoon geosynthetic cover

GMA Techline: Anchors, tie-rods and whalers

GMA Techline: Geomembranes for reinforcement?

GMA Techline: Installing a geomembrane low to high gradient?

Modular geosynthetics construction

PREVIOUS

NEXT

Leave a Reply

Your email address will not be published. Required fields are marked *

Comment

Comments are moderated and will show up after being approved.

Name *

Email *

Website

☐

Save my name, email, and website in this browser for the next time I comment.

Post Comment

Working Together to Advance the Industry

Geosynthetics Magazine is a publication of the Industrial Fabrics Association International

LEARN MORE ABOUT IFAI

SIGN UP FOR E-NEWSLETTER

Copyright ©2021 Industrial Fabrics Association International. All rights reserved.

1801 County Road B W
Roseville, MN 55113-4061, USA

651 222 2508 or 800 225 4324

Terms of Service
Privacy Policy

Publications

Specialty Fabrics Review
Geosynthetics
InTents
Marine Fabricator
Advanced Textiles Source
Fabric Architecture

Company

About IFAI
Events
Divisions
Publications

Support

Contact
Advertise
Support
FAQ

Membership

Member Benefits
Member Directory
Join IFAI Today

Geosynthetics Conference

Become a member today and get discounted pricing on registration

JOIN IFAI TODAY

Connect

ATTACHMENT D

Technical Guidance Document:
Quality Assurance and Quality Control for
Waste Containment Facilities
EPA/600/R-93/182

EPA/600/R-93/182
September 1993

Technical Guidance Document:

QUALITY ASSURANCE AND QUALITY CONTROL FOR WASTE CONTAINMENT FACILITIES

by

David E. Daniel
University of Texas at Austin
Department of Civil Engineering
Austin, Texas 78712

and

Robert M. Koerner
Geosynthetic Research Institute
West Wing, Rush Building No. 10
Philadelphia, Pennsylvania 19104

Cooperative Agreement No. CR-815546-01-0

Project Officer

David A. Carson
Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

Printed on Recycled Paper

DISCLAIMER

The information in the document has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement number CR-815546-01-0. It has been subject to the Agency's peer and administrative review and has been approved for publication as a U.S. EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document contains numerous references to various procedures for performing tests as part of the process of quality control and quality assurance. Standards published by the American Society for Testing and Materials (ASTM) are referenced wherever possible because ASTM procedures represent consensus standards. Other testing procedures referenced in this document were generally developed by an individual or a small group of individuals and, therefore, do not represent consensus standards. The mention of non-consensus standards does not constitute their endorsement.

The reader is cautioned against using this document for the direct preparation of site specific quality assurance plans or related documents without giving proper consideration to the site- and project-specific requirements. To do so would ignore the educational context of the accompanying text, innovations made since the publication of the document, and the prevailing unique and site-specific aspects of all waste containment facilities.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The United States Environmental Protection Agency (U.S. EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the U.S. EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the U.S. EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This document provides information needed to develop comprehensive quality assurance plans and to carry out quality control procedures at waste containment sites. It discusses quality assurance and quality control issues for compacted soil liners, soil drainage systems, geosynthetic drainage systems, vertical cutoff walls, ancillary materials, and appurtenances.

E. Timothy Oppelt
Director
Risk Reduction Engineering Laboratory

ABSTRACT

This Technical Guidance Document provides comprehensive guidance on procedures for quality assurance and quality control for waste containment facilities. The document includes a discussion of principles and concepts, compacted soil liners, soil drainage systems, geosynthetic drainage systems, vertical cutoff walls, ancillary materials, appurtenances, and other details. The guidance document outlines critical quality assurance (QA) and quality control (QC) issues for each major segment and recommends specific procedures, observations, tests, corrective actions, and record keeping requirements. For geosynthetics, QA and QC practices for both manufacturing and construction are suggested.

The main body of the text details recommended procedures for quality assurance and control. Appendices include a list of acronyms, glossary, and index. A companion document was under development by the American Society for Testing and Materials (ASTM) at the time of this writing that will contain all of the ASTM standards referenced in this guidance document as well as most, if not all, of the other test procedures that are referenced in this guidance document.

This report was submitted in fulfillment of CR-815546 by the University of Texas, Austin, under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 1991 to July 1993, and work was completed as of August 1993.

Table of Contents

List of Figures

List of Tables

Acknowledgments

The authors gratefully acknowledge the following individuals and organizations who provided many of the photographs included in this report: Stephen T. Butchko of Tensar Environmental Systems, Inc., Richard W. Carriker of James Clem Corporation, Steven R. Day of Geo-Con, Inc., Anthony E. Eith of RUST Environmental and Infrastructure, Inc., Vito Galante of Waste Management of North America, Inc., Gary Kolbasuk of National Seal Co., David C. Lauwers of Occidental Chemical Corp., David L. Snyder of Webtec, Edward Staff, Jr., of Staff Industries, Inc., Fred Struve of Gundle Lining Systems, Inc., Michael T. Taylor of JPS Elastomerics Corp., and Dennis B. Wedding of Hoechst Celanese Corp.

The authors wish to express their sincere appreciation to the following individuals, who reviewed and critiqued an earlier version of this manuscript: Craig H. Benson, Gordon P. Boutwell, Mark Cadwallader, Craig R. Calabria, James G. Collin, Jose D. Constantino, Steven R. Day, Robert Denis, Richard H. Dickinson, Thomas N. Dobras, Lee Embrey, Jeffrey C. Evans, Richard A. Goodrum, Dave Guram, Janice Hall, Bill Hawkins, Georg Heerten, William A. Hoffman III, Ted Koerner, David C. Lauwers, Larry D. Lydick, Lance Mabry, Stephen F. Maher, William C. Neal, Leo Overmann, Ian Peggs, Gregory N. Richardson, Charles Rivette, Mark D. Sieracke, Edward C. Staff, James Stenborg, Frank Taylor, Stephen J. Trautwein, James F. Urek, Luke van't Hoog, Mark H. Wayne, Felon R. Wilson, and John P. Workman. The authors also thank Joseph A. Dieltz who, through the Industrial Fabrics Association International, provided assistance in obtaining reviews of an earlier draft of this document.

The authors also gratefully acknowledge the many individuals, too numerous to name here, who over the years have shared their experiences and recommendations concerning quality assurance and quality control with the authors. The member organizations of the Geosynthetic Research Institute are thanked for support of this effort. Finally, the assistance of and input by Mr. Robert E. Landreth with the U.S. EPA is gratefully acknowledged.

Chapter 1

Manufacturing Quality Assurance (MQA) and Construction Quality Assurance (CQA) Concepts and Overview

1.1 Introduction

As a prelude to description of the detailed components of a waste containment facility, some introductory comments are felt to be necessary. These comments are meant to clearly define the role of the various parties associated with the manufacture, installation and inspection of all components of a total liner and/or closure system for landfills, surface impoundments and waste piles.

1.1.1 Scope

Construction quality assurance (CQA) and construction quality control (CQC) are widely recognized as critically important factors in overall quality management for waste containment facilities. The best of designs and regulatory requirements will not necessarily translate to waste containment facilities that are protective of human health and the environment unless the waste containment and closure facilities are properly constructed. Additionally, for geosynthetic materials, manufacturing quality assurance (MQA) and manufacturing quality control (MQC) of the manufactured product is equally important. Geosynthetics refer to factory fabricated polymeric materials like geomembranes, geotextiles, geonets, geogrids, geosynthetic clay liners, etc.

The purpose of this document is to provide detailed guidance for proper MQA and CQA procedures for waste containment facilities. (The document also is applicable to MQC and CQC programs on the part of the manufacturer and contractor). Although facility designs are different, MQA and CQA procedures are the same. In this document, no distinction is made concerning the type of waste to be contained (e.g., hazardous or nonhazardous waste) because the MQA and CQA procedures needed to inspect quality lining systems, fluid collection and removal systems, and final cover systems are the same regardless of the waste type. This technical guidance document has been written to apply to all types of waste disposal facilities, including new hazardous waste landfills and impoundments, new municipal solid waste landfills, nonhazardous waste liquid impoundments, and final covers for new facilities and site remediation projects.

This document is intended to aid those who are preparing MQA/CQA plans, reviewing MQA/CQA plans, performing MQA/CQA observations and tests, and reviewing field MQC/CQC and MQA/CQA procedures. Permitting agencies may use this document as a technical resource to aid in the review of site-specific MQA/CQA plans and to help in identification of any deficiencies in the MQA/CQA plan. Owner/operators and their MQA/CQA consultants may consult this document for guidance on the plan, the process, and the final certification report. Field inspectors may use this document and the references herein as a guide to field MQA/CQA procedures. Geosynthetic manufacturers may use the document to help in establishing appropriate MQC procedures and as a technical resource to explain the reasoning behind MQA procedures. Construction personnel may use this document to help in establishing appropriate CQC procedures and as a technical resource to explain the reasoning behind CQA procedures.

This technical guidance document is intended to update and expand EPA's Technical Guidance Document, "Construction Quality Assurance for Hazardous Waste Land Disposal

Facilities," (EPA, 1986). The scope of this document includes all natural and geosynthetic components that might normally be used in waste containment facilities, e.g., in liner systems, fluid collection and removal systems, and cover systems.

This document draws heavily upon information presented in three EPA Technical Guidance Documents: "Design, Construction, and Evaluation of Clay Liners for Waste Management Facilities" (EPA, 1988a), "Lining of Waste Containment and Other Impoundment Facilities" (1988b), and "Inspection Techniques for the Fabrication of Geomembrane Field Seams" (EPA, 1991a). In addition, general technical backup information concerning many of the principles involved in construction of liner and cover systems for waste containment facilities is provided in two additional EPA documents: "Requirements for Hazardous Waste Landfill Design, Construction, and Closure" (EPA, 1989) and "Design and Construction of RCRA/CERCLA Final Covers" (EPA, 1991b). Additionally, there are numerous books and technical papers in the open literature which form a large data base from which information and reference will be drawn in the appropriate sections.

1.1.2 Definitions

It is critical to define and understand the differences between MQC and MQA and between CQC and CQA and to counterpoint where the different activities contrast and/or complement one another. The following definitions are made.

- *Manufacturing Quality Control (MQC):* A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factory originated. MQC is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract plans.

- *Manufacturing Quality Assurance (MQA):* A planned system of activities that provides assurance that the materials were constructed as specified in the certification documents and contract plans. MQA includes manufacturing facility inspections, verifications, audits and evaluation of the raw materials and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if the manufacturer is in compliance with the product certification and contract plans for a project.

- *Construction Quality Control (CQC)*: A planned system of inspections that is used to directly monitor and control the quality of a construction project (EPA, 1986). Construction quality control is normally performed by the geosynthetics installer, or for natural soil materials by the earthwork contractor, and is necessary to achieve quality in the constructed or installed system. Construction quality control (CQC) refers to measures taken by the installer or contractor to determine compliance with the requirements for materials and workmanship as stated in the plans and specifications for the project.

- *Construction Quality Assurance (CQA)*: A planned system of activities that provides the owner and permitting agency assurance that the facility was constructed as specified in the design (EPA, 1986). Construction quality assurance includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility. Construction quality assurance (CQA) refers to measures taken by the CQA organization to assess if the installer or contractor is in compliance with the plans and specifications for a project.

MQA and CQA are performed independently from MQC and CQC. Although MQA/CQA and MQC/CQC are separate activities, they have similar objectives and, in a smoothly running construction project, the processes will complement one another. Conversely, an effective MQA/CQA program can lead to identification of deficiencies in the MQC/CQC process, but a MQA/CQA program by itself (in complete absence of a MQC/CQC program) is unlikely to lead to acceptable quality management. Quality is best ensured with effective MQC/CQC and MQA/CQA programs. See Fig. 1.1 for the usual interaction of the various elements in a total inspection program.

1.2 Responsibility and Authority

Many individuals are involved directly or indirectly in MQC/CQC and MQA/CQA activities. The individuals, their affiliation, and their responsibilities and authority are discussed below.

The principal organizations and individuals involved in designing, permitting, constructing, and inspecting a waste containment facility are:

- *Permitting Agency.* The permitting agency is often a state regulatory agency but may include local or regional agencies and/or the federal U. S. Environmental Protection Agency (EPA). Other federal agencies, such as the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, the U.S. Bureau of Mines, etc., or their regional or state affiliates are sometimes also involved. It is the responsibility of the permitting agency to review the owner/operator's permit application, including the site-specific MQA/CQA plan, for compliance with the agency's regulations and to make a decision to issue or deny a permit based on this review. The permitting agency also has the responsibility to review all MQA/CQA documentation during or after construction of a facility, possibly including visits to the manufacturing facility and construction site to observe the MQC/CQC and MQA/CQA practices, to confirm that the approved MQA/CQA plan was followed and that the facility was constructed as specified in the design.

- *Owner/Operator.* This is the organization that will own and operate the disposal unit. The owner/operator is responsible for the design, construction, and operation of the waste disposal unit. This responsibility includes complying with the requirements of the permitting agency, the submission of MQA/CQA documentation, and assuring the permitting agency that the facility was constructed as specified in the construction plans and specifications and as approved by the permitting agency. The owner/operator has the authority to select and dismiss organizations charged with design, construction, and MQA/CQA. If the owner and operator of a facility are different organizations, the owner is ultimately responsible for these activities. Often the owner/operator, or owner, will be a municipality rather than a private corporation. The interaction of a state office regulating another state or local organization should have absolutely no impact on procedures, intensity of effort and ultimate decisions of the MQA/CQA or MQC/CQC process as described herein.

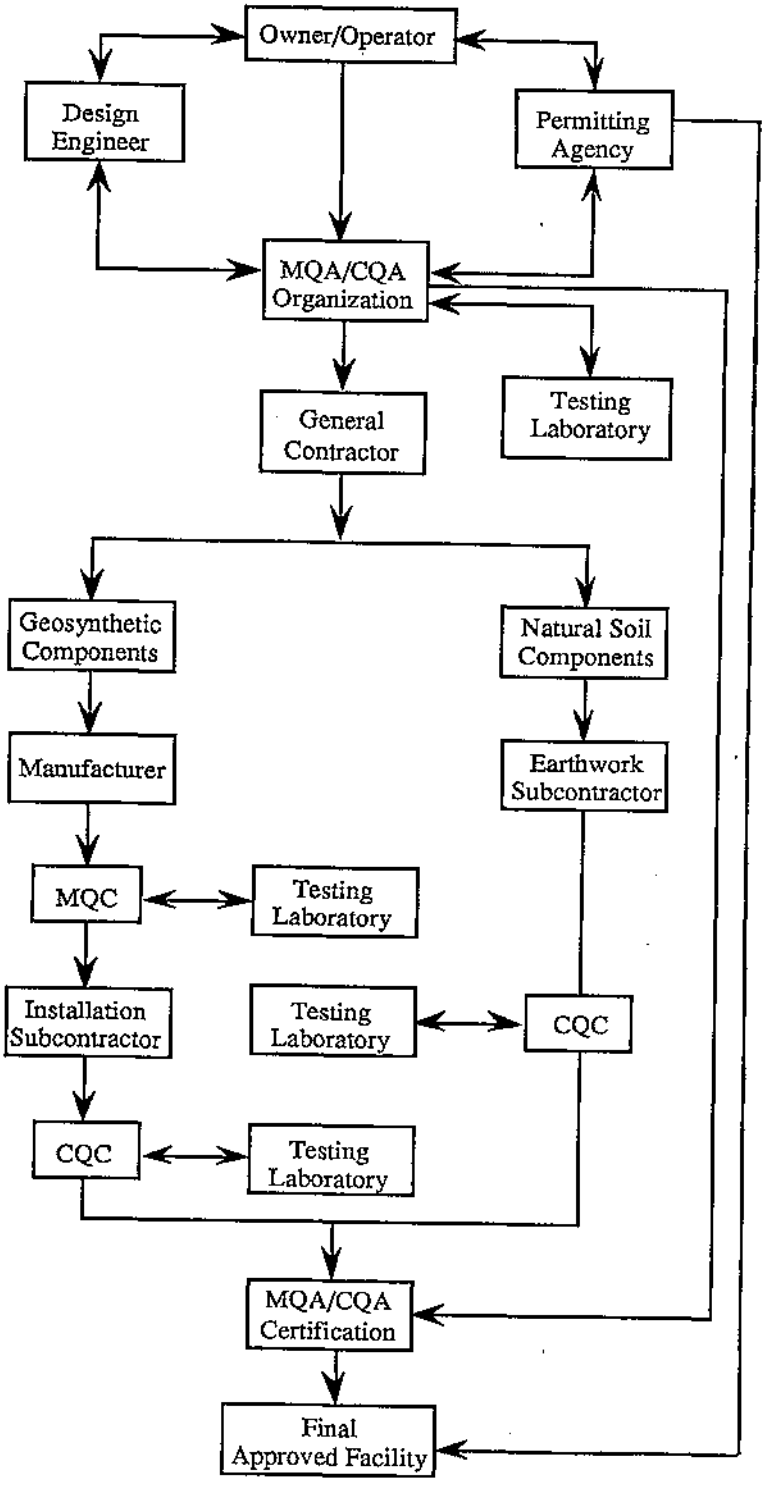


Figure 1.1 - Organizational Structure of MQA/CQA Inspection Activities

- *Owner's Representative.* The owner/operator usually has an official representative who is responsible for coordinating schedules, meetings, and field activities. This responsibility includes communications to other members in the owner/operator's organization, owner's representative, permitting agency, material suppliers, general contractor, specialty subcontractors or installers, and MQA/CQA engineer.

- *Design Engineer.* The design engineer's primary responsibility is to design a waste containment facility that fulfills the operational requirements of the owner/operator, complies with accepted design practices for waste containment facilities, and meets or exceeds the minimum requirements of the permitting agency. The design engineer may be an employee of the owner/operator or a design consultant hired by the owner/operator. The design engineer may be requested to change some aspects of the design if unexpected conditions are encountered during construction (e.g., a change in site conditions, unanticipated logistical problems during construction, or lack of availability of certain materials). Because design changes during construction are not uncommon, the design engineer is often involved in the MQA/CQA process. The plans and specifications referred to in this manual will generally be the product of the Design Engineer. They are a major and essential part of the permit application process and the subsequently constructed facility.

- *Manufacturer.* Many components, including all geosynthetics, of a waste containment facility are manufactured materials. The manufacturer is responsible for the manufacture of its materials and for quality control during manufacture, i.e., MQC. The minimum or maximum (when appropriate) characteristics of acceptable materials should be specified in the permit application. The manufacturer is responsible for certifying that its materials conform to those specifications and any more stringent requirements or specifications included in the contract of sale to the owner/operator or its agent. The quality control steps taken by a manufacturer are critical to overall quality management in construction of waste containment facilities. Such activities often take the form of process quality control, computer-aided quality control and the like. All efforts at producing better quality materials are highly encouraged. If requested, the manufacturer should provide information to the owner/operator, permitting agency, design engineer, fabricator, installer, or MQA engineer that describes the quality control (MQC) steps that are taken during the manufacturing of the product. In addition, the manufacturer should be willing to allow the owner/operator, permitting agency, design engineer, fabricator, installer, and MQA engineer to observe the manufacturing process and quality control procedures if they so desire. Such visits should be able to be made on an announced or unannounced basis. However, such visits might be coordinated with the manufacturer to assure that the appropriate people are present to conduct the tour and that the proper geosynthetic is scheduled for that date so as to obtain the most information from the visit. The manufacturer should have a designated individual who is in charge of the MQC program and to whom questions can be directed and/or through whom visits can be arranged. Random samples of materials should be able to be taken for subsequent analysis and/or archiving. However, the manufacturer should retain the right to insist that any proprietary information concerning the manufacturing of a product be held confidential. Signed agreements of confidentiality are at the option of the manufacturer. The owner/operator, permitting agency, design engineer, fabricator, installer, or MQA engineer may request that they be allowed to observe the manufacture and quality control of some or all of the raw materials and final product to be utilized on a particular job; the manufacturer should be willing to accommodate such requests. Note that these same comments apply to marketing organizations which represent a manufactured product made by others, as well as the manufacturing organization itself.

- *Fabricator.* Some materials are fabricated from manufactured components. For example, certain geomembranes are fabricated by seaming together smaller, manufactured geomembrane sheets at the fabricator's facility. The minimum characteristics of acceptable fabricated materials are specified in the permit application. The fabricator is responsible for certifying that its materials conform to those specifications and any more stringent requirements or specifications included in the fabrication contract with the owner/operator or its agent. The quality control steps taken by a fabricator are critical to overall quality in construction of waste containment facilities. If requested, the fabricator should provide information to the owner/operator, permitting agency, design engineer, installer, or MQA engineer that describes the quality control steps that are taken during the fabrication of the product. In addition, the fabricator should be willing to allow the owner/operator, permitting agency, design engineer, installer, or MQA engineer to observe the fabrication process and quality control procedures if they so desire. Such visits may be made on an announced or unannounced basis. However, such visits might be coordinated with the fabricator to assure that the appropriate people are present to conduct the tour and that the proper geosynthetic is scheduled for that date so as to obtain the most information from the visit. Random samples of materials should be able to be taken for subsequent analysis and/or archiving. However, the fabricator should retain the right to insist that any proprietary information concerning the fabrication of a product be held confidential. Signed agreements of confidentiality are at the option of the fabricator. The owner/operator, permitting agency, design engineer, or MQA engineer may request that they be allowed to observe the fabrication process and quality control of some or all fabricated materials to be utilized on a particular job; the fabricator should be willing to accommodate such a requests.

- *General Contractor.* The general contractor has overall responsibility for construction of a waste containment facility and for CQC during construction. The general contractor arranges for purchase of materials that meet specifications, enters into a contract with one or more fabricators (if fabricated materials are needed) to supply those materials, contracts with an installer (if separate from the general contractor's organization), and has overall control over the construction operations, including scheduling and CQC. The general contractor has the primary responsibility for ensuring that a facility is constructed in accord with the plans and specifications that have been developed by the design engineer and approved by the permitting agency. The general contractor is also responsible for informing the owner/operator and the MQA/CQA engineer of the scheduling and occurrence of all construction activities. Occasionally, a waste containment facility may be constructed without a general contractor. For example, an owner/operator may arrange for all the necessary material, fabrication, and installation contracts. In such cases, the owner/operator's representative will serve the same function as the general contractor.

- *Installation Contractor.* Manufactured products (such as geosynthetics) are placed and installed in the field by an installation contractor who is the general contractor, a subcontractor to the general contractor, or is a specialty contractor hired directly by the owner/operator. The installer's personnel may be employees of the owner/operator, manufacturer, or fabricator, or they may work for an independent installation company hired by the general contractor or by the owner/operator directly. The installer is responsible for handling, storage, placement, and installation of manufactured and/or fabricated materials. The installer should have a CQC plan to detail the proper manner that materials are handled, stored, placed, and installed. The installer is also responsible for informing the owner/operator and the MQA/CQA engineer of the scheduling and occurrence of all geosynthetic construction activities.

- *Earthwork Contractor.* The earthwork contractor is responsible for grading the site to elevations and grades shown on the plans and for constructing earthen components of the waste containment facility, e.g., compacted clay liners and granular drainage layers according to the specifications. The earthwork contractor may be hired by the general contractor or if the owner/operator serves as the general contractor, by the owner/operator directly. In some cases, the general contractor's personnel may serve as the earthwork contractor. The earthwork contractor is responsible not only for grading the site to proper elevations but also for obtaining suitable earthen materials, transport and storage of those materials, preprocessing of materials (if necessary), placement and compaction of materials, and protection of materials during and (in some cases) after placement. If a test pad is required, the earthwork contractor is usually responsible for construction of the test pad. It is highly suggested that the same earthwork contractor that constructs the test fill also construct the waste containment facility compacted clay liner so that the experience gained from the test fill process will not be lost. Earthwork functions must be carried out in accord with plans and specifications approved by the permitting agency. The earthwork contractor should have a CQC plan (or agree to one written by others) and is responsible for CQC operations aimed at controlling materials and placement of those materials to conform with project specifications. The earthwork contractor is also responsible for informing the owner/operator and the CQA engineer of the scheduling and occurrence of all earthwork construction activities.

- *CQC Personnel.* Construction quality control personnel are individuals who work for the general contractor, installation contractor, or earthwork contractor and whose job it is to ensure that construction is taking place in accord with the plans and specifications approved by the permitting agency. In some cases, CQC personnel, perhaps even a separate company, may also be part of the installation or construction crews. In other cases, supervisory personnel provide CQC or, for large projects, separate CQC personnel, perhaps even a separate company, may be utilized. It is recommended that a certain portion of the CQC staff should be certified* as per the implementation schedule of Table 1.1. The examinations have been available as of October, 1992.

- *MQA/CQA Engineer.* The MQA/CQA engineer has overall responsibility for manufacturing quality assurance and construction quality assurance. The engineer is usually an individual experienced in a variety of activities although particular specialists in soil placement, polymeric materials and geosynthetic placement will invariably be involved in a project. The MQA/CQA engineer is responsible for reviewing the MQA/CQA plan as well as general plans and specifications for the project so that the MQA/CQA plan can be implemented with no contradictions or unresolved discrepancies. Other responsibilities of the MQA/CQA engineer include education of inspection personnel on MQA/CQA requirements and procedures and special steps that are needed on a particular project, scheduling and coordinating of MQA/CQA inspection activities, ensuring that proper procedures are followed, ensuring that testing laboratories are conforming to MQA/CQA requirements and procedures, ensuring that sample custody procedures are followed, confirming that test data are accurately reported and that test data are maintained for later reporting, and preparation of periodic reports. The most important duty of the MQA/CQA engineer is overall responsibility for confirming that the facility was constructed in accord with plans and specifications approved by the

---

* A certification program is available from the National Institute for Certification of Engineering Technologies (NICET); 1420 King Street; Alexandria, Virginia 22314 (phone: 703-684-2835)

permitting agency. In the event of nonconformance with the project specifications or CQA Plan, the MQA/CQA engineer should notify the owner/operator as to the details and, if appropriate, recommend work stoppage and possibly remedial actions. The MQA/CQA engineer is normally hired by the owner/operator and functions separately of the contractors and owner/operator. The MQA/CQA engineer must be a registered professional engineer who has shown competency and experience in similar projects and is considered qualified by the permitting agency. It is recommended that the person's resume and record on like facilities must be submitted in writing and accordingly accepted by the permitting agency before activities commence. The permitting agency may request additional information from the prospective MQA/CQA engineer and his/her associated organization including experience record, education, registry and ownership details. The permitting agency may accept or deny the MQA/CQA engineer's qualifications based on such data and revelations. If the permitting agency requests additional information or denies the MQA/CQA engineer's qualifications it should be done prior to construction, so that alternatives can be made which do not negatively impact on the progress of the work. The MQA/CQA engineer is usually required to be at the construction site during all major construction operations to oversee MQA/CQA personnel. The MQA/CQA engineer is usually the MQA/CQA certification engineer who certifies the completed project.

Table 1.1 - Recommended Impentation Program for Construction Quality Control (CQC) for Geosynthetics* (Beginning January 1, 1993)

No. of Field Crews** At Each Site	End of 18 Months (i.e., June 30, 1994)	End of 36 Months (i.e., January 1, 1996)
1-4	1 - Level II	1 - Level III***
≥ 5	1 - Level II	1 - Level III***
	2 - Level I	1 - Level I

*Certification for natural materials is under development as of this writing
**Performing a Critical Operation; Typically 4 to 6 People/Crew
***Or PE with applicable experience

- *MQA/CQA Personnel.* Manufacturing quality assurance and construction quality assurance personnel are responsible for making observations and performing field tests to ensure that a facility is constructed in accord with the plans and specifications approved by the permitting agency. MQA/CQA personnel normally are employed by the same firm as the MQA/CQA engineer, or by a firm hired by the firm employing the MQA/CQA engineer. Construction MQA/CQA personnel report to the MQA/CQA engineer. A relatively large proportion (if not the entire group) of the MQA/CQA staff should be certified. Table 1.2 gives the currently recommended implementation schedule. As mentioned previously, certification examinations have been available as of October, 1992, from the National Institute for Certification of Engineering Technologies in Alexandria, Virginia.

- *Testing Laboratory.* Many MQC/CQC and MQA/CQA tests are performed by commercial laboratories. The testing laboratory should have its own internal QC plan to ensure that laboratory procedures conform to the appropriate American Society for Testing and Materials (ASTM) standards or other applicable testing standards. The testing laboratory is responsible for ensuring that tests are performed in accordance with applicable methods and standards, for following internal QC procedures, for maintaining sample chain-of-custody records, and for reporting data. The testing laboratory must be willing to allow the owner/operator, permitting agency, design engineer, installer, or MQA/CQA engineer to observe the sample preparation and testing procedures, or record-keeping procedures, if they so desire. The owner/operator, permitting agency, design engineer, or MQA/CQA engineer may request that they be allowed to observe some or all tests on a particular job at any time, either announced or unannounced. The testing laboratory personnel must be willing to accommodate such a request, but the observer should not interfere with the testing or slow the testing process.

Table 1.2 - Recommended Implementation Program for Construction Quality Assurance (CQA) for Geosynthetics* (Beginning January 1, 1993)

No. of Field Crews** At Each Site	End of 18 Months (i.e., June 30, 1994)	End of 36 Months (i.e., January 1, 1996)
1-2	1 - Level II	1 - Level III***
3-4	1 - Level II 1 - Level I	1 - Level III*** 1 - Level I
≥ 5	1 - Level II 2 - Level I	1 - Level III*** 1 - Level II 1 - Level I

*Certification for natural materials is under development as of this writing
**Performing a Critical Operation; Typically 4 to 6 People/Crew
***Or PE with applicable experience

- *MQA/CQA Certifying Engineer.* The MQA/CQA certifying engineer is responsible for certifying to the owner/operator and permitting agency that, in his or her opinion, the facility has been constructed in accord with plans and specifications and MQA/CQA document approved by the permitting agency. The certification statement is normally accompanied by a final MQA/CQA report that contains all the appropriate documentation, including daily observation reports, sampling locations, test results, drawings of record or sketches, and other relevant data. The MQA/CQA certifying engineer may be the MQA/CQA engineer or someone else in the MQA/CQA engineer's organization who is a registered professional engineer with experience and competency in certifying like installations.

1.3 Personnel Qualifications

The key individuals involved in MQA/CQA and their minimum recommended qualifications are listed in Table 1.3.

Table 1.3 - Recommended Personnel Qualifications

Individual	Minimum Recommended Qualifications
Design Engineer	Registered Professional Engineer
Owner's Representative	The specific individual designated by the owner with knowledge of the project, its plans, specifications and QC/QA documents.
Manufacturer/Fabricator	Experience in manufacturing, or fabricating, at least 1,000,000 m^2 (10,000,000 ft^2) of similar geosynthetic materials.
MQC Personnel	Manufacturer, or fabricator, trained personnel in charge of quality control of the geosynthetic materials to be used in the specific waste containment facility.
MQC Officer	The individual specifically designated by a manufacturer or fabricator, in charge of geosynthetic material quality control.
Geosynthetic Installer's Representative	Experience installing at least 1,000,000 m^2 (10,000,000 ft^2) of similar geosynthetic materials.
CQC Personnel	Employed by the general contractor, installation contractor or earthwork contractor involved in waste containment facilities; certified to the extent shown in Table 1.1.
CQA Personnel	Employed by an organization that operates separately from the contractor and the owner/operator; certified to the extent shown in Table 1.2.
MQA/CQA Engineer	Employed by an organization that operates separately from the contractor and owner/operator; registered Professional Engineer and approved by permitting agency.
MQA/CQA Certifying Engineer	Employed by an organization that operates separately from the contractor and owner/operator; registered Professional Engineer in the state in which the waste containment facility is constructed and approved by the appropriate permitting agency.

1.4 Written MQA/CQA Plan

Quality assurance begins with a quality assurance plan. This includes both MQA and CQA. These activities are never ad hoc processes that are developed while they are being implemented. A written MQA/CQA plan must precede any field construction activities.

The MQA/CQA plan is the owner/operator's written plan for MQA/CQA activities. The MQA/CQA plan should include a detailed description of all MQA/CQA activities that will be used during materials manufacturing and construction to manage the installed quality of the facility. The MQA/CQA plan should be tailored to the specific facility to be constructed and be completely integrated into the project plans and specifications. Differences should be settled before any construction work commences.

Most state and federal regulatory agencies require that a MQA/CQA plan be submitted by the owner/operator and be approved by that agency prior to construction. The MQA/CQA plan is usually part of the permit application.

A copy of the site-specific plans and specifications, MQA/CQA plan, and MQA/CQA documentation reports should be retained at the facility by the owner/operator or the MQA/CQA engineer. The plans, specifications, and MQA/CQA documents may be reviewed during a site inspection by the permitting agency and will be the chief means for the facility owner/operator to demonstrate to the permitting agency that MQA/CQA objectives for a project are being met.

Written MQA/CQA plans vary greatly from project to project. No general outline or suggested list of topics is applicable to all projects or all regulatory agencies. The elements covered in this document provides guidance on topics that should be addressed in the written MQA/CQA plan.

1.5 Documentation

A major purpose of the MQA/CQA process is to provide documentation for those individuals who were unable to observe the entire construction process (e.g., representatives of the permitting agency) so that those individuals can make informed judgments about the quality of construction for a project. MQA/CQA procedures and results must be thoroughly documented.

1.5.1 Daily Inspection Reports

Routine daily reporting and documentation procedures should be required. Inspectors should prepare daily written inspection reports that may ultimately be included in the final MQA/CQA document. Copies of these reports should be available from the MQA/CQA engineer. The daily reports should include information about work that was accomplished, tests and observations that were made, and descriptions of the adequacy of the work that was performed.

1.5.2 Daily Summary Reports

A daily written summary report should be prepared by the MQA/CQA engineer. This report provides a chronological framework for identifying and recording all other reports and aids in tracking what was done and by whom. As a minimum, the daily summary reports should contain the following (modified from Spigolon and Kelly, 1984, and EPA, 1986):

- Date, project name, location, waste containment unit under construction, personnel involved in major activities and other relevant identification information;
- Description of weather conditions, including temperature, cloud cover, and precipitation;
- Summaries of any meetings held and actions recommended or taken;
- Specific work units and locations of construction underway during that particular day;
- Equipment and personnel being utilized in each work task, including subcontractors;
- Identification of areas or units of work being inspected;
- Unique identifying sheet number of geomembranes for cross referencing and document control;
- Description of off-site materials received, including any quality control data provided by the supplier;
- Calibrations or recalibrations of test equipment, including actions taken as a result of recalibration;
- Decisions made regarding approval of units of material or of work, and/or corrective actions to be taken in instances of substandard or suspect quality;
- Unique identifying sheet numbers of inspection data sheets and/or problem reporting and corrective measures used to substantiate any MQA/CQA decisions described in the previous item;
- Signature of the MQA/CQA engineer.

1.5.3 Inspection and Testing Reports

All observations, results of field tests, and results of laboratory tests performed on site or off site should be recorded on a suitable data sheet. Recorded observations may take the form of notes, charts, sketches, photographs, or any combination of these. Where possible, a checklist may be useful to ensure that pertinent factors are not overlooked.

As a minimum, the inspection data sheets should include the following information (modified from Spigolon and Kelly, 1984, and EPA, 1986):

- Description or title of the inspection activity;
- Location of the inspection activity or location from which the sample was obtained;
- Type of inspection activity and procedure used (reference to standard method when appropriate or specific method described in MQA/CQA plan);
- Unique identifying geomembrane sheet number for cross referencing and document control;

- Recorded observation or test data;
- Results of the inspection activity (e.g., pass/fail); comparison with specification requirements;
- Personnel involved in the inspection besides the individual preparing the data sheet;
- Signature of the MQA/CQA inspector and review signature by the MQA/CQA engineer.

1.5.4 Problem Identification and Corrective Measures Reports

A problem is defined as material or workmanship that does not meet the requirements of the plans, specifications or MQA/CQA plan for a project or any obvious defect in material or workmanship, even if there is conformance with plans, specifications and the MQA/CQA plan. As a minimum, problem identification and corrective measures reports should contain the following information (modified from EPA, 1986):

- Location of the problem;
- Description of the problem (in sufficient detail and with supporting sketches or photographic information where appropriate) to adequately describe the problem;
- Unique identifying geomembrane sheet number for cross referencing and document control;
- Probable cause;
- How and when the problem was located (reference to inspection data sheet or daily summary report by inspector);
- Where relevant, estimation of how long the problem has existed;
- Any disagreement noted by the inspector between the inspector and contractor about whether or not a problem exists or the cause of the problem;
- Suggested corrective measure(s);
- Documentation of correction if corrective action was taken and completed prior to finalization of the problem and corrective measures report (reference to inspection data sheet, where applicable);
- Where applicable, suggested methods to prevent similar problems;
- Signature of the MQA/CQA inspector and review signature of MQA/CQA engineer.

1.5.5 Drawings of Record

Drawings of record (also called "as-built" drawings) should be prepared to document the actual lines and grades and conditions of each component of the disposal unit. For soil components, the record drawings shall include survey data that show bottom and top elevations of a particular component, the plan dimensions of the component, and locations of all destructive test samples. For geosynthetic components, the record drawings often show the dimensions of all geomembrane field panels, the location of each panel, identification of all seams and panels with appropriate identification numbering or lettering, location of all patches and repairs, and location of all destructive test samples. Separate drawings are often needed to show record cross sections and special features such as sump areas.

1.5.6 Final Documentation and Certification

At the completion of a project, or a component of a large project, the owner/operator should submit a final report to the permitting agency. This report may include all of the daily inspection reports, the daily MQA/CQA engineer's summary reports, inspection data sheets, problem identification and corrective measures reports, and other documentation such as quality control data provided by manufacturers or fabricators, laboratory test results, photographs, as-built drawings, internal MQA/CQA memoranda or reports with data interpretation or analyses, and design changes made by the design engineer during construction. The document should be certified correct by the MQA/CQA certifying engineer.

The final documentation should emphasize that areas of responsibility and lines of authority were clearly defined, understood, and accepted by all parties involved in the project (assuming that this was the case). Signatures of the owner/operator's representative, design engineer, MQA/CQA engineer, general contractor's representative, specialty subcontractor's representative, and MQA/CQA certifying engineer may be included as confirmation that each party understood and accepted the areas of responsibility and lines of authority outlined in the MQA/CQA plan.

1.5.7 Document Control

The MQA/CQA documents which have been agreed upon should be maintained under a document control procedure. Any portion of the document(s) which are modified must be communicated to and agreed upon by all parties involved. An indexing procedure should be developed for convenient replacement of pages in the MQA/CQA plan, should modifications become necessary, with revision status indicated on appropriate pages.

A control scheme should be implemented to organize and index all MQA/CQA documents. This scheme should be designed to allow easy access to all MQA/CQA documents and should enable a reviewer to identify and retrieve original inspection reports or data sheets for any completed work element.

1.5.8 Storage of Records

During construction, the MQA/CQA engineer should be responsible for all MQA/CQA documents. This includes a copy of the design criteria, plans, specifications, MQA/CQA plan, and originals of all data sheets and reports. Duplicate records should be kept at another location to avoid loss of this valuable information if the originals are destroyed.

Once construction is complete, the document originals should be stored by the owner/operator in a manner that will allow for easy access while still protecting them from damage. An additional copy should be kept at the facility if this is in a different location from the owner/operator's main files. A final copy should be kept by the permitting agency. All documentation should be maintained through the operating and post-closure monitoring periods of the facility by the owner/operator and the permitting agency in an agreed upon format (paper hard copy, microfiche, electronic medium, etc.).

1.6 Meetings

Communication is extremely important to quality management. Quality construction is easiest to achieve when all parties involved understand clearly their responsibility and authority. Meetings can be very helpful to make sure that responsibility and authority of each organization is clearly understood. During construction, meetings can help to resolve problems or misunderstandings and to find solutions to unanticipated problems that have developed.

1.6.1 Pre-Bid Meeting

The first meeting is held to discuss the MQA/CQA plan and to resolve differences of opinion before the project is let for bidding. The pre-bid meeting is held after the permitting agency has issued a permit for a waste containment facility and before a construction contract has been awarded. The pre-bid meeting is held before construction bids are prepared so that the companies bidding on the construction will better understand the level of MQA/CQA to be employed on the project. Also, if the bidders identify problems with the MQA/CQA plan, this affords the owner/operator an opportunity to rectify those problems early in the process.

1.6.2 Resolution Meeting

The objectives of the resolution meeting are to establish lines of communication, review construction plans and specifications, emphasize the critical aspects of a project necessary to ensure proper quality, begin planning and coordination of tasks, and anticipate any problems that might cause difficulties or delays in construction. The meeting should be attended by the owner/operator's representative, design engineer, representatives of the general contractor and/or major subcontractors, the MQA/CQA engineer, and the MQA/CQA certifying engineer.

The resolution meeting normally involves the following activities:

- An individual is assigned to take minutes (usually a representative of the owner/operator or of the MQA/CQA engineer's organization);
- Individuals are introduced to one another and their responsibilities (or potential responsibilities) are identified;
- Copies of the project plans and specifications are made available for discussion;
- The MQA/CQA plan is distributed;
- Copies of any special permit restrictions that are relevant to construction or MQA/CQA are distributed;
- The plans and specifications are described, any unique design features are discussed (so the contractors will understand the rationale behind the general design), any potential construction problems are identified and discussed, and questions from any of the parties concerning the construction are discussed;
- The MQA/CQA plan is reviewed and discussed, with the MQA/CQA engineer and MQA/CQA certifying engineer identifying their expectations and identifying the most critical components;

- Procedures for MQC/CQC proposed by installers and contractors are reviewed and discussed;
- Corrective actions to resolve potential construction problems are discussed;
- Procedures for documentation and distribution of documents are discussed;
- Each organization's responsibility, authority, and lines of communication are discussed;
- Suggested modifications to the MQA/CQA plan that would improve quality management on the project are solicited; and
- Construction variables (e.g., precipitation, wind, temperature) and schedule are discussed.

It is very important that the procedures for inspection and testing be known to all, that the criteria for pass/fail decisions be clearly defined (including the resolution of test data outliers), that all parties understand the key problems that the MQA/CQA personnel will be particularly careful to identify, that each individual's responsibilities and authority be understood, and that procedures regarding resolution of problems be understood. The resolution meeting may be held in conjunction with either the pre-bid meeting (rarely) or the pre-construction meeting (often).

1.6.3 Pre-construction Meeting

The pre-construction meeting is held after a general construction contract has been awarded and the major subcontractors and material suppliers are established. It is usually held concurrent with the initiation of construction. The purpose of this meeting is to review the details of the MQA/CQA plan, to make sure that the responsibility and authority of each individual is clearly understood, to agree on procedures to resolve construction problems, and to establish a foundation of cooperation in quality management. The pre-construction meeting should be attended by the owner/operator's representative, design engineer, representatives of the general contractor and major subcontractors, the MQA/CQA engineer, the MQA/CQA certifying engineer, and a representative from the permitting agency, if that agency expects to visit the site during construction or independently observe MQA/CQA procedures.

The pre-construction meeting should include the following activities:

- Assign an individual (usually representative of MQA/CQA engineer) to take minutes;
- Introduce parties and identify their responsibility and authority;
- Distribute the MQA/CQA plan, identify any revisions made after the resolution meeting, and answer any questions about the MQA/CQA plan, procedures, or documentation;
- Discuss responsibilities and lines of communication;
- Discuss reporting procedures, distribution of documents, schedule for any regular meetings, and resolution of construction problems;
- Review site requirements and logistics, including safety procedures;

- Review the design, discuss the most critical aspects of the construction, and discuss scheduling and sequencing issues;
- Discuss MQC procedures that the geosynthetics manufacturer(s) will employ;
- Discuss CQC procedures that the installer or contractor will employ, for example, establish and agree on geomembrane repair procedures;
- Make a list of action items that require resolution and assign responsibilities for these items.

1.6.4 Progress Meetings

Weekly progress meetings should be held. Weekly meetings can be helpful in maintaining lines of communication, resolving problems, identifying action items, and improving overall quality management. When numerous critical work elements are being performed, the frequency of these meetings can be increased to biweekly, or even daily. Persons who should attend this meeting are those involved in the specific issues being discussed. At all times the MQA/CQA engineer, or designated representative, should be present.

1.7 Sample Custody

All samples shall be identified as described in the MQA/CQA plan. Whenever a sample is taken, a chain of custody record should be made for that sample. If the sample is transferred to another individual or laboratory, records shall be kept of the transfer so that chain of custody can be traced. The purpose of keeping a record of sample custody is to assist in tracing the cause of anomalous test results or other testing problem, and to help prevent accidental loss of test samples.

Soil samples are usually discarded after testing. Destructive testing samples of geosynthetic materials are often taken in triplicate, with one sample tested by CQC personnel, one tested by CQA personnel, and the third retained in storage as prescribed in the CQA plan.

1.8 Weather

Weather can play a critical role in the construction of waste containment facilities. Installation of all geosynthetic materials (including geosynthetic clay liners) and natural clay liners is particularly sensitive to weather conditions, including temperature, wind, humidity, and precipitation. The contractor or installer is responsible for complying with the contract plans and specifications (along with the MQC/CQC plans for the various components of the system). Included in this information should be details which restrict the weather conditions in which certain activities can take place. It is the responsibility of the contractor or installer to make sure that these weather restrictions are observed during construction.

1.9 Work Stoppages

Unexpected work stoppages can occur due to a variety of causes, including labor strikes, contractual disputes, weather, QC/QA problems, etc. The MQA/CQA engineer should be particularly careful during such stoppages to determine (1) whether in-place materials are covered and protected from damage (e.g., lifting of a geomembrane by wind or premature hydration of geosynthetic clay liners); (2) whether partially covered materials are protected from damage (e.g., desiccation of a compacted clay liners); and (3) whether manufactured materials are properly stored and properly or adequately protected (e.g., whether geotextiles are protected from ultraviolet exposure). The cessation of construction should not mean the cessation of MQA/CQA inspection and documentation.

1.10 References

Spigolon, S.J., and M.F. Kelly (1984), "Geotechnical Assurance of Construction of Disposal Facilities," U. S. Environmental Protection Agency, EPA 600/2-84-040, Cincinnati, Ohio.

U.S. Environmental Protection Agency (1986), "Technical Guidance Document, Construction Quality Assurance for Hazardous Waste Land Disposal Facilities," EPA/530-SW-86-031, Cincinnati, Ohio, 88 p.

U.S. Environmental Protection Agency (1988a), "Design, Construction, and Evaluation of Clay Liners for Waste Management Facilities," EPA/530-SW-86-007F, Cincinnati, Ohio.

U.S. Environmental Protection Agency (1988b), "Lining of Waste Containment and Other Impoundment Facilities," EPA/600/2-88/052, Cincinnati, Ohio.

U. S. Environmental Protection Agency (1989), "Requirements for Hazardous Waste Landfill Design, Construction, and Closure," EPA/625/4-89/022, Cincinnati, Ohio.

U.S. Environmental Protection Agency (1991a), "Inspection Techniques for the Fabrication of Geomembrane Field Seams," EPA/530/SW-91/051, Cincinnati, Ohio.

U. S. Environmental Protection Agency (1991b), "Design and Construction of RCRA/CERCLA Final Covers," EPA/625/4-91/025, Cincinnati, Ohio.

Chapter 2

Compacted Soil Liners

2.1 Introduction and Background

2.1.1 Types of Compacted Soil Liners

Compacted soil liners have been used for many years as engineered hydraulic barriers for waste containment facilities. Some liner and cover systems contain a single compacted soil liner, but others may contain two or more compacted soil liners. Compacted soil liners are frequently used in conjunction with geomembranes to form a *composite liner,* which usually consists of a geomembrane placed directly on the surface of a compacted soil liner. Examples of soil liners used in liner and cover systems are shown in Fig. 2.1.

Compacted soil liners are composed of clayey materials that are placed and compacted in layers called *lifts*. The materials used to construct soil liners include natural mineral materials (natural soils), bentonite-soil blends, and other material

2.1.1.1 Natural Mineral Materials

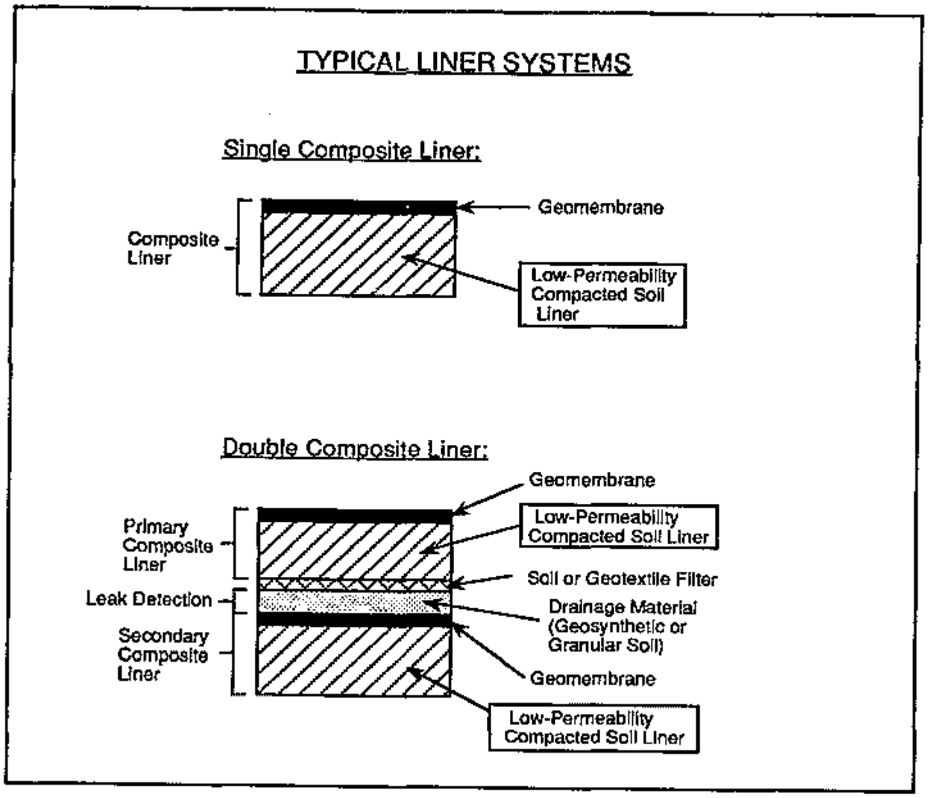
The most common type of compacted soil liner is one that is constructed from naturally occurring soils that contain a significant quantity of clay. Soils are usually classified as CL, CH, or SC soils in the Unified Soil Classification System (USCS) and ASTM D-2487. Soil liner materials are excavated from locations called *borrow pits.* These borrow areas are located either on the site or offsite. The soil in the borrow pit may be used directly without processing or may be processed to alter the water content, break down large pieces of material, or remove oversized particles. Sources of natural soil liner materials include lacustrine deposits, glacial tills, aeolian materials, deltaic deposits, residual soils, and other types of soil deposits. Weakly cemented or highly weathered rocks, e.g., mudstones and shales, can also be used for soil liner materials, provided they are processed properly.

2.1.1.2 Bentonite-Soil Blends

If the soils found in the vicinity of a waste disposal facility are not sufficiently clayey to be suitable for direct use as a soil liner material, a common practice is to blend natural soils available on or near a site with bentonite. The term *bentonite* is used in different ways by different people. For purposes of this discussion, bentonite is any commercially processed material that is composed primarily of the mineral smectite. Bentonite may be supplied in granular or pulverized form. The dominant adsorbed cation of commercial bentonite is usually sodium or calcium, although the sodium form is much more commonly used for soil sealing applications. Bentonite is mixed with native soils either in thin layers or in a pugmill.

2.1.1.3 Other

Other materials have occasionally been used for compacted soil liners. For example, bentonite may be blended with flyash to form a liner under certain circumstances. Modified soil minerals and commercial additives, e.g., polymers, have sometimes been used.



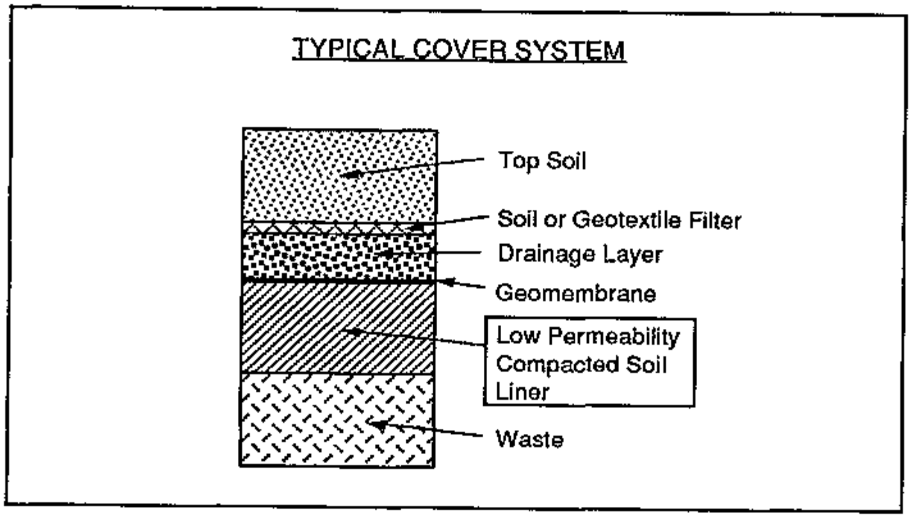


Figure 2.1 - Examples of Compacted Soil Liners in Liner and Cover Systems

2.1.2 Critical CQC and CQA Issues

The CQC and CQA processes for soil liners are intended to accomplish three objectives:

1. Ensure that soil liner materials are suitable.
2. Ensure that soil liner materials are properly placed and compacted.
3. Ensure that the completed liner is properly protected.

Some of these issues, such as protection of the liner from desiccation after completion, simply require application of common-sense procedures. Other issues, such preprocessing of materials, are potentially much more complicated because, depending on the material, many construction steps may be involved. Furthermore, tests alone will not adequately address many of the critical CQC and CQA issues -- visual observations by qualified personnel, supplemented by intelligently selected tests, provide the best approach to ensure quality in the constructed soil liner.

As discussed in Chapter 1, the objective of CQA is to ensure that the final product meets specifications. A detailed program of tests and observations is necessary to accomplish this objective. The objective of CQC is to control the manufacturing or construction process to meet project specifications. With geosynthetics, the distinction between CQC and CQA is obvious: the geosynthetics installer performs CQC while an independent organization conducts CQA. However, CQC and CQA activities for soils are more closely linked than in geosynthetics installation. For example, on many earthwork projects the CQA inspector will typically determine the water content of the soil and report the value to the contractor; in effect, the CQA inspector is also providing CQC input to the contractor. On some projects, the contractor is required to perform extensive tests as part of the CQC process, and the CQA inspector performs tests to check or confirm the results of CQC tests.

The lack of clearly separate roles for CQC and CQA inspectors in the earthwork industry is a result of historic practices and procedures. This chapter is focused on CQA procedures for soil liners, but the reader should understand that CQA and CQC practices are often closely linked in earthwork. In any event, the QA plan should clearly establish QA procedures and should consider whether there will be QC tests and observations to complement the QA process.

2.1.3 Liner Requirements

The construction of soil liners is a challenging task that requires many careful steps. A blunder concerning any one detail of construction can have disastrous impacts upon the hydraulic conductivity of a soil liner. For example, if a liner is allowed to desiccate, cracks might develop that could increase the hydraulic conductivity of the liner to above the specified requirement.

As stated in Section 2.1.2, the CQC and CQA processes for soil liners essentially consist of using suitable materials, placing and compacting the materials properly, and protecting the completed liner. The steps required to fulfill these requirements may be summarized as follows:

1. The subgrade on which the soil liner will be placed should be properly prepared.
2. The materials employed in constructing the soil liner should be suitable and should conform to the plans and specifications for the project.

3. The soil liner material should be preprocessed, if necessary, to adjust the water content, to remove oversized particles, to break down clods of soil, or to add amendments such as bentonite.

4. The soil should be placed in lifts of appropriate thickness and then be properly remolded and compacted.

5. The completed soil liner should be protected from damage caused by desiccation or freezing temperatures.

6. The final surface of the soil liner should be properly prepared to support the next layer that will be placed on top of the soil liner.

The six steps mentioned above are described in more detail in the succeeding subsections to provide the reader with a general introduction to the nature of CQC and CQA for soil liners. Detailed requirements are discussed later.

2.1.3.1 Subgrade Preparation

The subgrade on which a soil liner is placed should be properly prepared, i.e., provide adequate support for compaction and be free from mass movements. The compacted soil liner may be placed on a natural or geosynthetic material, depending on the particular design and the individual component in the liner or cover system. If the soil liner is the lowest component of the liner system, native soil or rock forms the subgrade. In such cases the subgrade should be compacted to eliminate soft spots. Water should be added or removed as necessary to produce a suitably firm subgrade per specification requirements. In other instances the soil liner may be placed on top of geosynthetic components of the liner system, e.g., a geotextile. In such cases, the main concern is the smoothness of the geosynthetic on which soil is placed and conformity of the geosynthetic to the underlying material (e.g., no bridging over ruts left by vehicle traffic).

Sometimes it is necessary to "tie in" a new section of soil liner to an old one, e.g., when a landfill is being expanded laterally. It is recommended that a lateral excavation be made about 3 to 6 m (10 to 20 ft) into the existing soil liner, and that the existing liner be stair-stepped as shown in Fig. 2.2 to tie the new liner into the old one. The surface of each of the steps in the old liner should be scarified to maximize bonding between the new and old sections.

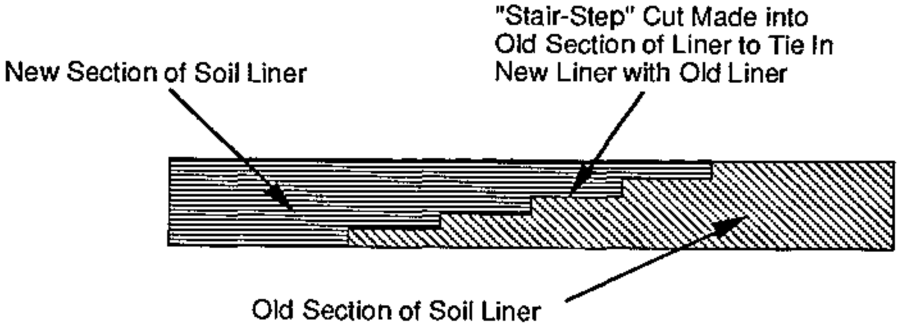


Figure 2.2 - Tie-In of New Soil Liner to Existing Soil Liner

2.1.3.2 Material Selection

Soil liner materials are selected so that a low hydraulic conductivity will be produced after the soil is remolded and compacted. Although the performance specification is usually hydraulic conductivity, CQA considerations dictate that restrictions be placed on certain properties of the soil used to build a liner. For example, limitations may be placed on the liquid limit, plastic limit, plasticity index, percent fines, and percent gravel allowed in the soil liner material.

The process of selecting construction materials and verifying the suitability of the materials varies from project to project. In general, the process is as follows:

1. A potential borrow source is located and explored to determine the vertical and lateral extent of the source and to obtain representative samples, which are tested for properties such as liquid limit, plastic limit, percent fines, etc.
2. Once construction begins, additional CQC and CQA observations and tests may be performed in the borrow pit to confirm the suitability of materials being removed.
3. After a lift of soil has been placed, additional CQA tests should be performed for final verification of the suitability of the soil liner materials.

On some projects, the process may be somewhat different. For example, a materials company may offer to sell soil liner materials from a commercial pit, in which case the first step listed above (location of borrow source) is not relevant.

A variety of tests is performed at various stages of the construction process to ensure that the soil liner material conforms with specifications. However, tests alone will not necessarily ensure an adequate material -- observations by qualified CQA inspectors are essential to confirm that deleterious materials (such as stones or large pieces of organic or other deleterious matter) are not present in the soil liner material.

2.1.3.3 Preprocessing

Some soil liner materials must be processed prior to use. The principal preprocessing steps that may be required include the following:

1. Drying of soil that is too wet.
2. Wetting of soil that is too dry.
3. Removal of oversized particles.
4. Pulverization of clods of soil.
5. Homogenization of nonuniform soil.
6. Addition of bentonite.

Tests are performed by CQA personnel to confirm proper preprocessing, but visual observations by CQC and CQA personnel are needed to confirm that proper procedures have been followed and that the soil liner material has been properly preprocessed.

2.1.3.4 Placement, Remolding, and Compaction

Soil liners are placed and compacted in lifts. The soil liner material must first be placed in a loose lift of appropriate thickness. If a loose lift is too thick, adequate compactive energy may not be delivered to the bottom of a lift.

The type and weight of compaction equipment can have an important influence upon the hydraulic conductivity of the constructed liner. The CQC/CQA program should be designed to ensure that the soil liner material will be properly placed, remolded, and compacted as described in the plans and specifications for the project.

2.1.3.5 Protection

The completed soil liner must be protected from damage caused by desiccation or freezing temperatures. Each completed lift of the soil liner, as well as the completed liner, must be protected.

2.1.3.6 Final Surface Preparation

The surface of the liner must be properly compacted and smoothed to serve as a foundation for an overlying geomembrane liner or other component of a liner or cover system. Verification of final surface preparation is an important part of the CQA process.

2.1.4 Compaction Requirements

One of the most important aspects of constructing soil liners that have low hydraulic conductivity is the proper remolding and compaction of the soil. Background information on soil compaction is presented in this subsection.

2.1.4.1 Compaction Curve

A compaction curve is developed by preparing several samples of soil at different water contents and then sequentially compacting each of the samples into a mold of known volume with a specified compaction procedure. The total unit weight (γ), which is also called the wet density, of each specimen is determined by weighing the compacted specimen and dividing the total weight by the total volume. The water content (w) of each compacted specimen is determined by oven drying the specimen. The dry unit weight (γ_d), which is sometimes called the dry density, is calculated as follows:

$$\gamma_d = \gamma/(1 + w) \qquad (2.1)$$

The (w, γ_d) points are plotted and a smooth curve is drawn between the points to define the compaction curve (Fig. 2.3). Judgment rather than an analytic algorithm is usually employed to draw the compaction curve through the measured points.

The *maximum dry unit weight* ($\gamma_{d,max}$) occurs at a water content that is called the *optimum water content*, w_{opt} (Fig. 2.3). The main reason for developing a compaction curve is to determine the optimum water content and maximum dry unit weight for a given soil and compaction procedure.

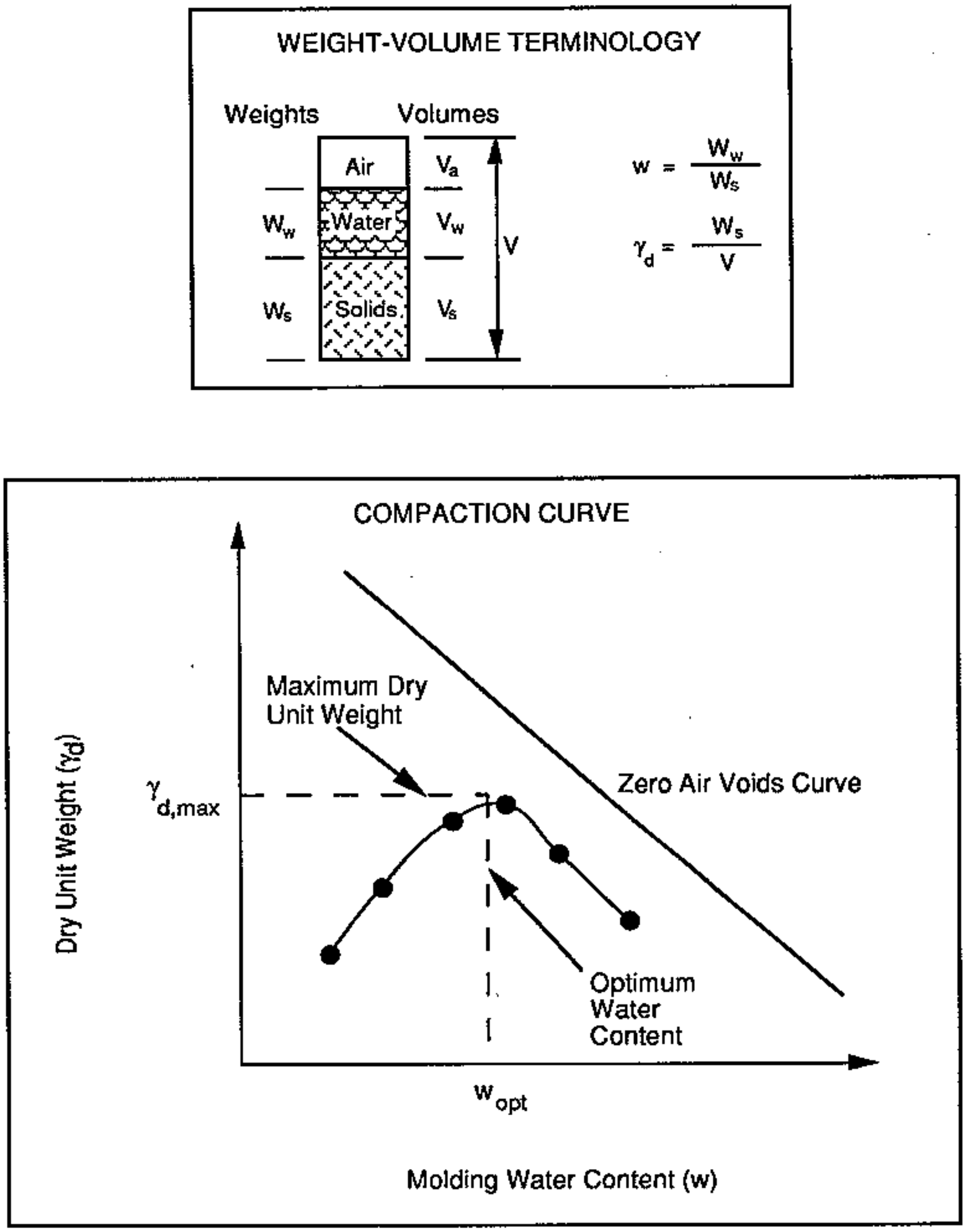


Figure 2.3 - Compaction Curve

The *zero air voids curve* (Fig. 2.3), also known as the *100% saturation curve,* is a curve that relates dry unit weight to water content for a saturated soil that contains no air. The equation for the zero air voids curve is:

$$\gamma_d = \gamma_w/[w + (1/G_s)] \tag{2.2}$$

where G_s is the specific gravity of solids (typically 2.6 to 2.8) and γ_w is the unit weight of water. If the soil's specific gravity of solids changes, the zero air voids curve will also change. Theoretically, no points on a plot of dry unit weight versus water content should lie above the zero air voids curve, but in practice some points usually lie slightly above the zero air voids curve as a result of soil variability and inherent limitations in the accuracy of water content and unit weight measurements (Schmertmann, 1989).

Benson and Boutwell (1992) summarize the maximum dry unit weights and optimum water content measured on soil liner materials from 26 soil liner projects and found that the degree of saturation at the point of (w_{opt}, $\gamma_{d,max}$) ranged from 71% to 98%, based on an assumed G_s value of 2.75. The average degree of saturation at the optimum point was 85%.

2.1.4.2 Compaction Tests

Several methods of laboratory compaction are commonly employed. The two procedures that are most commonly used are standard and modified compaction. Both techniques usually involve compacting the soil into a mold having a volume of 0.00094 m^3 (1/30 ft^3). The number of lifts, weight of hammer, and height of fall are listed in Table 2.1. The compaction tests are sometimes called *Proctor* tests after Proctor, who developed the tests and wrote about the procedures in several 1933 issues of Engineering News Record. Thus, the compaction curves are sometimes called Proctor curves, and the maximum dry unit weight may be termed the *Proctor density.*

Table 2.1 - Compaction Test Details

Compaction Procedure	Number of Lifts	Weight of Hammer	Height of Fall	Compactive Energy
Standard	3	24.5N (5.5 lbs)	305 mm (12 in.)	594 kN-m/m^3 (12,375 ft-lb/ft^3)
Modified	5	44.5N (10 lbs)	457 mm (18 in.)	2,693 kN-m/m^3 (56,250 ft-lb/ft^3)

Proctor's original test, now frequently called the *standard Proctor compaction test*, was developed to control compaction of soil bases for highways and airfields. The maximum dry unit weights attained from the standard Proctor compaction test were approximately equal to unit weights observed in the field on well-built fills using compaction equipment available in the 1920s and 1930s. During World War II, much heavier compaction equipment was developed and the unit weights attained from field compaction sometimes exceeded the laboratory values. Proctor's original procedure was modified by increasing compactive energy. By today's standards:

- Standard Compaction (ASTM D-698) produces maximum dry unit weights approximately equal to field dry unit weights for soils that are well compacted using modest-sized compaction equipment.
- Modified Compaction (ASTM D-1557) produces maximum dry unit weights approximately equal to field dry unit weights for soils that are well compacted using the heaviest compaction equipment available.

2.1.4.3 Percent Compaction

The compaction test is used to help CQA personnel to determine: 1) whether the soil is at the proper water content for compaction, and 2) whether the soil has received adequate compactive effort. Field CQA personnel will typically measure the water content of the field-compacted soil (w) and compare that value with the optimum water content (w_{opt}) from a laboratory compaction test. The construction specifications may limit the value of w relative to w_{opt}, e.g., specifications may require w to be between 0 and +4 percentage points of w_{opt}. Field CQC personnel should measure the water content of the soil prior to remolding and compaction to ensure that the material is at the proper water content before the soil is compacted. However, experienced earthwork personnel can often tell if the soil is at the proper water content from the look and feel of the soil. Field CQA personnel should measure the water content and unit weight after compaction to verify that the water content and dry unit weight meet specifications. Field CQA personnel often compute the percent compaction, P, which is defined as follows:

$$P = \gamma_d/\gamma_{d,max} \times 100\% \quad (2.3)$$

where γ_d is the dry unit weight of the field-compacted soil. Construction specifications often stipulate a minimum acceptable value of P.

In summary, the purpose of the laboratory compaction test as applied to CQC and CQA is to provide water content (w_{opt}) and dry unit weight ($\gamma_{d,max}$) reference points. The actual water content of the field-compacted soil liner may be compared to the optimum value determined from a specified laboratory compaction test. If the water content is not in the proper range, the engineering properties of the soil are not likely to be in the range desired. For example, if the soil is too wet, the shear strength of the soil may be too low. Similarly, the dry unit weight of the field-compacted soil may be compared to the maximum dry unit weight determined from a specified laboratory compaction test. If the percent compaction is too low, the soil has probably not been adequately compacted in the field. Compaction criteria may also be established in ways that do not involve percent compaction, as discussed later, but one way or another, the laboratory compaction test provides a reference point.

2.1.4.4 Estimating Optimum Water Content and Maximum Dry Unit Weight

Many CQA plans require that the water content and dry unit weight of the field-compacted soil be compared to values determined from laboratory compaction tests. Compaction tests are a routine part of nearly all CQA programs. However, from a practical standpoint, performing compaction tests introduces two problems:

1. A compaction test often takes 2 to 4 days to complete -- field personnel cannot wait for the completion of a laboratory compaction test to make “pass-fail” decisions.

2. The soil will inevitably be somewhat variable -- the optimum water content and maximum dry unit weight will vary. The values of w_{opt} and $\gamma_{d,max}$ appropriate for one location may not be appropriate for another location. This has been termed a "mismatch" problem (Noorany, 1990).

Because dozens (sometimes hundreds) of field water content and density tests are performed, it is impractical to perform a laboratory compaction test each and every time a field measurement of water content and density is obtained. Alternatively, simpler techniques for estimating the maximum dry unit weight are almost always employed for rapid field CQA assessments. These techniques are subjective assessment, one-point compaction test, and three-point compaction test.

2.1.4.4.1 Subjective Assessment

Relatively homogeneous fill materials produce similar results when repeated compaction tests are performed on the soil. A common approach is to estimate optimum water content and maximum dry unit weight based on the results of previous compaction tests. The results of at least 2 to 3 laboratory compaction tests should be available from tests on borrow soils prior to actual compaction of any soil liner material for a project. With subjective assessment, CQA personnel estimate the optimum water content and maximum dry unit weight based upon the results of the previously-completed compaction tests and their evaluation of the soil at a particular location in the field. Slight variations in the composition of fill materials will cause only slight variations in w_{opt} and $\gamma_{d,max}$. As an approximate guide, a relatively homogeneous borrow soil would be considered a material in which w_{opt} does not vary by more than ± 3 percentage points and $\gamma_{d,max}$ does not vary by more than ± 0.8 kN/ft^3 (5 pcf). The optimum water content and maximum dry unit weight should not be estimated in this manner if the soil is heterogeneous -- too much guess work and opportunity for error would exist.

2.1.4.4.2 One-Point Compaction Test

The results of several complete compaction tests should always be available for a particular borrow source prior to construction, and the data base should expand as a project progresses and additional compaction tests are performed. The idea behind a one-point compaction test is shown in Fig. 2.4. A sample of soil is taken from the field and dried to a water content that appears to be just dry of optimum. An experienced field technician can usually tell without much difficulty when the water content is just dry of optimum. The sample of soil is compacted into a mold of known volume according to the compaction procedure relevant to a particular project, e.g., ASTM D-698 or D-1557. The weight of the compacted specimen is measured and the total unit weight is computed. The sample is dried using one of the rapid methods of measurement discussed later to determine water content. Dry unit weight is computed from Eq. 2.2. The water content-dry unit weight point from the one-point compaction test is plotted as shown in Fig. 2.4 and used in conjunction with available compaction curves to estimate w_{opt} and $\gamma_{d,max}$. One assumes that the shape of the compaction is similar to the previously-developed compaction curves and passes through the one point that has been determined.

The dashed curve in Fig. 2.4 is the estimated compaction curve. The one-point compaction test is commonly used for variable soils. In extreme cases, a one-point compaction test may be required for nearly all field water content and density measurements for purposes of computing percent compaction. However, if the material is so variable to require a one-point compaction test for nearly all field density measurements, the material is probably too variable to be suitable for use in a soil liner. The best use of the one-point compaction test is to assist with estimation of the optimum water content and maximum dry unit weight for questionable materials and to fill in data gaps when results of complete compaction tests are not available quickly enough.

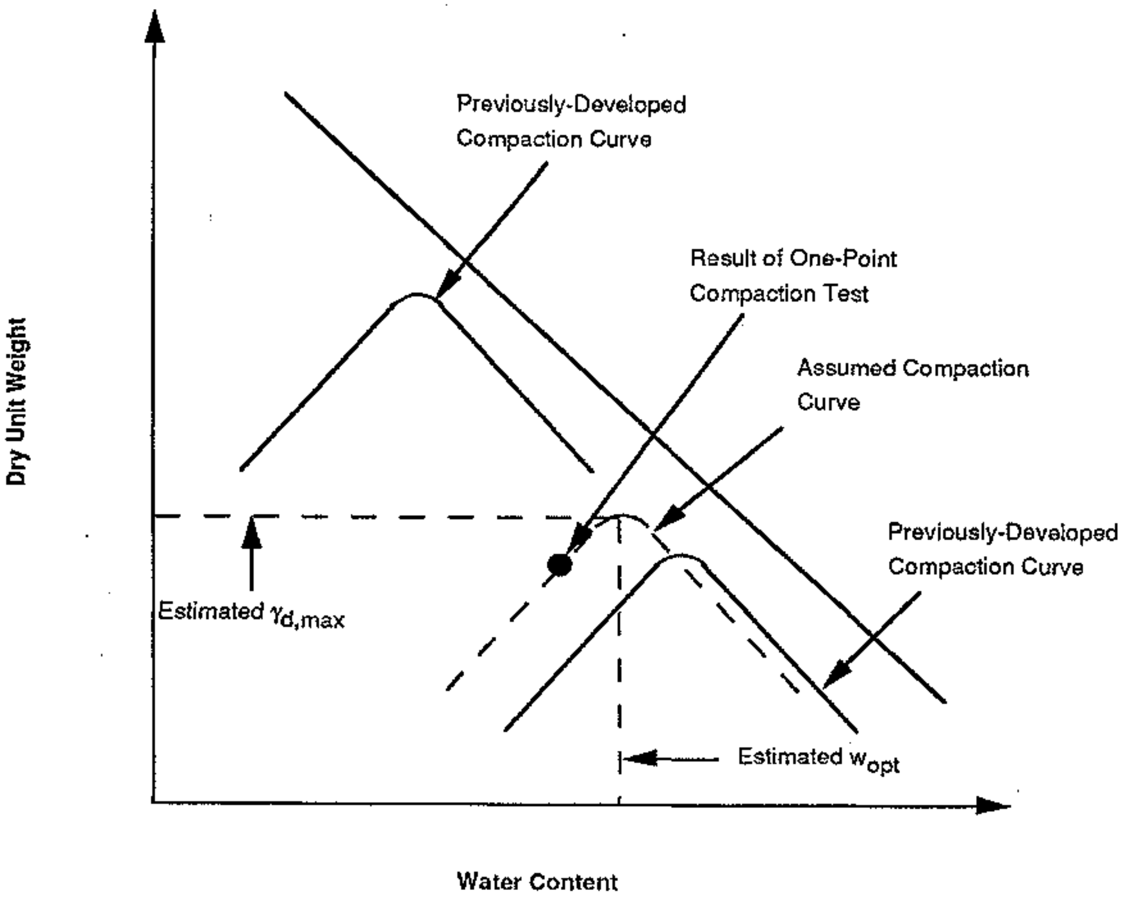


Figure 2.4 - One-Point Compaction Test

2.1.4.4.3 Three-Point Compaction Test (ASTM D-5080)

A more reliable technique than the one-point compaction test for estimating the optimum water content and maximum dry unit weight is to use a minimum of three compaction points to define a curve rather than relying on a single compaction point. A representative sample of soil is obtained from the field at the same location where the in-place water content and dry unit weight have been measured. The first sample of soil is compacted at the field water content. A second sample is prepared at a water content two percentage points wetter than the first sample and is compacted. However, for extremely wet soils that are more than 2% wet of optimum (which is often the case for soil liner materials), the second sample should be dried 2% below natural water content. Depending on the outcome of this compaction test, a third sample is prepared at a water content either two percentage points dry of the first sample or two percentage points wet of the second sample (or, for wet soil liners, 2 percentage points dry of the second sample). A parabola is fitted to the three compaction data points and the optimum water content and maximum dry unit weight are determined from the equation of the best-fit parabola. This technique is significantly more time consuming than the one-point compaction test but offers 1) a standard ASTM procedure and 2) greater reliability and repeatability in estimated w_{opt} and $\gamma_{d,max}$.

2.1.4.5 Recommended Procedure for Developing Water Content-Density Specification

One of the most important aspects of CQC and CQA for soil liners is documentation of the water content and dry unit weight of the soil immediately after compaction. Historically, the method used to specify water content and dry unit weight has been based upon experience with structural fill. Design engineers often require that soil liners be compacted within a specified range of water content and to a minimum dry unit weight. The "Acceptable Zone" shown in Fig. 2.5 represents the zone of acceptable water content/dry unit weight combinations that is often prescribed. The shape of the Acceptable Zone shown in Fig. 2.5 evolved empirically from construction practices applied to roadway bases, structural fills, embankments, and earthen dams. The specification is based primarily upon the need to achieve a minimum dry unit weight for adequate strength and limited compressibility. As discussed by Mundell and Bailey (1985), Boutwell and Hedges (1989), and Daniel and Benson (1990), this method of specifying water content and dry unit weight is not necessarily the best method for compacted soil liners.

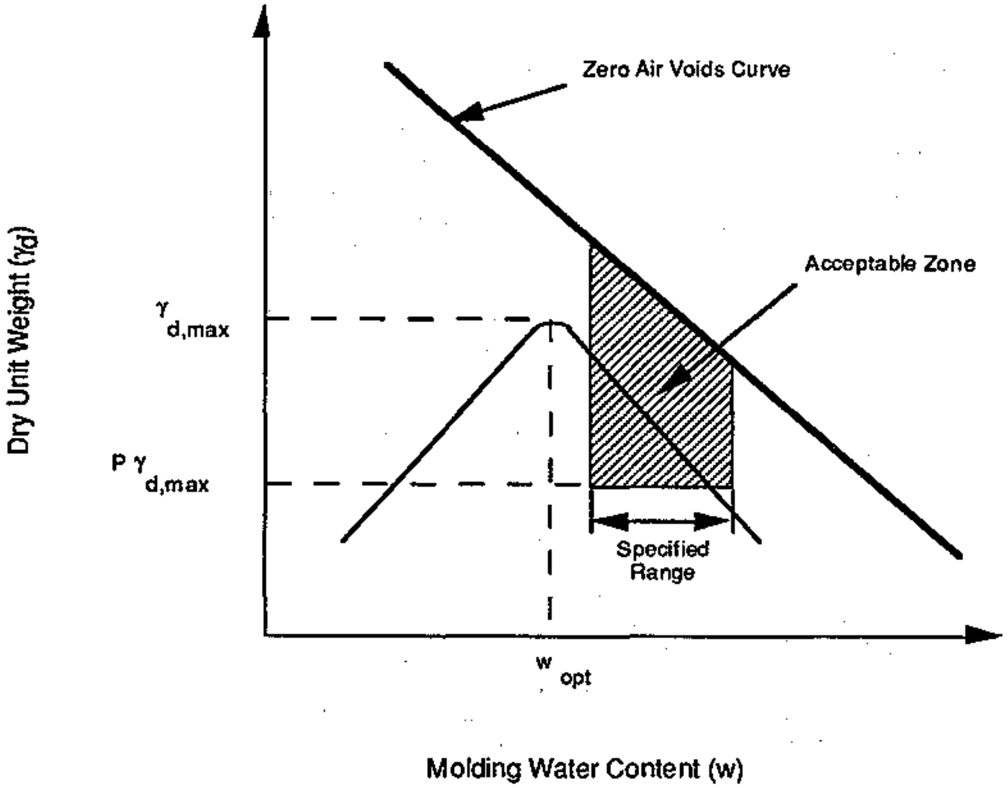


Figure 2.5 - Form of Water Content-Dry Unit Weight Specification Often Used in the Past

The recommended approach is intended to ensure that the soil liner will be compacted to a water content and dry unit weight that will lead to low hydraulic conductivity and adequate engineering performance with respect to other considerations, e.g., shear strength. Rational specification of water content/dry unit weight criteria should be based upon test data developed for each particular soil. Field test data would be better than laboratory data, but the cost of determining compaction criteria in the field through a series of test sections would almost always be prohibitive. Because the compactive effort will vary in the field, a logical approach is to select several compactive efforts in the laboratory that span the range of compactive effort that might be anticipated in the field. If this is done, the water content/dry unit weight criterion that evolves would be expected to apply to any reasonable compactive effort.

For most earthwork projects, modified Proctor effort represents a reasonable upper limit on the compactive effort likely to be delivered to the soil in the field. Standard compaction effort (ASTM D-698) likely represents a medium compactive effort. It is conceivable that soil in some locations will be compacted with an effort less than that of standard Proctor compaction. A reasonable lower limit of compactive energy is the "reduced compaction" procedure in which standard compaction procedures (ASTM D-698) are followed except that only 15 drops of the hammer per lift are used instead of the usual 25 drops. The reduced compaction procedure is the same as the 15 blow compaction test described by the U.S. Army Corps of Engineers (1970). The reduced compactive effort is expected to correspond to a reasonable minimum level of compactive energy for a typical soil liner or cover. Other compaction methods, e.g., kneading compaction, could be used. The key is to span the range of compactive effort expected in the field with laboratory compaction procedures.

One satisfactory approach is as follows:

1. Prepare and compact soil in the laboratory with modified, standard, and reduced compaction procedures to develop compaction curves as shown in Fig. 2.6a. Make sure that the soil preparation procedures are appropriate; factors such as clod size reduction may influence the results (Benson and Daniel, 1990). Other compaction procedures can be used if they better simulate field compaction and span the range of compactive effort expected in the field. Also, as few as two compaction procedures can be used if field construction procedures make either the lowest or highest compactive energy irrelevant.

2. The compacted specimens should be permeated, e.g., per ASTM D-5084. Care should be taken to ensure that permeation procedures are correct, with important details such as degree of saturation and effective confining stress carefully selected. The measured hydraulic conductivity should be plotted as a function of molding water content as shown in Fig. 2.6b.

3. As shown in Fig. 2.6c, the dry unit weight/water content points should be replotted with different symbols used to represent compacted specimens that had hydraulic conductivities greater than the maximum acceptable value and specimens with hydraulic conductivities less than or equal to the maximum acceptable value. An "Acceptable Zone" should be drawn to encompass the data points representing test results meeting or exceeding the design criteria. Some judgment is usually necessary in constructing the Acceptable Zone from the data points. Statistical criteria (e.g., Boutwell and Hedges, 1989) may be introduced at this stage.

4. The Acceptable Zone should be modified (Fig. 2.6d) based on other considerations such as shear strength. Additional tests are usually necessary in order to define the acceptable range of water content and dry unit weight that satisfies both hydraulic conductivity and shear strength criteria. Figure 2.7 illustrates how one might overlap Acceptable Zones defined from hydraulic conductivity and shear strength considerations to define a single Acceptable Zone. The same procedure can be applied to take into consideration other factors such as shrink/swell potential relevant to any particular project.

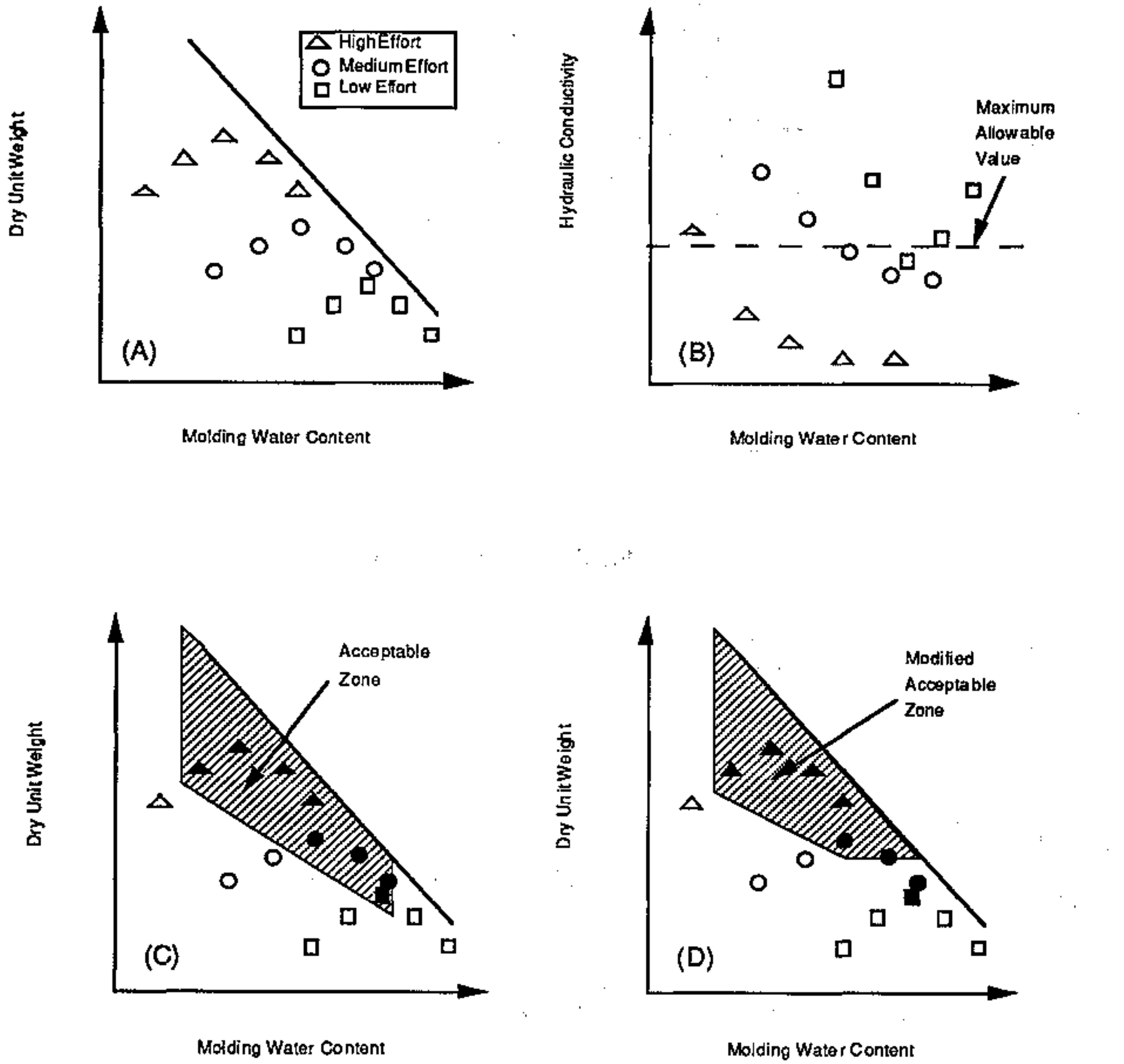


Figure 2.6 - Recommended Procedure to Determine Acceptable Zone of Water Content/Dry Unit Weight Values Based Upon Hydraulic Conductivity Considerations (after Daniel and Benson, 1990).

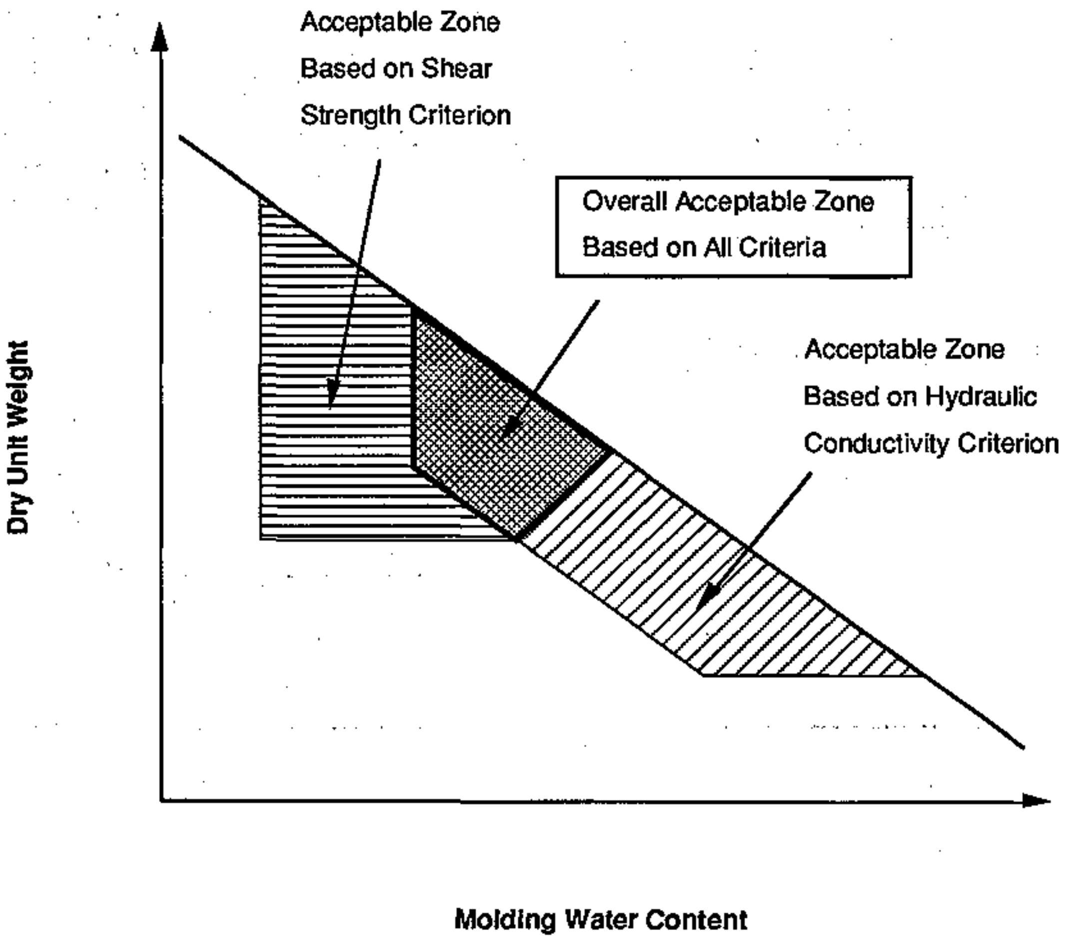


Figure 2.7 - Acceptable Zone of Water Content/Dry Unit Weights Determined by Superposing Hydraulic Conductivity and Shear Strength Data (after Daniel and Benson, 1990).

The same general procedure just outlined may also be used for soil-bentonite mixtures. However, to keep the scope of testing reasonable, the required amount of bentonite should be determined before the main part of the testing program is initiated. The recommended procedure for soil-bentonite mixes may be summarized as follows:

1. The type, grade, and gradation of bentonite that will be used should be determined. This process usually involves estimating costs from several potential suppliers. A sufficient quantity of the bentonite likely to be used for the project should be obtained and tested to characterize the bentonite (characterization tests are discussed later).

2. A representative sample of the soil to which the bentonite will be added should be obtained.

3. Batches of soil-bentonite mixtures should be prepared by blending in bentonite at several percentages, e.g., 2%, 4%, 6%, 8%, and 10% bentonite. Bentonite content is defined as the weight or mass of bentonite divided by the weight or mass of soil mixed with bentonite. For instance, if 5 kg of bentonite are mixed with 100 kg of soil, the bentonite content is 5%. Some people use the gross weight of bentonite rather than oven dry weight. Since air-dry bentonite usually contains 10% to 15% hygroscopic water by weight, the use of oven-dry, air-dry, or damp weight can make a difference in the percentage. Similarly, the weight of soil may be defined as either moist or dry (air- or oven-dry) weight. The contractor would rather work with total (moist) weights since the materials used in forming a soil-bentonite blend do contain some water. However, the engineering characteristics are controlled by the relative amounts of dry materials. A dry-weight basis is generally recommended for definition of bentonite content, but CQC and CQA personnel must recognize that the project specifications may or may not be on a dry-weight basis.

4. Develop compaction curves for each soil-bentonite mixture prepared from Step 3 using the method of compaction appropriate to the project, e.g., ASTM D-698 or ASTM D-1557.

5. Compact samples at 2% wet of optimum for each percentage of bentonite using the same compaction procedure employed in Step 4.

6. Permeate the soils prepared from Step 5 using ASTM D-5084 or some other appropriate test method. Graph hydraulic conductivity versus percentage of bentonite.

7. Decide how much bentonite to use based on the minimum required amount determined from Step 6. The minimum amount of bentonite used in the field should always be greater than the minimum amount suggested by laboratory tests because mixing in the field is usually not as thorough as in the laboratory. Typically, the amount of bentonite used in the field is one to four percentage points greater than the minimum percent bentonite indicated by laboratory tests.

8. A master batch of material should be prepared by mixing bentonite with a representative sample of soil at the average bentonite content expected in the field. The procedures described earlier for determining the Acceptable Zone of water content and dry unit weight are then applied to the master batch.

2.1.5 Test Pads

Test pads are sometimes constructed and tested prior to construction of the full-scale compacted soil liner. The test pad simulates conditions at the time of construction of the soil liner. If conditions change, e.g., as a result of emplacement of waste materials over the liner, the properties of the liner will change in ways that are not normally simulated in a test pad. The objectives of a test pad should be as follows:

1. To verify that the materials and methods of construction will produce a compacted soil liner that meets the hydraulic conductivity objectives defined for a project, hydraulic conductivity should be measured with techniques that will characterize the large-scale hydraulic conductivity and identify any construction defects that cannot be observed with small-scale laboratory hydraulic conductivity tests.

2. To verify that the proposed CQC and CQA procedures will result in a high-quality soil liner that will meet performance objectives.

3. To provide a basis of comparison for full-scale CQA: if the test pad meets the performance objectives for the liner (as verified by appropriate hydraulic conductivity tests) and the full-scale liner is constructed to standards that equal or exceed those used in building the test pad, then assurance is provided that the full-scale liner will also meet performance objectives.

4. If appropriate, a test pad provides an opportunity for the facility owner to demonstrate that unconventional materials or construction techniques will lead to a soil liner that meets performance objectives.

In terms of CQA, the test pad can provide an extremely powerful tool to ensure that performance objectives are met. The authors recommend a test pad for any project in which failure of the soil liner to meet performance objectives would have a potentially important, negative environmental impact.

A test pad need not be constructed if results are already available for a particular soil and construction methodology. By the same token, if the materials or methods of construction change, an additional test pad is recommended to test the new materials or construction procedures. Specific CQA tests and observations that are recommended for the test pad are described later in Section 2.10.

2.2 Critical Construction Variables that Affect Soil Liners

Proper construction of compacted soil liners requires careful attention to construction variables. In this section, basic principles are reviewed to set the stage for discussion of detailed CQC and CQA procedures.

2.2.1 Properties of the Soil Material

The construction specifications place certain restrictions on the materials that can be used in constructing a soil liner. Some of the restrictions are more important than others, and it is important for CQC and CQA personnel to understand how material properties can influence the performance of a soil liner.

2.2.1.1 Plasticity Characteristics

The plasticity of a soil refers to the capability of a material to behave as a plastic, moldable material. Soils are said to be either plastic or non-plastic. Soils that contain clay are usually plastic whereas those that do not contain clay are usually non-plastic. If the soil is non-plastic, the soil is almost always considered unsuitable for a soil liner unless additives such as bentonite are introduced.

The plasticity characteristics of a soil are quantified by three parameters: liquid limit, plastic limit, and plasticity index. These terms are defined as follows:

- Liquid Limit (LL): The water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil.

- Plastic Limit (PL): The water content corresponding to the arbitrary limit between the plastic and solid states of consistency of a soil.

- Plasticity Index (PI): The numerical difference between liquid and plastic limits, i.e., LL - PL.

The liquid limit and plastic limit are measured using ASTM D-4318.

Experience has shown that if the soil has extremely low plasticity, the soil will possess insufficient clay to develop low hydraulic conductivity when the soil is compacted. Also, soils that have very low PI's tend to grade into non-plastic soils in some locations. The question of how low the PI can be before the soil is not sufficiently plastic is impossible to answer universally. Daniel (1990) recommends that the soil have a PI $\geq$ 10% but notes that some soils with PI's as low as 7% have been used successfully to build soil liners with extremely low in situ hydraulic conductivity (Albrecht and Cartwright, 1989). Benson et al. (1992) compiled a data base from CQA documents and related the hydraulic conductivity measured in the laboratory on small, "undisturbed" samples of field-compacted soil to various soil characteristics. The observed relationship between hydraulic conductivity and plasticity index is shown in Fig. 2.8. The data base reflects a broad range of construction conditions, soil materials, and CQA procedures. It is clear from the data base that many soils with PI's as low as approximately 10% can be compacted to achieve a hydraulic conductivity $\leq 1 \times 10^{-7}$ cm/s.

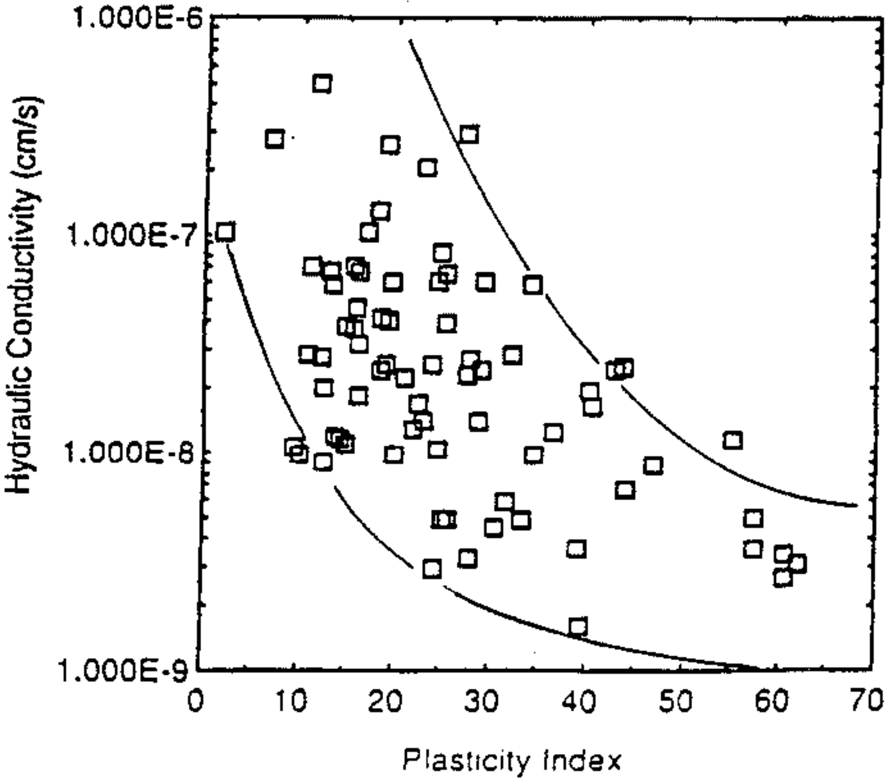


Figure 2.8 - Relationship between Hydraulic Conductivity and Plasticity Index (Benson et al., 1992)

Soils with high plasticity index (>30% to 40%) tend to form hard clods when dried and sticky clods when wet. Highly plastic soils also tend to shrink and swell when wetted or dried. With highly plastic soils, CQC and CQA personnel should be particularly watchful for proper processing of clods, effective remolding of clods during compaction, and protection from desiccation.

2.2.1.2 Percentage Fines

Some earthwork specifications place a minimum requirement on the percentage of fines in the soil liner material. *Fines* are defined as the fraction of soil that passes through the openings of the No. 200 sieve (opening size = 0.075 mm). Soils with inadequate fines typically have too little silt- and clay-sized material to produce suitably low hydraulic conductivity. Daniel (1990) recommends that the soil liner materials contain at least 30% fines. Data from Benson et al. (1992), shown in Fig. 2.9, suggest that a minimum of 50% fines might be an appropriate requirement for many soils. Field inspectors should check the soil to make sure the percentage of fines meets or exceeds the minimum stated in the construction specifications and should be particularly watchful for soils with less than 50% fines.

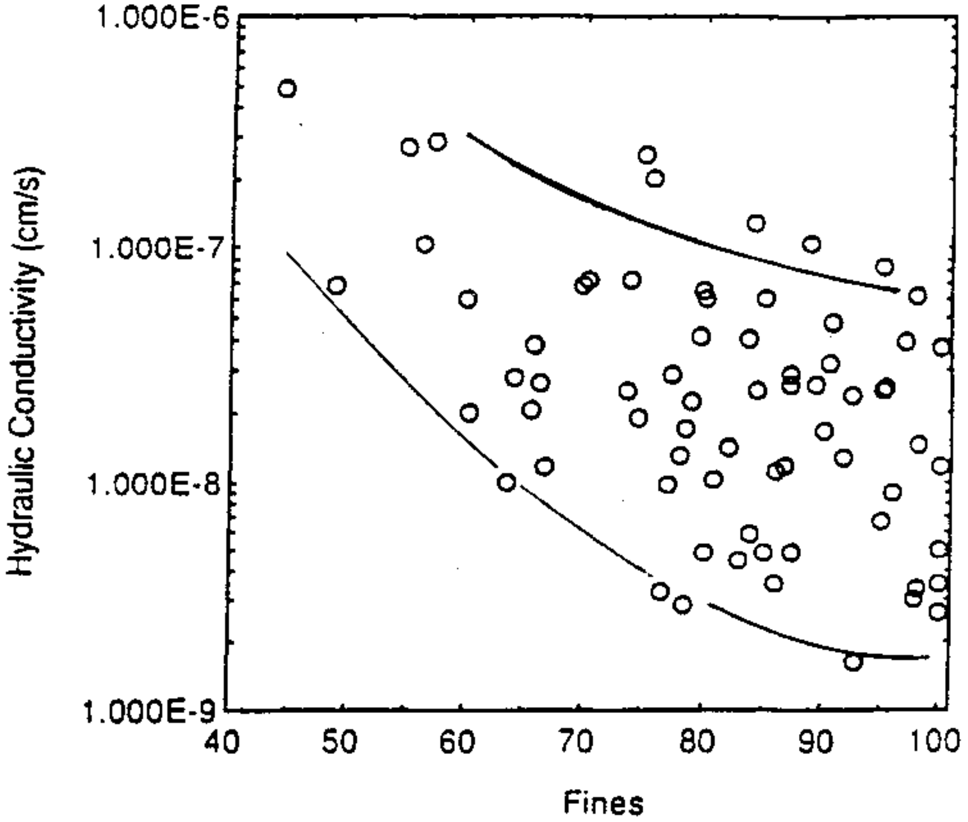


Figure 2.9 - Relationship between Hydraulic Conductivity and Percent Fines (Benson et al., 1992)

2.2.1.3 Percentage Gravel

Gravel is herein defined as particles that will not pass through the openings of a No. 4 sieve (opening size = 4.76 mm). Gravel itself has a high hydraulic conductivity. However, a relatively large percentage (up to about 50%) of gravel can be uniformly mixed with a soil liner material without significantly increasing the hydraulic conductivity of the material (Fig. 2.10). The hydraulic conductivity of mixtures of gravel and clayey soil is low because the clayey soil fills the voids between the gravel particles. The critical observation for CQA inspectors to make is for possible segregation of gravel into pockets that do not contain sufficient soil to plug the voids between the gravel particles. The uniformity with which the gravel is mixed with the soil is more important than the gravel content itself for soils with no more than 50% gravel by weight. Gravel also may possess the capability of puncturing geosynthetic materials -- the maximum size and the angularity of the gravel are very important for the layer of soil that will serve as a foundation layer for a geomembrane.

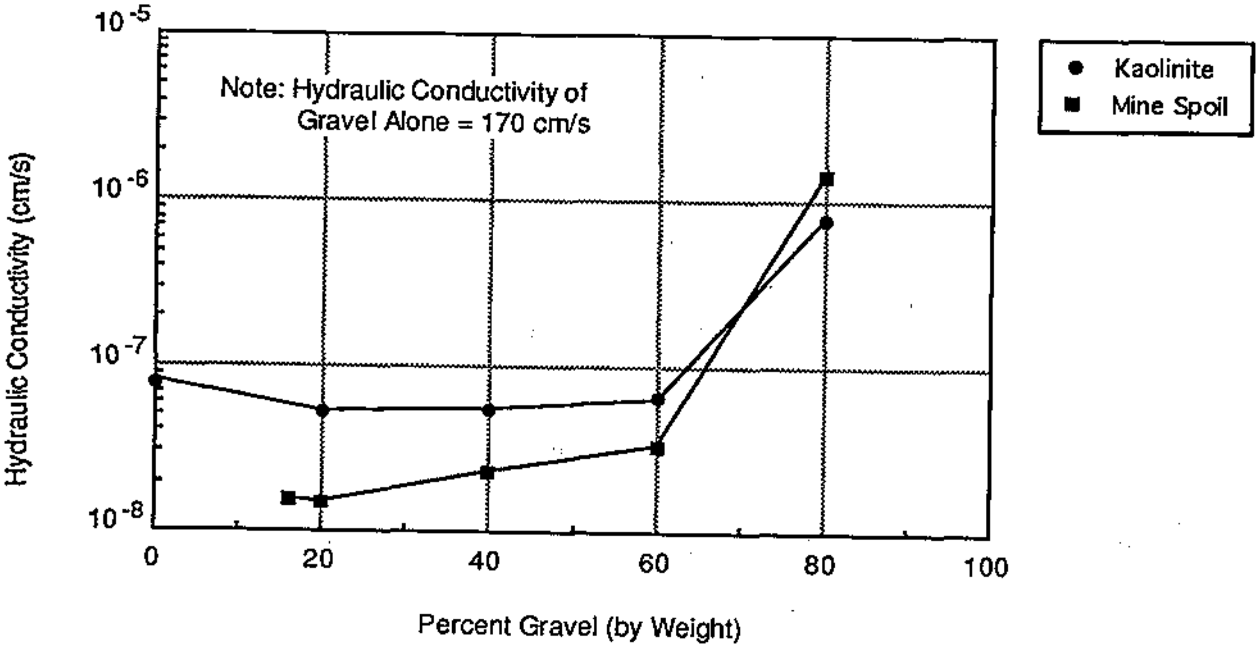


Figure 2.10 - Relationship between Hydraulic Conductivity and Percentage Gravel Added to Two Clayey Soils (after Shelley and Daniel, 1993).

2.2.1.4 Maximum Particle Size

The maximum particle size is important because: (1) cobbles or large stones can interfere with compaction, and (2) if a geomembrane is placed on top of the compacted soil liner, oversized particles can damage the geomembrane. Construction specifications may stipulate the maximum allowable particle size, which is usually between 25 and 50 mm (1 to 2 in.) for compaction considerations but which may be much less for protection against puncture of an adjacent geomembrane. If a geomembrane is to be placed on the soil liner, only the upper lift of the soil liner is relevant in terms of protection against puncture. Construction specifications may place one set of restrictions on all lifts of soil and place more stringent requirements on the upper lift to protect the geomembrane from puncture. Sieve analyses on small samples will not usually lead to detection of an occasional piece of oversized material. Observations by attentive CQC and CQA personnel are the most effective way to ensure that oversized materials have been removed. Oversized materials are particularly critical for the top lift of a soil liner if a geomembrane is to be placed on the soil liner to form a composite geomembrane/soil liner.

2.2.1.5 Clay Content and Activity

The clay content of the soil may be defined in several ways but it is usually considered to be the percentage of soil that has an equivalent particle diameter smaller than 0.005 or 0.002 mm, with 0.002 mm being the much more common definition. The clay content is measured by sedimentation analysis (ASTM D-422). Some construction specifications specify a minimum clay content but many do not.

A parameter that is sometimes useful is the activity, A, of the soil, which is defined as the plasticity index (expressed as a percentage) divided by the percentage of clay (< 0.002 mm) in the soil. A high activity (> 1) indicates that expandable clay minerals such as montmorillonite are present. Lambe and Whitman (1969) report that the activities of kaolinite, illite, and montmorillonite (three common clay minerals) are 0.38, 0.9, and 7.2, respectively. Activities for naturally occurring clay liner materials, which contain a mix of minerals, is frequently in the range of $0.5 \leq A \leq 1$.

Benson et al. (1992) related hydraulic conductivity to clay content (defined as particles < 0.002 mm) and reported the correlation shown in Fig. 2.11. The data suggest that soils must have at least 10% to 20% clay in order to be capable of being compacted to a hydraulic conductivity $\leq 1 \times 10^{-7}$ cm/s. However, Benson et al. (1992) also found that clay content correlated closely with plasticity index (Fig. 2.12). Soils with PI >10% will generally contain at least 10% to 20% clay.

It is recommended that construction specification writers and regulation drafters indirectly account for clay content by requiring the soil to have an adequate percentage of fines and a suitably large plasticity index -- by necessity the soil will have an adequate amount of clay.

2.2.1.6 Clod Size

The term *clod* refers to chunks of cohesive soil. The maximum size of clods may be specified in the construction specifications. Clod size is very important for dry, hard, clay-rich soils (Benson and Daniel, 1990). These materials generally must be broken down into small clods in order to be properly hydrated, remolded, and compacted. Clod size is less important for wet soils -- soft, wet clods can usually be remolded into a homogeneous, low-hydraulic-conductivity mass with a reasonable compactive effort.

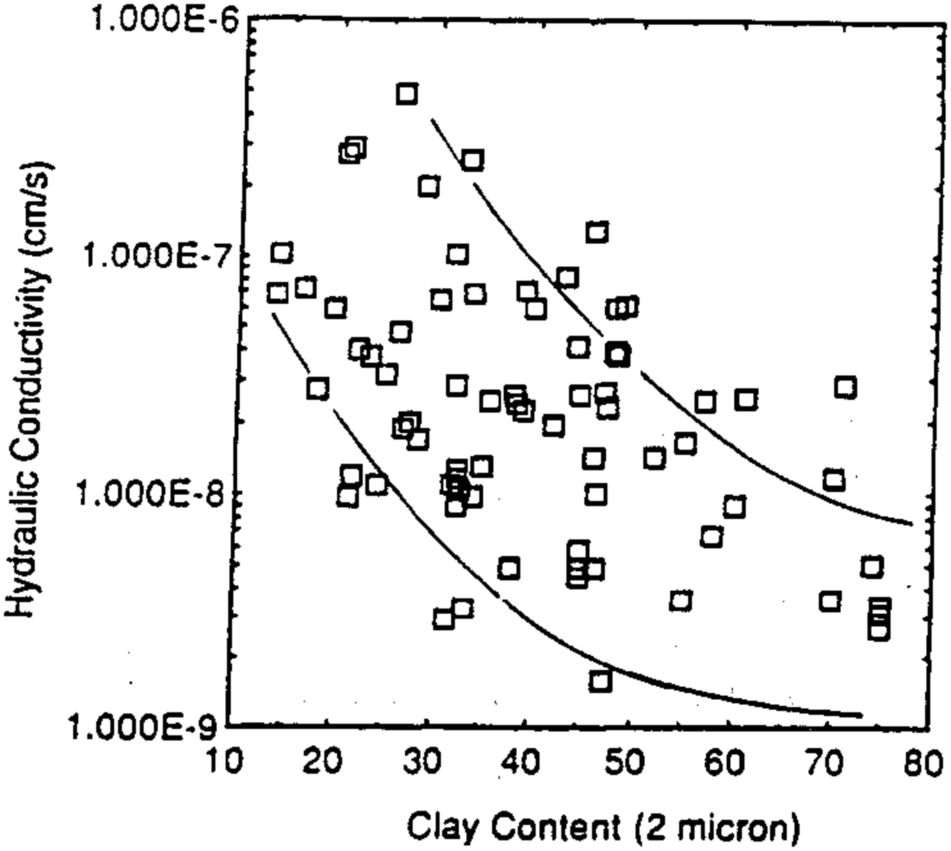


Figure 2.11 - Relationship between Hydraulic Conductivity and Clay Content (Benson et al., 1992)

No standard method is available to determine clod size. Inspectors should observe the soil liner material and occasionally determine the dimensions of clods by direct measurement with a ruler to verify conformance with construction specifications.

2.2.1.7 Bentonite

Bentonite may be added to clay-deficient soils in order to fill the voids between the soil particles with bentonite and to produce a material that, when compacted, has a very low hydraulic conductivity. The effect of the addition of bentonite upon hydraulic conductivity is shown in Fig. 2.13 for one silty sand. For this particular soil, addition of 4% sodium bentonite was sufficient to lower the hydraulic conductivity to less than 1 x 10^{-7} cm/s.

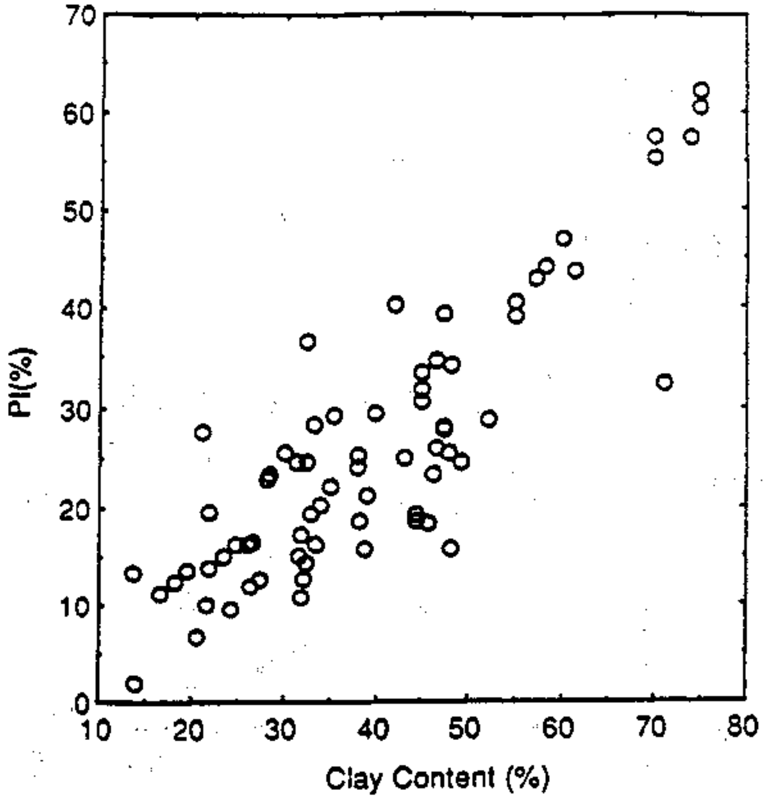


Figure 2.12 - Relationship between Clay Content and Plasticity Index (Benson et al., 1992)

The critical CQC and CQA parameters are the type of bentonite, the grade of bentonite, the grain size distribution of the processed bentonite, the amount of bentonite added to the soil, and the uniformity of mixing of the bentonite with the soil. Two types of bentonite are the primary commercial materials: sodium and calcium bentonite. Sodium bentonite has much greater water absorbency and swelling potential, but calcium bentonite may be more stable when exposed to certain chemicals. Sodium bentonite is used more frequently than calcium bentonite as a soil amendment for lining applications.

Any given type of bentonite may be available in several grades. The grade is a function of impurities in the bentonite, processing procedures, or additives. Some calcium bentonites are processed with sodium solutions to modify the bentonite to a sodium form. Some companies add polymers or other compounds to the bentonite to make the bentonite more absorbent of water or more resistant to alteration by certain chemicals.

Another variable is the gradation of the bentonite. A facet often overlooked by CQC and CQA inspectors is the grain size distribution of the processed bentonite. Bentonite can be ground to different degrees. A fine, powdered bentonite will behave differently from a coarse, granular bentonite -- if the bentonite was supposed to be finely ground but too coarse a grade was delivered, the bentonite may be unsuitable in the mixture amounts specified. Because bentonite is available in variable degrees of pulverization, a sieve analysis (ASTM D422) of the processed dry bentonite is recommended to determine the grain size distribution of the material.

The most difficult parameters to control are sometimes the amount of bentonite added to the soil and the thoroughness of mixing. Field CQC and CQA personnel should observe operational practices carefully.

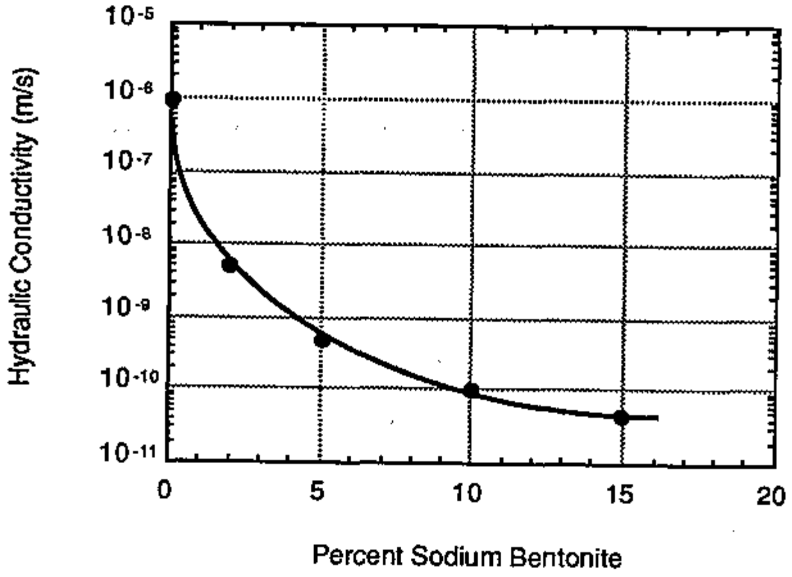


Figure 2.13 - Effect of Addition of Bentonite to Hydraulic Conductivity of Compacted Silty Sand

2.2.2 Molding Water Content

For natural soils, the degree of saturation of the soil liner material at the time of compaction is perhaps the single most important variable that controls the engineering properties of the compacted material. The typical relationship between hydraulic conductivity and molding water content is shown in Fig. 2.14. Soils compacted at water contents less than optimum (*dry of optimum*) tend to have a relatively high hydraulic conductivity; soils compacted at water contents greater than optimum (*wet of optimum*) tend to have a low hydraulic conductivity and low strength. For some soils, the water content relative to the plastic limit (which is the water content of the soil when the soil is at the boundary between being a solid and plastic material) may indicate the degree to which the soil can be compacted to yield low hydraulic conductivity. In general, if the water content is greater than the plastic limit, the soil is in a plastic state and should be capable of being remolded into a low-hydraulic-conductivity material. Soils with water contents dry of the plastic limit will exhibit very little "plasticity" and may be difficult to compact into a low-hydraulic-conductivity mass without delivering enormous compactive energy to the soil. With soil-bentonite mixes, molding water content is usually not as critical as it is for natural soils.

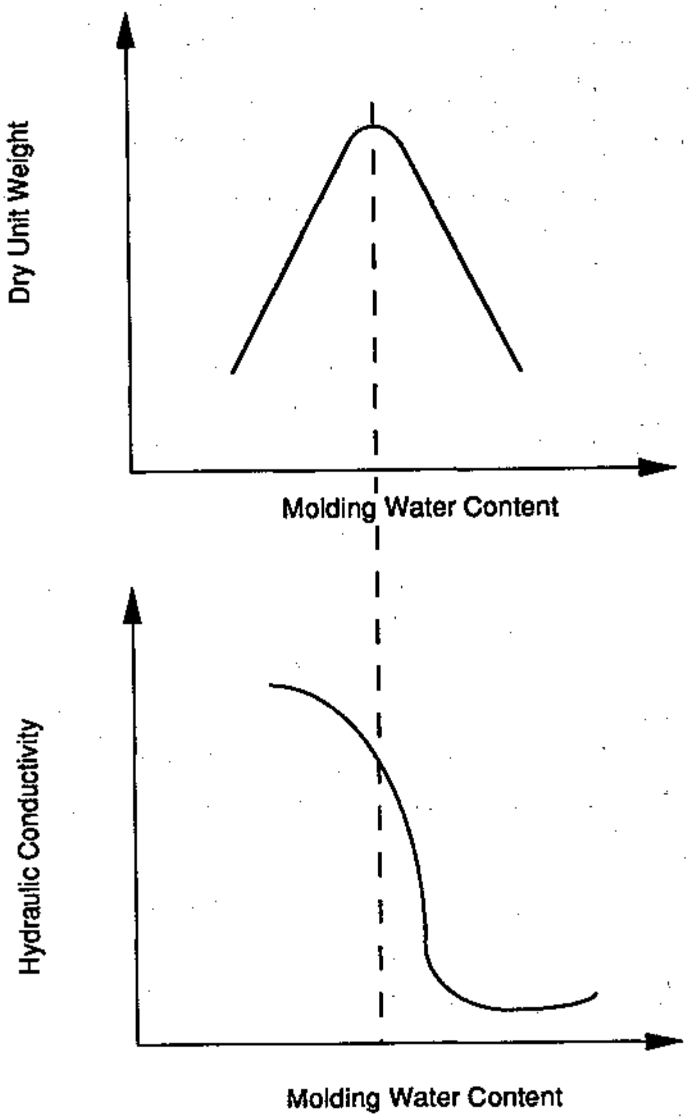


Figure 2.14 - Effect of Molding Water Content on Hydraulic Conductivity

The water content of highly plastic soils is particularly critical. A photograph of a highly plastic soil (PI = 41%) compacted 1% dry of the optimum water content of 17% is shown in Fig. 2.15. Large inter-clod voids are visible; the clods of clay were too dry and hard to be effectively remolded with the compactive effort used. A photograph of a compacted specimen of the same soil moistened to 3% wet of optimum and then compacted is shown in Fig. 2.16. At this water content, the soft soil could be remolded into a homogenous, low-hydraulic-conductivity mass.

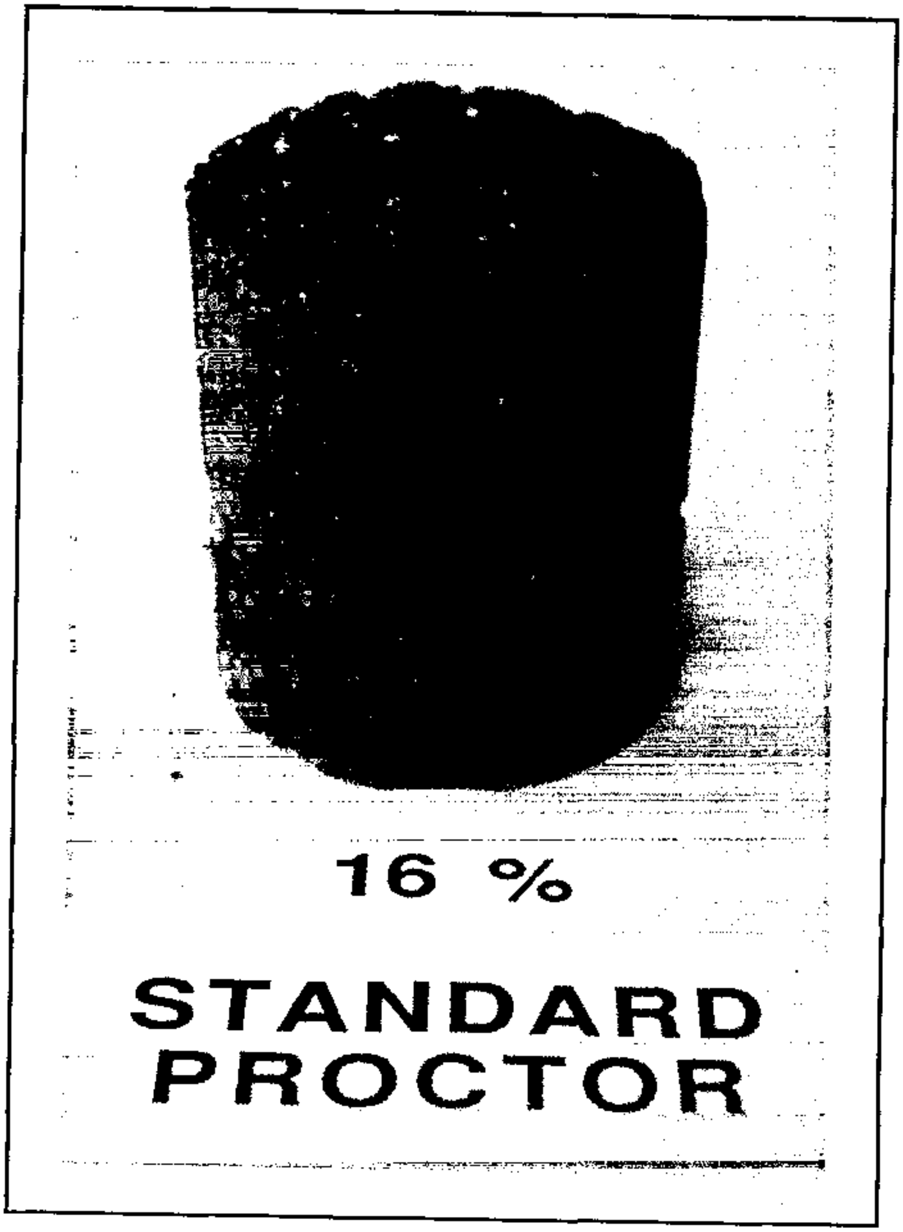


Figure 2.15 - Photograph of Highly Plastic Clay Compacted with Standard Proctor Effort at a Water Content of 16% (1% Dry of Optimum).

Figure 2.16 - Photograph of Highly Plastic Clay Compacted with Standard Proctor Effort at a Water Content of 20% (3% Wet of Optimum).

It is usually preferable to compact the soil wet of optimum to minimize hydraulic conductivity. However, the soil must not be placed at too high a water content. Otherwise, the shear strength may be too low, there may be great risk of desiccation cracks forming if the soil dries, and ruts may form when construction vehicles pass over the liner. It is critically important that CQC and CQA inspectors verify that the water content of the soil is within the range specified in the construction documents.

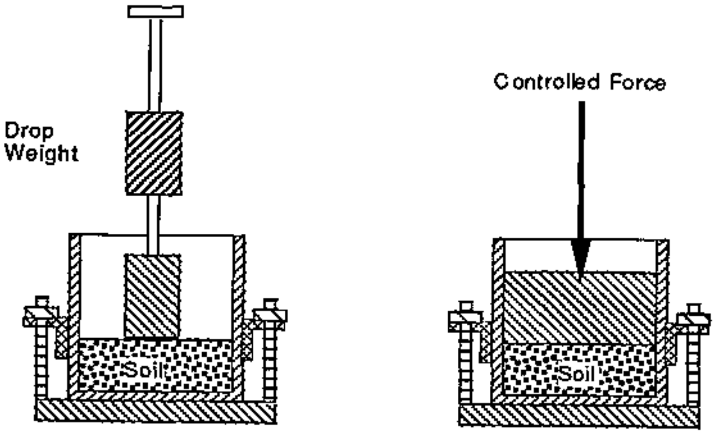
2.2.3 Type of Compaction

In the laboratory, soil can be compacted in four ways:

1. Impact Compaction: A ram is repeatedly raised and dropped to compact a lift soil into a mold (Fig. 2.17a), e.g., standard and modified Proctor.
2. Static Compaction: A piston compacts a lift of soil with a constant stress (Fig. 2.17b).
3. Kneading Compaction: A "foot" kneads the soil (Fig. 2.17c).
4. Vibratory Compaction: The soil is vibrated to densify the material (Fig. 2.17d).

A. Impact Compaction

B. Static Compaction



C. Kneading Compaction

D. Vibratory Compaction

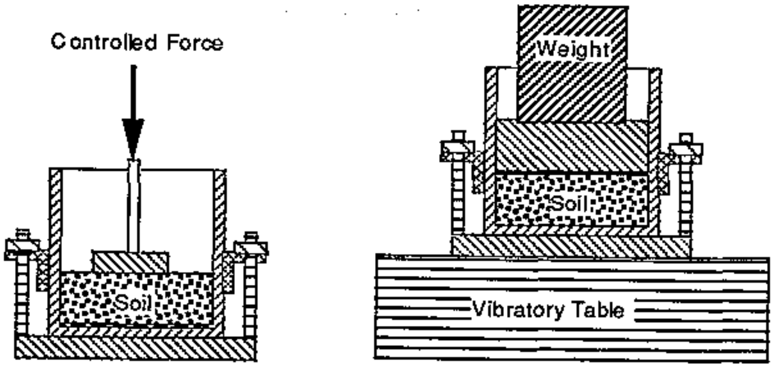


Figure 2.17 - Four Types of Laboratory Compaction Tests

Experience from the laboratory has shown that the type of compaction can affect hydraulic conductivity, e.g., as shown in Fig. 2.18. Kneading the soil helps to break down clods and remold the soil into a homogenous mass that is free of voids or large pores. Kneading of the soil is particularly beneficial for highly plastic soils. For certain bentonite-soil blends that do not form clods, kneading is not necessary. Most soil liners are constructed with "footed" rollers. The "feet" on the roller penetrate into a loose lift of soil and knead the soil with repeated passages of the roller. The dimensions of the feet on rollers vary considerably. Footed rollers with short feet (≈ 75 mm or 3 in.) are called "pad foot" rollers; the feet are said to be "partly penetrating" because the foot is too short to penetrate fully a typical loose lift of soil. Footed rollers with long feet (≈ 200 mm or 8 in.) are often called "sheepsfoot" rollers; the feet fully penetrate a typical loose lift. Figure 2.19 contrasts rollers with partly and fully penetrating feet.

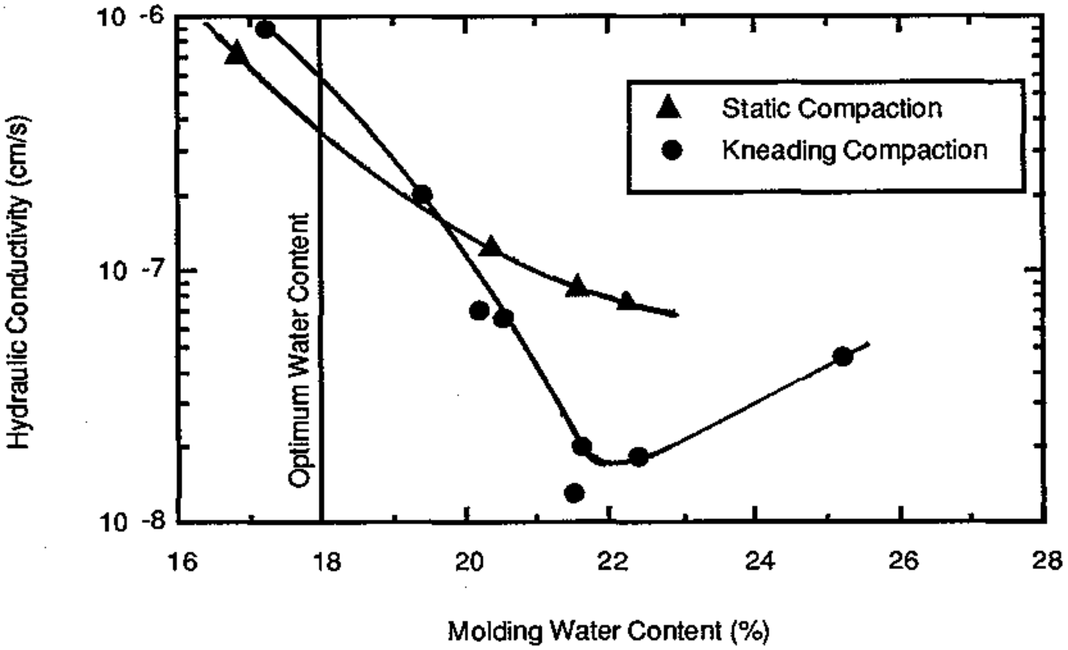


Figure 2.18 - Effect of Type of Compaction on Hydraulic Conductivity (from Mitchell et al., 1965)

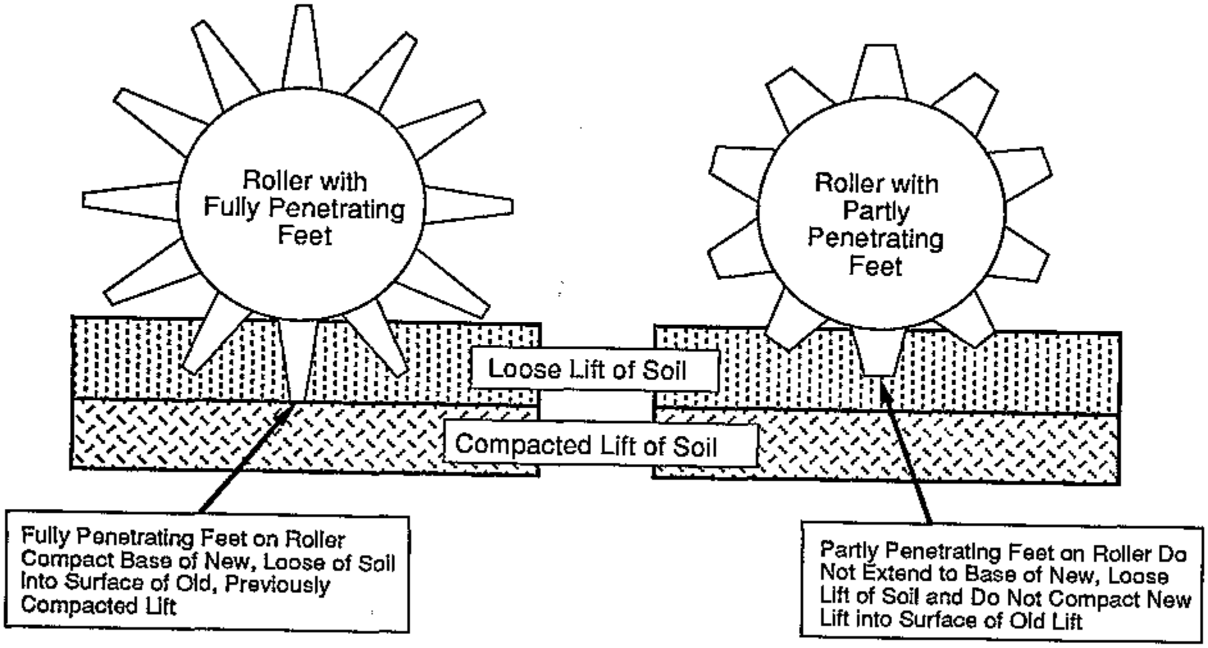


Figure 2.19 - Footed Rollers with Partly and Fully Penetrating Feet

Some construction specifications place limitations on the type of roller that can be used to compact a soil liner. Personnel performing CQC and CQA should be watchful of the type of roller to make sure it conforms to construction specifications. It is particularly important to use a roller with fully penetrating feet if such a roller is required; use of a non-footed roller or pad foot roller would result in less kneading of the soil.

2.2.4 Energy of Compaction

The energy used to compact soil can have an important influence on hydraulic conductivity. The data shown in Fig. 2.20 show that increasing the compactive effort produces soil that has a greater dry unit weight and lower hydraulic conductivity. It is important that the soil be compacted with adequate energy if low hydraulic conductivity is to be achieved.

In the field, compactive energy is controlled by:

1. The weight of the roller and the way the weight is distributed (greater weight produces more compactive energy).
2. The thickness of a loose lift (thicker lifts produce less compactive energy per unit volume of soil).
3. The number of passes of the compactor (more passes produces more compactive energy).

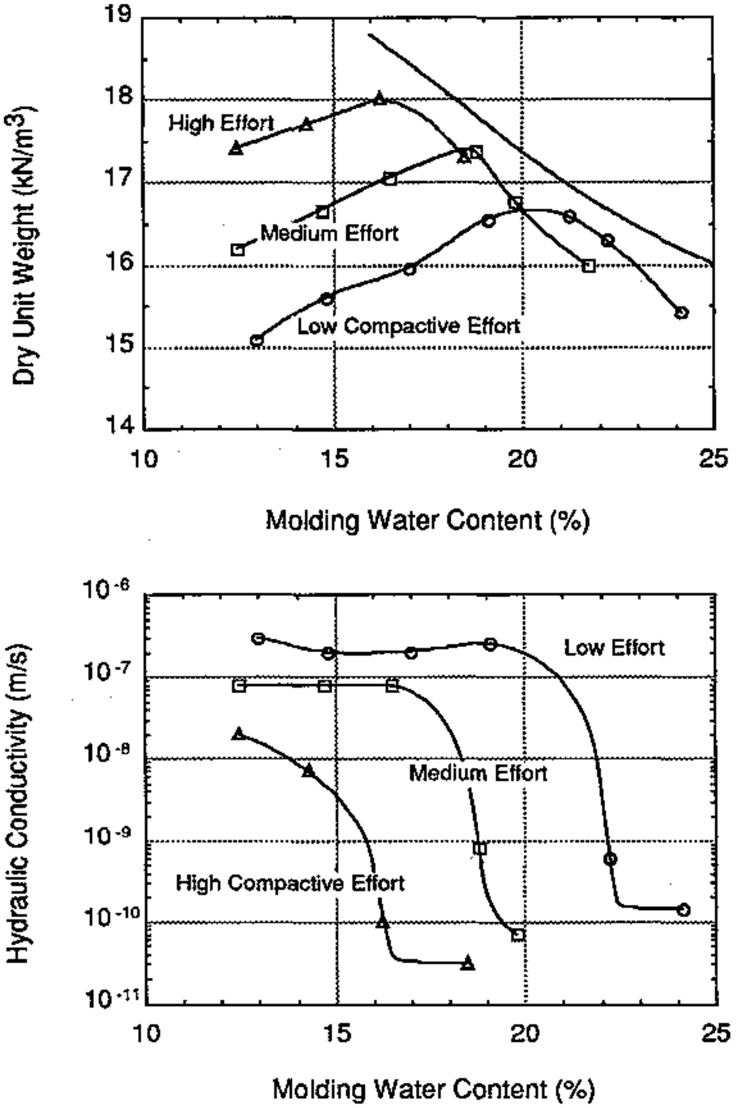


Figure 2.20 - Effect of Compactive Energy on Hydraulic Conductivity (after Mitchell et al., 1965)

Many engineers and technicians assume that percent compaction is a good measure of compactive energy. Indeed, for soils near optimum water content or dry of optimum, percent compaction is a good indicator of compactive energy: if the percent compaction is low, then the compactive energy was almost certainly low. However, for soil compacted wet of optimum, percent compaction is not a particularly good indicator of compactive energy. This is illustrated by the curves in Fig. 2.21. The same soil is compacted with Compactive Energy A and Energy B (Energy B > Energy A) to develop the compaction curves shown in Fig. 2.21. Next, two specimens are compacted to the same water content ($w_A = w_B$). The dry unit weights are practically identical ($\gamma_{d,A} \approx \gamma_{d,B}$) despite the fact that the energies of compaction were different. Further, the hydraulic conductivity (k) of the specimen compacted with the larger energy (Energy B) has a lower hydraulic conductivity than the specimen compacted with Energy A despite the fact that $\gamma_{d,A} \approx \gamma_{d,B}$. The percent compaction for the two compacted specimens is computed as follows:

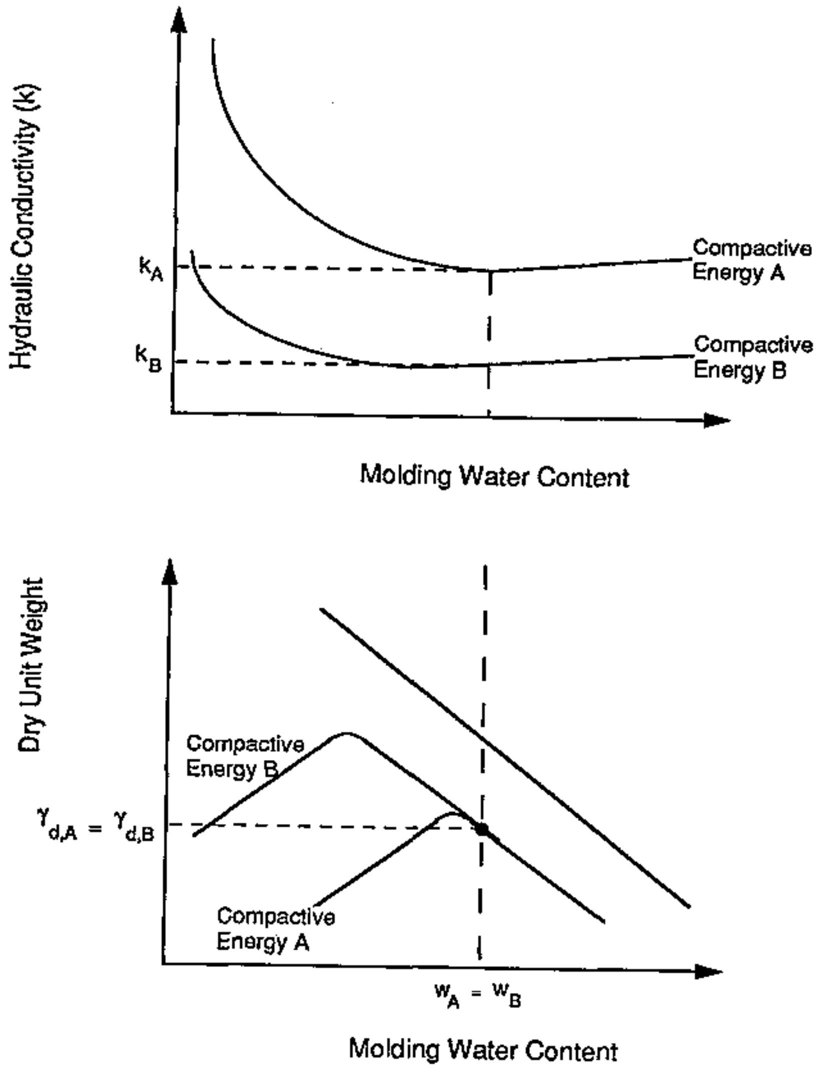


Figure 2.21 - Illustration of Why Dry Unit Weight Is a Poor Indicator of Hydraulic Conductivity for Soil Compacted Wet of Optimum

$$P_A = \gamma_{d,A}/[\gamma_{d,max}]_A \times 100\%$$

$$P_B = \gamma_{d,B}/[\gamma_{d,max}]_B \times 100\%$$

Since $\gamma_{d,A} = \gamma_{d,B}$ but $[\gamma_{d,max}]_B > [\gamma_{d,max}]_A$, then $P_A > P_B$. Thus, based on percent compaction, since $P_A > P_B$, one might assume Soil A was compacted with greater compactive energy than Soil B. In fact, just the opposite is true. CQC and CQA personnel are strongly encouraged to monitor equipment weight, lift thickness, and number of passes (in addition to dry unit weight) to ensure that appropriate compactive energy is delivered to the soil. Some CQC and CQA inspectors have failed to realize that footed rollers towed by a dozer must be filled with liquid to have the intended large weight.

Experience has shown that effective CQC and CQA for soil liners can be accomplished using the line of optimums as a reference. The "line of optimums" is the locus of (w_{opt}, $\gamma_{d,max}$) points for compaction curves developed on the same soil with different compactive energies (Fig. 2.22). The greater the percentage of actual (w,γ_d) points that lie above the line of optimums the better the overall quality of construction (Benson and Boutwell, 1992). Inspectors are encouraged to monitor the percentage of field-measured (w,γ_d) points that lie on or above the line of optimums. If the percentage is less than 80% to 90%, inspectors should carefully consider whether adequate compactive energy is being delivered to the soil (Benson and Boutwell, 1992).

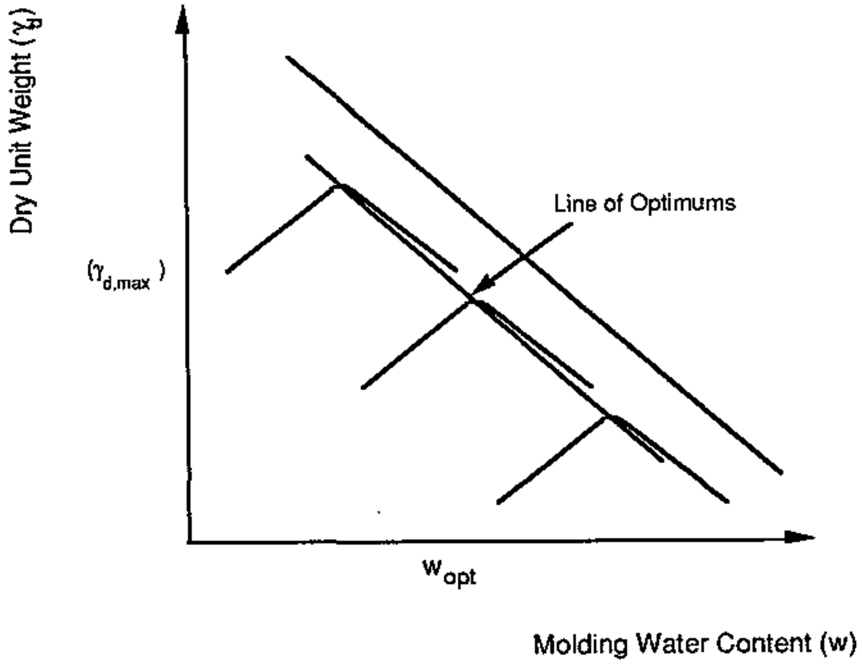


Figure 2.22 - Line of Optimums

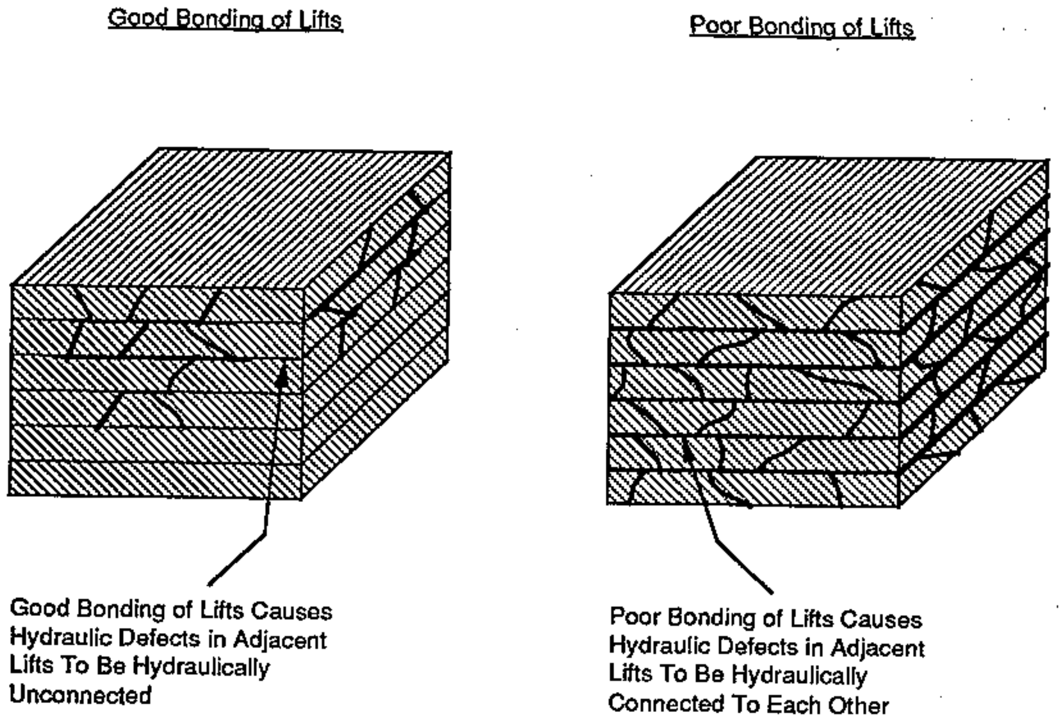
2.2.5 Bonding of Lifts

If lifts of soil are poorly bonded, a zone of high hydraulic conductivity will develop at interfaces between lifts. Poorly bonded lift interfaces provide hydraulic connection between more permeable zones in adjacent lifts (Fig. 2.23). It is important to bond lifts together to the greatest extent possible, and to maximize hydraulic tortuosity along lift interfaces, in order to minimize the overall hydraulic conductivity.

Bonding of lifts is enhanced by:

1. Making sure the surface of a previously-compacted lift is rough before placing the new lift of soil (the previously-compacted lift is often scarified with a disc prior to placement of a new lift), which promotes bonding and increased hydraulic tortuosity along the lift interface..
2. Using a fully-penetrating footed roller (the feet pack the base of the new lift into the surface of the previously-compacted lift).

Inspectors should pay particular attention to requirements for scarification and the length of feet on rollers.



Good Bonding of Lifts

Poor Bonding of Lifts

Good Bonding of Lifts Causes Hydraulic Defects in Adjacent Lifts To Be Hydraulically Unconnected

Poor Bonding of Lifts Causes Hydraulic Defects in Adjacent Lifts To Be Hydraulically Connected To Each Other

Figure 2.23 - Flow Pathways Created by Poorly Bonded Lifts

2.2.6 Protection Against Desiccation and Freezing

Clay soils shrink when they are dried and, depending on the amount of shrinkage, may crack. Cracks that extend deeper than one lift can be disastrous. Inspectors must be very careful to make sure that no significant desiccation occurs during or after construction. Water content should be measured if there are doubts.

Freezing of a soil liner will cause the hydraulic conductivity to increase. Damage caused by superficial freezing to a shallow depth is easily repaired by rerolling the surface. Deeper freezing is not so easily repaired and requires detailed investigation discussed in Section 2.9.2.3. CQC & CQA personnel should be watchful during periods when freezing temperatures are possible.

2.3 Field Measurement of Water Content and Dry Unit Weight

2.3.1 Water Content Measurement

2.3.1.1 Overnight Oven Drying (ASTM D-2216)

The standard method for determining the water content of a soil is to oven dry the soil overnight in a forced-convention oven at 110°C. This is the most fundemental and most accurate method for determining the water content of a soil. All other methods of measurement are referenced to the value of water content determined with this method.

Were it not for the fact that one has to wait overnight to determine water content with this method, undoubtedly ASTM D-2216 would be the only method of water content measurement used in the CQC and CQA processes for soil liners. However, field personnel cannot wait overnight to make decisions about continuation with the construction process.

2.3.1.2 Microwave Oven Drying (ASTM D-4643)

Soil samples can be dried in a microwave oven to obtain water contents much more quickly than can be obtained with conventional overnight oven drying. The main problem with microwave oven drying is that if the soil dries for too long in the microwave oven, the temperature of the soil will rise significantly above 110°C. If the soil is heated to a temperature greater than 110°C, one will measure a water content that is greater than the water content of the soil determined by drying at 110°C. Overheating the soil drives water out of the crystal structure of some minerals and thereby leads to too much loss of water upon oven drying.

To guard against overdrying the soil, ASTM method D-4643 requires that the soil be dried for three minutes and then weighed. The soil is then dried for an additional minute and reweighed. The process of drying for one minute and weighing the soil prevents overheating of the soil and forces the operator to cease the drying process once the weight of the soil has stabilized.

Under ideal conditions, microwave oven drying can yield water contents that are almost indistinguishable from values measured with conventional overnight oven drying. Problems that are sometimes encountered with microwave oven drying include problems in operating the oven if the soil contains significant metal and occasional problems with samples exploding from expansion of gas in the interior of the sample during microwave oven drying. Because errors can occasionally arise with microwave oven drying, the water content determined with microwave oven drying should be periodically checked with the value determined by conventional over-night oven drying (ASTM D-2216).

2.3.1.3 Direct Heating (ASTM D-4959)

Direct heating of the soil was common practice up until about two decades ago. To dry a soil with direct heating, one typically places a mass of soil into a metallic container (such as a cooking utensil) and then heats the soil over a flame, e.g., a portable cooking stove, until the soil first appears dry. The mass of the soil plus container is then measured. Next, the soil is heated some more and then re-weighed. This process is repeated until the mass ceases to decrease significantly (i.e., to change by < 0.1% or less).

The main problem with direct heating is that if the soil is overheated during drying, the water content that is measured will be too large. Although ASTM D-4959 does not eliminate this problem, the ASTM method does warn the user not to overheat the soil. Because errors can do arise with direct heating, the water content determined with direct heating should be regularly checked with the value determined by conventional over-night oven drying (ASTM D-2216).

2.3.1.4 Calcium Carbide Gas Pressure Tester (ASTM D-4944)

A known mass of moist soil is placed in a testing device and calcium carbide is introduced. Mixing is accomplished by shaking and agitating the soil with the aid of steel balls and a shaking apparatus. A measurement is made of the gas pressure produced. Water content is determined from a calibration curve. Because errors can occasionally arise with gas pressure testing, the water content determined with gas pressure testing should be periodically checked with the value determined by conventional over-night oven drying (ASTM D-2216).

2.3.1.5 Nuclear Method (ASTM D-3017)

The most widely used method of measuring the water content of compacted soil is the nuclear method. Measurement of water content with a nuclear device involves the moderation or thermalization of neutrons provided by a source of fast neutrons. Fast neutrons are neutrons with an energy of approximately 5 MeV. The radioactive source of fast neutrons is embedded in the interior part of a nuclear water content/density device (Fig. 2.24). As the fast neutrons move into the soil, they undergo a reduction in energy every time a hydrogen atom is encountered. A series of energy reductions takes place when a neutron sequentially encounters hydrogen atoms. Finally, after an average of nineteen collisions with hydrogen atoms, a neutron ceases to lose further energy and is said to be a "thermal" neutron with an energy of approximately 0.025 MeV. A detector in the nuclear device senses the number of thermal neutrons that are encountered. The number of thermal neutrons that are encountered over a given period of time is a function of the number of fast neutrons that are emitted from the source and the density of hydrogen atoms in the soil located immediately below the nuclear device. Through appropriate calibration, and with the assumption that the only source of hydrogen in the soil is water, the nuclear device provides a measure of the water content of the soil over an average depth of about 200 mm (8 in.).

There are a number of potential sources of error with the nuclear water content measuring device. The most important potential source of error is extraneous hydrogen atoms not associated with water. Possible sources of hydrogen other than water include hydrocarbons, methane gas, hydrous minerals (e.g., gypsum), hydrogen-bearing minerals (e.g., kaolinite, illite, and montmorillonite), and organic matter in the soil. Under extremely unfavorable conditions the nuclear device can yield water content measurements that are as much as ten percentage points in error (almost always on the high side). Under favorable conditions, measurement error is less than one percent. The nuclear device should be calibrated for site specific soils and changing conditions within a given site.

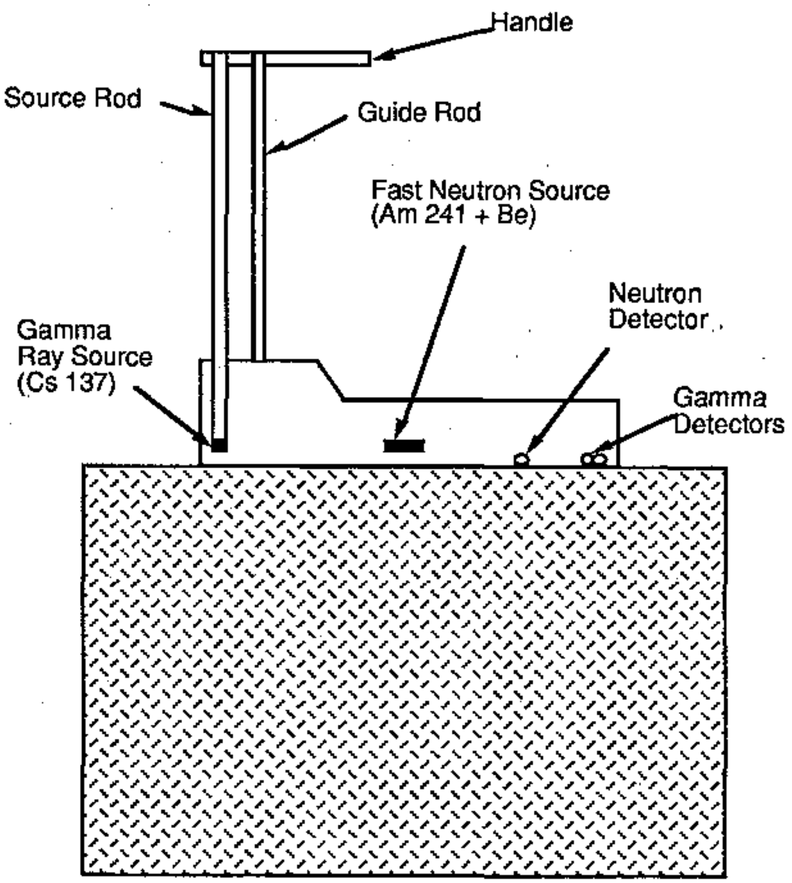


Figure 2.24 - Schematic Diagram of Nuclear Water Content - Density Device

Another potential source of error is the presence of individuals, equipment, or trenches located within one meter of the device (all of which can cause an error). The device must be warmed up for an adequate period of time or the readings may be incorrect. If the surface of the soil is improperly prepared and the device is not sealed properly against a smooth surface, erroneous measurements can result. If the standard count, which is a measure of the intensity of radiation from the source, has not been taken recently an erroneous reading may result. Finally, many nuclear devices allow the user to input a moisture adjustment factor to correct the water content reading by a fixed amount. If the wrong moisture adjustment factor is stored in the device's computer, the reported water content will be in error.

It is very important that the CQC and CQA personnel be well versed in the proper use of nuclear water content measurement devices. There are many opportunities for error if personnel are not properly trained or do not correctly use the equipment. As indicated later, the nuclear device should be checked with other types of equipment to ensure that site-specific variables are not influencing test results. Nuclear equipment may be checked against other nuclear devices (particularly new devices or recently calibrated devices) to minimize potential for errors.

2.3.2 Unit Weight

2.3.2.1 Sand Cone (ASTM D-1556)

The sand cone is a device for determining the volume of a hole that has been excavated into soil. The idea is to determine the weight of sand required to fill a hole of unknown volume. Through calibration, the volume of sand that fills the hole can be determined from the weight of sand needed to fill the hole. A schematic diagram of the sand cone is shown in Fig. 2.25.

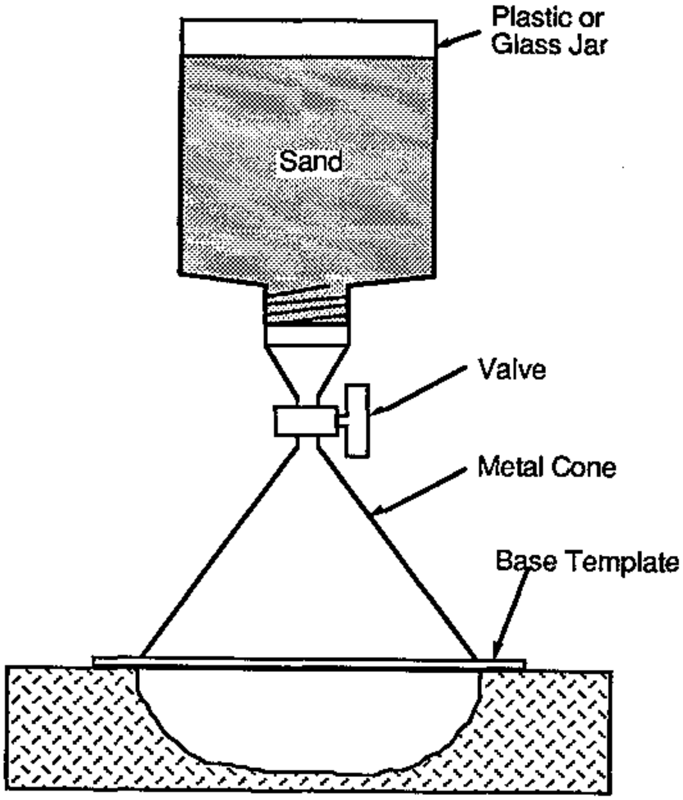


Figure 2.25 - Sand Cone Device

The sand cone is used as follows. First, a template is placed on the ground surface. A circle is scribed along the inside of the hole in the template. The template is removed and soil is excavated from within the area marked by the scribed circle. The soil that is excavated is weighed to determine the total weight (W) of the soil excavated. The excavated soil is oven dried (e.g., with a microwave oven) to determine the water content of the soil. The bottle in a sand cone device is filled with sand and the full bottle is weighed. The template is placed over the hole and the sand cone device is placed on top of the template. A valve on the sand cone device is opened, which allows sand to rain down through the inverted funnel of the device and inside the excavated hole.

When the hole and funnel are filled with sand, the valve is closed and the bottle containing sand is weighed. The difference in weight before and after the hole is dug is calculated. Through calibration, the weight of sand needed to fill the funnel is subtracted, and the volume of the hole is computed from the weight of sand that filled the hole. The total unit weight is calculated by dividing the weight of soil excavated by the computed volume of the excavated hole. The dry unit weight is then calculated from Eq. 2.1.

The sand cone device provides a reliable technique for determining the dry unit weight of the soil. The primary sources of error are improper calibration of the device, excavation of an uneven hole that has sharp edges or overhangs that can produce voids in the sand-filled hole, variations in the sand, excessively infrequent calibrations, contamination of the sand by soil particles if the sand is reused, and vibration as from equipment operating close to the sand cone.

2.3.2.2 Rubber Balloon (ASTM D-2167)

The rubber balloon is similar to the sand cone except that water is used to fill the excavated hole rather than sand. A rubber balloon device is sketched in Fig. 2.26. As with the sand cone test, the test is performed with the device located on the template over the leveled soil. Then a hole is excavated into the soil and the density measuring device is again placed on top of a template at the ground surface. Water inside the rubber balloon device is pressurized with air to force the water into the excavated hole. A thin membrane (balloon) prevents the water from entering the soil. The pressure in the water forces the balloon to conform to the shape of the excavated hole. A graduated scale on the rubber balloon device enables one to determine the volume of water required to fill the hole. The total unit weight is calculated by dividing the known weight of soil excavated from the hole by the volume of water required to fill the hole with the rubber balloon device. The dry unit weight is computed from Eq. 2.1.

The primary sources of error with the rubber balloon device are improper excavation of the hole (leaving small zones that cannot be filled by the pressurized balloon), excessive pressure that causes local deformation of the adjacent soil, rupture of the balloon, and carelessness in operating the device (e.g., not applying enough pressure to force the balloon to fill the hole completely).

2.3.2.3 Drive Cylinder (ASTM D-2937)

A drive cylinder is sketched in Fig. 2.27. A drop weight is used to drive a thin-walled tube sampler into the soil. The sampler is removed from the soil and the soil sample is trimmed flush to the bottom and top of the sampling tube. The soil-filled tube is weighed and the known weight of the sampling tube itself is subtracted to determine the gross weight of the soil sample. The dimensions of the sample are measured to enable calculation of volume. The unit weight is calculated by dividing the known weight by the known volume of the sample. The sample is oven dried (e.g., in a microwave oven) to determine water content. The dry unit weight is computed from Eq. 2.1.

The primary problems with the drive cylinder are sampling disturbance caused by rocks or stones in the soil, densification of the soil caused by compression resulting from driving of the tube into the soil, and nonuniform driving of the tube into the soil. The drive cylinder method is not recommended for stony or gravely soils. The drive cylinder method works best for relatively soft, wet clays that do not tend to densify significantly when the tube is driven into the soil and for soils that are free of gravel or stones. However, even under favorable circumstances, densification of the soil caused by driving the ring into the soil can cause an increase in total unit weight of 2 to 5 pcf (0.3 to 0.8 kN/m^3).

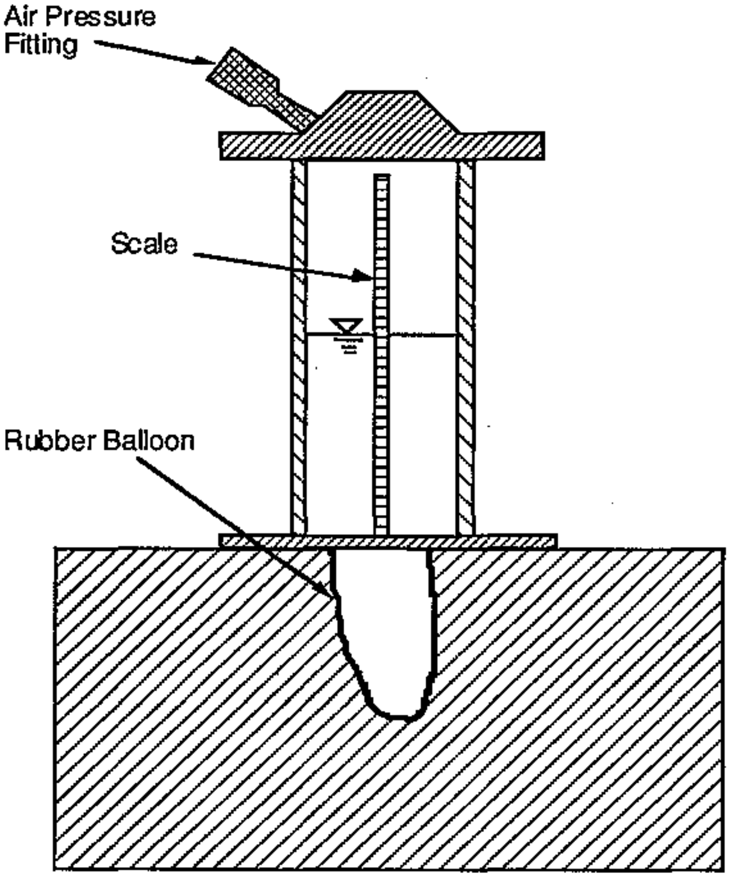


Figure 2.26 - Schematic Diagram of Rubber Balloon Device

2.3.2.4 Nuclear Method (ASTM D-2922)

Unit weight can be measured with a nuclear device operated in two ways as shown in Fig. 2.28. The most common usage is called *direct transmission* in which a source of gamma radiation is lowered down a hole made into the soil to be tested (Fig. 2.28a). Detectors located in the nuclear density device sense the intensity of gamma radiation at the ground surface. The intensity of gamma radiation detected at the surface is a function of the intensity of gamma radiation at the source and the total unit weight of the soil material. The second mode of operation of the nuclear density device is called *backscattering*. With this technique the source of gamma radiation is located at the ground surface (Fig. 2.28b). The intensity of gamma radiation detected at the surface is a function of the density of the soil as well as the radioactivity of the source. With the backscattering technique, the measurement is heavily dependent upon the density of the soil within the upper 25 to 50 mm of soil. The direct transmission method is the recommended technique for soil liners because direct transmission provides a measurement averaged over a greater depth than backscattering.

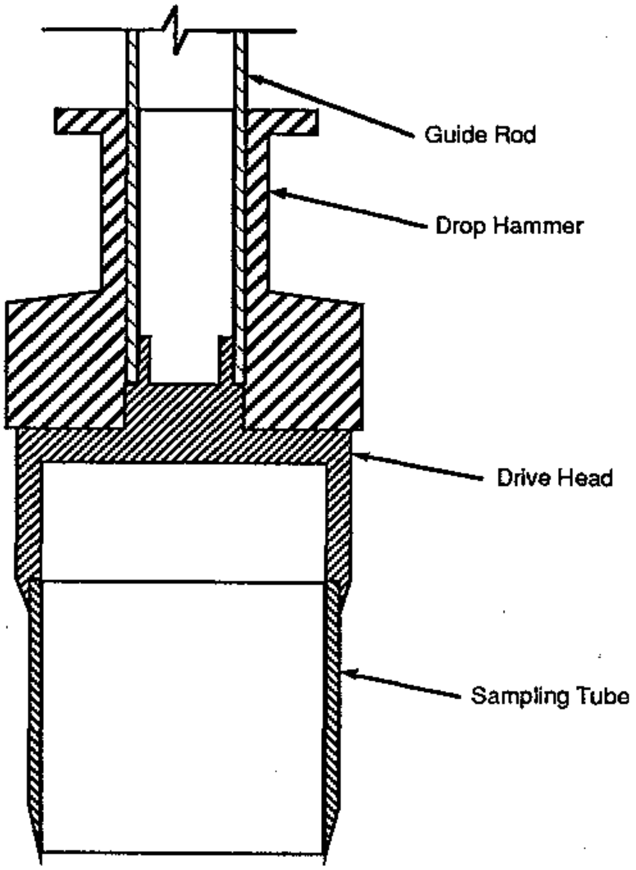
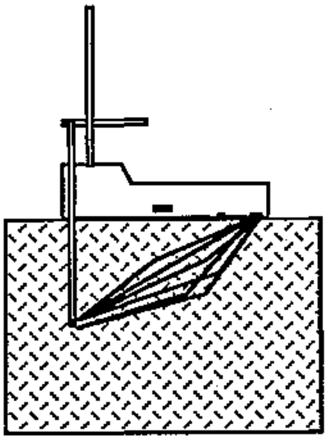


Figure 2.27 - Schematic Diagram of Drive Ring

The operation of a nuclear density device in the direct transmission mode is as follows. First, the area to be tested is smoothed, and a hole is made into the soil liner material by driving a rod (called the *drive rod*) into the soil. The diameter of the hole is approximately 25 mm (1 in.) and the depth of the hole is typically 50 mm (2 in.) greater than the depth to which the gamma radiation source will be lowered below the surface. The nuclear device is then positioned with the source rod directly over the hole in the soil liner material. The source rod is then lowered to a depth of approximately 50 mm (2 in.) above the base of the hole. The source is then pressed against the surface of the hole closest to the detector by pulling on the nuclear device and forcing the source to bear against the side of the hole closest to the detector. The intent is to have good contact between the source and soil along a direct line from source to detector. The intensity of radiation at the detector is measured for a fixed period of time, e.g., 30 or 60 s. The operator can select the period of counting. The longer the counting period, the more accurate the measurement. However, the counting period cannot be extended too much because productivity will suffer.

(A) Direct Transmission



(B) Backscattering

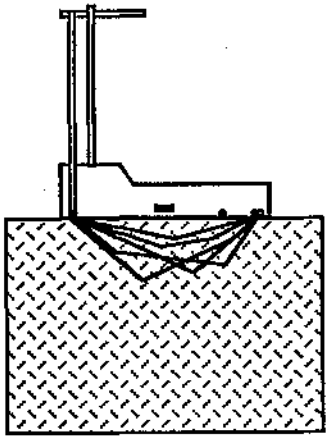


Figure 2.28 - Measurement of Density with Nuclear Device by (a) Direct Transmission and (B) Backscattering

After total unit weight has been determined, the measured water content is used to compute dry unit weight (Eq. 2.1). The potential sources of error with the nuclear device are fewer and less significant in the density-measuring mode compared to the water content measuring mode. The most serious potential source of error is improper use of the nuclear density device by the operator. One gross error that is sometimes made is to drive the source rod into the soil rather than inserting the source rod into a hole that had been made earlier with the drive rod. Improper separation of the source from the base of the hole, an inadequate period of counting, inadequate warm-up, spurious sources of gamma radiation, and inadequate calibration are other potential sources of error.

2.4 Inspection of Borrow Sources Prior to Excavation

2.4.1 Sampling for Material Tests

In order to determine the properties of the borrow soil, samples are often obtained from the potential borrow area for laboratory analysis prior to actual excavation but as part of the construction contract. Samples may be obtained in several ways. One method of sampling is to drill soil borings and recover samples of soil from the borings. This procedure can be very effective in identifying major strata and substrata within the borrow area. Small samples obtained from the borings are excellent for index property testing but often do not provide a very good indication of subtle stratigraphic changes in the borrow area. Test pits excavated into the borrow soil with a backhoe, frontend loader, or other excavation equipment can expose a large cross-section of the borrow soil. One can obtain a much better idea of the variability of soil in the potential borrow area by examining exposed cuts rather than viewing small soil samples obtained from borings.

Large bulk samples of soil are required for compaction testing in the laboratory. Small samples of soil taken with soil sampling devices do not provide a sufficient volume of soil for laboratory compaction testing. Some engineers combine samples of soil taken at different depths or from different borings to produce a composite sample of adequate volume. This technique is not recommended because a degree of mixing takes place in forming the composite laboratory test sample that would not take place in the field. Other engineers prefer to collect material from auger borings for use in performing laboratory compaction tests. This technique is likewise not recommended without careful borrow pit control because vertical mixing of material takes place during auguring in a way that would not be expected to occur in the field unless controlled vertical cuts are made. The best method for obtaining large bulk samples of material for laboratory compaction testing is to take a large sample of material from one location in the borrow source. A large, bulk sample can be taken from the wall or floor of a test pit that has been excavated into the borrow area. Alternatively, a large piece of drilling equipment such as a bucket auger can be used to obtain a large volume of soil from a discreet point in the ground.

2.4.2. Material Tests

Samples of soil must be taken for laboratory testing to ensure conformance with specifications for parameters such as percentage fines and plasticity index. The samples are sometimes taken in the borrow pit, are sometimes taken from the loose lift just prior to compaction, and are sometimes taken from both. If samples are taken from the borrow area, CQA inspectors track the approximate volumes of soil excavated and sample at the frequency prescribed in the CQA plan. Sometimes borrow-source testing is performed prior to issuing of a contract to purchase the borrow material. A CQA program cannot be implemented for work already completed. The CQA personnel will have ample opportunity to check the properties of soil materials later during excavation and placement of the soils. If the CQA personnel for a project did not observe borrow soil testing, the CQA personnel should review the results of borrow soil testing to ensure that the required tests have been performed. Additional testing of the borrow material may be required during excavation of the material.

The material tests that are normally performed on borrow soil are water content, Atterberg limits, particle size distribution, compaction curve, and hydraulic conductivity (Table 2.2). Each of these tests is discussed below.

Table 2.2 - Materials Tests

Parameter	ASTM Test Method	Title of ASTM Test
Water Content	D-2216	Laboratory Determination of Water (Moisture) Content of Soil and Rock
	D-4643	Determination of Water (Moisture) Content of Soil by the Microwave Oven Method
	D-4944	Field determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester Method
	D-4959	Determination of Water (Moisture) Content by Direct Heating Method
Liquid Limit, Plastic Limit, & Plasticity Index	D-4318	Liquid Limit, Plastic Limit, and Plasticity Index of Soils
Particle Size Distribution	D-422	Particle Size Analysis of Soil
Compaction Curve	D-698	Moisture-Density Relations for Soils and Soil-Aggregate Mixtures Using 5.5-lb. (2.48-kg) Rammer and 12-in. (305-mm) Drop
	D-1557	Moisture-Density Relations for Soils and Soil-Aggregate Mixtures Using 10-lb. (4.54-kg) Rammer and 18-in. (457-mm) Drop
Hydraulic Conductivity	D-5084	Measurement of Hydraulic Conductivity of Saturated Porous Materials Using A Flexible Wall Permeameter

2.4.2.1 Water Content

It is important to know the water content of the borrow soils so that the need for wetting or drying the soil prior to compaction can be identified. The water content of the borrow soil is normally measured following the procedures outlined in ASTM D-2216 if one can wait overnight for results. If not, other test methods described in Section 2.3.1 and listed in Table 2.2 can be used to produce results faster.

2.4.2.2 Atterberg Limits

Construction specifications for compacted soil liners often require a minimum value for the liquid limit and/or plasticity index of the soil. These parameters are measured in the laboratory with the procedures outlined in ASTM D-4318.

2.4.2.3 Particle Size Distribution

Construction specifications for soil liners often place limits on the minimum percentage of fines, the maximum percentage of gravel, and in some cases the minimum percentage of clay. Particle size analysis is performed following the procedures in ASTM D-422. Normally the requirements for the soil material are explicitly stated in the construction specifications. An experienced inspector can often judge the percentage of fine material and the percentage of sand or gravel in the soil. However, compliance with specifications is best documented by laboratory testing.

2.4.2.4 Compaction Curve

Compaction curves are developed utilizing the method of laboratory compaction testing required in the construction specifications. Standard compaction (ASTM D-698) and modified compaction (ASTM D-1557) are two common methods of laboratory compaction specified for soil liners. However, other compaction methods (particularly those unique to state highway or transportation departments) are sometimes specified.

Great care should be taken to follow the procedures for soil preparation outlined in the relevant test method. In particular, the drying of a cohesive material can change the Atterberg limits as well as the compaction characteristics of the soil. If the test procedure recommends that the soil not be dried, the soil should not be dried. Also, care must be taken when sieving the soil not to remove clods of cohesive material. Rather, clods of soil retained on a sieve should be broken apart by hand if necessary to cause them to pass through the openings of the sieve. Sieves should only be used to remove stones or other large pieces of material following ASTM procedures.

2.4.2.5 Hydraulic Conductivity

The hydraulic conductivity of compacted samples of borrow material may be measured periodically to verify that the soil liner material can be compacted to achieve the required low hydraulic conductivity. Several methods of laboratory permeation are available, and others are under development. ASTM D-5084 is the only ASTM procedure currently available. Care should be taken not to apply excessive effective confining stress to test specimens. If no value is specified in the CQA plan, a maximum effective stress of 35 kPa (5 psi) is recommended for both liner and cover systems.

Care should be taken to prepare specimens for hydraulic conductivity testing properly. In addition to water content and dry unit weight, the method of compaction and the compactive energy can have a significant influence on the hydraulic conductivity of laboratory-compacted soils. It is particularly important not to deliver too much compactive energy to attain a desired dry unit weight. The purpose of the hydraulic conductivity test is to verify that borrow soils can be compacted to the desired hydraulic conductivity using a reasonable compactive energy.

No ASTM compaction method exists for preparation of hydraulic conductivity test specimens. The following procedure is recommended:

1. Obtain a large, bulk sample of representative material with a mass of approximately 20 kg.

2. Develop a laboratory compaction curve using the procedure specified in the construction specifications for compaction control, e.g., ASTM D-698 or D-1557.

3. Determine the target water content (w_{target}) and dry unit weight ($\gamma_{d,target}$) for the hydraulic conductivity test specimen. The value of w_{target} is normally the lowest acceptable water content and $\gamma_{d,target}$ is normally the minimum acceptable dry unit weight (Fig. 2.29).

4. Enough soil to make several test specimens is mixed to w_{target}. The compaction procedure used in Step 2 is used to prepare a compacted specimen, except that the energy of compaction is reduced, e.g., by reducing the number of drops of the ram per lift. The dry unit weight (γ_d) is determined. If $\gamma_d \approx \gamma_{d,\ target}$, the compacted specimen may be used for hydraulic conductivity testing. If $\gamma_d \neq \gamma_{d,target}$, then another test specimen is prepared with a larger or smaller (as appropriate) compactive energy. Trial and error preparation of test specimens is repeated until $\gamma_d \approx \gamma_{d,\ target}$. The procedure is illustrated in Fig. 2.29. The actual compactive effort should be documented along with hydraulic conductivity.

5. Atterberg limits and percentage fines should be determined for each bulk sample. Water content and dry density should be reported for each compacted specimen.

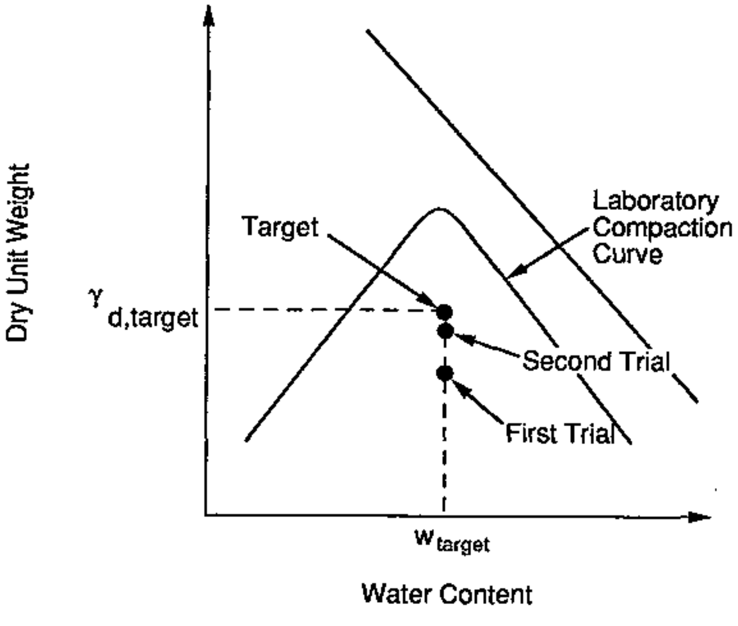


Figure 2.29 - Recommended Procedure for Preparation of a Test Specimen Using Variable (But Documented) Compactive Energy for Each Trial

2.4.2.6 Testing Frequency

The CQA plan should stipulate the frequency of testing. Recommended minimum values are shown in Table 2.3. The tests listed in Table 2.3 are normally performed prior to construction as part of the characterization of the borrow source. However, if time or circumstances do not permit characterization of the borrow source prior to construction, the samples for testing are obtained during excavation or delivery of the soil materials.

Table 2.3 - Recommended Minimum Testing Frequencies for Investigation of Borrow Source

Parameter	Frequency
Water Content	1 Test per 2000 m^3 or Each Change in Material Type
Atterberg Limits	1 Test per 5000 m^3 or Each Change in Material Type
Percentage Fines	1 Test per 5000 m^3 or Each Change in Material Type
Percent Gravel	1 Test per 5000 m^3 or Each Change in Material Type
Compaction Curve	1 Test per 5000 m^3 or Each Change in Material Type
Hydraulic Conductivity	1 Test per 10,000 m^3 or Each Change in Material Type

Note: 1 $yd^3 = 0.76$ m^3

2.5 Inspection during Excavation of Borrow Soil

It is strongly recommended that a qualified inspector who reports directly to the CQA engineer observe all excavation of borrow soil in the borrow pit. Often the best way to determine whether deleterious material is present in the borrow soil is to observe the excavation of the soil directly.

A key factor for inspectors to observe is the plasticity of the soil. Experienced technicians can often determine whether or not a soil has adequate plasticity by carefully examining the soil in the field. A useful practice for field identification of soils is ASTM D-2488, "Description and Identification of Soils (Visual-Manual Procedure)." The following procedure is used for identifying clayey soils.

- Dry strength: The technician selects enough soil to mold into a ball about 25 mm (1 in.) in diameter. Water is added if necessary to form three balls that each have a diameter of about 12 mm (1/2 in.). The balls are allowed to dry in the sun. The strength of the dry balls is evaluated by crushing them between the fingers. The dry strength is described with the criteria shown in Table 2.4. If the dry strength is none or low, inspectors should be alerted to the possibility that the soil lacks adequate plasticity.

- Plasticity: The soil is moistened or dried so that a test specimen can be shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about 3 mm (1/8 in.) in diameter. If the sample is too wet to roll easily it should be spread into a thin layer and allowed to lose some water by evaporation. The sample threads are re-rolled repeatedly until the thread crumbles at a diameter of about 3 mm (1/8 in.). The thread will crumble at a diameter of 3 mm when the soil is near the plastic limit. The plasticity is described from the criteria shown in Table 2.5, based upon observations made during the toughness test. Non-plastic soils are usually unsuitable for use as soil liner materials without use of amendments such as bentonite.

Table 2.4 - Criteria for Describing Dry Strength (ASTM D-2488)

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very High	The dry specimen cannot be broken between the thumb and a hard surface

Table 2.5 - Criteria for Describing Plasticity (ASTM D-2488)

Description	Criteria
Nonplastic	A 3 mm (1/8-in.) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	A thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

2.6 Preprocessing of Materials

Some soil liner materials are ready to be used for final construction immediately after they are excavated from the borrow pit. However, most materials require some degree of processing prior to placement and compaction of the soil.

2.6.1 Water Content Adjustment

Soils that are too wet must first be dried. If the water content needs to be reduced by no more than about three percentage points, the soil can be dried after it has been spread in a loose lift just prior to compaction. If the water content must be reduced by more than about 3 percentage points, it is recommended that drying take place in a separate processing area. The reason for drying in a separate processing area is to allow adequate time for the soil to dry uniformly and to facilitate mixing of the material during drying. The soil to be dried is spread in a lift about 225 to 300 mm (9 to 12 in.) thick and allowed to dry. Water content is periodically measured using one or more of the methods listed in Table 2.2. The contractor's CQC personnel should check the soil periodically to determine when the soil has reached the proper water content.

The CQA inspectors should check to be sure that the soil is periodically mixed with a disc or rototiller to ensure uniform drying. The soil cannot be considered to be ready for placement and compaction unless the water is uniformly distributed; water content measurements alone do not ensure that water is uniformly distributed within the soil.

If the soil must be moistened prior to compaction, the same principles discussed above for drying apply; water content adjustment in a separate preprocessing area is recommended if the water content must be increased by more than about 3 percentage points. Inspectors should be careful to verify that water is distributed uniformly to the soil (a spreader bar on the back of a water truck is the recommended device for moistening soil uniformly), that the soil is periodically mixed with a disc or rototiller, and that adequate time has been allowed for uniform hydration of the soil. If the water content is increased by more than three percentage points, at least 24 to 48 hours would normally be required for uniform absorption of water and hydration of soil particles. The construction specifications may limit the type of water that can be used; in some cases, contaminated water, brackish water, or sea water is not allowed.

2.6.2 Removal of Oversize Particles

Oversized stones and rocks should be removed from the soil liner material. Stones and rocks interfere with compaction of the soil and may create undesirable pathways for fluid to flow through the soil liner. The construction specifications should stipulate the maximum allowable size of particles in the soil liner material.

Oversized particles can be removed with mechanical equipment (e.g., large screens) or by hand. Inspectors should examine the loose lift of soil after the contractor has removed oversized particles to verify that oversized particles are not present. Sieve analyses alone do not provide adequate assurance that oversized materials have been removed -- careful visual inspection for oversized material should be mandatory.

2.6.3 Pulverization of Clods

Some specifications for soil liners place limitations on the maximum size of chunks or clods of clay present in the soil liner material. Discs, rototillers, and road recyclers are examples of mechanical devices that will pulverize clods in a loose lift. Visual inspection of the loose lift of material is normally performed to ensure that clods of soil have been pulverized to the extent required in the construction specifications. Inspectors should be able to visually examine the entire surface of a loose lift to determine whether clods have been adequately processed. No standard method exists for determining clod size. Inspectors normally measure the dimensions of an individual clod with a ruler.

2.6.4 Homogenizing Soils

CQC and CQA are very difficult to perform for heterogeneous materials. It may be necessary to blend and homogenize soils prior to their use in constructing soil liners in order to maintain proper CQC and CQA. Soils can be blended and homogenized in a pugmill. The best way to ensure adequate mixing of materials is through visual inspection of the mixing process itself.

2.6.5 Bentonite

Bentonite is a common additive to soil liner materials that do not contain enough clay to achieve the desired low hydraulic conductivity. Inspectors must ensure that the bentonite being used for a project is in conformance with specifications (i.e., is of the proper quality and gradation) and that the bentonite is uniformly mixed with soil in the required amounts.

The parameters that are specified for the bentonite quality vary considerably from project to project. The construction specifications should stipulate the criteria to be met by the bentonite and the relevant test methods. The quality of bentonite is usually measured with some type of measurement of water adsorption ability of the clay. Direct measurement of water adsorption can be accomplished using the plate water adsorption test (ASTM E-946). This test is used primarily in the taconite iron ore industry to determine the effectiveness of bentonite, which is used as a binder during the pelletizing process to soak up excess water in the ore. Brown (1992) reports that thousands of plate water adsorption tests have been performed on bentonite, but experience has been that the test is time consuming, cumbersome, and extremely sensitive to variations in the test equipment and test conditions. The plate water adsorption test is not recommended for CQC/CQA of soil liners.

Simple, alternative tests that provide an indirect indication of water adsorption are available. One indirect test for water adsorption is measurement of Atterberg (liquid and plastic) limits via ASTM D-4318. The higher the quality of the bentonite, the higher the liquid limit and plasticity index. Although liquid and plastic limits tests are very common for natural soils, they have not been frequently used as indicators of bentonite quality in the bentonite industry. A commonly-used test in the bentonite industry is the free swell test. The free swell test is used to determine the amount of swelling of bentonite when bentonite is exposed to water in a glass beaker. Unfortunately, there is currently no ASTM test for determining free swell of bentonite, although one is under development. Until such time as an ASTM standard is developed, the bentonite supplier may be consulted for a suggested testing procedure.

The liquid limit test and free swell test are recommended as the principal quality control tests for the quality of bentonite being used on a project. There are no widely accepted cutoff values for the liquid limit and free swell. However, the following is offered for the information of CQC and CQA inspectors. The liquid limit of calcium bentonite is frequently in the range of 100 to 150%. Sodium bentonite of medium quality is expected to have a liquid limit of approximately 300 to 500%. High-quality sodium bentonite typically has a liquid limit in the range of about 500 to 700%. According to Brown (1992), calcium bentonites usually have a free swell of less than 6 cc. Low-grade sodium bentonites typically have a free swell of 8 - 15 cc. High-grade bentonites often have free swell values in the range of 18 to 28 cc. If high-grade sodium bentonite is to be used on a project, inspectors should expect that the liquid limit will be ≥ 500% and the free swell will be ≥ 18 cc.

The bentonite must usually also meet gradational requirements. The gradation of the dry bentonite may be determined by carefully sieving the bentonite following procedures outlined in ASTM D-422. The CQA inspector should be particularly careful to ensure that the bentonite has been pulverized to the extent required in the construction specifications. The degree of pulverization is frequently overlooked. Finely-ground, powdered bentonite will behave differently when blended into soil than more coarsely ground, granular bentonite. CQC/CQA personnel should be particularly careful to make sure that the bentonite is sufficiently finely ground and is not delivered in too coarse a form (per project specifications); sieve tests on the raw bentonite received at a job site are recommended to verify gradation of the bentonite.

The bentonite supplier is expected to certify that the bentonite meets the specification requirements. However, CQA inspectors should perform their own tests to ensure compliance with the specifications. The recommended CQA tests and testing frequencies for bentonite quality and gradation are summarized in Table 2.6.

Table 2.6 - Recommended Tests on Bentonite to Determine Bentonite Quality and Gradation

Parameter	Frequency	Test Method
Liquid Limit	1 per Truckload or 2 per Rail Car	ASTM D-4318, "Liquid Limit, Plastic Limit, and Plasticity Index of Soils"
Free Swell	1 per Truckload or 2 per Rail Car	No Standard Procedure Is Available
Grain Size of Dry Bentonite	1 per Truckload or 2 per Rail Car	ASTM D-422, "Particle Size Analysis of Soil"

2.6.5.1 Pugmill Mixing

A pugmill is a device for mixing dry materials. A schematic diagram of a typical pugmill is shown in Fig. 2.30. A conveyor belt feeds soil into a mixing unit, and bentonite drops downward into the mixing unit. The materials are mixed in a large box that contains rotating rods with mixing paddles. Water may be added to the mixture in the pugmill, as well.

The degree of automation of pugmills varies considerably. The most sophisticated pugmills have computer-controlled devices to monitor the amounts of the ingredients being mixed. CQA personnel should monitor the controls on the mixing equipment.

2.6.5.2 In-Place Mixing

An alternative mixing technique is to spread the soil in a loose lift, distribute bentonite on the surface, and mix the bentonite and soil using a rototiller or other mixing equipment. There are several potential problems with in-place mixing. The mixing equipment may not extend to an adequate depth and may not fully mix the loose lift of soil with bentonite. Alternatively, the mixing device may dig too deeply into the ground and actually mix the loose lift in with underlying materials. Bentonite (particularly powdered bentonite) may be blown away by wind when it is placed on the surface of a loose lift, thus reducing the amount of bentonite that is actually incorporated into the soil. The mixing equipment may fail to pass over all areas of the loose lift and may inadequately mix certain portions of the loose lift. Because of these problems many engineers believe that pugmill mixing provides a more reliable means for mixing bentonite with soil. CQA personnel should carefully examine the mixing process to ensure that the problems outlined above, or other problems, do not compromise the quality of the mixing process. Visual examination of the mixture to verify plasticity (see Section 2.5 and Table 2.5) is recommended.

2.6.5.3 Measuring Bentonite Content

The best way to control the amount of bentonite mixed with soil is to measure the relative weights of soil and bentonite blended together at the time of mixing. After bentonite has been mixed with soil there are several techniques available to estimate the amount of bentonite in the soil. None of the techniques are particularly easy to use in all situations.

The recommended technique for measuring the amount of bentonite in soil is the methylene blue test (Alther, 1983). The methylene blue test is a type of titration test. Methylene blue is slowly titrated into a material and the amount of methylene blue required to saturate the material is determined. The more bentonite in the soil the greater the amount of methylene blue that must be added to achieve saturation. A calibration curve is developed between the amount of methylene blue needed to saturate the material and the bentonite content of the soil. The methylene blue test works very well when bentonite is added into a non-clayey soil. However, the amount of methylene blue that must be added to the soil is a function of the amount of clay present in the soil. If clay minerals other than bentonite are present, the clay minerals interfere with the determination of the bentonite content. There is no standard methylene blue test; the procedure outlined in Alther (1983) is suggested until such time as a standard test method is developed.

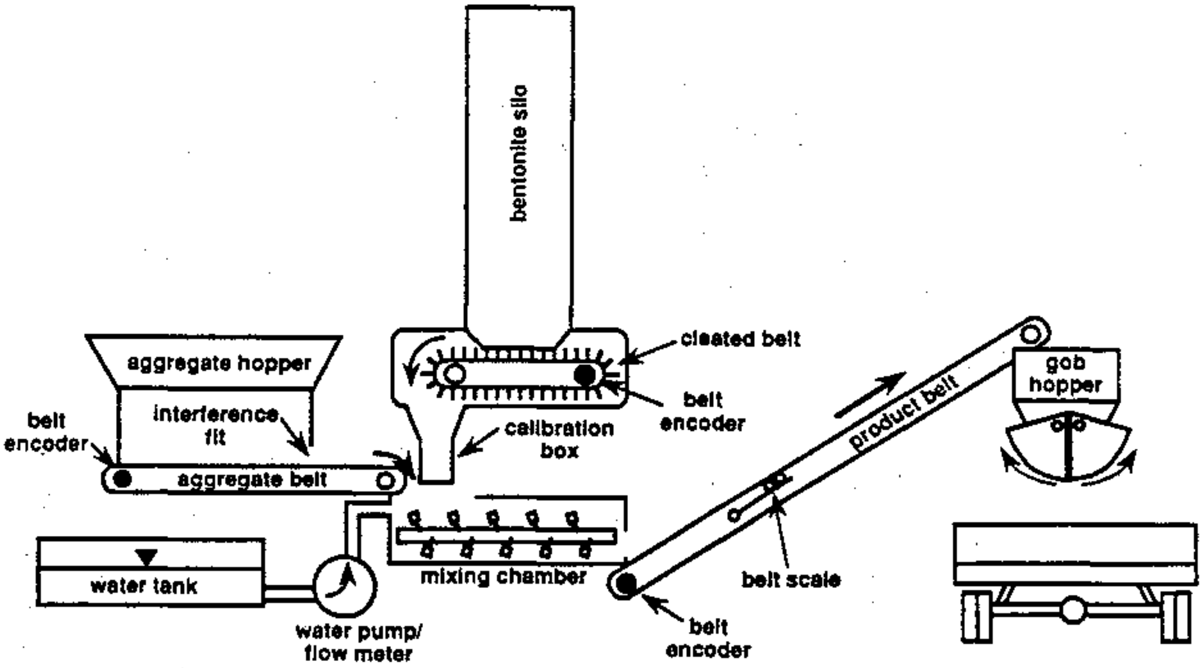


Figure 2.30 - Schematic Diagram of Pugmill

Another type of test that has been used to estimate bentonite content is the filter press test. This test is essentially a water absorbency test: the greater the amount of clay in a soil, the greater the water holding capacity. Like the methylene blue test, the filter press test works well if bentonite is the only source of clay in the soil. No specific test procedure was available at the time of this writing.

Measurement of hydraulic conductivity provides a means for verifying that enough bentonite has been added to the soil to achieve the desired low hydraulic conductivity. If insufficient bentonite has been added, the hydraulic conductivity should be unacceptably large. However, just because the hydraulic conductivity is acceptably low for a given sample does not necessarily mean that the required amount of bentonite has been added to the soil at all locations. Indeed, extra bentonite beyond the minimum amount required is added to soil so that there will be sufficient bentonite present even at those locations that are "lean" in bentonite.

The recommended tests and testing frequencies to verify proper addition of bentonite are summarized in Table 2.7. However, the CQA personnel must realize that the amount of testing depends on the degree of control in the mixing process: the more control during mixing, the less is the need for testing to verify the proper bentonite content.

Table 2.7 - Recommended Tests to Verify Bentonite Content

Parameter	Frequency	Test Method
Methylene Blue Test	1 per 1,000 m^3	Alther (1983)
Compaction Curve for Soil-Bentonite Mixture (Needed To Prepare Hydraulic Conductivity Test Specimen)	1 per 5,000 m^3	Per Project Specifications, e.g., ASTM D-698 or D-1557
Hydraulic Conductivity of Soil-Bentonite Mixture Compacted to Appropriate Water Content and Dry Unit Weight	3/ha/Lift (1/Acre/Lift)	ASTM D-5084, "Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter"

Note: 1 yd^3 = 0.76 m^3

2.6.6 Stockpiling Soils

After the soil has been preprocessed it is usually necessary to ensure that the water content does not change prior to use. The stockpiles can be of any size or shape. Small stockpiles should be covered so that the soil cannot dry or wet. For large stockpiles, it may not be necessary to cover the stockpile, particularly if the stockpile is sloped to promote drainage, moisture is added occasionally to offset drying at the surface, or other steps are taken to minimize wetting or drying of the stockpiled soil.

2.7 Placement of Loose Lift of Soil

After a soil has been fully processed, the soil is hauled to the final placement area. Soil should not be placed in adverse weather conditions, e.g., heavy rain. Inspectors are usually responsible for documenting weather conditions during all earthwork operations. The surface on which the soil will be placed must be properly prepared and the material must be inspected after placement to make sure that the material is suitable. Then the CQA inspectors must also verify that the lift is not too thick. For side slopes, construction specifications should clearly state whether lifts are parallel to the slope or horizontal. For slopes inclined at 3(H):1(V) or flatter, lifts are usually parallel to the slope. For slopes inclined at 2(H):1(V) or steeper, lifts are usually horizontal. However, horizontal lifts may present problems because the hydraulic conductivity for flow parallel to lifts is expected to be somewhat greater than for flow perpendicular to lifts. Details of testing are described in the following subsections.

Transport vehicles can pick up contaminants while hauling material from the borrow source or preprocessing area. If this occurs, measures should be taken to prevent contaminants from falling off transport vehicles into the soil liner material. These measures may include restricting vehicles to contaminant free haul roads or removing contaminants before the vehicle enters the placement area.

2.7.1 Surface Scarification

Prior to placement of a new lift of soil, the surface of the previously compacted lift of soil liner should be roughened to promote good contact between the new and old lifts. Inspectors should observe the condition of the surface of the previously compacted lift to make sure that the surface has been scarified as required in the construction specifications. When soil is scarified it is usually roughened to a depth of about 25 mm (1 in.). In some cases the surface may not require scarification if the surface is already rough after the end of compaction of a lift. It is very important that CQA inspectors ensure that the soil has been properly scarified if construction specifications require scarification. If the soil is scarified, the scarified zone becomes part of the loose lift of soil and should be counted in measuring the loose lift thickness.

2.7.2 Material Tests and Visual Inspection

2.7.2.1 Material Tests

After a loose lift of soil has been placed, samples are periodically taken to confirm the properties of the soil liner material. These samples are in addition to samples taken from the borrow area (Table 2.3). The types of tests and frequency of testing are normally specified in the CQA documents. Table 2.8 summarizes recommended minimum tests and testing frequencies. Samples of soils can be taken either on a grid pattern or on a random sampling pattern (see Section 2.8.3.2). Statistical tests and criteria can be applied but are not usually applied to soil liners in part because enough data have to be gathered to apply statistics, and yet decisions have to be made immediately, before very much data are collected.

2.7.2.2 Visual Observations

Inspectors should position themselves near the working face of soil liner material as it is being placed. Inspectors should look for deleterious materials such as stones, debris, and organic matter. Continuous inspection of the placement of soil liner material is recommended to ensure that the soil liner material is of the proper consistency.

2.7.2.3 Allowable Variations

Tests on soil liner materials may occasionally fail to conform with required specifications. It is unrealistic to think that 100% of a soil liner material will be in complete conformance with specifications. For example, if the construction documents require a minimum plasticity index it may be anticipated that a small fraction of the soil (such as pockets of sandy material) will fail to conform with specifications. It is neither unusual nor unexpected that occasional failing material will be encountered in soil liners. Occasional imperfections in soil liner materials are expected. Indeed, one of the reasons why multiple lifts are used in soil liners is to account for the inevitable variations in the materials of construction employed in building soil liners. Occasional deviations from construction specifications are not harmful. Recommended maximum allowable variations (failing tests) are listed in Table 2.9.

Table 2.8 - Recommended Materials Tests for Soil Liner Materials Sampled after Placement in a Loose Lift (Just Before Compaction)

Parameter	Test Method	Minimum Testing Frequency
Percent Fines (Note 1)	ASTM D-1140	1 per 800 m^3 (Notes 2 & 5)
Percent Gravel (Note 3)	ASTM D-422	1 per 800 m^3 (Notes 2 & 5)
Liquid & Plastic Limits	ASTM D-4318	1 per 800 m^3 (Notes 2 & 5)
Percent Bentonite (Note 4)	Alther (1983)	1 per 800 m^3 (Notes 2 & 5)
Compaction Curve	As Specified	1 per 4,000 m^3 (Note 5)
Construction Oversight	Observation	Continuous

Notes:

1. Percent fines is defined as percent passing the No. 200 sieve.
2. In addition, at least one test should be performed each day that soil is placed, and additional tests should be performed on any suspect material observed by CQA personnel.
3. Percent gravel is defined as percent retained on the No. 4 sieve.
4. This test is only applicable to soil-bentonite liners.
5. 1 $yd^3 = 0.76$ m^3.

Table 2.9 - Recommended Maximum Percentage of Failing Material Tests

Parameter	Maximum Allowable Percentage of Outliers
Atterberg Limits	5% and Outliers Not Concentrated in One Lift or One Area
Percent Fines	5% and Outliers Not Concentrated in One Lift or One Area
Percent Gravel	10% and Outliers Not Concentrated in One Lift or One Area
Clod Size	10% and Outliers Not Concentrated in One Lift or One Area
Percent Bentonite	5% and Outliers Not Concentrated in One Lift or One Area
Hydraulic Conductivity of Laboratory Compacted Soil	5% and Outliers Not Concentrated in One Lift or One Area

2.7.2.4 Corrective Action

If it is determined that the materials in an area do not conform with specifications, the first step is to define the extent of the area requiring repair. A sound procedure is to require the contractor to repair the lift of soil out to the limits defined by passing CQC/CQA tests. The contractor should not be allowed to guess at the extent of the area that requires repair. To define the limits of the area that requires repair, additional tests are often needed. Alternatively, if the contractor chooses not to request additional tests, the contractor should repair the area that extends from the failing test out to the boundaries defined by passing tests.

The usual corrective action is to wet or dry the loose lift of soil in place if the water content is incorrect. The water must be added uniformly, which requires mixing the soil with a disc or rototiller (see Section 2.6.1). If the soil contains oversized material, oversized particles are removed from the material (see Section 2.6.2). If clods are too large, clods can be pulverized in the loose lift (see Section 2.6.3). If the soil lacks adequate plasticity, contains too few fines, contains too much gravel, or lacks adequate bentonite, the material is normally excavated and replaced.

2.7.3 Placement and Control of Loose Lift Thickness

Construction specifications normally place limits on the maximum thickness of a loose lift of soil, e.g., 225 mm (9 in.). The thickness of a loose lift should not exceed this value with normal equipment. The thickness of a loose lift may be determined in several ways. One technique is for an inspector standing near the working face of soil being placed to observe the thickness of the lift. This is probably the most reliable technique for controlling loose lift thickness for CQA inspectors. If there is a question about loose lift thickness one should dig a pit through the loose lift of soil and into the underlying layer. A cross-beam is used to measure the depth from the surface of a loose lift to the top of the previously compacted lift. If the previously compacted lift was scarified, the zone of scarification should be counted in the loose lift thickness for the new layer of soil. Continuous observation of loose lift thickness is recommended during placement of soil liners.

Some earthwork contractors control lift thickness by driving grade stakes into the subsoil and marking the grade stake to indicate the proper thickness of the next layer. This practice is very convenient for equipment operators because they can tell at a glance whether the loose lift thickness is correct. However, this practice is strongly discouraged for the second and subsequent lifts of a soil liner because the penetrations into the previously-compacted lift made by the grade stakes must be repaired. Also, any grade stakes or fragments from grade stakes left in a soil liner could puncture overlying geosynthetics. Repair of holes left by grade stakes is very difficult because one must dig through the loose lift of soil to expose the grade stake, remove the grade stake without breaking the stake and leaving some of the stake in the soil, backfill the hole left by the grade stake, and then replace the loose soil in the freshly-placed lift. For the first lift of soil liner, repair of grade stake holes may not be relevant (depending on the subgrade and what its function is), but grade stakes are discouraged even for the first lift of soil because the stakes may be often broken off and incorporated into the soil. Grade stakes resting on a small platform or base do not need to be driven into the underlying material and are, therefore, much more desirable than ordinary grade stakes. If grade stakes are used, it is recommended that they be numbered and accounted for at the end of each shift; this will provide verification that grade stakes are not being abandoned in the fill material.

The recommended survey procedure for control of lift thickness involves laser sources and receivers. A laser beam source is set at a known elevation, and reception devices held by hand on rods or mounted to grading equipment are used to monitor lift thickness. However, lasers cannot be used at all sites. For instance, the liner may need to be a minimum distance above rock, and the grade lines may follow the contours of underlying rock. Further, every site has areas such as corners, sumps, and boundaries of cells, which preclude the use of lasers.

For those areas where lasers cannot be used, it is recommended that either flexible plastic grade stakes or metallic grade stakes (numbered and inventoried as part of the QA/QC process) be used. It is preferable if the stakes are mounded on a base so that the stakes do not have to be driven into the underlying lift. Repair of grade stake holes should be required; the repairs should be periodically inspected and the repairs documented. Alternatively (and preferably for small areas), spot elevations can be obtained on the surface of a loose lift with conventional level and rod equipment, and adjustments made by the equipment operator based on the levels.

When soil is placed, it is usually dumped into a heap at the working face and spread with dozers. QA/QC personnel should stand in front of the working face to observe the soil for oversized materials or other deleterious material, to visually observe loose lift thickness, and to make sure that the dozer does not damage an underlying layer.

2.8 Remolding and Compaction of Soil

2.8.1 Compaction Equipment

The important parameters concerning compaction equipment are the type and weight of the compactor, the characteristics of any feet on the drum, and the weight of the roller per unit length of drummed surface. Sometimes construction specifications will stipulate a required type of compactor or minimum weight of compactor. If this is the case inspectors should confirm that the compaction equipment is in conformance with specifications. Inspectors should be particularly cognizant of the weight of compactor and length of feet on drummed rollers. Heavy compactors with long feet that fully penetrate a loose lift of soil are generally thought to be the best type of compactor to use for soil liners. Footed rollers may not be necessary or appropriate for some bentonite-soil mixes; smooth-drum rollers or rubber tired rollers may produce best results for soil-bentonite mixtures that do not require kneading or remolding to achieve low hydraulic conductivity but only require densification.

Some compactors are self-propelled while other compactors are towed. Towed, footed rollers are normally ballasted by filling the drum with water to provide weight that will enable significant compactive effort to be delivered to the soil. Inspectors should be very careful to determine whether or not all drums on towed rollers have been filled with liquid.

Compacting soil liners on side slopes can present special challenges, particularly for slopes inclined at 3(H):1(V) or steeper. Inspectors should observe side-slope compaction carefully and watch for any tendency for the compactor to slip down slope or for slippage or cracking to take place in the soil. Inspectors should also be watchful to make sure that adequate compactive effort is delivered to the soil. For soils compacted in lifts parallel to the slope, the first lift of soil should be "knitted" into existing subgrade to minimize a preferential flow path along the interface and to minimize development of a potential slip plane.

Footed rollers can become clogged with soil between the feet. Inspectors should examine the condition of the roller to make sure that the space between feet is not plugged with soil. In addition, compaction equipment is intended to be operated at a reasonable speed. The maximum speed of the compactor should be specified in the construction specifications. CQC and CQA personnel should make sure the speed of the equipment is not too great.

When soils are placed directly on a fragile layer, such as a geosynthetic material, or a drainage material, great care must be taken in placing and compacting the first lift so as not to damage the fragile material or mix clay in with the underlying drainage material. Often, the first lift of soil is considered a sacrificial lift that is placed, spread with dozers, and only nominally compacted with the dozers or a smooth-drum or rubber-tire roller. QA/QC personnel should be particularly careful to observe all placement and compaction operations of the first lift of soil for compacted soil liners placed directly on a geosynthetic material or drainage layer.

It is not uncommon for a contractor to use more than one type of compaction equipment on a project. For example, initial compaction may be with a heavy roller having long feet that fully penetrate a loose lift of soil. Later, the upper part of a lift may be compacted with a heavy rubber-tired roller or other equipment that is particularly effective in compacting near-surface materials.

2.8.2 Number of Passes

The compactive effort delivered by a roller is a function of the number of passes of the roller over a given area of soil. A pass may defined as one pass of the construction equipment or one pass of a drum over a given point in the soil liner. It does not matter whether a pass is defined as a pass of the equipment or a pass of a drum, but the construction specifications and/or CQA plan should define what is meant by a pass. Normally, one pass of the vehicle constitutes a pass for self-propelled rollers and one pass of a drum constitutes a pass for towed rollers.

Some construction documents require a minimum coverage. Coverage (C) is defined as follows:

$$C = [A_f/A_d] \times N \times 100\% \qquad (2.4)$$

where N is the number of passes of the roller, A_f is the sum of the area of the feet on the drums of the roller, and A_d is the area the drum itself. Construction specifications sometimes require 150% -

200% coverage of the roller. For a given roller and minimum percent coverage, the minimum number of passes (N) may be computed.

The number of passes of a compactor over the soil can have an important influence on the overall hydraulic conductivity of the soil liner. It is recommended that periodic observations be made of the number of passes of the roller over a given point. Approximately 3 observations per hectare per lift (one observation per acre per lift) is the recommended frequency of measurement. The minimum number of passes that is reasonable depends upon many factors and cannot be stated in general terms. However, experience has been that at least 5 to 15 passes of a compactor over a given point is usually necessary to remold and compact clay liner materials thoroughly.

2.8.3 Water Content and Dry Unit Weight

2.8.3.1 Water Content and Unit Weight Tests

One of the most important CQA tests is measurement of water content and dry unit weight. Methods of measurement were discussed in Section 2.3. Recommended testing frequencies are listed in Table 2.10. It is stressed that the recommended testing frequencies are the minimum values. Some judgment should be applied to these numbers, and the testing frequencies should be increased or kept at the minimum depending on the specific project and other QA/QC tests and observations. For example, if hydraulic conductivity tests are not performed on undisturbed samples (see Section 2.8.4.2), more water content/density tests may be required than the usual minimum.

2.8.3.2 Sampling Patterns

There are several ways in which sample locations may be selected for water content and unit weight tests. The simplest and least desirable method is for someone in the field to select locations at the time samples must be taken. This is undesirable because the selector may introduce a bias into the sampling pattern. For example, perhaps on the previous project soils of one particular color were troublesome. If the individual were to focus most of the tests on the current project on soils of that same color a bias might be introduced.

A common method of selecting sample locations is to establish a grid pattern. The grid pattern is simple and ensures a high probability of locating defective areas so long as the defective areas are of a size greater than or equal to the spacing between the sampling points. It is important to stagger the grid patterns in successive lifts so that sampling points are not at the same location in each lift. One would not want to sample at the same location in successive lifts because repaired sample penetrations would be stacked on top of one another. The grid pattern sampling procedure is the simplest one to use that avoids the potential for bias described in the previous paragraph.

A third alternative for selecting sampling points is to locate sampling points randomly. Tables and examples are given in Richardson (1992). It is recommended that no sampling point be located within 2 meters of another sampling point. If a major portion of the area to be sampled has been omitted as a result of the random sampling process, CQA inspectors may add additional points to make sure the area receives some testing. Random sampling is sometimes preferred on large projects where statistical procedures will be used to evaluate data. However, it can be demonstrated that for a given number of sampling points, a grid pattern will be more likely to detect a problem area provided that the dimensions of the problem area are greater than or equal to the spacing between sampling points. If the problem area is smaller than the spacing between sampling points, the probability of locating the problem area is approximately the same with both a grid pattern and a random pattern of sampling.

Table 2.10 - Recommended Tests and Observations on Compacted Soil

Parameter	Test Method	Minimum Testing Frequency
Water Content (Rapid) (Note 1)	ASTM D-3017 ASTM D-4643 ASTM D-4944 ASTM D-4959	13/ha/lift (5/acre/lift) (Notes 2 & 7)
Water Content (Note 3)	ASTM D-2216	One in every 10 rapid water content tests (Notes 3 & 7)
Total Density (Rapid) (Note 4)	ASTM D-2922 ASTM D-2937	13/ha/lift (5/acre/lift) (Notes 2, 4 & 7)
Total Density (Note 5)	ASTM D-1556 ASTM D-1587 ASTM D-2167	One in every 20 rapid density tests (Notes 5, 6, & 7)
Number of Passes	Observation	3/ha/lift (1/acre/lift) (Notes 2 & 7)
Construction Oversight	Observation	Continuous

Notes:

1. ASTM D-3017 is a nuclear method, ASTM D-4643 is microwave oven drying, ASTM D-4944 is a calcium carbide gas pressure tester method, and ASTM D-4959 is a direct heating method. Direct water content determination (ASTM D-2216) is the standard against which nuclear, microwave, or other methods of measurements are calibrated for on-site soils.
2. In addition, at least one test should be performed each day soil is compacted and additional tests should be performed in areas for which CQA personnel have reason to suspect inadequate compaction.
3. Every tenth sample tested with ASTM D-3017, D-4643, D-4944, or D-4959 should be also tested by direct oven drying (ASTM D-2216) to aid in identifying any significant, systematic calibration errors.
4. ASTM D-2922 is a nuclear method and ASTM D-2937 is the drive cylinder method. These methods, if used, should be calibrated against the sand cone (ASTM D-1556) or rubber balloon (ASTM D-2167) for on-site soils. Alternatively, the sand cone or rubber balloon method can be used directly.
5. Every twentieth sample tested with D-2922 should also be tested (as close as possible to the same test location) with the sand cone (ASTM D-1556) or rubber balloon (ASTM D-2167) to aid in identifying any systematic calibration errors with D-2922.
6. ASTM D-1587 is the method for obtaining an undisturbed sample. The section of undisturbed sample can be cut or trimmed from the sampling tube to determine bulk density. This method should not be used for soils containing any particles > 1/6-th the diameter of the sample.
7. 1 acre = 0.4 ha.

No matter which method of determining sampling points is selected, it is imperative that CQA inspectors have the responsibility to perform additional tests on any suspect area. The number of additional testing locations that are appropriate varies considerably from project to project.

2.8.3.3 Tests with Different Devices to Minimize Systematic Errors

Some methods of measurement may introduce a systematic error. For example, the nuclear device for measuring water content may consistently produce a water content measurement that is too high if there is an extraneous source of hydrogen atoms besides water in the soil. It is important that devices that may introduce a significant systematic error be periodically correlated with measurements that do not have such error. Water content measurement tests have the greatest potential for systematic error. Both the nuclear method as well as microwave oven drying can produce significant systematic error under certain conditions. Therefore, it is recommended that if the nuclear method or any of the rapid methods of water content measurement (Table 2.2) are used to measure water content, periodic correlation tests should be made with conventional overnight oven drying (ASTM D-2216).

It is suggested that at the beginning of a project, at least 10 measurements of water content be determined on representative samples of the site-specific soil using any rapid measurement method to be employed on the project as well as ASTM D-2216. After this initial correlation, it is suggested (see Tables 2.10) that one in ten rapid water content tests be crossed check with conventional overnight oven drying. At the completion of a project a graph should be presented that correlates the measured water content with a rapid technique against the water content from conventional overnight oven drying.

Some methods of unit weight measurement may also introduce bias. For example, the nuclear device may not be properly calibrated and could lead to measurement of a unit weight that is either too high or too low. It is recommended that unit weight be measured independently on occasion to provide a check against systematic errors. For example, if the nuclear device is the primary method of density measurement being employed on a project, periodic measurements of density with the sand cone or rubber balloon device can be used to check the nuclear device. Again, a good practice is to perform about 10 comparative tests on representative soil prior to construction. During construction, one in every 20 density tests (see Table 2.10) should be checked with the sand cone or rubber balloon. A graph should be made of the unit weight measured with the nuclear device versus the unit weight measured with the sand cone or rubber balloon device to show the correlation. One could either plot dry unit weight or total unit weight for the correlation. Total unit weight in some ways is more sensible because the methods of measurement are actually total unit weight measurements; dry unit weight is calculated from the total unit weight and water content (Eq. 2.1.).

2.8.3.4 Allowable Variations and Outliers

There are several reasons why a field water content or density test may produce a failing result, i.e., value outside of the specified range. Possible causes for a variation include a human error in measurement of water content or dry unit weight, natural variability of the soil or the compaction process leading to an anomaly at an isolated location, limitations in the sensitivity and repeatability of the test methods, or inadequate construction procedures that reflect broader-scale deficiencies.

Measurement errors are made on every project. From time to time it can be expected that CQC and CQA personnel will incorrectly measure either the water content or the dry unit weight.

Periodic human errors are to be expected and should be addressed in the CQA plan.

If it is suspected that a test result is in error, the proper procedure for rectifying the error should be as follows. CQC or CQA personnel should return to the point where the questionable measurement was obtained. Several additional tests should be performed in close proximity to the location of the questionable test. If all of the repeat tests provide satisfactory results the questionable test result may be disregarded as an error. Construction quality assurance documents should specify the number of tests required to negate a blunder. It is recommended that approximately 3 passing tests be required to negate the results of a questionable test.

One of the main reasons why soil liners are built of multiple lifts is a realization that the construction process and the materials themselves vary. With multiple lifts no one particular point in any one lift is especially significant even if that point consists of unsatisfactory material or improperly compacted material. It should be expected that occasional deviations from construction specifications will be encountered for any soil liner. In fact, if one were to take enough soil samples, one can rest assured that a failing point on some scale would be located.

Measurement techniques for compacted soils are imperfect and produce variable results. Turnbull et al. (1966) discuss statistical quality control for compacted soils. Noorany (1990) describes 3 sites in the San Diego area for which 9 testing laboratories measured water content and percent compaction on the same fill materials. The ranges in percent compaction were very large: 81-97% for Site 1, 77-99% for Site 2, and 89-103% for Site 3.

Hilf (1991) summarizes statistical data from 72 earth dams; the data show that the standard deviation in water content is typically 1 to 2%, and the standard deviation in dry density is typically 0.3 to 0.6 kN/m^3 (2 to 4 pcf). Because the standard deviations are themselves on the same order as the allowable range of these parameters in many earthwork specifications, it is statistically inevitable that there will be some failing tests no matter how well built the soil liner is.

It is unrealistic to expect that 100% of all CQA tests will be in compliance with specifications. Occasional deviations should be anticipated. If there are only a few randomly-located failures, the deviations in no way compromise the quality or integrity of a multiple-lift liner.

The CQA documents may provide an allowance for an occasional failing test. The documents may stipulate that failing tests not be permitted to be concentrated in any one lift or in any one area. It is recommended that a small percentage of failing tests be allowed rather than insisting upon the unrealistic requirement that 100% of all tests meet project objectives. Statistically based requirements provide a convenient yet safe and reliable technique for handling occasional failing test results.. However, statistically based methods require that enough data be generated to apply statistics reliably. Sufficient data to apply statistical methods may not be available, particularly in the early stages of a project.

Another approach is to allow a small percentage of outliers but to require repair of any area where the water content is far too low or high or the dry unit weight is far too low. This approach is probably the simplest to implement -- recommendations are summarized in Table 2.11.

Table 2.11 - Recommended Maximum Percentage of Failing Compaction Tests

Parameter	Maximum Allowable Percentage of Outliers
Water Content	3% and Outliers Not Concentrated in One Lift or One Area, and No Water Content Less than 2% or More than 3% of the Allowable Value
Dry Density	3% and Outliers Not Concentrated in One Lift or One Area, and No Dry Density Less than 0.8 kN/m^3 (5 pcf) Below the Required Value
Number of Passes	5% and Outliers Not Concentrated in One Lift or One Area

2.8.3.5 Corrective Action

If it is determined that an area does not conform with specifications and that the area needs to be repaired, the first step is to define the extent of the area requiring repair. The recommended procedure is to require the contractor to repair the lift of soil out to the limits defined by passing CQC and CQA tests. The contractor should not be allowed to guess at the extent of the area that requires repair. To define the limits of the area that requires repair, additional tests are often needed. Alternatively, if the contractor chooses not to request additional tests, the contractor should repair the area that extends from the failing test out to the boundaries defined by passing tests.

The usual problem requiring corrective action at this stage is inadequate compaction of the soil. The contractor is usually able to rectify the problem with additional passes of the compactor over the problem area.

2.8.4 Hydraulic Conductivity Tests on Undisturbed Samples

Hydraulic conductivity tests are often performed on "undisturbed" samples of soil obtained from a single lift of compacted soil liner. Test specimens are trimmed from the samples and are permeated in the laboratory. Compliance with the stated hydraulic conductivity criterion is checked.

This type of test is given far too much weight in most QA programs. Low hydraulic conductivity of samples taken from the liner is necessary for a well-constructed liner but is not sufficient to demonstrate that the large-scale, field hydraulic conductivity is adequately low. For example, Elsbury et al. (1990) measured hydraulic conductivities on undisturbed samples of a poorly constructed liner that averaged 1×10^{-9} cm/s, and yet the actual in-field value was 1×10^{-5} cm/s. The cause for the discrepancy was the existence of macro-scale flow paths in the field that were not simulated in the small-sized (75 mm or 3 in. diameter) laboratory test specimens.

Not only does the flow pattern through a 75-mm-diameter test specimen not necessarily reflect flow patterns on a larger field scale, but the process of obtaining a sample for testing inevitably disturbs the soil. Layers are distorted, and gross alterations occur if significant gravel is present in the soil. The process of pushing a sampling tube into the soil densifies the soil, which lowers its hydraulic conductivity. The harder and drier the soil, the greater the disturbance. As a result of these various factors, the large-scale, field hydraulic conductivity is almost always greater than or equal to the small-scale, laboratory-measured hydraulic conductivity. The difference between values from a small laboratory scale and a large field scale depends on the quality of construction -- the better the quality of construction, the less the difference.

Laboratory hydraulic conductivity tests on undisturbed samples of compacted liner can be valuable in some situations. For instance, for soil-bentonite mixes, the laboratory test provides a check on whether enough bentonite has been added to the mix to achieve the desired hydraulic conductivity. For soil liners in which a test pad is not constructed, the laboratory tests provide some verification that appropriate materials have been used and compaction was reasonable (but hydraulic conductivity tests by themselves do not prove this fact).

Laboratory hydraulic conductivity tests constitute a major inconvenience because the tests usually take at least several days, and sometimes a week or two, to complete. Their value as QA tools is greatly diminished by the long testing time -- field construction personnel simply cannot wait for the results of the tests to proceed with construction, nor would the QA personnel necessarily want them to wait because opportunities exist for damage of the liner as a result of desiccation. Thus, one should give very careful consideration as to whether the laboratory hydraulic conductivity tests are truly needed for a given project and will serve a sufficiently useful purpose to make up for the inconvenience of this type of test.

Research is currently underway to determine if larger-sized samples from field-compacted soils can give more reliable results than the usual 75-mm (3 in.) diameter samples. Until further data are developed, the following recommendations are made concerning the approach to utilizing laboratory hydraulic conductivity tests for QA on field-compacted soils:

1. For gravely soils or other soils that cannot be consistently sampled without causing significant disturbance, laboratory hydraulic conductivity tests should not be a part of the QA program because representative samples cannot realistically be obtained. A test pad (Section 2.10) is recommended to verify hydraulic conductivity.
2. If a test pad is constructed and it is demonstrated that the field-scale hydraulic conductivity is satisfactory on the test pad, the QA program for the actual soil liner should focus on establishing that the actual liner is built of similar materials and to equal or better standards compared to the test pad -- laboratory hydraulic conductivity testing is not necessary to establish this.
3. If no test pad is constructed and it is believed that representative samples can be obtained for hydraulic conductivity testing, then laboratory hydraulic conductivity tests on undisturbed samples from the field are recommended.

2.8.4.1 Sampling for Hydraulic Conductivity Testing

A thin-walled tube is pushed into the soil to obtain a sample. Samples of soil should be taken in the manner that minimizes disturbance such as described in ASTM D-1587. Samples should be sealed and carefully stored to prevent drying and transported to the laboratory in a manner that minimizes soil disturbance as described in ASTM D-4220.

It is particularly important that the thin-walled sampling tube be pushed into the soil in the direction perpendicular to the plane of compaction. Many CQA inspectors will push the sampling tube into the soil using the blade of a dozer or compactor. This practice is not recommended because the sampling tube tends to rotate when it is pushed into the soil. The recommended way of sampling the soil is to push the sampling tube straight into the soil using a jack to effect a smooth, straight push.

Sampling of gravely soils for hydraulic conductivity testing is often a futile exercise. The gravel particles that are encountered by the sampling tube tend to tumble and shear during the push, which caused major disturbance of the soil sample. Experience has been that QA/QC personnel may take several samples of gravely soil before a sample that is sufficiently free of gravel to enable proper sampling is finally obtained; in these cases, the badly disturbed, gravely samples are discarded. Clearly, the process of discarding samples because they contain too much gravel to enable proper sampling introduces a bias into the process. Gravely soils are not amenable to undisturbed sampling.

2.8.4.2 Hydraulic Conductivity Testing

Hydraulic conductivity tests are performed utilizing a flexible wall permeameter and the procedures described in ASTM D-5084. Inspectors should be careful to make sure that the effective confining stress utilized in the hydraulic conductivity test is not excessive. Application of excessive confining stress can produce an artificially low hydraulic conductivity. The CQA plan should prescribe the maximum effective confining stress that will be used; if none is specified a value of 35 kPa (5 psi) is recommended for both liner and cover systems.

2.8.4.3 Frequency of Testing

Hydraulic conductivity tests are typically performed at a frequency of 3 tests/ha/lift (1 test/acre/lift) or, for very thick liners (≥ 1.2 m or 4 ft) per every other lift. This is the recommended frequency of testing, if hydraulic conductivity testing is required. The CQA plan should stipulate the frequency of testing.

2.8.4.4 Outliers

The results of the above-described hydraulic conductivity tests are often given far too much weight. A passing rate of 100% does not necessarily prove that the liner was well built, yet some inexperienced individuals falsely believe this to be the case. Hydraulic conductivity tests are performed on small samples; even though small samples may have low hydraulic conductivity, inadequate construction or CQA can leave remnant macro-scale defects such as fissures and pockets of poorly compacted soil. The fundamental problem is that laboratory hydraulic conductivity tests are usually performed on 75-mm (3 in.) diameter samples, and these samples are too small to contain a representative distribution of macro-scale defects (if any such defects are present). By the same token, an occasional failing test does not necessarily prove that a problem exists. An occasional failing test only shows that either: (1) there are occasional zones that fail to meet performance criteria, or (2) sampling disturbance (e.g., from the sampling tube shearing stones in the soil) makes confirmation of low hydraulic conductivity difficult or impossible. Soil liners built of multiple lifts are expected to have occasional, isolated imperfections -- this is why the liners are constructed from multiple lifts. Thus, occasional failing hydraulic conductivity tests by themselves do not mean very much. Even on the best built liners, occasional failing test results should be anticipated.

It is recommended that a multiple-lift soil liner be considered acceptable even if a small percentage (approximately 5%) of the hydraulic conductivity tests fail. However, one should allow a small percentage of hydraulic conductivity failures only if the overall CQA program is thorough. Further, it is recommended that failing samples have a hydraulic conductivity that is no greater than one-half to one order of magnitude above the target maximum value. If the hydraulic conductivity at a particular point is more than one-half to one order of magnitude too high, the zone should be retested or repaired regardless of how isolated it is.

2.8.5 Repair of Holes from Sampling and Testing

A number of tests, e.g., from nuclear density tests and sampling for hydraulic conductivity, require that a penetration be made into a lift of compacted soil. It is extremely important that all penetrations be repaired. The recommended procedure for repair is as follows. The backfill material should first be selected. Backfill may consist of the soil liner material itself, granular or pelletized bentonite, or a mixture of bentonite and soil liner material. The backfill material should be placed in the hole requiring repair with a loose lift thickness not exceeding about 50 mm (2 in.). The loose lift of soil should be tamped several times with a steel rod or other suitable device that compacts the backfill and ensures no bridging of material that would leave large air pockets. Next, a new lift of backfill should be placed and compacted. The process is repeated until the hole has been filled.

Because it is critical that holes be properly repaired, it is recommended that periodic inspections and written records made of the repair of holes. It is suggested that approximately 20% of all the repairs be inspected and that the backfill procedures be documented for these inspections. It is recommended that the inspector of repair of holes not be the same person who backfilled the hole.

2.8.6 Final Lift Thickness

Construction documents may place restrictions on the maximum allowable final (after-compaction) lift thickness. Typically, the maximum thickness is 150 mm (6 in.). Final elevation surveys should be used to establish thicknesses of completed earthwork segments. The specified maximum lift thickness is a nominal value. The actual value may be determined by surveys on the surface of each completed lift, but an acceptable practice (provided there is good CQA on loose lift thickness) is to survey the liner after construction and calculate the average thickness of each lift by dividing the total thickness by the number of lifts.

Tolerances should be specified on final lift thickness. Occasional outliers from these tolerances are not detrimental to the performance of a multi-lift liner. It is recommended by analogy to Table 2.9 that no more than 5% of the final lift thickness determinations be out of specification and that no out-of-specification thickness be more than 25 mm (1 in.) more than the maximum allowable lift thickness.

2.8.7 Pass/Fail Decision

After all CQA tests have been performed, a pass/fail decision must be made. Procedures for dealing with materials problems were discussed in Section 2.7.2.4. Procedures for correcting deficiencies in compaction of the soil were addressed in Section 2.8.3.5. A final pass/fail decision is made by the CQA engineer based upon all the data and test results. The hydraulic conductivity test results may not be available for several days after construction of a lift has been completed. Sometimes the contractor proceeds at risk with placement of additional lifts before all test results are available. On occasion, construction of a liner proceeds without final results from a test pad on the assumption that results will be acceptable. If a "fail" decision is made at this late stage, the defective soil plus any overlying materials that have been placed should be removed and replaced.

2.9 Protection of Compacted Soil

2.9.1 Desiccation

2.9.1.1 Preventive Measures

There are several ways to prevent compacted soil liner materials from desiccating. The soil may be smooth rolled with a steel drummed roller to produce a thin, dense skin of soil on the surface. This thin skin of very dense soil helps to minimize transfer of water into or out of the underlying material. However, the smooth-rolled surface should be scarified prior to placement of a new lift of soil.

A far better preventive measure is to water the soil periodically. Care must be taken to deliver water uniformly to the soil and not to create zones of excessively wet soil. Adding water by hand is not recommended because water is not delivered uniformly to the soil.

An alternative preventive measure is to cover the soil temporarily with a geomembrane, moist geotextile, or moist soil. The geomembrane or geotextile should be weighted down with sand bags or other materials to prevent transfer of air between the geosynthetic cover and soil. If a geomembrane is used, care should be taken to ensure that the underlying soil does not become heated and desiccate; a light-colored geomembrane may be needed to prevent overheating. If moist soil is placed over the soil liner, the moist soil is removed using grading equipment.

2.9.1.2 Observations

Visual observation is the best way to ensure that appropriate preventive measures have been taken to minimize desiccation. Inspectors should realize that soil liner materials can dry out very quickly (sometimes in a matter of just a few hours). Inspectors should be aware that drying may occur over weekends and provisions should be made to provide appropriate observations.

2.9.1.3 Tests

If there are questions about degree of desiccation, tests should be performed to determine the water content of the soil. A decrease in water content of one to two percentage points is not considered particularly serious and is within the general accuracy of testing. However, larger reductions in water content provide clear evidence that desiccation has taken place.

2.9.1.4 Corrective Action

If soil has been desiccated to a depth less than or equal to the thickness of a single lift, the desiccated lift may be disked, moistened, and recompacted. However, disking may produce large, hard clods of clay that will require pulverization. Also, it should be recognized that if the soil is wetted, time must be allowed for water to be absorbed into the clods of clay and hydration to take place uniformly. For this reason it may be necessary to remove the desiccated soil from the construction area, to process the lift in a separate processing area, and to replace the soil accordingly.

2.9.2 Freezing Temperatures

2.9.2.1 Compacting Frozen Soil

Frozen soil should never be used to construct soil liners. Frozen soils form hard pieces that cannot be properly remolded and compacted. Inspectors should be on the lookout for frozen chunks of soil when construction takes place in freezing temperatures.

2.9.2.2 Protection After Freezing

Freezing of soil liner materials can produce significant increases in hydraulic conductivity. Soil liners must be protected from freezing before and after construction. If superficial freezing takes place on the surface of a lift of soil, the surface may be scarified and recompacted. If an entire lift has been frozen, the entire lift should be disked, pulverized, and recompacted. If the soil is frozen to a depth greater than one lift, it may be necessary to strip away and replace the frozen material.

2.9.2.3 Investigating Possible Frost Damage

Inspectors usually cannot determine from an examination of the surface the depth to which freezing took place in a completed or partially completed soil liner that has been exposed to freezing. In such cases it may be necessary to investigate the soil liner material for possible frost damage. The extent of damage is difficult to determine. Freezing temperatures cause the development of tiny microcracks in the soil. Soils that have been damaged due to frost action develop fine cracks that lead to the formation of chunks of soil when the soil is excavated. The pushing of a sampling tube into the soil will probably close these cracks and mask the damaging effects of frost upon hydraulic conductivity. The recommended procedure for evaluating possible frost damage to soil liners involves three steps:

1. Measure the water content of the soil within and beneath the zone of suspected frost damage. Density may also be measured, but freeze/thaw has little effect on density and may actually cause an increase in dry unit weight. Freeze/thaw is often accompanied by desiccation; water content measurements will help to determine whether drying has taken place.

2. Investigate the morphology of the soil by digging into the soil and examining its condition. Soil damaged by freezing usually contains hairline cracks, and the soil breaks apart in chunks along larger cracks caused by freeze/thaw. Soil that has not been frozen should not have tiny cracks nor should it break apart in small chunks. The morphology of the soil should be examined by excavating a small pit into the soil liner and peeling off sections from the wall of the pit. One should not attempt to cut pieces from the sidewall; smeared soil will mask cracks. A distinct depth may be obvious; above this depth the soil breaks into chunks along frost-induced cracks, and below this depth there is no evidence of cracks produced by freezing.

3. One or more samples of soil should be carefully hand trimmed for hydraulic conductivity testing. The soil is usually trimmed with the aid of a sharpened section of tube of the appropriate inside diameter. The tube is set on the soil surface with the sharpened end facing downward, soil is trimmed away near the sharpened edge of the trimming ring, the tube is pushed a few millimeters into the soil, and the trimming is repeated. Samples may be taken at several depths to delineate the depth to which freeze/thaw damage occurred. The minimum diameter of a cylindrical test specimen should be 300 mm (12 in.). Small test specimens, e.g., 75 mm (3 in.) diameter specimens, should not be used because freeze/thaw can create morphological structure in the soil on a scale too large to permit representative testing with small samples. Hydraulic conductivity tests should be performed as described in ASTM D-5084. The effective confining stress should not exceed the

smallest vertical effective stress to which the soil will be subjected in the field, which is usually the stress at the beginning of service for liners. If no compressive stress is specified, a value of 35 kPa (5 psi) is recommended for both liner and cover system.

The test pit and all other penetrations should be carefully backfilled by placing soil in lifts and compacting the lifts. The sides of the test pit should be sloped so that the compactor can penetrate through to newly placed material without interference from the walls of the pit.

2.9.2.4 Repair

If it is determined that soil has been damaged by freezing, the damaged material is usually repaired as follows. If damage is restricted to a single lift, the lift may be disked, processed to adjust water content or to reduce clod size if necessary, and recompacted. If the damage extends deeper, damaged materials should be excavated and replaced.

2.9.3 Excess Surface Water

In some cases exposed lifts of liner material, or the completed liner, are subjected to heavy rains that soften the soil. Surface water creates a problem if the surface is uneven (e.g., if a footed roller has been used and the surface has not been smooth-rolled with a smooth, steel wheeled roller) -- numerous small puddles of water will develop in the depressions low areas. Puddles of water should be removed before further lifts of material, or other components of the liner or cover system, are constructed. The material should be disked repeatedly to allow the soil to dry, and when the soil is at the proper water content, the soil should be compacted. Alternatively, the wet soil may be removed and replaced.

Even if puddles have not formed, the soils may be too soft to permit construction equipment to operate on the soil without creating ruts. To deal with this problem, the soil may be allowed to dry slightly by natural processes (but care must be taken to ensure that it does not dry too much and does not crack excessively during the drying process). Alternatively, the soil may be disked, allowed to dry while it is periodically disked, and then compacted.

If soil is reworked and recompacted, QA/QC tests should be performed at the same frequency as for the rest of the project. However, if the area requiring reworking is very small, e.g., in a sump, tests should be performed in the confined area to confirm proper compaction even if this requires sampling at a greater frequency.

2.10 Test Pads

2.10.1 Purpose of Test Pads

The purpose of a test pad is to verify that the materials and methods of construction proposed for a project will lead to a soil liner with the required large-scale, in-situ, hydraulic conductivity. Unfortunately, it is impractical to perform large-scale hydraulic conductivity tests on the actual soil liner for two reasons: (1) the testing would produce significant physical damage to the liner, and the repair of the damage would be questionable; and (2) the time required to complete the testing would be too long -- the liner could become damaged due to desiccation while one waited for the test results.

A test pad may also be used to demonstrate that unusual materials or construction procedures will work. The process of constructing and testing a test pad is usually a good learning experience for the contractor and CQC/CQA personnel; overall quality of a project is usually elevated as a result of building and testing the test pad.

A test pad is constructed with the soil liner materials proposed for a project utilizing preprocessing procedures, construction equipment, and construction practices that are proposed for the actual liner. If the required hydraulic conductivity is demonstrated for the test pad, it is assumed that the actual liner will have a similar hydraulic conductivity, provided the actual liner is built of similar materials and to standards that equal or exceed those used in building the test pad. If a test pad is constructed and hydraulic conductivity is verified on the test pad, a key goal of CQA/CQC for the actual liner is to verify that the actual liner is built of similar materials and to standards that equal or exceed those used in building the test pad.

2.10.2 Dimensions

Test pads (Fig. 2.31) normally measure about 10 to 15 m in width by 15 to 30 m in length. The width of the test pad is typically at least four times the width of the compaction equipment, and the length must be adequate for the compactor to reach normal operating speed in the test area. The thickness of a test pad is usually no less than the thickness of the soil liner proposed for a facility but may be as little as 0.6 to 0.9 m (2 to 3 feet) if thicker liners are to be employed at full scale. A freely draining material such as sand is often placed beneath the test pad to provide a known boundary condition in case infiltrating water from a surface hydraulic conductivity test (e.g., sealed double ring infiltrometer) reaches the base of the liner. The drainage layer may be drained with a pipe or other means. However, infiltrating water will not reach the drainage layer if the hydraulic conductivity is very low; the drainage pipe would only convey water if the hydraulic conductivity turns out to be very large. The sand drainage material may not provide adequate foundation support for the first lift of soil liner unless the sand is compacted sufficiently. Also, the first lift of soil liner material on the drainage layer is often viewed as a sacrificial lift and is only compacted nominally to avoid mixing clayey soil in with the drainage material.

2.10.3 Materials

The test pad is constructed of the same materials that are proposed for the actual project. Processing equipment and procedures should be identical, too. The same types of CQC/CQA tests that will be used for the soil liner are performed on the test pad materials. If more than one type of material will be used, one test pad should be constructed for each type of material.

2.10.4 Construction

It is recommended that test strips be built before constructing the test pad. Test strips allow for the detection of obvious problems and provide an opportunity to fine-tune soil specifications, equipment selection, and procedures so that problems are minimized and the probability of the required hydraulic conductivity being achieved in the test pad is maximized. Test strips are typically two lifts thick, one and a half to two equipment widths wide, and about 10 m (30 ft) long.

The test pad is built using the same loose lift thickness, type of compactor, weight of compactor, operating speed, and minimum number of passes that are proposed for the actual soil liner. It is important that the test pad not be built to standards that will exceed those used in building the actual liner. For example, if the test pad is subjected to 15 passes of the compactor, one would want the actual soil liner to be subjected to at least 15 passes as well. It is critical that CQA personnel document the construction practices that are employed in building the test pad. It is best if the same contractor builds the test pad and actual liner so that experience gained from the test pad process is not lost. The same applies to CQC and CQA personnel.

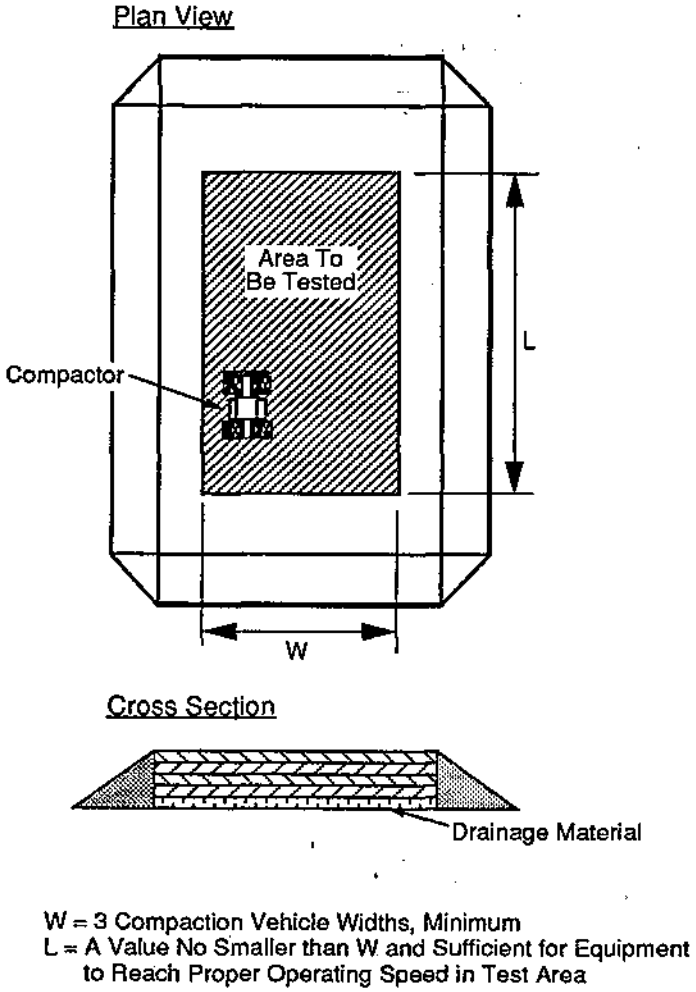


Figure 2.31 - Schematic Diagram of Soil Liner Test Pad

2.10.5 Protection

The test pad must be protected from desiccation, freezing, and erosion in the area where in situ hydraulic conductivity testing is planned. The recommended procedure is to cover the test pad with a sheet of white or clear plastic and then either spread a thin layer of soil on the plastic if no rain is anticipated or, if rain may create an undesirably muddy surface, cover the plastic with hay or straw.

2.10.6 Tests and Observations

The same types of CQA tests that are planned for the actual liner are usually performed on the test pad. However, the frequency of testing is usually somewhat greater for the test pad. Material tests such as liquid limit, plastic limit, and percent fines are often performed at the rate of one per lift. Several water content-density tests are usually performed per lift on the compacted soil. A typical rate of testing would be one water content-density test for each 40 m^2 (400 ft^2). The CQA plan should describe the testing frequency for the test pad.

There is a danger in over testing the test pad -- excessive testing could lead to a greater degree of construction control in the test pad than in the actual liner. The purpose of the test pad is to verify that the materials and methods of construction proposed for a project can result in compliance with performance objectives concerning hydraulic conductivity. Too much control over the construction of the test pad runs counter to this objective.

2.10.7 In Situ Hydraulic Conductivity

2.10.7.1 Sealed Double-Ring Infiltrometer

The most common method of measuring in situ hydraulic conductivity on test pads is the sealed double-ring infiltrometer (SDRI). A schematic diagram of the SDRI is shown Fig. 2.32. The test procedure is described in ASTM D-5093.

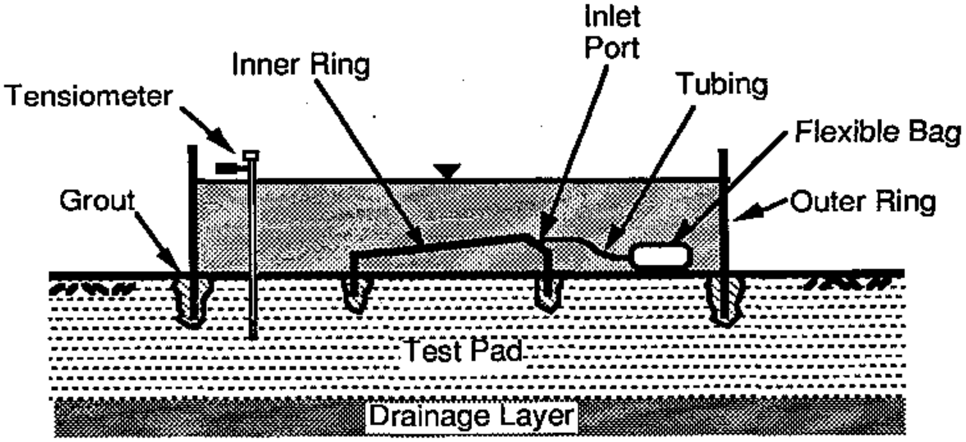


Figure 2.32 - Schematic Diagram of Sealed Double Ring Infiltrometer (SDRI)

With this method, the quantity of water that flows into the test pad over a known period of time is measured. This flow rate, which is called the infiltration rate (I), is computed as follows:

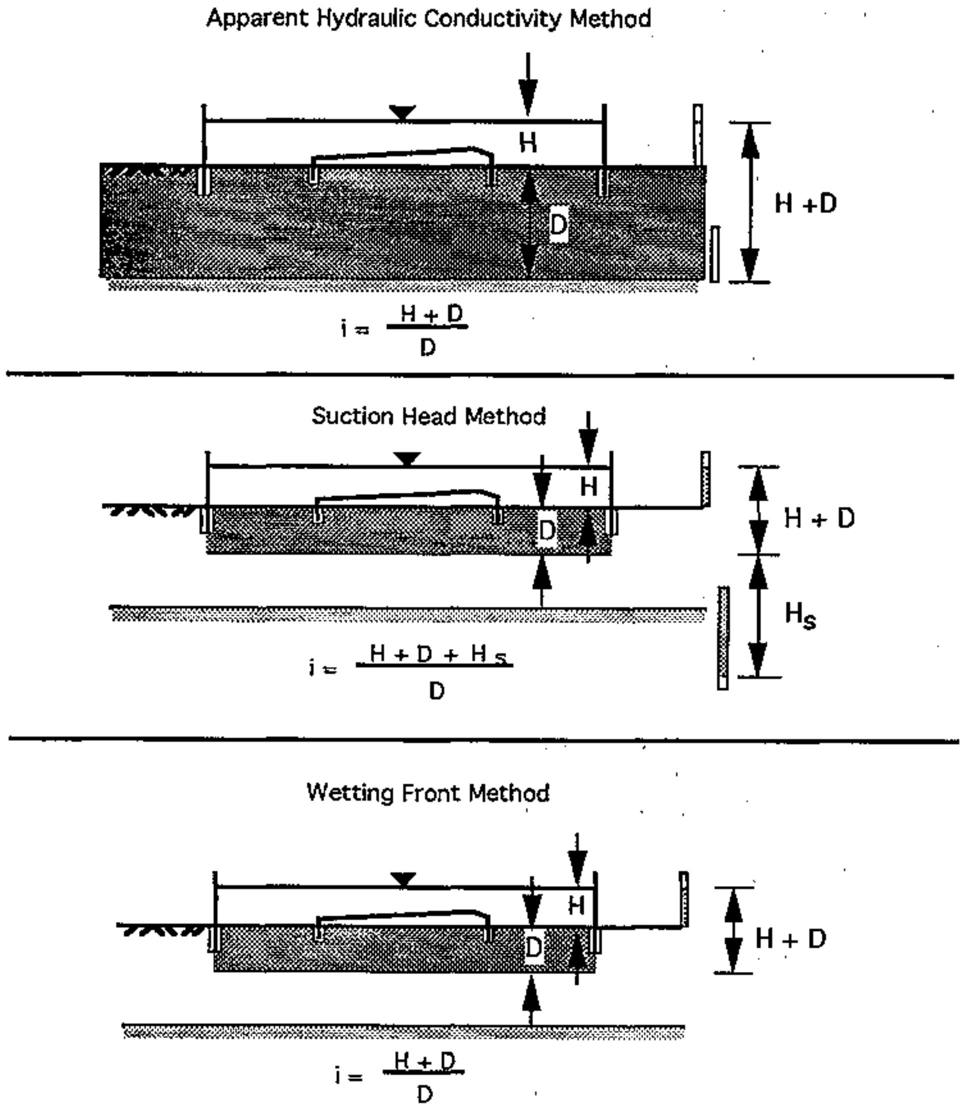
$$I = Q/At \qquad (2.5)$$

where Q is the quantity of water entering the surface of the soil through a cross-sectional area A and over a period of time t.

Hydraulic conductivity (K) is computed from the infiltration rate and hydraulic gradient (i) as follows:

$$K = I/i \tag{2.6}$$

Three procedures have been used to compute the hydraulic gradient. The procedures are called (1) apparent gradient method; (2) wetting front method; and (3) suction head method. The equation for computing hydraulic gradient from each method is shown in Fig. 2.33.


Apparent Hydraulic Conductivity Method

Suction Head Method

Wetting Front Method

Figure 2.33 - Three Procedures for Computing Hydraulic Gradient from Infiltration Test

The apparent gradient method is the most conservative of the three methods because this method yields the lowest estimate of i and, therefore, the highest estimate of hydraulic conductivity. The apparent gradient method assumes that the test pad is fully soaked with water over the entire depth of the test pad. For relatively permeable test pads, the assumption of full soaking is reasonable, but for soil liners with $K < 1 \times 10^{-7}$ cm/s, the assumption of full soaking is excessively conservative and should not be used unless verified.

The second and most widely used method is the wetting front method. The wetting front is assumed to partly penetrate the test pad (Fig. 2.33) and the water pressure at the wetting front is conservatively assumed to equal atmospheric pressure. Tensiometers are used to monitor the depth of wetting of the soil over time, and the variation of water content with depth is determined at the end of the test. The wetting front method is conservative but in most cases not excessively so. The wetting front method is the method that is usually recommended.

The third method, called the suction head method, is the same as the wetting front method except that the water pressure at the wetting front is not assumed to be atmospheric pressure. The suction head (which is defined as the negative of the pressure head) at the wetting front is H_s and is added to the static head of water in the infiltration ring to calculate hydraulic gradient (Fig. 2.37). The suction head H_s is identical to the wetting front suction head employed in analyzing water infiltration with the Green-Ampt theory. The suction head H_s <u>is not</u> the ambient suction head in the unsaturated soil and is generally very difficult to determine (Brakensiek, 1977). Two techniques available for determining H_s are:

1. Integration of the hydraulic conductivity function (Neuman, 1976):

$$H_s = \int_{h_{sc}}^{o} K_r dh_s \tag{2.7}$$

   where h_{sc} is the suction head at the initial (presoaked) water content of the soil, K_r is the relative hydraulic conductivity (K at particular suction divided by the value of K at full saturation), and h_s is suction.

2. Direct measurement with air entry permeameter (Daniel, 1989, and references therein).

Reimbold (1988) found that H_s was close to zero for two compacted soil liner materials. Because proper determination of H_s is very difficult, the suction head method cannot be recommended, unless the testing personnel take the time and make the effort to determine H_s properly and reliably.

Corrections may be made to account for various factors. For example, if the soil swells, some of the water that infiltrated into the soil was absorbed into the expanded soil. No consensus exists on various corrections and these should be evaluated case by case.

2.10.7.2 Two-Stage Borehole Test

The two-stage borehole hydraulic conductivity was developed by Boutwell (the test is sometimes called the Boutwell Test) and was under development as an ASTM standard at the time of this writing. The device is installed by drilling a hole (which is typically 100 to 150 mm in diameter), placing a casing in the hole, and sealing the annular space between the casing and borehole with grout as shown in Fig. 2.34. A series of falling head tests is performed and the hydraulic conductivity from this first stage (k_1) is computed. Stage one is complete when k_1 ceases to change significantly. The maximum vertical hydraulic conductivity may be computed by assuming that the vertical hydraulic conductivity is equal to k_1. However, the test may be continued for a second stage by removing the top of the casing and extending the hole below the casing as shown in Fig. 2.34. The casing is reassembled, the device is again filled with water, and falling head tests are performed to determine the hydraulic conductivity from stage two (k_2). Both horizontal and vertical hydraulic conductivity may be computed from the values of k_1 and k_2. Further details on methods of calculation are provided by Boutwell and Tsai (1992), although the reader is advised to refer to the ASTM standard when it becomes available.

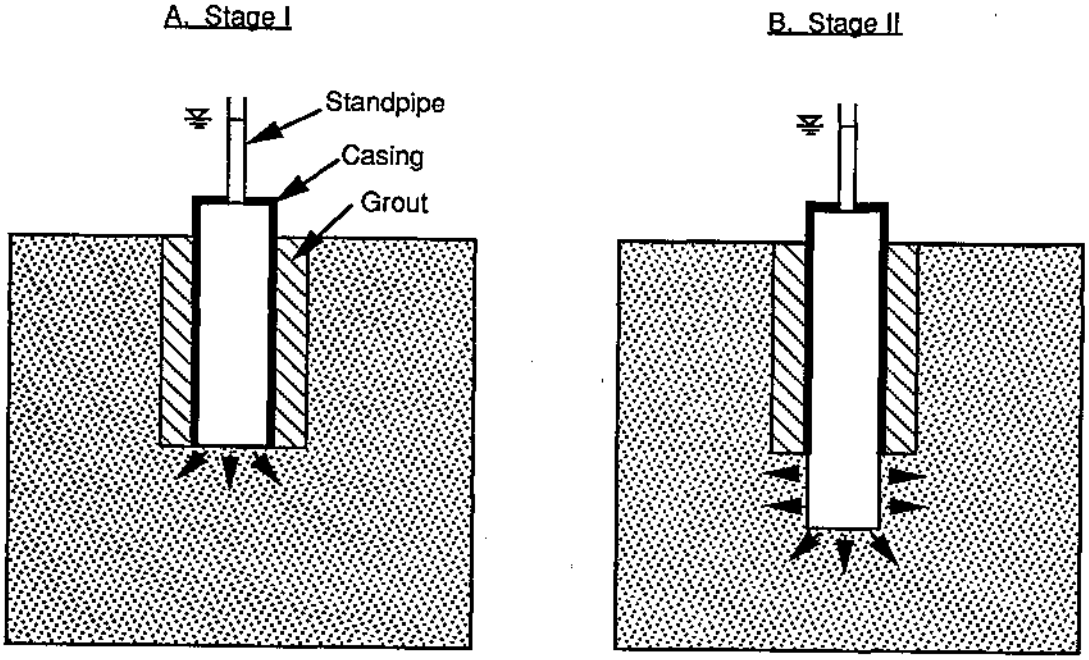


Figure 2.34 - Schematic Diagram of Two-Stage Borehole Test

The two-stage borehole test permeates a smaller volume of soil than the sealed double-ring infiltrometer. The required number of two-stage borehole tests for a test pad is a subject of current research. At the present time, it is recommended that at least 5 two-stage borehole tests be performed on a test pad if the two-stage test is used. If 5 two-stage borehole tests are performed, then one would expect that all five of the measured vertical hydraulic conductivities would be less than or equal to the required maximum hydraulic conductivity for the soil liner.

2.10.7.3 Other Field Tests

Several other methods of in situ hydraulic conductivity testing are available for soil liners. These methods include open infiltrometers, borehole tests with a constant water level in the borehole, porous probes, and air-entry permeameters. The methods are described by Daniel (1989) but are much less commonly used than the SDRI and two-stage borehole test.

2.10.7.4 Laboratory Tests

Laboratory hydraulic conductivity tests may be performed for two reasons:

1. If a very large sample of soil is taken from the field and permeated in the laboratory, the result may be representative of field-scale hydraulic conductivity. The question of how large the laboratory test specimen needs to be is currently a matter of research, but preliminary results indicate that a specimen with a diameter of approximately 300 mm (12 in.) may be sufficiently large (Benson et al., 1993).

2. If laboratory hydraulic conductivity tests are a required component of QA/QC for the actual liner, the same sampling and testing procedures are used for the test pad. Normally, undisturbed soil samples are obtained following the procedures outlined in ASTM D-1587, and soil test specimens with diameters of approximately 75 mm (3 in.) are permeated in flexible-wall permeameters in accordance with ASTM D-5084.

2.10.8 Documentation

A report should be prepared that describes all of the test results from the test pad. The test pad documentation provides a basis for comparison between test pad results and the CQA data developed on an actual construction project.

2.11 Final Approval

Upon completion of the soil liner, the soil liner should be accepted and approved by the CQA engineer prior to deployment or construction of the next overlying layer.

2.12 References

Albrecht, K .A., and K. Cartwright (1989), "Infiltration and Hydraulic Conductivity of a Compacted Earthen Liner," *Ground Water*, Vol. 27, No. 1, pp. 14-19.

Alther, G. R. (1983), "The Methylene Blue Test for Bentonite Liner Quality Control," *Geotechnical Testing Journal*, Vol. 6, No. 3, pp. 133-143.

ASTM D-422, "Particle-Size Analysis of Soils"

ASTM D-698, "Laboratory Compaction Characteristics of Soils Using Modified Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))"

ASTM D-1140, "Amount of Material in Soils Finer than the No. 200 (75-μm)Sieve"

ASTM D-1556, "Density and Unit Weight of Soil In Place by Sand-Cone Method"

ASTM D-1557, "Laboratory Compaction Characteristics of Soils Using Standard Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))"

ASTM D-1587, "Thin-Walled Tube Sampling of Soils"

ASTM D-2167, "Density and Unit Weight of Soil In Place by Rubber Balloon Method"

ASTM D-2216, "Laboratory Determination of Water (Moisture) Content of Soil and Rock"

ASTM D-2487, "Classification of Soils for Engineering Purposes (Unified Soil Classification System)"

ASTM D-2488, "Description and Identification of Soils (Visual-Manual Procedure)"

ASTM D-2922, "Density of Soil and Soil-Aggregate In Place by Nuclear Methods (Shallow Depth)

ASTM D-2937, "Density and Unit Weight of Soil In Place by Drive-Cylinder Method"

ASTM D-3017, "Water Content of Soil and Rock In Place by Nuclear Methods (Shallow Depth)"

ASTM D-4220, "Preserving and Transporting Soil Samples"

ASTM D-4318, "Liquid Limit, Plastic Limit, and Plasticity Index of Soils"

ASTM D-4643, "Determination of Water (Moisture) Content of Soil by Microwave Oven Method"

ASTM D-4944, "Field Determination of Water (Moisture) Content of Soil by Calcium Carbide Gas Pressure Tester Method"

ASTM D-4959, "Determination of Water (Moisture) Content of Soil by Direct Heating Method"

ASTM D-5080, "Rapid Determination of Percent Compaction"

ASTM D-5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter"

ASTM D-5093, "Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed Inner Ring"

ASTM E-946, "Water Adsorption of Bentonite by the Porous Plate Method"

Benson, C. H., and D.E. Daniel (1990), "Influence of Clods on Hydraulic Conductivity of Compacted Clay," *Journal of Geotechnical Engineering*, Vol. 116, No. 8, pp. 1231-1248.

Benson, C. H., and G. P. Boutwell (1992), "Compaction Control and Scale-Dependent Hydraulic Conductivity of Clay Liners," *Proceedings*, Fifteenth Annual Madison Waste Conference, Univ. of Wisconsin, Madison, Wisconsin, pp. 62-83..

Benson, C. H., Zhai, H., and Rashad, S. M. (1992), "Assessment of Construction Quality

Control Measurements and Sampling Frequencies for Compacted Soil Liners," Environmental Geotechnics Report No. 92-6, University of Wisconsin, Department of Civil and Environmental Engineering, Madison, Wisconsin, 100p.

Benson, C. H., Hardianto, F. S., and Motan, E. S. (1993), "Representative Sample Size for Hydraulic Conductivity Assessment of Compacted Soil Liners," *Hydraulic Conductivity and Waste Contaminant Transport in Soils, ASTM STP 1142*, D. E. Daniel and S. J. Trautwein (Eds.), American Society for Testing and Materials, Philadelphia, (in review).

Boutwell, G., and Hedges, C. (1989), "Evaluation of Waste-Retention Liners by Multivariate Statistics," *Proceedings of the Twelfth International Conference on Soil Mechanics and Foundation Engineering*, A. A. Balkema, Rotterdam, Vol. 2, pp. 815-818.1

Boutwell, G .P., and Tsai, C. N. (1992), "The Two-Stage Field Permeability Test for Clay Liners," *Geotechnical News*, Vol. 10, No. 2, pp. 32-34.

Brakensiek, D.L. (1977), "Estimating the Effective Capillary Pressure in the Green and Ampt Infiltration Equation," *Water Resources Research*, Vol. 12, No. 3, pp. 680-681.

Brown, R. K. (1992), Personal Communication.

Daniel, D.E. (1989), "In Situ Hydraulic Conductivity Tests for Compacted Clay," *Journal of Geotechnical Engineering*, Vol. 115, No. 9, pp. 1205-1226.

Daniel, D.E. (1990), "Summary Review of Construction Quality Control for Compacted Soil Liners," in *Waste Containment Systems: Construction, Regulation, and Performance*, R. Bonaparte (Ed.), American Society of Civil Engineers, New York, pp. 175-189.

Daniel, D.E., and C. H. Benson (1990), "Water Content - Density Criteria for Compacted Soil Liners," *Journal of Geotechnical Engineering*, Vol. 116, No. 12, pp. 1811-1830.

Elsbury, B. R., Daniel, D. E., Sraders, G. A., and Anderson, D. C. (1990), "Lessons Learned from Compacted Clay Liner," *Journal of Geotechnical Engineering*, Vol. 116, No. 11, pp. 1641-1660.

Hilf, J. W. (1991), "Compacted Fill," in *Foundation Engineering Handbook*, H. Y. Fang (Ed.), Van Nostrand Reinhold, New York, pp. 249-316.

Lambe, T. W., and Whitman, R. V. (1969), *Soil Mechanics*, John Wiley & Sons, New York, 533 p.

Mitchell, J. K., Hooper, D. R., and Campanella, R. G. (1965), "Permeability of Compacted Clay," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 91, No. SM4, pp. 41-65.

Mundell, J. A., and Bailey, B. (1985), "The Design and Testing of a Compacted Clay Barrier Layer to Limit Percolation through Landfill Covers," *Hydraulic Barriers in Soil and Rock, ASTM STP 874*, A. I. Johnson et al. (Eds.), American Society for Testing and Materials, Philadelphia, pp. 246-262.

Neuman, S.P. (1976), "Wetting Front Pressure Head in the Infiltration Model of Green and Ampt," *Water Resources Research*, Vol. 11, No. 3, pp. 564-565.

Noorany, I. (1990), "Variability in Compaction Control," *Journal of Geotechnical Engineering*, Vol. 116, No. 7, pp. 1132-1136.

Reimbold, M.W. (1988), "An Evaluation of Models for Predicting Infiltration Rates in Unsaturated Compacted Clay Soils," M.S. Thesis, The University of Texas at Austin, Austin, Texas, 128 p.

Richardson, G. N. (1992), "Construction Quality Management for Remedial Action and Remedial Design Waste Containment Systems," U.S. Environmental Protection Agency, EPA/540/R-92/073, Washington, DC.

Schmertmann, J.H. (1989), "Density Tests Above Zero Air Voids Line," *Journal of Geotechnical Engineering*, Vol. 115, No. 7, pp. 1003-1018.

Shelley, T. L., and Daniel, D. E. (1993), "Effect of Gravel on Hydraulic Conductivity of Compacted Soil Liners," *Journal of Geotechnical Engineering*, Vol. 119, No. 1, pp. 54-68.

Turnbull, W. J., Compton, J. P., and R. G. Ahlvin (1966), "Quality Control of Compacted Earthwork," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 92, No. SM1, pp. 93-103.

U.S. Army Corps of Engineers (1970), "Laboratory Soils Testing," Office of the Chief of Engineers, Washington, DC, EM1110-2-1906.

Chapter 3

Geomembranes

This chapter focuses upon the manufacturing quality assurance (MQA) aspects of geomembrane formulation, manufacture and fabrication, and on the construction quality assurance (CQA) of the complete installation of the geomembranes in the field. Note that in previous literature these liner materials were called *flexible membrane liners* (*FML's*), but the more generic name of geomembranes will be used throughout this document.

The geomembrane materials discussed in this document are those used most often at the time of writing. However, there are other polymer types that are also used. Aspects of quality assurance of these materials can be inferred from information contained in this document. In the future, new materials will be developed and the reader is advised to seek the appropriate information for evaluation of such new or modified materials.

3.1 Types of Geomembranes and Their Formulations

It must be recognized that all geomembranes are actually formulations of a parent resin (from which they derive their generic name) and several other ingredients. The most commonly used geomembranes for solid and liquid waste containment are listed below. They are listed according to their commonly referenced acronyms which will be explained in the text to follow. Other geomembranes in limited use or under initial field trials will also be mentioned where appropriate but will be covered in less detail than the types listed below.

Table 3.1 - Types of Commonly Used Geomembranes and Their Approximate Weight Percentage Formulations*

Geomembrane Type	Resin	Plasticizer	Filler	Carbon Black or Pigment	Additives
HDPE	95-98	0	0	2-3	0.25-1.0
VLDPE	94-96	0	0	2-3	1-4
Other Extruded Types **	95-98	0	0	2-3	1-2
PVC	50-70	25-35	0-10	2-5	2-5
CSPE***	40-60	0	40-50	5-40	5-15
Other Calendered Types**	40-97	0-30	0-50	2-30	0-7

* Note that this Table should not be directly used for MQA or CQA Documents, since neither the Agency nor the Authors of the Report intend to provide prescriptive formulations for manufacturers and their respective geomembranes.

** Other geomembranes than those listed in this Table will be described in the appropriate Section.

*** CSPE geomembranes are generally fabric (scrim) reinforced.

It must be recognized that Table 3.1 and the references to it in the text to follow are meant to reflect on the current state-of-the-art. The values mentioned are not meant to be prescriptive and future research and development may result in substantial changes.

3.1.1 High Density Polyethylene (HDPE)

As noted in Table 3.1, high density polyethylene (HDPE) geomembranes are made from polyethylene resin, carbon black and additives.

3.1.1.1 Resin

The polyethylene resin used for HDPE geomembranes is prepared by low pressure polymerization of ethylene as the principal monomer and having the characteristics listed in ASTM D-1248. As seen in Fig. 3.1, the resin is usually supplied to the manufacturer or formulator in an opaque pellet form.

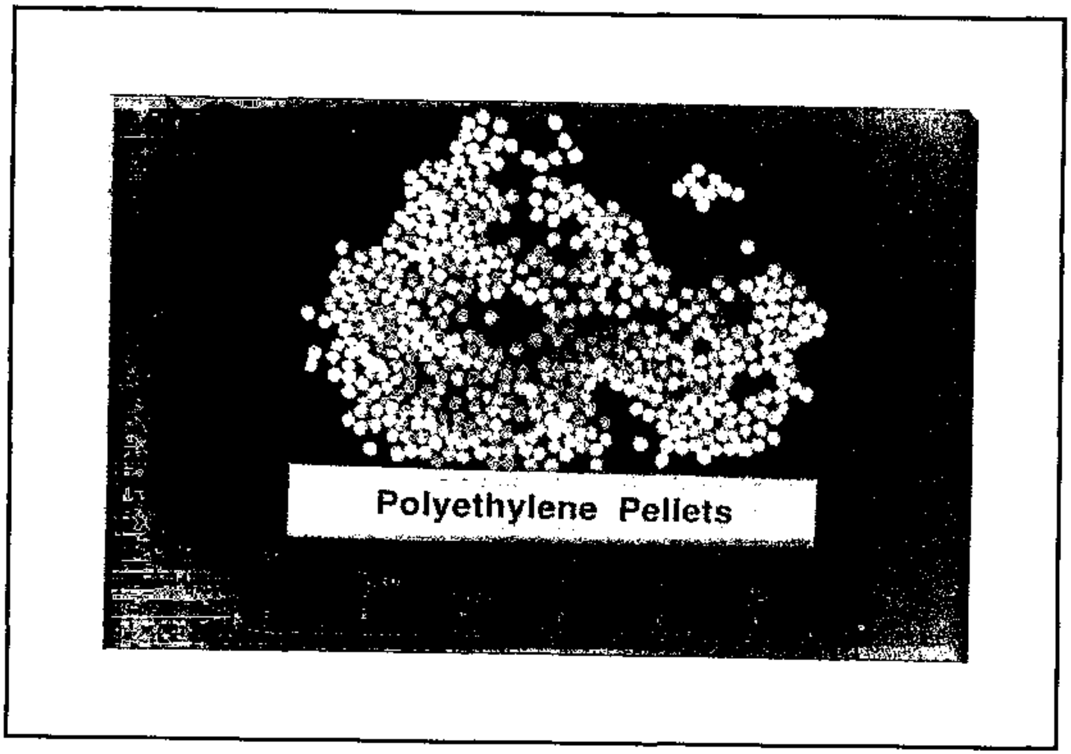


Figure 3.1 - HDPE Resin Pellets

Regarding the preparation of a specification or MQA document for the resin component of an HDPE geomembrane, the following items should be considered:

1. The polyethylene resin, which is covered in ASTM D-1248, is to be made from virgin, uncontaminated ingredients.

2. The quality control tests performed on the incoming resin will typically be density (either ASTM D-792 or D1505) and melt flow index which is ASTM D-1238.

3. Typical natural densities of the various resins used are between 0.934 and 0.940 g/cc. Note that according to ASTM D-1248 this is Type II polyethylene and is classified as medium density polyethylene.

4. Typical melt flow index values are between 0.1 and 1.0 g/10 min as per ASTM D-1238, Cond. 190/2.16.

5. Other tests which can be considered for quality control of the resin are melt flow ratio (comparing high-to-low weight melt flow values), notched constant tensile load test as per ASTM D-5397, and a single point notched constant load test, see Hsuan and Koerner (1992) for details. The latter tests would require a plaque to be made from the resin from which test specimens are taken. The single point notched constant load test is then performed at 30% yield strength and the test specimens are currently recommended not to fail within 200 hours.

6. Additional quality control certification procedures by the manufacturer (if any) should be implemented and followed.

7. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.

8. An HDPE geomembrane formulation should consist of at least 97% of polyethylene resin. As seen in Table 3.1 the balance is carbon black and additives. No fillers, extenders, or other materials should be mixed into the formulation.

9. It should be noted that by adding carbon black and additives to the resin, the density of the final formulation is generally 0.941 to 0.954 g/cc. Since this numeric value is now in the high density polyethylene category according to ASTM D-1248, geomembranes of this type are commonly referred to as high density polyethylene (HDPE).

10. Regrind or rework chips (which have been previously processed by the same manufacturer but never used as a geomembrane, or other) are often added to the extruder during processing. This topic will be discussed in section 3.2.2.

11. Reclaimed material (which is polymer material that has seen previous service life and is recycled) should never be allowed in the formulation in any quantity. This topic will be discussed in section 3.2.2.

3.1.1.2 Carbon Black

Carbon black is added into an HDPE geomembrane formulation for general stabilization purposes, particularly for ultraviolet light stabilization. It is sometimes added in a powder form at the geomembrane manufacturing facility during processing, or (generally) it is added as a preformulated concentrate in pellet form. The latter is the usual case. Figure 3.2 shows photographs of carbon black powder and of concentrate pellets consisting of approximately 25% carbon black in a polyethylene resin carrier.

Regarding the preparation of a specification or MQA document for the carbon black component of HDPE geomembranes, the following items should be considered.

1. The carbon black used in HDPE geomembranes should be a Group 3 category, or lower, as defined in ASTM D-1765.

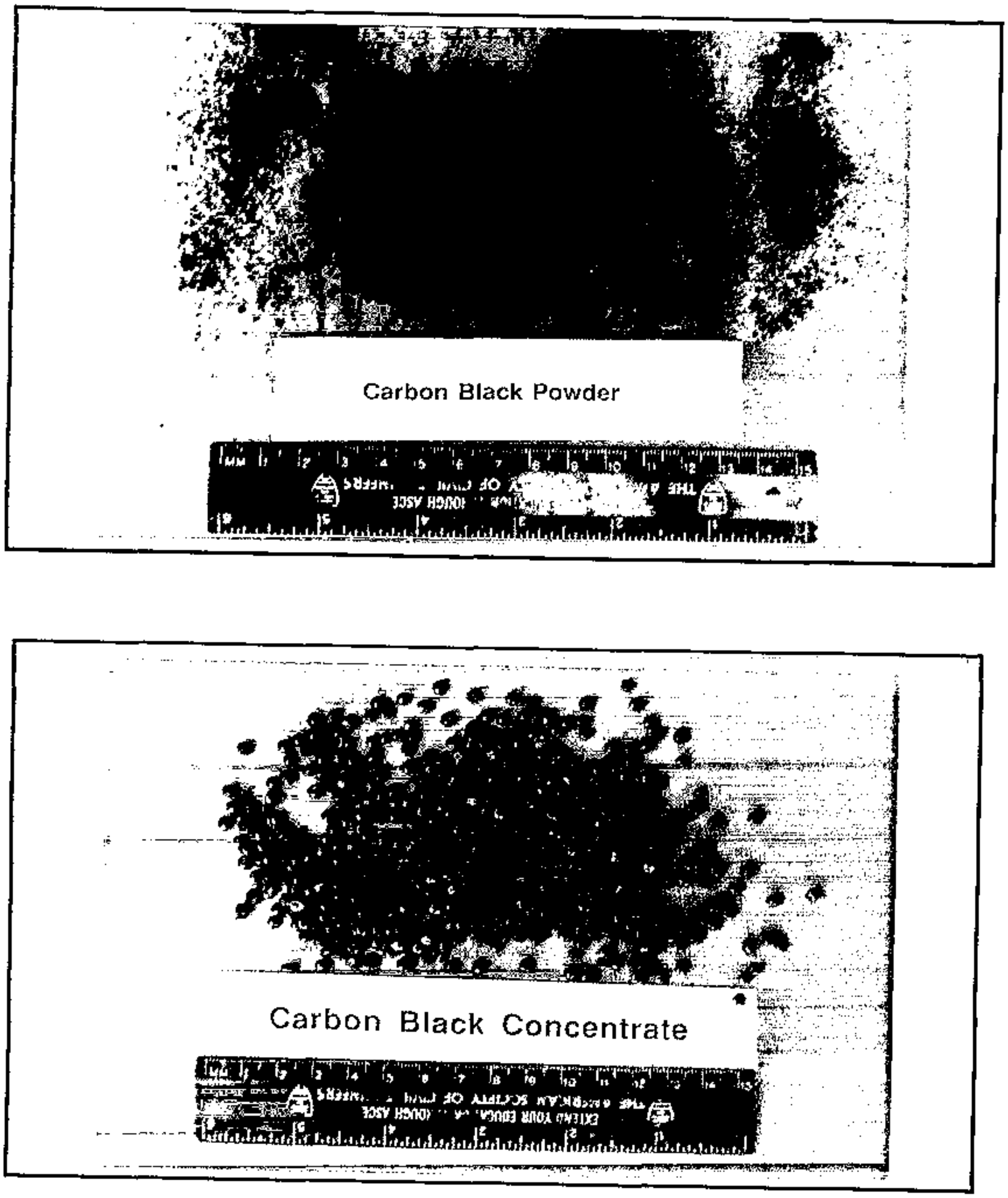


Figure 3.2 - Carbon Black in Particulate Form (Upper Photograph) and as a Concentrate (Lower Photograph)

2. Typical amounts of carbon black are from 2.0% to 3.0% by weight per ASTM D-1603. Values less than 2.0% do not appear to give adequate long-term ultraviolet protection; values greater than 3.0% begin to adversely effect physical and mechanical properties.

3. Current carbon black dispersion requirements in the final HDPE geomembrane are usually required to be A-1, A-2 or B-1 according to ASTM D-2663. Sample preparation is via ASTM D-3015. It should be noted, however, that this test method is directed at polymeric materials containing relatively large amounts of carbon black, e.g., thermoset elastomers with carbon black contents of approximately 18% by volume. ASTM D-35 Committee on Geosynthetics has a Task Group formulating a new standard focused at carbon black dispersion for formulations containing less than 5% carbon black. Thus this standard will be applicable for the 2 to 3% carbon black currently used in polyethylene formulations.

4. In the event that the carbon black is mixed into the formulation in the form of a concentrate rather than a powder, the carrier resin of the concentrate should be the same generic type as the base polyethylene resin.

3.1.1.3 Additives

Additives are introduced into an HDPE geomembrane formulation for the purposes of oxidation prevention, long-term durability and as a lubricant and/or processing aid during manufacturing. It is quite difficult to write a specification for HDPE geomembranes around a particular additive, or group of additives, because they are generally proprietary. Furthermore, there is research and development ongoing in this area and thus additives are subject to change over time.

If additives are included in a specification or MQA document, the description must be very general as to the type and amount. However, the amount can probably be bracketed as to an upper value.

1. The nature of the additive package used in the HDPE compound may be requested of the manufacturer.

2. The maximum amount of additives in a particular formulation should not exceed 1.0% by weight.

3.1.2 Very Low Density Polyethylene (VLDPE)

As seen in Table 3.1, very low density polyethylene (VLDPE) geomembranes are made from polyethylene resin, carbon black and additives. It should be noted that there are similarities between VLDPE and certain types of linear low density polyethylene (LLDPE). The linear structure and lack of long-chain branching in both LLDPE and VLDPE arise from their similar polymerization mechanisms although the catalyst technology is different. In the low-pressure polymerization of LLDPE, the random incorporation of alpha olefin comonomers produces sufficient short-chain branching to yield densities in the range of 0.915 to 0.930 g/cc. The even lower densities of VLDPE resins (from 0.890 to 0.912 g/cc) are achieved by adding more comonomer (which produces more short-chain branching than occurs in LLDPE, and thus a lower level of crystallinity) and using proprietary catalysts and reactor technology. Since VLDPE is more commonly used than LLDPE for geomembranes in waste containment applications, this section is written around VLDPE. It can be used for LLDPE if the density is at the low end of the above mentioned range. The situation is under discussion by many groups as of the writing of this document.

3.1.2.1 Resin

The polyethylene resin used for VLDPE geomembranes is a linear polymer of ethylene with other alpha-olefins. As with HDPE, the resin is generally supplied to the manufacturer in the form of pellets, recall Fig. 3.1.

Some specification or MQA document items for VLDPE resins follow:

1. The very low density polyethylene resin is to be made from completely virgin materials. The natural density of the resin is less than 0.912 g/cc, however, a unique category is not yet designated by ASTM.

2. A VLDPE geomembrane formulation should consist of approximately 94-96% polymer resin. As seen in Table 3.1, the balance is carbon black and additives.

3. Typical quality control tests for VLDPE resin will be density, via ASTM D-792 or D1505, and melt flow index via ASTM D-1238.

4. Additional quality control certification procedures of the manufacturer (if any) should be implemented and followed.

5. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.

6. Regrind or rework chips (which have been previously processed by the same manufacturer but never used as a geomembrane, or other) are often added to the formulation during processing. This topic will be discussed in section 3.2.2.

7. Reclaimed material (which is polymer that has seen previous service life and is recycled) should never be allowed in any quantity. This topic will be discussed in section 3.2.2.

3.1.2.2 Carbon Black

Carbon black is added to VLDPE geomembrane formulations for general stabilization purposes, particularly for ultraviolet light stabilization. It is added either in a powder form at the geomembrane manufacturing facility, or it is added as a preformulated concentrate in pellet form, recall Fig. 3.2.

Some items to be included in a specification or MQA document follow:

1. The carbon black used in VLDPE geomembranes should be a Group 3 category, or lower, as defined in ASTM D-1765.

2. Typical amounts of carbon black are from 2.0% to 3.0% by weight as per ASTM D-1603. Values less than 2.0% do not appear to give adequate long-term ultraviolet protection, while values greater than 3.0% begin to negatively effect physical and mechanical properties.

3. Current carbon black dispersion requirements in the final HDPE geomembrane are usually required to be A-1, A-2 or B-1 according to ASTM D-2663[(8)]. Sample

preparation is via ASTM D-3015. It should be noted, however, that this test method was directed at polymeric materials containing relatively large amounts of carbon black, e.g., thermoset elastomers with carbon black contents of approximately 18% by volume. ASTM D-35 Committee on Geosynthetics has a Task Group formulating a new standard focused at carbon black dispersion for formulations containing less than 5% carbon black which is the amount used in formulation of VLDPE geomembranes.

4. In the event that the carbon black is mixed into the formulation in the form of a concentrate rather than a powder, the carrier resin of the concentrate should be identified.

3.1.2.3 Additives

Additives are introduced into a VLDPE formulation for the purposes of anti-oxidation, long-term durability and as a lubricant and/or processing aid during manufacturing. It is quite difficult to write a specification for VLDPE geomembranes around a particular additive, or group of additives, because they are generally proprietary. Furthermore, there is research and development ongoing in this area and thus additives are subject to change over time.

If additives were included in a specification or MQA document, the description must be very general as to the type and amount. However, the amount can probably be bracketed as to an upper value.

1. The nature of the additive package used in the VLDPE compound may be requested of the manufacturer.

2. The maximum amount of additives in a particular formulation should not exceed 2.0% for smooth sheet or 4.0% for textured sheet by weight.

3.1.3 Other Extruded Geomembranes

Recently, there have been developed other variations of extruded geomembranes. Four have seen commercialization and will be briefly mentioned.

One variation is a coextruded light colored surface layer onto a black base layer for the purpose of reduced surface temperatures when the geomembrane is exposed for a long period of time. The usual application for this material is as a liner for surface impoundments which have no soil covering or sacrificial sheet covering. In the formulation of the light colored surface layer the carbon black is replaced by a pigment (often metal oxides, such as titanium dioxide) which acts as an ultraviolet screening agent. This results in a white, or other light colored surface. The coextruded surface layer is usually relatively thin, e.g., 5 to 10 percent of the total geomembrane's thickness.

A second coextrusion variation is HDPE/VLDPE/HDPE sheet where the two surface layers of HDPE are relatively thin with respect to the VLDPE core. Thickness percentages of 20/60/20 are sometimes used. The interface of these coextruded layers cannot be visually distinguished since the polymers merge into one another while they are in the molten state, i.e., such geomembranes are not laminated together after processing, but are coextruded during processing.

A third variation of coextrusion is to add a foaming agent, such as nitrogen gas, into the surface layer extruder(s). This foaming agent expands and bursts at the surface of the sheet as it cools. The resulting surface is very rough and is generally referred to as *textured*. This variation will be described in Sections 3.2.3.4 and 3.2.4.4 for HDPE and VLDPE, respectively.

A fourth variation of extruded geomembranes is a generic polymer group under the classification of fully crosslinked elastomeric alloys (FCEA). This group of polymers is described in ASTM D-5046. The particular geomembrane type that has been used in waste containment applications is a thermoplastic elastomeric alloy of polypropylene (PP) and ethylene-propylene diene monomer (EPDM). The EPDM is fully crosslinked and suspended in a PP matrix in a process called dynamic vulcanization. The mixed polymer is extruded in a manner similar to the geomembrane types discussed in this section.

3.1.4 Polyvinyl Chloride (PVC)

As seen in Table 3.1, polyvinyl chloride (PVC) geomembranes are made from polyvinyl chloride resin, plasticizer(s), fillers and additives.

3.1.4.1 Resin

The polyvinyl chloride resin used for PVC geomembranes is made by cracking ethylene dichloride into a vinyl chloride monomer. It is then polymerized to make PVC resin. The PVC resin (in the form of a white powder) is then compounded with other components to form a PVC compound.

In the preparation of a specification or MQA document, the following items concerning the PVC resin should be considered.

1. The polyvinyl chloride resin should be made from completely virgin materials.
2. A PVC compound will generally consist of 50-70% PVC resin, by weight.
3. Typical quality control tests on the resin powder will be contamination, relative viscosity, resin gels, color and dry time. The specific test procedures will be specified by the manufacturer. Often they are other than ASTM tests.
4. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.
5. Quality control certification procedures used by the manufacturer should be implemented and followed.

3.1.4.2 Plasticizer

Plasticizers are added to PVC formulations to impart flexibility, improve handling and modify physical and mechanical properties. When blended with the PVC resin the plasticizer(s) must be completely mixed into the resin. Since the resin is a powder, and the plasticizers are liquid, mixing of the two components continues until the liquid is completely absorbed by the powder. The result is usually a powder which can be readily conveyed. However, it is also possible to wet blend with acceptable results. There are two general categories of possible plasticizers; monomeric plasticizers and polymeric plasticizers. There are many specific types within each category. For example, monomeric plasticizers are sometimes phthalates, epoxides and phosphates, while polymeric plasticizers are sometimes polyesters, ethylene copolymers and nitrile rubber.

For a specification or MQA document written around PVC plasticizer(s), the following items should be considered.

1. If more than one type of plasticizer is used in a PVC formulation they must be compatible with one another.
2. The plasticizer(s) in a PVC compound are generally from 25-35% of the total compound by weight.
3. The exact type of plasticizer(s) used by the manufacturers are rarely identified. This is industry-wide practice and due to the long history of PVC is generally considered to be acceptable.
4. The plasticizer(s) should be certified by the manufacturer as having a successful past performance or as having been used on a specific number of projects.

3.1.4.3 Filler

The filler used in a PVC formulation is a relatively small component (recall Table 3.1), and (if used at all) is generally not identified. Calcium carbonate, in powder form, has been used but other options also exist. Certification as to successful past performance could be requested.

3.1.4.4 Additives

Other additives for the purpose of ease of manufacturing, coloring and stabilization are also added to the formulation. They are generally not identified. Certification as to successful past performance may be requested.

3.1.5 Chlorosulfonated Polyethylene (CSPE-R)

As seen in Table 3.1, chlorosulfonated polyethylene (CSPE) geomembranes consist of chlorosulfonated polyethylene resin, fillers, carbon black (or colorants) and additives. The finished geomembrane is usually fabricated with a fabric reinforcement, called a "scrim", between the individual plys of the material. It is then designated as CSPE-R.

3.1.5.1 Resin

There are two different types of chlorosulfonated polyethylene resin used to make CSPE geomembranes. One is a completely amorphous polymer while the other is a thermoplastic material containing a controlled amount of crystallinity to provide useful physical properties in the uncured state while maintaining flexibility without the need of any plasticizers. The second type is generally used to manufacture geomembranes. CSPE is made directly from branched polyethylene by adding chlorine and sulfur dioxide. The chlorosulfonic groups act as preferred cross-linking sites during the polymer aging process. In the typical commercial polymer there is one chlorosulfonyl group for each 200 backbone carbon atoms.

CSPE resin pieces usually arrive at the sheet manufacturing facility in large cartons. They are somewhat pillow shaped (about 1 cm diameter) and 2 cm in length. The resin pieces (see Fig. 3.3) are relatively spongy in their resistance to finger pressure. Alternatively, CSPE can be premixed with carbon black in slab form which is then referred to as a master batch. The master batch is usually made by a formulator and shipped to the manufacturing facility in a prepared form.

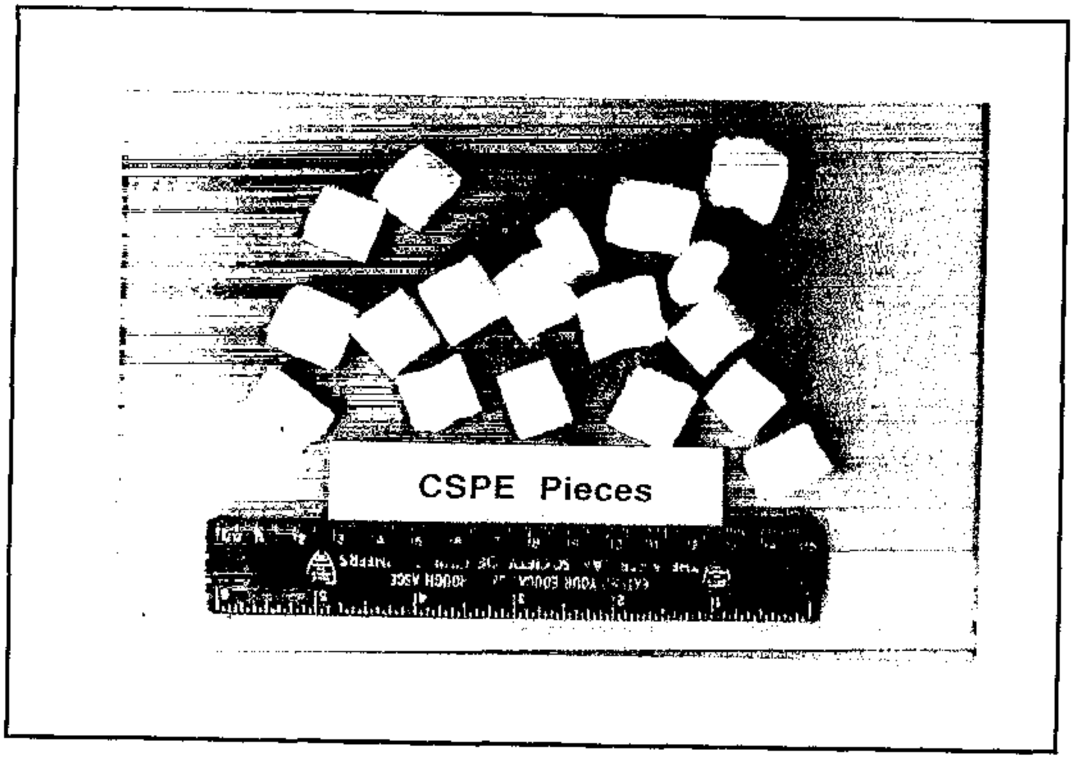


Fig. 3.3 - CSPE Resin Pieces

In preparation of a specification or MQA document, the following items concerning the CSPE resin should considered.

1. The CSPE resin should be made from completely virgin materials.
2. The formulation will usually be based on 40 to 60% of resin, by weight.
3. Typical MQC tests on the CSPE resin will be Mooney viscosity, chlorine content, sulfur content and a series of vulcanization properties (e.g., rheometry and high temperature behavior).
4. The CSPE resin can be premixed with carbon black in slab form (referred to as a "master batch") and shipped to the manufacturers facility.
5. Additional quality control certification procedures used by the manufacturer should be implemented and followed.
6. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.

3.1.5.2 Carbon Black

The amount of carbon black in CSPE geomembranes varies from 5 to 36%. The carbon black functions as an ultraviolet light blocking agent, as a filler and aids in processing. The usual types of carbon black used in CSPE formulations are N 630, N 774, N 762 and N 990 as per ASTM D-1765. When low percentages of carbon black are used N 110 to N 220 should be used. When the carbon black is premixed with the resin and produced in the form of a master batch of pellets, it is fed directly into the mixer with the other components, such as fillers, stabilizers and processing aids.

A specification on carbon black in CSPE geomembranes, could be framed around the type and amount of carbon black as just described, but this is rarely the case. Typical MQC certification procedures should be available and implemented.

3.1.5.3 Fillers

The purposes of blending fillers into the CSPE compound are to provide workability and processability. The common types of fillers are clay and calcium carbonate. Both are added in powder form and in quantities ranging from 40 to 50%.

Specifications are rarely written around this aspect of the material, however MQC certification procedures should be available and implemented.

3.1.5.4 Additives

Additives are used in CSPE compounds for the purpose of stabilization which is used to distinguish the various grades. The industrial grade of CSPE geomembranes uses lead oxide as a stabilizer, whereas the potable water grade uses magnesium oxide or magnesium hydroxide. These stabilizers function as acid acceptors during the polymer aging process. During aging, hydrogen chloride or sulfur dioxide releases from the polymer and the metal oxides react with these substances inducing cross linking over time.

Specifications are rarely written around the type and quantity of additives used in CSPE, however MQC certification procedures should be written around each additive, be available and be implemented.

3.1.5.5 Reinforcing Scrim

CSPE geomembranes are usually fabricated with a reinforcing "scrim" between two plys of polymer sheets. This results in a three-ply laminated geomembrane consisting of geomembrane, scrim, geomembrane which is sealed together, under pressure, to form a unitized system. The geomembrane is said to be reinforced and then carries the designation CSPE-R. Other options of multiple plys are also available. The scrim imparts dimensional stability to the material which is important during storage, placement and seaming. It also imparts a major increase in mechanical properties over the unreinforced type, particularly in the tensile strength, modulus of elasticity and tear resistance of the final geomembrane.

The reinforcing scrim for CSPE geomembranes is a woven fabric made from polyester yarns in a standard "basket" weave. Note that there are usually many fine fibers (of very fine diameter) per individual yarn, e.g., 100 to 200 fibers per yarn depending on the desired strength. The yarns, or "strands" as they are referenced in the industry, are spaced close enough to one another to achieve the desired properties, but far apart enough to allow open space between them so that the opposing geomembrane sheet surfaces can adhere together. This is sometimes referred to as "strike-through" and is measured by a ply-adhesion test. The designation of reinforcing scrim is based on the number of yarns, or strands, per inch of woven fabric. The general range is from 6 x 6 to 20 x 20, with 10 x 10 being the most common. A 10 x 10 scrim refers to 10 strands per inch in the machine (or warp) direction and an equal number of 10 strands per inch in the cross machine (or weft) direction.

It must also be mentioned that the polyester scrim yarns must be coated for them to have good bonding to the upper and lower CSPE sheets. Various coatings, including latex, polyvinyl chloride and others, have been used. The exact formulation of the coating material (or "ply enhancer") is usually proprietary.

Regarding a specification or MQA document for the fabric scrim in CSPE-R geomembranes the following applies.

1. The type of polymer used for the scrim is usually specified as polyester, although nylon has been used in the past. It should be identified accordingly.
2. The strength of the fabric scrim can be specified and, when done, is best accomplished in tensile strength units of pounds per individual yarn rather than individual fiber strength.
3. The strike-through is indirectly quantified in specifications on the basis of ply adhesion requirements. This will be discussed later.

3.1.6 Other Calendered Geomembranes

Within the category of calendered geomembranes there are other types that have not been described thus far. They will be briefly noted here along with similarities and/or differences to those just described.

Chlorinated polyethylene (CPE) has been used as a polymer resin in the past for either non-reinforced or scrim reinforced geomembranes. Its production and ingredients are similar to CSPE, or CSPE-R, with the obvious exception of the nature of the resin itself. In contrast to CSPE, CPE contains no sulfur in its formulation.

Ethylene interpolymer alloy (EIA) is always used as a reinforced geomembrane, thus EIA-R is its proper designation. The resin is a blend of ethylene vinyl acetate and polyvinyl chloride resulting in a thermoplastic elastomer. The fabric reinforcement is a tightly woven polyester which requires the polymer to be individually spread coated on both sides of the fabric. Note, however, that there are other related products being developed under different trademarks in this general category.

Among the newer geomembranes is polypropylene (PP) which is a very flexible olefinic polymer based on new polypropylene resin technology. This polymer has been converted into sheet by calendering, with and without scrim reinforcement, and by flat die and blown film extrusion processes. Factory fabrication of large panels is possible. The initial field trials of this type of geomembrane are currently ongoing.

3.2 Manufacturing

Once the specific type of geomembrane formulation that is specified has been thoroughly mixed it is then manufactured into a continuous sheet. The two major processes used for manufacturing of the various types of sheets of geomembranes are variations of either extrusion (e.g., for HDPE, VLDPE, and LLDPE) or calendering (e.g., for PVC, CSPE and PP). Spread coating (the least used process) will be briefly mentioned in section 3.2.8.

3.2.1 Blending, Compounding, Mixing and/or Masticating

Blending, compounding, mixing and/or masticating of the various components described in Section 3.1 is conventionally done on a weight percentage basis. However, each geomembrane's processing is somewhat unique in its equipment and procedures. Even for a particular type of geomembrane, manufacturers will use different procedures, e.g., batch methods versus continuous feed systems, for blending or mixing.

Nevertheless, a few general considerations are important to follow in the preparation of a specification or MQA document.

1. The blending, compounding, mixing and/or masticating equipment must be clean and completely purged from previously mixed materials of a different formulation. This might require sending a complete cycle of purging material through the system, sometimes referred to as a "blank".

2. The various components of the formulation are added on a weight percentage basis to an accuracy set by industry standards. Different components are often added to the mixture at different locations in the processing, i.e., the entire batch is not necessarily added at the outset.

3. By the time the complete formulation is ready for extrusion or calendering it must be completely homogenized. No traces of segregation, agglomeration, streaking or discoloration should be visually apparent in the finished product.

3.2.2 Regrind, Reworked or Trim Reprocessed Material

"Regrind", "reworked" or "trim" are all terms which can be defined as finished geomembrane sheet material which has been cut from edges or ends of rolls, or is off-specification from a surface blemish, thickness or other property point of view. Figure 3.4(a) shows a photograph of HDPE regrind chips. VLDPE chips appear similar to HDPE. Figure 3.4(b) shows a photograph of PVC edge strips i.e., edge of sheet material cut off to meet specific roll width requirements. Excess edge trimmings of PVC sheet is fed back into the production system. CSPE-R trim can be added similarly, however without any reinforcing scrim.

These materials are reintroduced during the blending, compounding and/or mixing stage in controlled amounts as a matter of cost efficiency on the part of the manufacturer. Note that regrind, rework and trim material must be clearly distinguished from "recycled", or "reclaimed", material which is finished sheet material that has actually seen some type of service performance and has subsequently been returned to the manufacturing facility for reuse into new sheet material.

In preparing a specification or MQA document on the use of reprocessed material, the following items should be considered:

1. Regrind, reworked or trim materials in the form of chips or edge strips may be added if the material is from the same manufacturer and is exactly the same formulation as the geomembrane being produced.

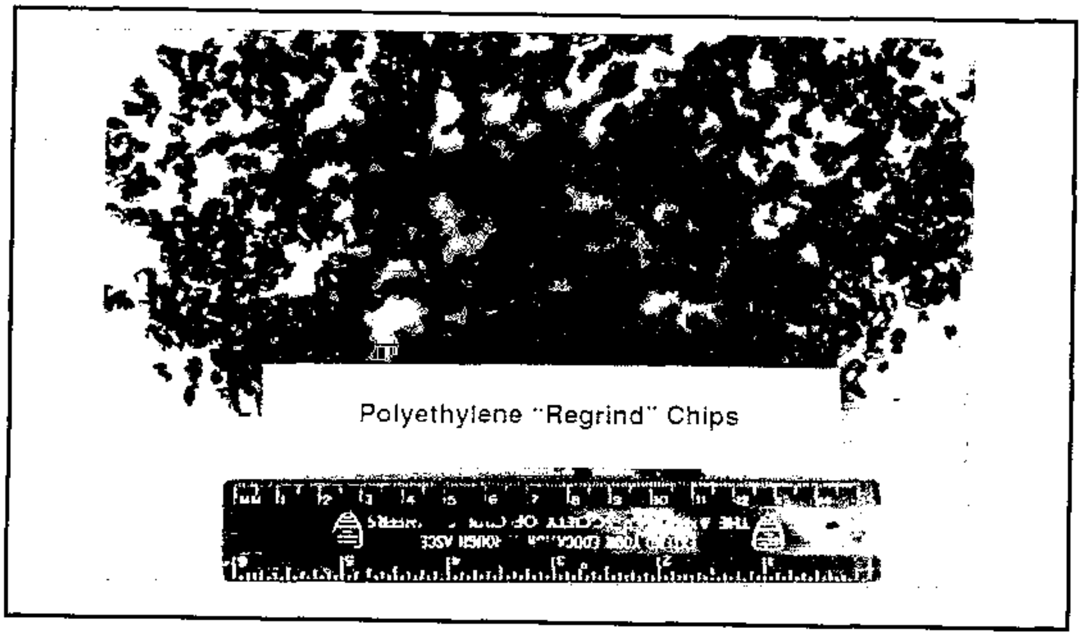


Figure 3.4(a) - HDPE Regrind Chips

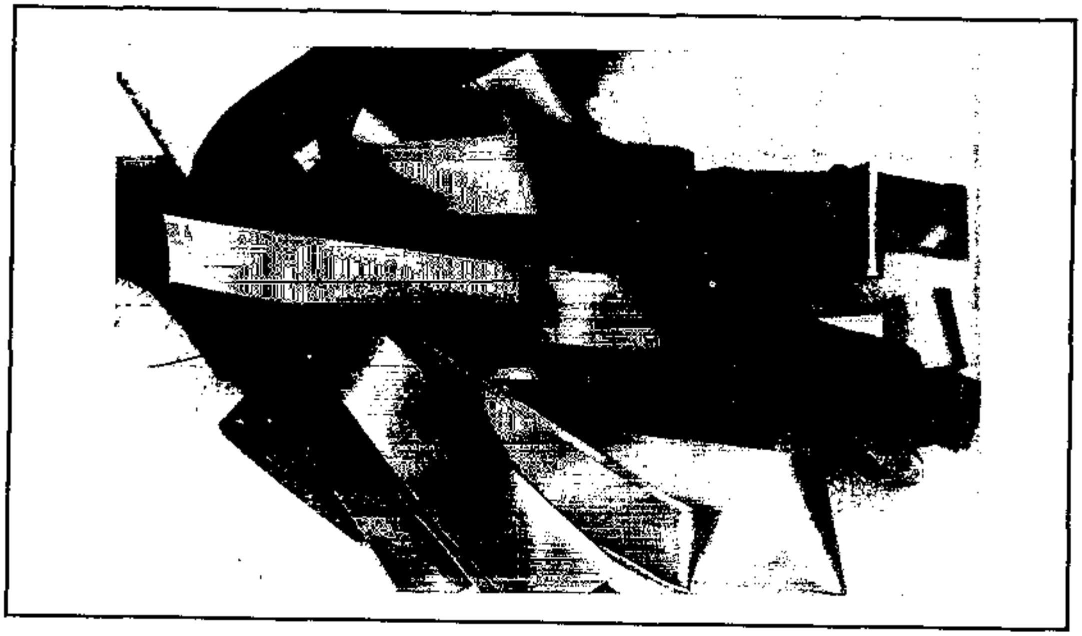


Figure 3.4(b) - PVC Edge Strips

Figure 3.4 - Photographs of Materials to be Reprocessed

2. Generally HDPE and VLDPE will be added in chip form as "regrind" in controlled amounts into the hopper of the extruder.

3. Generally PVC, CSPE and PP will be added in the form of a continuous strip of edge trimmings into the roll mill which precedes calendering. For scrim reinforced geomembranes it is important that the edge trim does not contain any portion of the fabric scrim.

4. The maximum amount of regrind, reworked or trim material to be added is a topic of considerable debate. Its occurrence in the completed sheet is extremely difficult, if not impossible, to identify much less to quantify by current chemical fingerprinting methods. Thus its maximum amount is not suggested in this manual. It should be mentioned that if regrind is not permitted to be used, the manufacturer may charge a premium over current practice.

5. It is generally accepted that no amount of "recycled", or "reclaimed" sheet material (in any form whatsoever) should be added to the formulation.

3.2.3 High Density Polyethylene (HDPE)

High density polyethylene (HDPE) geomembranes are manufactured by taking the mixed components described earlier and feeding them into a hopper which leads to a horizontal extruder, see Fig. 3.5. In the manufacturing of HDPE geomembranes many extruders are 200 mm (8.0 inch) diameter systems which are quite large, e.g., up to 9 m (30 ft. long). In an extruder, the components enter a feed hopper and are transported via a continuous screw through a feed section, compression stage, metering stage, filtering screen and are then pressure fed into a die. The die options currently used for HDPE geomembrane production are either flat horizontal dies or circular vertical dies, the latter production technique often being referred to as "blown film" extrusion. The length of flat dies and the circumference of circular dies determine the width of the finished sheet and vary greatly from manufacturer to manufacturer. Some detail is given below.

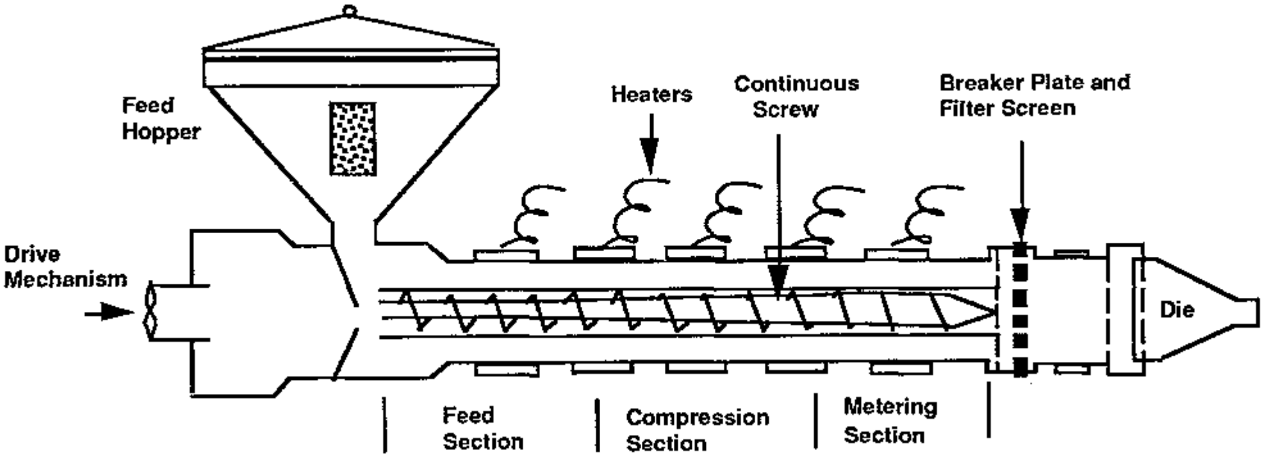


Figure 3.5 - Cross-Section Diagram of a Horizontal Single-Screw Extruder for Polyethylene

3.2.3.1 Flat Die - Wide Sheet

A conventional HDPE geomembrane sheet extruder can feed enough polymer to produce sheet up to approximately 4.5 m (15 ft.) wide in typical HDPE thicknesses of 0.75 to 3.0 mm (30 to 120 mils), see Fig. 3.6. Recently, one manufacturer has used two such extruders in parallel to produce sheet approximately 9.0 m (30 ft.) wide.

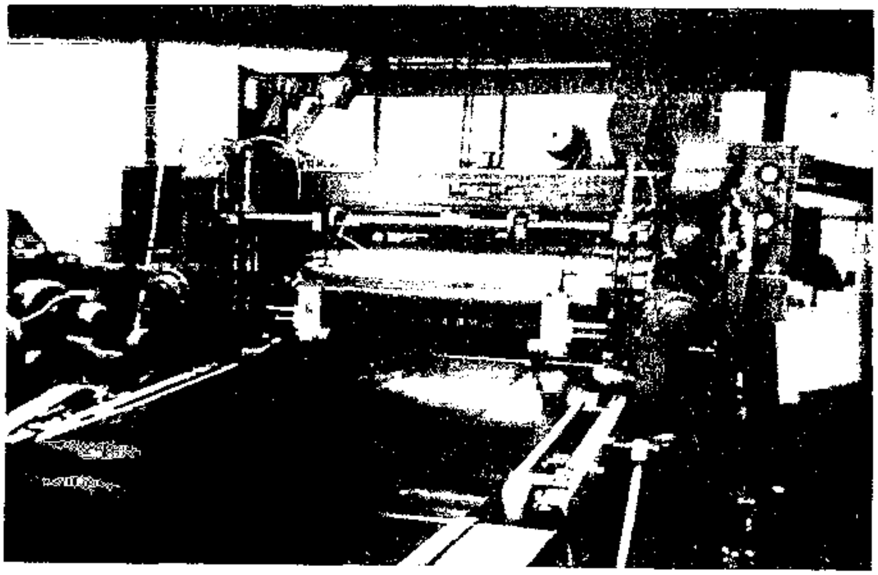


Figure 3.6 - Photograph of a Polyethylene Geomembrane Exiting from a Relatively Narrow Flat Horizontal Die

Insofar as a specification or MQA document for finished HDPE geomembranes made by flat die extrusion, the following items should be considered.

1. The finished geomembrane sheet must be free from pinholes, surface blemishes, scratches or other defects (e.g., nonuniform color, streaking, roughness, carbon black agglomerates, visually discernible regrind, etc.).
2. The nominal and minimum thicknesses of the sheet should be specified. The minimum value is usually related to the nominal thickness as a percentage. Values range from 5% to 10% less than nominal.

3. The maximum thickness of the sheet is rarely, if ever, specified. This is for the obvious reason that if a manufacturer wishes to supply sheet thicker than specified it is generally acceptable. It is also done, however, to allow for those manufacturers with unique variations of flat die extrusion (such as horizontal ribs or factory fabricated seams) to not be excluded from the market.
4. The finished sheet width should be controlled to be within a set tolerance. This is usually done by creating a sheet larger than called for, and trimming the edges immediately before final rolling onto the wind-up core. (The edge trim is subsequently ground into chips and used as regrind as previously described). Flat die extrusion of HDPE sheet should meet a ± 2.0% width specification.
5. Other MQC tests such as strength, puncture, tear, etc. should be part of a certification program which should be available and implemented.
6. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.
7. The trimmed and finished sheet is wound onto a hollow wind-up core which is usually heavy cardboard or (sometimes) plastic pipe. The outside diameter of the core should be at least 150 mm (6.0 in). It obviously must be stable enough to support the roll without buckling or otherwise failing during handling, storage and transportation.
8. Partial rolls for site specific project details may be cut and prepared for shipment per the contract drawings.

3.2.3.2 Flat Die - Factory Seamed

Since there are commercial extruders which produce sheets less than 6 m (20 ft) wide, the resulting sheet widths can be factory seamed into wider panels before shipment to the field. All of the specification details just described apply to narrow sheets as well as to wide sheets.

The method of factory seaming should be left to the discretion of the manufacturer. The factory seams, however, must meet the same specifications as the field seams (to be described later).

3.2.3.3 Blown Film

By using a vertically oriented circular die the extruder can feed molten polymer in an upward orientation creating a large cylinder of polyethylene sheet, see Fig. 3.7. Since the cylinder of polymer is closed at the top where it passes over a set of nip rollers which advances the cylinder, air is generally blown within it to maintain its dimensional stability. Note that upward moving air is also outside of the cylinder to further aid in stability. After passing through the nip rollers, the collapsed cylinder is cut longitudinally, opened to its full width, brought down to floor level and rolled onto a wind-up core. Note that collapsing the cylinder and passing it through the nip rollers results in two creases. After slitting the collapsed cylinder and opening it to full width, remnants of the two creases remain.

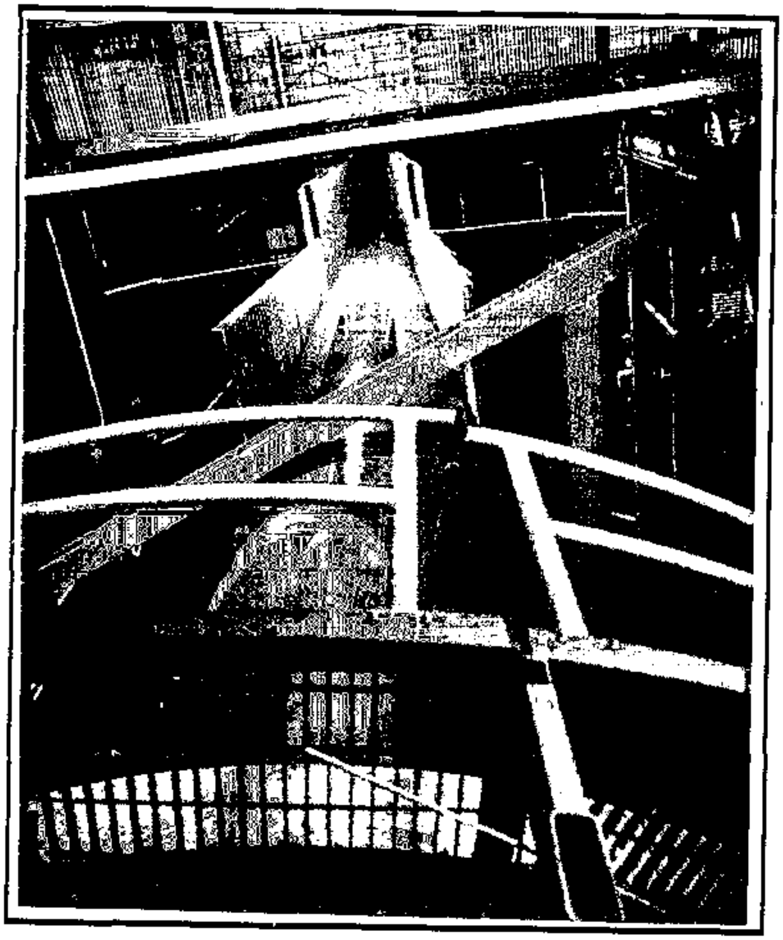


Figure 3.7 (a) - Photograph of Blown Film Manufacturing of Polyethylene Geomembranes

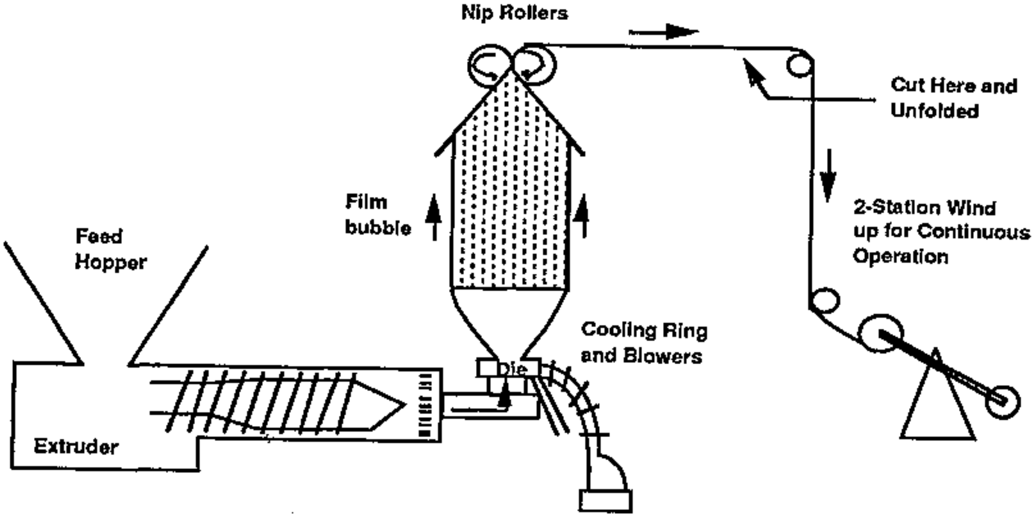


Fig. 3.7(b) - Sketch of Blown Film Manufacturing of Polyethylene Geomembranes

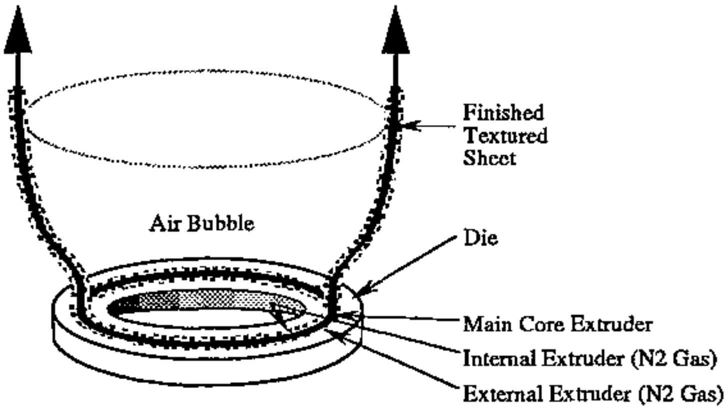
Regarding a specification or MQA document for blown film produced HDPE geomembranes, the following applies:

1. The finished geomembrane sheet shall be free from pinholes, surface blemishes, scratches or other defects (e.g., nonuniform color, streaking, roughness, carbon black agglomerates, visually discernible regrind, etc.). Note that two machine direction creases from nip rollers are automatically induced into the finished sheet at the 1/4 distances from each edge.
2. The nominal and minimum thickness of the sheet should be specified. The minimum value is usually related to the nominal thickness as a percentage. Values referenced range from 5% to 10% less than nominal.
3. The maximum thickness of the sheet is rarely, if ever, specified. This is for the obvious reason that if a manufacturer wishes to supply sheet thicker than specified it is generally acceptable.
4. The finished sheet width should be controlled to be within a set tolerance. HDPE geomembrane made from the blown film extrusion method should meet a ± 2.0% width specification.
5. Other MQC tests such as tensile strength, puncture, tear, etc., should be part of a certification program which should be available and implemented.
6. The finished sheet is wound onto a hollow wind-up core which is usually heavy cardboard or sometimes plastic pipe. The outside diameter of the core should be at least 150 mm (6.0 in.). It must be stable enough to support the roll without buckling or otherwise failing during handling, storage and transportation.
7. It is important that the two creases located at the 1/4-points from the edges of the sheet are wound on the core such that they will face upward when deployed in the field. The reason for this is so that scratches will not occur on the creases if the sheets are shifted on the soil subgrade when in an open and flat position.
8. Partial rolls for site specific project details may be cut and prepared for shipment as per the contract drawings.

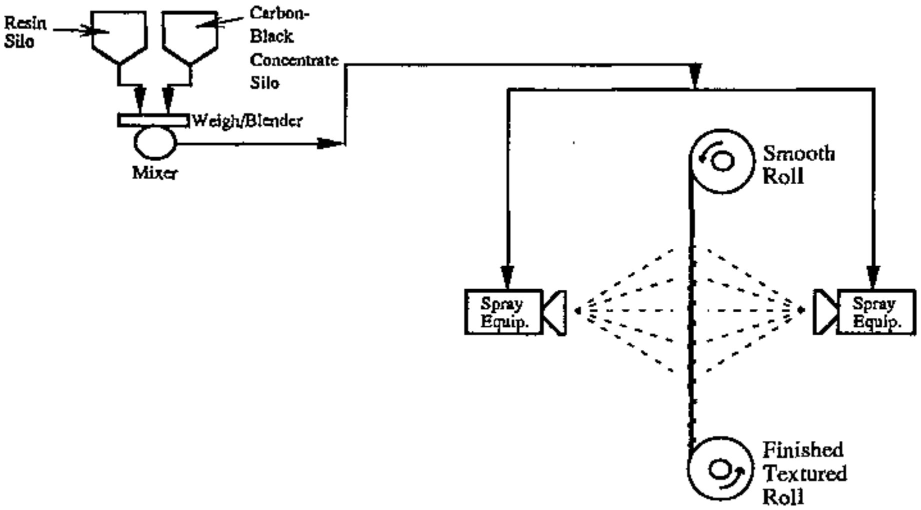
3.2.3.4 Textured Sheet

By creating a roughened surface on a smooth HDPE sheet, a process called "texturing" in this document, a high friction surface can be created. There are currently three methods used to texturize smooth HDPE geomembranes: coextrusion, impingement and lamination, see Fig. 3.8.

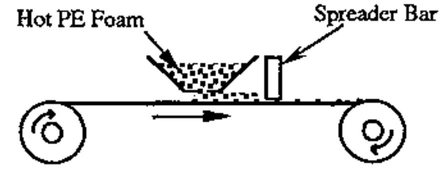
The *coextrusion* method utilizes a blowing agent in the molten extrudate and delivers it from a small extruder immediately adjacent to the main extruder. When both sides of the sheet are to be textured, two small extruders (one internal and one external to the main extruder) are necessary. As the extrudate from these smaller extruders meets the cool air the blowing agent expands, opens to the atmosphere and creates the textured surface(s).



(a) Coextrusion with Nitrogen Gas



(b) Impingement of Hot Polyethylene Particles



(Repeat Opposite Side for Double Sided Texture)

(c) Lamination with Polyethylene Foam

Figure 3.8 - Various Methods Currently Used to Create Textured Surfaces on HDPE Geomembranes

Impingement of hot HDPE particles against the finished HDPE sheet is a second method of texturing. In this case, hot particles are actually projected onto the previously prepared sheet on one or both of its surfaces in a secondary operation. The adhesion of the hot particles to the cold surface(s) should be as great, or greater, than the shear strength of the adjacent soil or other abutting material. The lengthwise edges of the sheets can be left non-textured for up to 300 mm (12 in.) so that thickness measurements and field seaming can be readily accomplished.

The third method for texturizing HDPE sheet is by *lamination* of an HDPE foam on the previously manufactured smooth sheet in a secondary operation. In this method a foaming agent contained within molten HDPE provides a froth which produces a rough textured laminate adhered to the previously prepared smooth sheet. The degree of adhesion is important with respect to the shear strength of the adjacent soil or other abutting material. If texturing on both sides of the geomembrane is necessary, the roll must go through another cycle but now on its opposite side. The lengthwise edges of the sheets can be left non-textured for up to 300 mm (12 in.) so that thickness measurements and field seaming can be readily accomplished.

Regarding the writing of a specification or MQA document on textured HDPE geomembranes the following points should be considered.

1. The surface texturing material should be of the same type of polymer and formulation as the base sheet polymer and its formulation. If other chemicals are added to the texturing material they must be identified in case of subsequent seaming difficulties.

2. The degree of texturing should be sufficient to develop the amount of friction as needed per the manufacturers specification and/or the project specifications.

3. The quality control of the texturing process can be assessed for uniformity using an inclined plane test method, e.g., GRI GS-7*.

4. The actual friction angle for design purposes should come from a large scale direct shear test simulating site specific conditions as closely as possible, e.g., ASTM D-5321.

5. The thickness of the base geomembrane should be micrometer measured (according to ASTM D-751) along the smooth edge strips of textured geomembranes made by impingement or lamination. For those textured geomembranes with no smooth edge strips, i.e., for blown film coextruded materials, an overall average thickness can be estimated on the basis of the roll weight divided by total area with suitable incorporation of the density of the material. Alternatively, a tapered point micrometer for measuring screw threads has also been used for point-to-point measurements.

6. Other MQC tests such as tensile strength, puncture, tear, etc., should be part of a certification program which should be available and implemented.

7. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.

---

* The Geosynthetic Research Institute (GRI) provides interim test methods for a variety of geosynthetic related topics until such time as consensus organizations (like ASTM) adopt a standard on the same topic. At that time the GRI standard is abandoned.

3.2.4 Very Low Density Polyethylene (VLDPE)

Very low density polyethylene (VLDPE) geomembranes are manufactured by taking the mixed components described earlier and feeding them into a hopper which leads to a horizontal extruder, recall Fig. 3.5. In the extruder, the blended components enter via a feed hopper and are transported via a continuous screw, through a feed section, compression stage, metering stage, filtering screen and are then pressure fed into a die. The die options currently used for VLDPE geomembrane production are either flat horizontal dies or circular vertical dies, the latter often being referred to as "blown film" extrusion. The width of flat dies and the circumference of circular dies vary greatly from manufacturer to manufacturer. The techniques are the same as were described in the manufacture of HDPE geomembranes.

3.2.4.1 Flat Die - Wide Sheet

A conventional VLDPE sheet extruder can feed enough polymer to produce sheet up to approximately 4.5 m (15 ft.) wide in typical VLDPE thicknesses of 0.75 to 3.0 mm (30 to 120 mils), recall Fig. 3.6. In developing a specification or MQA document for the manufacture of VLDPE geomembranes the following should be considered:

1. The finished geomembrane sheet must be free from pinholes, surface blemishes, scratches or other defects (e.g, carbon black agglomerates, visually discernible regrind, etc.).

2. The minimum thickness of the sheet should be specified. It is usually related to the nominal thickness as a percentage. Values range from 5% to 10% less than nominal.

3. The maximum thickness of the sheet is rarely, if ever, specified. This is for the obvious reason that if a manufacturer wishes to supply sheet thicker than specified it is generally acceptable. It is also done, however, to allow for those manufacturers with unique variations of flat die extrusion (such as horizontal ribs or factory fabricated seams) to not be excluded from the market.

4. The finished sheet width should be controlled to be within a set tolerance. This is usually done by creating a sheet larger than called for, and trimming the edges immediately before final rolling onto the wind-up core. (The edge trim is subsequently ground into chips and used as regrind as previously described). Flat die extrusion of VLDPE sheet can readily meet a ± 0.25% width specification.

5. Other MQC tests such as tensile strength, puncture, tear, etc. should be part of a certification program which should be available and implemented.

6. The trimmed and finished sheet is wound onto a hollow wind-up core which is usually heavy cardboard or sometimes plastic pipe. The outside diameter of the core should be at least 150 mm (6.0 in). It obviously must be stable enough to support the roll without buckling or otherwise failing.

7. Partial rolls for site specific project details may be cut and prepared for shipment as per contract drawings.

3.2.4.2 Flat Die - Factory Seamed

Since there are commercial extruders which produce significantly narrower sheet than just discussed, the resulting narrow sheet widths can be factory seamed into wider panels before shipment to the field. All of the specification details just described apply to narrow sheets as well as to wide sheets.

The method of factory seaming should be left to the discretion of the manufacturer. The factory seams, however, must be held to the same destructive and nondestructive testing procedures as with field seams (to be described later).

3.2.4.3 Blown Film

By using a circular die oriented vertically the extruder can feed molten polymer in an upward orientation creating a large cylinder of polymer, recall Fig. 3.7. Since the cylinder is closed at the top where it passes over a set of nip rollers which advances the cylinder, air is generally contained within it maintaining its dimensional stability. Note that upward moving air is also outside of the cylinder to further aid in stability. After passing beyond the nip rollers the cylinder is cut longitudinally, opened to its full width, brought down to floor level and rolled onto a stable core.

The following items should be considered in preparing a specification or MQA document for blown film VLDPE geomembranes.

1. The finished geomembrane sheet shall be free from pinholes, surface blemishes, scratches or other defects (carbon black agglomerates, visually discernible regrind, etc.). Note that two machine direction creases from nip rollers are automatically induced into the finished sheet at the 1/4 distances from each edge.

2. The minimum thickness of the sheet should be specified. It is usually related to the nominal thickness as a percentage. Values referenced range from 5% to 10% less than nominal.

3. The maximum thickness of the sheet is rarely, if ever, specified. This is for the obvious reason that if a manufacturer wishes to supply sheet thicker than specified it is generally acceptable.

4. The finished sheet width should be controlled to be within a set tolerance. VLDPE geomembrane made from the blown film extrusion method should meet a ± 2.0% width specification.

5. Other MQC tests such as tensile strength, puncture, tear, etc. should be part of a certification program which should be available and implemented.

6. The finished sheet is wound onto a hollow wind-up core which is usually heavy cardboard or sometimes plastic pipe. The outside diameter of the core should be at least 150 mm (6.0 in.). It obviously must be stable enough to support the roll without buckling or otherwise failing.

7. Partial rolls for site specific project details may be cut and prepared for shipment as per contract drawings.

3.2.4.4 Textured Sheet

By creating a roughened surface on a smooth VLDPE sheet, a process called "texturing" in this document, a high friction surface can be created. There are currently three methods used to texturize smooth VLDPE geomembranes: coextrusion, impingement and lamination, recall Fig. 3.8.

The *coextrusion* method utilizes a blowing agent in the molten extrudate and delivers it from a small extruder immediately adjacent to the main extruder. When both sides of the sheet are to be textured, two small extruders, one internal and one external to the main extruder, are necessary. As the extrudate from these smaller extruders meets the cool air the blowing agent expands, opens to the atmosphere and creates the textured surface(s).

Impingement of hot polyethylene particles against the finished VLDPE sheet is a second method of texturing. In this case, hot particles are actually projected onto the previously prepared sheet on one or both of its surfaces in a secondary operation. The adhesion of the hot particles to the cold surface(s) should be as great, or greater, than the shear strength of the adjacent soil or other abutting material. The lengthwise edges of the sheets can be left non-textured for up to 30 cm (12 in.) so that thickness measurements and field seaming can be readily accomplished.

The third method for texturizing VLDPE sheet is by *lamination* of a hot polyethylene foam on the previously manufactured smooth sheet in a secondary operation. In this method a foaming agent contained in molten polyethylene provides a froth which produces a rough textured laminate adhered to the previously prepared smooth sheet. The degree of adhesion is important with respect to the shear strength of the adjacent soil or other abutting material. If texturing of both sides of the geomembrane is necessary the roll must go through another cycle but now on its opposite side. The lengthwise edges of the sheets can be left non-textured for up to 300 mm (12 in.) so that thickness measurements and field seaming can be readily accomplished.

Regarding the writing of a specification or MQA document on textured VLDPE geomembranes the following points should be considered.

1. The surface texturing material should be polyethylene of density equal to the VLDPE, or greater. The latter is often the case. If other chemicals are added to the texturing material they must be identified in case of subsequent seaming difficulties.

2. The degree of texturing should be sufficient to develop the amount of friction as needed per the manufacturers specification and/or the project specifications.

3. The quality control of the texturing process can be assessed for uniformity using an inclined plane test method, e.g., GRI GS-7.

4. The actual friction angle for design purposes should come from a large scale direct shear test simulating site specific conditions as closely as possible, e.g., ASTM D-5321.

5. The thickness of the base geomembrane should be micrometer measured (according to ASTM D-751) along the smooth edge strips of textured geomembranes made by impingement or lamination. For those textured VLDPE geomembranes with no smooth edge strips, i.e., for blown film coextruded materials, an overall average thickness can be estimated on the basis of the roll weight divided by total area with suitable incorporation of the density of the material. Alternatively, a tapered point micrometer for measuring screw threads has also been used for point-to-point measurements. Care must be exercised, however, because VLDPE thickness measurements with a point micrometer are very sensitive to pressure.

6. Other MQC tests such as tensile strength, puncture, tear, etc., should be part of a certification program which should be available and implemented.

7. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.

3.2.5 Coextrusion Processes

As mentioned previously in Section 3.1.3, there are other variations of manufacturing polyethylene geomembranes. The basic manufacturing principle of adding the desired components to an extruder and having the molten polymer exit a flat horizontal die or a circular vertical die is always the same. What is different between these variations and the single component HDPE or VLDPE just described is the coextrusion process along with the idiosyncrasies of the particular materials utilized.

In coextrusion, two or three extruders simultaneously introduce molten polymer into the same die. As the different materials exit the die and are cooled they commingle with one another such that local blending and molecular entanglement occur and no discrete separation layer exists. Thus coextrusion is fundamentally different from the lamination of different surfaces together or of preformed sheets together under heat and pressure. Different variations of coextrusion of polyethylene geomembranes are described as follows.

Since polyethylene resin is supplied as a opaque pellet, the addition of colorants (rather than carbon black) can produce white, blue, green, etc., colored geomembranes. The benefit for geomembranes having these light colors is to reduce the surface temperature of the geomembrane when it is required to be exposed, e.g., as liners for surface impoundments or floating covers for reservoirs. Figure 3.9 shows how the temperature differences between white and black can be very significant. The white (or light) colors generally utilize titanium dioxide (or other metal oxides) in amounts not exceeding 1.0% by weight. Note that only a thin surface layer (approximately 10-20% of the total thickness) is treated in this manner. The balance of the geomembrane contains carbon black and is treated in the same manner as described previously.

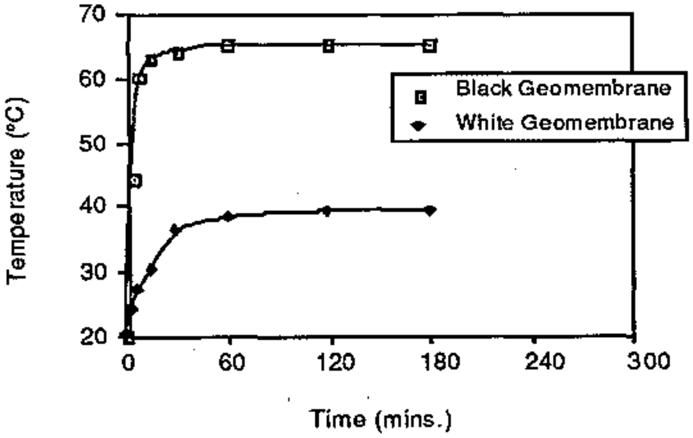


Figure 3.9 - Geomembrane Surface Temperature Differences Between Black and White Colors

A second variation of polyethylene is to coextrude a "sandwich" of HDPE on each side of VLDPE in the center. The purpose of such a combination is to provide high chemical resistance on the top and bottom of the sheet (via the HDPE) and to have high flexibility and out-of-plane elongation properties within the core (via the VLDPE). The thickness percentages of these components are approximately 20%, 60% and 20% of the total thickness of the sheet, respectively.

Third, it is possible to coextrude a surface layer to conventional HDPE or VLDPE which contains a gas that expands when cooled. Thus the molten polymer moves through the die in a regular manner only to have the expanding gas rapidly exit on its surface(s). This forms a roughened, or textured, surface which depends on the amount of gas and thickness of the coextruded surface layer. Similar extruders can be used on both sides of the parent sheet. The purpose of such texturing is to increase the interface friction between the textured geomembrane and the material above and/or below it, refer to Sections 3.2.3.4 and 3.2.4.4.

Lastly, it is possible to coextrude other polymers than polyethylene. As noted in Section 3.1.3, fully crosslinked elastomeric alloys (FCEA) can be extruded or could be coextruded with other polymers.

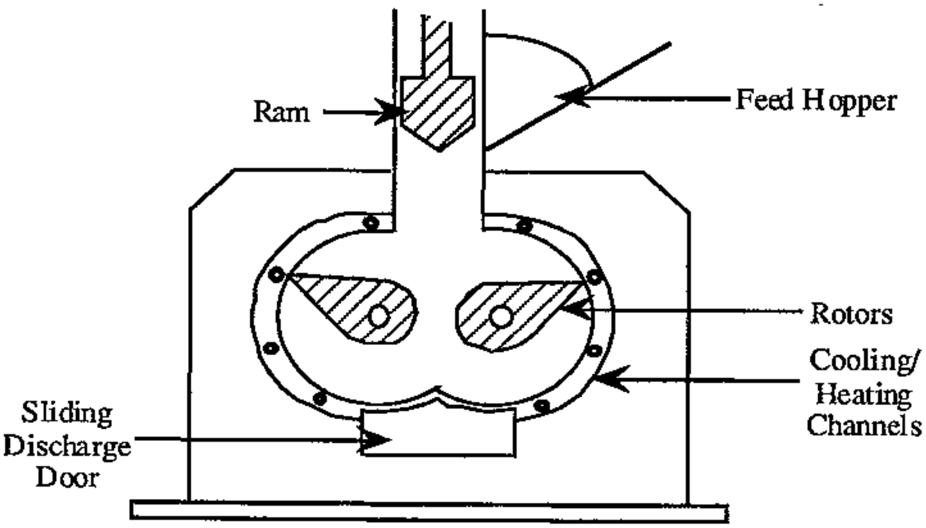
3.2.6 Polyvinyl Chloride (PVC)

Polyvinyl chloride (PVC) geomembranes are manufactured by taking proportional weight amounts of PVC resin (a dry powder) and plasticizer (a liquid) and premixing them until the plasticizer is absorbed into the resin. Filler (in the form of a dry powder) and other additives (also usually dry powders) are then added to the plasticized resin and the total formulation is mixed in a blender. Various types of high intensity or low intensity blenders can be used. Note that PVC rework in the form of chips, rather than edge trim, can be introduced at this point.

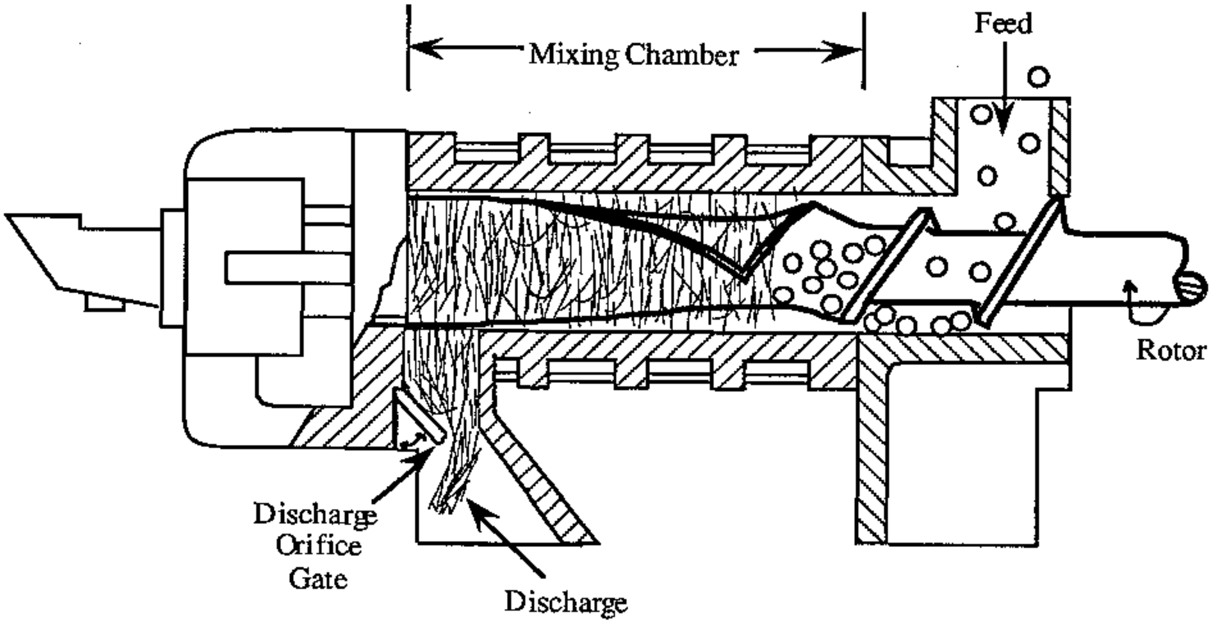
The resulting free-flowing powder compound is fed into a mixer which has heat introduced thereby initiating a reaction between the various components. These mixers can be either batch type (e.g., Banbury) or continuous types (e.g., Farrel), see Figs. 3.10(a) and (b), respectively. In these mixers, the temperature is approximately 180°C (350°F) which melts the mixture into a viscous mass. The mixed material is then removed from the discharge door or port onto a conveyor belt. From the conveyor belt the viscous material is further worked (called "masticating") in a rolling mill (or mills) into a smooth, consistent, uniform color, continuous mass of 100-150 mm (4-6 in.) in diameter. Finished product edge trim can also be introduced into the rolling mill at this point. The fully mixed formulation is then fed by conveyor directly into the sizing calender.

3.2.6.1 Calendering

PVC formulations, irrespective of the pre-processing procedures, are manufactured into continuous geomembrane sheets by a calendering process. The viscous feed of polymer coming from the rolling mill(s) is worked and flattened between counter-rotating rollers into a geomembrane sheet. Most calenders are "inverted-L" configurations, see Fig. 3.11, but other options also exist. The rollers are usually smooth surfaced (they can be slightly textured) stainless steel cylinders and are up to 200 cm (80 in.) in width. The opening distance between adjacent cylinders is set for the desired thickness of the final sheet. A rolling bank of molten material is formed between adjacent rolls. In an inverted four roll "L" calender, 3 such banks are formed. They act as reservoirs for the molten material, and help to fill the sheet to full thickness as it passes between the rolls. As the geomembrane exits from the calender, it enters an additional series of rollers for the purposes of pickoff, embossing, stripping, cooling and cutting. At least one, and perhaps two, rollers in PVC manufacturing are embossed so as to impart a surface texture on the geomembrane. The purpose of this embossing is to prevent the rolled geomembrane from sticking together, i.e., "blocking", during wind-up, storage and transportation.

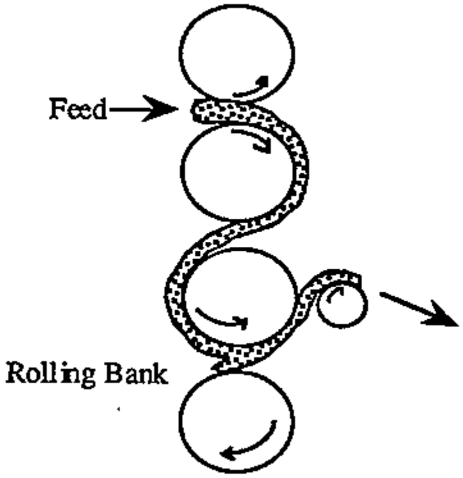


(a) Batch Process Mixer

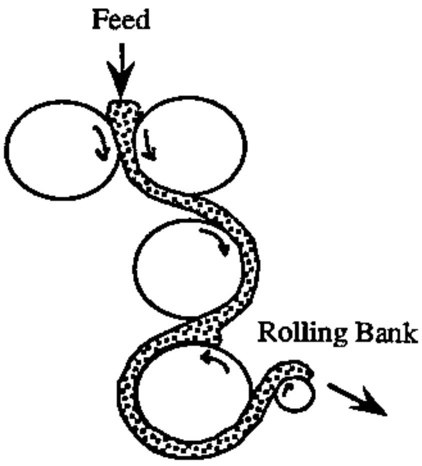


(b) Continuous Type Mixer

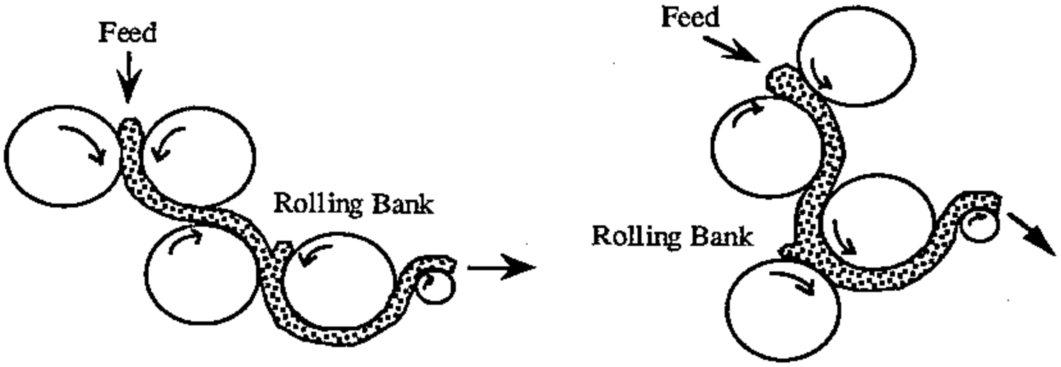
Figure 3.10 - Sketches of Various Process Mixers



(a) VERTICAL



(b) INVERTED L



(c) INCLINED Z

Figure 3.11 - Various Types of Four-Roll Calenders

In developing a specification or MQA document for the manufacturing of PVC geomembranes the following considerations are important:

1. The finished geomembrane sheet should be free from pinholes, surface blemishes, scratches or other defects (agglomerates of various additives or fillers, visually discernible rework, etc.)

2. The finished geomembrane sheet surfaces should be of a uniform color.

3. The addition of a dusting powder, such as talc, to eliminate blocking is <u>not</u> an acceptable practice. The powder will invariably attach to the sheet or be trapped within

the embossed irregularities and eventually be contained in the seamed area as a potential contaminant which could effect the adequacy of the seam.

4. The nominal and minimum thickness of the sheet should be specified. The minimum thickness of the finished geomembrane sheet is usually limited to the nominal thickness minus 5%.

5. The maximum thickness of the finished geomembrane sheet is generally not specified.

6. The width of the finished PVC geomembrane is dependent on the type of calender used by the manufacturer.

7. The geomembrane sheet should be edge trimmed to result in a specified width. This should be controlled to within ± 0.25%.

8. Various MQC tests such as tensile strength, puncture, tear, etc. should be part of a certification program which should be available and implemented.

9. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.

10. The finished geomembrane sheet should be rolled onto stable wind-up cores of at least 75 mm (3.0 in.) in diameter.

3.2.6.2 Panel Fabrication

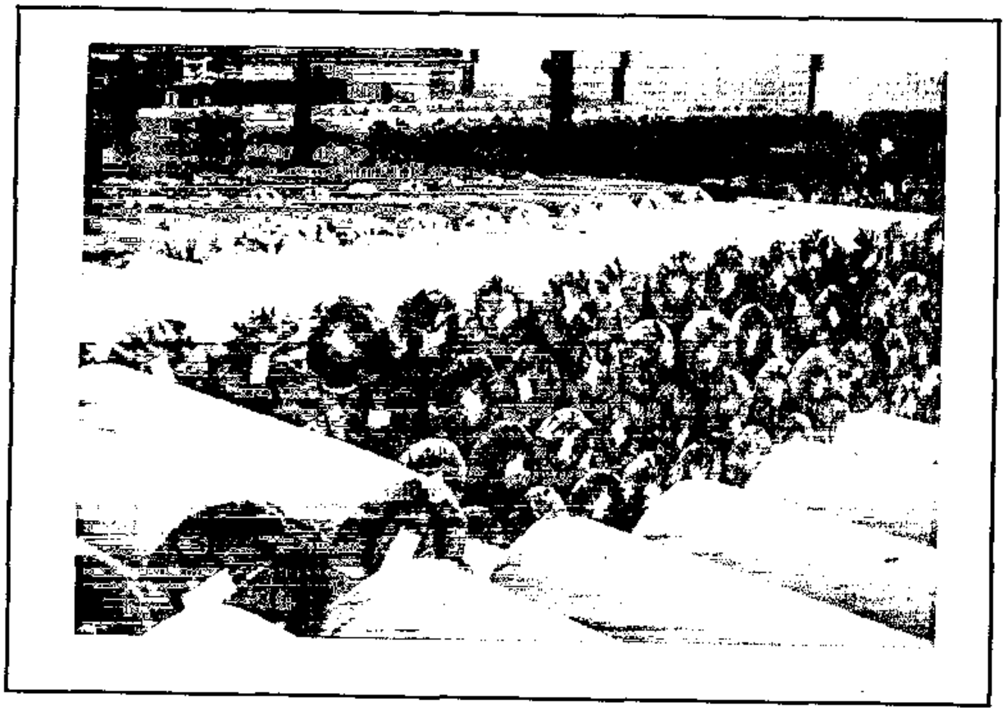
PVC geomembranes as just described are typically 100 to 200 cm (40 to 80 in.) wide and are transported in rolls weighing up to 6.7 kN (1500 pounds) to a panel fabrication facility, see Fig. 3.12 (upper photo). When a specific job order is placed, the rolls are unwound and placed directly on top of one another for factory seaming into a panel, see Fig. 3.12 (lower photo). A panel will typically consist of 5 to 10 rolls which are accordion seamed to one another, i.e., the left side of a particular roll is seamed to the underlying roll while the right side is seamed to the overlying roll. After seaming, the completed panel is again accordion folded (now in a lengthwise direction) and placed on a wooden pallet. It is then covered with a protective wrapper and shipped to the job site for deployment. To be noted is that some fabricators use other procedures for panel preparation.

Regarding a specification or MQA document for factory fabrication of PVC geomembrane panels, the following items should be considered.

1. The factory seaming of PVC rolls into panels should be performed by thermal or chemical seaming methods, see ASTM D-4545. It should be noted that dielectric seaming is a factory seaming method for joining PVC rolls. This is a thermal (or heat fusion) method that is acceptable and is unique to factory seaming of flexible thermoplastic geomembranes. It is currently not a field seaming method.

2. Factory seams should be subjected to the same type of destructive and nondestructive tests as field seams (to be described later).

3. When factory seams are made by chemical methods they are generally protected against blocking by covering them with a 100 mm (4 in.) wide strip of thin polyethylene film. When the panels are unfolded in the field these strips are discarded.



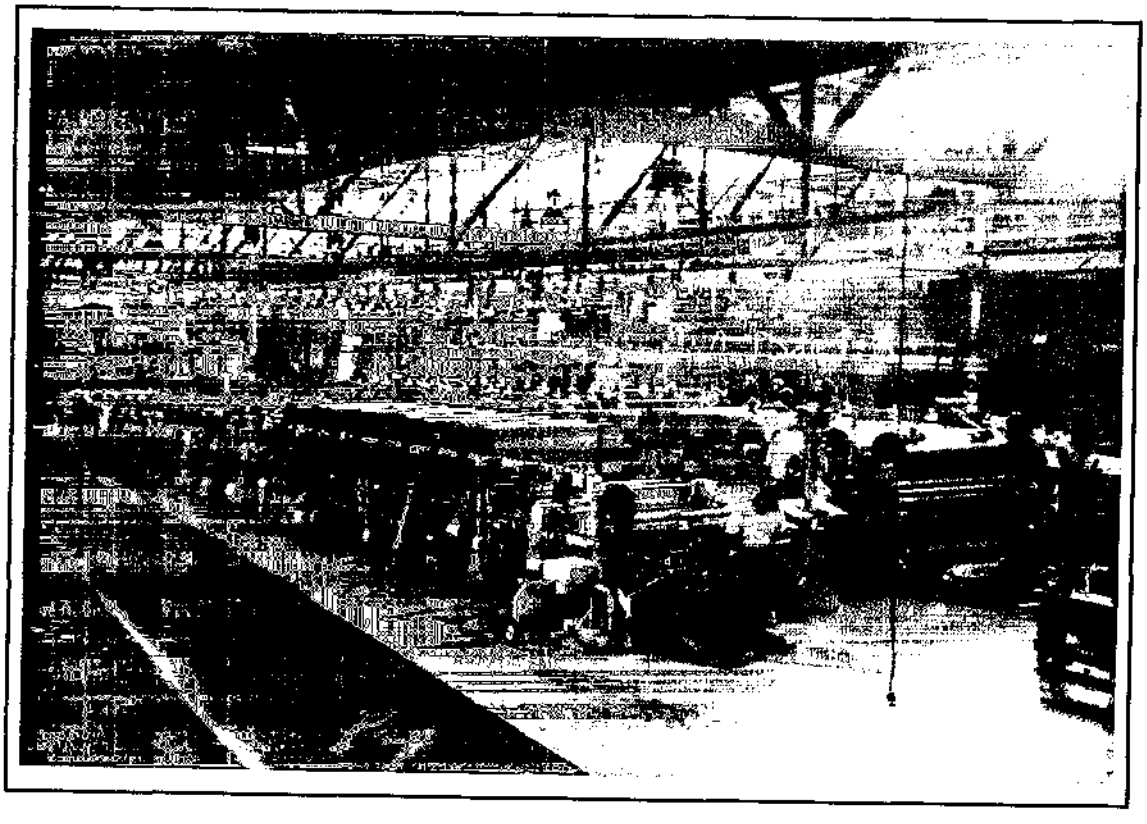


Figure 3.12 - Photographs of Calendered Rolls of Geomembranes After Manufacturing (Upper) and Factory Fabrication of Rolls into Large Panels for Field Deployment (Lower)

4. The finished and folded panels must be protected against accidental damage and excessive exposure during handling, transportation and storage. Usually they are protected by covering them in a heavy cardboard enclosure and placed on a wooden pallet for shipping.

5. The cardboard enclosures should be labeled and coded according to the specific job specifications.

3.2.7 Chlorosulfonated Polyethylene-Scrim Reinforced (CSPE-R)

Chlorosulfonated polyethylene geomembranes are made by mixing CSPE resin with carbon black (or their colorants) thereby making a "master batch" of these two components. Added to this master batch are fillers, additives and lubricants in a batch type mixer, e.g., a Banbury mixer, recall Fig. 3.10(a). Within the mixer the shearing action of the rotors against the ingredients generates enough heat to cause melting and subsequent chemical reactions to occur. After the mixing cycle is complete, the batch is dropped from the Banbury onto a two-roll mill, then to a conveyor leading to a second two-roll mill. In moving through the roll mill it is further mixed into a completely homogenized material having a uniform color and texture. It should be noted that edge trim is often taken from finished sheet and routed back to the roll mill for mixing and reuse.

A conveyor now transports the material directly to the calender, as shown in Fig. 3.11, and feeds it between the appropriate calender rolls.

3.2.7.1 Calendering

All CSPE formulations are manufactured into geomembrane sheets by a calendering process. Here the viscous ribbon of polymer is worked and flattened into a geomembrane sheet. Most calenders are "inverted-L" configurations, recall Fig. 3.11, but other options also exist. As the geomembrane exits the calender, it enters a series of rollers for the purposes of pickoff, stripping, cooling and cutting.

The inverted-L type calender provides an opportunity to introduce two simultaneous ribbons of the mixed and masticated polymeric compound thereby making two individual sheets of geomembranes. While this section of the manual is written around CSPE, it should be recognized that many other geomembrane types which are calendered can be made in multiple ply form as well. Since they are separately formed geomembrane sheets, they are brought together immediately upon exiting the calender to provide a laminated geomembrane consisting of two plys. Additional plys can also be added as desired, but this is not usually done in the manufacture of CSPE geomembranes.

While producing the two separate plys in an inverted-L calender as mentioned above, a woven fabric, called a reinforcing scrim, can be introduced between the two plys, see Fig. 3.13. The CSPE geomembrane is then said to be reinforced and is designed CSPE-R. It is common practice, however, to just use the acronym CSPE when referring to either the nonreinforced or reinforced variety of CSPE. The scrim is usually a woven polyester yarn with 6 x 6, 10 x 10 or 20 x 20 count. These numbers refer to the number of yarns per inch in the machine and cross machine directions, respectively. Other scrim counts are also possible.

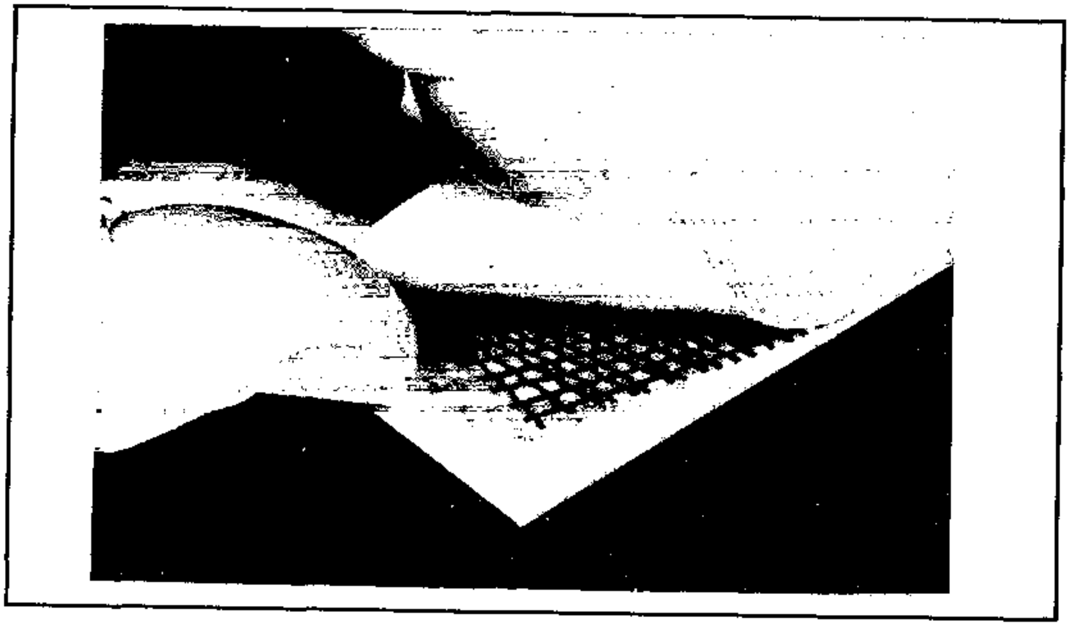


Figure 3.13 - Multiple-Ply Scrim Reinforced Geomembrane

Regarding the preparation of a specification or MQA document for multiple-ply scrim reinforced CSPE-R geomembranes the following should be considered.

1. The finished geomembrane should be free from surface blemishes, scratches and other defects (additive agglomerates, visually discernible rework, etc.).
2. The finished geomembrane sheet should be of a uniform color (which may be black, or by the addition of colorants, be white, tan, gray, blue, etc.), gloss and surface texture.
3. A uniform reinforcing scrim pattern should be reflected on both sides of the geomembrane and should be free from such anomalies as knots, gathering of yarns, delaminations or nonuniform and deformed scrim.
4. The sheet should not be embossed since the surface irregularities caused by the scrim are adequate to prohibit blocking.
5. The thickness of the sheet should be measured over the scrim and at a minimum should be the nominal thickness minus 10%.
6. The geomembrane sheet should have a salvage, i.e., geomembrane ply directly on geomembrane ply with no fabric scrim, on both edges. This salvage shall be approximately 6 mm (0.25 in.).
7. Various MQC tests such as strength, puncture, tear, ply adhesion, etc., should be part of a certification program which should be available and implemented.

8. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.
9. The finished geomembrane sheet should be rolled onto stable wind-up cores of at least 75 mm (3.0 in.) in diameter.

3.2.7.2 Panel Fabrication

CSPE-R geomembranes as just described are typically 100 to 200 cm (40 to 80 in.) wide and are transported in rolls weighing up to 6.7 kN (1500 pounds) to a panel fabrication facility. When a specific job order is placed, the rolls are unwound and placed on top of one another for factory seaming into a panel, recall Fig. 3.12. A panel will typically consist of 5 to 10 rolls accordion seamed to one another. After seaming, the panel is accordion folded in its length direction and placed onto a wooden pallet. It is then appropriately covered and shipped to the job site for deployment. To be noted is that some fabricators use other procedures for panel preparation.

In preparing a specification or MQA document for CSPE-R geomembrane panels, the following items should be considered.

1. Factory seaming of CSPE-R rolls should use thermal, chemical or bodied chemical fusion methods, see ASTM D-4545. It should be noted that dielectric seaming is a factory seaming method for joining CSPE-R rolls. This is a thermal, or heat fusion, method that is acceptable and is currently unique to factory seaming of flexible thermoplastic geomembranes. It is not a field seaming method.
2. Factory seams should be subjected to the same type of nondestructive tests as field seams (to be described later). A start-up seam is made prior to making panel production seams from which destructive tests are taken (to be described later).
3. When factory seams are made by chemical fusion methods they are generally protected against sticking to the adjacent sheet (i.e., blocking) by covering them with 100 mm (4 in.) wide thin strip of polyethylene film. When the panels are unfolded in the field these strips are discarded. Other systems may not require this film.
4. The folded panels must be protected against accidental damage and excessive exposure during handling, transportation and storage. Usually they are protected by containing them in a heavy cardboard enclosure and placed on a wooden pallet for shipping.
5. The cardboard enclosures are labeled and coded according to the specific job specifications.

3.2.8 Spread Coated Geomembranes

As mentioned previously, an exception to the calendering method of producing flexible geomembranes, is the spread coating process. This process is currently unique to a geomembrane type called ethylene interpolymer alloy (EIA-R), but has been used to produce other specialty geomembranes in the past. The process utilizes a dense fabric substrate, commonly either a woven or nonwoven textile, and spreads the molten polymer on its surface. Due to the dense structure of the fabric, penetration of the viscous polymer to the opposite side is usually not complete. When cooled, the sheet must be turned over and the process repeated on the opposite side. Adherence of the polymer to the fabric is essential.

Geomembranes produced by the spread coating method are indeed multiple-ply reinforced materials, but produced by a method other than calendering. MQC and MQA plans and specifications should be framed in a similar manner as described previously for CSPE-R geomembranes.

3.3 Handling

While there should be great concern and care focused on the manufacturers and installers of geomembranes, it is also incumbent that they are packaged, handled, stored, transported, re-stored, re-handled and deployed in a manner so as not to cause any damage. This section is written with these many ancillary considerations in mind.

3.3.1 Packaging

Different types of geomembranes require different types of packaging after they are manufactured. Generally HDPE and VLDPE are packaged around a core in roll form, while PVC and CSPE-R are accordion folded in two directions and packaged onto pallets.

3.3.1.1 Rolls

Both HDPE and VLDPE geomembranes are manufactured and fed directly to a wind-up core in full-width rolls. No external wrapping or covering is generally needed, nor provided. These rolls, which weigh up to 22 kN (5000 pounds), are either moved by fork-lifts using a long rod inserted into the core (called a "stinger") or they are picked up by fabric slings with a crane or hoist. Note that the slings are often dedicated to each particular roll and follow along with it until its actual deployment. The rolls are usually stored in an outdoor area. They are stacked such that one roll is nested into the valley of the two underlying rolls, see Fig. 3.14.

Regarding a specification or MQA document for finished rolls of HDPE geomembranes the following applies.

1. The cores on which the rolls of geomembranes are wound should be at least 150 mm (6.0 in.) outside diameter.
2. The cores should have a sufficient inside diameter such that fork lift stingers can be used for lifting and movement.
3. The cores should be sufficiently strong that the roll can be lifted by a stinger or with slings without excessively deflecting, nor structurally buckling the roll.
4. The stacking of rolls at the manufacturing facility should not cause buckling of the cores nor flattening of the rolls. In general, the maximum stacking limit is 5 rolls high.
5. If storage at the manufacturer's facility is for longer than 6 months, the rolls should be covered by a sacrificial covering, or placed within a temporary or permanent enclosure.
6. The manufacturer should identify all rolls with the manufacturer's name, product identification, thickness, roller number, roll dimensions and date manufactured.

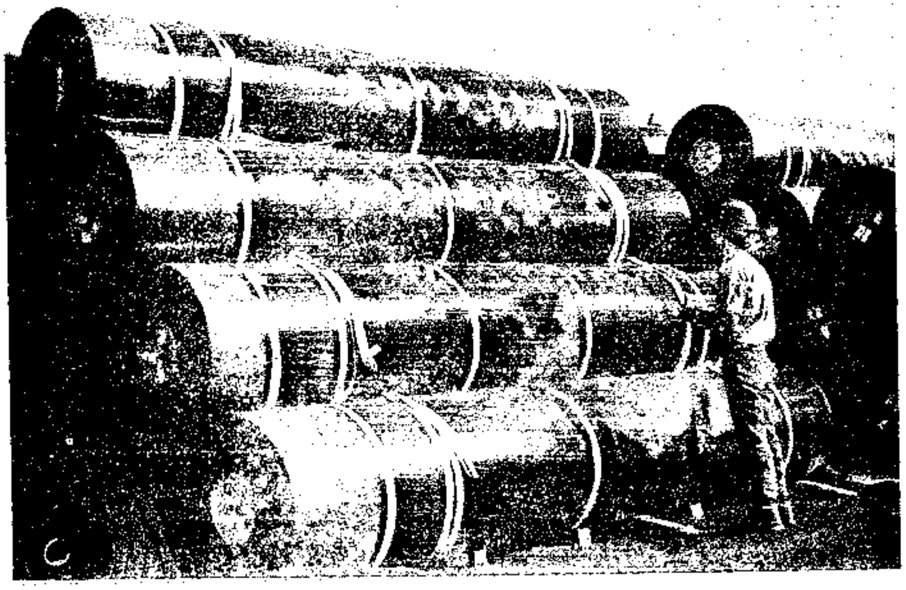


Figure 3.14 - Rolls of Polyethylene Awaiting Shipment to a Job Site

3.3.1.2 Accordion Folded

PVC and CSPE-R geomembranes are initially manufactured in rolls and are then sent to a fabricator for factory seaming into panels. At the fabrication facility they are unrolled directly on top of one another, factory seamed along alternate edges of the rolls and are then accordion folded both width-wise and length-wise and placed onto wooden pallets for packaging and shipment. PVC and CSPE-R geomembranes are generally not stored longer than a few weeks at the fabrication facility.

Regarding items for a specification or MQA document, the following applies.

1. The wooden pallets on which the accordion folded geomembranes are placed should be structurally sound and of good workmanship so that fork lifts or cranes can transport and maneuver them without structurally failing or causing damage to the geomembrane.

2. The wooden pallets should extend at least 75 mm (3 in.) beyond the edge of the folded geomembrane panel on all four sides.

3. The folded geomembrane panel should be packaged in treated cardboard or plastic wrapping for protection from precipitation and direct ultraviolet exposure.

4. Banding straps around the geomembrane and pallet should be properly cushioned so as not to cause damage to any part of the geomembrane panel.

5. Palleted geomembranes should be stored only on level surfaces since the folded material is susceptible to shifting and possible damage.
6. The stacking of palleted geomembrane panels on top of one another should not be permitted.
7. If storage at the fabricator's facility is for longer than 6 months, the palleted panels should be covered with a sacrificial covering, temporary shelter or placed within a permanent enclosure.
8. The fabricator should identify all panels with the manufacturers name, product information, thickness, panel number, panel dimensions and date manufactured.

3.3.2 Shipment, Handling and Site Storage

The geomembrane rolls or pallets are shipped to the job site, offloaded, and temporarily stored at a remote location on the job site, see Fig. 3.15.

Regarding items for a specification or CQA document*, the following applies:

1. Unloading of rolls or pallets at the job site's temporary storage location should be such that no damage to the geomembrane occurs.
2. Pushing, sliding or dragging of rolls or pallets of geomembranes should not be permitted.
3. Offloading at the job site should be performed with cranes or fork lifts in a workmanlike manner such that damage does not occur to any part of the geomembrane.
4. Temporary storage at the job site should be in an area where standing water cannot accumulate at any time.
5. The ground surface should be suitably prepared such that no stones or other rough objects which could damage the geomembranes are present.
6. Temporary storage of rolls of HDPE or VLDPE geomembranes in the field should not be so high that crushing of the core or flattening of the rolls occur. This limit is typically 5 rolls high.
7. Temporary storage of pallets of PVC or CSPE-R geomembranes by stacking should not be permitted.
8. Suitable means of securing the rolls or pallets should be used such that shifting, abrasion or other adverse movement does not occur.
9. If storage of rolls or pallets of geomembranes at the job site is longer than 6 months, a sacrificial covering or temporary shelter should be provided for protection against precipitation, ultraviolet exposure and accidental damage.

---

* Note that the designations of MQC and MQA will now shift to CQC and CQA since field construction personnel are involved. These designations will carry forward throughout the remainder of this Chapter.

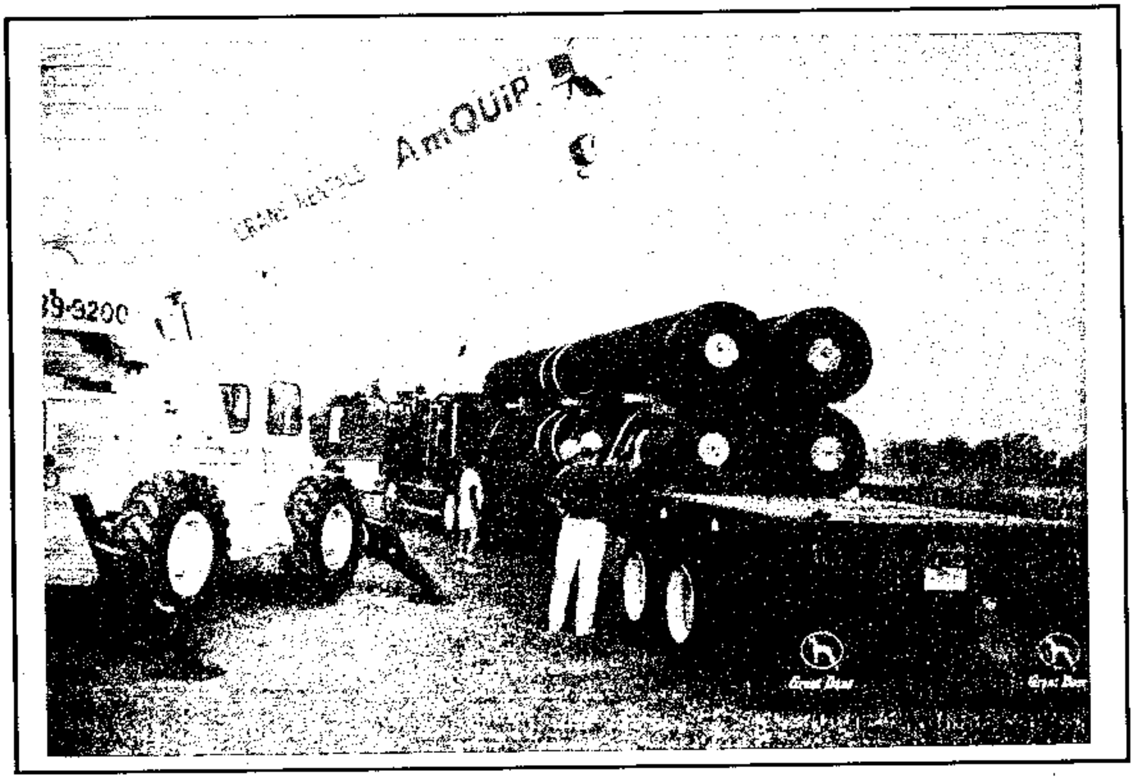


Figure 3.15 - Photograph of Truck Shipment of Geomembranes

3.3.3 Acceptance and Conformance Testing

It is the primary duty of the installation contractor, via the CQC personnel, to see that the geomembrane supplied to the job site is the proper material that was called for in the contract, as specified by the Plans and Specifications. It is also the duty of the CQA Engineer to verify this material to be appropriate. Clear marking should identify all rolls or pallets with the information described in Section 3.3.1. A complete list of roll numbers should be prepared for each material type.

Upon delivery of the rolls or pallets of geomembrane, the CQA Engineer should ensure that conformance test samples are obtained and sent to the proper laboratory for testing. This will generally be the laboratory of the CQA firm, but may be that of the CQC firm if so designated in the CQA documents. Alternatively, conformance testing could be performed at the manufacturers facility and when completed the particular lot should be marked for the particular site under investigation.

The following items should be considered for a specification or CQA document with regard to acceptance and conformance testing.

1. The particular tests selected for acceptance and conformance testing can be all of those listed previously, but this is rarely the case since MQC and MQA testing should have preceded the field operations. However, at a minimum, the following tests are recommended for field acceptance and conformance testing for the particular

geomembrane type.

(a) HDPE: thickness (ASTM D-5199), tensile strength and elongation (ASTM D-638) and possibly puncture (FTM Std 101C) and tear resistance (ASTM D-1004, Die C)

(b) VLDPE: thickness (ASTM D-5199), tensile strength and elongation (ASTM D-638), and possibly puncture (FTM Std 101C) and tear resistance (ASTM D-1004, Die C)

(c) PVC: thickness (ASTM D-5199), tensile strength and elongation (ASTM D-882), tear resistance (ASTM D-1004, Die C)

(d) CSPE-R: thickness (ASTM D-5199), tensile strength and elongation (ASTM D-751), ply adhesion (ASTM D-413, Machine Method, Type A)

2. The method of geomembrane sampling should be prescribed. For geomembranes on rolls, 1 m (3 ft.) from the entire width of the roll on the outermost wrap is usually cut and removed. For geomembranes folded on pallets, the protective covering must be removed, the uppermost accordion folded section opened and an appropriate size sample taken. Alternatively, factory seam retains can be shipped on top of fabricated panels for easy access and use in conformance testing.

3. The machine direction must be indicated with an arrow on all samples using a permanent marker.

4. Samples are usually taken on the basis of a stipulated area of geomembrane, e.g., one sample per 10,000 m^2 (100,000 ft^2). Alternatively, one could take samples at the rate of one per lot, however, a lot must be clearly defined. One possible definition could be that a lot is a group of consecutively numbered rolls or panels from the same manufacturing line.

5. All conformance test results should be reviewed, accepted and reported by the CQA Engineer before deployment of the geomembrane.

6. Any nonconformance of test results should be reported to the Owner/Operator. The method of a resolution of such differences should be clearly stated in the CQA document. One possible guidance document for failing conformance tests could be ASTM D-4759 titled "Determining the Specification Conformance of Geosynthetics".

3.3.4 Placement

When the subgrade or subbase (either soil or some other geosynthetic) is approved as being acceptable, the rolls or pallets of the temporarily stored geomembranes are brought to their intended location, unrolled or unfolded, and accurately spotted for field seaming, see Fig. 3.16.

3.3.4.1 Subgrade (Subbase) Conditions

Before beginning to move the geomembrane rolls or pallets from their temporary storage location at the job site, the soil subgrade (or other subbase material) should be checked for its preparedness.

Figure 3.16 - Photographs Showing the Unrolling (Upper) and Unfolding (Lower) of Geomembranes

Some items recommended for a specification or CQA document include the following:

1. The soil subgrade shall be of the specified grading, moisture content and density as required by the installer and as approved by the CQA engineer for placement of the geomembrane. See Chapter 2 for these details for compacted clay liner subgrades.

2. Construction equipment deploying the rolls or pallets shall not deform or rut the soil subgrade excessively. Tire or track deformations beneath the geomembrane should not be greater than 25 mm (1.0 in.) in depth.

3. The geomembrane shall not be deployed on frozen subgrade where ruts are greater than 12 mm (0.5 in.) in depth.

4. When placing the geomembrane on another geosynthetic material (geotextile, geonet, etc.), construction equipment should not be permitted to ride directly on the lower geosynthetic material. In cases where rolls must be moved over previously placed geosynthetics it is necessary to move materials by hand or by using small pneumatic tired lifting units. Tire inflation pressures should be limited to a maximum value of 40 kPa (6 lb/in^2).

5. Underlying geosynthetic materials (such as geotextiles or geonets) should have all folds, wrinkles and other undulations removed before placement of the geomembrane.

6. Care, and planning, should be taken to unroll or unfold the geomembrane close to its intended, and final, position.

3.3.4.2 Temperature Effects - Sticking/Cracking

High temperatures can cause geomembrane surfaces on rolls, or accordion folded on pallets, to stick together, a process commonly called "blocking". At the other extreme, low temperatures can cause geomembrane sheets to crack when unrolled or unfolded. Comments on unrolling, or unfolding of geomembranes at each of these temperature extremes follow.

For example, a specification or CQA document should have included in it the following items.

1. Geomembranes when unrolled or unfolded should not stick together to the extent where tearing, or visually observed straining of the geomembrane, occurs. The upper temperature limit is very specific to the particular type of geomembrane. A sheet temperature of 50°C (122°F) is the upper limit that a geomembrane should be unrolled or unfolded unless it is shown otherwise to the satisfaction of the CQA engineer.

2. Geomembranes which have torn or have been excessively deformed should be rejected, or shall be repaired per the CQA Document.

3. Geomembranes when unrolled or unfolded in cold weather should not crack, craze, or distort in texture. A sheet temperature of 0°C (32°F) is the lower limit that a geomembrane should be unrolled or unfolded unless it is shown otherwise to the satisfaction of the CQA engineer.

3.3.4.3 Temperature Effects - Expansion/Contraction

Polyethylene geomembranes expand when they are heated and contract when they are cooled. Other types of geomembranes may slightly contract when heated. This expansion and contraction must be considered when placing, seaming and backfilling geomembranes in the field. Fig. 3.17 shows a wrinkled polyethylene liner which has expanded due to thermal warming from the sun.

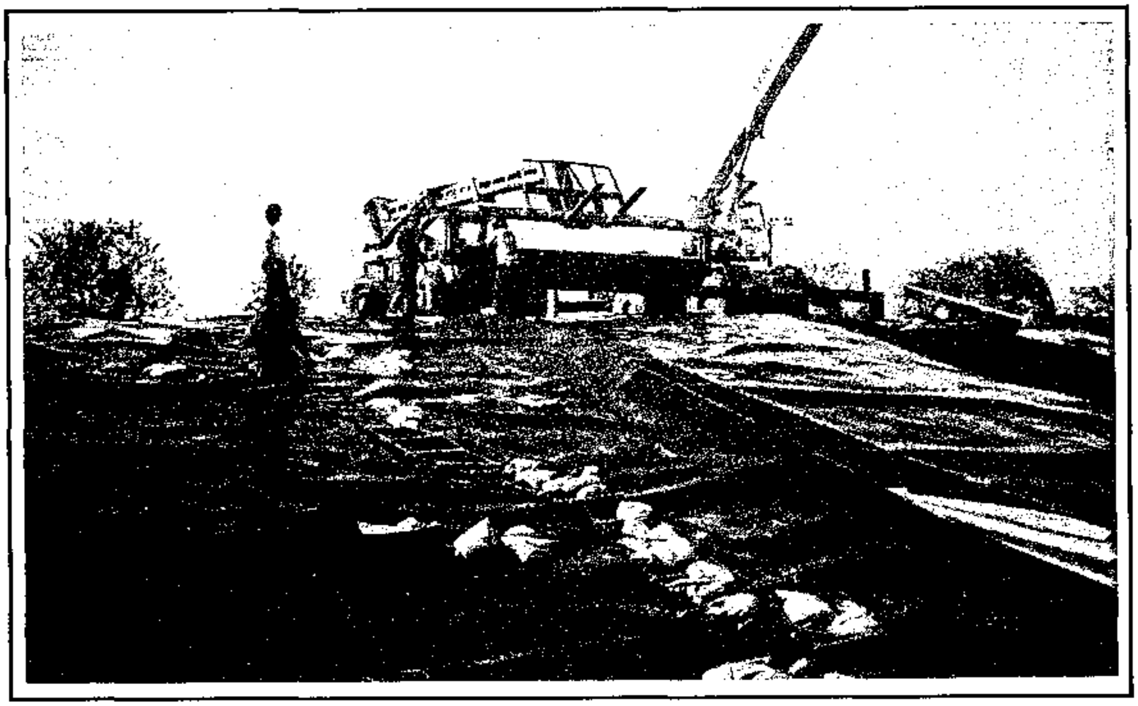


Figure 3.17 - HDPE Geomembrane Showing Sun Induced Wrinkles

Either the contract plans and specifications, or the CQA documents should cover the expansion/contraction situation on the basis of site specific and geomembrane specific conditions. Some items to consider include the following:

1. Sufficient slack shall be placed in the geomembrane to compensate for the coldest temperatures envisioned so that no tensile stresses are generated in the geomembrane or in its seams either during installation or subsequently after the geomembrane is covered.

2. The geomembrane shall have adequate slack such that it does not lift up off of the subgrade or substrate material at any location within the facility, i.e., no "trampolining" of the geomembrane shall be allowed to occur at any time.

3. The geomembrane shall not have excessive slack to the point where creases fold over upon themselves either during placement and seaming, or when the protective soil or drainage materials are placed on the geomembrane.
4. Permanent (fold-over type) creases in the covered geomembrane should not be permitted at any time.
5. The amount of slack to be added to the deployed and seamed geomembrane should be carefully considered and calculated, taking into account the type of geomembrane and the geomembrane's temperature during installation versus its final temperature in the completed facility.

3.3.4.4 Spotting

When a geomembrane roll or panel is deployed it is generally required that some shifting will be necessary before field seaming begins. This is called "spotting" by many installers.

Some items for a specification or CQA document should include the following:

1. Spotting of deployed geomembranes should be done with no disturbance to the soil subgrade or geosynthetic materials upon which they are placed.
2. Spotting should be done with a minimum amount of dragging of the geomembrane on soil subgrades.
3. Temporary tack welding (usually with a hand held hot air gun) of all types of thermoplastic geomembranes should be allowed at the installers discretion.
4. When temporary tack welds of geomembranes are utilized, the welds should not interfere with the primary seaming method, or with the ability to perform subsequent destructive seam tests.

3.3.4.5 Wind Considerations

Wind damage to geomembranes, unfortunately, is not an uncommon occurrence, see Fig. 3.18. Many deployed geomembranes have been uplifted by wind and have been damaged. In some cases the geomembranes have even been torn out of anchor trenches. This is sometimes referred to as "blow-out" by field personnel. Generally, but not always, the unseamed geomembrane rolls or panels acting individually are most vulnerable to wind uplift and damage.

The contract plans and specification, or at least the CQA documents, must be very specific as to resolutions regarding geomembranes that have been damaged due to shifting by wind. Some suggestions follow.

1. Geomembrane rolls or panels which have been displaced by wind should be inspected and approved by the CQA engineer before any further field operations commence.
2. Geomembrane rolls or panels which have been damaged (torn, punctured, or deformed excessively and permanently) shall be rejected and/or repaired as directed in the contract plans, specifications or CQA documents.
3. Permanent crease marks, or severely folded (crimped) locations, in geomembranes

should not be permitted unless it can be shown that such distortions have no adverse effect on the properties of the geomembrane. If this cannot be done, these areas should be cut out and properly patched as per the contract documents and approved by the CQA Engineer.

4. If patching of wind damaged geomembranes becomes excessive (to the limit set forth in the specifications or CQA plan), the entire roll or panel should be rejected.

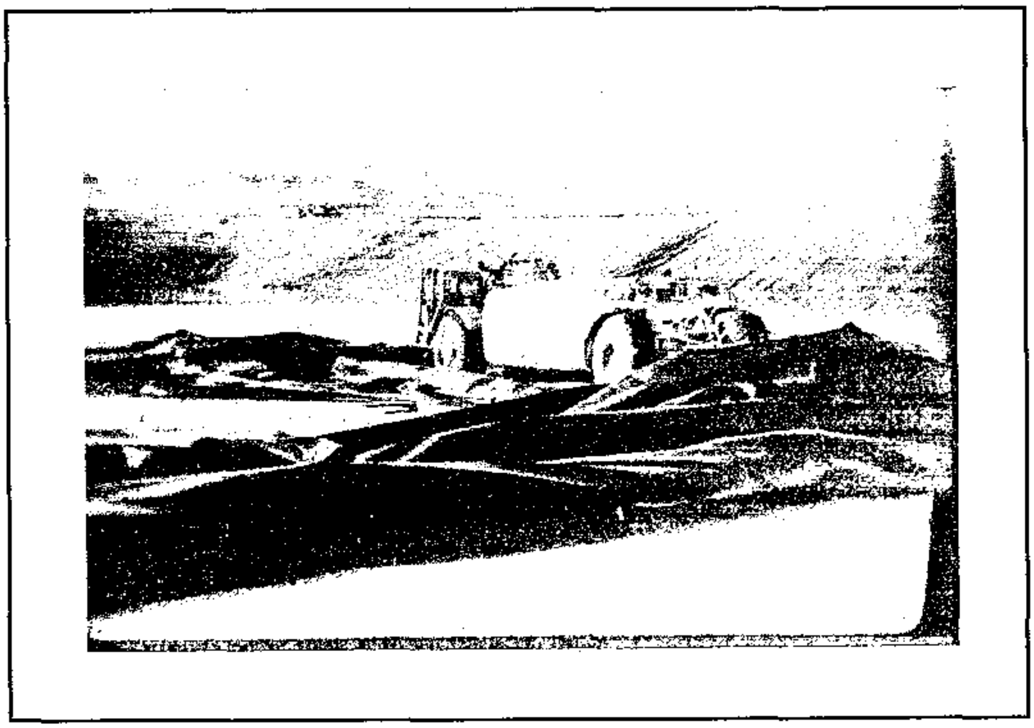


Figure 3.18 - Wind Damage to Deployed Geomembrane

3.4 Seaming and Joining

The field seaming of the deployed geomembrane rolls or panels is a critical aspect of their successful functioning as a barrier to liquid (and sometimes vapor) flow. This section describes the various seaming methods in current use, references a recently published EPA Technical Guidance Document on seam fabrication techniques (EPA, 1991), and describes the concept and importance of test strips (or trial seams).

3.4.1 Overview of Field Seaming Methods

The fundamental mechanism of seaming polymeric geomembrane sheets together is to temporarily reorganize, i.e., melt, the polymer structure of the two surfaces to be joined in a controlled manner that, after the application of pressure and after the passage of a certain amount of time, results in the two sheets being bonded together. This reorganization results from an input of energy that originates from either thermal or chemical processes. These processes may involve the addition of extra polymer in the bonded area.

Ideally, seaming two geomembrane sheets would result in no net loss of tensile strength across the two sheets and the joined sheets would perform as one single geomembrane sheet. However, due to stress concentrations resulting from the seam geometry, current seaming techniques may result in minor tensile strength loss relative to the parent geomembrane sheet. The characteristics of the seamed area are a function of the type of geomembrane and the seaming technique used. These characteristics, such as residual strength, geomembrane type, and seaming type, should be recognized by the designer when applying the appropriate design factors-of-safety for the overall geomembrane function and facility performance.

It should be noted that the seam can be the location of the lowest tensile strength in a geomembrane liner. Designers and inspectors should be aware of the importance of seeking only the highest quality geomembrane seams. The minimum seam tensile strengths (as determined by design) for various geomembranes must be predetermined by laboratory testing, knowledge of past field performance, manufacturers literature, various trade journals or other standards setting organizations that maintain current information on seaming techniques and technologies.

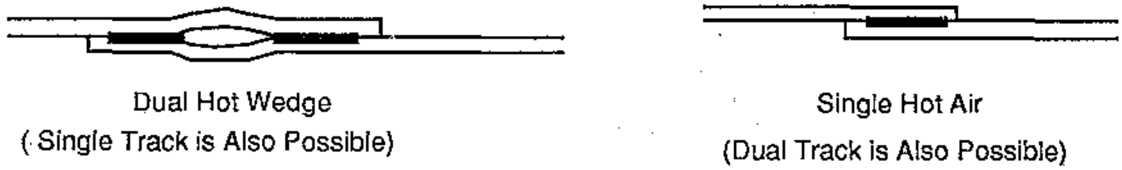
The methods of seaming at the time of the printing of this document and discussed herein are given in Table 3.2 and shown schematically in Fig. 3.19.

Table 3.2. Fundamental Methods Of Joining Polymeric Geomembranes

Thermal Processes	Chemical Processes
Extrusion:	Chemical:
• Fillet	• Chemical Fusion
• Flat	• Bodied Chemical Fusion
Fusion:	Adhesive:
• Hot Wedge	• Chemical Adhesive
• Hot Air	• Contact Adhesive

Within the entire group of thermoplastic geomembranes that will be discussed in this manual, there are four general categories of seaming methods extrusion welding, thermal fusion or melt bonding, chemical fusion and adhesive seaming. Each will be explained along with their specific variations so as to give an overview of field seaming technology.

(a) Extrusion Seams



(b) Fusion Seams

(c) Chemical Seams

(d) Adhesive Seams

Figure 3.19 - Various Methods Available to Fabricate Geomembrane Seams

Extrusion welding is presently used exclusively on geomembranes made from polyethylene. A ribbon of molten polymer is extruded over the edge of, or in between, the two surfaces to be joined. The molten extrudate causes the surfaces of the sheets to become hot and melt, after which the entire mass cools and bonds together. The technique is called extrusion fillet seaming when the extrudate is placed over the leading edge of the seam, and is called extrusion flat seaming when the extrudate is placed between the two sheets to be joined. It should be noted that extrusion fillet seaming is essentially the only practical method for seaming polyethylene geomembrane patches, for seaming in poorly accessible areas such as sump bottoms and around pipes and for seaming of extremely short seam lengths. Temperature and seaming rate both play important roles in obtaining an acceptable bond; excessive melting weakens the geomembrane and inadequate melting results in poor extrudate flow across the seam interface and low seam strength. The polymer used for the extrudate is also very important and should generally be the same polyethylene compound used to make the geomembrane. The designer should specify acceptable extrusion compounds and how to evaluate them in the specifications and CQA documents.

There are two thermal fusion or melt-bonding methods that can be used on all thermoplastic geomembranes. In both of them, portions of the opposing surfaces are truly melted. This being the case, temperature, pressure, and seaming rate all play important roles in that excessive melting weakens the geomembrane and inadequate melting results in low seam strength. The hot wedge, or hot shoe, method consists of an electrically heated resistance element in the shape of a wedge that travels between the two sheets to be seamed. As it melts the surface of the two sheets being seamed, a shear flow occurs across the upper and lower surfaces of the wedge. Roller pressure is applied as the two sheets converge at the tip of the wedge to form the final seam. Hot wedge units are controllable as far as temperature, amount of pressure applied and travel rate. A standard hot wedge creates a single uniform width seam, while a dual hot wedge (or "split" wedge) forms two parallel seams with a uniform unbonded space between them. This space can be used to evaluate seam quality and continuity of the seam by pressurizing the unbonded space with air and monitoring any drop in pressure that may signify a leak in the seam.

The hot air method makes use of a device consisting of a resistance heater, a blower, and temperature controls to force hot air between two sheets to melt the opposing surfaces. Immediately following the melting of the surfaces, pressure is applied to the seamed area to bond the two sheets. As with the hot wedge method, both single and dual seams can be produced. In selected situations, this technique may also be used to temporarily "tack" weld two sheets together until the final seam or weld is made and accepted.

Regarding the chemical fusion seam types; chemical fusion seams make use of a liquid chemical applied between the two geomembrane sheets to be joined. After a few seconds, required to soften the surface, pressure is applied to make complete contact and bond the sheets together. As with any of the chemical seaming processes to be described, the two adjacent materials to be bonded are transformed into a viscous phase. Care must be used to see that the proper amount of chemical is applied in order to achieve the desired results. Bodied chemical fusion seams are similar to chemical fusion seams except that 1% to 20% of the parent lining resin or compound is dissolved in the chemical and then is used to make the seam. The purpose of adding the resin or compound is to increase the viscosity of the liquid for slope work and/or adjust the evaporation rate of the chemical. This viscous liquid is applied between the two opposing surfaces to be bonded. After a few seconds, pressure is applied to make complete contact. Chemical adhesive seams make use of a dissolved bonding agent (an adherent) in the chemical or bodied chemical which is left after the seam has been completed and cured. The adherent thus becomes an additional element in the system. Contact adhesives are applied to both mating surfaces. After reaching the proper degree of tackiness, the two sheets are placed on top of one another, followed by application of roller pressure. The adhesive forms the bond and is an additional element in the system.

Other emerging seaming methods use ultrasonic, electrical conduction and magnetic induction energy sources. Since these methods are in the developmental stage, they will not be described further in this document. See EPA (1991) for further details.

In order to gain an overview as to which seaming methods are used for the various thermoplastic geomembranes described in this document, Table 3.3 is offered. It is generalized, but it is used to introduce the primary seaming methods versus the type of geomembrane that is customarily seamed by that method.

Table 3.3 Possible Field Seaming Methods for Various Geomembranes Listed in this Manual

Type of Seaming Method	Type of Geomembrane					
	HDPE	VLDPE	Other PE	PVC	CSPE-R	Other Flexible
extrusion (fillet and flat)	A	A	A	n/a	n/a	A
thermal fusion (hot wedge and hot air)	A	A	A	A	A	A
chemical (chemical and bodied chemical)	n/a	n/a	n/a	A	A	A
adhesive (chemical and contact)	n/a	n/a	n/a	A	A	A

Note: A = method is applicable
n/a = method is "not applicable"

3.4.2 Details of Field Seaming Methods

Full details of field seaming methods for the edges and ends of geomembrane rolls or panels has recently been described in EPA Technical Guidance Document, EPA/530/SW-91/051, entitled: "Inspection Techniques for the Fabrication of Geomembrane Seams". In this document (EPA, 1991) are separate chapters devoted to the following field seaming methods.

- extrusion fillet seams

- extrusion flat seams
- hot wedge seams
- hot air seams
- chemical and bodied chemical fused seams
- chemical adhesive seams

There is also a section on emerging technologies for geomembrane seaming. The interested reader should consult this document for details regarding all of these seaming methods.

Whenever the plans and specifications are not written around a particular seaming method the actual method which is used becomes a matter of choice for the installation contractor. As seen in Table 3.3, there are a number of available choices for each geomembrane type. Furthermore, even when the installation contractor selects the particular seaming method to be used, its specific details are rarely stipulated even in the specification or CQA documents. This is to give the installation contractor complete latitude in selecting seaming temperatures, travel rates, mechanical roller pressures, chemical type, tack time, hand rolling pressure, etc. The role of the plans, specifications and CQA documents is to adequately provide for destructive tests (on test strips and on production seams) and nondestructive tests (on production seams) to assure that the seams are fabricated to the highest quality and uniformity and are in compliance with the project's documents.

This is not to say that the specification never influences the type of seaming method. For example, if the specifications call for a nondestructive constant air pressure test to be conducted, the installation contractor must use a thermal fusion technique like the dual hot wedge or dual hot air methods since they are the only methods that can produce such a seam.

3.4.3 Test Strips and Trial Seams

Test strips and trial seams, also called qualifying seams, are considered to be an important aspect of CQC/CQA procedures. They are meant to serve as a prequalifying experience for personnel, equipment and procedures for making seams on the identical geomembrane material under the same climatic conditions as the actual field production seams will be made. The test strips are usually made on two narrow pieces of excess geomembrane varying in length between 1.0 to 3.0 m (3 to 10 ft.), see Fig. 3.20. The test strips should be made in sufficient lengths, preferably as a single continuous seam, for all required testing purposes.

The goal of these test strips is to reproduce all aspects of the actual production field seaming activities intended to be performed in the immediately upcoming work session so as to determine equipment and operator proficiency. Ideally, test strips can be used to estimate the quality of the production seams while minimizing damage to the installed geomembrane through destructive mechanical testing. Test strips are typically made every 4 hours (for example, at the beginning of the work shift and after the lunch break). They are also made whenever personnel or equipment are changed and when climatic conditions reflect wide changes in geomembrane temperature or when other conditions occur that could affect seam quality. These details should be stipulated in the contract specifications or CQA documents.

The destructive testing of the test strips should be done as soon as the installation contractor feels that the strength requirements of the contract specification or CQA documents can be met. Thus it behooves the contractor to have all aspects of the test strip seam fabrication in complete working order just as would be done in the case of fabricating production field seams. For extrusion and thermal fusion seams, destructive testing can be done as soon as the seam cools. For chemical fusion and adhesive seams this could take several days and the use of a field oven to accelerate the curing of the seam is advisable.

Figure 3.20 - Fabrication of a Geomembrane Test Strip

From two to six test specimens are cut from the test strip using a 25 mm (1.0 in. wide die). They are selected at random by the CQA inspector. The specimens are then tested in both peel and shear using a field tensiometer, see Fig. 3.21. (Generally peel tests are more informative in assessing the quality of the seam). If any of the test specimens fail, a new test strip is fabricated. If additional specimens fail, the seaming apparatus and seamer should not be accepted and should not be used for seaming until the deficiencies are corrected and successful trial welds are achieved. The CQA inspector should observe all trial seam procedures and tests. If the specimens pass, seaming operations can move directly to production seams in the field. Pass/fail criteria for destructive seam tests will be described in Section 3.5.

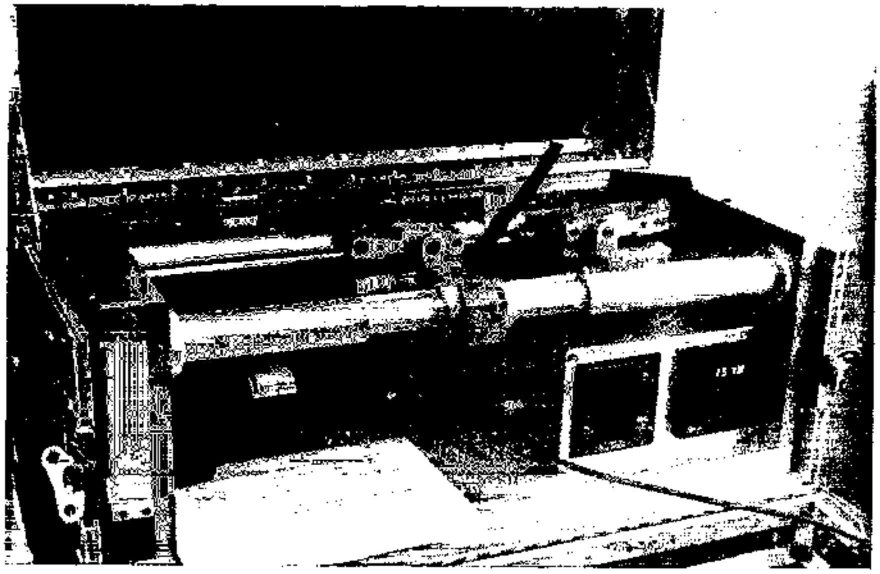


Figure 3.21 - Photograph of a Field Tensiometer Performing a Geomembrane Seam Test

The flow chart illustrated in Fig. 3.22 gives an idea of the various decisions that can be reached depending upon the outcome of destructive tests on test strip specimens. Here it is seen that failed test strips are linked to an increased frequency of destructive tests to be taken on production field seams made during the time interval between making the test strip and its testing. Furthermore, it is seen that there are only two chances at making adequate test strips before production field seaming is stopped and repairs are initiated. These details should be covered in either the project specification or the CQA documents.

Some specification or CQA document items regarding the fabrication of geomembrane seam test strips include the following:

1. The frequency of making test strips should be clearly stated. Typically this is at the beginning of the day, after the noon break and whenever changed conditions are encountered, e.g., changes in weather, equipment, personnel.

2. The CQA Engineer should have the option of requesting test strips of any field seaming crew or device at any time.

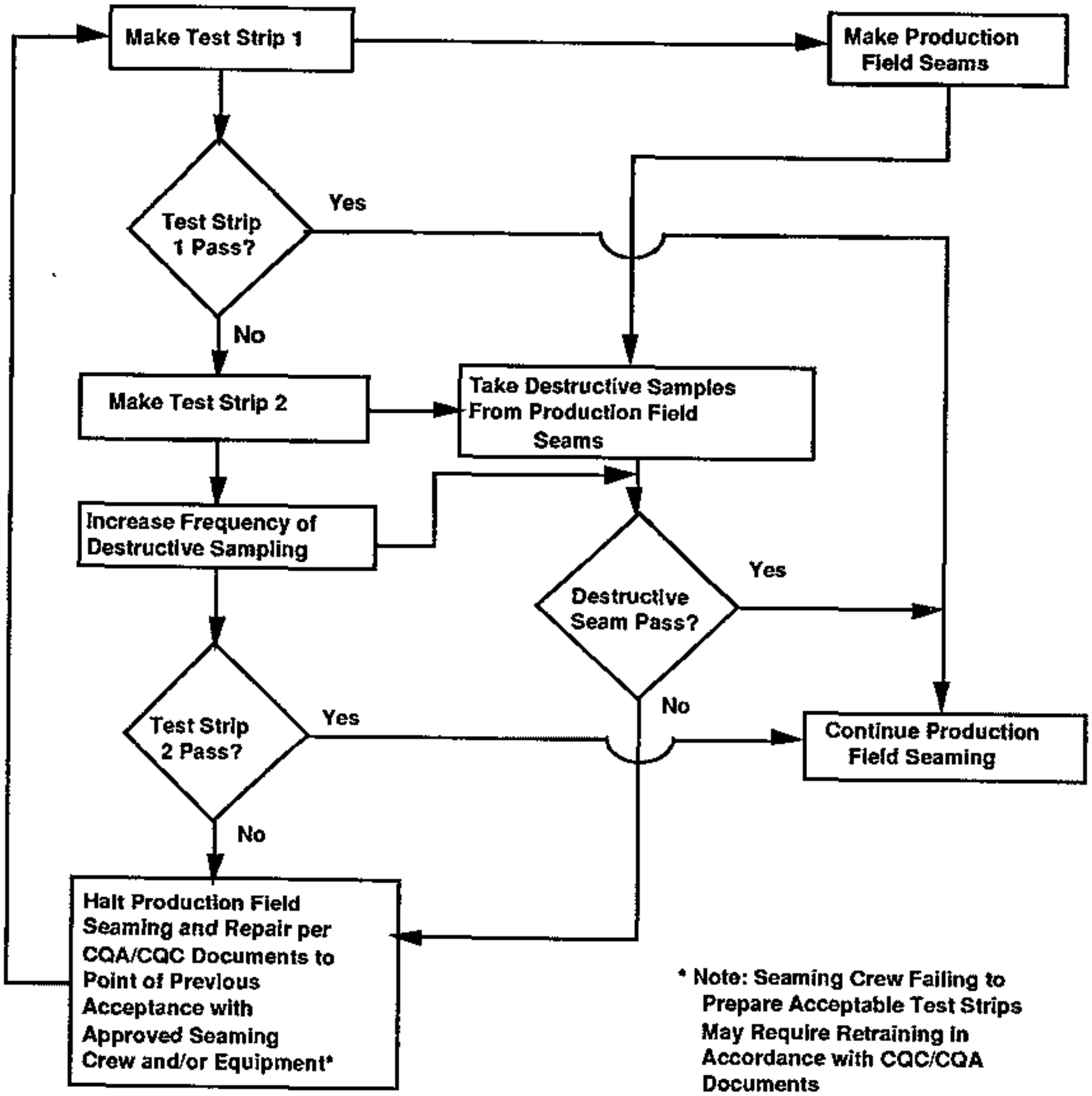


Figure 3.22 - Test Strip Process Flow Chart

3. The procedure for sampling and evaluating the field test strip samples should be clearly outlined, i.e., the number of peel and shear test specimens to be cut and tested from the test strip sample, the rate of testing and what the required strength values are in these two different modes of testing.

4. The fabrication of the field test strip and testing of test specimens should be observed by the CQA personnel.

5. The time for testing after the test strip is fabricated varies between seam types. For extrusion and fusion fabricated seams, the testing can commence immediately after the polymer cools to ambient temperature. For chemical fusion and adhesive fabricated seams, the testing must wait until adequate curing of the seam occurs. This can take as long as 1 to 7 days. During this time all production seaming must be tracked and documented.

6. Accelerated oven curing of chemical and adhesive fabricated seams is acceptable so as to hasten the curing process and obtain test results as soon as possible. GRI Test Method GM-7 can be used for this purpose.

7. The required inspection protocol and implications of failed test specimens from the test strips must be clearly stated. The protocol outlined in Fig. 3.22 is suggested.

8. Field test strips are usually discarded after the destructive test specimens are removed and tested. If this is not the case, it should be clearly indicated who receives the test strip samples and what should be the utilization (if any) of these samples.

3.5 Destructive Test Methods for Seams

The major reason that plans and specifications do not have to be specific about the type of seaming methods and their particular details is that geomembrane seams can be readily evaluated for their quality by taking samples and destructively testing them either at the job site or in a timely manner at a testing laboratory thereafter.

3.5.1 Overview

By destructively testing geomembrane seams it is meant to actually cut out (i.e., to sample) and remove a portion of the completed production seam, and then to further cut the sample into appropriately sized test specimens. These specimens are then tested according to a specified procedure to failure or to yield depending upon the type of geomembrane.

A possible procedure is to select the sampling location and cut two closely spaced 25 mm (1.0 in.) wide test specimens from the seam. The distance between these two test specimens is defined later. The individual specimens are then tested in a peel mode using a field tensiometer (recall Fig. 3.21). If the results are acceptable, the complete seam between the two field test specimens is removed and properly identified and distributed. If either test specimen fails, two new locations on either side of the failed specimen(s) are selected until acceptable seams are located. The seam distance between acceptable seams is usually repaired by cap-stripping but other techniques are also possible. The exact procedure must be stipulated in the specifications or CQA document.

The length dimension of the field seam sample between the two test specimens just described varies according to whatever is stipulated in the plans and specifications, or in accordance with the CQA documents. Some common options are to sample the seam for a distance of either 36 cm (14 in.), 71 cm (28 in.) or 106 cm (42 in.) along its length. Since the usual destructive seam tests are either shear or peel tests and both types are 25 mm (1.0 in.) wide test specimens, this allows for approximately 10, 20 or 30 tests (half shear and half peel) to be conducted on the respective lengths cited above. The sample width perpendicular to the seam is usually 30 cm (12 in.) with the seam being centrally located within this dimension.

The options of seam sample length between the two peel test specimens mentioned above that are seen in various plans, specifications, and CQA documents, are as follows:

- A 36 cm (14 in.) sample is taken from the seam and cut into 5 shear and 5 peel specimens. The tests are conducted in the field or at a remote laboratory by, or under the direction of, the responsible CQA organization.
- A 71 cm (28 in.) long sample is taken from the seam and cut in half. One half is further cut into 5 shear and 5 peel test specimens which are tested in the field or at a remote laboratory by the CQC organization (usually the installation contractor). The other half is sent to a remote laboratory for testing by the CQA organization who also does 5 shear and 5 peel tests. Alternatively, sometimes only the CQA organization does the testing and the second half of the sample is left intact and archived by the owner/operator.
- A 106 cm (42 in.) long sample is taken from the seam and cut into three individual 36 cm (14 in.) samples. Individual samples go to the CQC organization, the CQA organization and the owner/operator. The CQC and CQA organizations each cut their respective samples into 5 shear and 5 peel test specimens and conduct the appropriate tests immediately. The remaining sample is archived by the owner/operator.

Whatever is the strategy for taking samples from the production seams for destructive testing it must be clearly outlined in the contract plans and specifications and further defined and/or corroborated in the CQA documents.

Obviously, the hole created in the production seam from which the test sample was originally taken must be patched in an appropriate manner. See Fig. 3.23 for such a patched sampling location. Recognize that the seams of such patches are themselves candidates for field sampling and testing. If this is done, one would have the end result of patch on a patch, which is a rather unsightly and undesirable condition.

3.5.2 Sampling Strategies

The sampling of production seams of installed geomembranes represents a dilemma of major proportions. Too few samples results in a poor statistical representation of the strength of the seam, and too many samples requires an additional cost and a risk of having the necessary repair patches being problems in themselves. Unfortunately, there is no clear strategy for all cases, but the following are some of the choices that one has in formulating a specification or CQA plan.

Note also that in selecting a sampling strategy the sampling frequency is tied directly into the performance of the test strips described in Section 3.4.3. If the test strips fail during the time that production seaming is ongoing, the frequency of destructive sampling and testing must be increased. The following strategies, however, are for situations where geomembrane seam test strips are being made in an acceptable manner.

3.5.2.1 Fixed Increment Sampling

By far the most commonly used sampling strategy is the "fixed increment sampling" method. In this method, a seam sample is taken at fixed increments along the total length of the seams. Increments usually range from 75 to 225 m (250 to 750 ft) with a commonly specified value being one destructive test sample every 150 m (500 ft). Note that this value can be applied either directly to the record drawings during layout of the seams, to each seaming crew as they progress during the work period, or to each individual seaming device. Once the increment is decided upon, it should be held regardless of the location upon which it falls, e.g., along side slopes, in sumps, etc. Of course, if the CQA documents allow otherwise, exceptions such as avoiding sumps, connections, protrusions, etc. can be made.

Figure 3.23 - Completed Patch on a Geomembrane Seam Which had Previously Been Sampled for Destructive Tests

3.5.2.2 Randomly Selected Sampling

In random selection of destructive seam sample locations it is first necessary to preselect a preliminary estimate of the total number of samples to be taken. This is done by taking the total seam length of the facility and dividing it by an arbitrary interval, e.g., 150 m (500 ft), to obtain the total number of samples that are required. Two choices to define the actual sampling locations are now available: "stratified" random sampling, or "strict" random sampling. The stratified method takes each pre-selected interval (e.g., a 150 m (500 ft) length) and randomly selects a single sample location within this interval. Thus with stratified random sampling one has location variability within a fixed increment (unlike fixed frequency sampling which is always at the exact end of the increment). The strict method uses the total seam length of the facility (or cell) and randomly selects sample locations throughout the facility up to the desired number of samples. Thus with strict random sampling a group of samples may be taken in close proximity to one another, which necessarily leaves other areas with sparse sampling.

There are various ways of randomly selecting the specific location within an interval, e.g., in a specific region of great concern, or within the total project seam length. These are as follows:

- Use a random number generator from statistical tables to predetermine the sampling locations within each interval or for the entire project.
- Use a programmable pocket calculator with a random number generator program to select the sampling location in the field for each interval or for the entire project.
- Use a random number obtained by simply multiplying two large numbers together to form an 8-digit result. A pocket calculator with an adequate register will be necessary. The center two digits in such a procedure are quite randomly distributed and can be used to obtain the sampling location. For example, multiplication of the following two numbers "4567" by 4567" gives 20857489 where the central two digits, i.e., the "57", are used to select the location within the designated sampling interval. If this interval were 500 ft., the sampling location within it would be at 0.57 x 500 = 285 ft. from the beginning of the interval. The next location of the sample would require a new calculation resulting in a different central two-digit number somewhere within the next 500 ft. sampling interval and would be located in a similar fashion.

3.5.2.3 Other Sampling Strategies

There are two other sampling strategies which might be selected in determining how many destructive seam samples should be taken. Both are variable strategies in that repeated acceptable seam tests are rewarded by requiring fewer samples and repeated failures are penalized by requiring more frequent samples. These two strategies are called the "method of attributes" and the use of "control charts". Both set upper and lower bounds which require either fewer or more frequent testing than the initially prescribed sampling frequency. Each of these methods are described fully in Richardson (1992).

Whatever the sampling strategy used, it should never limit or prohibit the ability to select a destructive seam sample from a suspect area. This should ultimately be an option left to the CQA engineer.

3.5.3 Shear Testing of Geomembrane Seams

Shear testing of specimens taken from field fabricated geomembrane seams represents a reasonably simulated performance test. The possible exception is that a normal stress is not applied to the surfaces of the test specimen thus it is an "unconfined" tension test. A slight rotation may be induced during tensioning of the specimen, making the actual test results tend toward conservative values. The configuration of a shear test in a tension testing machine is shown in Fig. 3.24.

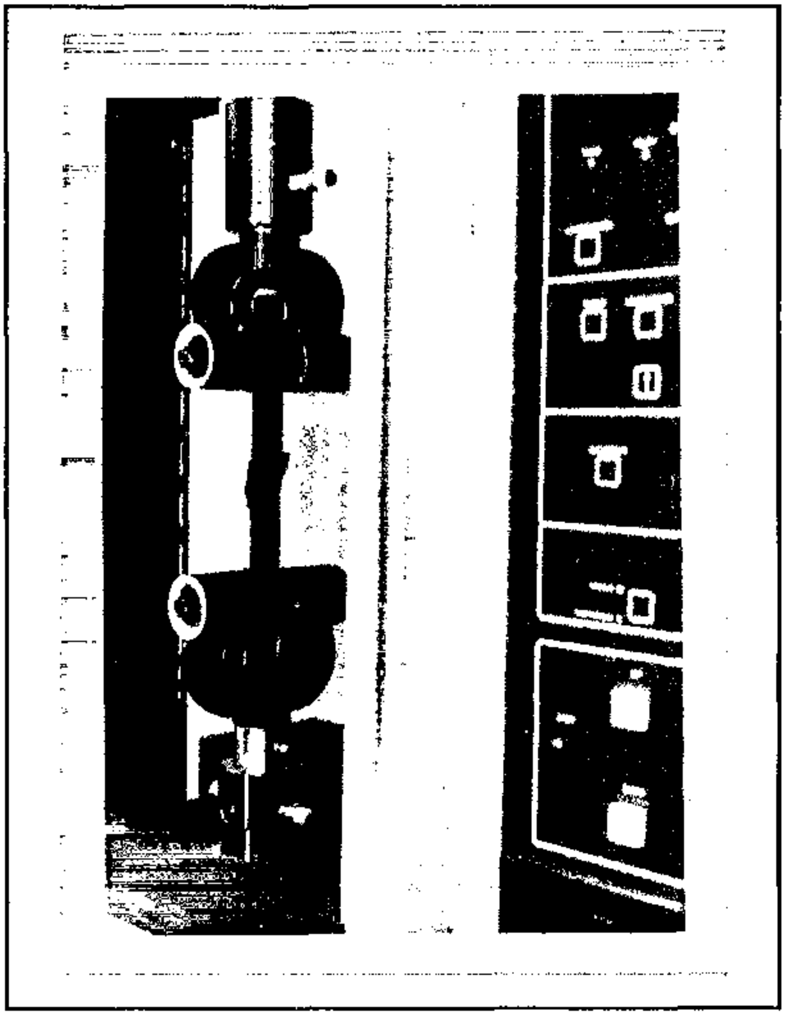


Figure 3.24 - Shear Test of a Geomembrane Seam Evaluated in a CQC/CQA Laboratory Environment

Commonly recommended shear tests for HDPE, PVC, CSPE-R and EIA-R seams, along with the methods of testing the unseamed sheet material in tension, are given in Table 3.4. The VLDPE data presented was included in a way so as to parallel the HDPE testing protocol except for the strain rate values which are faster since breaking values, rather than yield values are required. There is no pronounced yield value when tensile testing VLDPE geomembranes.

Table 3.4 Recommended Test Method Details for Geomembrane Seams in Shear and in Peel and for Unseamed Sheet

Type of Test	HDPE	VLDPE	PVC	CSPE-R
Shear Test on Seams				
ASTM Test Method	D4437	D4437	D3083	D751
Specimen Shape	Strip	Strip	Strip	Grab
Specimen Width (in.)	1.00	1.00	1.00	4.00 (1.00 grab)
Specimen Length (in.)	6.00 + seam	6.00 + seam	6.00 + seam	9.00 + seam
Gage Length (in.)	4.00 + seam	4.00 + seam	4.00 + seam	6.00 + seam
Strain Rate (ipm)	2.0	20	20	12
Strength (psi) or (ppi)	Force/(1.00×t)	Force/(1.00×t)	Force/(1.00×t)	Force
Peel Test on Seams				
ASTM Test Method	D4437	D4437	D413	D413
Specimen Shape	Strip	Strip	Strip	Strip
Specimen Width (in.)	1.00	1.00	1.00	1.00
Specimen Length (in.)	4.00	4.00	4.00	4.00
Gage Length (in.)	n/a	n/a	n/a	n/a
Strain Rate (ipm)	2.0	20	2.0	2.0
Strength (psi) or (ppi)	Force/(1.00×t)	Force/(1.00×t)	Force/1.00	Force/1.00
Tensile Test on Sheet				
ASTM Test Method	D638	D638	D882	D751
Specimen Shape	Dumbbell	Dumbbell	Strip	Grab
Specimen Width (in.)	0.25	0.25	1.00	4.00 (1.00 Grab)
Specimen Length (in.)	4.50	4.50	6.00	6.00
Gage Length (in.)	1.30	1.30	2.00	3.00
Strain Rate (ipm)	2.0	20	20	12
Strength (psi) or (lb)	Force/(0.25×t)	Force/(0.25×t)	Force/(1.00×t)	Force
Strain (in./in.)	Elong./1.30	Elong./1.30	Elong./2.00	Elong./3.00
Modulus (psi)	From Graph	From Graph	From Graph	n/a

where n/a = not applicable
t = geomembrane thickness
psi = pounds/square inch of specimen cross section
ppi = pounds/linear inch width of specimen
ipm = inches/minute
Force = maximum force attained at specimen failure (yield or break)

Insofar as the shear testing of nonreinforced geomembrane seams (HDPE, VLDPE and PVC), all use a 25 mm (1.0 in.) wide test specimen with the seam being centrally located within the testing grips. For the reinforced geomembranes (CSPE-R and EIA-R) a "grab" test specimen is used. In a grab tension test the specimen is 200 mm (4.0 in.) wide but is only gripped in the central 25 mm (1.0 in.). The test specimen is tensioned, at its appropriate strain rate, until failure occurs. If the seam delaminates (i.e., pulls apart in a seam separation mode), the seam fails in what is called a "non-film tear bond", or non-FTB. In this case, it is rejected as a failed seam. Details on various types of seam failures and on the interpretation of FTB are found in Haxo (1988). Conversely, if the seam does not delaminate, but fails in the adjacent sheet material on either side of the seam, it is an acceptable failure mode, i.e., called a "film tear bond", or FTB, and the seam strength is then calculated.

The seam strength (for HDPE, VLDPE and PVC) is the maximum force attained divided by either the original specimen width (resulting in units of force per unit width), or the original specimen cross sectional area (resulting in units of stress). It is general procedure to use force per unit width as it is an absolute strength value which can be readily compared to other test results. If stress units are desired, one can use the nominal thickness of the geomembrane, or continuously measure the actual thickness of each test specimen. This latter alternative requires considerable time and effort and is generally not recommended. The procedure is slightly different for the reinforced geomembranes (CSPE-R and EIA-R) which use a grab test method. Here the strength is based on the maximum tensile force that can be mobilized and a stress value is not calculated.

The resulting value of seam shear strength is then compared to the required seam strength (which is the usual case) or to the strength of the unseamed geomembrane sheet. If the latter, the procedures for obtaining this value are listed in Table 3.4. In each case the test protocol for seam and sheet are the same, except for HDPE and VLDPE. The sheet strength value for these polyethylene geomembranes are based on a ASTM D-638 "dumbbell-shaped" specimens, although the strength is calculated on the reduced section width. With all of these sheet tension tests, the nominal thickness of the unseamed geomembrane sheet is used for the comparison value. If actual thickness of the sheet is considered, the results will be reflected accordingly. Note, however, that this will require a large amount of additional testing (to get average strength values) and is not a recommended approach.

Knowing the seam shear strength and the unseamed sheet strength (ether by a specified value or by testing), allows for a seam shear efficiency calculation to be made as follows:

$$E_{\text{shear}} = \frac{T_{\text{seam in shear}}}{T_{\text{unseamed sheet}}} (100) \tag{3.1}$$

where

E_{shear} = seam efficiency in shear (%)

T_{seam} = seam shear strength (force or stress units)

T_{sheet} = sheet tensile strength (force or stress units)

The contract plans, specifications or CQA documents should give the minimum allowable seam shear strength efficiency. As a minimum, the guidance listed below can be used whereby percentages of seam shear efficiencies (or values) are listed:

HDPE = 95% of specified minimum yield strength
VLDPE = typically 1200 lb/in^2
PVC = 80%
CSPE-R = 80% (for 3-ply reinforced)
EIA-R = 80%

Generally an additional requirement of a film tear bond, or FTB, will also be required in addition to a minimum strength value. This means that the failure must be located in the sheet material on either side of the seam and not within the seam itself. Thus the seam cannot delaminate.

Lastly, the number of failures allowed per number of tests conducted should be addressed. If sets of 5 test specimens are performed for each field sample, many specifications allow for one failure out of the five tested. If the failure number is larger, then the plans, specifications or CQA documents must be clear on the implications.

When a destructive seam test sample fails, many specifications and CQA documents require two additional samples to be taken, one on each side of the original sample each spaced 3 m (10 ft) from it. If either one of these samples fail, the iterative process of sampling every 3 m (10 ft) is repeated until passing test results are observed. In this case the entire seam between the two successful test samples must be questioned. For example, remedies for polyethylene geomembranes are to cap strip the entire seam or if the seam is made with a thermal fusion method (hot air or hot wedge) to extrude a fillet weld over the outer seam edge. When such repairs are concluded the seams on the cap strip or extrusion fillet weld should be sampled and tested as just described.

Note that elongation of the specimens during shear testing is usually not monitored (although current testing trends are in this direction), the only value under consideration is the maximum force that the seam can sustain. It should also be mentioned that the test is difficult to perform on the inside of the tracks facing the air channel of a dual channel thermal fusion seam. For small air channels the tab available for gripping will be considerably less than that required in test methods as given in Table 3.4. Regarding the testing of the inside or outside tracks (away from the air channel) of a dual channel thermal fusion seam, or even both tracks, the specification or CQA document should be very specific.

3.5.4 Peel Testing of Geomembrane Seams

Peel testing of specimens taken from field fabricated geomembrane seams represent a quality control type of index test. Such tests are not meant to simulate in-situ performance but are very important indicators of the overall quality of the seam. The configuration of a peel test in a tension testing machine is shown in Fig. 3.25.

The recommended peel tests for HDPE, PVC, CSPE-R and EIA-R seams, along with the unseamed sheet material in tension are given in Table 3.4. The VLDPE data was included in a way so as to parallel the HDPE testing protocol.

Insofar as the peel testing of geomembrane seams is concerned, it is seen that all of the geomembranes listed have a 25 mm (1.0 in.) width test specimen. Furthermore, the specimen lengths and strain rate are also equal for all geomembrane types. The only difference is that HDPE and VLDPE use the thickness of the geomembrane to calculate a tensile strength value in stress units, whereas PVC, CSPE-R and EIA-R calculate the tensile strength value in units of force per unit width, i.e., in units of pounds per linear inch of seam.

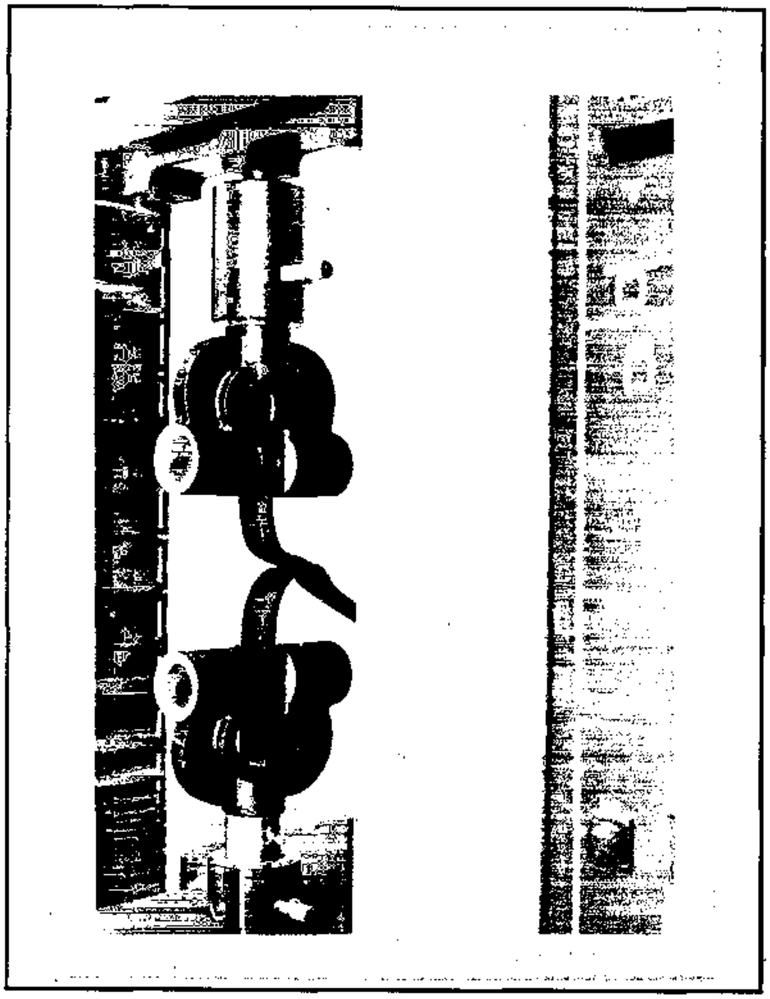


Fig. 3.25 - Peel Test of a Geomembrane Seam Evaluated in a CQC/CQA Laboratory Environment

In a peel test the test specimen is tensioned, at its appropriate strain rate, until failure occurs. If the seam delaminates (i.e., pulls apart in a seam separation mode), it is called a "non-film tear bond or non-FTB", and is recorded accordingly. Conversely, if the seam does not delaminate, but fails in the adjacent sheet material on either side of the seam it is called a "film tear bond or FTB" and the seam strength is calculated. Details on various types of seam failures and on the interpretation of FTB are found in Haxo (1988). The seam strength is the maximum force attained divided by the specimen width (resulting in units of force per unit width), or by the specimen cross sectional area (resulting in units of stress). The former procedure is the most common, i.e., peel strengths are measured in force per unit width units. If stress units are desired the thickness of the geomembrane sheet must be included. The nominal sheet thickness is usually used. If the actual sheet thickness is used, a large amount of thickness measurements will be required to obtain a statistically reliable value. It is not a recommended procedure.

The resulting value of seam peel strength is then compared to a specified value (the usual case) or to the strength of the unseamed geomembrane sheet. The testing procedures for obtaining these values are listed in Table 3.4. It can be seen, however, that only with PVC is the same width test specimen used for peel and sheet testing. For HDPE and VLDPE one is comparing a 1.0 in. uniform width peel test with a dumbbell shaped specimen, while for CSPE-R and EIA-R one is comparing a uniform width peel test with the strength from a grab shaped test specimen. If, however, one does have a specified sheet strength value or a measured value, a seam peel strength efficiency calculation can be made as follows:

$$E_{\text{peel}} = \frac{T_{\text{seam in peel}}}{T_{\text{unseamed sheet}}} (100) \tag{3.2}$$

where

E_{peel} = seam efficiency in peel (%)
T_{seam} = seam peel strength (force or stress units)
T_{sheet} = sheet tensile strength (force or stress units)

The contract plans, specifications or CQA documents should give the minimum allowable seam peel strength efficiency. As a minimum, the guidance listed below can be used whereby percentage peel efficiencies (or values) are listed as follows:

HDPE = 62% of specified minimum yield strength and FTB
VLDPE = typically 1000 lb/in^2
PVC = 10 lb/in.
CSPE-R = 10 lb/in. or FTB
EIA-R = 10 lb/in.

Lastly, the number of failures allowed per number of tests conducted should be addressed. If sets of 5 test specimens are performed for each field sample, many specifications allow for one failure out of the five tested. If the failure number is larger, then the plans, specifications or CQA documents must be clear on the implications.

When a destructive seam test sample fails, many specifications require an additional two samples to be taken, one on each side of the original spaced 3 m (10 ft) from it. If either one of these samples fail the iterative process of sampling every 3 m (10 ft) is repeated until successful samples result. In this case, the entire seam between the last successful test samples must be questioned. Remedies are to cap strip the entire seam or if the seam is HDPE or VLDPE made with a thermal fusion method (hot air or hot wedge) to extrude a fillet weld over the outer seam edge. When this is done the seams on the cap strip or extrusion fillet weld may be sampled and tested as just described.

Note that neither elongation of the specimen nor peel separation, during the test is usually monitored (although current testing trends are in this direction), the only value under consideration is the maximum tensile force that the seam can sustain. It should also be mentioned that both frontward and backward peel tests can be performed thereby challenging both sides of a seam. For dual channel seams, both insides of the tracks facing the air channel can be tested, but due to the narrow width of most air channels the tab available for gripping will be considerably less than that given in Table 3.4. Regarding the testing of the inside or outside tracks (away from the air channel) of a dual channel seam, or even both tracks, the specification or CQA document should be very specific.

3.5.5 General Specification Items

Regarding field sampling of geomembrane seams and their subsequent destructive testing, a specification or CQA document should consider the following items.

1. CQA personnel should observe all production seam sample cutting.
2. All samples should be adequately numbered and marked with permanent identification.
3. All sample locations should be indicated on the geomembrane layout (and record) drawings.
4. The reason for taking the sample should be indicated, e.g., statistical routine, suspicious feature, change in sheet temperature, etc.
5. The sample dimensions should be given insofar as the length of sample and its width. The seam will generally be located along the center of the length of the sample.
6. The distribution of various portions of the sample (if more than one) should be specified.
7. The number of shear and peel tests to be conducted on each sample (field tests and laboratory tests) should be specified.
8. The specifics of conducting the shear and peel tests should be specified, e.g., use of actual sheet thickness, or of nominal sheet thickness. The following are suggested ASTM test methods for each geomembrane type:

Geomembrane	Seam Shear Test	Seam Peel Test	Sheet Test
HDPE	D-4437	D-4437	D-638
VLDPE	D-4437	D-4437	D-638
PVC	D-3083	D-413	D-882
CSPE-R	D-751	D-413	D-751
EIA-R	D-751	D-751	D-751

9. The CQA personnel should witness all field tests and see that proper identification and details accompany the test results. Details should be provided in the CQA documents. Such details as follows are often required.

- date and time
- ambient temperature
- identification of seaming unit, group or machine
- name of master seamer
- welding apparatus temperature and pressure, or chemical type and mixture
- pass or fail description
- a copy of the report should be attached to the remaining portion of the sample

10. The CQA personnel should verify that samples sent to the testing laboratory are properly marked, packaged and shipped so as not to cause damage.

11. Results of the laboratory tests should come to the CQA Engineer in a stipulated time. For extrusion and thermally bonded seams, verbal test results are sometimes required with 24 to 72 hours after the laboratory receives the samples. For chemically bonded seams, the time frame is longer and depends on whether or not accelerated heat curing of the seams is required. In all cases, the CQA Engineer must inform the Owner's representative of the results and make appropriate recommendations.

12. The procedures for seam remediation in the event of failed destructive tests should be clear and unequivocal. Options usually are (a) to repair the entire seam between acceptable sampling locations, or (b) to retest the seam on both sides in the vicinity of the failed sample. If they are acceptable only this section of the seam is repaired. If they are not, a wider spaced set of samples are taken and tested.

13. Repairs to locations where destructive samples were removed should be stipulated. These repairs are specific to the type of geomembrane and to the seaming method. Guidance in this regard is available in EPA (1991).

14. Each repair of a patched seam where a test sample had been removed should be verified. This is usually done by an appropriate nondestructive test. If, however, the sampling strategy selected calls for a destructive test to be made at the exact location of a patch it should be accommodated. Thus the final situation will require a patch to be placed on an earlier patch. If this (unsightly) detail is to be avoided, it should be stated outright in the specifications or CQA document.

15. The time required to retain and store destructive test samples on the part of the CQC and CQA organizations should be stipulated.

3.6 Nondestructive Test Methods for Seams

3.6.1 Overview

Although it is obviously important to conduct destructive tests on the fabricated seams, such tests do not give adequate information on the continuity and completeness of the entire seam between sampling locations. It does little good if one section of a seam meets the specification requirements, only to have the section next to it missed completely by the field-seaming crew.

Thus continuous methods of a nondestructive testing (NDT) nature will be discussed here. In each of these methods the goal is to validate 100% of the seams or, at minimum, a major percentage of them.

3.6.2 Currently Available Methods

The currently available NDT methods for evaluating the adequacy of geomembrane field seams are listed in Table 3.5 in the order that they will be discussed.

The *air lance* method uses a jet of air at approximately 350 kPa (50 lb/in.^{2}) pressure coming through an orifice of 5 mm (3/16 in.) diameter. It is directed beneath the upper edge of the overlapped seam and is held within 100 mm (4.0 in.) from the edge of the seamed area in order to detect unbonded areas. When such an area is located, the air passes through the opening in the seam causing an inflation and fluttering in the localized area. A distinct change in sound emitted can generally be heard. The method works best on relatively thin, less than 1.1 mm (45 mils), flexible geomembranes, but works only if the defect is open at the front edge of the seam, where the air jet is directed. It is essentially a geomembrane installer's method to be used in a construction quality control (CQC) manner.

The *mechanical point stress or "pick" test* uses a dull tool, such as a blunt screw-driver, under the top edge of a seam. With care, an individual can detect an unbonded area, which would be easier to separate than a properly bonded area. It is a rapid test that obviously depends completely on the care and sensitivity of the person doing it. Detectability is similar to that of using the air lance, but both are very operator-dependent. This test is to be performed only by the geomembrane installer as a CQC method. Design or inspection engineers should not use the pick test but rather one or more of the techniques to be discussed later.

The *pressurized dual seam* method was mentioned earlier in connection with the dual hot wedge or dual hot air thermal seaming methods. The air channel that results between the dual bonded tracks is inflated using a hypodermic needle and pressurized to approximately 200 kPa (30 lb/in.^{2}). There is no limit as to the length of the seam that is tested. If the pressure drop is within an allowable amount in the designated time period (usually 5 minutes), the seam is acceptable; if a unacceptable drop occurs, a number of actions can be taken:

- The distance can be systematically halved until the leak is located.
- The section can be tested by some other leak detection method.
- An extrusion fillet weld can be placed over the entire edge.
- A cap strip can be seamed over the entire edge.

Details of the test can be found in GRI Test Method GM6. The test is an excellent one for long, straight-seam lengths. It is generally performed by the installation contractor, but usually with CQA personnel viewing the procedure and documenting the results.

Table 3.5 - Nondestructive Geomembrane Seam Testing Methods, Modified from Richardson and Koerner (1988)

Nondestructive Test Method	Primary User		General Comments					
	CQC	CQA	Cost of Equipment	Speed of Tests	Cost of Tests	Type of Result	Recording Method	Operator Dependency
1. air lance	yes	---	$200	fast	low	yes-no	manual	high
2. mechanical point (pick) stress	yes	---	nil	fast	nil	yes-no	manual	very high
3. dual seam (positive pressure)	yes	---	$200	fast	moderate	yes-no	manual	low
4. vacuum chamber (negative pressure)	yes	yes	$1000	slow	very high	yes-no	manual	moderate
5. electric wire	yes	yes	$500	fast	nil	yes-no	manual	high
6. electric field	yes	yes	$20,000	slow	high	yes-no	manual and automatic	low
7. ultrasonic pulse echo	---	yes	$5000	moderate	high	yes-no	automatic	moderate
8. ultrasonic impedance	---	yes	$7000	moderate	high	qualitative	automatic	unknown
9. ultrasonic shadow	---	yes	$5000	moderate	high	qualitative	automatic	moderate

The *vacuum chamber (box)* method uses a box up to 1.0 m (3 ft) long with a transparent top that is placed over the seam; a vacuum of approximately 20 kPa (3 lb/in.^{2}) is applied. When a leak is encountered the soapy solution originally placed over the seam shows bubbles thereby reducing the vacuum. This is due to air entering from beneath the geomembrane and passing through the unbonded zone. The test is slow to perform (a 10 sec dwell time is currently recommended) and is often difficult to make a vacuum-tight joint at the bottom of the box where it passes over the seam edges. Due to upward deformations of the liner into the vacuum box, only geomembrane thickness greater than 1.0 mm (40 mils) should be tested in this manner. For thinner, more flexible geomembranes an open grid wire mesh can be used along the bottom of the box to prevent uplift. It should also be noted that vacuum boxes are the most common form of nondestructive test currently used by design engineers and CQA inspectors for polyethylene geomembranes. It should be recognized that 100% of the field seams cannot be inspected by this method. The test cannot cover portions of sumps, anchor trenches, and pipe penetrations with any degree of assurance. The method is also very awkward to use on side slopes. The adequate downward pressure required to make a good seal is difficult to mobilize since it is usually done by standing on top of the box.

Electric sparking (not mentioned in Table 3.5) is a technique used to detect pinholes in thermoplastic liners. The method uses a high-voltage (15 to 30 kV) current, and any leakage to ground (through an opening or hole) results in sparking. The method is being investigated for possible field use. The *electric wire* method places a copper or stainless steel wire between the overlapped geomembrane region and actually embeds it into the completed seam. After seaming, a charged probe of about 20,000 volts is connected to one end of the wire and slowly moved over the length of the seam. A seam defect between the probe and the embedded wire results in an audible alarm from the unit.

The *electric field* test utilizes a potential which is applied across the geomembrane by placing a positive electrode in water within the geomembrane and a ground electrode in the subgrade or in the sump of the leak detection system. A current will only flow between the electrodes through a hole (leak) in the geomembrane. The potential gradients in the ponded water are measured by "walking" the area with a previously calibrated probe. The operator walks along a calibration grid layout and identifies where anomalies exist. Holes less than 1 mm diameter can be identified. These locations can be rechecked after the survey is completed by other methods, such as the vacuum box. In deep water, or for hazardous liquids, a remote probe can be dragged from one side of the impoundment to the other across the surface of the geomembrane. On side slopes that are not covered by water, a positively charged stream of water can be directed onto the surface of the geomembrane. When the water stream encounters and penetrates a hole, contact with the subgrade is made. At this point current flow is indicated, thus locating the hole. Pipe penetrations through the geomembrane and soil cover that goes up the side slope and contacts the subgrade reduce the sensitivity of the method.

The last group of nondestructive test methods noted in Table 3.5 can collectively be called *ultrasonic methods*. A number of ultrasonic methods are available for seam testing and evaluation. The *ultrasonic pulse echo* technique is basically a thickness measurement technique and is only for use with nonreinforced geomembranes. Here a high-frequency pulse is sent into the upper geomembrane and (in the case of good acoustic coupling and good contact between the upper and lower sheets) reflects off of the bottom of the lower one. If, however, an unbonded area is present, the reflection will occur at the unbonded interface. The use of two transducers, a pulse generator, and a CRT monitor are required. It cannot be used for extrusion fillet seams, because of their nonuniform thickness. The *ultrasonic impedance plane* method works on the principle of acoustic impedance. A continuous wave of 160 to 185 kHz is sent through the seamed geomembrane, and a characteristic dot pattern is displayed on a CRT screen. Calibration of the dot pattern is required to signify a good seam; otherwise, it is not. The method has potential for all types of geomembranes but still needs additional developmental work. The *ultrasonic shadow method* uses two roller transducers: one sends a signal into the upper geomembrane and the other receives the signal from the lower geomembrane on the other side of the seam (Richardson and Koerner, 1988). The technique can be used for all types of seams, even those in difficult locations, such as around manholes, sumps, appurtenances, etc. It is best suited for semicrystalline geomembranes, including HDPE, and will not work for scrim-reinforced liners.

3.6.3 Recommendations for Various Seam Types

The various NDT methods listed in Table 3.5 have certain uniqueness and applicability to specific seam and geomembrane types. Thus a specification should only be framed around the particular seam type and geomembrane type for which it has been developed. Table 3.6 gives guidance in this regard. Even within Table 3.6, there are certain historical developments. For example, the air lance method is used routinely on the flexible geomembranes seamed by chemical methods, whereas the vacuum chamber method is used routinely on the relatively stiff HDPE geomembranes. Also to be noted is that the dual seam can technically be used on all geomembranes, but only when they are seamed by a dual track thermal fusion method, i.e., by hot wedge or hot air seaming methods. Thus by requiring such a dual seam pressure test method one mandates the type of seam which is to be used by the installation contractor.

Lastly, it should be mentioned that only three of the nine methods listed in Table 3.5 are used routinely at this point in time. They are the air lance, dual seam and vacuum chamber methods. The others are either uniquely used by the installation contractor (pick test and electric wire), or are in the research and development stage (electric current and the various ultrasonic test methods).

3.6.4 General Specification Items

Regarding field evaluation of geomembrane seams and their nondestructive testing, a specification or CQA document should consider the following items:

1. The purpose of nondestructive testing should be clearly stated. For example, nondestructive testing is meant to verify the continuity of field seams and not to quantify seam strength.

2. Generally nondestructive testing is conducted as the seaming work progresses or as soon as a suitable length of seam is available.

3. Generally nondestructive testing of some type is required for 100% of the field seams. For geomembranes supplied in factory fabricated panels, the factory seams may, or may not, be specified to be nondestructively tested in the field. This decision depends on the degree of MQC (and MQA) required on factory fabricated seams.

4. The specification should recognize that the same type of nondestructive test cannot be used in every location. For example, in sumps and at pipe penetrations the dual air channel and vacuum box methods may not be usable.

5. It must be recognized that there are no current ASTM Standards on any of the NDT methods presented in Table 3.5 although many are in progress. Thus referencing to such consensus documents is not possible. For temporary guidance, there is a GRI Standard available for dual seam air pressure test method, GRI GM-6.

6. CQA personnel should observe all nondestructive testing procedures.
7. The location, data, test number, name of test person and outcome of tests must be recorded.
8. The Owner's representative should be informed of any deficiencies.
9. The method of repair of deficiencies found by nondestructive testing should be clearly outlined in the specifications or CQA documents, as should the retesting procedure.

Table 3.6 Applicability Of Various Nondestructive Test Methods To Different Seam Types And Geomembrane Types

NDT Method	Seam Types*	Geomembrane Types
1. air lance	C, BC, Chem A, Cont. A	all except HDPE
2. mechanical point stress	all	all
3. dual seam	HW, HA	all
4. vacuum chamber	all	all
5. electric wire	all	all
6. electric current	all	all
7. ultrasonic pulse echo	HW, HA C, BC, Chem. A, Cont. A	HDPE, VLDPE, PVC
8. ultrasonic impedance	HW, HA C, BC, Chem. A, Cont. A	HDPE, VLDPE, PVC
9. ultrasonic shadow	E Fil., E Flt., HW, HA	HDPE, VLDPE

*E Fil. = extrusion fillet
E Flt. = extrusion flat
HW = hot wedge
HA = hot air
C = chemical
BC = bodied chemical
Chem. A = chemical adhesive
Cont. A = contact adhesive

3.7 Protection and Backfilling

The field deployed and seamed geomembrane must be backfilled with soil or covered with a subsequent layer of geosynthetics in a timely manner after its acceptance by the CQA personnel. If the covering layer is soil, it will generally be a drainage material like sand or gravel depending upon the required permeability of the overlying layer. Depending upon the particle size, hardness and angularity of this soil, a geotextile or other type of protection layer may be necessary. If the covering layer is a geosynthetic, it will generally be a geonet or geocomposite drain, which is usually placed directly upon the geomembrane. This is obviously a critical step since geomembranes are relatively thin materials with puncture and tear strengths of finite proportions. Specifications should be very clear and unequivocal regarding this final step in the installation survivability of geomembranes.

3.7.1 Soil Backfilling of Geomembranes

There are at least three important considerations concerning soil backfilling of geomembranes: type of soil backfill material, type of placement equipment and considerations of slack in the geomembrane.

Concerning the type of soil backfilling material; its particle size characteristics, hardness and angularity are important with regard to the puncture and tear resistance of the geomembrane. In general, the maximum soil particle size is very important, with additional concerns over poorly graded soils, increased angularity and increased hardness being of significance. Past research on puncture resistance of geomembranes has shown that HDPE and CSPE-R geomembranes are more sensitive to puncture than are VLDPE and PVC geomembranes for conventional thicknesses of the respective types of geomembranes. Using truncated cones in laboratory tests to simulate the puncturing phenomenon (Hullings and Koerner, 1991), the critical cone height values which were obtained are listed in Table 3.7. It should be cautioned, however, that these values are not based on actual soil subgrades, nor on geostatic type stresses. The values are meant to give relative performance between the different geomembrane types.

Table 3.7. Critical Cone Heights For Selected Geomembranes In Simulated Laboratory Puncture Studies (Richardson and Koerner, 1988)

Geomembrane Type	Geomembrane Thickness		Critical Cone Height	
	mm	mil	mm	inch
HDPE	1.5	60	12	0.50
VLDPE	1.0	40	89	3.50
PVC	0.5	20	70	2.75
CSPE-R	0.9	36	15	0.60

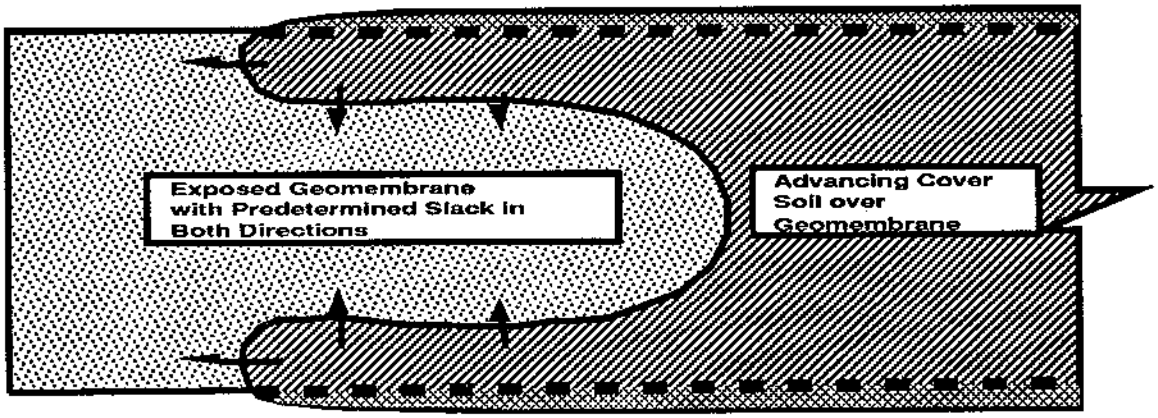
Although the truncated cone hydrostatic test is an extremely challenging index-type test, the data of Table 3.7 does not reflect creep and/or stress relaxation of the geomembrane. In reviewing numerous CQA documents it appears that the maximum backfill particle size for use with HDPE and CSPE-R geomembranes should not exceed 12-25 mm (0.5-1.0 in.). VLDPE and PVC geomembranes appear to be able to accommodate larger soil backfill particle sizes. If the soil particle size must exceed the approximate limits given (e.g., for reasons of providing high permeability in a drainage layer), then a protection material must be placed on top of the geomembrane and beneath the soil. Geotextiles, as well as other protection materials, have been used in this regard. New materials, e.g., recycled fiber geotextiles and rubber matting, are being evaluated.

Concerning the type of placement equipment, the initial lift height of the backfill soil is very important. (Note that construction equipment should never be allowed to move directly on any deployed geomembrane. This includes rubber tired vehicles such as automobiles and pickup trucks but does not include light weight equipment like all-terrain vehicles (ATV's). The minimum initial lift height should be determined for the type of placement equipment and soil under consideration, however, 150 mm (6 in.) is usually considered to be a minimum. Between this value and approximately 300 mm (12.0 in.), low ground pressure placement equipment should be specified. Ground contact pressure equipment of less than 35 kPa (5.0 lb/in^2) is recommended. For lift heights of greater than 300 mm (12.0 in.), proportionately heavier placement equipment can be used.

Placement of soil backfilling should proceed from a stable working area adjacent to the deployed geomembrane and gradually progress outward. Soil is never to be dropped from dump trucks or front end loaders directly onto the geomembrane. The soil should be pushed forward in an upward tumbling action so as not to impact directly on the geomembrane. It should be placed by a bulldozer or front end loader, never by a motor grader which would necessarily have its front wheels riding directly on the geomembrane. Sometimes "fingers" of backfill are pushed out over the geomembrane with controlled amounts of slack between them. Figure 3.26 shows a sketch and photograph of this type of soil covering placement. Backfill is then widened so as to connect the "fingers", with the controlled slack being induced into the geomembrane. This procedure is at the discretion of the design engineer and depends on site specific materials and conditions.

If a predetermined amount of slack is to be placed in the geomembrane, the temperature of the geomembrane itself during backfilling is important and should be contrasted against the minimum service temperature that the geomembrane will eventually experience. This difference in temperature, assuming the geomembrane temperature at the time of backfilling is higher than the minimum service temperature, is multiplied by the distance between backfilling "fingers" and by the coefficient of thermal expansion/ contraction of the particular geomembrane. Coefficients of thermal expansion/contraction found in the literature are given in Table 3.8. Note, however, that the coefficient of expansion/contraction of the site specific geomembrane should be available for such calculations.

While many geomembrane polymers fall in the same general range of coefficient of thermal expansion/contraction (as seen in Table 3.8), it is the stiff and relatively thick geomembranes, which are troublesome during backfilling. Here the slack accumulates in a wave which should not be allowed to crest over on itself, lest a fold is trapped beneath the backfill. In such cases, the "fingers" of backfilling must be relatively close together. If the situation becomes unwieldy due to very high geomembrane temperature, the backfilling should temporarily cease until the ambient temperature decreases. This will have the effect of requiring less slack to be placed in the geomembrane.



Note: Arrows Indicate Advancement of Cover Soil Over Geomembrane

Figure 3.26 - Advancing Primary Leachate Collection Gravel in "Fingers" Over the Deployed Geomembrane

Table 3.8 - Coefficients Of Thermal Expansion/Contraction Of Various Nonreinforced Geomembrane Polymers (Various References)*

Polymer Type	Thermal linear expansivity x 10^{-5} per 1°F	per 1°C
Polyethylene		
high density	7-12	12-22
medium density	6-8	11-15
low density	5-7	9-13
very low density	11-16	20-30
Polypropylene	3-5	5-9
Polyvinyl chloride		
unplasticized	3-10	5-18
plasticized	4-14	7-25

*Values are approximate and change somewhat with the particular formulation and with the actual temperature range over which the values are measured.

3.7.2 Geosynthetic Covering of Geomembranes

Various geosynthetic materials may be called upon to cover the deployed and seamed geomembrane. Often a geotextile or a geonet will be the covering material. Sometimes, however, it will be a geogrid (for cover soil reinforcement on slopes) or even a drainage geocomposite (again on slopes to avoid instability of natural drainage soils). As with the previous discussion on soil covering, no construction vehicles of any type should be allowed to move directly on the geomembrane (or any other geosynthetic for that matter). Generators, low tire inflation ATV's, and other seaming related equipment are allowed as long as they do not damage the geomembrane. As a result, the movement of large rolls of geotextile or geonet becomes very labor intensive. Proper planning and sequencing of the operations is important for logistical control. The geosynthetic materials are laid directly on the geomembrane with no bonding of any type to the geomembrane being allowed. For example, thermally fusing of a geonet to a geomembrane should not be permitted. Temperature compensation (as described earlier) should be added based on material characteristics.

The geosynthetics placed above the geomembrane will either be overlapped (as with some geotextiles), sewn (as with other geotextiles), connected with plastic ties (as with geonets), mechanically joined with rods or bars (as with geogrids), or male/female joined (as with drainage composites). These details will be described in Chapter 6 on geosynthetic materials other than geomembranes.

3.7.3 General Specification Items

The specification or CQA document for backfilling should be written around the concept that the geomembrane must be protected against damage by the overlying material. Since soil, usually sand or gravel, is the most common backfilling material, the items that follow should be considered.

1. The temperature during soil backfilling should be considered. Expansion, contraction, puncture, tear and other properties vary in accordance with the geomembrane temperature.
2. In general, backfilling in warm climates or during summer months should be performed at the coolest part of the day.
3. In extreme cases of excessively high temperatures, backfilling may be required during non-typical work hours, e.g., sunrise to 10:00 AM or 5:00 PM to sunset.
4. If soil backfilling is to be done between sunset and sunrise, i.e., at night, the work area should be suitably lit for safety, constructability and inspection considerations.
5. If soil backfilling is to be done at night, excessive equipment noise may not be tolerated by people in the local neighborhood. This is an important and obviously site specific condition which should be properly addressed.
6. When a geotextile or other protection layer is to be placed above the geomembrane it should be done so according to the plans and specifications.
7. Soil placement equipment should never move, or drive, directly on the geomembrane.
8. Personnel or materials vehicles (automobiles, pickup trucks, etc.) should never drive directly on the geomembrane.
9. The soil particle size characteristics should be stipulated as part of the design requirements.
10. The minimum soil lift thickness should be stipulated in the design requirements. Furthermore, the thickness should be clear as to whether it is loose or compacted thickness.
11. The maximum ground contact pressure of the placement equipment should be stipulated in the design requirements.
12. For areas regularly traversed by heavy equipment, e.g., the access route for loaded dump trucks, a larger than usual fill height should be required.
13. The CQA personnel should be available at all times during backfilling of the geomembrane. It is the last time when anyone will see the completely installed material.
14. Documentation should include the soil type, lift thickness, total thickness, density and moisture conditions (as appropriate).

3.8 References

ASTM D-413, "Rubber Property-Adhesion to Flexible Substrate"

ASTM D-638, "Tensile Properties of Plastics"

ASTM D-751, "Test Methods for Coated Fabrics"

ASTM D-792, "Specific Gravity and Density of Plastics by Displacement"

ASTM D-882, "Test Methods for Tensile Properties of Thin Plastic Sheeting"

ASTM D-1004, "Initial Tear Resistance of Plastic Film and Sheeting"

ASTM D-1238, "Flow Rates of Thermoplastics by Extrusion Plastometer"

ASTM D-1248, "Polyethylene Plastics and Extrusion Materials"

ASTM D-1505, "Density of Plastics by the Density-Gradient Technique"

ASTM D-1603, "Carbon Black in Olefin Plastics"

ASTM D-1765, "Classification System for Carbon Black Used in Rubber Products"

ASTM D-2663, "Rubber Compounds - Dispersion of Carbon Black"

ASTM D-3015, "Recommended Practice for Microscopical Examination of Pigment Dispersion in Plastic Compounds"

ASTM D-3083, "Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining"

ASTM D-4437, "Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes"

ASTM D-4545, "Practice for Determining the Integrity of Factory Seams Used in Joining Manufactured Flexible Sheet Geomembranes"

ASTM D-4759, "Determining the Specification Conformance of Geosynthetics"

ASTM D-5046, "Specification for Fully Crosslinked Elastomeric Alloys"

ASTM D-5199, "Measuring Nominal Thickness of Geotextiles and Geomembranes"

ASTM D-5321 "Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method"

ASTM D-5397, "Notched Constant Tensile Load Test for Polyolefin Geomembranes"

FTM Std. 101C, "Puncture Resistance and Elongation Test," Federal Test Method 2065," March 13, 1980.

GRI GM-6, "Pressurized Air Channel Test for Dual Seamed Geomembranes"

GRI GM-7, "Accelerated Curing of Geomembrane Test Strips Made by Chemical Fusion Methods"

GRI GS-7, "Determining the Index Friction Properties of Geosynthetics"

Haxo, H. E., (1988), "Lining of Waste Containment and Other Impoundment Facilities," EPA/600/2-88/052, Washington, DC.

Hsuan, Y. and Koerner, R. M. (1992), "Stress Cracking Potential and Behavior of HDPE Geomembranes," Final Report to U.S. EPA, Contract No. CR-815692.

Hullings, D. E. and Koerner, R. M. (1991), "Puncture Resistance of Geomembranes Using a Truncated Cone Test," *Proceedings*, Geosynthetics '91, IFAI, pp. 273-286.

Richardson, G. N. and Koerner, R. M. (1988), "Geosynthetic Design Guidance for Hazardous Waste Landfill Cells and Surface Impoundments," EPA/600/S2-87/097.

Richardson, G. N. (1992), "Construction Quality Management for Remedial Action and Remedial Design Waste Containment Systems," U.S. EPA, EPA/540/R-92/073, Washington, DC.

U. S. Environmental Protection Agency (1991) "Inspection Techniques for the Fabrication of Geomembrane Field Seams," EPA Technical Guidance Document, EPA/530/SW-91/051.

Chapter 4

Geosynthetic Clay Liners

4.1 Types and Composition of Geosynthetic Clay Liners

As with most types of manufactured products within a given category, there are sufficient differences such that no two products are truly equal to one another. Geosynthetic clay liners (GCLs) are no exception. Yet, there are a sufficient number of common characteristics such that the current commercially available products deserve a separate category and a separate treatment in this manual. GCLs can be defined as follows:

> "Geosynthetic clay liners (GCLs) are factory manufactured, hydraulic barriers typically consisting of bentonite clay or other very low permeability clay materials, supported by geotextiles and/or geomembranes which are held together by needling, stitching and/or chemical adhesives"

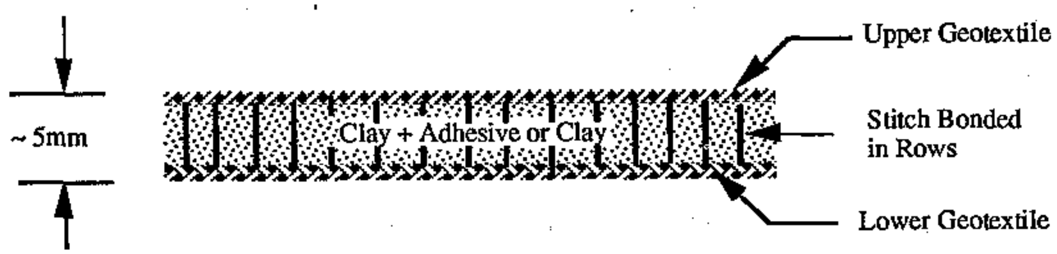
Other names that GCLs have been listed under, are "clay blankets", "clay mats", "bentonite blankets", "bentonite mats", "prefabricated bentonite clay blankets", etc. GCLs are hydraulic barriers to water, leachate or other liquids. As such, they are used to augment or replace compacted clay liners or geomembranes, or they are used in a composite manner to augment the more traditional clay liner or geomembrane materials.

Cross section sketches of the currently available GCLs at the time of writing are shown in Fig. 4.1. General comments regarding each type follow:

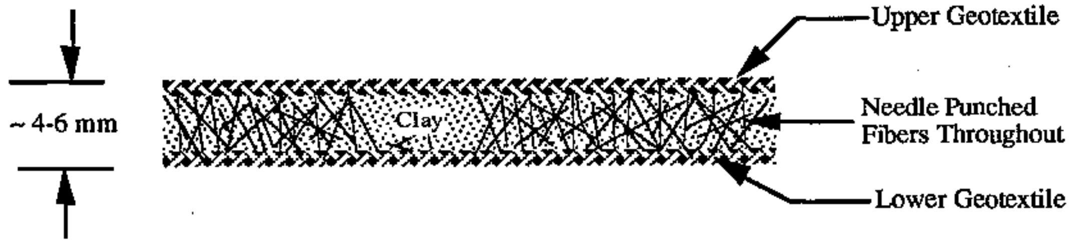
- Figure 4.1(a) illustrates a bentonite clay mixed with a water soluble adhesive which is supported by individual geotextiles on both its upper and lower surfaces.
- Figure 4.1(b) illustrates a stitchbonded variation of the above type of product whereby the upper and lower geotextiles are joined by continuous sewing in discrete rows throughout the machine direction of the product as well as a recent product which consists of bentonite powder alone with no admixed adhesive.
- Figure 4.1(c) illustrates a bentonite clay powder or granules, containing no adhesive, which is supported by individual geotextiles on its upper and lower surfaces and is needle punched throughout to provide for its stability. Several variations of this type of GCL are available including styles with clay infilled in the voids of the upper geotextile.
- Figure 4.1(d) illustrates a bentonite clay which is admixed with an adhesive and is supported by a geomembrane on its lower surface, as shown, or it can be used in an inverted manner with the geomembrane side facing upward. Variations of this product are also available with textured or raised geomembrane surfaces.

All of the GCL products available in North America use sodium bentonite clay (predominately smectite) powder or granules at as-manufactured mass per unit areas in the range of 3.2 to 6.0 kg/m^2 (0.66 to 1.2 lb/ft^2). The clay thickness in the various products vary between the range of 4.0 to 6.0 mm (160 to 320 mils). GCLs are delivered to the job site at moisture contents which

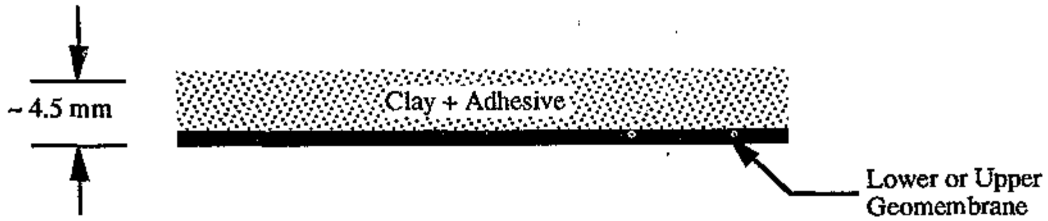
(a) Adhesive Bound Clay to Upper and Lower Geotextiles



(b) Stitch Bonded Clay Between Upper and Lower Geotextiles



(c) Needle Punched Clay Through Upper and Lower Geotextiles



(d) Adhesive Bound Clay to a Geomembrane

Figure 4.1 - Cross Section Sketches of Currently Available Geosynthetic Clay Liners (GCLs)

vary from 5 to 23%, depending upon the local humidity. Note that this is sometimes referred to in the technical literature as the "dry" state. The types of geotextiles used with the different products vary widely in their manufacturing style (e.g., woven slit film, needle punched nonwoven, spunlaced, heat bonded nonwovens, etc.) and in their mass per unit area [e.g., varying from 85 g/m^2 ($2.5 oz/yd^2$) to 1000 g/m^2 ($30 oz/yd^2$). The particular product with a geomembrane backing can also vary in its type, thickness and surface texture.

GCLs are factory made in widths of 2.2 to 5.2 m (7 to 17 ft) and lengths of 30 to 61 m (100 to 200 ft). Upon manufacturing GCLs are rolled onto a core and are covered with a plastic film to prevent additional moisture gain during storage, transportation ,and placement prior to their final covering with an overlying layer.

4.2 Manufacturing

This section on manufacturing of GCLs will discuss the various raw materials, manufacturing of the rolls, and covering of the rolls.

4.2.1 Raw Materials

The bentonite clay materials currently used in the manufacture of GCLs are all of the sodium montmorillonite variety which is a naturally occurring mineral in the Wyoming and North Dakota regions of the USA. After the clay is mined, it is dried, pulverized, sieved and stored in silos until it is transported to a GCL manufacturing facility.

The other raw material ingredient used in the manufacture of certain GCLs (recall Section 4.1) is an adhesive which is a proprietary product among the two manufacturers that produce this type of GCL. Additionally, geotextiles and/or geomembranes are used as substrate (below the clay) or superstrate (above the clay) layers which are product specific as was mentioned in the previous section.

Regarding a specification or MQA document for the various raw materials used in the manufacture of GCLs, the following items should be considered.

1. The clay should meet the GCL manufacturer's specification for quality control purposes. This is often 70% to 90% sodium montmorillonite clay from the Wyoming/North Dakota "Black Hills" region of bentonite deposits. A certificate of analysis should be submitted by the vendor for each lot of clay supplied. While the situation is far from established, the certificate may include the various compounds of the clay, per X-Ray diffraction or methylene-blue absorption, particle size per ASTM D-422 or C-136, moisture content per ASTM D-2216 or D-4643, bulk density per ASTM B-417, and free swell.

2. The GCL manufacturer should have a MQC plan which describes the procedures for accomplishing quality in the final product, various tests to be conducted and their frequency. This MQC document should be fully implemented and followed.

3. The MQC test methods that the GCL manufacturer performs on the clay component may include the following; free swell per USP-NF-XVIII or ASTM draft standard, "Determination of Volumetric Free Swell of Powdered Bentonite Clay," plate water absorption per ASTM E-946, moisture content per ASTM D-2216 or D-4643 and (sometimes) particle size per ASTM D-422, fluid loss per API 13B, pH per ASTM D-4972, and liquid/plastic limit per ASTM D-4318.

4. For those products which use adhesives, the composition of the proprietary adhesive is rarely specified. If a statement is required, it should signify that the adhesive selected has been successfully used in the past and to what extent.

5. The geotextiles used as the substrate or the superstrate, or the geomembrane vary according to the particular style of product. Manufacturers current literature should be used in this regard. If a statement is required it should signify that the products selected have been successfully used in the past and to what extent.

6. If further detail is needed as to a specification for the geotextiles, see Chapter 6. Similarly, specifications for geomembranes are found in Chapter 3.

7. The type of sewing thread (or yarn) which is used in joining the products is rarely specified. If a statement is required it should signify that the materials selected have been successfully used in the past and to what extent.

4.2.2 Manufacturing

The raw materials just described are used to make the final GCL product. The production facilities are all relatively large operations where the products are made in a continuous manner. Process quality control is obviously necessary and is practiced by all GCL manufacturers. Figure 4.2 illustrates, in schematic form, the various processing methods used for those GCLs which have adhesives mixed with the clay and those which are stitch bonded and needle punched. Figure 4.2(a) illustrates an adhesively bonded clay product which has an adhesive sprayed in a number of layers with intermittent additions of bentonite. The clay is placed either between geotextiles or on a geomembrane. Figure 4.2(b) illustrates the needle punching or stitch bonding of a bentonite clay powder after it is placed between the covering geotextiles. Windup around a core and placement of the protective covering is common among all GCLs.

There are numerous items which should be included in a specification or MQA document focused on the manufactured GCL product.

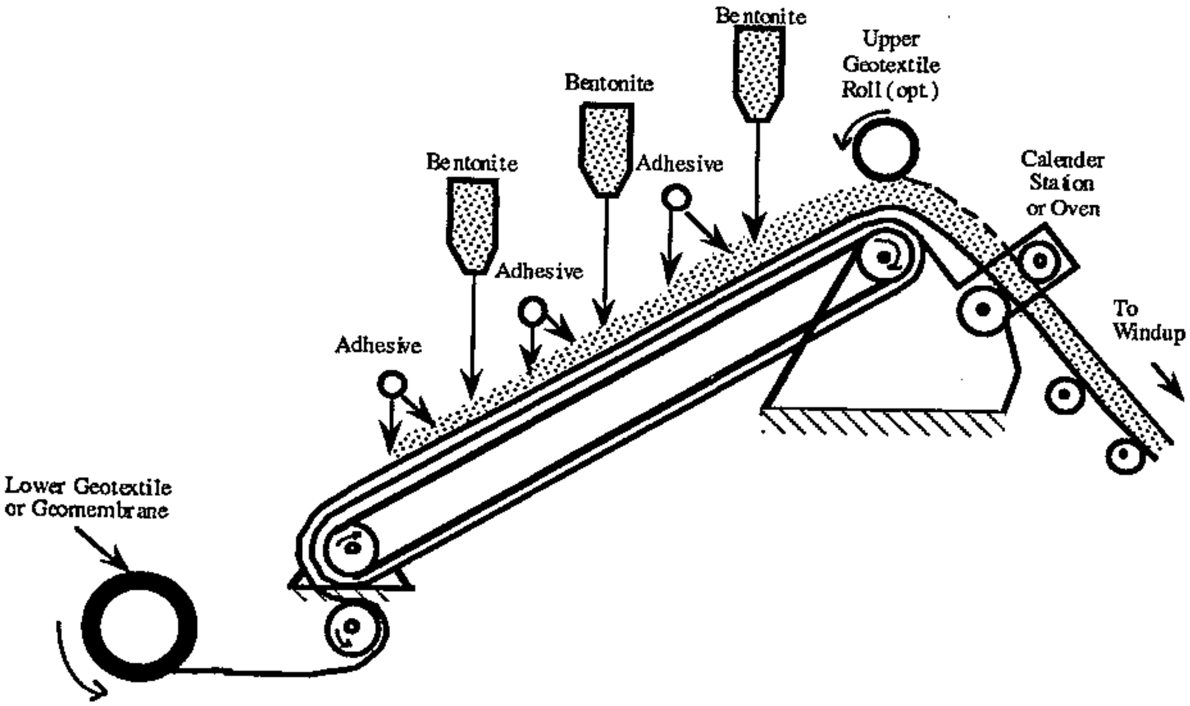
1. There should be verification that the actual geotextiles or geomembrane used meet the manufacturer's specification for that particular type and style.

2. A statement should be included that the geotextile property values are based on the minimum average roll value (MARV) concept. The geomembrane's properties are generally based on average values.

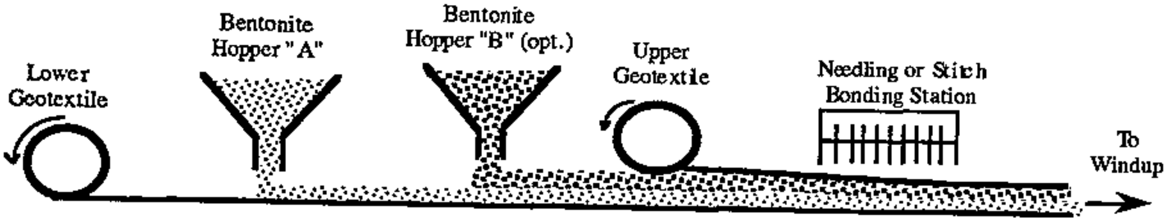
3. Verification that needle punched nonwoven geotextiles have been inspected continuously for the presence of broken needles using an in-line metal detector. There should also be a magnet, or other device, for removal of broken needles.

4. Verification that the proper mass per unit area of bentonite clay has been added to the product should be provided. At a minimum, this should consist of providing a calculated value based on the net weight of the final roll divided by its area (with deduction for the mass per unit area of the geosynthetics and the adhesive, if any).

5. Thickness measurements are product dependent, i.e., some GCLs can be quality controlled via thickness while others cannot.



(a) Adhesive Mixed with Clay



(b) Needle Punched or Stitch Bonded Through Clay

Figure 4.2 - Schematic Diagrams of the Manufacture of Different Types of Geosynthetic Clay Liners (GCLs)

6. It is recommended that the overlap distance on both sides of the GCL be marked with two continuous waterproof lines guiding the minimum overlap distances.

7. The product should be wrapped around a core which is structurally sound such that it can support the weight of the roll without excessive bending or buckling under normal handling conditions as recommended by the manufacturer.

8. The GCL manufacturer should have a MQC plan for the finished product, which includes sampling frequency, and it should be implemented and followed.

9. The manufacturer's quality control tests on the finished product should be stipulated and followed. Typical tests include thickness per ASTM D-1777 or ASTM D-5199, total product mass per unit area per ASTM D-5261, clay content mass per unit area per ASTM D-5261, hydraulic conductivity (permeability) per ASTM D-5084 or GRI GCL2 and sometimes shear strength at various locations such as top, mid-plane and bottom per ASTM D-5321. Other tests as recommended by the manufacturer are also acceptable.

4.2.3 Covering of the Rolls

The final step in the manufacturing of GCLs is their covering with a waterproof, tightly-fit, plastic covering. This covering is sometimes a spirally wound polyethylene film approximately 0.05 to 0.08 mm (2 to 5 mils) thick and is the final step in production. The covering can also be a plastic bag, or sheet, pulled over the product as a secondary operation. Figure 4.3 shows the factory storage of GCLs, with their protective covering, before shipment to the field.

Some items for a specification or MQA document with regard to the covering of GCLs are the following:

1. The manufacturer should clearly stipulate the type of protective covering and the manner of cover placement. The covering should be verified as to its capability for safe storage and proper transportation of the product.

2. The covering should be placed around the GCL in a workmanlike manner so as to effectively protect the product on all of its exposed surfaces and edges.

3. The central core should be accessible for handling by fork lift vehicles fitted with a long pole (i.e., a "stinger") attached. For wide GCLs, e.g., wider than approximately 3.5 m (11.5 ft), handling should be by overhead cranes utilizing two dedicated slings provided on each roll at approximately the one-third points.

4. Clearly visible labels should identify the name and address of the manufacturer, trademark, date of manufacture, location of manufacture, style, roll number, lot number, serial number, dimensions, weight and other important items for proper identification. Refer to ASTM D-4873 for proper labeling in this regard. In some cases, the roll number itself is adequate to trace the entire MQC record and documentation.

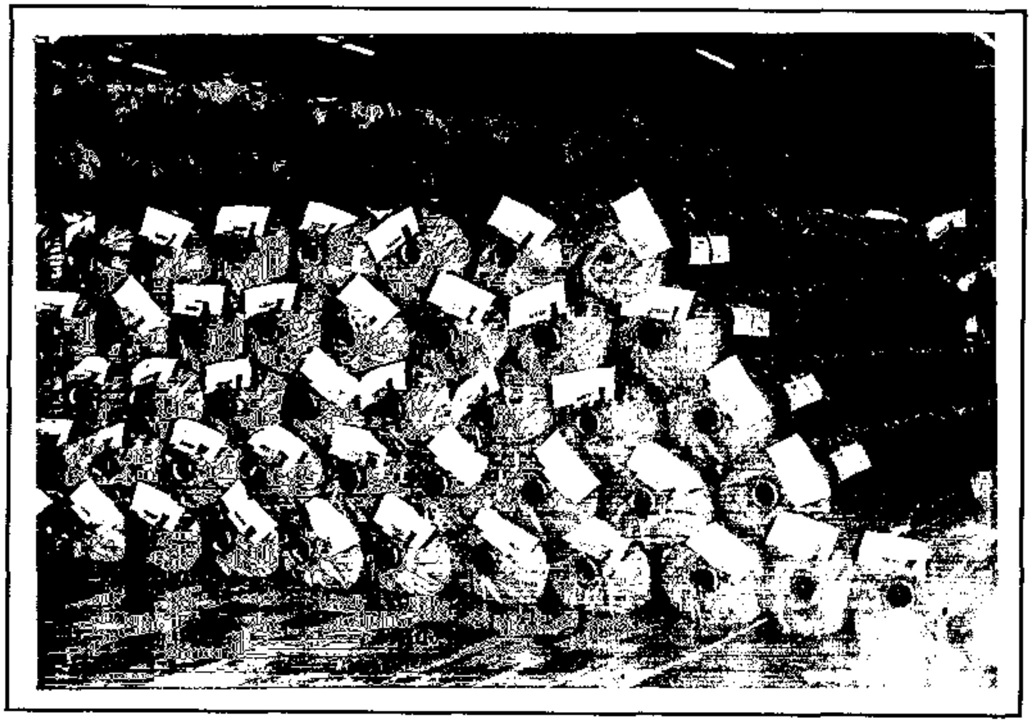


Figure 4.3 - Indoor Factory Storage of Geosynthetic Clay Liners (GCLs) Waiting for Shipment to a Job Site

4.3 Handling

A number of activities occur between the manufacture of a GCL, its final positioning in the field and subsequent backfilling. Topics such as storage at the factory, transportation, storage at the site and acceptance/conformance testing will be described in this section.

4.3.1 Storage at the Manufacturing Facility

Storage of GCLs at the manufacturers facility is common. Storage times typically range from days to six months. Figure 4.3 illustrated typical GCL storage at a fabrication facility.

Some specifications or MQA items to consider for storage and handling of GCLs are the following:

1. GCLs should always be stored indoors until they are ready to be transported to the field site.
2. Handling of the GCLs should be such that the protective wrapping is not damaged. If it is, it must be immediately rewrapped by machine or by hand. In the case of minor tears it may be taped.

3. Placement and stacking of rolls should be done in a manner so as to prevent thinning of the product at the points of contact with the storage frame or with one another. Storage in individually supported racks is common so as to more efficiently use floor space.

4.3.2 Shipment

Rolls of GCLs are shipped from the manufacturers storage facility to the job site via common carrier. Ships, railroads and trucks have all been used depending upon the locations of the origin and final destination. The usual carrier within the USA is truck, which should be with the GCLs contained in an enclosed trailer as shown in Fig. 4.4(a), or on an open flat-bed trailer which is tarpaulin covered as shown in Fig. 4.4(b). Some manufacturers have their own dedicated fleet of trucks. The rolls are sometimes handled by fork lift with a stinger attached. The "stinger" is a long tapered rod which fits inside the core upon which the GCL is wrapped, see Fig. 4.4(a). Alternatively, rolls can be handled using the two captive slings provided on each roll.

Insofar as a specification or MQA document is concerned, a few items should be considered.

1. The GCLs should be shipped by themselves with no other cargo which could damage them in transit, during stops, or while offloading other materials.

2. The method of loading the GCL rolls, transporting them and offloading them at the job site should not cause any damage to the GCL, its core, nor its protective wrapping.

3. Any protective wrapping that is damaged or stripped off of the rolls should be repaired immediately or the roll should be moved to a enclosed facility until its repair can be made to the approval of the quality assurance personnel.

4. If any of the clay has been lost during transportation or from damage of any type, the outer layers of GCL should be discarded until undamaged product is evidenced. The remaining roll must be rewrapped in accordance with the manufacturer's original method to prevent hydration or further damage to the remaining roll.

4.3.3 Storage at the Site

Storage of GCLs at the field site is cautioned due to the potential for moisture pickup (even through the plastic covering) or accidental damage. The concept of "just-in-time-delivery" can be used for GCLs transported from the factory to the field. When storage is required for a short period of time i.e., days or a few weeks, and the product is delivered in trailers, the trailers can be unhitched from their tractors and used as temporary storage. See the photograph of Fig. 4.5(a). Alternatively, storage at the job site can also be acceptable if the GCLs are properly positioned, protected and maintained, see Fig. 4.5(b).

If storage of GCLs is permitted on the job site, offloading of the rolls should be done in an acceptable manner. Some specification or CQA* document items to consider are the following.

1. Handling of rolls of GCLs should be done in a competent manner such that damage does not occur to the product nor to its protective wrapping. In this regard ASTM D-4873, "Identification, Storage and Handling of Geotextiles", should be referenced and followed.

---

* Note that the designations of MQC and MQA will now shift to CQC and CQA since field construction personnel are involved.

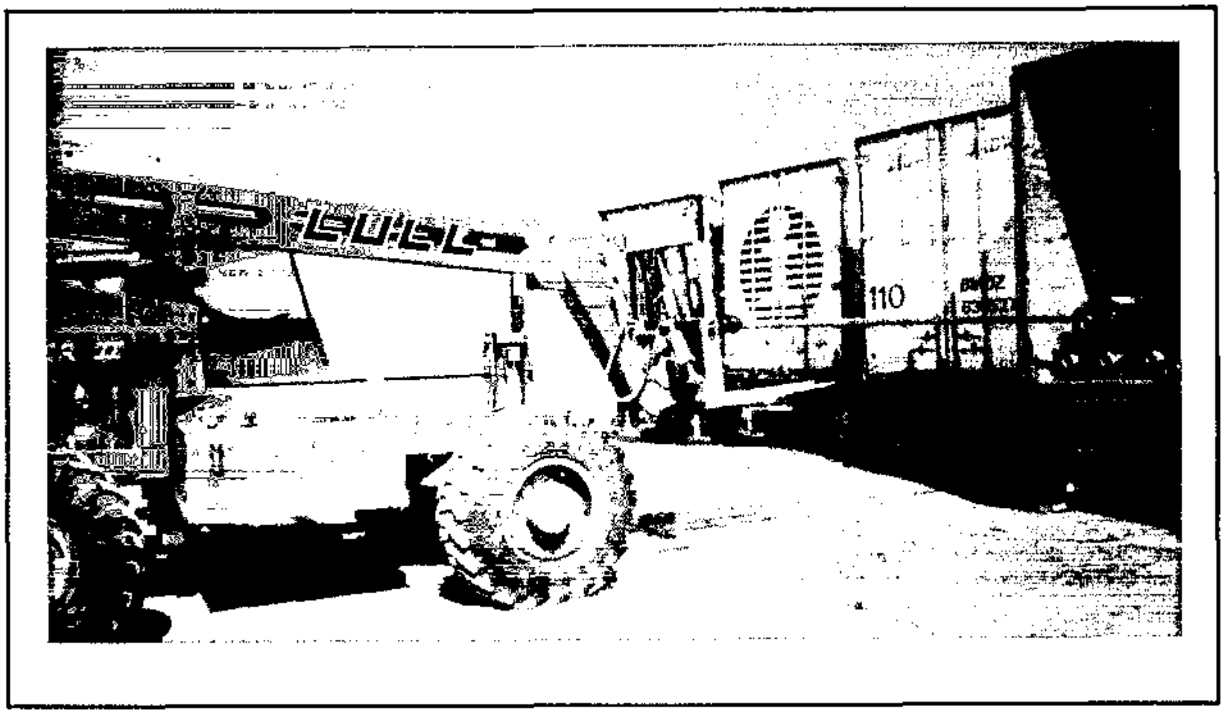


Figure 4.4(a) - Fork Lift Equipped with a "Stinger"

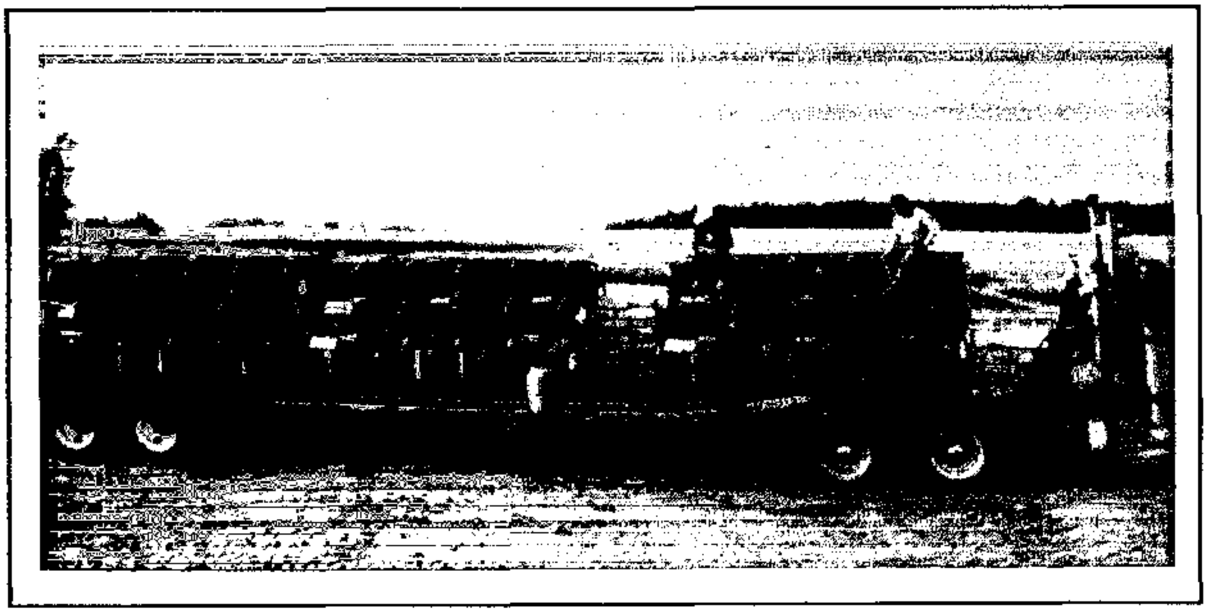


Figure 4.4(b) - GCL Rolls on a Flat-Bed Trailer

Figure 4.5(a) - Photograph of Temporary Storage of GCLs in their Shipping Trailers

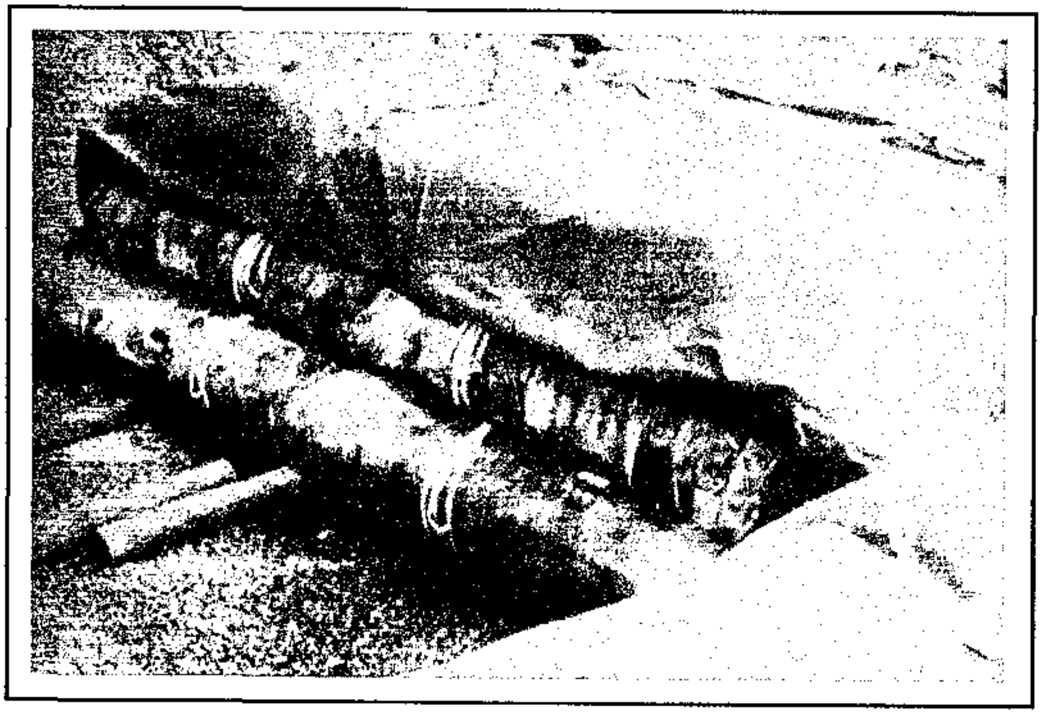


Figure 4.5(b) - Photograph of Temporary Storage of GCLs at Project Site

2. The location of temporary field storage should not be in areas where water can accumulate. The rolls should be stored on high flat ground or elevated off of the ground so as not to form a dam creating the ponding of water. It is recommended to construct a platform so that GCL rolls are continuously supported along their length.

3. The rolls should not be stacked so high as to cause thinning of the product at points of contact. Furthermore, they should be stacked in such a way that access for conformance testing is possible.

4. If outdoor storage of rolls is to be longer than a few weeks particular care, e.g., using tarpaulins, should be taken to minimize moisture pickup or accidental damage. For storage periods longer than one season a temporary enclosure should be placed over the rolls, or they should be moved within an enclosed facility.

4.3.4 Acceptance and Conformance Testing

Upon delivery of the GCLs to the field site, the CQA officer should see that conformance test samples are obtained. These samples are then sent to the CQA Laboratory for testing to ensure that the GCL conforms to the project plans and specifications. The samples are taken from selected rolls by removing the protective wrapping and cutting full-width, 1 m (3 ft.) long samples from the outer wrap of the selected roll(s). Sometimes one complete outer revolution of GCL is discarded before the test sample is taken. The rolls are immediately re-wrapped and replaced in the shipping trailers or in the temporary field storage area. Alternatively, conformance testing could be performed at the manufacturer's facility and when completed the particular lot should be identified for the particular project under investigation..

Items to consider for a specification or CQA document in this regard are the following:

1. The samples should be identified by type, style, lot and roll numbers. The machine direction should be noted on the sample(s) with a waterproof marker.

2. A lot is usually defined as a group of consecutively numbered rolls from the same manufacturing line. Other definitions are also possible and should be clearly stated in the CQA documents.

3. Sampling should be done according to the project specification and/or CQA documents. Unless otherwise stated, sampling should be based on a lot basis. Different interpretations of sampling frequency within a lot are based on total area or on number of rolls. For example, sampling could be based on 10,000 m^2 (100,000 ft^2) of area or on use of ASTM D-4354 which is based on rolls.

4. Testing at the CQA laboratory may include mass per unit area per ASTM D-5261, and free swell of the clay component per GRI-GCL1. The sampling frequency for these index tests should be based on ASTM D-4354. Other conformance tests, which are more performance oriented, could be required by the project specifications but at a reduced frequency compared to the above mentioned index tests. Examples are hydraulic conductivity (permeability) ASTM D-5084 (mod.) or GRI GCL2 and direct shear testing per ASTM D-5321. The sampling frequency for these performance tests might be based on area, e.g., one test per 10,000 m^2 (100,000 ft^2).

5. If testing of the geotextiles, or geomembrane, covering the GCLs is desired it should be done on the original rolls of the geotextiles, or geomembrane, before they are fabricated into the GCL product. Once fabricated their properties will change considerably due to the needling, stitching and/or gluing during manufacturing.

6. Peel testing of needle punched or stitch bonded GCLs should be done in accordance with ASTM D-413 (mod.). The sampling frequency is recommended to be one test per 2000 m^2 (20,000 ft^2).

7. Conformance test results should be sent to the CQA engineer prior to installation of any GCL from the lot under review.

8. The CQA engineer should review the results and should report any nonconformance to the Owner/Operator's Project Manager.

9. The resolution of failing conformance tests must be clearly stipulated in the specifications or CQA documents. Statements should be based upon ASTM D-4759 entitled "Determining the Specification Conformance of Geosynthetics."

4.4 Installation

This section will cover the placement, joining, repairing and covering of GCLs.

4.4.1 Placement

The installation contractor should remove the protective wrapping from the rolls to be deployed only after the substrate layer (soil or other geosynthetic) in the field has been approved by CQA personnel. The specification and CQA documents should be written in such a manner as to ensure that the GCLs are not damaged in any way. A CQA inspector should be present at all times during the handling, placement and covering of GCLs. Figure 4.6(a) shows the typical placement of a GCL in the field on soil subgrade and Fig. 4.6(b) shows placement (without heavy equipment) on an underlying geosynthetic.

The following items should be considered for inclusion in a specification or CQA document.

1. The installer should take the necessary precautions to protect materials underlying the GCL. If the substrate is soil, construction equipment can be used to deploy the GCL providing excessive rutting is not created. Excessive rutting should be clearly defined and quantified. In some cases 25 mm (1.0 in.) is the maximum rut depth allowed. If the ground freezes, the depth of ruts should be further reduced to a specified value. If the substrate is a geosynthetic material, GCL deployment should be by hand, or by use of small jack lifts or light weight equipment on pneumatic tires having low ground contact pressure.

2. The minimum overlap distance which is specified should be verified. This is typically 150 to 300 mm (6 to 12 in.) depending upon the particular product and site conditions.

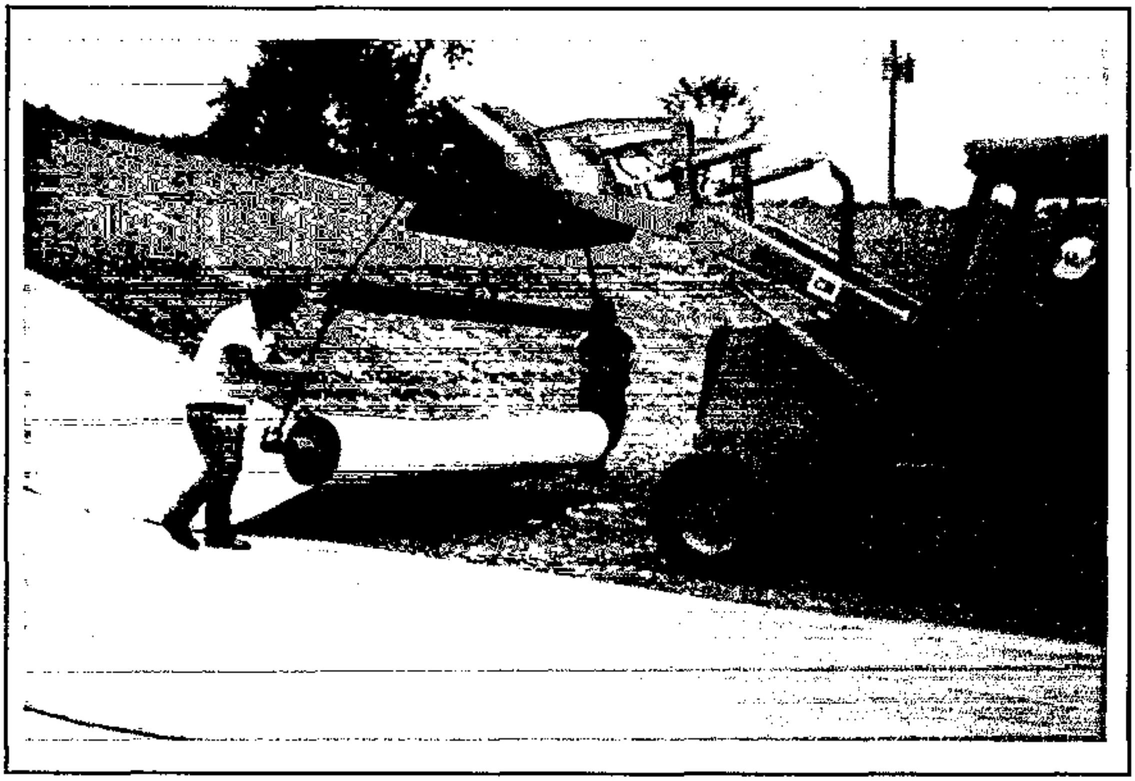


Figure 4.6(a) - Field Deployment of a GCL on a Soil Subgrade

Figure 4.6(b) - Field Deployment of a GCL on an Underlying Geosynthetic

3. Additional bentonite clay should be introduced into the overlap region with certain types of GCLs. There are typically those with needle punched nonwoven geotextiles on their surfaces. The clay is usually added by using a line spreader or line chalker with the bentonite clay in a dry state. Alternatively, a bentonite clay paste, in the mixture range of 4 to 6 parts water to 1 part of clay, can be extruded in the overlap region. Manufacturer's recommendations on type and quantity of clay to be added should be followed.

4. During placement, care must be taken not to entrap in or beneath the GCL, fugitive clay, stones, or sand that could damage a geomembrane, cause clogging of drains or filters, or hamper subsequent seaming of materials either beneath or above the GCL.

5. On side slopes, the GCL should be anchored at the top and then unrolled so as to keep the material free of wrinkles and folds.

6. Trimming of the GCL should be done with great care so that fugitive clay particles do not come in contact with drainage materials such as geonets, geocomposites or natural drainage materials.

7. The deployed GCL should be visually inspected to ensure that no potentially harmful objects are present, e.g., stones, cutting blades, small tools, sandbags, etc.

4.4.2 Joining

Joining of GCLs is generally accomplished by overlapping without sewing or other mechanical connections. The overlap distance requirements should be clearly stated. For all GCLs the required overlap distance should be marked on the underlying layer by a pair of continuous guidelines. The overlap distance is typically 150 to 300 mm (6 to 12 in.). For those GCLs, with needle punched nonwoven geotextiles on their surfaces, dry bentonite is generally placed in the overlapped region. If this is the case, utmost care should be given to avoid fugitive bentonite particles from coming into contact with leachate collection systems. Another variation, however, has been to extrude a moistened tube of bentonite into the overlapped region.

Items to consider for a specification or CQA document follow:

1. The amount of overlap for adjacent GCLs should be stated and adhered to in field placement of the materials.

2. The overlap distance is sometimes different for the roll ends versus the roll edges. The values should be stated and followed.

3. If dry or moistened bentonite clay (or other material) is to be placed in the overlapped region, the type and amount should be stated in accordance with the manufacturer's recommendations and/or design considerations. Index testing requirements for proper verification of the clay should be specified accordingly. Furthermore, the placement procedure should be clearly outlined so as to have enough material to make an adequately tight joint and yet not an excessive amount which could result in fugitive clay particles.

4.4.3 Repairs

For the geotextile-related GCLs, holes, tears or rips in the covering geotextiles made during transportation, handling, placement or anytime before backfilling should be repaired by patching using a geotextile. If the bentonite component of the GCL is disturbed either by loss of material or by shifting, it should be covered using a full GCL patch of the same type of product.

Some relevant specification or CQA document items follow.

1. Any patch, used for repair of a tear or rip in the geotextile, should be done using the same type as the damaged geotextile or other approved geotextile by the CQA engineer.
2. The size of the geotextile patch must extend at least 30 cm (12 in.) beyond any portion of the damaged geotextile and be adhesive or heat bonded to the product to avoid shifting during backfilling with soil or covering with another geosynthetic.
3. If bentonite particles are lost from within the GCL or if the clay has shifted, the patch should consist of the full GCL product. It should extend at least 30 cm (12 in.) beyond the extent of the damage at all locations. For those GCLs requiring additional bentonite clay in overlap seaming, the similar procedure should be use for patching.
4. Particular care should be exercised in using a GCL patch since fugitive clay can be lost which can find its way into drainage materials or onto geomembranes in areas which eventually are to be seamed together.

4.5 Backfilling or Covering

The layer of material placed above the deployed GCL will be either soil or another geosynthetic. Soils will vary from compacted clay layers to coarse aggregate drainage layers. Geosynthetics will generally be geomembranes although other geosynthetics may also be used depending on the site specific design. The GCL should generally be covered before a rainfall or snow event occurs. The reason for covering with the adhesive bonded GCLs is that hydration before covering can cause changes in thickness as a result of uneven swelling or whenever compressive or shear loads are encountered. Hydration before covering may be less of a concern for the needled and stitch bonded types of GCLs, but migration of the fully hydrated clay in these products might also be possible under sustained compressive or shear loading. Figure 4.7 shows the premature hydration of a GCL being gathered up by hand to be discarded in the adjacent landfill.

Some recommended specifications or CQA document items are as follows:

1. The GCL should be covered with its subsequent layer before a rainfall or snowfall occurs.
2. The GCL should not be covered before observation and approval by the CQA personnel. This requires close coordination between the installation crew and the CQA personnel.
3. If soil is to cover the GCL it should be done such that the GCL or underlying materials are not damaged. Unless otherwise specified, the direction of backfilling should proceed in the direction of downgradient shingling of the GCL overlaps. Continuous observation of the soil placement is recommended.
4. If a geosynthetic is to cover a GCL, both underlying and the newly deployed material should not be damaged.

5. The overlying material should not be deployed such that excess tensile stress is mobilized in the GCL. On side slopes, this requires soil backfill to proceed from the bottom of the slope upward. Other conditions are site specific and material specific.

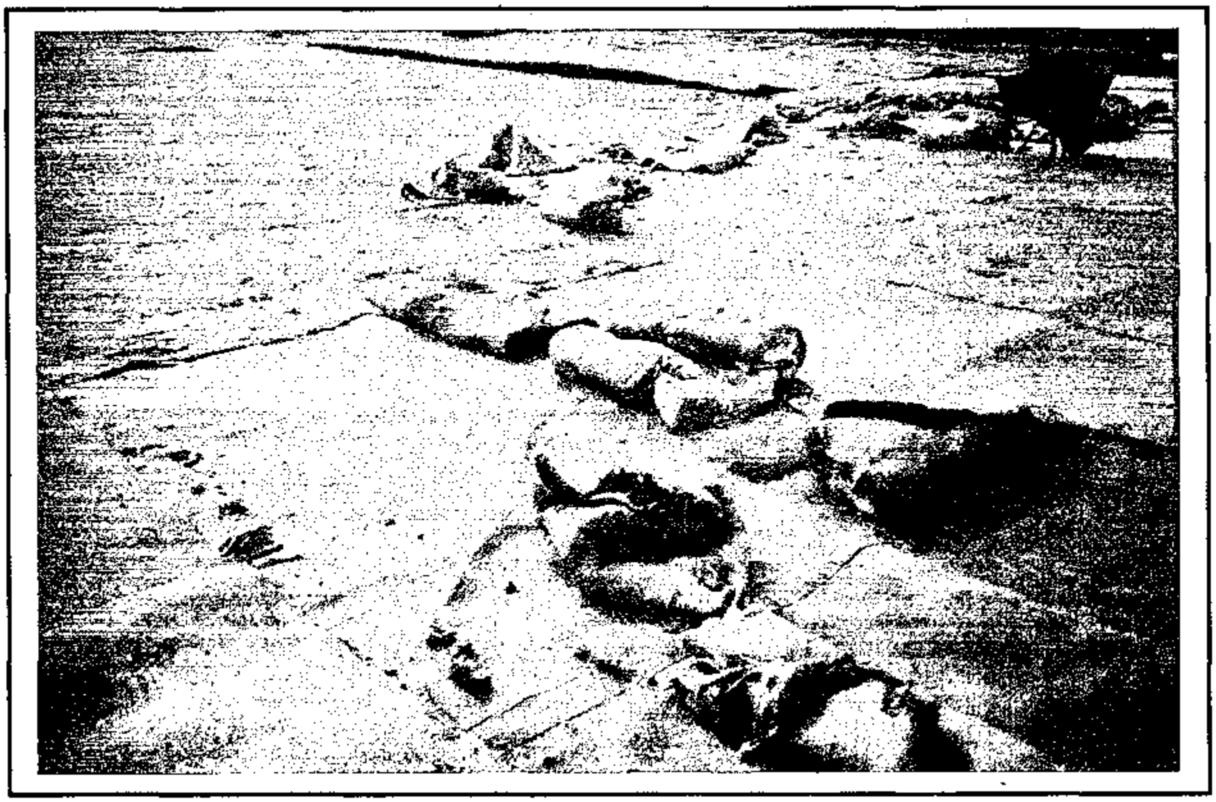


Figure 4.7 - Premature Hydration of a Geosynthetic Clay Liner Being Gathered and Discarded due to its Exposure to Rainfall Before Covering

4.6 References

API 13B, "Fluid Loss of Bentonite Clays"

ASTM B-417, "Apparent Density of Non Free-Flowing Metal Powders"

ASTM C-136, "Sieve Analysis of Fine and Coarse Aggregates"

ASTM D-413, "Rubber Property - Adhesion to Flexible Substrate"

ASTM D-422, "Particle Size Analysis of Soils"

ASTM D-1777, "Measuring Thickness of Textile Materials"

ASTM D-2216, "Laboratory Determination of Water (Moisture) Content of Soil and Rock"

ASTM D-4318, "Liquid Limit, Plastic Limit, and Plasticity Index of Soils"

ASTM D-4354, "Sampling of Geosynthetics for Testing"

ASTM D-4643, "Determination of Water (Moisture Content) of Soil by Microwave Oven Method"

ASTM D-4759, "Determining the Specification Conformance of Geosynthetics"

ASTM D-4873, "Identification, Storage and Handling of Geotextiles"

ASTM D-4972, "Method for pH of Soils"

ASTM D-5084, "Hydraulic Conductivity of Saturated Porous Material Using A Flexible Wall Permeameter"

ASTM D-5199, "Nominal Thickness of Geotextiles and Geomembranes"

ASTM D-5261, "Measuring Mass per Unit Area of Geotextiles"

ASTM D-5321, "Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method"

ASTM E-946, "Water Absorption of Bentonite of Porous Plate Method"

GRI GCL1, "Free Swell Conformance Test of Clay Component of a GCL"

GRI GCL2, "Permeability of Geosynthetic Clay Liners (GCLs)"

USP-NF-XVII, "Swell Index Test"

Chapter 5

Soil Drainage Systems

5.1 Introduction and Background

Natural soil drainage materials are used extensively in waste containment units. The most common uses are:

1. Drainage layer in final cover system to reduce the hydraulic head on the underlying barrier layer and to enhance slope stability by reducing seepage forces in the cover system.
2. Gas collection layer in final cover systems to channel gas to vents for controlled removal of potentially dangerous gases.
3. Leachate collection layer in liner systems to remove leachate for treatment and to remove precipitation from the disposal unit in areas where waste has not yet been placed.
4. Leak detection layer in double liner systems to monitor performance of the primary liner and, if necessary, to serve as a secondary leachate collection layer.
5. Drainage trenches to collect horizontally-flowing fluids, e.g., ground water and gas.

Drainage layers are also used in miscellaneous ways, such as to drain liquids from backfill behind retaining walls or to relieve excess water pressure in critical areas such as the toe of slopes.

5.2 Materials

Soil drainage systems are constructed of materials that have high hydraulic conductivity. High hydraulic conductivity is not only required initially, but the drainage material must also maintain a high hydraulic conductivity over time and resist plugging or clogging. The hydraulic conductivity of drainage materials depends primarily on the grain size of the finest particles present in the soil. An equation that is occasionally used to estimate hydraulic conductivity of granular materials is Hazen's formula:

$$k = (D_{10})^2 \qquad (5.1)$$

where k is the hydraulic conductivity (cm/s) and D_{10} is the equivalent grain diameter (mm) at which 10% of the soil is finer by weight. To determine the value of D_{10}, a plot is made of the grain-size distribution of the soil (measured following ASTM D-422) as shown in Fig. 5.1. The equivalent grain diameter (D_{10}) is determined from the grain size distribution curve as shown in Fig. 5.1.

Experimental data verify that the percentage of fine material in the soil dominates hydraulic conductivity. For example, the data in Table 5.1 illustrate the influence of a small amount of fines upon the hydraulic conductivity of a filter sand. The addition of just a few percent of fine material to a drainage material can reduce the hydraulic conductivity of the drainage material by 100 fold or more.

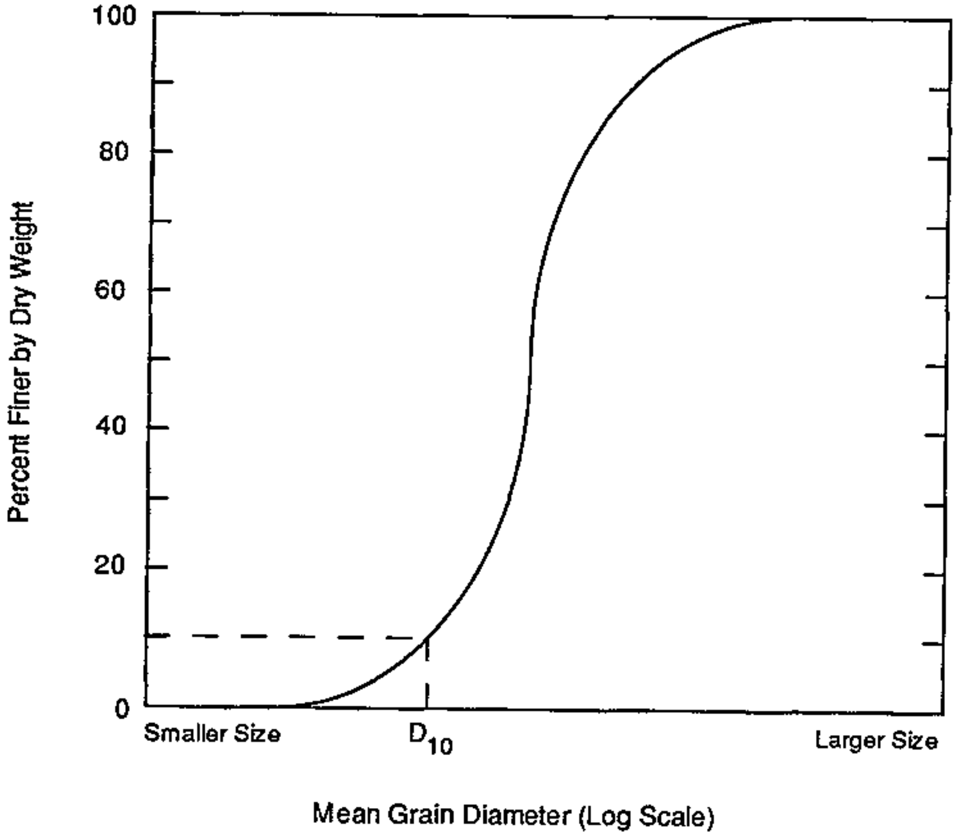


Figure 5.1 - Grain Size Distribution Curve

Construction specifications usually stipulate a minimum hydraulic conductivity for the drainage layer. The value specified varies considerably from project to project but is typically in the range of 0.01 to 1 cm/s. The method used to determine hydraulic conductivity in the laboratory is ASTM D-2434.

Table 5.1 Effect of Fines on Hydraulic Conductivity of a Washed Filter Aggregate (from Cedergren, 1989)

Percent Passing No. 100* Sieve	Hydraulic Conductivity (cm/s)
0	0.03 to 0.11
2	0.004 to 0.04
4	0.0007 to 0.02
6	0.0002 to 0.007
7	0.00007 to 0.001

*Opening size is 0.15 mm.

Drainage materials may also be required to serve as filters. For instance, as shown in Fig. 5.2, a filter layer may be needed to protect a drainage layer from plugging. The filter layer must serve three functions:

1. The filter must prevent passage of significant amounts of soil through the filter, i.e., the filter must retain soil.
2. The filter must have a relatively high hydraulic conductivity, e.g., the filter should be more permeable than the adjacent soil layer.
3. The soil particles within the filter must not migrate significantly into the adjacent drainage layer.

Filter specifications vary somewhat, but the design procedures are similar. The determination of requirements for a filter material proceeds as follows:

1. The grain size distribution curve of the soil to be retained (protected) is determined following procedures outlined in ASTM D-422. The size of the protected soil at which 15% is finer ($D_{15,\ soil}$) and 85% is finer ($D_{85,\ soil}$) is determined.
2. Experience shows that the particles of the protected soil will not significantly penetrate into the filter if the size of the filter at which 15% is finer ($D_{15,\ filter}$) is less than 4 to 5 times D_{85} of the protected soil:

$$D_{15,\ filter} \leq (4 \text{ to } 5)\ D_{85,\ soil} \qquad (5.2)$$

3. Experience shows that the hydraulic conductivity of the filter will be significantly greater than that of the protected soil if the following criterion is satisfied:

$$D_{15,\,\text{filter}} \geq 4\ D_{15,\,\text{soil}} \qquad (5.3)$$

4. To ensure that the particles within the filter do not tend to migrate excessively into the drainage layer, the following criterion may be applied:

$$D_{15,\,\text{drain}} \leq (4 \text{ to } 5)\ D_{15,\,\text{filter}} \qquad (5.4)$$

5. Experience shows that the hydraulic conductivity of the drain will be significantly greater than that of the filter if the following criterion is satisfied:

$$D_{15,\,\text{drain}} \geq 4\ D_{15,\,\text{filter}} \qquad (5.5)$$

Filter design is complicated significantly by the presence of biodegradable waste materials, e.g., municipal solid waste, directly on top of the filter. In such circumstances, the usual filter criteria may be modified to satisfy site-specific requirements. Some degree of reduction in hydraulic conductivity of the filter layer may be acceptable, so long as the reduction does not impair the ability of the drainage system to serve its intended function. A laboratory test method to quantify the hydraulic properties of both soil and geotextile filters that are exposed to leachate is ASTM D-1987. However, regardless of specific design criteria, the gradational characteristics of the filter material control the behavior of the filter. CQC/CQA personnel should focus their attention on ensuring that the drainage material and filter material meet the grain-size-distribution requirements set forth in the construction specifications, as well as other specified requirements such as mineralogy of the materials.

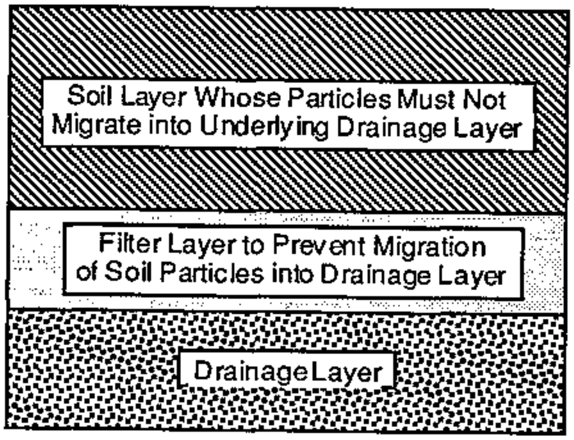


Figure 5.2 - Filter Layer Used to Protect Drainage Layer from Plugging

5.3 Control of Materials

The recommended procedure for verifying the hydraulic conductivity for a proposed drainage material is as follows. Samples of the proposed material should be obtained and shipped to a laboratory for testing. Samples should be compacted in the laboratory to a density that will be representative of the density to be used in the field. Hydraulic conductivity should be measured following procedures in ASTM D-2434 and compared with the required minimum values stated in the construction specifications. If the hydraulic conductivity exceeds the minimum value, the material is tentatively considered to be acceptable. However, it should be realized that the process of excavating and placing the drainage material will cause some degree of crushing of the drainage material and will produce additional fines. Thus, the construction process itself tends to increase the amount of fines in the drainage material and to decrease the hydraulic conductivity of the material. If the drainage material just barely meets the hydraulic conductivity requirements stated in the construction specifications from initial tests, there is a good possibility that the material will fail to meet the required hydraulic conductivity standard after the material has been placed. As a rule of thumb, approximately one-half to one percent of additional fines by weight will be generated every time a drainage material is handled, e.g., one-half to one percent additional fines would be generated when the drainage layer material is excavated and an additional one-half to one percent of fines would be generated when the material is placed. Also, the reproducibility of hydraulic conductivity tests is not well established; a material may just barely meet the hydraulic conductivity standard in one test but fail to meet minimum requirements in another test. Finally, if the drainage materials are found to be suitable prior to placement but unsuitable after placement, an extremely difficult situation arises -- it is virtually impossible to remove and replace the drainage material without risking damage to underlying geosynthetic components, e.g., a geomembrane. Therefore, some margin of safety should be factored into the selection of drainage material.

Because it is extremely difficult to remove and replace a drainage material without damaging an underlying geosynthetic component, testing of the drainage material should occur prior to placement of the material. The CQC personnel should have a high degree of confidence that the drainage material is suitable prior to placement of the material. Because the construction process may alter the characteristics of the drainage material, it is important that CQA tests also be performed on the material after it has been placed and compacted (if it is compacted).

The usual tests involve determination of the grain size distribution of the soil (ASTM D-422) and hydraulic conductivity of the soil (ASTM D-2434). Hydraulic conductivity tests tend to be time consuming and relatively difficult to reproduce precisely; the test apparatus that is employed, the compaction conditions for the drainage material, and other details of testing may significantly influence test results. Grain-size distribution analyses are simpler. Therefore, it is recommended that the CQA testing program emphasize grain-size distribution analyses, with particular attention paid to the amount of fines present in the drainage material, rather than hydraulic conductivity testing. The percent of fines is normally defined as the percent on a dry weight basis passing through a No. 200 sieve (openings of 0.075 mm). Again, it is emphasized that close testing and inspection of the borrow source or the supplier prior to placement of the material is critical, particularly if the drainage material is underlain by a geosynthetic material.

The recommended tests and frequency of testing are shown in Table 5.2. The same principles for sampling strategies discussed in Chapter 2 may be applied to location of tests or location of samples for drainage layer materials. Also, occasional failing tests may be allowed, but it is recommended that no more than 5% of the CQA tests be allowed to deviate from specifications, and the deviations should be relatively minor, i.e., no more than about 2% fines beyond the maximum value allowed and no less than about one-fifth the minimum allowable hydraulic conductivity.

Table 5.2 - Recommended Tests and Testing Frequencies for Drainage Material

Location of Sample	Type of Test	Minimum Frequency
Potential Borrow Source	Grain Size (ASTM D-422)	1 per 2,000 m^3
	Hydraulic Conductivity (ASTM D-2434)	1 per 2,000 m^3
	Carbonate Content* (ASTM D-4373)	1 per 2,000 m^3
On Site; After Placement and Compaction	Grain Size (ASTM D-422)	1 per Hectare for Drainage Layers; 1 per 500 m^3 for Other Uses
	Hydraulic Conductivity (ASTM D-2434)	1 per 3 Hectares for Drainage Layers; 1 per 1,500 m^3 for Other Uses
	Carbonate Content* (ASTM D-4373)	1 per 2,000 m^3

*The frequency of carbonate content testing should be greatly reduced to 1 per 20,000 m^3 for those drainage materials that obviously do not and cannot contain significant carbonates (e.g., crushed basalt).

5.4 Location of Borrow Sources

The construction specifications usually establish criteria that must be met by the drainage material. Earthwork contractors are normally given latitude in locating a suitable source of material that meets construction specifications. On occasion the materials may be available on site or from a nearby piece of property, but most frequently the materials are supplied by a commercial materials company. If the materials are supplied by an existing materials processor, stockpiles of materials are usually readily available for testing and no geotechnical investigations are required, other than to test the proposed borrowed material.

5.5 Processing of Materials

Materials may be processed in several ways. Oversized stones or rocks are typically removed by sieving. Fine material may also be removed by sieving. Washing the fines out of a sand or gravel can be particularly effective in removing silt and clay sized particles from granular material. For drainage layer materials that are supplied from a commercial processing facility, the facility owner is usually experienced in processing the material to remove fines.

For the CQA inspector the main processing issues are removal of oversized material, removal of angular material (if required to minimize potential to puncture a geomembrane), and assurance that excessive fines will not be present in the material.

On occasion the amount of limestone, dolostone, dolomite, calcite, or other carbonates in the drainage material may be an issue. Carbonate materials are slightly soluble in water. If the drainage material contains excessive carbonate, the carbonate may dissolve at one location and precipitate at another, plugging the material. CQA inspectors should also be cognizant of the need to make sure that carbonate components are not present in excessive amounts. If the specifications place a limit on carbonate content, tests should be performed to confirm compliance (Table 5.2).

5.6 Placement

Drainage materials may be placed in layers (e.g., as leachate collection layers) or they may be placed in drainage trenches (e.g., to provide drainage near the toe of a slope). Placement considerations differ depending on the application.

5.6.1 Drainage Layers

Granular drainage materials are usually hauled to the placement area in dump trucks, loosely dumped from the truck, and spread with bulldozers. The contractor should dump and spread the drainage material in a manner that minimizes generation of fine material. For instance, light-contact-pressure dozers can be used to spread the drainage material and minimize the stress on the granular material. Granular materials placed on top of geosynthetic components on side slopes should be placed from the bottom of the slope up.

When granular drainage material is placed on a previously-placed geomembrane or geotextile and spread with a dozer, the sand or gravel should be lifted and tumbled forward so as to minimize shear forces on the underlying geosynthetic. The dozer should not be allowed to "crowd" the blade into the granular material and drag it over the surface of the underlying geosynthetic material.

Granular materials are often placed with a backhoe in small, isolated areas such as sumps. Some drainage materials may even be placed by hand, e.g., in sumps and around drainage pipes.

CQA personnel should position themselves in front of the working face of the placement operation to be able to observe the materials as they are spread and to ensure that there is no puncture of underlying materials. CQA personnel should observe placement of drainage layers to ensure that fine-grained soil is not accidentally mixed with drainage material.

5.6.2 Drainage Trenches

Drainage materials are often placed in trenches to provide for subsurface drainage of water. A typical trench configuration is shown in Fig. 5.3. Often, a perforated pipe will be placed in the bottom of the trench. Geotextile filters are often required along the side walls to prevent migration of fine particles into the drainage material. CQA personnel should carefully review the plans and specifications to ensure that the drainage and filter components have been properly located in the trench prior to backfill.

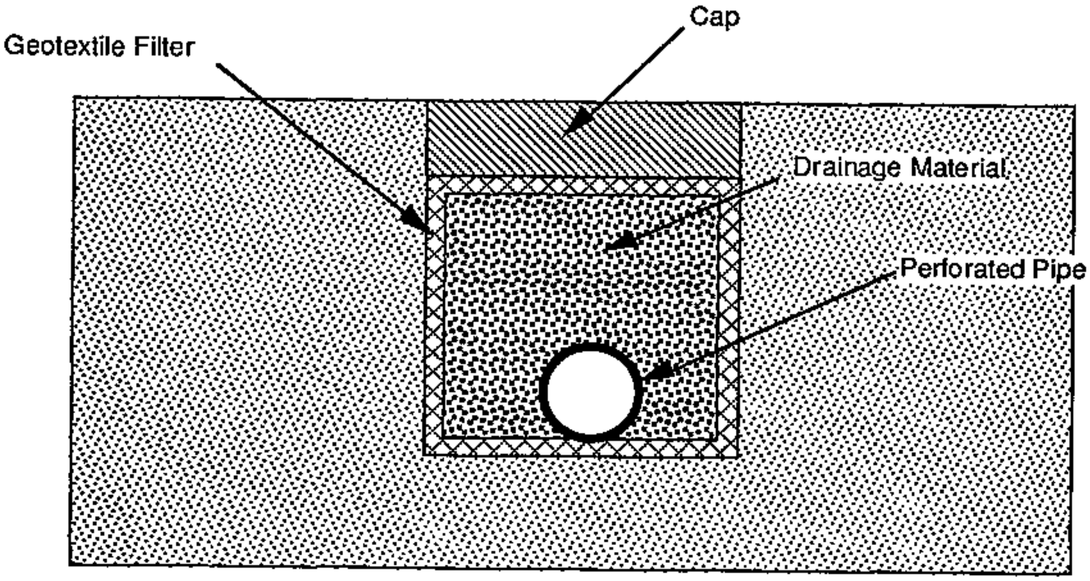


Figure 5.3 - Typical Design of a Drainage Trench

CQC/CQA personnel should be aware of all applicable safety requirements for inspection of trenches. Unsupported trenches can pose a hazard to personnel working in the trench or inspecting the trench. For trenches that are supported by shoring, CQA personnel should review with the contractor the plan for pulling the shoring in terms of the timing for placement of materials and ensure that the procedures are in accord with the specifications for the project.

Granular backfill is usually placed in a trench by a backhoe. For narrow trenches, a "tremie" is commonly used to direct the material into the trench without allowing the material to come into contact with soil on the sidewalls of the trench. Sometimes drainage materials are placed by hand for very small trenches.

A special type of trench involves support of the trench wall with a biodegradable ("biopolymer") slurry. The trench is excavated into soil using a biodegradable, viscous fluid to maintain the stability of the trench. The backfill is placed into the fluid-filled trench. An agent is introduced to promote degradation of the viscous drilling fluid, which quickly loses much of its viscosity and allows the granular backfill to attain a high hydraulic conductivity without any plugging effect from the slurry. This technology allows construction of deep, continuous drainage trenches but is used much more often for remediation of contaminated sites than in new waste containment facilities. Further details are given by Day (1990).

5.7 Compaction

Many construction specifications stipulate a minimum percentage compaction for granular drainage layers. There is rarely a need to compact drainage materials. However, on occasion, there may be a need to compact a drainage material for one of the following reasons:

1. If a settlement-sensitive structure is to be placed on top of the drainage layer, the drainage layer may need to be compacted to minimize settlement.
2. If dynamic loads might cause loose drainage material to liquefy or settle excessively, the material may need to be compacted.
3. If the drainage material must have exceptionally high strength, the material may need to be compacted.

Only in rare instances will the problems listed above be significant. Settlement-sensitive structures are rarely built on top of liner or cover systems. Liquefaction is rarely an issue because the hydraulic conductivity of the drainage material is normally sufficiently large to preclude the possibility of liquefaction. Strength is rarely a problem with granular materials. Reasons not to compact the drainage layer are as follows:

1. Compacting the drainage material increases the amount of fines in the drainage material, which decreases hydraulic conductivity.
2. Compacting the drainage layer reduces the porosity of the material, which decreases hydraulic conductivity.
3. Dynamic compaction stresses may damage underlying geosynthetics.

Unless there is a sound reason why the drainage material should be compacted, it is recommended that the drainage material not be compacted. The main goal of the drainage layer is to remove liquids, and this can only be accomplished if the drainage layer has high hydraulic conductivity. The uncompacted drainage layer may be slightly compressible, but the amount of compression is expected to be small.

There is a potential problem with drainage layer materials placed on side slopes. In some situations the friction between the drainage layer and underlying geosynthetic component may not be adequate to maintain stability of the side slope. CQA personnel should assume that the designer has analyzed slope stability and designed stable slide slopes for assumed materials and conditions. However, CQA personnel should be vigilant for evidence of slippage at the interface between the drainage layer and an underlying geosynthetic component. If problems are noted, the design engineer should be notified immediately.

5.8 Protection

The main protection required for the drainage layer is to ensure that large pieces of waste material do not penetrate excessively into the layer and that fines do not contaminate the layer. Many designs call for placement of protective soil or select waste on top of the leachate collection layer. As shown in Fig. 5.4, CQA personnel should stand near the working face of the first lift of solid waste placed on top of a leachate collection layer in a solid waste landfill to observe placement of select material.

Wind-borne fines may contaminate drainage materials. Soil erosion from adjacent slopes may also lead to accumulation of fines in the drainage material. The CQA personnel cannot complete their job until the drainage material is fully covered and protected.

Residual fines may be washed by rain from other soils, or the drainage material itself, during rain storms and accumulate in low areas. The accumulation of fines in sumps or other low points can reduce the effectiveness of the drainage system. CQC/CQA personnel should be aware of this potential problem and watch for (1) areas where fines may be washed into the drainage material; and (2) evidence of lack of free drainage in low-lying areas (e.g., development of ponds of water in the drainage material in low-lying areas). If excessive fines are washed into a portion of the drainage material, the design engineer should be contacted for further evaluation prior to covering the drainage material by the next successive layer in the system.

Figure 5.4 -- CQC and CQA Personnel Observing Placement of Select Waste on Drainage Layer.

5.9 References

ASTM D-422, "Particle Size Analysis of Soils"

ASTM D-1987, "Biological Clogging of Geotextile or Soil/Geotextile Filters"

ASTM D-2434, "Permeability of Granular Soils"

ASTM D-4373, "Calcium Carbonate Content of Soils"

Cedergren, H.R. (1989), *Seepage, Drainage, and Flow Nets*, Third Edition, John Wiley & Sons, New York, 465 p.

Day, S. R. (1990), "Excavation/Interception Trenches by the Bio-Polymer Slurry Drainage Trench Technique," *Superfund '90*, Hazardous Materials Control Research Institute, Silver Spring, Maryland, pp. 382-385.

Chapter 6

Geosynthetic Drainage Systems

6.1 Overview

The collection of liquids in waste containment systems, their drainage and eventual removal represents an important element in the successful functioning of these facilities. Focus in this chapter is on the primary and secondary leachate collection systems beneath solid waste and on surface water and gas removal systems in the cover above the waste. This chapter parallels Chapter 5 on natural soil drainage materials but now using geosynthetics. Combined systems such as geocomposites and geospacers are often used; however we will generally focus on the individual geosynthetic components. The individual materials to be described are the following:

- geotextiles used as filters over various drainage systems (geonets, geocomposites, sands and gravels)
- geotextiles used for gas collection
- geonets used as primary and/or secondary leachate collection systems, and gas collection
- other geosynthetic drainage systems used as surface water collection systems and possibly as primary and/or secondary leachate collection systems

The locations of the various geosynthetic materials listed above are illustrated in the sketch of Fig. 6.1.

6.2 Geotextiles

Geotextiles, which some refer to as filter fabrics or construction fabrics, consist of polymeric yarns (fibers) made into woven or nonwoven textile sheets and supplied to the job site in large rolls. When ready for placement, the rolls are removed from their protective covering, properly positioned and unrolled over the substrate material. The substrate upon which the geotextile is placed is usually a geonet, geocomposite, drainage soil or other soil material. The roll edges and ends are either overlapped for a specified distance, or are sewn together. After approval by the CQA personnel, the geotextile is covered with the overlying material. Depending on site specific conditions, this overlying material can be a geomembrane, geosynthetic clay liner, compacted clay liner, geonet, or drainage soil.

This section presents the MQA aspects of geotextiles insofar as their manufacturing is concerned and the CQA aspects as far as handling, seaming and backfilling is concerned.

6.2.1 Manufacturing of Geotextiles

The manufacturing of geotextiles made from polymeric fibers follows traditional textile manufacturing methods and uses similar equipment. It should be recognized at the outset that most manufacturing facilities have developed their respective geotextile products to the point where product quality control procedures and programs are routine and fully developed.

Three discrete stages in the manufacture of geotextiles should be recognized from an MQA perspective: (1) the polymeric materials; (2) yarn or fiber type; and (3) fabric type (IFAI, 1990).

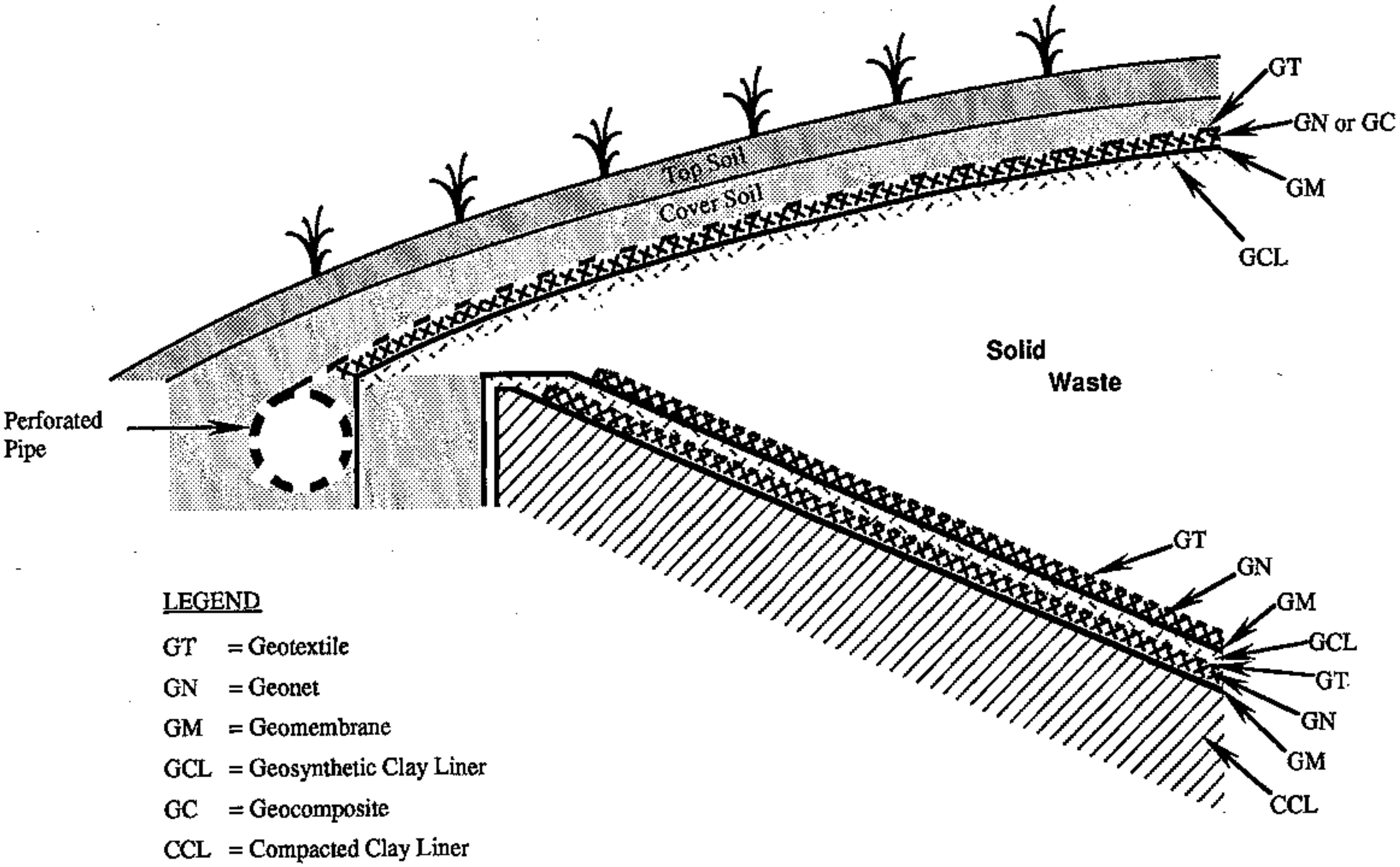


Figure 6.1 - Cross Section of a Landfill Illustrating the Use of Different Geosynthetics Involved in Waste Containment Drainage Systems

6.2.1.1 Resins and Their Additives

Approximately 75% of geotextiles used today are based on polypropylene resin. An additional 20% are polyester and the remaining 5% is a range of polymers including polyethylene, nylon and others used for specialty purposes. As with all geosynthetics, however, the base resin has various additives formulated with it resulting in the final compound. Additives for ultraviolet light protection and as processing aids are common, see Table 6.1.

Table 6.1 - Compounds Used in The Manufacture of Geotextiles (Values Are Percentages Based on Weight)

Generic Name	Resin	Carbon Black	Other Additives
Polypropylene	95 - 98	0 - 3	0 - 2
Polyester	97 - 98	0 - 1	0 - 2
Others	95 - 98	1 - 3	1 - 2

The resin is usually supplied in the form of pellets which is then blended with carbon black, either in the form of concentrate pellets or chips, or as a powder, and the additive package. The additive package is usually a powder and is proprietary with each particular manufacturer. For some manufacturers, the pellets are precompounded with carbon black and/or the entire additive package. Figure 6.2 shows polyester chips and carbon black concentrate pellets used in the manufacturer of polyester geotextiles. Polypropylene pellets and carbon black are similar to those shown in the manufacture of polyethylene geomembranes. Refer to Chapter 3 for details and in particular to Section 3.2.2 for use of recycled and/or reclaimed material.

The following items should be considered for a specification or MQA document for resins and additives used in the manufacture of geotextiles for waste containment applications.

1. The resin should meet MQC requirements. This usually requires a certificate of analysis to be submitted by the resin vendor for each lot supplied. Included will be various properties, their specification limits and the appropriate test methods. For polypropylene resin, the usual requirements are melt flow index, and other properties felt to be relevant by the manufacturer. For polyester resin, the usual requirements are intrinsic viscosity, solution viscosity, color, moisture content and other properties felt to be relevant by the manufacturer.

2. The internal quality control of the manufacturer should be reported to verify that the geotextile manufactured for the project meets the proper specifications.

3. The frequency of performing each of the preceding tests should be covered in the MQC plan and should be implemented and followed.

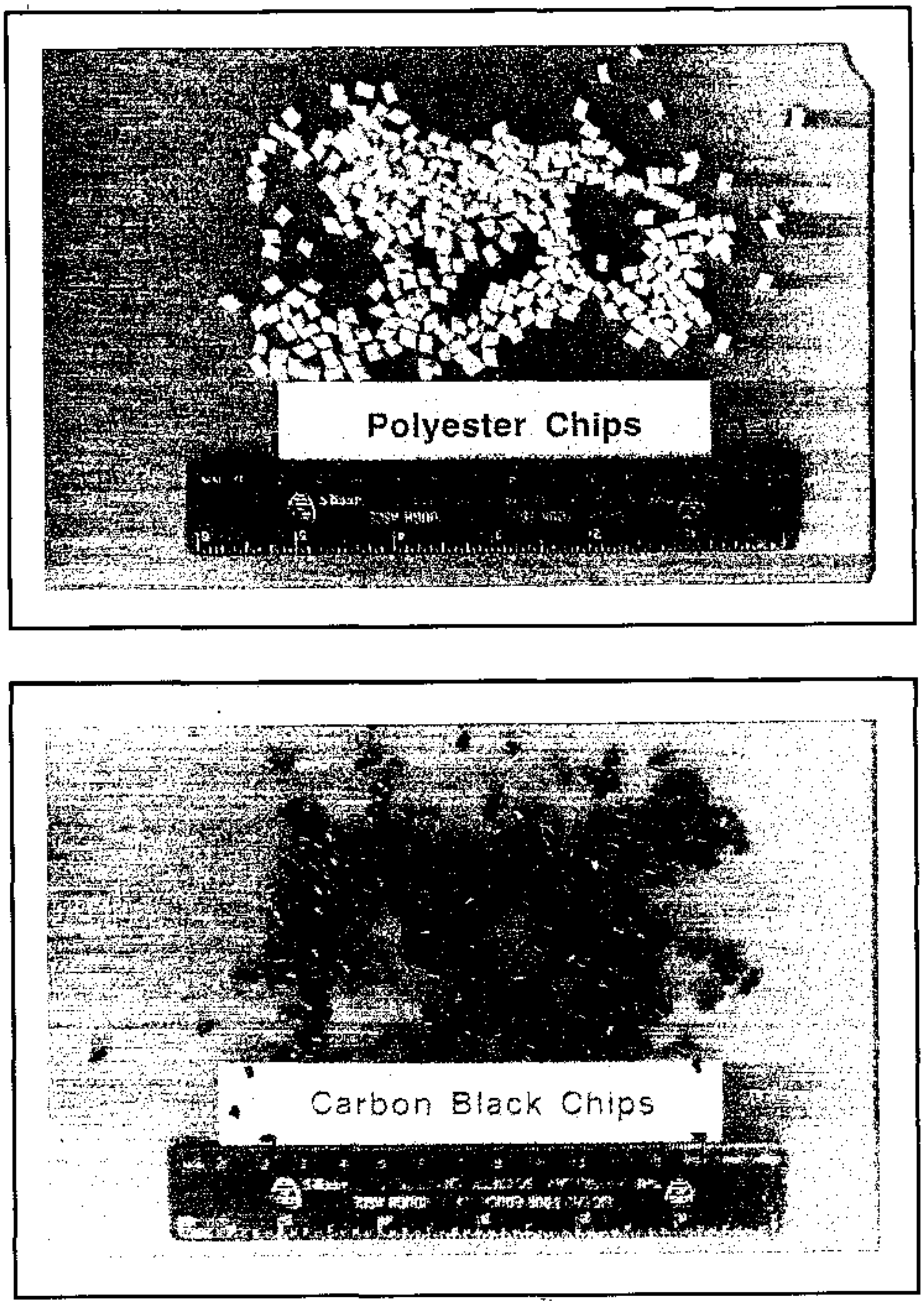


Figure 6.2 - Polyester Resin Chips (Upper) and Carbon Black Concentrate Pellets (Lower) Used for Geotextile Fiber Manufacturing

4. The percentage, according to ASTM D-1603, and type of carbon black should be specified for the particular formulation being used, although it is low in comparison to geomembranes.

5. The type and amount of stabilizers are rarely specified. If a statement is required it should signify that the stabilizer package has been successfully used in the past and to what extent.

6.2.1.2 Fiber Types

The resin, carbon black and stabilizers are introduced to an extruder which supplies heat, mixing action and filtering. It then forces the molten material to exit through a die containing many small orifices called a "spinnerette". Here the fibers, called "yarns", are usually drawn (work hardened) by mechanical tension, or impinged by air, as they are stretched and cooled. The resulting yarns, called "filaments", can be wound onto a bobbin, or can be used directly to form the finished product. Other yarn manufacturing variations include those made from staple fibers and flat, tape-like, yarns called "slit-film". Each type (filament, staple or slit-film) can be twisted together with others as shown in Fig. 6.3. Note that "yarn" is a generic term for any continuous strand (fiber, filament or tape) used to form a textile fabric. Thus all of the examples in Fig. 6.3 are yarns, except for staple, and can be used to manufacture geotextiles.

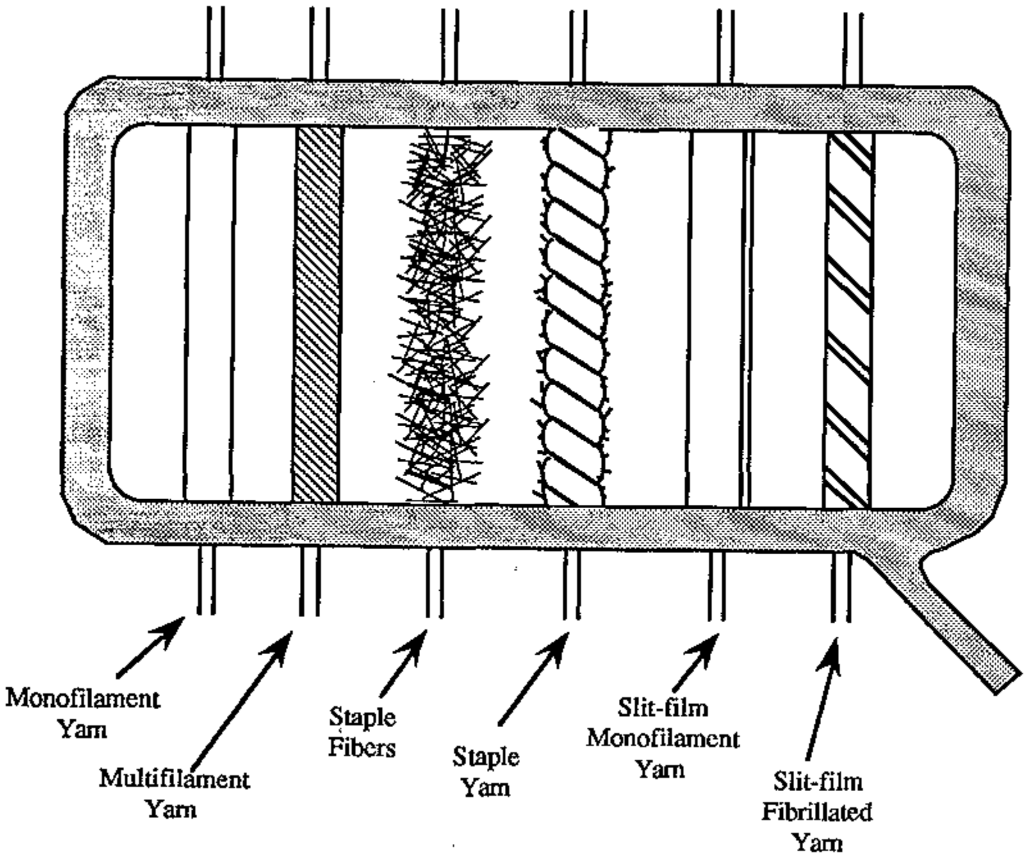


Figure 6.3 - Types of Polymeric Fibers Used in the Construction of Different Types of Geotextiles

6.2.1.3 Geotextile Types

The yarns just described are joined together to make a fabric, or geotextile. Generic classifications are woven, nonwoven and knit. Knit geotextiles, however, are rarely used in waste containment systems and will not be described further in this document.

The manufacturer of a woven geotextile uses the desired type of yarn from a bobbin and constructs the fabric on a weaving loom. Fabric weaving technology is well established over literally centuries of development. Most woven fabrics used for geotextiles are "simple", or "basket-type" weaves consisting of each yarn going over and under an intersecting yarn on an alternate basis. Figure 6.4(a) shows a micrograph of a typical woven geotextile pattern.

In contrast to this type of uniformly woven pattern are nonwoven fabrics as shown in Figs. 6.4(b) and (c). Here the yarns are utilized directly from the extruding spinnerette and laid down on a moving belt in a random fashion. The speed of the moving belt dictates the mass per unit area of the final product. While positioned on the belt the material is "lofty", and the yarns are not structurally bound in any way. Two variations of structural bonding can be used, which gives rise to two unique types of nonwoven geotextiles.

- Nonwoven, needlepunched geotextiles go through a needling process wherein barbed needles penetrate the fabric and entangle numerous fibers transverse to the plane of the fabric. Note the fiber entanglement pattern in Fig. 6.4(b). As a post-processing step, the fabric can be passed over a heated roller resulting in a singed or burnished surface of the yarns on one or both sides of the fabric.

- Nonwoven, heat bonded geotextiles are formed by passing the unbonded fiber mat through a source of heat, usually steam or hot air, thereby melting some of the fibers at various points. Note the fiber bonding pattern in Fig. 6.4(c). This compresses the mat and simultaneously joins the fibers at their intersections by melt bonding.

6.2.1.4 General Specification Items

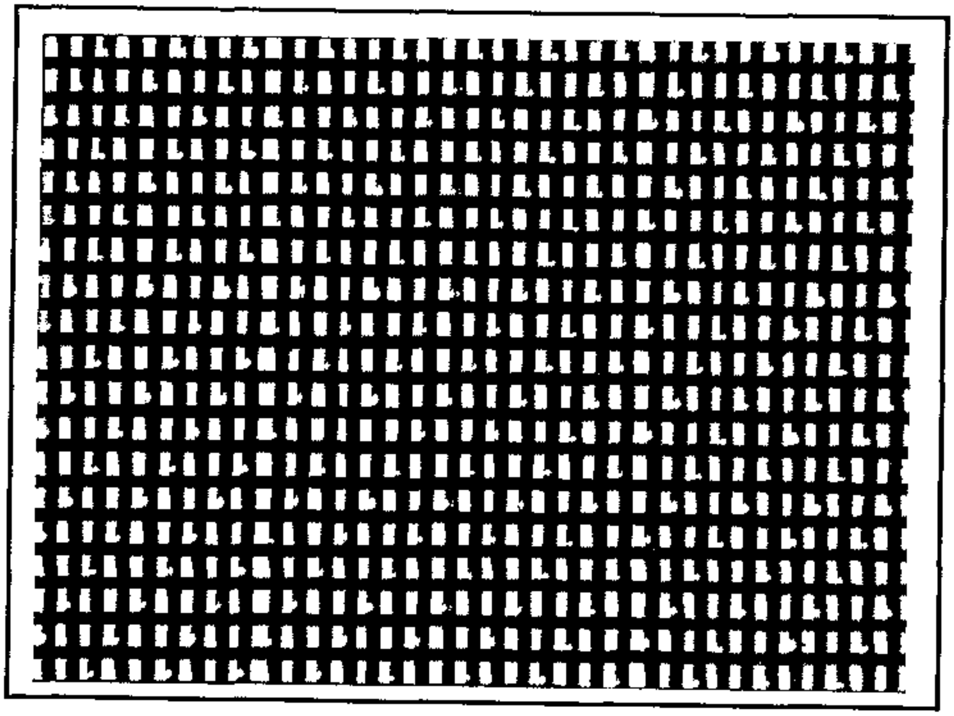
There are numerous items recommended for inclusion in a specification or MQA document for geotextiles used in waste containment facilities.

1. There should be verification and certification that the actual geotextile properties meet the manufacturers specification for that particular type and style.

2. Quality control certifications should include, at a minimum, mass per unit area per ASTM D-5261, grab tensile strength per ASTM D-4632, trapezoidal tear strength per ASTM D-4533, burst strength per ASTM D-3786, puncture strength per ASTM D-4833, thickness per ASTM D-5199, apparent opening size per ASTM D-4751, and permittivity per ASTM D-4491.

3. Values for each property should meet, or exceed, the project specification values, (note in some cases the property listed is a maximum value in which case lower values are acceptable).

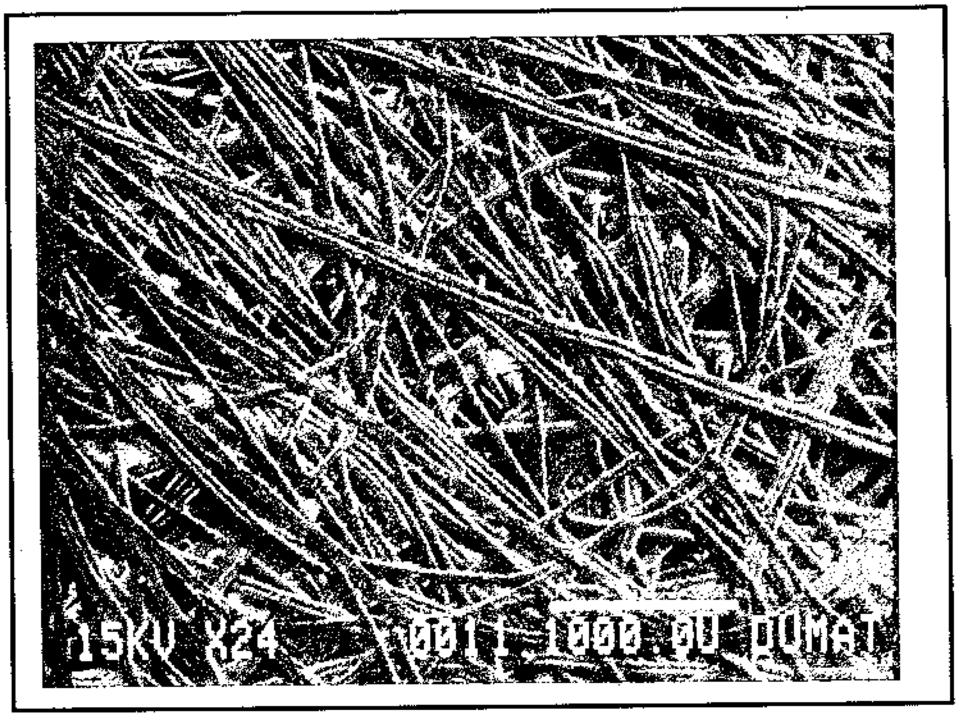
4. A statement should be included that the property values listed are based upon the minimum average roll value (MARV) concept.



(a) Woven Geotextile at 4X Magnification

(b) Nonwoven Needlepunched Geotextile at 24X Magnification

Figure 6.4 - Three Major Types of Geotextiles (Continued on Next Page).



(c) Nonwoven Heatbonded Geotextile at 24X Magnification

Figure 6.4 - Three Major Types of Geotextiles (Continued from Previous Page)

5. The ultraviolet light resistance should be specified which is usually a certain percentage of strength or elongation retained after exposure in a laboratory weathering device. Usually ASTM D-4355 is specified and retention after 500 hours is typically 50% to 90%.

6. The frequency of performing each of the preceding tests should be covered in the manufacturer's MQC plan and it should be implemented and followed.

7. Verification that needle-punched, nonwoven geotextiles have been inspected continuously for the presence of broken needles using an in-line metal detector with an adequate sweep rate should be provided. Furthermore, a needle removal system, e.g., magnets, should be implemented.

8. A statement indicating if, and to what extent, reworked polymer, or fibers, was added during manufacturing. If used, the statement should note that the rework polymer, or fibers, was of the same composition as the intended product.

9. Reclaimed or recycled, i.e., fibers or polymer that has been previously used, should not be added to the formulation unless specifically allowed for in the project

specifications. Note, however, that reclaimed fibers may be used in geotextiles in certain waste containment applications. The gas collection layer above the waste and the geotextile protection layer between drainage stone and a geomembrane are likely locations. These should be design decisions and should be made accordingly.

6.2.2 Handling of Geotextiles

A number of activities occur between the manufacture of geotextiles and their final positioning at the waste facility. These activities involve protective wrapping, storage at the manufacturing facility, shipment, storage at the site, product acceptance, conformance testing and final placement at the facility. Each of these topics will be described in this section.

6.2.2.1 Protective Wrapping

All rolls of geotextiles, irrespective of their type, must be enclosed in a protective wrapping that is opaque and waterproof. The object is to prevent any degradation from atmospheric exposure (ultraviolet light, ozone, etc.), moisture uptake (rain, snow) and to a limited extent, accidental damage. It must be recognized that geotextiles are the most sensitive of all geosynthetics to degradation induced by ultraviolet light exposure. Geotextile manufacturers use tightly wound plastic wraps or loosely fit plastic bags for this purpose. Quite often the plastic is polyethylene in the thickness range of 0.05 to 0.13 mm (2 to 5 mil). Several important issues should be considered in a specification or MQA document.

1. The protective wrapping should be wrapped around (or placed around) the geotextile in the manufacturing facility and should be included as the final step in the manufacturing process.

2. The packaging should not interfere with the handling of the rolls either by slings or by the utilization of the central core upon which the geotextile is wound.

3. The protective wrapping should prevent exposure of the geotextile to ultraviolet light, prevent it from moisture uptake and limit minor damage to the roll.

4. Every roll must be labeled with the manufacturers name, geotextile style and type, lot and roll numbers, and roll dimensions (length, width and gross weight). Details should conform to ASTM D-4873.

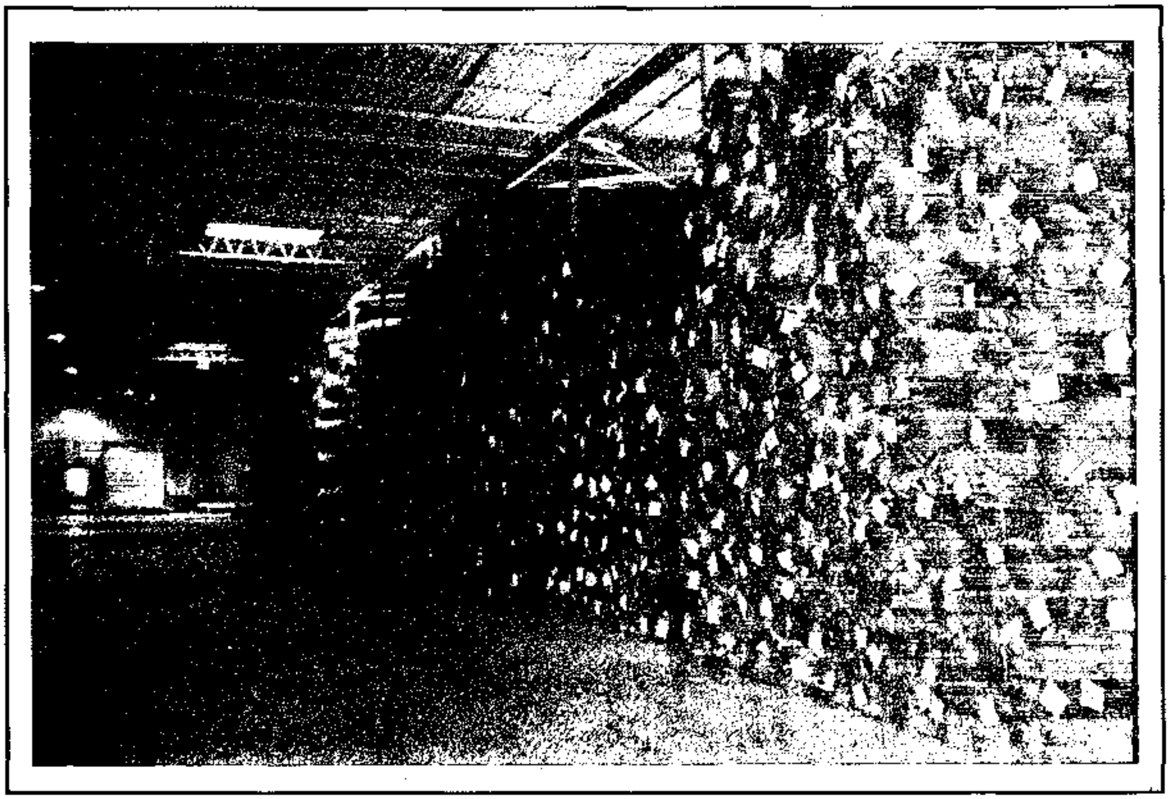
6.2.2.2 Storage at Manufacturing Facility

The manufacturing of geotextiles is such that temporary storage of rolls at the manufacturing facility is necessary. Storage times range from a few days to a year, or longer. Figure 6.5(a) shows geotextile storage at a manufacturer's facility.

Regarding specification and MQA document items, the following should be considered.

1. Handling of rolls of geotextiles should be done in a competent manner such that damage does not occur to the geotextile nor to its protective wrapping. In this regard ASTM D-4873 should be referenced and followed.

2. Rolls of geotextiles should not be stacked upon one another to the extent that deformation of the core occurs or to the point where accessibility can cause damage in handling.



(a) Storage at Manufacturing Facility

(b) Storage at Field Site

Figure 6.5 - Photographs of Temporary Storage of Geotextiles

3. Outdoor storage of rolls at the manufacturer's facility should not be longer than six months. For storage periods longer than six months a temporary enclosure should be put over the rolls, or they should be moved to within a enclosed facility.

6.2.2.3 Shipment

Geotextile rolls are shipped from the manufacturer's (or their representatives) storage facility to the job site via common carrier. Ships, railroads and trucks have all been used depending upon the locations of the origin and final destination. The usual carrier from within the USA, is truck. When using flat-bed trucks the rolls are usually loaded by means of a crane with slings wrapped around the individual rolls. When the truck bed is closed, i.e., an enclosed trailer, the rolls are usually loaded by fork lift with a "stinger" attached. The "stinger" is a long tapered rod which fits inside the core upon which the geotextile is wrapped.

Insofar as specification and MQA/CQA documents are concerned the following items should be considered.

1. The method of loading the geotextile rolls, transporting them and off-loading them at the job site should not cause any damage to the geotextile, its core, nor its protective wrapping.
2. Any protective wrapping that is accidentally damaged or stripped off of the rolls should be repaired immediately or the roll should be moved to a enclosed facility until its repair can be made to the approval of the CQA personnel.

6.2.2.4 Storage at Field Site

Off-loading of geotextile rolls at the site and temporary storage which must be done in an acceptable manner. Figure 6.5(b) shows typical storage at the field site. Some specification and CQA document items to consider are the following.

1. Handling of rolls of geotextiles should be done in a competent manner such that damage does not occur to the geotextile nor to its protective wrapping. In this regard ASTM D-4873 should be referenced and followed.
2. The location of field storage should not be in areas where water can accumulate. The rolls should be elevated off of the ground so as not to form a dam creating the ponding of water.
3. The rolls should be stacked in such a way that cores are not crushed nor is the geotextile damaged. Furthermore, they should be stacked in such a way that access for conformance testing is possible.
4. Outdoor storage of rolls should not exceed manufacturers recommendations or longer than six months, whichever is less. For storage periods longer than six months a temporary enclosure should be placed over the rolls, or they should be moved within an enclosed facility.

6.2.2.5 Acceptance and Conformance Testing

Upon delivery of the rolls of geotextiles to the project site, and temporary storage thereof, the CQA engineer should see that conformance test samples are obtained. These samples are then sent to the CQA laboratory for testing to ensure that the supplied geotextile conforms to the project plans and specifications. The samples are taken from selected rolls by removing the protective wrapping and cutting full-width, 1 m (3 ft) long samples off of the outer wrap of the selected roll(s). Sometimes the outer revolution of geotextile is discarded before the test sample is taken. The rolls are immediately re-wrapped and replaced in temporary field storage. The samples rolls must be relabeled for future identification. Alternatively, conformance testing could be performed at the manufacturer's facility and when completed the particular lot should be marked for the particular site under investigation. Items to be considered in a specification and CQA documents in this regard are the following:

1. The samples should be identified by type, style or, lot and roll numbers. The machine direction should be noted on the sample(s) with a waterproof marker.
2. A lot is defined as a unit of production, or a group of other units or packages having one or more common properties and being readily separable from other similar units. Other definitions are also possible and should be clearly stated in the CQA documents, see ASTM D-4354.
3. Sampling should be done according to the job specification and/or CQA documents. Unless otherwise stated, sampling should be based on one per lot. Note that a lot is sometimes defined as 10,000 m^2 (100,000 ft^2) of geotextile. Utilization of ASTM D-4354 may be referenced and followed in this regard but it might result in a different value for sampling than stated above.
4. Testing at the CQA laboratory may include mass per unit area per ASTM D-5261, grab tensile strength per ASTM D-4632, trapezoidal tear strength per ASTM D-4533, burst strength per ASTM D-3786, puncture strength per ASTM D-4833, and possibly apparent opening size per ASTM D-4751, and permittivity per ASTM D-4491. Other conformance tests may be required by the project specifications.
5. Conformance test results should be sent to the CQA engineer prior to deployment of any geotextile from the lot under review.
6. The CQA engineer should review the results and should report any nonconformance to the Owner/Operator's Project Manager.
7. The resolution of failing conformance tests must be clearly stipulated in the specifications or CQA documents. Statements should be based upon ASTM D-4759 entitled "Determining the Specification Conformance of Geosynthetics".
8. The geotextile rolls which are sampled should be immediately rewrapped in their protective covering to the satisfaction of the CQA personnel.

6.2.2.6 Placement

The geosynthetic installation contractor should remove the protective wrappings from the geotextile rolls to be deployed only after the substrate layer, soil or other geosynthetic, has been documented and approved by the CQA personnel. The specification and CQA documents should be written in such a manner as to ensure that the geotextiles are not damaged nor excessively exposed to ultraviolet degradation. The following items should be considered for inclusion in a specification or CQA document.

1. The installer should take the necessary precautions to protect the underlying layers upon which the geotextile will be placed. If the substrate is soil, construction equipment can be used provided that excess rutting is not created. Excess rutting should be clearly defined and quantified by the design engineer. In some cases 25 mm (1.0 in.) is the maximum rut depth allowed. If the ground freezes, the depth of ruts should be further reduced to a specified value. If the substrate is a geosynthetic material, deployment must be by hand, by use of small jack lifts on pneumatic tires having low ground contact pressure, or by use of all-terrain vehicles, ATV's, having low ground contact pressure.

2. During placement, care must be taken not to entrap (either within or beneath the geotextile) stones, excessive dust or moisture that could damage a geomembrane, cause clogging of drains or filters, or hamper subsequent seaming.

3. On side slopes, the geotextiles should be anchored at the top and then unrolled so as to keep the geotextile free of wrinkles and folds.

4. Trimming of the geotextiles should be performed using only an upward cutting hook blade.

5. Nonwoven geotextiles placed on textured geomembranes can be troublesome due to sticking and are difficult to align or even separate after they are placed on one another. A thin sheet of plastic on the geomembrane during deployment of the geotextile can be very helpful in this regard. Of course, it is removed after correct positioning of the geotextile.

6. The geotextile should be weighted with sandbags, or the equivalent, to provide resistance against wind uplift. This is a site-specific procedure and completely the installer's decision. Uplifted and moved geotextiles can generally be reused but only after approval by the owner and observation by the CQA personnel.

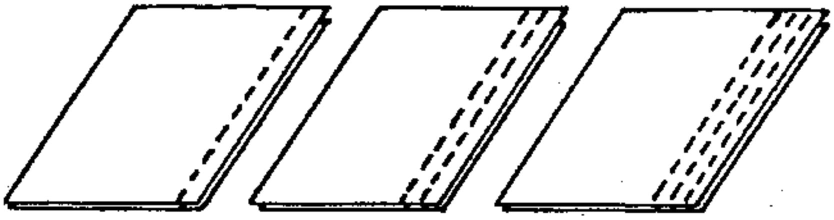
7. A visual examination of the deployed geotextile should be carried out to ensure that no potentially harmful objects are present, e.g., stones, sharp objects, small tools, sandbags, etc.

6.2.3 Seaming

Seaming of geotextiles, by sewing, is sometimes required (versus overlapping with no sewn seams) of all geotextiles placed in waste facilities. This generally should be the case for geotextiles used in filtration, but may be waived for geotextiles used in separation (e.g., as gas collection layers above the waste or as protective layers for geomembranes) as per the plans and specifications. In such cases, heat bonding is also an acceptable alternate method of joining separation geotextiles. In cases where overlapping is permitted, the overlapped distance requirements should be clearly stated in the specification and CQA documents. Geotextile seam types and procedures, seam tests and geotextile repairs are covered in this section.

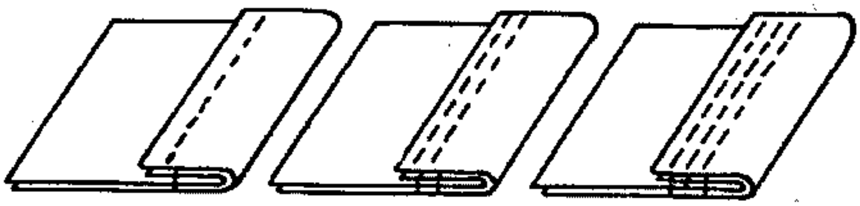
6.2.3.1 Seam Types and Procedures

The three types of sewn geotextile seams are shown in Fig. 6.6. They are the "flat" or "prayer" seam, the "J" seam and the "butterfly" seam. While each can be made by a single thread, or by a two-thread chain stitch, as illustrated, the latter stitch is recommended. Furthermore, a single, double, or even triple, row of stitches can be made as illustrated by the dashed lines in the figures. Figure 6.7 shows a photograph of the fabrication of a flat seam and see Diaz (1990) for further details regarding geotextile seaming.



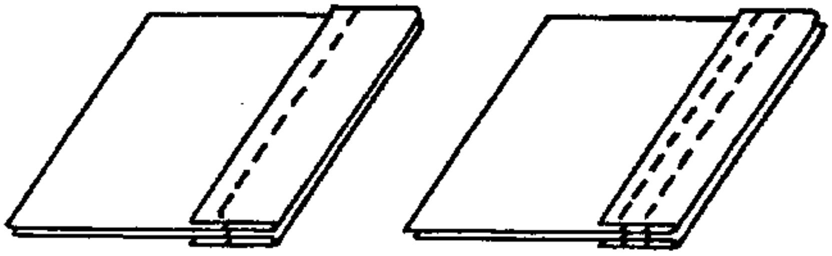
SSa-1 SSa-2 SSa-3

"Flat" or "Prayer" Seam



SSn-1 SSn-2 SSn-3

"J" Seam



SSd-1 SSd-2

"Butterfly" Seam

"101" Single Thread Chainstitch "401" Two-Thread Chainstitch

Figure 6.6 - Various Types of Sewn Seams for Joining Geotextiles (after Diaz, 1990)

Figure 6.7 - Fabrication of a Geotextile Field Seam in a "Flat" or "Prayer" Seam Type

The project specification or CQA documents should address the following considerations.

1. The type of seam, type of stitch, stitch count or number of stitches per inch and number of rows should be specified based on the tendency of the fabric to fray, strength need and toughness of the fabric. For filtration and separation geotextiles a flat seam using a two-thread chain stitch and one row is usually specified. For reinforcement geotextiles, stronger and more complex seams are utilized. Alternatively, a minimum seam strength, per ASTM D-4884, could be specified.

2. The seams should be continuous, i.e., spot sewing is generally not allowed.

3. On slopes greater than approximately 5 (horiz.) to 1 (vert.), seams should be constructed parallel to the slope gradient. Exceptions are permitted for small patches and repairs.

4. The thread type must be polymeric with chemical and ultraviolet light resistant properties equal or greater than that of the geotextile itself.

5. The color of the sewing thread should contrast that of the color of the geotextile for ease in visual inspection. This may not be possible due to polymer composition in some cases.

6. Heat seaming of geotextiles may be permitted for certain seams. A number of methods are available such as hot plate, hot knife and ultrasonic devices.

7. Overlapped seams of geotextiles may be permitted for certain seams. The overlap distance should be stated depending on the site specific conditions.

6.2.3.2 Seam Tests

For geotextiles used in filtration and separation, seam samples and subsequent strength testing are not generally required. If they are, however, they should be stipulated in the specifications or CQA documents. Also, the sampling and testing frequency should be noted accordingly. The test method to evaluate sewn seam test specimens is ASTM D-4884.

6.2.3.3 Repairs

Holes, or tears, in geotextiles made during placement or anytime before backfilling should be repaired by patching. Some relevant specifications and CQA document items follow.

1. The patch material used for repair of a hole or tear should be the same type of polymeric material as the damaged geotextile, or as approved by the CQA engineer.

2. The patch should extend at least 30 cm (12 in.) beyond any portion of the damaged geotextile.

3. The patch should be sewn in place by hand or machine so as not to accidentally shift out of position or be moved during backfilling or covering operations.

4. The machine direction of the patch should be aligned with the machine direction of the geotextile being repaired.

5. The thread should be of contrasting color to the geotextile and of chemical and ultraviolet light resistance properties equal or greater than that of the geotextile itself.

6. The repair should be made to the satisfaction of the specification and CQA documents.

6.2.4 Backfilling or Covering

The layer of material placed above the deployed geotextile will be either soil, waste or another geosynthetic. Soils will vary from compacted clay layers to coarse aggregate drainage layers. Waste should be what is referred to as “select” waste, i.e., carefully separated and placed so as not to cause damage. Geosynthetics will vary from geomembranes to geosynthetic clay liners. Some considerations for a specification and CQA document to follow:

1. If soil is to cover the geotextile it should be done such that the geotextile is not shifted from its intended position and underlying materials are not exposed or damaged.

2. If a geosynthetic is to cover the geotextile, both the underlying geotextile and the newly deployed material should not be damaged during the process.

3. If solid waste is to cover the geotextile, the type of waste should be specified and visual observation by CQA personnel should be required.

4. The overlying material should not be deployed such that excess tensile stress is mobilized in the geotextile. On side slopes, this requires soil backfill to proceed from the bottom of the slope upward.

5. Soil backfilling or covering by another geosynthetic, should be done within the time frame stipulated for the particular type of geotextile. Typical time frames for geotextiles are within 14 days for polypropylene and 28 days for polyester geotextiles.

6.3 Geonets and Geonet/Geotextile Geocomposites

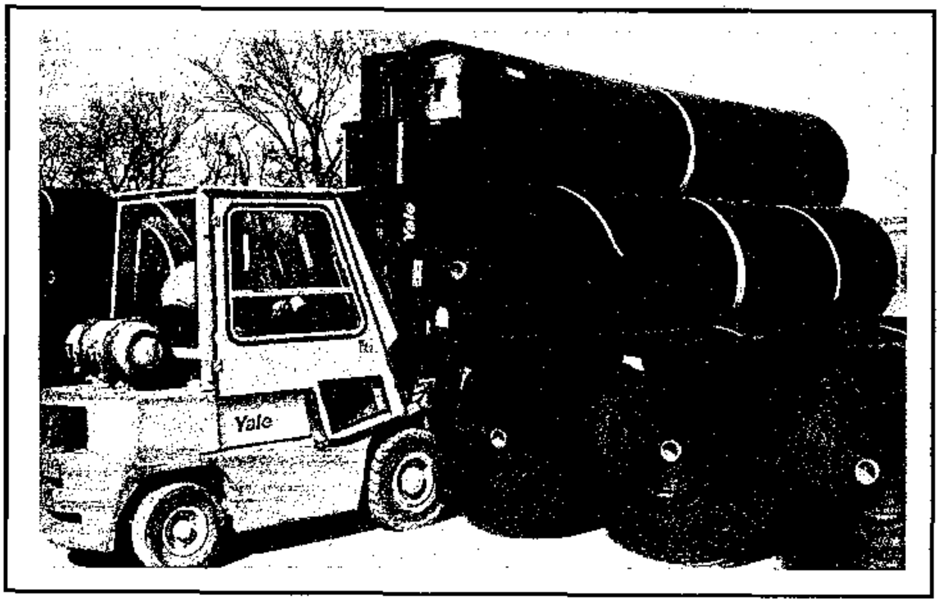
Geonets are unitized sets of parallel ribs positioned in layers such that liquid can be transmitted within their open spaces. Thus their primary function is drainage; recall Fig. 6.1. Figure 6.8(a) shows a photograph of rolls of geonets, while Fig. 6.8(b) shows a closeup of the intersection of a typical set of geonet ribs. Note that open space exists both in the plane of the geonet (above or under the parallel sets of ribs) and cross plane to the geonet (within the apertures between adjacent sets of ribs). In all cases, the apertures must be protected against migration and clogging by adjacent soil materials. Thus geonets always function with either geomembranes and/or geotextiles on their two planar surfaces. Whenever the geonet comes supplied with a geotextile on one or both of its surfaces, it is called a geocomposite. The geotextile(s) is usually bonded on the surface by heat fusing or by using an adhesive.

This section will describe the manufacturing and handling of geonets for waste containment facilities. Since continuity of liquid flow is necessary at the sides and ends of the rolls, joining methods will also be addressed, as will the placement of the covering layer. Also covered will be the bonding of geotextiles to geonets in the form of drainage geocomposites.

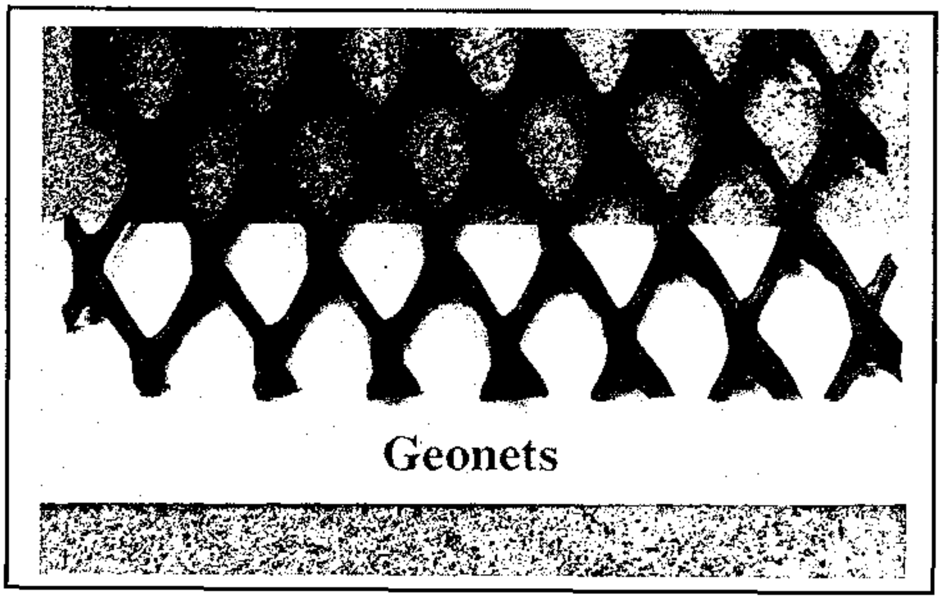
6.3.1 Manufacturing of Geonets

Geonets currently used in waste containment applications are formed using an extruder which accepts the intended polymer formulation and then melts, mixes, filters and feeds the molten material directly into a counter-rotating die. This die imparts parallel sets of ribs into the preform. Upon exiting the die, the ribs of the preform are opened by being forced over a steel spreading mandrel. Figure 6.9 shows a small laboratory size geonet as it is formed and expands into its final shape. The fully formed geonet is then water quenched, longitudinally cut in the machine direction, spread open as it exits the quench tank and rolled onto a handling core. The width of the rolls are determined by the maximum circumference of the spreading mandrel. Since the process is continuous in its operation, the roll length is determined on the basis of the manageable weight of a roll. The thickness of the geonet is based on the slot dimensions of the opposing halves of the counter-rotating mold. Thicknesses of commercially available geonets vary between 4.0 and 6.9 mm (160 - 270 mils).

Most of the commercially available resins used for geonets are polyethylene in the natural density range of 0.934 to 0.940 g/cc. Thus they are classified as medium density polyethylene according to ASTM D-1248. The final compound is approximately 97% polyethylene. An additional 2 to 3% is carbon black, added as a powder or as a concentrate, and the remaining 0.5 to 1.0% are additives. The additives are added as a powder as are antioxidants and processing aids, both of which are proprietary to the various geonet manufacturers. Formulations are often the same as for HDPE geomembranes (recall Chapter 3), or slight variations thereof.



(a) Rolls of Drainage Geonets



(b) Closeup of Rib Intersection

Figure 6.8 - Typical Geonets Used in Waste Containment Facilities

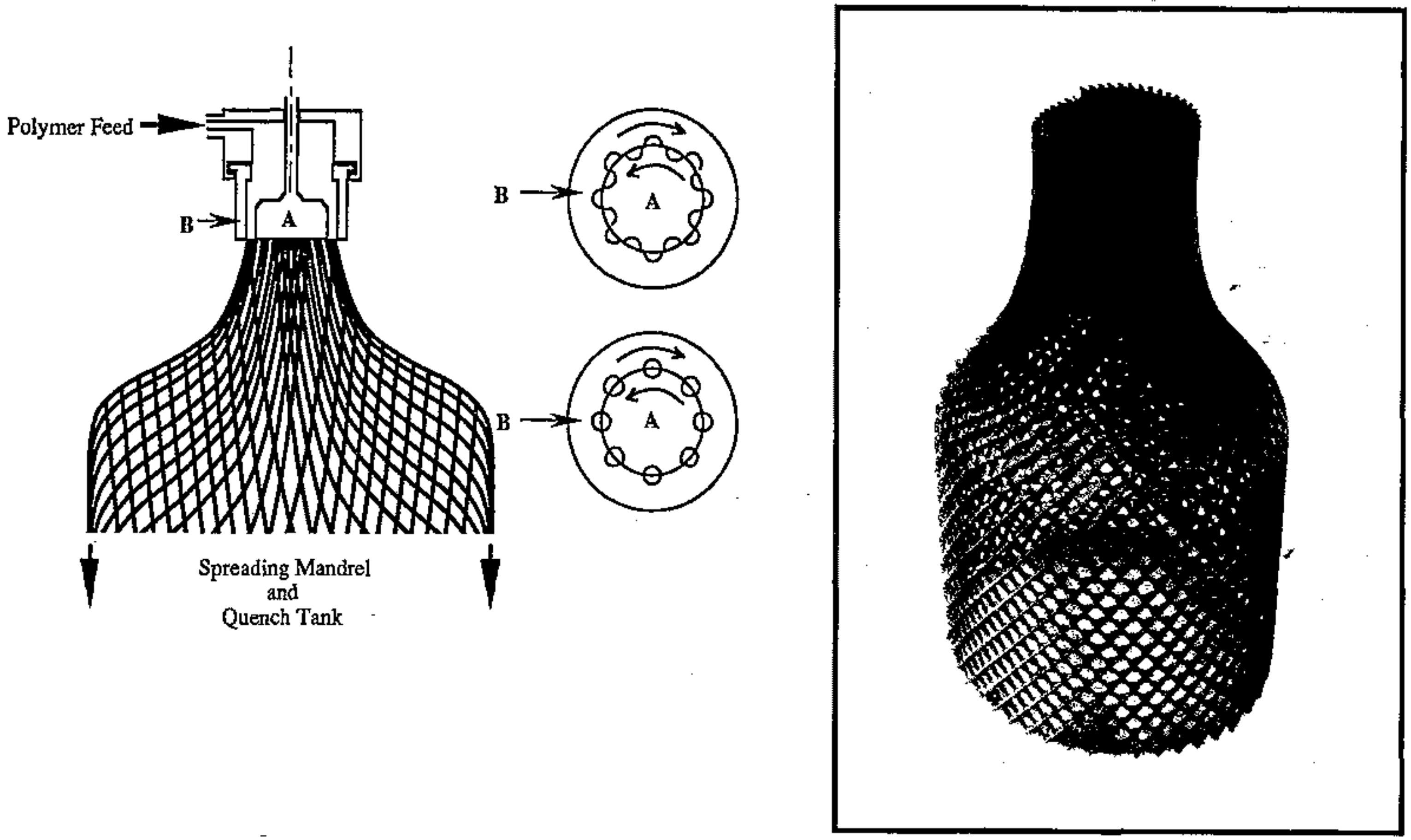


Figure 6.9 - Counter Rotating Die Technique (Left Sketch) for Manufacturing Drainage Geonets and Example of Laboratory Prototype (Right Photograph)

Regarding the preparation of a specification or MQA document for the resin component of HDPE geonets, the following items should be considered:

1. Specifications may call for the polyethylene resin to be made from virgin, uncontaminated ingredients. Alternatively, geonets can be made with off-spec geomembrane material as a large, or even major part, of their total composition provided this material is of the same formulation as the intended geonet and does not consist of recycled and/or reclaimed material. Recycled and/or reclaimed material is generally not allowed. It is acceptable, and is almost always the case, that the density of the resin is in the medium density range for polyethylene, i.e., that its density is equal to or less than 0.940 g/cc.

2. Typical quality control tests on the resin are density, via ASTM D-1505 or D-792 and melt flow index via ASTM D-1238.

3. An HDPE geonet formulation should consist of at least 97% of polyethylene resin, with the balance being carbon black and additives. No fillers, extenders, or other materials should be mixed into the formulation.

4. It should be noted that by adding carbon black and additives to the resin, the density of the final formulation is generally over 0.941 g/cc. Since this value is in the high density polyethylene category, according to ASTM D-1248, geonets of this type are customarily referred to as high density polyethylene (HDPE).

5. Regrind or reworked polymer which is previously processed HDPE geonet in chip form, is often added to the extruder during processing. It is acceptable if it is the same formulation as the geonet being produced.

6. No amount of "recycled" or "reclaimed" material, which has seen prior use in another product should be added to the formulation.

7. An acceptable variation of the process just described is to add a foaming agent into the extruder which then is processed in the standard manner. As the geonet is formed and is subsequently quenched, the foaming agent expands within the ribs creating innumerable small spherical voids. The voids are approximately 0.01 mm (0.5 mil) in diameter. This type of geonet is called a "foamed rib" geonet, in contrast to the standard type which is a "solid rib" geonet. Foamed rib geonets are currently seen less frequently in drainage systems than previously.

8. Quality control certificates from the manufacturer should include proper identification of the product and style and results of quality control tests.

9. The frequency of performing each of the preceding tests should be covered in the MQC plan and it should be implemented and followed.

6.3.2 Handling of Geonets

A number of activities occur between the manufacture of geonets and their final positioning where intended at the waste facility. These activities involve packaging, storage at the manufacturing facility, shipment, storage at the site, acceptance and conformance testing and final placement at the facility. Each of these topics will be described in this section.

6.3.2.1 Packaging

As geonets come from the quenching tank they are wound on a core until the desired length is reached. The geonet is then cut along its width and the entire roll contained by polymer straps so as not to unwind during subsequent handling. There is generally no protective wrapping placed around geonets, however, a plastic wrapping can be provided if necessary.

Specifications or a MQA document should be formed around a few important points.

1. The core must be stable enough to support the geonet roll while it is handled by either slings around it, or from a fork lift "stinger" inserted in it.
2. The core should have a minimum 100 mm (4.0 in.) inside diameter.
3. The banding straps around the outside of the roll should be made from materials with adequate strength yet should not damage the outer wrap(s) of the roll.

6.3.2.2 Storage at Manufacturing Facility

The storage of geonet rolls at the manufacturer's facility is similar to that described for HDPE geomembranes. Refer to Section 3.3.1 for a complete description.

6.3.2.3 Shipment

The shipment of geonet rolls from the manufacturer's facility to the project site is similar to that described for HDPE geomembranes. Refer to Section 3.3.2 for a complete description.

6.3.2.4 Storage at the Site

The storage of geonet rolls at the project site is similar to that described with HDPE geomembranes. Refer to section 3.3.2 for a complete description, see Fig. 6.10. An important exception is that a ground cloth should be placed under the geonets if they are stored on soil for any time longer than one month. This is to prevent weeds from growing into the lower rolls of the geonet. If weeds do grow in the geonet during storage, the broken pieces must be removed by hand on the job when the geonet is deployed.

6.3.2.5 Acceptance and Conformance Testing

The acceptance and conformance testing of geonets is similar to that described for HDPE geomembranes. Refer to Section 3.3.3 for a complete description. For geonets, the usual conformance tests are the following:

- density, per ASTM D-1505 or D-792
- mass per unit area, per ASTM D-5261
- thickness, per ASTM D-5199

Additional conformance tests such as compression per ASTM D-1621 and transmissivity per ASTM D-4716 may also be stipulated.

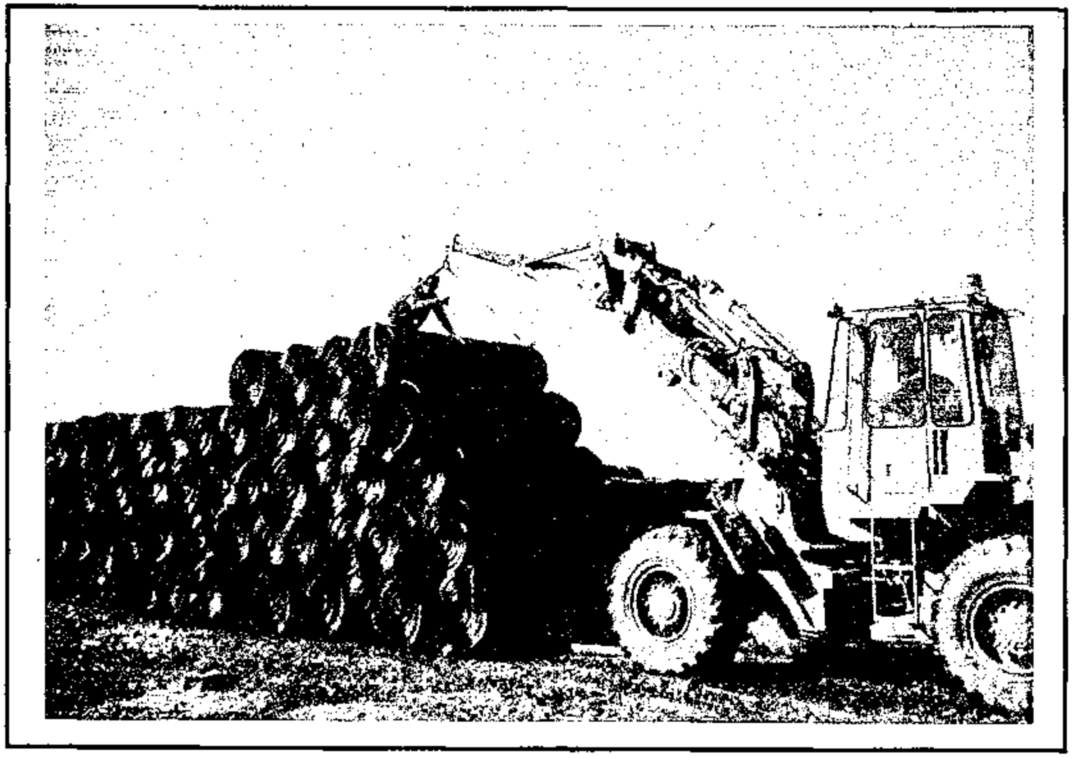


Figure 6.10 - Geonets Being Temporarily Stored at the Job Site

6.3.2.6 Placement

The placement of geonets in the field is similar to that described for geotextiles. Refer to Section 6.2.2.6 for a complete description.

6.3.3 Joining of Geonets

Geonets are generally joined together by providing a stipulated overlap and using plastic fasteners or polymer braid to tie adjacent ribs together at minimum intervals, see Fig. 6.11.

Recommended items for a specification or CQA document on the joining of geonets include the following:

1. Adjacent roll edges of geonets should be overlapped a minimum distance. This is typically 75-100 mm (3-4 in.).
2. The roll ends of geonets should be overlapped 150-200 mm (6-8 in.) since flow is usually in the machine direction.

Figure 6.11 - Photograph of Geonet Joining by Using Plastic Fasteners

3. All overlaps should be joined by tying with plastic fasteners or polymeric braid. Metallic ties or fasteners are not allowed.
4. The tying devices should be white or yellow, as contrasted to the black geonet, for ease of visual inspection.
5. The tying interval should be specified. Typically tie intervals are every 1.5 m (5.0 ft) along the edges and every 0.15 m (6.0 in.) along the ends and in anchor trenches.
6. Horizontal seams should not be allowed on side slopes. This requires that the length of the geonet should be at least as long as the side slope, anchor trench and a minimum run out at the bottom of the facility. If horizontal seams are allowed, they should be staggered from one roll to the adjacent roll.
7. In difficult areas, such as corners of side slopes, double layers of geonets are sometimes used. This should be stipulated in the plans and specifications.
8. If double geonets are used, they should be layered on top of one another such that interlocking does not occur.

9. If double geonets are used, roll edges and ends should be staggered so that the joints do not lie above one another.

10. Holes or tears in the geonet should be repaired by placing a geonet patch extending a minimum of 0.3 m (12 in.) beyond the edges of the hole or tear. The patch should be tied to the underlying geonet at 0.15 m (6.0 in.) spacings.

11. Holes or tears along more than 50% of the width of the geonet on side slopes should require the entire length of geonet to be removed and replaced.

6.3.4 Geonet/Geotextile Geocomposites

Geonets are always covered with either a geomembrane or a geotextile, i.e., they are never directly soil covered since the soil particles would fill the apertures of the geonet rendering it useless. Many geonets have a geotextile bonded to one, or both, surfaces. These are then referred to as geocomposites in the geonet manufacturer's literature. In this document, however, geocomposites will refer to many different types of drainage core structures. Clearly, covered geonets are included in this group. However, geocomposites also consist of fluted, nubbed and cuspated cores, covered with geotextiles and/or geomembranes and will be described separately in section 6.4. Still further, some manufacturers refer to the entire group of geosynthetic drainage materials as "geospacers".

Regarding a specification or CQA document for geonet/geotextile drainage geocomposites, a few comments are offered:

1. The geotextile(s) covering a geonet should be bonded together in such a way that neither component is compromised to the point where proper functioning is impeded. Thus adequate, but not excessive, bonding of the geotextile(s) to the geonet is necessary.

2. If bonding is by heating, the geotextile(s) strength cannot be compromised to the point where failure could occur. The transmissivity under load test, ASTM D-4716, should be performed on the intended geocomposite product.

3. If bonding is by adhesives, the type of adhesive must be identified, including its water solubility and organic content. Excessive adhesive cannot be used since it could fill up some of the geonet's void space. The transmissivity under load test, ASTM D-4716, should be performed on the intended geocomposite product. The geotextile's permittivity could be evaluated using ASTM D-4491.

4. If the shear strength of the geotextile(s) to the geonet is of concern an adapted form of an interface shear test, e.g., ASTM D-5321, can be performed with the geotextile firmly attached to a wooden substrate, or other satisfactory arrangement. Alternatively, a ply adhesion test may be adequate, see ASTM D-413 which might be suitably modified for geotextile-to-geonet adhesion.

5. For factory fabricated geocomposites with geotextiles placed on both sides of a geonet, the geonet must be free from all dirt, dust and accumulated debris before covering.

6. For field placed geotextiles, the geonet should be free of all soil, dust and accumulated debris before covering with a geomembrane or geotextile. In extreme cases this may require washing of the geonet to accumulate the particulate material at the low end (sump) area where it is subsequently removed by hand.

7. When placing geosynthetic clay liners (GCLs) above geocomposites, cleanliness is particularly important in assuring that fugitive bentonite clay particles do not find their way into the geonet.

8. Placement of a covering geomembrane should not shift the geotextile or geocomposite out of position nor damage the underlying geonet.

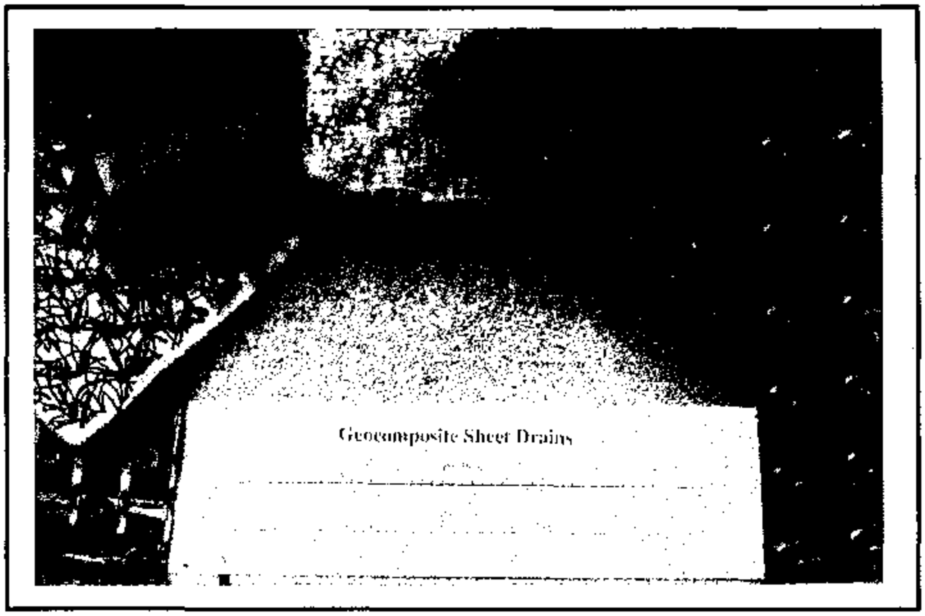
9. An overlying geomembrane or geotextile should not be deployed such that excess tensile stress is mobilized in the geocomposite.

6.4 Other Types of Geocomposites

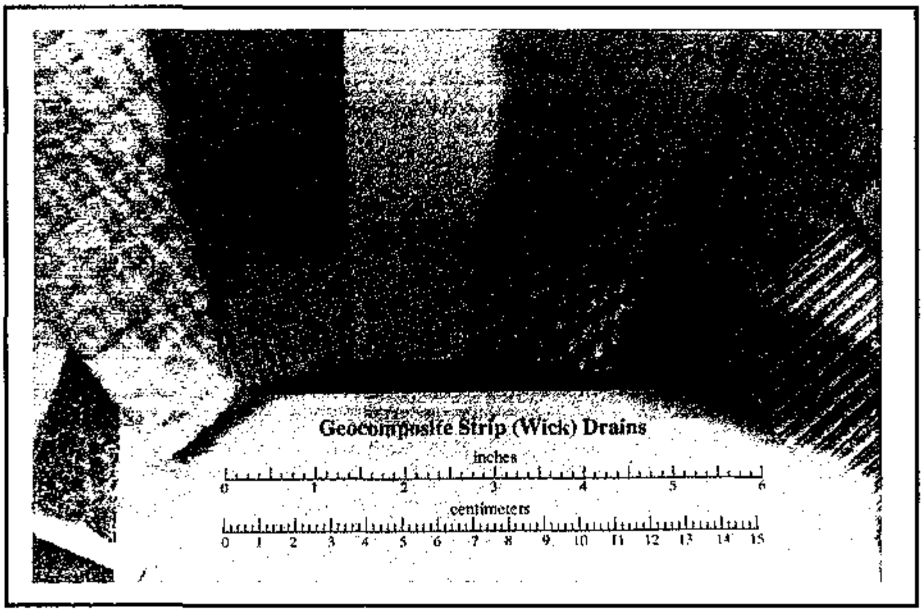
Geocomposite drainage systems consist of a polymer drainage core protected by a geotextile acting as both a filter and a separator to the adjacent material. Thus a geonet, with a geotextile attached to one surface or to both surfaces as described in section 6.3.4, is indeed a drainage geocomposite. However, for the drainage geocomposites discussed in this section the geotextile filter is always attached to the drainage core and the core can take a wide variety of non-geonet shapes and configurations. In some cases, the geotextile is only on one side of the core (the side oriented toward the inflowing liquid), in other cases it is wrapped completely around the drainage core.

There are three different types of drainage geocomposites referred to in this document; sheet drains, edge drains and strip (or wick) drains. Typical variations are shown in Fig. 6.12. For drainage systems associated with waste containment facilities, sheet drains, Fig. 6.12a, are sometimes used as surface water collectors and drains in cover systems of closed landfills and waste piles, refer to Fig. 6.1. Infiltration water that moves within the cover soil enters the sheet drain and flows gravitationally to the edge of the site (or cell) where it is generally collected by a perforated pipe, or edge drain. Pipes will be discussed separately in Chapter 8. The other possible use for sheet drains is for primary leachate collection systems in landfills. The required flow rate in some landfills is too great for a geonet, hence the greater drainage capacity of a geocomposite is sometimes required. Of course, when used in this application the drainage geocomposite must resist the compressive and shear stresses imposed by the waste and it must be chemically resistant to the leachate, but these are design considerations. The use of strip (wick) drains, Fig. 6.12b, in waste containment has been as vertical drains within a solid waste landfill to promote leachate communication between individual lifts. The edge drains, shown in Fig. 6.12(c), have potential applicability around the perimeter of a closed landfill facility to accumulate the surface water coming from a cap/closure system. A variety of perimeter drains could utilize such geocomposite edge drains.

Of the different types of drainage geocomposites shown in Fig. 6.12, only sheet drains will be described since they have the greatest applicability in waste containment systems.

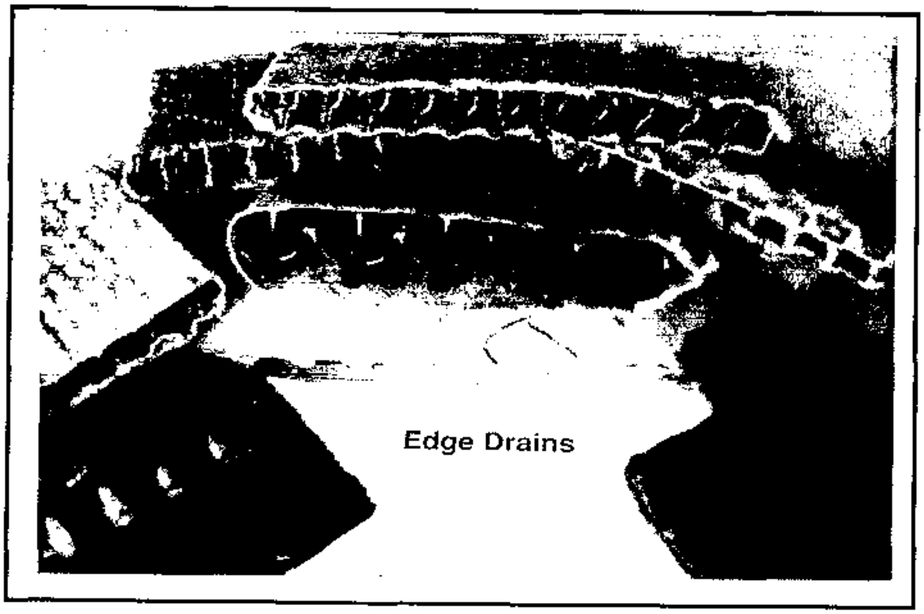


(a) Geocomposite Sheet Drains



(b) Geocomposite Strip (Wick) Drains

Figure 6.12 - Various Types of Drainage Geocomposites (Continued on Next Page)



(c) Geocomposite Edge Drains

Figure 6.12 - Various Types of Drainage Geocomposites (Continued from Previous Page)

6.4.1 Manufacturing of Drainage Composites

The manufacture of the drainage core of a geocomposite sheet drain is generally accomplished by taking the desired type of polymer sheet and then vacuum forming dimples, protrusions or cuspations which give rise to the protrusions. The polymer sheets of drainage geocomposites have been made from a wide variety of polymers. Commercial products that are currently available consist of the following polymer formulations:

- polystyrene
- nylon
- polypropylene
- polyvinyl chloride
- polyethylene
- polyethylene/polystyrene/polyethylene (coextrusion)

With coextrusion there exists a variety of possibilities in addition to those listed above. Recognize, however, that coarse fibers, entangled webs, filament mattings, and many other variations are also possible.

Upon deciding on the proper type and thickness of polymer sheet, a geocomposite core usually goes through a vacuum forming step. In this step a vacuum draws portions of the polymer sheet into cusps at prescribed locations. Depending on the particular product, the protrusions are at 12 to 25 mm (0.5 to 1.0 in.) centers and are of a controlled depth and shape. Figure 6.13 shows a sketch of a vacuum forming system. In many of the systems the protrusions are tapered for ease in manufacturing during release of the vacuum and for a convenient male-to-female coupling of the edges and/or ends of the product in the field. The different types of drainage geocomposites are made in either continuous rolls or in discrete panels.

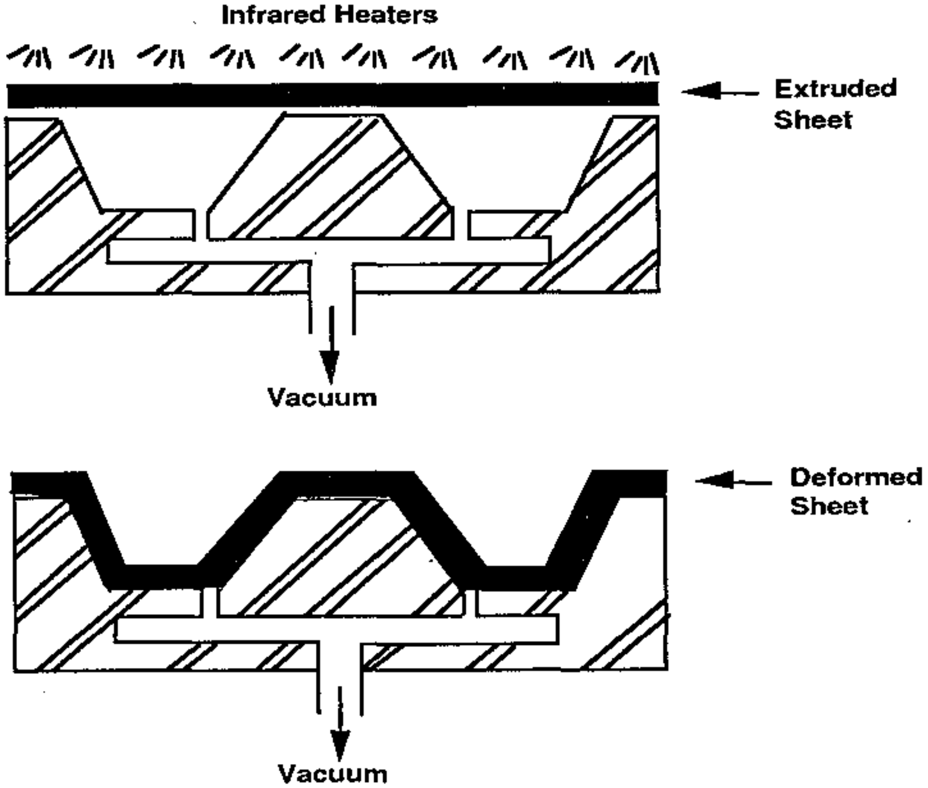


Figure 6.13 - Vacuum Forming System for Fabrication of a Drainage Geocomposite

The geotextile, which acts as both a filter to allow liquid into the drainage core and as a separator to keep soil out of the core by spanning from cusp to cusp is put onto the core as a secondary operation. Quite often an adhesive is placed on the tops of the cusps to adhere the geotextile to the core. Alternatively, heat bonding can be utilized. A variety of geotextiles can be used and the site specific design will dictate the actual selection. As far as the MQA/CQA of the geotextile it is the same as was described in Section 6.2.

There are several items which should be included in a specification or MQA document for drainage geocomposite cores.

1. There should be verification and certification that the actual geocomposite core properties meet the manufacturers specification for that particular type and style.

2. Quality control certificates should include at a minimum, polymer composition, thickness of sheet per ASTM D-5199, height of raised cusps, spacing of cusps, compressive strength behavior (both strength and deformation values at core failure) per ASTM D-1621, and transmissivity using site specific conditions per ASTM D-4716.

3. For drainage systems consisting of coarse fibers, entangled webs and/or filament mattings the thickness under load per ASTM D-5199 and transmissivity under load per ASTM D-4716 are the main tests for QC purposes.

4. Values for each property should meet, or exceed, the manufacturers listed values or the project specification values, whichever are higher.

5. A statement indicating if, and to what extent, regrind polymer was added during manufacturing. No amount of reclaimed polymer should be allowed.

6. The frequency of performing each of the preceding tests should be covered in the MQC plans and it should be implemented and followed.

Additionally, there are several items which should be included in a specification or MQA document for the geotextile(s)/drainage core geocomposite.

1. The type of geotextile(s) should be identified and properly evaluated. See section 6.2 for these details.

2. For strip (wick) drains and edge drains, see Figs. 6.12(b) and (c) respectively, the geotextile complete surrounds the drainage core and generally no fixity is required. For sheet drains, Fig. 6.12(a), this is not the case.

3. The geotextile(s) covering of a drainage core should be bonded in such a way that neither component is compromised to the point where proper functioning is impeded. Thus adequate, but not excessive, bonding of the geotextile(s) to the drainage core is necessary.

4. If bonding is by heating, the geotextile(s) strength cannot be compromised to the point where failure could occur. The transmissivity under load test, ASTM D-4716, should be performed on the intended geocomposite product.

5. If bonding is by adhesives, the type of adhesive must be identified, including its water solubility and organic content. Excessive adhesive cannot be used since it could fill up some of the drainage core's void space. The transmissivity under load test, ASTM D-4716, should be performed on the intended geocomposite product. The geotextile's permittivity could be evaluated using ASTM D-4491.

6. If the shear strength of the geotextile(s) to the core is of concern an adapted form of an interface shear test, e.g., ASTM D-5321, can be performed with a wooden substrate, or other satisfactory arrangement. Alternatively, a ply adhesion test may be adequate, see ASTM D-413 which might be suitably modified for geotextile-to-core adhesion.

7. For factory fabricated geocomposites with geotextiles placed on both sides of the drainage core, the core must be free from all dirt, dust and accumulated debris before covering.

6.4.2 Handling of Drainage Geocomposites

A number of activities occur between the manufacture of drainage geocomposites and their final positioning where intended at the waste facility. These activities involve packaging, storage at the manufacturing facility, shipment, storage at the site, acceptance and conformance testing, and final placement at the facility. Each of these topics will be described although most will be by reference to the appropriate geotextile section.

6.4.2.1 Packaging

Usually a manufacturer will not attach the geotextile to the core until an order is received and shipment is imminent. Thus warehousing is not a major issue. The cores are either rolled onto themselves or are laid flat if they are in panel form. When an order is received, the geotextile is bonded to the core, the rolls are banded together with polymer straps and, if panels, they are banded in a similar manner.

6.4.2.2 Storage at Manufacturing Facility

Storage of the drainage cores at the manufacturing facility is usually not a major issue. The cores are generally stored indoors and are thus protected from atmospheric conditions.

6.4.2.3 Shipment

Shipment of drainage geocomposites (with the geotextile attached) is quite simple due to the light weight of these geosynthetics compared to other types. The text in Section 6.2.2.3 should be utilized, however, since accidental damage can always occur.

6.4.2.4 Storage at Field Site

The storage of drainage geocomposites at the project site is similar to that described for geotextiles, recall Section 6.2.2.4.

6.4.2.5 Acceptance and Conformance Testing

The acceptance and conformance testing of the geotextile portion of a drainage geocomposite is the same as described in Section 6.2.2.5. The acceptance and conformance testing of the core portion of a drainage geocomposite is project specific with the exception of the conformance tests themselves which are different. The recommended conformance tests for geocomposite drainage cores are the following:

- thickness of sheet per ASTM D-5199 or thickness of the geocomposite per ASTM D-5199

- thickness of raised cusps per ASTM D-1621
- spacing of raised cusps per ASTM D-1621

Optional conformance tests such as compression per ASTM D-1621 and transmissivity per ASTM D-4716 may also be stipulated. The frequency of conformance tests of the drainage core must be stipulated. In general, one test per 5,000 m^2 (50,000 ft^2) should be the minimum test frequency.

6.4.2.6 Placement

The placement of drainage geocomposites in the field is similar to that described for geotextiles. Refer to Section 6.2.2.6 for details.

6.4.3 Joining of Drainage Geocomposites

Drainage geocomposites are usually joined together by folding back the geotextile from the lower core and inserting it into the bottom void space of the upper core, see Fig. 6.14. Where this is not possible a tab should be available at the edges of the core material for the purpose of overlapping. The geotextile must be refolded over the connection area assuring a complete covering of the core surface.

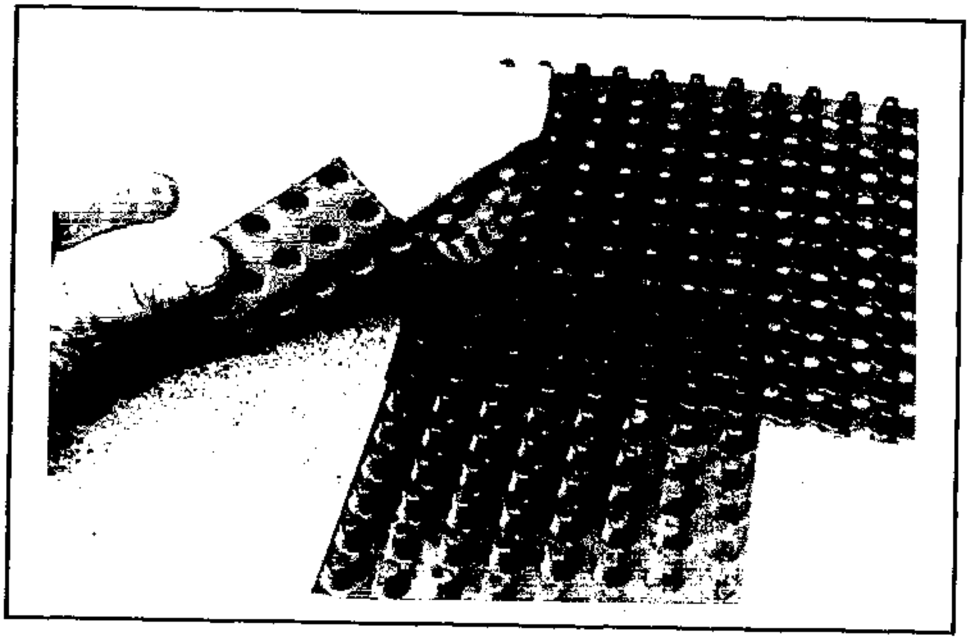


Figure 6.14 - Photograph of Drainage Core Joining via Male-to-Female Interlock

Recommended items for a specification or CQA document on the joining of drainage geocomposites include the following:

1. Adjacent edges of drainage cores should be overlapped for at least two rows of cusps.
2. The ends of drainage cores (in the direction of flow) should be overlapped for at least four rows of cusps.
3. The geotextiles covering the joined cores must provide a complete seal against backfill soil entering into the core.
4. Horizontal seams should not be allowed on sideslopes. This requires that the drainage geocomposite be provided in rolls which are at least as long as the side slope.
5. Holes or tears in drainage cores are repaired by placing a patch of the same type of material over the damaged area. The patch should extend at least four cusps beyond the edges of the hole or tear.
6. Holes or tears of more than 50% of the width of the drainage core on side slopes should require the entire length of the drainage core to be removed and replaced.
7. Holes or tears in the geotextile covering the drainage core should be repaired as described in Section 6.2.3.3.

6.4.4 Covering

Drainage geocomposites, with an attached geotextile, are covered with either soil, waste or in some cases a geomembrane. Regarding a specification or CQA document some comments should be included.

1. The core of the drainage geocomposite should be free of soil, dust and accumulated debris before backfilling or covering with a geomembrane. In extreme cases this may require washing of the core to accumulate the particulate material to the low end (sump) area for removal.
2. Placement of the backfilling soil, waste or geomembrane should not shift the position of the drainage geocomposite nor damage the underlying drainage geocomposite, geotextile or core.
3. When using soil or waste as backfill on side slopes, the work progress should begin at the toe of the slope and work upward.

6.5 References

ASTM D-413, "Rubber Property-Adhesion to Flexible Substrate"

ASTM D-792, "Specific Gravity and Density of Plastics by Displacement"

ASTM D-1238, "Flow Rates of Thermoplastics by Extrusion Plastometer"

ASTM D-1248, "Polyethylene Plastics and Extrusion Materials"

ASTM D-1505, "Density of Plastics by the Density-Gradient Technique"

ASTM D-1603, "Carbon Black in Olefin Plastics"

ASTM D-1621, "Compressive Properties of Rapid Cellular Plastics"

ASTM D-3786, "Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics: Diaphragm Bursting Strength Tester Method"

ASTM D-4354, "Sampling of Geosynthetics for Testing"

ASTM D-4355, "Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon-Arc Type Apparatus)"

ASTM D-4491, "Water Permeability of Geotextiles by Permittivity"

ASTM D-4533, "Trapezoidal Tearing Strength of Geotextiles"

ASTM D-4632, "Breaking Load and Elongation of Geotextiles (Grab Method)"

ASTM D-4716, "Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products"

ASTM D-4751, "Determining the Apparent Opening Size of a Geotextile"

ASTM D-4759, "Determining the Specification Conformance of Geosynthetics"

ASTM D-4833, "Index Puncture Resistance of Geotextiles, Geomembranes and Related Products"

ASTM D-4873, "Identification, Storage and Handling of Geosynthetics"

ASTM D-4884, "Seam Strength of Sewn Geotextiles"

ASTM D-5199, "Measuring Nominal Thickness of Geotextiles and Geomembranes"

ASTM D-5261, "Measuring Mass Per Unit Area of Geotextiles"

ASTM D-5321, "Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method"

Diaz, V. A. (1990), "The Seaming of Geosynthetics," IFAI Publ., St. Paul, MN, 1990.

IFAI (1990), "A Design Primer: Geotextiles and Related Materials," Industrial Fabrics Association International, St. Paul, MN.

Chapter 7

Vertical Cutoff Walls

7.1 Introduction

Situations occasionally arise in which it is necessary or desirable to restrict horizontal movement of liquids with vertical cutoff walls. Examples of the use of vertical cutoff walls include the following:

1. Control of ground water seepage into an excavated disposal cell to maintain stable side slopes or to limit the amount of water that must be pumped from the excavation during construction (Fig. 7.1).
2. Control of horizontal ground water flow into buried wastes at older waste disposal sites that do not contain a liner (Fig. 7.2).
3. Provide a "seal" into an aquitard (low-permeability stratum), thus "encapsulating" the waste to limit inward movement of clean ground water in areas where ground water is being pumped out and treated (Fig. 7.3).
4. Long-term barrier to impede contaminant transport (Fig. 7.4).

Vertical walls are also sometimes used to provide drainage. Drainage applications are discussed in Chapters 5 and 6.

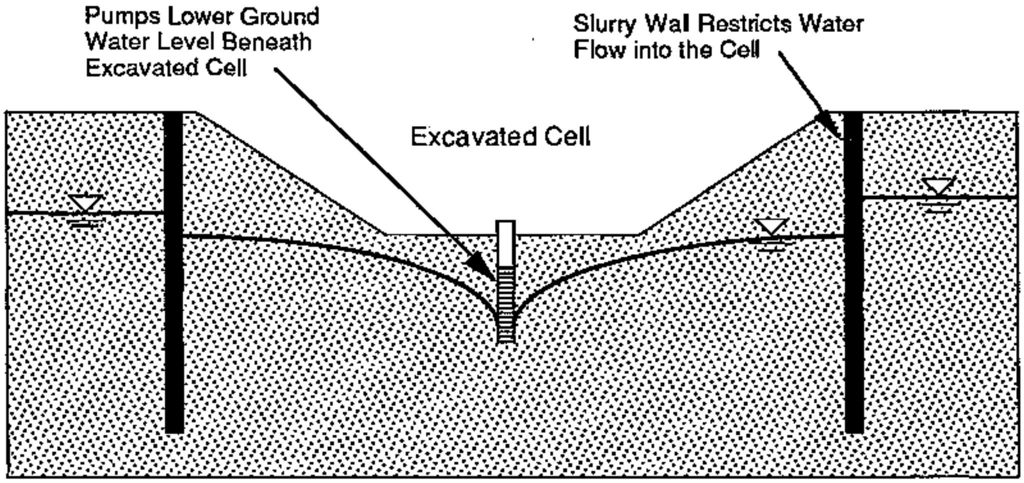


Figure 7.1 - Example of Vertical Cutoff Wall to Limit Flow of Ground Water into Excavation.

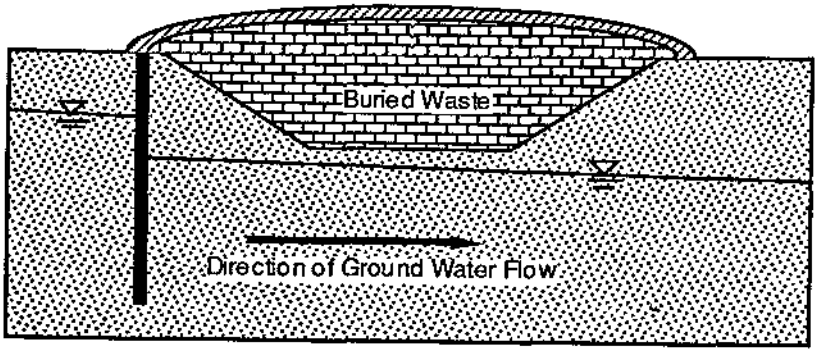


Figure 7.2 - Example of Vertical Cutoff Wall to Limit Flow of Ground Water through Buried Waste.

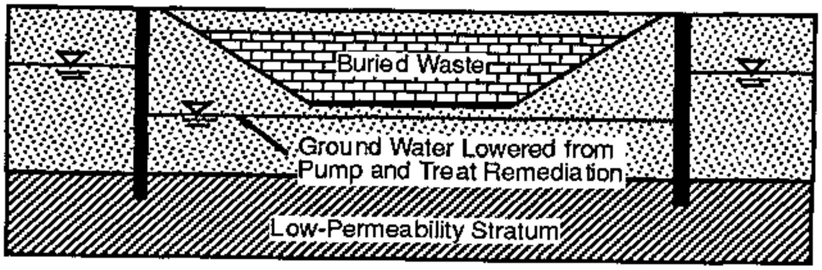


Figure 7.3 - Example of Vertical Cutoff Wall to Restrict Inward Migration of Ground Water.

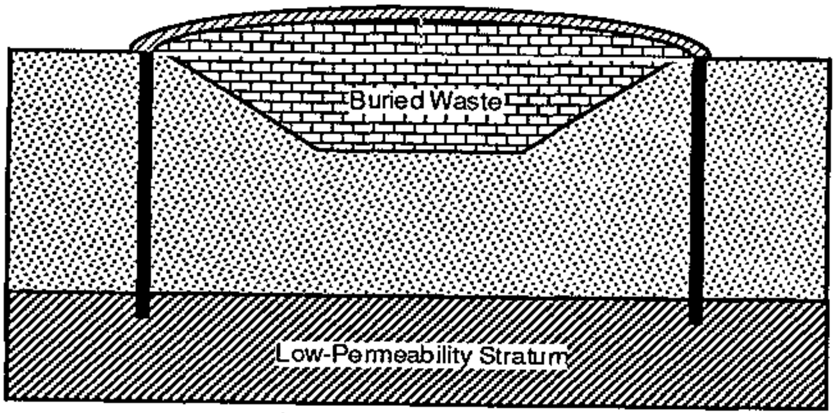


Figure 7.4 - Example of Vertical Cutoff Wall to Limit Long-Term Contaminant Transport.

7.2 Types of Vertical Cutoff Walls

The principal types of vertical cutoff walls are sheet pile walls, geomembrane walls, and slurry trench cutoff walls. Other techniques, such as grouting and deep soil mixing, are also possible, but have rarely been used for waste containment applications.

7.2.1 Sheet Pile Walls

Sheet pile walls are interlocking sections of steel or plastic materials (Fig. 7.5). Steel sheet piles are used for a variety of excavation shoring applications; the same type of steel sheet piles are used for vertical cutoff walls. Plastic sheet piles are a relatively recent development and are used on a limited basis for vertical cutoff walls. Sheet piles measure approximately 0.5 m (18 in.) in width, and interlocks join individual sheets together (Fig. 7.5). Lengths are essentially unlimited, but sheet piles are rarely longer than about 10 to 15 m (30 to 45 ft).

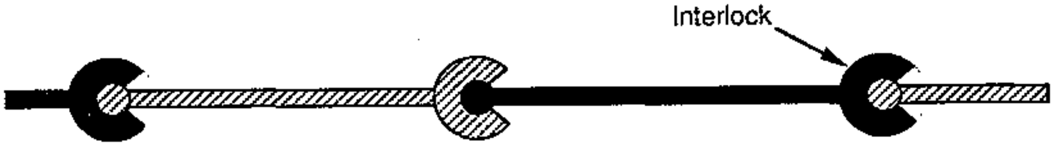


Figure 7.5 - Interlocking Steel Sheet Piles.

Plastic sheet piles are different from geomembrane panels, which are discussed later. Plastic sheet piles tend to be relatively thick-walled (wall thickness > 3 mm or 1/8 in.) and rigid; geomembrane panels tend to have a smaller thickness (< 2.5 mm or 0.1 in.), greater width, and lower rigidity.

Sheet pile walls are installed by driving or vibrating interlocking steel sheet piles into the ground. Alternatively, plastic sheet piles can be used, but special installation devices may be needed, e.g., a steel driving plate to which the plastic sheet piles are attached. To promote a seal, a cord of material that expands when hydrated and attains a very low permeability may be inserted in the interlock. Other schemes have been devised and will continue to be developed for attaining a water-tight seal in the interlock.

Sheet pile walls have a long history of use for dewatering applications, particularly where the sheet pile wall is also used as a structural wall. Sheet pile walls also have been used on several occasions to cutoff horizontal seepage through permeable strata that underlie dams (Sherard et al., 1963).

Sheet pile walls have historically suffered from problems with leakage through interlocks, although much of the older experience may not be applicable to modern sheet piles with expanding material located in the interlock (the expandable material is a relatively recent development).

Leakage through sheet pile interlocks depends primarily on the average width of openings in the interlocking connections, the percentage of the interlocks that leak, and the quality and integrity of any sealant placed in the interlock. The sheet piles may be damaged during installation, which can create ruptures in the sheet pile material or separation of sheet piles at interlocks. Because of these problems, sheet pile cutoffs have not been used for waste containment facilities as extensively as some other types of vertical cutoff walls. Sheet pile walls are not discussed further in this report.

7.2.2 Geomembrane Walls

Geomembrane walls represent a relatively new type of vertical barrier that is rapidly gaining in popularity. The geomembrane wall consists of a series of geomembrane panels joined with special interlocks (examples of interlocks are sketched in Fig. 7.6) or installed as a single unit. If the geomembrane panels contain interlocks, a water-expanding cord is used to seal the interlock.

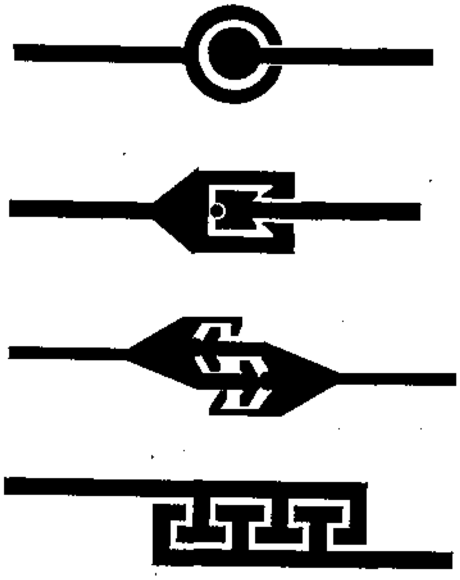


Figure 7.6 - Examples of Interlocks for Geomembrane Walls (Modified from Manassero and Pasqualini, 1992)

The technology has its roots in Europe, where slurry trench cutoff walls that are backfilled with cement-bentonite have been commonly used for several decades. One of the problems with cement-bentonite backfill, as discussed later, is that it is difficult to make the hydraulic conductivity of the cement-bentonite backfill less than or equal to 1×10^{-7} cm/s, which is often required of regulatory agencies in the U.S. To overcome this limitation in hydraulic conductivity and to improve the overall containment provided by the vertical cutoff wall, a geomembrane may be inserted into the cement-bentonite backfill. The geomembrane may actually be installed either in a slurry-filled trench or it may be installed directly into the ground using a special insertion plate.

7.2.3 Walls Constructed with Slurry Techniques

Walls constructed by slurry techniques (sometimes called "slurry trench cutoff walls") are described by Xanthakos (1979), D'Appolonia (1980), EPA (1984), Ryan (1987), and Evans (1993). With this technique, an excavation is made to the desired depth using a backhoe or clamshell. The trench is filled with a clay-water suspension ("mud" or "slurry"), which maintains stability of sidewalls via hydrostatic pressure. As the trench is advanced, the slurry tends to flow into the surrounding soil. Clay particles are filtered out, forming a thin skin of relatively impermeable material along the wall of the trench called a "filter cake." The filter cake has a very low hydraulic conductivity and allows the pressure from the slurry to maintain stable walls on the trench (Fig. 7.7). However, the level of slurry must generally be higher than the surrounding ground water table in order to maintain stability. If the water table is at or above the surface, a dike may be constructed to raise the surface elevation along the alignment of the slurry trench cutoff wall.

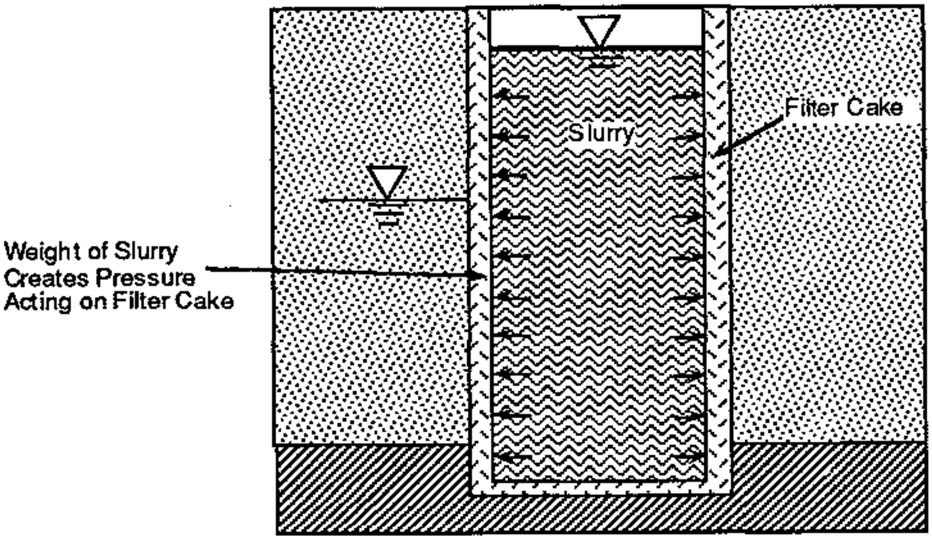


Figure 7.7 - Hydrostatic Pressure from Slurry Maintains Stable Walls of Trench.

In most cases, sodium bentonite is the clay used in the slurry. A problem with bentonite is that it does not gel properly in highly saline water or in some heavily contaminated ground waters. In such cases, an alternative clay mineral such as attapulgite may be used, or other special materials may be used to maintain a viscous slurry.

The slurry trench must either be backfilled or the slurry itself must harden into a stable material -- otherwise clay will settle out of suspension, the slurry will cease to support the walls of the trench, and the walls may eventually collapse. If the slurry is allowed to harden in place, the slurry is usually a cement-bentonite (CB) mixture. If the slurry trench is backfilled, the backfill is usually a soil-bentonite (SB) mixture, although plastic concrete may also be used (Evans, 1993).

In the U.S., slurry trenches backfilled with SB have been the most commonly used vertical cutoff trenches for waste containment applications. In Europe, the CB method of construction has been used more commonly. The reason for the different practices in the U.S. and Europe stems at least in part upon the fact that abundant supplies of high-quality sodium bentonite are readily available in the U.S. but not in Europe. Also, in most situations, SB backfill will have a somewhat lower hydraulic conductivity than cured CB slurry, and in the U.S. regulations have tended to drive the requirements for hydraulic conductivity to lower values than in Europe.

The construction sequence for a soil-bentonite backfilled trench is shown schematically in Fig. 7.8.

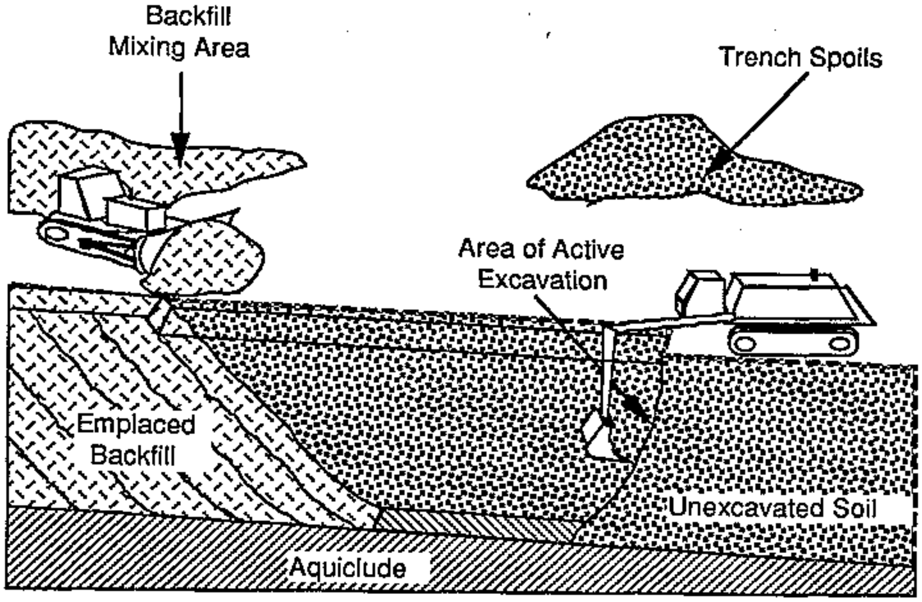


Figure 7.8 - Diagram of Construction Process for Soil-Bentonite-Backfilled Slurry Trench Cutoff Wall.

The main reasons why slurry trench cutoff walls are so commonly used for vertical cutoff walls are:

1. The depth of the trench may be checked to confirm penetration to the desired depth, and excavated materials may be examined to confirm penetration into a particular stratum;

2. The backfill can be checked prior to placement to make sure that its properties are as desired and specified;

3. The wall is relatively thick (compared to a sheet pile wall or a geomembrane wall);
4. There are no joints between panels or construction segments with the most common type of slurry trench cutoff wall construction.

In general, in comparison to sheet-pile walls, deep-soil-mixed walls, and grouted walls, there is more opportunity with a slurry trench cutoff wall to check the condition of the wall and confirm that the wall has been constructed as designed. In contrast, it is much more difficult to confirm that a sheet pile wall has been installed without damage, that grout has fully penetrated all of the desired pore spaces in the soil, or that deep mixing as taken place as desired.

7.3 Construction of Slurry Trench Cutoff Walls

The major construction activities involved in building a slurry cutoff wall are preconstruction planning and mobilization, preparation of the site, slurry mixing and hydration, excavation of soil, backfill preparation, placement of backfill, clean-up of the site, and demobilization. These activities are described briefly in the paragraphs that follow.

7.3.1 Mobilization

The first major construction activity is to make an assessment of the site and to mobilize for construction. The contractor locates the slurry trench cutoff wall in the field with appropriate surveys. The contractor determines the equipment that will be needed, amounts of materials, and facilities that may be required. Plans are made for mobilizing personnel and moving equipment to the site.

A preconstruction meeting between the designer, contractor, and CQA engineer is recommended. In this meeting, materials, construction procedures, procedures for MQA of the bentonite and CQA of all aspects of the project, and corrective actions are discussed (see Chapter 1).

7.3.2 Site Preparation

Construction begins with preparation of the site. Obstacles are removed, necessary relocations of utilities are made, and the surface is prepared. One of the requirements of slurry trench construction is that the level of slurry in the trench be greater than the level of ground water. If the ground water table is high, it may be necessary to construct a dike to ensure that the level of slurry in the trench is above the ground water level (Fig. 7.9). There may be grade restrictions in the construction specifications which will require some regrading of the surface or construction of dikes in low-lying areas. The site preparation work will typically also include preparation of working surfaces for mixing materials. Special techniques may be required for exacavation around utility lines.

7.3.3 Slurry Preparation and Properties

Before excavation begins, as well as during excavation, the slurry must be prepared. The slurry usually consists of a mixture of bentonitic clay with water, but sometimes other clays such as attapulgite are used. If the clay is bentonite, the specifications should stipulate the criteria to be met, e.g., filtrate loss, and the testing technique by which the parameter is to be determined. The criteria can vary considerably from project to project.

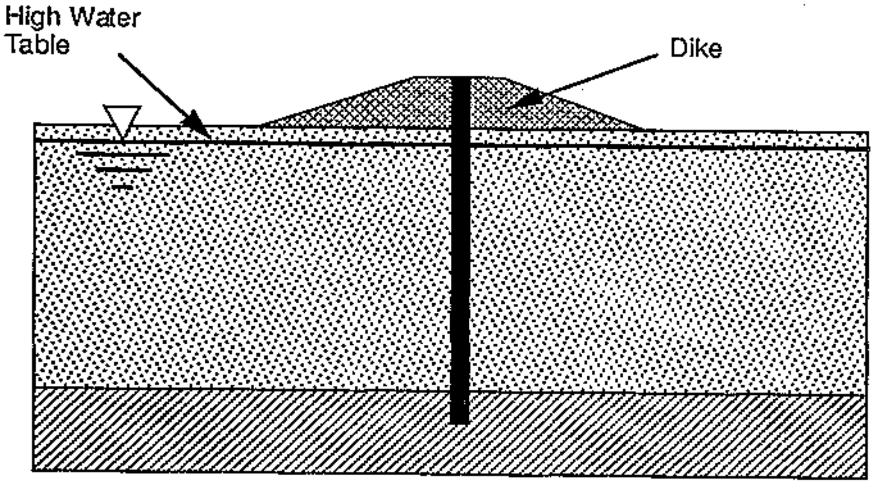


Figure 7.9 - Construction of Dike to Raise Ground Surface for Construction of Slurry Trench.

The clay may be mixed with water in either a batch or flash mixing operation. In the batch system specified quantities of water and bentonite are added in a tank and mixed at high speeds with a pump, paddle mixer, or other device that provides adequate high-speed colloidal shear mixing. Water and clay are mixed until hydration is complete and the desired properties of the slurry have been achieved. Complete mixing is usually achieved in a few minutes. The size of batch mixers varies, but typically a batch mixer will produce several cubic meters of mixed slurry at a time.

Flash mixing is achieved with a venturi mixer. With this system, bentonite is fed at a predetermined rate into a metered water stream that is forced through a nozzle at a constant rate. The slurry is subjected to high shear mixing for only a fraction of a second. The problem with this technique is that complete hydration does not take place in the short period of mixing. After the clay is mixed with water, the resulting slurry is tested to make sure the density and viscosity are within the requirements set forth in the CQA plan.

The mixed slurry may be pumped directly to the trench or to a holding pond or tank. If the slurry is stored in a tank or pond, CQA personnel should check the properties of the slurry periodically to make sure that the properties have not changed due to thixotropic processes or sedimentation of material from the slurry. The specifications for the project should stipulate mixing or circulation requirements for slurry that is stored after mixing.

The properties of the slurry used to maintain the stability of the trench are important. The following pertains to a bentonite slurry that will ultimately be displaced by soil-bentonite or other backfill; requirements for cement-bentonite slurry are discussed later in section 7.3.6. The slurry must be sufficiently dense and viscous to maintain stability of the trench. However, the slurry must not be too dense or viscous: otherwise, it will be difficult to displace the slurry when backfill is placed. Construction specifications normally set limits on the properties of the slurry. Typically about 4-8% bentonite by weight is added to fresh water to form a slurry that has a specific gravity of about 1.05 to 1.15. During excavation of the trench additional fines may become suspended in the slurry, and the specific gravity is likely to be greater than the value of the freshly mixed slurry. The specific gravity of the slurry during excavation is typically on the order of 1.10 - 1.25.

The density of the slurry is measured with the procedures outlined in ASTM D-4380. A known volume of slurry is poured into a special "mud balance," which contains a cup on one end of a balance. The weight is determined and density calculated from the known volume of the cup.

The viscosity of the slurry is usually measured with a Marsh funnel. To determine the Marsh viscosity, fluid is poured into the funnel to a prescribed level. The number of seconds required to discharge 946 mL (1 quart) of slurry into a cup is measured. Water has a Marsh viscosity of about 26 seconds at 23°C. Freshly hydrated bentonite slurry should have a Marsh viscosity in the range of about 40 - 50 seconds. During excavation, the viscosity typically increases to as high as about 65 Marsh seconds. If the viscosity becomes too large the thick slurry must be replaced, treated (e.g., to remove sand), or diluted with additional fresh slurry.

The sand content of a slurry may also be specified. Although sand is not added to fresh slurry, the slurry may pick up sand in the trench during the construction process. The sand content by volume is measured with ASTM D-4381. A special glass measuring tube is used for the test. The slurry is poured onto a No. 200 sieve (0.075 mm openings), which is repeatedly washed until the water running through the sieve is clear. The sand is washed into the special glass measuring tube, and the sand content (volumetric) is read directly from graduation marks.

Other criteria may be established for the slurry. However, filtrate loss and density, coupled with viscosity, are the primary control variables. The specifications should set limits on these parameters as well as specify the test method. Standards of the American Petroleum Institute (1990) are often cited for slurry test methods. Limits may also be set on pH, gel strength, and other parameters, depending on the specific application.

The primarily responsibility for monitoring the properties of the slurry rests with the construction quality control (CQC) team. The properties of the slurry directly affect construction operations but may also impact the final quality of the slurry trench cutoff wall . For example, if the slurry is too dense or viscous, the slurry may not be properly displaced by backfill. On the other hand, if the slurry is too thin and lacks adequate bentonite, the soil-bentonite backfill (formed by mixing soil with the bentonite slurry) may also lack adequate bentonite. The CQA inspectors may periodically perform tests on the slurry, but these tests are usually conducted primarily to verify test results from the CQC team. CQA personnel should be especially watchful to make sure that: (1) the slurry has a sufficiently high viscosity and density (if not, the trench walls may collapse); (2) the level of the slurry is maintained near the top of the trench and above the water table (usually the level must be at least 1 m above the ground water table to maintain a stable trench); and (3) the slurry does not become too viscous or dense (otherwise backfill will not properly displace the slurry).

7.3.4 Excavation of Slurry Trench

The slurry trench is excavated with a backhoe (Fig. 7.10) or a clam shell (Fig. 7.11). Long-stick backhoes can dig to depths of approximately 20 to 25 m (60 to 80 ft). For slurry trenches that can be excavated with a backhoe, the backhoe is almost always the most economical means of excavation. For trenches that are too deep to be excavated with a backhoe, a clam shell is normally used. The trench may be excavated first with a backhoe to the maximum depth of excavation that is achievable with the backhoe and to further depths with a clam shell. Special chopping, chiseling, or other equipment may be used as necessary. The width of the excavation tool is usually equal to the width of the trench and is typically 0.6 to 1.2 m (2 to 4 ft).

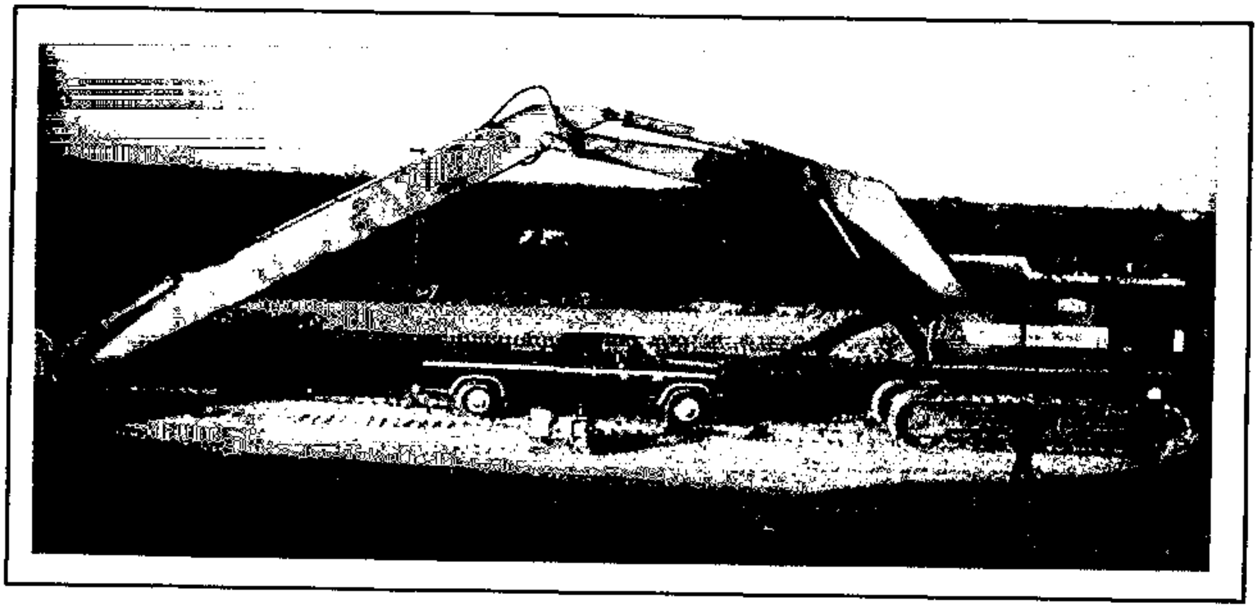


Figure 7.10 - Backhoe for Excavating Slurry Trench.

In most instances, the slurry trench cutoff wall is keyed into a stratum of relatively low hydraulic conductivity. In some instances, the vertical cutoff wall may be relatively shallow. For example, if a floating non-aqueous phase liquid such as gasoline is to be contained, the slurry trench cutoff wall may need to extend only a short distance below the water table surface, depending upon the site-specific circumstances. CQC/CQA personnel monitor the depth of excavation of the slurry trench and should log excavated materials to verify the types of materials present and to ensure specified penetration into a low-permeability layer. Monitoring normally involves examining soils that are excavated and direct measurement of the depth of trench by lowering a weight on a measuring tape down through the slurry. Additional equipment such as air lifts may be needed to remove sandy materials from the bottom of the trench prior to backfill.

7.3.5 Soil-Bentonite (SB) Backfill

Soil is mixed with the bentonite-water slurry to form soil-bentonite (SB) backfill. If the soil is too coarse, additional fines can be added. Dry, powdered bentonite may also be added, although it is difficult to ensure that the dry bentonite is uniformly distributed. In special applications in which the properties of the bentonite are degraded by the ground water, other types of clay may be used, e.g., attapulgite, to form a mineral-soil backfill. If possible, soil excavated from the trench is used for the soil component of SB backfill. However, if excavated soil is excessively contaminated or does not have the proper gradation, excavated soil may be hauled off for treatment and disposal.

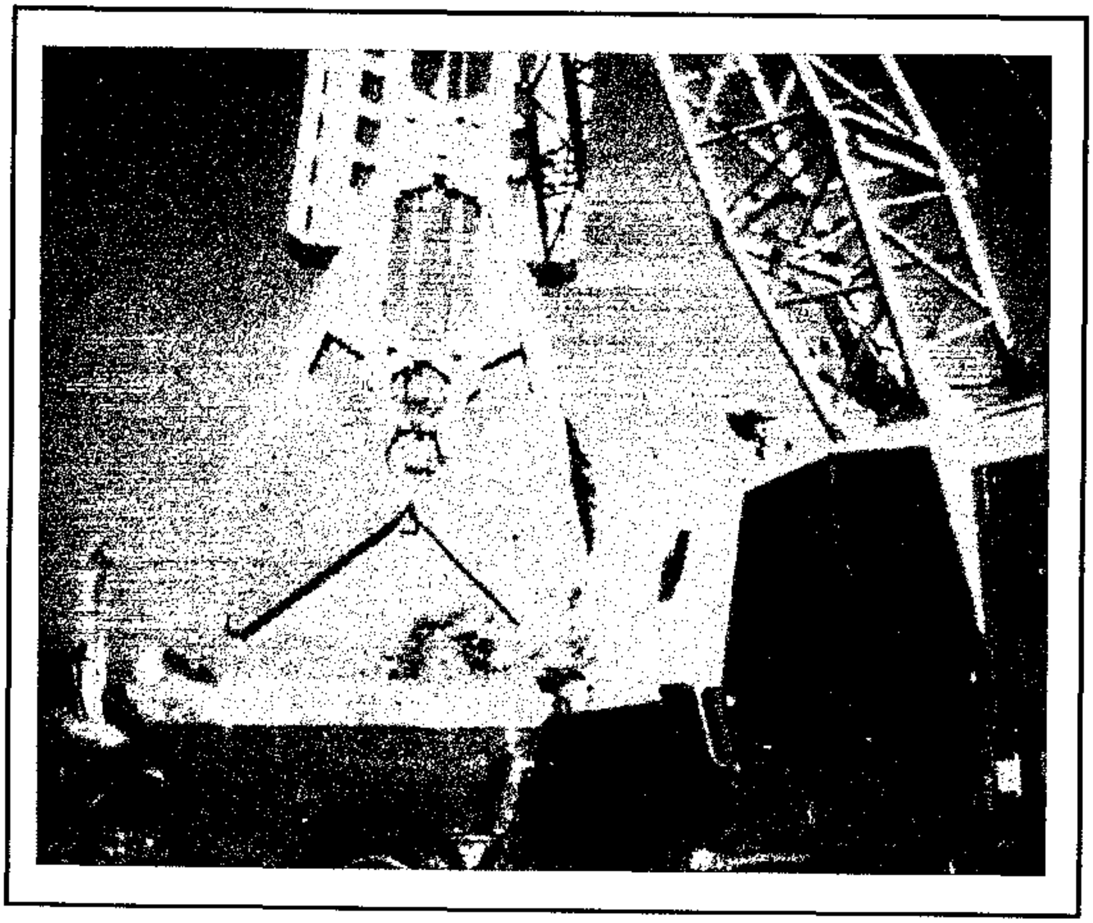


Figure 7.11. Clamshell for Excavating Slurry Trench.

Two parameters concerning the backfill are very important: (1) the presence of extremely coarse material (i.e., coarse gravel and cobbles), and (2) the presence of fine material. Coarse gravel is defined as material with particle sizes between 19 and 75 mm (ASTM D-2487). Cobbles are materials with particle sizes greater than 75 mm. Fine material is material passing the No. 200 sieve, which has openings of 0.075 mm. Cobbles will tend to settle and segregate in the backfill; coarse gravel may also segregate, but the degree of segregation depends on site-specific conditions. In some cases, the backfill may have to be screened to remove pieces that exceed the maximum size allowed in the specifications. The hydraulic conductivity of the backfill is affected by the percentage of fines present (D'Appolonia, 1980; Ryan, 1987; and Evans, 1993). Often, a minimum percentage of fines is specified. Ideally, the backfill material should contain at least 10 to 30% fines to achieve low hydraulic conductivity ($< 10^{-7}$ cm/s).

The bentonite may be added in two ways: (1) soil is mixed with the bentonite slurry (usually with a dozer, as shown in Fig. 7.12) to form a viscous SB material; and (2) additional dry powdered bentonite may be added to the soil-bentonite slurry mixture. Dry, powdered bentonite may or may not be needed. D'Appolonia (1980) and Ryan (1987) discuss many of the details of SB backfill design.

Figure 7.12 - Mixing Backfill with Bentonite Slurry.

When SB backfill is used, a more-or-less continuous process of excavation, preparation of backfill, and backfilling is used. To initiate the process, backfill is placed by lowering it to the bottom of the trench, e.g., with a clamshell bucket, or placing it below the slurry surface with a tremie pipe (similar to a very long funnel) until the backfill rises above the surface of the slurry trench at the starting point of the trench. Additional SB backfill is then typically pushed into the trench with a dozer (Fig. 7.13). The viscous backfill sloughs downward and displaces the slurry in the trench. As an alternative method to initiate backfilling, a separate trench that is not part of the final slurry trench cutoff wall, called a lead-in trench, may be excavated outside at a point outside of the limits of the final slurry trench and backfilled with the process just described, to achieve full backfill at the point of initiation of the desired slurry trench.

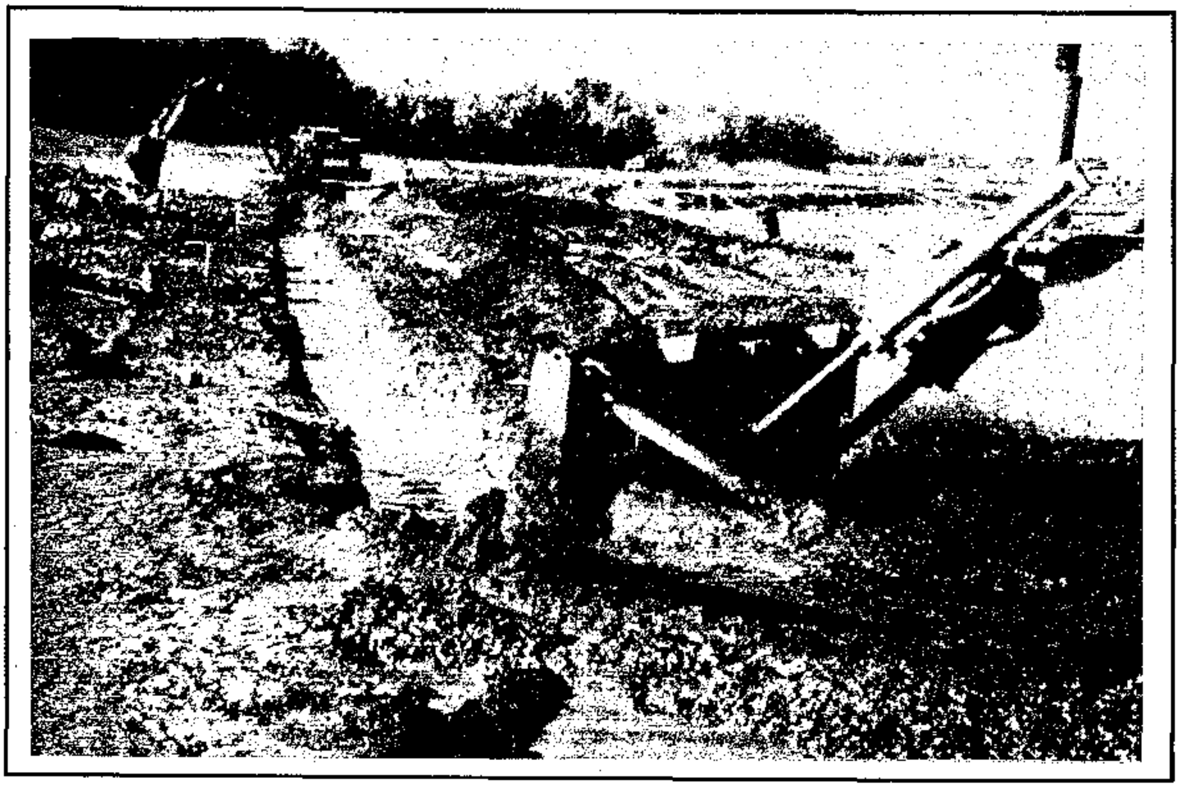


Figure 7.13 - Pushing Soil-Bentonite Backfill Into Slurry Trench with Dozer.

After the trench has been backfilled, low hydraulic conductivity is achieved via two mechanisms: (1) the SB backfill itself has low hydraulic conductivity (typical design value is $\leq 10^{-7}$ cm/s), and (2) the filter cake enhances the overall function of the wall as a barrier. Designers do not normally count on the filter cake as a component of the barrier; it is viewed as a possible source of added impermeability that enhances the reliability of the wall.

The compatibility of the backfill material with the ground water at a site should be assessed prior to construction. However, CQA personnel should be watchful for ground water conditions that may differ from those assumed in the compatibility testing program. CQA personnel should familiarize themselves with the compatibility testing program. Substances that are particularly aggressive to clay backfills include non-water-soluble organic chemicals, high and low pH liquids, and highly saline water. If there is any question about ground water conditions in relationship to the conditions covered in the compatibility testing program, the CQA engineer and/or design engineer should be consulted.

Improper backfilling of slurry trench cutoff walls can produce defects (Fig. 7.14). More details are given by Evans (1993). CQA personnel should watch out for accumulation of sandy materials during pauses in construction, e.g., during shutdowns or overnight; an airlift can be used to remove or resuspend the sand, if necessary.

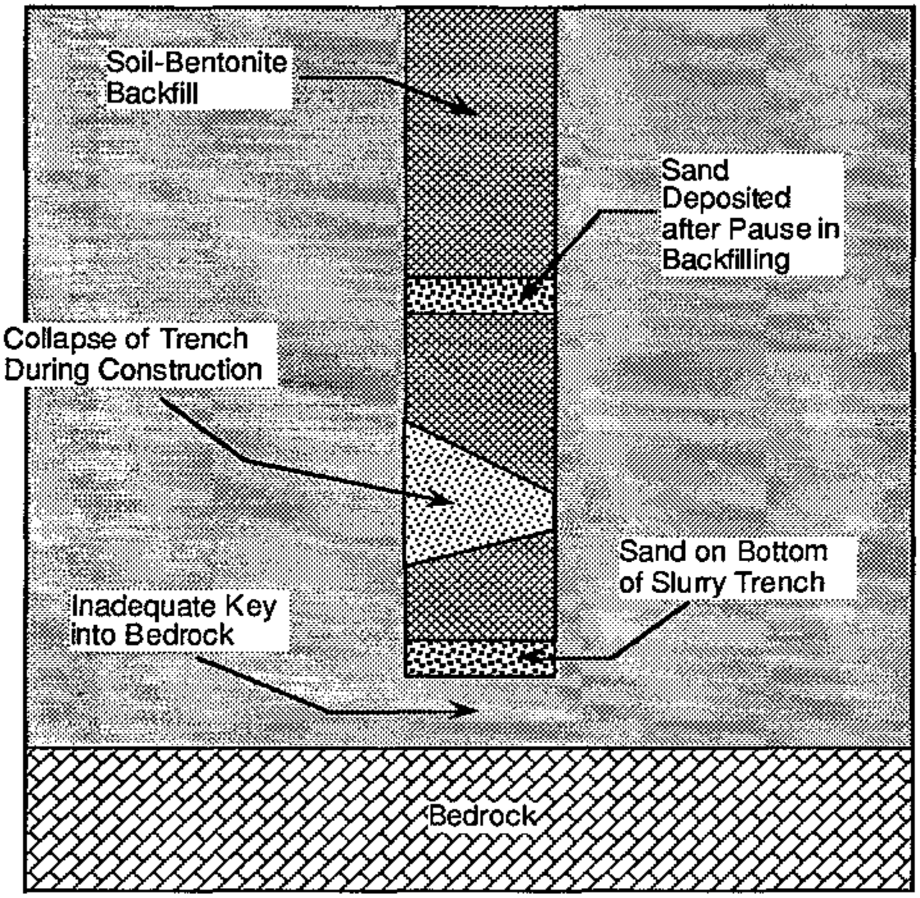


Figure 7.14 - Examples of Problems Produced by Improper Backfilling of Slurry Trench.

Some slurry trench cutoff walls fully encircle an area. As the slurry trench reaches the point of initiation of the slurry trench cutoff wall, closure is accomplished by excavating into the previously-backfilled wall.

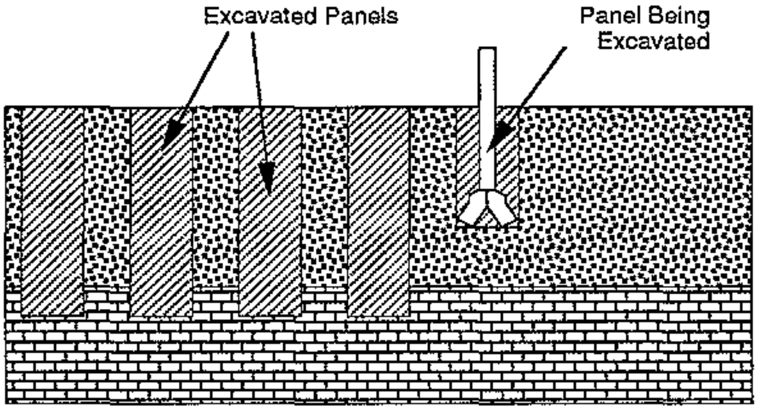
Hydraulic conductivity of SB backfill is normally measured by testing of small cylinders of material formed from field samples. Ideally, a sample of backfill material is scooped up from the backfill, placed in a cylinder of a specified type, consolidated to a prescribed effective stress, and permeated. It is rare for borings to be drilled into the backfill to obtain samples for testing.

7.3.6 Cement-Bentonite (CB) Cutoff Walls

A cement-bentonite (CB) cutoff wall is constructed with a cement-bentonite-water mixture that hardens and attains low hydraulic conductivity. The slurry trench is excavated, and excavated soils are hauled away. Then the trench is backfilled in one of two ways. In the usual method, the slurry used to maintain a stable trench during construction is CB rather than just bentonite-water, and the slurry is left in place to harden. A much-less-common technique is to construct the slurry trench with a bentonite-water slurry in discrete diaphragm cells (Fig. 7.15), and to displace the bentonite-water slurry with CB in each cell.

The CB mixture cures with time and hardens to the consistency of a medium to stiff clay (CB backfill is not nearly as strong as structural concrete). A typical CB slurry consists on a weight basis of 75 to 80% water, 15 to 20% cement, 5% bentonite, and a small amount of viscosity reducing material. Unfortunately, CB backfill is usually more permeable than SB backfill. Hydraulic conductivity of CB backfill is often in the range of 10^{-6} to 10^{-5} cm/s, which is about an order of magnitude or more greater than typical SB cutoff walls.

(A) Excavate Panels



(B) Excavate Between Panels

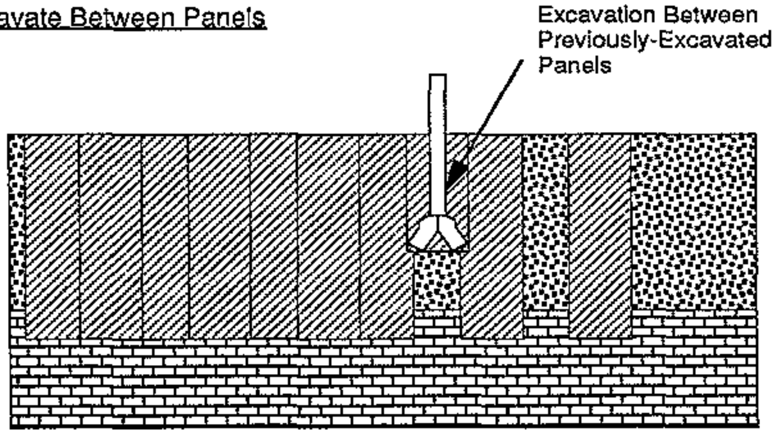


Figure 7.15 - Diaphragm-Wall Construction.

The CB cutoff wall is constructed using procedures almost identical to those employed in building structural diaphragm walls . In Europe, CB backfilled slurry trench cutoff walls are much more common than in the U.S., at least partly because the diaphragm-wall construction capability is more broadly available in Europe and because high-grade sodium bentonite (which is critical for soil-bentonite backfilled walls) is not readily available in Europe. In Europe, the CB often contains other ingredients besides cement, bentonite, and water, e.g., slag and fly ash.

7.3.7 Geomembrane in Slurry Trench Cutoff Walls

Geomembranes may be used to form a vertical cutoff wall. The geomembrane may be installed in one of at least two ways:

1. The geomembrane may be inserted in a trench filled with CB slurry to provide a composite CB-geomembrane barrier (Manassero and Pasqualini, 1992). The geomembrane is typically mounted to a frame, and the frame is lowered into the slurry. The base of the geomembrane contains a weight such that when the geomembrane is released from the frame, the frame can be removed without the geomembrane floating to the top. CQA personnel should be particularly watchful to ensure that the geomembrane is properly weighted and does not float out of position. Interlocks between geomembrane panels (Fig. 7.6) provide a seal between panels. The panels are typically relatively wide (of the order of 3 to 7 m) to minimize the number of interlocks and to speed installation. The width of a panel may be controlled by the width of excavated sections of CB-filled panels (Fig. 7.15).

2. The geomembrane may be driven directly into the CB backfill or into the native ground. Panels of geomembrane with widths of the order of 0.5 to 1 m (18 to 36 in.) are attached to a guide or insertion plate, which is driven or vibrated into the subsurface. If the panels are driven into a CB backfill material, the panels should be driven before the backfill sets up. Interlocks between geomembrane panels (Fig. 7.6) provide a seal between panels. This methodology is essentially the same as that of a sheet pile wall.

Although use of geomembranes in slurry trench cutoff walls is relatively new, the technology is gaining popularity. The promise of a practically impermeable vertical barrier, plus excellent chemical resistance of HDPE geomembranes, are compelling advantages. Development of more efficient construction procedures will make this type of cutoff wall increasingly attractive.

7.3.8 Other Backfills

Structural concrete could be used as a backfill, but if concrete is used, the material normally contains bentonite and is termed *plastic concrete* (Evans, 1993). Plastic concrete is a mixture of cement, bentonite, water, and aggregate. Plastic concrete is different from structural concrete because it contains bentonite and is different from SB backfill because plastic concrete contains aggregate. Other ingredients, e.g., fly ash, may be incorporated into the plastic concrete. Construction is typically with the panel method (Fig. 7.15). Hydraulic conductivity of the backfill can be $< 10^{-8}$ cm/s. High cost of plastic concrete limits its use.

A relatively new type of backfill is termed soil-cement-bentonite (SCB). The SCB wall uses native soils (not aggregates, as with plastic concrete). Placement is in a continuous trench rather than panel method.

7.3.9 Caps

A cutoff wall cap represents the final surface cap on top of the slurry trench cutoff wall. The cap may be designed to minimize infiltration, withstand traffic loadings, or serve other purposes. CQA personnel should also inspect the cap as well as the wall itself to ensure that the cap conforms with specification.

7.4 Other Types of Cutoff Walls

Evans (1993) discusses other types of cutoff walls. These include vibrating beam cutoff walls, deep soil mixed walls, and other types of cutoff walls. These are not discussed in detail here because these types of walls have been used much less frequently than the other types.

7.5 Specific CQA Requirements

No standard types of tests or frequencies of testing have evolved in the industry for construction of vertical cutoff walls. Among the reasons for this is the fact that construction materials and technology are continually improving. Recommendations from this section were taken largely from recommendations provided by Evans (personal communication).

For slurry trench cutoff walls, the following comments are applicable. The raw bentonite (or other clay) that is used to make the slurry may have specific requirements that must be met. If so, tests should be performed to verify those properties. There are no standard tests or frequency of tests for the bentonite. The reader may wish to consult Section 2.6.5 for a general discussion of tests and testing frequencies for bentonite-soil liners. For the slurry itself, common tests include viscosity, unit weight, and filtrate loss, and other tests often include pH and sand content. The properties of the slurry are normally measured on a regular basis by the contractor's CQC personnel; CQA personnel may perform occasional independent checks.

The soil that is excavated from the trench should be continuously logged by CQA personnel to verify that subsurface conditions are similar to those that were anticipated. The CQA personnel should look for evidence of instability in the walls of the trench (e.g., sloughing at the surface next to the trench or development of tension cracks). If the trench is to extend into a particular stratum (e.g., an aquitard), CQA personnel should verify that adequate penetration has occurred. The recommended procedure is to measure the depth of the trench once the excavator has encountered the aquitard and to measure the depth again, after adequate penetration is thought to have been made into the aquitard.

After the slurry has been prepared, and CQC tests indicate that the properties are adequate, additional samples are often taken of the slurry from the trench. The samples are often taken from near the base of the trench using a special sampler that is capable of trapping slurry from the bottom of the trench. The unit weight is particularly important because sediment may collect near the bottom of the trench. For SB backfill, the slurry must not be heavier than the backfill. The depth of the trench should also be confirmed by CQA personnel just prior to backfilling. Often, sediments can accumulate near the base of the trench -- the best time to check for accumulation is just prior to backfilling. CQA personnel should be particularly careful to check for sedimentation after periods when the slurry has not been agitated, e.g., after an overnight work stoppage.

Testing of SB backfill usually includes unit weight, slump, gradation, and hydraulic conductivity. Bentonite content may also be measured, e.g., using the methylene blue test (Alther, 1983). Slump testing is the same as for concrete (ASTM C-143). Hydraulic conductivity testing is often performed using the API (1990) fixed-ring device for the filter press test. Occasional comparative tests with ASTM D-5084 should be conducted. There is no widely-applied frequency of testing backfill materials.

7.6 Post Construction Tests for Continuity

At the present time, no testing procedures are available to determine the continuity of a completed vertical cutoff wall.

7.7 References

Alther, G. R. (1983), "The Methylene Blue Test for Bentonite Liner Quality Control," *Geotechnical Testing Journal*, Vol. 6, No. 3, pp. 133-143.

American Petroleum Institute (1990), *Recommended Practice for Standard Procedure for Field Testing Drilling Fluids,* API Recommended Practice 13-B-1, Dallas, Texas.

ASTM C-143, "Slump of Hydraulic Cement Concrete."

ASTM D-2487, "Classification of Soils for Engineering Purposes (Unified Soil Classification System)."

ASTM D-4380, "Density of Bentonitic Slurries."

ASTM D-4381, "Sand Content by Volume of Bentonite Slurries."

ASTM D-5084, "Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter."

D'Appolonia, D. J. (1980), "Soil-Bentonite Slurry Trench Cutoffs," *Journal of Geotechnical Engineering*, Vol. 106, No. 4, pp. 399-417.

Evans, J. C. (1993), "Vertical Cutoff Walls," in *Geotechnical Practice for Waste Disposal*, D. E. Daniel (Ed.), Chapman and Hall, London, pp. 430-454.

Manassero, M., and E. Pasqualini (1992), "Ground Pollutant Containment Barriers," in *Environmental Geotechnology*, M.A. Usmen and Y.B. Acar (Eds.), A.A. Balkema, Rotterdam, pp. 195-204.

Ryan, C. R. (1987), "Soil-Bentonite Cutoff Walls," in *Geotechnical Practice for Waste Disposal '87*, R. D. Woods (Ed.), American Society of Civil Engineers, New York, pp. 182-204.

Sherard, J. L., Woodward, R. J., Gizienski, S. F., and W. A. Clevenger (1963), *Earth and Earth-Rock Dams*, John Wiley and Sons, Inc., New York, 725 p.

U.S. Environmental Protection Agency (1984), "Slurry Trench Construction for Pollution Migration Control," Office of Emergency and Remedial Response, Washington, DC, EPA-540/2-84-001.

Xanthakos, P. P. (1979), *Slurry Walls*, McGraw-Hill Book Company, New York, 822 p.

Chapter 8

Ancillary Materials, Appurtenances and Other Details

This chapter is devoted toward ancillary materials used within a waste containment facility, various appurtenances which are necessary for proper functioning of the system and other important details. Ancillary materials such as plastic pipe for leachate transmission, sumps for collection of leachate, manholes and pipe risers for removal of leachate will be covered in this chapter. Appurtenances, such as penetrations made through various barrier materials, will be covered. Lastly, other important details requiring careful inspection, such as anchor trenches, internal dikes and berms, and access ramps, will also be addressed.

8.1 Plastic Pipe (aka "Geopipe")

Whenever the primary or secondary leachate collection system at the bottom of a waste containment facility is a natural soil material, such as sand or gravel, a perforated piping system should be located within it to rapidly transmit the leachate to a sump and removal system. Figure 8.1 illustrates the cross section of such a pipe system which is generally located directly on top of the geomembrane or geotextile to 225 mm (9.0 in.) above the primary liner material. This is a design issue and the plans and specifications must be clear and detailed regarding these dimensions.

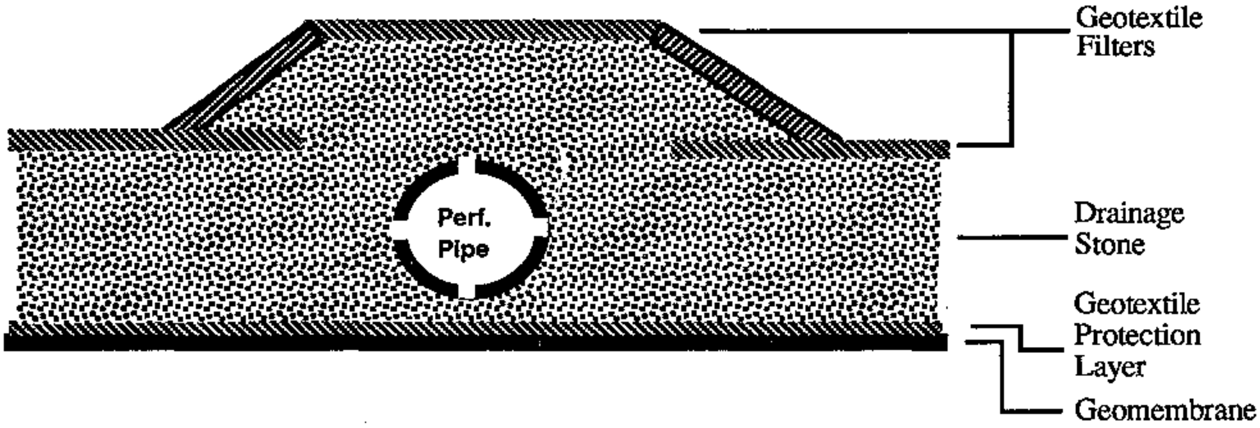


Figure 8.1 - Cross Section of a Possible Removal Pipe Scheme in a Primary Leachate Collection and Removal System (for illustration purposes only).

The pipes are sometimes placed in a manifold configuration with feeder lines framing into a larger main trunk line thus covering the entire footprint of the landfill unit or cell, see Fig. 8.2. The entire pipe network flows gravitationally to a low point where the sump and removal system

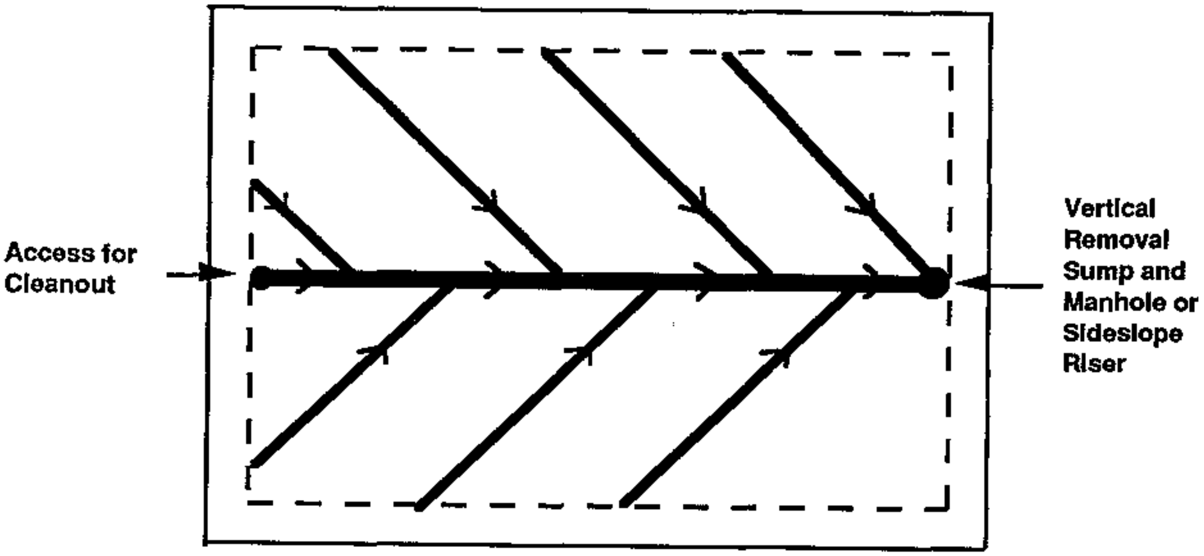


Figure 8.2 - Plan View of a Possible Removal Pipe Scheme in a Primary Leachate Collection and Removal System (for illustration purposes only).

consisting of either a manhole or pipe riser is located. The diagonal feeder pipes, if included, are always perforated to allow the leachate to enter into them. The central trunk lines may or may not be perforated depending on the site specific design. It must be recognized, however, that there is a large variety of schemes that are possible and it is clearly a design issue which must be unequivocally presented in the plans and specifications.

Leachate collection and transmission lines in most waste containment facilities are plastic pipe, with polyvinyl chloride (PVC) and high density polyethylene (HDPE) being the two major material types in current use. Furthermore, there are two types of HDPE pipe in current use, solid wall and corrugated types. Each of these types of plastic pipes will be described.

8.1.1 Polyvinyl Chloride (PVC) Pipe

Polyvinyl chloride (PVC) pipe has been used in waste containment systems for leachate collection and removal in a number of different locations and configurations. The pipes can be perforated or not depending on the site specific design. The pipes are often supplied in 6.1 m (20 ft) lengths which are joined by couplings or utilize bell and spigot ends. The PVC material typically consists of resin, fillers, carbon black/pigment and additives. PVC pipe does not contain any liquid plasticizers, see Fig. 8.3.

Regarding a specification or a MQA document for PVC pipe and fittings the following items should be considered.

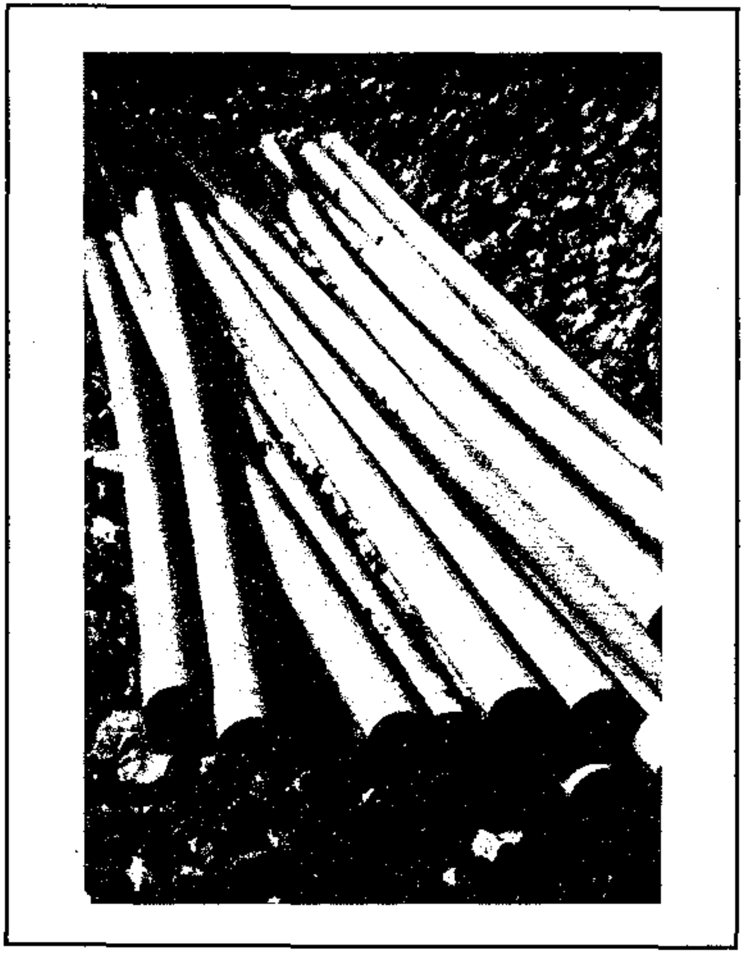


Figure 8.3 - Photograph of PVC Pipe to be Used in a Landfill Leachate Collection System.

1. The basic resin should be made from PVC as defined in ASTM D-1755. Details are contained therein.
2. Other materials in the formulation, such as fillers, carbon black/pigment and additives should be stipulated and certified as to the extent of their prior use in plastic pipe.
3. Clean rework material, generated from the manufacturer's own pipe or fitting production may be used by the same manufacturer providing that the rework material meets the above requirements. See section 3.2.2 for a description of possible use of reworked and/or recycled material.
4. Pipe tolerances and properties must meet the applicable standards for the particular grade required by the plans and specifications. For PVC pipe specified as Schedule 40, 80 and 120, the appropriate specification is ASTM D-1785. For PVC pipe in the standard dimension ratio (SDR) series, the applicable specification is ASTM D-2241.

5. Both of the above referenced ASTM Standards have sections on product marking and identification which should be followed as well as requiring the manufacturer to provide a certification statement stating that the applicable standard has been followed.

6. PVC pipe fittings should be in accordance with ASTM D-3034. This standard includes comments on solvent cement and elastomeric gasket joints as well as a section on product marking and certification.

8.1.2 High Density Polyethylene (HDPE) Smooth Wall Pipe

High density polyethylene (HDPE) smooth wall pipe has been used in waste containment systems for leachate collection and removal in a number of different locations and configurations. The pipe can be perforated or not depending on the site specific design. The pipes are often supplied in 6.1 m (20 ft) lengths which are generally joined together using butt-end fusion using a hot plate as per the gas pipe construction industry. Other joining variations such as bell and spigot, male-to-female and threading are also available. The HDPE material itself consists of 97-98% resin, approximately 2% carbon black and up to 1% additives. Figure 8.4 illustrates the use of HDPE smooth pipe.

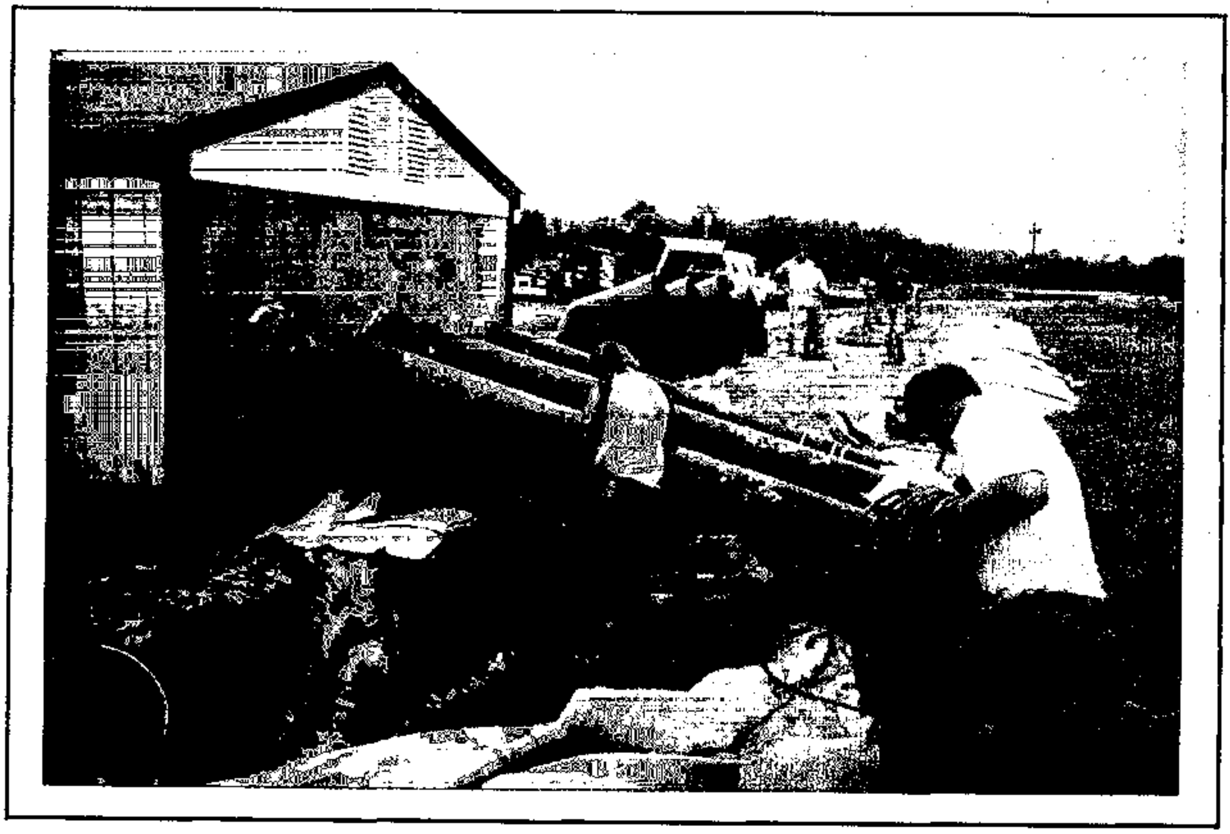


Figure 8.4 - Photograph of HDPE Smooth Wall Pipe Risers Used as Primary and Secondary Removal Systems from Sump Area to Pump and Monitoring Station.

The following items should be considered regarding the contract specification or MQA document on HDPE solid wall pipe and fittings:

1. The basic material should be made of HDPE resin and should conform to the requirements of ASTM D-1248. Details are contained therein.

2. Quality control tests on the resin are typically density and melt flow index. The appropriate designations are ASTM D-1505 or D-792 and D-1238, respectively. Other in-house quality control tests should be encouraged and followed by the manufacturer.

3. Typical densities for HDPE pipe resins are 0.950 to 0.960 g/cc. This is a Type III HDPE resin according to ASTM D-1248 and is higher than the density of the resin used in HDPE geomembranes and geonets.

4. Carbon black can be added as a concentrate, as it customarily is, or as a powder. The type and amount of carbon black, as well as the type of carrier resin if concentrated pellets are used, should be stated and certified by the manufacturer.

5. The amount of additives used should be stated by the manufacturer. If certification is required it would typically not state the type of additive, since they are usually proprietary, but should state that the additive package has successfully been used in the past and to what extent.

8.1.3 High Density Polyethylene (HDPE) Corrugated Pipe

Corrugated high density polyethylene (HDPE), also called "profiled" pipe, has been used in waste containment systems for leachate collection and removal in a number of different locations and configurations. The pipe can be perforated or slotted depending on the site specific design. The inside can be smooth lined or not depending on the site specific design. The pipes are often supplied in 6.1 m (20 ft) lengths which are joined together by couplings made by the same manufacturer as the pipe itself. This is important since the couplings are generally not interchangeable among different pipe manufacturer's products. The HDPE material itself consists of 97-98% resin, approximately 2% carbon black and up to 1% additives. Figure 8.5 illustrates HDPE corrugated pipe.

Regarding the contract specification or MQA document on HDPE corrugated pipe and fittings, the following items should be considered:

1. The basic material should be made of HDPE resin and should conform to the requirements of ASTM D-1248. Details are contained therein.

2. Quality control tests are typically density and melt flow index. Their designations are ASTM D-1505 or D-792 and D-1238, respectively. Other in-house quality control tests are to be encouraged and followed by the manufacturer.

3. Typical densities for HDPE pipe resins are 0.950 to 0.960 g/cc. This is a Type III HDPE resin according to ASTM D-1248 and is higher than the resin density used in HDPE geomembranes.

4. Carbon black can be added as a concentrate as it customarily is, or as a powder. The type and amount of carbon black, as well as the type of carrier resin if concentrated pellets are used, should be stated and certified by the manufacturer.

5. The amount of additives used should be stated by the manufacturer. If certification is required it would typically not state the type of additive, since they are usually proprietary, but should state that the additive package has successfully been used in the past.

6. The lack of ASTM documents for HDPE corrugated pipe should be noted. There is an AASHTO Specification available for corrugated polyethylene pipe in the 300 to 900 mm (12 to 36 in.) diameter range under the designation M294-90 and another for 75 to 250 mm (3 to 10 in.) diameter pipe under the designation of M252-90.

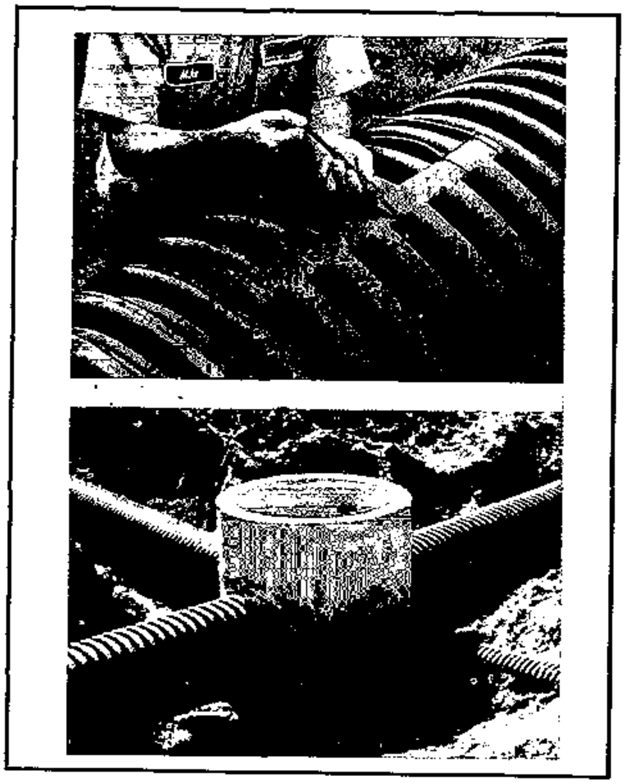


Figure 8.5 - Photograph of HDPE Corrugated Pipe Being Coupled and After Installed.

8.1.4 Handling of Plastic Pipe

As with all other geosynthetic materials a number of activities occur between the manufacturing of the pipe and its final positioning in the waste facility. These activities include packaging, storage at the manufacturers facility, shipment, storage at the field site, conformance testing and the actual placement.

8.1.4.1 Packaging

Both PVC pipe and HDPE pipe are manufactured in long lengths of approximately 6.1 m (20 ft) with varying wall thicknesses and configurations. They are placed on wooden pallets and bundled together with plastic straps for bulk handling and shipment. The packaging is such that either fork lifts or cranes using slings can be used for handling and movement. As the diameter and wall thickness increases, however, this may not be the case and above 610 mm (24 in.) diameter the pipes are generally handled individually.

8.1.4.2 Storage at Manufacturing Facility

Bundles of plastic pipe can be stored at the manufacturing facility for relatively long periods of time with respect to other geosynthetics. However, if stored outdoors for over 12 months duration, a temporary enclosure should be used to cover the pipe from ultraviolet exposure and high temperatures. Indoors, there is no defined storage time limitation. Pipe fittings are usually stored in a container or plastic net.

8.1.4.3 Shipment

Bundled pallets of plastic pipe are shipped from the manufacturer's or their representative's storage facility to the job site via common carrier. Ships, railroads and trucks have all been used depending upon the locations of the origin and final destination. The usual carrier from within the USA, is truck. When using flatbed trucks, the pallated pipe is usually loaded by means of a fork lift or a crane with slings wrapped around the entire unit. When the truck bed is closed, i.e., an enclosed trailer, the units are usually loaded by fork lift. Large size pipes above 610 mm (24 in.) in diameter are handled individually.

8.1.4.4 Storage at Field Site

Offloading of palleted plastic pipe at the site and temporary storage is a necessary follow-up task which must be done in an acceptable manner.

Items to be considered for the contract specification or CQA document are the following:

1. Handling of pallets of plastic pipe should be done in a competent manner such that damage does not occur to the pipe.
2. The location of field storage should not be in areas where water can accumulate. The pallets should be on level ground and oriented so as not to form a dam creating the ponding of water.
3. The pallets should not be stacked more than three high. Furthermore, they should be stacked in such a way that access for conformance testing is possible.
4. Outdoor storage of plastic pipe should not be longer than 12 months. For storage periods longer than 12 months a temporary covering should be placed over the pipes, or they should be moved to within an enclosed facility.

8.1.5 Conformance Testing and Acceptance

Upon delivery of the plastic pipe to the project site, and temporary storage thereof, the CQA engineer should see that conformance test samples are obtained. These samples are then sent to the

CQA laboratory for testing to ensure that the pipe supplied conforms to the project plans and specifications.

Items to consider for the contract specification or CQA document in this regard are the following:

1. The pipe should be identified according to its proper ASTM standard:
    - (a) for PVC Schedule 40, 80 and 120: see ASTM D-1785
    - (b) for PVC SDR Series: see ASTM D-2241
    - (c) for PVC pipe fittings: see ASTM D-3034
    - (d) for HDPE SDR Series: see ASTM D-1248 and ASTM F-714
    - (e) for HDPE corrugated pipe and fittings: see AASHTO M294-90 and M252-90.
2. The conformance test samples should make use of the same identification system as the appropriate ASTM standard, if one is available.
3. A lot should be defined as a group of consecutively numbered pipe sections from the same manufacturing line. Other definitions are also possible and should be clearly stated in the CQA documents.
4. Sampling should be done according to the contract specification and/or CQA documents. Unless otherwise stated, sampling should be based on one sample per lot, not to exceed one sample per 300 m (1000 ft) of pipe.
5. Conformance tests at the CQA Laboratory should include the following:
    - (a) for PVC pipe and fitting: physical dimensions according to ASTM D-2122, density according to ASTM D-792, plate bearing test according to ASTM D-2412, and impact resistance according to ASTM D-2444.
    - (b) for HDPE solid-wall and corrugated pipe: physical dimensions according to ASTM D-2122, density according to ASTM D-1505, plate bearing test according to ASTM D-2412 and impact resistance according to ASTM D-2444.
    - (c) for HDPE corrugated pipe in the 300 to 900 mm (12 to 36 in.) range see AASHTO M294-90 and in the 75 to 250 mm (3 to 10 in.) range see AASHTO M252-90.
6. Conformance test results should be sent to the CQA engineer prior to deployment of any pipe from the lot under review.
7. The CQA engineer should review the results and should report any non-conformance to the Project Manager.
8. The resolution of failing conformance tests should be clearly stipulated in the specifications or CQA documents.

8.1.6 Placement

Plastic pipe is usually placed in a prepared trench or within other prepared subgrade materials. If the pipe is to be placed on or near to a geomembrane, as in the leachate collection system shown in Fig. 8.1, the drainage sand or stone should be placed first. There may be a requirement to lightly compact sand to 90% relative density according to ASTM D-4254. Small excavations of slightly greater than the diameter of the pipe are then made, and the pipe is placed in these shallow excavations. Thus a trench, albeit a shallow one, is constructed in all cases of pipe placement in leachate collection sand or stone.

Where plastic pipe is placed at other locations adjacent to the containment facility and the soil is cohesive, compaction is critical if high stresses are to be encountered. Compaction control is necessary, e.g., 95% of standard Proctor compaction ASTM D-698 is recommended so as to prevent subsidence of the pipe while in service.

The importance of the density of the material beneath, adjacent and immediately above a plastic pipe insofar as its load-carrying capability is concerned cannot be overstated. Figure 8.6 shows the usual configuration and soil backfill terminology related to the various materials and their locations.

Regarding a specification or CQA document for plastic pipe placement, ASTM D-2321 should be referenced. For waste containment facilities the following should be considered:

1. The soil beneath, around and above the pipe shall be Class IA, IB or II according to ASTM D-2321.
2. The backfill soil should extend a minimum of one pipe diameter above the pipe, or 300 mm (12 in.) which ever is smaller.
3. Other conditions should be taken directly according to ASTM D-2321.
4. Pipe fittings should be in accordance with the specific pipe manufacturer's recommendations.

8.2 Sumps, Manholes and Risers

Leachate which migrates along the bottom of landfills and waste piles flows gravitationally to a low point in the facility or cell where it is collected in a sump. Two general variations exist; one is a prefabricated sump, made either in-situ or off-site, with a manhole extension rising vertically through the waste and final cover, the other is a low area formed in the liner itself with a solid wall pipe riser coming up the side slope where it eventually penetrates the final cover. Both variations are shown schematically in the sketches of Fig. 8.7. In addition, the sump and sidewall riser of a secondary leachate collection system typically used in double lined facilities is shown in the right sketch of Fig. 8.7(b), i.e., a leak detection system. Each type of system will be briefly described.

Many existing landfills have been constructed with primary leachate collection and removal sumps and manholes constructed to the site specific plans and specifications as shown in the left hand sketch of Fig. 8.7(a). The vertical riser is either a concrete or plastic standpipe placed in 3 m (10 ft) sections. It is extended as the waste is placed in the facility and eventually it must penetrate the final cover. Leachate is removed from this manhole, on an as demanded basis, by a submersible pump which is permanently located in the sump.

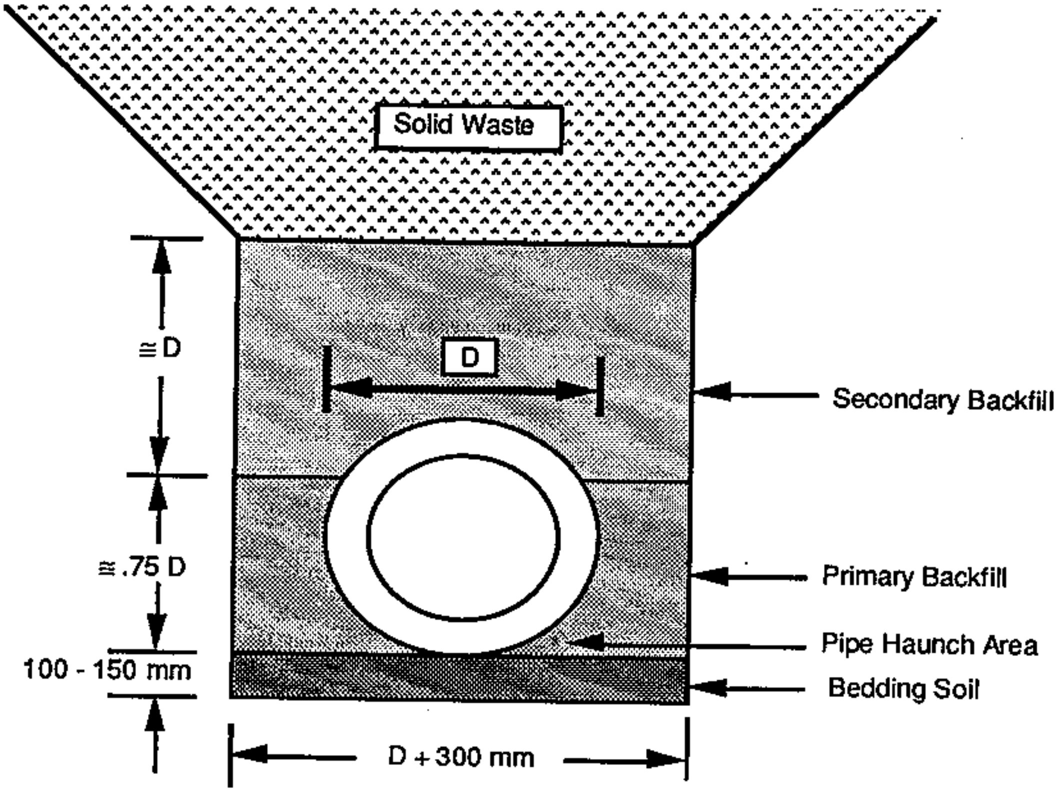
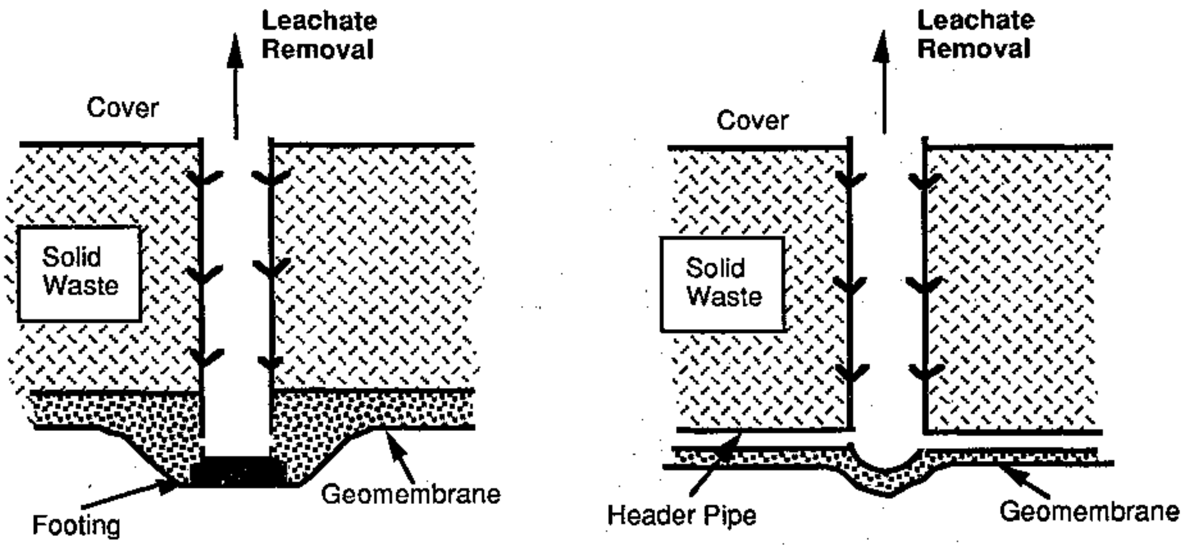


Figure 8.6 - A Possible Buried Pipe Trench Cross Section Scheme Showing Soil Backfill Terminology and Approximate Dimensions (for illustration purposes only).

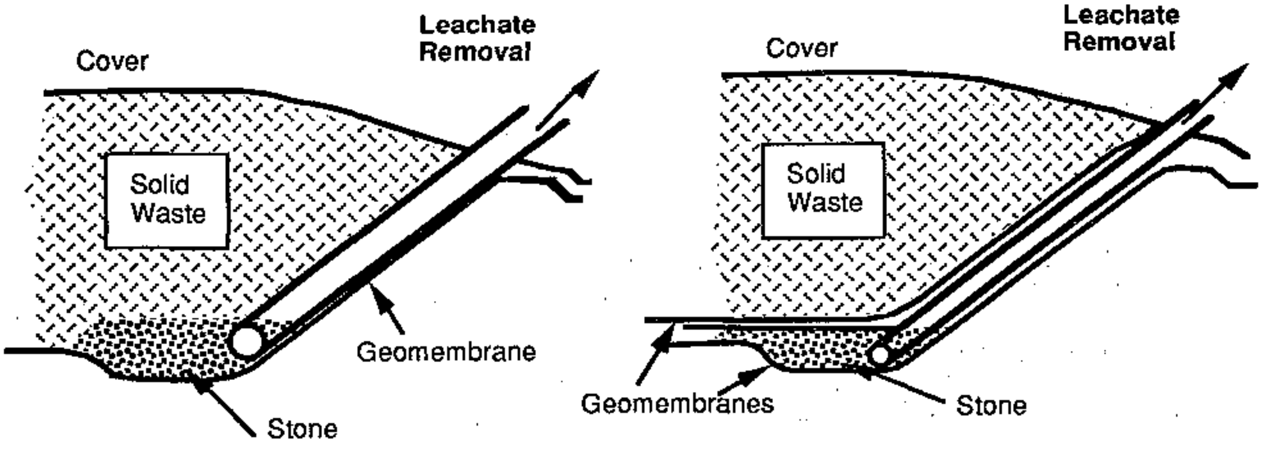
A more recent variation of the above removal system is an off-site factory fabricated sump and manhole system wherein the leachate collection pipe network frames directly into the sump, see the right hand sketch of Fig. 8.7(a). Various standardized sump capacities are available. This type of system requires the least amount of field fabrication. The riser is extended in sections as the waste is placed in the facility and eventually it must penetrate the final cover. Leachate is removed from the manhole by a submersible pump which is permanently located in the sump.

Quite a different variation for primary leachate removal is a well defined low area in the primary geomembrane into which the leachate collection pipe network flows. This low area creates a sump which is then filled with crushed stone and from which a pipe riser extends up the side slope. The pipe riser is usually a solid wall pipe with no perforations. When the facility is eventually filled with solid waste, the riser must penetrate the cover as shown in the left hand sketch of Fig. 8.7(b). The leachate is withdrawn using a submersible pump which is lowered down the pipe riser on a sled and left in place except for maintenance and/or replacement, recall Fig. 8.4.



In-Situ Fabrication **Factory Fabrication**

(a) Types of Primary Leachate Collection Sumps and Manholes with Vertical Standpipe Going through the Waste and Cover



(b) Types of Primary (Left) and Secondary (Right) Leachate Collection Sumps and Pipe Risers Going Up the Side Slopes

Figure 8.7 - Various Possible Schemes for Leachate Removal

In a similar manner as above, but now for secondary leachate removal, a sump can be formed in the secondary liner system which is filled with gravel as shown in the right hand sketch of Fig. 8.7(b). A solid wall pipe riser, perforated in its lower section, extends up the sidewall between the primary and secondary liner where it must penetrate both the primary liner, and eventually the cover system liner, see the right hand sketch of Fig. 8.7(b). This pipe riser is often a solid wall pipe in the 100-200 (4 to 8 in.) diameter range with no perforations. The leachate is withdrawn and/or monitored using a small diameter sampling pump which is lowered down the riser and left in place except for maintenance and/or replacement, recall Fig. 8.4.

Some specification and CQA document considerations for the various sump, manhole and riser schemes just described are as follows. Note, however, that there are other possible design schemes that are available in addition to those mentioned above.

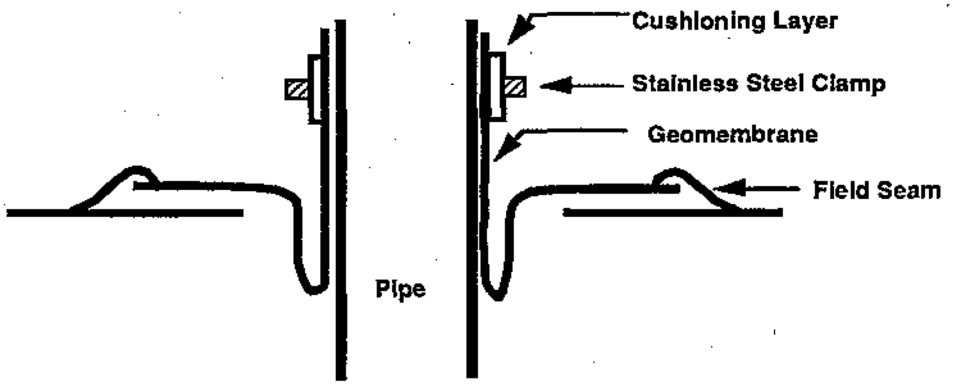
1. In-situ fabrication of sumps requires a considerable amount of hand labor in the field. Seams for HDPE and VLDPE geomembranes are extrusion fillet welded, while PVC and CSPE-R geomembranes are usually bodied chemical seams (EPA, 1991). Careful visual inspection is necessary.
2. The soil support beneath the sumps and around the manhole risers of plastic pipes is critically important. The specification should reference ASTM D-2321 with only backfill types IA, IB and II being considered.
3. Riser pipes for primary and secondary leachate removal are generally not perforated, except for the lowest section of pipe which accepts the leachate.
4. Riser pipe joints for primary and secondary leachate removal require special visual attention since neither destructive nor nondestructive tests can usually be accommodated.
5. The sump, manholes and risers must be documented by the CQA engineer before acceptance and placement of solid waste.

8.3 Liner System Penetrations

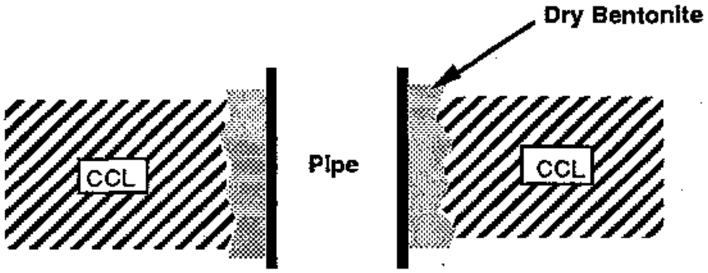
Although the intention of most designers of waste containment facilities is to avoid liner penetrations, leachate removal is inevitably required at some location(s) of the barrier system. Recall Fig. 8.7 where the cover is necessarily penetrated for primary leachate removal. For leak detection both the primary liner and the cover liner must be penetrated. It should also be recognized that the penetrations will include geomembranes, compacted clay liners and/or geosynthetic clay liners. Figure 8.8 illustrates some details of pipe penetrations through all three types of barrier materials.

The following recommendations are made for a specification or CQA document:

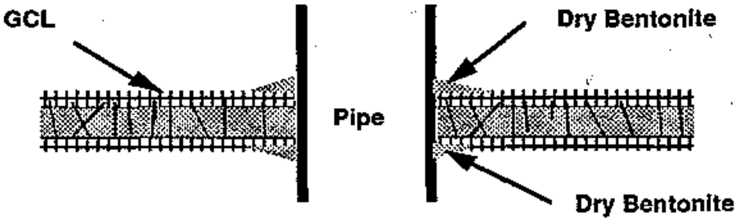
1. Geomembrane pipe boots are usually factory fabricated to a size which tightly fits the outside diameter of the penetrating pipe. Unique situations, however, will require field fabrication, e.g., when pipe penetration angles are unknown until final installation.
2. The skirt of the pipe boot which flares away from the pipe penetration should have at least 300 mm (12 in.) of geomembrane on all sides of the pipe.
3. The skirt of the pipe boot should be seamed to the base geomembrane by extrusion fillet or bodied chemical seaming depending on the type of geomembrane (EPA, 1991).



(a) Geomembrane Penetration



(b) Compacted Clay Liner (CCL) Penetration



(c) Geosynthetic Clay Liner (GCL) Penetration

Figure 8.8 - Pipe Penetrations through Various Types of Barrier Materials

4. The nondestructive testing of the skirt of the pipe boot should be by vacuum box or air lance depending on the type of geomembrane. Refer to Section 3.6.2.
5. The pipe boot should be of the same type of geomembrane as that of the liner through which the penetration is being made.
6. Pipe penetrations should be positioned with sufficient clearance to allow for proper welding and inspection.
7. Stainless steel pipe clamps used to attach pipe boots to the penetrating pipes should be of an adequate size to allow for a cushion of compressible material to be placed between the inside surface of the clamp and that of the geomembrane portion of the pipe boot.
8. Location of pipe clamps should be as directed on the plans and specifications.
9. Pipe penetrations through compacted clay liners and geosynthetic clay liners should use an excess of hand placed dry bentonite clay as directed in the plans and specifications.

8.4 Anchor Trenches

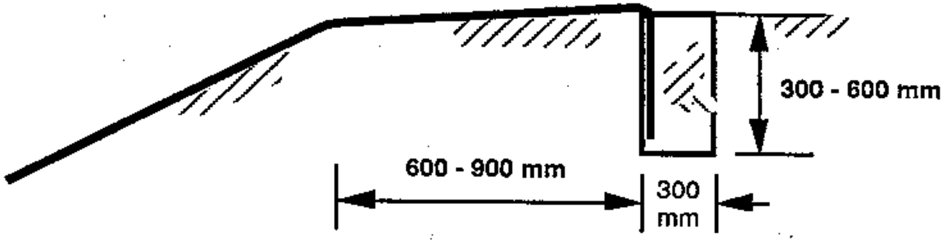
Generally, the geosynthetics used to line or cover a waste facility end in an anchor trench around the individual cell or around the entire site.

8.4.1 Geomembranes

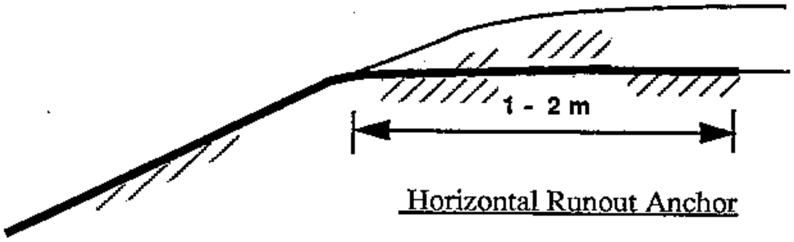
The termination of a geomembrane at the perimeter of landfill cells or at the perimeter of the entire facility generally ends in an anchor trench. As shown in Fig. 8.9, the variations are numerous. Such details should be specifically addressed in the construction plans and specifications.

Some general items that should be addressed in the specification or CQA documents regarding geomembrane termination in anchor trenches are as follows:

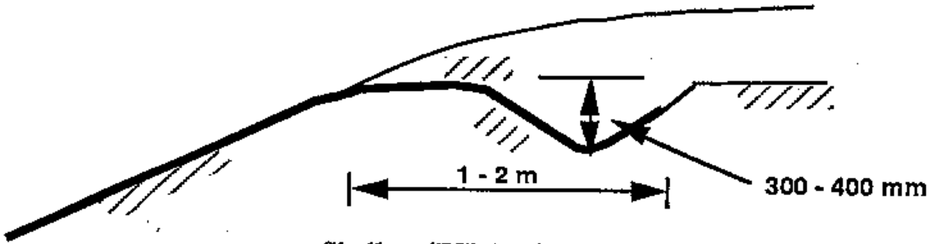
1. The seams of adjacent sheets of geomembranes should be continuous into the anchor trench to the full extent indicated in the plans and specifications.
2. Seaming of geomembranes within the anchor trench can be accomplished by temporarily supporting the adjacent sheets to be seamed on a wooden support platform in order that horizontal seaming can be accomplished continuously to the end of the geomembrane sheets. The temporary support is removed after the seam is complete and the geomembrane is then allowed to drop into the anchor trench.
3. Destructive seam samples can be taken while the seamed geomembrane is temporarily supported in the horizontal position.
4. Nondestructive tests can also be performed while the seamed geomembrane is temporarily supported in the horizontal position.
5. The anchor trench is generally backfilled after the geomembrane has been documented by the CQA engineer, but may be at a later date depending upon the site specific plans and specifications.



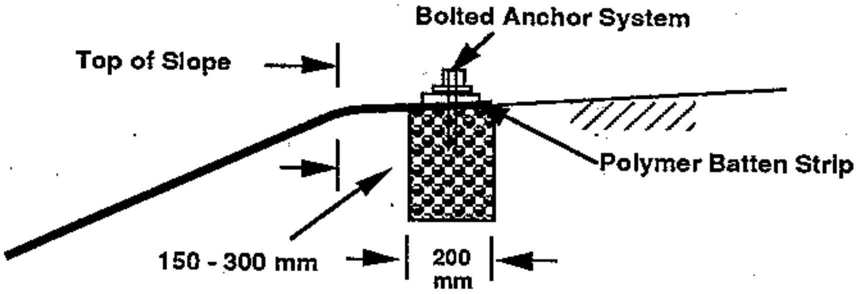
Typical Anchor Trench



Horizontal Runout Anchor



Shallow "V" Anchor Trench



Concrete Anchor Block

Figure 8.9 - Various Types of Geomembrane Anchors Trenches (Dimensions are Typical and for Example Only).

6. The anchor trench itself should be made with slightly rounded corners so as to avoid sharp bends in the geomembrane. Loose soil should not be allowed to underlie the geomembrane in the anchor trench.
7. The anchor trench should be adequately drained to prevent ponding of water or softening of the adjacent soils while the trench is open.
8. Backfilling in the anchor trench should be accomplished with approved backfill soils placed at their required moisture content and compacted to the required density.
9. The plans and specifications should provide detailed construction requirements for anchor trenches regardless if soils or other backfill materials are used.

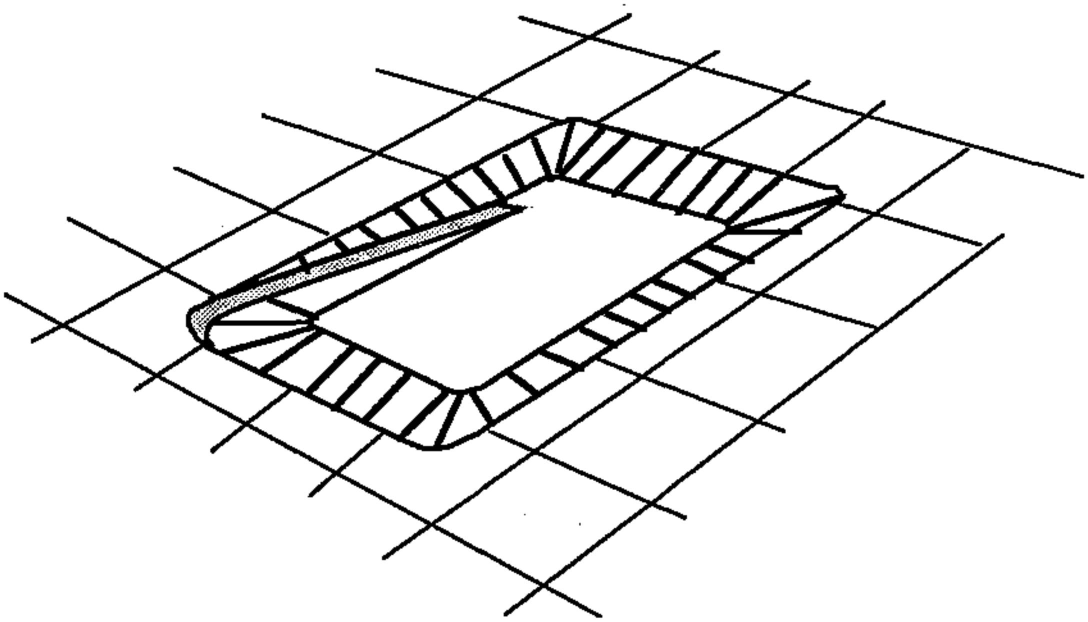
8.4.2 Other Geosynthetics

Since all geosynthetics, not only geomembranes, need adequate termination, some additional comments are offered for plans, specifications or CQA documents.

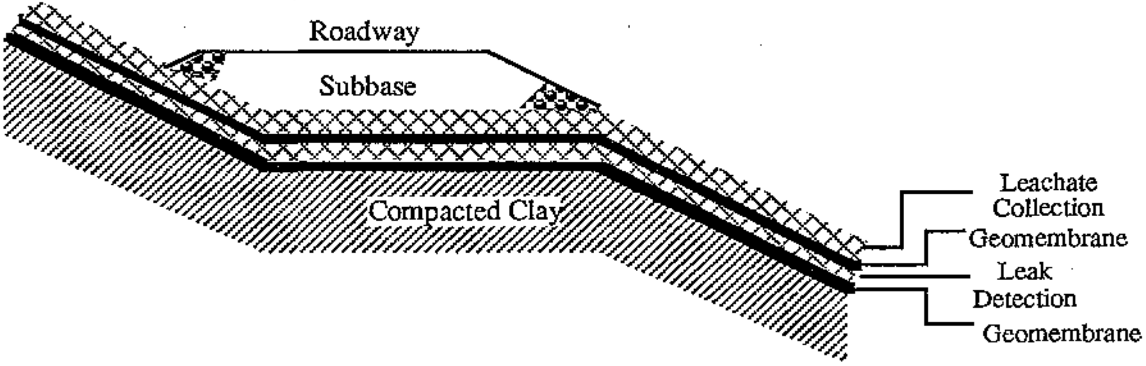
1. Geotextiles, either beneath or above geomembranes, usually follow their associated geomembrane into the same type of anchor trenches as shown in Fig. 8.9.
2. Geonets may or may not terminate in the anchor trench. Water transmission from beyond the waste containment may be a concern when requiring termination of the geonet within the geomembrane's anchor trench or in a separate trench by itself. Thus termination of a geonet may be short of the associated geomembrane's anchor trench. This is obviously a design issue and must be clearly detailed in the contract plans and specifications.
3. When used by themselves, geosynthetic clay liners (GCLs) will generally terminate in a anchor trench in soil of the type shown in Fig. 8.9. When GCLs are with an associated geomembrane, as in a composite liner, each component will sometimes end in a separate anchor trench. These are design decisions.
4. Double liner systems will generally have separate anchor trenches for primary and secondary liner systems. This is a design decision.
5. In all of the above cases, the plans and specifications should provide detailed dimensions and construction requirements for anchor trenches of all geosynthetic components.
6. The plans and specifications should also show details of how natural soil components, e.g., compacted clay liners and sand or gravel drainage layers, terminate with respect to one another and with respect to the geosynthetic components.

8.5 Access Ramps

Heavily loaded vehicles must enter the landfill facility during construction activities and during placement of the solid waste. Typical access ramps will be up to 5.5 m (18 ft.) in width and have grades up to 12%. The general geometry of an access ramp is shown in Fig. 8.10(a).



(a) Geometry of a Typical Ramp



(b) Cross Section of Ramp Roadway

Figure 8.10 - Typical Access Ramp Geometry and Cross Section

The traffic loads on such a ramp can be extremely large and generally involve some degree of dynamic force due to the constant breaking action which drivers use when descending the steep grades. Note that the entire liner cross section must extend uninterrupted from the upper slope to the lower slope and in doing so must necessarily pass beneath the roadway base course. When working with a double lined facility this can involve numerous geosynthetic and natural soil layers. Further complicating the design issues is that drainage from the upper side slopes must communicate beneath the roadway base course layer or travel parallel to it and be contained accordingly. A reinforcing element (geotextile or geogrid) can be incorporated in the roadway base course material. This can serve several purposes; i.e., to protect long-term integrity of underlying systems, to minimize potential sliding failures, and to minimize potential rutting and bearing capacity failures. These are critical design issues and must be well defined in the plans and specifications.

Regarding recommendations for the contract specifications or CQA document, the following items apply:

1. Many facilities will limit the number of vehicles on the access ramp at a given time. Such stipulations should be strictly enforced.

2. Vehicle speeds on access ramps should be strictly enforced.

3. Regular inspection should be required to observe if tension cracks open in the roadway base coarse soils. This may indicate some degree of slippage of the soil and possible damage to the liner system.

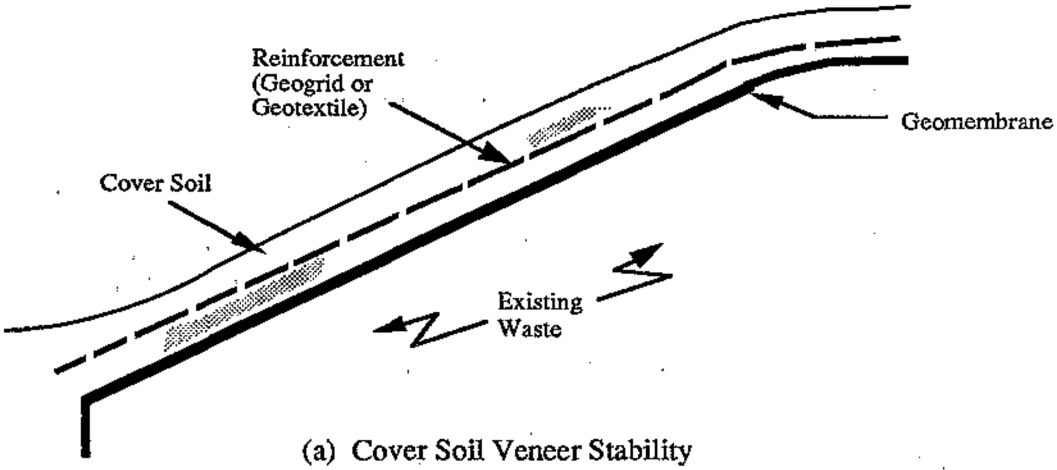
4. Ponding of upper slope runoff water against the roadway profile should be observed for possible erosion effects and loss of base course material. If a drainage ditch or pipe system is indicated on the plans, it should be constructed as soon as possible after completion of the roadway subbase soils.

5. The roadway base course profile should be fully maintained for the active lifetime of the facility.

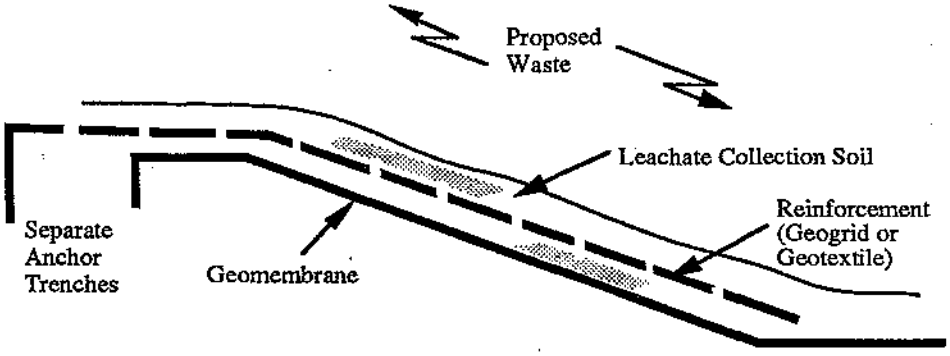
8.6 Geosynthetic Reinforcement Materials

For landfill and waste pile covers with slopes greater than 3 horizontal to 1 vertical (3H:1V), stability issues regarding downgradient sliding begin to be important. Additionally, the stability of primary leachate collection systems for landfill and waste pile liners with slopes greater than 3H : 1V is suspect at least until the solid waste material within the unit raises to a stabilizing level. Such issues, of course, must be considered during the design phase and the contract plans and specifications must be very clear on the method of reinforcement, if any. If reinforcement is necessary it can be accomplished by using geotextiles or geogrids within the layer contributing to the instability to offset some, or even all, of the gravitational stresses. Refer to Fig. 8.11(a) and (b) for the general orientation of such reinforcement, which is sometimes called "veneer reinforcement".

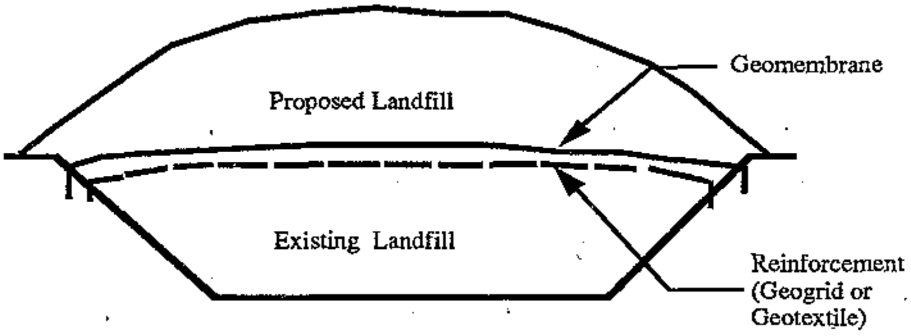
The concept of using geogrid or geotextile reinforcement to support a liner or liner system when a new landfill is built above, or adjacent to, an existing landfill has recently been developed. The technique has been referred to as "piggybacking" when vertical expansions are involved, see Fig. 8.11(c). The main focus of the reinforcement is to provide stability against differential settlement which can occur in the existing landfill.



(a) Cover Soil Veneer Stability



(b) Leachate Collection Soil Veneer Stability



(c) Liner System Reinforcement for "Piggy backing"

Figure 8.11 - Geogrid or Geotextile Reinforcement of (a) Cover Soil above Waste, (b) Leachate Collection Layer beneath Waste, and (c) Liner System Placed above Existing Waste ("Piggybacking")

Since geotextiles were described previously from a manufacturing standpoint and for separation and filtration applications, they will be discussed here only from their reinforcement perspective. Geogrids will be described from both their manufacturing and reinforcement perspectives.

8.6.1 Geotextiles for Reinforcement

The manufacturing of geotextiles was described in section 6.2 along with recommendations for MQC and MQA documents. Regarding CQC and CQA, the focus was on separation and filtration applications. Some specific recommendations regarding reinforcement geotextiles for a specification or CQA document are as follows:

1. A manufacturer's certification should be provided that the geotextile meets the property criteria specified for the geotextile that was approved for use on the project via the plans and specifications.
2. CQA personnel should check that the geotextile delivered to the job site is the proper and intended material. This is done by verifying the identification label and its coding and by visual identification of the product, its construction and other visual details.
3. Conformance samples of the geotextile supplied to the job site should be obtained as per ASTM D-4759. Typically, the outer wrap of the rolls are used for such sampling.
4. Conformance tests should be the following. Wide width tensile strength per ASTM D-4595, trapezoidal tear strength per ASTM D-4533 and puncture strength per ASTM D-4833. Additional conformance tests which may be considered are polymer identification via thermogravimetric analysis (TGA) and grab tensile strength, via ASTM D-4632.
5. Field placement of geotextiles should be at the locations indicated on the contract plans and in the specifications. Details of overlapping or seaming should be included.
6. Geotextile deployment is usually from the top of slope downward, so that the geotextile is taut before soil backfilling proceeds.
7. If the upper end of the geotextile should be anchored in an anchor trench, the details shown in the contract plans should be fulfilled.
8. Soil backfilling should proceed from the bottom of the slope upward, with a minimum backfill thickness of 220 mm (9 in.) of cover using light ground contact construction equipment of 40 kPa (6 lb/in^2) contact pressure or less.
9. Seams in geotextiles on side slopes are generally not allowed. If permitted, they should be located as close to the bottom of the slope as possible. Seams should be as approved by the CQA engineer. Test strips of seams should be requested for conformance tests in the CQA laboratory following ASTM D-4884.

8.6.2 Geogrids

Geogrids are reinforcement geosynthetics formed by intersecting and joining sets of longitudinal and transverse ribs with resulting open spaces called "apertures". Two different classes of geogrids are currently available, see Fig. 8.12(a). They are the following: (a) stiff, unitized, geogrids made from polyethylene or polypropylene sheet material which is cold worked into a post-yield state, and (b) flexible, textile-like geogrids made from high tenacity polyester yarns which are joined at their intersections and coated with a polymer or bitumen. Figure 8.12 (b) shows geogrids being used as veneer reinforcement.

Some recommended contract specification or CQA document items that should be addressed when using geogrids as reinforcement materials are as follows:

1. A manufacturer's certification should be provided that the geogrid meets the property criteria specified for the geogrid that was approved for use on the project per the plans and specifications.

2. CQA personnel should check that the geogrid delivered to the job site is the proper and intended material. This is done by verifying the identification label and its coding and by visual identification of the product, its rib joining, thickness and aperture size. If the geogrid has a primary strength direction it must be so indicated.

3. Conformance samples of the geogrid supplied to the job site should be obtained as per ASTM D-4759. Typically, the outer wrap of the rolls are used for such sampling.

4. Conformance tests should be the following. Aperture size by micrometer or caliper measurement, rib thickness and junction thickness by ASTM D-1777, and wide width tensile strength by ASTM D-4595 suitably modified for geogrids. Additional conformance tests which may be considered are polymer identification via thermal analysis methods and single rib tensile strength, via GRI GG1.

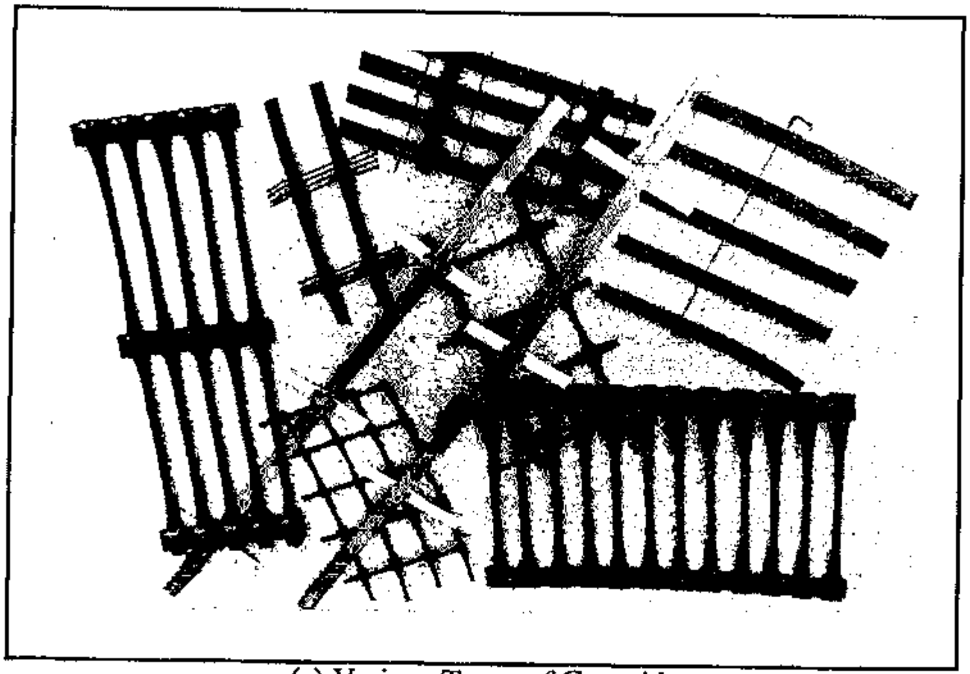
5. Field placement of geogrids should be at the locations indicated on the contract plans and in the specifications. Details of overlapping or seaming should be included.

6. Geogrid deployment is usually from the top of slope downward, so that the geogrid is taut before soil backfilling proceeds.

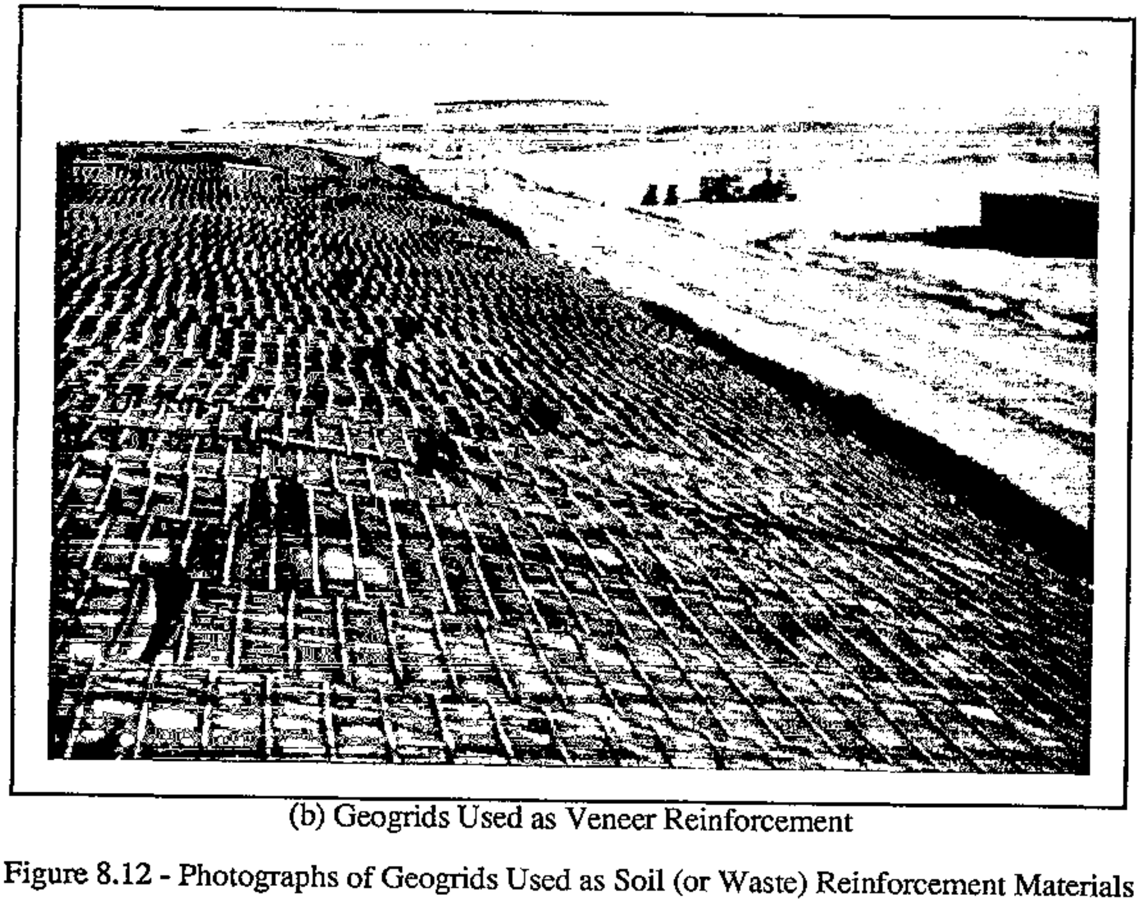
7. If the upper end of the geogrids are to be anchored in an anchor trench, the details shown in the contract plans should be fulfilled.

8. Soil backfilling should proceed from the bottom of the slope upward, with a minimum backfill thickness of 22 cm (9.0 in.) of cover using light ground contact construction equipment of 40 kPa (6 lb/in^2) contact pressure or less.

9. Connections of geogrid rolls on side slopes should generally be avoided. If permitted, they should be located as close to the bottom of the slope as possible. Connections should be as approved by the CQA engineer. Test strips of connections should be requested for conformance tests in the CQA laboratory following ASTM D-4884 (mod.) test method.



(a) Various Types of Geogrids



(b) Geogrids Used as Veneer Reinforcement

Figure 8.12 - Photographs of Geogrids Used as Soil (or Waste) Reinforcement Materials

8.7 Geosynthetic Erosion Control Materials

Often on sloping solid waste landfill covers soil loss in the form of rill, gully or sheet erosion occurs in the topsoil and sometimes extends down into the cover soil. This requires continuous maintenance until the phenomenon is halted and the long-term vegetative growth is established. Alternatively, the design may call for a temporary, or permanent, erosion control system to be deployed within or on top of the topsoil layer. Additional concerns regarding erosion control are on perimeter trenches, drainage ditches, and other surface water control structures associated with waste containment facilities. Listed below are a number of alternative erosion control systems ranging from the traditional hand distributed mulching to fully paved cover systems. They fall into two major groups; temporary degradable and permanent nondegradable.

Temporary Erosion Control and Revegetation Mats (TERMs)

- Mulches (hand or machine applied straw or hay)
- Mulches (hydraulically applied wood fibers or recycled paper)
- Jute Meshes
- Fiber Filled Containment Meshes
- Woven Geotextile Erosion Control Meshes
- Fiber Roving systems (continuous fiber systems)

Permanent Erosion Control and Revegetation Mats (PERMs)

- Geosynthetic Systems
  - turf reinforcement and revegetation mats (TRMs)
  - erosion control and revegetation mats (ECRMs)
  - geomatting systems
  - geocellular containment systems
- Hard Armor Systems
  - cobbles, with or without geotextiles
  - rip-rap, with or without geotextiles
  - articulated concrete blocks, with or without geotextiles
  - grout injected between geotextiles
  - partially or fully paved systems

Temporary degradable systems are used to enhance the establishment of vegetation and then degrade leaving the vegetation to provide the erosion protection required. Challenging sites that require protection above and beyond what vegetation can provide need to use a permanent nondegradation system, i.e., high flow channels, over steepened slopes etc. Of these various alternatives, jute meshes, containment meshes and geosynthetic systems are used regularly on landfill and waste pile cover systems, see Fig. 8.13.

Some items which are recommended for contract specifications or CQA document for these particular systems are as follows:

1. The CQA personnel should check the erosion control material upon delivery to see that the proper materials have been received.
2. Water and ultraviolet sensitive materials should be stored in dry conditions and protected from sunlight.
3. If the erosion control material has defects, tears, punctures, flaws, deterioration or damage incurred during manufacture, transportation or storage it should be rejected or suitably repaired to the satisfaction of the CQA personnel.
4. If the material is to be repaired, torn or punctured sections should be removed by cutting a cross section of the material out and replacing it with a section of undamaged material. The ends of the new section should overlap the damaged section by 30 cm (12 in.) and should be secured with ground anchors.
5. All ground surfaces should be prepared so that the material lies in complete contact with the underlying soil.
6. Ground anchors, called "pins", should be at least 30 cm (12 in.) long with an attached oversized washer 50 mm (2.0 in.) in diameter, or "staples" number 8 gauge "U" shaped wire at least 20 cm (8.0 in.) long. For less severe temporary applications e.g., TERMS's, one may consider 15 cm (6 in.) number 11 gauge "U" shaped wire staples.
7. Adjacent rolls of erosion control material shall be overlapped a minimum of 75 mm (3.0 in.). Staples should secure the overlaps at 75 cm (2.5 ft) intervals. The roll ends should overlap a minimum of 45 cm (18 in.) and be shingled downgradient. The end overlaps should be stapled at 45 cm (1.5 ft) intervals, or closer, or as recommended by the manufacturer.
8. If required on the plans and specifications, the erosion control material should be filled with topsoil, lightly raked or brushed into the mat to either fill it completely or to a maximum depth of 25 mm (1.0 in.).
9. For geosynthetic materials used in drainage ditches, their overlaps should always be shingled downgradient with overlaps as recommended by the manufacturer or plans and specifications whichever is the greatest.
10. If required by the plans and specifications, the manufacturer of the erosion control or drainage ditch material should provide a qualified and experienced representative on site to assist the installation contractor at the start of construction. After an acceptable routine is established, the representative should be available on an as-needed basis, at the CQA engineer's request.

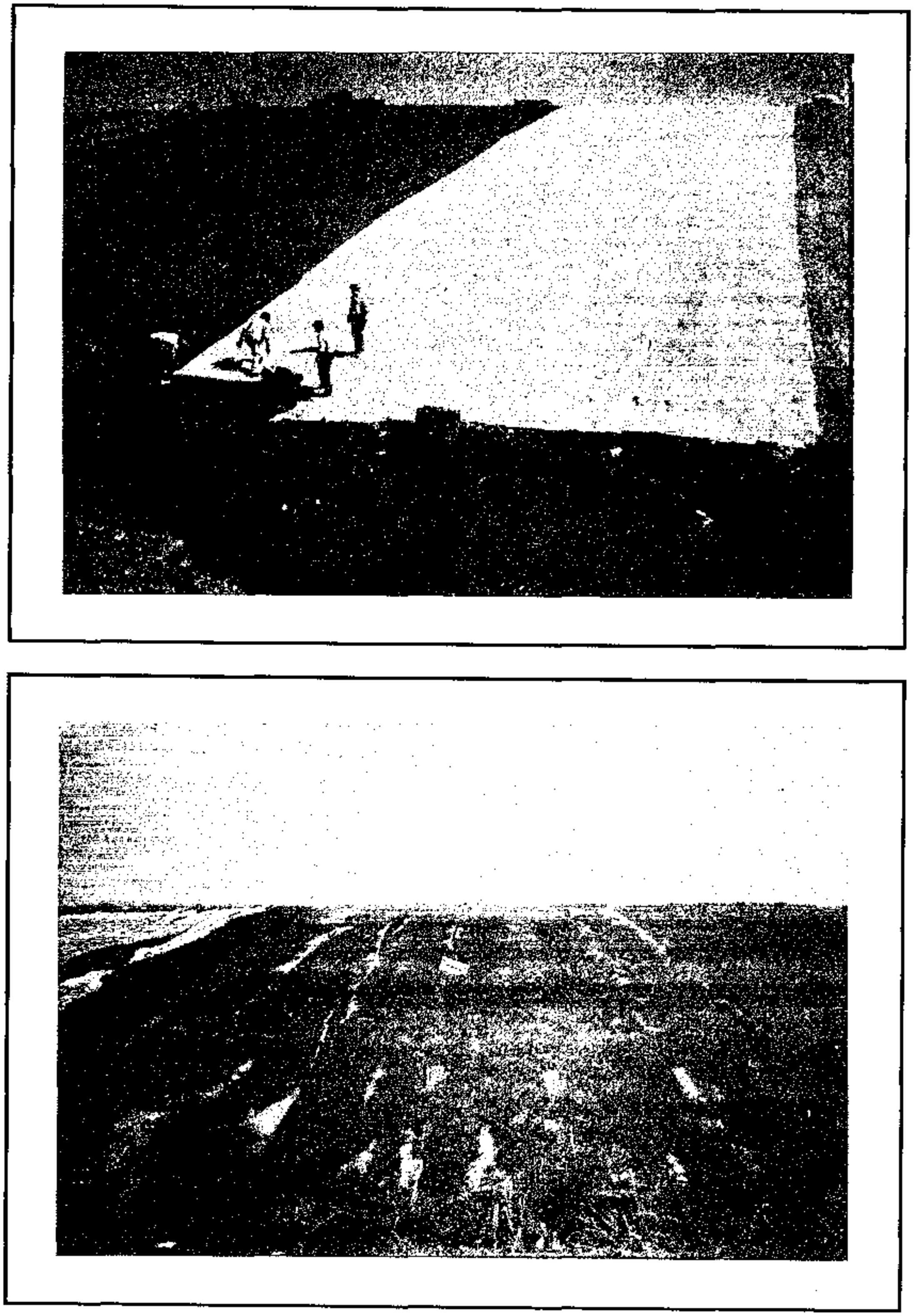


Figure 8.13 - Examples of Geosynthetic Erosion Control Systems

Figure 8.13 - Continued

8.8 Floating Geomembrane Covers for Surface Impoundments

In concluding this Chapter, it was felt that a short section on geomembrane floating covers for liquid wastes contained in surface impoundments is appropriate. These floating covers are geomembranes of the types discussed in Chapter 3. Hence all details such as polymer type, production, conformance testing, etc., are applicable here as well. The uniqueness of the application is that the geomembrane is always exposed to the atmosphere, thus subject to sunlight, heat, damage, etc., and furthermore it must be rigidly anchored to a concrete anchor trench or other similar structure, surrounding the perimeter of the facility, see Fig. 8.14.

Some items in addition to those mentioned in Chapter 3 on geomembranes that are recommended for a contract specification or a CQA document are as follows:

1. Acceptance of the geomembrane should have some verification as to its weatherability characteristics. The tests most frequently referenced are ASTM D-4355 and ASTM G-26. There is also a growing body of data being developed under the ASTM G-53 test method.

2. Other conformance tests, e.g., physical and mechanical property tests, are product specific and have been described in Chapter 3.

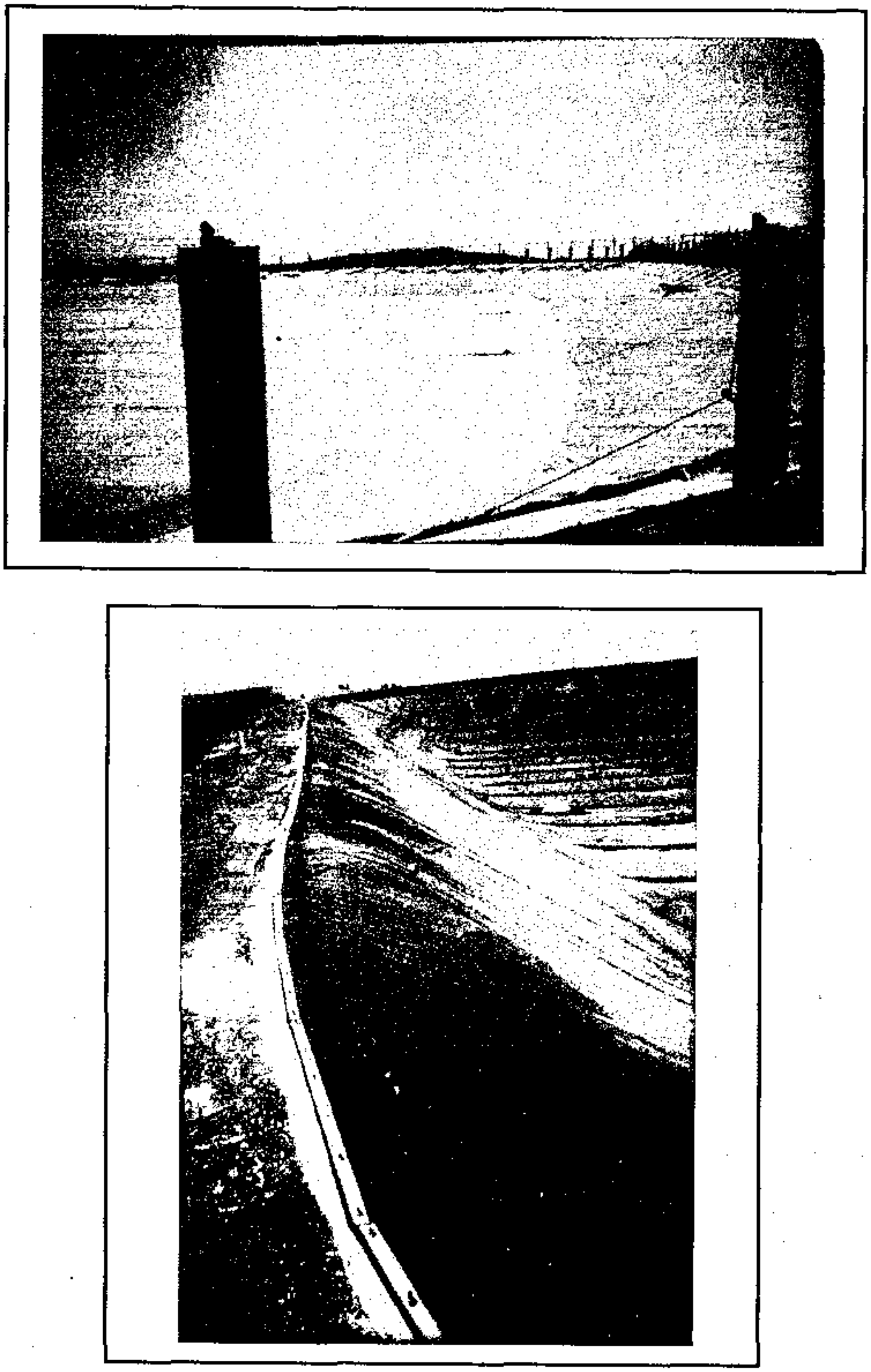


Figure 8.14 - Surface Impoundments with Geomembrane Floating Covers along with Typical Details of the Support System and/or Anchor Trench and Batten Strips

3. The anchorage detail for floating covers is critically important. Construction plans and specifications must be followed explicitly. To be noted is that there are very different anchorage schemes that are currently available. Some use concrete anchor blocks with embedded bolts which attach the geomembrane under a batten strip. Other anchorages are patented systems consisting of tensioned geomembranes attached to movable dead weights riding inside of stationary columns. Additional schemes are also possible. In each case the manufacturer's recommendations should be cited in the contract documents and must be followed completely.

4. The manufacturer/fabricator of the floating cover should provide a qualified and experienced representative on site to assist the installation contractor at the start of construction. After an initial start-up point, the representative should be available on an as needed basis, at the CQA engineer's request.

8.9 References

AASHTO M252-90, "Corrugated Polyethylene Drainage Tubing"

AASHTO M294-90, "Corrugated Polyethylene Pipe, 12- to 36-in. Diameter"

ASTM D-698, "Moisture Density Relations of Soils and Soil/Aggregate Mixtures"

ASTM D-792, "Specific Gravity and Density of Plastics by Displacement"

ASTM D-1238, "Flow Rates of Thermoplastics by Extrusion Plastomer"

ASTM D-1248, "Polyethylene Plastics and Extrusion Materials"

ASTM D-1505, "Density of Plastics by the Density-Gradient Technique"

ASTM D-1755, "Poly (Vinyl Chloride) (PVC) Resins"

ASTM D-1777, "Measuring Thickness of Textile Materials"

ASTM D-1785, "Poly (Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80 and 120"

ASTM D-2122, "Determining Dimensions of Thermoplastic Pipe and Fittings"

ASTM D-2241, "Poly (Vinyl Chloride) (PVC) Pressure Rated Pipe (SDR-Series)"

ASTM D-2321, "Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity - Flow Applications"

ASTM D-2412, "External Loading Properties of Plastic Pipe by Parallel Plate Loading"

ASTM D-2444, "Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)"

ASTM D-3034, "Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings"

ASTM D-4254, "Maximum Index Density of Soils and Calculation of Relative Density"

ASTM D-4355, "Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon-Arc Type Apparatus)

ASTM D-4533, "Trapezoidal Tearing Strength of Geotextiles"

ASTM D-4595, "Tensile Properties of Geotextiles by Wide Width Strip Method"

ASTM D-4632, "Breaking Load and Elongation of Geotextiles (Grab Method)"

ASTM D-4759, "Determining the Specification Conformance of Geosynthetics"

ASTM D-4833, "Index Puncture Resistance of Geotextiles, Geomembranes and Related Products"

ASTM D-4884, "Seam Strength of Sewn Geotextiles"

ASTM F-714, "Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter"

ASTM G-26, "Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials"

ASTM G-53, "Operating Light- and Water-Exposure Apparatus (Fluorescent UV - Condensation Type) for Exposure of Nonmetallic Materials"

GRI GG1, "Geogrid Rib Tensile Strength"

U.S. Environmental Protection Agency (1991), "Inspection Techniques for the Fabrication of Geomembrane Field Seams," Technical Resource Document, U.S. EPA, EPA/530/SW-91/051.

Appendix A

List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
ATV	All-Terrain Vehicle
CB	Cement-Bentonite
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CH	Fat Clay (ASTM D-2487)
CL	Lean Clay (ASTM D-2487)
CPE	Chlorinated Polyethylene
CQA	Construction Quality Assurance
CQC	Construction Quality Control
CSPE	Chlorosulfonated Polyethylene
CSPE-R	Chlorosulfonated Polyethylene (Scrim Reinforced)
ECRM	Erosion Control and Revegetation Mat
EIA	Ethylene Interpolymer Alloy
EIA-R	Ethylene Interpolymer Alloy - Reinforced
EPA	Environmental Protection Agency
EPDM	Ethylene Propylene Diene Monomer
FCEA	Fully Crosslinked Elastomeric Alloy
FML	Flexible Membrane Liner
FTB	Film Tear Bond
FTM	Federal Test Method
GCL	Geosynthetic Clay Liner
GRI	Geosynthetic Research Institute

HDPE	High Density Polyethylene
IFAI	Industrial Fabrics Association International
LL	Liquid Limit
LLDPE	Linear Low Density Polyethylene
MARV	Mimimum Average Roll Value
MQA	Manufacturing Quality Assurance
MQC	Manufacturing Quality Control
NDT	Nondestructive Testing
NICET	National Institute for Certification in Engineering Technologies
PE	Professional Engineer or Polyethylene
PERM	Permanent Erosion Control and Revegetation Mat
PI	Plasticity Index
PL	Plastic Limit
PP	Polypropylene
PVC	Polyvinyl Chloride
QA	Quality Assurance
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
SB	Soil-Bentonite
SC	Clayey Sand (ASTM D-2487)
SCB	Soil-Cement-Bentonite
SDR	Standard Dimension Ratio
TERM	Temporary Erosion Control and Revegetation Mats
TGA	Thermogravimetric Analysis
TRM	Turf Reinforcement and Revegetation Mat
USCS	Unified Soil Classification System

USP	U.S. Pharmaceutical
VLDPE	Very Low Density Polyethylene

Appendix B

Glossary

Activity—Plasticity index (expressed as a percentage) divided by the clay content (expressed as a percentage and defined as material finer than 0.002 mm).

Adhesion—The state in which two surfaces are held together by interfacial forces which may consist of molecular forces or interlocking action or both: (a) measured in shear and peel modes for geomembranes, (b) measured by direct shear testing for geosynthetics-to-soil.

Adhesive—A chemical system used in the bonding of geomembranes. The adhesive residue results in an additional element in the seamed area. (Manufacturers and installers should be consulted for the various types of adhesives used with specific geomembranes).

Aeolian Deposit—Soil deposited by wind.

Air Lance—A commonly used nondestructive geomembrane test method performed with a stream of air forced through a nozzle at the end of a hollow metal tube to determine seam continuity and tightness of relatively thin, flexible geomembranes.

All-Terrain Vehicles (ATVs)—Mobile 3-, or 4-wheeled vehicles with low pressure balloon tires which are used to move small equipment and materials around project sites.

Anchor Trench—The terminus of most geosynthetic materials as they exit a waste containment facility usually consisting of a small trench where the geosynthetic is embedded and suitably backfilled.

Antioxidants—Primary types include phenols and amines that scavenge extraneous free radicals which cause degradation of geosynthetics. Secondary types include decomposed peroxides as a source of free radicals.

Anvil—In hot wedge seaming of geomembranes, the anvil is the wedge of metal above and below which the sheets to be joined must pass. The temperature controllers and thermocouples of most hot wedge devices are located within the anvil.

Apertures—The openings between adjacent sets of longitudinal and transverse ribs of geogrids and geonets.

Appurtenances—Detailed items related to the proper functioning of a waste containment facility, such as pipes, sumps, risers, manholes, vents, penetrations and related items.

Atterberg Limits—Liquid limit and plastic limit of a soil.

Basis Weight—A deprecated term for mass per unit area.

Bedding Soil—Compacted layer of soil immediately beneath a leachate collection pipe.

Bentonite—Any commercially processed clay material consisting primarily of the mineral group smectite.

Berm—The upper edge of an excavation which isolates one cell in a containment system from another. The ends of a geosynthetic are buried to hold them in place or to anchor the geosynthetics.

Blocking—Unintentional adhesion between geomembrane sheets or between a geomembrane and another surface usually occurring during storage or shipping.

Blown Film—An extrusion method for producing geomembranes whereby the molten polymer vertically exits a circular die in the form of a huge cylinder which is subsequently cut longitudinally, unfolded and rolled into cores.

Blow-Out—Geomembrane rolls or panels which have been unintentionally displaced from their correct position by wind.

Bodied Chemical Fusion Agent—A chemical fluid containing a portion of the parent geomembrane that, after the application of pressure and after the passage of a certain amount of time, results in the chemical fusion of two essentially similar geomembrane sheets, leaving behind only that portion of the parent material. (Manufacturers and installers should be consulted for the various types of chemical fluids used with specific geomembranes in order to inform workers and inspectors.)

Bodied Solvent Adhesive—An adhesive consisting of a solution of the liner compound used in the seaming of geomembranes.

Boot—A bellows-type covering of a penetration through a geomembrane to exclude dust, dirt, moisture, etc.

Borrow Material—Excavated material used to construct a component of a waste containment facility.

Borrow Pit—Excavation area adjacent to, or off-site, the waste containment facility from which soil will be taken for construction purposes.

Buffing—An inaccurate term often used to describe the grinding of polyethylene geomembranes to remove surface oxides and waxes in preparation of extrusion seaming.

Calender—A machine equipped with three or more heavy internally heated or cooled rolls, revolving in opposite direction. Used for preparation of continuous sheeting or plying up of rubber compounds and frictioning or coating of fabric with rubber or plastic compounds. [B. F. Goodrich Co. Akron, OH].

Chemical-Adhesive Fusion Agent—A chemical fluid that may or may not contain a portion of the parent geomembrane and an adhesive that, after the application of pressure and after passage of a certain amount of time, results in the chemical fusion of two geomembrane sheets, leaving behind an adhesive layer that is dissimilar from the parent liner material. (Manufacturers and installers should be consulted for the various types of chemical fluids used with specific geomembrane to inform workers and inspectors.)

Chemical Fusion—The chemically-induced reorganization in the polymeric structure of the surface of a polymer geomembrane that, after the application of pressure and the passage of a certain amount of time, results in the chemical fusion of two essentially similar geomembrane sheets being permanently joined together.

Chemical Fusion Agent—A chemical fluid that, after the application of the passage of a certain amount of time, results in the chemical fusion of two essentially similar geomembrane sheets without any other polymeric or adhesive additives. (Manufacturers and installers should be consulted for the various types of chemical fusion agents used with specific geomembranes to inform workers and inspectors.)

Chlorinated Polyethylene (CPE)—Family of polymers produced by the chemical reaction of chlorine with polyethylene. The resultant polymers presently contain 25-45% chlorine by weight and 0-25% crystallinity.

Chlorinated Polyethylene-Reinforced (CPE-R)—Sheets of CPE with an encapsulated fabric reinforcement layer, called a "scrim".

Chlorosulfonated Polyethylene (CSPE)—Family of polymers produced by the reaction of polyethylene with chlorine and sulphur dioxide. Present polymers contain 23 to 43% chlorine and 1.0 to 1.4% sulphur. A "low water absorption" grade is identified as significantly different from standard grades.

Chlorosulfonated Polyethylene-Reinforced (CSPE-R)—Sheets of CSPE with an encapsulated fabric reinforcement layer, called a "scrim".

Clay Content—The percentage of a material (dry weight basis) with an mean equivalent grain diameter smaller than a specified size (usually 0.002 or 0.005 mm).

Clod—Term referring to "chunks" of cohesive soil when used for compacted clay liners.

Coated Fabric—Fabric that has been impregnated and/or coated with a rubbery or plastic material in the form of a solution, dispersion, hot melt, or powder. The term also applies to materials resulting from the application of a pre-formed film to a fabric by means of calendering.

Coextrusion—A manufacturing process whereby multiple extruders eject molten polymer into a die for the purpose of distinguishing properties or materials across the thickness of the geosynthetic material, as in coextruded HDPE/VLDPE/HDPE geomembranes.

Compaction Curve—An experimentally obtained curve obtained by plotting dry unit weight versus molding water content, typically used with soil liners.

Composite Liner—A geomembrane placed directly on the surface of a compacted soil liner or geosynthetic clay liner.

Concentrate—Term commonly used for carbon black premixed with a carrier resin resulting in pellets which are added to the extruder in the manufacturing of geosynthetic materials.

Construction Quality Control (CQC)—A planned system of inspections that are used to directly monitor and control the quality of a construction project (EPA, 1986). Construction quality control is normally performed by the geosynthetics manufacturer or installer, or for natural soil materials by the earthwork contractor, and is necessary to achieve quality in the constructed or installed system. Construction quality control (CQC) refers to measures taken by the installer or contractor to determine compliance with the requirements for materials and workmanship as stated in the plans and specifications for the project.

Construction Quality Assurance (CQA)—A planned system of activities that provide assurance that the facility was constructed as specified in the design (EPA, 1986). Construction quality assurance includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility. Construction quality assurance (CQA) refers to measures taken by the CQA organization to assess if the installer or contractor is in compliance with the plans and specifications for a project.

Corrugated Pipe—Built-up sections of HDPE drainage pipe manufactured by methods of corrugation, profiling or spirally wrapping small pipe around an internal core.

CQC Personnel—Individuals who work for contractor whose job it is to ensure that construction is taking place in accord with the plans and specifications approved by the permitting agency.

Crystal Structure—The geometrical arrangement of the molecules that occupy the space lattice of the crystalline portion of a polymer.

Curing—The strength gain over time of a chemically fused, bodied chemically fused, or chemical adhesive geomembrane seam due primarily to evaporation of solvents or crosslinking of the organic phase of the mixture.

Curing Time—The time required for full curing as indicated by no further increase in strength over time.

Deltaic Deposit—Soil deposited in a river delta.

Denier—A unit used in the textile industry to indicate the fineness of continuous filaments as applies to geotextiles. Fineness in deniers equals the mass in grams of 9000-m length of the filament.

Density—(a) For geosynthetics, the mass per unit volume of a polymeric material (since there is no void space, per se); and (b) for soils, the mass per total unit volume, including void space (note: if the mass is the total mass, i.e., solids plus water, the density is the total density or bulk density; if the mass is just the dry mass of solids, the density is the dry density of the soil).

Desiccation—Drying that is sufficient to change the properties, such as hydraulic conductivity, of the material.

Design Engineer—An organization or person who designs a waste containment facility that fulfills the operational requirements of the owner/operator, complies with accepted design practices for waste containment facilities and meets or exceeds the minimum requirements of the permitting agency.

Destructive Tests—Tests performed on geomembrane seam samples cut out of a field installation or test strip to verify specification performance requirements, e.g., shear and peel tests of geomembrane seams during which the specimens are tested to failure.

Direction, Cross-Machine—The direction perpendicular to the long, machine or manufactured direction.

Direction, Machine—The direction parallel to the long, machine or manufactured direction (synonyms, lengthwise, or long direction).

Dispersion—A qualitative term used to identify the degree of mixing of one component of a formulation within the total mass, e.g., carbon black dispersion.

Drive Rollers—Knurled or rubber rollers which grip two geomembrane sheets to be joined via applied pressure and propel the seaming device at a controlled rate of travel.

Dumbbell Shaped—Geomembrane test specimens in the shape of a dumbbell or dogbone, for subsequent tensile testing.

Dwell Time—The time required for a chemical fusion, bodied chemical fusion or adhesive seam to take its initial "tack", enabling the two opposing geomembranes to be joined together.

Earthwork Contractor—The organization that is awarded the subcontract from the general contractor, or contract from the owner/operator, to construct the earthen components of the waste containment facility.

Embossing—A method of providing a textured, a roughened, surface to calendered geomembranes for the purpose of increasing its friction to adjacent materials.

Ethylene Interpolymer Alloy (EIA)—A blend of ethylene vinyl acetate and polyvinyl chloride resulting in a thermoplastic elastomer.

Ethylene Interpolymer Alloy-Reinforced (EIA-R)—Sheets of EIA with an encapsulated fabric reinforcement layer.

Extrudate—The molten polymer which is emitted from an extruder during seaming using either extrusion fillet or extrusion flat methods. The polymer is initially in the form of a ribbon, rod, bead or pellets.

Extruder—A machine with a driver screw for continuous forming of polymeric compounds by forcing through a die; two types are used in the manufacturing of geomembranes, flat die and blown film.

Extrusion Seams—A seam of two geomembrane sheets achieved by heat-extruding a polymer material between or over the overlap areas followed by the application of pressure.

Fabricator—The organization that factory assembles rolls of geosynthetic materials into large panels for subsequent field deployment.

Fabric, Composite—A textile structure produced by combining nonwoven, woven, or knit manufacturing methods.

Fabric, Knit—A textile structure produced by interloping one or more ends of yarn or comparable material.

Fabric, Nonwoven—For geotextiles, a planar and essentially random textile structure produced by bonding, interlocking of fibers, or both, accomplished by mechanical, chemical, thermal, or solvent means, and combinations thereof.

Fabric, Reinforcement—A fabric, scrim, and so on, used to add structural strength to a two-or more ply polymeric sheet. Such geomembranes are referred to as being supported.

Fabric, Woven—A planar textile structure produced by interlacing two or more sets of elements, such as yarns, fibers, roving, or filaments, where the elements pass each other, usually at right angles and one set of elements are parallel to the fabric axis.

Factory Seams—The seaming of geomembrane rolls together in a factory to make large panels to reduce the number of field seams.

Field Seams—The seaming of geomembrane rolls or panels together in the field thereby making a continuous liner system.

Filament Yarn—The yarn made from continuous filament fibers.

Fill—As used in textile technology refers to the threads or yarns in a fabric running at right angles to the warp. Also called filler threads.

Filling Direction—See Direction, cross-machine. Note: For use with woven geotextiles only.

Film Tear Bond (FTB)—Description of a destructive geomembrane seam test (shear or peel) wherein the sheet on either side of the seam fails rather than delamination of the seam itself.

Filter Cloth—A deprecated term for geotextile.

Fines—Material passing through the No. 200 sieve (opennings of 0.075 mm)

Fishmouth—The uneven mating of two geomembranes to be joined wherein the upper sheet has excessive length that prevents it from being bonded flat to the lower sheet. The resultant opening is often referred to as a "fishmouth".

Flashing—The molten extrudate or sheet material which is extruded beyond the die edge or molten edge of a thermally bonded geomembrane seam, also called "squeeze-out".

Flat Die—An extrusion method for producing geomembranes whereby the molten polymer horizontally exists a flat die in the form of a wide sheet which is subsequently rolled onto cores.

Flexible Membrane Liner (FML)—Name previously given in EPA literature for the more generic term of geomembrane. The latter is used exclusively in this manual.

Flood Coating—The generous application of a bodied chemical compound, or chemical adhesive compound to protect exposed yarns in scrim reinforced geomembranes.

Formulation—The blending of several components (resin plus additives) to make a mixture for subsequent processing into a geosynthetic material.

Fully Crosslinked Elastomeric Alloy (FCEA)—A thermoplastic elastomeric alloy of polypropylene (PP) and ethylene-propylene diene monomer (EPDM).

Gage—Deprecated term for the thickness of a geosynthetic material.

General Contractor—The organization that is awarded a contract from the owner/operator to construct a waste containment facility.

Geocell—A three-dimensional structure filled with soil, thereby forming a mattress for increased bearing capacity and maneuverability on loose or compressible subsoils.

Geocomposite—A manufactured material using geotextiles, geogrids, geonets, and/or geomembranes in laminated or composite form.

Geogrid—A geosynthetic used for reinforcement which is formed by a regular network of tensile elements with apertures of sufficient size to allow strike-through of surrounding soil, rock, or other geotechnical materials..

Geomembrane—An essentially impermeable geosynthetic composed of one or more synthetic sheets.

Geonet—A geosynthetic consisting of integrally connected parallel sets of ribs overlying similar sets at various angles for planar drainage of liquids and gases.

Geosynthetic Clay Liner (GCL)—Factory manufactured, hydraulic barrier typically consisting of bentonite clay or other very low permeability material, supported by geotextiles and/or geomembranes which are held together by needling, stitching and/or chemical adhesives.

Geosynthetics—The generic term for all synthetic materials used in geotechnical engineering applications; the term includes geotextiles, geogrids, geonets, geomembranes, geosynthetic clay liners and geocomposites.

Geotechnical Engineering—The engineering application of geotechnics.

Geotechnics—The application of scientific methods and engineering principles to the acquisition, interpretation, and use of knowledge of materials of the earth's crust to the solution of engineering problems; it embraces the field of soil mechanics, rock mechanics, and many of the engineering aspects of geology, geophysics, hydrology, and related sciences.

Geotextile—A permeable geosynthetic comprised solely of textiles. Current manufacturing techniques produce nonwoven fabrics, knitted (non-tubular) fabrics, and woven fabrics.

Glacial Till—A soil of varied grain sizes deposited by glacial action.

Gravel—Material that will not pass through the openings of a No. 4 sieve (4.76 mm openings)

Grinding—The removal of oxide layers and waxes from the surface of a polyethylene sheet in preparation of extrusion fillet or extrusion flat seaming.

Gun—Synonymous term for hand held extrusion fillet device or hand held hot air device.

Haunch Area—The location of a buried pipe which extends for the lower 180° around the bottom outside of the pipe.

Heat Bonded—See Melt-bonded.

Heat-Seaming—The process of joining two or more thermoplastic geomembranes by heating areas in contract with each other to the temperature at which fusion occurs. The process is usually aided by a controlled pressure. In dielectric seaming the heat is induced by means of radio-frequency waves.

High Density Polyethylene (HDPE)—A polymer prepared by low-pressure polymerization of ethylene as the principal monomer and having the characteristics of ASTM D-1348 Type III and IV polyethylene. Such polymer resins have density greater than or equal to 0.941 g/cc as noted in ASTM D-1248.

Hook Blade—A shielded knife blade confined in such a way that the blade cuts upward or is drawn toward the person doing the cutting to avoid damage to underlying sheets.

Hydraulic Conductivity—The rate of discharge of water under laminar flow conditions through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions (20°C).

Initial Reaction Time—(See dwell time).

Installation Contractor—The organization that is awarded a subcontract from the general contractor or owner/operator, to install geosynthetic materials in the waste containment facility.

Kneading Compaction—Compaction of a soil liner whereby a foot or prong is repeatedly passed into and through a lift of soil.

Lacustrine Deposit—A soil deposited in a stagnent body of water, e.g., lake.

Lapped Seam—A seam made by placing one surface to be joined partly over another surface and bonding the overlapping portions.

Leachate—Liquid that has percolated through or drained from solid waste or other man-emplaced materials and contains soluble, partially soluble, or miscible components removed from such waste.

Let-Down—Term used for the addition of carbon black powder or concentrated pellets into an extruder in the manufacture of geosynthetic materials.

Lift—Term applied to the construction of a discrete layer of a soil liner, usually 150 to 225 mm (6 to 9 in.) in thickness.

Liner—A layer of emplaced materials beneath a surface impoundment or landfill which serves to restrict the escape of waste or its constituents from the impoundment or landfill. The term can apply to soil liners, geomembranes or geosynthetic clay liners.

Linear Low Density Polyethylene (LLDPE)—A polyethylene material produced by a low pressure polymerization process with random incorporation of comonomers to produce a density of 0.915 to 0.930 g/cc.

Liquid Limit (LL)—The water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil .

Manhole—A vertical pipe rising from a sump area through the waste mass and eventually penetrating the cover for the purpose of leachate removal.

Manufacturer—The organization that manufactures geosynthetic materials used at a waste containment facility.

Manufacturing Quality Assurance (MQA)—A planned system of activities that provide assurance that the materials were constructed as specified in the certification documents and contract plans. MQA includes manufacturing facility inspections, verifications, audits and evaluation of raw materials and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if the manufacturer is in compliance with the product certification and contract plans for a project.

Manufacturing Quality Control (MQC)—A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factor originated. MQC is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract plans.

Mass Per Unit Area—The proper term to represent and compare the amount of material per unit area (units are oz./yd.^{2} or g/m^2). Often called “weight” or “basis weight”.

Medium Density Polyethylene (MDPE)—A polymer prepared by low-pressure polymerization of ethylene as the principal monomer and having the characteristics of ASTM D-1348 Type II polyethylene. Such polymer resins have density less than 0.941 g/cc as noted in ASTM D-1248.

Melt-Bonded—Thermally bonded by melting the fibers to form weld points.

Membrane—A continuous sheet of material, whether prefabricated as a geomembrane or sprayed or coated in the field, as a sprayed-on asphalt/polymer mixture.

Minimum Average Roll Value (MARV)—A statistical value of a particular test property which embraces the 95% confidence level of all possible values of that property. For a normally distributed set of data it is approximately the mean value plus and minus two standard deviations.

Modified Compaction—A laboratory technique that produces maximum dry unit weights approximately equal to field dry units weights for soils that are well compacted using the heaviest compaction equipment available (ASTM D-1557).

Mouse—Synonymous term for hot wedge, or hot shoe, seaming device.

MQA/CQA Certifying Engineer—The individual who is responsible for certifying to the owner/operator and permitting agency that, in his or her opinion, the facility has been constructed in accord with the plans and specifications and MQA/CQA document approved by the permitting agency.

MQA/CQA Engineer—The individual who has overall responsibility for manufacturing quality assurance and construction quality assurance.

MQA/CQA Personnel—Those individuals responsible for making observations and performing field tests to ensure that the facility is constructed in accord with the plans and specifications approved by the permitting agency.

MQA/CQA Plan—A written plan, or document, prepared on behalf of the owner/operator which includes a detailed description of all MQA/CQA activities that will be used during materials manufacturing and construction to manage the installed quality of the facility.

Needle-Punched—A nonwoven geotextile which is mechanically bonded by needling with barbed needles.

NICET—An acronym for the National Institute for Certification in Engineering Technologies, an organization who administers examinations for geosynthetic and earthen materials for waste containment facilities. [NICET, 1420 King Street, Alexandria, VA 22314]

Nondestructive Test—A test method which does not require the removal of samples from, nor damage to, the installed liner system. The evaluation is done in an in-situ manner. The results do not indicate the seam's mechanical strength but are performed for examination for the seam's continuity.

Nonwoven—See Fabric, nonwoven.

Normal Direction—For geotextiles, the direction perpendicular to the plane of a geotextile.

Outliers—Experimental data points which do not fit into the anticipated and/or required maxima, or minima, specified values.

Owner/Operator—The organization that will own and operate the disposal unit.

Owner's Representative—The official representative who is responsible for coordinating schedules, meetings and field activities.

Oxide Layer—The reacting of atmospheric oxygen with the surface of a polymer geomembrane.

Padfoot Roller—Footed, or padded, roller typically consisting of 4.0 in. long pads used to compact soil liners.

Panels—The factory fabrication of geomembrane rolls into relatively large sections, or panels, so as to reduce the number of field seams.

Peel Test—A geomembrane seam test wherein the seam is placed in a tension state as the geomembrane ends are pulled apart.

Permeability—(1) The capacity of a porous medium to conduct or transmit fluid; (2) the amount of liquid moving through a barrier in a unit time, unit area, and unit gradient not normalized for, but directly related to, thickness. See Hydraulic Conductivity.

Permitting Agency—Often a state regulatory agency but may include local or regional agencies and/or other federal agencies.

Permittivity—For a geotextile, the volumetric flow rate of water per unit cross-section area, per unit head, under laminar flow conditions, in the normal direction through the fabric.

pH—A measure of the acidity or alkalinity of a solution; numerically equal to the logarithm of the reciprocal of the hydrogen ion concentration in gram equivalents per liter of solution. pH is represented on a scale of 0 to 14; 7 represents a neutral state; 0 represents the most acid, and 14 the most alkaline.

Pinholes—Very small imperfections in geomembranes which may allow for escape of the contained liquid.

Piping—The phenomenon of soil fines migrating out of a soil mass by flow of liquid leaving a small channel, or pipe, in the upstream soil mass.

Plastic—A material that contains as an essential ingredient one or more organic polymeric substances of large molecular weight which is solid in its finished state and at some stage in its manufacture or processing into finished articles can be shaped by flow [ASTM].

Plastic Index (PI)—The numerical difference between liquid and plastic limits, i.e., LL-PL.

Plastic Limit (PL)—The water content corresponding to the arbitrary limit between the plastic and solid states of consistency of a soil .

Plasticizer—A plasticizer is a material, frequently "solventlike," incorporated in a plastic or a rubber to increase its ease of workability, its flexibility, or distensibility. Adding the plasticizer may lower the melt viscosity, the temperature of the second-order transition, or the elastic modulus of the polymer. Plasticizers may be monomeric liquids (phthalate esters), low-molecular-weight liquid polymers (polyesters), or rubbery high polymers (EVA). The most important use of plasticizers in geosynthetics is with PVC geomembranes, where the choice of plasticizer will dictate under what conditions the liner may be used.

Plugging—The phenomenon of soil fines migrating into and clogging the voids of larger particle sized soils within a soil mass or geotextile filter.

Ply—Individual layer of material, usually sheet of geomembrane, which is laminated to another, or several, layers to form the complete geomembrane.

Ply Adhesion—The bonding force required to break the adhesive bond of one layer, or material, to another. It is usually evaluated by some type of tension peel test.

Polyester Fiber—Generic name for a manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of an ester of a dihydric alcohol and terephthalic acid.

Polyethylene (PE)—A polyolefin formed by bulk polymerization (for low density) or solution polymerization (for high density) where the ethylene monomer is placed in a reactor under high pressure and temperature. The oxygen produces free radicals which initiate the chain polymerization. For solution polymerization the monomer is first dissolved in an inert solvent. Catalysts are sometimes required to initiate the reaction.

Polymer—A macromolecular material formed by the chemical combination of monomers having either the same or different chemical composition. Plastics, rubbers, and textile fibers are all high-molecular-weight polymers.

Polymeric Liner—Plastic or rubber sheeting used to line disposal sites, pits, ponds, lagoons, canals, and so on.

Polyolefin—A family of polymeric materials that includes polypropylene and polyethylene, the former being very common in geotextiles, the latter in geomembranes. Many variations of each exist.

Polypropylene—A polyolefin formed by solution polymerization as was described for high density polyethylene.

Polyvinyl Chloride (PVC)—A synthetic thermoplastic polymer prepared from vinylchloride. PVC can be compounded into flexible and rigid forms through the use of plasticizers, stabilizers, fillers, and other modifiers; rigid forms used in pipes and well screens: flexible forms used in manufacture of geomembranes.

Pressure Rollers—Rollers accompanying a seaming technique which apply pressure to the opposing geomembrane sheets to be joined. They closely follow the actual melting process and are self-contained within the seaming device.

Pressurized Dual Seam—A thermal fusion method of making a geomembrane whereby a unbonded space is left between two parallel bonded tracks. The unbonded space is subsequently used for a nondestructive air pressure test.

Proctor Test—The tests utilized to obtain a laboratory compaction curve. Synonymous to compaction test.

Puckering—A heat related sign of localized strain caused by improper seaming using extrusion or fusion methods. It often occurs on the bottom of the lower geomembrane and in the shape of a shallow inverted "V".

Pugmill—A mechanical device used for mixing of dry soil materials.

Quality Assurance (QA)—A planned system of activities that provide assurance that the facility was constructed as specified in the design.

Quality Control (QC)—A planned system of inspections that are used to directly monitor and control the quality of a construction project.

Reclaim—Small pieces, or chips, of previously used polymer materials which are entered into the processing of a geosynthetic material,. Synonymous with "reprocess" and "recycle".

Record Drawings—Drawings which document the actual lines and grades and conditions of each component of the disposal unit. Synonymous with "as-built" drawings.

Regrind—Small pieces, or chips, of previously fabricated geosynthetic material which are re-entered into the processing of the same type of geosynthetic material, synonymous with "rework".

Residual Soil—Soil formed in place from weathering of parent rock.

Risers—Pipelines extending from primary or secondary leachate collection sumps up the sideslope of the facility and exiting to a shed or manhole.

Rolling Bank—A charge of molten polymer used in the calendering production method of geomembranes for the purpose of directing the flow of polymer in the desired roll direction.

Scrim Designation—The weight of number of yarns of fabric reinforcement per inch of length and width, e.g., a 10 × 10 scrim has 10 yarns per inch in both the machine and cross machine directions.

Scrim (or Fabric) Reinforcement—The fabric reinforcement layer used with some geomembranes for the purpose of increased strength and dimensional stability.

Sealant—A viscous chemical used to seal the exposed edges of scrim reinforced geomembranes. (Manufacturers and installers should be consulted for the various types of sealant used with specific geomembranes).

Sealed Double Ring Infiltrometer (SDRI)—A device used for measuring in-situ hydraulic conductivity of a test pad for a soil liner.

Seam Strength—Strength of a seam of liner material measured either in shear or peel modes. Strength of the seams is reported either in absolute units (e.g., pounds per inch of width) or as a percent of the strength of the geomembrane.

Seaming Boards—Smooth wooden planks placed beneath the area to be seamed to provide a uniform resistance to applied roller pressure in the fabrication of geomembrane seams.

Selvage—The longitudinal edges of woven geotextile in which the weft yarns fold back upon themselves. In fabric reinforced geomembranes selvage refers to edge of the rolls where no scrim is present.

Shear Test—A geomembrane seam test wherein the seam is placed in a shear state as the geomembrane ends are pulled apart.

Sheepsfoot Roller—Footed, or pronged, roller typically consisting of 8.0 in. long feet used to compact soil liners.

Sheeting—A form of plastic or rubber in which the thickness is very small in proportion to length and width and in which the polymer compound is present as a continuous phase throughout, with or without fabric, synonymous with geomembrane.

Shielded Blade—A knife within a housing which protects the blade from being used in an open fashion, i.e., a protected knife.

Slope—Deviation of a surface from the horizontal expressed as a percentage, by a ratio, or in degrees. In engineering, usually expressed as a percentage of vertical to horizontal change [EPA].

Slurry Wall—A construction technique whereby a vertical sided trench is supported by means of the hydrostatic pressure of a clay-water suspension ("slurry") placed within it.

Smectite—A group of expandable clay minerals with a very large ratio of surface area to mass, a large negative surface charge, a high cation exchange capacity, and a high shrink-swell potential.

Soil Liners—Low-hydraulic-conductivity materials constructed of earthen materials that usually contain a significant amount of clay.

Solvent, Bodied Solvent and Solvent Adhesive—See Chemical Fusion, Bodied Chemical Fusion and Chemical Adhesive.

Spotting—The final placement, or positioning, of a geomembrane roll or panel prior to field seaming.

Spread-Coating—A manufactured process whereby a polymeric material is spread in a continuous fashion on a geotextile substrate thereby forming a reinforced geomembrane composite.

Squeeze-Out—See "flashing".

Standard Compaction—A laboratory technique which produces maximum dry unit weights approximately equal to field dry unit weights for soil that are well compacted using modest-sized compaction equipment.

Staple—Short fibers in the range 0.5 to 3.0 in. (1 cm to 8 cm) long.

Staple Yarn—Yarn made from staple fibers.

Stinger—A long steel rod on the end of a front end loader or fork lift which is inserted into the core of a roll of geosynthetic material for the purpose of lifting and maneuvering.

Stress Crack— An external or internal crack in a plastic caused by tensile stresses less than its short-time mechanical strength. Note: The development of such cracks is frequently accelerated by the environment to which the plastic is exposed. The stresses which cause cracking may be present internally or externally or may be combinations of these stresses.

Strike-through—The penetration of one material into and/or through the openings of an adjacent planar material.

Substrate—The layer, or unit, that is immediately beneath the layer under consideration.

Sumps—A low area in a waste facility which gravitationally collects leachate from either the primary or secondary leachate collection system.

Superstrate—The layer, or unit, that is immediately above the layer under consideration.

Support Sheeting—See Fabric reinforcement.

Tack—Stickiness of a geomembrane or the temporarily welding of geomembranes together.

Tenacity—The fiber strength on a grams per denier basis.

Tensiometer—A field measuring device containing a set of opposing grips used to place a geomembrane sheet or seam in tension for evaluating its strength.

Testing Laboratory—The testing laboratory(s) providing testing services to verify physical, mechanical, hydraulic or endurance properties of the materials used to construct the waste containment facility.

Test Pads—Prototype layer or layers of soil materials constructed for the purpose of simulating construction conditions and/or measuring performance characteristics. Test pads are most frequently used to verify that the materials and methods of construction proposed for a soil liner will lead to development of the desired low hydraulic conductivity.

Test Strips—Trial sections of seamed geomembranes used (1) to establish machine settings of temperature, pressure and travel rate for a specific geomembrane under a specific set of atmospheric conditions for machine-assisted seaming and (2) to establish methods and materials for chemical and chemical adhesive seams under a specific set of atmospheric conditions.

Test Welds—See "test strips".

Tex—Denier multiplied by 9 and is the weight in grams of 1000 m of yarn.

Textured Sheet—Polyethylene geomembranes which are produced with a roughened surface via coextrusion, impingement or lamination so as to create a high friction surface(s).

Thermal Fusion—The temporary, thermally-induced reorganization in the polymeric make-up of the surface of a polymeric geomembrane that, after the application of pressure and the passage of a certain amount of time, results in the two geomembranes being permanently joined together.

Thermoplastic Polymer—A polymer that can be heated to a softening point, shaped by pressure, and cooled to retain that shape. The process can be done repeatedly.

Thermoset Polymer—A polymer that can be heated to a softening point, shaped by pressure, and, if desired, removed from the hot mold without cooling. The process cannot be repeated since the polymer cannot be resoftened by the application of heat.

Trampolining—The lifting of a geomembrane off of its subbase material due to thermal contraction and inadequate slack which can occur at the toe of slope or in corners of a facility.

Transmissivity—For a geotextile, the volumetric flow rate per unit thickness under laminar flow conditions, within the in-plane direction of the fabric.

Transverse Direction—A deprecated term for cross-machine direction.

Tremie—A method of hydraulic placement of soil, or other material, under a head of water.

Ultraviolet Degradation—The breakdown of polymeric structure when exposed to natural light.

Unsupported Geomembrane—A polymeric geomembrane consisting of one or more piles without a reinforcing-fabric layer or scrim.

Vacuum Box—A commonly used type of nondestructive test method which develops a vacuum in a localized region of a geomembrane seam in order to evaluate the seam's tightness and suitability.

Veneer Reinforcement—Geogrid or geotextile reinforcement layer(s) which placed in the soil covering a geomembrane for the purpose of side slope stabilization.

Very Low Density Polyethylene (VLDPE)—A linear polymer of ethylene with other alpha-olefins with a density of 0.890 to 0.912 g/cc.

Virgin Ingredients—Components of a geosynthetic formulation which have never been used in a prior formulation or product.

Warp—In textiles, the lengthwise yarns in a woven fabric.

Waxes—The low molecular weight components of some polyethylene compounds which migrate to the surface over time and must be removed by grinding (for polyethylene) or be mixed into the melt zone using thermal seaming methods.

Weft—A deprecated term for cross-machine direction.

Wicking—The phenomenon of liquid transmission within the fabric yarns of reinforced geomembranes via capillary action.

Width—For a geotextile, the cross-direction edge-to-edge measurement of a fabric in a relaxed condition on a flat surface.

Woof—A deprecated term for cross-machine direction.

Woven—See Fabric, woven.

Woven, Monofilament—The woven geotextile produced with monofilament yarns.

Woven, Multifilament—The woven geotextile produced with multifilament yarns.

Woven, Slit-Film—The woven fabric produced with yarns produced from slit film.

Woven, Split-Film—See Woven, slit-film.

Yarn—A generic term for continuous strands of textile fibers or filaments in a form suitable for knitting, weaving, or otherwise intertwining to form a textile fabric. Yarn may refer to (1) a number of fibers twisted together, (2) a number of filaments laid together without twist (a zero-twist yarn), (3) a number of filaments laid together with more or less twist, or (4) a single filament with or without twist (a monofilament).

Zero Air Voids Curve—A curve that relates dry unit weight to water content for a saturated soil that contains no air.

Appendix C

Index

*U.S. GOVERNMENT PRINTING OFFICE 1993 -750 -002 /80296

Available Companion Document of Standards

To

Quality Control and Quality Assurance for Waste Containment Facilities,
EPA/600/R-93/182

A compilation of standards referenced in this document (*Quality Control and Quality Assurance for Waste Containment Facilities*, EPA/600/R-93/182) is available from The American Society for Testing and Materials (ASTM). It is intended as a companion for this document and for engineers and researchers who are involved with quality assurance and quality control practices concerning all components of waste containment.

The ASTM document is entitled *ASTM and other Specifications and Test Methods on the Quality Assurance of Landfill Liner Systems*, and is identified by the following numbers:

Publication Code Number (PCN): 03-435193-38
International Standard Book Number (ISBN): 0-8031-1784-1

It contains 79 ASTM standards and 10 non-ASTM references that are cited in the EPA guidance document, consists of approximately 500 pages, and has a soft cover. The first printing in late 1993 is available at the following prices:

ASTM-member price: $69.00, non-member price: $77.00
Quantity discounts of the *same* publication are available.

ASTM Document Ordering Instructions:

Contact:

ASTM Publications
1916 Race Street
Philadelphia, Pennsylvania, 19103
USA

Telephone: (215) 299-5585
Facsimile: (215) 977-9679

1) List each publication by quantity, Publication Code Number (PCN as listed above), title and price.

2) Add any additional handling charges to subtotal of order:

	USA and Canada	All other countries
Prepaid	No charge	10% ($1.50 minimum)
Bill/Ship	7% ($1.50 minimum)	15% ($1.50 minimum)

3) Residents of Canada, and Pennsylvania and Maryland in the USA, please add applicable sales tax to your order.

4) Unless indicated otherwise, all orders will be shipped fourth class.

Please note: This companion document is offered by ASTM entirely independent of U.S. EPA, hence no credit for its development or responsibility can be assumed for the use of its contents. This page is for information only and does not constitute endorsement.
Prices are subject to change without notice.

R2070, October, 1993

ATTACHMENT E

Eco-profiles of the European Plastics Industry
High Density Polyethylene (HDPE)

PlasticsEurope
Association of Plastics Manufacturers

Eco-profiles of the European Plastics Industry

HIGH DENSITY POLYETHYLENE (HDPE)

A report by

I Boustead

for

Plastics*Europe*

Data last calculated

March 2005

IMPORTANT NOTE

Before using the data contained in this report, you are strongly recommended to look at the following documents:

1. Methodology

This provides information about the analysis technique used and gives advice on the meaning of the results.

2. Data sources

This gives information about the number of plants examined, the date when the data were collected and information about up-stream operations.

In addition, you can also download data sets for most of the upstream operations used in this report. All of these documents can be found at: www.plasticseurope.org.

Plastics*Europe* may be contacted at

Ave E van Nieuwenhuyse 4
Box 3
B-1160 Brussels

Telephone: 32-2-672-8259
Fax: 32-2-675-3935

CONTENTS

OLEFIN POLYMERS

High density polyethylene (HDPE) is one of the olefin polymers and it is useful to examine briefly the four major olefin polymers because it highlights the differences between them and indicates why these different polymers are produced. The polymers are shown in Table 1.

Table 1
Large tonnage polyolefins produced in Europe in 1999.

Polymer	Acronym	Production ('000 tonne)[1]
Low density polyethylene	LDPE	4793
High density polyethylene	HDPE	4308
Linear low density polyethylene	LLDPE	1934
Polypropylene	PP	7395

The polyolefins are chemically the simplest of all polymer structures. They can be produced commercially from olefin (alkene) monomers because the olefins contain a reactive double bond. Schematically the process of converting monomer to polymer is illustrated in Figure 1 for ethylene. Essentially the double bond in the ethylene molecule is opened to form a reactive *radical,* which then attaches itself to another radical. The process repeats itself to produce a long chain molecule or polymer terminating only when the propagating radical attaches itself to an unreactive species.[2] The starting material, ethylene, is called the *monomer* and the final compound consisting of many thousands of ethylene units is called the *polymer.*[3]

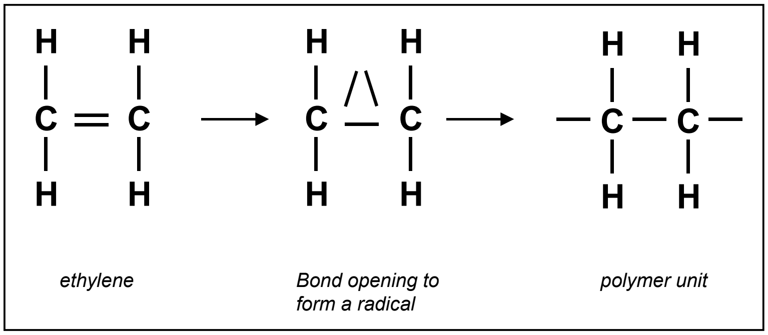


Figure 1
Schematic diagram of the formation of polyethylene.

---

[1] APME Annual Report 2001.

[2] The actual polymerisation process is somewhat more complex than this but the concept of opening the double bond is a useful way to think of addition polymerisation.

[3] The terms *monomer* and *polymer* are due to Berzelius (1830) from the Greek: poly = many; meros = part; mono = single or alone

Such polymers are often referred to as *addition polymers* because they are formed by continually adding further monomer units to the growing polymer chain and the polymerisation mechanism is known as *free radical polymerisation*.[4]

CHARACTERISTICS OF OLEFIN POLYMERS

All olefin polymers have an unbroken carbon backbone and in its simplest form the structure of polyethylene is schematically of the form shown in Figure 2. (Polyethylene with this highly linear structure is often referred to as polymethylene).

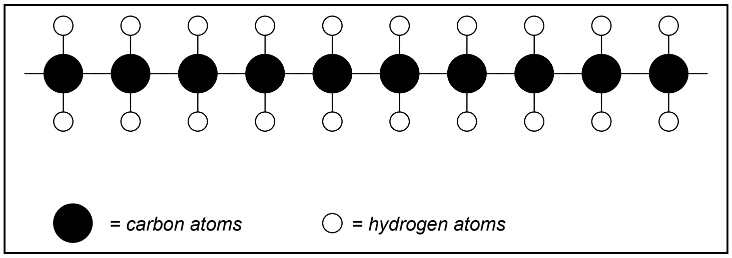


Figure 2
Schematic structure of linear polyethylene

When a highly regular polymer such as that shown in Figure 2 is cooled from the melt, the polymer chains do not remain as a random tangle. Instead they tend to fold and lie alongside each other as shown in Figure 3.

These ordered regions inside polymer solids behave as crystalline regions. However, unlike atomic crystals, the whole of the long molecules cannot be incorporated into these ordered regions and so there will always be regions where the molecules are randomly arranged. These are amorphous regions. Because of the closer packing in the crystalline regions, their density is higher (~ 1000 kg m^{-3}) than the amorphous regions (~850 kg m^{-3}). Thus the higher the density of a specified polymer type, the greater the crystallinity.

The amount of crystallinity in a polymer directly affects the properties because the crystalline regions exhibit superior mechanical properties and for most applications the higher the crystallinity the better.

---

[4] All addition polymers rely on the opening of a double bond to form the polymer backbone and this concept presents a useful way of determining polymer structures once the structural formula of the monomer is known.

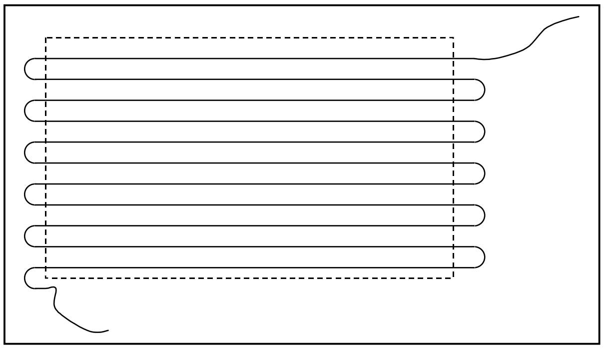


Figure 3
Chain folding in regular polymers. The region inside the broken line is regarded as a polymer crystal.

A critical factor in promoting the formation of crystalline regions in polymers is the regularity of the polymer chains. In practice, when ethylene is polymerised it does not form a simple linear chain of the type shown in Figure 2. Instead, it grows side branches. These side branches may be short (up to 8 carbon atoms) or very long (up to several thousand carbon atoms). Short, irregularly positioned side branches of different length tend to inhibit crystal formation but long side branches can usually be incorporated into the crystalline regions. The production technology determines the number, positioning and length of the side branches.

HISTORICAL BACKGROUND

The first record of polyolefin production was in 1898 when von Pechmann in Germany produced the first polymethylene structure in the laboratory. It was not, however, until 1935 that Perrin at ICI showed that it was possible to produce large quantities of low density polyethylene by subjecting ethylene to pressures up to 350 MPa and temperatures up to 350°C. This process was developed commercially and production of LDPE started in 1938 in the UK.

In 1950, Hogan and Bank at Phillips Petroleum Co invented a catalyst containing chromium oxide on silica that allowed polymerisation at lower pressures (3 – 4 MPa) and temperatures (70 - 100°C). These Phillips catalysts were used to produce the first HDPE.

In 1953, Ziegler in Germany developed catalysts containing titanium halides and alkylaluminium which promoted polymerisation at atmospheric pressure and temperatures of 50 - 100°C. By adjusting the precise composition of the catalyst, he found that it was possible to obtain a wide range of polyethylenes that could be used in different applications. In 1954, Natta at Montecatini modified the Ziegler catalysts to produce isotactic polypropylene and commercial production of polypropylene started in 1957.

During the period 1956-1976 considerable research by Phillips, Solvay, Montedison and Mitsui Petrochemical went into different catalyst systems with the aim of obtaining high yield isotactic polypropylene.

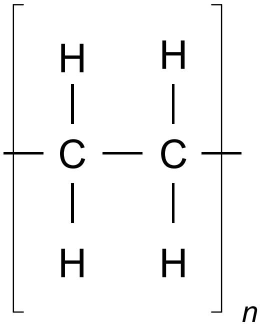
In 1976, Kaminsky and Sunn developed a new family of catalysts which allowed the production of ethylene polymers and copolymers and controlled the regularity of the chain branching. These were the catalysts that allowed the first commercial production of LLDPE.

As this brief history shows, most of the research in this area has been concerned with catalysts which achieve two main factors: obtaining more benign production conditions and producing polymers with more controlled structures.

POLYETHYLENE

Low density polyethylene

The repeat unit of polyethylene is:



$$\left[- \overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}} - \overset{\displaystyle H}{\underset{\displaystyle H}{\overset{|}{\underset{|}{C}}}} - \right]_n$$

Low density polyethylene (LDPE) has traditionally been defined as polyethylene with a density less than 940 kg m^{-3}. It is produced by a high pressure process and so is often referred to as high pressure polyethylene. The polymer contains both long and short chain side branching with the number of branches being from 2 and 50 per 1000 carbon atoms on the carbon backbone. LDPE can be produced with chain lengths ranging from 50,000 to 100,000 repeat units, with crystallinities in the range 35 to 75% and with densities in the range 915 to 940 kg m^{-3}.

High density polyethylene

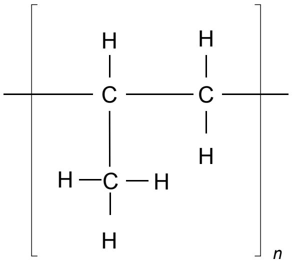
High density polyethylene (HDPE) has the same repeat unit as LDPE and is usually regarded as polyethylene with a density greater than 940 kg m^{-3}. It is produced in low pressure reactors and so is often referred to as low pressure polyethylene. It differs from LDPE in that it contains fewer side branches at 5 to 10 per 1000 carbon atoms on the backbone. Most of the side branches are short with long side branches being rare. Molecular weights are similar to low density polyethylene but crystallinities are usually high (50 – 85%) and densities range from 940 to 960 kg m^{-3}.

Linear low density polyethylene

Linear low density polyethylene (LLDPE) is a copolymer of ethylene with another short chain olefin. The most common co-monomers are 1-butene, 1-hexene, 4-methyl-1-pentene and 1-octene. The comonomer is usually present in concentrations of 2.5 to 3.5% and this results in densities in the range 915 to 925 kg m^{-3} with crystallinities of 30 to 45%. The range of molecular weights of LLDPE are considerably narrower than for LDPE and HDPE; typically they lie in the range 50,000 to 200,000.

POLYPROPYLENE

The repeat unit for polypropylene is:



The CH_3 side group can be arranged in three different ways in polypropylene and the three possibilities are shown in Figure 4. In *isotactic polypropylene*, the methyl side groups all lie on the same side of the polymer chain. In three dimensions, the polymer chain forms a helix and can fold to form crystalline regions similar to Figure 3. These crystalline regions have a density of 936 kg m^{-3} In *syndiotactic polypropylene*, the methyl side groups are arranged regularly on alternate side of the polymer chain. In three dimensions, syndiotactic polypropylene also forms a helical structure although it is more open that the isotactic form and so, although it too can fold to form crystalline regions, the crystal density is lower at 910 kg m^{-3}. In *atactic polypropylene*, the methyl side groups are randomly arranged on either side of the chain. The resultant structure is amorphous. Of the three forms, isotactic has the most superior properties and so manufacture aims to maximise this form. Some atactic polymer is invariably produced in small quantities and this is often used as a waterproof mastic.

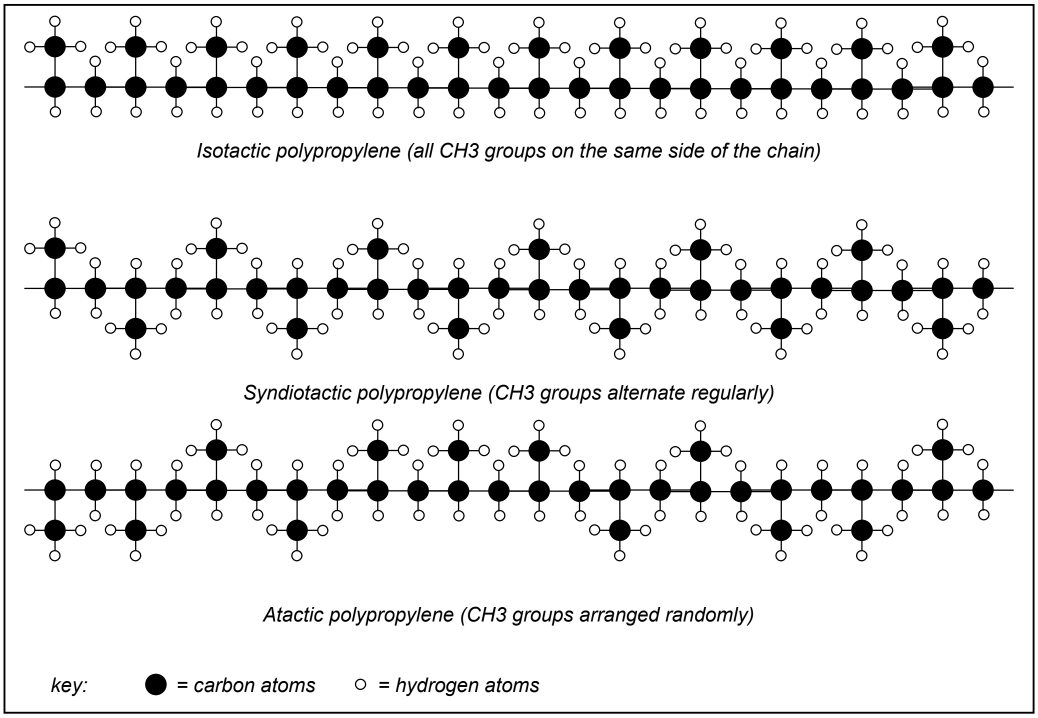


Figure 4
Different types of polypropylene depending on the arrangement of the methyl side group.

PRODUCTION PROCESSES

Three main techniques are employed in the production of polyolefins: high pressure technology, solution or slurry processes and gas phase polymerisation.

High pressure technology

When monomer is held at high pressures and temperatures above the polymer melting point, the monomer/polymer mixture can act as a polymerisation medium. Initiators and catalysts can be added to this medium. This technology is used only for LDPE and employs pressures up to 300 MPa[5] and temperatures up to 300°C.

There are two major problems with this type of technology. The first is the obvious one of handling materials under such high pressures and the second is that of temperature control. Two types of reactor are used to solve these problems. The *stirred autoclave* is essentially a cylindrical, thick-walled reaction vessel stirred by paddles. Because of the very thick walls needed to withstand the pressure, external heat extraction is not possible and temperature is controlled using the monomer as a heat sink. The residence time is usually less than a minute and the conversion per pass is usually less than 20%. Unreacted monomer is cooled and reused. In the *tubular reactor*, the monomer is passed along the inner of a pair of concentric tubes. Coolant passes between the inner and outer tubes. Conversion rates per pass are up to 35% and again, unreacted monomer is recovered for reuse.

Solution/slurry polymerisation

Many low molecular weight, saturated hydrocarbons will dissolve polyolefins. If the temperature is higher than the melting point of the polymer and the concentration of the polymer is low, the polymer will remain as a true solution. However, at lower temperatures and higher concentrations, the polymer will form a suspension or mobile slurry. Using solutions or slurries as the polymerisation medium requires relatively low temperatures (70 - 110°C) and relatively low pressures (1 – 5 MPa).

Reaction vessels can be either stirred tank reactors using solvents such as hexane or closed loop, cooled pipe reactors using solvents such as isopentane. In slurry reactors, the slurry concentration is usually maintained at ~25% and settling chambers at the base of the reactor allow polymer to be removed continuously. The recovered solvent is reused and conversions can be as high as 98%.

Gas phase polymerisation

A gas phase reactor is essentially a fluidised bed of dry polymer particles maintained either by stirring or by passing gas at high speeds through it. Pressures are usually relatively low at ~2MPa and temperatures are usually in the range 70 - 110°C. A variety of different configurations are used mainly to obtain an acceptable particle size and shape in the final product. Gas phase polymerisation is used for HDPE, PP and LLDPE.

---

[5] To put these pressures in perspective, 1 atmosphere pressure is approximately 0.101MPa

ECO-PROFILE OF HIGH DENSITY POLYETHYLENE

Data have been obtained for the production of 3.87 million tonnes of HDPE. This represents 89.7% of all West European production. The average gross energy required to produce 1 kg of high density polyethylene is 76 MJ with a range extending from 56 MJ to 91 MJ. Table 2 shows the breakdown of this gross energy and Table 3 gives these same data expressed in terms of primary fuels. Table 4 shows the energy data expressed as masses of fuels. Table 5 shows the raw materials requirements and Table 6 shows the demand for water. Table 7 shows the gross air emissions and Table 8 shows the corresponding carbon dioxide equivalents of these air emissions. Table 9 gives the emissions to water. Table 10 shows the gross solid waste generated and Table 11 gives this solid waste in EU format.

Table 2

Gross energy required to produce 1 kg of high density polyethylene. (Totals may not agree because of rounding)

Fuel type	Fuel prod'n & delivery energy (MJ)	Energy content of delivered fuel (MJ)	Energy use in transport (MJ)	Feedstock energy (MJ)	Total energy (MJ)
Electricity	5.96	2.45	0.58	-	8.98
Oil fuels	0.24	7.39	0.11	32.09	39.82
Other fuels	0.26	5.39	0.02	22.23	27.91
Totals	6.47	15.22	0.70	54.32	76.71

Table 3
Gross primary fuels required to produce 1 kg of high density polyethylene. (Totals may not agree because of rounding)

Fuel type	Fuel prod'n & delivery energy (MJ)	Energy content of delivered fuel (MJ)	Fuel use in transport (MJ)	Feedstock energy (MJ)	Total energy (MJ)
Coal	1.48	1.24	0.19	<0.01	2.90
Oil	0.88	7.66	0.20	32.09	40.83
Gas	1.52	6.46	0.17	22.23	30.39
Hydro	0.33	0.25	<0.01	-	0.58
Nuclear	2.07	0.93	0.13	-	3.13
Lignite	<0.01	<0.01	<0.01	-	<0.01
Wood	<0.01	<0.01	<0.01	<0.01	<0.01
Sulphur	<0.01	<0.01	<0.01	<0.01	<0.01
Biomass (solid)	0.05	0.03	<0.01	<0.01	0.09
Hydrogen	<0.01	<0.01	<0.01	-	<0.01
Recovered energy	<0.01	-1.40	<0.01	-	-1.40
Unspecified	<0.01	<0.01	<0.01	-	<0.01
Peat	0.01	0.01	<0.01	-	0.02
Geothermal	0.02	0.01	<0.01	-	0.03
Solar	<0.01	<0.01	<0.01	-	<0.01
Wave/tidal	<0.01	<0.01	<0.01	-	<0.01
Biomass (liquid/gas)	0.03	0.01	0.01	-	0.05
Industrial waste	0.02	0.01	<0.01	-	0.03
Municipal Waste	0.04	0.02	<0.01	-	0.06
Wind	0.01	0.01	<0.01	-	0.02
Totals	6.47	15.22	0.70	54.32	76.71

Table 4
Gross primary fuels used to produce 1 kg of high density polyethylene expressed as mass.

Fuel type	Input in mg
Crude oil	910000
Gas/condensate	580000
Coal	100000
Metallurgical coal	70
Lignite	3
Peat	1900
Wood	2

Table 5
Gross raw materials required to produce 1 kg of high density polyethylene.

Raw material	Input in mg
Air	260000
Animal matter	<1
Barytes	<1
Bauxite	5
Bentonite	33
Biomass (including water)	16000
Calcium sulphate (CaSO4)	3
Chalk (CaCO3)	<1
Clay	<1
Cr	<1
Cu	<1
Dolomite	2
Fe	170
Feldspar	<1
Ferromanganese	<1
Fluorspar	<1
Granite	<1
Gravel	1
Hg	<1
Limestone (CaCO3)	130
Mg	<1
N2	170000
Ni	<1
O2	3
Olivine	2
Pb	1
Phosphate as P2O5	<1
Potassium chloride (KCl)	<1
Quartz (SiO2)	<1
Rutile	<1
S (bonded)	<1
S (elemental)	52
Sand (SiO2)	84
Shale	9
Sodium chloride (NaCl)	350
Sodium nitrate (NaNO3)	<1
Talc	<1
Unspecified	<1
Zn	15

Table 6
Gross water consumption required for the production of 1 kg of high density polyethylene. (Totals may not agree because of rounding)

Source	Use for processing (mg)	Use for cooling (mg)	Totals (mg)
Public supply	1800000	160000	1900000
River canal	970000	59000	1000000
Sea	130000	11000000	11000000
Well	95000	<1	95000
Unspecified	430000	17000000	18000000
Totals	3400000	29000000	32000000

Table 7
Gross air emissions associated with the production of 1 kg of high density polyethylene. (Totals may not agree because of rounding)

Emission	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	From biomass (mg)	From fugitive (mg)	Totals (mg)
dust (PM10)	310	74	2	250	-	-	640
CO	1300	11000	21	490	-	-	12000
CO2	420000	950000	8800	190000	-2	-	1600000
SOX as SO2	2100	1400	140	510	-	-	4100
H2S	<1	-	<1	<1	-	-	<1
mercaptan	<1	<1	<1	<1	-	-	<1
NOX as NO2	1500	1500	56	170	-	-	3200
NH3	<1	-	<1	<1	-	-	<1
Cl2	<1	<1	<1	<1	-	-	<1
HCl	42	20	<1	<1	-	-	62
F2	<1	<1	<1	<1	-	-	<1
HF	2	<1	<1	<1	-	-	2
hydrocarbons not specified	740	83	17	3300	-	<1	4100
aldehyde (-CHO)	<1	-	<1	<1	-	-	<1
organics	<1	<1	<1	60	-	-	60
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Hg+compounds as Hg	<1	-	<1	<1	-	-	<1
metals not specified elsewhere	<1	1	<1	1	-	-	2
H2SO4	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	<1	-	-	<1
H2	40	<1	<1	2	-	-	41
dichloroethane (DCE) C2H4Cl2	<1	-	<1	<1	-	<1	<1
vinyl chloride monomer (VCM)	<1	-	<1	<1	-	<1	<1
CFC/HCFC/HFC not specified	<1	-	<1	1	-	-	1
organo-chlorine not specified	<1	-	<1	<1	-	-	<1
HCN	<1	-	<1	<1	-	-	<1
CH4	9900	240	<1	4100	-	<1	14000
aromatic HC not specified elsewhere	<1	-	<1	85	-	<1	86
polycyclic hydrocarbons (PAH)	<1	<1	<1	<1	-	-	<1
NMVOC	<1	-	<1	150	-	-	150
CS2	<1	-	<1	<1	-	-	<1
methylene chloride CH2Cl2	<1	-	<1	<1	-	-	<1
Cu+compounds as Cu	<1	<1	<1	<1	-	-	<1
As+compounds as As	-	-	-	<1	-	-	<1
Cd+compounds as Cd	<1	-	<1	<1	-	-	<1
Ag+compounds as Ag	-	-	-	<1	-	-	<1
Zn+compounds as Zn	<1	-	<1	<1	-	-	<1
Cr+compounds as Cr	<1	<1	<1	<1	-	-	<1
Se+compounds as Se	-	-	-	<1	-	-	<1
Ni+compounds as Ni	<1	<1	<1	<1	-	-	<1
Sb+compounds as Sb	-	-	<1	<1	-	-	<1
ethylene C2H4	-	-	<1	2	-	-	2
oxygen	-	-	-	<1	-	-	<1
asbestos	-	-	-	<1	-	-	<1
dioxin/furan as Teq	-	-	-	<1	-	-	<1
benzene C6H6	-	-	-	<1	-	<1	<1
toluene C7H8	-	-	-	<1	-	<1	<1
xylenes C8H10	-	-	-	<1	-	<1	<1
ethylbenzene C8H10	-	-	-	<1	-	<1	<1
styrene	-	-	-	<1	-	<1	<1
propylene	-	-	-	1	-	-	1

Table 8
Carbon dioxide equivalents corresponding to the gross air emissions for the production of 1 kg of high density polyethylene. (Totals may not agree because of rounding)

Type	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	From biomass (mg)	From fugitive (mg)	Totals (mg)
20 year equiv	1000000	990000	8900	450000	-2	<1	2500000
100 year equiv	650000	980000	8900	290000	-2	<1	1900000
500 year equiv	490000	970000	8900	230000	-2	<1	1700000

Table 9

Gross emissions to water arising from the production of 1 kg of high density polyethylene. (Totals may not agree because of rounding).

Emission	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	Totals (mg)
COD	1	-	<1	190	190
BOD	<1	-	<1	21	21
Pb+compounds as Pb	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	<1	<1
Na+compounds as Na	<1	-	<1	77	77
acid as H+	1	-	<1	1	2
NO3-	<1	-	<1	2	2
Hg+compounds as Hg	<1	-	<1	<1	<1
metals not specified elsewhere	<1	-	<1	7	7
ammonium compounds as NH4+	1	-	<1	2	3
Cl-	<1	-	<1	160	160
CN-	<1	-	<1	<1	<1
F-	<1	-	<1	<1	<1
S+sulphides as S	<1	-	<1	<1	<1
dissolved organics (non-	<1	-	<1	10	10
suspended solids	26	-	3	170	200
detergent/oil	<1	-	<1	6	6
hydrocarbons not specified	4	<1	<1	<1	4
organo-chlorine not specified	<1	-	<1	<1	<1
dissolved chlorine	<1	-	<1	<1	<1
phenols	<1	-	<1	2	2
dissolved solids not specified	<1	-	<1	21	21
P+compounds as P	<1	-	<1	<1	<1
other nitrogen as N	<1	-	<1	1	1
other organics not specified	<1	-	<1	<1	<1
SO4--	<1	-	<1	830	830
dichloroethane (DCE)	<1	-	<1	<1	<1
vinyl chloride monomer (VCM)	<1	-	<1	<1	<1
K+compounds as K	<1	-	<1	1	1
Ca+compounds as Ca	<1	-	<1	3	3
Mg+compounds as Mg	<1	-	<1	<1	<1
Cr+compounds as Cr	<1	-	<1	<1	<1
ClO3--	<1	-	<1	<1	<1
BrO3--	<1	-	<1	<1	<1
TOC	<1	-	<1	11	11
AOX	<1	-	<1	<1	<1
Al+compounds as Al	<1	-	<1	1	1
Zn+compounds as Zn	<1	-	<1	<1	<1
Cu+compounds as Cu	<1	-	<1	<1	<1
Ni+compounds as Ni	<1	-	<1	<1	<1
CO3--	-	-	<1	29	29
As+compounds as As	-	-	<1	<1	<1
Cd+compounds as Cd	-	-	<1	<1	<1
Mn+compounds as Mn	-	-	<1	<1	<1
organo-tin as Sn	-	-	<1	<1	<1
Sr+compounds as Sr	-	-	<1	<1	<1
organo-silicon	-	-	-	<1	<1
benzene	-	-	-	<1	<1
dioxin/furan as Teq	-	-	<1	<1	<1

Table 10
Gross solid waste associated with the production of 1 kg of high density polyethylene. (Totals may not agree because of rounding)

Emission	From fuel prod'n (mg)	From fuel use (mg)	From transport (mg)	From process (mg)	Totals (mg)
Plastic containers	<1	-	<1	<1	<1
Paper	<1	-	<1	<1	<1
Plastics	<1	-	<1	630	630
Metals	<1	-	<1	<1	<1
Putrescibles	<1	-	<1	<1	<1
Unspecified refuse	990	-	<1	<1	990
Mineral waste	24	-	33	140	190
Slags & ash	7600	850	13	840	9400
Mixed industrial	-270	-	1	1100	860
Regulated chemicals	1200	-	<1	820	2000
Unregulated chemicals	910	-	<1	2000	2900
Construction waste	<1	-	<1	<1	<1
Waste to incinerator	<1	-	<1	870	870
Inert chemical	<1	-	<1	720	720
Wood waste	<1	-	<1	<1	<1
Wooden pallets	<1	-	<1	<1	<1
Waste to recycling	<1	-	<1	4500	4500
Waste returned to mine	20000	-	1	51	20000
Tailings	1	-	1	60	62
Municipal solid waste	-5500	-	-	<1	-5500
Note: Negative values correspond to consumption of waste e.g. recycling or use in electricity generation.					

Table 11
Gross solid waste in EU format associated with the production of 1 kg of high density polyethylene. Entries marked with an asterisk (*) are considered hazardous as defined by EU Directive 91/689/EEC

Emission	Totals (mg)
010101 metallic min'l excav'n waste	140
010102 non-metal min'l excav'n waste	20000
010306 non 010304/010305 tailings	2
010308 non-010307 powdery wastes	2
010399 unspecified met. min'l wastes	1
010408 non-010407 gravel/crushed rock	<1
010410 non-010407 powdery wastes	<1
010411 non-010407 potash/rock salt	1
010499 unsp'd non-met. waste	<1
010505*oil-bearing drilling mud/waste	1200
010508 non-010504/010505 chloride mud	910
010599 unspecified drilling mud/waste	990
020107 wastes from forestry	<1
050106*oil ind. oily maint'e sludges	3
050107*oil industry acid tars	210
050199 unspecified oil industry waste	190
050699 coal pyrolysis unsp'd waste	16
060101*H2SO4/H2SO3 MFSU waste	<1
060102*HCl MFSU waste	<1
060106*other acidic MFSU waste	<1
060199 unsp'd acid MFSU waste	<1
060204*NaOH/KOH MFSU waste	<1
060299 unsp'd base MFSU waste	<1
060313*h. metal salt/sol'n MFSU waste	1
060314 other salt/sol'n MFSU waste	<1
060399 unsp'd salt/sol'n MFSU waste	3
060404*Hg MSFU waste	<1
060405*other h. metal MFSU waste	<1
060499 unsp'd metallic MFSU waste	<1
060602*dangerous sulphide MFSU waste	<1
060603 non-060602 sulphide MFSU waste	<1
060701*halogen electrol. asbestos waste	<1
060702*Cl pr. activated C waste	<1
060703*BaSO4 sludge with Hg	<1
060704*halogen pr. acids and sol'ns	<1
060799 unsp'd halogen pr. waste	<1
061002*N ind. dangerous sub. waste	<1
061099 unsp'd N industry waste	<1
070101*organic chem. aqueous washes	<1
070103*org. halogenated solv'ts/washes	<1
070107*hal'd still bottoms/residues	<1
070108*other still bottoms/residues	7
070111*org. chem. dan. eff. sludge	<1
070112 non-070111 effluent sludge	<1
070199 unsp'd organic chem. waste	13
070204*polymer ind. other washes	<1

continued over …..

Table 11 - continued
Gross solid waste in EU format associated with the production of 1 kg of high density polyethylene. Entries marked with an asterisk (*) are considered hazardous as defined by EU Directive 91/689/EEC

070207*polymer ind. hal'd still waste	<1
070208*polymer ind. other still waste	3000
070209*polymer ind. hal'd fil. cakes	<1
070213 polymer ind. waste plastic	3800
070214*polymer ind. dan. additives	1400
070215 non-0702130 additive waste	130
070216 polymer ind. silicone wastes	<1
070299 unsp'd polymer ind. waste	1200
080199 unspecified paint/varnish waste	<1
100101 non-100104 ash, slag & dust	8200
100102 coal fly ash	1000
100104*oil fly ash and boiler dust	<1
100105 FGD Ca-based reac. solid waste	<1
100113*emulsified hyrdocarbon fly ash	<1
100114*dangerous co-incin'n ash/slag	46
100115 non-100115 co-incin'n ash/slag	3
100116*dangerous co-incin'n fly ash	<1
100199 unsp'd themal process waste	<1
100202 unprocessed iron/steel slag	52
100210 iron/steel mill scales	4
100399 unspecified aluminium waste	<1
100501 primary/secondary zinc slags	<1
100504 zinc pr. other dust	<1
100511 non-100511 Zn pr. skimmings	<1
101304 lime calcin'n/hydration waste	5
130208*other engine/gear/lub. oil	<1
150101 paper and cardboard packaging	<1
150102 plastic packaging	<1
150103 wooden packaging	<1
150106 mixed packaging	<1
170107 non-170106 con'e/brick/tile mix	<1
170904 non-170901/2/3 con./dem'n waste	<1
190199 unspecified incin'n/pyro waste	<1
190905 sat./spent ion exchange resins	720
200101 paper and cardboard	<1
200108 biodeg. kitchen/canteen waste	<1
200138 non-200137 wood	<1
200139 plastics	<1
200140 metals	<1
200199 other separately coll. frac'ns	-1300
200301 mixed municipal waste	1
200399 unspecified municipal wastes	-4400
Note: Negative values correspond to consumption of waste e.g. recycling or use in electricity generation.	

ATTACHMENT F

Annual and Quarterly Groundwater Monitoring Report
Joliet #29 Generating Station
January 21, 2021

ANNUAL and QUARTERLY GROUNDWATER MONITORING REPORT JOLIET #29 GENERATING STATION

January 21, 2021

Ms. Andrea Rhodes
Illinois Environmental Protection Agency
Division of Public Water Supplies
MC#19
1021 North Grand Avenue East
Springfield, IL 62794-9276

VIA FEDEX

Re: Annual and Quarterly Groundwater Monitoring Results – Fourth Quarter 2020
Joliet #29 Generating Station – Former Ash Impoundments
Compliance Commitment Agreement VN W-2012-00059; ID# 6284

Dear Ms. Rhodes:

The fourth quarterly groundwater sampling for 2020 has been completed for the former ash pond monitoring wells located at the Midwest Generation, LLC (Midwest Generation) Joliet #29 Generating Station in accordance with the signed Compliance Commitment Agreement (CCA) with Illinois Environmental Protection Agency (IEPA) dated October 24, 2012. This Quarterly Monitoring Report is being submitted summarizing the results of the monitoring event. This report is also intended to serve as the Annual Report and includes historical data analysis/summaries.

Well Inspection and Sampling Procedures

The groundwater monitoring network around the existing ponds at this facility consists of eleven wells (MW-01 through MW-11) as shown on Figure 1. As part of sampling procedures, the integrity of all monitoring wells was inspected and water levels were obtained using an electronic water level meter (see summary of water level discussion below). All wells were generally found in good condition with locked protector casings and the concrete surface seals were intact.

Groundwater samples at well locations MW-03 through MW-08, MW-10 and MW-11 were collected using the low-flow sampling technique. Based on historical water levels at monitoring well locations MW-01 and MW-02, it was determined that there was not enough water column within these wells (generally less than two feet of water column within each well) to allow for the placement of dedicated pumping systems. Instead, at these two well locations, sample collection is completed using a peristaltic pump when sufficient water is available for sampling. During this sampling event, there was not enough water volume within both of these wells to allow for sample collection. The dedicated pump for MW-09 was found to be nonoperational during the fourth quarter, therefore a bailer was used to obtain groundwater samples at well location MW-09 during the most recent round of groundwater sampling. A new bladder pump has been ordered for this well and will be replaced prior to the next round of sampling.

One duplicate sample was collected at well MW-04. In addition, a de-ionized water trip blank accompanied the groundwater samples bottles from and back to the laboratory. The groundwater monitoring samples and the duplicate sample were analyzed for the compounds listed in Illinois Administrative Code (IAC) 620.410(a), 620.410(d) and 620.410(e), excluding radium 226/228. The trip blank was analyzed for the volatile organic compounds (VOCs) listed in IAC 620.410(d).

Groundwater Flow Evaluation

Water level data from the most recent round of sampling along with historical water levels obtained from each well are summarized in Table 1. The water levels were used to generate a groundwater flow map which is provided on Figure 2. It is noted that the water level at well MW-04 appeared slightly elevated relative to surrounding wells and is believed to be an anomalous measurement. The water elevation data indicates a general southeasterly flow. The flow conditions observed during this sampling are consistent with historical conditions reported for the site. Relative to an annual evaluation of groundwater levels, a historical hydrograph is presented in Attachment 1.

Summary of Analytical Data

A copy of the analytical data package is provided in Attachment 2. The field parameter and analytical data from the most recent sampling, along with the previous eight quarters of data, are summarized in Table 2. It is noted that some elevated metals concentrations were detected at well MW-09 relative to previous concentration (e.g., arsenic and lead) and may be reflective of the previously noted change in sample collection method due to dedicated pump failure. Subsequent sampling will determine the nature of these detections.

All duplicate values were within an acceptable range (+/- 30%). All wells for which the sampling data reports a value above groundwater comparison standards are located within the area of the approved Groundwater Management Zone (GMZ).

Relative to an annual evaluation of the water chemistry data, time versus concentration curves are provided for each parameter analyzed in Attachment 3. The curves include the Class I drinking water standard for reference, where applicable.

As noted previously, all wells for which the sampling data reports a value above one or more applicable groundwater standards are located within the area of the approved GMZ.

If there are any questions, please contact either Sharene Shealey of NRG Energy at 724-255-3220 or Richard Gnat of KPRG and Associates, Inc. at 262-781-0475.

Sincerely,

William Naglosky
Station Manager

cc: Mike Summers/Lynn Dunaway, IEPA
Peter O'Day, Midwest Generation, LLC
Sharene Shealey, NRG Energy
Richard Gnat, KPRG and Associates, Inc.

FIGURES

NOTE:
BACKGROUND MAP RETRIEVED FROM GOOGLE MAPS 2013

N

0 250'
APPROXIMATE SCALE

ENVIRONMENTAL CONSULTATION & REMEDIATION

KPRG

KPRG and Associates, inc.

14665 West Lisbon Road, Suite 1A Brookfield, Wisconsin 53005 Telephone 262-781-0475 Facsimile 262-781-0478

414 Plaza Drive, Suite 106 Westmont, Illinois 60559 Telephone 630-325-1300 Facsimile 630-325-1593

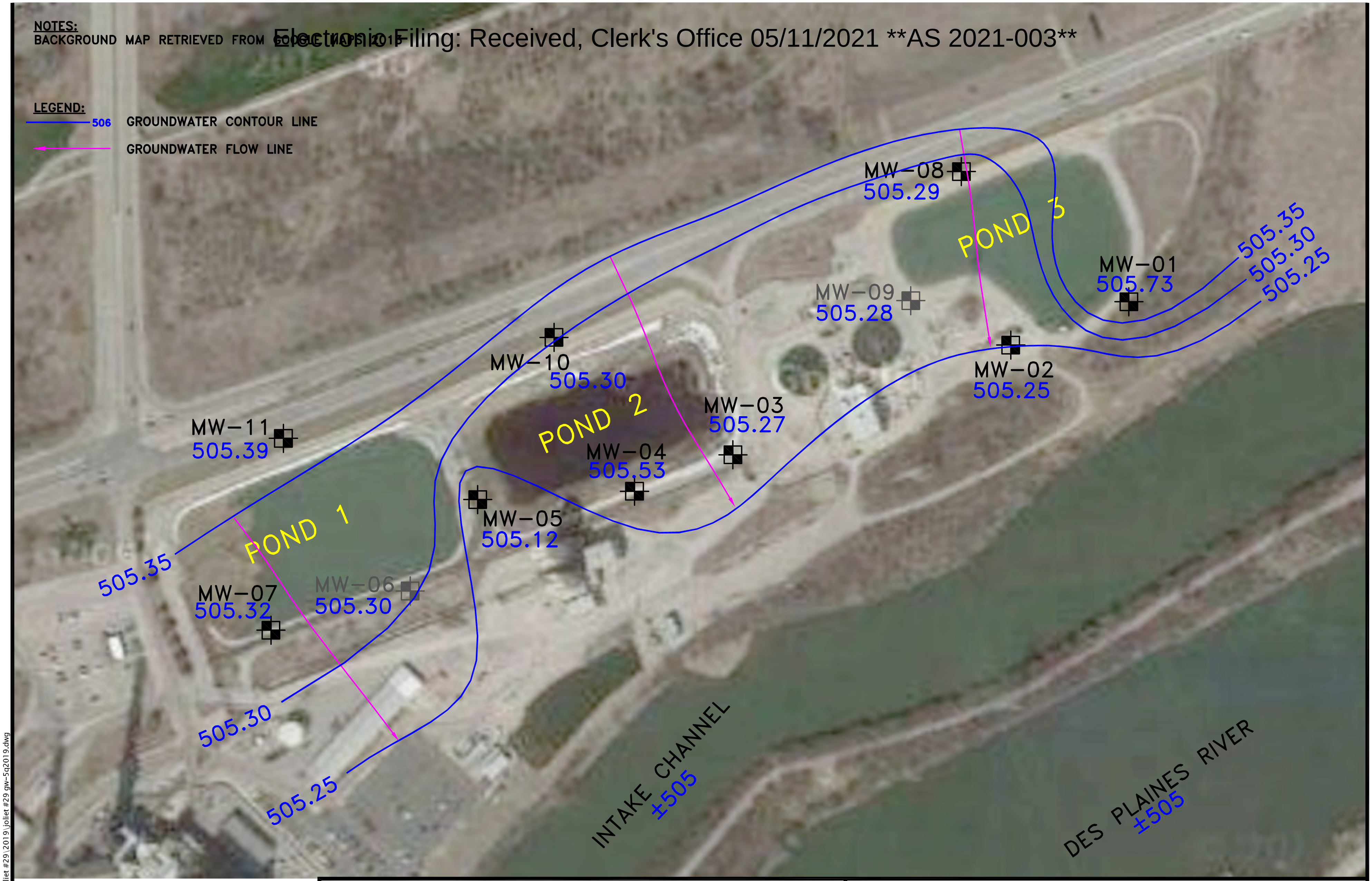
SITE MAP

JOLIET #29 GENERATING STATION
JOLIET, ILLINOIS

Scale: 1" = 250'	Date: January 23, 2019
KPRG Project No. 12313.0	FIGURE 1

NOTES:
BACKGROUND MAP RETRIEVED FROM GOOGLE MAPS 2019

LEGEND:
506 GROUNDWATER CONTOUR LINE
GROUNDWATER FLOW LINE



0 250'
APPROXIMATE SCALE

N

ENVIRONMENTAL CONSULTATION & REMEDIATION

KPRG

KPRG and Associates, inc.

14665 West Lisbon Road, Suite 1A Brookfield, Wisconsin 53005 Telephone 262-781-0475 Facsimile 262-781-0478

414 Plaza Drive, Suite 106 Westmont, Illinois 60559 Telephone 630-325-1300 Facsimile 630-325-1593

GROUNDWATER CONTOUR MAP 10/2020

JOLIET #29 GENERATING STATION
JOLIET, ILLINOIS

Scale: 1" = 250'	Date: October 31, 2020
KPRG Project No. 12313.0	FIGURE 2

W:\projects\midwest generation\12313\figures\joliet #29\2019\joliet #29 gw-5q2019.dwg

TABLES

Table 1. Groundwater Elevations - Midwest Generation, LLC, Joliet Station #29, Joliet, IL

Well ID	Date	Top of Casing (TOC) Elevation (ft above MSL)	Ground Elevation (ft above MSL)	Groundwater Elevation (ft above MSL)	Sampling Groundwater Elevation (ft above MSL)	Bottom of Well Elevation (ft above MSL)	Depth to Groundwater (ft below TOC)	Sampling Depth to Groundwater (ft below TOC)	Depth to Bottom of Well (ft below TOC)
MW-01	02/10/15	534.76	531.46	NM	NM	504.88	NM	NM	29.88
	05/27/15	534.76	531.46	NM	NM	504.88	NM	NM	29.88
	08/04/15	534.76	531.46	NM	NM	504.88	NM	NM	29.88
	10/27/15	534.76	531.46	NM	NM	504.88	NM	NM	29.88
	02/09/16	534.03	531.56	NM	NM	505.50	NM	NM	28.53
	05/10/16	534.03	531.56	505.90	506.18	505.50	28.13	27.85	28.53
	08/30/16	534.03	531.56	506.85	506.91	505.50	27.18	27.12	28.53
	11/01/16	534.03	531.56	505.89	505.53	505.50	28.14	28.50	28.53
	02/06/17	534.03	531.56	NM	NM	505.50	NM	NM	28.53
	04/25/17	534.03	531.56	NM	NM	505.50	NM	NM	28.53
	08/01/17	534.03	531.56	506.59	506.53	505.50	27.44	27.50	28.53
	10/17/17	534.03	531.56	508.87	508.85	505.50	25.16	25.18	28.53
	02/21/18	534.03	531.56	506.37	509.54	505.50	27.66	24.49	28.53
	04/25/18	534.03	531.56	505.89	505.58	505.50	28.14	28.45	28.53
	07/31/18	534.03	531.56	505.75	505.50	505.50	28.28	28.53	28.53
	10/16/18	534.03	531.56	506.22	505.93	505.50	27.81	28.10	28.53
	02/04/19	534.03	531.56	505.73	NM	505.50	28.30	NM	28.53
	05/06/19	534.03	531.56	509.00	509.00	505.50	25.03	25.03	28.53
	08/06/19	534.03	531.56	505.88	NM	505.50	28.15	NM	28.53
	11/06/19	534.03	531.56	507.38	NM	505.50	26.65	NM	28.53
	02/12/20	534.03	531.56	505.69	NM	505.50	28.34	NM	28.53
	05/21/20	534.03	531.56	511.60	NM	505.50	22.43	NM	28.53
	07/30/20	534.03	531.56	505.74	NM	505.50	28.29	NM	28.53
	10/21/20	534.03	531.56	505.73	NM	505.50	28.30	NM	28.53
MW-02	02/10/15	534.28	531.19	505.17	510.69	504.05	29.11	23.59	30.23
	05/27/15	534.28	531.19	505.34	505.32	504.05	28.94	28.96	30.23
	08/04/15	534.28	531.19	505.14	505.13	504.05	29.14	29.15	30.23
	10/27/15	534.28	531.19	504.89	505.09	504.05	29.39	29.19	30.23
	02/09/16	534.30	531.17	505.59	505.57	504.07	28.71	28.73	30.23
	05/10/16	534.30	531.17	505.89	506.09	504.07	28.41	28.21	30.23
	08/30/16	534.30	531.17	506.83	506.97	504.07	27.47	27.33	30.23
	11/01/16	534.30	531.17	505.90	505.89	504.07	28.40	28.41	30.23
	02/06/17	534.30	531.17	505.46	505.74	504.07	28.84	28.56	30.23
	04/25/17	534.30	531.17	505.69	505.70	504.07	28.61	28.60	30.23
	08/01/17	534.30	531.17	506.59	506.52	504.07	27.71	27.78	30.23
	10/17/17	534.30	531.17	508.82	508.82	504.07	25.48	25.48	30.23
	02/21/18	534.30	531.17	506.35	509.65	504.07	27.95	24.65	30.23
	04/25/18	534.30	531.17	505.87	505.81	504.07	28.43	28.49	30.23
	08/01/18	534.30	531.17	505.22	505.14	504.07	29.08	29.16	30.23
	10/16/18	534.30	531.17	506.17	506.11	504.07	28.13	28.19	30.23
	02/04/19	534.30	531.17	505.68	505.65	504.07	28.62	28.65	30.23
	05/06/19	534.30	531.17	508.95	508.29	504.07	25.35	26.01	30.23
	08/06/19	534.30	531.17	505.16	NM	504.07	29.14	NM	30.23
	11/06/19	534.30	531.17	507.27	NM	504.07	27.03	NM	30.23
	02/12/20	534.30	531.17	505.49	NM	504.07	28.81	NM	30.23
	05/21/20	534.30	531.17	510.37	NM	504.07	23.93	23.94	30.23
	07/30/20	534.30	531.17	504.98	NM	504.07	29.32	NM	30.23
	10/21/20	534.30	531.17	505.25	NM	504.07	29.05	NM	30.23
MW-03	02/10/15	538.78	535.54	505.19	505.20	494.68	33.59	33.58	44.10
	05/27/15	538.78	535.54	505.36	505.35	494.68	33.42	33.43	44.10
	08/04/15	538.78	535.54	505.22	505.22	494.68	33.56	33.56	44.10
	10/27/15	538.78	535.54	504.91	505.04	494.68	33.87	33.74	44.10
	02/09/16	538.79	535.53	505.62	505.51	494.68	33.17	33.28	44.10
	05/10/16	538.79	535.53	505.97	505.99	494.68	32.82	32.80	44.10
	08/30/16	538.79	535.53	506.91	507.22	494.68	31.88	31.57	44.10
	11/01/16	538.79	535.53	505.91	505.94	494.68	32.88	32.85	44.10
	02/06/17	538.79	535.53	505.54	505.54	494.68	33.25	33.25	44.10
	04/26/17	538.79	535.53	505.73	505.78	494.68	33.06	33.01	44.10
	08/01/17	538.79	535.53	506.43	506.44	494.68	32.36	32.35	44.10
	10/18/17	538.79	535.53	508.76	508.54	494.68	30.03	30.25	44.10
	02/20/18	538.79	535.53	506.38	506.56	494.68	32.41	32.23	44.10
	04/24/18	538.79	535.53	505.96	505.96	494.68	32.83	32.83	44.10
	07/31/18	538.79	535.53	505.23	505.25	494.68	33.56	33.54	44.10
	10/17/18	538.79	535.53	506.21	506.09	494.68	32.58	32.70	44.10
	02/04/19	538.79	535.53	505.74	505.81	494.68	33.05	32.98	44.10
	05/06/19	538.79	535.53	508.84	508.61	494.68	29.95	30.18	44.10
	08/06/19	538.79	535.53	505.26	505.29	494.68	33.53	33.50	44.10
	11/06/19	538.79	535.53	505.41	505.29	494.68	33.38	33.50	44.10
	02/12/20	538.79	535.53	505.61	505.29	494.68	33.18	33.50	44.10
	05/20/20	538.79	535.53	511.66	511.66	494.68	27.13	27.13	44.10
	07/30/20	538.79	535.53	505.06	505.04	494.68	33.73	33.75	44.10
	10/21/20	538.79	535.53	505.27	505.46	494.68	33.52	33.33	44.10

Table 1. Groundwater Elevations - Midwest Generation, LLC, Joliet Station #29, Joliet, IL

Well ID	Date	Top of Casing (TOC) Elevation (ft above MSL)	Ground Elevation (ft above MSL)	Groundwater Elevation (ft above MSL)	Sampling Groundwater Elevation (ft above MSL)	Bottom of Well Elevation (ft above MSL)	Depth to Groundwater (ft below TOC)	Sampling Depth to Groundwater (ft below TOC)	Depth to Bottom of Well (ft below TOC)
MW-04	02/10/15	539.03	535.80	505.19	505.18	496.13	33.84	33.85	42.90
	05/27/15	539.03	535.80	505.39	505.37	496.13	33.64	33.66	42.90
	08/04/15	539.03	535.80	505.19	505.19	496.13	33.84	33.84	42.90
	10/27/15	539.03	535.80	504.98	505.00	496.13	34.05	34.03	42.90
	02/09/16	539.01	535.83	505.59	505.44	496.11	33.42	33.57	42.90
	05/10/16	539.01	535.83	505.94	505.95	496.11	33.07	33.06	42.90
	08/30/16	539.01	535.83	506.93	507.19	496.11	32.08	31.82	42.90
	11/01/16	539.01	535.83	505.85	505.87	496.11	33.16	33.14	42.90
	02/06/17	539.01	535.83	505.50	505.52	496.11	33.51	33.49	42.90
	04/26/17	539.01	535.83	505.72	505.74	496.11	33.29	33.27	42.90
	08/01/17	539.01	535.83	506.92	506.39	496.11	32.09	32.62	42.90
	10/18/17	539.01	535.83	508.73	508.50	496.11	30.28	30.51	42.90
	02/20/18	539.01	535.83	505.37	506.69	496.11	33.64	32.32	42.90
	04/24/18	539.01	535.83	505.91	505.92	496.11	33.10	33.09	42.90
	07/31/18	539.01	535.83	505.20	505.22	496.11	33.81	33.79	42.90
	10/17/18	539.01	535.83	506.16	506.03	496.11	32.85	32.98	42.90
	02/04/19	539.01	535.83	505.72	505.72	496.11	33.29	33.29	42.90
	05/06/19	539.01	535.83	509.18	508.57	496.11	29.83	30.44	42.90
	08/06/19	539.01	535.83	505.22	505.21	496.11	33.79	33.80	42.90
	11/06/19	539.01	535.83	507.36	505.21	496.11	31.65	33.80	42.90
	02/12/20	539.01	535.83	505.56	505.26	496.11	33.45	33.75	42.90
	05/20/20	539.01	535.83	511.61	511.61	496.11	27.40	27.40	42.90
	07/30/20	539.01	535.83	505.01	505.04	496.11	34.00	33.97	42.90
	10/21/20	539.01	535.83	505.53	505.46	496.11	33.48	33.55	42.90
MW-05	02/11/15	539.69	536.43	505.12	505.12	494.64	34.57	34.57	45.05
	05/27/15	539.69	536.43	505.26	505.25	494.64	34.43	34.44	45.05
	08/04/15	539.69	536.43	505.14	505.14	494.64	34.55	34.55	45.05
	10/27/15	539.69	536.43	504.78	504.95	494.64	34.91	34.74	45.05
	02/09/16	539.64	536.36	505.46	505.33	494.59	34.18	34.31	45.05
	05/10/16	539.64	536.36	505.83	505.86	494.59	33.81	33.78	45.05
	08/30/16	539.64	536.36	506.82	507.09	494.59	32.82	32.55	45.05
	11/01/16	539.64	536.36	505.74	505.74	494.59	33.90	33.90	45.05
	02/06/17	539.64	536.36	505.41	505.40	494.59	34.23	34.24	45.05
	04/26/17	539.64	536.36	505.60	505.66	494.59	34.04	33.98	45.05
	08/01/17	539.64	536.36	506.52	506.24	494.59	33.12	33.40	45.05
	10/18/17	539.64	536.36	508.61	508.59	494.59	31.03	31.05	45.05
	02/20/18	539.64	536.36	506.35	506.74	494.59	33.29	32.90	45.05
	04/24/18	539.64	536.36	505.85	505.82	494.59	33.79	33.82	45.05
	07/31/18	539.64	536.36	505.10	505.11	494.59	34.54	34.53	45.05
	10/17/18	539.64	536.36	506.03	505.91	494.59	33.61	33.73	45.05
	02/04/19	539.64	536.36	505.97	505.96	494.59	33.67	33.68	45.05
	05/06/19	539.64	536.36	509.09	508.98	494.59	30.55	30.66	45.05
	08/06/19	539.64	536.36	505.09	505.09	494.59	34.55	34.55	45.05
	11/06/19	539.64	536.36	507.24	505.09	494.59	32.40	34.55	45.05
	02/12/20	539.64	536.36	505.48	504.59	494.59	34.16	35.05	45.05
	05/20/20	539.64	536.36	511.48	511.48	494.59	28.16	28.16	45.05
	07/30/20	539.64	536.36	504.87	504.88	494.59	34.77	34.76	45.05
	10/21/20	539.64	536.36	505.12	506.09	494.59	34.52	33.55	45.05
MW-06	02/10/15	539.06	535.86	505.23	505.23	496.86	33.83	33.83	42.20
	05/28/15	539.06	535.86	505.46	505.45	496.86	33.60	33.61	42.20
	08/05/15	539.06	535.86	505.11	505.12	496.86	33.95	33.94	42.20
	10/27/15	539.06	535.86	504.88	504.93	496.86	34.18	34.13	42.20
	02/09/16	539.05	535.89	505.61	505.46	496.85	33.44	33.59	42.20
	05/10/16	539.05	535.89	506.00	506.94	496.85	33.05	32.11	42.20
	08/30/16	539.05	535.89	506.96	507.36	496.85	32.09	31.69	42.20
	11/01/16	539.05	535.89	505.88	505.91	496.85	33.17	33.14	42.20
	02/06/17	539.05	535.89	505.56	505.57	496.85	33.49	33.48	42.20
	04/27/17	539.05	535.89	505.74	505.77	496.85	33.31	33.28	42.20
	08/01/17	539.05	535.89	506.65	506.28	496.85	32.40	32.77	42.20
	10/19/17	539.05	535.89	508.74	508.14	496.85	30.31	30.91	42.20
	02/21/18	539.05	535.89	506.57	509.45	496.85	32.48	29.60	42.20
	04/25/18	539.05	535.89	505.94	505.86	496.85	33.11	33.19	42.20
	07/31/18	539.05	535.89	505.27	505.25	496.85	33.78	33.80	42.20
	10/18/18	539.05	535.89	506.16	506.00	496.85	32.89	33.05	42.20
	02/04/19	539.05	535.89	506.12	506.12	496.85	32.93	32.93	42.20
	05/06/19	539.05	535.89	509.19	508.22	496.85	29.86	30.83	42.20
	08/06/19	539.05	535.89	505.26	505.33	496.85	33.79	33.72	42.20
	11/06/19	539.05	535.89	507.36	505.33	496.85	31.69	33.72	42.20
	02/12/20	539.05	535.89	505.63	505.60	496.85	33.42	33.45	42.20
	05/21/20	539.05	535.89	511.51	511.45	496.85	27.54	27.60	42.20
	07/30/20	539.05	535.89	505.08	505.08	496.85	33.97	33.97	42.20
	10/21/20	539.05	535.89	505.30	505.37	496.85	33.75	33.68	42.20
MW-07	02/10/15	539.35	535.86	505.24	505.24	496.12	34.11	34.11	43.23
	05/28/15	539.35	535.86	505.50	505.50	496.12	33.85	33.85	43.23
	08/05/15	539.35	535.86	505.18	505.17	496.12	34.17	34.18	43.23
	10/27/15	539.35	535.86	504.93	505.00	496.12	34.42	34.35	43.23
	02/09/16	539.35	535.87	505.66	505.51	496.12	33.69	33.84	43.23
	05/10/16	539.35	535.87	506.34	507.02	496.12	33.01	32.33	43.23
	08/30/16	539.35	535.87	507.04	507.41	496.12	32.31	31.94	43.23
	11/01/16	539.35	535.87	505.91	505.93	496.12	33.44	33.42	43.23
	02/06/17	539.35	535.87	505.59	505.62	496.12	33.76	33.73	43.23
	04/27/17	539.35	535.87	505.77	505.82	496.12	33.58	33.53	43.23
	08/01/17	539.35	535.87	506.68	506.30	496.12	32.67	33.05	43.23
	10/19/17	539.35	535.87	508.76	508.07	496.12	30.59	31.28	43.23
	02/21/18	539.35	535.87	506.67	509.64	496.12	32.68	29.71	43.23
	04/25/18	539.35	535.87	505.98	505.89	496.12	33.37	33.46	43.23
	08/01/18	539.35	535.87	505.30	505.31	496.12	34.05	34.04	43.23
	10/18/18	539.35	535.87	506.17	506.03	496.12	33.18	33.32	43.23
	02/04/19	539.35	535.87	506.19	506.19	496.12	33.16	33.16	43.23
	05/06/19	539.35	535.87	509.22	508.51	496.12	30.13	30.84	43.23
	08/06/19	539.35	535.87	505.33	505.33	496.12	34.02	34.02	43.23
	11/06/19	539.35	535.87	507.40	505.33	496.12	31.95	34.02	43.23
	02/12/20	539.35	535.87	505.65	505.65	496.12	33.70	33.70	43.23
	05/21/20	539.35	535.87	511.53	511.53	496.12	27.82	27.82	43.23
	07/30/20	539.35	535.87	505.14	505.14	496.12	34.21	34.21	43.23
	10/21/20	539.35	535.87	505.32	505.65	496.12	34.03	33.70	43.23

Table 1. Groundwater Elevations - Midwest Generation, LLC, Joliet Station #29, Joliet, IL

Well ID	Date	Top of Casing (TOC) Elevation (ft above MSL)	Ground Elevation (ft above MSL)	Groundwater Elevation (ft above MSL)	Sampling Groundwater Elevation (ft above MSL)	Bottom of Well Elevation (ft above MSL)	Depth to Groundwater (ft below TOC)	Sampling Depth to Groundwater (ft below TOC)	Depth to Bottom of Well (ft below TOC)
MW-08	02/10/15	536.87	533.72	505.18	505.19	498.81	31.69	31.68	38.06
	05/27/15	536.87	533.72	505.36	505.38	498.81	31.51	31.49	38.06
	08/04/15	536.87	533.72	505.19	505.20	498.81	31.68	31.67	38.06
	10/27/15	536.87	533.72	504.93	504.98	498.81	31.94	31.89	38.06
	02/09/16	536.96	533.77	505.72	505.72	498.90	31.24	31.24	38.06
	05/10/16	536.96	533.77	498.00	498.24	498.90	38.96	38.72	38.06
	08/30/16	536.96	533.77	507.05	507.09	498.90	29.91	29.87	38.06
	11/01/16	536.96	533.77	506.01	506.03	498.90	30.95	30.93	38.06
	02/06/17	536.96	533.77	505.58	505.62	498.90	31.38	31.34	38.06
	04/25/17	536.96	533.77	505.74	505.79	498.90	31.22	31.17	38.06
	08/01/17	536.96	533.77	506.78	506.76	498.90	30.18	30.20	38.06
	10/17/17	536.96	533.77	509.02	508.99	498.90	27.94	27.97	38.06
	02/20/18	536.96	533.77	506.00	506.55	498.90	30.96	30.41	38.06
	08/01/18	536.96	533.77	505.23	505.26	498.90	31.73	31.70	38.06
	10/16/18	536.96	533.77	506.36	506.35	498.90	30.60	30.61	38.06
	02/04/19	536.96	533.77	506.04	506.04	498.90	30.92	30.92	38.06
	05/06/19	536.96	533.77	509.22	509.13	498.90	27.74	27.83	38.06
	08/06/19	536.96	533.77	505.27	505.27	498.90	31.69	31.69	38.06
	11/06/19	536.96	533.77	507.54	507.16	498.90	29.42	29.80	38.06
	02/12/20	536.96	533.77	505.56	505.56	498.90	31.40	31.40	38.06
	05/20/20	536.96	533.77	511.82	511.63	498.90	25.14	25.33	38.06
	07/30/20	536.96	533.77	505.13	505.12	498.90	31.83	31.84	38.06
	10/28/20	536.96	533.77	505.29	505.41	498.90	31.67	31.55	38.06
MW-09	02/10/15	534.44	531.13	505.22	504.70	496.29	29.22	29.74	38.15
	05/27/15	534.44	531.13	505.37	504.98	496.29	29.07	29.46	38.15
	08/04/15	534.44	531.13	505.22	504.91	496.29	29.22	29.53	38.15
	10/27/15	534.44	531.13	504.96	504.83	496.29	29.48	29.61	38.15
	02/09/16	534.41	531.08	505.64	505.49	496.26	28.77	28.92	38.15
	05/10/16	534.41	531.08	505.90	506.39	496.26	28.51	28.02	38.15
	08/30/16	534.41	531.08	506.98	506.94	496.26	27.43	27.47	38.15
	11/01/16	534.41	531.08	505.89	505.32	496.26	28.52	29.09	38.15
	02/06/17	534.41	531.08	505.51	505.66	496.26	28.90	28.75	38.15
	04/25/17	534.41	531.08	505.66	505.54	496.26	28.75	28.87	38.15
	08/01/17	534.41	531.08	506.64	506.27	496.26	27.77	28.14	38.15
	10/17/17	534.41	531.08	508.89	508.73	496.26	25.52	25.68	38.15
	02/20/18	534.41	531.08	506.39	506.99	496.26	28.02	27.42	38.15
	04/26/18	534.41	531.08	505.89	505.58	496.26	28.52	28.83	38.15
	08/01/18	534.41	531.08	505.18	505.05	496.26	29.23	29.36	38.15
	10/16/18	534.41	531.08	506.23	506.12	496.26	28.18	28.29	38.15
	02/04/19	534.41	531.08	506.02	505.99	496.26	28.39	28.42	38.15
	05/06/19	534.41	531.08	509.08	508.09	496.26	25.33	26.32	38.15
	08/06/19	534.41	531.08	505.23	504.61	496.26	29.18	29.80	38.15
	11/06/19	534.41	531.08	507.42	504.61	496.26	26.99	29.80	38.15
	02/12/20	534.41	531.08	505.53	504.89	496.26	28.88	29.52	38.15
	05/20/20	534.41	531.08	511.06	510.76	496.26	23.35	23.65	38.15
	07/30/20	534.41	531.08	505.02	505.05	496.26	29.39	29.36	38.15
	10/21/20	534.41	531.08	505.28	505.05	496.26	29.13	29.36	38.15
MW-10	02/11/15	540.03	536.95	505.27	505.27	496.10	34.76	34.76	43.93
	05/28/15	540.03	536.95	505.48	505.48	496.10	34.55	34.55	43.93
	08/04/15	540.03	536.95	505.29	505.30	496.10	34.74	34.73	43.93
	10/27/15	540.03	536.95	504.93	505.07	496.10	35.10	34.96	43.93
	02/09/16	540.02	536.98	505.70	505.61	496.09	34.32	34.41	43.93
	05/10/16	540.02	536.98	506.00	506.66	496.09	34.02	33.36	43.93
	08/30/16	540.02	536.98	507.05	507.38	496.09	32.97	32.64	43.93
	11/01/16	540.02	536.98	505.98	505.97	496.09	34.04	34.05	43.93
	02/06/17	540.02	536.98	505.60	505.62	496.09	34.42	34.40	43.93
	04/26/17	540.02	536.98	505.80	505.84	496.09	34.22	34.18	43.93
	08/01/17	540.02	536.98	506.84	506.50	496.09	33.18	33.52	43.93
	10/18/17	540.02	536.98	508.89	508.61	496.09	31.13	31.41	43.93
	02/21/18	540.02	536.98	506.19	509.42	496.09	33.83	30.60	43.93
	04/24/18	540.02	536.98	506.05	506.02	496.09	33.97	34.00	43.93
	08/01/18	540.02	536.98	505.27	505.27	496.09	34.75	34.75	43.93
	10/17/18	540.02	536.98	506.29	506.14	496.09	33.73	33.88	43.93
	02/04/19	540.02	536.98	506.11	506.10	496.09	33.91	33.92	43.93
	05/06/19	540.02	536.98	509.44	508.82	496.09	30.58	31.20	43.93
	08/06/19	540.02	536.98	505.32	505.32	496.09	34.70	34.70	43.93
	11/06/19	540.02	536.98	507.60	505.32	496.09	32.42	34.70	43.93
	02/12/20	540.02	536.98	505.67	505.67	496.09	34.35	34.35	43.93
	05/20/20	540.02	536.98	511.83	511.86	496.09	28.19	28.16	43.93
	07/30/20	540.02	536.98	505.14	505.12	496.09	34.88	34.90	43.93
	10/21/20	540.02	536.98	505.30	505.30	496.09	34.72	34.72	43.93
MW-11	02/11/15	539.47	536.52	505.49	505.49	497.14	33.98	33.98	42.33
	05/28/15	539.47	536.52	505.96	505.97	497.14	33.51	33.50	42.33
	08/04/15	539.47	536.52	505.65	505.64	497.14	33.82	33.83	42.33
	10/27/15	539.47	536.52	505.16	505.32	497.14	34.31	34.15	42.33
	02/09/16	539.41	536.62	506.10	505.88	497.08	33.31	33.53	42.33
	05/10/16	539.41	536.62	507.33	506.60	497.08	32.08	32.81	42.33
	08/30/16	539.41	536.62	508.27	508.85	497.08	31.14	30.56	42.33
	11/01/16	539.41	536.62	506.32	506.28	497.08	33.09	33.13	42.33
	02/06/17	539.41	536.62	505.90	505.92	497.08	33.51	33.49	42.33
	04/26/17	539.41	536.62	506.17	506.17	497.08	33.24	33.24	42.33
	08/01/17	539.41	536.62	507.47	507.38	497.08	31.94	32.03	42.33
	10/19/17	539.41	536.62	509.61	509.16	497.08	29.8	30.25	42.33
	02/21/18	539.41	536.62	506.45	509.85	497.08	32.96	29.56	42.33
	04/25/18	539.41	536.62	505.48	506.40	497.08	33.93	33.01	42.33
	08/01/18	539.41	536.62	505.53	505.54	497.08	33.88	33.87	42.33
	10/17/18	539.41	536.62	506.63	506.51	497.08	32.78	32.90	42.33
	02/04/19	539.41	536.62	506.19	506.19	497.08	33.22	33.22	42.33
	05/06/19	539.41	536.62	510.58	509.98	497.08	28.83	29.43	42.33
	08/06/19	539.41	536.62	505.66	505.66	497.08	33.75	33.75	42.33
	11/06/19	539.41	536.62	508.26	505.66	497.08	31.15	33.75	42.33
	02/12/20	539.41	536.62	505.88	505.81	497.08	33.53	33.60	42.33
	05/20/20	539.41	536.62	512.83	512.81	497.08	26.58	26.60	42.33
	07/30/20	539.41	536.62	505.53	505.48	497.08	33.88	33.93	42.33
	10/21/20	539.41	536.62	505.39	505.39	497.08	34.02	34.02	42.33

Note: Values for Depth to Bottom of Well are from prior to the installation of the dedicated pumps.
NM - Not Measured

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-01	Date	8/1/2018		10/17/2018		2/4/2019		5/7/2019		8/6/2019		11/7/2019		2/13/2020		5/21/2020		7/30/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	NS	NS	0.003	ND	0.003	NS	0.003	ND	0.003	NS	0.003	ND	0.003	NS	0.003	0.0066	NS	NS	NS	NS
Arsenic	0.01	NS	NS	0.001	ND	0.001	NS	0.001	ND	0.001	NS	0.001	ND	0.001	NS	0.001	0.0012	NS	NS	NS	NS
Barium	2	NS	NS	0.0025	0.12	0.0025	NS	0.0025	0.054	0.0025	NS	0.0025	0.051	0.0025	NS	0.0025	0.076	NS	NS	NS	NS
Beryllium	0.004	NS	NS	0.001	ND^	0.001	NS	0.001	ND ^	0.001	NS	0.001	ND	0.001	NS	0.001	ND ^	NS	NS	NS	NS
Boron	2	NS	NS	0.05	0.23	0.05	NS	0.05	0.22	0.05	NS	0.05	0.22	0.05	NS	0.05	0.35	NS	NS	NS	NS
Cadmium	0.005	NS	NS	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	NS	NS	NS	NS
Chloride	200	NS	NS	10	130	10	NS	10	280	10	NS	10	60	10	NS	10	140	NS	NS	NS	NS
Chromium	0.1	NS	NS	0.005	ND	0.005	NS	0.005	ND	0.005	NS	0.005	ND	0.005	NS	0.005	ND	NS	NS	NS	NS
Cobalt	1	NS	NS	0.001	ND	0.001	NS	0.001	ND	0.001	NS	0.001	ND	0.001	NS	0.001	0.0011	NS	NS	NS	NS
Copper	0.65	NS	NS	0.002	ND	0.002	NS	0.002	ND	0.002	NS	0.002	ND	0.002	NS	0.002	ND	NS	NS	NS	NS
Cyanide	0.2	NS	NS	0.01	ND	0.01	NS	0.01	ND	0.01	NS	0.01	ND	0.01	NS	0.01	ND	NS	NS	NS	NS
Fluoride	4	NS	NS	0.1	0.36	0.1	NS	0.1	0.42	0.1	NS	0.1	0.34	0.1	NS	0.1	0.4	NS	NS	NS	NS
Iron	5	NS	NS	0.1	ND	0.1	NS	0.1	0.1	0.1	NS	0.1	ND	0.1	NS	0.1	ND	NS	NS	NS	NS
Lead	0.0075	NS	NS	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	NS	NS	NS	NS
Manganese	0.15	NS	NS	0.0025	ND	0.0025	NS	0.0025	ND	0.0025	NS	0.0025	ND	0.0025	NS	0.0025	ND	NS	NS	NS	NS
Mercury	0.002	NS	NS	0.0002	ND	0.0002	NS	0.0002	ND	0.0002	NS	0.0002	ND	0.0002	NS	0.0002	ND	NS	NS	NS	NS
Nickel	0.1	NS	NS	0.002	ND	0.002	NS	0.002	ND	0.002	NS	0.002	ND	0.002	NS	0.002	0.0023	NS	NS	NS	NS
Nitrogen/Nitrate	10	NS	NS	0.1	1.8	0.1	NS	0.1	2.9	0.1	NS	0.1	1.6	0.1	NS	0.1	2.1	NS	NS	NS	NS
Nitrogen/Nitrate, Nitrite	NA	NS	NS	0.1	1.8	0.1	NS	0.1	2.9	0.1	NS	0.1	1.6	0.1	NS	0.1	2.1	NS	NS	NS	NS
Nitrogen/Nitrite	NA	NS	NS	0.02	ND	0.02	NS	0.02	ND	0.02	NS	0.02	ND	0.02	NS	0.02	ND	NS	NS	NS	NS
Perchlorate	0.0049	NS	NS	0.004	ND	0.004	NS	0.004	ND	0.004	NS	0.004	ND	0.004	NS	0.004	ND	NS	NS	NS	NS
Selenium	0.05	NS	NS	0.0025	0.0071	0.0025	NS	0.0025	0.016	0.0025	NS	0.0025	ND	0.0025	NS	0.0025	0.0075	NS	NS	NS	NS
Silver	0.05	NS	NS	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	NS	NS	NS	NS
Sulfate	400	NS	NS	20	56	20	NS	20	84	20	NS	20	42	20	NS	20	120	NS	NS	NS	NS
Thallium	0.002	NS	NS	0.002	ND	0.002	NS	0.002	ND	0.002	NS	0.002	ND	0.002	NS	0.002	ND	NS	NS	NS	NS
Total Dissolved Solids	1,200	NS	NS	10	720	10	NS	10	940	10	NS	10	510	10	NS	10	730	NS	NS	NS	NS
Vanadium	0.049	NS	NS	0.005	ND^	0.005	NS	0.005	ND	0.005	NS	0.005	ND	0.005	NS	0.005	0.005	NS	NS	NS	NS
Zinc	5	NS	NS	0.02	ND	0.02	NS	0.02	ND ^	0.02	NS	0.02	ND	0.02	NS	0.02	ND	NS	NS	NS	NS
Benzene	0.005	NS	NS	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	NS	NS	NS	NS
BETX	11.705	NS	NS	0.0025	ND	0.0025	NS	0.0025	ND	0.0025	NS	0.0025	ND	0.0025	NS	0.0025	ND	NS	NS	NS	NS
pH	6.5 - 9.0	NS	NS	NA	7.20	NA	NS	NA	7.42	NA	NS	NA	7.9	NA	NS	NA	7.01	NS	NS	NS	NS
Temperature	NA	NS	NS	NA	13.12	NA	NS	NA	14.8	NA	NS	NA	11.25	NA	NS	NA	12.7	NS	NS	NS	NS
Conductivity	NA	NS	NS	NA	0.91	NA	NS	NA	2.25	NA	NS	NA	90.6	NA	NS	NA	1.226	NS	NS	NS	NS
Dissolved Oxygen	NA	NS	NS	NA	9.88	NA	NS	NA	8.62	NA	NS	NA	12.51	NA	NS	NA	8.61	NS	NS	NS	NS
ORP	NA	NS	NS	NA	30.4	NA	NS	NA	-246.5	NA	NS	NA	-29.4	NA	NS	NA	87.6	NS	NS	NS	NS

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^{c}	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-02	Date	8/1/2018		10/16/2018		2/4/2019		5/7/2019		8/6/2019		11/7/2019		2/13/2020		5/21/2020		7/30/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	NS	0.003	ND	0.003	NS	0.003	ND	NS	NS	NS	NS
Arsenic	0.01	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	NS	0.001	ND	0.001	NS	0.001	ND	NS	NS	NS	NS
Barium	2	0.0025	0.071	0.0025	0.063	0.0025	0.071	0.0025	0.11	0.0025	NS	0.0025	0.065	0.0025	NS	0.0025	0.089	NS	NS	NS	NS
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	NS	0.001	ND	0.001	NS	0.001	ND ^	NS	NS	NS	NS
Boron	2	0.05	0.14	0.05	0.15	0.05	0.14	0.05	0.15	0.05	NS	0.05	0.18	0.05	NS	0.05	0.24	NS	NS	NS	NS
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	NS	NS	NS	NS
Chloride	200	10	200	10	120	10	150	10	500	10	NS	10	100	10	NS	10	260	NS	NS	NS	NS
Chromium	0.1	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	NS	0.005	ND	0.005	NS	0.005	ND	NS	NS	NS	NS
Cobalt	1	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	NS	0.001	ND	0.001	NS	0.001	ND	NS	NS	NS	NS
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	NS	0.002	ND	0.002	NS	0.002	ND	NS	NS	NS	NS
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	NS	0.01	ND	0.01	NS	0.01	ND	NS	NS	NS	NS
Fluoride	4	0.1	0.4	0.1	0.43	0.1	0.39	0.1	0.41	0.1	NS	0.1	0.38	0.1	NS	0.1	0.41	NS	NS	NS	NS
Iron	5	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	NS	0.1	ND	0.1	NS	0.1	ND	NS	NS	NS	NS
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	NS	NS	NS	NS
Manganese	0.15	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	NS	0.0025	ND	0.0025	NS	0.0025	ND	NS	NS	NS	NS
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	NS	0.0002	ND	0.0002	NS	0.0002	ND	NS	NS	NS	NS
Nickel	0.1	0.002	0.003	0.002	ND	0.002	0.0027	0.002	0.0034	0.002	NS	0.002	0.0021	0.002	NS	0.002	0.0046	NS	NS	NS	NS
Nitrogen/Nitrate	10	0.1	0.81	0.1	0.68	0.1	1.0	0.1	1.8	0.1	NS	0.1	1.2	0.1	NS	0.1	2.9	NS	NS	NS	NS
Nitrogen/Nitrate, Nitrite	NA	0.1	0.81	0.1	0.68	0.1	1.0	0.1	1.8	0.1	NS	0.1	1.2	0.1	NS	0.1	2.9	NS	NS	NS	NS
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	NS	0.02	ND	0.02	NS	0.02	ND	NS	NS	NS	NS
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	NS	0.004	ND	0.004	NS	0.004	ND	NS	NS	NS	NS
Selenium	0.05	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	NS	0.0025	ND	0.0025	NS	0.0025	0.0045	NS	NS	NS	NS
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	NS	NS	NS	NS
Sulfate	400	20	76	20	45	20	71	20	73	20	NS	20	34	20	NS	20	160	NS	NS	NS	NS
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	NS	0.002	ND	0.002	NS	0.002	ND	NS	NS	NS	NS
Total Dissolved Solids	1,200	10	760	10	520	10	690	10	1,100	10	NS	10	580	10	NS	10	910	NS	NS	NS	NS
Vanadium	0.049	0.005	ND	0.005	ND^	0.005	ND	0.005	ND	0.005	NS	0.005	ND	0.005	NS	0.005	ND	NS	NS	NS	NS
Zinc	5	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	NS	0.02	ND	0.02	NS	0.02	ND	NS	NS	NS	NS
Benzene	0.005	0.0005	0.001	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	NS	0.0005	ND	0.0005	NS	0.0005	ND	NS	NS	NS	NS
BETX	11.705	0.0025	0.0142	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	NS	0.0025	ND	0.0025	NS	0.0025	ND	NS	NS	NS	NS
pH	6.5 - 9.0	NA	7.36	NA	7.70	NA	7.32	NA	7.3	NA	NS	NA	7.16	NA	NS	NA	6.99	NS	NS	NS	NS
Temperature	NA	NA	17.40	NA	14.68	NA	13.4	NA	19.3	NA	NS	NA	12.61	NA	NS	NA	14.5	NS	NS	NS	NS
Conductivity	NA	NA	0.961	NA	0.735	NA	1.1	NA	3.0	NA	NS	NA	9.67	NA	NS	NA	1.577	NS	NS	NS	NS
Dissolved Oxygen	NA	NA	5.36	NA	6.25	NA	6.20	NA	6.98	NA	NS	NA	9.1	NA	NS	NA	7.77	NS	NS	NS	NS
ORP	NA	NA	85.9	NA	36.6	NA	125.6	NA	NA	NA	NS	NA	-10.5	NA	NS	NA	82.1	NS	NS	NS	NS

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^{c}	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-03	Date	7/31/2018		10/17/2018		2/4/2019		5/7/2019		8/7/2019		11/7/2019		2/17/2020		5/20/2020		7/30/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND
Arsenic	0.01	0.001	0.0012	0.001	0.001	0.001	0.0011	0.001	0.001	0.001	ND	0.001	0.0012	0.001	0.0015	0.001	0.0015	0.001	0.001	0.001	ND
Barium	2	0.0025	0.099	0.0025	0.1	0.0025	0.089	0.0025	0.11	0.0025	0.088	0.0025	0.081	0.0025	0.09	0.0025	0.11	0.0025	0.093	0.0025	0.1
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND ^	0.001	ND	0.001	ND
Boron	2	0.05	0.33	0.05	0.22	0.05	0.36	0.05	0.41	0.05	0.36	0.05	0.32	0.05	0.33	0.05	0.36	0.05	0.28	0.05	0.29
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Chloride	200	10	260	10	250	10	160	10	270 F1	10	220	10	150	10	130	10	230	10	170	10	180
Chromium	0.1	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Cobalt	1	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.005	0.0062	0.01	ND
Fluoride	4	0.1	0.42	0.1	0.4	0.1	0.43	0.1	0.41	0.1	0.39	0.1	0.41	0.1	0.46	0.1	0.42	0.1	0.45	0.1	0.44
Iron	5	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Manganese	0.15	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0035	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND
Nickel	0.1	0.002	0.0025	0.002	0.0049	0.002	0.0033	0.002	0.0035	0.002	ND	0.002	0.0028	0.002	ND	0.002	ND	0.002	ND	0.002	0.0031
Nitrogen/Nitrate	10	0.1	1.4	0.1	0.94	0.1	1.0	0.1	2.1	0.1	2.7	0.1	1.8	0.1	1.7	0.1	2.1	0.1	3	0.1	2.8
Nitrogen/Nitrate, Nitrite	NA	0.1	1.4	0.1	0.94	0.1	1.0	0.1	2.1	0.1	2.7	0.1	1.8	0.1	1.7	0.1	2.1	0.5	3	0.5	2.8
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND
Selenium	0.05	0.0025	0.0038	0.0025	ND	0.0025	0.0032	0.0025	0.0056	0.0025	0.0037	0.0025	0.0025	0.0025	0.0025	0.0025	0.0039	0.0025	0.0028	0.0025	ND
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Sulfate	400	25	110	25	84	25	100	25	160	25	71	25	73	25	65	25	100	25	77	15	91
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Total Dissolved Solids	1,200	10	920	10	860	10	770	10	900	10	760	10	740	10	610	10	910	30	680	30	760
Vanadium	0.049	0.005	ND	0.005	ND^	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Zinc	5	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Benzene	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
BETX	11.705	0.0025	0.001	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
pH	6.5 - 9.0	NA	7.22	NA	7.04	NA	7.44	NA	7.27	NA	7.34	NA	7.32	NA	7.31	NA	7.56	NA	7.1	NA	7.23
Temperature	NA	NA	20.13	NA	11.69	NA	11.00	NA	12.00	NA	13.00	NA	11.86	NA	12.00	NA	11.50	NA	12.50	NA	12.60
Conductivity	NA	NA	1.206	NA	1.070	NA	123.700	NA	2.35	NA	1.37	NA	11.87	NA	9.37	NA	9.92	NA	1.36	NA	1.35
Dissolved Oxygen	NA	NA	6.75	NA	9.38	NA	7.10	NA	6.48	NA	6.09	NA	8.23	NA	5.7	NA	3.98	NA	7.65	NA	4.22
ORP	NA	NA	142.0	NA	101.7	NA	194.7	NA	-237.9	NA	157.7	NA	-9.8	NA	154.4	NA	160.7	NA	157.4	NA	180.0

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^c	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-04	Date	7/31/2018		10/17/2018		2/4/2019		5/7/2019		8/6/2019		11/6/2019		2/17/2020		5/20/2020		7/31/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND
Arsenic	0.01	0.001	0.0011	0.001	0.001	0.001	0.0012	0.001	0.001	0.001	ND	0.001	0.001	0.001	0.0014	0.001	0.0014	0.001	ND	0.001	ND
Barium	2	0.0025	0.089	0.0025	0.093	0.0025	0.085	0.0025	0.091	0.0025	0.08	0.0025	0.082	0.0025	0.085	0.0025	0.085	0.0025	0.082	0.0025	0.09
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Boron	2	0.05	0.35	0.05	0.29	0.05	0.44	0.05	0.77	0.05	0.26	0.05	0.28	0.05	0.25	0.05	0.25	0.05	0.23	0.05	0.29
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Chloride	200	10	250	10	210	10	190	10	310	10	220	10	140	10	160	10	160	10	170	10	190
Chromium	0.1	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Cobalt	1	0.001	0.008	0.001	ND	0.001	0.0046	0.001	ND	0.001	0.0057	0.001	0.0016	0.001	0.0071	0.001	0.0071	0.001	0.0031	0.001	0.0041
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.005	0.0057	0.01	ND
Fluoride	4	0.1	0.43	0.1	0.46	0.1	0.46	0.1	0.43	0.1	0.39	0.1	0.42	0.1	0.46	0.1	0.46	0.1	0.47	0.1	0.49
Iron	5	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Manganese	0.15	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND
Nickel	0.1	0.002	ND	0.002	0.0021	0.002	0.0022	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Nitrogen/Nitrate	10	0.1	1.7	0.1	1.4	0.1	1.4	0.1	2.5	0.1	2.5	0.1	1.8	0.1	1.6	0.1	1.6	0.1	2.7	0.1	3.4
Nitrogen/Nitrate, Nitrite	NA	0.1	1.7	0.1	1.4	0.1	1.4	0.1	2.5	0.1	2.5	0.1	1.8	0.1	1.6	0.1	1.6	0.5	2.7	0.5	3.4
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND
Selenium	0.05	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0076	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Sulfate	400	50	110	25	91	25	130	25	150	25	74	25	53	25	94	25	94	25	75	15	82
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Total Dissolved Solids	1,200	10	1000	10	790	10	840	10	980	10	770	10	690	10	710	10	710	30	700	30	760
Vanadium	0.049	0.005	ND	0.005	ND^	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Zinc	5	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Benzene	0.005	0.0005	0.0024	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
BETX	11.705	0.0025	0.0082	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
pH	6.5 - 9.0	NA	7.58	NA	7.20	NA	7.41	NA	7.27	NA	7.31	NA	7.33	NA	7.26	NA	7.26	NA	7.23	NA	7.15
Temperature	NA	NA	16.54	NA	12.53	NA	11.30	NA	11.60	NA	12.70	NA	11.72	NA	11.20	NA	11.20	NA	14.20	NA	14.40
Conductivity	NA	NA	1.125	NA	1.086	NA	1.336	NA	2.520	NA	1.440	NA	1.080	NA	1.016	NA	1.016	NA	1.428	NA	0.292
Dissolved Oxygen	NA	NA	7.54	NA	8.36	NA	6.32	NA	7.10	NA	52.40	NA	6.65	NA	6.23	NA	6.23	NA	7.32	NA	5.33
ORP	NA	NA	96.5	NA	58.0	NA	163.9	NA	-233.6	NA	182.3	NA	192.0	NA	167.2	NA	167.2	NA	128.4	NA	178.4

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^c	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-05	Date	7/31/2018		10/17/2018		2/5/2019		5/6/2019		8/6/2019		11/7/2019		2/13/2020		5/20/2020		7/31/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND
Arsenic	0.01	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	0.0033	0.001	ND	0.001	0.0011	0.001	ND	0.001	ND
Barium	2	0.0025	0.061	0.0025	0.067	0.0025	0.076	0.0025	0.094	0.0025	0.062	0.0025	0.062	0.0025	0.072	0.0025	0.074	0.0025	0.054	0.0025	0.07
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND ^	0.001	ND	0.001	ND
Boron	2	0.05	0.58	0.05	0.31	0.05	0.28	0.05	0.34	0.05	0.5	0.05	0.32	0.05	0.43	0.05	0.29	0.05	0.47	0.05	0.47
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Chloride	200	10	120	10	200	10	180	10	470	10	120	10	130	10	170	10	280	10	180	10	180
Chromium	0.1	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	0.0053	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Cobalt	1	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	0.0015	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	0.0063	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.005	ND	0.01	ND
Fluoride	4	0.1	0.38	0.1	0.33	0.1	0.33	0.1	0.31	0.1	0.31	0.1	0.31	0.1	0.36	0.1	0.37	0.1	0.38	0.1	0.38
Iron	5	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	4.1	0.1	ND	0.1	0.11	0.1	ND	0.1	ND
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	0.0033	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Manganese	0.15	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.14	0.0025	ND	0.0025	0.0025	0.0025	ND	0.0025	ND
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND
Nickel	0.1	0.002	0.0034	0.002	ND	0.002	ND	0.002	ND	0.002	0.0024	0.002	0.0072	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Nitrogen/Nitrate	10	0.1	1.7	0.1	1.3	0.1	0.92	0.1	1.8	0.1	1.3	0.1	1.2	0.1	1.2	0.1	1.4	0.1	1.3	0.1	0.99
Nitrogen/Nitrate, Nitrite	NA	0.1	1.7	0.1	1.3	0.1	0.92	0.1	1.8	0.1	1.3	0.1	1.2	0.1	1.2	0.1	1.4	0.1	1.3	0.1	0.99
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND
Selenium	0.05	0.0025	0.023	0.0025	0.0028	0.0025	ND	0.0025	ND	0.0025	0.011	0.0025	ND	0.0025	0.0025	0.0025	0.0048	0.0025	0.0029	0.0025	0.0032
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Sulfate	400	50	190	25	110	25	110	25	90	25	180	25	68	25	ND	25	190	25	79	15	84
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Total Dissolved Solids	1,200	10	1000	10	800	10	720	10	1,400	10	770	10	630	10	700	10	920	30	680	30	690
Vanadium	0.049	0.005	0.0077	0.005	ND^	0.005	ND	0.005	ND	0.005	ND	0.005	0.012	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Zinc	5	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	0.027	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Benzene	0.005	0.0005	0.00096	0.0005	ND	0.0005	ND	0.0005	0.0007	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
BETX	11.705	0.0025	0.00396	0.0025	ND	0.0025	ND	0.0025	0.0007	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
pH	6.5 - 9.0	NA	7.61	NA	7.29	NA	7.40	NA	7.11	NA	7.03	NA	7.44	NA	7.02	NA	7.03	NA	7.28	NA	7.16
Temperature	NA	NA	18.49	NA	14.72	NA	10.70	NA	13	NA	14.2	NA	10.34	NA	13.2	NA	12.8	NA	13.7	NA	14.5
Conductivity	NA	NA	1.122	NA	1.050	NA	1.116	NA	2.95	NA	1.28	NA	10.56	NA	1.058	NA	1.534	NA	1.381	NA	0.278
Dissolved Oxygen	NA	NA	5.67	NA	7.68	NA	5.97	NA	4.48	NA	3.53	NA	7.84	NA	6.2	NA	6.85	NA	5.7	NA	4.34
ORP	NA	NA	77.8	NA	42.1	NA	150.3	NA	-281.1	NA	170.6	NA	-11.9	NA	136.4	NA	142.8	NA	119.9	NA	161.3

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^c	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-06	Date	7/31/2018		10/18/2018		2/5/2019		5/6/2019		8/7/2019		11/7/2019		2/13/2020		5/21/2020		7/31/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND
Arsenic	0.01	0.001	0.0012	0.001	0.001	0.001	0.0011	0.001	0.0014	0.001	ND	0.001	0.0011	0.001	0.0014	0.001	0.0017	0.001	0.001	0.001	ND
Barium	2	0.0025	0.1	0.0025	0.13	0.0025	0.12	0.0025	0.15	0.0025	0.11	0.0025	0.13	0.0025	0.14	0.0025	0.14	0.0025	0.13	0.0025	0.13
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND ^	0.001	ND	0.001	ND
Boron	2	0.05	0.21	0.05	0.22	0.05	0.24	0.05	0.3	0.05	0.21	0.05	0.24	0.05	0.2	0.05	0.49	0.05	0.18	0.05	0.23
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Chloride	200	10	140	10	150	10	170 F1	10	420	10	130	10	99	10	150	10	180	10	160	10	160
Chromium	0.1	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Cobalt	1	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.005	0.0051	0.01	ND
Fluoride	4	0.1	0.31	0.1	0.34	0.1	0.33	0.1	0.34	0.1	0.26	0.1	0.3	0.1	0.37	0.1	0.37	0.1	0.32	0.1	0.31
Iron	5	0.1	ND	0.1	ND	0.1	ND	0.1	0.26	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Manganese	0.15	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.017	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND
Nickel	0.1	0.002	ND	0.002	ND	0.002	ND	0.002	0.0024	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Nitrogen/Nitrate	10	0.1	0.43	0.1	0.34	0.1	2.2	0.1	1.7	0.1	0.47	0.1	0.61	0.1	0.75	0.1	1.9	0.1	0.66	0.1	0.56
Nitrogen/Nitrate, Nitrite	NA	0.1	0.43	0.1	0.34	0.1	2.2	0.1	1.7	0.1	0.47	0.1	0.61	0.1	0.75	0.1	1.9	0.1	0.66	0.1	0.56
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND
Selenium	0.05	0.0025	ND	0.0025	0.0034	0.0025	0.0026	0.0025	0.026	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.053	0.0025	ND	0.0025	ND
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND F1	0.0005	ND	0.0005	ND	0.0005	ND
Sulfate	400	25	76	20	89	20	130	20	110	20	7.8	20	78	20	130	20	160	25	110	15	83
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Total Dissolved Solids	1,200	10	620	10	640	10	720	10	1,200	10	620	10	620	10	710	10	830	30	650	30	640
Vanadium	0.049	0.005	ND	0.005	ND^	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	0.0056	0.005	ND	0.005	ND
Zinc	5	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Benzene	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
BETX	11.705	0.0025	0.0023	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
pH	6.5 - 9.0	NA	7.54	NA	7.63	NA	7.62	NA	7.42	NA	7.39	NA	7.27	NA	7.42	NA	7.06	NA	7.44	NA	6.95
Temperature	NA	NA	19.68	NA	12.51	NA	13.1	NA	11.7	NA	12.8	NA	13.84	NA	13.2	NA	12.5	NA	13.2	NA	17.1
Conductivity	NA	NA	1.265	NA	0.825	NA	1159	NA	2.83	NA	1.06	NA	9.34	NA	0.983	NA	1.141	NA	1.306	NA	1.2
Dissolved Oxygen	NA	NA	7.19	NA	10.56	NA	5.93	NA	5.82	NA	51.00	NA	9.01	NA	7.71	NA	7.98	NA	7.06	NA	3.67
ORP	NA	NA	71.6	NA	2.2	NA	112.0	NA	-265.1	NA	187.4	NA	-11.6	NA	157.2	NA	224.6	NA	152.0	NA	157.4

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^c	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-07	Date	8/1/2018		10/18/2018		2/5/2019		5/6/2019		8/6/2019		11/7/2019		2/13/2020		5/21/2020		7/31/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND
Arsenic	0.01	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	0.0011	0.001	ND	0.001	ND	0.001	ND
Barium	2	0.0025	0.093	0.0025	0.12	0.0025	0.13	0.0025	0.1	0.0025	0.11	0.0025	0.11	0.0025	0.14	0.0025	0.095	0.0025	0.11	0.0025	0.13
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND ^	0.001	ND	0.001	ND
Boron	2	0.05	0.18	0.05	0.25	0.05	0.19	0.05	0.24	0.05	0.23	0.05	0.19	0.05	0.23	0.05	0.38	0.05	0.19	0.05	0.34
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Chloride	200	10	130	10	140	10	180	10	400 F1	10	130	10	87	10	190	10	190	10	210	10	150
Chromium	0.1	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Cobalt	1	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.005	ND	0.01	ND
Fluoride	4	0.1	0.29	0.1	0.26	0.1	0.26	0.1	0.3	0.1	0.24	0.1	0.26	0.1	0.3	0.1	0.33	0.1	0.29	0.1	0.28
Iron	5	0.1	ND	0.1	0.58	0.1	0.45	0.1	0.2	0.1	0.16	0.1	ND	0.1	0.13	0.1	ND	0.1	ND	0.1	ND
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	0.0005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Manganese	0.15	0.0025	0.0026	0.0025	0.015	0.0025	0.017	0.0025	0.0068	0.0025	0.0063	0.0025	ND	0.0025	0.004	0.0025	ND	0.0025	0.0041	0.0025	ND
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND
Nickel	0.1	0.002	ND	0.002	0.0021	0.002	0.0022	0.002	0.0022	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Nitrogen/Nitrate	10	0.1	0.29	0.1	0.29	0.1	0.85	0.1	1.6	0.1	0.23	0.1	0.68	0.1	0.88	0.1	1.4	0.1	0.54	0.1	0.93
Nitrogen/Nitrate, Nitrite	NA	0.1	0.29	0.1	0.29	0.1	0.85	0.1	1.6	0.1	0.23	0.1	0.68	0.1	0.88	0.1	1.4	0.1	0.54	0.1	0.93
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND
Selenium	0.05	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0048	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0038	0.0025	ND	0.0025	0.0025
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Sulfate	400	20	64	20	90	20	87	20	97	20	48	20	83	20	96	20	140	25	85	15	97
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Total Dissolved Solids	1,200	10	580	10	680	10	670	10	1,300	10	590	10	540	10	710	10	750	30	630	30	680
Vanadium	0.049	0.005	ND	0.005	ND^	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Zinc	5	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Benzene	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
BETX	11.705	0.0025	0.0018	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
pH	6.5 - 9.0	NA	7.47	NA	7.51	NA	7.48	NA	7.36	NA	7.31	NA	7.55	NA	7.27	NA	7.09	NA	7.23	NA	7.06
Temperature	NA	NA	21.38	NA	12.69	NA	12.70	NA	12.10	NA	12.40	NA	13.75	NA	12.80	NA	12.00	NA	13.10	NA	14.50
Conductivity	NA	NA	1.143	NA	0.784	NA	1.129	NA	2.720	NA	1.020	NA	8.950	NA	1.052	NA	1.100	NA	1.327	NA	1.230
Dissolved Oxygen	NA	NA	3.97	NA	9.73	NA	2.96	NA	6.71	NA	27.40	NA	5.54	NA	7.22	NA	6.48	NA	4.62	NA	3.98
ORP	NA	NA	92.9	NA	6.0	NA	113.5	NA	-281.3	NA	189.6	NA	-22.6	NA	158.8	NA	282.5	NA	187.6	NA	150.9

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^c	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-08	Date	8/1/2018		10/16/2018		2/5/2019		5/6/2019		8/6/2019		11/7/2019		2/12/2020		5/20/2020		7/30/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND
Arsenic	0.01	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Barium	2	0.0025	0.037	0.0025	0.044	0.0025	0.046	0.0025	0.031	0.0025	0.027	0.0025	0.034	0.0025	0.054	0.0025	0.041	0.0025	0.047	0.0025	0.062
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND ^	0.001	ND	0.001	ND
Boron	2	0.05	0.15	0.05	0.15	0.05	0.089	0.05	0.09	0.05	0.12	0.05	0.14	0.05	0.11	0.05	0.14	0.05	0.11	0.05	0.18
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Chloride	200	10	120	10	85	10	200	10	310	10	270	10	70	10	230	10	370	10	160	10	180
Chromium	0.1	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Cobalt	1	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.005	0.0062	0.01	ND
Fluoride	4	0.1	0.31	0.1	0.3	0.1	0.34	0.1	0.4	0.1	0.28	0.1	0.26	0.1	0.33	0.1	0.34	0.1	0.3	0.1	0.27
Iron	5	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Manganese	0.15	0.0025	ND	0.0025	0.0027	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND
Nickel	0.1	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	0.0055	0.002	0.0024	0.002	ND	0.002	0.002
Nitrogen/Nitrate	10	0.1	0.49	0.1	0.63	0.1	0.89	0.1	2.3	0.1	0.76	0.1	0.94	0.1	1	0.1	3.6	0.1	1.4	0.1	1.4
Nitrogen/Nitrate, Nitrite	NA	0.1	0.49	0.1	0.63	0.1	0.89	0.1	2.3	0.1	0.76	0.1	0.94	0.1	1	0.1	3.6	0.1	1.4	0.1	1.4
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND
Selenium	0.05	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0043	0.0025	ND	0.0025	ND
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Sulfate	400	20	43	20	31	20	26	20	39	20	16	20	29	20	63	20	89	25	83	15	140
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Total Dissolved Solids	1,200	10	520	10	480	10	560	10	930	10	420	10	470	10	750	10	1100	30	650	30	800
Vanadium	0.049	0.005	ND	0.005	ND^	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Zinc	5	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Benzene	0.005	0.0005	0.0022	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
BETX	11.705	0.0025	0.0249	0.0025	0.0016	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
pH	6.5 - 9.0	NA	7.41	NA	7.47	NA	7.45	NA	7.38	NA	7.41	NA	7.01	NA	7.25	NA	7.10	NA	6.97	NA	7.14
Temperature	NA	NA	18.27	NA	14.62	NA	14.20	NA	13.80	NA	12.40	NA	11.31	NA	13.30	NA	12.80	NA	13.20	NA	12.90
Conductivity	NA	NA	0.854	NA	0.691	NA	1.062	NA	2.200	NA	0.850	NA	8.020	NA	1.112	NA	1.860	NA	1.297	NA	1.880
Dissolved Oxygen	NA	NA	5.48	NA	5.97	NA	5.22	NA	6.50	NA	48.30	NA	6.97	NA	7.14	NA	9.68	NA	6.97	NA	3.88
ORP	NA	NA	85.3	NA	83.5	NA	112.6	NA	-291.4	NA	190.0	NA	-24.4	NA	177.6	NA	139.8	NA	185.2	NA	189.0

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^c	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-09	Date	8/1/2018		10/16/2018		2/5/2019		5/7/2019		8/7/2019		11/7/2019		2/12/2020		5/20/2020		8/5/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND
Arsenic	0.01	0.001	0.0013	0.001	0.0013	0.001	0.0023	0.001	0.0042	0.001	0.0016	0.001	0.0047	0.001	0.0038	0.001	0.0062	0.001	0.001	0.001	0.034
Barium	2	0.0025	0.0083	0.0025	0.011	0.0025	0.011	0.0025	0.012	0.0025	0.0084	0.0025	0.012	0.0025	0.01	0.0025	0.013	0.0025	0.01	0.0025	0.086
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND ^	0.001	ND	0.001	ND ^
Boron	2	0.05	0.29	0.05	0.27	0.05	0.35	0.05	0.45	0.05	0.33	0.05	0.73	0.05	0.33	0.05	0.3	0.05	0.29	0.05	0.37
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	0.0021
Chloride	200	10	210	10	210	10	140	10	57	10	180	10	23	10	75	10	6.1 F1	10	140	10	190
Chromium	0.1	0.005	ND	0.005	ND	0.005	0.005	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	0.028
Cobalt	1	0.001	0.021	0.001	0.022	0.001	0.033	0.001	0.059	0.001	0.031	0.001	0.065	0.001	0.032	0.001	0.04	0.001	0.016	0.001	0.046
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	0.041
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.005	0.0053	0.01	ND
Fluoride	4	0.1	0.38	0.1	0.43	0.1	0.46	0.1	0.57	0.1	0.41	0.1	0.63	0.1	0.52	0.1	0.71	0.1	0.66	0.1	0.66
Iron	5	1	750	1	530	1	1200	1	2,700	1	630	1	1800	1	960	1	1900	10	400	0.5	970
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	0.036
Manganese	0.15	0.0025	1.3	0.0025	0.96	0.0025	2.1	0.0025	4.2	0.0025	1.4	0.0025	4.4	0.0025	2.2	0.0025	3	0.0025	0.96	0.0025	2.3
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND
Nickel	0.1	0.002	0.046	0.002	0.03	0.002	0.077	0.002	0.2	0.002	0.051	0.002	0.22	0.002	0.084	0.002	0.13	0.002	0.036	0.002	0.1
Nitrogen/Nitrate	10	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND
Nitrogen/Nitrate, Nitrite	NA	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND F1	0.1	ND	5	ND	0.1	ND
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND
Selenium	0.05	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0027
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Sulfate	400	500	2500	500	1900	500	3400	500	8900	500	2800	500	7100	500	ND	500	6800	250	2000	250	1500
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Total Dissolved Solids	1,200	13	4900	10	3700	10	5900	10	15000	10	5000	10	11000	10	6600	10	11000	150	2900	150	3000
Vanadium	0.049	0.005	ND	0.005	ND^	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	0.026
Zinc	5	0.02	0.56	0.02	0.3	0.02	0.74	0.02	4.1	0.02	0.6	0.02	2.6	0.02	1	0.02	2.4	0.02	0.42	0.02	1.2
Benzene	0.005	0.0005	0.0039	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
BETX	11.705	0.0025	0.0252	0.0025	0.0011	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
pH	6.5 - 9.0	NA	7.30	NA	6.47	NA	6.16	NA	5.70	NA	6.07	NA	5.53	NA	5.74	NA	5.41	NA	6.26	NA	5.73
Temperature	NA	NA	22.20	NA	14.34	NA	12.60	NA	12.40	NA	13.10	NA	12.17	NA	12.60	NA	12.10	NA	13.90	NA	17.70
Conductivity	NA	NA	3.619	NA	2.920	NA	4.982	NA	13.650	NA	4.050	NA	7.426	NA	4.789	NA	7.209	NA	3.080	NA	4.030
Dissolved Oxygen	NA	NA	1.32	NA	2.45	NA	1.58	NA	0.48	NA	0.36	NA	1.18	NA	5.13	NA	1.17	NA	NS	NA	0.47
ORP	NA	NA	35.8	NA	39.2	NA	-41.8	NA	-402.4	NA	-25.1	NA	35.2	NA	24.8	NA	25.9	NA	-44.5	NA	-91.4

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^c	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-10	Date	8/1/2018		10/17/2018		2/5/2019		5/7/2019		8/6/2019		11/7/2019		2/12/2020		5/20/2020		7/30/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND
Arsenic	0.01	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Barium	2	0.0025	0.042	0.0025	0.04	0.0025	0.044	0.0025	0.05	0.0025	0.037	0.0025	0.033	0.0025	0.044	0.0025	0.045	0.0025	0.036	0.0025	0.04
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND ^	0.001	ND	0.001	ND
Boron	2	0.05	0.27	0.05	0.6	0.05	0.25	0.05	0.49	0.05	0.35	0.05	0.29	0.05	0.29	0.05	0.7	0.05	0.24	0.05	0.29
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Chloride	200	10	240	10	170	10	210	10	410	10	200	10	130	10	180	10	250	2	170	10	230
Chromium	0.1	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Cobalt	1	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	0.0029	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.005	ND	0.01	ND
Fluoride	4	0.1	0.39	0.1	0.4	0.1	0.41	0.1	0.4	0.1	0.35	0.1	0.37	0.1	0.44	0.1	0.42	0.1	0.42	0.1	0.41
Iron	5	0.1	ND	0.1	ND	0.1	ND	0.1	0.44	0.1	ND	0.1	0.25	0.1	ND	0.1	1.8	0.1	ND	0.1	ND
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Manganese	0.15	0.0025	ND	0.0025	0.0028	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0029	0.0025	ND	0.0025	0.0034	0.0025	ND	0.0025	ND
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND
Nickel	0.1	0.002	ND	0.002	0.0021	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	0.0023	0.002	ND	0.002	ND	0.002	ND
Nitrogen/Nitrate	10	0.1	1.7	0.1	0.96	0.1	1.3	0.1	2.4	0.1	ND	0.1	1.8	0.1	1.7	0.1	1.4	0.1	2.8	0.1	3.8
Nitrogen/Nitrate, Nitrite	NA	0.1	1.7	0.1	0.96	0.1	1.3	0.1	2.4	0.1	2.3	0.1	1.8	0.1	1.7	0.1	1.4	0.5	2.8	0.5	3.8
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND
Selenium	0.05	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0041	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0035	0.0025	ND	0.0025	ND
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Sulfate	400	25	110	25	120	25	85	25	100	25	95	25	ND	25	110	25	170	25	88	15	94
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Total Dissolved Solids	1,200	10	1000	10	750	10	910	10	1000	10	810	10	660	10	810	10	1000	30	720	30	850
Vanadium	0.049	0.005	ND	0.005	ND^	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Zinc	5	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Benzene	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
BETX	11.705	0.0025	0.0024	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
pH	6.5 - 9.0	NA	7.35	NA	7.30	NA	7.31	NA	7.17	NA	7.4	NA	7.4	NA	7.28	NA	6.9	NA	6.95	NA	7.11
Temperature	NA	NA	17.55	NA	14.62	NA	12.5	NA	11.8	NA	12.3	NA	11.89	NA	12.9	NA	12.5	NA	12.3	NA	12.7
Conductivity	NA	NA	1.147	NA	1.113	NA	1.39	NA	2.74	NA	1.45	NA	1.085	NA	1.133	NA	1.61	NA	1.405	NA	1.51
Dissolved Oxygen	NA	NA	7.00	NA	8.75	NA	5.60	NA	7.18	NA	5.45	NA	9.30	NA	7.73	NA	8.65	NA	7.68	NA	4.79
ORP	NA	NA	89.1	NA	34.6	NA	127.7	NA	-231.3	NA	167.5	NA	-12.2	NA	166.3	NA	133.9	NA	138.6	NA	172.5

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^c	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

Table 2. Groundwater Analytical Results - Midwest Generation LLC, Joliet Station #29, Joliet, IL

Sample: MW-11	Date	8/1/2018		10/17/2018		2/5/2019		5/7/2019		8/6/2019		11/7/2019		2/13/2020		5/20/2020		7/30/2020		10/22/2020	
Parameter	Standards	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result	DL	Result
Antimony	0.006	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND	0.003	ND
Arsenic	0.01	0.001	0.0012	0.001	0.0015	0.001	0.0013	0.001	0.0019	0.001	0.0011	0.001	ND	0.001	0.0014	0.001	0.0023	0.001	0.0011	0.001	ND
Barium	2	0.0025	0.046	0.0025	0.064	0.0025	0.063	0.0025	0.058	0.0025	0.051	0.0025	0.033	0.0025	0.065	0.0025	0.085	0.0025	0.051	0.0025	0.055
Beryllium	0.004	0.001	ND	0.001	ND^	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND ^	0.001	ND	0.001	ND
Boron	2	0.05	1.2 V	0.05	1.2	0.05	2.7	0.05	0.98	0.05	1.1	0.05	0.29	0.05	1.4	0.05	0.51	0.05	0.86	0.05	0.44
Cadmium	0.005	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Chloride	200	10	120	10	160	10	170	10	290	10	130	10	130	10	200	10	520	10	170	10	170
Chromium	0.1	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Cobalt	1	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND	0.001	ND
Copper	0.65	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	0.0029	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Cyanide	0.2	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.01	ND	0.005	ND	0.01	ND
Fluoride	4	0.1	0.29	0.1	0.27	0.1	0.27	0.1	0.34	0.1	0.24	0.1	0.37	0.1	0.3	0.1	0.34	0.1	0.3	0.1	0.28
Iron	5	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	ND	0.1	0.25	0.1	ND	0.1	0.23	0.1	ND	0.1	ND
Lead	0.0075	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Manganese	0.15	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	0.0029	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
Mercury	0.002	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND	0.0002	ND
Nickel	0.1	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Nitrogen/Nitrate	10	0.1	0.41	0.1	0.66	0.1	0.92	0.1	1.4	0.1	0.34	0.1	1.8	0.1	0.79	0.1	2	0.1	0.85	0.1	0.59
Nitrogen/Nitrate, Nitrite	NA	0.1	0.41	0.1	0.66	0.1	0.92	0.1	1.4	0.1	0.34	0.1	1.8	0.1	0.79	0.1	2	0.1	0.85	0.1	0.59
Nitrogen/Nitrite	NA	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND F1	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Perchlorate	0.0049	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND	0.004	ND
Selenium	0.05	0.0025	0.0032 F1	0.0025	0.0029	0.0025	0.0056	0.0025	0.0056	0.0025	0.003	0.0025	ND	0.0025	0.0029	0.0025	0.0039	0.0025	ND	0.0025	ND
Silver	0.05	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
Sulfate	400	25	84	50	93	50	91	50	81	50	78	50	ND	50	110	50	82	25	100	15	89
Thallium	0.002	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND	0.002	ND
Total Dissolved Solids	1,200	10	720	10	740	10	780	10	810	10	590	10	660	10	710	10	1400	30	670	30	710
Vanadium	0.049	0.005	ND	0.005	ND^	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND	0.005	ND
Zinc	5	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND	0.02	ND
Benzene	0.005	0.0005	0.0029	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND	0.0005	ND
BETX	11.705	0.0025	0.0106	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND	0.0025	ND
pH	6.5 - 9.0	NA	7.39	NA	7.37	NA	7.33	NA	7.45	NA	7.42	NA	7.4	NA	7.3	NA	7.12	NA	7.13	NA	7.11
Temperature	NA	NA	18.04	NA	14.41	NA	13.1	NA	10.9	NA	12.3	NA	11.89	NA	13.7	NA	12.2	NA	12.1	NA	12.7
Conductivity	NA	NA	0.965	NA	0.866	NA	1.212	NA	2.24	NA	1.05	NA	1.085	NA	1.138	NA	2.323	NA	1.332	NA	1.51
Dissolved Oxygen	NA	NA	5.84	NA	8.17	NA	7.00	NA	10.94	NA	7.00	NA	9.30	NA	8.76	NA	11.05	NA	9.19	NA	4.79
ORP	NA	NA	88.9	NA	30.5	NA	122.0	NA	-234.2	NA	163.4	NA	-12.2	NA	156.1	NA	139.8	NA	140.8	NA	172.5

Notes: Standards obtained from IAC, Title 35, Chapter I, Part 620, Subpart D, Section 620.410 - Groundwater Quality Standards for Class I: Potable Resource Groundwater

All values are in mg/L (ppm) unless otherwise noted.

Temperature	°C	degrees Celsius
Conductivity	ms/cm^c	millisiemens/centimeters
Dissolved Oxygen	mg/L	milligrams/liter
Oxygen Reduction Potential (ORP)	mV	millivolts

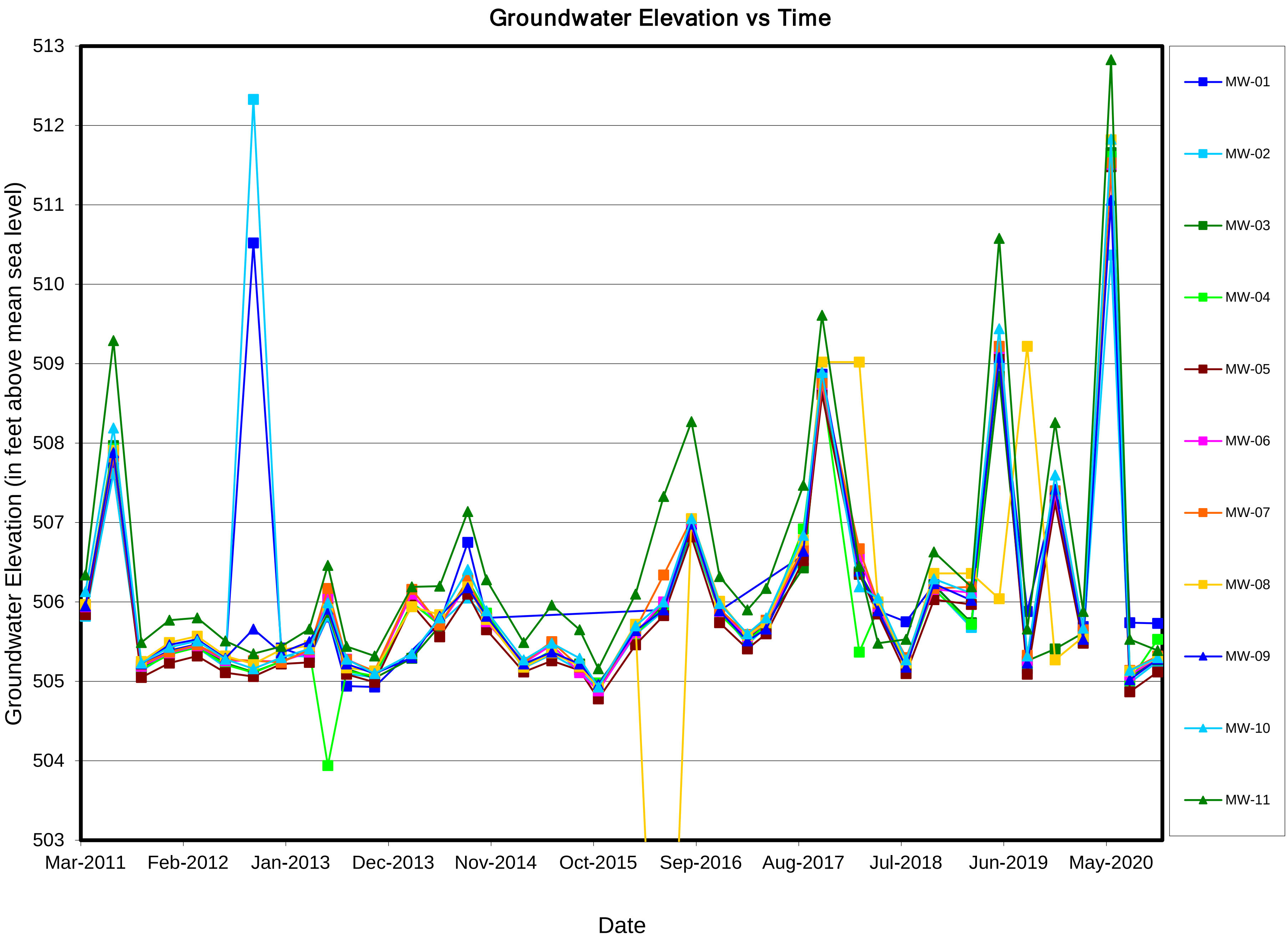
DL - Detection limit
NA - Not Applicable
ND - Not Detected
NS - Not Sampled

^ - Instrument related QC outside limit.
F1- MS and/or MSD recovery exceeds control limits.
J- Estimated concentration. Less than RL but at or above MDL.

ATTACHMENT 1

Hydrograph

Midwest Generation Joliet Station #29, Joliet, IL



ATTACHMENT 2

Analytical Data Package

eurofins

Environment Testing
America

1
2
3
4
5
6
7
8
9
10
11
12
13
14

ANALYTICAL REPORT

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Tel: (708)534-5200

Laboratory Job ID: 500-189929-1
Client Project/Site: Joliet #29 Station Ash Ponds (CCA)

For:
KPRG and Associates, Inc.
14665 West Lisbon Road,
Suite 1A
Brookfield, Wisconsin 53005

Attn: Richard Gnat

Diana Mockler

Authorized for release by:
11/13/2020 3:31:31 PM

Diana Mockler, Project Manager I
(219)252-7570
Diana.Mockler@Eurofinset.com

LINKS

Review your project results through
Total Access

Have a Question?
Ask The Expert

Visit us at:
www.eurofinsus.com/Env

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

Table of Contents

Case Narrative

Job ID: 500-189929-1

Laboratory: Eurofins TestAmerica, Chicago

Narrative

Job Narrative
500-189929-1

Comments
No additional comments.

Receipt
The samples were received on 10/22/2020 6:20 PM; the samples arrived in good condition, and where required, properly preserved and on ice. The temperatures of the 3 coolers at receipt time were 5.4º C, 5.7º C and 5.8º C.

Receipt Exceptions

The following sample was submitted for analysis; however, it was not listed on the Chain-of-Custody (COC): Duplicate (500-189929-9) Added to COC and logged in.

GC/MS VOA
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

Metals
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

Field Service / Mobile Lab
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

General Chemistry
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

Method Summary

Method	Method Description	Protocol	Laboratory
8260B	Volatile Organic Compounds (GC/MS)	SW846	TAL CHI
314.0	Perchlorate (IC)	EPA	TAL SAC
6020A	Metals (ICP/MS)	SW846	TAL CHI
7470A	Mercury (CVAA)	SW846	TAL CHI
9014	Cyanide	SW846	TAL CHI
9038	Sulfate, Turbidimetric	SW846	TAL CHI
9251	Chloride	SW846	TAL CHI
Nitrate by calc	Nitrogen, Nitrate-Nitrite	SM	TAL CHI
SM 2540C	Solids, Total Dissolved (TDS)	SM	TAL CF
SM 4500 F C	Fluoride	SM	TAL CHI
SM 4500 NO2 B	Nitrogen, Nitrite	SM	TAL CHI
SM 4500 NO3 F	Nitrogen, Nitrate	SM	TAL CHI
5030B	Purge and Trap	SW846	TAL CHI
7470A	Preparation, Mercury	SW846	TAL CHI
9010B	Cyanide, Distillation	SW846	TAL CHI
Soluble Metals	Preparation, Soluble	None	TAL CHI

Protocol References:

EPA = US Environmental Protection Agency
None = None
SM = "Standard Methods For The Examination Of Water And Wastewater"
SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

TAL CF = Eurofins TestAmerica, Cedar Falls, 3019 Venture Way, Cedar Falls, IA 50613, TEL (319)277-2401
TAL CHI = Eurofins TestAmerica, Chicago, 2417 Bond Street, University Park, IL 60484, TEL (708)534-5200
TAL SAC = Eurofins TestAmerica, Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Sample Summary

Client: KPRG and Associates, Inc.
Project/Site: Joliet #29 Station Ash Ponds (CCA)

Job ID: 500-189929-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received	Asset ID
500-189929-1	MW-03	Water	10/22/20 10:18	10/22/20 18:20	
500-189929-2	MW-04	Water	10/22/20 11:11	10/22/20 18:20	
500-189929-3	MW-05	Water	10/22/20 12:46	10/22/20 18:20	
500-189929-4	MW-06	Water	10/22/20 15:12	10/22/20 18:20	
500-189929-5	MW-07	Water	10/22/20 14:14	10/22/20 18:20	
500-189929-6	MW-08	Water	10/22/20 09:23	10/22/20 18:20	
500-189929-7	MW-10	Water	10/22/20 12:05	10/22/20 18:20	
500-189929-8	MW-11	Water	10/22/20 13:31	10/22/20 18:20	
500-189929-9	Duplicate	Water	10/22/20 00:00	10/22/20 18:20	
500-189929-10	Trip Blank	Water	10/22/20 00:00	10/22/20 18:20	

Client Sample Results

Client Sample ID: MW-03

Lab Sample ID: 500-189929-1

Date Collected: 10/22/20 10:18
Matrix: Water
Date Received: 10/22/20 18:20

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/31/20 02:41	1
Toluene	<0.00050		0.00050		mg/L			10/31/20 02:41	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/31/20 02:41	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/31/20 02:41	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*114*		*75 - 126*		*10/31/20 02:41*	*1*
Toluene-d8 (Surr)	*100*		*75 - 120*		*10/31/20 02:41*	*1*
4-Bromofluorobenzene (Surr)	*98*		*72 - 124*		*10/31/20 02:41*	*1*
Dibromofluoromethane	*115*		*75 - 120*		*10/31/20 02:41*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/27/20 15:16	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:08	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:08	1
Barium	**0.10**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:08	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:08	1
Boron	**0.29**		0.050		mg/L		11/02/20 12:38	11/02/20 14:08	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:08	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:08	1
Cobalt	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:08	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:08	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:08	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:08	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:08	1
Nickel	**0.0031**		0.0020		mg/L		11/02/20 12:38	11/02/20 14:08	1
Selenium	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:08	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:08	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:08	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:08	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:08	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:26	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**760**		30		mg/L			10/27/20 16:49	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 13:25	1
Sulfate	**91**		15		mg/L			10/30/20 12:00	3
Chloride	**180**		10		mg/L			11/03/20 09:43	5
Nitrogen, Nitrate	**2.8**		0.10		mg/L			11/08/20 12:23	1
Fluoride	**0.44**		0.10		mg/L			11/04/20 14:02	1

Client Sample Results

Client Sample ID: MW-03
Lab Sample ID: 500-189929-1
Date Collected: 10/22/20 10:18
Matrix: Water
Date Received: 10/22/20 18:20

General Chemistry - Dissolved (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:18	1
Nitrogen, Nitrate Nitrite	**2.8**		0.50		mg/L			11/05/20 13:22	5

Client Sample Results

1 2 3 4 5 6 7 8 9 10 11 12 13 14

Client Sample ID: MW-04

Lab Sample ID: 500-189929-2

Date Collected: 10/22/20 11:11

Matrix: Water

Date Received: 10/22/20 18:20

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/31/20 03:09	1
Toluene	<0.00050		0.00050		mg/L			10/31/20 03:09	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/31/20 03:09	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/31/20 03:09	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*113*		*75 - 126*		*10/31/20 03:09*	*1*
Toluene-d8 (Surr)	*100*		*75 - 120*		*10/31/20 03:09*	*1*
4-Bromofluorobenzene (Surr)	*96*		*72 - 124*		*10/31/20 03:09*	*1*
Dibromofluoromethane	*112*		*75 - 120*		*10/31/20 03:09*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/27/20 16:11	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:11	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:11	1
Barium	**0.090**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:11	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:11	1
Boron	**0.29**		0.050		mg/L		11/02/20 12:38	11/02/20 14:11	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:11	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:11	1
Cobalt	**0.0041**		0.0010		mg/L		11/02/20 12:38	11/02/20 14:11	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:11	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:11	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:11	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:11	1
Nickel	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:11	1
Selenium	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:11	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:11	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:11	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:11	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:11	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:28	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**760**		30		mg/L			10/27/20 16:49	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 13:27	1
Sulfate	**82**		15		mg/L			10/30/20 12:01	3
Chloride	**190**		10		mg/L			11/03/20 09:44	5
Nitrogen, Nitrate	**3.4**		0.10		mg/L			11/08/20 12:23	1
Fluoride	**0.49**		0.10		mg/L			11/04/20 14:13	1

Client Sample Results

Client Sample ID: MW-04
Lab Sample ID: 500-189929-2
Date Collected: 10/22/20 11:11
Matrix: Water
Date Received: 10/22/20 18:20

General Chemistry - Dissolved (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:23	1
Nitrogen, Nitrate Nitrite	**3.4**		0.50		mg/L			11/05/20 13:14	5

Client Sample ID: MW-05

Date Collected: 10/22/20 12:46
Date Received: 10/22/20 18:20

Lab Sample ID: 500-189929-3
Matrix: Water

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/31/20 03:38	1
Toluene	<0.00050		0.00050		mg/L			10/31/20 03:38	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/31/20 03:38	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/31/20 03:38	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*116*		*75 - 126*		*10/31/20 03:38*	*1*
Toluene-d8 (Surr)	*100*		*75 - 120*		*10/31/20 03:38*	*1*
4-Bromofluorobenzene (Surr)	*99*		*72 - 124*		*10/31/20 03:38*	*1*
Dibromofluoromethane	*115*		*75 - 120*		*10/31/20 03:38*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/27/20 16:29	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:14	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:14	1
Barium	**0.070**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:14	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:14	1
Boron	**0.47**		0.050		mg/L		11/02/20 12:38	11/02/20 14:14	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:14	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:14	1
Cobalt	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:14	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:14	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:14	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:14	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:14	1
Nickel	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:14	1
Selenium	**0.0032**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:14	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:14	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:14	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:14	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:14	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:31	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**690**		30		mg/L			10/27/20 16:49	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 13:28	1
Sulfate	**84**		15		mg/L			10/30/20 12:01	3
Chloride	**180**		10		mg/L			11/03/20 09:45	5
Nitrogen, Nitrate	**0.99**		0.10		mg/L			11/08/20 12:23	1
Fluoride	**0.38**		0.10		mg/L			11/04/20 14:16	1

Client Sample Results

Client Sample ID: MW-05
Date Collected: 10/22/20 12:46
Date Received: 10/22/20 18:20

Lab Sample ID: 500-189929-3
Matrix: Water

General Chemistry - Dissolved (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:23	1
Nitrogen, Nitrate Nitrite	**0.99**		0.10		mg/L			11/04/20 11:07	1

Client Sample Results

1
2
3
4
5
6
7
8
9
10
11
12
13
14

Client Sample ID: MW-06

Date Collected: 10/22/20 15:12
Date Received: 10/22/20 18:20

Lab Sample ID: 500-189929-4

Matrix: Water

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/31/20 04:06	1
Toluene	<0.00050		0.00050		mg/L			10/31/20 04:06	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/31/20 04:06	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/31/20 04:06	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*114*		*75 - 126*		*10/31/20 04:06*	*1*
Toluene-d8 (Surr)	*100*		*75 - 120*		*10/31/20 04:06*	*1*
4-Bromofluorobenzene (Surr)	*95*		*72 - 124*		*10/31/20 04:06*	*1*
Dibromofluoromethane	*115*		*75 - 120*		*10/31/20 04:06*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/27/20 16:48	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:18	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:18	1
Barium	**0.13**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:18	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:18	1
Boron	**0.23**		0.050		mg/L		11/02/20 12:38	11/02/20 14:18	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:18	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:18	1
Cobalt	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:18	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:18	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:18	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:18	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:18	1
Nickel	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:18	1
Selenium	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:18	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:18	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:18	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:18	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:18	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:33	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**640**		30		mg/L			10/27/20 16:49	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 13:30	1
Sulfate	**83**		15		mg/L			10/30/20 12:01	3
Chloride	**160**		10		mg/L			11/03/20 09:45	5
Nitrogen, Nitrate	**0.56**		0.10		mg/L			11/08/20 12:23	1
Fluoride	**0.31**		0.10		mg/L			11/04/20 14:18	1

Client Sample Results

Client Sample ID: MW-06
Date Collected: 10/22/20 15:12
Date Received: 10/22/20 18:20

Lab Sample ID: 500-189929-4
Matrix: Water

General Chemistry - Dissolved (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:24	1
Nitrogen, Nitrate Nitrite	**0.56**		0.10		mg/L			11/04/20 11:09	1

Client Sample Results

Client Sample ID: MW-07

Lab Sample ID: 500-189929-5

Date Collected: 10/22/20 14:14

Matrix: Water

Date Received: 10/22/20 18:20

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/31/20 04:34	1
Toluene	<0.00050		0.00050		mg/L			10/31/20 04:34	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/31/20 04:34	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/31/20 04:34	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*115*		*75 - 126*		*10/31/20 04:34*	*1*
Toluene-d8 (Surr)	*100*		*75 - 120*		*10/31/20 04:34*	*1*
4-Bromofluorobenzene (Surr)	*98*		*72 - 124*		*10/31/20 04:34*	*1*
Dibromofluoromethane	*114*		*75 - 120*		*10/31/20 04:34*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/27/20 17:06	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:42	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:42	1
Barium	**0.13**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:42	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:42	1
Boron	**0.34**		0.050		mg/L		11/02/20 12:38	11/02/20 14:42	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:42	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:42	1
Cobalt	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:42	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:42	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:42	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:42	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:42	1
Nickel	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:42	1
Selenium	**0.0025**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:42	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:42	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:42	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:42	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:42	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:35	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**680**		30		mg/L			10/27/20 16:49	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 13:32	1
Sulfate	**97**		15		mg/L			10/30/20 12:03	3
Chloride	**150**		10		mg/L			11/03/20 09:47	5
Nitrogen, Nitrate	**0.93**		0.10		mg/L			11/08/20 12:23	1
Fluoride	**0.28**		0.10		mg/L			11/04/20 14:22	1

Client Sample Results

Client Sample ID: MW-07
Lab Sample ID: 500-189929-5
Date Collected: 10/22/20 14:14
Matrix: Water
Date Received: 10/22/20 18:20

General Chemistry - Dissolved (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:24	1
Nitrogen, Nitrate Nitrite	**0.93**		0.10		mg/L			11/04/20 11:11	1

Client Sample Results

Client: KPRG and Associates, Inc.
Project/Site: Joliet #29 Station Ash Ponds (CCA)

Job ID: 500-189929-1

Client Sample ID: MW-08

Date Collected: 10/22/20 09:23
Date Received: 10/22/20 18:20

Lab Sample ID: 500-189929-6
Matrix: Water

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/31/20 05:03	1
Toluene	<0.00050		0.00050		mg/L			10/31/20 05:03	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/31/20 05:03	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/31/20 05:03	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*115*		*75 - 126*		*10/31/20 05:03*	*1*
Toluene-d8 (Surr)	*99*		*75 - 120*		*10/31/20 05:03*	*1*
4-Bromofluorobenzene (Surr)	*97*		*72 - 124*		*10/31/20 05:03*	*1*
Dibromofluoromethane	*115*		*75 - 120*		*10/31/20 05:03*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/28/20 16:16	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:45	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:45	1
Barium	**0.062**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:45	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:45	1
Boron	**0.18**		0.050		mg/L		11/02/20 12:38	11/02/20 14:45	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:45	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:45	1
Cobalt	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:45	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:45	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:45	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:45	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:45	1
Nickel	**0.0020**		0.0020		mg/L		11/02/20 12:38	11/02/20 14:45	1
Selenium	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:45	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:45	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:45	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:45	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:45	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:37	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**800**		30		mg/L			10/27/20 16:49	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 16:15	1
Sulfate	**140**		15		mg/L			10/30/20 12:03	3
Chloride	**180**		10		mg/L			11/03/20 09:48	5
Nitrogen, Nitrate	**1.4**		0.10		mg/L			11/08/20 12:23	1
Fluoride	**0.27**		0.10		mg/L			11/04/20 14:26	1

Client Sample Results

Client Sample ID: MW-08
Lab Sample ID: 500-189929-6
Date Collected: 10/22/20 09:23
Matrix: Water
Date Received: 10/22/20 18:20

General Chemistry - Dissolved (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:25	1
Nitrogen, Nitrate Nitrite	**1.4**		0.10		mg/L			11/04/20 11:13	1

Client Sample Results

Client Sample ID: MW-10

Lab Sample ID: 500-189929-7
Date Collected: 10/22/20 12:05
Matrix: Water
Date Received: 10/22/20 18:20

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/31/20 05:31	1
Toluene	<0.00050		0.00050		mg/L			10/31/20 05:31	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/31/20 05:31	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/31/20 05:31	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*116*		*75 - 126*		*10/31/20 05:31*	*1*
Toluene-d8 (Surr)	*100*		*75 - 120*		*10/31/20 05:31*	*1*
4-Bromofluorobenzene (Surr)	*100*		*72 - 124*		*10/31/20 05:31*	*1*
Dibromofluoromethane	*114*		*75 - 120*		*10/31/20 05:31*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/28/20 17:11	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:49	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:49	1
Barium	**0.040**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:49	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:49	1
Boron	**0.29**		0.050		mg/L		11/02/20 12:38	11/02/20 14:49	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:49	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:49	1
Cobalt	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:49	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:49	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:49	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:49	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:49	1
Nickel	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:49	1
Selenium	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:49	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:49	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:49	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:49	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:49	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:39	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**850**		30		mg/L			10/28/20 13:56	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 16:17	1
Sulfate	**94**		15		mg/L			10/30/20 12:03	3
Chloride	**230**		10		mg/L			11/03/20 09:48	5
Nitrogen, Nitrate	**3.8**		0.10		mg/L			11/08/20 12:23	1
Fluoride	**0.41**		0.10		mg/L			11/04/20 14:38	1

Client Sample Results

Client Sample ID: MW-10
Date Collected: 10/22/20 12:05
Date Received: 10/22/20 18:20

Lab Sample ID: 500-189929-7
Matrix: Water

General Chemistry - Dissolved (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:25	1
Nitrogen, Nitrate Nitrite	**3.8**		0.50		mg/L			11/05/20 13:16	5

Client Sample Results

Client Sample ID: MW-11

Lab Sample ID: 500-189929-8

Date Collected: 10/22/20 13:31

Matrix: Water

Date Received: 10/22/20 18:20

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/31/20 05:59	1
Toluene	<0.00050		0.00050		mg/L			10/31/20 05:59	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/31/20 05:59	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/31/20 05:59	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*115*		*75 - 126*		*10/31/20 05:59*	*1*
Toluene-d8 (Surr)	*100*		*75 - 120*		*10/31/20 05:59*	*1*
4-Bromofluorobenzene (Surr)	*97*		*72 - 124*		*10/31/20 05:59*	*1*
Dibromofluoromethane	*115*		*75 - 120*		*10/31/20 05:59*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/28/20 17:29	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:52	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:52	1
Barium	**0.055**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:52	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:52	1
Boron	**0.44**		0.050		mg/L		11/02/20 12:38	11/02/20 14:52	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:52	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:52	1
Cobalt	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:52	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:52	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:52	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:52	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:52	1
Nickel	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:52	1
Selenium	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:52	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:52	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:52	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:52	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:52	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:41	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**710**		30		mg/L			10/28/20 13:56	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 16:19	1
Sulfate	**89**		15		mg/L			10/30/20 12:03	3
Chloride	**170**		10		mg/L			11/03/20 09:50	5
Nitrogen, Nitrate	**0.59**		0.10		mg/L			11/08/20 12:24	1
Fluoride	**0.28**		0.10		mg/L			11/04/20 14:41	1

Client Sample Results

Client Sample ID: MW-11
Lab Sample ID: 500-189929-8
Date Collected: 10/22/20 13:31
Matrix: Water
Date Received: 10/22/20 18:20

General Chemistry - Dissolved (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:25	1
Nitrogen, Nitrate Nitrite	**0.59**		0.10		mg/L			11/13/20 09:36	1

Client Sample Results

Client Sample ID: Duplicate

Lab Sample ID: 500-189929-9

Date Collected: 10/22/20 00:00
Matrix: Water
Date Received: 10/22/20 18:20

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/31/20 06:28	1
Toluene	<0.00050		0.00050		mg/L			10/31/20 06:28	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/31/20 06:28	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/31/20 06:28	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*117*		*75 - 126*		*10/31/20 06:28*	*1*
Toluene-d8 (Surr)	*100*		*75 - 120*		*10/31/20 06:28*	*1*
4-Bromofluorobenzene (Surr)	*99*		*72 - 124*		*10/31/20 06:28*	*1*
Dibromofluoromethane	*113*		*75 - 120*		*10/31/20 06:28*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/28/20 17:48	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:56	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:56	1
Barium	**0.091**		0.0025		mg/L		11/02/20 12:38	11/02/20 14:56	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:56	1
Boron	**0.28**		0.050		mg/L		11/02/20 12:38	11/02/20 14:56	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:56	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:56	1
Cobalt	**0.0052**		0.0010		mg/L		11/02/20 12:38	11/02/20 14:56	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:56	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:56	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:56	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:56	1
Nickel	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:56	1
Selenium	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:56	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:56	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:56	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:56	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:56	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:54	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**740**		30		mg/L			10/28/20 13:56	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 16:20	1
Sulfate	**82**		15		mg/L			10/30/20 12:04	3
Chloride	**190**		10		mg/L			11/03/20 09:50	5
Nitrogen, Nitrate	**3.4**		0.10		mg/L			11/08/20 12:23	1
Fluoride	**0.48**		0.10		mg/L			11/04/20 14:45	1

Client Sample Results

Client Sample ID: Duplicate **Lab Sample ID: 500-189929-9**
Date Collected: 10/22/20 00:00 **Matrix: Water**
Date Received: 10/22/20 18:20

General Chemistry - Dissolved (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:27	1
Nitrogen, Nitrate Nitrite	**3.4**		0.50		mg/L			11/05/20 13:24	5

Client Sample Results

Client Sample ID: Trip Blank

Lab Sample ID: 500-189929-10

Date Collected: 10/22/20 00:00
Matrix: Water
Date Received: 10/22/20 18:20

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/30/20 23:23	1
Toluene	<0.00050		0.00050		mg/L			10/30/20 23:23	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/30/20 23:23	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/30/20 23:23	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*115*		*75 - 126*		*10/30/20 23:23*	*1*
Toluene-d8 (Surr)	*101*		*75 - 120*		*10/30/20 23:23*	*1*
4-Bromofluorobenzene (Surr)	*98*		*72 - 124*		*10/30/20 23:23*	*1*
Dibromofluoromethane	*113*		*75 - 120*		*10/30/20 23:23*	*1*

Definitions/Glossary

Qualifiers

General Chemistry

Qualifier	Qualifier Description
4	MS, MSD: The analyte present in the original sample is greater than 4 times the matrix spike concentration; therefore, control limits are not applicable.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

QC Association Summary

GC/MS VOA

Analysis Batch: 569473

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Total/NA	Water	8260B	
500-189929-2	MW-04	Total/NA	Water	8260B	
500-189929-3	MW-05	Total/NA	Water	8260B	
500-189929-4	MW-06	Total/NA	Water	8260B	
500-189929-5	MW-07	Total/NA	Water	8260B	
500-189929-6	MW-08	Total/NA	Water	8260B	
500-189929-7	MW-10	Total/NA	Water	8260B	
500-189929-8	MW-11	Total/NA	Water	8260B	
500-189929-9	Duplicate	Total/NA	Water	8260B	
500-189929-10	Trip Blank	Total/NA	Water	8260B	
MB 500-569473/6	Method Blank	Total/NA	Water	8260B	
LCS 500-569473/4	Lab Control Sample	Total/NA	Water	8260B	
500-189929-9 MS	Duplicate	Total/NA	Water	8260B	
500-189929-9 MSD	Duplicate	Total/NA	Water	8260B	

HPLC/IC

Analysis Batch: 425701

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Total/NA	Water	314.0	
500-189929-2	MW-04	Total/NA	Water	314.0	
500-189929-3	MW-05	Total/NA	Water	314.0	
500-189929-4	MW-06	Total/NA	Water	314.0	
500-189929-5	MW-07	Total/NA	Water	314.0	
MB 320-425701/5	Method Blank	Total/NA	Water	314.0	
LCS 320-425701/6	Lab Control Sample	Total/NA	Water	314.0	
MRL 320-425701/4	Lab Control Sample	Total/NA	Water	314.0	
500-189929-1 MS	MW-03	Total/NA	Water	314.0	
500-189929-1 MSD	MW-03	Total/NA	Water	314.0	

Analysis Batch: 426124

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-6	MW-08	Total/NA	Water	314.0	
500-189929-7	MW-10	Total/NA	Water	314.0	
500-189929-8	MW-11	Total/NA	Water	314.0	
500-189929-9	Duplicate	Total/NA	Water	314.0	
MB 320-426124/5	Method Blank	Total/NA	Water	314.0	
LCS 320-426124/6	Lab Control Sample	Total/NA	Water	314.0	
MRL 320-426124/4	Lab Control Sample	Total/NA	Water	314.0	
500-189929-6 MS	MW-08	Total/NA	Water	314.0	
500-189929-6 MSD	MW-08	Total/NA	Water	314.0	

Metals

Prep Batch: 569235

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	7470A	
500-189929-2	MW-04	Dissolved	Water	7470A	
500-189929-3	MW-05	Dissolved	Water	7470A	
500-189929-4	MW-06	Dissolved	Water	7470A	
500-189929-5	MW-07	Dissolved	Water	7470A	
500-189929-6	MW-08	Dissolved	Water	7470A	

QC Association Summary

Metals (Continued)

Prep Batch: 569235 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-7	MW-10	Dissolved	Water	7470A	
500-189929-8	MW-11	Dissolved	Water	7470A	
500-189929-9	Duplicate	Dissolved	Water	7470A	
MB 500-569235/12-A	Method Blank	Total/NA	Water	7470A	
LCS 500-569235/13-A	Lab Control Sample	Total/NA	Water	7470A	
500-189929-8 MS	MW-11	Dissolved	Water	7470A	
500-189929-8 MSD	MW-11	Dissolved	Water	7470A	
500-189929-8 DU	MW-11	Dissolved	Water	7470A	

Analysis Batch: 569446

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	7470A	569235
500-189929-2	MW-04	Dissolved	Water	7470A	569235
500-189929-3	MW-05	Dissolved	Water	7470A	569235
500-189929-4	MW-06	Dissolved	Water	7470A	569235
500-189929-5	MW-07	Dissolved	Water	7470A	569235
500-189929-6	MW-08	Dissolved	Water	7470A	569235
500-189929-7	MW-10	Dissolved	Water	7470A	569235
500-189929-8	MW-11	Dissolved	Water	7470A	569235
500-189929-9	Duplicate	Dissolved	Water	7470A	569235
MB 500-569235/12-A	Method Blank	Total/NA	Water	7470A	569235
LCS 500-569235/13-A	Lab Control Sample	Total/NA	Water	7470A	569235
500-189929-8 MS	MW-11	Dissolved	Water	7470A	569235
500-189929-8 MSD	MW-11	Dissolved	Water	7470A	569235
500-189929-8 DU	MW-11	Dissolved	Water	7470A	569235

Prep Batch: 569853

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	Soluble Metals	
500-189929-2	MW-04	Dissolved	Water	Soluble Metals	
500-189929-3	MW-05	Dissolved	Water	Soluble Metals	
500-189929-4	MW-06	Dissolved	Water	Soluble Metals	
500-189929-5	MW-07	Dissolved	Water	Soluble Metals	
500-189929-6	MW-08	Dissolved	Water	Soluble Metals	
500-189929-7	MW-10	Dissolved	Water	Soluble Metals	
500-189929-8	MW-11	Dissolved	Water	Soluble Metals	
500-189929-9	Duplicate	Dissolved	Water	Soluble Metals	
MB 500-569853/1-A	Method Blank	Soluble	Water	Soluble Metals	
LCS 500-569853/2-A	Lab Control Sample	Soluble	Water	Soluble Metals	
500-189929-4 MS	MW-06	Dissolved	Water	Soluble Metals	
500-189929-4 MSD	MW-06	Dissolved	Water	Soluble Metals	
500-189929-4 DU	MW-06	Dissolved	Water	Soluble Metals	

Analysis Batch: 570004

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	6020A	569853
500-189929-2	MW-04	Dissolved	Water	6020A	569853
500-189929-3	MW-05	Dissolved	Water	6020A	569853
500-189929-4	MW-06	Dissolved	Water	6020A	569853
500-189929-5	MW-07	Dissolved	Water	6020A	569853
500-189929-6	MW-08	Dissolved	Water	6020A	569853

Metals (Continued)

Analysis Batch: 570004 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-7	MW-10	Dissolved	Water	6020A	569853
500-189929-8	MW-11	Dissolved	Water	6020A	569853
500-189929-9	Duplicate	Dissolved	Water	6020A	569853
MB 500-569853/1-A	Method Blank	Soluble	Water	6020A	569853
LCS 500-569853/2-A	Lab Control Sample	Soluble	Water	6020A	569853
500-189929-4 MS	MW-06	Dissolved	Water	6020A	569853
500-189929-4 MSD	MW-06	Dissolved	Water	6020A	569853
500-189929-4 DU	MW-06	Dissolved	Water	6020A	569853

General Chemistry

Analysis Batch: 297244

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Total/NA	Water	SM 2540C	
500-189929-2	MW-04	Total/NA	Water	SM 2540C	
500-189929-3	MW-05	Total/NA	Water	SM 2540C	
500-189929-4	MW-06	Total/NA	Water	SM 2540C	
500-189929-5	MW-07	Total/NA	Water	SM 2540C	
500-189929-6	MW-08	Total/NA	Water	SM 2540C	
MB 310-297244/1	Method Blank	Total/NA	Water	SM 2540C	
LCS 310-297244/2	Lab Control Sample	Total/NA	Water	SM 2540C	

Analysis Batch: 297381

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-7	MW-10	Total/NA	Water	SM 2540C	
500-189929-8	MW-11	Total/NA	Water	SM 2540C	
500-189929-9	Duplicate	Total/NA	Water	SM 2540C	
MB 310-297381/1	Method Blank	Total/NA	Water	SM 2540C	
LCS 310-297381/2	Lab Control Sample	Total/NA	Water	SM 2540C	
500-189929-8 DU	MW-11	Total/NA	Water	SM 2540C	

Analysis Batch: 568249

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	SM 4500 NO2 B	
500-189929-2	MW-04	Dissolved	Water	SM 4500 NO2 B	
500-189929-3	MW-05	Dissolved	Water	SM 4500 NO2 B	
500-189929-4	MW-06	Dissolved	Water	SM 4500 NO2 B	
500-189929-5	MW-07	Dissolved	Water	SM 4500 NO2 B	
500-189929-6	MW-08	Dissolved	Water	SM 4500 NO2 B	
500-189929-7	MW-10	Dissolved	Water	SM 4500 NO2 B	
500-189929-8	MW-11	Dissolved	Water	SM 4500 NO2 B	
500-189929-9	Duplicate	Dissolved	Water	SM 4500 NO2 B	
MB 500-568249/9	Method Blank	Total/NA	Water	SM 4500 NO2 B	
LCS 500-568249/10	Lab Control Sample	Total/NA	Water	SM 4500 NO2 B	
500-189929-1 MS	MW-03	Dissolved	Water	SM 4500 NO2 B	
500-189929-1 MSD	MW-03	Dissolved	Water	SM 4500 NO2 B	

Analysis Batch: 569487

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	9038	
500-189929-2	MW-04	Dissolved	Water	9038	

General Chemistry (Continued)

Analysis Batch: 569487 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-3	MW-05	Dissolved	Water	9038	
500-189929-4	MW-06	Dissolved	Water	9038	
500-189929-5	MW-07	Dissolved	Water	9038	
500-189929-6	MW-08	Dissolved	Water	9038	
500-189929-7	MW-10	Dissolved	Water	9038	
500-189929-8	MW-11	Dissolved	Water	9038	
500-189929-9	Duplicate	Dissolved	Water	9038	
MB 500-569487/15	Method Blank	Total/NA	Water	9038	
LCS 500-569487/16	Lab Control Sample	Total/NA	Water	9038	

Analysis Batch: 570023

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	9251	
500-189929-2	MW-04	Dissolved	Water	9251	
500-189929-3	MW-05	Dissolved	Water	9251	
500-189929-4	MW-06	Dissolved	Water	9251	
500-189929-5	MW-07	Dissolved	Water	9251	
500-189929-6	MW-08	Dissolved	Water	9251	
500-189929-7	MW-10	Dissolved	Water	9251	
500-189929-8	MW-11	Dissolved	Water	9251	
500-189929-9	Duplicate	Dissolved	Water	9251	
MB 500-570023/12	Method Blank	Total/NA	Water	9251	
LCS 500-570023/13	Lab Control Sample	Total/NA	Water	9251	
500-189929-7 MS	MW-10	Dissolved	Water	9251	
500-189929-7 MSD	MW-10	Dissolved	Water	9251	

Analysis Batch: 570289

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-3	MW-05	Dissolved	Water	SM 4500 NO3 F	
500-189929-4	MW-06	Dissolved	Water	SM 4500 NO3 F	
500-189929-5	MW-07	Dissolved	Water	SM 4500 NO3 F	
500-189929-6	MW-08	Dissolved	Water	SM 4500 NO3 F	
MB 500-570289/203	Method Blank	Total/NA	Water	SM 4500 NO3 F	
LCS 500-570289/204	Lab Control Sample	Total/NA	Water	SM 4500 NO3 F	
LCSD 500-570289/205	Lab Control Sample Dup	Total/NA	Water	SM 4500 NO3 F	

Analysis Batch: 570407

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	SM 4500 F C	
500-189929-2	MW-04	Dissolved	Water	SM 4500 F C	
500-189929-3	MW-05	Dissolved	Water	SM 4500 F C	
500-189929-4	MW-06	Dissolved	Water	SM 4500 F C	
500-189929-5	MW-07	Dissolved	Water	SM 4500 F C	
500-189929-6	MW-08	Dissolved	Water	SM 4500 F C	
500-189929-7	MW-10	Dissolved	Water	SM 4500 F C	
500-189929-8	MW-11	Dissolved	Water	SM 4500 F C	
500-189929-9	Duplicate	Dissolved	Water	SM 4500 F C	
MB 500-570407/3	Method Blank	Total/NA	Water	SM 4500 F C	
LCS 500-570407/4	Lab Control Sample	Total/NA	Water	SM 4500 F C	
500-189929-1 MS	MW-03	Dissolved	Water	SM 4500 F C	
500-189929-1 MSD	MW-03	Dissolved	Water	SM 4500 F C	

General Chemistry

Prep Batch: 570453

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	9010B	
500-189929-2	MW-04	Dissolved	Water	9010B	
500-189929-3	MW-05	Dissolved	Water	9010B	
500-189929-4	MW-06	Dissolved	Water	9010B	
500-189929-5	MW-07	Dissolved	Water	9010B	
MB 500-570453/1-A	Method Blank	Total/NA	Water	9010B	
HLCS 500-570453/2-A	Lab Control Sample	Total/NA	Water	9010B	
LCS 500-570453/3-A	Lab Control Sample	Total/NA	Water	9010B	
LLCS 500-570453/4-A	Lab Control Sample	Total/NA	Water	9010B	

Prep Batch: 570455

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-6	MW-08	Dissolved	Water	9010B	
500-189929-7	MW-10	Dissolved	Water	9010B	
500-189929-8	MW-11	Dissolved	Water	9010B	
500-189929-9	Duplicate	Dissolved	Water	9010B	
MB 500-570455/1-A	Method Blank	Total/NA	Water	9010B	
HLCS 500-570455/2-A	Lab Control Sample	Total/NA	Water	9010B	
LCS 500-570455/3-A	Lab Control Sample	Total/NA	Water	9010B	
LLCS 500-570455/4-A	Lab Control Sample	Total/NA	Water	9010B	

Analysis Batch: 570507

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	SM 4500 NO3 F	
500-189929-2	MW-04	Dissolved	Water	SM 4500 NO3 F	
500-189929-7	MW-10	Dissolved	Water	SM 4500 NO3 F	
500-189929-9	Duplicate	Dissolved	Water	SM 4500 NO3 F	
MB 500-570507/46	Method Blank	Total/NA	Water	SM 4500 NO3 F	
LCS 500-570507/47	Lab Control Sample	Total/NA	Water	SM 4500 NO3 F	
LCSD 500-570507/76	Lab Control Sample Dup	Total/NA	Water	SM 4500 NO3 F	

Analysis Batch: 570534

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	9014	570453
500-189929-2	MW-04	Dissolved	Water	9014	570453
500-189929-3	MW-05	Dissolved	Water	9014	570453
500-189929-4	MW-06	Dissolved	Water	9014	570453
500-189929-5	MW-07	Dissolved	Water	9014	570453
MB 500-570453/1-A	Method Blank	Total/NA	Water	9014	570453
HLCS 500-570453/2-A	Lab Control Sample	Total/NA	Water	9014	570453
LCS 500-570453/3-A	Lab Control Sample	Total/NA	Water	9014	570453
LLCS 500-570453/4-A	Lab Control Sample	Total/NA	Water	9014	570453

Analysis Batch: 570535

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-6	MW-08	Dissolved	Water	9014	570455
500-189929-7	MW-10	Dissolved	Water	9014	570455
500-189929-8	MW-11	Dissolved	Water	9014	570455
500-189929-9	Duplicate	Dissolved	Water	9014	570455
MB 500-570455/1-A	Method Blank	Total/NA	Water	9014	570455
HLCS 500-570455/2-A	Lab Control Sample	Total/NA	Water	9014	570455

General Chemistry (Continued)

Analysis Batch: 570535 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
LCS 500-570455/3-A	Lab Control Sample	Total/NA	Water	9014	570455
LLCS 500-570455/4-A	Lab Control Sample	Total/NA	Water	9014	570455

Analysis Batch: 570885

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-1	MW-03	Dissolved	Water	Nitrate by calc	
500-189929-2	MW-04	Dissolved	Water	Nitrate by calc	
500-189929-3	MW-05	Dissolved	Water	Nitrate by calc	
500-189929-4	MW-06	Dissolved	Water	Nitrate by calc	
500-189929-5	MW-07	Dissolved	Water	Nitrate by calc	
500-189929-6	MW-08	Dissolved	Water	Nitrate by calc	
500-189929-7	MW-10	Dissolved	Water	Nitrate by calc	
500-189929-8	MW-11	Dissolved	Water	Nitrate by calc	
500-189929-9	Duplicate	Dissolved	Water	Nitrate by calc	

Analysis Batch: 572019

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-189929-8	MW-11	Dissolved	Water	SM 4500 NO3 F	
MB 500-572019/25	Method Blank	Total/NA	Water	SM 4500 NO3 F	
LCS 500-572019/26	Lab Control Sample	Total/NA	Water	SM 4500 NO3 F	

Surrogate Summary

Method: 8260B - Volatile Organic Compounds (GC/MS)

Matrix: Water **Prep Type: Total/NA**

		Percent Surrogate Recovery (Acceptance Limits)			
		DCA	**TOL**	**BFB**	**DBFM**
Lab Sample ID	**Client Sample ID**	**(75-126)**	**(75-120)**	**(72-124)**	**(75-120)**
500-189929-1	MW-03	114	100	98	115
500-189929-2	MW-04	113	100	96	112
500-189929-3	MW-05	116	100	99	115
500-189929-4	MW-06	114	100	95	115
500-189929-5	MW-07	115	100	98	114
500-189929-6	MW-08	115	99	97	115
500-189929-7	MW-10	116	100	100	114
500-189929-8	MW-11	115	100	97	115
500-189929-9	Duplicate	117	100	99	113
500-189929-9 MS	Duplicate	113	100	98	112
500-189929-9 MSD	Duplicate	112	100	96	110
500-189929-10	Trip Blank	115	101	98	113
LCS 500-569473/4	Lab Control Sample	111	100	98	110
MB 500-569473/6	Method Blank	113	101	96	111

Surrogate Legend

DCA = 1,2-Dichloroethane-d4 (Surr)
TOL = Toluene-d8 (Surr)
BFB = 4-Bromofluorobenzene (Surr)
DBFM = Dibromofluoromethane

Method: 8260B - Volatile Organic Compounds (GC/MS)

Lab Sample ID: MB 500-569473/6 **Client Sample ID: Method Blank**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 569473

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			10/30/20 22:27	1
Toluene	<0.00050		0.00050		mg/L			10/30/20 22:27	1
Ethylbenzene	<0.00050		0.00050		mg/L			10/30/20 22:27	1
Xylenes, Total	<0.0010		0.0010		mg/L			10/30/20 22:27	1

Surrogate	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*113*		*75 - 126*		*10/30/20 22:27*	*1*
Toluene-d8 (Surr)	*101*		*75 - 120*		*10/30/20 22:27*	*1*
4-Bromofluorobenzene (Surr)	*96*		*72 - 124*		*10/30/20 22:27*	*1*
Dibromofluoromethane	*111*		*75 - 120*		*10/30/20 22:27*	*1*

Lab Sample ID: LCS 500-569473/4 **Client Sample ID: Lab Control Sample**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 569473

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Benzene	0.0500	0.0583		mg/L		117	70 - 120
Toluene	0.0500	0.0549		mg/L		110	70 - 125
Ethylbenzene	0.0500	0.0535		mg/L		107	70 - 123
Xylenes, Total	0.100	0.109		mg/L		109	70 - 125

Surrogate	*LCS %Recovery*	*LCS Qualifier*	*Limits*
1,2-Dichloroethane-d4 (Surr)	*111*		*75 - 126*
Toluene-d8 (Surr)	*100*		*75 - 120*
4-Bromofluorobenzene (Surr)	*98*		*72 - 124*
Dibromofluoromethane	*110*		*75 - 120*

Lab Sample ID: 500-189929-9 MS **Client Sample ID: Duplicate**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 569473

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Benzene	<0.00050		0.0500	0.0575		mg/L		115	70 - 120
Toluene	<0.00050		0.0500	0.0534		mg/L		107	70 - 125
Ethylbenzene	<0.00050		0.0500	0.0529		mg/L		106	70 - 123
Xylenes, Total	<0.0010		0.100	0.106		mg/L		106	70 - 125

Surrogate	*MS %Recovery*	*MS Qualifier*	*Limits*
1,2-Dichloroethane-d4 (Surr)	*113*		*75 - 126*
Toluene-d8 (Surr)	*100*		*75 - 120*
4-Bromofluorobenzene (Surr)	*98*		*72 - 124*
Dibromofluoromethane	*112*		*75 - 120*

Method: 8260B - Volatile Organic Compounds (GC/MS) (Continued)

Lab Sample ID: 500-189929-9 MSD
Matrix: Water
Analysis Batch: 569473

Client Sample ID: Duplicate
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Benzene	<0.00050		0.0500	0.0582		mg/L		116	70 - 120	1	20
Toluene	<0.00050		0.0500	0.0551		mg/L		110	70 - 125	3	20
Ethylbenzene	<0.00050		0.0500	0.0537		mg/L		107	70 - 123	2	20
Xylenes, Total	<0.0010		0.100	0.109		mg/L		109	70 - 125	3	20

Surrogate	*MSD %Recovery*	*MSD Qualifier*	*Limits*
1,2-Dichloroethane-d4 (Surr)	*112*		*75 - 126*
Toluene-d8 (Surr)	*100*		*75 - 120*
4-Bromofluorobenzene (Surr)	*96*		*72 - 124*
Dibromofluoromethane	*110*		*75 - 120*

Method: 314.0 - Perchlorate (IC)

Lab Sample ID: MB 320-425701/5
Matrix: Water
Analysis Batch: 425701

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/27/20 11:38	1

Lab Sample ID: LCS 320-425701/6
Matrix: Water
Analysis Batch: 425701

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Perchlorate	0.0500	0.0507		mg/L		101	85 - 115

Lab Sample ID: MRL 320-425701/4
Matrix: Water
Analysis Batch: 425701

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	MRL Result	MRL Qualifier	Unit	D	%Rec	%Rec. Limits
Perchlorate	4.00	<4.0		ug/L		95	75 - 125

Lab Sample ID: 500-189929-1 MS
Matrix: Water
Analysis Batch: 425701

Client Sample ID: MW-03
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Perchlorate	<0.0040		0.0500	0.0472		mg/L		94	80 - 120

Lab Sample ID: 500-189929-1 MSD
Matrix: Water
Analysis Batch: 425701

Client Sample ID: MW-03
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Perchlorate	<0.0040		0.0500	0.0469		mg/L		94	80 - 120	0	20

QC Sample Results

Method: 314.0 - Perchlorate (IC) (Continued)

Lab Sample ID: MB 320-426124/5
Matrix: Water
Analysis Batch: 426124

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			10/28/20 11:32	1

Lab Sample ID: LCS 320-426124/6
Matrix: Water
Analysis Batch: 426124

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Perchlorate			0.0500	0.0504		mg/L		101	85 - 115		

Lab Sample ID: MRL 320-426124/4
Matrix: Water
Analysis Batch: 426124

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte			Spike Added	MRL Result	MRL Qualifier	Unit	D	%Rec	%Rec. Limits		
Perchlorate			4.00	4.09		ug/L		102	75 - 125		

Lab Sample ID: 500-189929-6 MS
Matrix: Water
Analysis Batch: 426124

Client Sample ID: MW-08
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits		
Perchlorate	<0.0040		0.0500	0.0462		mg/L		92	80 - 120		

Lab Sample ID: 500-189929-6 MSD
Matrix: Water
Analysis Batch: 426124

Client Sample ID: MW-08
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Perchlorate	<0.0040		0.0500	0.0460		mg/L		92	80 - 120	1	20

Method: 6020A - Metals (ICP/MS)

Lab Sample ID: 500-189929-4 MS
Matrix: Water
Analysis Batch: 570004

Client Sample ID: MW-06
Prep Type: Dissolved
Prep Batch: 569853

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits		
Antimony	<0.0030		0.500	0.498		mg/L		100	75 - 125		
Arsenic	<0.0010		0.100	0.106		mg/L		106	75 - 125		
Barium	0.13		0.500	0.655		mg/L		105	75 - 125		
Beryllium	<0.0010		0.0500	0.0480		mg/L		96	75 - 125		
Boron	0.23		1.00	1.22		mg/L		99	75 - 125		
Cadmium	<0.00050		0.0500	0.0516		mg/L		103	75 - 125		
Chromium	<0.0050		0.200	0.199		mg/L		100	75 - 125		
Cobalt	<0.0010		0.500	0.487		mg/L		97	75 - 125		
Copper	<0.0020		0.250	0.257		mg/L		103	75 - 125		
Iron	<0.10		1.00	1.01		mg/L		101	75 - 125		
Lead	<0.00050		0.100	0.103		mg/L		103	75 - 125		
Manganese	<0.0025		0.500	0.497		mg/L		99	75 - 125		
Nickel	<0.0020		0.500	0.485		mg/L		97	75 - 125		

Method: 6020A - Metals (ICP/MS) (Continued)

Lab Sample ID: 500-189929-4 MS
Matrix: Water
Analysis Batch: 570004

Client Sample ID: MW-06
Prep Type: Dissolved
Prep Batch: 569853

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Selenium	<0.0025		0.100	0.113		mg/L		111	75 - 125
Silver	<0.00050		0.0500	0.0459		mg/L		92	75 - 125
Thallium	<0.0020		0.100	0.107		mg/L		107	75 - 125
Vanadium	<0.0050		0.500	0.499		mg/L		99	75 - 125
Zinc	<0.020		0.500	0.521		mg/L		104	75 - 125

Lab Sample ID: 500-189929-4 MSD
Matrix: Water
Analysis Batch: 570004

Client Sample ID: MW-06
Prep Type: Dissolved
Prep Batch: 569853

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Antimony	<0.0030		0.500	0.508		mg/L		102	75 - 125	2	20
Arsenic	<0.0010		0.100	0.107		mg/L		107	75 - 125	1	20
Barium	0.13		0.500	0.655		mg/L		106	75 - 125	0	20
Beryllium	<0.0010		0.0500	0.0477		mg/L		95	75 - 125	1	20
Boron	0.23		1.00	1.24		mg/L		101	75 - 125	2	20
Cadmium	<0.00050		0.0500	0.0518		mg/L		104	75 - 125	0	20
Chromium	<0.0050		0.200	0.202		mg/L		101	75 - 125	2	20
Cobalt	<0.0010		0.500	0.491		mg/L		98	75 - 125	1	20
Copper	<0.0020		0.250	0.259		mg/L		104	75 - 125	1	20
Iron	<0.10		1.00	1.02		mg/L		102	75 - 125	1	20
Lead	<0.00050		0.100	0.105		mg/L		105	75 - 125	2	20
Manganese	<0.0025		0.500	0.498		mg/L		100	75 - 125	0	20
Nickel	<0.0020		0.500	0.495		mg/L		99	75 - 125	2	20
Selenium	<0.0025		0.100	0.113		mg/L		111	75 - 125	0	20
Silver	<0.00050		0.0500	0.0459		mg/L		92	75 - 125	0	20
Thallium	<0.0020		0.100	0.108		mg/L		108	75 - 125	1	20
Vanadium	<0.0050		0.500	0.494		mg/L		98	75 - 125	1	20
Zinc	<0.020		0.500	0.516		mg/L		103	75 - 125	1	20

Lab Sample ID: 500-189929-4 DU
Matrix: Water
Analysis Batch: 570004

Client Sample ID: MW-06
Prep Type: Dissolved
Prep Batch: 569853

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Antimony	<0.0030		<0.0030		mg/L		NC	20
Arsenic	<0.0010		<0.0010		mg/L		NC	20
Barium	0.13		0.131		mg/L		3	20
Beryllium	<0.0010		<0.0010		mg/L		NC	20
Boron	0.23		0.233		mg/L		2	20
Cadmium	<0.00050		<0.00050		mg/L		NC	20
Chromium	<0.0050		<0.0050		mg/L		NC	20
Cobalt	<0.0010		<0.0010		mg/L		NC	20
Copper	<0.0020		<0.0020		mg/L		NC	20
Iron	<0.10		<0.10		mg/L		NC	20
Lead	<0.00050		<0.00050		mg/L		NC	20
Manganese	<0.0025		<0.0025		mg/L		NC	20
Nickel	<0.0020		<0.0020		mg/L		NC	20
Selenium	<0.0025		0.00292		mg/L		NC	20

Method: 6020A - Metals (ICP/MS) (Continued)

Lab Sample ID: 500-189929-4 DU
Matrix: Water
Analysis Batch: 570004

Client Sample ID: MW-06
Prep Type: Dissolved
Prep Batch: 569853

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Silver	<0.00050		<0.00050		mg/L		NC	20
Thallium	<0.0020		<0.0020		mg/L		NC	20
Vanadium	<0.0050		<0.0050		mg/L		NC	20
Zinc	<0.020		<0.020		mg/L		NC	20

Lab Sample ID: MB 500-569853/1-A
Matrix: Water
Analysis Batch: 570004

Client Sample ID: Method Blank
Prep Type: Soluble
Prep Batch: 569853

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		11/02/20 12:38	11/02/20 14:01	1
Arsenic	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:01	1
Barium	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:01	1
Beryllium	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:01	1
Boron	<0.050		0.050		mg/L		11/02/20 12:38	11/02/20 14:01	1
Cadmium	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:01	1
Chromium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:01	1
Cobalt	<0.0010		0.0010		mg/L		11/02/20 12:38	11/02/20 14:01	1
Copper	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:01	1
Iron	<0.10		0.10		mg/L		11/02/20 12:38	11/02/20 14:01	1
Lead	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:01	1
Manganese	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:01	1
Nickel	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:01	1
Selenium	<0.0025		0.0025		mg/L		11/02/20 12:38	11/02/20 14:01	1
Silver	<0.00050		0.00050		mg/L		11/02/20 12:38	11/02/20 14:01	1
Thallium	<0.0020		0.0020		mg/L		11/02/20 12:38	11/02/20 14:01	1
Vanadium	<0.0050		0.0050		mg/L		11/02/20 12:38	11/02/20 14:01	1
Zinc	<0.020		0.020		mg/L		11/02/20 12:38	11/02/20 14:01	1

Lab Sample ID: LCS 500-569853/2-A
Matrix: Water
Analysis Batch: 570004

Client Sample ID: Lab Control Sample
Prep Type: Soluble
Prep Batch: 569853

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Antimony	0.500	0.464		mg/L		93	80 - 120
Arsenic	0.100	0.0971		mg/L		97	80 - 120
Barium	0.500	0.485		mg/L		97	80 - 120
Beryllium	0.0500	0.0463		mg/L		93	80 - 120
Boron	1.00	1.01		mg/L		101	80 - 120
Cadmium	0.0500	0.0502		mg/L		100	80 - 120
Chromium	0.200	0.201		mg/L		101	80 - 120
Cobalt	0.500	0.491		mg/L		98	80 - 120
Copper	0.250	0.247		mg/L		99	80 - 120
Iron	1.00	0.986		mg/L		99	80 - 120
Lead	0.100	0.0987		mg/L		99	80 - 120
Manganese	0.500	0.498		mg/L		100	80 - 120
Nickel	0.500	0.486		mg/L		97	80 - 120
Selenium	0.100	0.0969		mg/L		97	80 - 120
Silver	0.0500	0.0494		mg/L		99	80 - 120

Method: 6020A - Metals (ICP/MS) (Continued)

Lab Sample ID: LCS 500-569853/2-A
Matrix: Water
Analysis Batch: 570004

Client Sample ID: Lab Control Sample
Prep Type: Soluble
Prep Batch: 569853

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Thallium			0.100	0.100		mg/L		100	80 - 120		
Vanadium			0.500	0.482		mg/L		96	80 - 120		
Zinc			0.500	0.498		mg/L		100	80 - 120		

Method: 7470A - Mercury (CVAA)

Lab Sample ID: MB 500-569235/12-A
Matrix: Water
Analysis Batch: 569446

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 569235

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		10/29/20 10:20	10/30/20 08:22	1

Lab Sample ID: LCS 500-569235/13-A
Matrix: Water
Analysis Batch: 569446

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 569235

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Mercury			0.00200	0.00210		mg/L		105	80 - 120		

Lab Sample ID: 500-189929-8 MS
Matrix: Water
Analysis Batch: 569446

Client Sample ID: MW-11
Prep Type: Dissolved
Prep Batch: 569235

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits		
Mercury	<0.00020		0.00100	0.000958		mg/L		96	75 - 125		

Lab Sample ID: 500-189929-8 MSD
Matrix: Water
Analysis Batch: 569446

Client Sample ID: MW-11
Prep Type: Dissolved
Prep Batch: 569235

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Mercury	<0.00020		0.00100	0.000940		mg/L		94	75 - 125	2	20

Lab Sample ID: 500-189929-8 DU
Matrix: Water
Analysis Batch: 569446

Client Sample ID: MW-11
Prep Type: Dissolved
Prep Batch: 569235

Analyte	Sample Result	Sample Qualifier		DU Result	DU Qualifier	Unit	D			RPD	RPD Limit
Mercury	<0.00020			<0.00020		mg/L				NC	20

Method: 9014 - Cyanide

Lab Sample ID: MB 500-570453/1-A
Matrix: Water
Analysis Batch: 570534

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 570453

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 12:42	1

Method: 9014 - Cyanide (Continued)

Lab Sample ID: HLCS 500-570453/2-A
Matrix: Water
Analysis Batch: 570534

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 570453

Analyte	Spike Added	HLCS Result	HLCS Qualifier	Unit	D	%Rec	%Rec. Limits
Cyanide, Total	0.500	0.473		mg/L		95	90 - 110

Lab Sample ID: LCS 500-570453/3-A
Matrix: Water
Analysis Batch: 570534

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 570453

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Cyanide, Total	0.100	0.111		mg/L		111	85 - 115

Lab Sample ID: LLCS 500-570453/4-A
Matrix: Water
Analysis Batch: 570534

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 570453

Analyte	Spike Added	LLCS Result	LLCS Qualifier	Unit	D	%Rec	%Rec. Limits
Cyanide, Total	0.0500	0.0445		mg/L		89	75 - 125

Lab Sample ID: MB 500-570455/1-A
Matrix: Water
Analysis Batch: 570535

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 570455

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/05/20 10:35	11/05/20 15:32	1

Lab Sample ID: HLCS 500-570455/2-A
Matrix: Water
Analysis Batch: 570535

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 570455

Analyte	Spike Added	HLCS Result	HLCS Qualifier	Unit	D	%Rec	%Rec. Limits
Cyanide, Total	0.500	0.458		mg/L		92	90 - 110

Lab Sample ID: LCS 500-570455/3-A
Matrix: Water
Analysis Batch: 570535

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 570455

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Cyanide, Total	0.100	0.105		mg/L		105	85 - 115

Lab Sample ID: LLCS 500-570455/4-A
Matrix: Water
Analysis Batch: 570535

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 570455

Analyte	Spike Added	LLCS Result	LLCS Qualifier	Unit	D	%Rec	%Rec. Limits
Cyanide, Total	0.0500	0.0521		mg/L		104	75 - 125

QC Sample Results

Method: 9038 - Sulfate, Turbidimetric

Lab Sample ID: MB 500-569487/15
Client Sample ID: Method Blank
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 569487

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<5.0		5.0		mg/L			10/30/20 11:59	1

Lab Sample ID: LCS 500-569487/16
Client Sample ID: Lab Control Sample
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 569487

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Sulfate			20.0	19.3		mg/L		96	80 - 120		

Method: 9251 - Chloride

Lab Sample ID: MB 500-570023/12
Client Sample ID: Method Blank
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 570023

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<2.0		2.0		mg/L			11/03/20 08:56	1

Lab Sample ID: LCS 500-570023/13
Client Sample ID: Lab Control Sample
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 570023

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Chloride			50.0	49.5		mg/L		99	80 - 120		

Lab Sample ID: 500-189929-7 MS
Client Sample ID: MW-10
Matrix: Water
Prep Type: Dissolved
Analysis Batch: 570023

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits		
Chloride	230		50.0	268	4	mg/L		81	75 - 125		

Lab Sample ID: 500-189929-7 MSD
Client Sample ID: MW-10
Matrix: Water
Prep Type: Dissolved
Analysis Batch: 570023

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Chloride	230		50.0	264	4	mg/L		73	75 - 125	2	20

Method: SM 2540C - Solids, Total Dissolved (TDS)

Lab Sample ID: MB 310-297244/1
Client Sample ID: Method Blank
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 297244

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	<30		30		mg/L			10/27/20 16:49	1

Method: SM 2540C - Solids, Total Dissolved (TDS) (Continued)

Lab Sample ID: LCS 310-297244/2 **Client Sample ID: Lab Control Sample**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 297244

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Total Dissolved Solids	1000	946		mg/L		95	90 - 110

Lab Sample ID: MB 310-297381/1 **Client Sample ID: Method Blank**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 297381

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	<30		30		mg/L			10/28/20 13:56	1

Lab Sample ID: LCS 310-297381/2 **Client Sample ID: Lab Control Sample**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 297381

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Total Dissolved Solids	1000	982		mg/L		98	90 - 110

Lab Sample ID: 500-189929-8 DU **Client Sample ID: MW-11**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 297381

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Total Dissolved Solids	710		712		mg/L		0.8	24

Method: SM 4500 F C - Fluoride

Lab Sample ID: MB 500-570407/3 **Client Sample ID: Method Blank**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 570407

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Fluoride	<0.10		0.10		mg/L			11/04/20 13:53	1

Lab Sample ID: LCS 500-570407/4 **Client Sample ID: Lab Control Sample**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 570407

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Fluoride	10.0	10.9		mg/L		109	80 - 120

Lab Sample ID: 500-189929-1 MS **Client Sample ID: MW-03**
Matrix: Water **Prep Type: Dissolved**
Analysis Batch: 570407

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Fluoride	0.44		5.00	6.02		mg/L		112	75 - 125

Method: SM 4500 F C - Fluoride (Continued)

Lab Sample ID: 500-189929-1 MSD
Client Sample ID: MW-03
Matrix: Water
Prep Type: Dissolved
Analysis Batch: 570407

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Fluoride	0.44		5.00	6.05		mg/L		112	75 - 125	0	20

Method: SM 4500 NO2 B - Nitrogen, Nitrite

Lab Sample ID: MB 500-568249/9
Client Sample ID: Method Blank
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 568249

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			10/23/20 08:17	1

Lab Sample ID: LCS 500-568249/10
Client Sample ID: Lab Control Sample
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 568249

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Nitrogen, Nitrite	0.100	0.0989		mg/L		99	80 - 120

Lab Sample ID: 500-189929-1 MS
Client Sample ID: MW-03
Matrix: Water
Prep Type: Dissolved
Analysis Batch: 568249

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Nitrogen, Nitrite	<0.020		0.100	0.0910		mg/L		91	75 - 125

Lab Sample ID: 500-189929-1 MSD
Client Sample ID: MW-03
Matrix: Water
Prep Type: Dissolved
Analysis Batch: 568249

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Nitrogen, Nitrite	<0.020		0.100	0.0915		mg/L		92	75 - 125	1	20

Method: SM 4500 NO3 F - Nitrogen, Nitrate

Lab Sample ID: MB 500-570289/203
Client Sample ID: Method Blank
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 570289

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrate Nitrite	<0.10		0.10		mg/L			11/04/20 10:31	1

Lab Sample ID: LCS 500-570289/204
Client Sample ID: Lab Control Sample
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 570289

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Nitrogen, Nitrate Nitrite	1.00	1.03		mg/L		103	80 - 120

QC Sample Results

Method: SM 4500 NO3 F - Nitrogen, Nitrate (Continued)

Lab Sample ID: LCSD 500-570289/205
Client Sample ID: Lab Control Sample Dup
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 570289

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Nitrogen, Nitrate Nitrite			1.00	1.10		mg/L		110	80 - 120	2	20

Lab Sample ID: MB 500-570507/46
Client Sample ID: Method Blank
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 570507

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrate Nitrite	<0.10		0.10		mg/L			11/05/20 13:05	1

Lab Sample ID: LCS 500-570507/47
Client Sample ID: Lab Control Sample
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 570507

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Nitrogen, Nitrate Nitrite			1.00	1.12		mg/L		112	80 - 120

Lab Sample ID: LCSD 500-570507/76
Client Sample ID: Lab Control Sample Dup
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 570507

Analyte			Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Nitrogen, Nitrate Nitrite			1.00	1.16		mg/L		116	80 - 120	5	20

Lab Sample ID: MB 500-572019/25
Client Sample ID: Method Blank
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 572019

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrate Nitrite	<0.10		0.10		mg/L			11/13/20 09:12	1

Lab Sample ID: LCS 500-572019/26
Client Sample ID: Lab Control Sample
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 572019

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Nitrogen, Nitrate Nitrite			1.00	0.978		mg/L		98	80 - 120

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Phone: 708-534-5200 Fax: 708-534-5211

Chain of Custody Record

eurofins | Environment Testing America

Client Information

Sampler:
Lab PM: Mockler, Diana J
Carrier Tracking No(s):
COC No: 500-85987-38853.1

Client Contact: Erin Bulson
Phone:
E-Mail: Diana.Mockler@Eurofinset.com
Page: Page 1 of 2

Company: KPRG and Associates, Inc.
Job #: 500-189929

Address: 14665 West Lisbon Road, Suite 1A
Due Date Requested:
City: Brookfield
TAT Requested (days):
State, Zip: WI, 53005
Phone: 815-671-2258(Tel)
PO #: 4500051862
Email: erinb@kprginc.com
WO #:
Project Name: Midwest Generation Joliet Groundwater
Project #: 50005078
Site:
SSOW#:

500-189929 COC

Analysis Requested

Preservation Codes:

A - HCL	M - Hexane
B - NaOH	N - None
C - Zn Acetate	O - AsNaO2
D - Nitric Acid	P - Na2O4S
E - NaHSO4	Q - Na2SO3
F - MeOH	R - Na2S2O3
G - Amchlor	S - H2SO4
H - Ascorbic Acid	T - TSP Dodecahydrate
I - Ice	U - Acetone
J - DI Water	V - MCAA
K - EDTA	W - pH 4-5
L - EDA	Z - other (specify)

Other:

Sample Identification	Sample Date	Sample Time	Sample Type (C=comp, G=grab)	Matrix (W=water, S=solid, O=waste/oil, BT=Tissue, A=Air)	Field Filtered Sample (Yes or No)	Perform MS/MSD (Yes or No)	6020, 7470A	2540C, 4500_F_C, 9251	SM4500_NO2_B - Nitrogen, Nitrite	9014 - Total Cyanide	SM4500_NO3_F - Nitrogen, Nitrate Nitrite	8260B - BTEX	314.0 - Perchlorate	9056A - Sulfate	Total Number of containers	Special Instructions/Note:
				Preservation Code:			D	N	N	B	S	A	N	N		
MW-01				Water												
MW-02				Water												
1 MW-03	10-22	1018		Water												
2 MW-04		1111		Water												
3 MW-05		1246		Water												
4 MW-06		1512		Water												
5 MW-07		1414		Water												
6 MW-08	10-22	0923		Water												
MW-09				Water												
7 MW-10	10-22	1205		Water												
8 MW-11	10-22	1331		Water												

Possible Hazard Identification
☐ *Non-Hazard* ☐ *Flammable* ☐ *Skin Irritant* ☐ *Poison B* ☐ *Unknown* ☐ *Radiological*

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☐ *Disposal By Lab* ☐ *Archive For* ______ *Months*

Deliverable Requested: I, II, III, IV, Other (specify)
Special Instructions/QC Requirements:

Empty Kit Relinquished by:	Date:	Time:	Method of Shipment:

Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company
	10-22 1820		Aaron Kimbrough	10/22/20 18:20	TAI

Custody Seals Intact: Δ Yes Δ No
Custody Seal No.:
Cooler Temperature(s) °C and Other Remarks: 5.8, 5.4, 5.7

* All samples taken 10-22-20

Ver: 01/16/2019

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Phone: 708-534-5200 Fax: 708-534-5211

Chain of Custody Record

eurofins | Environment Testing America

1 2 3 4 5 6 7 8 9 10 11 12 13 14

Client Information	Sampler:	Lab PM: Mockler, Diana J	Carrier Tracking No(s):	COC No: 500-85987-38853.2
Client Contact: Erin Bulson	Phone:	E-Mail: Diana.Mockler@Eurofinset.com		Page: Page 2 of 2
Company: KPRG and Associates, Inc.		**Analysis Requested**		Job #: 500-189929
Address: 14665 West Lisbon Road, Suite 1A	**Due Date Requested:**			**Preservation Codes:**
City: Brookfield	**TAT Requested (days):**			
State, Zip: WI, 53005				
Phone: 815-671-2258(Tel)	PO #: 4500051862			
Email: erinb@kprginc.com	WO #:			
Project Name Midwest Generation Joliet Groundwater	Project #: 50005078			
Site	SSOW#:			Other:

Preservation Codes:

A - HCL	M - Hexane
B - NaOH	N - None
C - Zn Acetate	O - AsNaO2
D - Nitric Acid	P - Na2O4S
E - NaHSO4	Q - Na2SO3
F - MeOH	R - Na2S2O3
G - Amchlor	S - H2SO4
H - Ascorbic Acid	T - TSP Dodecahydrate
I - Ice	U - Acetone
J - DI Water	V - MCAA
K - EDTA	W - pH 4-5
L - EDA	Z - other (specify)

Sample Identification	**Sample Date**	**Sample Time**	**Sample Type** (C=comp, G=grab)	**Matrix** (W=water, S=solid, O=waste/oil, BT=Tissue, A=Air)	**Field Filtered Sample (Yes or No)**	**Perform MS/MSD (Yes or No)**	**6020, 7470A**	**2540C, 4500_F_C, 9251**	**SM4500_NO2_B - Nitrogen, Nitrite**	**9014 - Total Cyanide**	**SM4500_NO3_F - Nitrogen, Nitrate Nitrite**	**8260B - BTEX**	**314.0 - Perchlorate**	**9056A - Sulfate**						**Total Number of containers**	**Special Instructions/Note:**
				Preservation Code:	☒	☒	D	N	N	B	S	A	N	N						☒	
9 Duplicate				Water																	Added by TA
10 Trip Blank				Water																	
				Water																	
				Water																	

Possible Hazard Identification
☐ *Non-Hazard* ☐ *Flammable* ☐ *Skin Irritant* ☐ *Poison B* ☐ *Unknown* ☐ *Radiological*

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☐ *Disposal By Lab* ☐ *Archive For* ________ *Months*

Deliverable Requested: I, II, III, IV, Other (specify)

Special Instructions/QC Requirements:

Empty Kit Relinquished by:	Date:	Time:	Method of Shipment:

Relinquished by:	Date/Time: 10-22 1820	Company	Received by: Aaron Kimbrough	Date/Time: 10/22/20 18:20	Company TAI
Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company
Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company

Custody Seals Intact: Δ Yes Δ No	Custody Seal No.:	Cooler Temperature(s) °C and Other Remarks:

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Phone: 708-534-5200 Fax: 708-534-5211

Chain of Custody Record

eurofins | Environment Testing America

Client Information (Sub Contract Lab)	Sampler:	Lab PM: Mockler, Diana J	Carrier Tracking No(s):	COC No: 500-141335.1
Client Contact: Shipping/Receiving	Phone:	E-Mail: Diana.Mockler@Eurofinset.com	State of Origin: Illinois	Page: Page 1 of 1
Company: TestAmerica Laboratories, Inc		Accreditations Required (See note): NELAP - Illinois		Job #: 500-189929-1
Address: 3019 Venture Way,	**Due Date Requested:** 11/4/2020	**Analysis Requested**		**Preservation Codes:**
City: Cedar Falls	**TAT Requested (days):**			
State, Zip: IA, 50613				
Phone: 319-277-2401(Tel) 319-277-2425(Fax)	PO #:			
Email:	WO #:			
Project Name: Joliet #29 Station Ash Ponds (CCA)	Project #: 50005078			
Site:	SSOW#:			Other:

Preservation Codes:

A - HCL	M - Hexane
B - NaOH	N - None
C - Zn Acetate	O - AsNaO2
D - Nitric Acid	P - Na2O4S
E - NaHSO4	Q - Na2SO3
F - MeOH	R - Na2S2O3
G - Amchlor	S - H2SO4
H - Ascorbic Acid	T - TSP Dodecahydrate
I - Ice	U - Acetone
J - DI Water	V - MCAA
K - EDTA	W - pH 4-5
L - EDA	Z - other (specify)

Sample Identification - Client ID (Lab ID)	Sample Date	Sample Time	Sample Type (C=comp, G=grab)	Matrix (W=water, S=solid, O=waste/oil, BT=Tissue, A=Air)	Field Filtered Sample (Yes or No)	Perform MS/MSD (Yes or No)	2540C_Calcd/ Total Dissolved Solids	Total Number of containers	Special Instructions/Note:
			Preservation Code:						
MW-03 (500-189929-1)	10/22/20	10:18 Central		Water			X	1	
MW-04 (500-189929-2)	10/22/20	11:11 Central		Water			X	1	
MW-05 (500-189929-3)	10/22/20	12:46 Central		Water			X	1	
MW-06 (500-189929-4)	10/22/20	15:12 Central		Water			X	1	
MW-07 (500-189929-5)	10/22/20	14:14 Central		Water			X	1	
MW-08 (500-189929-6)	10/22/20	09:23 Central		Water			X	1	
MW-10 (500-189929-7)	10/22/20	12:05 Central		Water			X	1	
MW-11 (500-189929-8)	10/22/20	13:31 Central		Water			X	1	
Duplicate (500-189929-9)	10/22/20	Central		Water			X	1	

Note: Since laboratory accreditations are subject to change, Eurofins TestAmerica places the ownership of method, analyte & accreditation compliance upon out subcontract laboratories. This sample shipment is forwarded under chain-of-custody. If the laboratory does not currently maintain accreditation in the State of Origin listed above for analysis/tests/matrix being analyzed, the samples must be shipped back to the Eurofins TestAmerica laboratory or other instructions will be provided. Any changes to accreditation status should be brought to Eurofins TestAmerica attention immediately. If all requested accreditations are current to date, return the signed Chain of Custody attesting to said complicance to Eurofins TestAmerica.

Possible Hazard Identification *Unconfirmed*		***Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)*** ☐ *Return To Client* ☐ *Disposal By Lab* ☐ *Archive For ________ Months*	
Deliverable Requested: I, II, III, IV, Other (specify)	Primary Deliverable Rank: 2	Special Instructions/QC Requirements:	
Empty Kit Relinquished by:	Date:	Time:	Method of Shipment:

Relinquished by:	Date/Time: 10/23/20 1700	Company: TA	Received by:	Date/Time: 10-24-20 0950	Company
Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company
Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company
Custody Seals Intact: Δ Yes Δ No	Custody Seal No.:		Cooler Temperature(s) °C and Other Remarks:		

Ver: 01/16/2019

eurofins | Environment Testing
TestAmerica

Place COC scanning label here

Cooler/Sample Receipt and Temperature Log Form

Client Information

Client: ETA chicago

City/State: CITY University Park STATE IL | Project: Joilet #29 Station Ash Pond (CCR)

Receipt Information

Date/Time Received: DATE 10-24-20 TIME 0950 | Received By: ER

Delivery Type: ☐ UPS ☒ FedEx SAT ☐ FedEx Ground ☐ US Mail ☐ Spee-Dee
☐ Lab Courier ☐ Lab Field Services ☐ Client Drop-off ☐ Other:______

Condition of Cooler/Containers

Sample(s) received in Cooler?	☒ Yes	☐ No	*If yes:* Cooler ID:	
Multiple Coolers?	☐ Yes	☒ No	*If yes:* Cooler # ____ of ____	
Cooler Custody Seals Present?	☒ Yes	☐ No	*If yes:* Cooler custody seals intact? ☒ Yes	☐ No
Sample Custody Seals Present?	☐ Yes	☒ No	*If yes:* Sample custody seals intact? ☐ Yes	☐ No
Trip Blank Present?	☐ Yes	☒ No	*If yes:* Which VOA samples are in cooler? ↓	

Temperature Record

Coolant: ☒ Wet ice ☐ Blue ice ☐ Dry ice ☐ Other:______ ☐ NONE

Thermometer ID: O | Correction Factor (°C): 0.0

• Temp Blank Temperature – If no temp blank, or temp blank temperature above criteria, proceed to Sample Container Temperature

Uncorrected Temp (°C): 10-24-20 ER | Corrected Temp (°C):

• Sample Container Temperature

	CONTAINER 1	CONTAINER 2
Container(s) used:	plastic 250 mL	
Uncorrected Temp (°C):	1.8	
Corrected Temp (°C):	1.8	

Exceptions Noted

1) If temperature exceeds criteria, was sample(s) received same day of sampling? ☐ Yes ☐ No
a) *If yes:* Is there evidence that the chilling process began? ☐ Yes ☐ No

2) If temperature is <0°C, are there obvious signs that the integrity of sample containers is compromised? (e.g., bulging septa, broken/cracked bottles, frozen solid?) ☐ Yes ☐ No

NOTE: If yes, contact PM before proceeding. If no, proceed with login

Additional Comments

Document: CF-LG-WI-002
Revision: 25
Date: 06/17/2019

Eurofins TestAmerica, Cedar Falls

General temperature criteria is 0 to 6°C
Bacteria temperature criteria is 0 to 10°C

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Phone: 708-534-5200 Fax: 708-534-5211

Chain of Custody Record

eurofins Environment Testing America

Client Information (Sub Contract Lab)	Sampler:	Lab PM: Mockler, Diana J	Carrier Tracking No(s):	COC No: 500-141340.1
Client Contact: Shipping/Receiving	Phone:	E-Mail: Diana.Mockler@Eurofinset.com	State of Origin: Illinois	Page: Page 1 of 1
Company: TestAmerica Laboratories, Inc.		Accreditations Required (See note): NELAP - Illinois		Job #: 500-189929-1
Address: 880 Riverside Parkway, ,	**Due Date Requested:** 11/4/2020	**Analysis Requested**		**Preservation Codes:**
City: West Sacramento	**TAT Requested (days):**			
State, Zip: CA, 95605				
Phone: 916-373-5600(Tel) 916-372-1059(Fax)	PO #:			
Email:	WO #:			
Project Name: Joliet #29 Station Ash Ponds (CCA)	Project #: 50005078			
Site:	SSOW#:			Other:

Preservation Codes:
- A - HCL
- B - NaOH
- C - Zn Acetate
- D - Nitric Acid
- E - NaHSO4
- F - MeOH
- G - Amchlor
- H - Ascorbic Acid
- I - Ice
- J - DI Water
- K - EDTA
- L - EDA
- M - Hexane
- N - None
- O - AsNaO2
- P - Na2O4S
- Q - Na2SO3
- R - Na2S2O3
- S - H2SO4
- T - TSP Dodecahydrate
- U - Acetone
- V - MCAA
- W - pH 4-5
- Z - other (specify)

Sample Identification - Client ID (Lab ID)	Sample Date	Sample Time	Sample Type (C=comp, G=grab)	Matrix (W=water, S=solid, O=waste/oil, BT=Tissue, A=Air)	Field Filtered Sample (Yes or No)	Perform MS/MSD (Yes or No)	314.0/ Perchlorate	Total Number of containers	Special Instructions/Note:
			Preservation Code:		X	X		X	
MW-03 (500-189929-1)	10/22/20	10:18 Central		Water			X	1	
MW-04 (500-189929-2)	10/22/20	11:11 Central		Water			X	1	
MW-05 (500-189929-3)	10/22/20	12:46 Central		Water			X	1	
MW-06 (500-189929-4)	10/22/20	15:12 Central		Water			X	1	
MW-07 (500-189929-5)	10/22/20	14:14 Central		Water			X	1	
MW-08 (500-189929-6)	10/22/20	09:23 Central		Water			X	1	
MW-10 (500-189929-7)	10/22/20	12:05 Central		Water			X	1	
MW-11 (500-189929-8)	10/22/20	13:31 Central		Water			X	1	
Duplicate (500-189929-9)	10/22/20	Central		Water			X	1	

Note: Since laboratory accreditations are subject to change, Eurofins TestAmerica places the ownership of method, analyte & accreditation compliance upon out subcontract laboratories. This sample shipment is forwarded under chain-of-custody. If the laboratory does not currently maintain accreditation in the State of Origin listed above for analysis/tests/matrix being analyzed, the samples must be shipped back to the Eurofins TestAmerica laboratory or other instructions will be provided. Any changes to accreditation status should be brought to Eurofins TestAmerica attention immediately. If all requested accreditations are current to date, return the signed Chain of Custody attesting to said complicance to Eurofins TestAmerica.

Possible Hazard Identification
Unconfirmed

Deliverable Requested: I, II, III, IV, Other (specify) Primary Deliverable Rank: 2

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☐ *Disposal By Lab* ☐ *Archive For ________ Months*

Special Instructions/QC Requirements:

Empty Kit Relinquished by:		Date:	Time:	Method of Shipment:	
Relinquished by:	Date/Time: 10/23/20 1700	Company TA	Received by:	Date/Time: 10/24/20 09:15	Company ETA-SAC
Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company
Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company
Custody Seals Intact: [✓ Yes] Δ No	Custody Seal No.: 1346997		Cooler Temperature(s) °C and Other Remarks: OB: 0.5 CORR: 0.0		

Ver: 01/16/2019

Login Sample Receipt Checklist

Client: KPRG and Associates, Inc.

Job Number: 500-189929-1

Login Number: 189929
List Number: 1
Creator: Scott, Sherri L

List Source: Eurofins TestAmerica, Chicago

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	True	
The cooler's custody seal, if present, is intact.	True	
Sample custody seals, if present, are intact.	True	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	5.8,5.4,5.7
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	False	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Login Sample Receipt Checklist

Client: KPRG and Associates, Inc.

Job Number: 500-189929-1

Login Number: 189929
List Number: 3
Creator: Bovy, Lorrainna L

List Source: Eurofins TestAmerica, Cedar Falls
List Creation: 10/26/20 09:56 AM

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	N/A	
The cooler's custody seal, if present, is intact.	True	
Sample custody seals, if present, are intact.	N/A	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	False	Received project as a subcontract.
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Login Sample Receipt Checklist

Client: KPRG and Associates, Inc.

Job Number: 500-189929-1

Login Number: 189929
List Number: 2
Creator: Saephan, Kae C

List Source: Eurofins TestAmerica, Sacramento
List Creation: 10/24/20 11:38 AM

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	True	
The cooler's custody seal, if present, is intact.	True	1346997
Sample custody seals, if present, are intact.	N/A	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	ob: 0.5c corr: 0.0c
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	False	Received project as a subcontract.
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	N/A	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Accreditation/Certification Summary

Laboratory: Eurofins TestAmerica, Chicago

The accreditations/certifications listed below are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Illinois	NELAP	IL00035	04-29-21

Laboratory: Eurofins TestAmerica, Cedar Falls

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
AIHA-LAP, LLC	Industrial Hygiene Laboratory Accreditation Program (IHLAP)	101044	10-28-20
Colorado	Petroleum Storage Tank Program	IA100001 (OR)	09-29-21
Georgia	State	IA100001 (OR)	09-29-21
Illinois	NELAP	200024	11-29-20
Iowa	State	007	12-01-21
Kansas	NELAP	E-10341	01-31-21
Minnesota	NELAP	019-999-319	11-02-20
Minnesota (Petrofund)	State	3349	08-22-21
North Dakota	State	R-186	09-29-21
Oregon	NELAP	IA100001	09-29-21
USDA	US Federal Programs	P330-19-00003	01-02-22

Laboratory: Eurofins TestAmerica, Sacramento

Unless otherwise noted, all analytes for this laboratory were covered under each accreditation/certification below.

Authority	Program	Identification Number	Expiration Date
Illinois	NELAP	200060	03-17-21

The following analytes are included in this report, but the laboratory is not certified by the governing authority. This list may include analytes for which the agency does not offer certification.

Analysis Method	Prep Method	Matrix	Analyte
314.0		Water	Perchlorate

1
2
3
4
5
6
7
8
9
10
11
12
13
14

eurofins | **Environment Testing**
TestAmerica

Sacramento
Sample Receiving Notes

500-189929 Field Sheet

Job: ____

Tracking #: 189344499056

SO / ~~PO~~ / FO / [✓ SAT] / 2-Day / Ground / UPS / CDO / Courier
GSO / OnTrac / Goldstreak / USPS / Other ____

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations.
File in the job folder with the COC.

Therm. ID: AK-5 Corr. Factor: (+ / [✓ -]) 0.5 °C

Ice X Wet X Gel ____ Other ____

Cooler Custody Seal: 1346997

Cooler ID: –

Temp Observed: 0.5 °C Corrected: 0.0 °C

From: Temp Blank ☐ Sample ☑

Opening/Processing The Shipment	**Yes**	**No**	**NA**
Cooler compromised/tampered with?	☐	☑	☐
Cooler Temperature is acceptable?	☑	☐	☐

Initials: ____ Date: 10/24/20

Unpacking/Labeling The Samples	**Yes**	**No**	**NA**
CoC is complete w/o discrepancies?	☑	☐	☐
Samples compromised/tampered with?	☐	☑	☐
Sample containers have legible labels?	☑	☐	☐
Sample custody seal?	☐	☐	☑
Containers are not broken or leaking?	☑	☐	☐
Sample date/times are provided?	☑	☐	☐
Appropriate containers are used?	☑	☐	☐
Sample bottles are completely filled?	☐	☑	☐
Sample preservatives verified?	☐	☐	☑
Samples w/o discrepancies?	☑	☐	☐
Zero headspace?*	☐	☐	☑
Alkalinity has no headspace?	☐	☐	☑
Perchlorate has headspace? (Methods [✓ 314], 331, 6850)	☑	☐	☐
Multiphasic samples are not present?	☑	☐	☐

*Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")

Initials: ____ Date: 10/24/20

Notes: ____

Trizma Lot #(s): ____

Login Completion	**Yes**	**No**	**NA**
Receipt Temperature on COC?	☑	☐	☐
Samples received within hold time?	☑	☐	☐
NCM Filed?	☐	☐	☑
Log Release checked in TALS?	☐	☐	☑

Initials: ____ Date: 10/24/20

\\TACORP\CORP\QA\QA_FACILITIES\SACRAMENTO-QA\DOCUMENT-MANAGEMENT\FORMS\QA-812 SAMPLE RECEIVING NOTES.DOC QA-812 TGT 6/11/2020

W25

eurofins

Environment Testing
America

1 2 3 4 5 6 7 8 9 10 11 12 13 14

ANALYTICAL REPORT

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Tel: (708)534-5200

Laboratory Job ID: 500-190570-1
Client Project/Site: Joliet #29 Station Ash Ponds (CCA)

For:
KPRG and Associates, Inc.
14665 West Lisbon Road,
Suite 1A
Brookfield, Wisconsin 53005

Attn: Richard Gnat

Diana Mockler

Authorized for release by:
11/23/2020 2:38:39 PM

Diana Mockler, Project Manager I
(219)252-7570
Diana.Mockler@Eurofinset.com

LINKS

Review your project results through
TotalAccess

Have a Question?
Ask The Expert

Visit us at:
www.eurofinsus.com/Env

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

Table of Contents

Case Narrative

Job ID: 500-190570-1

Laboratory: Eurofins TestAmerica, Chicago

Narrative

Job Narrative
500-190570-1

Comments
No additional comments.

Receipt
The sample was received on 11/4/2020 3:30 PM; the sample arrived in good condition, and where required, properly preserved and on ice. The temperature of the cooler at receipt was 5.1º C.

GC/MS VOA
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

Metals
Method 6020A: The low level continuing calibration verification (CCVL) at line 59, associated with batch 500-571798 recovered above the upper control limit for Beryllium. The samples associated with this CCVL were non-detects for the affected analyte; therefore, the data have been reported.

Method 6020A: The continuing calibration blank and verification (CCV/CCB) at lines 39 and 40 were outside the control limits for Boron bracketing the laboratory control sample (LCS). The LCS was within the method control limits. The associated samples were bracketed by CCV/CCB that were within control limits. Therefore, the data have been reported.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Field Service / Mobile Lab
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

General Chemistry
Method 9038: Due to an instrument error, the low level CCV (CCVL) was not analyzed for the samples analyzed at the end of Sulfate batch 500-571365. All sample results were in the upper portion of the curve (greater than the LCS). The high level CCV (CCVH) was analyzed as expected and met criteria; therefore, data has been reported. The following samples were affected: MW-09 (500-190570-1), (LCS 500-571365/121) and (MB 500-571365/120).

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Method Summary

Client: KPRG and Associates, Inc.
Project/Site: Joliet #29 Station Ash Ponds (CCA)

Job ID: 500-190570-1

Method	Method Description	Protocol	Laboratory
8260B	Volatile Organic Compounds (GC/MS)	SW846	TAL CHI
314.0	Perchlorate (IC)	EPA	TAL SAC
6020A	Metals (ICP/MS)	SW846	TAL CHI
7470A	Mercury (CVAA)	SW846	TAL CHI
9014	Cyanide	SW846	TAL CHI
9038	Sulfate, Turbidimetric	SW846	TAL CHI
9251	Chloride	SW846	TAL CHI
Nitrate by calc	Nitrogen, Nitrate-Nitrite	SM	TAL CHI
SM 2540C	Solids, Total Dissolved (TDS)	SM	TAL CF
SM 4500 F C	Fluoride	SM	TAL CHI
SM 4500 NO2 B	Nitrogen, Nitrite	SM	TAL CHI
SM 4500 NO3 F	Nitrogen, Nitrate	SM	TAL CHI
3005A	Preparation, Total Recoverable or Dissolved Metals	SW846	TAL CHI
5030B	Purge and Trap	SW846	TAL CHI
7470A	Preparation, Mercury	SW846	TAL CHI
9010C	Cyanide, Distillation	SW846	TAL CHI
Filtration	Sample Filtration	None	TAL CF
FILTRATION	Sample Filtration	None	TAL CHI

Protocol References:

EPA = US Environmental Protection Agency
None = None
SM = "Standard Methods For The Examination Of Water And Wastewater"
SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

TAL CF = Eurofins TestAmerica, Cedar Falls, 3019 Venture Way, Cedar Falls, IA 50613, TEL (319)277-2401
TAL CHI = Eurofins TestAmerica, Chicago, 2417 Bond Street, University Park, IL 60484, TEL (708)534-5200
TAL SAC = Eurofins TestAmerica, Sacramento, 880 Riverside Parkway, West Sacramento, CA 95605, TEL (916)373-5600

Sample Summary

Client: KPRG and Associates, Inc.
Job ID: 500-190570-1
Project/Site: Joliet #29 Station Ash Ponds (CCA)

Lab Sample ID	Client Sample ID	Matrix	Collected	Received	Asset ID
500-190570-1	MW-09	Water	11/04/20 14:00	11/04/20 15:30	

Client Sample Results

Client: KPRG and Associates, Inc.
Project/Site: Joliet #29 Station Ash Ponds (CCA)

Job ID: 500-190570-1

1
2
3
4
5
6
7
8
9
10
11
12
13
14

Client Sample ID: MW-09

Date Collected: 11/04/20 14:00
Date Received: 11/04/20 15:30

Lab Sample ID: 500-190570-1
Matrix: Water

Method: 8260B - Volatile Organic Compounds (GC/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			11/09/20 19:09	1
Toluene	<0.00050		0.00050		mg/L			11/09/20 19:09	1
Ethylbenzene	<0.00050		0.00050		mg/L			11/09/20 19:09	1
Xylenes, Total	<0.0010		0.0010		mg/L			11/09/20 19:09	1

Surrogate	*%Recovery*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*111*		*75 - 126*		*11/09/20 19:09*	*1*
Toluene-d8 (Surr)	*96*		*75 - 120*		*11/09/20 19:09*	*1*
4-Bromofluorobenzene (Surr)	*96*		*72 - 124*		*11/09/20 19:09*	*1*
Dibromofluoromethane	*94*		*75 - 120*		*11/09/20 19:09*	*1*

Method: 314.0 - Perchlorate (IC)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			11/16/20 18:51	1

Method: 6020A - Metals (ICP/MS) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Silver	<0.00050		0.00050		mg/L		11/11/20 08:01	11/12/20 13:17	1
Arsenic	**0.034**		0.0010		mg/L		11/11/20 08:01	11/12/20 13:17	1
Boron	**0.37**		0.050		mg/L		11/11/20 08:01	11/12/20 13:17	1
Barium	**0.086**		0.0025		mg/L		11/11/20 08:01	11/12/20 13:17	1
Beryllium	<0.0010	^	0.0010		mg/L		11/11/20 08:01	11/12/20 13:17	1
Cadmium	**0.0021**		0.00050		mg/L		11/11/20 08:01	11/12/20 13:17	1
Cobalt	**0.046**		0.0010		mg/L		11/11/20 08:01	11/12/20 13:17	1
Chromium	**0.028**		0.0050		mg/L		11/11/20 08:01	11/12/20 13:17	1
Copper	**0.041**		0.0020		mg/L		11/11/20 08:01	11/12/20 13:17	1
Iron	**970**		0.50		mg/L		11/11/20 08:01	11/12/20 13:21	5
Manganese	**2.3**		0.0025		mg/L		11/11/20 08:01	11/12/20 13:17	1
Nickel	**0.10**		0.0020		mg/L		11/11/20 08:01	11/12/20 13:17	1
Lead	**0.036**		0.00050		mg/L		11/11/20 08:01	11/12/20 13:17	1
Antimony	<0.0030		0.0030		mg/L		11/11/20 08:01	11/12/20 13:17	1
Selenium	**0.0027**		0.0025		mg/L		11/11/20 08:01	11/12/20 13:17	1
Thallium	<0.0020		0.0020		mg/L		11/11/20 08:01	11/12/20 13:17	1
Vanadium	**0.026**		0.0050		mg/L		11/11/20 08:01	11/12/20 13:17	1
Zinc	**1.2**		0.020		mg/L		11/11/20 08:01	11/12/20 13:17	1

Method: 7470A - Mercury (CVAA) - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		11/13/20 09:15	11/16/20 07:50	1

General Chemistry - Dissolved

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Cyanide, Total	<0.010		0.010		mg/L		11/18/20 17:30	11/18/20 19:06	1
Sulfate	**1500**		250		mg/L			11/10/20 16:33	50
Chloride	**190**		10		mg/L			11/12/20 09:01	5
Nitrogen, Nitrate	<0.10		0.10		mg/L			11/23/20 13:32	1
Total Dissolved Solids	**3000**		150		mg/L			11/11/20 15:48	1
Fluoride	**0.66**		0.10		mg/L			11/18/20 14:46	1
Nitrogen, Nitrite	<0.020		0.020		mg/L			11/05/20 09:15	1
Nitrogen, Nitrate Nitrite	<0.10		0.10		mg/L			11/22/20 11:20	1

Definitions/Glossary

Qualifiers

Metals

Qualifier	Qualifier Description
^	ICV,CCV,ICB,CCB, ISA, ISB, CRI, CRA, DLCK or MRL standard: Instrument related QC is outside acceptance limits.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CFU	Colony Forming Unit
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MCL	EPA recommended "Maximum Contaminant Level"
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
MPN	Most Probable Number
MQL	Method Quantitation Limit
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
NEG	Negative / Absent
POS	Positive / Present
PQL	Practical Quantitation Limit
PRES	Presumptive
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)
TNTC	Too Numerous To Count

QC Association Summary

Client: KPRG and Associates, Inc.
Job ID: 500-190570-1
Project/Site: Joliet #29 Station Ash Ponds (CCA)

GC/MS VOA

Analysis Batch: 571009

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Total/NA	Water	8260B	
MB 500-571009/9	Method Blank	Total/NA	Water	8260B	
LCS 500-571009/5	Lab Control Sample	Total/NA	Water	8260B	

HPLC/IC

Analysis Batch: 432093

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Total/NA	Water	314.0	
MB 320-432093/5	Method Blank	Total/NA	Water	314.0	
LCS 320-432093/6	Lab Control Sample	Total/NA	Water	314.0	
MRL 320-432093/4	Lab Control Sample	Total/NA	Water	314.0	

Metals

Filtration Batch: 571221

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	FILTRATION	
MB 500-571221/1-C	Method Blank	Dissolved	Water	FILTRATION	
MB 500-571221/1-G	Method Blank	Dissolved	Water	FILTRATION	

Prep Batch: 571464

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	3005A	571221
MB 500-571221/1-C	Method Blank	Dissolved	Water	3005A	571221
LCS 500-571464/2-A	Lab Control Sample	Total Recoverable	Water	3005A	

Analysis Batch: 571798

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	6020A	571464
500-190570-1	MW-09	Dissolved	Water	6020A	571464
MB 500-571221/1-C	Method Blank	Dissolved	Water	6020A	571464
LCS 500-571464/2-A	Lab Control Sample	Total Recoverable	Water	6020A	571464

Prep Batch: 571982

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	7470A	571221
MB 500-571221/1-G	Method Blank	Dissolved	Water	7470A	571221
MB 500-571982/12-A	Method Blank	Total/NA	Water	7470A	
LCS 500-571982/15-A	Lab Control Sample	Total/NA	Water	7470A	

Analysis Batch: 572324

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	7470A	571982
MB 500-571221/1-G	Method Blank	Dissolved	Water	7470A	571982
MB 500-571982/12-A	Method Blank	Total/NA	Water	7470A	571982
LCS 500-571982/15-A	Lab Control Sample	Total/NA	Water	7470A	571982

QC Association Summary

General Chemistry

Filtration Batch: 298972

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	Filtration	
MB 310-298972/1-A	Method Blank	Dissolved	Water	Filtration	
500-190570-1 DU	MW-09	Dissolved	Water	Filtration	

Analysis Batch: 299001

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	SM 2540C	298972
MB 310-298972/1-A	Method Blank	Dissolved	Water	SM 2540C	298972
LCS 310-299001/2	Lab Control Sample	Total/NA	Water	SM 2540C	
500-190570-1 DU	MW-09	Dissolved	Water	SM 2540C	298972

Analysis Batch: 571059

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	SM 4500 NO2 B	571221
MB 500-571059/9	Method Blank	Total/NA	Water	SM 4500 NO2 B	
LCS 500-571059/10	Lab Control Sample	Total/NA	Water	SM 4500 NO2 B	

Filtration Batch: 571221

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	FILTRATION	

Analysis Batch: 571365

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	9038	
MB 500-571365/120	Method Blank	Total/NA	Water	9038	
LCS 500-571365/121	Lab Control Sample	Total/NA	Water	9038	

Analysis Batch: 571749

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	9251	571781

Filtration Batch: 571781

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	FILTRATION	

Analysis Batch: 572899

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	SM 4500 F C	573346

Prep Batch: 572904

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	9010C	573346

Analysis Batch: 573064

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	9014	572904

Filtration Batch: 573346

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	FILTRATION	
500-190570-1	MW-09	Dissolved	Water	FILTRATION	

QC Association Summary

General Chemistry

Analysis Batch: 573490

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	SM 4500 NO3 F	573580
LCS 500-573490/83	Lab Control Sample	Total/NA	Water	SM 4500 NO3 F	

Filtration Batch: 573580

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	FILTRATION	

Analysis Batch: 573642

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190570-1	MW-09	Dissolved	Water	Nitrate by calc	571221

Surrogate Summary

Method: 8260B - Volatile Organic Compounds (GC/MS)

Matrix: Water **Prep Type: Total/NA**

		Percent Surrogate Recovery (Acceptance Limits)			
		DCA	TOL	BFB	DBFM
Lab Sample ID	Client Sample ID	(75-126)	(75-120)	(72-124)	(75-120)
500-190570-1	MW-09	111	96	96	94
LCS 500-571009/5	Lab Control Sample	107	97	93	96
MB 500-571009/9	Method Blank	105	96	94	92

Surrogate Legend

DCA = 1,2-Dichloroethane-d4 (Surr)
TOL = Toluene-d8 (Surr)
BFB = 4-Bromofluorobenzene (Surr)
DBFM = Dibromofluoromethane

Method: 8260B - Volatile Organic Compounds (GC/MS)

Lab Sample ID: MB 500-571009/9 **Client Sample ID: Method Blank**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 571009

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Benzene	<0.00050		0.00050		mg/L			11/09/20 12:47	1
Toluene	<0.00050		0.00050		mg/L			11/09/20 12:47	1
Ethylbenzene	<0.00050		0.00050		mg/L			11/09/20 12:47	1
Xylenes, Total	<0.0010		0.0010		mg/L			11/09/20 12:47	1

Surrogate	*MB %Recovery*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
1,2-Dichloroethane-d4 (Surr)	*105*		*75 - 126*		*11/09/20 12:47*	*1*
Toluene-d8 (Surr)	*96*		*75 - 120*		*11/09/20 12:47*	*1*
4-Bromofluorobenzene (Surr)	*94*		*72 - 124*		*11/09/20 12:47*	*1*
Dibromofluoromethane	*92*		*75 - 120*		*11/09/20 12:47*	*1*

Lab Sample ID: LCS 500-571009/5 **Client Sample ID: Lab Control Sample**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 571009

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Benzene			0.0500	0.0476		mg/L		95	70 - 120		
Toluene			0.0500	0.0469		mg/L		94	70 - 125		
Ethylbenzene			0.0500	0.0473		mg/L		95	70 - 123		
Xylenes, Total			0.100	0.0922		mg/L		92	70 - 125		

Surrogate	*LCS %Recovery*	*LCS Qualifier*	*Limits*
1,2-Dichloroethane-d4 (Surr)	*107*		*75 - 126*
Toluene-d8 (Surr)	*97*		*75 - 120*
4-Bromofluorobenzene (Surr)	*93*		*72 - 124*
Dibromofluoromethane	*96*		*75 - 120*

Method: 314.0 - Perchlorate (IC)

Lab Sample ID: MB 320-432093/5 **Client Sample ID: Method Blank**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 432093

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Perchlorate	<0.0040		0.0040		mg/L			11/16/20 14:24	1

Lab Sample ID: LCS 320-432093/6 **Client Sample ID: Lab Control Sample**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 432093

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Perchlorate			0.0500	0.0526		mg/L		105	85 - 115		

Lab Sample ID: MRL 320-432093/4 **Client Sample ID: Lab Control Sample**
Matrix: Water **Prep Type: Total/NA**
Analysis Batch: 432093

Analyte			Spike Added	MRL Result	MRL Qualifier	Unit	D	%Rec	%Rec. Limits		
Perchlorate			4.00	<4.0		ug/L		99	75 - 125		

QC Sample Results

Method: 6020A - Metals (ICP/MS)

Lab Sample ID: LCS 500-571464/2-A
Matrix: Water
Analysis Batch: 571798

Client Sample ID: Lab Control Sample
Prep Type: Total Recoverable
Prep Batch: 571464

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Silver	0.0500	0.0463		mg/L		93	80 - 120
Arsenic	0.100	0.0949		mg/L		95	80 - 120
Boron	1.00	0.976	^	mg/L		98	80 - 120
Barium	2.00	1.95		mg/L		97	80 - 120
Beryllium	0.0500	0.0495	^	mg/L		99	80 - 120
Cadmium	0.0500	0.0476		mg/L		95	80 - 120
Cobalt	0.500	0.502		mg/L		100	80 - 120
Chromium	0.200	0.203		mg/L		102	80 - 120
Copper	0.250	0.259		mg/L		104	80 - 120
Iron	1.00	1.03		mg/L		103	80 - 120
Manganese	0.500	0.496		mg/L		99	80 - 120
Nickel	0.500	0.506		mg/L		101	80 - 120
Lead	0.100	0.104		mg/L		104	80 - 120
Antimony	0.500	0.459		mg/L		92	80 - 120
Selenium	0.100	0.0996		mg/L		100	80 - 120
Thallium	0.100	0.106		mg/L		106	80 - 120
Vanadium	0.500	0.496		mg/L		99	80 - 120
Zinc	0.500	0.505		mg/L		101	80 - 120

Lab Sample ID: MB 500-571221/1-C
Matrix: Water
Analysis Batch: 571798

Client Sample ID: Method Blank
Prep Type: Dissolved
Prep Batch: 571464

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Silver	<0.00050		0.00050		mg/L		11/11/20 08:01	11/12/20 13:14	1
Arsenic	<0.0010		0.0010		mg/L		11/11/20 08:01	11/12/20 13:14	1
Boron	<0.050		0.050		mg/L		11/11/20 08:01	11/12/20 13:14	1
Barium	<0.0025		0.0025		mg/L		11/11/20 08:01	11/12/20 13:14	1
Beryllium	<0.0010	^	0.0010		mg/L		11/11/20 08:01	11/12/20 13:14	1
Cadmium	<0.00050		0.00050		mg/L		11/11/20 08:01	11/12/20 13:14	1
Cobalt	<0.0010		0.0010		mg/L		11/11/20 08:01	11/12/20 13:14	1
Chromium	<0.0050		0.0050		mg/L		11/11/20 08:01	11/12/20 13:14	1
Copper	<0.0020		0.0020		mg/L		11/11/20 08:01	11/12/20 13:14	1
Iron	<0.10		0.10		mg/L		11/11/20 08:01	11/12/20 13:14	1
Manganese	<0.0025		0.0025		mg/L		11/11/20 08:01	11/12/20 13:14	1
Nickel	<0.0020		0.0020		mg/L		11/11/20 08:01	11/12/20 13:14	1
Lead	<0.00050		0.00050		mg/L		11/11/20 08:01	11/12/20 13:14	1
Antimony	<0.0030		0.0030		mg/L		11/11/20 08:01	11/12/20 13:14	1
Selenium	<0.0025		0.0025		mg/L		11/11/20 08:01	11/12/20 13:14	1
Thallium	<0.0020		0.0020		mg/L		11/11/20 08:01	11/12/20 13:14	1
Vanadium	<0.0050		0.0050		mg/L		11/11/20 08:01	11/12/20 13:14	1
Zinc	<0.020		0.020		mg/L		11/11/20 08:01	11/12/20 13:14	1

QC Sample Results

1 2 3 4 5 6 7 8 9 10 11 12 13 14

Method: 7470A - Mercury (CVAA)

Lab Sample ID: MB 500-571982/12-A
Matrix: Water
Analysis Batch: 572324

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 571982

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		11/13/20 09:15	11/16/20 07:10	1

Lab Sample ID: LCS 500-571982/15-A
Matrix: Water
Analysis Batch: 572324

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 571982

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Mercury	0.00200	0.00193		mg/L		96	80 - 120

Lab Sample ID: MB 500-571221/1-G
Matrix: Water
Analysis Batch: 572324

Client Sample ID: Method Blank
Prep Type: Dissolved
Prep Batch: 571982

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		11/13/20 09:15	11/16/20 07:27	1

Method: 9038 - Sulfate, Turbidimetric

Lab Sample ID: MB 500-571365/120
Matrix: Water
Analysis Batch: 571365

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<5.0		5.0		mg/L			11/10/20 16:28	1

Lab Sample ID: LCS 500-571365/121
Matrix: Water
Analysis Batch: 571365

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	20.0	21.0		mg/L		105	80 - 120

Method: SM 2540C - Solids, Total Dissolved (TDS)

Lab Sample ID: LCS 310-299001/2
Matrix: Water
Analysis Batch: 299001

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Total Dissolved Solids	1000	1020		mg/L		102	90 - 110

Lab Sample ID: MB 310-298972/1-A
Matrix: Water
Analysis Batch: 299001

Client Sample ID: Method Blank
Prep Type: Dissolved

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	<30		30		mg/L			11/11/20 15:48	1

Method: SM 2540C - Solids, Total Dissolved (TDS) (Continued)

Lab Sample ID: 500-190570-1 DU
Client Sample ID: MW-09
Matrix: Water
Prep Type: Dissolved
Analysis Batch: 299001

Analyte	Sample Result	Sample Qualifier		DU Result	DU Qualifier	Unit	D			RPD	RPD Limit
Total Dissolved Solids	3000			3040		mg/L				0	24

Method: SM 4500 NO2 B - Nitrogen, Nitrite

Lab Sample ID: MB 500-571059/9
Client Sample ID: Method Blank
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 571059

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Nitrogen, Nitrite	<0.020		0.020		mg/L			11/05/20 09:02	1

Lab Sample ID: LCS 500-571059/10
Client Sample ID: Lab Control Sample
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 571059

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Nitrogen, Nitrite			0.100	0.103		mg/L		103	80 - 120		

Method: SM 4500 NO3 F - Nitrogen, Nitrate

Lab Sample ID: LCS 500-573490/83
Client Sample ID: Lab Control Sample
Matrix: Water
Prep Type: Total/NA
Analysis Batch: 573490

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Nitrogen, Nitrate Nitrite			1.00	1.03		mg/L		103	80 - 120		

Chain of Custody Record

375541

eurofins | Environment Testing
TestAmerica

Address:

Regulatory Program: ☐ DW ☐ NPDES ☐ RCRA ☐ Other:

TAL-8210

Client Contact			
Company Name: KRRG and Assoc. Inc	Project Manager: Diana Mockler	Site Contact:	Date: 11/4/2020
Address: 14165 W Lisbon Rd 1A	Tel/Email:	Lab Contact:	Carrier:
City/State/Zip: Brookfield, WI 53005			
Phone: (262) 781-0475			
Fax:			
Project Name: Midwest Generation ~~[illegible]~~			
Site: Joliet 29 Groundwater			
P O# CCA			

COC No: 1 of 1 COCs

Sampler: Erin Bulson

For Lab Use Only:
Walk-in Client: X
Lab Sampling:

Job / SDG No.: 500-190570

500-190570 COC

Analysis Turnaround Time
☐ CALENDAR DAYS ☐ WORKING DAYS
TAT if different from Below
☐ 2 weeks
☐ 1 week
☐ 2 days
☐ 1 day

Sample Identification	Sample Date	Sample Time	Sample Type (C=Comp, G=Grab)	Matrix	# of Cont.	Filtered Sample (Y / N)	Perform MS / MSD (Y / N)	6020, 7470A	2540C, 4500_F-C, 9038, 9251	SM4500_NO2_B: Nitrogen, Nitrite	SM4500_NO3_F-Nitrogen, Nitrate Nitrite	9014	9260B-BTEX	Sample Specific Notes:
MW-09	11/4	1400		Water		N		X	X	X	X	X	X	Needs to be filtered preservatives were removed from sample bottles

Preservation Used: 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH; 6= Other

Possible Hazard Identification:
Are any samples from a listed EPA Hazardous Waste? Please List any EPA Waste Codes for the sample in the Comments Section if the lab is to dispose of the sample.
☐ Non-Hazard ☐ Flammable ☐ Skin Irritant ☐ Poison B ☐ Unknown

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ Return to Client ☐ Disposal by Lab ☐ Archive for ______ Months

Special Instructions/QC Requirements & Comments:

Custody Seals Intact: ☐ Yes ☐ No
Custody Seal No.:
Cooler Temp. (°C): Obs'd: 4.7 Corr'd: 5.1 Therm ID No.:

Relinquished by: Erin Bulson	Company: KRRG	Date/Time: 11/4/20 1530	Received by:	Company:	Date/Time:
Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
Relinquished by:	Company:	Date/Time:	Received in Laboratory by:	Company: ETA	Date/Time: 11/4/20 1530

eurofins | Environment Testing
TestAmerica

500-190570 Chain of Custody

Cooler/Sample Receipt and Temperature

Client Information

Client: ETA - Chicago

City/State: CITY University Park STATE IL | Project: Joliet

Receipt Information

Date/Time Received: DATE 11/5/20 TIME 1010 | Received By: MRH

Delivery Type: ☐ UPS ☒ FedEx ☐ FedEx Ground ☐ US Mail ☐ Spee-Dee
☐ Lab Courier ☐ Lab Field Services ☐ Client Drop-off ☐ Other:

Condition of Cooler/Containers

Sample(s) received in Cooler?	☒ Yes	☐ No	*If yes:* Cooler ID:
Multiple Coolers?	☐ Yes	☒ No	*If yes:* Cooler # ____ of ____
Cooler Custody Seals Present?	☒ Yes	☐ No	*If yes:* Cooler custody seals intact? ☒ Yes ☐ No
Sample Custody Seals Present?	☐ Yes	☒ No	*If yes:* Sample custody seals intact? ☐ Yes ☐ No
Trip Blank Present?	☐ Yes	☒ No	*If yes:* Which VOA samples are in cooler? ↓

Temperature Record

Coolant: ☒ Wet ice ☐ Blue ice ☐ Dry ice ☐ Other: ☐ NONE

Thermometer ID: 0 | Correction Factor (°C): 0

• Temp Blank Temperature – If no temp blank, or temp blank temperature above criteria, proceed to Sample Container Temperature

Uncorrected Temp (°C): ~~tt~~ MRH 11/5/20 | Corrected Temp (°C):

• Sample Container Temperature

	CONTAINER 1	CONTAINER 2
Container(s) used:	1L Plas NT	
Uncorrected Temp (°C):	1.1	
Corrected Temp (°C):	1.1	

Exceptions Noted

1) If temperature exceeds criteria, was sample(s) received same day of sampling? ☐ Yes ☐ No
a) *If yes:* Is there evidence that the chilling process began? ☐ Yes ☐ No

2) If temperature is <0°C, are there obvious signs that the integrity of sample containers is compromised? (e.g., bulging septa, broken/cracked bottles, frozen solid?) ☐ Yes ☐ No

NOTE: If yes, contact PM before proceeding. If no, proceed with login

Additional Comments

Document: CF-LG-WI-002
Revision: 25
Date: 06/17/2019

Eurofins TestAmerica, Cedar Falls

General temperature criteria is 0 to 6°C
Bacteria temperature criteria is 0 to 10°C

1 2 3 4 5 6 7 8 9 10 11 12 13 14

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Phone: 708-534-5200 Fax: 708-534-5211

Chain of Custody Record

eurofins Environment Testing America

Client Information (Sub Contract Lab)

Sampler:

Lab PM: Mockler, Diana J

Carrier Tracking No(s):

COC No: 500-141787.1

Client Contact: Shipping/Receiving

Phone:

E-Mail: Diana.Mockler@Eurofinset.com

State of Origin: Illinois

Page: Page 1 of 1

Company: TestAmerica Laboratories, Inc

Accreditations Required (See note): NELAP - Illinois

Job #: 500-190570-1

Address: 3019 Venture Way, ,

Due Date Requested: 11/16/2020

City: Cedar Falls

TAT Requested (days):

State, Zip: IA, 50613

Phone: 319-277-2401(Tel) 319-277-2425(Fax)

PO #:

Email:

WO #:

Project Name: Joliet #29 Station Ash Ponds (CCA)

Project #: 50005078

Site:

SSOW#:

Analysis Requested

Preservation Codes:

A - HCL	M - Hexane
B - NaOH	N - None
C - Zn Acetate	O - AsNaO2
D - Nitric Acid	P - Na2O4S
E - NaHSO4	Q - Na2SO3
F - MeOH	R - Na2S2O3
G - Amchlor	S - H2SO4
H - Ascorbic Acid	T - TSP Dodecahydrate
I - Ice	U - Acetone
J - DI Water	V - MCAA
K - EDTA	W - pH 4-5
L - EDA	Z - other (specify)

Other:

Sample Identification - Client ID (Lab ID)	Sample Date	Sample Time	Sample Type (C=comp, G=grab)	Matrix (W=water, S=solid, O=waste/oil, BT=Tissue, A=Air)	Field Filtered Sample (Yes or No)	Perform MS/MSD (Yes or No)	2540C_Calcd/Filtration_WC Total Dissolved Solids	Total Number of containers	Special Instructions/Note:
			Preservation Code:						
MW-09 (500-190570-1)	11/4/20	14:00 Central		Water			X	1	

Note: Since laboratory accreditations are subject to change, Eurofins TestAmerica places the ownership of method, analyte & accreditation compliance upon out subcontract laboratories. This sample shipment is forwarded under chain-of-custody. If the laboratory does not currently maintain accreditation in the State of Origin listed above for analysis/tests/matrix being analyzed, the samples must be shipped back to the Eurofins TestAmerica laboratory or other instructions will be provided. Any changes to accreditation status should be brought to Eurofins TestAmerica attention immediately. If all requested accreditations are current to date, return the signed Chain of Custody attesting to said complicance to Eurofins TestAmerica.

Possible Hazard Identification

Unconfirmed

Deliverable Requested: I, II, III, IV, Other (specify)

Primary Deliverable Rank: 2

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)

☐ *Return To Client* ☐ *Disposal By Lab* ☐ *Archive For* ____________ *Months*

Special Instructions/QC Requirements:

Empty Kit Relinquished by:

Date:

Time:

Method of Shipment:

Relinquished by: Date/Time: 11/4/20 1700 Company: ETA Received by: Date/Time: 11/5/20 1010 Company:

Relinquished by: Date/Time: Company: Received by: Date/Time: Company:

Relinquished by: Date/Time: Company: Received by: Date/Time: Company:

Custody Seals Intact: △ Yes △ No

Custody Seal No.:

Cooler Temperature(s) °C and Other Remarks:

Ver: 01/16/2019

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Phone: 708-534-5200 Fax: 708-534-5211

Chain of Custody Record

eurofins | Environment Testing America

Client Information (Sub Contract Lab)	Sampler:	Lab PM: Mockler, Diana J	Carrier Tracking No(s):	COC No: 500-141791.1
Client Contact: Shipping/Receiving	Phone:	E-Mail: Diana.Mockler@Eurofinset.com	State of Origin: Illinois	Page: Page 1 of 1
Company: TestAmerica Laboratories, Inc.		Accreditations Required (See note): NELAP - Illinois		Job #: 500-190570-1
Address: 880 Riverside Parkway, ,	**Due Date Requested:** 11/16/2020	**Analysis Requested**		**Preservation Codes:**
City: West Sacramento	**TAT Requested (days):**			
State, Zip: CA, 95605				
Phone: 916-373-5600(Tel) 916-372-1059(Fax)	PO #:			
Email:	WO #:			
Project Name: Joliet #29 Station Ash Ponds (CCA)	Project #: 50005078			
Site:	SSOW#:			**Other:**

Preservation Codes:
A - HCL
B - NaOH
C - Zn Acetate
D - Nitric Acid
E - NaHSO4
F - MeOH
G - Amchlor
H - Ascorbic Acid
I - Ice
J - DI Water
K - EDTA
L - EDA
M - Hexane
N - None
O - AsNaO2
P - Na2O4S
Q - Na2SO3
R - Na2S2O3
S - H2SO4
T - TSP Dodecahydrate
U - Acetone
V - MCAA
W - pH 4-5
Z - other (specify)

Sample Identification - Client ID (Lab ID)	**Sample Date**	**Sample Time**	**Sample Type** (C=comp, G=grab)	**Matrix** (W=water, S=solid, O=waste/oil, BT=Tissue, A=Air)	**Field Filtered Sample (Yes or No)**	**Perform MS/MSD (Yes or No)**	**314.0/ Perchlorate**	**Total Number of containers**	**Special Instructions/Note:**
			Preservation Code:						
MW-09 (500-190570-1)	11/4/20	14:00 Central		Water			X	1	

Note: Since laboratory accreditations are subject to change, Eurofins TestAmerica places the ownership of method, analyte & accreditation compliance upon out subcontract laboratories. This sample shipment is forwarded under chain-of-custody. If the laboratory does not currently maintain accreditation in the State of Origin listed above for analysis/tests/matrix being analyzed, the samples must be shipped back to the Eurofins TestAmerica laboratory or other instructions will be provided. Any changes to accreditation status should be brought to Eurofins TestAmerica attention immediately. If all requested accreditations are current to date, return the signed Chain of Custody attesting to said complicance to Eurofins TestAmerica.

Possible Hazard Identification
Unconfirmed

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ *Return To Client* ☐ *Disposal By Lab* ☐ *Archive For* ______ *Months*

Deliverable Requested: I, II, III, IV, Other (specify)
Primary Deliverable Rank: 2
Special Instructions/QC Requirements:

Empty Kit Relinquished by:
Date:
Time:
Method of Shipment:

Relinquished by:	Date/Time: 11/4/20 1700	Company: ETA	Received by:	Date/Time: 11/05/20 900	Company: eta Sac
Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company
Relinquished by:	Date/Time:	Company	Received by:	Date/Time:	Company

Custody Seals Intact: [✓ Δ Yes] Δ No
Custody Seal No.: 1363666
Cooler Temperature(s) °C and Other Remarks: 0.9

Ver: 01/16/2019

Login Sample Receipt Checklist

Client: KPRG and Associates, Inc.

Job Number: 500-190570-1

Login Number: 190570
List Number: 1
Creator: Scott, Sherri L

List Source: Eurofins TestAmerica, Chicago

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	True	
The cooler's custody seal, if present, is intact.	True	
Sample custody seals, if present, are intact.	True	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	5.1
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Login Sample Receipt Checklist

Client: KPRG and Associates, Inc.

Job Number: 500-190570-1

Login Number: 190570
List Number: 2
Creator: Homolar, Dana J

List Source: Eurofins TestAmerica, Cedar Falls
List Creation: 11/05/20 12:18 PM

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	N/A	
The cooler's custody seal, if present, is intact.	True	
Sample custody seals, if present, are intact.	N/A	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	False	Received project as a subcontract.
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Login Sample Receipt Checklist

Client: KPRG and Associates, Inc.

Job Number: 500-190570-1

Login Number: 190570
List Number: 3
Creator: Saephan, Kae C

List Source: Eurofins TestAmerica, Sacramento
List Creation: 11/05/20 11:32 AM

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	True	
The cooler's custody seal, if present, is intact.	True	1363666
Sample custody seals, if present, are intact.	N/A	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	ob: 0.9c corr: 0.9c
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	False	Received project as a subcontract.
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	False	Method requires headspace.
Sample Preservation Verified.	N/A	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Accreditation/Certification Summary

Laboratory: Eurofins TestAmerica, Chicago

The accreditations/certifications listed below are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Illinois	NELAP	IL00035	04-29-21

Laboratory: Eurofins TestAmerica, Cedar Falls

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Colorado	Petroleum Storage Tank Program	IA100001 (OR)	09-29-21
Georgia	State	IA100001 (OR)	09-29-21
Illinois	NELAP	200024	11-29-20
Iowa	State	007	12-01-21
Kansas	NELAP	E-10341	01-31-21
Minnesota	NELAP	019-999-319	12-31-21
Minnesota (Petrofund)	State	3349	08-22-21
North Dakota	State	R-186	09-29-21
Oregon	NELAP	IA100001	09-29-21
USDA	US Federal Programs	P330-19-00003	01-02-22

Laboratory: Eurofins TestAmerica, Sacramento

Unless otherwise noted, all analytes for this laboratory were covered under each accreditation/certification below.

Authority	Program	Identification Number	Expiration Date
Illinois	NELAP	200060	03-17-21

The following analytes are included in this report, but the laboratory is not certified by the governing authority. This list may include analytes for which the agency does not offer certification.

Analysis Method	Prep Method	Matrix	Analyte
314.0		Water	Perchlorate

eurofins | **Environment Testing TestAmerica**

Sacramento
Sample Receiving Notes

500-190570 Field Sheet

Job:

Tracking # : 1893 4450 0384

SO / [✓ PO] / FO / SAT / 2-Day / Ground / UPS / CDO / Courier
GSO / OnTrac / Goldstreak / USPS / Other

Use this form to record Sample Custody Seal, Cooler Custody Seal, Temperature & corrected Temperature & other observations.
File in the job folder with the COC.

Therm. ID: L-01 Corr. Factor: (+ / -) 0 °C

Ice ✓ Wet ___ Gel ___ Other ___

Cooler Custody Seal: 1363666

Cooler ID: –

Temp Observed: 0.9 °C Corrected: 0.9 °C

From: Temp Blank ☐ Sample ☑

Opening/Processing The Shipment	**Yes**	**No**	**NA**
Cooler compromised/tampered with?	☐	☑	☐
Cooler Temperature is acceptable?	☑	☐	☐

Initials: MAN Date: 11/05/20

Unpacking/Labeling The Samples	**Yes**	**No**	**NA**
CoC is complete w/o discrepancies?	☑	☐	☐
Samples compromised/tampered with?	☐	☑	☐
Sample containers have legible labels?	☑	☐	☐
Sample custody seal?	☐	☐	☑
Containers are not broken or leaking?	☑	☐	☐
Sample date/times are provided?	☑	☐	☐
Appropriate containers are used?	☑	☐	☐
Sample bottles are completely filled?	☐	☑	☐
Sample preservatives verified?	☐	☐	☑
Samples w/o discrepancies?	☑	☐	☐
Zero headspace?*	☐	☐	☑
Alkalinity has no headspace?	☐	☐	☑
Perchlorate has headspace? (Methods 314, 331, 6850)	☑	☐	☐
Multiphasic samples are not present?	☑	☐	☐

**Containers requiring zero headspace have no headspace, or bubble < 6 mm (1/4")*

Initials: Date: 11/05/20

Notes:

Trizma Lot #(s):

Login Completion	**Yes**	**No**	**NA**
Receipt Temperature on COC?	☑	☐	☐
Samples received within hold time?	☑	☐	☐
NCM Filed?	☐	☐	☑
Log Release checked in TALS?	☐	☐	☑

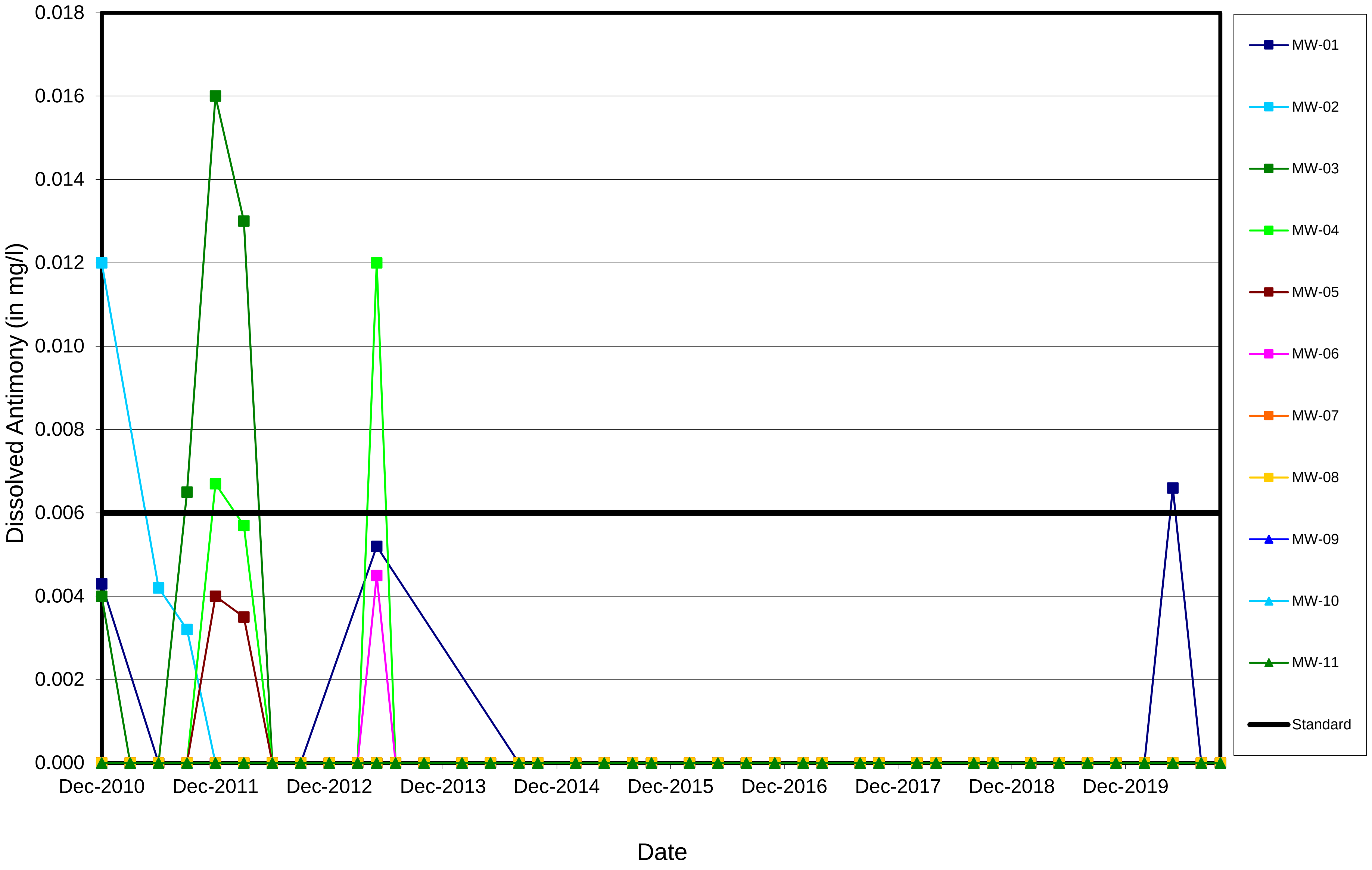
Initials: Date: 11/05/20

ATTACHMENT 3

Time Vs. Concentration Curves

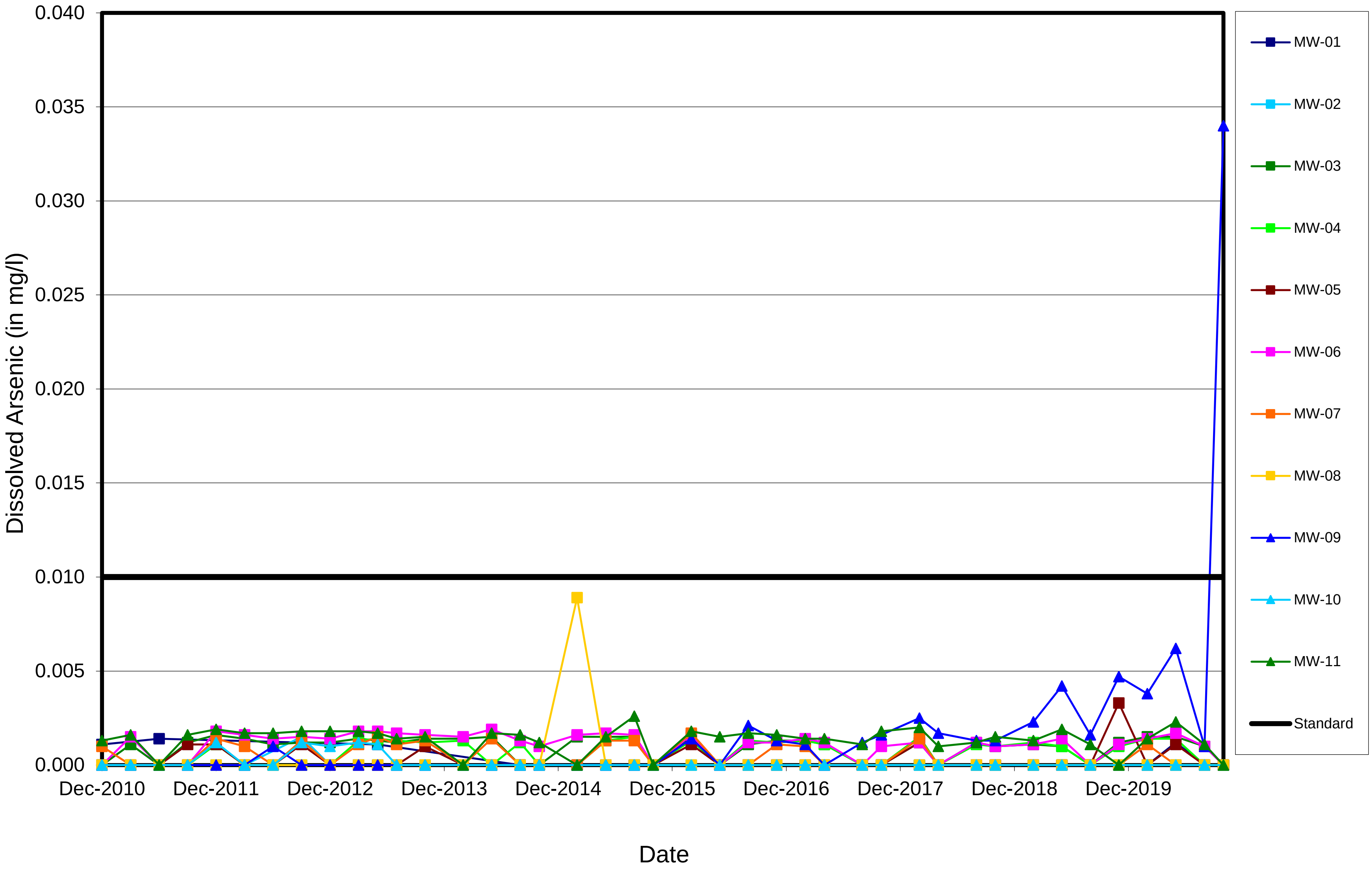
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Antimony vs. Time



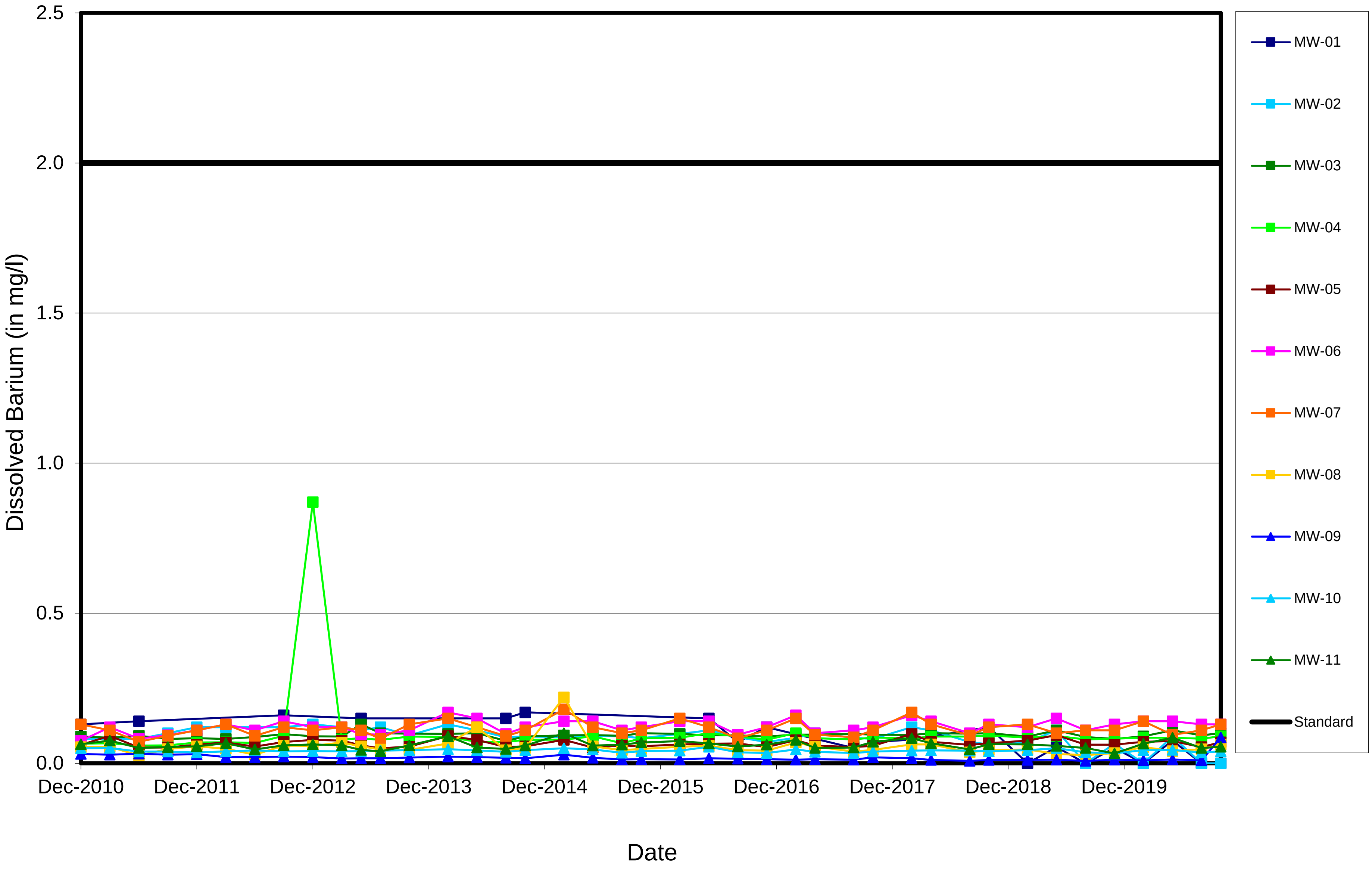
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Arsenic vs. Time



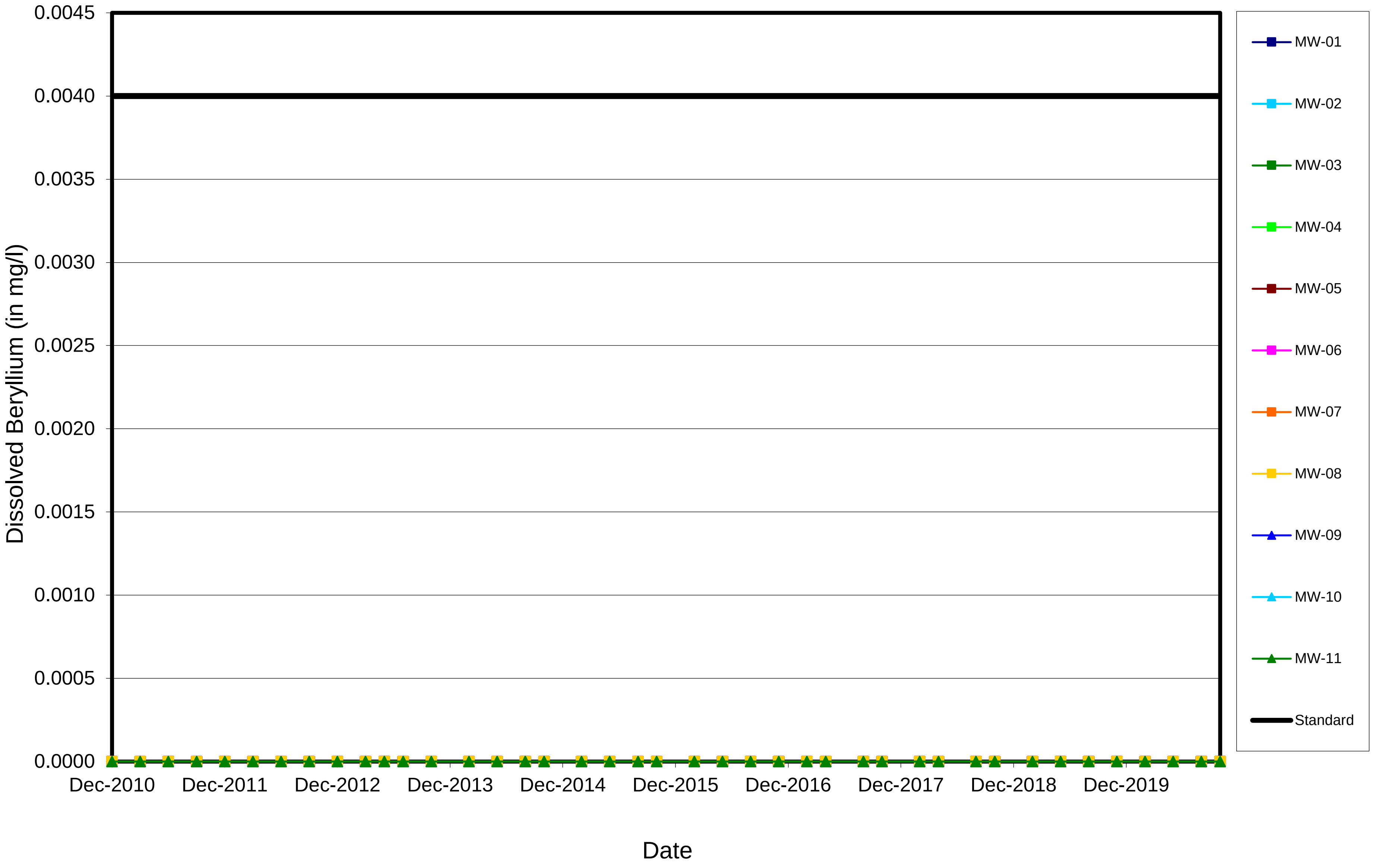
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Barium vs. Time



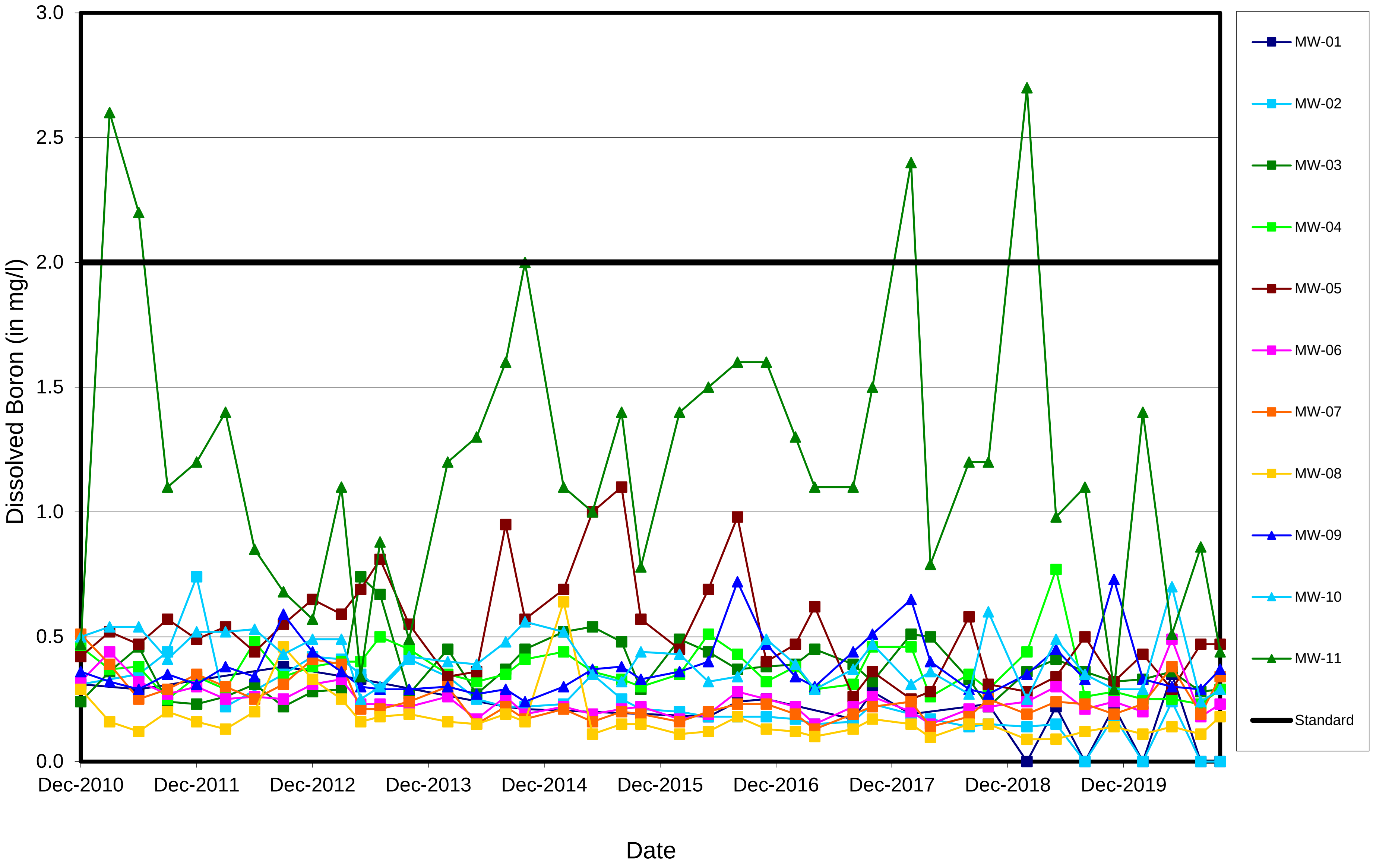
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Beryllium vs. Time



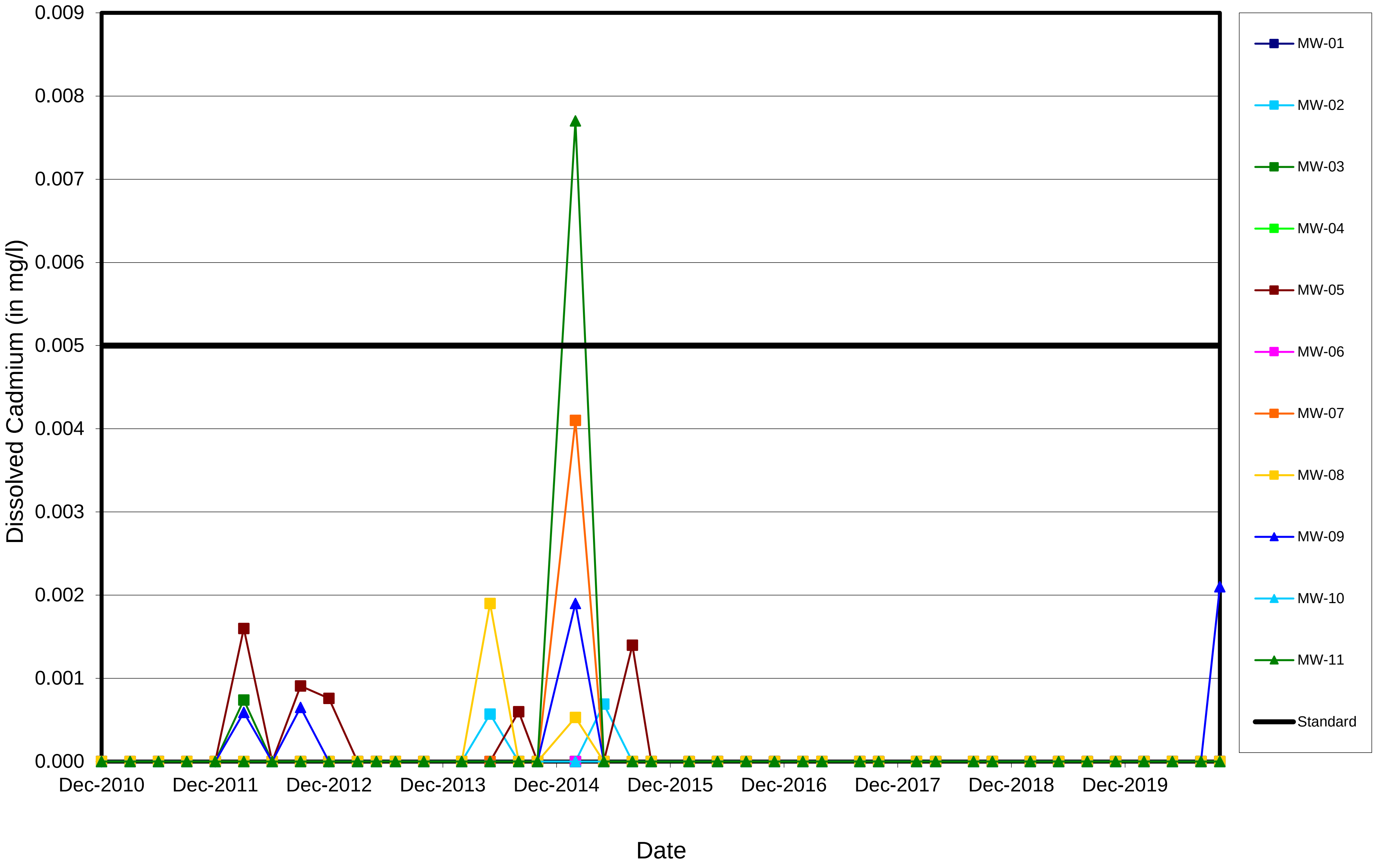
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Boron vs. Time



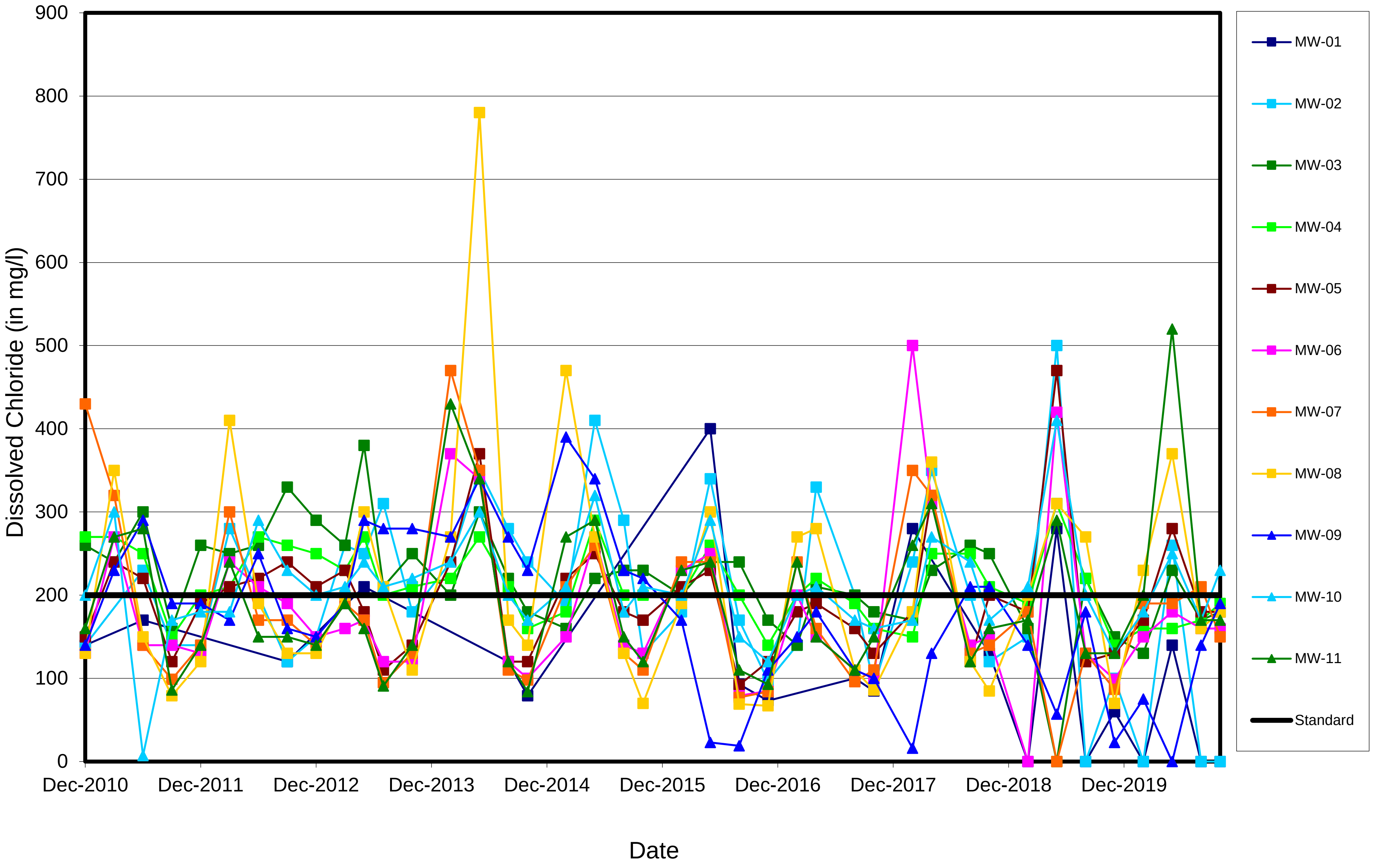
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Cadmium vs. Time



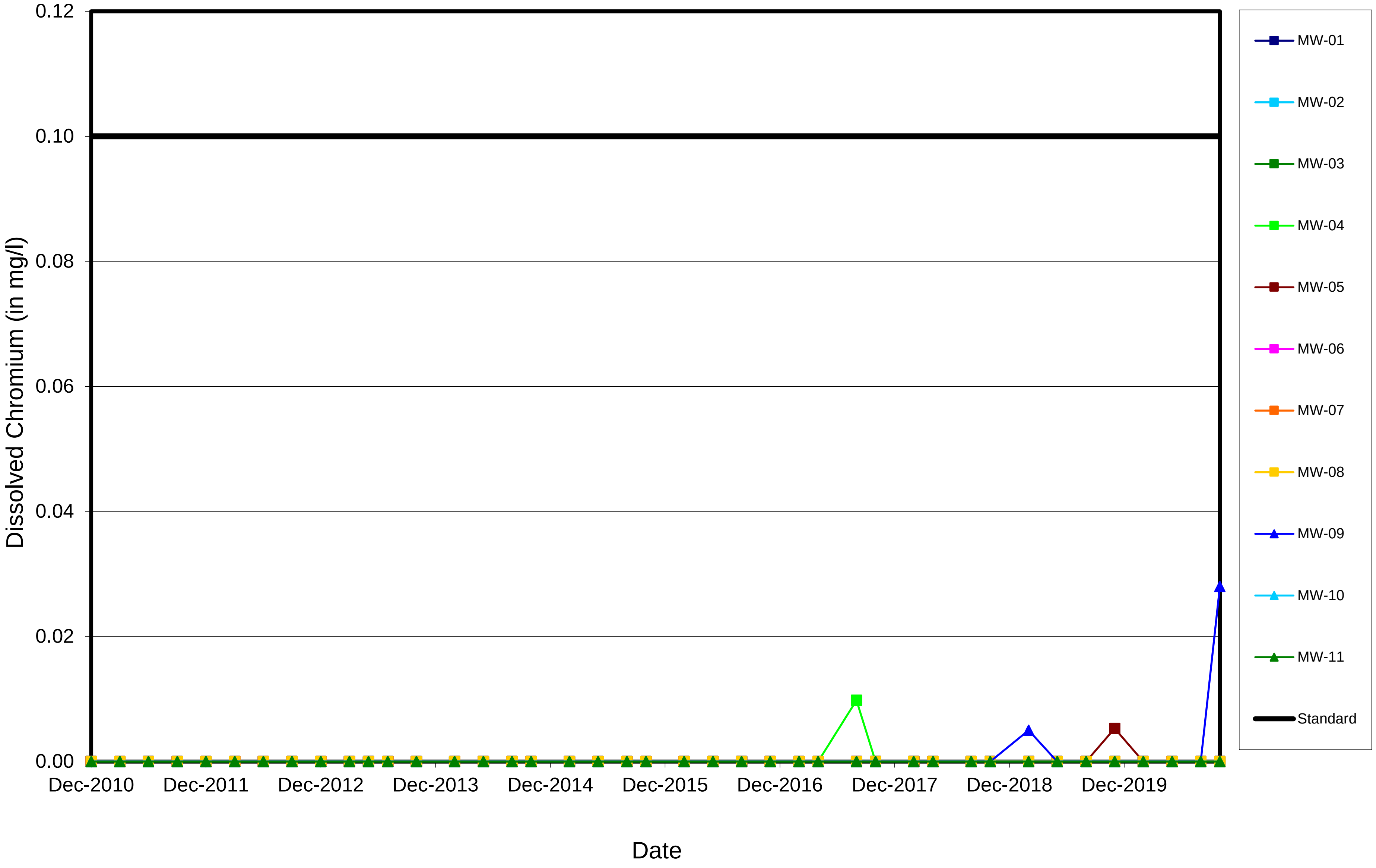
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Chloride vs. Time



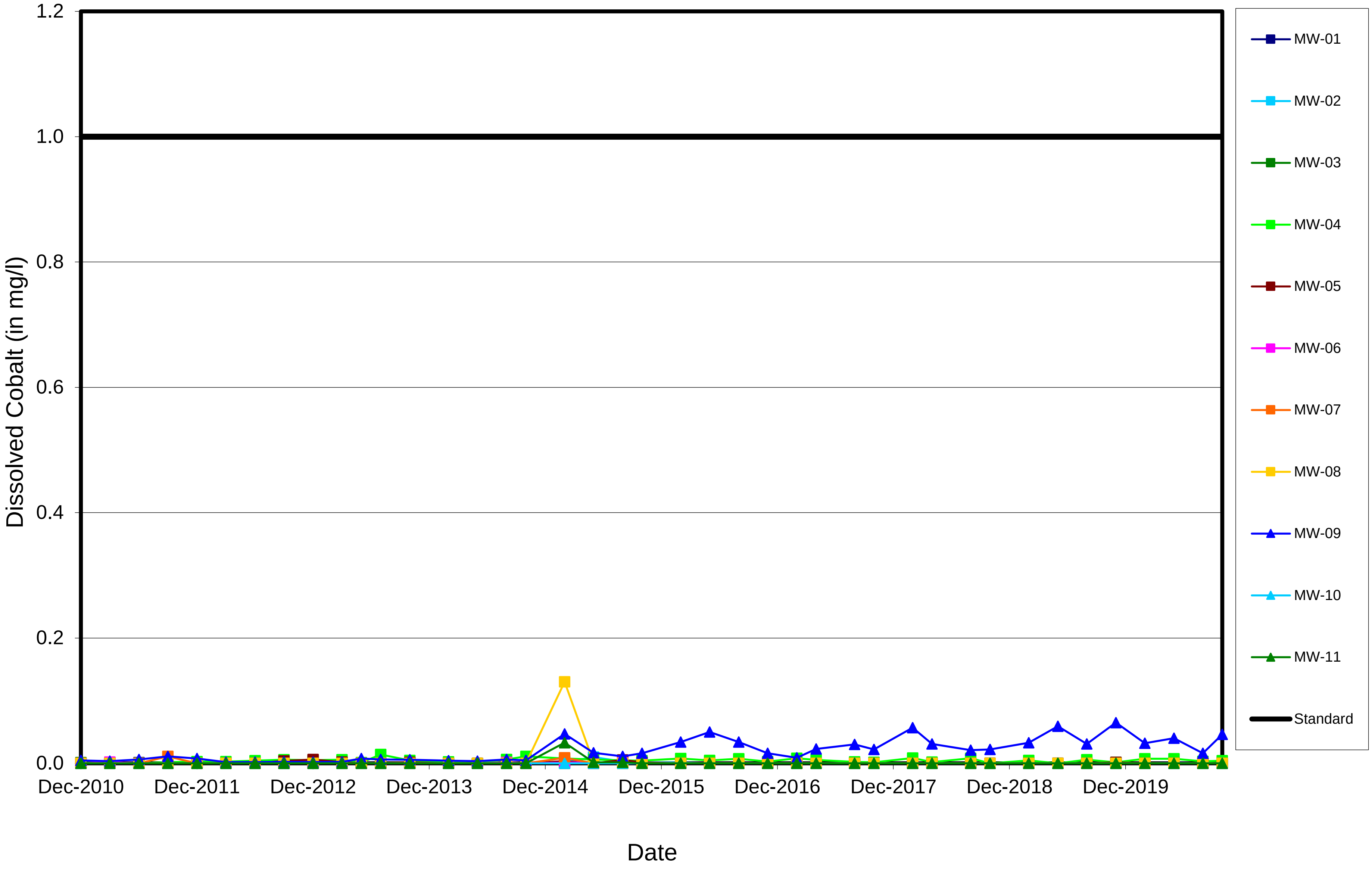
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Chromium vs. Time



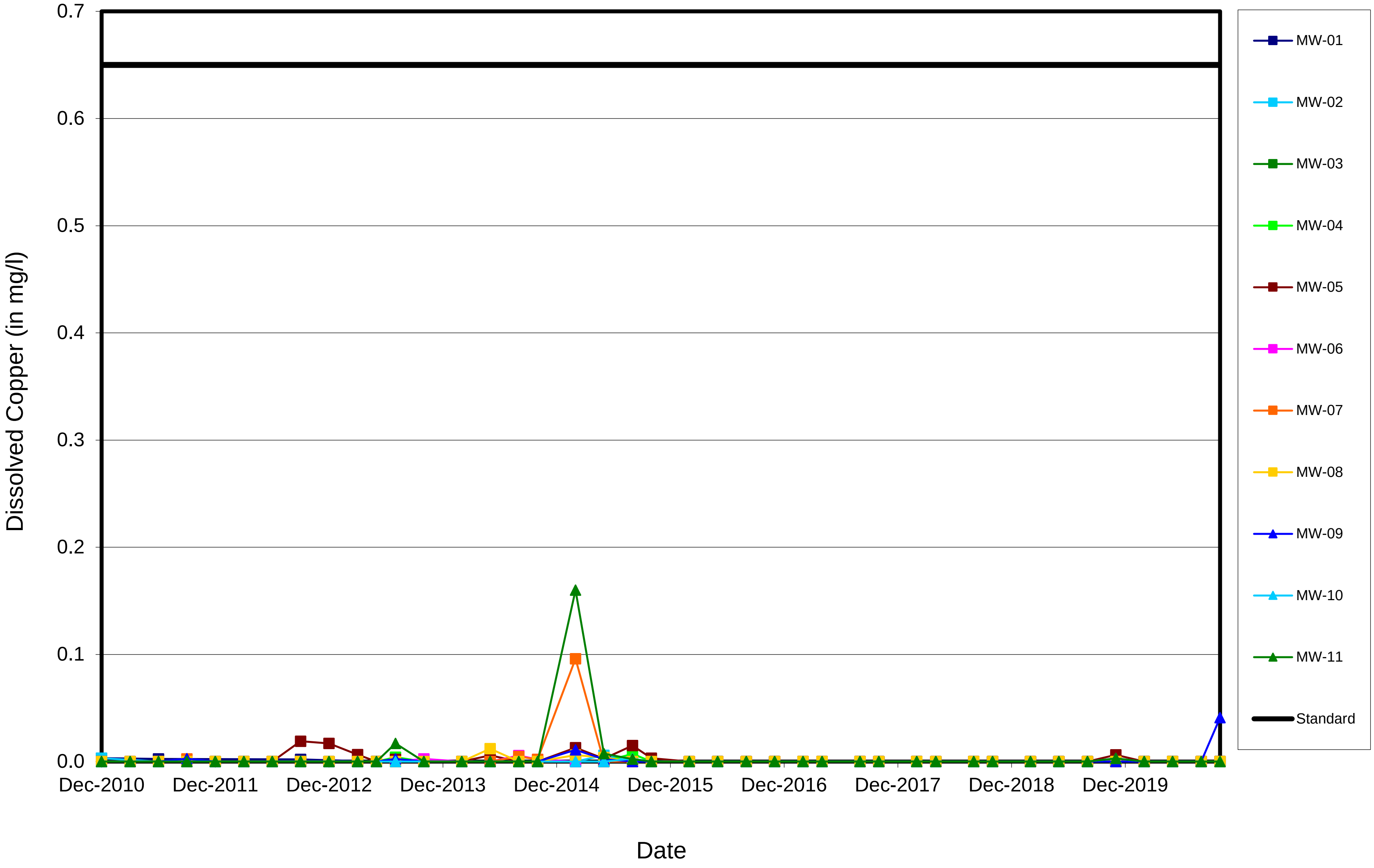
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Cobalt vs. Time



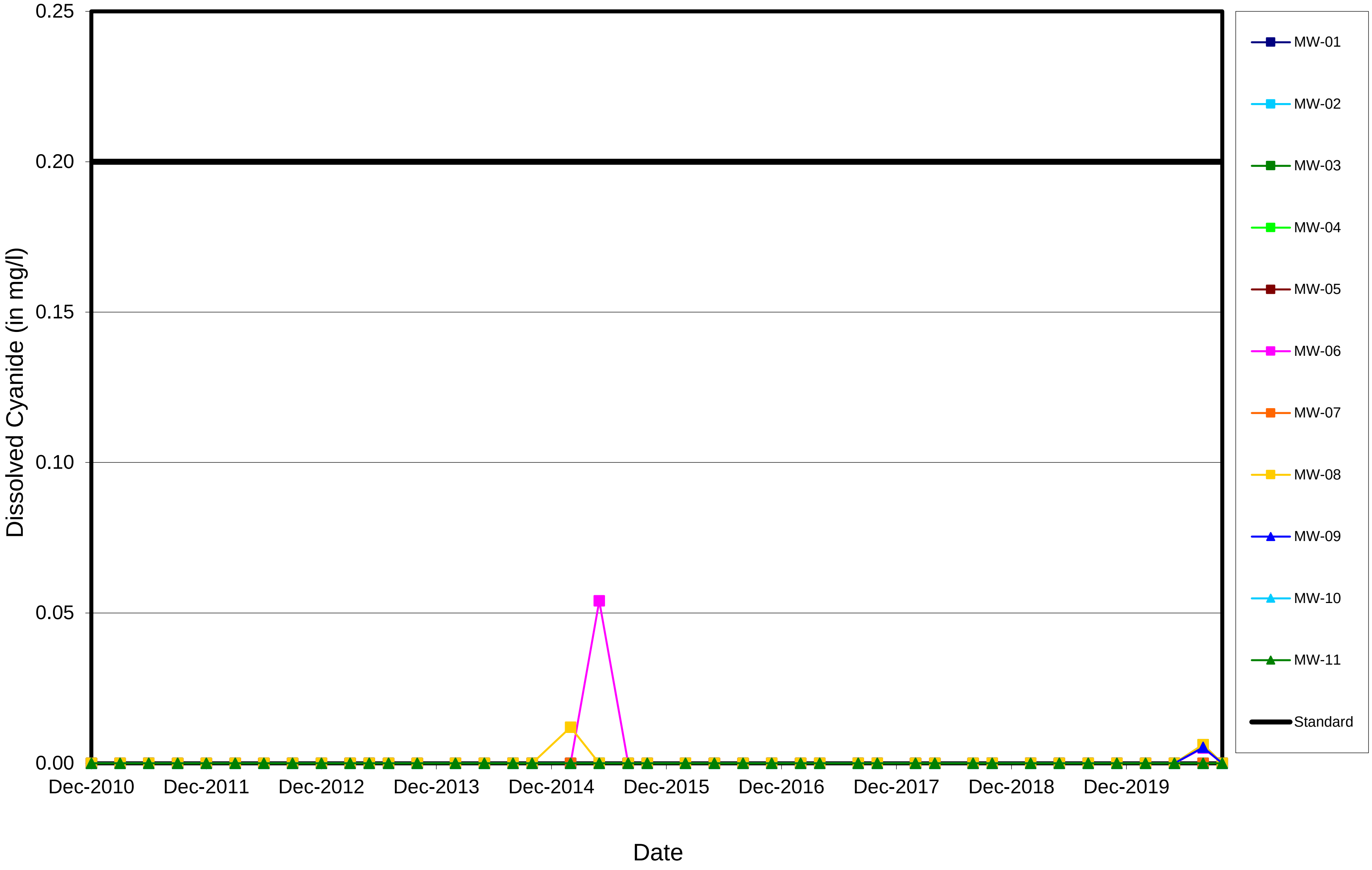
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Copper vs. Time



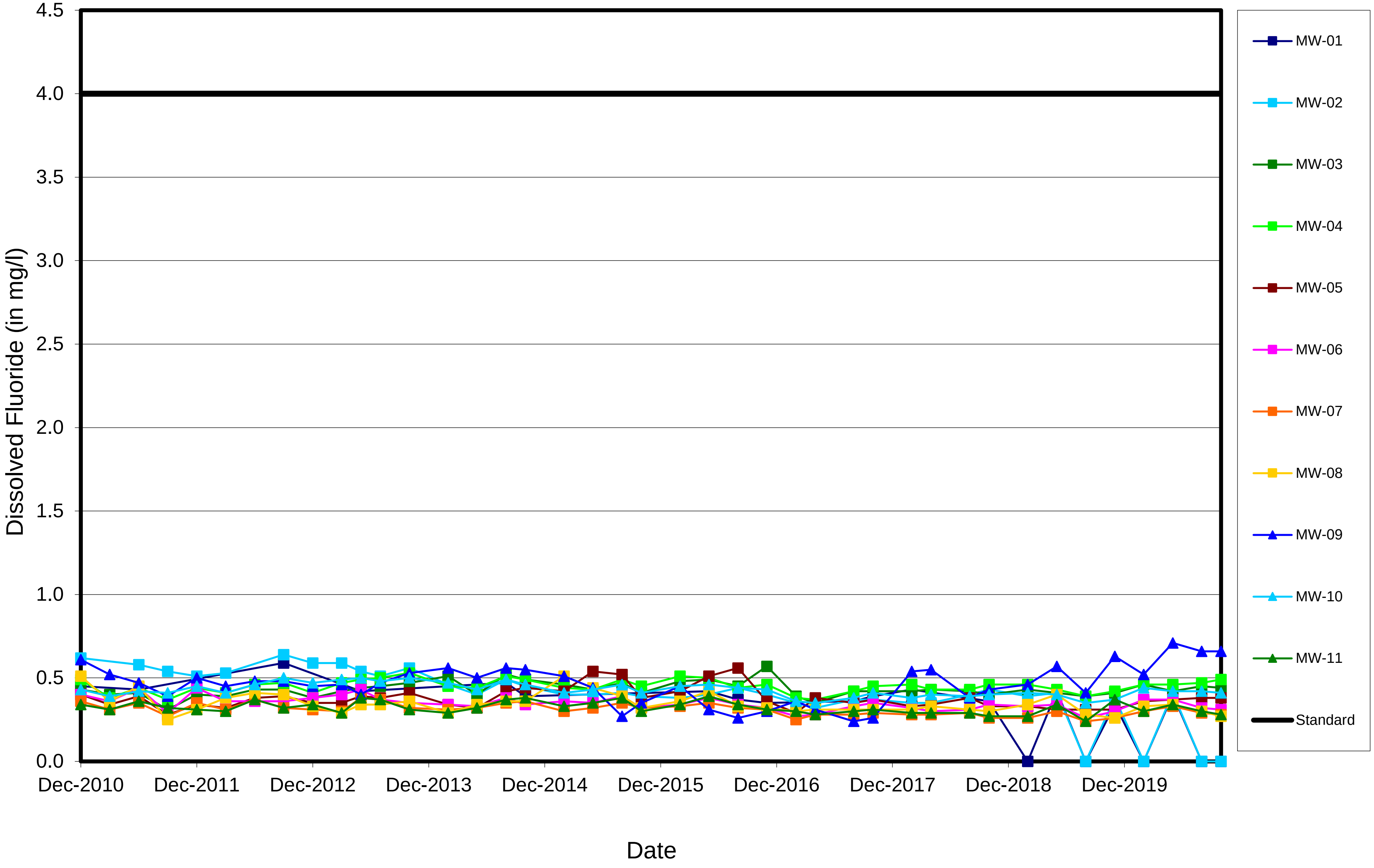
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Cyanide vs. Time



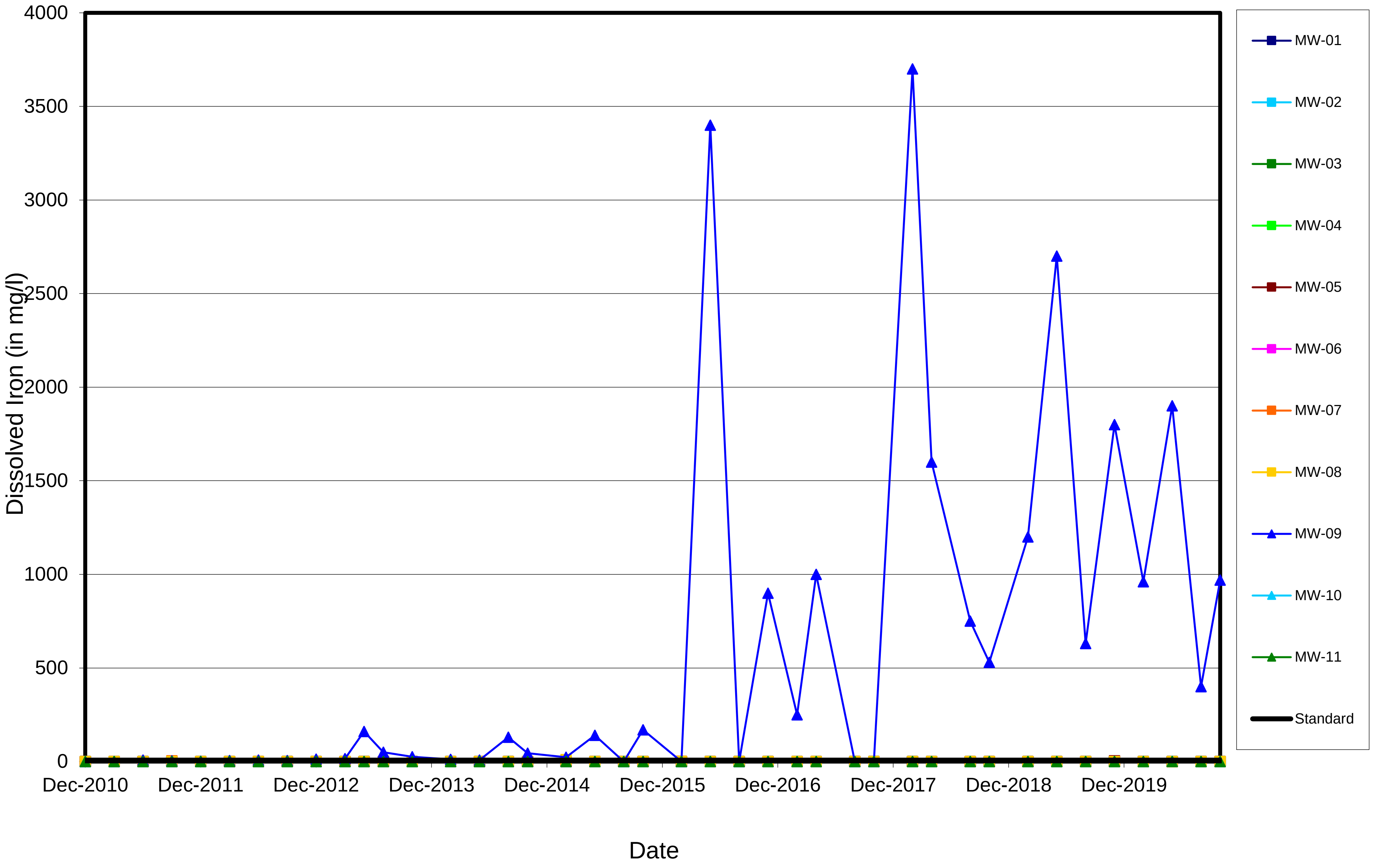
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Fluoride vs. Time



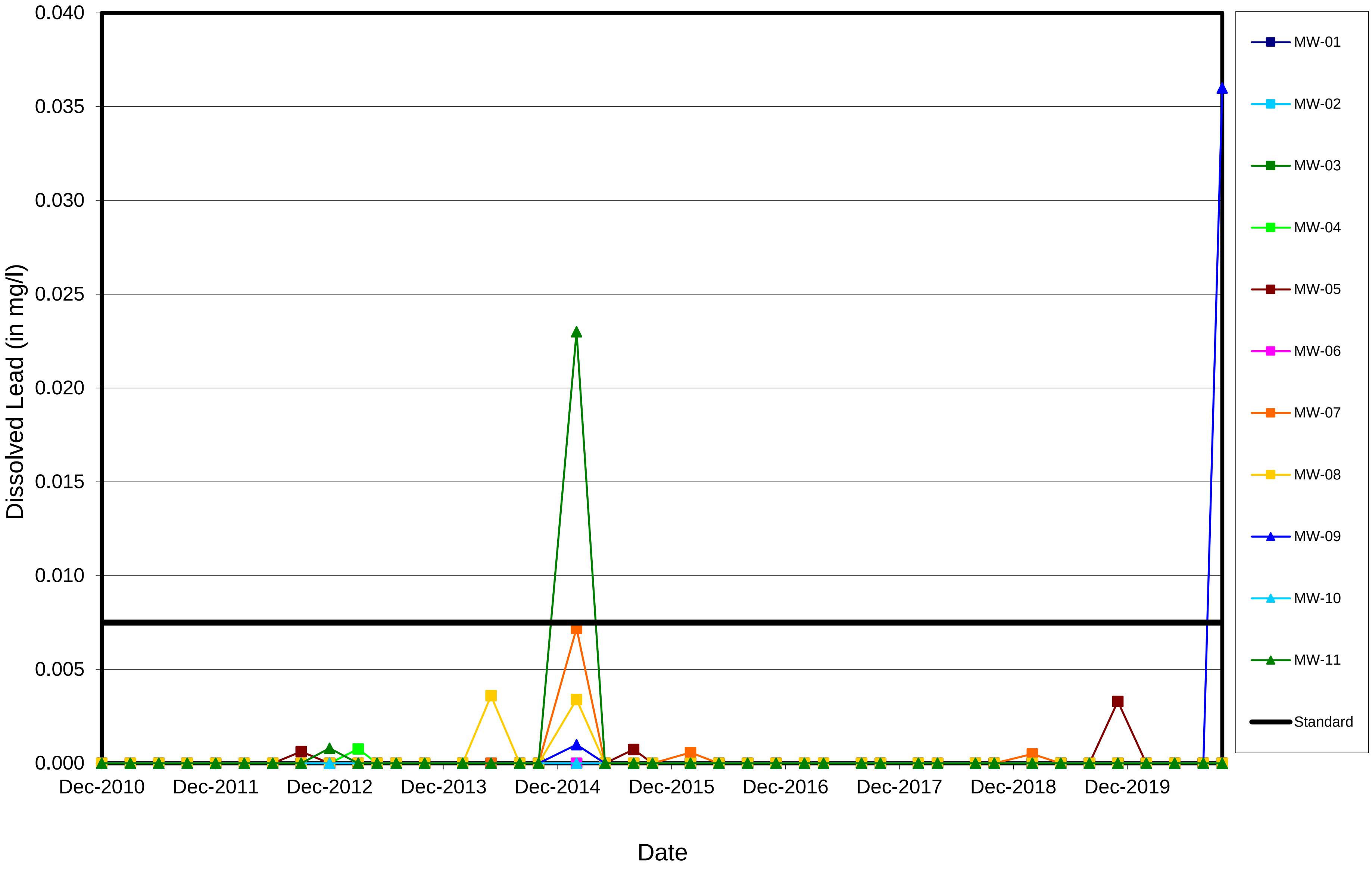
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Iron vs. Time



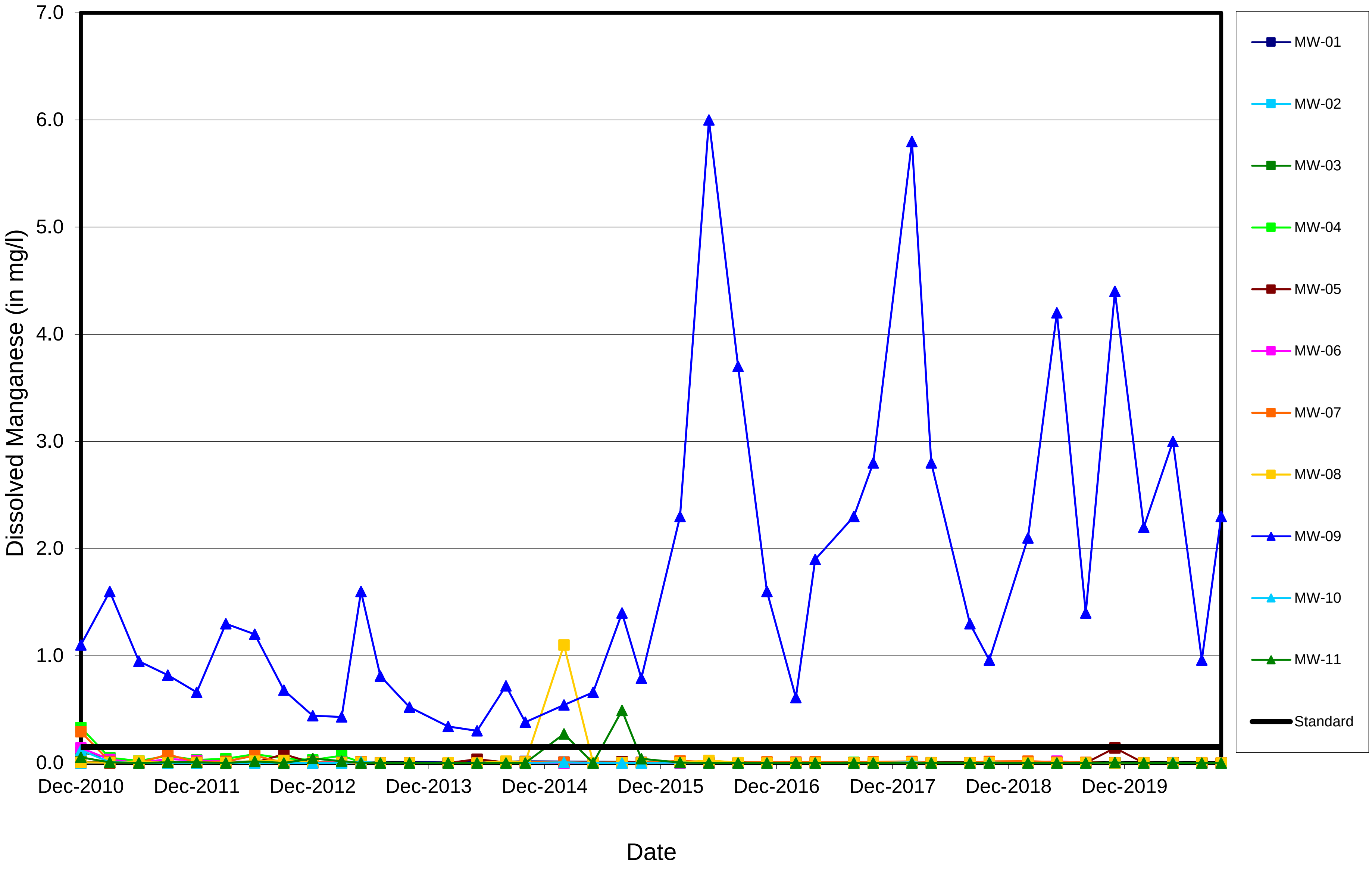
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Lead vs. Time



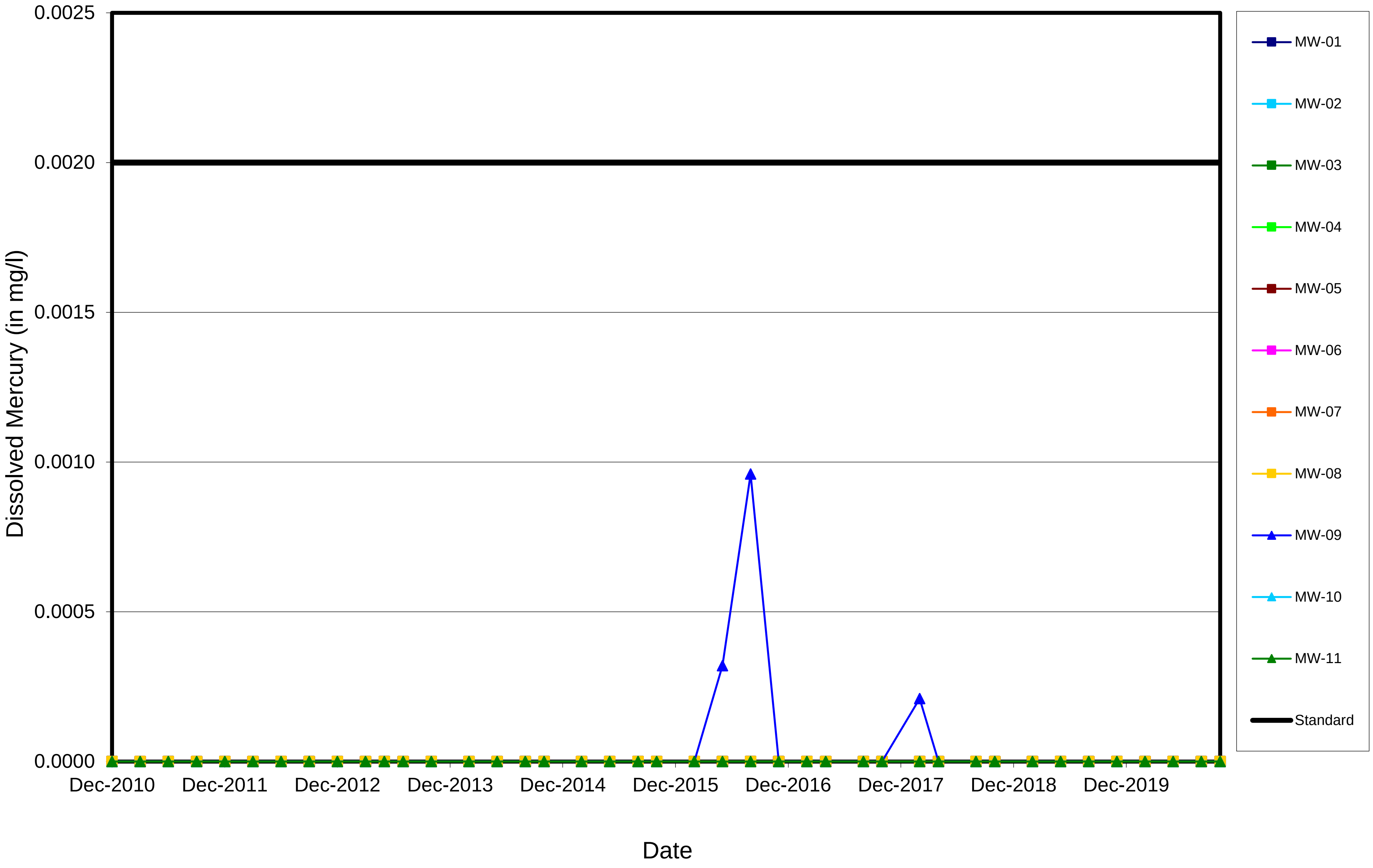
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Manganese vs. Time



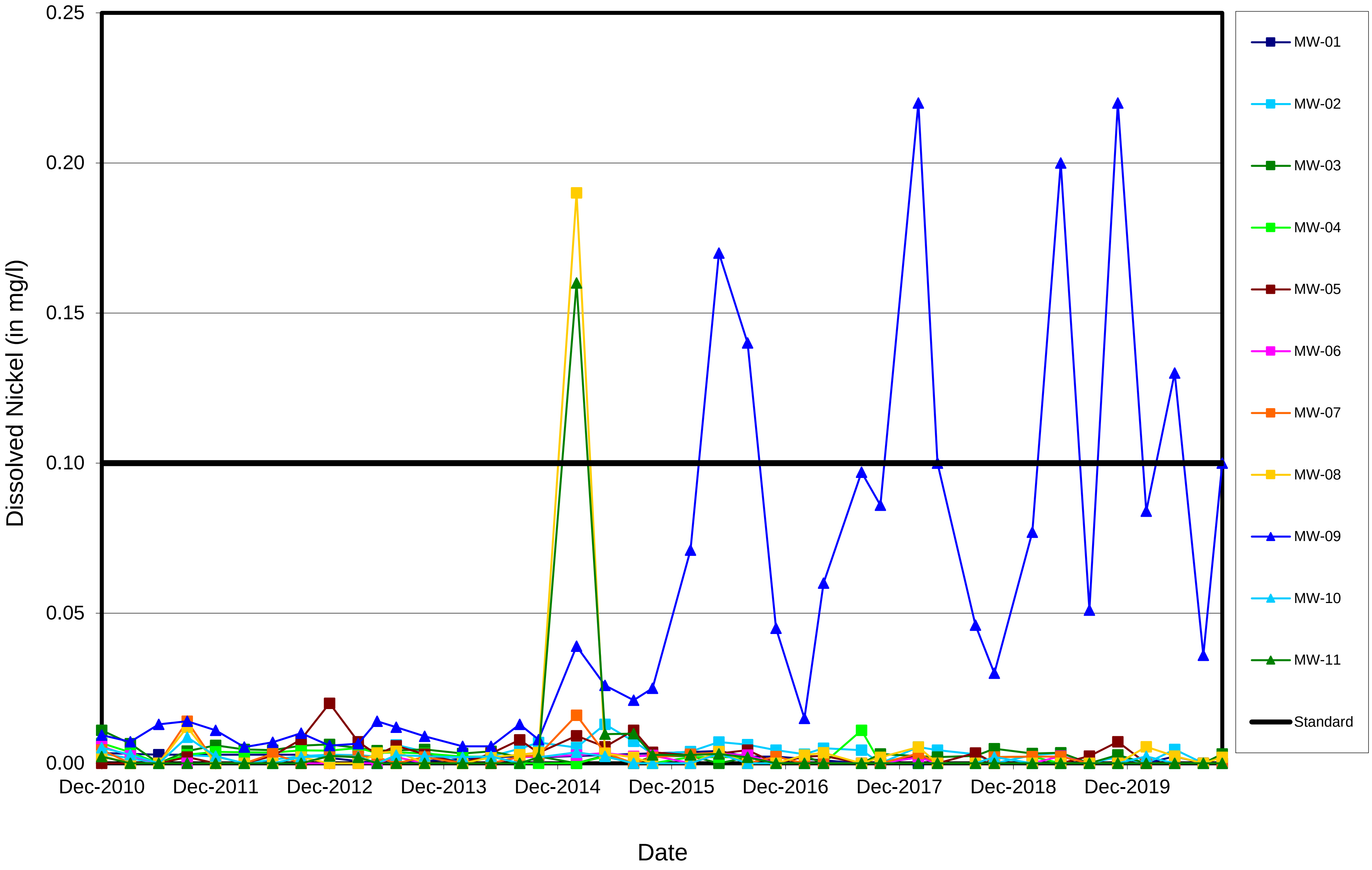
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Mercury vs. Time



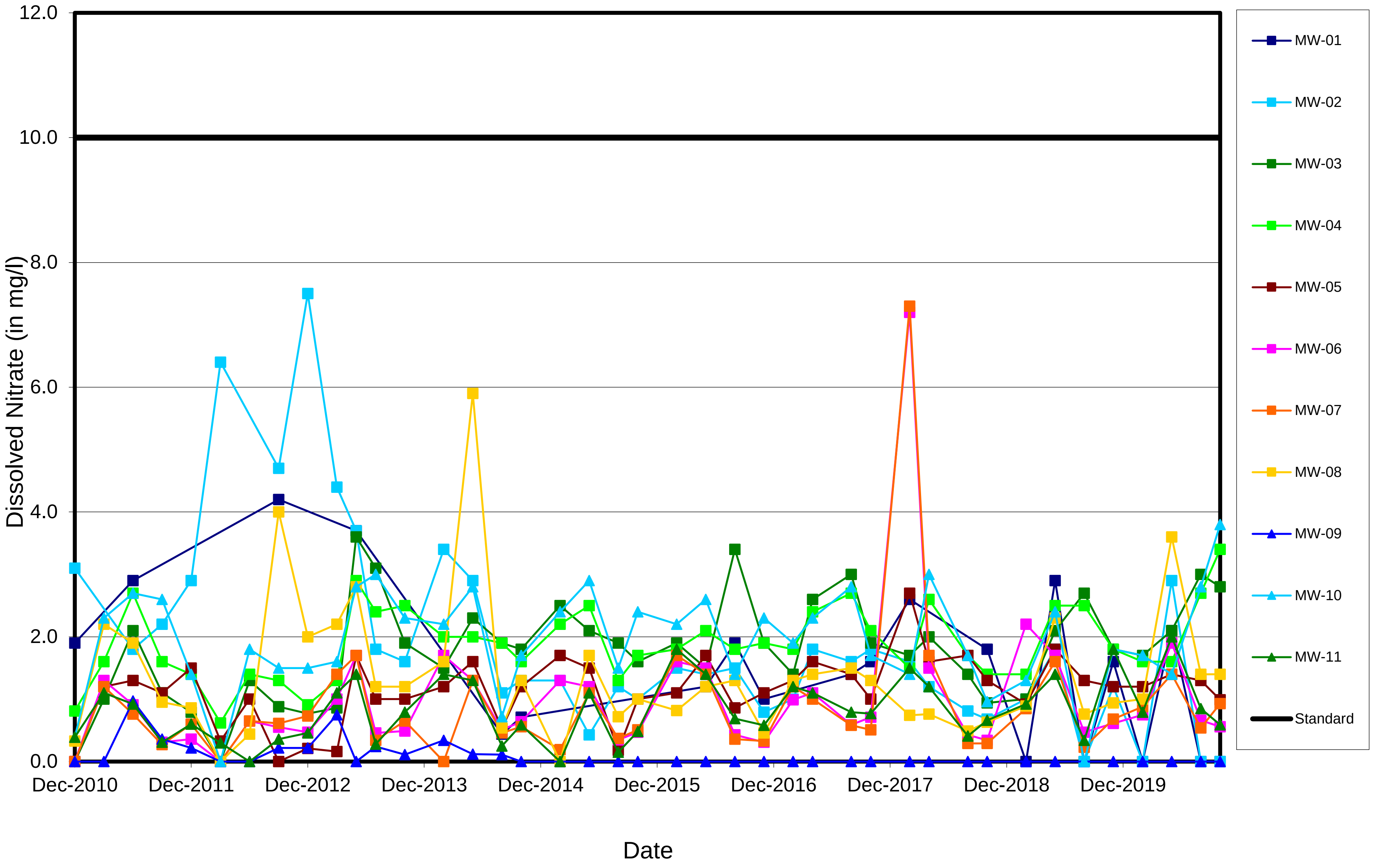
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Nickel vs. Time



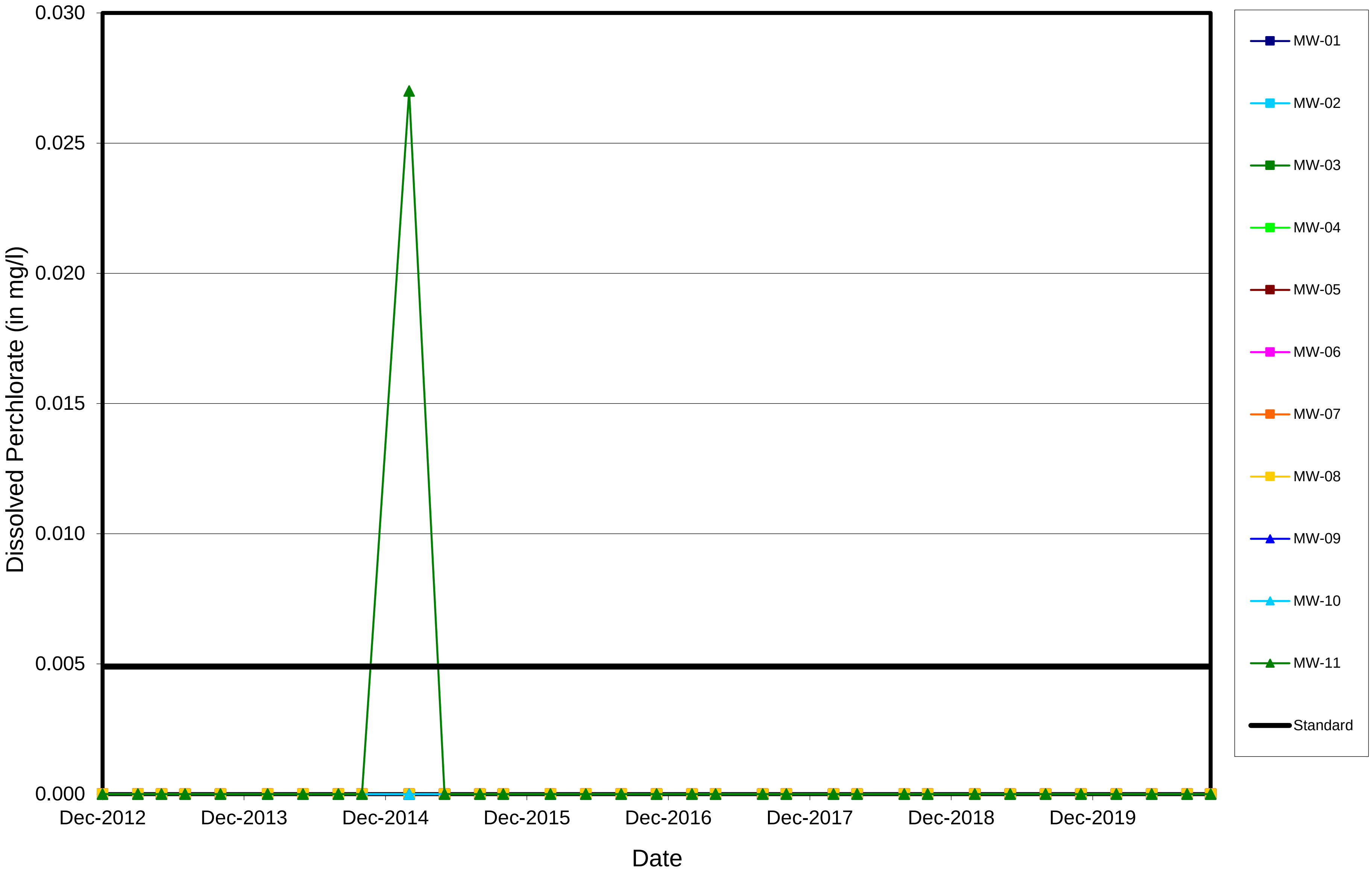
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Nitrate vs. Time



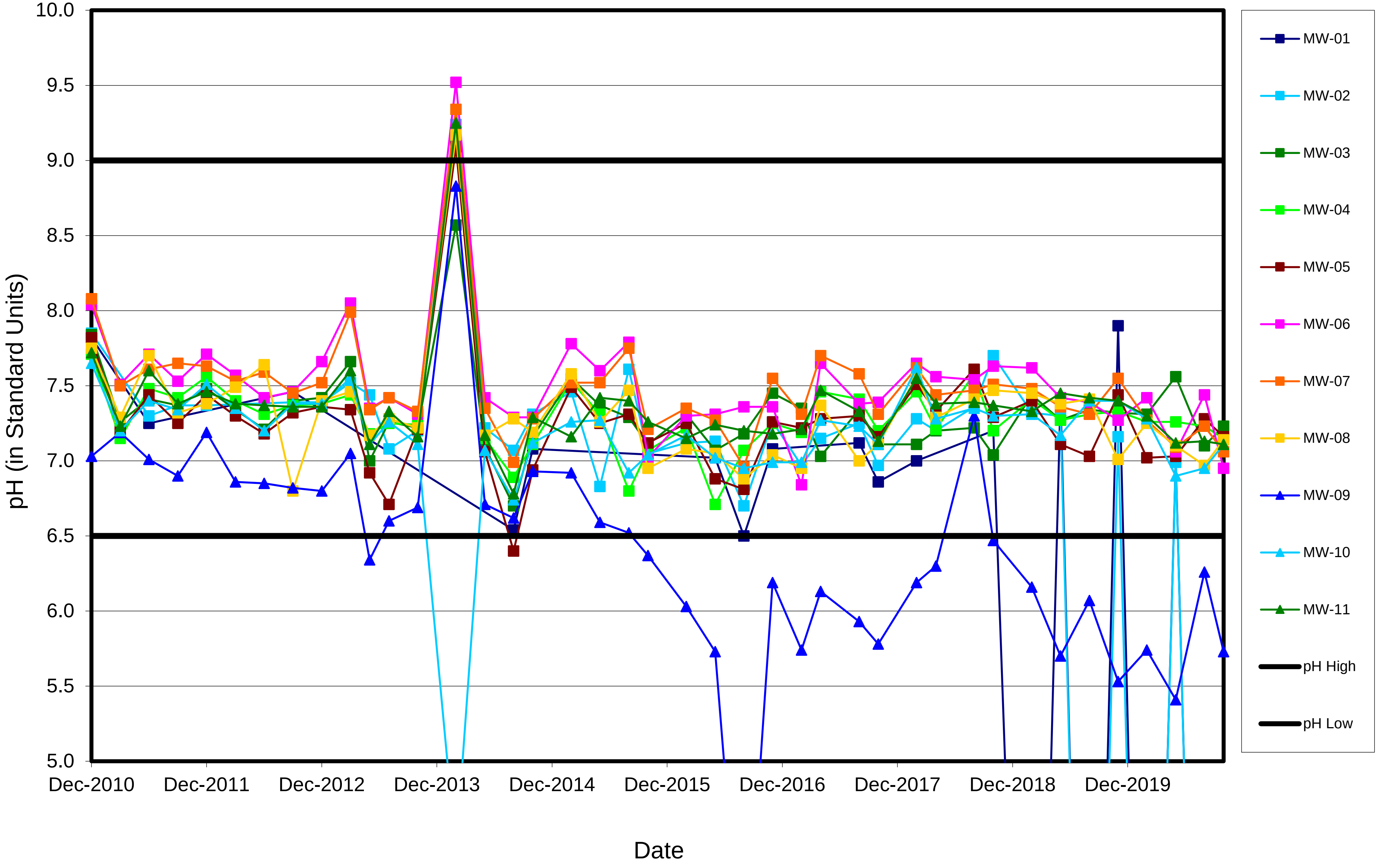
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Perchlorate vs. Time



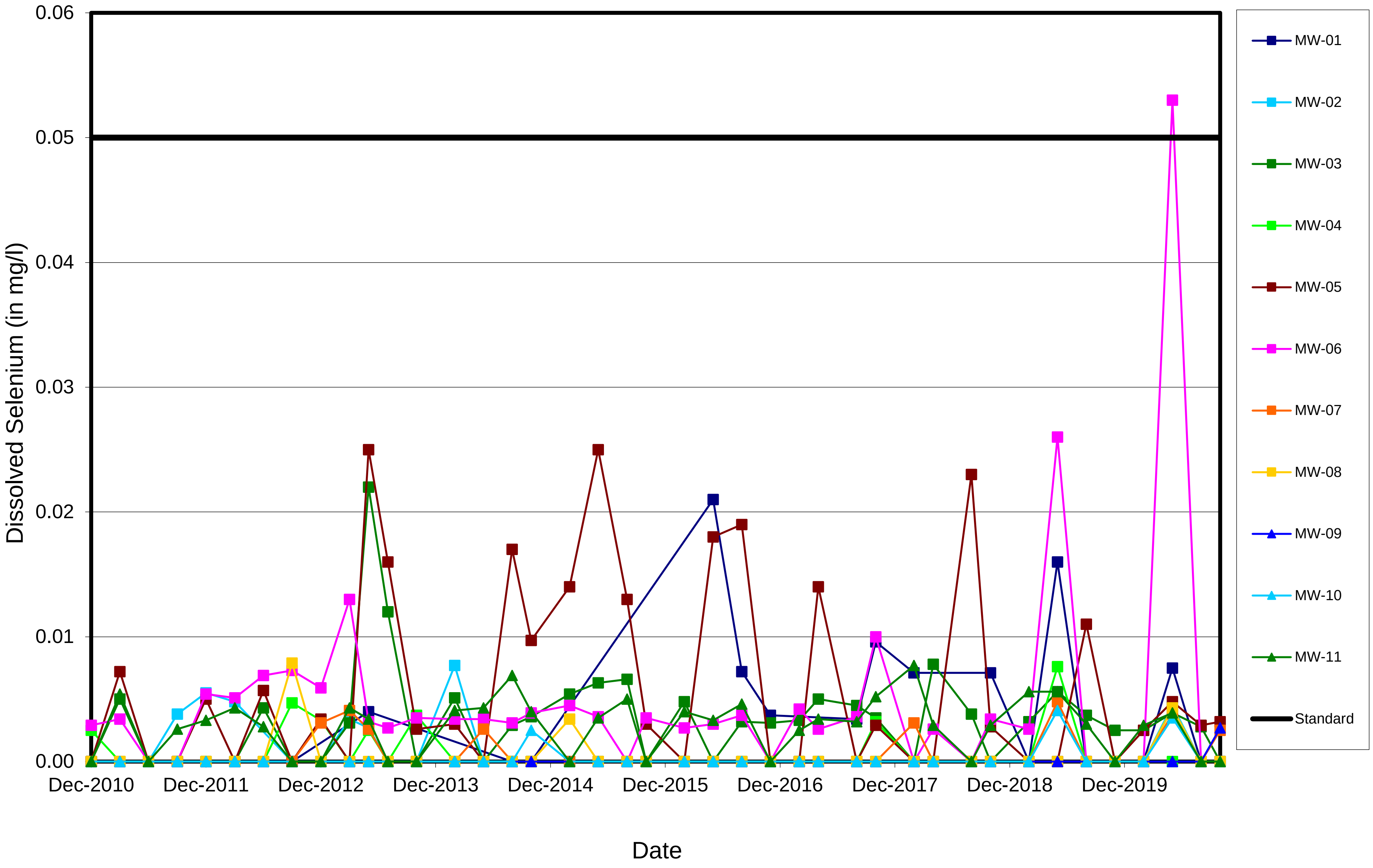
Midwest Generation Joliet Station #29, Joliet, IL

pH vs. Time



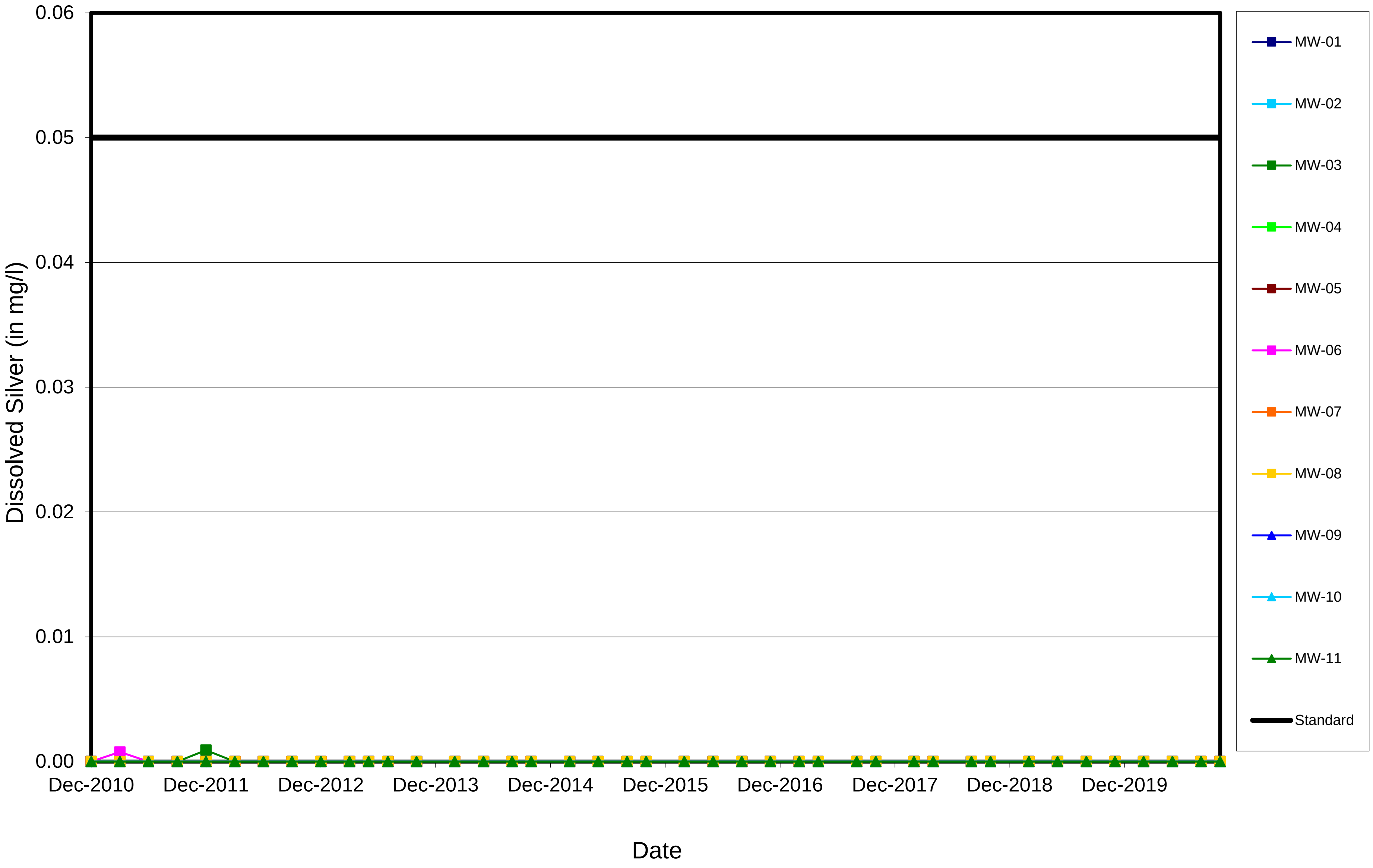
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Selenium vs. Time



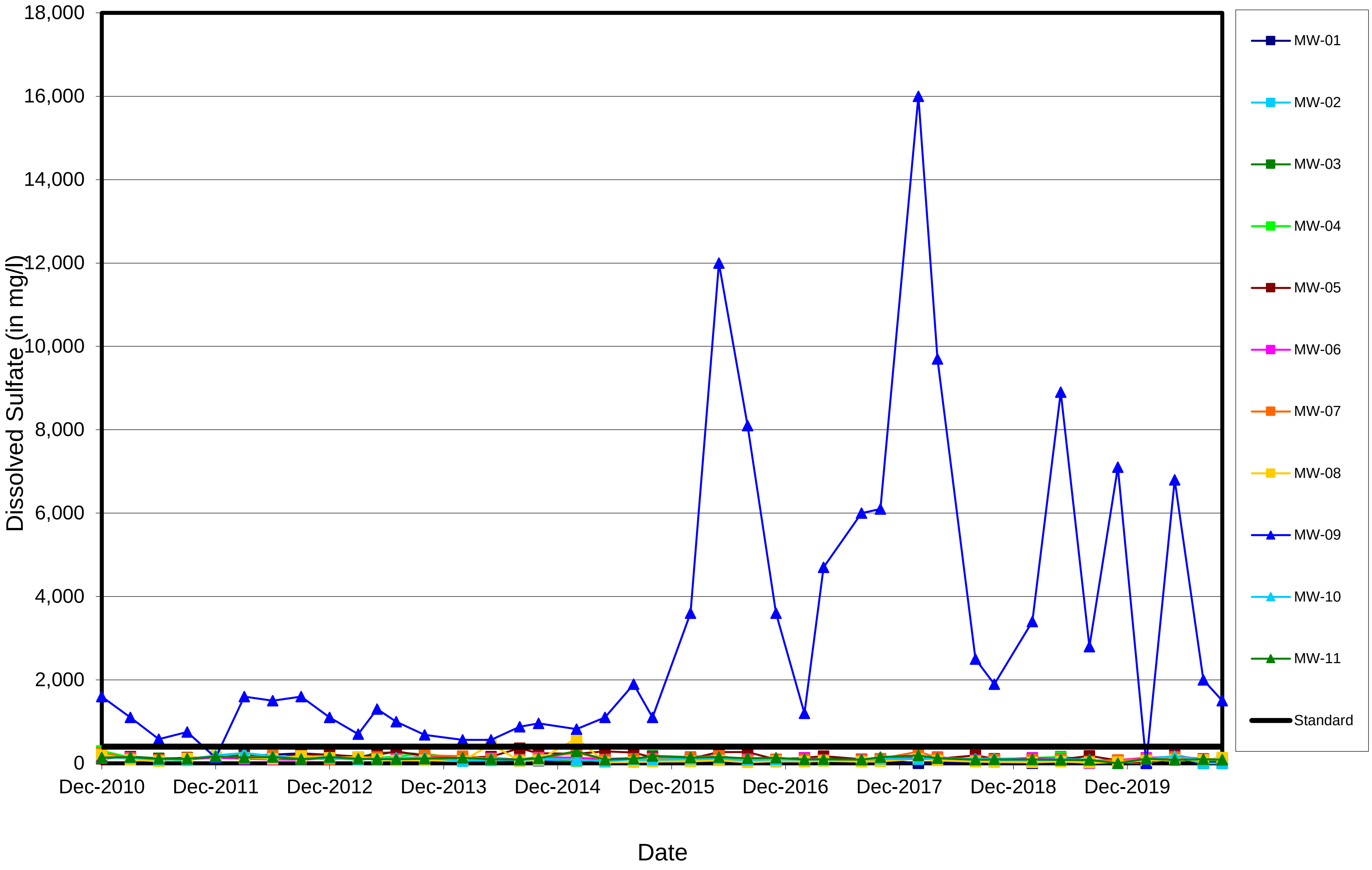
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Silver vs. Time



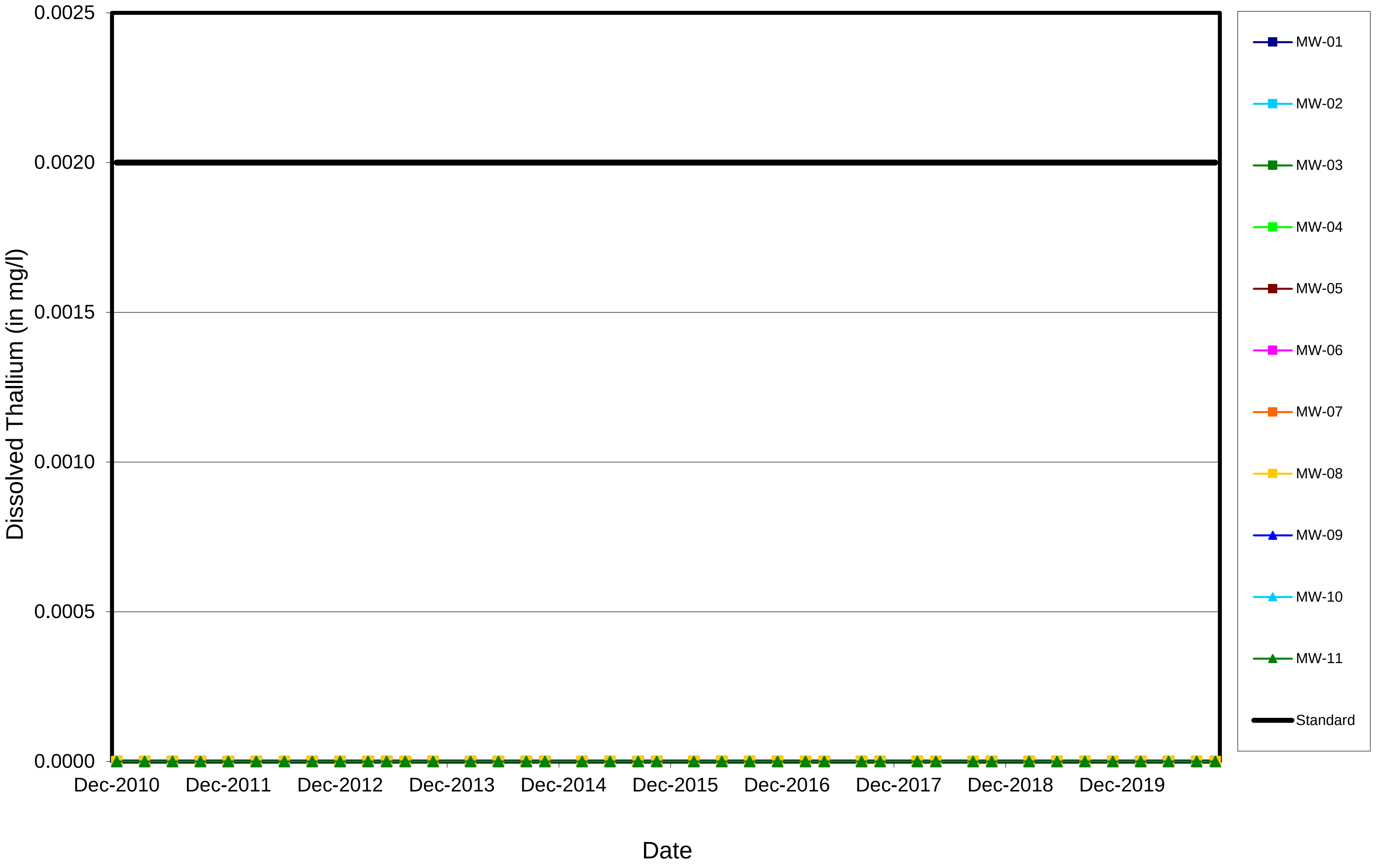
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Sulfate vs. Time



Midwest Generation Joliet Station #29, Joliet, IL

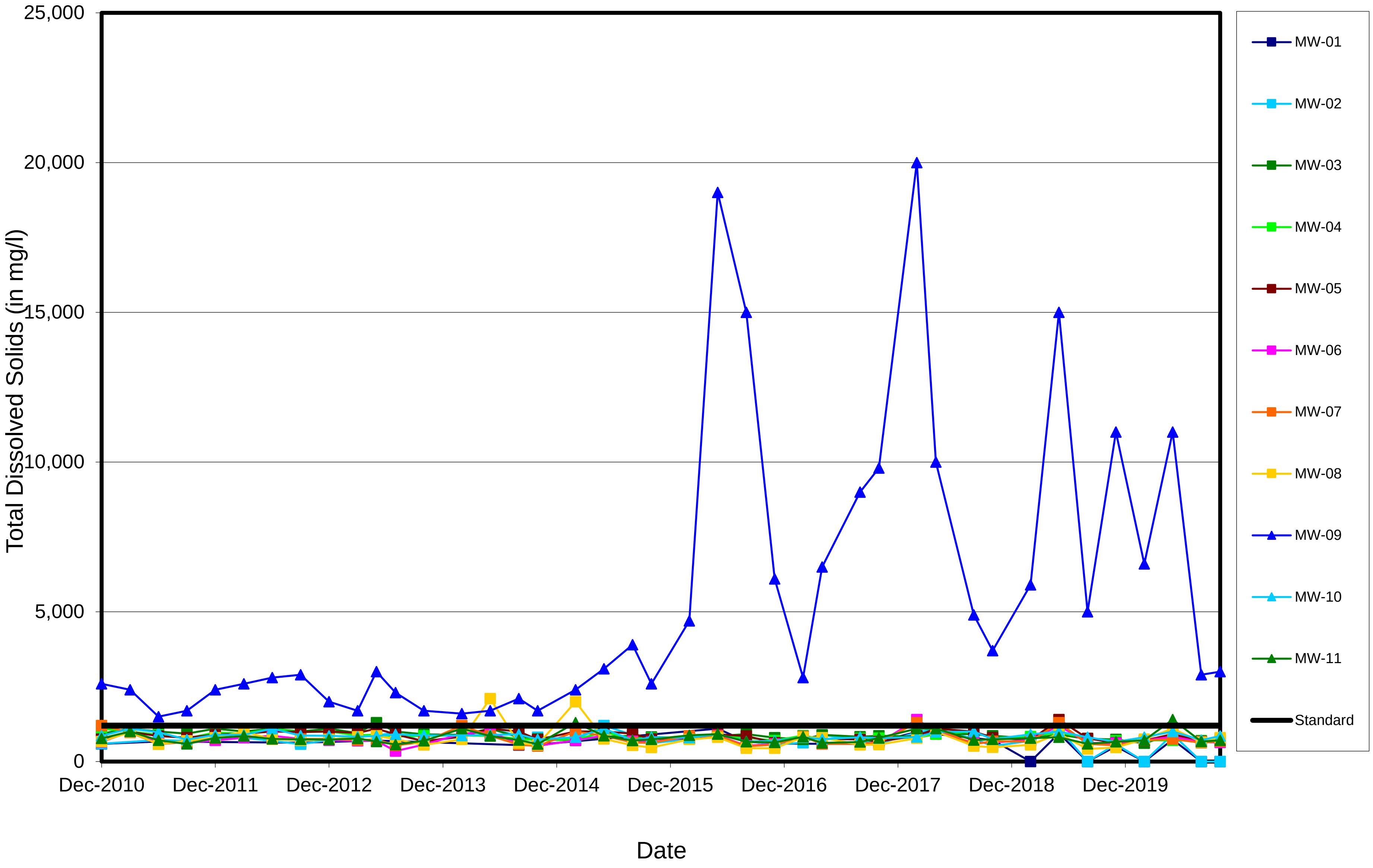
Dissolved Thallium vs. Time



Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

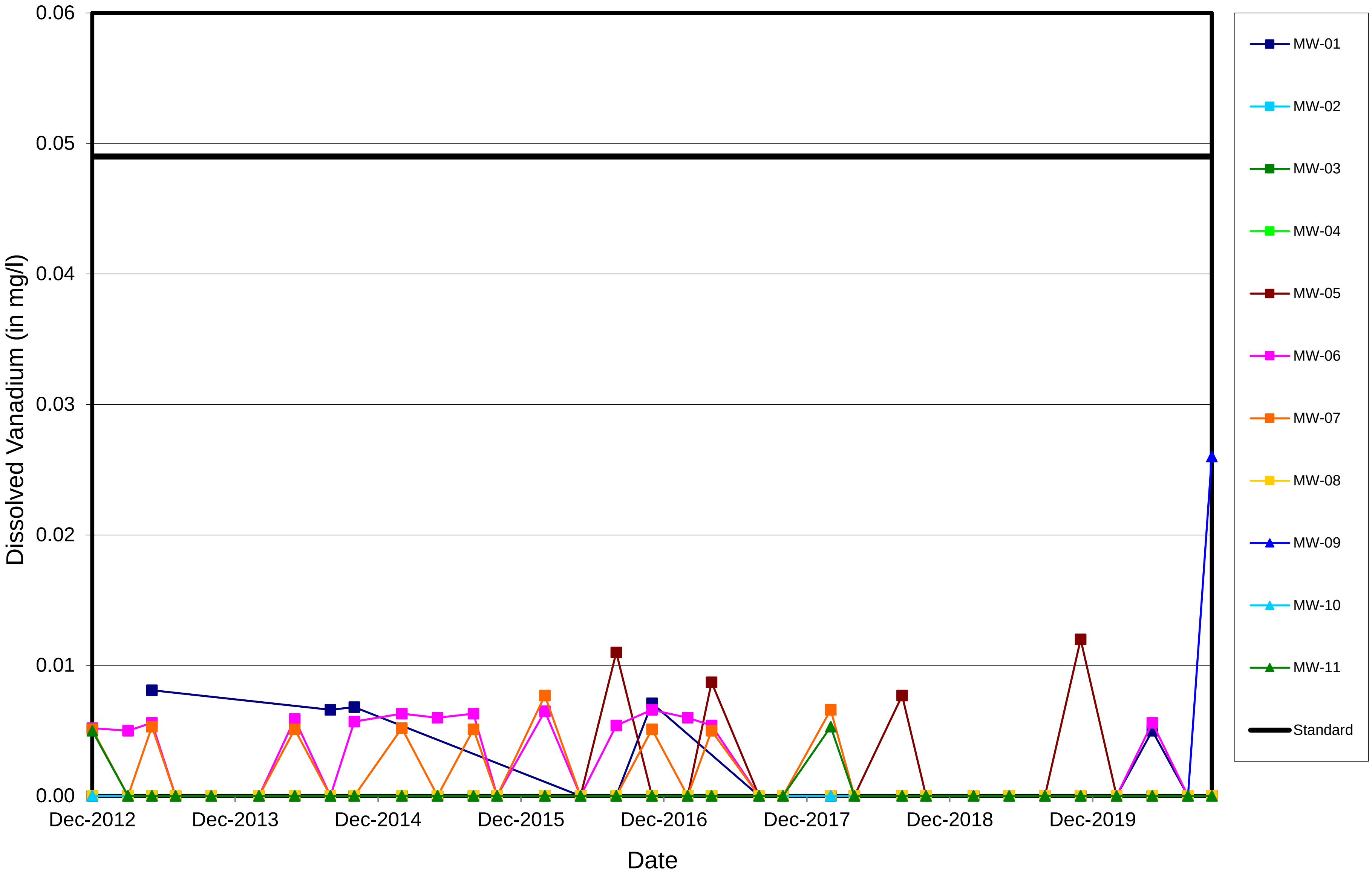
Midwest Generation Joliet Station #29, Joliet, IL

Total Dissolved Solids vs. Time



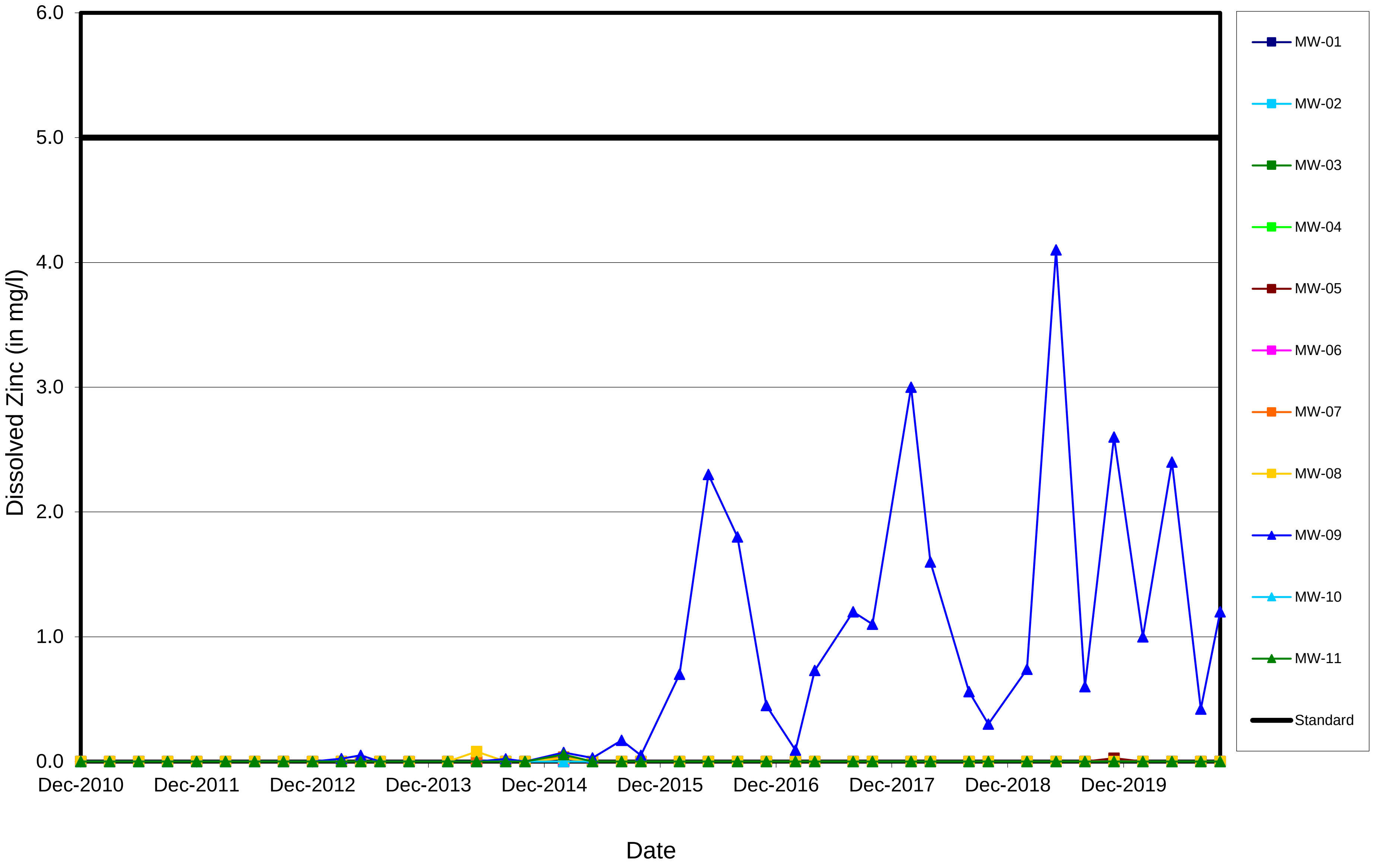
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Vanadium vs. Time



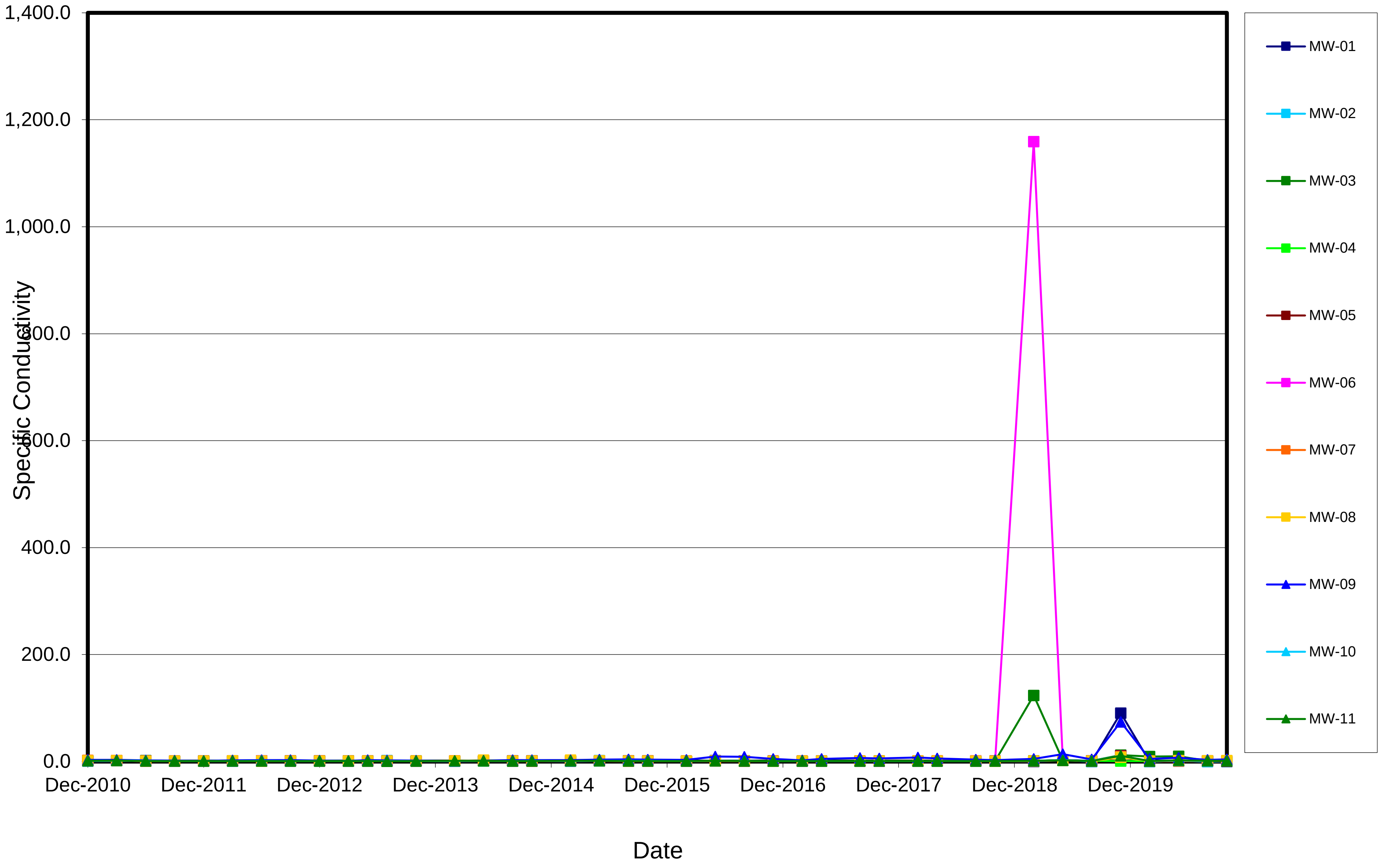
Midwest Generation Joliet Station #29, Joliet, IL

Dissolved Zinc vs. Time



Midwest Generation Joliet Station #29, Joliet, IL

Specific Conductivity vs. Time



ATTACHMENT G

David E Nielson
Curriculum Vitae

DAVID E. NIELSON

Geotechnical Engineer
Sr. Consultant / Sr. Manager

Sargent & Lundy

EDUCATION

Utah State University – B.S. Civil and Environmental Engineering - 1988

REGISTRATIONS

Professional Engineer – Illinois, Indiana, Michigan, Washington, Nevada

Previously Licensed Water Well Driller – Indiana, Tennessee and Louisiana

PROFICIENCIES

- Design of embankments, dikes and containment structures
- Evaluation of existing conditions of dams, dikes, landfills & other earthen structures
- Design and evaluation of production and monitoring well systems
- Selection of design parameters for foundation and earthen structures
- Design of shallow and deep foundation systems
- Design of pavement systems
- Reinforced earth structure design
- Geosynthetics applications in geotechnical and geo-environmental areas
- Geotechnical field and laboratory instrumentation, field testing and data acquisition
- Construction material field and laboratory instrumentation, field testing and data acquisition
- Forensic evaluation of concrete structures and earthen structures

RESPONSIBILITIES

Mr. Nielson is the process owner of geotechnical and groundwater well process in the S&L quality program. He is responsible for the selection of geotechnical design parameters, design and construction monitoring of foundation systems for projects at fossil and nuclear powered electric generating stations. Mr. Nielson performs and reviews examinations of dikes, dams and landfills at both nuclear and coal fired power plants. Additionally, Mr. Nielson actively participates in engineering geology evaluation of potential plant sites and plant structure foundations. Mr. Nielson serves as a committee member on the DFI Auger Cast Pile subcommittee.

EXPERIENCE

Mr. Nielson has over 30 years of experience in geotechnical engineering and construction material testing services. He has successfully performed shallow and deep foundation design for projects in virtually all geologic settings and directed construction material quality control services in over 30 states and over 10 countries. Additionally, he has specified, directed, and performed over one-thousand subsurface exploration programs.

In addition to the design and consultation services on earthen embankments, ponds, lakes and landfills, he supervises and performs annual examination of eight dams, which are up to 8 miles in length with residential properties within 1/8 mile of the dam toe.

He has designed numerous production wells, monitoring well programs, and structure under-drain/dewatering systems to mitigate the effects of groundwater seepage in several construction projects. Moreover, he has provided design and construction recommendations for tunnels under and bridges over Midwestern rivers.

He has served as an expert witness for construction defect litigation in the areas of soil and concrete.

He provides our clients with an unusual perspective and experience. In addition to his design experience, he has worked as a construction laborer on the construction of a large coal fired power plant in Utah, geotechnical driller and geotechnical engineer with design work and quality control services in many of the major physiographic regions of the U.S.

Mr. Nielson's relevant experience with Sargent & Lundy LLC (since 2008) includes:

- **Hydroelectric Dam – Peruvian Andes**
  Before visiting the site, Mr. Nielson reviewed the prior design documents, prior reports, studies and repair designs to aid in our evaluation of the repair of a vertical crack and the general integrity of the confidential hydroelectric dam. The existing dam is an arched concrete gravity structure with an 88-meter maximum height and a crest length of 274 m. Our evaluation of the structure included recommendations for physical repairs of an abutment to improve stability and supplemental monitoring equipment to provide insight into the structure's response to loading (2018).

- **Power Stations – Wyoming**
  Performing conceptual and detailed design of several new impoundments to serve as evaporation and disposal ponds for Coal Combustion Residual waste streams. Dam heights will range up to 50 feet and the total impoundment area will exceed 400 acres. (2017 - 2020)

- **Two Power Stations – Texas**
  The two stations represent over 4400 megawatts of coal fired generating capacity. Served as Owner's Engineer to develop closure plans, hazard classifications, structural stability and annual inspections of coal ash ponds and landfills (2015 - 2018).

- **Power Station – Indiana**
  Performed emergency dam inspection to evaluate damage and recommend repair alternatives for a sand filled dam which experienced significant erosion during beyond design basis storm event. (2012)

- **Power Station – Pennsylvania**
  Formulated of design parameters for shallow spread, drilled piers and deep micropile foundation systems for SCR system constructed above existing precipitators and other plant features (2010-2012).

- **Power Station – Pennsylvania**
  Developed of geotechnical exploration specifications and formulated ACIP foundation design details, specifications, and performance criteria (2009).

- **Power Station – Nebraska**
  Developed specification for geotechnical exploration and formulated design criteria for foundation systems for major emission control project (2008).

- **Generation Project – Upper Midwest**
  Prepared a study of groundwater availability for a new combined cycle generating station (2016).

Mr. Nielson's relevant experience with other firms (1988 - 2008) includes:

- **Elkhart County Jail – Elkhart, Indiana**
  Determination of engineering design parameters for shallow foundations and utility tunnels for 1000-bed, seven building correctional campus. This work included monitoring and designing repairs to control seepage into a major utility tunnel that was constructed with inferior concrete (2004 - 2008).

- **Elkhart County Landfill/Jail – Elkhart, Indiana**
  Mr. Nielson designed extraction, compression and transmission system to remove landfill gas and transport it for beneficial use at the 1000 bed jail (2006 - 2008).

- **Earth Movers Landfill – Elkhart County, Indiana**
  Directed Construction Quality Control and Assurance (CQA/CQC) services to assure state regulators the clay and membrane liners were constructed in accordance with the permit requirements (2007).

- **Prairie View Landfill – St. Joseph County, Indiana**
  Directed Construction Quality Control and Assurance (CQA/CQC) services to assure state regulators the clay and membrane liners were constructed in accordance with the permit requirements (2006).

MEMBERSHIP

Deep Foundation Institute

EXHIBIT 4

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
STANDARDS FOR THE DISPOSAL	)	
OF COAL COMBUSTION RESIDUALS	)	R 2020-019
IN SURFACE IMPOUNDMENTS:	)	(Rulemaking - Water)
PROPOSED NEW 35 ILL. ADM.	)	
CODE 845	)	

PRE-FILED TESTIMONY OF DAVID E. NIELSON, P.E.

Introduction

My name is David E. Nielson I am a Sr. Consultant and Sr. Manager with Sargent & Lundy (S&L). S&L is an Illinois-based engineering firm with over 125 years of history focused on the design of electric power generation and transmission systems. I have over 30 years of professional experience as a geotechnical and civil engineer. I have been a licensed professional engineer (civil) in the state of Illinois in good standing since 1993. My professional career has included services associated with coal combustion residuals (CCR), industrial waste surface impoundments, industrial waste landfills, and municipal solid waste (MSW) landfills in numerous states and regulatory environments since 1990. My curriculum vitae is attached.

I have been retained on behalf of Midwest Generation to review and comment on the Illinois Environmental Protection Agency's (IEPA) proposed Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (Reference 1, which is referred to herein as the "Proposed Illinois CCR Rule").

My testimony will focus on the following sections of the Proposed Illinois CCR Rule:

- Section 845.420: Leachate Collection and Removal System
- Section 845.770: Retrofitting

COMMENTS ON SECTION 845.420
LEACHATE COLLECTION AND REMOVAL SYSTEM

Leachate Collection & Removal System Requirements

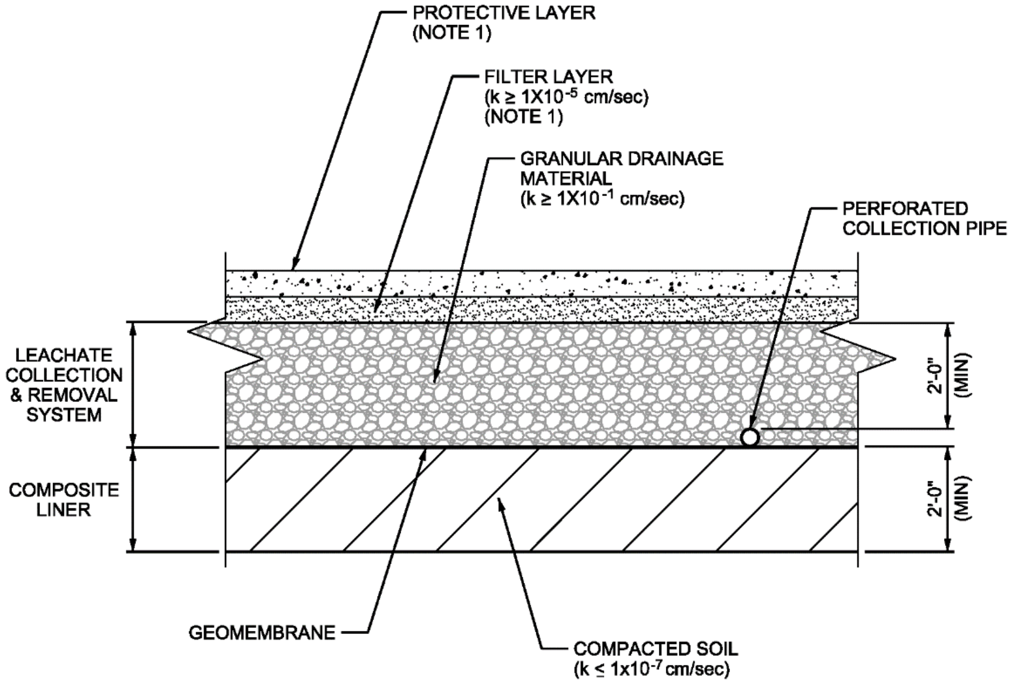
The IEPA has incorporated a leachate collection requirement for new and retrofitted CCR surface impoundments in Section 845.420 of the Proposed Illinois CCR Rule. This essentially requires a drainage layer at the base of new and retrofitted CCR surface impoundments with the purpose of reducing the hydraulic head on the impoundment's composite liner system. Per the IEPA:

> "A new CCR surface impoundment must be designed, constructed, operated and maintained with a leachate collection and removal system. The purpose of this Section is to minimize the amount of head on the liner system which will decrease the potential for the movement of fluids through the liner. The system is similar to leachate collection systems required for solid waste landfills." (Reference 1, Statement of Reason, Part IV [1] ("Regulatory Proposal: Language"), Section 845.420: Leachate Collection and Removal System)

Section 845.420 of the Proposed Illinois CCR Rule details the requirements for leachate collection systems for new and retrofitted CCR surface impoundments. For this testimony, I am focusing on the following excerpts from the Proposed Illinois CCR Rule (paragraph numbering from the rule is preserved for clarity):

a) The leachate collection and removal system must:
   1) be placed above the liner required by Section 845.400 or Section 845.410;
   2) have placed above it a filter layer that has a hydraulic conductivity of no less than 1 x10^{-5} cm/sec;
   4) be constructed of drainage materials with a hydraulic conductivity of 1 x 10^{-1} cm/sec or more and a thickness of 24 inches or more above the crown of the collection pipe; or constructed of synthetic drainage materials with a transmissivity of 6 x 10^{-4} m^2/sec or more;
   7) have collection pipes
      A) designed such that leachate is collected at a sump and is pumped or flows out of the CCR surface impoundment;

These requirements are graphically depicted in Figure 1. When a new or retrofitted CCR surface impoundment is operating, the CCR transport water (leachate) will be directly above the protective layer, which would likely be gravel or crushed limestone.



<u>MINIMUM REQUIREMENTS PROPOSED BY ILLINOIS EPA FOR CCR SURFACE IMPOUNDMENT LINER & LEACHATE COLLECTION & REMOVAL SYSTEM</u>

<u>FIGURE 1</u>

<u>NOTE 1:</u> PROPOSED 35 ILL. ADM. CODE 845.420 DOES NOT SPECIFY THICKNESS REQUIREMENTS FOR THE PROTECTIVE AND FILTER LAYERS.

The Federal CCR Rule (Reference 2) does not require leachate collection and removal systems for the transport water in CCR surface impoundments. During the rulemaking phase of these federal CCR disposal standards, the US EPA evaluated if a leachate collection and removal system should be required for new and retrofitted CCR surface impoundments. In the 2010 proposed rule (Reference 3), the US EPA proposed a leachate collection and removal system be installed between the flexible membrane liner (FML, i.e., geomembrane) and low-permeability soil components of the impoundment's composite liner system. This was a modification of the double liner system required by the US EPA for hazardous waste land disposal units, which was justified by the US EPA's initial CCR risk assessment in which the agency concluded that "composite liners effectively reduce risks from all constituents to below the risk criteria for both landfills and surface impoundments" (Reference 3, p. 35174). The US EPA continued, "[T]he Agency believes a composite liner system would be adequately protective of human health and the environment and a double liner system would be unnecessarily burdensome" (Reference 3, p. 35174).

Following several years of additional research and review of comments on the 2010 proposed rule, in 2015 the US EPA finalized the Federal CCR Rule, in which the agency concluded that it was counterproductive and erroneous to require a leachate collection and removal system between the two component's of a CCR surface impoundment's composite liner system (Reference 2, p. 21369). The agency stated:

> "The proposed requirement for CCR surface impoundments to construct a leachate collection system between the FML and soil components would prevent the direct and uniform contact of the upper and lower components and, therefore, compromise the integrity of the composite liner. For this reason, EPA is not requiring a leachate collection and removal system for new surface impoundments or any lateral expansion of a CCR surface impoundment." (Reference 2, p. 21369)

It is notable that the US EPA did not require a leachate collection and removal system for CCR surface impoundments. The agency could have required the leachate collection and removal system be installed above the impoundment's composite liner system (as the Proposed Illinois CCR Rule), which would maintain the integrity of the liner. However, after performing an exhaustive risk assessment, which included modeling of and reviewing the available data on both proven and potential damage cases , the agency determined that a leachate collection and removal system was not necessary for CCR surface impoundments to be protective of human health and the environment.

Risk Evaluation of CCR Surface Impoundments Without Leachate Collection and Removal Systems

The US EPA performed an exhaustive risk assessment during the development of the Federal CCR Rule. This EPA risk assessment used mathematical models to determine the rate at which chemical constituents may be released from different CCR waste management units, to predict the fate and transport of these constituents through the environment, and to estimate the resulting risks to human and ecological receptors. In addition to extensive sensitivity analysis and as a further method of validation, EPA compared the results of the sensitivity and uncertainty analyses with proven and potential damage cases. Together these analyses and comparisons show that there is a high degree of confidence in the principal findings of the probabilistic analysis.

The findings from this analysis are presented in a detailed public report (Reference 4). The stated purpose of this study was:

> "…to characterize the risks that may result from the current disposal practices for coal combustion residuals (CCRs) and provide a scientific basis for the development of regulations necessary to protect human health and the environment under the Resource Conservation and Recovery Act (RCRA)." (Reference 4, p. ES-1)

One of the conclusions of this risk analysis was:

> "**Composite liners** were the only liner type modeled that **effectively reduced risks** from all pathways and constituents **far below human health and ecological criteria** in every sensitivity analysis conducted." (Bolding added for emphasis) (Reference 4, p. ES-7)

To validate the modeling, the study also compared the results to proven and potential damage cases. This comparison was summarized:

> "Due to the differing nature of these two sources of information, a direct comparison would not be relevant. However, general characteristics and conclusions from the damage cases are relevant to support the findings of the risk assessment, and are discussed below. …**No damage cases were identified for composite-lined units**. This agrees well with the results of the sensitivity analyses, which showed … … that **risks for composite-lined units were far below all cancer and noncancer criteria**." (Bolding added for emphasis)
> (Reference 4, p. 5-47)

Based on the conclusions made in US EPA's Risk Assessment (Reference 4) and the lack of damage cases for composite-lined CCR surface impoundments, I agree with the US EPA's determination that a leachate collection and removal system is not necessary for CCR surface impoundments to be protective of human health and the environment.

In written questions regarding the US EPA's Risk Assessment (Reference 4) the IEPA was asked, "Has IEPA reviewed that risk assessment?" The IEPA response was "No. The Agency is aware this document exists." (Reference 5, Page 37, Agency's response to Q 3.a). When asked "Did IEPA rely upon U.S. EPA's risk assessment to support its Part 845 proposal?" the agency responded, "Only to the extent that USEPA's risk assessment was used by USEPA to develop the requirements of Part 257." (Reference 5, Page 37, Q 3.b).

As a licensed professional engineer, I believe that valid scientific studies, similar to the US EPA's Risk Assessment, should be the primary basis for environmental regulation, which does not appear to be the case for the leachate collection and removal system requirements in the Proposed Illinois CCR Rule. Understanding that the IEPA and the Illinois Pollution Control Board are on a very short deadline pursuant to the new Section 22.59 of the Illinois Environmental Protection Act, both agencies should look to the thorough study and analysis conducted by the US EPA when they developed the Federal CCR Rule, as well as the recommendations against leachate collection systems in impoundments. Following a thorough review of this information by the IEPA and the Pollution Control Board, I suggest that the Pollution Control Board should not require a leachate collection and removal system for new and retrofitted CCR surface impoundments in Illinois.

Operational Implications of Leachate Collection and Removal from Impoundments

The collection and removal of leachate from MSW landfills is a well-established requirement and an industry standard. However, removing CCR transport water (leachate) from surface impoundments is not an industry standard because it is not practical given the inherent operation of a surface impoundment. In fact, calling the transport water "leachate" is a bit of a misnomer. Leachate from an MSW landfill is very different than transport water used to move CCR from a power station; the volume and purpose of liquid is vastly different. MSW landfill leachate is the combination of precipitation that falls on open cells that percolates through the waste to the leachate collection system and the liquid generated as the solid waste degrades and compresses in the landfill. The flow rate of leachate collected in an MSW landfill is typically less than 1/10th of the typical flow rate of CCR transport water system, which are usually about 3,000 to 5,000 gpm. One additional significant difference in MSW landfill leachate and transport water is that while MSW leachate is a waste product, the transport water is a vital part of the operation of a power plant to cool and move the CCR from a power station to waste treatment unit such as a CCR surface impoundment.

The IEPA's basis for requiring a leachate collection and removal system is to reduce the hydraulic head on an impoundment's liner as a proactive means of protecting groundwater (Reference 1, p. 19). However, the Proposed Illinois CCR Rule does not mandate the removal of leachate or the maximum hydraulic head level on a pond liner system. Moreover, during the August 12, 2020 Hearing, Ms. Gale asked, "So are you saying that under these rules the head should be limited to 30 centimeters?" and Mr. Buscher of the IEPA responded "… no, I don't think that can be done because it's an operational consideration of the CCR impoundment. I think that that might not allow the owner or operator of a CCR impoundment the flexibility they would need to properly operate the impoundment." (Reference 6, p. 141. l. 15 – 24). I concur with Mr. Buscher's opinion regarding mandating a maximum water level above the liner of CCR impoundments in Illinois. In my opinion, the decision whether to install a leachate collection and removal system that will be operated as determined by the Owner/Operator should be made by the Owner/Operator.

Installing a leachate collection and removal system in a CCR surface impoundment is not practical because, if the system was to operate, the pond would likely be dry, causing negative consequences such as fugitive dust emissions.

To better understand the implications of collection and removal of leachate from a pond floor, consider the following hypothetical scenario. The flow rate through the filter layer, which is the most restrictive layer above the leachate collection system, as required by the Proposed Illinois CCR Rule, for a hypothetical 20-acre CCR surface impoundment is calculated using Darcy's Law for flow through porous media. The flow per unit area (Q/A) is:

$Q/A = k \times ((h/t) + 1)$, (Reference 2, p. 21474)

where:

Q = flow rate (cubic feet/second);
A = surface area of the area considered (square feet);
k = hydraulic conductivity of the filter layer (feet/second);
Assume $k = 1 \times 10^{-5}$ cm/sec = 3.28×10^{-7} ft/sec
h = hydraulic head above the filter layer (feet); Assume impoundment water is 20 ft deep; and
t = thickness of the filter layer (feet); Although not specified, assume 6 inches or 0.5 ft..

$Q/A = 3.28 \times 10^{-7}$ ft/sec x $((20/.5) + 1) = 1.3 \times 10^{-5}$ ft/sec = 0.048 ft/hr

Assuming the hydraulic conductivity of the filter layer is the minimum permitted by the Proposed Illinois CCR rule (1×10^{-5} cm/sec $=3.28 \times 10^{-7}$ cm/sec), the water in the pond is 20-feet deep, and the filter layer is 6-in. thick (it is noted that no minimum thickness is specified by the Proposed Illinois CCR Rule), the total flow per hour in the 20-acre pond is:

Q = 20 ac x 43,560 ft^2/ac x 0.048 ft/hr = 42,000 ft^3/hr = 5,300 gpm = 7.5 million gal/day

Since the hydraulic conductivity used in this example was the lowest permeability allowed by the Proposed Illinois CCR Rule, and since the filter layer thickness was assumed to be six inches, the calculated flow could be significantly higher with more permeable or thinner filter materials. It is noted that in my experience with CCR sluice systems, the flow rate into the pond is typically on the order of 3,000 to 5,000 gpm. Thus, this hypothetical CCR surface impoundment would not be able to contain significant free water since the flow rate into the leachate collection and removal system would be effectively equal to the flow rate of CCR into the impoundment. Consequently, this hypothetical pond would generally be dry, which would result in a higher likelihood of fugitive dust risks to the environment.

The IEPA clarified that water collected by a leachate collection and removal system could be returned to the impoundment (Reference 5, p. 16, Agency's Answer to Question 36.a). But that creates other issues, including the impracticality of having one pump system designed to remove water from the leachate collection system and return it to the pond, and a second pump system to reuse the water that is typically impounded as the source for the CCR sluicing system, which is the typical process flow for sluice water system. If these two systems are operated simultaneously, they would require "tank like" water storage for the sluice water return system to operate. Additionally, when the sluice system is not operational, the leachate collection and removal system is not really what its name suggests; instead it is a filtration system that constantly circulates the transport water without serving any other purpose.

Alternatively, the Proposed Illinois CCR Rule could suggest that the leachate collection and removal system would not operate until the closure of the CCR surface impoundment. However, I do not believe the Illinois CCR Rule should require installation of a leachate control and removal system that would be idle until closure, since other dewatering options are available. The installation of a leachate collection and removal system in the hypothetical 20-acre surface impoundment presented earlier is expected to require the mining, transportation, and placement of over 70,000 cubic yards (3,500 to 4,500 truckloads) of free-draining gravel, which may not be considered to be a prudent use of natural resources, given the US EPAs position on the adequacy of composite liners without leachate collection.

Approved State CCR Rules and Leachate Collection & Removal Systems for CCR Surface Impoundments

To date, two states (Oklahoma and Georgia) have obtained US EPA approval of their CCR programs. Neither of these states have a requirement to install a leachate collection and removal system in a CCR surface impoundment. Also, I am not aware of any other state requiring (or proposing to require) a leachate collection and removal system in a CCR surface impoundment

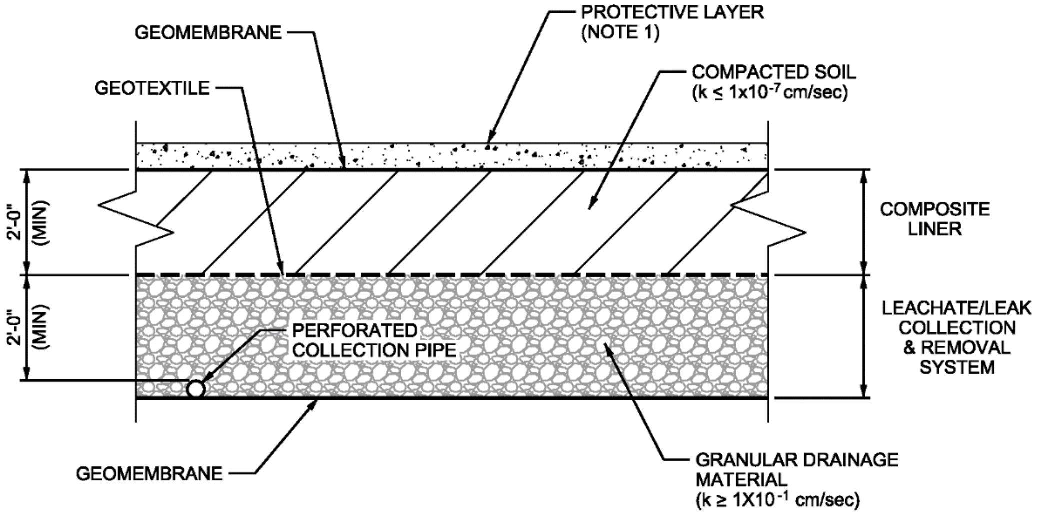
Groundwater Protection

Since the IEPA's stated reason for this leachate collection and removal system is to "minimize the amount of head on the liner system which will decrease the potential for the movement of fluids through the liner," protection of the groundwater is further considered. The Federal CCR Rule and the Proposed Illinois CCR Rule both require a system of groundwater monitoring wells near the waste boundary of a CCR surface impoundment (Reference 1, Section 845.630.a.2), which is effectively an early leak detection system and thus allow any required remedial actions to be implemented before offsite groundwater impacts.

Alternate Leachate Collection System

Based on the preceding discussions, I do not believe that a leachate collection and removal system is necessary in a CCR surface impoundment to protect human health and the environment. Further, I do not agree that the one design as mandated by IEPA should be to only acceptable "one size fits all option" in the event leachate collection remains within this rule.

I recognize that the IEPA is seeking a more proactive measure in protecting groundwater than the protection provided by the composite liner system and regular groundwater monitoring. Given my concerns with the system described in the Proposed Illinois CCR Rule, I suggest the Illinois Pollution Control Board should allow an alternative method of leachate collection that is at least as protective as the system required by the Proposed Illinois CCR Rule. For example, a collection system similar to that shown in Figure 2 would provide a proactive means of protecting groundwater since the lower geomembrane liner would impede the flow of any leakage from the primary composite liner and direct the flow to the leachate pumping system. The leachate collection and removal system in this case would effectively act as a leak detection system, which would provide immediate notice to the owner or operator that the surface impoundment's liner is leaking. Conversely, leaks through the CCR surface impoundment design specified in the Proposed Illinois CCR Rule would not be detected until the next groundwater monitoring well sampling event. Finally, this alternative system also has the advantage of requiring less energy to operate relative to the system proposed by the IEPA since the composite liner would significantly limit the flow into the leachate collection and removal system.



POSSIBLE ALTERNATE LINER FOR CCR SURFACE IMPOUNDMENTS WITH PROACTIVE LEAK COLLECTION SYSTEM IN LIEU OF LEACHATE COLLECTION SYSTEM

FIGURE 2

NOTE 1: PROPOSED 35 ILL. ADM. CODE 845.420 DOES NOT SPECIFY THICKNESS REQUIREMENTS FOR THE PROTECTIVE LAYER.

Conclusions

The Federal CCR Rule was based on an exhaustive risk analysis performed by the US EPA, and it does not require leachate collection and removal systems for CCR surface impoundments. This risk assessment notes that CCR surface impoundments with composite liners, as required by the Federal CCR Rule as well as the Proposed Illinois CCR Rule (without leachate collection system) provide a level of protection “that effectively [reduce] risks from all pathways and constituents far below human health and ecological criteria in every sensitivity analysis.” Moreover, when evaluating proven and potential damage cases, the US EPA’s analysis concluded, “No damage cases were identified for composite-lined units.” Thus, I conclude that the use of composite liners in CCR surface impoundments, without leachate collection, is appropriately protective of human health and the environment. As a licensed professional engineer, I believe that valid scientific studies should be the basis for environmental regulation, which does not appear to be the case for the leachate collection and removal requirements in the Proposed Illinois CCR Rule.

If the proposal to require a leachate collection and removal system for a new or retrofitted CCR surface impoundment is not modified, any operation of the system, will result in very large flow rates and significant water management challenges for Illinois power plants. Any proposed requirement to attempt to reduce the hydrostatic pressure on a liner system through operation of a leachate collection and removal system is burdensome and, based on the US EPA risk assessment, provides no material long term benefit to the protection of human health or the environment relative to the burden placed on Illinois power plants.

A properly designed and monitored system of groundwater monitoring wells can identify future failures in a CCR surface impoundment's composite liner system. When identified early (i.e., when impacted water is at the edge of waste), a remedial program can be implemented to protect the offsite groundwater quality.

I encourage the Pollution Control Board to implement pond design requirements that are identical to those in the Federal CCR Rule. The Federal CCR Rule is the result of many thousands of hours of thoughtful work by scientists, engineers, and regulators of the US EPA and other interested parties, which in my opinion, is an appropriate regulation for the protection of human health and the environment. Specifically, I encourage the Illinois Pollution Control Board to remove Section 845.420 of the Proposed Illinois CCR Rule along with any references to leachate collection and removal systems.

Alternatively, if the Board concludes that more proactive measures are required for protecting groundwater than those prescribed by the Federal CCR Rule, I suggest that the Board include language in 845.420 that would allow an entity to install an alternative leachate collection system that is at least as protective as the system required in 845.420(a).

COMMENTS ON SECTION 845.770
RETROFITTING

Background

The Federal CCR Rule uses the term retrofit as the process of removing CCR and contaminated soils and sediments from the CCR surface impoundments to allow relining in accordance with the current regulation. Thus, retrofitting is a method to allow existing impoundments to be improved to allow ongoing use of the CCR surface impoundment. The Proposed Illinois CCR Rule, Section 845.120 (Reference 1) defines retrofit as:

> "Retrofit" means to remove all CCR and contaminated soils and sediments from the CCR surface impoundment, and to ensure the surface impoundment complies with the requirements in Section 845.410."

Although the Illinois definition of retrofit essentially matches the Federal CCR Rule, Section 845.770(a)(1) of the Proposed Illinois CCR Rule (Reference 1) requires that any liners be removed when an impoundment is retrofitted.

Evaluation

The Proposed Illinois CCR Rule does not clearly define the type of liners that would require removal. This testimony is based on responses provided by the IEPA in the August 25 Hearing that the IEPA intends for any existing geomembrane liners to be removed as well as any clay liners.

In answer to why the Agency required removal of a liner, "The Agency would consider the liner system to be contaminated with CCR" (Reference 5, p. 32, Agency's Answer to Question 84), yet gave no other explanation. The responses provided by the IEPA in the August 25, 2020 Hearing indicate that the Agency believes that all liners are considered contaminated.

Geomembrane liners are flexible membranes that are manufactured of resins such as polyethylene (HDPE, LLDPE, LDPE) and polyvinyl chloride (PVC), which are energy intensive to manufacture and very low permeability. ASTM International defines geomembrane "an essentially impermeable geosynthetic composed of one or more synthetic sheets." (Reference 7, p. 3)

I assume the Agency believes that a geomembrane liner would become saturated with CCR constituents such that it would allow these constituents to migrate into the environment. While this may be true of clay liners, there is no basis to conclude that it is true of geomembrane liners, such as

HDPE. In fact, I am not aware of a study that shows that polymer liners become saturated with CCR constituents. Accordingly, there is no basis to conclude that a geomembrane liner would be saturated with CCR constituents such that the only method of decontamination is removal.

It is recognized that the existing geomembrane liner cannot be considered as a component of a new compliant composite liner system. Although not incorporated into the composite liner system, it is my opinion that allowing existing, effective liners to stay in place could add an additional level of protection of the environment. It is certainly a better alternative than requiring removal of a decontaminated liner and transporting it to a solid waste landfill, which in my opinion is not in compliance the reuse and energy conservation concepts that are fundamental to environmental stewardship.

Conclusion

I recommend that the language of section 845.770 be modified to allow existing geomembrane liners to be decontaminated, similar to the Federal CCR Rule requirements. The decontamination could include cleaning with high-pressure water washes, visual inspections for any damage, repair if damage was a result of the removal of CCR, and reuse as a supplemental layer below a new composite liner as suggested in Figure 2.

REFERENCES

1. IEPA, 2020 – Proposed New 35 ILL. ADM. CODE 845, "Standards For The Disposal of Coal Combustion Residuals in Surface Impoundments", as published March 2020 (referred to as the "Proposed Illinois CCR Rule")
2. US EPA, 2015 – 40 CFR Part 257 Subpart D, "Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments", as published April 17, 2015 (herein referred to as "Federal CCR Rule")
3. US EPA, 2010 – "Hazardous and Solid Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals From Electric Utilities," 75 Fed. Reg. 35128, June 21, 2010.
4. US EPA 2014 – "Human and Ecological Risk Assessment of Coal Combustion Residuals", December 2014, Regulation Identifier Number: 2050-AE81
5. IEPA, 2020 – "FIRST SUPPLEMENT TO IEPA'S PRE-FILED ANSWER" filed with the Clerk's Office August 5, 2020 by Christine Zeivel.
6. Illinois Pollution Control Board, 2020 – "REPORT OF THE PROCEEDINGS … … before Hearing Officer Vanessa Horton, called by the Illinois Pollution Control Board, taken by Steven Brickey, CSR, RMR, for the State of Illinois … … on the 12th day of August 2020, commencing at the hour of 8:01 a.m."
7. ASTM International Standard Terminology for Geosynthetics, ASTM D4439 - 20, January 2020

Thank you, this concludes my pre-filed testimony .

David E. Nielson, P.E.

August 27, 2020

DAVID E. NIELSON

Geotechnical Engineer
Sr. Consultant / Sr. Manager

Sargent & Lundy

EDUCATION

Utah State University – B.S. Civil and Environmental Engineering - 1988

REGISTRATIONS

Professional Engineer – Illinois, Indiana, Michigan, Washington, Nevada

Previously Licensed Water Well Driller – Indiana, Tennessee and Louisiana

PROFICIENCIES

- Design of embankments, dikes and containment structures
- Evaluation of existing conditions of dams, dikes, landfills & other earthen structures
- Design and evaluation of production and monitoring well systems
- Selection of design parameters for foundation and earthen structures
- Design of shallow and deep foundation systems
- Design of pavement systems
- Reinforced earth structure design
- Geosynthetics applications in geotechnical and geo-environmental areas
- Geotechnical field and laboratory instrumentation, field testing and data acquisition
- Construction material field and laboratory instrumentation, field testing and data acquisition
- Forensic evaluation of concrete structures and earthen structures

RESPONSIBILITIES

Mr. Nielson is the process owner of geotechnical and groundwater well process in the S&L quality program. He is responsible for the selection of geotechnical design parameters, design and construction monitoring of foundation systems for projects at fossil and nuclear powered electric generating stations. Mr. Nielson performs and reviews examinations of dikes, dams and landfills at both nuclear and coal fired power plants. Additionally, Mr. Nielson actively participates in engineering geology evaluation of potential plant sites and plant structure foundations. Mr. Nielson serves as a committee member on the DFI Auger Cast Pile subcommittee.

EXPERIENCE

Mr. Nielson has over 30 years of experience in geotechnical engineering and construction material testing services. He has successfully performed shallow and deep foundation design for projects in virtually all geologic settings and directed construction material quality control services in over 30 states and over 10 countries. Additionally, he has specified, directed, and performed over one-thousand subsurface exploration programs.

In addition to the design and consultation services on earthen embankments, ponds, lakes and landfills, he supervises and performs annual examination of eight dams, which are up to 8 miles in length with residential properties within 1/8 mile of the dam toe.

He has designed numerous production wells, monitoring well programs, and structure under-drain/dewatering systems to mitigate the effects of groundwater seepage in several construction projects. Moreover, he has provided design and construction recommendations for tunnels under and bridges over Midwestern rivers.

He has served as an expert witness for construction defect litigation in the areas of soil and concrete.

He provides our clients with an unusual perspective and experience. In addition to his design experience, he has worked as a construction laborer on the construction of a large coal fired power plant in Utah, geotechnical driller and geotechnical engineer with design work and quality control services in many of the major physiographic regions of the U.S.

Mr. Nielson's relevant experience with Sargent & Lundy LLC (since 2008) includes:

- **Hydroelectric Dam – Peruvian Andes**
  Before visiting the site, Mr. Nielson reviewed the prior design documents, prior reports, studies and repair designs to aid in our evaluation of the repair of a vertical crack and the general integrity of the confidential hydroelectric dam. The existing dam is an arched concrete gravity structure with an 88-meter maximum height and a crest length of 274 m. Our evaluation of the structure included recommendations for physical repairs of an abutment to improve stability and supplemental monitoring equipment to provide insight into the structure's response to loading (2018).

- **Power Stations – Wyoming**
  Performing conceptual and detailed design of several new impoundments to serve as evaporation and disposal ponds for Coal Combustion Residual waste streams. Dam heights will range up to 50 feet and the total impoundment area will exceed 400 acres. (2017 - 2020)

- **Two Power Stations – Texas**
  The two stations represent over 4400 megawatts of coal fired generating capacity. Served as Owner's Engineer to develop closure plans, hazard classifications, structural stability and annual inspections of coal ash ponds and landfills (2015 - 2018).

- **Power Station – Indiana**
  Performed emergency dam inspection to evaluate damage and recommend repair alternatives for a sand filled dam which experienced significant erosion during beyond design basis storm event. (2012)

- **Power Station – Pennsylvania**
  Formulated of design parameters for shallow spread, drilled piers and deep micropile foundation systems for SCR system constructed above existing precipitators and other plant features (2010-2012).

- **Power Station – Pennsylvania**
  Developed of geotechnical exploration specifications and formulated ACIP foundation design details, specifications, and performance criteria (2009).

- **Power Station – Nebraska**
  Developed specification for geotechnical exploration and formulated design criteria for foundation systems for major emission control project (2008).

- **Generation Project – Upper Midwest**
  Prepared a study of groundwater availability for a new combined cycle generating station (2016).

Mr. Nielson's relevant experience with other firms (1988 - 2008) includes:

- **Elkhart County Jail – Elkhart, Indiana**
  Determination of engineering design parameters for shallow foundations and utility tunnels for 1000-bed, seven building correctional campus. This work included monitoring and designing repairs to control seepage into a major utility tunnel that was constructed with inferior concrete (2004 - 2008).

- **Elkhart County Landfill/Jail – Elkhart, Indiana**
  Mr. Nielson designed extraction, compression and transmission system to remove landfill gas and transport it for beneficial use at the 1000 bed jail (2006 - 2008).

- **Earth Movers Landfill – Elkhart County, Indiana**
  Directed Construction Quality Control and Assurance (CQA/CQC) services to assure state regulators the clay and membrane liners were constructed in accordance with the permit requirements (2007).

- **Prairie View Landfill – St. Joseph County, Indiana**
  Directed Construction Quality Control and Assurance (CQA/CQC) services to assure state regulators the clay and membrane liners were constructed in accordance with the permit requirements (2006).

MEMBERSHIP

Deep Foundation Institute

EXHIBIT 5

Electronic Filing: Received, Clerk's Office 05/11/2021 **R2021-003**
Electronic Filing: Received, Clerk's Office 10/23/2020

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:)
)
Standards for the Disposal) No. R20-19
of Coal Combustion) (Rulemaking - Land)
Residuals in Surface)
Impoundments: Proposed new)
35 Ill. Adm. Code 845)

REPORT OF THE PROCEEDINGS held in the above entitled cause before Hearing Officer Vanessa Horton, called by the Illinois Pollution Control Board, taken by Pamela L. Cosentino, Certified Shorthand Reporter for the State of Illinois, at James R. Thompson Center, 100 West Randolph Street, Room 9-040, Chicago, Illinois, on the 30th day of September, 2020, commencing at the hour of 9:00 a.m.

a visual clarification, visual classification, in particular, to remove.

I think it would be reasonable for the Agency to consider visual. I think it would be reasonable for the Agency to require a swab, an occasional swab test to be submitted for analytical testing.

But these are very low-permeability plastic products that are nonabsorptive, and I'm confident that the professionals of the Agency and the professionals working for industry can come to a reasonable meeting of the mind during the permitting process.

Q. And you say some states use visual. Can you name those states for me that you are aware of?

A. The very first clean closure I did following the implementation of the CCR Rules in Minnesota and visual was the criteria.

Q. Is Minnesota the only one that comes to mind?

A. I can think of two others, but since there's a question on one, I'm going to hold off. So Minnesota is the one I'm willing to share.

Q. All right. Thank you.

How would an owner or operator demonstrate that a liner is not contaminated?

EXHIBIT 6

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
STANDARDS FOR THE DISPOSAL OF COAL COMBUSTION RESIDUALS IN SURFACE IMPOUNDMENTS: PROPOSED NEW 35 ILL. ADM. CODE 845	)	R 20-19 (Rulemaking – Land)
	)	

MIDWEST GENERATION LLC'S PRE-FILED ANSWERS

Midwest Generation, L.L.C. ("Midwest Generation" or "MWG"), by and through its attorneys, Nijman Franzetti, LLP, submits the following Pre-filed Answers on behalf of its witnesses Sharene Shealey, Richard Gnat, and David Nielson in response to Pre-filed Questions submitted by the Illinois Pollution Control Board, the Illinois Environmental Protection Agency ("Illinois EPA"), and the "Environmental Group" (collectively the Environmental Law and Policy Center, Prairie Rivers Network, and Sierra Club).

I. Sharene Shealey's Answer to the Illinois Pollution Control Board's Question

17. On page 15, you state, "[r]emoval and replacement of a competent liner that is not contaminated with CCR constituents adds even more unnecessary costs for retrofitting a CCR surface impoundment without any added benefit or protection. Accordingly, MWG recommends that the Board remove the phrase "including any liners" from 845.770(a)(1) so that existing liners that are not contaminated and in fact may be protective can remain in place for retrofitting." Please comment on whether it would be acceptable to MWG, if the Board were to revise Section 845.770(a)(1) to specify "including any contaminated liners."

Answer: Yes, that proposed modification is acceptable to MWG.

II. Sharene Shealey's Answers to the Environmental Group's Questions

1. On page 3 of your testimony, you state "Since MWG began operating the Stations in 1999, the coal ash ponds have been used only for temporary storage of coal ash until the material is removed from the ponds for beneficial reuse."
   a. Is this statement true about operations prior to MWG's ownership?

Answer: MWG objects to the question to the extent it requests site specific information. The Hearing Officer has limited questioning to general questions, and has held that site-specific information is outside the scope of the rulemaking. *See* 8/13/20 Tr., PCB20-19, pp. 17:7-10, 215:23-216:3; *See also Public*

The system proposed as a possible alternate in my testimony has the following advantages:

- If any leak occurs through the composite system, which is unlikely, it detects and collects leaks as they occur.
- It has a significantly lower impact on parasitic load (*i.e.* - power requirements to operate the equipment at generating stations) and plant operations.
- Is not likely to become fouled by fly ash and FGD waste streams.
- It does not increase the risk of fugitive dust throughout the operating life of the surface impoundment.
- It does not require the construction of very large tanks to hold and manage the transport water for re-use in the closed loop ash transport system.
- It allows a CCR surface impoundment to conduct its primary function, which is to separate the ash and slurry water, as well as store the ash transport water which is recycled in the closed loop system.

13. Does reduction of hydraulic head on the composite liner reduce the potential for the migration of contaminants through the composite liner? If not, why?

Response:

See my responses to the following questions by the IL EPA 8.c., 8.d., 9.b., and 10.

14. In your testimony regarding Section 845.770, you discuss the potential of decontaminating liners.

a. Do synthetic liners have holes and imperfections?

Response:

There are numerous types of synthetic liners used for various purposes. Depending on the use, installation process including the quality assurance and quality control ("QA/QC"), and quality of a liner, it is possible that there may be holes and imperfections. If a properly designed and installed geomembrane liner is installed following proper QA/QC measures, then the likelihood of imperfections and holes is minimized. Moreover, if a liner is somehow compromised during operations, such as a hole, then there are methods to repair the liner such that the seal of the liner is restored.

It is also noted that the Risk Assessment assumed small holes in the geomembrane liner element of composite lined systems and still did not identify any risk to human health or the environment. The Risk Assessment (p. 4-1) was conducted using the EPA Composite Model for Leachate Migration with

Transformation Products (EPACMTP). The 2003 version of the EPACMTP Technical Background Document, which is reference EPA 2003a in the Risk Assessment p. A-1 states:

> "For composite-lined Sis [surface impoundments], we used the Bonaparte (1989) equation to calculate the infiltration rate assuming circular (pin-hole) leaks with a uniform leak size of 6 mm^2 , and using the distribution of leak densities (number of leaks per hectare) assembled from the survey of composite-lined units (TetraTech, 2001).

Therefore, I conclude that the Risk Assessment accounted for potential holes in the geomembrane component of composite liners and the Risk Assessment did not identify statistically significant risks to health and the environment for composite lined CCR surface impoundments.

b. Could the heavy equipment that is likely to be used for removing CCR damage the liner?

Response:

If the operators are aware and focused on avoiding damage, then the likelihood of damage to a liner is diminished. Due to the possibility of damage to a liner during CCR removal, I suggested an inspection and repair in the final paragraph of my pre-filed testimony. *See* D. Nielson Pre-filed Testimony, p. 13

c. Could tears too small to see compromise the integrity of the liner?

Response:

While that may be true, my testimony is supporting the reuse of the liner as a supplemental liner system or as part of a different process entirely, and would not be in contact with CCR. If a decontaminated existing geomembrane liner is reused as a supplemental liner system, in addition to the regulatory mandated composite liner system, the combined liners would be more protective than the Federal CCR Rule or any other state rule requirement. *See* response to Illinois EPA Question 14.a.

d. How do you believe an owner or operator would assure the clay portion of a composite liner was decontaminated, which you agree can become saturated with CCR constituents, without removing the synthetic?

Response:

MWG objects to the question as a mischaracterization of Mr. Nielson's Pre-filed testimony. In no part of the testimony did I suggest that the clay portion of a composite liner system (*i.e.* had a geomembrane liner *and* a clay liner) could become saturated with CCR constituents. In fact, I stated the opposite. I stated that there was no basis to conclude that a geomembrane liner could become saturated with CCR constituents. D. Nielson Pre-filed Testimony, pp. 12-13. It appears that Illinois EPA misread this section, because in the sentence before I stated that clay-liners *alone* may become saturated with CCR constituents. *Id*. However, I then distinguished the clay-liners to the geomembrane liners, which are one part of the composite liner system. *Id*. As stated in my testimony, I am not aware of any study showing that a geomembrane liner may become saturated with CCR constituents. *Id*. By extension, I am not aware of a composite liner system that became saturated with CCR constituents. Additionally, as stated in my Answer to Illinois Pollution Control Board Question 18.b., there has been no damage case found for a CCR surface impoundment with a composite liner – a geomembrane liner with a clay-liner underneath.

e. Have you ever been involved with or overseen a project where the decontamination of a composite liner in a CCR surface impoundment has been performed? If so, please provide a summary of the site(s), the liners, and the processes used.

Response:

I am not personally aware of any instance where a composite lined CCR impoundment has been taken out of service.

f. Have you read or researched about a project where the decontamination of a composite liner in a CCR surface impoundment has been performed? If so, please provide a summary of the site(s), the liners, and the processes used.

Response:

See my response to question 14.e.

g. For what purpose would the allegedly decontaminated liner be reused?

Response:

MWG objects to the question because it is premised on the assumption that a geomembrane liner may not be decontaminated. I am not aware of any study showing that a geomembrane liner becomes saturated with CCR constituents. I am also not aware of any study or information demonstrating that a geomembrane liner may not become decontaminated. Moreover, no party to this rulemaking has entered into the record any study or information showing that a geomembrane liner may not be decontaminated. In fact, for retrofitting a CCR surface impoundment, the Federal CCR rule does not require removal of a liner system, but instead only requires removal of any contaminated soils and sediments. 40 CFR 257. 102(k)(i).

Because of the absence of such studies or information, I do not believe HDPE will become contaminated with CCR constituents such that decontamination methods will be ineffective.

As stated in my testimony, the possible purposes of reuse for a decontaminated liner are:

> "It is recognized that the existing geomembrane liner cannot be considered as a component of a new compliant composite liner system. Although not incorporated into the composite liner system, it is my opinion that allowing existing, effective liners to stay in place could add an additional level of protection of the environment. It is certainly a better alternative than requiring removal of a decontaminated liner and transporting it to a solid waste landfill…"
>
> "I recommend that the language of section 845.770 be modified to allow existing geomembrane liners to be decontaminated, similar to the Federal CCR Rule requirements. The decontamination could include cleaning with high-pressure water washes, visual inspections for any damage, repair if damage was a result of the removal of CCR, and reuse as a supplemental layer below a new composite liner as suggested in Figure 2." D. Nielson Pre-filed Testimony, p. 13.

Additionally, a decontaminated liner could be used for holding process waters at a generating station.

I have had an opportunity to review the suggested language by the Illinois Pollution Control Board in its Question 17 to Sharene Shealey. I believe the Board's suggested revision to Section 845.770(a)(1) to state "including any contaminated liners" will resolve the concerns expressed in my testimony.

IX. David E. Nielson's Answers to the Environmental Group's Questions

1. On Page 2 of your testimony, you state: "This essentially requires a drainage layer at the base of new and retrofitted CCR surface impoundments with the purpose of reducing the hydraulic head on the impoundment's composite liner system." As used in this quoted sentence:

   a. What does "drainage layer" mean?

   Response:

   A drainage layer is a layer in the engineered system, that is specifically designed and constructed to allow rapid drainage (removal) of water (leachate) from an impoundment (pond).

   b. What does "hydraulic head" mean?

   Response:

   In static (minimal flow or movement) conditions, hydraulic head is the vertical measurement from the surface of the water or another fluid to the point of

EXHIBIT 7

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	R 2020-019
STANDARDS FOR THE DISPOSAL	)	
OF COAL COMBUSTION RESIDUALS	)	(Rulemaking - Water)
IN SURFACE IMPOUNDMENTS:	)	
PROPOSED NEW 35 ILL. ADM.	)	
CODE 845	)	

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY'S FINAL POST-HEARING COMMENTS

NOW COMES the Illinois Environmental Protection Agency ("Illinois EPA" or "Agency"), by and through one if its attorneys, and hereby submits its Final Post Hearing Comments as directed by the Hearing Officer Orders entered on October 4 and 20, 2020 in the above captioned rulemaking.

I. Procedural Background

On March 31, 2020, the Illinois EPA filed its proposed rulemaking for coal combustion residual surface impoundments pursuant to Section 22.59 of the Illinois Environmental Protection Act, along with a Statement of Reasons ("SOR") in support. On April 24, 2020 the Illinois Pollution Control Board ("Board") accepted Illinois EPA's proposal for hearing and set prehearing deadlines. On June 2, 2020, Illinois EPA filed with the Board pre-filed testimony of eight witnesses: Lynn Dunaway, Darin LeCrone, Melinda Shaw, William Buscher, Lauren Martin, Amy Zimmer, Chris Pressnall, and Robert Mathis (Hrg, Ex. 1). Illinois EPA filed Answers to Pre-Filed Questions from the Board, Little Village Environmental Justice Organization, the Environmental Law and Policy Center, Prairie Rivers Network, and Sierra Club ("Environmental Groups," collectively), Springfield City Water, Light, and Power, the Illinois Environmental Regulatory Group, Ameren, Midwest Generation, and Dynegy on August 3 (Hrg. Ex. 2), August 5 (Hrg. Ex.

1. Proposed Part 845, filed by the Agency on March 30, 2020, incorporated requirements that had been proposed by USEPA in 85 Fed. Reg. (Mar. 3, 2020), 12456, but have not yet been adopted by USEPA. Among other things, the proposed changes to Part 257 addressed closure by removal (referred to as "Part B"). The current version of Part 257 treats closure by removal and all associated corrective action as a single process, with closure not being complete until all corrective action has been completed. Hrg. Ex. 8 as amended by 85 Fed. Reg. 53516, (Aug. 28, 2020). The USEPA proposal divides closure by removal into a two-step process. The first step is the physical removal of all CCR, containment systems and related structures, while the second step is the completion of any necessary groundwater corrective action.

The Agency had testified that it believed Part 845 would have to be revised, if USEPA had not adopted the "Part B" requirements. Hrg. Ex. 2, p. 139. However, upon reexamination of the "Part B" requirements, the Agency concludes they are more protective and comprehensive than Part 257 as it currently exists. For example, "Part B" requires a deed notation until corrective action is complete. The requirement for a deed notation is not required by the current version of Part 257, but the Agency included the requirement for a deed notation in Part 845 as proposed. Part 845 requires financial assurance for corrective action, thereby affording additional protection of public funds should an owner or operator default. Also "Part B" specifies that in addition to meeting groundwater protection standards to terminate groundwater corrective action after closure by removal has been completed, compliance with the groundwater protection standards must be demonstrated for three consecutive years, prior to terminating groundwater corrective action and the associated groundwater monitoring. These requirements are also included in Part 845 as drafted. However, Section 845.740(a) as drafted contains the generalized language that removal and decontamination of areas affected by releases must be completed for closure by removal. Therefore, as shown below, the Agency has proposed a revision to Section 845.740(a) using specific language from the "Part B" proposal describing how to complete closure by removal and an additional statement that closure by removal must be completed before groundwater corrective action.

> a) Closure by removal of CCR. An owner or operator may elect to close a CCR surface impoundment by removing all CCR and removing and decontaminating all areas affected by releases of CCR from the CCR surface impoundment. CCR removal and decontamination of the CCR surface impoundment are complete when all CCR and CCR residues, containment system components such as the impoundment liner and contaminated subsoils, and CCR impoundment structures and ancillary equipment have been removed. Closure by removal shall be completed before the completion of a groundwater corrective action pursuant to Subpart F. ~~the CCR in the surface impoundment and any areas affected by releases from the CCR surface impoundment have been removed.~~

2. The Agency proposed a revision to Section 845.700(d), and a corresponding requirement for a new subsection 845.800(d)(19), relative to Part 257.103. The Agency has also proposed a revision to Section 845.770(a)(3), required to clarify that owners and operators seeking extensions to retrofit a CCR surface impoundment must submit a preliminary retrofit plan to make the Agency aware of their intent to retrofit a CCR surface impoundment. Those proposed revisions required the renumbering of Section 845.800(d) cross-references in subsections (d), (e) and (f) of 845.740.

> d) At the end of each month where CCR is being removed from a CCR surface impoundment, the owner or operator must prepare a report that describes the weather, precipitation amounts, the amount of CCR removed from the CCR surface impoundment, the amount and location of CCR being stored on-site, the amount of CCR transported offsite, the implementation of good housekeeping procedures required by Section 845.740(c)(4)(C), the implementation of dust control measures, and documents worker safety measures implemented. The owner or operator of the CCR surface impoundment must place the monthly report in the facility's operating record as required by Section 845.800(d)(~~22~~23).

EXHIBIT 8

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
STANDARDS FOR THE DISPOSAL OF	)	
COAL COMBUSTION RESIDUALS IN	)	**R20-19**
SURFACE IMPOUNDMENTS: PROPOSED	)	**(Rulemaking – Water)**
35 ILL.ADM. CODE PART 845	)	

MIDWEST GENERATION, LLC'S RESPONSE TO POST-HEARING COMMENTS

I. Introduction

Midwest Generation, LLC ("Midwest Generation" or "MWG") appreciates the opportunity to provide a response to certain post-hearing comments submitted in this rulemaking proceeding for the Illinois Pollution Control Board's ("Board") consideration. MWG generally supports the post-hearing comments filed by Dynegy and the City of Springfield d/b/a City Water, Light, and Power. MWG also supports certain sections of the post-hearing comments filed by the Illinois Environmental Protection Agency ("Illinois EPA" or "Agency"), however, as described herein, MWG disagrees with other sections. Additionally, MWG provides responses to the final comments and suggested modifications by the Sierra Club, Prairie Rivers Network, Environmental Law and Policy Center and Little Village Environmental Justice Organization (collectively the "Environmental Group").

II. The Board Should Not Adopt the Sections of the Proposed CCR Rule That Are Not Supported by the Record.

MWG objects to Illinois EPA's substantial, substantive proposed changes to the closure by removal requirements in Section 847.770. Agency Final Comment, pp. 86-87. These significant changes come at the eleventh hour without any basis or explanation and without any opportunity for stakeholders to present rebuttal evidence or testimony. If significant changes to proposed rules are first presented in a final post-hearing Agency comment, it essentially nullifies the due process rights of stakeholders like Midwest Generation that a rulemaking proceeding is intended to afford and protect. There is no meaningful opportunity now to evaluate and respond to the Agency's proposed changes. The Board should reject the change and implement the language Illinois EPA originally proposed.

Illinois EPA also has failed to provide technical or scientific support for its proposed inclusion of a leachate collection system requirement for coal combustion residual ("CCR") surface impoundments. Not only does this proposal conflict with the requirements of the Federal Coal Combustion Residual Rule ("Federal CCR Rule"), it is unnecessary, particularly for smaller surface impoundments that close by removal. At most, any leachate collection system requirement should only apply to CCR surface impoundments that are larger than 20 acres. This approach would be consistent with the Agency's underlying rationale that such systems are only needed to assist in dewatering impoundments during closure in place activities and their subsequent post-closure care. The hearing testimony showed not only that small CCR surface impoundments predominantly close by removal, not closure in place, and that dewatering and removing CCR in these impoundments is not difficult and does not require the assistance of a leachate collection system to complete the dewatering process.

The Board should not adopt the Agency's position that a single detection above the groundwater protection standards of one constituent in one quarter is a "confirmed exceedance." As the hearing testimony of Richard Gnat clearly showed, single detection anomalies can and do occur. Owners or operators should not be denied the limited opportunity to determine if the single detection of an exceedance is an anomaly. The rule should instead allow for a second sampling event to confirm that the exceedance is a real value before requiring an owner or operator to expend further resources to address it. The very limited additional time to confirm that an exceedance in fact has occurred will not endanger either human health or the environment. It will, however, prevent investigations of single detection exceedances that really don't exist.

Similarly, a requirement to develop background concentrations in only six months is unreasonable. The hearing testimony shows that the development of accurate background data requires evaluation of the seasonal changes in the groundwater and also samples taken sufficiently spaced apart in time to assure independent data - neither of which can be accomplished in six months' time. Finally, MWG submits that the final rule should allow an owner or operator to reduce the constituents evaluated where the data collected shows that certain constituents do not require further evaluation.

a. The Board Should Reject Illinois EPA's New Language for Closure by Removal

For the first time and without any prior indication or explanation, the Agency presents new requirements for closure by removal in its post-hearing comments. Agency Final Comment, pp.

86-87. The original language for closure by removal in the proposed Disposal of Coal Combustion Residuals ("CCR") in Surface Impoundments Rule (the "Proposed CCR Rule") states that:

> An owner may close by removing and decontaminating all areas affected by releases from the CCR surface impoundment. CCR removal and decontamination of the CCR surface impoundment are complete when the CCR in the surface impoundment and any areas affected by releases from the CCR surface impoundment have been removed.
> Proposed 35 Ill. Adm. Code 845.740(a).

This is the same language that is in the federal CCR Rule. 40 CFR 257.102(c). Ex. 8, 483. Now, the Agency is suddenly and belatedly proposing a wholesale revision of that section. The Agency's new language states that for closure by removal, an owner/operator must also remove "containment system components such as the impoundment liner and contaminated subsoils, and CCR impoundment structures and ancillary equipment." Agency Final Comment, p. 87. The Agency provided no explanation or technical support to show that the containment system components associated with the CCR surface impoundment must be removed.

The Agency has not provided any information on the technical feasibility nor the economic reasonableness of removing the containment equipment associated with a CCR surface impoundment for closure by removal. Section 27(a) of the Act sets out the procedures the Board must follow to enact regulations, including a requirement to take into account the technical feasibility and economic reasonableness of measuring or reducing the particular type of pollution. 415 ILCS 5/27(a). If the Board fails to follow the procedures under Section 27(a), then the rule is invalid. *See Waste Mgmt. of Ill., Inc. v. Pollution Control Bd.,* 231 Ill. App. 3d 278, 288-289, 172 Ill. Dec. 501, 508, (1st Dist. 1992). (Court found Board regulation requiring certain air monitoring of chemicals invalid because the record contained no evidence concerning the technical feasibility and economic reasonableness of measuring the chemicals.)

Here, the Agency has provided no information to show that its proposed change to Section 845.740(a) is technically feasible or economically reasonable. The Agency claims the revision is necessary to be consistent with the Federal Part B Rule, that was proposed on March 3, 2020 and is attached here as Attachment A. But the Agency's proposed language is inconsistent with the proposed Part B regulation. The March 3, 2020 proposed federal CCR rule for closure by removal states:

> "Closure by removal activities include removing ***or*** *decontaminating* all CCR and CCR residues, containment system components such as the unit liner, contaminated subsoils, contaminated groundwater, and CCR unit structures and ancillary equipment."
> Proposed 40 CFR 257.102(c) (emphasis added)

The proposed Part B regulation does not require removal of the containment systems. The Agency does not explain why it significantly deviated from the federal March 3, 2020 proposed language. The Agency's proposed change also diverges from its own admonition that as "frequently reminded" by the U.S.EPA, the Agency's goal was "to keep the language and function of Part 257 as similar as possible." Agency Final Comment, p. 10. By failing to replicate the proposed Part B language, the Agency is failing to follow the U.S.EPA's direct instructions.

The Agency has created – without explanation and for the first time in its final comments – new language requiring removal not only of the CCR, but all of the equipment and liners associated with the CCR surface impoundment regardless of its condition. There is nothing in the record here to demonstrate that the equipment and the liner associated with CCR is so contaminated that it may not be decontaminated. Instead, the testimony demonstrates precisely the opposite. Mr. Nielson testified that a synthetic liner (or "geomembrane liner") is not likely to be contaminated with CCR constituents merely because it was in contact with CCR. Ex. 54, p. 12-13. Geosynthetic liners are nonabsorptive and can be decontaminated so that they are suitable to reuse as part of a CCR surface impoundment retrofit. Ex. 54, p. 12-13; ASTM D4439; 9/30/2020 Tr., p. 199:7-8. The Illinois EPA admits that it is simply assuming that liners become contaminated and cannot be decontaminated without providing any other basis, including any scientific studies or analysis, to support that assumption. 8/25/2020 Tr., pp. 73:20-23, 76:14-17.

Turning to the other components that the Agency now proposes also must be removed, it again fails to explain why it believes that these components cannot be decontaminated. Because the record is closed, MWG and any other affected party, is foreclosed from providing additional evidence and expert opinion explaining why the components associated with a CCR surface impoundment may be decontaminated such that their removal is not required. It is unfair, unreasonable, and arbitrary to substantially change the scope of the requirements for closure by removal at such a late stage in this proceeding when the record is closed, and affected parties do not have an opportunity to present evidence demonstrating that the Agency's proposal is flawed.

It appears the Agency's impetus for recommending this substantial change is a sentence in the preamble to the proposed March 3, 2020 federal rule that refers to removal of all of the equipment regardless of whether it can be decontaminated. Ex. 1, p. 12469-12470. But such reliance is both inconsistent and contrary to the Agency's testimony that it rejects the preamble language, and instead prefers "to utilize regulation as opposed to utilizing the preamble." 8/11/20 Tr. p. 70: 12-14, p. 71:8-10. The Agency explained that it preferred to use the regulation language, because Part 257 has changed over time, thus the preference "is to utilize the regulation." 8/11/20 Tr. p. 71:10-11.

The federal March 3, 2020 proposal regarding closure by removal is only a proposal. It has not been adopted by the U.S.EPA. On October 15, 2020, USEPA finalized a part of the March 2020 proposed regulation. U.S.EPA, Hazardous and Solid Waste Management System: Disposal of Coal Combustion Residuals from Electric Utilities: Final Rule (pre-publication, October 15, 2020). The sections that the U.S.EPA adopted related to 40 CFR 257.102(d) and the alternative final cover system design. The U.S.EPA stated that the other provisions from the proposed rule (including closure by removal activities) "will be addressed in a subsequent rulemaking action." *Id.*, p. 7. As the Illinois EPA stated at hearing, the USEPA has changed the rule often, so there is no basis to believe that their proposed rule, and their statements in the preamble, will remain the same.

An isolated and unjustified preamble statement in a *proposed Federal rule* is an insufficient basis for including a requirement to remove every piece of equipment connected to CCR regardless of its condition. The Federal CCR Rule - which the Agency otherwise follows – states only that the equipment must be decontaminated. 40 CFR 257.102. Neither the preamble nor the Agency's post-hearing comments provides any technical basis supporting either equipment removal or the inability to decontaminate it. The record here shows exactly the opposite - - that the liners used for CCR surface impoundments can be decontaminated. Based on the record, the Board should reject the Agency's proposed language, and use the language that the Illinois EPA originally proposed, which is based upon and similar in function to Section 257.102(c) of the current Federal CCR Rule and on which the stakeholders have had an opportunity to comment. Ex. 8, p. 483.

EXHIBIT 9

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

```
IN THE MATTER OF:              )
                               )
Standards for the Disposal     )   No. R20-19
of Coal Combustion             )  (Rulemaking - Land)
Residuals in Surface           )
Impoundments:  Proposed new    )
35 Ill. Adm. Code 845          )
```

REPORT OF THE PROCEEDINGS held in the above entitled cause before Hearing Officer Vanessa Horton, called by the Illinois Pollution Control Board, taken by Pamela L. Cosentino, Certified Shorthand Reporter for the State of Illinois, at James R. Thompson Center, 100 West Randolph Street, Room 9-040, Chicago, Illinois, on the 25th day of August, 2020, commencing at the hour of 9:15 a.m.

things at least in play for leaving a liner in place during removal, any time you remove ash, generally, you're using machinery and you're on the liner. There will be damage. Could be significant damage.

The other possibility is there could be impacts to groundwater beneath the liner, whatever levels they may be. So there could be -- those are two reasons that we believe the liner needs to be removed.

MS. GALE: Okay. And to be clear, I'm talking about polymer liners here, which are plastic HDPE, to make sure we're just on the same baseline.

So the Agency doesn't think a polymer liner cannot be decontaminated by a washing, a plastic liner?

MS. ZIMMER: Amy Zimmer. Once again, any type of liner could be damaged, probably would be damaged by removing the ash and fully cleaning it during ash removal.

MS. GALE: So that's an assumption you're making?

MS. ZIMMER: Amy Zimmer. Based on information and belief.

MS. GALE: And also, the basis of my question

MS. GALE: Did the Agency consider the volume of material that would go into landfills even though the groundwater protection standards are established, instead of reusing the material?

MS. ZIMMER: Amy Zimmer. No.

MS. GALE: Okay. Considering the energy and manufacturing impacts associated with manufacturing of plastic HDPE liners, isn't it more environmentally responsible to reuse this resource if it's able to be cleaned?

MS. ZIMMER: Amy Zimmer. That would require the Agency to speculate because we don't know what the next use would be.

MS. GALE: Well, you've already speculated that the liner has leaks in it, right? You have made that assumption?

MS. ZIMMER: Yes. Amy Zimmer.

MS. GALE: So you can't speculate this way as well?

MS. ZEIVEL: The question was asked and answered.

MS. GALE: Okay.

HEARING OFFICER HORTON: I hate to interrupt, but could we pause here for lunch?

EXHIBIT 10

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

1021 NORTH GRAND AVENUE EAST, P.O. BOX 19276, SPRINGFIELD, ILLINOIS 62794-9276 • (217) 782-3397
BRUCE RAUNER, GOVERNOR **ALEC MESSINA, DIRECTOR**

217/782-0610

April 10, 2017

Waukegan Generating Station
Received

APR 14 2017

Midwest Generation, LLC
401 East Greenwood Ave.
Waukegan, IL 60087

Re: Waukegan Generating Station
NPDES Permit No. IL0002259
Modification of NPDES Permit (After Public Notice)

Gentlemen:

The Illinois Environmental Protection Agency has examined the request for modification of the above-referenced NPDES Permit as stated in your letter of September 30, 2013. Our final determination is to modify the permit as follows:

1. Trona Mill Wash was added as subwastestream 7 at outfall D01.
2. In special condition 16 the minimum reporting limit for chloride was changed from 0.1 mg/l to 1.0 mg/l and sulfate was changed from 0.1 mg/l to 10 mg/l to be consistent with the minimum reporting limits used at the IEPA lab.
3. Removal of Ion Exchange discharges and replacement with RO discharges tributary to outfall B01.
4. Special Condition 6 was revised to reflect the new electronic reporting rule.

Enclosed is a copy of the modified Permit. You have the right to appeal any condition of the Permit to the Illinois Pollution Control Board within a 35 day period following the issuance date.

Should you have questions concerning the Permit, please contact Jaime Rabins at 217/782-0610.

Sincerely,

Alan Keller

Alan Keller, P.E.
Manager, Permit Section
Division of Water Pollution Control

SAK:JAR:15042301

Attachments: Modified Permit

cc: Records Unit
Des Plaines FOS
Compliance Assurance Section
Billing
CMAP
US EPA

4302 N. Main St., Rockford, IL 61103 (815) 987-7760
9511 Harrison St., Des Plaines, IL 60016 (847) 294-4000
595 S. State, Elgin, IL 60123 (847) 608-3131
2125 S. First St., Champaign, IL 61820 (217) 278-5800
2009 Mall St., Collinsville, IL 62234 (618) 346-5120
412 SW Washington St., Suite D, Peoria, IL 61602 (309) 671-3022
2309 W. Main St., Suite 116, Marion, IL 62959 (618) 993-7200
100 W. Randolph, Suite 10-300, Chicago, IL 60601

PLEASE PRINT ON RECYCLED PAPER

Waukegan Generating Station
Received
APR 14 2017

NPDES Permit No. IL0002259

Illinois Environmental Protection Agency
Division of Water Pollution Control
1021 North Grand Avenue East
Post Office Box 19276
Springfield, Illinois 62794-9276

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

Modified (NPDES) Permit

Expiration Date: March 31, 2020

Issue Date: March 25, 2015
Modification Date: April 10, 2017

Name and Address of Permittee:

Midwest Generation, LLC
401 East Greenwood Ave.
Waukegan, IL 60087

Facility Name and Address:

Midwest Generation, LLC
Waukegan Generating Station
401 East Greenwood Ave.
Waukegan, Illinois 60087
(Lake County)

Discharge Number and Name:		Receiving Waters:
001	Condenser Cooling Water and House Service Water	Lake Michigan
A01	Boiler Blowdown	
B01	Reverse Osmosis Wastes	
C01	Wastewater Treatment System	
D01	East Yard Collection Basin Overflow	
F01	Unit 7 Demineralized Water Storage Tank Drain	
G01	Non-Chemical Metal Cleaning Wastes	

In compliance with the provisions of the Illinois Environmental Protection Act, Title 35 of Ill. Adm. Code, Subtitle C and/or Subtitle D, Chapter 1, and the Clean Water Act (CWA), the above-named permittee is hereby authorized to discharge at the above location to the above-named receiving stream in accordance with the standard conditions and attachments herein.

Permittee is not authorized to discharge after the above expiration date. In order to receive authorization to discharge beyond the expiration date, the permittee shall submit the proper application as required by the Illinois Environmental Protection Agency (IEPA) not later than 180 days prior to the expiration date.

Alan Keller

Alan Keller, P.E.
Manager, Permit Section
Division of Water Pollution Control

SAK:JAR:15042301

Effluent Limitations and Monitoring

From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

PARAMETER	LOAD LIMITS lbs/day DAF (DMF) 30 DAY AVERAGE	LOAD LIMITS lbs/day DAF (DMF) DAILY MAXIMUM	CONCENTRATION LIMITS mg/l 30 DAY AVERAGE	CONCENTRATION LIMITS mg/l DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE

Outfall 001: Condenser Cooling Water and House Service Water (DAF = 739 MGD)

This discharge consists of:

1.	Condenser cooling water	589 MGD
2.	House service water	29.7 MGD
3.	Boiler blowdown	Intermittent
4.	Reverse osmosis wastes	0.06 MGD
5.	Wastewater treatment system effluent	8.13 MGD
6.	East yard runoff basin overflow/discharge	0.676 MGD
7.	Demineralized water (storage tank drainage and steam relief)	Intermittent
8.	Intake screen backwash	0.172 MGD

PARAMETER	LOAD LIMITS lbs/day DAF (DMF) 30 DAY AVERAGE	LOAD LIMITS lbs/day DAF (DMF) DAILY MAXIMUM	CONCENTRATION LIMITS mg/l 30 DAY AVERAGE	CONCENTRATION LIMITS mg/l DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Flow (MGD)	See Special Condition 1				Daily	Continuous
pH	See Special Condition 2				Weekly	Grab
Total Residual Chlorine	See Special Condition 3			0.05	*	Grab
Temperature	See Special Condition 4				Daily	Continuous
Heat Rejection Rate				5301 million BTU's per hour	Daily	Continuous

The monthly maximum temperature and the monthly maximum BTU's per hour shall be reported on the DMR under temperature and heat rejection rate, respectively.

*Total Residual Chlorine shall be sampled whenever chlorination or biocide addition is being performed or residuals are likely to be present in the discharge. If chlorination and biocide addition are not used during the month it shall be so indicated on the DMR.

Effluent Limitations and Monitoring

From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

	LOAD LIMITS lbs/day DAF (DMF)		CONCENTRATION LIMITS mg/l			
PARAMETER	30 DAY AVERAGE	DAILY MAXIMUM	30 DAY AVERAGE	DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Outfall A01: Boiler Blowdown (Intermittent Discharge)						
The discharge consists of:				Approximate Flow		
1. Boiler blowdown				0.018 MGD		
2. Boiler drains				0.018 MGD		
Flow (MGD)	See Special Condition 1				2/Month When Discharging	Calculated 24-Hour Total
Total Suspended Solids			15	30	2/Month When Discharging	8-Hour Composite
Oil and Grease			15	20	2/Month When Discharging	Grab

Effluent Limitations and Monitoring

From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

PARAMETER	LOAD LIMITS lbs/day DAF (DMF) 30 DAY AVERAGE	LOAD LIMITS lbs/day DAF (DMF) DAILY MAXIMUM	CONCENTRATION LIMITS mg/l 30 DAY AVERAGE	CONCENTRATION LIMITS mg/l DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Outfall B01: Reverse Osmosis Wastes (DAF = 0.06 MGD)						
The discharge consists of:				Approximate Flow		
1. Reverse Osmosis Reject				65 gpm		
2. Reverse Osmosis Regeneration				450 gallons/cleaning		
Flow (MGD)	See Special Condition 1				2/Month	24-Hour Total
Total Suspended Solids			15	30	2/Month	8-Hour Composite
Oil and Grease			15	20	2/Month	Grab

Total Suspended Solids and Oil and Grease sampling may obtained using a Grab Sample if the equalization tank is in service.

NPDES Permit No. IL0002259

Effluent Limitations and Monitoring

From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

	LOAD LIMITS lbs/day DAF (DMF)		CONCENTRATION LIMITS mg/l			
PARAMETER	30 DAY AVERAGE	DAILY MAXIMUM	30 DAY AVERAGE	DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Outfall C01: Wastewater Treatment System (DAF = 8.13 MGD)						
This Discharge consists of:				Approximate Flow		
1. Bottom Ash Sluice				1.6 MGD		
2. Ash hopper overflow				Intermittent		
3. Coal pile runoff collection basin discharge				1.0 MGD		
a. Coal pile area runoff				0.5 MGD		
b. West yard area runoff				0.5 MGD		
i. West yard area runoff						
ii. Car dumper area runoff						
iii. Main switch yard area runoff						
iv. West yard polymer building drains						
v. Peaker sump discharges						
vi. West turbine area roof drains						
4. Non-chemical metal cleaning waste				Intermittent		
5. Supernatant from dredge spoil lagoons				Intermittent		
6. Main collection tank discharge				2.0 MGD		
a. Unit 8 low point sump (roof, floor, & equipment drains)				Intermittent		
b. Ash sluice head tank overflow				Intermittent		
c. Slag drain line				Intermittent		
d. Slag tank overflows				Intermittent		
e. RO filter backwash (alternate route)				Intermittent		
f. Floor drains (alternate route)				Intermittent		
Flow (MGD)	See Special Condition 1				Daily	Continuous
Total Suspended Solids			15	30	2/Month	24-Hour Composite
Oil and Grease			15	20	2/Month	Grab

Effluent Limitations and Monitoring

From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

	LOAD LIMITS lbs/day DAF (DMF)		CONCENTRATION LIMITS mg/l			
PARAMETER	30 DAY AVERAGE	DAILY MAXIMUM	30 DAY AVERAGE	DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE

Outfall D01: East Yard Collection Basin Overflow (DAF = 0.676 MGD)

This discharge consists of:	Approximate Flow
1. East yard area runoff	Intermittent
2. Units 1-4 roof and floor drainage	Intermittent
3. East yard polymer building drains	Intermittent
4. RO filter backwash	0.078 MGD
5. Laboratory sink drains	Intermittent
6. Units 5-8 roof and floor drains	Intermittent
7. Trona Mill Wash	800 gpd

PARAMETER	30 DAY AVERAGE	DAILY MAXIMUM	30 DAY AVERAGE	DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Flow (MGD)	See Special Condition 1				1/Week	24-Hour Total
Total Suspended Solids			15	30	2/Month	24-Hour Composite
Oil and Grease			15	20	2/Month	Grab

Effluent Limitations and Monitoring

From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

PARAMETER	LOAD LIMITS lbs/day DAF (DMF) 30 DAY AVERAGE	LOAD LIMITS lbs/day DAF (DMF) DAILY MAXIMUM	CONCENTRATION LIMITS mg/l 30 DAY AVERAGE	CONCENTRATION LIMITS mg/l DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Outfall F01: Unit 7 Demineralized Water Storage Tank Drain(Intermittent Discharge)						
Flow (MGD)	See Special Condition 1				1/Week When Discharging	Estimate
Total Suspended Solids			15	30	1/Week When Discharging	Grab
Oil and Grease			15	20	1/Week When Discharging	Grab

NPDES Permit No. IL0002259

Effluent Limitations and Monitoring

From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

PARAMETER	LOAD LIMITS lbs/day DAF (DMF) 30 DAY AVERAGE	LOAD LIMITS lbs/day DAF (DMF) DAILY MAXIMUM	CONCENTRATION LIMITS mg/l 30 DAY AVERAGE	CONCENTRATION LIMITS mg/l DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Outfall G01: Non-Chemical Metal Cleaning Wastes (DAF = Intermittent Discharge)						
Flow (MGD)	See Special Condition 1				Daily When Discharging	Continuous
Total Suspended Solids			30	100	Daily When Discharging	24-Hour Composite
Oil and Grease			15	20	Daily When Discharging	Grab
Iron			1.0	1.0	Daily When Discharging	24-Hour Composite
Copper			1.0	1.0	Daily When Discharging	24-Hour Composite

Special Conditions

SPECIAL CONDITION 1. Flow shall be measured in units of Million Gallons per Day (MGD) and reported as a monthly average and a daily maximum value on the monthly Discharge Monitoring Report.

SPECIAL CONDITION 2. The pH shall be in the range 7.0 to 9.0. The monthly minimum and monthly maximum values shall be reported on the DMR form.

The permittee shall achieve compliance with the above pH limitation at outfall 001 as soon as possible but not later than 18 months from the effective date of this permit in accordance with the following schedule:

	ITEM	COMPLETION DATE
1.	Initial Report	6 Months from the Effective Date
2.	Interim Report	12 Months from the Effective Date
3.	Final Report and Compliance	18 Months from the Effective Date

From the effective date of the permit, pH shall be monitored at outfall 001 weekly as specified on page 2 of the permit. The initial report shall include a summary of this data and a determination of whether or not additional treatment is necessary to achieve and maintain compliance with the applicable pH limit. If additional treatment is determined not to be necessary, compliance with the applicable pH limit is required 6 months from the effective date of this permit. All reports shall be submitted to the IEPA at the address in special condition 6.

SPECIAL CONDITION 3. All samples for total residual chlorine (TRC) shall be analyzed by an applicable method contained in 40 CFR 136, equivalent in accuracy to low-level amperometric titration. Any analytical variability of the method used shall be considered when determining the accuracy and precision of the results obtained.

SPECIAL CONDITION 4. Pursuant to Illinois Pollution Control Board Order 77-82, dated August 3, 1978 the discharge is limited to a heat rejection rate of 5301 million BTU's per hour in lieu of the standards of 35 Ill. Adm. Code 302.507. The Permittee's demonstration for the Waukegan Generating Station in accordance with Section 316(a) of the CWA was approved by the Illinois Pollution Control Board in Order PCB 78-72, -73 Consolidated dated September 21, 1978.

Compliance with this part shall be determined on a continuous basis by the following equation:

$$H = 0.0005Q_{CW}\,(T_{CW} - T_{US})$$

H	Heat Rejection Rate in million BTU's per hour.
T_{CW}	Actual condenser cooling water discharge temperature in degrees Fahrenheit from continuous temperature monitor located at the condenser outlet waterbox.
Q_{CW}	Condenser cooling water flow in gallons per minute based on the number of circulating water pumps on at the time in question. Each of Unit 7's four circulating water pumps is rated at 64,000 gpm and each of Unit 8's two circulating water pumps is rated at 110,000 gpm.
T_{US}	Intake cooling water temperature in degrees Fahrenheit from the continuous temperature monitor located at the condenser inlet waterbox.

As a condition of the continuation of the facility's 316(a) thermal variance (PCB 72-73 Consolidated, dated September 21, 1978), the permittee shall conduct the following activities and studies:

1. Within six months of the permit issuance date:
    a. Complete a literature search for biological studies conducted in Lake Michigan in the general vicinity of the facility, including but not limited to, relevant biological monitoring data from state or federal agencies.
    b. Prepare a Representative Important Species (RIS) List, including an explanation of the rationale for selection of each species on the list; and
    c. Based on the results of the biological studies literature search and the RIS List, prepare a study plan for biological sampling and thermal monitoring, including as appropriate thermal modeling. The study plan shall be submitted to the Agency for approval prior to initiation. The study plan shall include the RIS List. The permittee shall also send a copy of the study plan and RIS List to the U.S. EPA Region 5 to provide it with an opportunity to review and comment on the study plan prior to commencement of the study.
2. Upon the Agency's approval of the study plan for biological and thermal monitoring, perform thermal plume surveys on the facility's discharge and any appropriate thermal model development and field verification within eighteen months of the receipt of the Agency's approval. In the event that the Agency's approval of the study plan is not received within nine months of the permit issuance date, the permittee may proceed to implement the study plan pending receipt of the Agency's approval.
3. Based on the information obtained from thermal plume surveys, the permittee shall finalize the specific sampling locations for,

and conduct, the biological monitoring study plan.

If the permittee intends to request the continuation of the 316(a) thermal variance in its renewed NPDES permit, the permittee shall submit to the Agency a report containing the results of the biological and thermal monitoring, including any applicable thermal modeling, and any other information necessary to comply with 35 Ill. Adm. Code 106.1180 concurrent with its next NPDES permit renewal application.

Alternately, the Permittee may demonstrate to the Agency that alternate thermal standards of PCB 77-82, or other site specific water quality standards for temperature approved by the Illinois Pollution Control Board, and USEPA, meets the requirements of 40 CFR 131 and the Illinois Environmental Protection Act.

SPECIAL CONDITION 5. Samples taken in compliance with the effluent monitoring requirements shall be taken at a point representative of the discharge, but prior to entry into the receiving stream.

SPECIAL CONDITION 6. The Permittee shall record monitoring results on Discharge Monitoring Report (DMR) Forms using one such form for each outfall each month.

In the event that an outfall does not discharge during a monthly reporting period, the DMR Form shall be submitted with no discharge indicated.

The Permittee will be required to submit electronic DMRs (NetDMRs) instead of mailing paper DMRs to the IEPA beginning December 21, 2016 unless a waiver has been granted by the Agency. More information, including registration information for the NetDMR program, can be obtained on the IEPA website, http://www.epa.state.il.us/water/net-dmr/index.html.

The completed Discharge Monitoring Report forms shall be submitted to IEPA no later than the 28th day of the following month, unless otherwise specified by the permitting authority.

Permittees that have been granted a waiver shall mail Discharge Monitoring Reports with an original signature to the IEPA at the following address:

Illinois Environmental Protection Agency
Division of Water Pollution Control
Attention: Compliance Assurance Section, Mail Code # 19
1021 North Grand Avenue East
Post Office Box 19276
Springfield, Illinois 62794-9276

SPECIAL CONDITION 7. Cooling Water Intake Structure. Based on available information, the Agency has determined that the operation of the cooling water intake structure meets the equivalent of Best Technology Available (BTA) in accordance with the Best Professional Judgment provisions of 40 CFR 125.3 and 40 CFR 125.90(b), based on information available at the time of permit reissuance.

However, the Permittee shall comply with the requirements of the Cooling Water Intake Structure Existing Facilities Rule as found at 40 CFR 122 and 125. Any application materials and submissions required for compliance with the Existing Facilities Rule, shall be submitted to the Agency no later than 4 years from the effective date of this permit.

If for any reason, the Cooling Water Intake Structure Existing Facilities Rule is stayed or remanded by the courts, the Permittee shall comply with the requirements below. The information required below is necessary to further evaluate cooling water intake structure operations based on the most up to date information, in accordance with the Best Professional Judgment provisions of 40 CFR 125.3 and 40 CFR 125.90(b), in existence prior to the effective date of the new Existing Facilities Rule:

A. The permittee shall submit the following information/studies within 4 years of the effective date of the permit:

   1. Source Water Physical Data to include:

      a. A narrative description and scaled drawings showing the physical configuration of all source water bodies used by the facility including aerial dimensions, depths, salinity and temperature regimes;

      b. Identification and characterization of the source waterbody's hydrological and geomorphological features, as well as the methods used to conduct any physical studies to determine the intake's area of influence and the results of such studies; and

      c. Location maps.

   2. Source Waterbody Flow Information

The permittee shall provide the annual mean flow of the waterbody, any supporting documentation and engineering calculations to support the analysis of whether the design intake flow is greater than five percent of the mean annual flow of the river or stream for purposes of determining applicable performance standards. Representative historical data (from a period of time up to 10 years) shall be used, if available.

3. Impingement Mortality and Entrainment Characterization Study

   The permittee shall submit an Impingement Mortality and Entrainment Characterization Study whose purpose is to provide information to support the development of a calculation baseline for evaluating impingement mortality and entrainment and to characterize current impingement mortality and entrainment. The Study shall include the following in sufficient detail to support establishment of baseline conditions:

   a. Taxonomic identification of all life stages of fish and shellfish and any species protected under Federal, State, or Tribal law (including threatened or endangered species) that are in the vicinity of the cooling water intake structure(s) and are susceptible to impingement and entrainment;

   b. A characterization of all life stages of fish and shellfish, and any species protected under Federal, or State law, including a description of the abundance and temporal and spatial characteristics in the vicinity of the cooling water intake structure(s). These may include historical data that are representative of the current operation of the facility and of biological conditions at the site; and

   c. Documentation of the current impingement mortality and entrainment of all life stages of fish, shellfish, and any species protected under Federal , State, or Tribal Law (including threatened or endangered species) and an estimate of impingement mortality and entrainment to be used as the calculation baseline. The documentation may include historical data that are representative of the current operation of the facility and of biological conditions at the site. Impingement mortality and entrainment samples to support the calculations required must be collected during periods of representative operational flows for the cooling water intake structure and the flows associated with the samples must be documented.

B. The permittee shall comply with the following requirements:

1. At all times properly operate and maintain the intake equipment as demonstrated in the application material supporting the BTA determination.

2. Inform IEPA of any proposed changes to the cooling water intake structure or proposed changes to operations at the facility that affect impingement mortality and/or entrainment.

3. Debris collected on intake screens is prohibited from being discharged back to the canal. Debris does not include living fish or other living aquatic organisms.

4. Compliance Alternatives. The permittee must evaluate each of the following alternatives for establishing best available technology for minimizing adverse environmental impacts at the facility due to operation of the intake structure:

   a. Evaluate operational procedures and/or propose facility modifications to reduce the intake through-screen velocity to less than 0.5 ft/sec. The operational evaluation may consider modified circulating water pump operation; reduced flow associated with capacity utilization, recalculation or determination of actual total water withdrawal capacity. The evaluation report and any implementation plan for the operational changes and/ or facility modification shall be submitted to the Agency with the renewal application for this permit.

   b. Complete a fish impingement and entrainment mortality minimization alternatives evaluation. The evaluation may include an assessment of modification of the traveling screens, consideration of a separate fish and debris return system and include time frames and cost analysis to implement these measures. The evaluation report and implementation plan for any operational changes and/ or facility modifications shall be submitted to the Agency with the renewal application for this permit.

C. All required reports shall be submitted to the Industrial Unit, Permit Section and Compliance Assurance Section at the address in special condition 6.

This special condition does not relieve the permittee of the responsibility of complying with any other laws, regulations, or judicial orders issued pursuant to Section 316(b) of the Clean Water Act.

SPECIAL CONDITION 8. If an applicable effluent standard or limitation is promulgated under Sections 301(b)(2)(C) and (D), 304(b)(2), and 307(a)(2) of the Clean Water Act and that effluent standard or limitation is more stringent than any effluent limitation in the permit or controls a pollutant not limited in the NPDES Permit, the Agency shall revise or modify the permit in accordance with the more stringent standard or prohibition and shall so notify the permittee.

SPECIAL CONDITION 9. The use or operation of this facility shall be by or under the supervision of a Certified Class K operator.

SPECIAL CONDITION 10. In the event that the permittee shall require changes in the use of water treatment additives, the permittee must request a change in this permit in accordance with the Standard Conditions -- Attachment H.

SPECIAL CONDITION 11. The cooling water prior to entering the intake structure and at outfall 001 shall be sampled once per week as a grab sample at the same time of day within ½ hour of each other between 9:00 a.m. and 3:00 p.m. in a random fashion for dissolved oxygen. The results in mg/l and the time of day the influent and effluent sample was taken shall be reported to the Agency as an attachment to the DMR. After 2 years of data has been submitted to the Agency, the permittee may apply to Agency to have the monitoring reduced or eliminated.

SPECIAL CONDITION 12. There shall be no discharge of polychlorinated biphenyl compounds.

SPECIAL CONDITION 13. The bypass provisions of 40 CFR 122.41(m) and upset provisions of 40 CFR 122.41(n) are hereby incorporated by reference.

SPECIAL CONDITION 14. The Agency has determined that the effluent limitations for outfall 001 constitute BAT/BCT for storm water which is treated in the existing treatment facilities for purposes of this permit reissuance, and no pollution prevention plan will be required for such storm water. In addition to the chemical specific monitoring required elsewhere in this permit, the permittee shall conduct an annual inspection of the facility site to identify areas contributing to a storm water discharge associated with industrial activity, and determine whether any facility modifications have occurred which result in previously-treated storm water discharges no longer receiving treatment. If any such discharges are identified the permittee shall request a modification of this permit within 30 days after the inspection. Records of the annual inspection shall be retained by the permittee for the term of this permit and be made available to the Agency on request.

SPECIAL CONDITION 15. There shall be no discharge of complexed metal bearing wastestreams and associated rinses from chemical metal cleaning unless this permit has been modified to include the new discharge.

SPECIAL CONDITION 16. The Permittee shall monitor the effluent from outfall 001 for the following parameters on a semi-annual basis. This Permit may be modified with public notice to establish effluent limitations if appropriate, based on information obtained through sampling. The sample shall be a 24-hour effluent composite except as otherwise specifically provided below and the results shall be submitted to the address in special condition 6 in June and December. The parameters to be sampled and the minimum reporting limits to be attained are as follows:

STORET CODE	PARAMETER	Minimum reporting limit
01002	Arsenic	0.05 mg/L
01007	Barium	0.5 mg/L
01022	Boron	0.1 mg/L
01027	Cadmium	0.001 mg/L
00940	Chloride	1.0 mg/L
01032	Chromium (hexavalent) (grab)	0.01 mg/L
01034	Chromium (total)	0.05 mg/L
01042	Copper	0.005 mg/L
00718	Cyanide (grab) (available *** or amendable to chlorination))	5.0 ug/L
00720	Cyanide (grab not to exceed 24 hours) (total)	5.0 ug/L
00951	Fluoride	0.1 mg/L
01045	Iron (total)	0.5 mg/L
01046	Iron (Dissolved)	0.5 mg/L
01051	Lead	0.05 mg/L
01055	Manganese	0.5 mg/L
71900	Mercury (grab)**	1.0 ng/L*
01067	Nickel	0.005 mg/L
00556	Oil (hexane soluble or equivalent) (Grab Sample only)	5.0 mg/L
32730	Phenols (grab)	0.005 mg/L
01147	Selenium	0.005 mg/L
00945	Sulfate	10 mg/L
01077	Silver (total)	0.003 mg/L
01092	Zinc	0.025 mg/L

Special Conditions

Unless otherwise indicated, concentrations refer to the total amount of the constituent present in all phases, whether solid, suspended or dissolved, elemental or combined, including all oxidation states.

*1.0 ng/L = 1 part per trillion.
**Utilize USEPA Method 1631E and the digestion procedure described in Section 11.1.1.2 of 1631E. Mercury shall be monitored monthly for the first two years and quarterly thereafter. This Permit may be modified with public notice to establish effluent limitations if appropriate, based on information obtained through sampling. The quarterly monitoring results shall be submitted on the March, June, September and December DMRs.
***USEPA Method OIA-1677

SPECIAL CONDITION 17. The effluent, alone or in combination with other sources, shall not cause a violation of any applicable water quality standard outlined in 35 Ill. Adm. Code 302.

Attachment H
Standard Conditions

Definitions

Act means the Illinois Environmental Protection Act, 415 ILCS 5 as Amended.

Agency means the Illinois Environmental Protection Agency.

Board means the Illinois Pollution Control Board.

Clean Water Act (formerly referred to as the Federal Water Pollution Control Act) means Pub. L 92-500, as amended. 33 U.S.C. 1251 et seq.

NPDES (National Pollutant Discharge Elimination System) means the national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 402, 318 and 405 of the Clean Water Act.

USEPA means the United States Environmental Protection Agency.

Daily Discharge means the discharge of a pollutant measured during a calendar day or any 24-hour period that reasonably represents the calendar day for purposes of sampling. For pollutants with limitations expressed in units of mass, the "daily discharge" is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurements, the "daily discharge" is calculated as the average measurement of the pollutant over the day.

Maximum Daily Discharge Limitation (daily maximum) means the highest allowable daily discharge.

Average Monthly Discharge Limitation (30 day average) means the highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month.

Average Weekly Discharge Limitation (7 day average) means the highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges measured during that week.

Best Management Practices (BMPs) means schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the State. BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Aliquot means a sample of specified volume used to make up a total composite sample.

Grab Sample means an individual sample of at least 100 milliliters collected at a randomly-selected time over a period not exceeding 15 minutes.

24-Hour Composite Sample means a combination of at least 8 sample aliquots of at least 100 milliliters, collected at periodic intervals during the operating hours of a facility over a 24-hour period.

8-Hour Composite Sample means a combination of at least 3 sample aliquots of at least 100 milliliters, collected at periodic intervals during the operating hours of a facility over an 8-hour period.

Flow Proportional Composite Sample means a combination of sample aliquots of at least 100 milliliters collected at periodic intervals such that either the time interval between each aliquot or the volume of each aliquot is proportional to either the stream flow at the time of sampling or the total stream flow since the collection of the previous aliquot.

(1) **Duty to comply.** The permittee must comply with all conditions of this permit. Any permit noncompliance constitutes a violation of the Act and is grounds for enforcement action, permit termination, revocation and reissuance, modification, or for denial of a permit renewal application. The permittee shall comply with effluent standards or prohibitions established under Section 307(a) of the Clean Water Act for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirements.

(2) **Duty to reapply.** If the permittee wishes to continue an activity regulated by this permit after the expiration date of this permit, the permittee must apply for and obtain a new permit. If the permittee submits a proper application as required by the Agency no later than 180 days prior to the expiration date, this permit shall continue in full force and effect until the final Agency decision on the application has been made.

(3) **Need to halt or reduce activity not a defense.** It shall not be a defense for a permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of this permit.

(4) **Duty to mitigate.** The permittee shall take all reasonable steps to minimize or prevent any discharge in violation of this permit which has a reasonable likelihood of adversely affecting human health or the environment.

(5) **Proper operation and maintenance.** The permittee shall at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used by the permittee to achieve compliance with conditions of this permit. Proper operation and maintenance includes effective performance, adequate funding, adequate operator staffing and training, and adequate laboratory and process controls, including appropriate quality assurance procedures. This provision requires the operation of back-up, or auxiliary facilities, or similar systems only when necessary to achieve compliance with the conditions of the permit.

(6) **Permit actions.** This permit may be modified, revoked and reissued, or terminated for cause by the Agency pursuant to 40 CFR 122.62 and 40 CFR 122.63. The filing of a request by the permittee for a permit modification, revocation and reissuance, or termination, or a notification of planned changes or anticipated noncompliance, does not stay any permit condition.

(7) **Property rights.** This permit does not convey any property rights of any sort, or any exclusive privilege.

(8) **Duty to provide information.** The permittee shall furnish to the Agency within a reasonable time, any information which the Agency may request to determine whether cause exists for modifying, revoking and reissuing, or terminating this permit, or to determine compliance with the permit. The permittee shall also furnish to the Agency upon request, copies of records required to be kept by this permit.

(9) **Inspection and entry.** The permittee shall allow an authorized representative of the Agency or USEPA (including an authorized contractor acting as a representative of the Agency or USEPA), upon the presentation of credentials and other documents as may be required by law, to:
- (a) Enter upon the permittee's premises where a regulated facility or activity is located or conducted, or where records must be kept under the conditions of this permit;
- (b) Have access to and copy, at reasonable times, any records that must be kept under the conditions of this permit;
- (c) Inspect at reasonable times any facilities, equipment (including monitoring and control equipment), practices, or operations regulated or required under this permit; and
- (d) Sample or monitor at reasonable times, for the purpose of assuring permit compliance, or as otherwise authorized by the Act, any substances or parameters at any location.

(10) **Monitoring and records.**
- (a) Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity.
- (b) The permittee shall retain records of all monitoring information, including all calibration and maintenance records, and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for this permit, for a period of at least 3 years from the date of this permit, measurement, report or application. Records related to the permittee's sewage sludge use and disposal activities shall be retained for a period of at least five years (or longer as required by 40 CFR Part 503). This period may be extended by request of the Agency or USEPA at any time.
- (c) Records of monitoring information shall include:
  - (1) The date, exact place, and time of sampling or measurements;
  - (2) The individual(s) who performed the sampling or measurements;
  - (3) The date(s) analyses were performed;
  - (4) The individual(s) who performed the analyses;
  - (5) The analytical techniques or methods used; and
  - (6) The results of such analyses.
- (d) Monitoring must be conducted according to test procedures approved under 40 CFR Part 136, unless other test procedures have been specified in this permit. Where no test procedure under 40 CFR Part 136 has been approved, the permittee must submit to the Agency a test method for approval. The permittee shall calibrate and perform maintenance procedures on all monitoring and analytical instrumentation at intervals to ensure accuracy of measurements.

(11) **Signatory requirement.** All applications, reports or information submitted to the Agency shall be signed and certified.
- (a) **Application.** All permit applications shall be signed as follows:
  - (1) For a corporation: by a principal executive officer of at least the level of vice president or a person or position having overall responsibility for environmental matters for the corporation:
  - (2) For a partnership or sole proprietorship: by a general partner or the proprietor, respectively; or
  - (3) For a municipality, State, Federal, or other public agency: by either a principal executive officer or ranking elected official.
- (b) **Reports.** All reports required by permits, or other information requested by the Agency shall be signed by a person described in paragraph (a) or by a duly authorized representative of that person. A person is a duly authorized representative only if:
  - (1) The authorization is made in writing by a person described in paragraph (a); and
  - (2) The authorization specifies either an individual or a position responsible for the overall operation of the facility, from which the discharge originates, such as a plant manager, superintendent or person of equivalent responsibility; and
  - (3) The written authorization is submitted to the Agency.
- (c) **Changes of Authorization.** If an authorization under (b) is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, a new authorization satisfying the requirements of (b) must be submitted to the Agency prior to or together with any reports, information, or applications to be signed by an authorized representative.
- (d) **Certification.** Any person signing a document under paragraph (a) or (b) of this section shall make the following certification:

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

(12) **Reporting requirements.**
- (a) **Planned changes.** The permittee shall give notice to the Agency as soon as possible of any planned physical alterations or additions to the permitted facility.
  Notice is required when:
  - (1) The alteration or addition to a permitted facility may meet one of the criteria for determining whether a facility is a new source pursuant to 40 CFR 122.29 (b); or
  - (2) The alteration or addition could significantly change the nature or increase the quantity of pollutants discharged. This notification applies to pollutants which are subject neither to effluent limitations in the permit, nor to notification requirements pursuant to 40 CFR 122.42 (a)(1).
  - (3) The alteration or addition results in a significant change in the permittee's sludge use or disposal practices, and such alteration, addition, or change may justify the application of permit conditions that are different from or absent in the existing permit, including notification of additional use or disposal sites not reported during the permit application process or not reported pursuant to an approved land application plan.
- (b) **Anticipated noncompliance.** The permittee shall give advance notice to the Agency of any planned changes in the permitted facility or activity which may result in noncompliance with permit requirements.
- (c) **Transfers.** This permit is not transferable to any person except after notice to the Agency.
- (d) **Compliance schedules.** Reports of compliance or noncompliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of this permit shall be submitted no later than 14 days following each schedule date.

(e) **Monitoring reports.** Monitoring results shall be reported at the intervals specified elsewhere in this permit.
  (1) Monitoring results must be reported on a Discharge Monitoring Report (DMR).
  (2) If the permittee monitors any pollutant more frequently than required by the permit, using test procedures approved under 40 CFR 136 or as specified in the permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the DMR.
  (3) Calculations for all limitations which require averaging of measurements shall utilize an arithmetic mean unless otherwise specified by the Agency in the permit.

(f) **Twenty-four hour reporting.** The permittee shall report any noncompliance which may endanger health or the environment. Any information shall be provided orally within 24-hours from the time the permittee becomes aware of the circumstances. A written submission shall also be provided within 5 days of the time the permittee becomes aware of the circumstances. The written submission shall contain a description of the noncompliance and its cause; the period of noncompliance, including exact dates and time; and if the noncompliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the noncompliance. The following shall be included as information which must be reported within 24-hours:
  (1) Any unanticipated bypass which exceeds any effluent limitation in the permit.
  (2) Any upset which exceeds any effluent limitation in the permit.
  (3) Violation of a maximum daily discharge limitation for any of the pollutants listed by the Agency in the permit or any pollutant which may endanger health or the environment.

  The Agency may waive the written report on a case-by-case basis if the oral report has been received within 24-hours.

(g) **Other noncompliance.** The permittee shall report all instances of noncompliance not reported under paragraphs (12) (d), (e), or (f), at the time monitoring reports are submitted. The reports shall contain the information listed in paragraph (12) (f).

(h) **Other information.** Where the permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application, or in any report to the Agency, it shall promptly submit such facts or information.

(13) **Bypass.**

(a) Definitions.
  (1) Bypass means the intentional diversion of waste streams from any portion of a treatment facility.
  (2) Severe property damage means substantial physical damage to property, damage to the treatment facilities which causes them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss caused by delays in production.

(b) Bypass not exceeding limitations. The permittee may allow any bypass to occur which does not cause effluent limitations to be exceeded, but only if it also is for essential maintenance to assure efficient operation. These bypasses are not subject to the provisions of paragraphs (13)(c) and (13)(d).

(c) Notice.
  (1) Anticipated bypass. If the permittee knows in advance of the need for a bypass, it shall submit prior notice, if possible at least ten days before the date of the bypass.
  (2) Unanticipated bypass. The permittee shall submit notice of an unanticipated bypass as required in paragraph (12)(f) (24-hour notice).

(d) Prohibition of bypass.
  (1) Bypass is prohibited, and the Agency may take enforcement action against a permittee for bypass, unless:
    (i) Bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;
    (ii) There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if adequate back-up equipment should have been installed in the exercise of reasonable engineering judgment to prevent a bypass which occurred during normal periods of equipment downtime or preventive maintenance; and
    (iii) The permittee submitted notices as required under paragraph (13)(c).
  (2) The Agency may approve an anticipated bypass, after considering its adverse effects, if the Agency determines that it will meet the three conditions listed above in paragraph (13)(d)(1).

(14) **Upset.**

(a) Definition. Upset means an exceptional incident in which there is unintentional and temporary noncompliance with technology based permit effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

(b) Effect of an upset. An upset constitutes an affirmative defense to an action brought for noncompliance with such technology based permit effluent limitations if the requirements of paragraph (14)(c) are met. No determination made during administrative review of claims that noncompliance was caused by upset, and before an action for noncompliance, is final administrative action subject to judicial review.

(c) Conditions necessary for a demonstration of upset. A permittee who wishes to establish the affirmative defense of upset shall demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:
  (1) An upset occurred and that the permittee can identify the cause(s) of the upset;
  (2) The permitted facility was at the time being properly operated; and
  (3) The permittee submitted notice of the upset as required in paragraph (12)(f)(2) (24-hour notice).
  (4) The permittee complied with any remedial measures required under paragraph (4).

(d) Burden of proof. In any enforcement proceeding the permittee seeking to establish the occurrence of an upset has the burden of proof.

(15) **Transfer of permits.** Permits may be transferred by modification or automatic transfer as described below:
   (a) Transfers by modification. Except as provided in paragraph (b), a permit may be transferred by the permittee to a new owner or operator only if the permit has been modified or revoked and reissued pursuant to 40 CFR 122.62 (b) (2), or a minor modification made pursuant to 40 CFR 122.63 (d), to identify the new permittee and incorporate such other requirements as may be necessary under the Clean Water Act.
   (b) Automatic transfers. As an alternative to transfers under paragraph (a), any NPDES permit may be automatically transferred to a new permittee if:
      (1) The current permittee notifies the Agency at least 30 days in advance of the proposed transfer date;
      (2) The notice includes a written agreement between the existing and new permittees containing a specified date for transfer of permit responsibility, coverage and liability between the existing and new permittees; and
      (3) The Agency does not notify the existing permittee and the proposed new permittee of its intent to modify or revoke and reissue the permit. If this notice is not received, the transfer is effective on the date specified in the agreement.

(16) All manufacturing, commercial, mining, and silvicultural dischargers must notify the Agency as soon as they know or have reason to believe:
   (a) That any activity has occurred or will occur which would result in the discharge of any toxic pollutant identified under Section 307 of the Clean Water Act which is not limited in the permit, if that discharge will exceed the highest of the following notification levels:
      (1) One hundred micrograms per liter (100 ug/l);
      (2) Two hundred micrograms per liter (200 ug/l) for acrolein and acrylonitrile; five hundred micrograms per liter (500 ug/l) for 2,4-dinitrophenol and for 2-methyl-4,6 dinitrophenol; and one milligram per liter (1 mg/l) for antimony.
      (3) Five (5) times the maximum concentration value reported for that pollutant in the NPDES permit application; or
      (4) The level established by the Agency in this permit.
   (b) That they have begun or expect to begin to use or manufacture as an intermediate or final product or byproduct any toxic pollutant which was not reported in the NPDES permit application.

(17) All Publicly Owned Treatment Works (POTWs) must provide adequate notice to the Agency of the following:
   (a) Any new introduction of pollutants into that POTW from an indirect discharge which would be subject to Sections 301 or 306 of the Clean Water Act if it were directly discharging those pollutants; and
   (b) Any substantial change in the volume or character of pollutants being introduced into that POTW by a source introducing pollutants into the POTW at the time of issuance of the permit.
   (c) For purposes of this paragraph, adequate notice shall include information on (i) the quality and quantity of effluent introduced into the POTW, and (ii) any anticipated impact of the change on the quantity or quality of effluent to be discharged from the POTW.

(18) If the permit is issued to a publicly owned or publicly regulated treatment works, the permittee shall require any industrial user of such treatment works to comply with federal requirements concerning:
   (a) User charges pursuant to Section 204 (b) of the Clean Water Act, and applicable regulations appearing in 40 CFR 35;
   (b) Toxic pollutant effluent standards and pretreatment standards pursuant to Section 307 of the Clean Water Act; and
   (c) Inspection, monitoring and entry pursuant to Section 308 of the Clean Water Act.

(19) If an applicable standard or limitation is promulgated under Section 301(b)(2)(C) and (D), 304(b)(2), or 307(a)(2) and that effluent standard or limitation is more stringent than any effluent limitation in the permit, or controls a pollutant not limited in the permit, the permit shall be promptly modified or revoked, and reissued to conform to that effluent standard or limitation.

(20) Any authorization to construct issued to the permittee pursuant to 35 Ill. Adm. Code 309.154 is hereby incorporated by reference as a condition of this permit.

(21) The permittee shall not make any false statement, representation or certification in any application, record, report, plan or other document submitted to the Agency or the USEPA, or required to be maintained under this permit.

(22) The Clean Water Act provides that any person who violates a permit condition implementing Sections 301, 302, 306, 307, 308, 318, or 405 of the Clean Water Act is subject to a civil penalty not to exceed $25,000 per day of such violation. Any person who willfully or negligently violates permit conditions implementing Sections 301, 302, 306, 307, 308, 318 or 405 of the Clean Water Act is subject to a fine of not less than $2,500 nor more than $25,000 per day of violation, or by imprisonment for not more than one year, or both.
Additional penalties for violating these sections of the Clean Water Act are identified in 40 CFR 122.41 (a)(2) and (3).

(23) The Clean Water Act provides that any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000, or by imprisonment for not more than 2 years, or both. If a conviction of a person is for a violation committed after a first conviction of such person under this paragraph, punishment is a fine of not more than $20,000 per day of violation, or by imprisonment of not more than 4 years, or both.

(24) The Clean Water Act provides that any person who knowingly makes any false statement, representation, or certification in any record or other document submitted or required to be maintained under this permit, including monitoring reports or reports of compliance or non-compliance shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 6 months per violation, or by both.

(25) Collected screening, slurries, sludges, and other solids shall be disposed of in such a manner as to prevent entry of those wastes (or runoff from the wastes) into waters of the State. The proper authorization for such disposal shall be obtained from the Agency and is incorporated as part hereof by reference.

(26) In case of conflict between these standard conditions and any other condition(s) included in this permit, the other condition(s) shall govern.

(27) The permittee shall comply with, in addition to the requirements of the permit, all applicable provisions of 35 Ill. Adm. Code, Subtitle C, Subtitle D, Subtitle E, and all applicable orders of the Board or any court with jurisdiction.

(28) The provisions of this permit are severable, and if any provision of this permit, or the application of any provision of this permit is held invalid, the remaining provisions of this permit shall continue in full force and effect.

United States
Environmental Protection Agency

Office of Enforcement and
Compliance Assurance

September 2015

Final NPDES Electronic Reporting Rule

On 24 September 2015, Administrator Gina McCarthy signed the final National Pollutant Discharge Elimination System (NPDES) Electronic Reporting Rule for publication in the Federal Register. The publication of this rule is the latest step in an extensive multi-year outreach effort with EPA's state, tribal and territorial partners. This rule will replace most paper-based Clean Water Act (CWA) NPDES permitting and compliance monitoring reporting requirements with electronic reporting.

Purpose of the Final Rule

This final rule is designed to save authorized state, tribe, or territorial NPDES programs considerable resources, make reporting easier for NPDES-regulated entities, streamline permit renewals, ensure full exchange of basic NPDES permit data between states and EPA, improve environmental decision-making, and better protect human health and the environment.

This final rule requires that NPDES regulated entities electronically submit the following permit and compliance monitoring information instead of using paper reports:

- Discharge Monitoring Reports (DMRs);
- Notices of Intent to discharge in compliance with a general permit; and
- Program reports.

Authorized NPDES programs will also electronically submit NPDES program data to EPA to ensure that there is consistent and complete reporting nationwide, and to expedite the collection and processing of the data, thereby making it more accurate and timely. Importantly, while the rule changes the method by which information is provided (i.e., electronic rather than paper-based), it does not increase the amount of information required from NPDES regulated entities facilities under existing regulations.

Overview of Benefits

EPA anticipates that the final rule will save significant resources for states, tribes, and territories as well as EPA and NPDES permittees, while resulting in a more complete, accurate, and nationally-consistent set of data about the NPDES program. With full implementation (5 years after the effective date), the anticipated savings are:

- Authorized State NPDES programs: $22.6 million annually,
- NPDES regulated entities: $0.5 million annually, and
- EPA: $1.2 million annually.

As an example demonstrating the benefits of electronic reporting is the State of Ohio's electronic reporting program for Discharge Monitoring Reports, which has a 99.9 percent adoption rate. This program has increased data quality and improved environmental protection, while also saving significant time and resources (e.g., Ohio was able to shift resources from five full-time staff to less than one to support the DMR program). The benefits of this final rule should allow NPDES-authorized programs in states, tribes, and territories to shift precious resources from data management activities to those more targeted to solving water quality issues.

Separate from this rulemaking, to promote transparency and accountability, EPA intends to make this more complete set of data available to the public, providing communities and citizens with information on facility and government performance. This can serve to elevate the importance of permitting and compliance information and environmental performance within regulated entities, providing opportunities for them to quickly address any potential environmental problems.

The final rule will also lighten the reporting burden currently placed on the states. Upon successful implementation, the final rule would provide states with regulatory relief from reporting associated with the Quarterly Non-Compliance Report, the Annual Non-Compliance Report, the Semi-Annual Statistical Summary Report, and the biosolids information required to be submitted to EPA annually by states.

Implementation

EPA will phase in the requirements of the rule over a five year period following the effective date of the final rule.

Phase 1 – One year after effective date of final rule

In Phase 1, EPA will begin to electronically receive information from authorized states, tribes, and territories regarding inspections, violation determinations, and enforcement actions. EPA, states, tribes, and territories will electronically receive Discharge Monitoring Report (DMR) information from NPDES permittees – the largest volume of data for the NPDES program. Also included in Phase 1 are the Sewage Sludge/Biosolids Annual Program Reports for the 42 states where EPA implements the Federal Biosolids Program.

Additionally, one year after the effective date of the final rule, authorized NPDES programs will submit an implementation plan for meeting the Phase 2 data requirements for EPA to review.

Phase 2—Five years after effective date of final rule

For Phase 2, EPA and authorized state NPDES programs have five years to begin electronically collecting, managing, and sharing the remaining set of NPDES program information. This information includes: general permit reports (e.g. Notice of Intent to be covered (NOI); Notice of Termination (NOT); No Exposure Certification (NOE); Low Erosivity Waiver and Other Waivers from Stormwater Controls (LEW)); Sewage Sludge/Biosolids Annual Program Report (where the state is the authorized NPDES biosolids program); and all other remaining NPDES program reports. These program reports include:

- Sewage Sludge/Biosolids Annual Program Reports [40 CFR 503] (for the 8 states that implement the Federal Biosolids Program)
- Concentrated Animal Feeding Operation (CAFO) Annual Program Reports [40 CFR 122.42(e)(4)]
- Municipal Separate Storm Sewer System (MS4) Program Reports [40 CFR 122.34(g)(3) and 122.42(c)]
- Pretreatment Program Reports [40 CFR 403.12(i)]
- Significant Industrial User Compliance Reports in Municipalities Without Approved Pretreatment Programs [40 CFR 403.12(e) and (h)]
- Sewer Overflow/Bypass Event Reports [40 CFR 122.41(l)(4), (l)(6) and (7), (m)(3)]
- CWA Section 316(b) Annual Reports [40 CFR 125 Subpart J]

How the final rule addresses comments

In response to concerns about implementation raised during the comment periods, the final rule provides authorized NPDES programs more flexibility to implement the final rule by providing them up to three additional years to electronically collect, manage, and share their data. Authorized NDPES Programs will also have more flexibility in how they can grant electronic reporting waivers.

Further Information

For additional information, please contact Messrs. John Dombrowski, Director, Enforcement Targeting and Data Division (202-566-0742) or Carey A. Johnston (202-566-1014), Office of Compliance (mail code 2222A), Environmental Protection Agency, 1200 Pennsylvania Avenue, N.W., Washington, DC, 20460; e-mail addresses: dombrowkski.john@epa.gov or johnston.carey@epa.gov.

Useful Final Rule Link:

Email sign up for outreach events
https://public.govdelivery.com/accounts/USAEPAOECA/subscriber/new?

EXHIBIT 11

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
WATER POLLUTION CONTROL PERMIT

LOG NUMBERS: 2016-61340

PERMIT NO.: 2016-EB-61340

FINAL PLANS, SPECIFICATIONS, APPLICATION AND SUPPORTING DOCUMENTS
PREPARED BY: Geosyntec Consultants, Inc.

DATE ISSUED: August 17, 2016

SUBJECT: MIDWEST GENERATION, LLC – Waukegan Generating Station – East and West Ash Basins – Discharge Tributary to Lake Michigan

PERMITTEE TO CONSTRUCT AND OPERATE

Midwest Generation, LLC
401 E. Greenwood Avenue
Waukegan, IL 60087

Permit is hereby granted to the above designated permittee(s) to construct and operate water pollution control facilities described as follows:

The crest of the eastern embankment of the East Ash Basin will be lowered 2 feet and the downstream slope will be flattened to a maximum inclination of 2:1 (horizontal: vertical). The West Ash Basin will not be modified.

This operating permit expires on July 31, 2021.

This Permit is issued subject to the following Special Condition(s). If such Special Condition(s) require(s) additional or revised facilities, satisfactory engineering plan documents must be submitted to this Agency for review and approval for issuance of a Supplemental Permit.

SPECIAL CONDITION 1: The Permittee to Construct shall be responsible for obtaining an NPDES Storm Water Permit prior to initiating construction if the construction activities associated with this project will result in the disturbance of one (1) or more acres total land area.

An NPDES Storm Water Permit may be obtained by submitting a properly completed Notice of Intent (NOI) form by certified mail to the Agency's Division of Water Pollution Control Permit Section.")

SPECIAL CONDITION 2: The discharge from East and West Ash Basin shall be governed by NPDES Permit No. IL0002259.

SPECIAL CONDITION 3: The applicant shall replace all monitoring wells damaged or destroyed during the permitted impoundment modification activities such that:

1) Replacement monitoring well(s) shall be located as close to the original location as practical;
2) Replacement monitoring well(s) shall use the same well configuration (e.g. casing, screen length and depth, sand pack, seals etc.) as the replaced monitoring well(s);

THE STANDARD CONDITIONS OF ISSUANCE INDICATED ON THE REVERSE SIDE MUST BE COMPLIED WITH IN FULL. READ ALL CONDITIONS CAREFULLY.

SAK:JAR:2016-61340

DIVISION OF WATER POLLUTION CONTROL

Alan Keller by DEL

Alan Keller, P.E.
Manager, Permit Section

cc: EPA-Des Plaines FOS
Geosyntec Consultants, Inc.
Records - Industrial

3) Replacement monitoring wells shall be installed within 30 days of completing impoundment modifications;
4) Replacement monitoring well(s) shall be constructed in compliance with the Illinois Water Well Construction Code (77 Ill. Adm. Code 920.170).

SPECIAL CONDITION 4: The applicant shall sample each monitoring well at the Waukegan Station for the constituents listed in 35 Ill. Adm. Code 620.410(a), with the exception of perchlorate, and the addition of field pH and static water elevation.

1) The applicant shall report the analytical results and field measurements to the Agency quarterly.
2) Two copies of the quarterly reports shall be submitted to:

Groundwater Section
Illinois Environmental Protection Agency
Division of Public Water Supplies
MC#13
1021 North Grand Avenue East
Springfield, Illinois 62794-9276

EXHIBIT 12

ENVIRONMENTAL CONSULTATION & REMEDIATION

K P R G

KPRG and Associates, inc.

14665 West Lisbon Road, Suite 1A Brookfield, Wisconsin 53005 Telephone 262-781-0475 Facsimile 262-781-0478

414 Plaza Drive, Suite 106 Westmont, Illinois 60559 Telephone 630-325-1300 Facsimile 630-325-1593

GROUNDWATER CONTOUR MAP 11/2020

WAUKEGAN STATION
WAUKEGAN, ILLINOIS

Scale: 1" = 500'

Date: December 30, 2020

KPRG Project No. 12313.2

FIGURE 3

\Common\Projects\Midwest Generation\12313 Ash Pond Groundwater\Figures\Waukegan\CCR 2020

EXHIBIT 13

November 30, 2020

Andrew Wheeler
Administrator
US EPA
One Potomac Yard
2777 S. Crystal Drive
Arlington, Virginia 22202-3553

RE: Waukegan Generating Station, Midwest Generation, LLC
Alternate Closure Demonstration, 40 CFR Part 257.103

Administrator Wheeler,

The purpose of this correspondence is to submit to the United States Environmental Protection Agency (USEPA) a Demonstration for a Site-Specific Alternative Deadline to Initiate Closure documentation for the Waukegan Generating Station, located at 401 East Greenwood Avenue, Waukegan, Illinois 60087. Waukegan Generating Station (the Station) is owned and operated by Midwest Generation, LLC (MWG).

The Station is subject to 40 CFR Part 257 Subpart D "The Federal CCR Rule", effective April 17, 2015 and subsequent amendments including ***Hazardous and Solid Waste Management System: Disposal of Coal Combustion Residuals from Electric Utilities: A Holistic Approach to Closure Part A: Deadline to Initiate Closure, effective September 28, 2020***. The facility's East Ash Pond currently does not meet the liner design criteria as promulgated by 40 CFR Part 257.71 and by rule the Station must cease placing the CCR and non-CCR wastestreams currently sent to the East Ash Pond and initiate closure as soon as technically feasible but no later than April 11, 2021, unless an alternative closure timeline is granted by the EPA in accordance with 40 CFR 257.103 based on a Site-Specific Demonstration for No Alternative Disposal Capacity.

MWG has concluded that no alternative disposal capacity is available and that it is technically infeasible to obtain alternative disposal capacity for these wastestreams on- or off-site by April 11, 2021. Accordingly, pursuant to 40 CFR 257.103(f)(1)(iv)(A), MWG has prepared the following demonstration and workplan detailing its proposed development of alternative disposal capacity and a timeline to replace the East Ash Pond.

We look forward to working with the USEPA on this request and proceeding with our project to establish alternative capacity. Please contact me at (302)-540-0327 or david.bacher@nrgenergy.com to address any questions or concerns regarding this submittal.

Sincerely,

David Bacher
Senior Regional Manager
Environmental Business, NRG Energy, Inc.
29416 Power Plant Road
Dagsboro, Delaware 19939

CC: Kirsten Hillyer (US EPA), Frank Behan (USEPA), Richard Huggins (USEPA)
W. Stone (NRG), S. Shealey (MWG), W. Shander (MWG)

MWG

Midwest Generation, LLC
Waukegan Generating Station

Demonstration for a Site-Specific Alternative Deadline to Initiate Closure

Report SL-015556
Revision 0
November 30, 2020
Issue Purpose: Use
Project No.: 12661-098

55 East Monroe Street
Chicago, IL 60603-5780 USA
312-269-2000
www.sargentlundy.com

Sargent & Lundy

LEGAL NOTICE

This workplan was prepared by Sargent & Lundy, L.L.C. (S&L) expressly for the sole use of Midwest Generation, LLC (Client) in accordance with the contract agreement between S&L and Client. This workplan was prepared using the degree of skill and care ordinarily exercised by engineers practicing under similar circumstances. Client acknowledges: (1) S&L prepared this workplan subject to the particular scope limitations, budgetary and time constraints, and business objectives of Client; (2) information and data provided by others, including Client, may not have been independently verified by S&L; and (3) the information and data contained in this workplan are time-sensitive and changes in the data, applicable codes, standards, and acceptable engineering practices may invalidate the findings of this workplan. Any use or reliance upon this workplan by third parties shall be at their sole risk.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The East Ash Pond and West Ash Pond at the Waukegan Generating Station (“Waukegan” or the “Station”) in Waukegan, Illinois do not meet the liner design criteria promulgated by 40 CFR Part 257 Subpart D (“the EPA CCR Rule”). Therefore, Waukegan must cease placing CCR and non-CCR wastestreams into the East and West Ash Ponds as soon as technically feasible but no later than April 11, 2021, unless an alternative deadline is granted by the EPA in accordance with 40 CFR 257.103. Because the Station does not need to have both of its CCR surface impoundments in service to generate power – and pursuant to the revised EPA CCR Rule – Waukegan will not send CCR or non-CCR wastestreams to the West Ash Pond after April 11, 2021 and does not plan on sending any wastestreams to that basin in the interim. However, after evaluating several on- and off-site alternative disposal solutions for the wastestreams currently being sent to the East Ash Pond – both permanent and temporary – Midwest Generation, LLC (MWG), the operator of the Station, has concluded that no alternative disposal capacity is available for these wastestreams, and that it is technically infeasible to obtain alternative disposal capacity for these wastestreams on- or off-site by April 11, 2021. Accordingly, pursuant to 40 CFR 257.103(f)(1)(iv)(A), MWG has prepared the following workplan detailing its proposed development of alternative disposal capacity to replace the East Ash Pond.

Waukegan currently sends the following CCR and non-CCR wastestreams to the East Ash Pond: Unit 7 and 8 ash sluice water (CCR), overflow from the Unit 7 Ash Sluice Overflow Tank (CCR), overflow from the Station’s Coal Yard Runoff Basin (non-CCR), and effluent from the Station’s Main Collection Tank (non-CCR). After evaluating several options for providing alternative disposal capacity to the East Ash Pond for these waste streams, MWG elected to install a multiple technology system: install a remote SSC for Waukegan’s CCR wastestreams and construct a new Low Volume Waste Pond for the Station’s non-CCR wastestreams that are currently being managed by the East Ash Pond. This multiple technology system will be developed in two phases. The first phase will bring Waukegan into compliance with the EPA CCR Rule and will separate the CCR and non-CCR wastestreams that are currently being commingled in the East Ash Pond. This will set up the second phase in which MWG will bring the Station into compliance with the EPA’s recently-revised effluent limitation guidelines for steam electric power generating stations (“ELG Rule”) by converting Waukegan’s bottom ash-handling system into a closed-loop system.

MWG will begin developing this multiple technology system by clean-closing the eastern channel of the West Ash Pond. After it has been closed, the northern portion of the channel will be repurposed to support the installation and operation of the remote SSC. To install the remote SSC, structural fill will be placed in the northern area within the clean-closed portion of the West Ash Pond to support the SSC, its ancillary equipment, and its enclosure. The remote SSC will be tied into Waukegan’s bottom ash-handling system by extending new ash sluice piping to the existing ash sluice lines adjacent to the West Ash Pond’s northern dike. Effluent from the SSC will first be sent through a clarifier to reduce the concentration of total suspended solids (TSS) in the water before it drains to the Station’s Recycle Water Sump. Additional TSS controls like lamella plates and chemical injection will also be implemented to ensure the concentrations are conducive to the existing recycle pumps in the Recycle Water Sump.

Ash that settles out of the sluice water in the SSC will be collected in a hopper and subsequently conveyed up an inclined ramp where it will then be discharged into a temporary ash storage pile within the SSC enclosure's ash dewatering bunker. Water that drains from the ash pile will be collected by a trench network and sump pit, which will subsequently pump collected water to the Recycle Water Sump. Once the ash is dewatered enough to handle, it will be recovered from the bunker using front-end loaders or similar earthwork equipment and transferred onto haul trucks which will transport the ash to a permitted disposal or beneficial use facility offsite. The dewatering bunker will be sized to provide several days' worth of ash storage based on the Station's anticipated ash make rate.

The southern portion of the West Ash Pond's east channel that is not being repurposed to support the remote SSC will be repurposed as the Station's new Low Volume Waste Pond to handle the non-CCR wastestreams currently being sent to the East Ash Pond. To construct this new pond, a new dike between the east and west channels of the existing West Ash Pond will be constructed. The cleaned pond floor will be regraded and compacted as necessary before ultimately being relined with a geomembrane liner. To convey non-CCR wastestreams to this new Low Volume Waste Pond, MWG will tie into the existing low-volume waste piping and Coal Yard Runoff Basin overflow piping at the northern end of the West Ash Pond with new piping that will extend along the West Ash Pond's existing partition dike. The pond inlet will be at the southern end of the pond. An outlet structure with a sump pump will be installed at the opposite end of the new pond to convey pond effluent to the Recycle Water Sump to be recirculated back into Station operations.

This proposed multiple technology solution to replace the East Ash Pond will be installed in accordance with the EPA CCR Rule and with the Illinois EPA's forthcoming regulations and permit program for CCR surface impoundments ("Final Illinois CCR Rule"), which is expected to be adopted by the Illinois Pollution Control Board into the Illinois Administrative Code in late March 2021. Pursuant to the Illinois Public Act authorizing the Illinois EPA to prepare and the Illinois Pollution Control Board to adopt the Final Illinois CCR Rule, MWG cannot "close any CCR surface impoundment without a permit granted by the [Illinois EPA]." Accordingly, both the design of and timeframes for the first phase of this proposed project is highly dependent on the future regulations and permitting requirements established by the Final Illinois CCR Rule.

Based on the anticipated timeframes for engineering/designing, permitting, constructing, and commissioning the remote SSC and Low Volume Waste Pond, MWG is requesting the EPA allow the East Ash Pond to continue receiving the noted CCR wastestreams until October 11, 2023 and the noted non-CCR wastestreams until June 16, 2023. Further details on the East Ash Pond, the wastestreams currently being managed therein, the forthcoming Illinois CCR Rule, and MWG's development of alternative disposal capacity for these wastestreams are provided throughout this workplan. Finally, MWG's demonstration of Waukegan's compliance with the EPA CCR Rule is also provided herein.

1.0 DEVELOPMENT OF ALTERNATIVE CAPACITY

This section presents the option selected by Midwest Generation, LLC (MWG) to provide alternative disposal capacity for the coal combustion residual (CCR) and non-CCR wastestreams currently sent to the East and West Ash Ponds at the Waukegan Generating Station. This section also provides background information on the Waukegan Generating Station, the routine operations of the East and West Ash Ponds and the wastestreams managed within the two CCR surface impoundments, and the adverse impact to plant operations if the East and West Ash Ponds were both shut down by April 11, 2021. This section also describes the processes MWG undertook to select the alternative disposal capacity that is being proposed in this workplan and provides a narrative description of the alternative disposal capacity design. Finally, an explanation and justification for the time being requested to operate the East Ash Pond beyond April 11, 2021 is provided in this section.

1.1 BACKGROUND INFORMATION

1.1.1 WAUKEGAN GENERATING STATION

MWG operates the Waukegan Generating Station (“Waukegan” or the “Station”), which is a coal-fired steam electric power generating station located in Waukegan, Illinois, adjacent to and west of Lake Michigan. The Station’s address is 401 East Greenwood Avenue, Waukegan, IL 60087. The plant consists of two operating units, Units 7 and 8, which are pulverized coal boilers with an approximate nameplate capacity of 680 megawatts (MW). Drawing WKG-CSK-001 in Appendix A shows the location of the Station and a general layout of the facilities pertinent to this demonstration.

1.1.2 EAST & WEST ASH PONDS

Waukegan has two active CCR surface impoundments regulated by the EPA’s CCR Rule (40 CFR Part 257 Subpart D, Ref. 1): the East Ash Pond and the West Ash Pond. As shown on drawing WKG-CSK-001, these ponds are adjacent to each other and are located south of the plant’s power block and coal yard. Characteristics for both ponds are listed in Table 1.

Table 1 – West Ash Pond & East Ash Pond Characteristics

Pond	Crest Elevation (ft)	Floor Elevation (ft)	Storage Area (acres)	Storage Capacity (cu. yd.)
West Ash Pond	603	585	10.0	223,000
East Ash Pond	600	585	9.8	184,000

Note: Listed elevations are based on the North American Vertical Datum of 1988 (NAVD 88).

1.1.2.1 ASH POND OPERATIONS

The primary purpose of the East and West Ash Ponds is to manage the ash sluice water from Waukegan's generating units prior to being recirculated back into station operations or being discharged to Lake Michigan in accordance with the Station's National Pollutant Discharge Elimination System (NPDES) permit (NPDES Permit No. IL0002259). Both Units 7 and 8 are equipped with an ash-handling system that sluices bottom ash, economizer ash, and boiler slag to the East and West Ash Ponds. These CCR materials are sluiced to this area via several outdoor pipes spanning from Waukegan's power block.

Only one ash pond operates at any given time. Ash sluice water enters the operating ash pond through a concrete distribution trough, which is located in the northeast corner of the East Ash Pond and the northwest corner of the West Ash Pond. The ash transport water is then treated via sedimentation, whereby the ash particles suspended in the sluice water settle to the pond floor as the wastewater migrates from the concrete distribution trough towards the pond's outlet into the Recycle Water Sump located between the two ash ponds. Water that enters the Recycle Water Sump is then pumped back to the station's Sluice Water Head Tank and ultimately reused in the bottom ash handling systems for Units 7 and 8 during normal operating conditions. In situations where there is a surplus of make-up water, the excess water is instead conveyed from the Sluice Water Head Tank to two clarifiers southwest of the power block before ultimately being discharged to Lake Michigan via NPDES-permitted Outfall 001. This process is illustrated on drawing WKG-CSK-PFD-001, which is a process flow diagram (PFD) that shows how Waukegan currently manages the wastestreams produced by its coal-fired steam electric generating process.

When one pond reaches its respective storage capacity, ash transport water from Units 7 and 8 is re-directed to the other pond. The station then draws down the free surface water in the full pond. Waukegan's "Ash Management Contractor" will then mobilize to the site and begin dewatering the pond's inventory of CCR. After the ash has been dewatered sufficiently to handle the material, the Ash Management Contractor will then dredge/excavate the dry-to-moist CCR out of the pond and transport it offsite to a beneficial-use or permitted-disposal facility.

Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

1.1.2.2 POND INFLOWS

Per Waukegan's NPDES permit (NPDES Permit No. IL0002259), sluice water containing bottom ash and economizer ash is pumped from Units 7 and 8 to the West or East Ash Pond (whichever is active) at an average rate of 1.9 million gallons per day (MGD). Another CCR wastestream sent to the ash ponds is overflow sluice water from Unit 7's bottom ash hoppers, which is initially collected in the unit's Ash Sluice Overflow Tank prior to being discharged to the ash ponds.

In addition to the preceding CCR wastestreams, two non-CCR, low-volume wastestreams are sent to Waukegan's ash ponds for treating the streams' concentrations of suspended solids prior to being recirculated back into station operations or being conveyed to one of the Station's two clarifiers before final discharge to Lake Michigan. As illustrated on drawing WKG-CSK-PFD-001, these two wastestreams are:

- Effluent discharged from the Station's Coal Pile Runoff Basin, and
- Effluent discharged from the Station's Main Collection Tank.

Table 2 summarizes the Waukegan wastestreams currently managed in the East and West Ash Ponds pursuant to the Station's NPDES permit. Of the four flows (CCR and non-CCR) listed in the table, two are continuously produced during power-generating operations (*i.e.*, “typical” flows): the ash sluice water from Units 7 and 8 and the effluent from the Station's Main Collection Tank. Based on the flow rates listed in the table, these wastestreams collectively account for 3.6 MGD of wastewater placed into the East and West Ash Ponds.

In addition to the two aforementioned typical inflows, the East and West Ash Ponds receive two intermittent wastestreams: effluent from the Unit 7 Ash Sluice Overflow Tank and overflow from the Coal Yard Runoff Basin. Unit 7's Ash Sluice Overflow Tank receives overflow from the unit's bottom ash hoppers. This tank intermittently discharges wastewater to the ash ponds as needed to maintain a working volume in the tank. This intermittent flow has an average daily flow rate of approximately 0.3 MGD.

Meanwhile, the Coal Yard Runoff Basin collects stormwater run-off from the Station's Coal Yard and various Waukegan coal-handling facilities (*i.e.*, “contact” stormwater). This basin also receives overflow from the Station's West Yard Area Runoff Basin, which collects contact stormwater run-off from various facilities on the west side of the Station's property. To prevent overtopping of the pond during significant storm events, water in the Coal Yard Runoff Basin will overflow into the East Ash Pond or the West Ash Pond depending on which pond is in service at the time of the storm event. This intermittent flow has an average daily flow rate of approximately 1.0 MGD.

Table 2 – Inflows into Waukegan East Ash Pond / West Ash Pond

Wastestream	Description	Average Flow, MGD (Type)
CCR Wastestreams		**1.9**
Ash Sluice Water	Sluice water from Units 7 and 8 containing suspended bottom ash, economizer ash, and boiler slag particles.	1.6 (Typical)
Unit 7 Ash Sluice Overflow Tank Effluent	Effluent discharged from the Unit 7 Ash Sluice Overflow Tank, which collects overflow water from the bottom ash hoppers.	0.3 (Intermittent)
Non-CCR Wastestreams		**3.0**
Coal Yard Runoff Basin Overflow	Overflow water from the Station’s Coal Yard Runoff Basin. In addition to contact stormwater run-off from the coal yard, includes: • Dredge sand pile run-off, • Car dumper washwater, • Coal Breaker Building washwater and run-off, and • Overflow from the West Yard Area Runoff Basin.	1.0 (Intermittent)
Main Collection Tank Effluent	Effluent discharged from the Station’s Main Collection Tank, which collects wastewater from: • Slag tank overflow, • Slag tank drains, • Unit 8 low point sump (roof, floor, and equipment drains), • Sluice Water Head Tank overflow, and • Recycle water from the Station’s clarifiers.	2.0 (Typical)

Source: Waukegan NPDES Permit (NPDES Permit No. IL0002259)

1.1.2.3 APPLICABLE REGULATIONS

1.1.2.3.1 FEDERAL & STATE CCR REGULATIONS

Since the rule went into effect in October 2015, the East and West Ash Ponds have been regulated by the EPA CCR Rule. Per the 2016 Water Infrastructure Improvements for the Nation (WIIN) Act, the East and West Ash Ponds will continue to be subject to the requirements prescribed in the EPA CCR Rule until the EPA approves a CCR permit program developed and submitted by the Illinois EPA. On July 30, 2019, the governor of Illinois signed Illinois Public Act 101-0171 (Ref. 2, also formerly known as “Illinois Senate Bill 9”) into law which instructed the Illinois EPA to prepare regulations for CCR surface impoundments owned and/or operated by the state’s coal-fired power plants. In December 2019, the Illinois EPA published its draft regulations for CCR surface impoundments for public comment. The Illinois EPA accepted public comments on its draft regulations until mid-January 2020, after which the agency reviewed and considered these comments as it continued preparing a proposed rule to submit to the Illinois Pollution Control Board.

On March 30, 2020, the Illinois EPA submitted its final proposal for regulating CCR surface impoundments in the state of Illinois to the Illinois Pollution Control Board. These proposed regulations are hereafter referred to collectively as the “Proposed Illinois CCR Rule” and are provided in Appendix D. As required by Illinois Public Act 101-0171, the Illinois EPA proposed regulations that the agency considers to be at least as protective as the EPA CCR Rule and also proposed a corresponding statewide CCR surface impoundment permit program. Per Illinois Public Act 101-0171, the Illinois Pollution Control Board (IPCB) has a year to adopt the CCR surface impoundment regulations into Title 35 of the Illinois Administrative Code (35 Ill. Adm. Code). This timeline would establish a Final Illinois CCR Rule and corresponding CCR permit program by the end of March 2021. In the interim, the IPCB held several hearings with stakeholders and the general public on the Proposed Illinois CCR Rule. MWG was an active participant in this rulemaking process.

The Illinois EPA has yet to publish a timeline for submitting its proposed CCR permit program to the EPA for approval. Therefore, it is currently unknown when the EPA would accept the Illinois EPA’s CCR surface impoundment regulations and permitting program to operate in lieu of the EPA CCR Rule. Consequently, Illinois is currently considered a Nonparticipating State per 40 CFR 257.53. However, the Proposed Illinois CCR Rule generally appears to be at least as comprehensive and protective as the EPA CCR Rule, with some specific design and closure criteria proposed in the rule seemingly being more protective. Therefore, it is anticipated that the EPA will accept the Final Illinois CCR Rule to operate in lieu of the federal version at some point during the development of alternative CCR disposal capacity at Waukegan. However, until that time, Waukegan’s CCR surface impoundments will be subject to both the federal and state rules.

1.1.2.3.2 FEDERAL ELG RULE

In addition to the federal and state regulations for CCR surface impoundments, the operation of the East and West Ash Ponds – specifically discharges through NPDES-permitted Outfall 001 – is also subject to compliance with the EPA's effluent limitation guidelines for steam electric power plants ("ELG Rule"). The 2020 update to the ELG Rule (Ref. 3) sets new limits for discharging bottom ash transport water and other wastestreams generated by steam electric power plants to waters of the U.S. Pursuant to the new 40 CFR 423.13(k)(1)(i) and (k)(2)(i)(A), the ELG Rule establishes a zero-liquid discharge (ZLD) standard for Waukegan's bottom ash transport water – including any low-volume wastestreams that come into contact with bottom ash transport water – except under the following conditions:

- To maintain the bottom ash system's water balance during:
    - Significant precipitation events (10-year, 24-hour storm event or longer), and
    - Situations where excessive quantities of other wastestreams regularly handled by the bottom ash system compromise the system's ability to handle recycled bottom ash transport water;
- To maintain the bottom ash system's water chemistry, and
- To conduct maintenance when water volumes cannot be managed by redundancies, tanks, etc.

In any of the preceding situations, the plant would not be permitted to purge more than 10% of the bottom ash system's maximum volumetric capacity for bottom ash transport water (calculated on a 30-day rolling average and excluding redundancies, maintenance systems, *etc*.).

Waukegan will be subject to the ZLD standard for bottom ash transport water promulgated by the updated ELG Rule upon incorporation into the facility's NPDES permit by a date determined by the Illinois EPA, which is required by the new 40 CFR 423.13(k)(1)(i) to occur no later than December 31, 2025.

1.1.2.3.3 ILLINOIS EPA NPDES PERMIT

Waukegan discharges wastestreams to Lake Michigan in accordance with its NPDES permit issued by the Illinois EPA (NPDES Permit No. IL0002259). The Station's existing permit was effective on April 1, 2015 and expired on March 31, 2020. In September 2019, more than 180 days before the permit's expiration date, MWG submitted an NPDES permit renewal application to the Illinois EPA. So, although the Station's existing NPDES permit has expired, it has been administratively continued until the permit renewal is issued by the Illinois EPA. To date, MWG has not received a draft NPDES permit renewal for Waukegan.

1.1.2.4 FUTURE REPLACEMENT

While both ponds are lined with a high-density polyethylene (HDPE) geomembrane liner, the East and West Ash Ponds are not compliant with the liner design criteria promulgated by 40 CFR 257.71(a)(3). Thus, per 40 CFR 257.101(a)(1) and (a)(3), Waukegan must cease placing the CCR and non-CCR wastestreams listed in

Table 2 into these ponds as soon as technically feasible and no later than April 11, 2021, unless an alternative deadline is granted by the EPA. Pursuant to 40 CFR 257.103(f)(1)(vi)(A), the maximum possible alternative deadline extension for an unlined CCR surface impoundment is October 15, 2023 unless that unit is an "eligible unlined CCR surface impoundment," in which case the maximum extension permissible is October 15, 2024. Per 40 CFR 257.53, an "eligible unlined CCR surface impoundment is an existing CCR surface impoundment that meets all of the following conditions:

1. The owner or operator has documented that the CCR unit is in compliance with the location restrictions specified under [40 CFR 257.60] through 257.64;
2. The owner or operator has documented that the CCR unit is in compliance with the periodic safety factor assessment requirements under [40 CFR 257.73(e)] and (f); and
3. No constituent listed in Appendix IV to [40 CFR Part 257] has been detected at a statistically significant level exceeding a groundwater protection standard defined under [40 CFR 257.95(h)].

As documented on Waukegan's public CCR website, the East and West Ash Ponds are in compliance with the location restrictions specified under 40 CFR 257.60 through 257.64. Both ash ponds are also in compliance with the periodic safety factor assessments specified under 40 CFR 257.73(e) and (f); the most recent assessment is provided in Appendix C.4 of this demonstration. Finally, no groundwater protection standard exceedances have been detected at the Waukegan site that are attributable to the East and West Ash Ponds. Thus, the East and West Ash Ponds are "eligible unlined CCR surface impoundments" and are eligible to operate until October 15, 2024 if that time is required to develop alternative disposal capacity for any of the wastestreams currently managed therein. In June 2020, Waukegan took the West Ash Pond out of service for routine cleaning. Since the Station does not need to have both of its CCR surface impoundments in service to generate power and – pursuant to the revised EPA CCR Rule – Waukegan will not send CCR or non-CCR wastestreams to the West Ash Pond after April 11, 2021 and does not plan on sending any wastestreams to that pond in the interim. However, as detailed herein, MWG is requesting that the EPA allow Waukegan to continue sending the CCR and non-CCR wastestreams listed in Table 2 to the East Ash Pond after April 11, 2021, while MWG develops alternative capacity to replace this pond because: (1) no existing alternative disposal capacity is available on- or off-site for these wastestreams, and (2) it was technically infeasible to develop the alternative capacity selected by April 11, 2021 for these wastestreams.

1.1.3 ADVERSE IMPACT TO PLANT OPERATIONS WITHOUT THE EAST ASH POND

In order to generate power at Waukegan, it is necessary to dispose of the bottom and economizer ash produced during the Station's coal-fired steam electric generating process. As demonstrated herein, the East Ash Pond is the only available site for Waukegan's bottom and economizer ash disposal. There is currently no alternative on- or off-site disposal available for Waukegan's bottom and economizer ash. Therefore, if Waukegan was no longer able to use the East Ash Pond to dispose of its bottom and economizer ash, the

Station could no longer generate power and would be forced to shut down until MWG develops alternative disposal capacity for the Station's ash, which is not expected to be completed until October 11, 2023.

There are three MWG facilities affected by the EPA CCR Rule – the Waukegan, Powerton, and Will County Generating Stations. None of these generating facilities have alternative options for ash disposal, and if they cannot dispose of their ash at existing locations they will also be forced to shut down. All three plants are located in the same subregion of the regional power market. Specifically, they are located in the ComEd zone of the PJM regional transmission organization. The ComEd zone consists of most of northern Illinois including the Chicago metropolitan area. These three MWG facilities provide 2,730 megawatts of installed capacity to electricity customers in PJM, or more than 10% of the total capacity needed in the ComEd zone. All three facilities have "cleared" in the PJM forward capacity auction to meet the region's reliability needs and therefore have an obligation to supply this capacity in future years. Ceasing use of the East Ash Pond at Waukegan and the other CCR surface impoundments at the Powerton and Will County Generating Stations would cause the loss of this substantial quantity of capacity beginning in April 2021. Shutdown would cause major financial harm and loss of jobs and could potentially increase the cost of capacity for ComEd zone customers. The financial impact could be so great as to cause the permanent shutdown of Waukegan and the other two MWG power plants. The potential for substantial harm from loss of this capacity is disproportionate with the low risk of allowing operation of the East Ash Pond for the additional time needed to bring alternative disposal capacity into service without major disruptions to the company, its employees, and its customers.

1.2 GENERAL STRATEGY FOR COMPLIANCE WITH EPA REGULATIONS

MWG has evaluated several different handling and/or disposal alternatives for Waukegan's CCR and non-CCR wastestreams since 2015, shortly after the EPA's new CCR Rule and the amendment to its ELG Rule were published. Given the ZLD standards established for bottom ash transport water in the 2015 ELG Rule (Ref. 4), wastestreams which included (and still include) non-CCR wastestreams that are commingled with bottom ash transport water, MWG evaluated alternatives that either eliminated Waukegan's need for bottom ash transport water or allowed it to be recirculated back into the plant's bottom ash system in a closed-loop system. In options where bottom ash transport water would be recirculated in a closed-loop system, MWG sought to separate Waukegan's CCR and non-CCR wastestreams (which are currently commingled in the East and West Ash Ponds) to ensure the latter were not subject to the stricter ELGs for bottom ash transport water.

1.3 ALTERNATIVE DISPOSAL SOLUTIONS CONSIDERED

As discussed in more detail in Section 1.5.1, MWG has been evaluating different disposal alternatives to replace the East and West Ash Ponds in some capacity since 2015. In accordance with MWG's strategy for compliance with the EPA's CCR and ELG Rules, these evaluations assessed not only permanent disposal solutions for Waukegan's bottom ash transport water, but also the low-volume wastestreams managed by these ponds as required by the amended EPA CCR Rule. After the August 2018 *Utility Solid Waste Activities Group* (*USWAG*) decision by the U.S. Court of Appeals for the D.C. Circuit (Ref. 5), in which the Court ordered the provisions in the EPA CCR Rule allowing unlined ash ponds to continue operating be vacated and remanded, MWG started refining the conceptual designs of the potential disposal alternatives identified in previous studies for the East and West Ash Ponds and started preparing budgetary cost estimates and implementation schedules. In addition, MWG has continued evaluating and refining these alternative disposal options throughout Illinois's rulemaking process towards a Final Illinois CCR Rule. The final assessment of alternative disposal solutions considered to replace Waukegan's East and West Ash Ponds is summarized in Section 1.3.3.

Pursuant to the recently-revised alternative closure requirements for CCR surface impoundments in the EPA CCR Rule, MWG also evaluated whether existing capacity is available on- or off-site for each wastestream currently being sent to the East Ash Pond. For those wastestreams where existing capacity is not available, MWG evaluated whether it was technically feasible to obtain alternative disposal capacity – either temporary or permanent – by April 11, 2021. The following subsections discuss the alternative disposal solutions considered for each wastestream managed in the East Ash Pond and how these wastestreams were ultimately dispositioned.

1.3.1 EXISTING ON-SITE DISPOSAL SOLUTIONS

As shown in the PFD on drawing WKG-CSK-PFD-001 in Appendix B, Waukegan relies on several settling ponds to treat the total suspended solids (TSS) in wastestreams produced during the Station's steam electric generating process and in contact stormwater from various plant facilities. These settling ponds are shown on drawing WKG-CSK-001 and are referred to as:

- East Ash Pond (CCR surface impoundment),
- West Ash Pond (CCR surface impoundment),
- Coal Yard Runoff Basin (non-CCR surface impoundment),
- West Yard Area Runoff Basin (non-CCR surface impoundment), and
- East Yard Collection Basin (non-CCR surface impoundment).

1.3.1.1 CCR WASTESTREAMS

Waukegan's ash sluice water and Ash Sluice Overflow Tank effluent contain suspended CCR particles (bottom ash, economizer ash, and boiler slag), and are therefore considered CCR wastestreams. Consequently, these wastestreams must be disposed of in a CCR unit. Per the preceding list, the only two CCR units at Waukegan are the East and West Ash Ponds. As previously stated, both ponds are not compliant with the EPA CCR Rule's liner design criteria. Thus, there is no existing, compliant alternative disposal capacity to the East Ash Pond at Waukegan for the Station's ash sluice water and Ash Sluice Overflow Tank effluent.

1.3.1.2 NON-CCR WASTESTREAMS

MWG evaluated three general scenarios for providing alternative disposal capacity for the non-CCR wastestreams currently being sent to the East Ash Pond: (1) divert a given non-CCR wastestream to the Station's East Yard Collection Basin, (2) divert a given non-CCR wastestream to the Station's clarifiers, or (3) hold a given non-CCR wastestream in its existing temporary storage facility/unit upstream of the East Ash Pond.

1.3.1.2.1 DIVERT TO EAST YARD COLLECTION BASIN

Waukegan has three non-CCR surface impoundments on site. Of these, the East Yard Collection Basin would be the only surface impoundment to divert the non-CCR wastestreams currently going into the East Ash Pond since wastewater collected in the Coal Yard Runoff and West Yard Area Runoff Basins currently overflows into the East Ash Pond (the West Yard Runoff Basin overflows into the Coal Yard Runoff Basin which overflows into the East Ash Pond). As shown on drawing WKG-CSK-001 in Appendix A, the East Yard Collection Basin is located east of Waukegan's generating units and north of the Station's Intake Channel. Per the PFD on drawing WKG-CSK-PFD-001, this non-CCR surface impoundment currently manages contact stormwater from the eastern portion of Waukegan's property; wastewater collected by the roof and floor drains in the Station's generating units, auxiliary boiler drains, laboratory drains, and polymer building drains; stormwater run-off from the sorbent mill, and several wastestreams from the Station's reverse osmosis system for its make-up water (membrane reject, cleaning waste, and filter backwash). Treated effluent from the East Yard Collection Basin is discharged through an internal outfall (NPDES-permitted Outfall D01) before ultimately being discharged to Lake Michigan via NPDES-permitted Outfall 001.

To divert the Main Collection Tank effluent and Coal Yard Runoff Basin overflow water to the East Yard Collection Basin, MWG would need at least four to five months after initiating the project to perform the engineering and design work to determine the mechanical infrastructure required to convey these wastestreams to the basin, which is approximately 1,500 feet and 2,700 feet away from the Main Collection Tank and Coal Yard Runoff Basin, respectively. This work would include routing and designing new pipes, which would need to be routed through the congested Unit 7 and 8 boiler areas and over a new pipe bridge spanning the portion of the Intake Channel south of the generating units. New pumps would also have to be evaluated and procured to convey the wastestreams these significant distances to the East Yard Collection Basin. In addition, MWG would need to verify that the East Yard Collection Basin can in fact manage these non-CCR wastestreams in addition to the inflows it already handles without an interim treatment or storage facility (*e.g.*, tank) upstream of it. Finally, the engineering and design work would include preparation of revised PFDs and other necessary documentation to be included in the NPDES permit application forms for this project.

The East Yard Collection Basin has a capacity of approximately 4.9 million gallons. Per Table 2, the Station would need to redirect the 3 million gallons of non-CCR wastestreams currently being sent to the East Ash Pond to the East Yard Collection Basin per day; this is about 60 percent of the basin's available capacity. Additionally, when comparing the two surface impoundments, the capacity of the East Ash Pond is more than seven times larger (37.2 million gallons per Table 1) than the East Yard Collection Basin. Because of the significant capacity reduction from the East Ash Pond, either the discharge rate from the East Yard Collection Basin would need to be increased or interim capacity would need to be installed to handle the increased flow.

Because the handling and treatment of these non-CCR wastestreams would be changed, MWG would need to apply for an NPDES construction permit to install the system and eventually modify its existing NPDES permit with the Illinois EPA to incorporate this new treatment method. MWG cannot currently modify Waukegan's existing NPDES permit because, as discussed in Section 1.1.2.3.3, the Station's current permit expired in March 2020 and is administratively extended by MWG's timely permit renewal application that was submitted in September 2019. To date, MWG has not received a draft NPDES permit renewal from the Illinois EPA.

Based on recent experience in obtaining NPDES construction and renewal permits from the Illinois EPA, MWG anticipates an NPDES construction permit and the NPDES renewal permit would take approximately six and 18 months, respectively, given the time required for the agency to perform an initial review, accept public comments, review public comments, and draft the permits, not to mention the agency's current focus on establishing a CCR permit program. Finally, it would likely take another five to six months to install and commission this system, assuming a contractor has already been procured by the time the necessary permits are issued by the Illinois EPA. This installation time accounts for the time required to install the length of piping required to connect the Coal Yard Runoff Basin and Main Collection Tank to the East Yard Collection Basin, which will require constructing a new pipe bridge over the Intake Channel, routing pipes through the congested boiler areas, and erecting new pipe racks in between the source basins and the East Yard Collection Basin. Commissioning time would also be required to ensure the Station can meet the discharge limits established in its NPDES permit.

Given the preceding timeframe, MWG expects that it would take almost three years (*i.e.*, fall 2023) to temporarily divert the non-CCR wastestreams from the Coal Yard Runoff Basin and Main Collection Tank to the East Yard Collection Basin while permanent alternative disposal capacity is being developed. As shown in the visual timeline representation in Section 2.0, MWG expects to develop new alternative disposal capacity for the non-CCR wastestreams currently being sent to the East Ash Pond within a shorter timeframe

(June 16, 2023). Consequently, MWG does not consider the East Yard Collection Basin to be an appropriate alternative disposal solution for the non-CCR wastestreams currently going into the East Ash Pond.

Even if MWG could receive an NPDES construction permit and Waukegan's NPDES renewal permit for this project sooner than forecasted (six and 18 months, respectively), MWG would be submitting at least one more permit application for the Illinois EPA to review for this site (the NPDES construction permit) in addition to the four CCR permit applications (two operating and two construction) that will need to be submitted to comply with the Final Illinois CCR Rule and to develop the alternative disposal capacity selected to replace the East and West Ash Ponds. (An NPDES permit renewal application will be required for either project.) Given the Illinois EPA's current focus on developing and implementing a new permit program for the 73 CCR surface impoundments the agency identified across 23 Illinois power plants (Ref. 6; Statement of Reasons, VI. Affected Facilities), MWG believes it is a more appropriate use of the agency's resources to submit only the permit applications necessary to develop the permanent alternative disposal solution proposed for Waukegan rather than submitting additional permit applications for a temporary solution that may or may not be permitted faster than the permanent solution. Moreover, given that MWG's proposed alternative disposal capacity solution for Waukegan includes closing the East and West Ash Ponds, and given Illinois's general focus on its current rulemaking process for regulating CCR surface impoundments, MWG expects that the Illinois EPA would prioritize the CCR surface impoundment closure construction permit applications included in the permanent solution than the NPDES construction permit application required for temporarily diverting wastestreams to a non-CCR surface impoundment at Waukegan.

In conclusion, diverting the non-CCR wastestreams currently entering the East Ash Pond to the East Yard Collection Basin would not be an appropriate solution given the longer path to compliance anticipated with the NPDES permitting timeframes.

1.3.1.2.2 DIVERT TO CLARIFIERS

In lieu of redirecting the Coal Yard Runoff Basin overflow and Main Collection Tank effluent to the East Yard Collection Basin, MWG evaluated sending these wastestreams directly to the Station's two clarifiers instead. These clarifiers are currently used to remove suspended solids remaining in the effluent from the East and West Ash Ponds prior to being discharged to Lake Michigan if the effluent is not otherwise recycled back into station operations. This typically only occurs when there is a surplus of make-up water in the system. Given the detention time provided by the surface impoundments and temporary storage facilities upstream of these clarifiers (*e.g.*, East and West Ash Ponds) and the infrequency of sending wastewater to the clarifiers, the clarifiers do not collect or treat a large volume of sludge. The sludge that is collected is removed by on-site vacuum trucks on an as-needed basis.

Given the proximity of the Station's clarifiers to the Coal Yard Runoff Basin and Main Collection Tank – approximately 750 and 400 feet, respectively – it would take less time to design and install new piping, pipe racks, and pumps to convey the non-CCR wastestreams from these units to the clarifiers. However, MWG would need to design modifications to the clarifiers to handle these flows which will increase the volume and frequency of inflows to the clarifiers. To handle this additional flow, the clarifiers would need to be upgraded and sludge pumps and a sludge dewatering system would need to be installed. The latter system would allow the clarifier to remove sludge from the clarifier underflow in lieu of using vacuum trucks, which would otherwise have to be used at a higher frequency to manage the increased volume of solids removed by the clarifiers. Finally, as would be required for diverting non-CCR wastestreams to the East Yard Collection Basin, the change in treatment for these wastestreams would still necessitate an NPDES construction permit and a renewal of Waukegan's NPDES permit.

Because the infrastructure required to implement this temporary solution would be relatively simpler than that required to divert non-CCR wastestreams to the East Yard Collection Basin, the Coal Yard Runoff Basin overflow and Main Collection Tank effluent could likely be diverted to the Station's clarifiers within 2.5 years instead of 3 years. This time reduction would be due to less time needed to design and install the clarifier upgrades and the balance of plant components (*i.e.*, pumps, pipes, and supports). However, this timeframe for a temporary solution is still similar to the duration MWG expects it will take to develop the permanent alternative disposal capacity for all of the wastestreams currently going into the East Ash Pond. Moreover, and as discussed in the evaluation for diverting non-CCR wastestreams to the East Yard Collection Basin, MWG would be submitting at least one more permit application for the Illinois EPA to review for this site (the NPDES construction permit) in addition to the four CCR permit applications (two operating and two construction) that will need to be submitted to comply with the Final Illinois CCR Rule and to develop the alternative disposal capacity selected to replace the East and West Ash Ponds. (An NPDES permit renewal application will be required for either project.)

Given the Illinois EPA's current focus on developing and implementing a new permit program for the 73 CCR surface impoundments the agency identified across 23 Illinois power plants (Ref. 6; Statement of Reasons, VI. Affected Facilities), MWG believes it is a more appropriate use of the agency's resources to submit only the permit applications necessary to develop the permanent alternative disposal solution proposed for Waukegan rather than submitting additional permit applications for a temporary solution that may or may not be permitted faster than the permanent solution. Moreover, given that MWG's proposed alternative disposal capacity solution for Waukegan includes closing the East and West Ash Ponds, and given Illinois's general focus on its current rulemaking process for regulating CCR surface impoundments, MWG expects that the Illinois EPA would prioritize the CCR surface impoundment closure construction permit applications included in the permanent solution than the NPDES construction permit application required for temporarily diverting wastestreams to a non-CCR surface impoundment at Waukegan.

In conclusion, diverting the non-CCR wastestreams currently entering the East Ash Pond to the Station's clarifiers (which would have to be upgraded for this purpose) would not be an appropriate solution given the longer path to compliance anticipated with the NPDES permitting timeframes.

1.3.1.2.3 HOLD IN EXISTING TEMPORARY STORAGE FACILITY

Finally, MWG evaluated whether it would be possible to hold any of the non-CCR wastestreams currently going into the East Ash Pond at their sources in lieu of discharging them to the ash pond. This evaluation is only appropriate for the intermittent Coal Yard Runoff Basin overflow, however, since the Main Collection Tank was designed to discharge to the ash ponds at regular intervals and would inherently not have sufficient capacity for long-term storage of the wastestreams it receives from plant operations.

Based on MWG's projected date of obtaining alternative disposal capacity for the non-CCR wastestreams currently going into the East Ash Pond (June 16, 2023), the Coal Yard Runoff Basin would need to be capable of providing approximately 2.5 years' worth of storage for the wastestreams it receives. The basin has an approximate storage capacity of 3.5 million gallons. Based on an average flow of 1.0 MGD of contact stormwater into the Coal Yard Runoff Basin (see Table 2), this basin would become full within 3.5 days. Thus, the Coal Yard Runoff Basin would not be capable of retaining the stormwater sent to it until the summer of 2023 without discharging to the East Ash Pond.

1.3.2 OFF-SITE DISPOSAL

Although the EPA itself has acknowledged that it is not feasible to transport wet-generated CCR to an off-site disposal facility (Ref. 7), MWG performed its due diligence and evaluated the feasibility of temporarily transporting the average daily volume of CCR and non-CCR wastestreams currently being sent to the East Ash Pond to an off-site disposal facility. Because the Illinois EPA generally prohibits solid waste landfills from receiving bulk or noncontainerized liquid wastes (Ref. 8), wastewater treatment plants (WWTPs) are the only technically feasible alternative disposal facilities off-site for the CCR and non-CCR wastestreams currently being sent to the East Ash Pond. Per the average flow rates listed in Table 2, an average daily volume of 4.9 million gallons of CCR and non-CCR wastewater would need to be sent to a WWTP. Thus, to be a viable option, a WWTP would need to receive the full or significant portion of the 4.9 MGD of CCR and non-CCR wastewater generated by Waukegan in addition to the daily volume of wastewater the WWTP currently manages.

Seven WWTPs were identified within 20 miles of the Station, and four of these plants had listed design capacities of 4 MGD or less. The other three plants had design capacities greater than 20 MGD and therefore may be technically feasible solutions for temporarily handling the CCR and non-CCR wastestreams currently going into the East Ash Pond. The technically feasibility of this temporary solution is contingent on MWG's ability to transport the wastewater to one (or multiple) of these three plants. Given the Station's existing infrastructure, trucks with tank trailers (“tankers”) would likely be the only transportation method that could be established for the Station’s CCR and non-CCR wastestreams prior to the April 11, 2021 deadline for ceasing all flows into the East Ash Pond. In this scenario, new infrastructure would be installed as necessary to pump a given wastestream from its interim holding facility (*e.g.*, Main Collection Tank) into a tanker.

Illinois state law limits the overall gross vehicle weight to 80,000 pounds (Ref. 9). Assuming the specific weight of suspended solids in the subject CCR and non-CCR wastestreams is equal to that of water (*i.e.*, 62.4 pounds per cubic foot (pcf)), and assuming an empty tanker weight of 12,000 pounds, an 8,200-gallon tank trailer would be the largest tank trailer that would be permitted to transport wastewater off-site. Therefore, it would take almost 600 truckloads to transport the 4.9 MGD of CCR and non-CCR wastewater currently being sent to the East Ash Pond. Even if trucks were operating 24 hours a day, 7 days a week (“24/7”), this would require a truck to enter the Waukegan site, get cleared by security, load the wastewater, and leave the site travelling over City of Waukegan roadways approximately every 2.5 minutes, on average. This is not technically feasible, especially during winter weather conditions (*i.e.*, snow and ice) which would only exacerbate the logistical issues of hauling this volume of waste to an off-site disposal facility.

Even if the Station could support the number of tankers required to keep up with its daily production of CCR and non-CCR wastewater, there would be significant logistics concerns in coordinating 600 trips to and from the Station’s property. Trucks would have to enter the Waukegan site via East Greenwood Avenue, which they would likely access via Illinois State Route 137 that follows the Lake Michigan shoreline near the Station. Based on traffic data compiled by the Illinois Department of Transportation (Ref. 10), the average annual daily traffic (AADT) in 2018 for commercial trucks along this road near the entrance to the Waukegan facility was 555 trucks. Therefore, the 600 truckloads required to transport the East Ash Pond’s daily intake of CCR and non-CCR wastewater would more than double the daily volume of truck traffic currently on Illinois State Route 137 at East Greenwood Avenue.

Based on the preceding estimates, transporting Waukegan’s daily generation of CCR and non-CCR wastestreams off-site would impose an increase in air pollution emissions, congestion issues on the four-lane state road, and an increased potential for traffic accidents. These factors may pose short-term risks to human health and the environment that have not been present at the East Ash Pond, which is lined with a 60-mil HDPE geomembrane liner and has not caused any groundwater protection standard exceedances. Finally, it is not technically feasible to route 600 trips’ worth of trucks per day to an off-site disposal facility until alternative disposal capacity is available on-site.

1.3.3 NEW ON-SITE DISPOSAL SOLUTIONS

Based on the preceding evaluations, no alternative disposal capacity currently exists on- or off-site for the CCR and non-CCR wastestreams currently being sent to the East Ash Pond. Consequently, MWG is in the process of developing alternative disposal capacity at Waukegan for these wastestreams. This subsection presents the alternatives MWG evaluated as potential replacements for the East and West Ash Ponds, the alternative disposal capacity option that MWG ultimately selected, and why MWG selected this solution.

1.3.3.1 EVALUATION OF BOTTOM ASH DISPOSAL METHODS

In the summer of 2015, shortly after the EPA finalized its new CCR rule, MWG started developing and subsequently evaluating conceptual designs for different disposal alternatives for the bottom ash wastestreams at its Waukegan, Powerton, and Will County facilities. When the 2015 update to the EPA ELG Rule was published, MWG expanded the scopes of these studies to evaluate multiple technology solutions that would provide compliance with the revised ELGs. Then following the Illinois EPA's publication of its draft regulations for CCR surface impoundments, MWG updated these conceptual designs and the corresponding analysis as needed to comply with the draft CCR regulations and align with the EPA's proposed ELG regulations. Finally, in the second quarter of 2020, MWG performed a final update to its conceptual alternative disposal solutions after the Illinois EPA published the Proposed Illinois CCR Rule at the end of March of 2020.

For Waukegan, MWG evaluated the following options for managing the Station's bottom ash transport water in lieu of the existing East and West Ash Ponds:

- Retrofitting the West Ash Pond,
- Installing geotextile filter tubes,
- Installing a concrete ash-settling tank,
- Installing an under-boiler or remote submerged scraper conveyer.

1.3.3.1.1 RETROFITTED WEST ASH POND

Given the West Ash Pond's compliance with all other parts of the Proposed Illinois CCR Rule, it would be suitable for future bottom ash disposal provided it was retrofitted with an Illinois EPA-compliant liner system. In this scenario, MWG would first draw down the water level in the pond and then dewater and remove the ash stored therein (including any impacted soils). Pursuant to the proposed 35 Ill. Adm. Code 845.770, the pond's existing liner would also be removed. Following the removal of these materials, the pond would be retrofitted with a composite liner consisting of a 60-mil HDPE geomembrane over a 2-ft-thick, compacted clay layer with a permeability no greater than 1×10^{-7} cm/sec.

Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

In addition to the composite liner, the Proposed IL CCR Rule also requires a leachate collection and removal system (LCRS) be installed within retrofitted CCR surface impoundments. The proposed 35 Ill. Adm. Code 845.420 requires the LCRS to be placed above the composite liner; consist of highly permeable, granular drainage material; contain collection pipes; extend at least two feet above the collection pipes; have a filter layer placed above it; and have a slope of at least 3% towards the collection pipes. The LCRS conceptualized for this retrofit option would consist of, from bottom to top:

- A collection pipe network (4-in.-diameter, perforated polyvinyl-chloride (PVC) pipes) installed within a 6-in.-thick sand drainage layer,
- A 22-in.-thick gravel drainage layer, and
- A non-woven geotextile to filter out solids from the water to prevent fouling of the gravel drainage layer and clogging of the collection pipes.

In order to protect the geotextile and LCRS components from being damaged by equipment excavating CCR throughout the retrofitted pond’s lifetime in accordance with historical Station cleaning practices, an 18-in.-thick protective soil layer would be installed over the engineered liner system. This protective layer would consist of six inches of crushed stone installed over 12 inches of sand.

1.3.3.1.2 GEOTEXTILE FILTER TUBES

Another option that was considered for replacing the East and West Ash Ponds was installing a series of geotextile filter tubes, which are containers with oval-shaped cross sections that are composed of engineered fabric that can filter out fine particles within water. Thus, Waukegan’s CCR could be sluiced directly to these tubes to filter out the bottom ash, economizer ash, and slag particles still in suspension in the transport water. As the ash and slag particles are consolidated within each tube, filtered sluice water would percolate out of each tube’s outer fabric onto an impermeable pad with appropriate run-off control measures. Once a tube is full of ash particles, the bottom ash transport water would be redirected to another tube while the full tube is dewatered. After the filtered ash has been sufficiently dewatered, the full tube would be cut open, loaded onto trucks, and transported off-site to a beneficial-use or permitted-disposal facility.

1.3.3.1.3 CONCRETE ASH-SETTLING TANK

MWG also considered replacing Waukegan’s two ash-settling surface impoundments with a concrete ash-settling tank. This self-supporting, reinforced concrete tank would operate similar to the East and West Ash Ponds. It would be comprised of two primary settling cells in parallel trains with a common surge cell. New piping would be installed to convey the Station’s bottom ash transport water to the primary settling cells, which would function like the existing ash ponds. The Station would sluice CCR to one primary cell at a time, switching after the given cell reaches capacity to permit dewatering and cleaning of the full cell. Water in each primary cell would overflow into the common surge cell where the remaining finer ash particles would settle. Effluent from the surge cell would then be discharged into the existing Recycle Water Sump before ultimately being recirculated back to the Station.

Ash stored in each primary cell of the concrete ash-settling tank would be removed with a front-end loader, backhoe, or similar equipment. Excavated CCR would be piled onto a concrete slab for dewatering. Concrete curbs and pushwalls would contain the stacked ash and water therefrom within the dewatering area, and water from the stacked ash would ultimately drain back into the cells. Following dewatering, the CCR would be loaded onto trucks and transported offsite to a beneficial-use or permitted-disposal facility.

1.3.3.1.4 SUBMERGED SCRAPER CONVEYOR

Finally, MWG considered replacing Waukegan's East and West Ash Ponds with a submerged scraper conveyor (SSC). Both an under-boiler SSC and a remote SSC were considered. Other than physical location, both SSC types operate similarly. An SSC contains a water-filled trough that promotes sedimentation of suspended ash particles in the transport water. As its name suggests, the trough in an under-boiler SSC is positioned directly under the boiler to catch and cool falling bottom ash. Conversely, piping is used to sluice ash to a remote SSC located elsewhere on the plant site. Chains and flight scrapers then move the ash along the trough to an inclined ramp. As the ash is conveyed up the ramp, gravity causes it to dewater. Water removed from the ash as it moves up the inclined ramp is ultimately drained down the ramp back into the trough. Once the ash reaches the top of the ramp, the ash is deposited into a temporary storage bunker where it is ultimately recovered and transported off-site to a beneficial-use or permitted-disposal facility.

1.3.3.2 OPTION SELECTED & JUSTIFICATION

Ultimately, MWG elected to replace the East and West Ash Ponds with a multiple technology solution:

- Installing a remote SSC within a repurposed portion of the West Ash Pond to manage Waukegan's ash sluice water, and
- Repurpose another portion of the West Ash Pond as a new Low Volume Waste Pond so that the area can continue managing the non-CCR wastestreams currently managed therein.

Of the new, permanent on-site disposal alternatives considered to replace the East and West Ash Ponds, the multiple technology system selected – install a remote SSC and repurpose a portion of the West Ash Pond as a new Low Volume Waste Pond – is the alternative disposal capacity option that is technically feasible and expected to be implemented the fastest. The selected multiple technology solution takes advantage of the station's existing infrastructure – primarily the ash sluice and low volume waste piping and the recirculation equipment – which reduces design and construction time. Moreover, MWG intends to install a portable remote SSC with a modularized design, which significantly reduces the lead time required to install this type of equipment relative to more traditional designs (see Section 1.4.1.3). This option also separates the CCR and non-CCR wastestreams in the primary treatment facility for those wastestreams (remote SSC for CCR wastestreams and Low Volume Waste Pond for non-CCR wastestreams). Although both facilities will ultimately discharge to the Recycle Water Sump in the interim, this option will allow MWG to readily implement a closed-loop bottom ash recirculation system for ELG Rule compliance.

Retrofitting the existing West Ash Pond would require a similar amount of time to implement as installing the remote SSC and the new Low Volume Waste Pond in a repurposed portion of the ash pond. Because both options require modifying the West Ash Pond, MWG cannot start constructing either option without a corresponding construction permit from the Illinois EPA in accordance with the Final Illinois CCR Rule. Accordingly, MWG would start constructing either option at the same point in time. Per the visual timeline representation of the project schedule presented in Section 2.0, MWG expects earthwork to start in January of 2023.

Although the remote SSC area will require filling the northeastern corner with structural fill up to existing grade, it will require a similar amount of structural fill to establish a 3% grade for the retrofitted pond floor in accordance with the proposed 35 Ill. Adm. Code 845.420. The contractor performing the work would then require approximately two months to install the composite liner system required for a retrofitted ash pond – 60-mil HDPE geomembrane over a 2-ft-thick compacted clay layer. Afterwards, the contractor would begin installing the LCRS required by the proposed 35 Ill. Adm. Code 845.420. It is anticipated that it would take the contractor another two months to install the leachate collection pipe network, sand and gravel drainage layers, geotextile filter layer, and protective layers comprising the LCRS.

Based on the preceding timeframes, MWG estimates that it would take approximately four months to retrofit the West Ash Pond after the structural fill has been placed to establish the lines and grades for the retrofitted pond's composite liner system and LCRS. Per the visual timeline representation of the project schedule presented in Section 2.0, MWG expects the remote SSC to be installed in a similar timeframe and for the Low Volume Waste Pond to be constructed sooner. Thus, the selected option provides alternative disposal capacity for the non-CCR wastestreams currently going into the East Ash Pond faster than retrofitting the West Ash Pond, while providing a similar timeline for providing alternative disposal capacity for Waukegan's CCR wastestreams. Moreover, the multiple technology solution selected to replace the East and West Ash Ponds provides separation of the CCR and non-CCR wastestreams currently being commingled in the ash ponds. Thus, not only does this option provide faster compliance with the EPA CCR Rule than retrofitting the West Ash Pond, it also facilitates compliance with the EPA ELG Rule in the next phase of this project in which MWG plans to install a closed-loop bottom ash recirculation system.

Although geotextile filter tubes have been successfully installed and operated to serve a variety of industrial purposes (including dewatering bottom ash ponds) and could also be installed relatively quickly, they could be considered a “first-of-a-kind” technology for dewatering a power plant’s daily ash production. Moreover, limited information is available on the successful operation of geotextile filter tubes in winter conditions. Because Waukegan operates under peak load conditions during the winter months, the reliable operation of geotextile tubes during this time would be crucial. Consequently, this option has significant uncertainties, especially as it pertains to dewatering and filtering out very fine economizer ash particles. Therefore, physical trials of geotextile tubes at the Waukegan site would be warranted to determine filter aids that would be necessary to ensure the finer ash particles in the Station’s bottom ash transport water are captured by the geotextile filter tubes. Testing would also be required during the winter months to certify with a high degree of certainty that this option is a technically feasible replacement for the East Ash Pond.

While a concrete ash-settling tank is being installed at MWG’s Powerton Generating Station, it will be located downstream of dewatering tanks that will remove most of the ash in the sluice water before the wastewater enters the concrete tank. Conversely, Waukegan would be conveying its ash sluice water directly to the concrete ash-settling tank, which would then be the primary treatment facility for settling the suspended ash particles in the sluice water. Settling out the Station’s full economizer ash load may not be technically feasible without the aid of another ash-handling technology (*e.g.*, dewatering bins) or converting the economizer ash system to a dry system.

Given the technical feasibility concerns for geotextile filter tubes and a concrete ash-settling tank being able to manage Waukegan’s ash sluice water, MWG opted to install an SSC, an industry-tested and proven technology for managing bottom ash transport water. MWG elected to install a remote SSC in lieu of an under-boiler SSC because there is not enough space under the Unit 7 and 8 boilers to install and operate the latter.

1.4 CONCEPTUAL DESIGN OF MULTIPLE TECHNOLOGY SOLUTION

This section describes MWG’s conceptual designs for the remote SSC to manage Waukegan’s CCR wastestreams and for the new Low Volume Waste Pond within a repurposed portion of the West Ash Pond so that the pond can continue managing the low-volume wastestreams currently managed therein. The conceptual designs for the remote SSC and Low Volume Waste Pond are graphically illustrated on the drawings in Appendix A, and the modifications to Waukegan’s management of the CCR and non-CCR wastestreams impacted by this multiple technology solution are shown in the modified PFD on drawing WKG-CSK-PFD-002 in Appendix B. This PFD reflects the point at which Waukegan has developed alternative disposal capacity for the CCR and non-CCR wastestreams currently entering the East Ash Pond.

1.4.1 REMOTE SUBMERGED SCRAPER CONVEYOR

1.4.1.1 SITE SELECTION

MWG selected the northeastern corner of the existing West Ash Pond as the future site for Waukegan's remote SSC primarily because of its proximity to the Station's existing ash-handling infrastructure, specifically the ash sluice piping and Recycle Water Sump, which provides the fastest means of installing the mechanical and electrical infrastructure required to tie the SSC into the Station's existing bottom ash-handling system. However, this site requires MWG to first clean close the northeastern portion of the West Ash Pond and repurpose the area for this use, which requires MWG to first obtain a closure construction permit from the Illinois EPA under the forthcoming Final Illinois CCR Rule. Given this potential delay in installing a remote SSC relative to an undeveloped site, MWG evaluated three potential sites of adequate size near the Recycle Water Sump on Waukegan's property:

1. Area east of the East Ash Pond,
2. Area west of the West Ash Pond, and
3. Southwestern area of the Station's Coal Yard.

Per the U.S. Fish and Wildlife Service's National Wetlands Inventory (Ref. 11), the entire area east of the East Ash Pond on Waukegan's property has been mapped as a potential wetland. This area of Waukegan's property is within a 160-acre area that the Lake County Wetland Inventory (Ref. 12) has mapped as a potential wetland along the Lake Michigan shoreline. Based on these findings, MWG eliminated this area from consideration as a potential site due to the unlikelihood of it being permitted.

Approximately 10 acres of undeveloped land are available on Waukegan's property west of the West Ash Pond, which would provide more than enough area to construct and operate a remote SSC and its ancillary equipment. However, the Illinois EPA has identified this area using 1930s-vintage historical photographs as a potential ash pond on its map of CCR surface impoundments that will be regulated by the Final Illinois CCR Rule (Ref. 13). It is not prudent for MWG to construct anything on this area until MWG and the Illinois EPA have resolved whether or not this area may be a potential CCR site and subject to the Final Illinois CCR Rule. Consequently, MWG eliminated this area from consideration as a potential site.

Finally, MWG evaluated whether an area in the southwestern portion of the Station's Coal Yard could be repurposed to construct and operate a remote SSC. Like the northeastern corner of the West Ash Pond, this area of the Coal Yard is near the existing bottom ash-handling infrastructure (ash sluice piping, return pumps and piping, recycle pumphouse, *etc*.), but at an elevation 20 feet below the existing recycle equipment. The area was evaluated to determine if it would be faster to fabricate the additional infrastructure associated with the Coal Yard site or to utilize the West Ash Pond site and address the permitting requirements associated with closing the ash pond.

This site also generated safety concerns related to operating ash trucks in the vicinity of the Coal Yard dozers as traffic issues in the condensed footprint could not be resolved. To access ash temporarily stored in a dewatering bunker at this site, trucks would need to approach from an existing road crossing over the piping to the East and West Ash Ponds (located South of the Coal Breaker Building) or from the existing road along the northern dike of the East Ash Pond. Waukegan personnel raised potential safety concerns about sharing the northern roadway with haul trucks traveling to the site to pick up the ash stored in the SSC's ash dewatering bunker. This roadway is currently used by Station dozers to access the Coal Yard, and standard operating procedures at power plants is to prohibit shared road use (unless absolutely necessary) due to the size and/or visibility restrictions associated with operating large dozers. Truck traffic could be restricted to accessing the site from only road along the northern dike of the East Ash Pond, but such an access road would have a rather steep grade given the 20- to 25-foot elevation difference between the dike and the Coal Yard. Such a steep grade may be impassable during particularly icy road conditions during the winter.

In addition to access concerns, the southwest corner of the Coal Yard is the current collection area for stormwater run-off from the Coal Yard before it ultimately drains through a concrete trench into the Coal Yard Run-Off Basin (see drawing WKG-CSK-001). Therefore, the entire Coal Yard stormwater run-off system would need to be reconfigured to around the remote SSC area if this site was selected. Moreover, the approximately two acres required to install the SSC, its enclosure, and its appurtenances (see drawing WKG-CSK-101) would cause the station to lose approximately 15% of its coal storage area. Although the Station does not presently have a concern with sacrificing this amount of storage, the loss of this storage area could be problematic if the station's capacity utilization rating increases in the future. Ultimately, MWG concluded that it would be technically infeasible to repurpose the southwest corner of the Coal Yard to construct and operate a remote SSC.

Based on the preceding evaluation, MWG concluded that siting the remote SSC in the northeastern corner of the West Ash Pond was the only technically feasible solution of the options considered.

1.4.1.2 SITE DEVELOPMENT

As shown on drawing WKG-CSK-100 in Appendix A, MWG plans to install the remote SSC in the northeastern corner of the West Ash Pond, adjacent to the Recycle Water Sump. MWG primarily selected this site because of its proximity to the Station's existing ash-handling infrastructure, specifically the ash sluice piping and Recycle Water Sump. Accordingly, this site provides the fastest means of installing the mechanical and electrical infrastructure required to tie the SSC into the Station's existing bottom ash-handling system. Only about 150 feet of new ash sluice piping will be required to tie into the ash sluice piping north of the West Ash Pond to redirect Waukegan's CCR wastestreams to the SSC. Locating the SSC adjacent to the Recycle Water Sump will also keep effluent piping from the SSC and ancillary equipment to a minimum, and the effluent can be pumped back to the Station's Sluice Water Head Tank using the existing pump system and return piping. Finally, power can likely be provided from the pumphouse north of the Recycle Water Sump that provides power for the recirculation pumps in the sump, and service water and air piping for the SSC can be routed from the Station's Coal Breaker Building near the site (see drawing WKG-CSK-001).

In order to construct the SSC in a portion of the existing West Ash Pond, MWG must first repurpose this area for this use by clean closing the area in accordance with the Proposed Illinois CCR Rule. MWG generally plans to clean close the entire West Ash Pond by removing the CCR and any impacted soils from the pond in accordance with the proposed 35 Ill. Adm. Code 845.740. However, MWG will first prioritize clean closing the east channel of the West Ash Pond so that the area can immediately be repurposed to support the new SSC and Low Volume Waste Pond (see Section 1.4.2). A benefit of siting the remote SSC and new Low Volume Waste Pond in the east channel is that minimal CCR and therefore CCR-impacted soils (if any) are anticipated to be in this area since CCR wastewater enters the West Ash Pond in the northern portion of the pond's west channel (per location of the concrete distribution trough shown on drawing WKG-CSK-001). Consequently, most of the CCR stored in the West Ash Pond is anticipated to be in the west channel and closer to the concrete distribution trough.

As previously stated, Waukegan has already taken the West Ash Pond out of service for routine cleaning. Consistent with the Station's current ash-handling operations, the Station will draw down the water level in the pond, and then Waukegan's Ash Management Contractor will begin dewatering and removing the ash therein. Ash will be removed down to the top of the existing liner, loaded onto trucks, and ultimately transported offsite to a beneficial-use or permitted-disposal facility.

Pursuant to the Proposed Illinois CCR Rule, the West Ash Pond's existing liner will also be removed. Prior to removing the liner, however, MWG will submit a closure construction permit application to the Illinois EPA pursuant to the proposed 35 Ill. Adm. Code 845.220. After receiving a final permit from the agency, the contractor hired to execute the pond closure work will mobilize to the site and start excavating and/or dredging the existing liner materials and any underlying soils impacted by CCR near the Recycle Water Sump. All materials removed from the basin will be transported offsite in accordance with the requirements stipulated in the proposed 35 Ill. Adm. Code 845.740(b)(1). Finally, after this area of the West Ash Pond has been certified as closed in accordance with the proposed 35 Ill. Adm. Code 845.740(e), the contractor will begin placing structural fill to bring the grade elevation for the future SSC area up to the existing road elevation (*i.e.*, existing dike crest elevation). Once the structural fill for the SSC has been placed, the contractor will then proceed with clean closing the area of the West Ash Pond that will be repurposed as the Station's new Low Volume Waste Pond (see Section 1.4.2).

1.4.1.3 SSC COMPONENTS

MWG will purchase the remote SSC from a vendor who specializes in designing, furnishing, manufacturing, delivering, and installing this type of ash-handling system. MWG has already engaged in high-level conceptual design discussions with potential SSC vendors for budgetary purposes and, after considering multiple available options for this type of system, has elected to install a remote SSC that is prefabricated and a modularized design. Consequently, the lead time for installing this type of SSC is significantly less than that for a more traditional SSC.

The remote SSC will be tied into Waukegan's bottom ash-handling system by extending new ash sluice piping to the existing ash sluice lines adjacent to the West Ash Pond's northern dike. Effluent from the SSC system will drain via gravity to the existing Recycle Water Sump like the effluent from the existing ash ponds. Given the presence of economizer ash particles in Waukegan's ash sluice water, the SSC will be outfitted with lamella plates at its rear to further reduce the TSS in the sluice water. To improve the level of TSS removed from the sluice water prior to being discharged the Recycle Water Sump, MWG also intends to install a mobile clarifier downstream of the SSC. Finally, flocculant, coagulant, and caustic may be injected into the SSC to further reduce the TSS levels in the ash sluice water as necessary to reach levels conducive to the existing recycle pumps in the Recycle Water Sump.

Ash that settles out of the sluice water in the SSC will be collected in a hopper and subsequently conveyed up an inclined ramp. When the ash reaches the top of the ramp at the head of the SSC, it will be discharged into a temporary ash storage pile within the SSC enclosure's ash dewatering bunker. Water that drains from the ash pile will be collected by a trench network and sump pit, which will subsequently pump collected water to the Recycle Water Sump. Once the ash is dewatered enough to handle, it will be recovered from the bunker using front-end loaders or similar earthwork equipment and transferred onto haul trucks which will transport the ash to a permitted disposal or beneficial use facility offsite. The dewatering bunker will be sized to provide several days' worth of ash storage based on the Station's anticipated ash make rate.

1.4.1.4 BALANCE OF PLANT COMPONENTS

The SSC will be installed within an enclosed structure to prevent fugitive dust emissions from the temporary ash pile in the dewatering bunker and to protect the SSC from detrimental weather conditions (*e.g.*, severe cold during winter). Per drawing WKG-CSK-101 in Appendix A, the building will be divided into three areas: the process area, the ash dewatering bunker, and the truck loading area. Except for the end of its inclined ramp, the SSC will be located in the processing area which will also include the mechanical and electrical equipment ancillary to the SSC's operation. This equipment will include service air and water piping and a power distribution center (PDC). The latter will house the motor control centers (MCCs) and switchgear required to operate the remote SSC. Power is expected to be fed from the existing recirculation pumphouse that powers the return pumps in the Recycle Water Sump. A transformer will be installed adjacent to the

PDC to step the voltage down as necessary. Finally, MWG intends to construct a building large enough to support a second remote SSC that would provide redundancy in case one SSC breaks down unexpectedly which would cause an unplanned outage at the Station.

As previously discussed, temporary storage of the dewatered ash deposited by the SSC will be contained within the SSC enclosure's ash dewatering bunker. In accordance with the proposed 35 Ill. Adm. Code 845.120, concrete pushwalls will be installed along the perimeter of this area to contain the CCR material as its handled by the equipment loading it into trucks to be hauled offsite. The walls will be sufficiently designed to resist the impact forces from the equipment operating in this area (*e.g.*, front-end loader), and appropriate measures will be taken to ensure the walls are sufficiently durable to withstand repeated occurrences of these impact forces. Finally, the concrete floors in the bunker area will be sloped away from the temporary ash storage pile towards a runoff collection trench to ensure the CCR-impacted water is contained within the enclosure. This water will be ultimately collected by a sump and pumped to the Recycle Water Sump to be recirculated back into Station operations.

Currently, MWG intends to erect a fabric enclosure over the remote SSC, dewatering bunker, and truck loading area. MWG would procure a fabric enclosure from a vendor specializing in these types of structures. This fabric enclosure would be supported by an internal metal roof truss spanning between and supported by the external concrete walls of the SSC enclosure.

Finally, MWG plans to repave the existing gravel roads at the ash pond area with asphalt so that the roads can withstand the increased truck traffic to this area, especially during the winter. Trucks hauling the dewatered ash offsite will receive the material within a delineated area adjacent to the SSC enclosure's dewatering bunker. The pavement in this area will be sloped towards the storage area's collection trench to ensure any CCR-impacted runoff is contained. Appropriate fugitive dust control measures will be implemented during the loading process, including the use of water sprays or similar dust suppressants.

1.4.2 LOW VOLUME WASTE POND

Once the CCR and CCR-impacted materials are removed from the east channel of the West Ash Pond, this area of the West Ash Pond will be certified as closed in accordance with the proposed 35 Ill. Adm. Code 845.740. At this point, the portion of east channel not being repurposed for the remote SSC will be repurposed as the Station's new Low Volume Waste Pond to handle the non-CCR wastestreams currently being sent to the East Ash Pond. As shown on drawing WKG-CSK-102 in Appendix A, this new pond will provide approximately 3.5 acres of storage area for non-CCR wastestreams produced by the Station. MWG plans to line the pond with a geomembrane liner.

To construct the Station's new Low Volume Waste Pond, the contractor that placed the structural fill to support the remote SSC – which will form the northern "dike" for the new pond – will first regrade the pond floor as necessary to restore it to a relatively smooth surface after the existing liner and underlying soils have been excavated during the closure work. As the pond is re-graded, it will be compacted and/or rolled smooth and then lined with new geomembrane panels. Finally, a new dike between the east and west channels of the existing West Ash Pond will be constructed to form the new pond's storage area.

To convey non-CCR wastestreams to this new Low Volume Waste Pond, MWG will tie into the existing low-volume waste piping and Coal Yard Runoff Basin overflow piping at the northern end of the West Ash Pond with new piping that will extend along the West Ash Pond's existing partition dike. The pond inlet will be at the southern end of the pond. An outlet structure with a sump pump will be installed at the opposite end of the new pond to convey pond effluent to the Recycle Water Sump to be recirculated back into Station operations.

1.5 EXPLANATION & JUSTIFICATION OF TIME REQUESTED

Per the visual timeline representation and narrative discussion of the project schedule presented in Sections 2.0 and 3.0, respectively, MWG is requesting the EPA allow the East Ash Pond to continue operating until construction of the multiple technology solution discussed in the previous section is completed, which is currently expected to be October 11, 2023. During this period, the following CCR and non-CCR wastestreams would be placed into the East Ash Pond since they do not currently have alternative disposal options available at Waukegan or offsite:

- Unit 7 and 8 ash sluice water (until October 11, 2023),
- Unit 7 Ash Sluice Overflow Tank effluent (until October 11, 2023),
- Coal Yard Runoff Basin overflow water (until June 16, 2023), and
- Main Collection Tank effluent (until June 16, 2023).

MWG is requesting this additional time to continue operating the East Ash Pond because it is technically infeasible to clean close the east channel of the West Ash Pond and repurpose it to support installation of a remote SSC and construction of a new Low Volume Waste Pond prior to April 11, 2021. This is primarily due to the ongoing Illinois rulemaking for regulating CCR surface impoundments. A detailed explanation and justification for the time required to clean close the east channel of the West Ash Pond, install the remote SSC and construct the Low Volume Waste Pond are provided in the narrative of the project schedule in Section 3.0.

Finally, pursuant to the recently-revised alternative closure requirements in the EPA CCR Rule, MWG also evaluated whether temporary storage could be provided for the preceding CCR and non-CCR wastestreams that will be sent to the East Ash Pond until the remote SSC and Low Volume Waste Pond are operational. This evaluation is summarized in Section 1.5.3.

1.5.1 DEVELOPMENT & EVALUATION OF ALTERNATIVE DISPOSAL METHODS

The analysis of alternative disposal capacity options to replace Waukegan's East and West Ash Ponds presented in Section 1.4 is the result of several years' worth of evaluations and studies performed by MWG. In the summer of 2015, shortly after the EPA finalized its new CCR Rule, MWG initiated a study of potential alternative bottom ash disposal options to replace the existing East and West Ash Ponds in case they were determined to violate the Rule's groundwater protection standards or uppermost aquifer location restriction and therefore be subject to the closure-for-cause provisions in 40 CFR 257.101. Following the 2015 update to the EPA ELG Rule, MWG expanded the scope of this study to evaluate multiple technology solutions that would provide compliance with both the EPA CCR and ELG Rules for the CCR and non-CCR wastestreams currently managed in the East and West Ash Ponds. Although there was no regulatory driver to replace the East or West Ash Ponds at the time as neither pond required corrective measures be implemented to remedy statistically significant exceedances of groundwater protection standards, MWG continued to evaluate and refine the conceptual designs for the multiple technology solutions proposed in this study through 2016 and 2017.

As shown in the visual timeline representation of the project schedule in Section 2.0, and as previously stated in Section 1.3, MWG commenced detailed assessments of the different alternative disposal methods for the CCR wastestreams at its Waukegan, Powerton, and Will County facilities shortly after the August 2018 *USWAG* decision since the active CCR surface impoundments at these three facilities were all determined to be non-compliant with the EPA CCR Rule's liner design criteria. These assessments expanded the studies performed between 2015 and 2017 and evaluated each option's technical feasibility and implementation requirements (*e.g.*, schedule and physical space). During this planning phase, MWG also prepared budgetary cost estimates and high-level implementation schedules for each option to determine forthcoming capital expenditures and asset retirement obligations.

1.5.2 ILLINOIS EPA RULEMAKING

While MWG was refining its conceptual designs for developing alternative bottom ash disposal capacity at Waukegan, Illinois Senate Bill 9 was introduced in the Illinois Senate, which sought to establish state-specific regulations for constructing, operating, and closing CCR surface impoundments at Illinois power plants. Illinois Senate Bill 9 was first introduced in the Illinois Senate in early January 2019 (Ref. 14) and ultimately passed by the Illinois General Assembly on May 27, 2019. On July 30, 2019, the governor signed the bill into law as Illinois Public Act 101-0171. A primary purpose of the Act was to authorize and instruct the Illinois EPA to propose rules regulating the construction, operation, and closure of CCR surface impoundments at Illinois power plants (Ref. 2, § 22.59(g)). Moreover, § 22.59(b)(2) of the Act prohibits the construction, installation, modification, operation, or closure of any CCR surface impoundment without a permit issued by the Illinois EPA. Thus, MWG cannot implement the multiple technology solution selected to replace the East and West Ash Ponds at Waukegan or, in fact, any solution involving the construction of a new CCR surface impoundment and/or retrofit or closure of Waukegan's existing CCR surface impoundments until a Final Illinois CCR Rule is adopted by the Illinois Pollution Control Board and the Illinois EPA issues the appropriate construction permits.

As discussed in Section 1.1.2.3.1, the Illinois EPA published its draft regulations for CCR surface impoundments in December of 2019 for public comment. At this time, MWG reviewed the draft regulations and updated its 2018-2019 evaluation of alternative bottom ash disposal options for Waukegan based on the Illinois EPA's draft regulations. MWG performed a similar update after the Illinois EPA finalized its draft regulations and submitted the Proposed Illinois CCR Rule to the Illinois Pollution Control Board on March 30, 2020. Per § 22.59(g) of Illinois Public Act 101-0171, the Illinois Pollution Control Board has one year to adopt the Final Illinois CCR Rule into 35 Ill. Adm. Code. This timeline would establish a Final Illinois CCR Rule and corresponding permit program by the end of March 2021.

As previously discussed in Section 1.4.1.1, three other potential sites were evaluated within the Station's property in addition to the northeastern corner of the West Ash Pond to install the SSC and its ancillary equipment. Ultimately, MWG concluded that the West Ash Pond site was the only location where it would be technically feasible to install a remote SSC. However, given the statutory limitations on constructing, modifying, and closing CCR surface impoundments at Illinois power plants and the ongoing rulemaking and development of the Illinois EPA's permitting program, MWG is unable to initiate the work required to repurpose the East or the West Ash Pond to support the multiple technology solution selected to replace these non-compliant ash ponds.

Because a Final Illinois CCR Rule and corresponding permit program is not expected until the end of March 2021, it is technically infeasible for MWG to implement this solution – or any solution involving the modification of the East and West Ash Ponds and/or construction of a new CCR surface impoundment – by April 11, 2021. Further, MWG is unable to complete final engineering and initiate any procurement activity until the Final Illinois CCR Rule is published, the Illinois EPA's requirements are known, and planning is approved by the Illinois EPA within the agency's permit process. However, as previously discussed, planning components of the multiple technology solution that could be initiated without a Final Illinois CCR Rule are indeed ongoing. Accordingly, MWG has developed a plan for implementing the option selected that minimizes the schedule impacts of the Illinois EPA's current rulemaking and future permitting processes, thereby providing alternative disposal capacity for the CCR and non-CCR wastestreams currently being sent to the East Ash Pond as soon as technically feasible. This plan is illustrated in the visual representation of the project schedule and corresponding narrative discussion in Sections 2.0 and 3.0, respectively.

1.5.3 TEMPORARY ON-SITE DISPOSAL OF WASTESTREAMS

MWG considered two temporary disposal solutions for the CCR and non-CCR wastestreams that will continue to be sent to the East Ash Pond until the remote SSC and Low Volume Waste Pond are operational on October 11, 2023 and June 16, 2023, respectively: tanks and water treatment trailers.

1.5.3.1 STORAGE TANKS

Based on MWG’s current forecast of obtaining permanent alternative disposal capacity to replace the East Ash Pond, enough tanks would need to be procured and installed at the site to provide approximately 35 months’ worth of storage for the CCR wastestreams produced by the plant. Similarly, the station would need to install enough tanks to provide about 30 months’ worth of storage for the non-CCR wastewater produced by the plant that is currently being sent to the East Ash Pond. Given the average daily inflows of 1.9 and 3.0 MGD of CCR and non-CCR wastewater currently going into the East Ash Pond (see Table 2), these temporary tanks would need to provide almost 4.8 billion gallons’ worth of storage.

A temporary solution to store the CCR and non-CCR wastestreams currently going into the East Ash Pond would be to install a network of large modular tanks on the Station’s available property. The largest modular tank identified during MWG’s review of tanks available on the market for temporary wastewater storage was a 1.7-million-gallon tank (Ref. 15). The effluent from Waukegan’s Coal Yard Runoff Basin, which is contact stormwater runoff from the Coal Yard and western portion of the Station’s property, is the smallest wastestream (based on flow) currently managed by the East Ash Pond (1.0 MGD per Table 2). For this wastestream, approximately 540 of these modular tanks would need to be installed to provide adequate storage for just this wastestream. Assuming 540 of these tanks are available on the market, approximately 490 acres of land would need to be identified at the Waukegan site to support this many tanks (each tank occupies approximately 0.90 of an acre). Waukegan’s property only consists of approximately 200 acres of land which has been predominately developed to support the Station’s operations. Thus, modular tanks are not a technically feasible solution for this wastestream or the other CCR and non-CCR wastestreams currently being sent to the East Ash Pond.

1.5.3.2 WASTEWATER TREATMENT TRAILERS

While it is technically infeasible to use tanks to temporarily store and/or treat the large CCR and non-CCR flows currently going into the East Ash Pond, wastewater treatment trailers from a vendor that specializes in such technology could provide a temporary solution for these wastestreams. These trailers can remove TSS, oil, and grease from and neutralize the pH of the CCR and non-CCR wastestreams currently going into the East Ash Pond (all of which are required under Waukegan’s existing NPDES permit), among other treatment capabilities. These trailers can also remove heavy metals from the CCR wastestreams. The amount of wastewater a trailer can treat is dependent on the water chemistry, but 1 MGD is generally achievable.

Per Table 2, approximately 4.9 MGD of CCR and non-CCR wastestreams are currently being managed by the East Ash Pond. Therefore, it would take about five wastewater treatment trailers to handle and treat the wastestreams currently going into the East Ash Pond. While it may be feasible to find space on the plant site for five trailers, the implementation of this temporary system would require time to perform the engineering and design of piping to and from the trailers, obtain an NPDES construction permit, and installation of the system itself. Moreover, it should be recognized that there is a limited number of these wastewater treatment trailers available on the market, which is an important consideration given the number of power plants that may need to implement temporary treatment solutions to comply with the alternative closure standards in the EPA CCR Rule.

Assuming Waukegan is able to procure and find space for five wastewater treatment trailers, it would take a similar timeframe to implement this temporary solution as it would to divert the non-CCR wastestreams from the East Ash Pond to the Station's clarifiers (2.5 years). Based on the discussion in Section 1.3.1.2.2 about utilizing the existing Station clarifiers for the subject non-CCR wastestreams, MWG does not consider wastewater treatment trailers to be an appropriate alternative solution for the wastestreams currently being sent to the East Ash Pond because (1) the permanent alternative disposal capacity solution system proposed herein will be operational within a similar timeframe, and (2) the Illinois EPA will likely prioritize the closure construction permit applications for the East and West Ash Ponds incorporated into the modified bottom ash treatment system proposed herein over the permit applications required to construct a temporary treatment system.

2.0 PROJECT SCHEDULE: VISUAL TIMELINE

This section presents a visual timeline representation of MWG's schedule for installing a remote SSC and its ancillary equipment and constructing a new Low Volume Waste Pond. Pursuant to 40 CFR 257.103(f)(iv)(1)(A)(*2*), the following visual timeline representation of the project schedule shows:

- How each phase and the steps within that phase interact with or are dependent on each other and the other phases,
- All of the steps and phases that can be completed concurrently, and
- The total time needed to install a remote SSC and its ancillary equipment and to construct a new Low Volume Waste Pond.

As shown in its visual timeline representation, the project schedule is divided into the following phases:

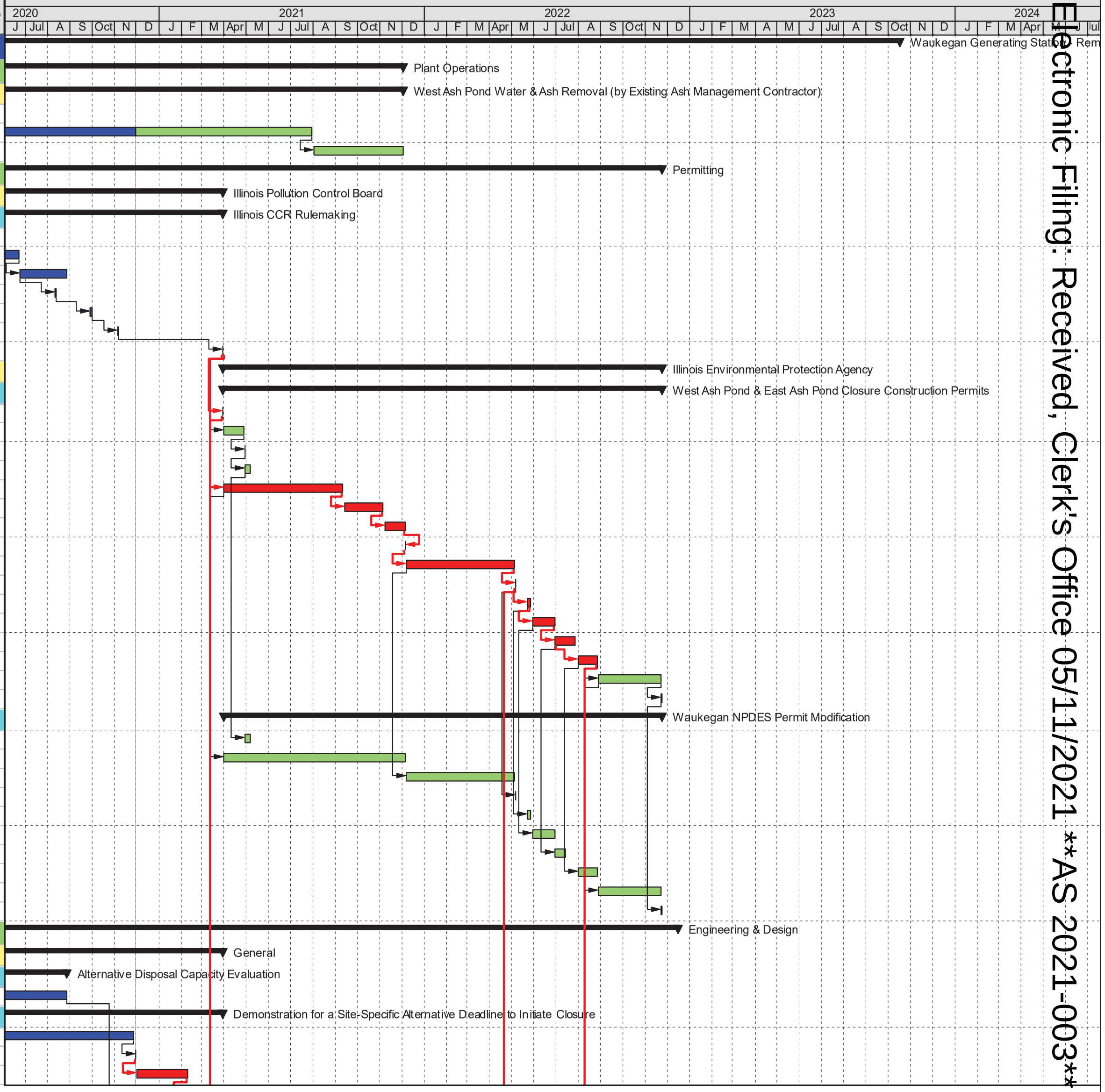
- Plant Operations,
- Permitting,
- Engineering & Design,
- Contractor Selection,
- Equipment Fabrication & Delivery,
- Construction, and
- Start-Up & Implementation.

See Section 3.0 for the corresponding narrative discussion of the project schedule.

Midwest Generation, LLC
Waukegan Generating Station - Remote SSC

Engineering, Procurement and Construction Schedule

Activity ID	Activity Name	Dur	Start	Finish	% Comp
Waukegan Generating Station - Remote SSC					
Plant Operations					
West Ash Pond Water & Ash Removal (by Existing Ash Management Contractor)					
1.1.1	Take West Ash Pond Out of Service for Cleaning	0	01-Jun-20 A	01-Jun-20 A	100%
1.1.2	Draw Down Water & Dewater Impounded Ash	304	02-Jun-20 A	30-Jul-21	0%
1.1.3	Excavate Ash & Transport to Offsite Facility	90	02-Aug-21	03-Dec-21	0%
Permitting					
Illinois Pollution Control Board					
Illinois CCR Rulemaking					
2.1.1.1	Illinois EPA Submits Proposed Illinois CCR Rule to IPCB	0	30-Mar-20 A	30-Mar-20 A	100%
2.1.1.2	Prepare & Submit Pre-Filed Questions to Illinois EPA	60	31-Mar-20 A	23-Jun-20 A	100%
2.1.1.3	Prepare & Submit Pre-Filed Testimonies to IPCB	46	24-Jun-20 A	27-Aug-20 A	100%
2.1.1.4	Participate in First IPCB Hearing on Proposed Illinois CCR Rule	2	11-Aug-20 A	13-Aug-20 A	100%
2.1.1.5	Participate in Second IPCB Hearing on Proposed Illinois CCR Rule	2	29-Sep-20 A	01-Oct-20 A	100%
2.1.1.6	IPCB Closes Record on Proposed Illinois CCR Rulemaking	1	06-Nov-20 A	06-Nov-20 A	100%
2.1.1.7	IPCB Adopts CCR Regulations into Title 35 of Illinois Admin. Code	1	30-Mar-21	30-Mar-21	0%
Illinois Environmental Protection Agency					
West Ash Pond & East Ash Pond Closure Construction Permits					
2.2.1.01	Illinois EPA Publishes Permit Application Forms	1	30-Mar-21	30-Mar-21	0%
2.2.1.02	Determine Closure Category Designation (845.700(c))	21	31-Mar-21	28-Apr-21	0%
2.2.1.03	Submit Closure Category Designation (845.700(c))	1	29-Apr-21	29-Apr-21	0%
2.2.1.04	Pre-Application Meeting with Illinois EPA	5	30-Apr-21	06-May-21	0%
2.2.1.05	Perform Closure Alternatives Analysis (845.710(b))	118	31-Mar-21	10-Sep-21	0%
2.2.1.06	Schedule & Hold Public Meetings (845.710(e) & 845.240(a))	40	13-Sep-21	05-Nov-21	0%
2.2.1.07	Finalize Closure Plan (845.710(f) & 845.720(b))	21	08-Nov-21	06-Dec-21	0%
2.2.1.08	Submit Closure Construction Permit Applications	1	06-Dec-21	06-Dec-21	0%
2.2.1.09	Illinois EPA Reviews Permit Application	108	07-Dec-21	05-May-22	0%
2.2.1.10	Illinois EPA Issues Draft Permit (845.250)	1	06-May-22	06-May-22	0%
2.2.1.11	Illinois EPA Publishes Public Notice of Draft Permit (845.260(b))	5	23-May-22	27-May-22	0%
2.2.1.12	Illinois EPA Accepts Public Comments (845.260(c))	23	30-May-22	29-Jun-22	0%
2.2.1.13	Illinois EPA Issues Notice of Public Hearing (845.260(e))	20	30-Jun-22	27-Jul-22	0%
2.2.1.14	Illinois EPA Holds Public Hearing (845.260(d))	20	01-Aug-22	26-Aug-22	0%
2.2.1.15	Illinois EPA Reviews Public Comments (845.270(a))	62	29-Aug-22	22-Nov-22	0%
2.2.1.16	Illinois EPA Issues Final Permit (845.270(b))	1	23-Nov-22	23-Nov-22	0%
Waukegan NPDES Permit Modification					
2.2.2.01	Pre-Application Meeting with Illinois EPA	5	30-Apr-21	06-May-21	0%
2.2.2.02	Prepare & Submit Permit Application	179	31-Mar-21	06-Dec-21	0%
2.2.2.03	Illinois EPA Reviews Permit Application	108	07-Dec-21	05-May-22	0%
2.2.2.04	Illinois EPA Issues Draft Permit	1	06-May-22	06-May-22	0%
2.2.2.05	Illinois EPA Publishes Public Notice of Draft Permit	5	23-May-22	27-May-22	0%
2.2.2.06	Illinois EPA Accepts Public Comments	23	30-May-22	29-Jun-22	0%
2.2.2.07	Illinois EPA Issues Notice of Public Hearing	10	30-Jun-22	13-Jul-22	0%
2.2.2.08	Illinois EPA Holds Public Hearing	20	01-Aug-22	26-Aug-22	0%
2.2.2.09	Illinois EPA Reviews Public Comments	62	29-Aug-22	22-Nov-22	0%
2.2.2.10	Illinois EPA Issues Final Permit	1	23-Nov-22	23-Nov-22	0%
Engineering & Design					
General					
Alternative Disposal Capacity Evaluation					
3.1.1.1	Develop & Evaluate Alternative Disposal Capacity Solutions	507	19-Sep-18 A	28-Aug-20 A	100%
Demonstration for a Site-Specific Alternative Deadline to Initiate Closure					
3.1.2.1	Prepare & Review	242	26-Dec-19 A	27-Nov-20 A	100%
3.1.2.2	Submit to U.S. EPA	1	30-Nov-20	30-Nov-20	0%
3.1.2.3	U.S. EPA Reviews Demonstration	51	01-Dec-20	09-Feb-21	0%



Actual Work	Critical Remaining Work
Remaining Work	Current Milestone
◆ Actual Milestone	Summary
WBS Summary Act	

Page 1 of 5

TASK filter: All Activities

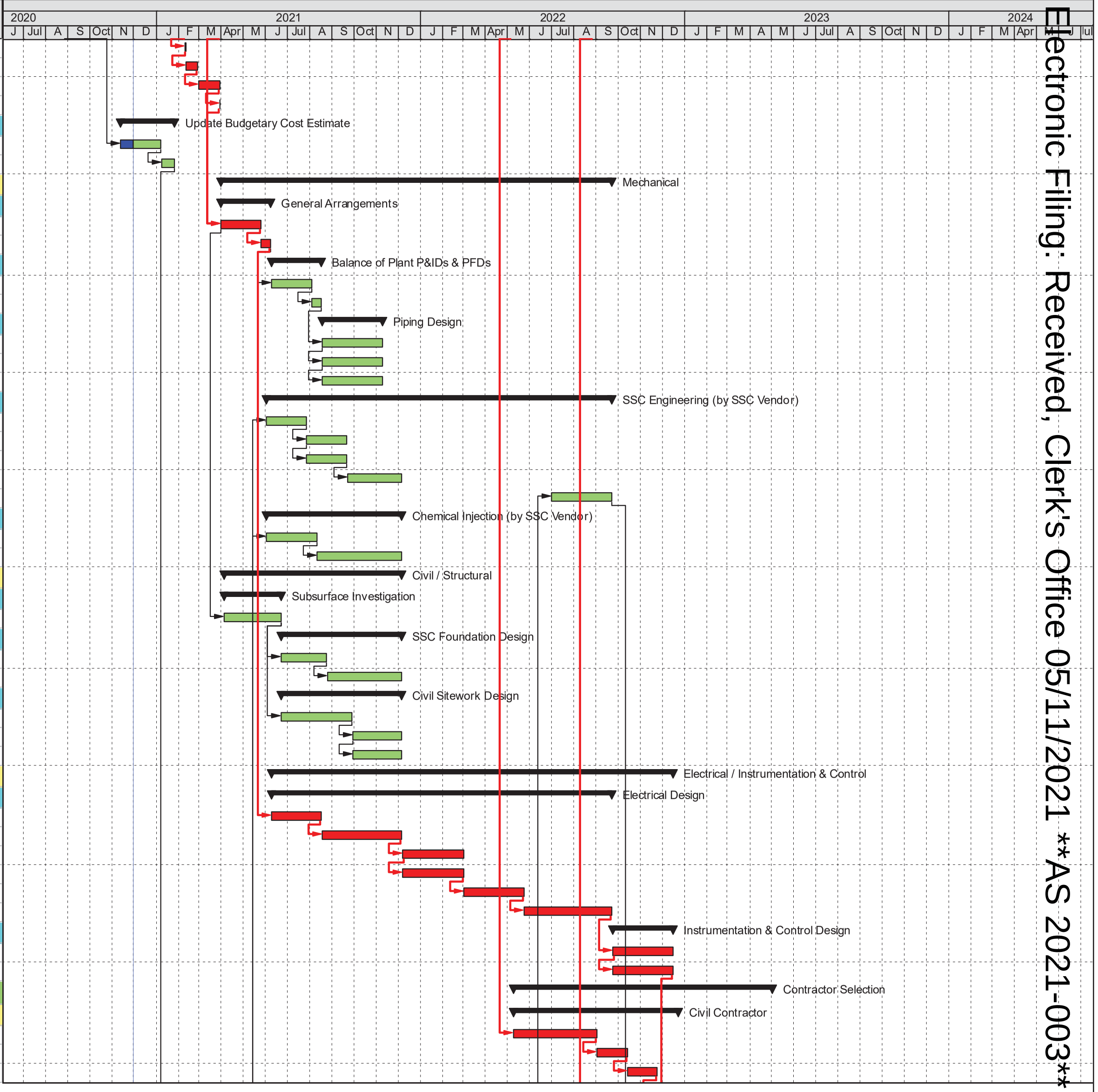
Database Location: FPT04>WGS Layout:Waukegan WBS

Date: 30-Nov-20
Data Date: 30-Nov-20

Midwest Generation, LLC
Waukegan Generating Station - Remote SSC

Engineering, Procurement and Construction Schedule

Activity ID	Activity Name	Dur	Start	Finish	% Comp
3.1.2.4	U.S. EPA Publishes Proposed Decision	1	10-Feb-21	10-Feb-21	0%
3.1.2.5	Public Comment Period on U.S. EPA Proposed Decision	12	11-Feb-21	26-Feb-21	0%
3.1.2.6	U.S. EPA Reviews Public Comments	21	01-Mar-21	29-Mar-21	0%
3.1.2.7	U.S. EPA Publishes Final Decision	1	30-Mar-21	30-Mar-21	0%
Update Budgetary Cost Estimate					
3.1.3.1	Prepare & Review	40	13-Nov-20 A	07-Jan-21	0%
3.1.3.2	Issue for Use	12	08-Jan-21	25-Jan-21	0%
Mechanical					
General Arrangements					
3.2.1.1	Prepare & Review	40	31-Mar-21	25-May-21	0%
3.2.1.2	Issue for Use	10	26-May-21	08-Jun-21	0%
Balance of Plant P&IDs & PFDs					
3.2.2.1	Prepare & Review	40	09-Jun-21	03-Aug-21	0%
3.2.2.2	Issue for Use	10	04-Aug-21	17-Aug-21	0%
Piping Design					
3.2.3.1	Design Low-Volume Waste Pond Pipes & Size Return Pump	60	18-Aug-21	09-Nov-21	0%
3.2.3.2	Design Bunker Sump Drain Pipe	60	18-Aug-21	09-Nov-21	0%
3.2.3.3	Size SSC Water & Service Air Piping	60	18-Aug-21	09-Nov-21	0%
SSC Engineering (by SSC Vendor)					
3.2.4.1	Create General Arrangement Drawings for SSC Equipment	40	02-Jun-21	27-Jul-21	0%
3.2.4.2	Create P&IDs for SSC Equipment	40	28-Jul-21	21-Sep-21	0%
3.2.4.3	Design Structural Steel Supports	40	28-Jul-21	21-Sep-21	0%
3.2.4.4	Design New Ash Sluice Piping to SSC	54	22-Sep-21	06-Dec-21	0%
3.2.4.5	Design Programmable Logic Controller (PLC) for SSC	60	01-Jul-22	22-Sep-22	0%
Chemical Injection (by SSC Vendor)					
3.2.5.1	Sample & Analyze Ash Sluice Water	50	02-Jun-21	10-Aug-21	0%
3.2.5.2	Design Chemical Injection	84	11-Aug-21	06-Dec-21	0%
Civil / Structural					
Subsurface Investigation					
3.3.1.1	Perform Subsurface Investigation	57	05-Apr-21	22-Jun-21	0%
SSC Foundation Design					
3.3.2.1	Design SSC Foundation - Geotechnical	45	23-Jun-21	24-Aug-21	0%
3.3.2.2	Design SSC Foundation - Structural	74	25-Aug-21	06-Dec-21	0%
Civil Sitework Design					
3.3.3.1	Design Low-Volume Waste Pond	70	23-Jun-21	28-Sep-21	0%
3.3.3.2	Design Access Roads	49	29-Sep-21	06-Dec-21	0%
3.3.3.3	Design Site Grading	49	29-Sep-21	06-Dec-21	0%
Electrical / Instrumentation & Control					
Electrical Design					
3.4.1.1	Electrical Load List	50	09-Jun-21	17-Aug-21	0%
3.4.1.2	Grounding Design	79	18-Aug-21	06-Dec-21	0%
3.4.1.3	Prepare Single Line Diagrams	61	07-Dec-21	01-Mar-22	0%
3.4.1.4	Cable Design	61	07-Dec-21	01-Mar-22	0%
3.4.1.5	Prepare Triple Line Diagrams	59	02-Mar-22	23-May-22	0%
3.4.1.6	Prepare Cable Tabulations & Master Schematic Diagrams	88	24-May-22	22-Sep-22	0%
Instrumentation & Control Design					
3.4.2.1	Design Wiring from SSC PLC to Coal Breaker Building	61	23-Sep-22	16-Dec-22	0%
3.4.2.2	Design DCS Hardware Modifications	61	23-Sep-22	16-Dec-22	0%
Contractor Selection					
Civil Contractor					
4.1.1	Prepare & Issue Technical Specification & Commerical Terms	84	09-May-22	01-Sep-22	0%
4.1.2	Bid Period	30	02-Sep-22	13-Oct-22	0%
4.1.3	Bid Evaluation	29	14-Oct-22	23-Nov-22	0%



🟦 Actual Work	🟩 Remaining Work
🟥 Critical Remaining Work	◆ Current Milestone
◆ Actual Milestone	WBS Summary Act
Summary	

TASK filter: All Activities

Database Location: FPT04>WGS Layout:Waukegan WBS

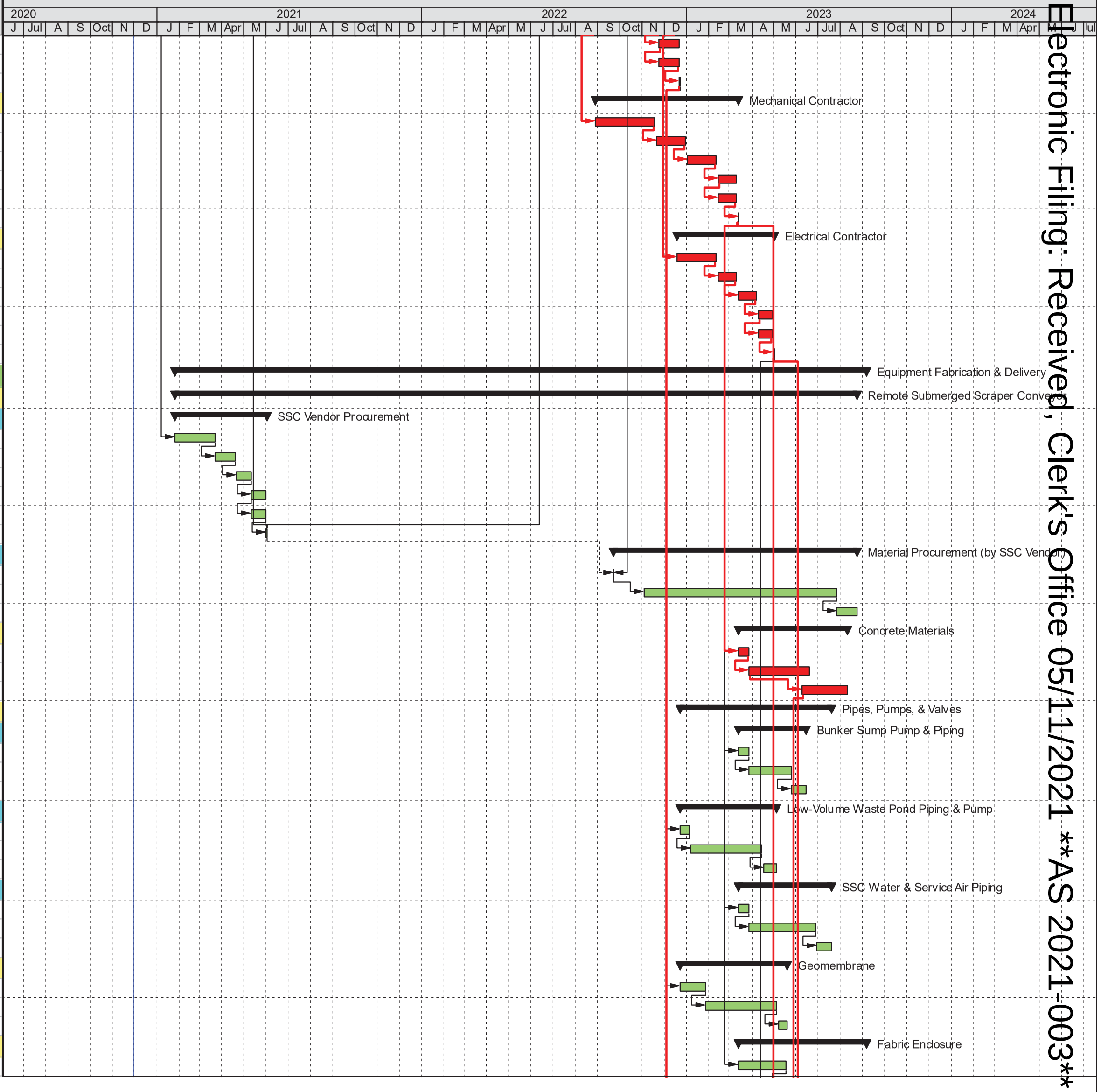
Date: 30-Nov-20
Data Date: 30-Nov-20

Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

Midwest Generation, LLC
Waukegan Generating Station - Remote SSC

Engineering, Procurement and Construction Schedule

Activity ID	Activity Name	Dur	Start	Finish	% Comp
4.1.4	Contract Negotiation	20	24-Nov-22	21-Dec-22	0%
4.1.5	Conform Technical Specfication for Contract	20	24-Nov-22	21-Dec-22	0%
4.1.6	Contract Award	1	22-Dec-22	22-Dec-22	0%
Mechanical Contractor					
4.2.1	Prepare & Issue Technical Specfication & Commerical Terms	60	29-Aug-22	18-Nov-22	0%
4.2.2	Bid Period	30	21-Nov-22	30-Dec-22	0%
4.2.3	Bid Evaluation	30	02-Jan-23	10-Feb-23	0%
4.2.4	Contract Negotiation	20	13-Feb-23	10-Mar-23	0%
4.2.5	Conform Technical Specfication for Contract	20	13-Feb-23	10-Mar-23	0%
4.2.6	Contract Award	1	13-Mar-23	13-Mar-23	0%
Electrical Contractor					
4.3.1	Prepare & Issue Technical Specfication & Commerical Terms	40	19-Dec-22	10-Feb-23	0%
4.3.2	Bid Period	20	13-Feb-23	10-Mar-23	0%
4.3.3	Bid Evaluation	20	13-Mar-23	07-Apr-23	0%
4.3.4	Contract Negotiation	15	10-Apr-23	28-Apr-23	0%
4.3.5	Conform Technical Specfication for Contract	15	10-Apr-23	28-Apr-23	0%
4.3.6	Contract Award	1	01-May-23	01-May-23	0%
Equipment Fabrication & Delivery					
Remote Submerged Scraper Conveyor					
SSC Vendor Procurement					
5.1.1.1	Prepare & Issue Technical Specfication & Commercial Terms	40	26-Jan-21	22-Mar-21	0%
5.1.1.2	Bid Period	20	23-Mar-21	19-Apr-21	0%
5.1.1.3	Bid Evaluation	15	20-Apr-21	10-May-21	0%
5.1.1.4	Contract Negotiation	15	11-May-21	31-May-21	0%
5.1.1.5	Conform Technical Specfication for Contract	15	11-May-21	31-May-21	0%
5.1.1.6	Contract Award	1	01-Jun-21	01-Jun-21	0%
Material Procurement (by SSC Vendor)					
5.1.2.1	Material Order Received	1	22-Sep-22	22-Sep-22	0%
5.1.2.2	Fabrication	190	03-Nov-22	26-Jul-23	0%
5.1.2.3	Delivery	20	27-Jul-23	23-Aug-23	0%
Concrete Materials					
5.2.1	Material Order	10	14-Mar-23	27-Mar-23	0%
5.2.2	Fabrication (Detailing, Shop Drawing Approval)	60	28-Mar-23	19-Jun-23	0%
5.2.3	Delivery	45	09-Jun-23	10-Aug-23	0%
Pipes, Pumps, & Valves					
Bunker Sump Pump & Piping					
5.3.1.1	Material Order	10	14-Mar-23	27-Mar-23	0%
5.3.1.2	Fabrication	43	28-Mar-23	25-May-23	0%
5.3.1.3	Delivery	15	26-May-23	15-Jun-23	0%
Low-Volume Waste Pond Piping & Pump					
5.3.2.1	Material Order	10	23-Dec-22	05-Jan-23	0%
5.3.2.2	Fabrication	71	06-Jan-23	14-Apr-23	0%
5.3.2.3	Delivery	15	17-Apr-23	05-May-23	0%
SSC Water & Service Air Piping					
5.3.3.1	Material Order	10	14-Mar-23	27-Mar-23	0%
5.3.3.2	Fabrication	67	28-Mar-23	28-Jun-23	0%
5.3.3.3	Delivery	15	29-Jun-23	19-Jul-23	0%
Geomembrane					
5.4.1	Material Order	25	23-Dec-22	26-Jan-23	0%
5.4.2	Fabrication	71	27-Jan-23	05-May-23	0%
5.4.3	Delivery	10	08-May-23	19-May-23	0%
Fabric Enclosure					
5.5.1	Material Order	47	14-Mar-23	17-May-23	0%



Actual Work	Critical Remaining Work	◆ Actual Milestone	Summary
Remaining Work	◇ Current Milestone	WBS Summary Act	

TASK filter: All Activities

Database Location: FPT04>WGS Layout:Waukegan WBS

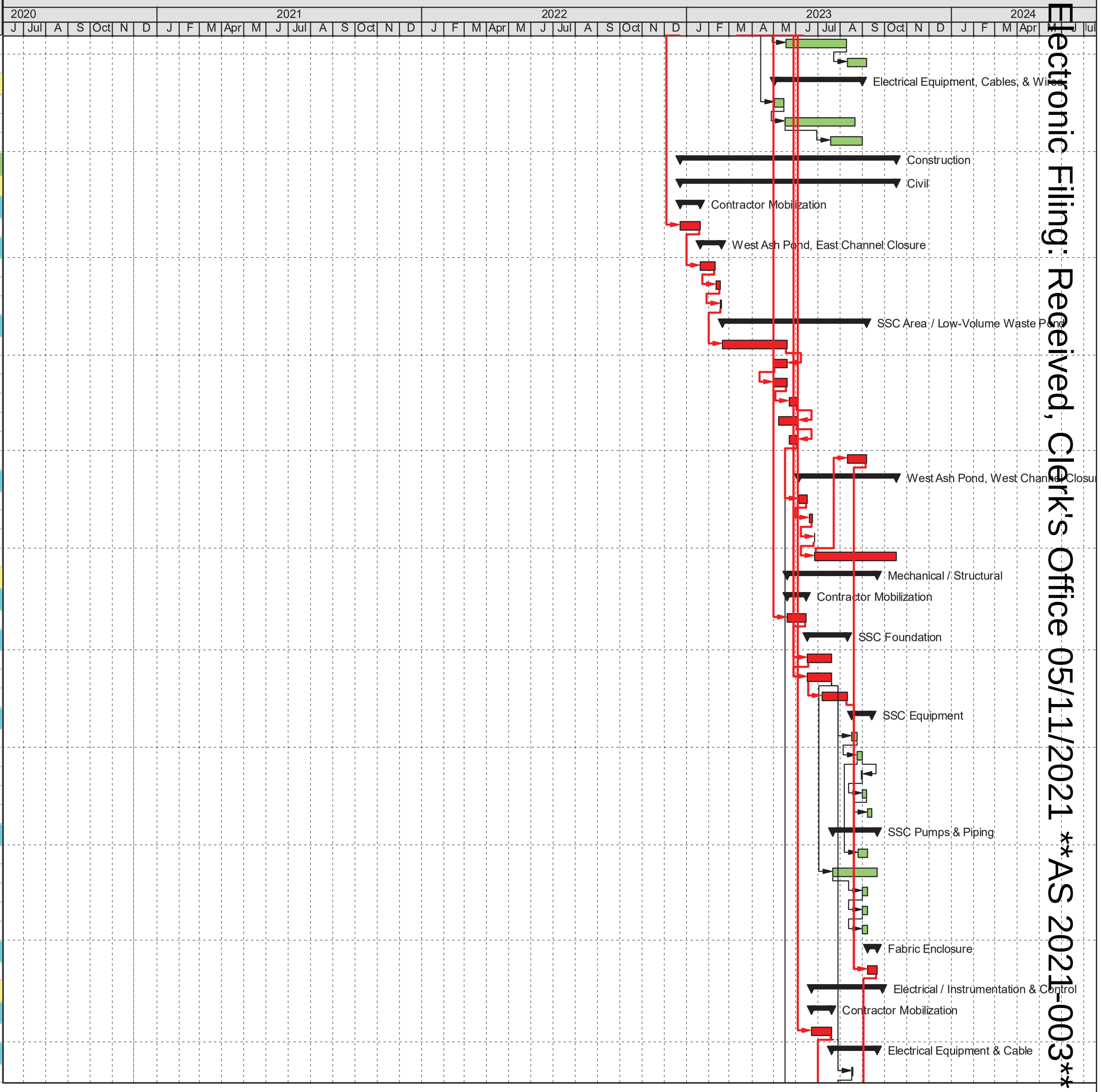
Date: 30-Nov-20
Data Date: 30-Nov-20

Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

Midwest Generation, LLC
Waukegan Generating Station - Remote SSC

Engineering, Procurement and Construction Schedule

Activity ID	Activity Name	Dur	Start	Finish	% Comp
5.5.2	Fabrication	60	18-May-23	09-Aug-23	0%
5.5.3	Delivery	20	10-Aug-23	06-Sep-23	0%
Electrical Equipment, Cables, & Wires					
5.6.1	Material Order	10	02-May-23	15-May-23	0%
5.6.2	Fabrication	70	16-May-23	21-Aug-23	0%
5.6.3	Delivery	31	19-Jul-23	30-Aug-23	0%
Construction					
Civil					
Contractor Mobilization					
6.1.1.1	Civil Work Contractor Mobilizes	20	23-Dec-22	19-Jan-23	0%
West Ash Pond, East Channel Closure					
6.1.2.1	Excavate Existing Liner & CCR-Impacted Soils (if Any)	15	20-Jan-23	09-Feb-23	0%
6.1.2.2	Decontaminate Pond Floor & Appurtenances	5	10-Feb-23	16-Feb-23	0%
6.1.2.3	Certify Closure of East Channel of West Ash Pond	1	17-Feb-23	17-Feb-23	0%
SSC Area / Low-Volume Waste Pond					
6.1.3.1	Place & Compact Structural Fill in SSC Area	65	20-Feb-23	19-May-23	0%
6.1.3.2	Prepare Subgrade in Low-Volume Waste Pond Area	15	01-May-23	19-May-23	0%
6.1.3.3	Place & Compact Structural Fill for Southern Dike	15	01-May-23	19-May-23	0%
6.1.3.4	Place Geomembrane Liner	10	22-May-23	02-Jun-23	0%
6.1.3.5	Install New Effluent Piping to Low-Volume Waste Pond	20	08-May-23	02-Jun-23	0%
6.1.3.6	Install New Return Piping / Pump to Recycle Water Sump	10	22-May-23	02-Jun-23	0%
6.1.3.7	Install New Access Roads at SSC Area	20	10-Aug-23	06-Sep-23	0%
West Ash Pond, West Channel Closure					
6.1.4.1	Excavate Existing Liner & CCR-Impacted Soils (if Any)	10	05-Jun-23	16-Jun-23	0%
6.1.4.2	Decontaminate Pond Floor & Appurtenances	5	19-Jun-23	23-Jun-23	0%
6.1.4.3	Certify Closure of West Channel of West Ash Pond	1	26-Jun-23	26-Jun-23	0%
6.1.4.4	Place Sand Fill in West Channel of West Ash Pond	80	27-Jun-23	16-Oct-23	0%
Mechanical / Structural					
Contractor Mobilization					
6.2.1.1	Mechanical Contractor Mobilizes	20	19-May-23	15-Jun-23	0%
SSC Foundation					
6.2.2.1	Install Electrical Grounding	25	16-Jun-23	20-Jul-23	0%
6.2.2.2	Install Concrete Base Mat	25	16-Jun-23	20-Jul-23	0%
6.2.2.3	Install SSC Enclosure & Bunker Walls	25	07-Jul-23	10-Aug-23	0%
SSC Equipment					
6.2.3.1	Install Structural Steel Supports for SSC	5	17-Aug-23	23-Aug-23	0%
6.2.3.2	Assemble Prefabricated Sections of SSC	5	24-Aug-23	30-Aug-23	0%
6.2.3.3	Assemble Clarifier	1	30-Aug-23	30-Aug-23	0%
6.2.3.4	Install Chain, Flights and Hydraulic Power Unit (HPU)	5	31-Aug-23	06-Sep-23	0%
6.2.3.5	Install Platforms, Handrails, and Ladders	5	07-Sep-23	13-Sep-23	0%
SSC Pumps & Piping					
6.2.4.1	Install New Ash Sluice Piping to SSC	10	25-Aug-23	07-Sep-23	0%
6.2.4.2	Install Water & Service Air Piping to SSC	44	21-Jul-23	20-Sep-23	0%
6.2.4.3	Install SSC Overflow Piping to Clarifier	6	31-Aug-23	07-Sep-23	0%
6.2.4.4	Install Clarifier Overflow Piping to Recycle Water Sump	6	31-Aug-23	07-Sep-23	0%
6.2.4.5	Install Clarifier Sludge Pump & Piping to SSC	6	31-Aug-23	07-Sep-23	0%
Fabric Enclosure					
6.2.5.1	Erect Fabric Enclosure	10	07-Sep-23	20-Sep-23	0%
Electrical / Instrumentation & Control					
Contractor Mobilization					
6.3.1.1	Electrical Contractor Mobilizes	20	22-Jun-23	19-Jul-23	0%
Electrical Equipment & Cable					
6.3.2.1	Install Transformer	1	17-Aug-23	17-Aug-23	0%



🟦 Actual Work	🟥 Critical Remaining Work
🟩 Remaining Work	◆ Actual Milestone
◇ Current Milestone	▼ Summary
▼ WBS Summary Act	

Page 4 of 5

TASK filter: All Activities

Database Location: FPT04>WGS Layout:Waukegan WBS

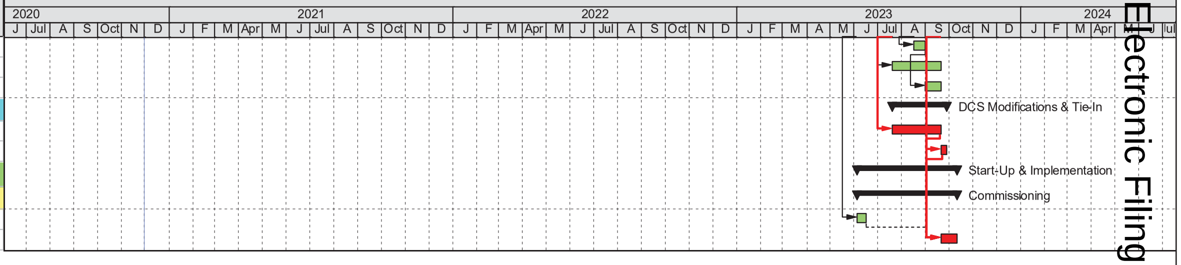
Date: 30-Nov-20
Data Date: 30-Nov-20

Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

Midwest Generation, LLC
Waukegan Generating Station - Remote SSC

Engineering, Procurement and Construction Schedule

Activity ID	Activity Name	Dur	Start	Finish	% Comp
6.3.2.2	Install MCCs	10	17-Aug-23	30-Aug-23	0%
6.3.2.3	Install Cable from Recirculation Pumphouse to PDC	45	20-Jul-23	20-Sep-23	0%
6.3.2.4	Install Cable from PDC to SSC	15	31-Aug-23	20-Sep-23	0%
DCS Modifications & Tie-In					
6.3.3.1	Install Wiring from SSC PLC to Coal Breaker Building	45	20-Jul-23	20-Sep-23	0%
6.3.3.2	Install DCS Hardware Modifications	5	21-Sep-23	27-Sep-23	0%
Start-Up & Implementation					
Commissioning					
7.1.1	Commission Low-Volume Waste Pond	10	05-Jun-23	16-Jun-23	0%
7.1.2	Commission SSC	15	21-Sep-23	11-Oct-23	0%



🟦 Actual Work 🟥 Critical Remaining Work ◆ Actual Milestone Summary
🟩 Remaining Work ◇ Current Milestone WBS Summary Act

Page 5 of 5

TASK filter: All Activities
Database Location: FPT04>WGS Layout:Waukegan WBS

Date: 30-Nov-20
Data Date: 30-Nov-20

3.0 PROJECT SCHEDULE: NARRATIVE DISCUSSION

This section presents a narrative of the project steps and sequencing necessary to develop the alternative disposal capacity selected to replace the East and West Ash Ponds. This narrative follows and supplements the visual timeline representation of the project schedule provided in Section 2.0.

Section 3.1 presents the steps MWG will take to install the remote SSC at Waukegan and its ancillary equipment and to construct the new Low Volume Waste Pond, and the general sequence in which these steps will occur. This workflow is based on the steps necessary to execute the project and is considered to be the fastest feasible timeline in which MWG can establish an EPA CCR Rule-compliant system at Waukegan for addressing the CCR and non-CCR wastestreams currently managed in the East and West Ash Ponds. The subsequent sections discuss the steps that occur within each phase of the project (as shown in the visual timeline representation), including the tasks that occur during each of those steps.

See Section 4.0 for a narrative discussion of the progress MWG has made to date in developing this alternative disposal capacity for the East and West Ash Ponds.

3.1 INSTALLATION ACTIVITIES & PROJECTED WORKFLOW

As currently designed, a new, EPA CCR Rule-compliant ash management system will be installed at Waukegan by executing the following sequence of activities:

- Cleaning the West Ash Pond;
- Preparing and permitting the final closure plan for the West Ash Pond;
- Procuring a vendor specializing in the design of SSCs to design, furnish, manufacture, and deliver a remote SSC to the Waukegan site;
- Designing the new Low Volume Waste Pond;
- Designing the balance-of-plant (BOP) components for the remote SSC;
- Procuring contractors to close the West Ash Pond, install the remote SSC and its BOP components, and construct the new Low Volume Waste Pond;
- Closing the east channel of the West Ash Pond and repurposing it for the remote SSC area and the new Low Volume Waste Pond, which will include:
    - Removing the existing liner and excavating CCR-impacted soils (if any), and
    - Certifying the pond’s closure in accordance with the Illinois EPA closure construction permit;
- Installing the remote SSC and its BOP components, which will include:
    - Placing and compacting structural fill,
    - Placing concrete for the SSC foundation and ash dewatering bunker,
    - Installing the remote SSC and clarifier;
    - Install the SSC piping, electrical cables and equipment, instrumentation, and controls,

    - Erecting a fabric enclosure, and
    - Constructing new access roads to and around the remote SSC area.
- Installing the new Low Volume Waste Pond, which will include:
    - Constructing a new dike,
    - Installing a geomembrane liner, and
    - Installing effluent piping to and return piping from the pond area; and
- Commissioning the remote SSC and the new Low Volume Waste Pond.

3.2 PLANT OPERATIONS

Although the West Ash Pond cannot be closed until MWG receives a closure construction permit from the Illinois EPA, Waukegan can remove the ash currently stored in the pond in accordance with historical Station cleaning practices(see Section 1.1.2.1). This work will expedite the future closure of the West Ash Pond. Once a closure construction permit is received, the only work left to clean close the West Ash Pond will be to remove the existing liner and to decontaminate the pond area and pond appurtenances.

Before any water or ash can be removed from the West Ash Pond, Waukegan must first cease sending all CCR and non-CCR wastestreams to the pond. Indeed, the Station recently took the West Ash Pond out of service for routine cleaning earlier this year. The Station will now draw down the water in the West Ash Pond and then dewater the ash currently stored therein.

Waukegan intends to remove the initial volume of free surface water from the West Ash Pond by natural means (*e.g.*, evaporation) and by allowing the water to drain towards the Recycle Water Sump in the northeast corner of the pond. Once the water level falls below the overflow weir elevation, the Station's Ash Management Contractor may excavate sumps and trenches within the impounded material to promote additional drainage and dewatering. The contractor may also use portable pumps to remove additional water by pumping water over the weir into the Recycle Water Sump. Finally, the contractor may utilize earthmoving equipment to move the ash within the pond to promote additional drainage and dewatering.

Once it has been dewatered enough to handle, the ash in the West Ash Pond will be dredged and removed from the pond, loaded onto trucks, and transported offsite to a beneficial-use or permitted disposal facility. Fugitive dust control measures (*e.g.*, water spray, dust suppressants) will be implemented to minimize airborne CCR particulates while the CCR is being handled.

Drawdown of the free surface water in the West Ash Pond is expected to continue through the winter of 2020 and into the summer of 2021. Waukegan's Ash Management Contractor is expected to mobilize to the site in the third quarter of 2021 and implement the necessary procedures to remove the remaining free water in the pond as well as to dewater the ash. It is currently anticipated that the contractor will start removing ash from the West Ash Pond by mid-summer 2021. Based upon the size of the West Ash Pond, it is expected that

Waukegan's Ash Management Contractor can remove the CCR stored in the pond by the end of the fall of 2021. Therefore, the West Ash Pond is currently scheduled to be emptied (*i.e.*, only small amounts of CCR and the liner remaining) by mid-November 2021.

It should be noted that the removal of ash in the West Ash Pond is not on the critical path of the overall project schedule so long as the ash is removed before the final closure work can start on the West Ash Pond (*i.e.*, Illinois EPA issues final permit and contractor mobilizes to the site). Given that contractor responsible for closing the West Ash Pond is not expected to be fully mobilized to the site until January of 2023 after the appropriate permits have been issued, this work by Waukegan's Ash Management Contractor is expected to be completed more than a year in advance of the final closure activities for the pond. As previously stated, removing the water and ash currently stored in the West Ash Pond in 2021 will expedite the pond's final closure and subsequent installation of the remote SSC and new Low Volume Waste Pond in 2023.

3.3 PERMITTING

MWG will need two permits from the Illinois EPA to implement the planned modifications to the bottom-ash handling operations at Waukegan. First, MWG will need construction permits under the forthcoming Final Illinois CCR Rule to close the West Ash Pond so that it can then be repurposed to support the remote SSC and the new Low Volume Waste Pond. Second, MWG will need to renew Waukegan's NPDES permit since the existing permit has expired and the current treatment methods are being modified for the Station's CCR wastestreams and some of its non-CCR wastestreams prior to being discharged to Lake Michigan via permitted Outfall 001. Since both permits will be issued by the Illinois EPA and are based on the same project, MWG intends to prepare both the CCR construction permit and NPDES permit renewal/modification applications concurrently and submit them at the same time. Imbedded in this strategy is MWG's hope that a renewed Waukegan NPDES permit can be obtained sooner than previous modifications, which have historically taken six to 12 months to receive after closure of the public comment period (*i.e.*, not including the Illinois EPA's initial review time or the time of the public comment period itself).

3.3.1 ILLINOIS CCR RULEMAKING

To better understand the Illinois EPA's intentions for regulating CCR surface impoundments at Illinois power plants, MWG has actively participated in the corresponding rulemaking process. After the Illinois EPA submitted its Proposed Illinois CCR Rule to the IPCB in late March 2020, stakeholders began preparing questions for the Illinois EPA to answer prior to the first IPCB hearing on the new rule in mid-August 2020. These questions were filed in late June 2020, and MWG received responses in early August 2020. MWG reviewed these responses and asked follow-up questions during the first IPCB hearing in which the Illinois EPA responded to questions from other stakeholders. As discussed later in Section 3.4.1, the Illinois EPA's responses to MWG's and the other stakeholders' questions were used to finalize MWG's selection of alternative disposal capacity for Waukegan's East and West Ash Ponds.

In addition to asking the Illinois EPA questions on its Proposed Illinois CCR Rule, MWG also prepared expert testimonies on the proposed regulations and suggested changes. MWG started preparing these testimonies after submitting its pre-filed questions to the Illinois EPA with the IPCB in late June 2020. These testimonies were the focus of the second IPCB hearing in late September 2020 and were filed with the IPCB in late August 2020, one month prior to the hearing.

3.3.2 WEST ASH POND & EAST ASH POND CLOSURE CONSTRUCTION PERMITS

3.3.2.1 PERMIT APPLICATIONS

Prior to closing the West and East Ash Ponds, MWG must first receive closure construction permits from the Illinois EPA to perform the work. Indeed, per Illinois Public Act 101-0171, MWG cannot "close any CCR surface impoundment without a permit granted by the [Illinois EPA]." Preparation of the closure construction permit applications for these two CCR surface impoundments is also contingent on when the Illinois EPA publishes the corresponding application form. Per the Illinois EPA's answers to pre-filed questions it received ahead of the August 2020 Illinois Pollution Control Board or "IPCB" hearings on the Proposed Illinois CCR Rule, the agency will be making "every effort to have CCR permit specific application forms available by March 31, 2021" (Ref. 17). Accordingly, MWG expects to start preparing the closure construction permit application form for closing the East and West Ash Ponds by the beginning of April 2021, which is also when MWG expects to start preparing the final written closure plan for the East and West Ash Ponds and the required closure alternatives analysis. Since both documents are required in the permit application, MWG intends to prepare the closure construction permit application forms for closing the West and East Ash Ponds concurrently with the ponds' final written closure plans and the closure alternatives analysis.

Early in the permit application preparation process, MWG will seek to hold a pre-application meeting with the Illinois EPA to discuss the overall project, the preliminary closure method for the West and East Ash Ponds, and the agency's requirements and expectations. This meeting will likely occur in early May 2021 after MWG has submitted the closure category designations for the West and East Ash Ponds and has performed some preliminary engineering and design work.

Although not required to develop alternative disposal capacity for the East and West Ash Ponds, it is important to note that MWG will also need to prepare and submit operating permit applications for both ponds while simultaneously preparing the closure construction permit applications. Per the proposed 35 Ill. Adm. Code 845.230(d), MWG expects to have the initial operating permit applications for the East and West Ash Ponds completed and submitted to the Illinois EPA by September 30, 2021. Pursuant to the proposed 35 Ill. Adm. Code 845.230(d)(2), this application must contain, at a minimum:

- The ponds' histories of construction;

- An analysis of the chemical constituents found within the CCR and non-CCR wastestreams placed in both ponds (including all chemical additives and sorbent materials);
- Demonstrations that the ponds comply with the Proposed Illinois CCR Rule's location standards;
- Evidence that the permanent name markers for the ponds have been installed;
- Documentation that both ponds will be operated and maintained with a form of slope protection specified by the Proposed Illinois CCR Rule (*e.g.*, vegetative cover);
- Certifications of the ponds' Emergency Action Plans and fugitive dust control plans;
- Information on the ponds' groundwater monitoring program;
- Preliminary written closure plan;
- Initial written post-closure plan;
- Documentation on whether the ponds' liners comply with the proposed rule's liner design criteria; and
- Documentation of known groundwater protection standard exceedances and any corrective action taken.

In order to develop alternative disposal capacity for the East and West Ash Ponds as soon as technically feasible, MWG intends to prepare the closure construction and operating permit applications for both ponds at the same time once the Final Illinois CCR Rule is published. Accordingly, many of MWG's resources will be relied on to prepare both sets of applications for not only the East and West Ash Ponds but also for their CCR surface impoundments at Powerton, Will County, and Joliet. While many of the preceding documents are expected to be similar if not equivalent to the EPA CCR Rule compliance documentation already prepared for the East and West Ash Ponds, some documents may require more information to comply with the Final Illinois CCR Rule's requirements relative to those of the EPA CCR Rule. In the case of the chemical constituent analysis, MWG will need to sample the wastestreams currently going into the East and West Ash Ponds and have each sample analyzed for its chemical constituents.

3.3.2.2 CLOSURE PRIORITIZATION CATEGORY

The first step in the closing the East and West Ash Ponds will be determining each pond's closure prioritization category pursuant to the proposed 35 Ill. Adm. Code 845.700(g). The closure prioritization categories range from Category 1 (highest priority) to Category 7 (lowest priority) and will ultimately influence the permitting timeframe for closing the West Ash Pond. The Illinois EPA will prioritize issuing construction permits for Category 1 closures, then Category 2 closures, then Category 3 closures, and so forth. In accordance with the proposed 35 Ill. Adm. Code 845.700(c), MWG will assign and submit the closure category designations for the East and West Ash Ponds to the Illinois EPA within 30 days after the effective date of the Final Illinois CCR Rule. Based on an effective rule date of March 30, 2021, MWG therefore expects to submit a closure category designation for the East and West Ash Ponds to the Illinois EPA by the end of April 2021.

As its name indicates, the closure prioritization category establishes the Illinois EPA's priority for reviewing and processing closure construction permit applications. Accordingly, pursuant to 845.700(h), owners or operators of CCR surface impoundments with the highest closure priorities (Categories 1 through 4) are required to submit a closure construction permit application to the Illinois EPA no later than January 1, 2022. Conversely, closure construction permit applications for Category 5 CCR surface impoundments are not due to the Illinois EPA until July 1, 2022. Finally, Category 6 and 7 CCR surface impoundments do not require a closure construction permit application be submitted to the Illinois EPA until July 1, 2023.

Because the Station is located in an area of environmental justice concern as defined by the Illinois EPA (Ref. 16), MWG anticipates the West and East Ash Ponds will both be considered Category 3 CCR surface impoundments pursuant to the proposed 35 Ill. Adm. Code 845.700(g)(1). Conversely, MWG expects the Illinois EPA to have a lower closure priority for the Ash Surge and Bypass Basins at the Powerton Generating Station in Pekin, Illinois given that those ash ponds are not located in an area of environmental justice concern, have not impacted a potable water supply, are in compliance with the safety factors and location restrictions promulgated by the Proposed Illinois CCR Rule, and have not caused an exceedance of groundwater protection standards (Category 7 per the proposed 35 Ill. Adm. Code 845.700(g)(1)).

3.3.2.3 CLOSURE ALTERNATIVES ANALYSIS

Concurrent with determining the Illinois EPA closure prioritization categories for the East and West Ash Ponds, MWG will also commence an analysis of closure alternatives for both ponds. As stipulated in the proposed 35 Ill. Adm. Code 845.710(b), this analysis – which is also required by Illinois Public Act 101-0171 to be in the Final Illinois CCR Rule – must be performed before MWG can formally select a method for closing the West Ash Pond and thus before MWG can finalize the written closure plan for the pond. Pursuant to the proposed 35 Ill. Adm. Code 845.710(c), MWG must evaluate the following criteria for each closure method considered in the analysis:

- Level of effectiveness and protectiveness in the short- and long-terms;
- Ability to control future releases to the environment;
- Degree of difficulty to implement the closure method; and
- Extent to which concerns of residents impacted by the closure method are addressed, including CCR handling, transportation, and final disposal.

In addition to the preceding criteria, MWG must also:

- Evaluate whether a landfill can be constructed at the Waukegan site to dispose of the CCR removed from the East and/or West Ash Ponds,

- Prepare a Class 4 cost estimate per the Association for the Advancement of Cost Engineering's (AACE) classification standards,
- Perform groundwater contaminant transport modeling and corresponding calculations to demonstrate how each closure alternative will achieve compliance with the site's groundwater protection standards,
- Describe the fate and transport of contaminants in each closure method over time, and
- Evaluate each closure method's impact to waters in Illinois.

While the tasks required for the closure alternatives analysis can generally be performed concurrently, the overall analysis requires a thorough and exhaustive evaluation of potential methods for closing the East and West Ash Ponds and of the CCR contaminants therein. Moreover, MWG will also be preparing the written closure plans and the operating permit application forms (see Section 3.3.2.1) for both ponds concurrent with this closure alternatives analysis. Accordingly, this analysis is expected to take approximately five months to complete. Based on the IPCB publishing the Final Illinois CCR Rule by the end of March 2021, which will include the final requirements for the closure alternatives analysis, MWG plans to have the analysis completed and a preliminary closure method selected by mid-September 2021.

3.3.2.4 PUBLIC MEETINGS ON PROPOSED CLOSURE METHOD

Once MWG has completed the closure alternatives analysis required by the Proposed IL CCR Rule for the East and West Ash Ponds and has selected a preliminary closure method, MWG can then hold the public meetings with parties interested and/or affected by the ponds' future closures. Per the proposed 35 Ill. Adm. Code 845.240 and 845.710(e), MWG must hold at least two public meetings to discuss the proposed closure activities and the results from the closure alternatives analysis at least 30 days before submitting the corresponding closure construction permit application. It is anticipated that these meetings will take place approximately 60 days after MWG completes the closure alternatives analysis. To conduct a public meeting on the proposed closure method for Waukegan's ash ponds, MWG would first need to secure an accessible facility, hire a translator for non-English speaking residents, and provide recording services (30 days); then mail and post notices of the proposed project and meeting dates (10 days); and finally conduct the meetings (at least 14 days after anticipated last notice receipt date). This time is also necessary for MWG to adequately prepare for these meetings, which will include coordinating with their consultants and preparing presentation materials. Therefore, based on the closure alternatives analysis being completed by mid-September 2021, it is anticipated that MWG will hold these public meetings in early November 2021.

3.3.2.5 FINAL WRITTEN CLOSURE PLANS

After conducting the public meetings on the proposed method for closing the East and West Ash Ponds, MWG will select a final closure method pursuant to the proposed 35. Ill. Adm. Code 845.710(f). This final closure method will be described in each pond's final written closure plan, which will include the results of MWG's alternatives closure analysis and will address comments received during the public meetings as necessary. Although most of the written closure plan can and will be prepared as MWG performs the closure alternatives analysis, it cannot be finalized until after the public meetings. Pursuant to the proposed 35 Ill. Adm. Code 845.240(a), MWG will submit the final written closure plans, closure alternatives analysis, and closure construction permit applications for the East and West Ash Ponds no sooner than 30 days after holding the last public meeting. During these 30 days, MWG will review public comments, finalize the written closure plans, and finish preparing the closure construction permit application forms (see Section 3.3 for permitting requirements). Therefore, MWG expects to have the final written closure plans for the East and West Ash Ponds prepared and ready to submit to the Illinois EPA by early December 2021, approximately one month in advance of the deadline for submitting closure construction permit applications for Category 3 CCR surface impoundments pursuant to the proposed 35 Ill. Adm. Code 845.700(h).

3.3.2.6 ILLINOIS EPA REVIEW & PERMIT ISSUANCE

After MWG submits the closure construction permit applications for the East and West Ash Ponds to the Illinois EPA in early December 2021, the agency will begin reviewing applications and supplemental information (*i.e.*, closure plans and results from the closure alternatives analysis). The time required for the agency to perform its review and make a tentative determination on issuing a closure construction permit is unknown. However, MWG expects the initial Illinois EPA review to take at least five months because:

- The agency will likely receive a large volume of operating and closure construction permit applications for the 73 CCR surface impoundments the Illinois EPA has identified across 23 Illinois power plants;
- The agency will need to review the substantial amount of information required to be in the closure alternatives analysis (Ref. 6, § 845.710), which may also require reviews by other state agencies (*e.g.*, Illinois Department of Natural Resources); and
- The agency will need to efficiently allocate its resources to simultaneously cover NPDES permit modifications and renewals, ELG Rule assessments, and its new permit program for CCR surface impoundments.

Despite the preceding factors, MWG expects the closure construction permit applications for Waukegan's East and West Ash Ponds to be of a relatively high priority for the Illinois EPA given that they are located in an area of environmental justice concern (Ref. 16). Indeed, MWG expects the Illinois EPA to prioritize the closure construction permit application for the East and West Ash Ponds over the application it plans to submit for the Ash Surge and Bypass Basins at its own Powerton Generating Station, which is not located in an area of environmental justice concern. Thus, considering the amount of operating and closure permit applications the Illinois EPA is likely to receive by the end of 2021 and the relatively high closure priority for the Waukegan ash ponds, MWG presumes the earliest the Illinois EPA will be able to issue draft closure construction permits for the East and West Ash Ponds would be five months from the date MWG submits the corresponding application. Therefore, MWG expects the Illinois EPA to issue draft permits for closing the East and West Ash Ponds by early May 2022.

It should be noted that the assumed timeframe for receiving a draft permit from the Illinois EPA is significantly shorter than MWG's recent experience in renewing/modifying an NPDES permit with the agency. MWG submitted a renewal permit application for Waukegan's NPDES permit in September 2019 and has yet to receive the draft permit. However, given the recent focus by the Illinois EPA, the IPCB, the Illinois General Assembly, and the public on regulating CCR surface impoundments, MWG assumes that draft permits for operating, modifying, and closing ash ponds in Illinois will be issued in a more expeditious manner than previous experience with the Illinois EPA NPDES permitting program.

Upon issuing the draft closure construction permit for the East and West Ash Ponds, the Illinois EPA will prepare and distribute a public notice of its tentative decision to issue the permit. Per the proposed 35 Ill. Adm. Code 845.260(b), the Illinois EPA would distribute this notice at least 15 days after issuing the draft permit in early May 2022. Once the public notice is distributed, a 30-day public comment period on the draft permit would commence in accordance with the proposed 35 Ill. Adm. Code 845.260(c). Therefore, it is expected that the public comment period on the draft construction permits for closing the East and West Ash Ponds will span the month of June 2022.

During the public comment period, any person may submit a request for the Illinois EPA to hold a public hearing on the draft closure construction permits. Per the proposed 35 Ill. Adm. Code 845.260(d)(1), the Illinois EPA may hold this public hearing if "there exists a significant degree of public interest in the proposed permit." During the August 12, 2020 IPCB hearing on the Proposed Illinois CCR Rule, a representative from the Illinois EPA stated that the agency has historically held a public hearing for NDPES draft permits if anyone requests such a hearing (Ref. 19). The representative added, "I can't think of a recent example where we have denied anyone." Given this agency precedent; the statutory mandate in Illinois Public Act 101-0171 that the IPCB adopt final CCR regulations that "specify meaningful public participation procedures for the issuance of CCR surface impoundment construction and operating permits, including, but not limited to…an opportunity for a public hearing prior to permit issuance" (Ref. 2, § 22.59(g)(6)); and the general level of public participation made throughout Illinois's rulemaking process, MWG presumes that a public hearing will be requested during the 30-day public comment period on the East and West Ash Ponds closure construction permits and that the Illinois EPA will grant the public hearing.

Pursuant to the proposed 35 Ill. Adm. Code 845.260(e)(1), the Illinois EPA cannot hold a public hearing sooner than 30 days after notifying the public of the hearing date. Assuming it takes the agency approximately four weeks to schedule the hearing (reserving a location, notifying the public, hiring a translator for non-English speaking persons *etc*.), the public hearing cannot not occur until at least 60 days after the Illinois EPA agrees to hold one. Presuming a public hearing will be called near the end of the public comment period in late June 2022, it is anticipated that the public hearing will be held in late August 2022.

After consideration of the public comments the agency receives on the draft closure construction permit, including those submitted during the public hearing, the Illinois EPA will then make a final permit determination. During this time, the Illinois EPA will consider all timely comments submitted by the public and will prepare written responses to these comments. In MWG's experience with renewing its NPDES permits with the Illinois EPA for its power plants, it has generally taken the Illinois EPA several months to issue final permits after the completion of the public comment period. Moreover, the Illinois EPA has often extended the public comment period beyond the public hearing date (typically 30 days), which would be permitted under the proposed 35 Ill. Adm. Code 845.260(c)(4). In its response to pre-filed questions ahead of the August 2020 Illinois Pollution Control Board hearings (Ref. 14), the Illinois EPA states, "The proposed permitting process was modeled after the existing NPDES permit program, which also does not include a time frame for a final Agency decision. The complex nature of these applications, public notice requirements, and the opportunity for a public hearing, make it difficult to complete the process within a defined timeframe. Like the NPDES program, robust public participation is an essential part of this proposal. Not having a specific deadline allows for the maximum flexibility during the public notice and hearing processes."

Given the Illinois EPA's lack of a decision deadline for a final permit, MWG's experience in receiving final NPDES permits from the agency, and the precedence of the agency extending the public comment period beyond a public hearing, MWG presumes the Illinois EPA will require a few months after the public hearing to respond to public comments and finalize the closure construction permits for the East and West Ash Ponds. However, MWG also expects the Illinois EPA to prioritize issuing final permits for closing non-compliant CCR surface impoundments like the East and West Ash Ponds given the state's recent focus on establishing regulations and a corresponding permitting program for CCR surface impoundments in general and the public participation throughout the rulemaking process. Moreover, these ash ponds are located in an area of environmental justice concern. Thus, MWG assumes the agency will finish reviewing public comments approximately three months after the public hearing is held. This timeline would result in MWG receiving the final closure construction permits for the East and West Ash Ponds from the Illinois EPA by mid- to late November 2022, approximately 11 months after submitting the corresponding permit application to the agency.

As previously stated, this overall permitting timeline is based on MWG's experience with obtaining other permits from the Illinois EPA; the agency's need to allocate its resources to implement its new CCR permit program and to renew or modify the NPDES permits at power plants in Illinois in accordance with the EPA's revised ELG Rule; and the closure prioritization categories in the proposed 35 Ill. Adm. Code 845.700(g). A delay in this permitting timeframe may result in a delay in implementing the alternative disposal capacity selected for the East and West Ash Ponds within the requested timeframe.

3.3.3 WAUKEGAN NPDES PERMIT RENEWAL & MODIFICATION

Because this project will modify the treatment methods used for Waukegan's CCR wastestreams prior to being discharged to the Illinois River via permitted Outfall 001 and because the Station's NPDES permit has expired, MWG will need to renew Waukegan's NPDES permit and modify the current treatment methods historically implemented in accordance with the permit. Since this permit renewal is related to the same project for which the East and West Ash Ponds closure construction permit applications are being submitted, MWG intends to prepare the application for modifying Waukegan's NPDES permit concurrently with its preparation of the East and West Ash Ponds closure construction permits. By submitting the NPDES and CCR permit applications together, MWG expects that both permits can be processed together and will follow the same (or at least similar) review and public participation timeframes. Thus, MWG anticipates submitting the application for renewing Waukegan's NPDES permit to the Illinois EPA by early December 2021 and expects to have the final permit by mid- to late November 2022.

3.4 ENGINEERING & DESIGN

As Waukegan works to draw down the water level in the West Ash Pond, MWG will commence the final engineering and design work for the project. The engineering and design work for this project is expected to be performed by multiple disciplines. Accordingly, this work has been organized in the project schedule as follows:

- General,
- Mechanical,
- Civil / Structural, and
- Electrical / Instrumentation & Control.

In general, MWG plans to perform the general, mechanical, and civil / structural engineering and design work for the project concurrently with its preparation of the permit applications for closing the West and East Ash Ponds and for renewing and modifying Waukegan's NPDES permit. This will ensure that the engineering drawings and data necessary to support these permit applications for the new bottom ash and low volume waste-handling systems are provided (remote SSC and Low Volume Waste Pond, respectively). As MWG goes through the permitting process for the project, the final electrical and instrumentation and control (I&C) engineering and design work will be performed, with the goal of having all engineering and design work completed by mid-December 2022, shortly after the time MWG expects to have final CCR and NPDES construction permits from the Illinois EPA (*i.e.*, late November 2022).

3.4.1 GENERAL

General engineering and design commenced in September 2018, approximately one month after the *USWAG* decision, and focused on developing permanent alternative disposal capacity solutions for the

Waukegan CCR and non-CCR wastestreams sent to the East and West Ash Ponds. As previously discussed, this work focused on refining and adding to conceptual alternative disposal capacity designs developed in 2015 in addition to evaluating each design's technical feasibility, physical space requirements, implementation schedule, and capital cost. MWG also assessed the potential impacts of the EPA's forthcoming (at the time) revision to the ELG Rule to each potential solution.

After the Illinois EPA published its draft CCR surface impoundment regulations for comment in December of 2019, MWG reviewed the draft regulations and incorporated them into its alternative disposal capacity evaluation. MWG has continued updating its evaluation of alternative disposal capacity options for the East and West Ash Ponds throughout Illinois's CCR rulemaking and has actively participated in this rulemaking to better understand the Illinois EPA's intentions, including future permitting priorities and timeframes (see Section 3.3.1). Shortly after the IPCB's first hearing on the Proposed Illinois CCR Rule in mid-August 2020, during which the Illinois EPA responded to stakeholder questions on the proposed regulations (including MWG questions), MWG finalized its evaluation of alternative disposal capacity solutions for Waukegan's two CCR surface impoundments and selected the multiple technology solution described herein.

Shortly after the EPA published its proposed revisions to the alternative closure requirements in 40 CFR 257.103 in early December 2019, MWG began preparing this demonstration for a site-specific alternative deadline to initiate closure. MWG updated this demonstration concurrent with updates to its evaluation of alternative disposal capacity solutions for the bottom ash transport water sent to the East and West Ash Ponds in response to the Illinois rulemaking process for CCR surface impoundments. Pursuant to the final amendment to 40 CFR 257.103 published in late August 2020, MWG incorporated its evaluation of alternative disposal capacity solutions for the non-CCR wastestreams sent to both CCR surface impoundments at Waukegan. In accordance with 40 CFR 257.103(f)(3)(i), MWG has submitted this demonstration to the EPA for approval by November 30, 2020.

Upon completing this demonstration, MWG will begin updating the budgetary cost estimate prepared in 2019 for the multiple technology solution described in this demonstration in accordance with the revisions and refinements that have since been made to this alternative disposal capacity solution. MWG will then use this updated cost estimate to ensure adequate funding is allocated for this project. This work will include acquiring and/or confirming budgetary cost estimates and lead times from vendors (*e.g.*, remote SSC, fabric enclosure), revising and adding material quantities as necessary, and updating labor rates as necessary. Given that a budgetary cost estimate has already been prepared for this solution and only requires updating, it is expected the updated estimate will be prepared by early January 2021 and subsequently finalized by the end of that month. Once the budget for the project has been established, MWG will begin the process of procuring a vendor to design, furnish, manufacture, and deliver a remote SSC to the Waukegan site ("SSC Vendor") (see Section 3.6.1.1).

3.4.2 MECHANICAL

3.4.2.1 BALANCE OF PLANT COMPONENTS

After the Final Illinois CCR Rule is published in late March 2021, MWG can begin finalizing its plan for closing the West Ash Pond in accordance with the final Illinois EPA regulations. At this time, MWG will start finalizing the general arrangement for the remote SSC area and new Low Volume Waste Pond to be located within the eastern channel of the West Ash Pond, which will be clean closed and repurposed for these uses. MWG plans to prepare initial drafts of the general arrangement drawings for the project to present to the Illinois EPA during the planned pre-application meeting in early May 2021, a little more than a month after the final state rule has been promulgated (see Section 3.3.2.1). MWG will continue developing the general arrangement drawings after meeting with the Illinois EPA, incorporating design inputs from the agency on the proposed scheme as necessary. Final general arrangement drawings are expected to be issued for use in early June 2021 as design input for the SSC Vendor and the different engineering disciplines working on the project.

Once the general arrangement drawings have been issued for use, MWG will begin preparing the piping and instrumentation diagrams (P&IDs) and PFDs for the project’s BOP piping, equipment, and instrumentation required to operate the remote SSC and the new Low Volume Waste Pond. These diagrams are expected to be prepared concurrently with the SSC Vendor’s preparation of the corresponding general arrangement drawings and P&IDs for the remote SSC equipment, which will ensure all BOP piping and instrumentation required to operate the SSC equipment is accounted. This work will also include preparing the P&IDs and PFDs for the new piping, equipment, and instrumentation for operating the new Low Volume Waste Pond. Given these design activities and anticipated design iterations in collaboration with the SSC Vendor, MWG expects the BOP P&IDs and PFDs to be substantially completed within 2.5 months. Based on a start date of early June 2021, MWG expects to have the P&IDs and PFDs issued for use as design input for the SSC Vendor and the different engineering disciplines working on the project by mid-August 2021.

Once the BOP P&IDs and PFDs have been finalized, the final engineering and design work for the corresponding piping and mechanical equipment can commence. This work will include routing, sizing, designing supports for, and preparing isometric drawings for the piping to and from the Low Volume Waste Pond, the service air and water piping for the SSC, and the drain pipe from the ash dewatering bunker in the SSC enclosure to the Recycle Water Sump. The required size of the new pumps to convey effluent from the Low Volume Waste Pond to the Recycle Water Sump via the new return pipeline will also be determined at this time. This engineering and design work is expected to take three months to complete and therefore is scheduled to be completed by early November 2021.

3.4.2.2 REMOTE SSC COMPONENTS

As discussed in Section 1.4.1.3, MWG plans to procure a remote SSC for this project that is modular and for which the internal engineering and design for the equipment has been completed (*i.e.*, pre-engineered). Therefore, the engineering and design work for the remote SSC components is expected to be limited to the following activities that are site-specific to incorporating the equipment into Waukegan's bottom ash-handling system:

- Creating general arrangement drawings for the SSC equipment,
- Creating P&IDs for the SSC equipment,
- Designing structural support steel for the SSC equipment,
- Designing the ash sluice piping extension to the SSC equipment,
- Designing the programmable logic controller (PLC) for the SSC equipment to be tied into Waukegan's distributed control system (DCS), and
- Designing the chemical injection system for the SSC.

MWG anticipates having the SSC Vendor under contract by the beginning of June 2021 (see Section 3.6.1). At this time the SSC Vendor will begin preparing the general arrangement drawings for the SSC equipment and coordinating the overall design scheme with the BOP engineering and design work. Like the general arrangement drawings for the BOP components for this project, it is expected that the general arrangement for the new remote SSC at Waukegan will be completed within two months of starting the work. Based on the remote SSC engineering and design contract being awarded in early June 2021, it is expected that the general arrangement for the remote SSC equipment will be finalized by the end of July 2021.

Once the general arrangement for the remote SSC is finalized, the SSC Vendor can begin preparing the P&IDs for the SSC equipment and designing the structural steel supports for the equipment on its foundation. The latter will be used as design input for the engineering and design of the base mat for the SSC area. Accordingly, this work will be performed concurrently with the engineering and design work for the BOP piping and the SSC foundation. After finalizing the P&IDs for the SSC equipment, the SSC Vendor will begin routing, sizing, designing supports for, and preparing isometric drawings for the ash sluice piping to the remote SSC, which will tie into the Station's existing ash sluice piping near the SSC area (see drawing WKG-CSK-100). As previously mentioned, this work is expected to be completed concurrently with the closure construction and NPDES renewal permit applications that MWG is preparing to repurpose the West Ash Pond's eastern channel for this use. Accordingly, MWG expects the engineering and design work for the remote SSC to be substantially completed by early December 2021.

As shown on PFD WKG-CSK-PFD-002 in Appendix B, effluent from the SSC area will be conveyed to the existing Recycle Water Sump and recirculated back to the Station (similar to existing plant operations for the ash ponds). Accordingly, the TSS in the effluent discharged to the Recycle Water Sump will need to be reduced to a level conducive to the existing recycle pumps, which is a particular concern for the very fine economizer ash particles in Waukegan's bottom ash transport water. MWG intends to minimize the TSS in the SSC overflow water by (1) having lamella plates installed in the SSC, (2) installing a mobile clarifier, and (3) incorporating a chemical injection system into the SSC design. All three elements will be designed and procured by the SSC Vendor.

Of the three preceding methods for reducing TSS in the effluent sent to the Recycle Water Sump, the chemical injection system design will be site-specific to Waukegan. In general, this system will inject flocculant, coagulant, and caustic as necessary to reduce the TSS in the effluent from the mobile clarifier downstream of the SSC. A flocculant will promote conglomeration of the ash particles to promote faster sedimentation, and a coagulate will further promote settling of the finer economizer ash particles. Finally, a caustic solution will control the pH level of the effluent recirculated to the Station's boilers.

In order to estimate the amount of TSS being conveyed to the SSC, and therefore the amount of TSS that needs to be removed to support recirculation, the SSC Vendor will sample and analyze the ash sluice water at Waukegan. This activity will occur shortly after the SSC Vendor is awarded the contract for procuring the remote SSC and will help determine the impacts of the finer economizer ash particles on the SSC effluent's TSS. Using these test results, the SSC vendor will then be able to design an appropriate chemical injection system catered specifically to Waukegan's ash sluice water. This engineering and design work is expected to occur concurrently with the rest of the engineering and design activities for the remote SSC. Therefore, MWG expects the chemical injection system design to be substantially completed by early December 2021.

3.4.3 CIVIL / STRUCTURAL

The civil / structural engineering and design work will be completed concurrently with the mechanical engineering and design work described in the preceding section. The first design task will be to perform a subsurface investigation at the proposed SSC and Low Volume Waste Pond sites in the West Ash Pond in order to obtain geotechnical data to support the foundation work for the SSC and the new dike for the Low Volume Waste Pond. Within this investigation, the contractor will drill soil borings and collect soil samples for laboratory testing. The data collected in the field and recorded during the laboratory tests will then be evaluated and incorporated into the SSC foundation and Low Volume Waste Pond dike designs.

The subsurface investigation work is expected to take approximately three months to complete, which includes the time required to perform the field work, conduct the laboratory tests, and prepare a report documenting the subsurface investigator's observations and results. To ensure adequate time is available to evaluate and incorporate this data into the SSC foundation and civil sitework designs, MWG plans to commence a subsurface investigation in the early spring of 2021. Thus, MWG expects to have the geotechnical data necessary to proceed with the designs of the SSC foundation and Low Volume Waste Pond by mid- to late June 2021.

Once the subsurface investigation is completed in mid- to late June 2021, the process of designing the SSC foundation and Low Volume Waste Pond will begin. This engineering and design work will be completed in two phases: geotechnical and structural. First, the geotechnical engineering and design work will utilize the data reported in the subsurface investigator's final report to size the SSC foundation to provide an adequate factor of safety against a bearing capacity failure and to limit settlement. This work will also include a slope stability analysis for the structural fill supporting the SSC foundation. Overall, this geotechnical engineering and design work is expected to be completed by mid-August 2021, approximately two months after the final subsurface investigation report is available.

The structural engineering and design work for the SSC foundation will begin once the geotechnical engineering and design work has been completed and while the SSC Vendor is finalizing the structural steel supports for the remote SSC equipment (and therefore finalizing the loads on the base mat foundation). In this phase of the SSC foundation design, the base mat thickness and reinforcement will be designed to support the remote SSC, its ancillary equipment, and the BOP piping and equipment. The concrete walls for the SSC enclosure will also be designed at this time using loads from the vendor procuring the pre-engineered fabric enclosure for the SSC (see Section 3.6.5). In addition, the pushwalls in the ash dewatering bunker will be designed to accommodate the impact forces of equipment recovering ash from the bunker for off-site disposal. Finally, trenches and sumps within the enclosure will be designed to collect and control run-off from the dewatering ash and the remote SSC equipment. Overall, this portion of the engineering and design work is expected to be completed within 3.5 months by the beginning of December 2021 (*i.e.*, when MWG plans to submit its CCR closure construction and NPDES permit applications to the Illinois EPA).

The civil sitework for the project will be completed concurrently with the preceding engineering and design work for the SSC foundation. Like the structural fill for the SSC foundation, a slope stability assessment will be performed to design the new dike between the West Pond's east and west channels that will form the new Low Volume Waste Pond. This work will commence after the subsurface investigation data for this area is available in mid- to late June 2021. In addition to evaluating the slope stability of the new Low Volume Waste Pond, the civil engineering and design work for the pond will include designing slope protection (*e.g.*, riprap) and the new geomembrane liner, including anchorage and ballasting. The engineering and design work specific to the new Low Volume Waste Pond is scheduled to be completed in approximately three months, finishing by the end of September 2021.

Once the Low Volume Waste Pond has been designed and the SSC base mat foundation size has been determined, the design of the access roads and the site grading will commence. The access road will be designed within the West Ash Pond footprint to connect the existing plant road and the existing road along the berm of the pond to the new SSC equipment and the new Low Volume Waste Pond. This work will include developing an asphalt pavement design to accommodate the increase in truck traffic that will be accessing this area, especially for the winter months. The site grading will be designed in order to promote positive drainage away from the SSC foundation and to establish alignments for the new / modified access roads. Both of these engineering and design tasks are expected to be completed by the time MWG submits its CCR closure construction and NPDES renewal permit applications to the Illinois EPA in early December 2021.

3.4.4 ELECTRICAL / INSTRUMENTATION & CONTROL

Given that most of the electrical and I&C work for the project will not be installed until relatively late in the construction schedule (see Section 3.7.3), the corresponding engineering and design work will not commence until after the mechanical and civil / structural work is finished. Two notable exceptions to this are preparation of the electrical load list and design of the grounding system. Once the general arrangement is completed and issued for use in early June 2021, the electrical loads required to power the system will be determined. These loads are expected to be determined by the time the BOP P&IDs and PFDs are finalized in mid-August 2021. The grounding design will commence around this time with the structural design of the SSC foundation to ensure the grounding system is incorporated into the foundation design. Accordingly, this work is expected to be completed concurrently with the SSC foundation in early December 2021.

The remaining electrical and I&C engineering and design work is expected to be completed in 2022 while MWG goes through the permitting process for closing the East and West Ash Ponds and renewing Waukegan’s NPDES permit. These activities have been scheduled to be completed by the time MWG places the material order with the SSC Vendor for the remote SSC equipment in mid- to late September 2022 (see Section 3.6.1.2). First, in late 2021 or early 2022, single line diagrams will be developed to conceptual the overall auxiliary power design. Routing and design of electrical cables to power the remote SSC and its components will also be established at this time. About three months later, in March 2022, detailed wiring diagrams (*i.e.*, three-line diagrams) will be prepared followed by cable tabulations and electrical schematic diagrams.

While the BOP electrical engineering and design work is ongoing, the SSC Vendor will design and finalize the SSC’s control panel and programmable logic controller (PLC) processor. This work is expected to be completed by the time SSC Vendor beings fabricating the SSC equipment in mid- to late September 2022 to ensure timely delivery to the site in the summer of 2023. After the I&C engineering and design by the SSC Vendor is completed, the BOP I&C engineering and design will commence to tie the SSC PLC into the Station’s DCS. This design work will include preparing wiring diagrams to route wiring from the SSC area to the Coal Breaker Building, where the tie-in to the Station’s DCS is expected to occur. During this time, the necessary DCS hardware modifications will be designed. Both of these I&C engineering and design tasks are expected to be completed by mid-December 2022, within three months of starting.

3.5 CONTRACTOR SELECTION

MWG intends to hire three separate contractors to execute this project, each corresponding to a different phase of construction. This contracting strategy will allow MWG to hire contractors specialized in the different scopes of work specified within this project. As outlined in Section 3.7 and in the visual timeline representation of the project schedule in Section 2.0, construction will be divided into the following four principal phases:

1. Civil
2. Mechanical / Structural
3. Electrical

The first contractor will be the Civil Contractor who will be responsible for closing the West Ash Pond, placing and compacting the structural fill for the SSC area, and installing the new Low Volume Waste Pond and its appurtenances. The second contractor will be the Mechanical Contractor who will be charged with constructing the SSC foundation, installing the remote SSC and its ancillary equipment and piping, and erecting the fabric enclosure for the SSC. Finally, the third contractor will be the Electrical Contractor who will be responsible for installing the electrical equipment and cables, instrumentation, and controls.

3.5.1 CIVIL CONTRACTOR

MWG plans to start clean closing the West Ash Pond as soon as possible after receiving a final closure construction permit from the Illinois EPA. Given that the permit will establish the agency's requirements and expectations for closing the pond, MWG will begin preparing the technical requirements and commercial terms and conditions upon receipt of the draft permit from the Illinois EPA. Per Section 3.3.1, this is currently anticipated to be completed in early May 2022.

Given the public comment period and likely public hearing that will be held between the Illinois EPA's issuance of the draft and final permits for the West Ash Pond closure work, MWG does not plan on issuing the corresponding bid package until after the public hearing, at which time MWG will have some reasonable certainty that the project will be approved as proposed or will require some modifications. Bidding the work beforehand would leave MWG susceptible to potential material changes required by the Illinois EPA to MWG's closure plan which would then require MWG to rebid the work, causing unavoidable delays to the project. Thus, MWG does not anticipate issuing the West Ash Pond closure work for bids until after the public hearing on Illinois EPA's draft permit is held in late August 2022.

MWG intends to provide the prospective Civil Contractor approximately six weeks to review the bid package materials, including the draft closure construction permit from the Illinois EPA. After the bid period concludes in mid-October 2022, MWG will review the submitted bids. MWG expects to take approximately six weeks to thoroughly review the submitted bids before ultimately selecting the Civil Contractor with the intention of having a final closure construction permit from the Illinois EPA before beginning contract negotiations with the selected contractor (expected mid-to late November 2022 per Section 3.3.2.6). This final permit will be incorporated into the final contract documents and conformed technical specification. Ultimately, MWG expects to award the pond closure work to the Civil Contractor by mid- to late December 2022 following a month-long contract negotiation phase.

3.5.2 MECHANICAL CONTRACTOR

Because the Mechanical Contractor will not need to mobilize to the site until the spring of 2023 (see Section 3.7.2), MWG intends to start procuring the contractor responsible for installing the SSC equipment and its ancillary equipment after the Civil Contractor has been selected. MWG will begin preparing the technical requirements and commercial terms and conditions following the public hearing on the Illinois EPA's draft permit in late August 2022. The subsequent tasks and corresponding timeframes for procuring the Mechanical Contractor are then expected to follow the same sequence as that for the Civil Contractor described in the preceding section. Accordingly, MWG expects to have the Mechanical Contractor hired by mid-March 2023.

3.5.3 ELECTRICAL CONTRACTOR

Since the electrical equipment and components will not need to be installed until late in the construction schedule, MWG will award the electrical general work contract last of the three installation contracts. Preparation of the technical requirements and commercial terms and conditions will start after the corresponding engineering and design work for the electrical and I&C components is finished in mid-December 2022. MWG plans to issue the bid package for the electrical general work approximately two months later. Given the smaller scope of work for this contractor relative to the Civil and Mechanical Contractors, MWG expects the timeframes for procuring the Electrical Contractor to be shorter. Accordingly, MWG expects the bid period and bid evaluation phases to only take about one month each (compared to six weeks for the other two contractors). After selecting a contractor, MWG expects to take three weeks to negotiate the contract and conform the technical specification to that contract. Thus, MWG expects to have the Electrical Contractor procured for this project by May 2023.

3.6 EQUIPMENT FABRICATION & DELIVERY

The major equipment and materials being fabricated for this bottom ash-handling modification project at Waukegan are the remote SSC and its ancillary equipment; the structural materials to construct the SSC's base mat foundation and ash dewatering bunker; piping, pumps, and valves for the remote SSC, its ancillary equipment, and the Low Volume Waste Pond; geomembrane liner for the Low Volume Waste Pond; the fabric enclosure for the remote SSC; and electrical equipment, cables, and wires for the system. The following subsections discuss how MWG anticipates these various items will be procured for the project.

3.6.1 REMOTE SUBMERGED SCRAPER CONVEYOR

3.6.1.1 SSC VENDOR PROCUREMENT

Once the project budget has been established in late January 2021 (see Section 3.4.1), MWG will begin preparing the technical specification and commercial terms to procure a vendor specialized in SSC equipment to design, furnish, manufacture, and deliver the components and equipment required for this project. MWG anticipates issuing these contract documents in a bid package to prospective vendors by the end of March 2021. Because MWG has already engaged in high-level conceptual design discussions with potential SSC vendors for budgetary purposes, MWG expects a month-long bid period to be sufficient for the prospective vendors to evaluate the scope of work, refine their design and manufacturing strategies (if required), and to ultimately submit bids. MWG will then start evaluating the bids and ultimately select a vendor. Given the anticipated timing of the bid period and bid evaluation phases (late March to mid-May 2021), MWG will also have the opportunity to incorporate changes to the proposed design and request updated bids should the Final Illinois CCR Rule published in late March 2021 require such changes. Immediately after selecting the winning bidder, MWG will negotiate the commercial terms with the selected vendor and to conform the technical specification with these terms. This contract negotiation phase is expected to take about three weeks to complete, which would have MWG awarding the contract to the SSC Vendor receiving by June 1, 2021.

3.6.1.2 MATERIAL PROCUREMENT

Upon receiving the contract to design, furnish, manufacture, and deliver a remote SSC to the Waukegan site, the SSC Vendor will begin the corresponding engineering and design work for the remote SSC and its ancillary equipment. The scope of work for the remote SSC design and respective timeframes are provided in the preceding Section 3.4.2.2. Based on the budgetary cost estimates MWG has received from potential SSC vendors, MWG expects the remote SSC and its ancillary equipment to be delivered to the project site between 45 and 50 weeks of placing the material order. Given that the SSC equipment is scheduled to be installed in August 2023 (see Section 3.7.2), MWG will need to place the material order with the SSC Vendor by mid- to late September 2022. Upon receiving the material order, the SSC Vendor will begin fabricating the components and pieces for the remote SSC and its ancillary equipment.

It is expected that the SSC Vendor will work with third-party suppliers to procure and/or fabricate the equipment and components required for installing the SSC equipment consistent with the vendor’s engineering and design. Once the SSC Vendor submits a material release and purchase order to its supplier(s), the supplier(s) would first prepare and submit shop drawings to the SSC Vendor to review and approve. Once approved, the equipment and/or components would be fabricated and inspected for conformance with the shop drawings and/or the vendor's design. Fabrication is expected to occur between November 2022 and July 2023. Thus, the equipment and components for installing the SSC are expected to be ready for delivery to the project site by late July 2023. This would allow for the remote SSC equipment and components to be delivered to the project site by late August 2023

3.6.2 CONCRETE MATERIALS

Shortly after being awarded the contract to construct the foundation and enclosure for the remote SSC in mid-March 2023, the Mechanical Contractor will begin contacting concrete and rebar suppliers to furnish and deliver the materials required to install the concrete components of the project.

Once the rebar supplier receives the design drawings for the remote SSC's foundation and enclosure from the Mechanical Contractor, the supplier will begin preparing rebar shop drawings for the base mat foundation, bunker wall, enclosure walls, *etc*. Given the SSC foundation's size; the rebar detailing required for the enclosure walls, ash dewatering bunker pushwalls, and trenches; and the anticipated embedments (*e.g.*, anchor rods), it is expected that the rebar supplier will prepare and issue shop drawings to the Mechanical Contractor and MWG for review in phases. Rebar shop drawings will likely first be issued for the base mat foundation, followed by the bunker and enclosure walls, and finally the special details for the trenches and curbs. The first set of shop drawings are expected to be prepared within two to three weeks of the Mechanical Contractor placing the material order. After a two-week review period and ultimate approval of a given shop drawing, the rebar supplier will begin fabricating the steel reinforcement. Fabrication is also expected to take approximately two weeks to complete, after which the rebar supplier will start delivering the rebar to the project site. Based on these timeframes and given the mechanical / structural general work contract being awarded in mid-March 2023, it is expected that the rebar supplier will furnish and deliver the ash-settling pond's reinforcement to the project site between the beginning of June and the middle of August 2023 (corresponding to the anticipated installation schedules for the base mat foundation and walls).

Several potential ready-mix concrete suppliers are located within a 20-mile radius of the Waukegan site, including the city of Waukegan, Illinois, itself. Therefore, it is expected that concrete for this project will be prepared at one of these plants and delivered to the site via ready-mix trucks. Given the proximity of these plants, ready-mix trucks should have adequate time to deliver and discharge the concrete in accordance with ASTM C94, "Standard Specification for Ready-Mixed Concrete," which requires concrete be discharged within 90 minutes after hydration commences.

3.6.3 PIPES, PUMPS, & VALVES

3.6.3.1 CIVIL CONTRACTOR

The Civil Contractor will be responsible for installing the piping to and from the new Low Volume Waste Pond as well as a new pump to convey effluent from the pond to the Recycle Water Sump. However, since the Civil Contractor will be clean closing the West Ash Pond's east channel and then installing the structural fill for the remote SSC area before constructing the new Low Volume Waste Pond, the piping for the Low Volume Waste Pond will not need to be procured immediately. Indeed, the piping for the Low Volume Waste Pond will not be needed on site until May 2023 (see Section 3.7.1). It is currently anticipated that the Civil Contractor will arrange to have all piping delivered to the site just as the contractor begins installing it. Based on a contract award date of late December 2022, this schedule should provide adequate lead time for a pipe supplier to fulfill the Civil Contractor's order.

3.6.3.2 MECHANICAL CONTRACTOR

The Mechanical Contractor will be responsible for the effluent piping from the ash dewatering bunker sump and the service water and service air piping for the SSC. The contractor will likely order both sets of piping shortly after being awarded the contract for the work in mid-March 2023. The effluent piping from the ash dewatering bunker sump will need to be procured first since this pipe will likely be embedded in the foundation for the remote SSC. Therefore, this piping will need to be fabricated and delivered to the site by mid-June 2023 at the onset of the foundation installation work. Conversely, more lead time is available to the Mechanical Contractor to procure the service water and service air piping for the remote SSC, which will not need to be installed until mid- to late July 2023.

3.6.4 GEOMEMBRANE

Once the Civil Contractor is awarded the contract for closing the West Ash Pond and repurposing a portion of it as the new Low Volume Waste Pond, the contractor will place the material order for the geomembrane panels required to line the subject area of the West Ash Pond after it has been clean-closed. Although geomembrane can be a long-lead time component for solid waste facility construction projects, the relatively small size of the new Low Volume Waste Pond (approximately three acres) should facilitate a shorter lead time and thus timely delivery of the geomembrane panels. Therefore, MWG expects the geomembrane panels for the new Low Volume Waste Pond to be delivered to the project site by mid- to late May 2023 shortly after the Civil Contractor has finished placing the structural fill in the SSC area, preparing the subgrade for the new Low Volume Waste Pond, and constructing a new dike at the southern end of the existing West Ash Pond (see Section 3.7.1).

3.6.5 FABRIC ENCLOSURE

After awarding the mechanical / structural general work contract in mid-March 2023, MWG will order the fabric enclosure for the SSC. Based on a budgetary cost estimate from a vendor specializing in these enclosures, MWG expects a 60- to 90-day lead time for this enclosure. Given that the SSC walls are expected to be installed by mid-August 2023, ordering the enclosure between mid-March and mid-May 2023 should provide plenty of time for the selected vendor to fabricate and deliver the fabric enclosure to the Waukegan site in time for the Mechanical Contractor to erect it over the new SSC once the concrete walls have achieved their design strength (approximately one month after installation).

3.6.6 ELECTRICAL EQUIPMENT, CABLES, & WIRES

Upon receiving the contract for the project's electrical and I&C installation work, the Electrical Contractor will begin ordering the electrical equipment to power the SSC and its ancillary components. This equipment will include the new transformer and MCCs for the PDC within the SSC enclosure. The contractor will also begin procuring the cables required to deliver power to the SSC area and the Low Volume Waste Pond return pump. Finally, the wiring for the I&C work will be ordered at this time. Given that the electrical equipment, cables, and wires for the project are expected to be installed in late July and through September of 2023, ordering these electrical components in early to mid-May 2023 should provide plenty of lead time for the supplier(s) to fabricate and deliver these materials to the Waukegan site in time for the Electrical Contractor to install them at the new SSC site.

3.7 CONSTRUCTION

Like the engineering and design work for this project, construction of this modified bottom ash-handling system for Waukegan is expected to occur in three phases. This phased approach will allow MWG to install the different components of the project as soon as technically feasible while accommodating the different regulatory and procurement timeframes discussed earlier. Accordingly, construction of the alternative disposal capacity to replace the East Ash Pond is expected to be executed in the following three phases:

1. Civil: Clean Close & Repurpose West Ash Pond for SSC & Low Volume Waste Pond (by Civil Contractor)
2. Mechanical / Structural: Construct SSC Foundation & Enclosure, Install Remote SSC Equipment, & Install BOP Piping (by Mechanical Contractor), and
3. Electrical: Install BOP Electrical & I&C Components (by Electrical Contractor).

The following construction schedule assumes that each of the three contractors hired to execute this project and their respective subcontractors (if any) will normally work five days per week at 10 hours per day.

3.7.1 CIVIL INSTALLATION WORK

3.7.1.1 CLOSE WEST ASH POND (EAST CHANNEL)

Closure activities for the east channel of the West Ash Pond are expected to commence in mid- to late January 2023, approximately one month after the Civil Contractor has been awarded the corresponding contract. All closure work will be performed in accordance with the final closure construction permit issued by the Illinois EPA (expected mid- to late November 2022).

Upon fully mobilizing to the site in mid- to late January 2023, the Civil Contractor will begin removing any CCR remaining on the liner of the West Ash Pond’s east channel from the initial cleaning performed by Waukegan’s Ash Management Contractor (see Section 3.2) and will then remove the existing liner system. The liner system consists of 18 inches of fill on the floor and a 60-mil HDPE geomembrane liner on the side slopes of the pond. In addition to removing the liner, the Civil Contractor will also be responsible for removing all CCR and CCR-impacted soils beneath the liner (if any). All liner, CCR, and CCR-impacted materials will be removed by excavating them out of the pond, loading them onto trucks, and transporting them offsite to a permitted disposal facility. As the existing liner is removed, the subgrade will be visually inspected to ensure all CCR constituents have been removed from the pond area. Finally, after all the excavation work is complete, the Civil Contractor will begin decontaminating the external faces of the Recycle Water Sump in the area, if necessary.

Given the size of the West Ash Pond’s east channel (approximately 5.7 acres), it is expected that the Civil Contractor will be able to remove any CCR remaining on the pond’s liner, remove the liner, and excavate any CCR-impacted soils within three weeks of fully mobilizing to the site. It is anticipated that the subsequent decontamination of the area and the appurtenant structures can be completed within one week after the pond’s liner has been removed. Therefore, it is expected that the east channel of the West Ash Pond will be clean closed and certified as such by mid-February 2023.

3.7.1.2 PLACE STRUCTURAL FILL FOR SSC AREA

Once the east channel of the West Ash Pond has been certified as clean-closed, the Civil Contractor will perform the initial sitework required to install the base mat for the SSC and its enclosure. This work will begin by placing and compacting the structural fill from the onsite dredged sand pile adjacent to the Station’s Coal Yard. The site where the SSC will be installed will be raised 18 feet to match the elevation of the dikes surrounding the pond, which is anticipated to require over 70,000 cubic yards of sand.

Due to this earthwork occurring in the winter, it is expected to take longer for the Civil Contractor to place and compact this structural fill relative to it being installed in the spring or summer. In addition to general labor inefficiencies associated with winter construction, additional time will be required at the start of a given day to remove any fill placed the previous day that has frozen and then replace it with non-frozen material.

Accordingly, it is expected that the Civil Contractor will need just over three months to place and compact over 70,000 cubic yards of sand to establish the site for the new remote SSC at Waukegan. Therefore, given a start date of mid-February 2023, the SSC site is expected to be ready for foundation work by mid- to late May 2023.

Assuming MWG would not be permitted to actively perform a subsurface investigation in the West Ash Pond prior to closing the pond (drilling a soil boring in the West Ash Pond prior to closure would require cutting through the existing liner), there would be some uncertainty in the materials supporting the new structural fill. While the native soils at the Waukegan site are predominately sand given its proximity to Lake Michigan, the presence of clays or clay-like materials under the sand fill could result in some settlement given that the sand being placed in the pond area is about twice as heavy as the water that has historically been impounded in this area (120 pcf v. 62.4 pcf). Indeed, discontinuous seams of peat and silty sand have been identified in soil borings drilled at the ash pond site (see Appendix C.2). To minimize the amount of settlement that occurs after the SSC foundation and equipment are installed (relatively minor loads relative to the sand fill), MWG is planning to allow one month between the Civil Contractor finishing the installation of the sand fill and the Mechanical Contractor starting the SSC foundation work. This will allow for the consolidation and subsequent settlement of any clay or clay-like materials that may be present under the ponds. Therefore, the Mechanical Contractor is expected to start the foundation work by mid-June 2023 (see Section 3.7.2.1).

3.7.1.3 CONSTRUCT LOW VOLUME WASTE POND

As the Civil Contractor has finished placing the sand fill in the SSC area, which will form the northern dike for the new Low Volume Waste Pond, the Civil Contractor will begin repurposing the area south of the SSC area into the new Low Volume Waste Pond. First, the Civil Contractor will prepare the subgrade to receive a new geomembrane liner. This work will include any re-grading necessary to restore the pond floor to a relatively smooth surface after the existing liner and underlying soils have been excavated during the West Ash Pond closure work. As the floor is being re-graded, it will be compacted and/or rolled smooth and then lined with new geomembrane panels. Finally, while the pond subgrade is being prepared, the Civil Contractor will also be constructing the new dike between the east and west channels of the West Ash Pond to establish the storage area for the new Low Volume Waste Pond.

Given the pond's small area (about 3 acres) and the relatively small volume of fill required to construct the new dike (just over 10,000 cubic yards) as compared to the structural fill for the SSC area, the earthwork associated with its construction is expected to be completed within a few weeks. Accordingly, it is expected that the Civil Contractor will not start this work until more favorable construction conditions in the spring of 2023 and will time the completion of the new dike and pond floor with the completion of the structural fill for the SSC area. At this point, the Civil Contractor can begin deploying the geomembrane panels for the Low

Volume Waste Pond's liner, which is expected to take approximately two weeks to install. Thus, it is currently anticipated that the Low Volume Waste Pond will be constructed and lined by early June 2023.

Installation of the effluent piping to and from the new Low Volume Waste Pond is expected to start so that the piping is installed once the pond is almost fully lined. Given the proximity of the existing low volume waste piping to the Low Volume Waste Pond, installation of the new piping between the existing piping and the new pond's inlet is expected to start first (currently scheduled to commence in early May 2023). A couple weeks later, the Civil Contractor will begin installing the new return piping from the Low Volume Waste Pond's outlet structure to the Recycle Water Sump, which will be a significantly shorter length than the new pond's inlet piping. Given that the new Low Volume Waste Pond is expected to be lined by early June 2023, both pipelines are also expected to be installed by early June 2023, after which the Low Volume Waste Pond will be ready for commissioning (see Section 3.8.1).

3.7.1.4 CLOSE WEST ASH POND (WEST CHANNEL)

Although not explicitly required to execute this project, the Civil Contractor will begin clean closing the west channel of the West Ash Pond after the new Low Volume Waste Pond is installed. The contractor will perform this work throughout the remainder of the construction of the new remote SSC area. The Civil Contractor is expected to need a slightly shorter timeframe to clean close this area of the pond relative to the east channel (2 weeks) since the west channel is a similar size and the earthwork will take place in the summer instead of the winter. Given that the contractor is expected to start removing any remaining CCR in the area and the existing liner in early June 2023, it is expected that the west channel will be certified as clean closed by the end of June 2023. At this time, the Civil Contractor will begin placing sand fill in the area and grading it to promote positive drainage of stormwater and to allow MWG to potentially reuse the site for a different purpose. This work is expected to continue throughout the summer and fall of 2023.

3.7.1.5 CONSTRUCT NEW ACCESS ROADS

Ahead of the fabric enclosure being erected over the SSC area (see Section 3.7.3), the Civil Contractor will start constructing the new asphalt roads to the SSC area for trucks to access the site for reclaiming the dewatered ash for beneficial use or disposal in a permitted solid waste facility. The contractor is expected to start this work closest to the SSC area to provide adequate time for the asphalt surfacing to set before the fabric enclosure is erected in mid-September 2023. The Civil Contractor will then construct and pave the new turnaround area over the sand fill south of the SSC enclosure and finally repave the existing gravel roads along the West Ash Pond's northern dike. This work is expected to be completed just as the Mechanical Contractor starts erecting the fabric enclosure over the SSC area.

3.7.2 MECHANICAL / STRUCTURAL INSTALLATION WORK

3.7.2.1 INSTALL SSC FOUNDATION

The Mechanical Contractor is expected to be fully mobilized to the project site by mid-June 2023 after the structural fill placed in the area has had adequate time to mitigate any potential settlement. At this time, the contractor will begin installing the base mat foundation for the remote SSC and the electrical grounding system. The base mat foundation will be constructed by first forming out the area, then installing the specified rebar, and finally placing the concrete. Forming and placing rebar is expected to take one to two weeks per “pour” depending on the rebar detailing and density. For example, more time will likely be required to place the rebar in the ash dewatering bunker relative to the rest of the SSC enclosure given the rebar density expected in the pushwalls. Finally, the dowels for the enclosure and bunker walls and the embedments for the SSC supports will also be installed at this time.

Given the anticipated size of this base mat (approximately 200 ft by 80 ft per drawing WKG-CSK-101 in Appendix A), the concrete will likely be placed in two to three “pours.” As previously mentioned, the concrete is expected to be installed via ready-mix trucks from a nearby concrete supplier. (A similar process will be following for placing the concrete walls and curbs.) Based on the expected number of concrete “pours” and the amount of rebar to be installed, it is expected that the Mechanical Contractor will have the base mat foundation installed within five weeks. Thus, based on starting the installation work in mid-June 2023, it is anticipated that the base mat foundation will be installed by mid- to late July 2023.

In order to place the concrete for the bunker and enclosure walls once the concrete strength for the base mat foundation has been verified, it is expected that the Mechanical Contractor will begin forming and installing the rebar for these vertical concrete elements within three to four weeks after starting work on the base mat foundation (*i.e.*, early July 2023). Installation of these walls is expected to follow a similar sequence as the base mat foundation: place formwork, place rebar, install the building enclosure anchorage, and finally place the concrete. Like the base mat foundation, the concrete walls are expected to take approximately five weeks to install. Therefore, based on starting this work in early July 2023, it is expected that the concrete pushwalls and enclosure walls will be completed by early to mid-August 2023.

3.7.2.2 INSTALL SSC EQUIPMENT

After the base mat foundation has reached its design strength (within 28 days per standard practice), the Mechanical Contractor can begin installing structural steel supports supplied by the SSC Vendor for the remote SSC. Based on the base mat being installed by mid- to late July 2023, the Mechanical Contractor can start installing the structural steel supports for the remote SSC equipment in mid-August 2023. Once the supports are installed, the contractor can begin assembling the SSC itself. This SSC is expected to arrive to the project site in three prefabricated sections: (1) the settling/surge hopper, (2) the ramp/discharge head section, and (3) the tail/tensioner section. Given its size and modular construction, the remote SSC is not expected to take longer than two weeks to install. Thus, the primary SSC components are expected to be installed by the end of August 2023.

Once the main components of the remote SSC are installed, the Mechanical Contractor can begin installing its internal components and ancillary equipment. This includes the SSC's chain; flights; hydraulic power unit; and access platforms, handrails, and ladders. In addition, the Mechanical Contractor can start assembling the mobile clarifier downstream of the SSC. Similar to the SSC, the clarifier is expected to be delivered to the Waukegan site in prefabricated pieces. Based on the current conceptual design, it is anticipated that the clarifier can be fully assembled the day it is delivered to the project site. Meanwhile, the SSC's internal components and access components are expected to be installed within two weeks. Thus, it is expected that the Mechanical Contractor will finish installing the remote SSC equipment and clarifier in early to mid-September 2023, approximately one month after starting the work.

3.7.2.3 INSTALL SSC PUMPS & PIPING

Upon mobilizing to the to the project site in mid- to late July 2020, and concurrent with installing the SSC foundation, the Mechanical Contractor will begin installing the new service water and air piping from the Coal Breaker Building to the SSC area. Once the primary SSC equipment has been installed in late August 2023, the contractor can then begin installing the pumps and other piping to and from the equipment. This includes the new ash sluice piping (provided by the SSC Vendor), SSC overflow piping, clarifier overflow piping, and the clarifier sludge pump and corresponding return piping to the SSC. Given their relatively short spans within the SSC enclosure, it is expected that the both sets of overflow piping and the clarifier sludge pump and piping will be fully installed within about a week. Given the proximity of the remote SSC to the existing ash sluice piping, it is expected that the new ash sluice piping extension can be installed within two weeks. Finally, the service water and air piping spanning from the Coal Breaker Building to the remote SSC and their corresponding supports are expected to be installed within a couple of months, finishing just as MWG starts commissioning the new SSC in mid-September 2023.

3.7.3 ERECT FABRIC ENCLOSURE

The Mechanical Contractor can begin erecting the fabric enclosure once the concrete walls for the SSC enclosure have been constructed and have achieved their specified design strength, approximately one month after they have been placed (mid-August 2023). Based on a budgetary cost estimate from a vendor specializing in these structures, MWG expects the structure to be erected in two weeks. Thus, MWG currently anticipates the SSC enclosure to be constructed by mid- to late September 2023.

3.7.4 ELECTRICAL & I&C COMPONENTS

Once the Mechanical Contractor starts installing the service air and service water piping from the Coal Breaker Building to the remote SSC area in mid- to late July 2023, the Electrical Contractor will mobilize to the site and start installing cables and wires from the Coal Breaker Building to set up the future tie-in to the Station's DCS. Once the base mat has reached its design strength in mid-August 2023, the Electrical Contractor will start installing the transformer and MCCs to provide power to the SSC. Cables will also be routed from the pumphouse adjacent to the Recycle Water Sump, which provides power for the recirculation pumps, to the transformer at this time. The MCCs will be installed within the PDC area within the SSC enclosure and are expected to take approximately two weeks to install.

Once the PDC has been installed, the Electrical Contractor will work with the SSC Vendor to route cables and wires from the PDC to the SSC. This work is expected to take approximately three weeks to complete, at which time the Electrical Contractor will tie the SSC equipment and PLC into the Station's DCS by making the necessary hardware modifications to control the SSC via the latter. Thus, based on the Electrical Contractor starting the PDC installation work by mid-August 2023, it is expected that all of the electrical and I&C components for the project will be fully installed by the time the fabric enclosure for the SSC is erected in mid- to late September 2023.

3.8 START-UP & IMPLEMENTATION

Given the preceding construction schedules, commissioning of Waukegan's new bottom ash treatment system is expected to occur in two phases: first the new Low Volume Waste Pond, then the remote SSC.

3.8.1 COMMISSION LOW VOLUME WASTE POND

Upon installation of the new Low Volume Waste Pond's geomembrane liner and inlet and effluent pipelines, MWG can begin commissioning the pond. This work will include inspecting and testing the new pipelines and outlet structure to ensure they are functional, operate as designed, and are reliable. Should issues arise during the commissioning process, appropriate modifications will be made to ensure the design requirements are met.

After the new Low Volume Waste Pond has been commissioned and MWG has accepted the Civil Contractor's work, Waukegan may start using the new system for non-CCR wastestreams currently being sent to the East Ash Pond. Commissioning the new Low Volume Waste Pond is expected to take two weeks to ensure it has been installed in accordance with the design specifications, operates in accordance with the applicable permits, and is reliable. Thus, it is expected that Waukegan will have a new Low Volume Waste Pond for the non-CCR wastestreams currently being sent to the East Ash Pond by June 16, 2023.

3.8.2 COMMISSION REMOTE SSC

Once the Mechanical and Electrical Contractors complete the installation of the mechanical, electrical, and I&C components to support operation of the SSC and its ancillary equipment, MWG can beginning commissioning the SSC to ensure it operates as intended. The fabric enclosure must also be erected before commissioning can start, otherwise the ash placed in the ash dewatering bunker during commissioning would be considered a “CCR storage pile” pursuant to the proposed 35 Ill. Adm. Code 845.120 and would require a groundwater monitoring system and active fugitive dust control measures (tarping, periodic wetting, *etc*.).

Field service engineers from the SSC Vendor will use a prepared start-up plan to ensure each piece of equipment for the remote SSC is operational and functional. The commissioning process will also include inspecting and testing the new effluent pipelines to ensure they are functional, operate as designed, and are reliable. Once the SSC has been commissioned as a system, the SSC Vendor will work with the Station to optimize and tune the system as necessary to ensure it operates at maximum efficiency in accordance with the design specifications. Modifications will be made as necessary in order to meet the performance requirements.

Overall, the commissioning process for the entire remote SSC system is expected to take approximately three weeks. Thus, MWG expects to have alternative disposal capacity at Waukegan for the CCR wastestreams currently being sent to the East Ash Pond by October 11, 2023.

4.0 PROJECT SCHEDULE: PROGRESS TO DATE

This section presents a narrative of the progress MWG has made in installing a new bottom ash treatment system at Waukegan to replace the non-compliant East and West Ash Ponds. The project commenced in the fall of 2018 with the development of conceptual engineering solutions for the non-compliant ash ponds at MWG's Waukegan, Powerton, and Will County stations. Per the project schedule presented and discussed in Sections 2.0 and 3.0, MWG intends to start procuring a vendor to design, furnish, manufacture, and deliver a remote SSC to Waukegan in January 2021. The corresponding detailed engineering and design work for the BOP components is set to commence in late March 2021 upon adoption of the Final Illinois CCR Rule into Title 35 of the Illinois Administrative Code.

To date, MWG has completed the following steps to develop the new bottom ash treatment system that will replace the East and West Ash Ponds at Waukegan:

- Took the West Ash Pond out of service for routine cleaning,
- Evaluated several options for obtaining alternative disposal capacity to replace the non-compliant East and West Ash Ponds,
- Developed a conceptual design for the new bottom ash treatment system to be installed at Waukegan,
- Actively participated in Illinois's rulemaking for CCR surface impoundments, and
- Engaged in preliminary discussions with vendors for installing a remote SSC and for erecting a fabric enclosure for the new SSC equipment.

5.0 DEMONSTRATION OF COMPLIANCE

Pursuant to criteria listed in 40 CFR 257.103(f)(1)(iv)(B), the following information demonstrates that Waukegan's East and West Ash Ponds are in compliance with the EPA CCR Rule.

5.1 SIGNED CERTIFICATION OF COMPLIANCE

In accordance with 40 CFR 257.103(f)(1)(iv)(B)(*1*), a certification of compliance signed by Waukegan's plant manager is included with this demonstration in Appendix C.1.

5.2 VISUAL REPRESENTATION OF SITE HYDROGEOLOGY

In accordance with 40 CFR 257.103(f)(1)(iv)(B)(*2*), the following information is provided in Appendix C.2 to provide a visual representation of hydrogeology at and around the East and West Ash Ponds that supports the design, construction, and installation of the unit's groundwater monitoring system:

- Maps showing the locations of the groundwater monitoring wells,
- Well construction diagrams and drilling logs for the groundwater monitoring wells, and
- Maps characterizing the direction of groundwater flow under the East and West Ash Ponds (including seasonal variations).

As noted in Appendix C.2, the well construction diagrams and drilling logs for monitoring wells MW-11 and MW-14 are not currently available. The year in which these monitoring wells were installed as part of a site investigation of the former Greiss-Pfleger Tannery (1995 through 1997) predates the program records available through the Illinois EPA's online archive (Ref. 18). In accordance with Illinois EPA's guidance for its archive, a Freedom of Information Act (FOIA) request has been made for these records. To date, the Illinois EPA has not yet responded to this request.

5.3 GROUNDWATER MONITORING CONSTITUENT CONCENTRATIONS

In accordance with 40 CFR 257.103(f)(1)(iv)(B)(*3*), a table summarizing the constituent concentrations recorded during each sampling event at each groundwater monitoring around the East and West Ash Ponds is provided in Appendix C.3.

5.4 NARRATIVE OF SITE HYDROGEOLOGY

In accordance with 40 CFR 257.103(f)(1)(iv)(B)(*4*), a narrative description of the Waukegan site's hydrogeology and stratigraphic cross sections are provided in Appendix C.2.

5.5 CORRECTIVE MEASURES ASSESSMENTS

To date, Waukegan has not had to perform a corrective measures assessment required by 40 CFR 257.96 for the East and West Ash Ponds. Accordingly, no corrective measures assessment is included in this demonstration.

5.6 CORRECTIVE ACTION REMEDY REPORTS

To date, Waukegan has not had to perform any corrective action remedies required by 40 CFR 257.97 for the East and West Ash Ponds. Accordingly, no corrective action remedy reports are included in this demonstration.

5.7 STRUCTURAL STABILITY ASSESSMENT

In accordance with 40 CFR 257.103(f)(1)(iv)(B)(*7*), the most recent structural stability assessment demonstrating the East and West Ash Ponds' compliance with 40 CFR 257.73(d), dated October 2016, is provided in Appendix C.4. Within the structural assessment, Geosyntec identified an area of deficiency where the interior a pipe labeled "4W" needed to be relined. This pipe was taken out of service until the repair was complete and, per 40 CFR 257.73(d)(2), a report was placed in the operating record signaling a "Notice of Remedy." This notice is also provided in Appendix C.4.

5.8 SAFETY FACTOR ASSESSMENT

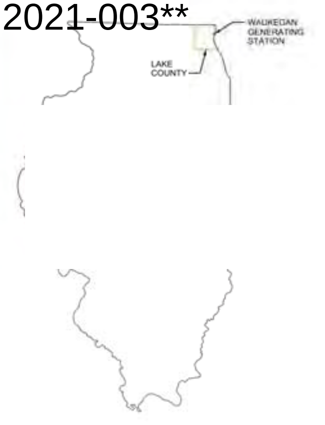
In accordance with 40 CFR 257.103(f)(1)(iv)(B)(*8*), the most recent safety factor assessment demonstrating the East and West Ash Ponds' compliance with 40 CFR 257.73(e), dated October 2016, is provided in Appendix C.4.

6.0 REFERENCES

1. 40 CFR Part 257 Subpart D, “Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments.”
2. Illinois Public Act 101-0171, “Coal Ash Pollution Prevention,” Effective 07/30/2019, http://www.ilga.gov/legislation/publicacts/101/PDF/101-0171.pdf, Accessed 11/25/2020.
3. U.S. Environmental Protection Agency, “Steam Electric Reconsideration Rule,” 85 Fed. Reg. 198, pp. 64650–64723, 10/13/2020.
4. U.S. Environmental Protection Agency, “Effluent Limitations Guidelines and Standards for the Steam Electric power Generating Point Source Category,” 80 Fed. Reg. 212, pp. 67838– 67903, 11/03/2015.
5. U.S. Court of Appeals, District of Columbia Circuit, *Utility Solid Waste Activities Group et al. v. Environmental Protection Agency*, No. 15-1219, 08/21/2018.
6. Proposed 35 Ill. Adm. Code Part 845, “Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments.” Published 03/30/2020.
7. U.S. Environmental Protection Agency, “Hazardous and Solid Waste Management System: Disposal of Coal Combustion Residuals from Electric Utilities, Part VI (Development of Final Rule – Technical Requirements),” 80 Fed. Reg. 74, p. 21423, 04/17/2015.
8. Title 35 Illinois Administrative Code Section 811.107, "Standards for New Solid Waste Landfills, Operating Standards.”
9. Illinois Department of Transportation, “Understanding the Illinois Size & Weight Laws,” 2019.
10. Illinois Department of Transportation, “Getting Around Illinois, Annual Average Daily Traffic,” http://www.gettingaroundillinois.com/gai.htm?mt=aadt, Accessed 11/25/2020.
11. Fish and Wildlife Service, “National Wetlands Inventory, Wetlands Mapper,” https:// https://www.fws.gov/wetlands/data/Mapper.html, Accessed 11/25/2020.
12. Lake County Wetland Inventory, https://data-lakecountyil.opendata.arcgis.com/datasets/lake-county-wetland-inventory, Accessed 11/25/2020.
13. Illinois Environmental Protection Agency, “Illinois EPA Ash Impoundment Web Page,” http://illinois-epa.maps.arcgis.com/apps/webappviewer/index.html?id=558102bb7b304d20907d3420ddcdf9eb, Accessed 11/25/2020.
14. Illinois General Assembly, “Bill Status of SB0009, 101st General Assembly,” https://www.ilga.gov/legislation/billstatus.asp?DocNum=0009&GAID=15&GA=101&DocTypeID=SB&LegID=113581&SessionID=108&SpecSess=, Accessed 11/25/2020.
15. Rain For Rent, “B-40 LakeTank,” http://www.rainforrent.com/equipment/b-40-laketank/, Accessed 11/25/2020.
16. Illinois Environmental Protection Agency, “Illinois EPA EJ Start, EJ Tracker 2019,” http://illinois-epa.maps.arcgis.com/apps/webappviewer/index.html?id=f154845da68a4a3f837cd3b880b0233c, Accessed 11/25/2020.
17. “Illinois EPA’s Pre-Filed Answers.” Illinois Pollution Control Board Case No. R2020-019. 08/03/2020.
18. Illinois Environmental Protection Agency, “IEPA Document Explorer,” https://external.epa.illinois.gov/DocumentExplorer/Home/About, Accessed 11/25/2020.
19. “Transcript of August 12, 2020 Hearing.” Illinois Pollution Control Board Case No. R20-19. 08/12/2020.

APPENDIX A — CONCEPTUAL DESIGN DRAWINGS

Drawing No.	Drawing Title	Rev.	Date
WKG-CSK-001	Site Plan	0	11-25-2020
WKG-CSK-100	Project Site Plan	0	11-25-2020
WKG-CSK-101	SSC Foundation & Enclosure Plan	0	11-25-2020
WKG-CSK-102	Low Volume Waste Pond Plan	0	11-25-2020
WKG-CSK-103	Low Volume Waste Pond Sections and Details	0	11-25-2020



ILLINOIS KEY PLAN

SCALE: N.T.S

LAKE COUNTY PLAN

SCALE: N.T.S

NORTH

200' 400'

GRAPHIC SCALE

NOTES

1.

REFERENCE DRAWINGS

UNDERGROUND OR EMBEDDED UTILITIES MAY BE LOCATED WITHIN OR ADJACENT TO THE AREA IN WHICH EXCAVATION, DEMOLITION, FOUNDATION OR MODIFICATION WORK IS TO BE PERFORMED.

REFERENCES RELATING TO THE UNDERGROUND OR EMBEDDED UTILITIES ARE PROVIDED TO ASSIST THE CONTRACTOR/INSTALLER IN THE FIELD LOCATING THOSE UTILITIES AND OTHER POSSIBLE UNDERGROUND OR EMBEDDED INTERFERENCES WITH THE WORK.

THE CONTRACTOR/INSTALLER SHALL EXERCISE DUE CAUTION DURING ALL EXCAVATION/FOUNDATION/DEMOLITION WORK.

PRELIMINARY
NOT FOR CONSTRUCTION

HOLD INFORMATION

NO.	DESCRIPTION

CONTRACTOR/INSTALLER SHALL TAKE ALL APPROPRIATE PRECAUTIONS TO ENSURE THE SAFETY OF ALL PEOPLE LOCATED ON THE WORK SITE, INCLUDING CONTRACTOR'S/INSTALLER'S PERSONNEL (OR THAT OF ITS SUB-CONTRACTOR(S)) PERFORMING THE WORK.

RELEASE INFORMATION

REV.	DATE	DESCRIPTION
0	11-25-2020	FOR USE

ISSUE PURPOSE: FOR USE
SPECIFICATION:
PROJECT NO.: 12667-096

CAD FILE NAME: WKG-CSK-001.DGN
PREPARED BY: J. CHAVEZ
REVIEWED BY: T. DEHLIN
APPROVED BY: T. DEHLIN

ANY MODIFICATION OR ADDITION TO THIS DRAWING BY AN ORGANIZATION OTHER THAN SARGENT & LUNDY, IS NOT THE RESPONSIBILITY OF SARGENT & LUNDY.

SARGENT & LUNDY
55 EAST MONROE STREET
CHICAGO, ILLINOIS 60603-5780

MWG

PROJECT

MIDWEST GENERATION, LLC
WAUKEGAN
GENERATING STATION
UNITS 7 & 8

DRAWING TITLE

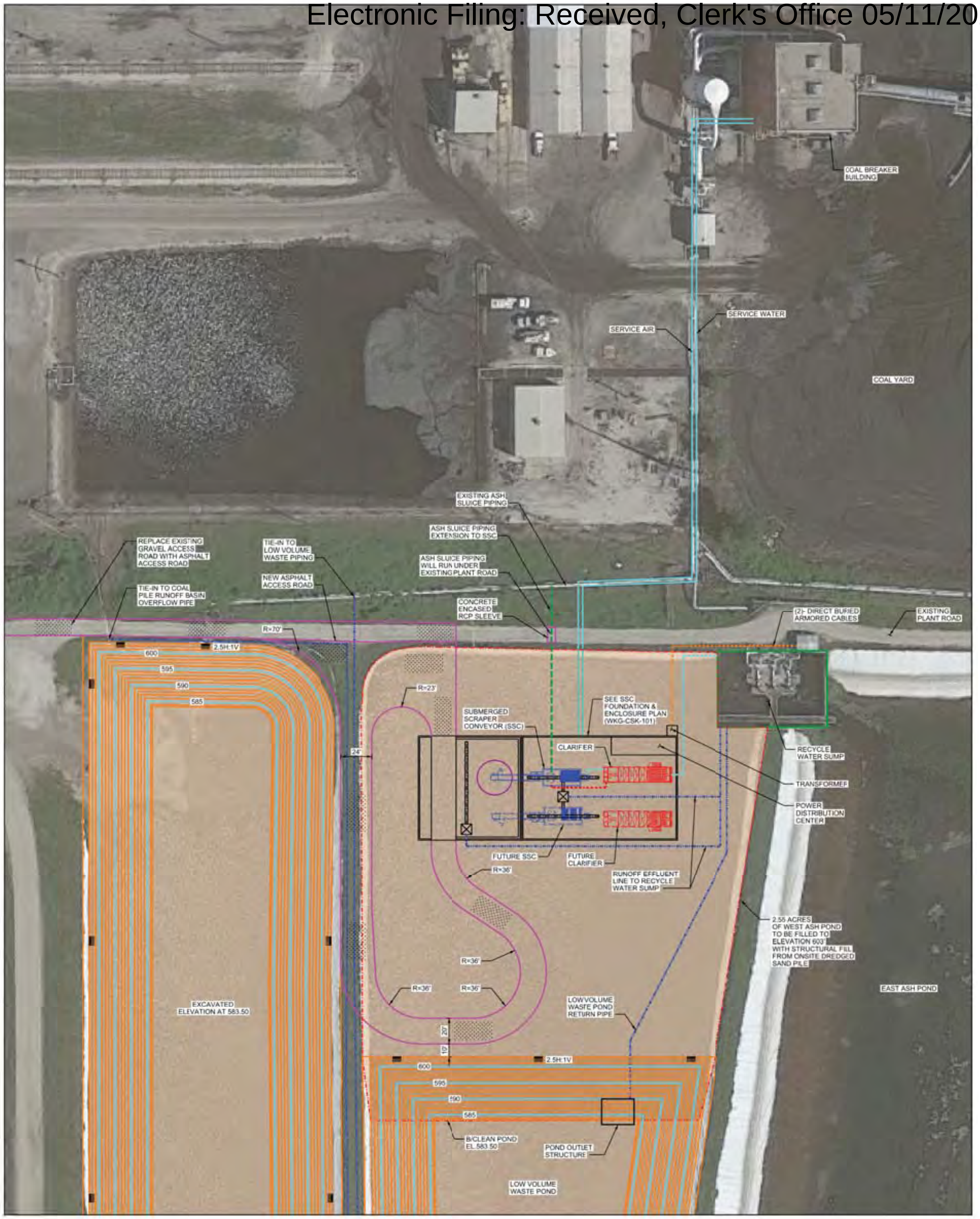
SITE PLAN

DRAWING NUMBER	REVISION
WKG-CSK-001	0

SHEET 1 OF 1

P01153/DM1864/S:#C1
Form GDG-0401-01-08, ANSI (Imperial) MicroStation Border - Size E - 34 x 44
Revision 11A, Revision Date: 04-30-2010

11/25/2020 11:45:01 AM
...drawings\WKG-CSK-001.dgn



KEY PLAN
SCALE: 1" = 6000'

PRELIMINARY
NOT FOR CONSTRUCTION

NORTH

30' 60'
GRAPH

LEGEND

600	MAJOR CON
599	MINOR CON
▭	SAND FILL
▨	ASPHALT

NOTES

1. AERIAL IMAGE IS FROM GO [illegible] DATED 07/06/2018.
2. ELEVATIONS ARE BASED O [illegible] DATUM OF 1988 (NAVD 88).

REFERENCE DRAWINGS

WKG-CSK-001	SITE PLAN
WKG-CSK-101	SSC FOUNDATION & ENCLOSURE PLAN
WKG-CSK-102	LOW VOLUME WASTE POND PLAN
WKG-CSK-103	LOW VOLUME WASTE POND SECTIONS AND DETAILS

UNDERGROUND OR EMBEDDED UTILITIES MAY BE LOCATED WITHIN OR ADJACENT TO THE AREA IN WHICH EXCAVATION, DEMOLITION, FOUNDATION, OR MODIFICATION WORK IS TO BE PERFORMED.

REFERENCES RELATING TO THE UNDERGROUND OR EMBEDDED UTILITIES ARE PROVIDED TO ASSIST THE CONTRACTOR/INSTALLER IN THE FIELD LOCATING THOSE UTILITIES AND OTHER POSSIBLE UNDERGROUND OR EMBEDDED INTERFERENCES WITH THE WORK.

THE CONTRACTOR/INSTALLER SHALL EXERCISE DUE CAUTION DURING ALL EXCAVATION/FOUNDATION/DEMOLITION WORK.

HOLD INFORMATION

NO.	DESCRIPTION

CONTRACTOR/INSTALLER SHALL TAKE ALL APPROPRIATE PRECAUTIONS TO ENSURE THE SAFETY OF ALL PEOPLE LOCATED ON THE WORK SITE, INCLUDING CONTRACTOR'S/INSTALLER'S PERSONNEL (OR THAT OF ITS SUB-CONTRACTOR(S)) PERFORMING THE WORK.

RELEASE INFORMATION

REV.	DATE	DESCRIPTION
0	11-25-2020	FOR USE

ISSUE PURPOSE: FOR USE
SPECIFICATION:
PROJECT NO.: [illegible]2661-096

CAD FILE NAME: WKG-CSK-100.DGN
PREPARED BY: J. CHAVEZ
REVIEWED BY: T. DEHLIN
APPROVED BY: T. DEHLIN

ANY MODIFICATION OR ADDITION TO THIS DRAWING BY AN ORGANIZATION OTHER THAN SARGENT & LUNDY, IS NOT THE RESPONSIBILITY OF SARGENT & LUNDY.

Sargent & Lundy LLC
SARGENT & LUNDY LLC
55 EAST MONROE STREET
CHICAGO, ILLINOIS 60603-5780

MWG

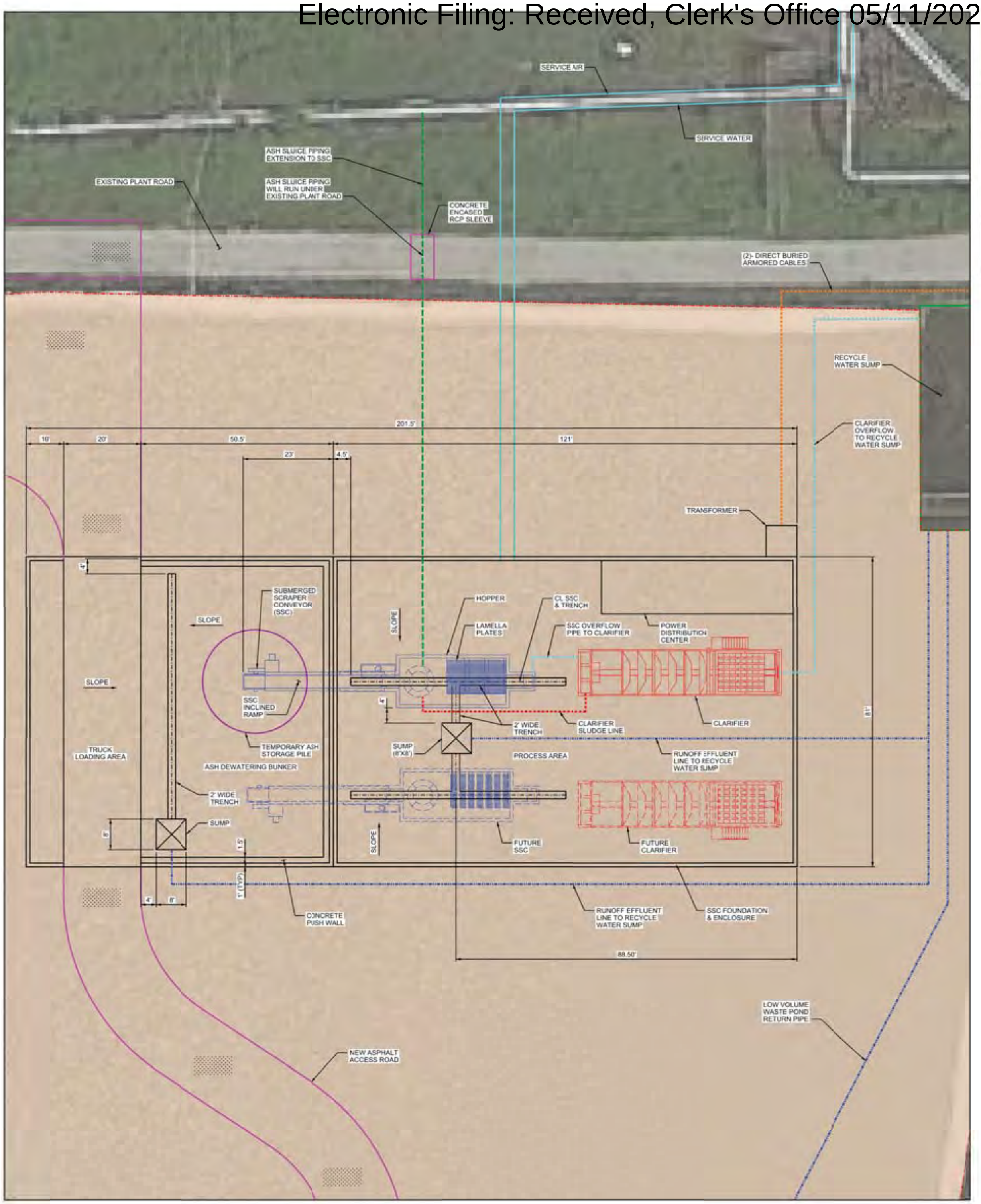
PROJECT
MIDWEST GENERATION, LLC
WAUKEGAN
GENERATING STATION
UNITS 7 & 8

DRAWING TITLE
PROJECT SITE PLAN

DRAWING NUMBER	REVISION
WKG-CSK-100	0
SHEET 1 OF 1	

11/24/2020 11:39:54 AM ...\Drawings\WKG-CSK-100.dgn

PD11153/DM1864/S:\C\
Form GDC-0401-01-08, ANSI (Imperial) MicroStation Border - Size E - 34 x 44
Revision 11A, Revision Date: 04-30-2010



KEY PLAN
SCALE: 1" = 6000'

PRELIMINARY
NOT FOR CONSTRUCTION

LEGEND

▨	SAND
▨	[illegible]

NOTES

1. [illegible] SEE DRAWING WKG-CSK-100.
2. AERIAL [illegible] GOOGLE EARTH PRO V7.3 AND IS [illegible]

REFERENCE DRAWINGS

WKG-CSK-001	SITE PLAN
WKG-CSK-100	PROJECT SITE PLAN
WKG-CSK-102	LOW VOLUME WASTE PLAN
WKG-CSK-103	LOW VOLUME WASTE POND SECTIONS AND DETAILS

UNDERGROUND OR EMBEDDED UTILITIES MAY BE LOCATED WITHIN OR ADJACENT TO THE AREA IN WHICH EXCAVATION, DEMOLITION, FOUNDATION, OR MODIFICATION WORK IS TO BE PERFORMED.

REFERENCES RELATING TO THE UNDERGROUND OR EMBEDDED UTILITIES ARE PROVIDED TO ASSIST THE CONTRACTOR/INSTALLER IN THE FIELD LOCATING THOSE UTILITIES AND OTHER POSSIBLE UNDERGROUND OR EMBEDDED INTERFERENCES WITH THE WORK.

THE CONTRACTOR/INSTALLER SHALL EXERCISE DUE CAUTION DURING ALL EXCAVATION/FOUNDATION/DEMOLITION WORK.

HOLD INFORMATION

NO.	DESCRIPTION

CONTRACTOR/INSTALLER SHALL TAKE ALL APPROPRIATE PRECAUTIONS TO ENSURE THE SAFETY OF ALL PEOPLE LOCATED ON THE WORK SITE, INCLUDING CONTRACTOR'S/INSTALLER'S PERSONNEL (OR THAT OF ITS SUB-CONTRACTOR(S)) PERFORMING THE WORK.

RELEASE INFORMATION

REV.	DATE	DESCRIPTION
0	11-25-2020	FOR USE

ISSUE PURPOSE: FOR USE
SPECIFICATION:
PROJECT NO.: 12667-096

CAD FILE NAME: WKG-CSK-101.DGN
PREPARED BY: J. CHAVEZ
REVIEWED BY: T. DEHLIN
APPROVED BY: T. DEHLIN

ANY MODIFICATION OR ADDITION TO THIS DRAWING BY AN ORGANIZATION OTHER THAN SARGENT & LUNDY, IS NOT THE RESPONSIBILITY OF SARGENT & LUNDY.

Sargent & Lundy
SARGENT & LUNDY
55 EAST MONROE STREET
CHICAGO, ILLINOIS 60603-5780

MWG

PROJECT

MIDWEST GENERATION, LLC
WAUKEGAN
GENERATING STATION
UNITS 7 & 8

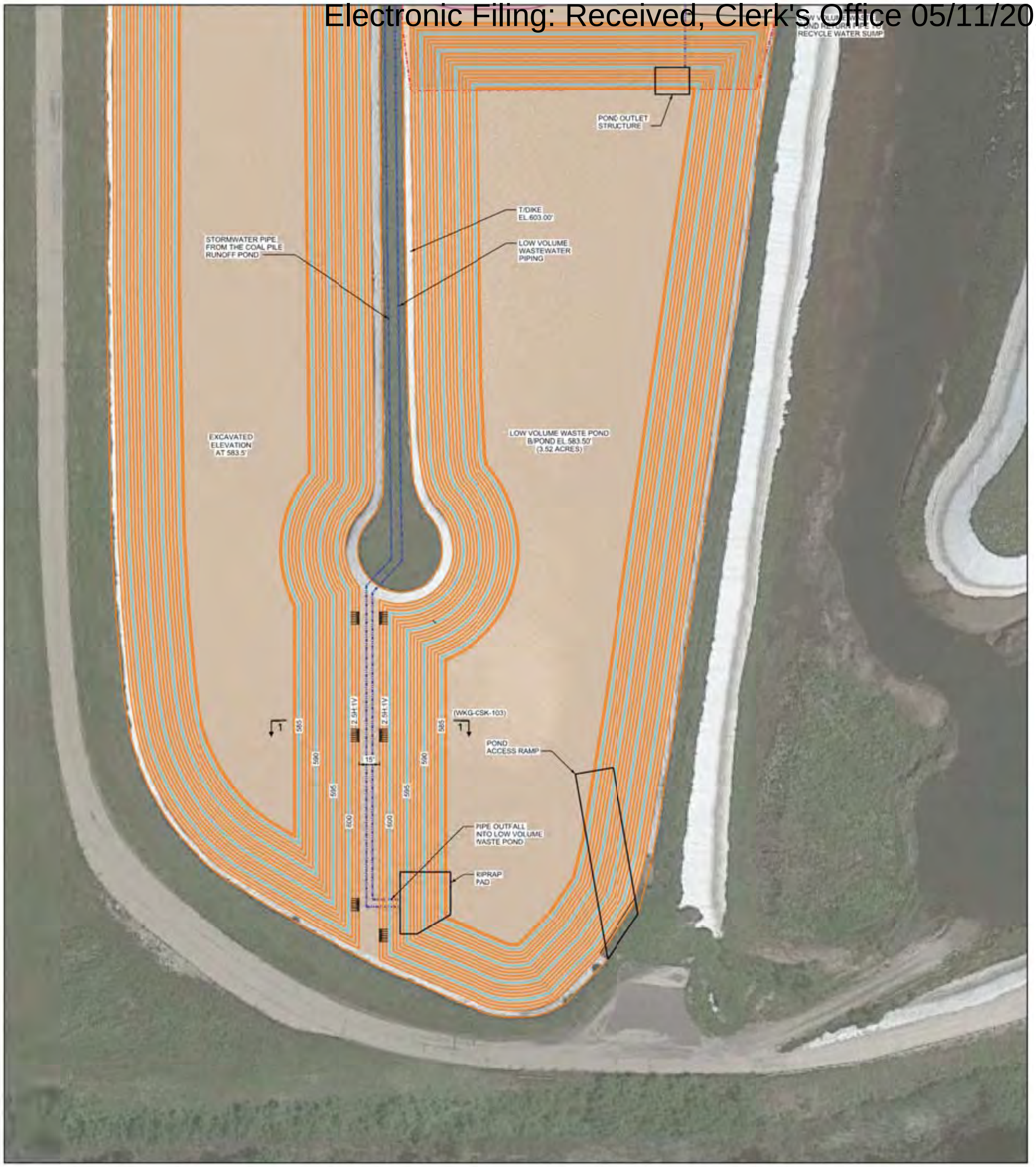
DRAWING TITLE

SSC FOUNDATION & ENCLOSURE PLAN

DRAWING NUMBER	REVISION
WKG-CSK-101	0
SHEET 1 OF 1	

PD11153/DM1864/S1#C?i
Form ODC-0401-01-08, ANSI (Imperial) MicroStation Border - Size E - 34 x 44
Revision 114; Revision Date: 04-30-2010

11/25/2020 11:51:07 AM ...\Drawings\WKG-CSK-101.dgn



KEY PLAN
SCALE: 1" = 6000'

GRAPHIC SCALE

LEGEND

—600—	MAJOR CONTOUR
—599—	MINOR CONTOUR
▨	SAND FILL

NOTES

1. AERIAL IMAGE IS FROM GOOGLE EARTH PRO ... DATED 07/06/2018.
2. ELEVATIONS ARE BASED ON THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD 88).

REFERENCE DRAWINGS

WKG-CSK-001	SITE PLAN
WKG-CSK-100	PROJECT SITE PLAN
WKG-CSK-101	SSC FOUNDATION & ENCLOSURE PLAN
WKG-CSK-103	LOW VOLUME WASTE POND SECTIONS AND DETAILS

UNDERGROUND OR EMBEDDED UTILITIES MAY BE LOCATED WITHIN OR ADJACENT TO THE AREA IN WHICH EXCAVATION, DEMOLITION, FOUNDATION, OR MODIFICATION WORK IS TO BE PERFORMED.

REFERENCES RELATING TO THE UNDERGROUND OR EMBEDDED UTILITIES ARE PROVIDED TO ASSIST THE CONTRACTOR/INSTALLER IN THE FIELD LOCATING THOSE UTILITIES AND OTHER POSSIBLE UNDERGROUND OR EMBEDDED INTERFERENCES WITH THE WORK.

THE CONTRACTOR/INSTALLER SHALL EXERCISE DUE CAUTION DURING ALL EXCAVATION/FOUNDATION/DEMOLITION WORK.

PRELIMINARY
NOT FOR CONSTRUCTION

HOLD INFORMATION

NO.	DESCRIPTION

CONTRACTOR/INSTALLER SHALL TAKE ALL APPROPRIATE PRECAUTIONS TO ENSURE THE SAFETY OF ALL PEOPLE LOCATED ON THE WORK SITE, INCLUDING CONTRACTOR'S/INSTALLER'S PERSONNEL (OR THAT OF ITS SUB-CONTRACTOR(S)) PERFORMING THE WORK.

RELEASE INFORMATION

REV.	DATE	DESCRIPTION
0	11-25-2020	FOR USE

ISSUE PURPOSE: FOR USE
SPECIFICATION:
PROJECT NO.: 12667-036

CAD FILE NAME: WKG-CSK-102.DGN
PREPARED BY: J. CHAVEZ
REVIEWED BY: T. DEHLIN
APPROVED BY: T. DEHLIN

ANY MODIFICATION OR ADDITION TO THIS DRAWING BY AN ORGANIZATION OTHER THAN SARGENT & LUNDY, IS NOT THE RESPONSIBILITY OF SARGENT & LUNDY.

Sargent & Lundy LLC

SARGENT & LUNDY LLC
55 EAST MONROE STREET
CHICAGO, ILLINOIS 60603-5780

MWG

PROJECT

MIDWEST GENERATION, LLC
WAUKEGAN
REMOTE SUBMERGED
GENERATING STATION
UNITS 7 & 8

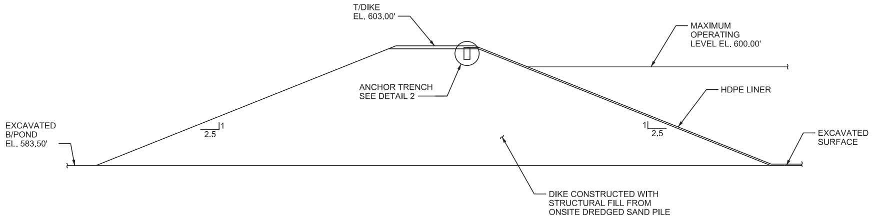
DRAWING TITLE

LOW VOLUME WASTE POND
PLAN

DRAWING NUMBER	REVISION
WKG-CSK-102	0
SHEET 1 OF 1	

11/25/2020 11:53:47 AM
...\Drawings\WKG-CSK-102.dgn

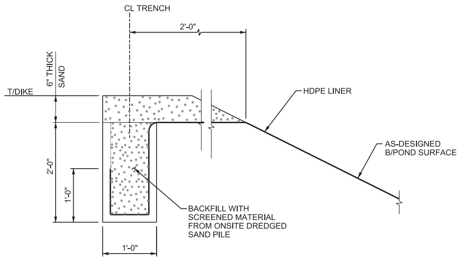
P011153/DM1864/S:*C1
Form GDG-0401-01-08, ANSI (Imperial) MicroStation Border - Size E - 34 x 44
Revision 11A, Revision Date: 04-30-2010



NEW LOW VOLUME WASTE POND SOUTH DIKE

SECTION 1

N.T.S.



LINER ANCHOR TRENCH

DETAIL 2

N.T.S.

NOTES

1. ALL ELEVATIONS ARE BASED ON THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)

REFERENCE DRAWINGS

WKG-CSK-001	SITE PLAN
WKG-CSK-100	PROJECT SITE PLAN
WKG-CSK-101	SSC FOUNDATION & ENCLOSURE PLAN
WKG-CSK-102	LOW VOLUME WASTE POND PLAN

UNDERGROUND OR EMBEDDED UTILITIES MAY BE LOCATED WITHIN OR ADJACENT TO THE AREA IN WHICH EXCAVATION, DEMOLITION, FOUNDATION, OR MODIFICATION WORK IS TO BE PERFORMED.

REFERENCES RELATING TO THE UNDERGROUND OR EMBEDDED UTILITIES ARE PROVIDED TO ASSIST THE CONTRACTOR/INSTALLER IN THE FIELD LOCATING THOSE UTILITIES AND OTHER POSSIBLE UNDERGROUND OR EMBEDDED INTERFERENCES WITH THE WORK.

THE CONTRACTOR/INSTALLER SHALL EXERCISE DUE CAUTION DURING ALL EXCAVATION/FOUNDATION/DEMOLITION WORK.

PRELIMINARY
NOT FOR CONSTRUCTION

HOLD INFORMATION

NO.	DESCRIPTION

CONTRACTOR/INSTALLER SHALL TAKE ALL APPROPRIATE PRECAUTIONS TO ENSURE THE SAFETY OF ALL PEOPLE LOCATED ON THE WORK SITE, INCLUDING CONTRACTOR'S/INSTALLER'S PERSONNEL (OR THAT OF ITS SUB-CONTRACTOR(S)) PERFORMING THE WORK.

RELEASE INFORMATION

REV.	DATE	DESCRIPTION
0	11-25-2020	FOR USE

ISSUE PURPOSE: FOR USE
SPECIFICATION: ---
PROJECT NO.: 12661-098

CAD FILE NAME: WKG-CSK-103.DGN
PREPARED BY: J. CHAVEZ
REVIEWED BY: T. DEHLIN
APPROVED BY: T. DEHLIN

ANY MODIFICATION OR ADDITION TO THIS DRAWING BY AN ORGANIZATION OTHER THAN SARGENT & LUNDY, IS NOT THE RESPONSIBILITY OF SARGENT & LUNDY.

Sargent & Lundy LLC

SARGENT & LUNDY LLC
55 EAST MONROE STREET
CHICAGO, ILLINOIS 60603-5780

MWG

PROJECT

MIDWEST GENERATION, LLC
WAUKEGAN
GENERATING STATION
UNITS 7 & 8

DRAWING TITLE

LOW VOLUME WASTE POND
SECTIONS AND DETAILS

DRAWING NUMBER	REVISION
WKG-CSK-103	0

SHEET 1 OF 1

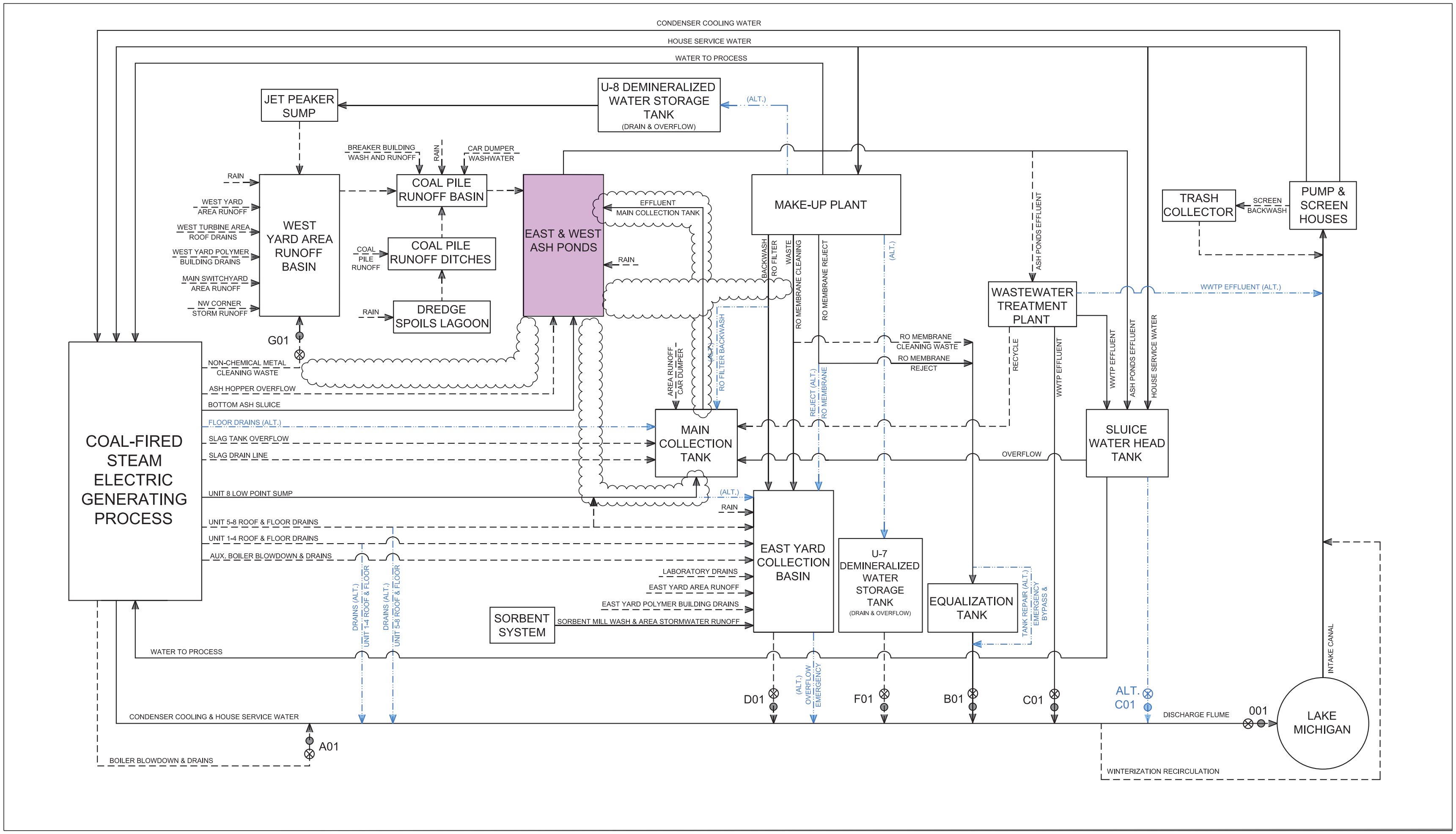
PD11153/OM1864/S:*CivilDesign*2-Waukegan- CCR*Drawings*WKG-CSK-103.dgn
Form GDG-0401-01-08, ANSI (Imperial) MicroStation Border - Size E - 34 x 44
Revision 11A, Revision Date: 04-30-2010

11/25/2020 11:58:12 AM
...*Drawings*WKG-CSK-103.dgn

Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

APPENDIX B — PROCESS FLOW DIAGRAMS

Drawing No.	Drawing Title	Rev.	Date
WKG-CSK-PFD-001	Existing Water Block Flow Diagram	0	11-25-2020
WKG-CSK-PFD-002	Proposed Water Block Flow Diagram for EPA CCR Rule Compliance	0	11-25-2020



LEGEND

———	TYPICAL
– – – –	INTERMITTENT
–·· –·· –	ALTERNATE
●	OUTFALL NUMBER
⊗	SAMPLING POINT
▨	CCR TREATMENT/STORAGE FACILITY

NOTES

1. THIS DRAWING WAS DEVELOPED USING MIDWEST GENERATION, LLC DRAWING "GENERAL FLOW DIAGRAM WITH NPDES OUTFALLS, NPDES PERMIT NO. IL0002259," PREPARED BY APTIM ENVIRONMENTAL & INFRASTRUCTURE, LLC (DATED SEPTEMBER 2019) AND USED WITH PERMISSION FROM MIDWEST GENERATION, LLC. SARGENT & LUNDY HAS NOT INDEPENDENTLY VERIFIED THE INFORMATION SHOWN ON THIS DRAWING.
2. SCOPED AREAS ON THIS DRAWING REPRESENT CHANGES TO THE ORIGINAL WATER BLOCK FLOW DIAGRAM (SEE NOTE 1) BASED ON INPUT FROM MIDWEST GENERATION, LLC.

HOLD INFORMATION

NO.	DESCRIPTION

RELEASE INFORMATION

REV.	DATE	DESCRIPTION
0	11-25-2020	FOR USE

ISSUE PURPOSE: FOR USE
SPECIFICATION: ---
PROJECT NO.: 12661-098

CAD FILE NAME: WKG-CSK-PFD-001.DGN
PREPARED BY: J. CHAVEZ
REVIEWED BY: T. DEHLIN
APPROVED BY: T. DEHLIN

ANY MODIFICATION OR ADDITION TO THIS DRAWING BY AN ORGANIZATION OTHER THAN SARGENT & LUNDY, IS NOT THE RESPONSIBILITY OF SARGENT & LUNDY.

Sargent & Lundy LLC

SARGENT & LUNDY LLC
55 EAST MONROE STREET
CHICAGO, ILLINOIS 60603-5780

MWG

PROJECT

MIDWEST GENERATION, LLC
WAUKEGAN
GENERATING STATION
UNITS 7 & 8

DRAWING TITLE

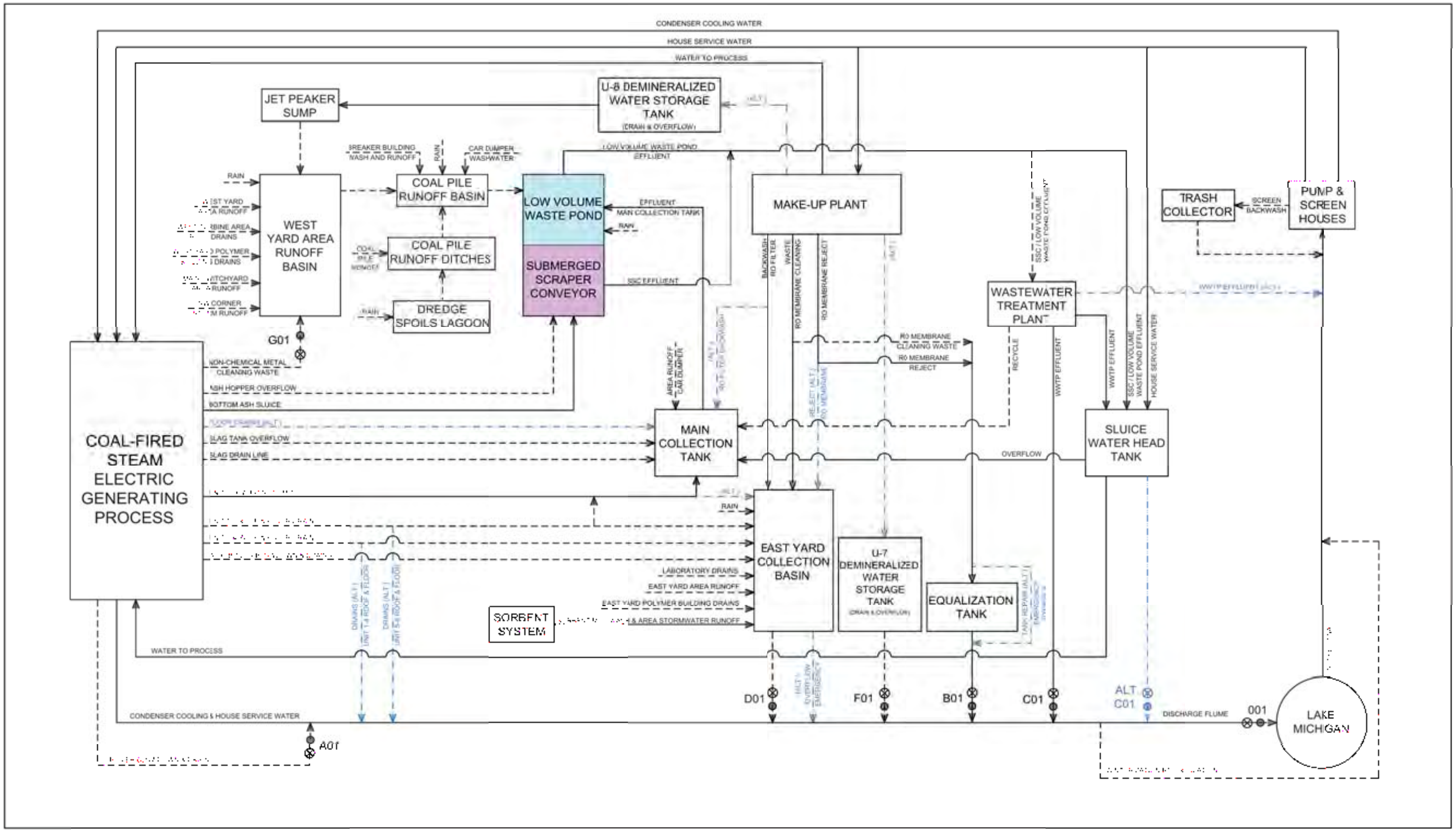
EXISTING WATER BLOCK
FLOW DIAGRAM

DRAWING NUMBER	REVISION
WKG-CSK-PFD-001	0

SHEET 1 OF 1

PD11153/0M1864/S:*CivilDesign*2-Waukegan- CCR*Drawings*WKG-CSK-PFD-001.dgn
Form GDG-0401-01-08, ANSI (Imperial) MicroStation Border - Size E - 34 x 44
Revision 11A, Revision Date: 04-30-2010

11/25/2020 12:00:50 PM
...*Drawings*WKG-CSK-PFD-001.dgn



HOLD INFORMATION

NO.	DESCRIPTION

RELEASE INFORMATION

REV.	DATE	DESCRIPTION
0	11-25-2020	FOR USE

ISSUE PURPOSE: FOR USE
SPECIFICATION:
PROJECT NO.: 12661-096

CAD FILE NAME: WKG-CSK-PFD-002.DGN
PREPARED BY: J. CHAVEZ
REVIEWED BY: T. DEHLIN
APPROVED BY: T. DEHLIN

ANY MODIFICATION OR ADDITION TO THIS DRAWING BY AN ORGANIZATION OTHER THAN SARGENT & LUNDY, IS NOT THE RESPONSIBILITY OF SARGENT & LUNDY.

Sargent & Lundy

SARGENT & LUNDY
55 EAST MONROE STREET
CHICAGO, ILLINOIS 60603-5780

MWG

LEGEND

——	TYPICAL
- - - -	INTERMITTENT
— — —	ALTERNATE
●	OUTFALL NUMBER
⊗	SAMPLING POINT
🟪	CCR TREATMENT SYSTEM FACILITY
🟦	REPURPOSED

NOTES

1. THIS DRAWING WAS DEVEL[illegible] GENERATION, LLC DRAWIN[illegible] NPDES OUTFALLS, NPDES [illegible] BY APTIM ENVIRONMENTAL [illegible] (DATED SEPTEMBER 2019) [illegible] MIDWEST GENERATION, LL[illegible] INDEPENDENTLY VERIFIED THE INFORMATION SHOWN ON THIS DRAWING.

PROJECT

MIDWEST GENERATION, LLC
WAUKEGAN
GENERATING STATION
UNITS 7 & 8

DRAWING TITLE

PROPOSED WATER BLOCK
FLOW DIAGRAM FOR
EPA CCR RULE COMPLIANCE

DRAWING NUMBER	REVISION
WKG-CSK-PFD-002	0
SHEET 1 OF 1	

11/25/2020 11:38:59 AM ...Drawings\WKG-CSK-PFD-002.dgn

P011153/OM1864/S:HCl
Form GDG-0401-01-08, ANSI (Imperial) MicroStation Border - Size E - 34 x 44
Revision 1(A), Revision Date: 04-30-2010

APPENDIX C — COMPLIANCE DOCUMENTATION

Appendix No.	Document Title
C.1	Certification of Compliance
C.2	Geology/Hydrogeology
C.3	Analytical Data Tables Thru 2nd Quarter 2020
C.4	Structural Stability & Safety Factor Assessments

EXHIBIT 14

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

1021 NORTH GRAND AVENUE EAST, P.O. BOX 19276, SPRINGFIELD, ILLINOIS 62794-9276 • (217) 782-3397
PAT QUINN, GOVERNOR
JOHN J. KIM, INTERIM DIRECTOR

217-785-0561

October 24, 2012

CERTIFIED MAIL # 7011 1150 0001 0859 0102
RETURN RECEIPT REQUESTED

John Kennedy
Senior Vice President, Generation
235 Remington, Suite A
Bolingbrook, IL 60440

Re: Compliance Commitment Acceptance
Violation Notice: W-2012-00056
Midwest Generation, LLC, Waukegan Generating Station; ID Number: 6281

Dear Mr. Kennedy:

The Illinois Environmental Protection Agency ("Illinois EPA") has approved the Compliance Commitment Agreement ("CCA") for Midwest Generation, LLC, Waukegan Generating Station. Please find enclosed an executed copy of the CCA for your records.

Failure to fully comply with the CCA may, at the sole discretion of the Illinois EPA, result in referral of this matter to the Office of the Attorney General, the State's Attorney or the United States Environmental Protection Agency.

The CCA does not constitute a waiver or modification of the terms and conditions of any license or permit issued by the Illinois EPA or any other unit or department of local, state or federal government or of any local, state or federal statute or regulatory requirement.

Questions regarding this matter should be directed to Andrea Rhodes at 217/785-0561. Written communications should be directed to the Illinois Environmental Protection Agency, Bureau of Water, CAS #19, P.O. Box 19276, Springfield, IL 62794-9276, and all communications shall include reference to your Violation Notice Number W-2012-00056.

Sincerely,

Michael Crumly
Manager, Compliance Assurance Section
Division of Public Water Supplies
Bureau of Water

Attachments

cc: Basil G. Constantelos
Maria Race
Susan M. Franzetti

RECEIVED
OCT 29 2012

BOW ID: W0971900021 CASE ID: 2012-006

4302 N. Main St., Rockford, IL 61103 (815)987-7760
595 S. State, Elgin, IL 60123 (847)608-3131
2125 S. First St., Champaign, IL 61820 (217)278-5800
2009 Mall St., Collinsville, IL 62234 (618)346-5120
9511 Harrison St., Des Plaines, IL 60016 (847)294-4000
5407 N. University St., Arbor 113, Peoria, IL 61614 (309)693-5462
2309 W. Main St., Suite 116, Marion, IL 62959 (618)993-7200
100 W. Randolph, Suite 11-300, Chicago, IL 60601 (312)814-6026

PLEASE PRINT ON RECYCLED PAPER

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

RECEIVED
OCT 17 2012
IEPA/CAS

IN THE MATTER OF:)
)
MIDWEST GENERATION, LLC,)
WAUKEGAN GENERATING STATION)
WAUKEGAN, LAKE COUNTY, IL)
ID NUMBER: 6281)
)
) ILLINOIS EPA VN W-2012-00056
) BUREAU OF WATER
)

COMPLIANCE COMMITMENT AGREEMENT

I. Jurisdiction

1. This Compliance Commitment Agreement ("CCA") is entered into voluntarily by the Illinois Environmental Protection Agency ("Illinois EPA") and Midwest Generation, LLC, Waukegan Generating Station ("Respondent") (collectively, the "Parties") under the authority vested in the Illinois EPA pursuant to Section 31(a)(7)(i) of the Illinois Environmental Protection Act ("Act"), 415 ILCS 5/31(a)(7)(i).

II. Allegation of Violations

2. Respondent owns and operates Waukegan Generating Station in Waukegan, Lake County, Illinois ("Waukegan Station").

3. Pursuant to Violation Notice ("VN") W-2012-00056 issued on June 11, 2012, the Illinois EPA contends that Respondent has violated the following provisions of the Act and Illinois Pollution Control Board ("Board") Regulations:

   a) Operations at ash impoundments have resulted in violations of the Groundwater Quality Standards at monitoring wells MW-1, MW-2, MW-3, MW-4, and MW-5. Section 12 of the Act, 415 ILCS 5/12, 35 Ill. Adm. Code 620.115, 620.301, 620.401, 620.405, and 620.410.

III. Compliance Activities

4. On September 4, 2012, the Illinois EPA received Respondent's response to VN W-2012-00056, which included proposed terms for a CCA. The Illinois EPA has reviewed Respondent's proposed CCA terms, as well as considered whether any additional terms and conditions are necessary to attain compliance with the alleged violations cited in the VN.

5. Respondent agrees to undertake and complete the following actions, which the Illinois EPA has determined are necessary to attain compliance with the allegations contained in VN W-2012-00056:

   a) The ash ponds at Waukegan Station shall not be used as permanent disposal sites and shall continue to function as treatment ponds to precipitate ash. Ash shall continue to be removed from the ponds on a periodic basis.

   b) The ash treatment ponds shall be maintained and operated in a manner which protects the integrity of the existing liners. During the removal of ash from the ponds, appropriate procedures shall be followed to protect the integrity of the existing liners, including operating the ash removal equipment in a manner which minimizes the risk of any damage to the liner.

   c) During the ash removal process, visual inspections of the ponds shall be conducted to identify any signs of a breach in the integrity of the pond liners. In the event that a breach of the pond liners is detected, Midwest Generation shall promptly notify the Illinois EPA and shall implement a corrective action plan for repair or replacement as necessary, of the liner. Upon the Illinois EPA's approval, and the issuance of any necessary construction permit, Midwest Generation will implement the corrective action plan.

   d) Midwest Generation shall install two additional groundwater monitoring wells on the Waukegan Station property, at locations approved by the Illinois EPA, within 90 days of the effective date of the CCA.

   e) Midwest Generation shall monitor the two new wells and the existing five groundwater monitoring wells quarterly for constituents in 35 Ill. Adm. Code 620.410(a) and (d), with the exception of radium 226 and 228, and report its findings to the Illinois EPA within 30 days of the end of each quarter. In addition, Midwest Generation shall record and report groundwater elevation and submit a potentiometric surface map with the above quarterly groundwater monitoring report.

   f) Midwest Generation shall enter into an Environmental Land Use Control (ELUC) to cover the remaining Waukegan Station property to the east that is not already included in the existing ComEd Former Tannery Site ELUC. Midwest Generation shall submit a proposed ELUC to the Illinois EPA for review and approval within 90 days of the effective date of the CCA.

g) Midwest Generation shall record the ELUC within 30 days of approval of the ELUC by the Illinois EPA.

i) Once the new monitoring wells have been installed and the ELUC has been approved Midwest Generation may submit either the attached "Illinois EPA Compliance Statement" or another similar writing to satisfy the statement of compliance within one year of the effective date of the CCA.

IV. Terms and Conditions

6. Respondent shall comply with all provisions of this CCA, including, but not limited to, any appendices to this CCA and all documents incorporated by reference into this CCA. Pursuant to Section 31(a)(10) of the Act, 415 ILCS 5/31(a)(10), if Respondent complies with the terms of this CCA, the Illinois EPA shall not refer the alleged violations that are the subject of this CCA, as described in Section II above, to the Office of the Illinois Attorney General or the State's Attorney of the county in which the alleged violations occurred. Successful completion of this CCA or an amended CCA shall be a factor to be weighed, in favor of the Respondent, by the Office of the Illinois Attorney General in determining whether to file a complaint on its own motion for the violations cited in VN W-2012-00056.

7. This CCA is solely intended to address the violations alleged in Illinois EPA VN W-2012-00056. The Illinois EPA reserves and this CCA is without prejudice to, all rights of the Illinois EPA against Respondent with respect to noncompliance with any term of this CCA, as well as to all other matters. Nothing in this CCA is intended as a waiver, discharge, release, or covenant not to sue for any claim or cause of action, administrative or judicial, civil or criminal, past or future, in law or in equity, which the Illinois EPA may have against Respondent, or any other person as defined by Section 3.315 of the Act, 415 ILCS 5/3.315. This CCA in no way affects the responsibilities of Respondent to comply with any other federal, state or local laws or regulations, including but not limited to the Act, and the Board Regulations [and Permit, if applicable].

8. Pursuant to Section 42(k) of the Act, 415 ILCS 5/42(k), in addition to any other remedy or penalty that may apply, whether civil or criminal, Respondent shall be liable for an additional civil penalty of $2,000 for violation of any of the terms or conditions of this CCA.

9. This CCA shall apply to and be binding upon the Illinois EPA, and on Respondent and Respondent's officers, directors, employees, agents, successors, assigns, heirs, trustees, receivers, and upon all persons, including but not limited to contractors and consultants, acting on behalf of Respondent, as well as upon subsequent purchasers of Respondent's Waukegan Station in Waukegan, Lake County, Illinois.

10. In any action by the Illinois EPA to enforce the terms of this CCA, Respondent consents to and agrees not to contest the authority or jurisdiction of the Illinois EPA to enter into or enforce this CCA, and agrees not to contest the validity of this CCA or its terms and conditions.

11. This CCA shall only become effective:

    a) If, within 30 days of receipt, Respondent executes this CCA and submits it, via certified mail, to Illinois EPA, Bureau of Water, Andrea Rhodes, MC #19, 1021 North Grand Ave East, Springfield, IL 62702. If Respondent fails to execute and submit this CCA within 30 days of receipt, via certified mail, this CCA shall be deemed rejected by operation of law; and

    b) Upon execution by all Parties.

12. Pursuant to Section 31(a)(7.5) of the Act, 415 ILCS 5/31(a)(7.5), this CCA shall not be amended or modified prior to execution by the Parties. Any amendment or modification to this CCA by Respondent prior to execution by all Parties shall be considered a rejection of the CCA by operation of law. This CCA may only be amended subsequent to its effective date, in writing, and by mutual agreement between the Illinois EPA and Respondent's signatory to this CCA, Respondent's legal representative, or Respondent's agent.

AGREED:
FOR THE ILLINOIS ENVIRONMENTAL PROTECTION AGENCY:

BY: DATE: 10/24/12
Michael Crumly
Manager, Compliance Assurance Section
Division of Public Water Supplies
Bureau of Water

FOR RESPONDENT:

BY: DATE: Oct 15, 2012
John Kennedy
Senior Vice President, Generation
Midwest Generation, LLC

Illinois EPA Compliance Statement

The owner of the facility must acknowledge that all compliance commitment agreement (CCA) measures have been successfully completed.

Please complete, sign, and return.

I ______________________________ *(print name)*, hereby certify that all violations addressed in Violation Notice (VN) number ____________________ have been addressed and that all CCA measures were completed on ____________________________ *(date)*.

____
Signature

____
Title

____
Telephone Number

____
Date

Be sure to retain copies of this document for your files. Should you need additional notification forms, please contact this office at (217)785-0561. Return this completed form to:

Illinois Environmental Protection Agency
Compliance Assurance Section #19
Bureau of Water
1021 North Grand Avenue East
P.O. Box 19276
Springfield, Illinois 62794-9276

"Any person who knowingly makes a false, fictitious, or fraudulent material statement, orally or in writing, to the Agency,.....related to or required by this Act, a regulation adopted under this Act, any federal law or regulation for which the Agency has responsibility, or any permit, term, or condition thereof, commits a Class 4 felony..." (415 ILCS 5/44(h) (8))

EXHIBIT 15

KPRG

ENVIRONMENTAL CONSULTATION & REMEDIATION

KPRG and Associates, Inc.

ALTERNATE SOURCE DEMONSTRATION
CCR GROUNDWATER MONITORING
WAUKEGAN GENERATING STATION

March 11, 2019

Ms. Sharene Shealey
Midwest Generation, LLC
529 E. Romeo Road
Romeoville, IL 60446

VIA E-MAIL

Re: Alternate Source Demonstration – MW-16 Calcium and TDS
Waukegan Generating Station – Ash Impoundments

Dear Ms. Shealey:

The initial Detection Monitoring requirements in accordance with the Federal Register, Environmental Protection Agency, 40 CFR Parts 257.94, Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule dated April 17, 2015 (CCR Rule) have been completed for the ash pond monitoring wells located at the Midwest Generation, LLC (Midwest Generation) Waukegan Generating Station. The wells sampled were selected to meet the monitoring requirements of the CCR Rule for both the West and East Ash Ponds. The CCR monitoring well network around these ponds consists of eight monitoring wells (MW-01 though MW-04, MW-09, MW-11, MW-14 and MW-16). Wells MW-09, MW-11 and MW-14 are upgradient wells. The monitoring well network is shown on Figure 1 along with another upgradient monitoring well (MW-05) that is not part of the CCR monitoring network as discussed further below. A statistical evaluation of the initial detection monitoring data completed in accordance with the CCR Compliance Statistical Approach for Groundwater Data Evaluation, Midwest Generation Waukegan Generating Station on October 10, 2017. The evaluation included outlier testing, spatial/temporal variability testing, distributional testing, and the establishment of statistical Prediction Limits (PLs) for all Appendix III compounds to which the ninth round of groundwater detection monitoring data were compared to determine whether there may be a statistically significant increase (SSI) for a specific compound at each well location. The evaluation was performed with the assistance of the Sanitas™ statistical software package and provided in the Statistical Evaluation Summary – 2017 CCR Groundwater Monitoring Waukegan Generating Station dated January 12, 2018. An initial Alternate Source Demonstration (ASD) in accordance with

40 CFR 257.94(e)(2) was completed for potential statistically significant increases (SSIs) in boron, sulfate and pH at several monitoring locations. The results of the initial ASD were summarized in a report dated April 12, 2018 which determined that the noted SSIs were not related to the regulated units but rather to other potential source(s). It was recommended at the time to continue with routine semi-annual detection monitoring.

The second semi-annual detection monitoring event for 2018 identified potential SSIs for calcium and total dissolved solids (TDS) at monitoring well location MW-16. Since calcium and TDS were not part of the initial ASD dated April 12, 2018, a recommendation was made to complete another ASD for these parameters to determine the proper next course of action relative to CCR monitoring requirements.

This report summarizes the results of the ASD completed for the Waukegan Station West and East Ash Ponds in accordance with 40 CFR 257.94(e)(2) for calcium and TDS at well location MW-16. The report is structured to provide a documentation of field investigation activities, a summary of Leaching Environmental Assessment Framework (LEAF) Test data observations, an alternate source evaluation of the SSI parameters, conclusions and recommendations. Each is discussed separately below. The statistical evaluation data tables from the December 2018 (second semi-annual) groundwater monitoring event are provided in Attachment 1 for reference. Based on the data evaluation, the noted SSIs for calcium and TDS at monitoring well MW-16 are not the result of leakage of leachate from the regulated units (West and East Ash Ponds) but rather from other potential source(s).

DOCUMENTATION OF FIELD ACTIVITIES

As part of the initial ASD dated April 12, 2018, pond water and ash samples were collected. The pond water was analyzed for CCR Appendix III parameters. The ash samples from the East and West Ponds were analyzed using the LEAF Test using Method 1313. Under this method, each ash sediment sample underwent leaching over a range of eight pH values plus under “Natural pH” conditions. The Natural pH condition is the actual pH of the ash itself measured in the laboratory prior to any pH modifications performed under the LEAF Test. The collected leachate from each pH value was analyzed for CCR Appendix III detection monitoring parameters. The analytical data packages are provided in Attachment 2. The January 2018 data for the ASD are representative of current conditions and valid for use in this evaluation, because the plant operations and the source of coal being burned have not changed since the ASD sampling occurred. The specific field sampling procedures are detailed in the April 12, 2018 report.

LEAF TEST DATA OBSERVATIONS

The results of the pond water and the ash LEAF Test analyses are provided in Tables 1 and 2, respectively. A review of Tables 1 and 2 indicates that the Natural pH of the ash is 9.7 standard units (su) which is higher than the pH of the pond water sample (8.8 su). Based on this observation, the focus of this analysis will rely on the results of the LEAF Test data and in particular the data from the Natural pH samples of the ash.

Focusing on the LEAF Test data for calcium and TDS, Figures 2 and 3 illustrate in graphical form these parameters as a function of pH. On those figures are also plotted the results of the Natural pH samples (the East Pond Natural data plots coincide with the West Pond Natural data on the graphs so only West Pond Natural point is apparent) and the most recent sampling data for well MW-16 from the December 2018 sampling event (the semi-annual detection monitoring event identifying potential SSIs for these parameters in MW-16). In general, the following observations are made:

- Calcium – The calcium leachate concentration is a clear function of pH with decreasing concentrations with increasing pH. The Natural pH sample data for both the East and West Ponds plots close to where it would be expected on the LEAF Test curve. The calcium concentration in well MW-16 also plots below the LEAF Test curve but at a higher calcium concentration than the Natural pH test analyses for both ash samples.

- Total Dissolved Solids (TDS) – The TDS LEAF Test curve shows leachate TDS concentrations decreasing to a pH of 9 and then increasing as pH increases. The TDS values of the Natural pH samples both plot slightly below the LEAF Test curve. The TDS concentration in well MW-16 also plots below the LEAF test curve but at a concentration higher than the Natural pH test analyses of both ash samples.

ALTERNATE SOURCE EVALUATION OF THE SSI PARAMETERS

Monitoring well MW-16 is completed within the southern berm of the ash ponds. A mixture of fill and beneficially reused coal combustion by-product (CCB) were likely used for the construction of the berms for the ash ponds as demonstrated by the CCB documented within the well bore column of this monitoring well. Monitoring well MW-05 is immediately upgradient of the West Ash Pond and of well MW-16 and is completed within the western berm of the ash ponds. MW-05 is not part of the CCR monitoring network. However, knowing the chemistry of the groundwater upgradient, immediately prior to passing beneath the ash ponds and well MW-16, is important in evaluating potential releases of leachate from the regulated units.

Figures 4 and 5 focus in on the LEAF Test pH range of 5 to 10 su for calcium and TDS, respectively. Also included on these figures is the calcium and TDS data from monitoring well MW-16 from the time of initial CCR sampling in November 2015 through the most recent sampling in November/December 2018. In addition, TDS data (Figure 5) for monitoring well MW-05 is also included for this time period (this well is not analyzed for calcium).

The pH range of the groundwater at well MW-16 over the subject time period (i.e., 11/2015 through 12/2018) was from 5.76 to 7.57 with an average of 6.88 and a median of 7.00. For MW-05 the pH range was from 6.18 to 7.78 with an average of 6.96 and a median of 6.93. The data on Figures 4 and 5 indicates that there is no correlation between calcium and TDS concentrations, respectively, with pH at well MW-16. Figure 5 also shows no correlation of TDS with pH at well MW-05.

The calcium concentration range over the noted CCR monitoring period at well MW-16 was 130 mg/l to 380 mg/l with an average concentration of approximately 246 mg/l and a median concentration of 215 mg/l. The two Natural pH leachate samples have calcium concentrations of 42 mg/l and 43 mg/l and the Pond water sample had calcium at 70 mg/l. The TDS concentration range over the noted CCR monitoring period at well MW-16 was 760 mg/l to 1,900 mg/l with an average of approximately 1,323 mg/l and a median of 1,250 mg/l. The two Natural pH leachate samples had TDS at 240 mg/l and 270 mg/l and the Pond water sample had TDS at 430 mg/l.

As discussed above, the Natural pH of the ash sample leachate was 9.7 and the pond water sample was at 8.8. The two semi-annual 2018 sampling events at well MW-16 indicated pH concentrations at 6.53 to 6.78. Both of these pH measurements are lower than the last four sampling events in 2017 which ranged from 7.04 to 7.94. If leakage from the ash ponds was associated with the elevated calcium and TDS concentrations, the pH at well MW-16 would be shifted towards the alkaline side of the scale (i.e., more than 7.0) as opposed to the noted acidic side of the scale (i.e., less than 7.0). In addition, an upward shift in concentrations as noted in the last round of sampling would also not be expected because the calcium and TDS concentrations in the Natural pH ash leachate samples and the Pond water sample are less than the concentrations of these parameters routinely detected at well MW-16.

Additionally, if there was a temporary downward shift in pH within the ash ponds (water and leachate) then there should be a very substantial increase in both calcium and TDS within well MW-16 based on the data from the LEAF Test curves for both of these parameters (i.e., concentrations of calcium and TDS increase very quickly and substantially below a pH of 8 in ash leachate). There was no such substantial increase in either calcium of TDS at well location MW-16. This is further supported by a trend analysis using both Linear Regression and Senn's Slope Estimator methods performed using Sanitas™ statistical software for calcium, TDS and pH at MW-16 over time which shows no statistically significant trends (see Attachment 3).

Figure 6 provides a plot of calcium versus TDS at monitoring well MW-16. This graph shows a clear and strong relationship between these two parameters (i.e., when TDS increases so does calcium). Figure 7 shows a time versus concentration plot for TDS at monitoring wells MW-16 and MW-05, which shows that the two curves indicate a good parallel relationship with increases in TDS at well MW-16 corresponding with increases in TDS at upgradient well MW-05. Accordingly, fluctuations in TDS, and by correlation fluctuations in calcium, at well MW-16 are related to other sources affecting the water quality at upgradient well MW-05 as opposed to a potential release of leachate from the ash ponds.

CONCLUSIONS/RECOMMENDATIONS

Based on the data evaluation and discussions provided above, it is concluded that the noted SSIs for calcium and TDS at monitoring well MW-16 are not the result of leakage of leachate from the regulated units (West and East Ash Ponds) but rather from other potential source(s). This is based on the following:

- The pH levels are not increasing at well MW-16, indicating that there is no leakage of leachate from the ash ponds. Additionally, an increase in the pH levels would result in decreased concentrations of calcium and TDS rather than the documented increased concentrations.

- If there was some unexpected and unlikely downward shift in leachate/pond water pH, the increases in calcium and TDS would be much greater than observed at MW-16 based on the LEAF Test pH relationship of these constituents in the pond ash samples.

- Linear Regression and Senn's Slope Estimator trend analyses performed for calcium, TDS and pH for data from well MW-16 do not indicate any statistically significant trends in these parameters at this well.

- There is a strong positive correlation between calcium and TDS concentrations at well MW-16. The fluctuating TDS concentrations at MW-16 are correlated to fluctuations in TDS at upgradient well MW-05 which is believed to have water quality impacted by other potential source(s) and not associated with a potential release of leachate from the ash pond regulated units.

Based on this conclusion, it is recommended to continue with detection monitoring at this time.

Sincerely,
KPRG and Associates, Inc.

Richard R Gnat

Richard R. Gnat, P.G.
Principal

Timothy Stohner, P.E.
Project Manager/Sr. Engineer

cc: David Bacher, NRG
Fred Veenbaas, Midwest Generation

CERTIFICATION

In accordance with Section 257.94(e)(2) of the CCR Rule, I hereby certify based on a review of the information contained within this CCR Alternate Source Demonstration dated March 11, 2019, that the information contained in this report is accurate to the best of my knowledge.

Certified by:

TIMOTHY J. STOHNER
062-057635

Date: March 11, 2019

Timothy Stohner, P.E.
Illinois Professional Engineer Registration No.: 062.057635
KPRG and Associates, Inc.

FIGURES

NOTE:
BACKGROUND MAP RETRIEVED FROM MAPQUEST 2012

LOCATION:
SECTION 15, TOWNSHIP 45 N, RANGE 12 E

ENVIRONMENTAL CONSULTATION & REMEDIATION

KPRG

KPRG and Associates, inc.

14665 West Lisbon Road, Suite 2B Brookfield, Wisconsin 53005 Telephone 262-781-0475 Facsimile 262-781-0478

414 Plaza Drive, Suite 106 Westmont, Illinois 60559 Telephone 630-325-1300 Facsimile 630-325-1593

CCR MONITORING WELL SITE MAP

WAUKEGAN STATION
WAUKEGAN, ILLINOIS

Scale: 1" = 550'
Date: March 26, 2018

KPRG Project No. 23517
FIGURE 1

W:\projects\midwest generation\attorney-client privilege\gw evaluations\alt. source\waukegan map.dwg

Figure 2. Calcium Concentration vs. pH Value - Waukegan Station

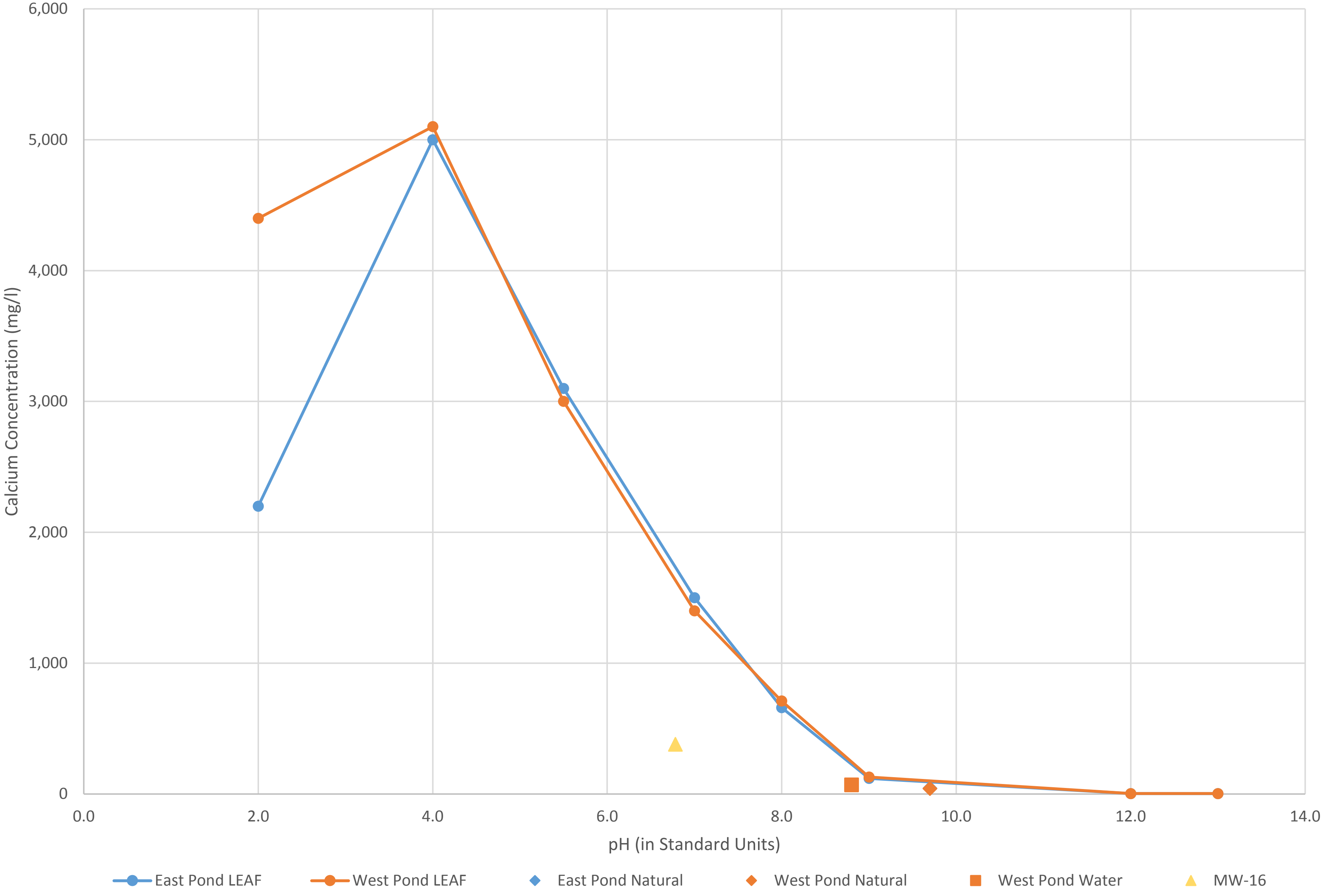
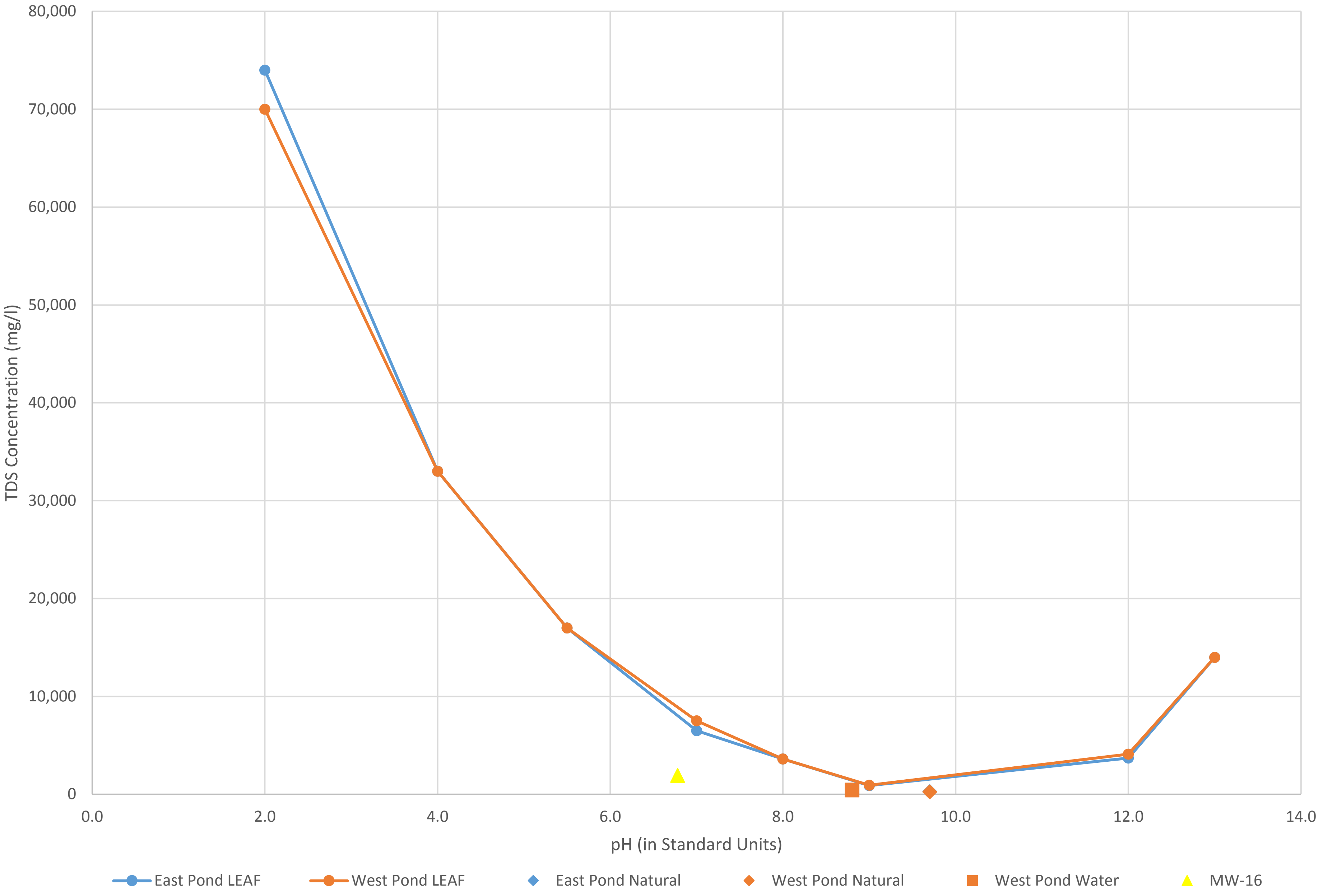


Figure 3. TDS Concentration vs. pH Value - Waukegan Station



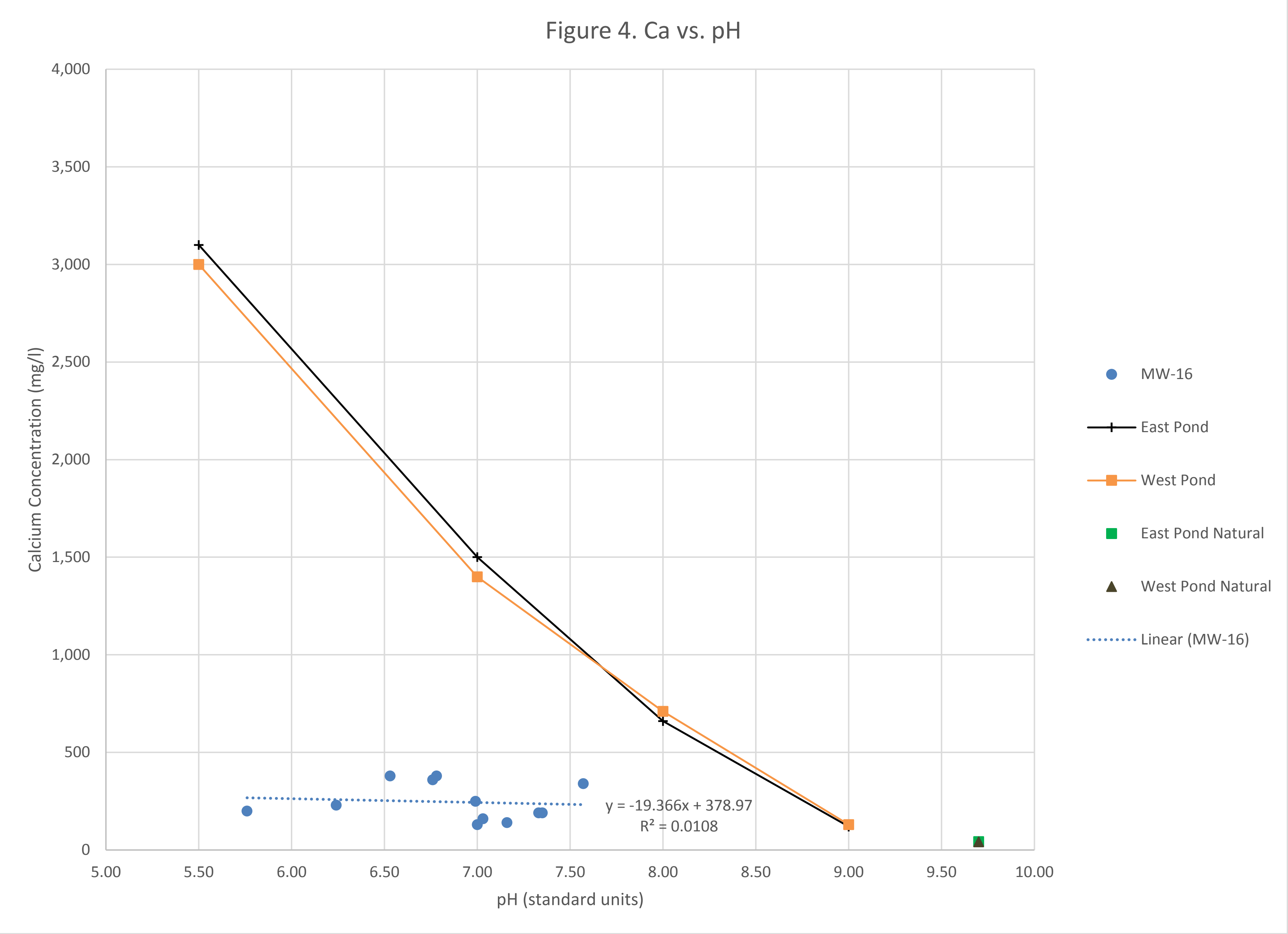


Figure 4. Ca vs. pH
Calcium Concentration (mg/l)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
9.50
10.00
pH (standard units)
y = -19.366x + 378.97
R² = 0.0108
MW-16
East Pond
West Pond
East Pond Natural
West Pond Natural
Linear (MW-16)

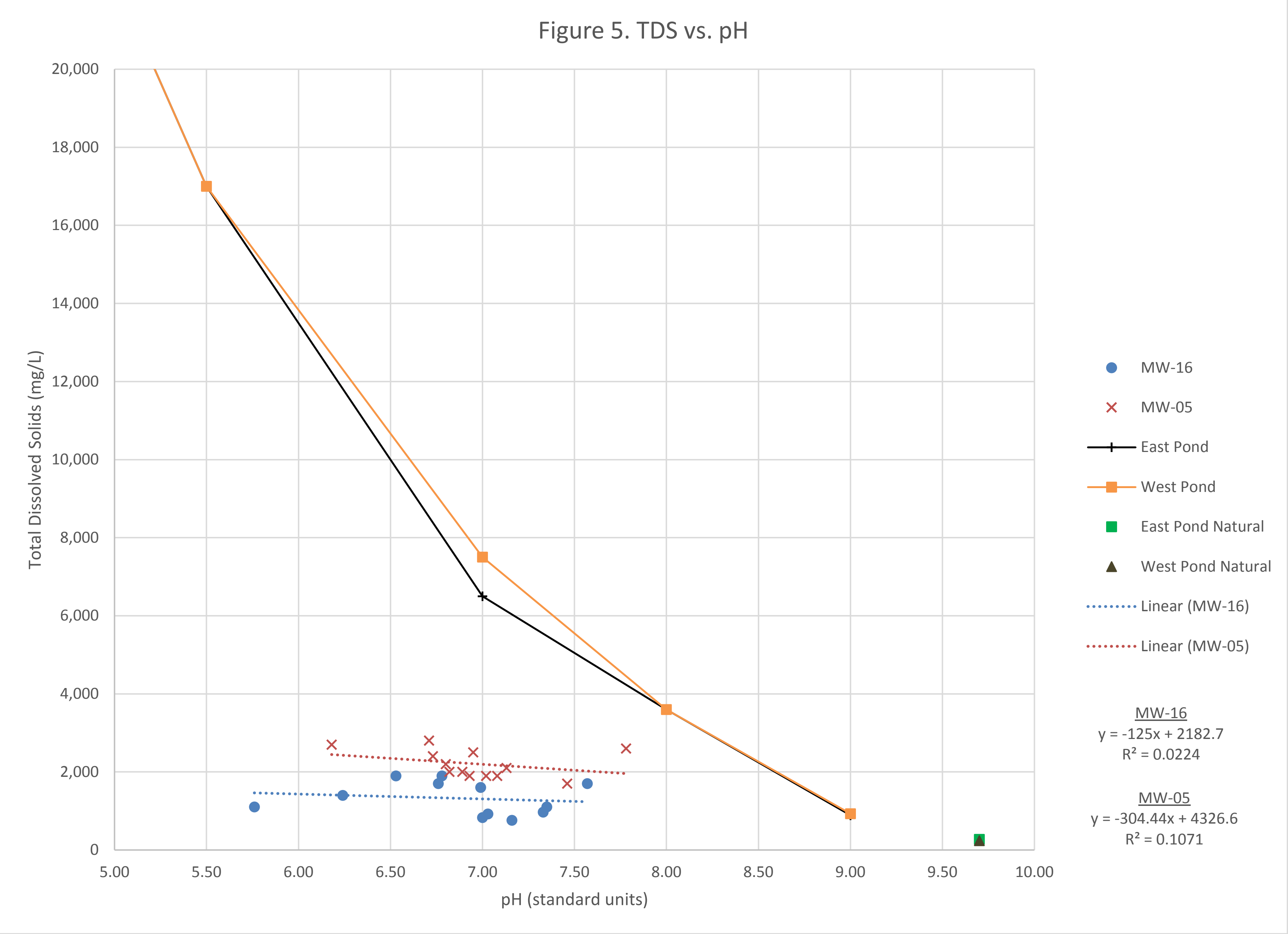
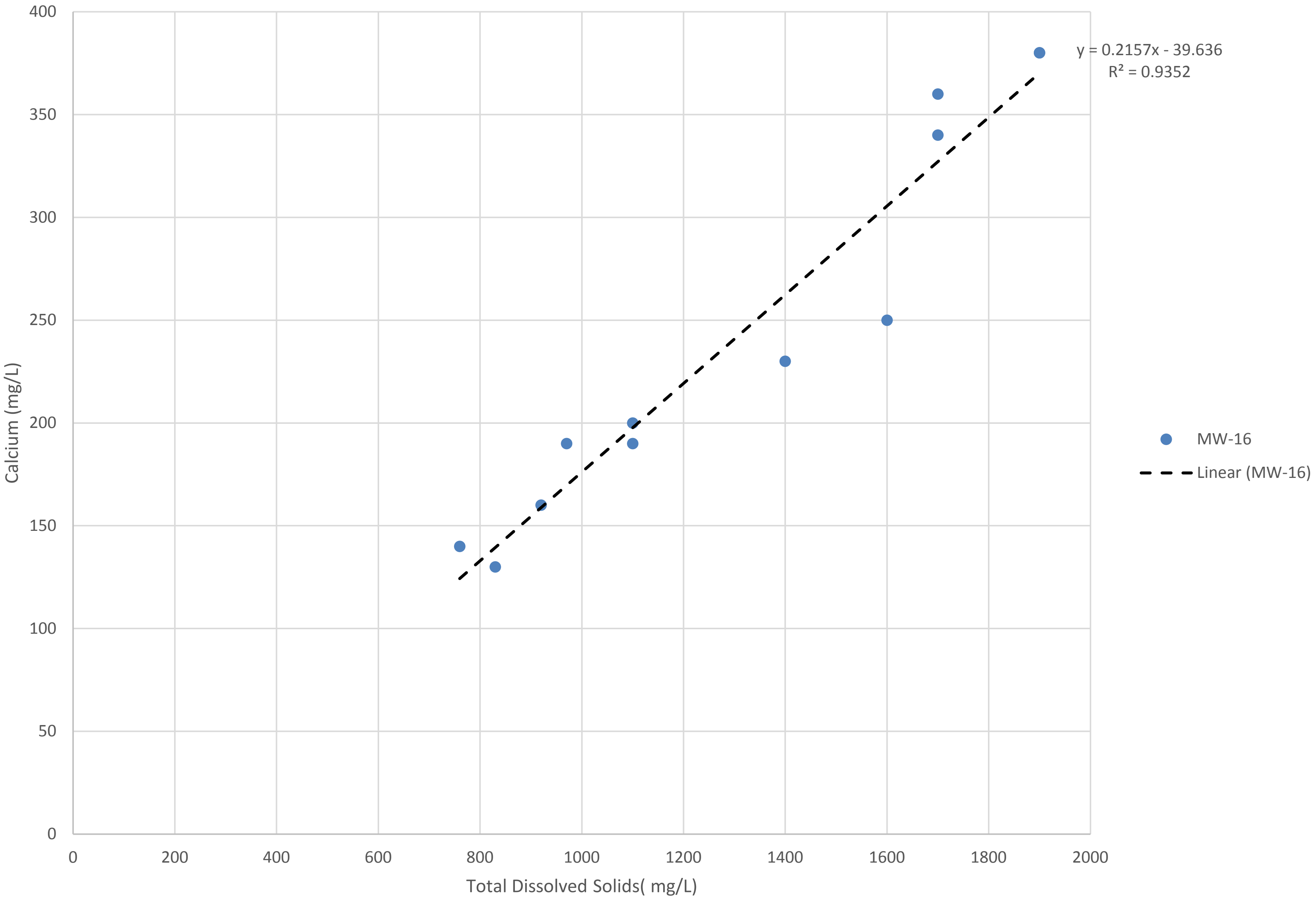


Figure 5. TDS vs. pH
Total Dissolved Solids (mg/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
9.50
10.00
pH (standard units)
MW-16
MW-05
East Pond
West Pond
East Pond Natural
West Pond Natural
Linear (MW-16)
Linear (MW-05)
MW-16
y = -125x + 2182.7
R² = 0.0224
MW-05
y = -304.44x + 4326.6
R² = 0.1071

Figure 6. MW-16: Calcium vs. Total Dissolved Solids



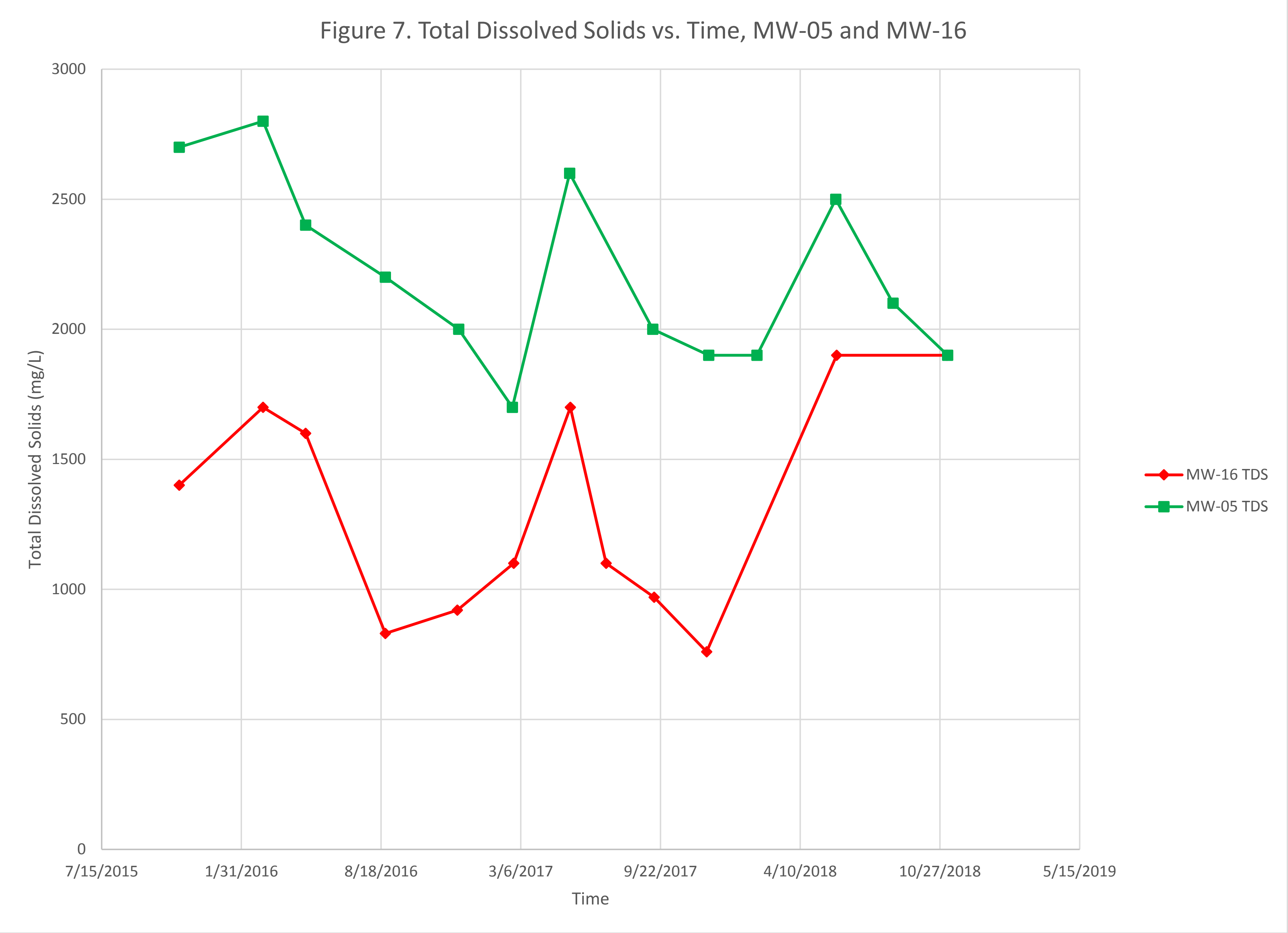


Figure 7. Total Dissolved Solids vs. Time, MW-05 and MW-16
Total Dissolved Solids (mg/L)
3000
2500
2000
1500
1000
500
0
7/15/2015
1/31/2016
8/18/2016
3/6/2017
9/22/2017
4/10/2018
10/27/2018
5/15/2019
Time
MW-16 TDS
MW-05 TDS

TABLES

Table 1. Pond Water Results - Midwest Generation Waukegan Station, Waukegan, Illinois

PARAMETER	UNITS	West Pond
Boron	mg/L	0.87
Calcium	mg/L	70
Chloride	mg/L	52
Fluoride	mg/L	0.21
pH	SU	8.8
Sulfate	mg/L	90
TDS	mg/L	430

Notes: Units are as noted.
TDS - Total Dissolved Solids

Table 2. LEAF Test Results from Ash Samples- Midwest Generation Waukegan Station, Waukegan, Illinois

EAST POND ASH		LEAF TEST TARGETED pH VALUES								
PARAMETER	UNITS	13.0	12.0	9.0	8.0	7.0	5.5	4.0	2.0	Natural*
Boron	mg/L	3.5	3.4	2.0	3.0	4.3	6.4	11.0	5.1	2.0
Calcium	mg/L	3.7	3.5	120	660	1,500	3,100	5,000	2,200	43.0
Chloride	mg/L	<50	<25	2.8	<2.5	<10	<25	<25	<100	2.9
Fluoride	mg/L	<5.0	<2.5	0.51	<0.50	<1.0	<2.5	7.5	<10	0.32
ORP	millivolts	-50	-7.0	230	260	290	310	400	660	170
pH	SU	12.8	12.5	8.9	7.7	7.0	5.8	3.8	2.1	9.7
Spec Cond	umhos/cm	47,000	13,000	1,300	4,700	8,500	18,000	30,000	64,000	390
Sulfate	mg/L	120	110	110	130	140	170	330	180	130
TDS	mg/L	14,000	3,700	890	3,600	6,500	17,000	33,000	74,000	270

WEST POND ASH		LEAF TEST TARGETED pH VALUES								
PARAMETER	UNITS	13.0	12.0	9.0	8.0	7.0	5.5	4.0	2.0	Natural*
Boron	mg/L	3.7	3.7	1.8	2.9	4.3	6.2	11.0	11.0	1.9
Calcium	mg/L	3.8	3.8	130	710	1,400	3,000	5,100	4,400	42.0
Chloride	mg/L	<50	<25	2.2	<5.0	<10	<25	<25	<100	17
Fluoride	mg/L	<5.0	<2.5	0.2	<0.50	<1.0	<2.5	7.7	<10	0.53
ORP	millivolts	-32	-10	250	280	300	320	410	490	170
pH	SU	12.8	12.4	8.7	7.5	7.0	5.9	3.8	2.5	9.7
Spec Cond	umhos/cm	46,000	13,000	1,300	4,800	8,600	18,000	30,000	59,000	400
Sulfate	mg/L	120	120	100	130	130	160	360	180	38
TDS	mg/L	14,000	4,100	930	3,600	7,500	17,000	33,000	70,000	240

Notes: Units are as noted.
ORP - Oxidation Reduction Potential
Spec Cond - Specific Conductivity
TDS - Total Dissolved Solids
Natural* - pH of ash as measured in the laboratory prior to any pH test modifications.

ATTACHMENT 1

Statistical Data Evaluation Tables – December, 2018

Table 4. Detection Monitoring - Appendix III Groundwater Analytical Results through 2018 - Midwest Generation, LLC, Waukegan Station, Waukegan, IL.

Well	Date	Boron	Calcium	Chloride	Fluoride	pH	Sulfate	Total Dissolved Solids
MW-09 up-gradient	11/4/2015	13	210	450	0.14	6.60	370	1700
	3/2/2016	35	380	720	0.11	7.02	970	2800
	5/3/2016	16	310	620	0.12	7.02	740	2500
	8/25/2016	4.5	130	270	0.21	7.13	190	1100
	12/8/2016	15	200	330	0.18	7.01	270	1300
	2/23/2017	14	190	290	0.12	7.68	320	1300
	5/16/2017	27	160	67	0.29	8.15	420	970
	7/6/2017	21	220	430	0.13	7.18	610	1800
	Pred. Limit*	**43.9**	**449**	**963**	**0.33**	**8.53-5.92**	**1214**	**3499**
	9/13/2017	21	250	420	0.14	7.17	520	1800
	11/29/2017	26	200	390	0.13	7.05	390	1600
	5/31/2018	32	200	29	0.1	6.85	490	1000
	11/6/2018	30	170	23	0.11	7.33	290	930
MW-11 up-gradient	11/5/2015	5.2	140	240	0.13	6.51	190	1100
	3/2/2016	4.0	170	240	0.1	7.16	210	1200
	5/5/2016	5.0	140	280	0.11	7.17	160	1000
	8/26/2016	3.5	180	240	0.13	6.97	110	1100
	12/7/2016	3.0	170	270	0.12	7.06	110	1200
	2/24/2017	2.4	180	220	4.9	6.61	170	1200
	5/18/2017	1.8	160	170	0.12	7.42	120	1000
	7/6/2017	2.4	160	190	0.14	7.33	130	1100
	Pred. Limit*	**6.83**	**206**	**333**	**4.9**	**7.91-6.14**	**255**	**1341**
	9/13/2017	1.9	140	150	0.26	7.16	96	870
	11/30/2017	2.2	170	200	0.14	6.99	93	1100
	5/31/2018	1.5	210	160	0.1	6.74	130	1100
	11/6/2018	2.3	170	150	0.12	7.21	78	990
MW-14 up-gradient	11/5/2015	1.4	150	190	0.19	6.78	140	1000
	3/2/2016	0.93	150	110	0.17	7.24	150	870
	5/5/2016	1.2	170	120	0.18	7.17	190	980
	8/26/2016	1.5	200	210	0.12	7.00	190	1300
	12/7/2016	0.95	240	340	0.25	6.81	120	1100
	2/23/2017	0.73	150	99	0.19	6.88	110	730
	5/18/2017	0.81	120	130	0.3	7.62	70	590
	7/6/2017	1.2	190	180	0.13	7.29	190	1300
	Pred. Limit*	**1.85**	**274**	**389**	**0.35**	**7.89-6.31**	**266**	**1676**
	9/13/2017	**2.3**	180	190	0.15	7.20	**270**	1200
	11/30/2017	0.85	170	130	0.19	7.33	99	940
	6/1/2018	0.54	100	57	0.28	6.89	42	410
	11/6/2018	0.98	160	110	0.24	7.36	53	610
MW-01 down-gradient	11/2/2015	1.8	64	71	0.46	10.93	310	560
	3/1/2016	V 1.9	58	63	0.26	11.13	270	570
	5/4/2016	2.0	45	60	0.3	11.09	210	490
	8/23/2016	2.0	42	60	0.26	10.49	240	550
	12/5/2016	2.2	55	65	0.34	10.46	180	560
	2/21/2017	2.2	50	61	0.29	11.30	250	540
	5/15/2017	2.1	52	59	0.37	10.69	330	570
	7/5/2017	2.3	44	51	0.34	10.83	320	570
	Pred. Limit	**1.83**	**227****	**345****	**4.9****	**7.70-6.43****	**233****	**1461****
	Pred. Limit*	**2.52**	**NC**	**NC**	**NC**	**11.7-10.03**	**411.6**	**NC**
	9/14/2017	**2.4**	71	47	0.24	**10.45**	***430***	770
	11/27/2017	***2.7***	84	43	0.11	**7.85**	**330**	840
	5/29/2018	**2.4**	54	58	0.33	**8.44**	**350**	610
	11/5/2018	**2.0**	38	43	0.25	**8.70**	210	630

Notes: All units are in mg/l except pH is in standard units.
Pred. Limit - Prediction Limit
Italics Date - Detection Monitoring and resample after statistical background establishment.
* - Intrawell Prediction Limit. All others are interwell comparisons.
** - Based on pooled background from MW-11/MW-14. All others based on MW-14 as background.
V- Serial dilution exceeds the control limits.
R- Resampling event
NA - Not analyzed. No confirmation resample required.

BOLD - Potential statistically significant increase relative to interwell Prediction Limit.
BOLD Potential statistically significant increase relative to intrawell Prediction Limit.
BOLD Above both interwell and intrawell Prediction Limits.
NC- Not Calculated.

Table 4. Detection Monitoring - Appendix III Groundwater Analytical Results through 2018 - Midwest Generation, LLC, Waukegan Station, Waukegan, IL.

Well	Date	Boron	Calcium	Chloride	Fluoride	pH	Sulfate	Total Dissolved Solids
MW-02 down-gradient	11/2/2015	3.0	32	47	0.78	8.27	230	460
	3/1/2016	4.1	39	47	1.3	8.57	220	510
	5/4/2016	3.3	34	51	1.5	8.19	180	440
	8/23/2016	3.1	42	59	1.3	7.52	250	500
	12/5/2016	3.1	28	56	1.0	8.62	160	430
	2/21/2017	3.3	31	52	0.8	8.75	190	420
	5/15/2017	3.6	85	48	0.6	8.33	320	640
	7/5/2017	4.2	100	52	0.4	7.92	300	710
	Pred. Limit	**1.83**	**227****	**345****	**4.9****	**7.70-6.43****	**233****	**1461****
	Pred. Limit*	**4.73**	**NC**	**NC**	**NC**	**9.38-7.16**	**386.6**	**NC**
	9/14/2017	**2.5**	87	54	0.4	**8.19**	**340**	780
	11/27/2017	**3.4**	69	57	0.6	7.34	200	570
	5/29/2018	**4.5**	160	43	0.4	***6.85***	***420***	990
	11/5/2018	**3.1**	77	59	0.61	**8.06**	180	610
MW-03 down-gradient	11/2/2015	2.3	72	87	0.51	9.26	270	570
	3/1/2016	2.9	61	70	0.33	7.33	220	530
	5/4/2016	2.4	42	74	0.56	7.25	170	470
	8/24/2016	2.0	70	59	0.3	9.13	200	430
	12/5/2016	2.4	57	60	0.41	7.62	120	440
	2/21/2017	2.2	56	65	0.33	7.56	180	460
	5/16/2017	3.9	110	61	0.27	7.90	320	820
	7/5/2017	3.0	60	60	0.28	7.46	200	470
	Pred. Limit	**1.83**	**227****	**345****	**4.9****	**7.70-6.43****	**233****	**1461****
	Pred. Limit*	**4.31**	**NC**	**NC**	**NC**	**9.26-7.25**	**378.9**	**NC**
	9/14/2017	**2.1**	86	57	0.26	7.53	**260**	680
	11/28/2017	**2.6**	69	63	0.56	***6.96***	120	500
	5/29/2018	**2.4**	67	61	0.38	***6.84***	190	480
	11/5/2018	**2.4**	54	54	0.50	**8.99**	150	500
MW-04 down-gradient	11/3/2015	1.8	66	62	0.51	6.68	240	480
	3/1/2016	2.0	58	51	0.5	7.17	170	450
	5/4/2016	1.6	44	49	0.61	6.92	140	340
	8/24/2016	2.0	46	58	0.56	7.01	120	370
	12/5/2016	3.4	200	60	0.21	7.40	300	1000
	2/22/2017	2.4	150	41	0.17	7.44	290	850
	5/16/2017	2.5	170	29	0.32	7.94	400	970
	7/5/2017	3.6	200	51	0.29	7.09	520	1100
	Pred. Limit	**1.83**	**227****	**345****	**4.9****	**7.70-6.43****	**233****	**1461****
	Pred. Limit*	**4.42**	**NC**	**NC**	**NC**	**8.26-6.15**	**647.3**	**NC**
	9/14/2017	**2.5**	180	45	0.28	7.04	**480**	1100
	11/28/2017	**2.3**	110	32	0.28	7.04	130	560
	5/30/2018	**3.0**	150	21	0.38	6.57	200	700
	11/6/2018	**2.5**	150	58	0.37	6.83	**240**	900
MW-16 down-gradient	11/3/2015	4.1	230	87	0.43	6.24	610	1400
	3/2/2016	3.1	360	130	0.35	6.76	990	1700
	5/2/2016	4.9	250	150	0.49	6.99	620	1600
	8/24/2016	3.6	130	53	0.71	7.00	330	830
	12/5/2016	3.8	160	52	0.51	7.03	280	920
	2/24/2017	6.5	200	67	0.2	5.76	570	1100
	5/16/2017	2.6	340	130	0.15	7.57	760	1700
	7/6/2017	9.5	190	70	0.57	7.35	480	1100
	Pred. Limit	**1.83**	**227****	**345****	**4.9****	**7.70-6.43****	**233****	**1461****
	Pred. Limit*	**10.94**	**NC**	**NC**	**NC**	**8.45-5.23**	**1206**	**NC**
	9/13/2017	**2.8**	190	55	0.61	7.33	**460**	970
	11/27/2017	**4.2**	140	58	0.71	7.16	**270**	760
	6/1/2018	**3**	**380**	130	0.32	6.53	**890**	**1900**
	8/22/2018 (R)	NA	190	NA	NA	NA	NA	1200
	11/6/2018	**3.9**	**380**	150	0.39	6.78	**550**	**1900**
	12/4/2018 (R)	NA	**320**	NA	NA	NA	NA	**1600**

Notes: All units are in mg/l except pH is in standard units.
Pred. Limit - Prediction Limit
Italics Date - Detection Monitoring and resample after statistical background establishment.
* - Intrawell Prediction Limit. All others are interwell comparisons.
** - Based on pooled background from MW-11/MW-14. All others based on MW-14 as background.
V- Serial dilution exceeds the control limits.
R- Resampling event
NA - Not analyzed. No confirmation resample required.

BOLD - Potential statistically significant increase relative to interwell Prediction Limit.
BOLD Potential statistically significant increase relative to intrawell Prediction Limit.
BOLD Above both interwell and intrawell Prediction Limits.
NC- Not Calculated.

ATTACHMENT 2

Pond Water and LEAF Test Analytical Data Packages

1
2
3
4
5
6
7
8
9
10
11
12

TestAmerica

THE LEADER IN ENVIRONMENTAL TESTING

ANALYTICAL REPORT

TestAmerica Laboratories, Inc.
TestAmerica Chicago
2417 Bond Street
University Park, IL 60484
Tel: (708)534-5200

TestAmerica Job ID: 500-139827-1
Client Project/Site: Waukegan CCR

For:
KPRG and Associates, Inc.
14665 West Lisbon Road,
Suite 2B
Brookfield, Wisconsin 53005

Attn: Richard Gnat

Authorized for release by:
1/30/2018 1:18:47 PM

Eric Lang, Manager of Project Management
(708)534-5200
eric.lang@testamericainc.com

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

LINKS

Review your project results through TotalAccess

Have a Question? Ask The Expert

Visit us at:
www.testamericainc.com

Table of Contents

Case Narrative

Job ID: 500-139827-1

Laboratory: TestAmerica Chicago

Narrative

Job Narrative
500-139827-1

Comments
No additional comments.

Receipt
The sample was received on 1/18/2018 9:55 AM; the sample arrived in good condition, properly preserved and, where required, on ice. The temperature of the cooler at receipt was 3.4° C.

Metals
Method(s) 6020A: The continuing calibration verification (CCV) at line 37 in AD batch 417738 was outside the control limits for Boron. This CCV bracketed the method blank (MB) and laboratory control sample (LCS) only. Both the MB and LCS were within the method control limits. The associated samples were bracketed by CCV that were within control limits. Therefore, the data have been reported.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

General Chemistry
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

Method Summary

Client: KPRG and Associates, Inc.
Project/Site: Waukegan CCR

TestAmerica Job ID: 500-139827-1

Method	Method Description	Protocol	Laboratory
6020A	Metals (ICP/MS)	SW846	TAL CHI
9040C	pH	SW846	TAL CHI
SM 2540C	Solids, Total Dissolved (TDS)	SM	TAL CHI
SM 4500 Cl- E	Chloride, Total	SM	TAL CHI
SM 4500 F C	Fluoride	SM	TAL CHI
SM 4500 SO4 E	Sulfate, Total	SM	TAL CHI

Protocol References:

SM = "Standard Methods For The Examination Of Water And Wastewater",
SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

TAL CHI = TestAmerica Chicago, 2417 Bond Street, University Park, IL 60484, TEL (708)534-5200

Sample Summary

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
500-139827-1	West Pond	Water	01/17/18 10:31	01/18/18 10:41

Client Sample Results

Client Sample ID: West Pond

Lab Sample ID: 500-139827-1

Date Collected: 01/17/18 10:31

Matrix: Water

Date Received: 01/18/18 10:41

Method: 6020A - Metals (ICP/MS) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**0.87**		0.050		mg/L		01/18/18 15:10	01/23/18 14:39	1
Calcium	**70**		0.20		mg/L		01/18/18 15:10	01/23/18 14:39	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**8.8**	**HF**	0.2		SU			01/18/18 16:28	1
Total Dissolved Solids	**430**		10		mg/L			01/19/18 04:41	1
Chloride	**52**		2.0		mg/L			01/19/18 00:03	1
Fluoride	**0.21**		0.10		mg/L			01/25/18 13:00	1
Sulfate	**90**		25		mg/L			01/19/18 07:57	5

Definitions/Glossary

Qualifiers

Metals

Qualifier	Qualifier Description
^	ICV,CCV,ICB,CCB, ISA, ISB, CRI, CRA, DLCK or MRL standard: Instrument related QC is outside acceptance limits.

General Chemistry

Qualifier	Qualifier Description
HF	Field parameter with a holding time of 15 minutes. Test performed by laboratory at client's request.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
PQL	Practical Quantitation Limit
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)

QC Association Summary

Metals

Prep Batch: 417296

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-139827-1	West Pond	Total Recoverable	Water	3005A	
MB 500-417296/1-A	Method Blank	Total Recoverable	Water	3005A	
LCS 500-417296/2-A	Lab Control Sample	Total Recoverable	Water	3005A	

Analysis Batch: 417738

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-139827-1	West Pond	Total Recoverable	Water	6020A	417296
MB 500-417296/1-A	Method Blank	Total Recoverable	Water	6020A	417296
LCS 500-417296/2-A	Lab Control Sample	Total Recoverable	Water	6020A	417296

General Chemistry

Analysis Batch: 417329

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-139827-1	West Pond	Total/NA	Water	SM 2540C	
MB 500-417329/1	Method Blank	Total/NA	Water	SM 2540C	
LCS 500-417329/2	Lab Control Sample	Total/NA	Water	SM 2540C	
500-139827-1 DU	West Pond	Total/NA	Water	SM 2540C	

Analysis Batch: 417361

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-139827-1	West Pond	Total/NA	Water	SM 4500 SO4 E	
MB 500-417361/3	Method Blank	Total/NA	Water	SM 4500 SO4 E	
LCS 500-417361/4	Lab Control Sample	Total/NA	Water	SM 4500 SO4 E	

Analysis Batch: 417368

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-139827-1	West Pond	Total/NA	Water	9040C	
500-139827-1 DU	West Pond	Total/NA	Water	9040C	

Analysis Batch: 417451

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-139827-1	West Pond	Total/NA	Water	SM 4500 Cl- E	
MB 500-417451/4	Method Blank	Total/NA	Water	SM 4500 Cl- E	
LCS 500-417451/5	Lab Control Sample	Total/NA	Water	SM 4500 Cl- E	

Analysis Batch: 418006

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-139827-1	West Pond	Total/NA	Water	SM 4500 F C	
MB 500-418006/31	Method Blank	Total/NA	Water	SM 4500 F C	
LCS 500-418006/32	Lab Control Sample	Total/NA	Water	SM 4500 F C	
500-139827-1 MS	West Pond	Total/NA	Water	SM 4500 F C	
500-139827-1 MSD	West Pond	Total/NA	Water	SM 4500 F C	

Method: 6020A - Metals (ICP/MS)

Lab Sample ID: MB 500-417296/1-A
Matrix: Water
Analysis Batch: 417738

Client Sample ID: Method Blank
Prep Type: Total Recoverable
Prep Batch: 417296

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	<0.050	^	0.050		mg/L		01/18/18 15:10	01/23/18 12:40	1
Calcium	<0.20		0.20		mg/L		01/18/18 15:10	01/23/18 12:40	1

Lab Sample ID: LCS 500-417296/2-A
Matrix: Water
Analysis Batch: 417738

Client Sample ID: Lab Control Sample
Prep Type: Total Recoverable
Prep Batch: 417296

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Boron			1.00	0.927	^	mg/L		93	80 - 120		
Calcium			10.0	10.4		mg/L		104	80 - 120		

Method: 9040C - pH

Lab Sample ID: 500-139827-1 DU
Matrix: Water
Analysis Batch: 417368

Client Sample ID: West Pond
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier		DU Result	DU Qualifier	Unit	D			RPD	RPD Limit
pH	8.8	HF		8.8		SU				0.2	

Method: SM 2540C - Solids, Total Dissolved (TDS)

Lab Sample ID: MB 500-417329/1
Matrix: Water
Analysis Batch: 417329

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	<10		10		mg/L			01/19/18 04:03	1

Lab Sample ID: LCS 500-417329/2
Matrix: Water
Analysis Batch: 417329

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Total Dissolved Solids			250	288		mg/L		115	80 - 120		

Lab Sample ID: 500-139827-1 DU
Matrix: Water
Analysis Batch: 417329

Client Sample ID: West Pond
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier		DU Result	DU Qualifier	Unit	D			RPD	RPD Limit
Total Dissolved Solids	430			458		mg/L				5	5

Method: SM 4500 Cl- E - Chloride, Total

Lab Sample ID: MB 500-417451/4
Matrix: Water
Analysis Batch: 417451

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<2.0		2.0		mg/L			01/18/18 23:43	1

Lab Sample ID: LCS 500-417451/5
Matrix: Water
Analysis Batch: 417451

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Chloride			50.0	49.7		mg/L		99	85 - 115		

Method: SM 4500 F C - Fluoride

Lab Sample ID: MB 500-418006/31
Matrix: Water
Analysis Batch: 418006

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Fluoride	<0.10		0.10		mg/L			01/25/18 12:53	1

Lab Sample ID: LCS 500-418006/32
Matrix: Water
Analysis Batch: 418006

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Fluoride			10.0	10.1		mg/L		101	80 - 120		

Lab Sample ID: 500-139827-1 MS
Matrix: Water
Analysis Batch: 418006

Client Sample ID: West Pond
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits		
Fluoride	0.21		5.00	5.00		mg/L		96	75 - 125		

Lab Sample ID: 500-139827-1 MSD
Matrix: Water
Analysis Batch: 418006

Client Sample ID: West Pond
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Fluoride	0.21		5.00	5.03		mg/L		96	75 - 125	1	20

Method: SM 4500 SO4 E - Sulfate, Total

Lab Sample ID: MB 500-417361/3
Matrix: Water
Analysis Batch: 417361

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<5.0		5.0		mg/L			01/19/18 07:43	1

Method: SM 4500 SO4 E - Sulfate, Total (Continued)

Lab Sample ID: LCS 500-417361/4
Matrix: Water
Analysis Batch: 417361

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	20.0	19.5		mg/L		97	80 - 120

TestAmerica
THE LEADER IN ENVIRONMENTAL TESTING
2417 Bond Street, University Park, IL 60484
Phone: 708.534.5200 Fax: 708.534.5211

Chain of Custody Record

Report To (optional)
Contact:
Company:
Address:
Address:
Phone:
Fax:
E-Mail:

Bill To (optional)
Contact:
Company:
Address:
Address:
Phone:
Fax:
PO#/Reference#

Lab Job #: 500-139827
Chain of Custody Number:
Page ____ of ____
Temperature °C of Cooler: 1.9 73.4

Client: KPRG & Assoc.	Client Project #: 23517
Project Name: NRG	
Project Location/State: IL	Lab Project #
Sampler: LR/MW	Lab PM

Lab ID	MS/MSD	Sample ID	Sampling Date	Sampling Time	# of Containers	Matrix	Preservative: 3 Parameter: B, Ca	Preservative: 8 Parameter: Cl, Fl, pH, SO4, TDS	Comments
1		West Pond	1/17/18	1031	2	W	X	X	

Preservative Key
1. HCL, Cool to 4°
2. H2SO4, Cool to 4°
3. HNO3, Cool to 4°
4. NaOH, Cool to 4°
5. NaOH/Zn, Cool to 4°
6. NaHSO4
7. Cool to 4°
8. None
9. Other

500-139827 COC

Turnaround Time Required (Business Days)
___ 1 Day ___ 2 Days ___ 5 Days ___ 7 Days ___ 10 Days ___ 15 Days _____ Other
Requested Due Date ________

Sample Disposal
☐ Return to Client ☑ Disposal by Lab ☐ Archive for ____ Months (A fee may be assessed if samples are retained longer than 1 month)

Relinquished By	Company	Date	Time	Received By	Company	Date	Time
	KPRG	1/17/18	1325		TA	1-17-18	1325
	TA	1-17-18	1700	Ariel Sandz	TALHS	01/18/18	0955

Lab Courier:
Shipped: FX Priority
Hand Delivered:

Matrix Key
WW - Wastewater
W – Water
S – Soil
SL - Sludge
MS - Miscellaneous
OL - Oil
A – Air
SE – Sediment
SO – Soil
L – Leachate
WI – Wipe
DW – Drinking Water
O – Other

Client Comments

Lab Comments:

TAL-4124-500 (1209)

Login Sample Receipt Checklist

Client: KPRG and Associates, Inc.

Job Number: 500-139827-1

Login Number: 139827

List Number: 1

Creator: Sanchez, Ariel M

List Source: TestAmerica Chicago

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	True	
The cooler's custody seal, if present, is intact.	True	
Sample custody seals, if present, are intact.	True	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	3.4
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	N/A	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Accreditation/Certification Summary

Client: KPRG and Associates, Inc.
Project/Site: Waukegan CCR

TestAmerica Job ID: 500-139827-1

Laboratory: TestAmerica Chicago

The accreditations/certifications listed below are applicable to this report.

Authority	Program	EPA Region	Identification Number	Expiration Date
Illinois	NELAP	5	100201	04-30-18

TestAmerica

THE LEADER IN ENVIRONMENTAL TESTING

1
2
3
4
5
6
7
8
9
10
11
12
13

ANALYTICAL REPORT

TestAmerica Laboratories, Inc.
TestAmerica Pittsburgh
301 Alpha Drive
RIDC Park
Pittsburgh, PA 15238
Tel: (412)963-7058

TestAmerica Job ID: 180-74229-1
Client Project/Site: Midwest Generation

For:
KPRG and Associates, Inc.
14665 West Lisbon Road,
Suite 2B
Brookfield, Wisconsin 53005

Attn: Richard Gnat

Carrie A. Gamber

Authorized for release by:
2/27/2018 10:38:12 AM

Carrie Gamber, Senior Project Manager
(412)963-2428
carrie.gamber@testamericainc.com

LINKS

Review your project results through TotalAccess

Have a Question? Ask The Expert

Visit us at:
www.testamericainc.com

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

Table of Contents

Job ID: 180-74229-1

Laboratory: TestAmerica Pittsburgh

Narrative

CASE NARRATIVE

Client: KPRG and Associates, Inc.

Project: Midwest Generation

Report Number: 180-74229-1

With the exceptions noted as flags or footnotes, standard analytical protocols were followed in the analysis of the samples and no problems were encountered or anomalies observed. In addition all laboratory quality control samples were within established control limits, with any exceptions noted below. Each sample was analyzed to achieve the lowest possible reporting limit within the constraints of the method. In some cases, due to interference or analytes present at high concentrations, samples were diluted. For diluted samples, the reporting limits are adjusted relative to the dilution required.

Calculations are performed before rounding to avoid round-off errors in calculated results.

All holding times were met and proper preservation noted for the methods performed on these samples, unless otherwise detailed in the individual sections below.

RECEIPT

The samples were received on 1/18/2018 12:20 PM; the samples arrived in good condition, properly preserved and, where required, on ice. The temperature of the cooler at receipt was 0.4° C.

IC

Several samples were diluted due to the nature of the sample matrix. Dilutions were based on the conductivity readings during pre-screen. Elevated reporting limits (RLs) are provided.

Several samples were diluted due to the level of analytes detected in the samples. Elevated reporting limits (RLs) are provided.

METALS

Several samples were diluted due to the nature of the sample matrix and/or to bring the concentration of boron and calcium within the linear range. Elevated reporting limits (RLs) are provided.

GENERAL CHEMISTRY

Due to the sample matrix and amount of sample generated, the initial volumes used for several samples deviated from the standard procedure for TDS. The reporting limits (RLs) have been adjusted proportionately.

Definitions/Glossary

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
PQL	Practical Quantitation Limit
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)

Accreditation/Certification Summary

Laboratory: TestAmerica Pittsburgh

Unless otherwise noted, all analytes for this laboratory were covered under each accreditation/certification below.

Authority	**Program**	**EPA Region**	**Identification Number**	**Expiration Date**
Illinois	NELAP	5	200005	06-30-18

The following analytes are included in this report, but are not accredited/certified under this accreditation/certification:

Analysis Method	Prep Method	Matrix	Analyte
SM 2510B		Solid	Specific Conductance
SM 2540C		Solid	Total Dissolved Solids

The following analytes are included in this report, but accreditation/certification is not offered by the governing authority:

Analysis Method	Prep Method	Matrix	Analyte
2540G		Solid	Percent Moisture
2540G		Solid	Percent Solids
SM 2580B		Solid	Oxidation Reduction Potential

Sample Summary

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
180-74229-1	EAST POND - PRETEST	Solid	01/17/18 10:18	01/18/18 12:20
180-74229-2	EAST POND - PH 13.0	Solid	01/17/18 10:18	01/18/18 12:20
180-74229-3	EAST POND - PH 12.0	Solid	01/17/18 10:18	01/18/18 12:20
180-74229-5	EAST POND - PH 9.0	Solid	01/17/18 10:18	01/18/18 12:20
180-74229-6	EAST POND - PH 8.0	Solid	01/17/18 10:18	01/18/18 12:20
180-74229-7	EAST POND - PH 7.0	Solid	01/17/18 10:18	01/18/18 12:20
180-74229-8	EAST POND - PH 5.5	Solid	01/17/18 10:18	01/18/18 12:20
180-74229-9	EAST POND - PH 4.0	Solid	01/17/18 10:18	01/18/18 12:20
180-74229-10	EAST POND - PH 2.0	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-11	EAST POND - NATURAL	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-12	WEST POND - PRETEST	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-13	WEST POND - PH 13.0	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-14	WEST POND - PH 12.0	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-16	WEST POND - PH 9.0	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-17	WEST POND - PH 8.0	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-18	WEST POND - PH 7.0	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-19	WEST POND - PH 5.5	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-20	WEST POND - PH 4.0	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-21	WEST POND - PH 2.0	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-22	WEST POND - NATURAL	Solid	01/17/18 10:37	01/18/18 12:20
180-74229-23	EAST POND - AIR DRIED	Solid	01/17/18 10:18	01/18/18 12:20
180-74229-24	WEST POND - AIR DRIED	Solid	01/17/18 10:37	01/18/18 12:20

Method Summary

Method	Method Description	Protocol	Laboratory
EPA 9056A	Anions, Ion Chromatography	SW846	TAL PIT
EPA 6020A	Metals (ICP/MS)	SW846	TAL PIT
2540G	SM 2540G	SM22	TAL PIT
EPA 9040C	pH	SW846	TAL PIT
SM 2510B	Conductivity, Specific Conductance	SM	TAL PIT
SM 2540C	Solids, Total Dissolved (TDS)	SM	TAL PIT
SM 2580B	Reduction-Oxidation (REDOX) Potential	SM	TAL PIT

Protocol References:

SM = "Standard Methods For The Examination Of Water And Wastewater",

SM22 = SM22

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

TAL PIT = TestAmerica Pittsburgh, 301 Alpha Drive, RIDC Park, Pittsburgh, PA 15238, TEL (412)963-7058

Lab Chronicle

Client Sample ID: EAST POND - PRETEST

Lab Sample ID: 180-74229-1

Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Analysis	2540G		1			234978	01/24/18 09:55	CLL	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.5 g	950 mL	237107	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:07	MTW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.5 g	950 mL	237107	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:16	MTW	TAL PIT
	Instrument ID:	NOEQUIP								

Client Sample ID: EAST POND - PH 13.0

Lab Sample ID: 180-74229-2

Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		50			236553	02/09/18 19:50	CMR	TAL PIT
	Instrument ID:	CHICS2000								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236440	02/08/18 11:28	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			236729	02/10/18 00:39	WTR	TAL PIT
	Instrument ID:	A								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236440	02/08/18 11:28	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			236828	02/13/18 03:43	WTR	TAL PIT
	Instrument ID:	M								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			236465	02/07/18 12:13	MTW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			236475	02/07/18 12:01	MTW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	3 mL	100 mL	237078	02/15/18 14:59	KXW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			236472	02/07/18 11:54	MTW	TAL PIT
	Instrument ID:	NOEQUIP								

Client Sample ID: EAST POND - PH 12.0

Lab Sample ID: 180-74229-3

Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT

Lab Chronicle

Client: KPRG and Associates, Inc.
Project/Site: Midwest Generation

TestAmerica Job ID: 180-74229-1

Client Sample ID: EAST POND - PH 12.0

Lab Sample ID: 180-74229-3

Date Collected: 01/17/18 10:18
Date Received: 01/18/18 12:20

Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	EPA 9056A		25			237859	02/26/18 13:35	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	237311	02/19/18 13:03	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			237590	02/21/18 01:20	WTR	TAL PIT
	Instrument ID: A									
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	237311	02/19/18 13:03	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			237713	02/22/18 04:30	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237737	02/16/18 13:32	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237752	02/16/18 13:16	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	10 mL	100 mL	237329	02/19/18 15:41	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237751	02/16/18 13:18	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: EAST POND - PH 9.0

Lab Sample ID: 180-74229-5

Date Collected: 01/17/18 10:18
Date Received: 01/18/18 12:20

Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		1			236732	02/13/18 17:11	MJH	TAL PIT
	Instrument ID: CHIC2100A									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		5			236891	02/14/18 16:40	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236807	02/13/18 13:38	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			237198	02/15/18 23:15	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:19	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237425	02/12/18 15:01	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT

Lab Chronicle

Client Sample ID: EAST POND - PH 9.0

Lab Sample ID: 180-74229-5

Date Collected: 01/17/18 10:18

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	SM 2540C		1	100 mL	100 mL	237077	02/15/18 14:55	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237422	02/12/18 15:02	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: EAST POND - PH 8.0

Lab Sample ID: 180-74229-6

Date Collected: 01/17/18 10:18

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		2.5			236732	02/13/18 17:43	MJH	TAL PIT
	Instrument ID: CHIC2100A									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		5			236891	02/14/18 16:56	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236807	02/13/18 13:38	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			237198	02/15/18 23:06	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:10	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237425	02/12/18 14:51	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	25 mL	100 mL	237077	02/15/18 14:55	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237422	02/12/18 14:49	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: EAST POND - PH 7.0

Lab Sample ID: 180-74229-7

Date Collected: 01/17/18 10:18

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		10			236997	02/15/18 14:02	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT

Lab Chronicle

Client Sample ID: EAST POND - PH 7.0

Lab Sample ID: 180-74229-7

Date Collected: 01/17/18 10:18

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	EPA 9056A		10			237100	02/16/18 07:20	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236807	02/13/18 13:38	KA	TAL PIT
Leach	Analysis	EPA 6020A		10			237323	02/16/18 20:43	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:13	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237425	02/12/18 14:56	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	25 mL	100 mL	237077	02/15/18 14:55	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237422	02/12/18 14:55	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: EAST POND - PH 5.5

Lab Sample ID: 180-74229-8

Date Collected: 01/17/18 10:18

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		25			236997	02/15/18 14:18	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		25			237100	02/16/18 07:36	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236807	02/13/18 13:38	KA	TAL PIT
Leach	Analysis	EPA 6020A		10			237323	02/16/18 20:47	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:23	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237425	02/12/18 15:07	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	10 mL	100 mL	237077	02/15/18 14:55	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT

Client Sample ID: EAST POND - PH 5.5

Lab Sample ID: 180-74229-8

Date Collected: 01/17/18 10:18

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	SM 2580B		1			237422	02/12/18 15:08	MTW	TAL PIT
	Instrument ID:	NOEQUIP								

Client Sample ID: EAST POND - PH 4.0

Lab Sample ID: 180-74229-9

Date Collected: 01/17/18 10:18

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		25			236553	02/09/18 18:15	CMR	TAL PIT
	Instrument ID:	CHICS2000								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236440	02/08/18 11:28	KA	TAL PIT
Leach	Analysis	EPA 6020A		10			236828	02/13/18 04:00	WTR	TAL PIT
	Instrument ID:	M								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			236465	02/07/18 11:39	MTW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			236475	02/07/18 11:21	MTW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	4 mL	100 mL	236825	02/13/18 15:26	KXW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			236472	02/07/18 11:16	MTW	TAL PIT
	Instrument ID:	NOEQUIP								

Client Sample ID: EAST POND - PH 2.0

Lab Sample ID: 180-74229-10

Date Collected: 01/17/18 10:37

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	EPA 9056A		100			237859	02/26/18 11:59	MJH	TAL PIT
	Instrument ID:	CHICS2000								
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	237311	02/19/18 13:03	KA	TAL PIT
Leach	Analysis	EPA 6020A		10			237713	02/22/18 04:48	WTR	TAL PIT
	Instrument ID:	M								
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237737	02/16/18 13:38	MTW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT

Lab Chronicle

Client: KPRG and Associates, Inc.
Project/Site: Midwest Generation

TestAmerica Job ID: 180-74229-1

Client Sample ID: EAST POND - PH 2.0

Lab Sample ID: 180-74229-10

Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	SM 2510B		1			237752	02/16/18 13:24	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	2 mL	100 mL	237329	02/19/18 15:41	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237751	02/16/18 13:26	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: EAST POND - NATURAL

Lab Sample ID: 180-74229-11

Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		1			236373	02/08/18 11:47	MJH	TAL PIT
	Instrument ID: CHICS2100B									
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236437	02/08/18 11:22	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			236729	02/09/18 23:12	WTR	TAL PIT
	Instrument ID: A									
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236437	02/08/18 11:22	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			236828	02/13/18 01:15	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			236465	02/07/18 14:19	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			236475	02/07/18 14:45	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	100 mL	100 mL	236825	02/13/18 15:26	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.5 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			236472	02/07/18 14:47	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: WEST POND - PRETEST

Lab Sample ID: 180-74229-12

Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Analysis	2540G		1			234978	01/24/18 09:55	CLL	TAL PIT

Lab Chronicle

Client: KPRG and Associates, Inc.
Project/Site: Midwest Generation

TestAmerica Job ID: 180-74229-1

Client Sample ID: WEST POND - PRETEST

Lab Sample ID: 180-74229-12

Date Collected: 01/17/18 10:37
Date Received: 01/18/18 12:20
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Analysis	2540G		1			234978	01/24/18 09:55	CLL	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	950 mL	237107	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:32	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	950 mL	237107	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:35	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: WEST POND - PH 13.0

Lab Sample ID: 180-74229-13

Date Collected: 01/17/18 10:37
Date Received: 01/18/18 12:20
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		50			236553	02/09/18 20:22	CMR	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236440	02/08/18 11:28	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			236729	02/10/18 00:50	WTR	TAL PIT
	Instrument ID: A									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236440	02/08/18 11:28	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			236828	02/13/18 04:05	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			236465	02/07/18 11:27	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			236475	02/07/18 11:07	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	3 mL	100 mL	236825	02/13/18 15:26	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			236472	02/07/18 11:04	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: WEST POND - PH 12.0

Lab Sample ID: 180-74229-14

Date Collected: 01/17/18 10:37
Date Received: 01/18/18 12:20
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT

Lab Chronicle

Client Sample ID: WEST POND - PH 12.0

Lab Sample ID: 180-74229-14

Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	EPA 9056A		25			237859	02/26/18 14:06	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	237311	02/19/18 13:03	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			237590	02/21/18 01:25	WTR	TAL PIT
	Instrument ID: A									
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	237311	02/19/18 13:03	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			237713	02/22/18 04:53	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237737	02/16/18 13:43	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237752	02/16/18 13:31	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	10 mL	100 mL	237329	02/19/18 15:41	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237751	02/16/18 13:34	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: WEST POND - PH 9.0

Lab Sample ID: 180-74229-16

Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		1			236997	02/15/18 14:33	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		10			237100	02/16/18 07:52	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236807	02/13/18 13:38	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			237198	02/15/18 23:51	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:44	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237425	02/12/18 15:38	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT

Client Sample ID: WEST POND - PH 9.0 Lab Sample ID: 180-74229-16

Date Collected: 01/17/18 10:37 **Matrix: Solid**
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	SM 2540C		1	100 mL	100 mL	237077	02/15/18 14:55	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237422	02/12/18 15:40	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: WEST POND - PH 8.0 Lab Sample ID: 180-74229-17

Date Collected: 01/17/18 10:37 **Matrix: Solid**
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		5			236997	02/15/18 15:05	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		5			237100	02/16/18 08:08	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236807	02/13/18 13:38	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			237198	02/15/18 23:24	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:26	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237425	02/12/18 15:12	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	25 mL	100 mL	237077	02/15/18 14:55	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237422	02/12/18 15:14	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: WEST POND - PH 7.0 Lab Sample ID: 180-74229-18

Date Collected: 01/17/18 10:37 **Matrix: Solid**
Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		10			236997	02/15/18 15:21	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT

Lab Chronicle

Client Sample ID: WEST POND - PH 7.0

Lab Sample ID: 180-74229-18

Date Collected: 01/17/18 10:37

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	EPA 9056A		10			237100	02/16/18 08:24	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236807	02/13/18 13:38	KA	TAL PIT
Leach	Analysis	EPA 6020A		10			237323	02/16/18 20:52	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:29	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237425	02/12/18 15:17	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	10 mL	100 mL	237077	02/15/18 14:55	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237422	02/12/18 15:21	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: WEST POND - PH 5.5

Lab Sample ID: 180-74229-19

Date Collected: 01/17/18 10:37

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		25			236997	02/15/18 15:37	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		25			237100	02/16/18 08:40	MJH	TAL PIT
	Instrument ID: CHICS2000									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236807	02/13/18 13:38	KA	TAL PIT
Leach	Analysis	EPA 6020A		10			237323	02/16/18 20:57	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237380	02/12/18 15:41	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			237425	02/12/18 15:33	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	10 mL	100 mL	237077	02/15/18 14:55	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236722	02/10/18 08:30	LWM	TAL PIT

Lab Chronicle

Client Sample ID: WEST POND - PH 5.5

Lab Sample ID: 180-74229-19

Date Collected: 01/17/18 10:37

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	SM 2580B		1			237422	02/12/18 15:34	MTW	TAL PIT
	Instrument ID:	NOEQUIP								

Client Sample ID: WEST POND - PH 4.0

Lab Sample ID: 180-74229-20

Date Collected: 01/17/18 10:37

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		25			236553	02/09/18 18:47	CMR	TAL PIT
	Instrument ID:	CHICS2000								
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236440	02/08/18 11:28	KA	TAL PIT
Leach	Analysis	EPA 6020A		10			236828	02/13/18 04:10	WTR	TAL PIT
	Instrument ID:	M								
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			236465	02/07/18 11:58	MTW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			236475	02/07/18 11:36	MTW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	4 mL	100 mL	236825	02/13/18 15:26	KXW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			236472	02/07/18 11:33	MTW	TAL PIT
	Instrument ID:	NOEQUIP								

Client Sample ID: WEST POND - PH 2.0

Lab Sample ID: 180-74229-21

Date Collected: 01/17/18 10:37

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	EPA 9056A		100			237859	02/26/18 12:31	MJH	TAL PIT
	Instrument ID:	CHICS2000								
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	237311	02/19/18 13:03	KA	TAL PIT
Leach	Analysis	EPA 6020A		10			237713	02/22/18 04:58	WTR	TAL PIT
	Instrument ID:	M								
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			237737	02/16/18 13:49	MTW	TAL PIT
	Instrument ID:	NOEQUIP								
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT

Lab Chronicle

Client Sample ID: WEST POND - PH 2.0

Lab Sample ID: 180-74229-21

Date Collected: 01/17/18 10:37

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Analysis	SM 2510B		1			237752	02/16/18 13:38	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	2 mL	100 mL	237329	02/19/18 15:41	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	237165	02/14/18 08:00	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			237751	02/16/18 13:43	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: WEST POND - NATURAL

Lab Sample ID: 180-74229-22

Date Collected: 01/17/18 10:37

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9056A		1			236373	02/08/18 12:03	MJH	TAL PIT
	Instrument ID: CHICS2100B									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236437	02/08/18 11:22	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			236729	02/09/18 23:14	WTR	TAL PIT
	Instrument ID: A									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Prep	3010A			50 mL	50 mL	236437	02/08/18 11:22	KA	TAL PIT
Leach	Analysis	EPA 6020A		1			236828	02/13/18 01:20	WTR	TAL PIT
	Instrument ID: M									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	EPA 9040C		1			236465	02/07/18 14:23	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2510B		1			236475	02/07/18 14:49	MTW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2540C		1	100 mL	100 mL	236785	02/13/18 10:45	KXW	TAL PIT
	Instrument ID: NOEQUIP									
Leach	Leach	1313			40.6 g	400 mL	236165	02/05/18 11:30	LWM	TAL PIT
Leach	Analysis	SM 2580B		1			236472	02/07/18 14:51	MTW	TAL PIT
	Instrument ID: NOEQUIP									

Client Sample ID: EAST POND - AIR DRIED

Lab Sample ID: 180-74229-23

Date Collected: 01/17/18 10:18

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Analysis	2540G		1			235859	02/02/18 11:37	SES	TAL PIT

1 2 3 4 5 6 7 8 9 10 11 12 13

Client Sample ID: EAST POND - AIR DRIED

Lab Sample ID: 180-74229-23

Date Collected: 01/17/18 10:18

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Analysis	2540G		1			235859	02/02/18 11:37	SES	TAL PIT

Instrument ID: NOEQUIP

Client Sample ID: WEST POND - AIR DRIED

Lab Sample ID: 180-74229-24

Date Collected: 01/17/18 10:37

Matrix: Solid

Date Received: 01/18/18 12:20

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Analysis	2540G		1			235859	02/02/18 11:37	SES	TAL PIT

Instrument ID: NOEQUIP

Laboratory References:

TAL PIT = TestAmerica Pittsburgh, 301 Alpha Drive, RIDC Park, Pittsburgh, PA 15238, TEL (412)963-7058

Analyst References:

Lab: TAL PIT

Batch Type: Leach
LWM = Larry Matko

Batch Type: Prep
KA = Kayla Kalamasz

Batch Type: Analysis
CLL = Cheryl Loheyde
CMR = Carl Reagle
KXW = Kaitlyn White
MJH = Matthew Hartman
MTW = Michael Wesoloski
SES = Samantha Strauser
WTR = Bill Reinheimer

Client Sample Results

Client Sample ID: EAST POND - PRETEST

Lab Sample ID: 180-74229-1

Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture	**14.8**		0.1		%			01/24/18 09:55	1
Percent Solids	**85.2**		0.1		%			01/24/18 09:55	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**12.8**		0.1		SU			02/12/18 15:07	1
pH	**3.6**		0.1		SU			02/12/18 15:16	1

Client Sample ID: EAST POND - PH 13.0

Lab Sample ID: 180-74229-2

Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<50		50		mg/L			02/09/18 19:50	50
Fluoride	<5.0		5.0		mg/L			02/09/18 19:50	50
Sulfate	**120**		50		mg/L			02/09/18 19:50	50

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**3500**		80		ug/L		02/08/18 11:28	02/13/18 03:43	1
Calcium	**3700**		500		ug/L		02/08/18 11:28	02/10/18 00:39	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**12.8**		0.1		SU			02/07/18 12:13	1
Specific Conductance	**47000**		1.0		umhos/cm			02/07/18 12:01	1
Total Dissolved Solids	**14000**		330		mg/L			02/15/18 14:59	1
Oxidation Reduction Potential	**- 50**		10		millivolts			02/07/18 11:54	1

Client Sample ID: EAST POND - PH 12.0

Lab Sample ID: 180-74229-3

Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<25		25		mg/L			02/26/18 13:35	25
Fluoride	<2.5		2.5		mg/L			02/26/18 13:35	25
Sulfate	**110**		25		mg/L			02/26/18 13:35	25

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**3400**		80		ug/L		02/19/18 13:03	02/22/18 04:30	1
Calcium	**3500**		500		ug/L		02/19/18 13:03	02/21/18 01:20	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**12.5**		0.1		SU			02/16/18 13:32	1
Specific Conductance	**13000**		1.0		umhos/cm			02/16/18 13:16	1
Total Dissolved Solids	**3700**		100		mg/L			02/19/18 15:41	1
Oxidation Reduction Potential	**- 7**		10		millivolts			02/16/18 13:18	1

Client Sample Results

Client Sample ID: EAST POND - PH 9.0

Lab Sample ID: 180-74229-5
Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	**2.8**		1.0		mg/L			02/13/18 17:11	1
Fluoride	**0.51**		0.50		mg/L			02/14/18 16:40	5
Sulfate	**110**		1.0		mg/L			02/13/18 17:11	1

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**2000**		80		ug/L		02/13/18 13:38	02/15/18 23:15	1
Calcium	**120000**		500		ug/L		02/13/18 13:38	02/15/18 23:15	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**8.9**		0.1		SU			02/12/18 15:19	1
Specific Conductance	**1300**		1.0		umhos/cm			02/12/18 15:01	1
Total Dissolved Solids	**890**		10		mg/L			02/15/18 14:55	1
Oxidation Reduction Potential	**230**		10		millivolts			02/12/18 15:02	1

Client Sample ID: EAST POND - PH 8.0

Lab Sample ID: 180-74229-6
Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<2.5		2.5		mg/L			02/13/18 17:43	2.5
Fluoride	<0.50		0.50		mg/L			02/14/18 16:56	5
Sulfate	**130**		2.5		mg/L			02/13/18 17:43	2.5

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**3000**		80		ug/L		02/13/18 13:38	02/15/18 23:06	1
Calcium	**660000**		500		ug/L		02/13/18 13:38	02/15/18 23:06	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**7.7**		0.1		SU			02/12/18 15:10	1
Specific Conductance	**4700**		1.0		umhos/cm			02/12/18 14:51	1
Total Dissolved Solids	**3600**		40		mg/L			02/15/18 14:55	1
Oxidation Reduction Potential	**260**		10		millivolts			02/12/18 14:49	1

Client Sample ID: EAST POND - PH 7.0

Lab Sample ID: 180-74229-7
Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<10		10		mg/L			02/15/18 14:02	10
Fluoride	<1.0		1.0		mg/L			02/15/18 14:02	10
Sulfate	**140**		10		mg/L			02/16/18 07:20	10

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**4300**		800		ug/L		02/13/18 13:38	02/16/18 20:43	10

Client Sample ID: EAST POND - PH 7.0
Lab Sample ID: 180-74229-7
Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 6020A - Metals (ICP/MS) - Leach (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Calcium	**1500000**		5000		ug/L		02/13/18 13:38	02/16/18 20:43	10

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**7.0**		0.1		SU			02/12/18 15:13	1
Specific Conductance	**8500**		1.0		umhos/cm			02/12/18 14:56	1
Total Dissolved Solids	**6500**		40		mg/L			02/15/18 14:55	1
Oxidation Reduction Potential	**290**		10		millivolts			02/12/18 14:55	1

Client Sample ID: EAST POND - PH 5.5
Lab Sample ID: 180-74229-8
Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<25		25		mg/L			02/15/18 14:18	25
Fluoride	<2.5		2.5		mg/L			02/15/18 14:18	25
Sulfate	**170**		25		mg/L			02/16/18 07:36	25

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**6400**		800		ug/L		02/13/18 13:38	02/16/18 20:47	10
Calcium	**3100000**		5000		ug/L		02/13/18 13:38	02/16/18 20:47	10

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**5.8**		0.1		SU			02/12/18 15:23	1
Specific Conductance	**18000**		1.0		umhos/cm			02/12/18 15:07	1
Total Dissolved Solids	**17000**		100		mg/L			02/15/18 14:55	1
Oxidation Reduction Potential	**310**		10		millivolts			02/12/18 15:08	1

Client Sample ID: EAST POND - PH 4.0
Lab Sample ID: 180-74229-9
Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<25		25		mg/L			02/09/18 18:15	25
Fluoride	**7.5**		2.5		mg/L			02/09/18 18:15	25
Sulfate	**330**		25		mg/L			02/09/18 18:15	25

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**11000**		800		ug/L		02/08/18 11:28	02/13/18 04:00	10
Calcium	**5000000**		5000		ug/L		02/08/18 11:28	02/13/18 04:00	10

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**3.8**		0.1		SU			02/07/18 11:39	1
Specific Conductance	**30000**		1.0		umhos/cm			02/07/18 11:21	1
Total Dissolved Solids	**33000**		250		mg/L			02/13/18 15:26	1

Client Sample Results

Client Sample ID: EAST POND - PH 4.0

Lab Sample ID: 180-74229-9
Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

General Chemistry - Leach (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Oxidation Reduction Potential	**400**		10		millivolts			02/07/18 11:16	1

Client Sample ID: EAST POND - PH 2.0

Lab Sample ID: 180-74229-10
Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<100		100		mg/L			02/26/18 11:59	100
Fluoride	<10		10		mg/L			02/26/18 11:59	100
Sulfate	**180**		100		mg/L			02/26/18 11:59	100

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**5100**		800		ug/L		02/19/18 13:03	02/22/18 04:48	10
Calcium	**2200000**		5000		ug/L		02/19/18 13:03	02/22/18 04:48	10

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**2.1**		0.1		SU			02/16/18 13:38	1
Specific Conductance	**64000**		1.0		umhos/cm			02/16/18 13:24	1
Total Dissolved Solids	**74000**		500		mg/L			02/19/18 15:41	1
Oxidation Reduction Potential	**660**		10		millivolts			02/16/18 13:26	1

Client Sample ID: EAST POND - NATURAL

Lab Sample ID: 180-74229-11
Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	**2.9**		1.0		mg/L			02/08/18 11:47	1
Fluoride	**0.32**		0.10		mg/L			02/08/18 11:47	1
Sulfate	**130**		1.0		mg/L			02/08/18 11:47	1

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**2000**		80		ug/L		02/08/18 11:22	02/13/18 01:15	1
Calcium	**43000**		500		ug/L		02/08/18 11:22	02/09/18 23:12	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**9.7**		0.1		SU			02/07/18 14:19	1
Specific Conductance	**390**		1.0		umhos/cm			02/07/18 14:45	1
Total Dissolved Solids	**270**		10		mg/L			02/13/18 15:26	1
Oxidation Reduction Potential	**170**		10		millivolts			02/07/18 14:47	1

Client Sample ID: WEST POND - PRETEST

Lab Sample ID: 180-74229-12
Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture	**38.6**		0.1		%			01/24/18 09:55	1
Percent Solids	**61.4**		0.1		%			01/24/18 09:55	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**12.7**		0.1		SU			02/12/18 15:32	1
pH	**3.7**		0.1		SU			02/12/18 15:35	1

Client Sample ID: WEST POND - PH 13.0

Lab Sample ID: 180-74229-13
Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<50		50		mg/L			02/09/18 20:22	50
Fluoride	<5.0		5.0		mg/L			02/09/18 20:22	50
Sulfate	**120**		50		mg/L			02/09/18 20:22	50

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**3700**		80		ug/L		02/08/18 11:28	02/13/18 04:05	1
Calcium	**3800**		500		ug/L		02/08/18 11:28	02/10/18 00:50	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**12.8**		0.1		SU			02/07/18 11:27	1
Specific Conductance	**46000**		1.0		umhos/cm			02/07/18 11:07	1
Total Dissolved Solids	**14000**		330		mg/L			02/13/18 15:26	1
Oxidation Reduction Potential	**- 32**		10		millivolts			02/07/18 11:04	1

Client Sample ID: WEST POND - PH 12.0

Lab Sample ID: 180-74229-14
Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<25		25		mg/L			02/26/18 14:06	25
Fluoride	<2.5		2.5		mg/L			02/26/18 14:06	25
Sulfate	**120**		25		mg/L			02/26/18 14:06	25

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**3700**		80		ug/L		02/19/18 13:03	02/22/18 04:53	1
Calcium	**3800**		500		ug/L		02/19/18 13:03	02/21/18 01:25	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**12.4**		0.1		SU			02/16/18 13:43	1
Specific Conductance	**13000**		1.0		umhos/cm			02/16/18 13:31	1
Total Dissolved Solids	**4100**		100		mg/L			02/19/18 15:41	1
Oxidation Reduction Potential	**- 10**		10		millivolts			02/16/18 13:34	1

1 2 3 4 5 6 7 8 9 10 11 12 13

Client Sample ID: WEST POND - PH 9.0

Lab Sample ID: 180-74229-16
Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	**2.2**		1.0		mg/L			02/15/18 14:33	1
Fluoride	**0.20**		0.10		mg/L			02/15/18 14:33	1
Sulfate	**100**		10		mg/L			02/16/18 07:52	10

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**1800**		80		ug/L		02/13/18 13:38	02/15/18 23:51	1
Calcium	**130000**		500		ug/L		02/13/18 13:38	02/15/18 23:51	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**8.7**		0.1		SU			02/12/18 15:44	1
Specific Conductance	**1300**		1.0		umhos/cm			02/12/18 15:38	1
Total Dissolved Solids	**930**		10		mg/L			02/15/18 14:55	1
Oxidation Reduction Potential	**250**		10		millivolts			02/12/18 15:40	1

Client Sample ID: WEST POND - PH 8.0

Lab Sample ID: 180-74229-17
Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<5.0		5.0		mg/L			02/15/18 15:05	5
Fluoride	<0.50		0.50		mg/L			02/15/18 15:05	5
Sulfate	**130**		5.0		mg/L			02/16/18 08:08	5

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**2900**		80		ug/L		02/13/18 13:38	02/15/18 23:24	1
Calcium	**710000**		500		ug/L		02/13/18 13:38	02/15/18 23:24	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**7.5**		0.1		SU			02/12/18 15:26	1
Specific Conductance	**4800**		1.0		umhos/cm			02/12/18 15:12	1
Total Dissolved Solids	**3600**		40		mg/L			02/15/18 14:55	1
Oxidation Reduction Potential	**280**		10		millivolts			02/12/18 15:14	1

Client Sample ID: WEST POND - PH 7.0

Lab Sample ID: 180-74229-18
Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<10		10		mg/L			02/15/18 15:21	10
Fluoride	<1.0		1.0		mg/L			02/15/18 15:21	10
Sulfate	**130**		10		mg/L			02/16/18 08:24	10

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**4300**		800		ug/L		02/13/18 13:38	02/16/18 20:52	10

Client Sample ID: WEST POND - PH 7.0

Lab Sample ID: 180-74229-18
Matrix: Solid

Date Collected: 01/17/18 10:37
Date Received: 01/18/18 12:20

Method: EPA 6020A - Metals (ICP/MS) - Leach (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Calcium	**1400000**		5000		ug/L		02/13/18 13:38	02/16/18 20:52	10

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**7.0**		0.1		SU			02/12/18 15:29	1
Specific Conductance	**8600**		1.0		umhos/cm			02/12/18 15:17	1
Total Dissolved Solids	**7500**		100		mg/L			02/15/18 14:55	1
Oxidation Reduction Potential	**300**		10		millivolts			02/12/18 15:21	1

Client Sample ID: WEST POND - PH 5.5

Lab Sample ID: 180-74229-19
Matrix: Solid

Date Collected: 01/17/18 10:37
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<25		25		mg/L			02/15/18 15:37	25
Fluoride	<2.5		2.5		mg/L			02/15/18 15:37	25
Sulfate	**160**		25		mg/L			02/16/18 08:40	25

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**6200**		800		ug/L		02/13/18 13:38	02/16/18 20:57	10
Calcium	**3000000**		5000		ug/L		02/13/18 13:38	02/16/18 20:57	10

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**5.9**		0.1		SU			02/12/18 15:41	1
Specific Conductance	**18000**		1.0		umhos/cm			02/12/18 15:33	1
Total Dissolved Solids	**17000**		100		mg/L			02/15/18 14:55	1
Oxidation Reduction Potential	**320**		10		millivolts			02/12/18 15:34	1

Client Sample ID: WEST POND - PH 4.0

Lab Sample ID: 180-74229-20
Matrix: Solid

Date Collected: 01/17/18 10:37
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<25		25		mg/L			02/09/18 18:47	25
Fluoride	**7.7**		2.5		mg/L			02/09/18 18:47	25
Sulfate	**360**		25		mg/L			02/09/18 18:47	25

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**11000**		800		ug/L		02/08/18 11:28	02/13/18 04:10	10
Calcium	**5100000**		5000		ug/L		02/08/18 11:28	02/13/18 04:10	10

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**3.8**		0.1		SU			02/07/18 11:58	1
Specific Conductance	**30000**		1.0		umhos/cm			02/07/18 11:36	1
Total Dissolved Solids	**33000**		250		mg/L			02/13/18 15:26	1

Client Sample Results

Client Sample ID: WEST POND - PH 4.0

Lab Sample ID: 180-74229-20
Matrix: Solid

Date Collected: 01/17/18 10:37
Date Received: 01/18/18 12:20

General Chemistry - Leach (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Oxidation Reduction Potential	**410**		10		millivolts			02/07/18 11:33	1

Client Sample ID: WEST POND - PH 2.0

Lab Sample ID: 180-74229-21
Matrix: Solid

Date Collected: 01/17/18 10:37
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<100		100		mg/L			02/26/18 12:31	100
Fluoride	<10		10		mg/L			02/26/18 12:31	100
Sulfate	**180**		100		mg/L			02/26/18 12:31	100

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**11000**		800		ug/L		02/19/18 13:03	02/22/18 04:58	10
Calcium	**4400000**		5000		ug/L		02/19/18 13:03	02/22/18 04:58	10

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**2.5**		0.1		SU			02/16/18 13:49	1
Specific Conductance	**59000**		1.0		umhos/cm			02/16/18 13:38	1
Total Dissolved Solids	**70000**		500		mg/L			02/19/18 15:41	1
Oxidation Reduction Potential	**490**		10		millivolts			02/16/18 13:43	1

Client Sample ID: WEST POND - NATURAL

Lab Sample ID: 180-74229-22
Matrix: Solid

Date Collected: 01/17/18 10:37
Date Received: 01/18/18 12:20

Method: EPA 9056A - Anions, Ion Chromatography - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	**17**		1.0		mg/L			02/08/18 12:03	1
Fluoride	**0.53**		0.10		mg/L			02/08/18 12:03	1
Sulfate	**38**		1.0		mg/L			02/08/18 12:03	1

Method: EPA 6020A - Metals (ICP/MS) - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	**1900**		80		ug/L		02/08/18 11:22	02/13/18 01:20	1
Calcium	**42000**		500		ug/L		02/08/18 11:22	02/09/18 23:14	1

General Chemistry - Leach

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
pH	**9.7**		0.1		SU			02/07/18 14:23	1
Specific Conductance	**400**		1.0		umhos/cm			02/07/18 14:49	1
Total Dissolved Solids	**240**		10		mg/L			02/13/18 10:45	1
Oxidation Reduction Potential	**170**		10		millivolts			02/07/18 14:51	1

Client Sample Results

Client Sample ID: EAST POND - AIR DRIED

Lab Sample ID: 180-74229-23
Date Collected: 01/17/18 10:18
Matrix: Solid
Date Received: 01/18/18 12:20

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture	1.2		0.1		%			02/02/18 11:37	1
Percent Solids	98.8		0.1		%			02/02/18 11:37	1

Client Sample ID: WEST POND - AIR DRIED

Lab Sample ID: 180-74229-24
Date Collected: 01/17/18 10:37
Matrix: Solid
Date Received: 01/18/18 12:20

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Percent Moisture	1.4		0.1		%			02/02/18 11:37	1
Percent Solids	98.6		0.1		%			02/02/18 11:37	1

QC Sample Results

Method: EPA 9056A - Anions, Ion Chromatography

Lab Sample ID: MB 180-236373/6
Matrix: Solid
Analysis Batch: 236373

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<1.0		1.0		mg/L			02/08/18 06:17	1
Fluoride	<0.10		0.10		mg/L			02/08/18 06:17	1
Sulfate	<1.0		1.0		mg/L			02/08/18 06:17	1

Lab Sample ID: LCS 180-236373/5
Matrix: Solid
Analysis Batch: 236373

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Chloride	25.0	25.0		mg/L		100	80 - 120
Fluoride	1.25	1.02		mg/L		82	80 - 120
Sulfate	25.0	24.0		mg/L		96	80 - 120

Lab Sample ID: MB 180-236553/16
Matrix: Solid
Analysis Batch: 236553

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<1.0		1.0		mg/L			02/09/18 16:56	1
Fluoride	<0.10		0.10		mg/L			02/09/18 16:56	1
Sulfate	<1.0		1.0		mg/L			02/09/18 16:56	1

Lab Sample ID: LCS 180-236553/15
Matrix: Solid
Analysis Batch: 236553

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Chloride	25.0	25.9		mg/L		103	80 - 120
Fluoride	1.25	1.20		mg/L		96	80 - 120
Sulfate	25.0	22.0		mg/L		88	80 - 120

Lab Sample ID: MB 180-236732/6
Matrix: Solid
Analysis Batch: 236732

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<1.0		1.0		mg/L			02/13/18 05:33	1
Sulfate	<1.0		1.0		mg/L			02/13/18 05:33	1

Lab Sample ID: LCS 180-236732/5
Matrix: Solid
Analysis Batch: 236732

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Chloride	25.0	25.9		mg/L		103	80 - 120
Sulfate	25.0	25.1		mg/L		100	80 - 120

Method: EPA 9056A - Anions, Ion Chromatography (Continued)

Lab Sample ID: MB 180-236891/6
Matrix: Solid
Analysis Batch: 236891
Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<1.0		1.0		mg/L			02/14/18 11:05	1
Fluoride	<0.10		0.10		mg/L			02/14/18 11:05	1
Sulfate	<1.0		1.0		mg/L			02/14/18 11:05	1

Lab Sample ID: LCS 180-236891/5
Matrix: Solid
Analysis Batch: 236891
Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Chloride	50.0	51.9		mg/L		104	80 - 120
Fluoride	2.50	2.58		mg/L		103	80 - 120
Sulfate	50.0	49.2		mg/L		98	80 - 120

Lab Sample ID: MB 180-236997/6
Matrix: Solid
Analysis Batch: 236997
Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<1.0		1.0		mg/L			02/15/18 09:09	1
Fluoride	<0.10		0.10		mg/L			02/15/18 09:09	1
Sulfate	<1.0		1.0		mg/L			02/15/18 09:09	1

Lab Sample ID: LCS 180-236997/5
Matrix: Solid
Analysis Batch: 236997
Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Chloride	50.0	49.6		mg/L		99	80 - 120
Fluoride	2.50	2.35		mg/L		94	80 - 120
Sulfate	50.0	45.6		mg/L		91	80 - 120

Lab Sample ID: MB 180-237100/6
Matrix: Solid
Analysis Batch: 237100
Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<1.0		1.0		mg/L			02/16/18 06:07	1
Fluoride	<0.10		0.10		mg/L			02/16/18 06:07	1
Sulfate	<1.0		1.0		mg/L			02/16/18 06:07	1

Lab Sample ID: LCS 180-237100/5
Matrix: Solid
Analysis Batch: 237100
Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	50.0	45.2		mg/L		90	80 - 120

Method: EPA 9056A - Anions, Ion Chromatography (Continued)

Lab Sample ID: MB 180-237859/6
Matrix: Solid
Analysis Batch: 237859

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Chloride	<1.0		1.0		mg/L			02/26/18 08:06	1
Fluoride	<0.10		0.10		mg/L			02/26/18 08:06	1
Sulfate	<1.0		1.0		mg/L			02/26/18 08:06	1

Lab Sample ID: LCS 180-237859/5
Matrix: Solid
Analysis Batch: 237859

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Chloride	25.0	26.4		mg/L		106	80 - 120
Fluoride	1.25	1.23		mg/L		99	80 - 120
Sulfate	25.0	22.5		mg/L		90	80 - 120

Method: EPA 6020A - Metals (ICP/MS)

Lab Sample ID: MB 180-236437/1-A
Matrix: Solid
Analysis Batch: 236729

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 236437

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Calcium	<500		500		ug/L		02/08/18 11:22	02/09/18 22:43	1

Lab Sample ID: MB 180-236437/1-A
Matrix: Solid
Analysis Batch: 236828

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 236437

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	<80		80		ug/L		02/08/18 11:22	02/13/18 00:25	1

Lab Sample ID: LCS 180-236437/2-A
Matrix: Solid
Analysis Batch: 236729

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 236437

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Calcium	50000	53100		ug/L		106	80 - 120

Lab Sample ID: LCS 180-236437/2-A
Matrix: Solid
Analysis Batch: 236828

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 236437

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Boron	1000	1010		ug/L		101	80 - 120

Lab Sample ID: LCSD 180-236437/3-A
Matrix: Solid
Analysis Batch: 236729

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 236437

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Calcium	50000	52500		ug/L		105	80 - 120	1	20

Method: EPA 6020A - Metals (ICP/MS) (Continued)

Lab Sample ID: LCSD 180-236437/3-A
Matrix: Solid
Analysis Batch: 236828

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 236437

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Boron	1000	1030		ug/L		103	80 - 120	2	20

Lab Sample ID: MB 180-236440/1-A
Matrix: Solid
Analysis Batch: 236729

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 236440

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Calcium	<500		500		ug/L		02/08/18 11:28	02/10/18 00:04	1

Lab Sample ID: MB 180-236440/1-A
Matrix: Solid
Analysis Batch: 236828

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 236440

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	<80		80		ug/L		02/08/18 11:28	02/13/18 02:47	1

Lab Sample ID: LCS 180-236440/2-A
Matrix: Solid
Analysis Batch: 236729

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 236440

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Calcium	50000	52800		ug/L		106	80 - 120

Lab Sample ID: LCS 180-236440/2-A
Matrix: Solid
Analysis Batch: 236828

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 236440

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Boron	1000	916		ug/L		92	80 - 120

Lab Sample ID: LCSD 180-236440/3-A
Matrix: Solid
Analysis Batch: 236729

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 236440

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Calcium	50000	51500		ug/L		103	80 - 120	2	20

Lab Sample ID: LCSD 180-236440/3-A
Matrix: Solid
Analysis Batch: 236828

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 236440

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Boron	1000	917		ug/L		92	80 - 120	0	20

Lab Sample ID: MB 180-236807/1-A
Matrix: Solid
Analysis Batch: 237198

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 236807

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	<80		80		ug/L		02/13/18 13:38	02/15/18 21:43	1

QC Sample Results

Method: EPA 6020A - Metals (ICP/MS) (Continued)

Lab Sample ID: MB 180-236807/1-A
Matrix: Solid
Analysis Batch: 237198
Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 236807

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Calcium	<500		500		ug/L		02/13/18 13:38	02/15/18 21:43	1

Lab Sample ID: LCS 180-236807/2-A
Matrix: Solid
Analysis Batch: 237198
Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 236807

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Boron	1000	866		ug/L		87	80 - 120
Calcium	50000	46700		ug/L		93	80 - 120

Lab Sample ID: LCSD 180-236807/3-A
Matrix: Solid
Analysis Batch: 237198
Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 236807

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Boron	1000	879		ug/L		88	80 - 120	1	20
Calcium	50000	46500		ug/L		93	80 - 120	1	20

Lab Sample ID: MB 180-237311/1-A
Matrix: Solid
Analysis Batch: 237590
Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 237311

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Calcium	<500		500		ug/L		02/19/18 13:03	02/21/18 00:31	1

Lab Sample ID: MB 180-237311/1-A
Matrix: Solid
Analysis Batch: 237713
Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 237311

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Boron	<80		80		ug/L		02/19/18 13:03	02/22/18 03:08	1

Lab Sample ID: LCS 180-237311/2-A
Matrix: Solid
Analysis Batch: 237590
Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 237311

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Calcium	50000	48400		ug/L		97	80 - 120

Lab Sample ID: LCS 180-237311/2-A
Matrix: Solid
Analysis Batch: 237713
Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 237311

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Boron	1000	1010		ug/L		101	80 - 120

QC Sample Results

Method: EPA 6020A - Metals (ICP/MS) (Continued)

Lab Sample ID: LCSD 180-237311/3-A
Matrix: Solid
Analysis Batch: 237590
Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 237311

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Calcium	50000	48200		ug/L		96	80 - 120	0	20

Lab Sample ID: LCSD 180-237311/3-A
Matrix: Solid
Analysis Batch: 237713
Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 237311

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Boron	1000	1020		ug/L		102	80 - 120	0	20

Method: 2540G - SM 2540G

Lab Sample ID: 180-74229-1 DU
Matrix: Solid
Analysis Batch: 234978
Client Sample ID: EAST POND - PRETEST
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Percent Moisture	14.8		17.0		%		14	20
Percent Solids	85.2		83.0		%		3	20

Method: EPA 9040C - pH

Lab Sample ID: LCS 180-236465/1
Matrix: Solid
Analysis Batch: 236465
Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
pH	7.00	7.0		SU		100	99 - 101

Lab Sample ID: LCS 180-236465/24
Matrix: Solid
Analysis Batch: 236465
Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
pH	7.00	7.0		SU		100	99 - 101

Lab Sample ID: LCS 180-236465/47
Matrix: Solid
Analysis Batch: 236465
Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
pH	7.00	7.0		SU		100	99 - 101

Lab Sample ID: LCS 180-237380/1
Matrix: Solid
Analysis Batch: 237380
Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
pH	7.00	7.0		SU		100	99 - 101

Method: EPA 9040C - pH (Continued)

Lab Sample ID: LCS 180-237737/1
Matrix: Solid
Analysis Batch: 237737

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
pH	7.00	7.0		SU		100	99 - 101

Method: SM 2510B - Conductivity, Specific Conductance

Lab Sample ID: MB 180-236475/17
Matrix: Solid
Analysis Batch: 236475

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Specific Conductance	<1.0		1.0		umhos/cm			02/07/18 11:58	1

Lab Sample ID: MB 180-236475/2
Matrix: Solid
Analysis Batch: 236475

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Specific Conductance	<1.0		1.0		umhos/cm			02/07/18 11:03	1

Lab Sample ID: MB 180-236475/43
Matrix: Solid
Analysis Batch: 236475

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Specific Conductance	<1.0		1.0		umhos/cm			02/07/18 13:32	1

Lab Sample ID: LCS 180-236475/1
Matrix: Solid
Analysis Batch: 236475

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Specific Conductance	84.0	85.1		umhos/cm		101	90 - 110

Lab Sample ID: LCS 180-236475/16
Matrix: Solid
Analysis Batch: 236475

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Specific Conductance	84.0	85.0		umhos/cm		101	90 - 110

Lab Sample ID: LCS 180-236475/42
Matrix: Solid
Analysis Batch: 236475

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Specific Conductance	84.0	85.1		umhos/cm		101	90 - 110

Method: SM 2510B - Conductivity, Specific Conductance (Continued)

Lab Sample ID: MB 180-237425/2
Matrix: Solid
Analysis Batch: 237425

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Specific Conductance	<1.0		1.0		umhos/cm			02/12/18 10:05	1

Lab Sample ID: LCS 180-237425/1
Matrix: Solid
Analysis Batch: 237425

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Specific Conductance			84.0	85.0		umhos/cm		101	90 - 110		

Lab Sample ID: MB 180-237752/2
Matrix: Solid
Analysis Batch: 237752

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Specific Conductance	<1.0		1.0		umhos/cm			02/16/18 08:07	1

Lab Sample ID: LCS 180-237752/1
Matrix: Solid
Analysis Batch: 237752

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Specific Conductance			84.0	85.1		umhos/cm		101	90 - 110		

Method: SM 2540C - Solids, Total Dissolved (TDS)

Lab Sample ID: MB 180-236785/2
Matrix: Solid
Analysis Batch: 236785

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	<10		10		mg/L			02/13/18 10:45	1

Lab Sample ID: LCS 180-236785/1
Matrix: Solid
Analysis Batch: 236785

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Total Dissolved Solids			339	388		mg/L		114	80 - 120		

Lab Sample ID: MB 180-236825/2
Matrix: Solid
Analysis Batch: 236825

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	<10		10		mg/L			02/13/18 15:26	1

Method: SM 2540C - Solids, Total Dissolved (TDS) (Continued)

Lab Sample ID: LCS 180-236825/1
Matrix: Solid
Analysis Batch: 236825

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Total Dissolved Solids	339	364		mg/L		107	80 - 120

Lab Sample ID: MB 180-237077/2
Matrix: Solid
Analysis Batch: 237077

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	<10		10		mg/L			02/15/18 14:55	1

Lab Sample ID: LCS 180-237077/1
Matrix: Solid
Analysis Batch: 237077

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Total Dissolved Solids	339	346		mg/L		102	80 - 120

Lab Sample ID: MB 180-237078/2
Matrix: Solid
Analysis Batch: 237078

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	<10		10		mg/L			02/15/18 14:59	1

Lab Sample ID: LCS 180-237078/1
Matrix: Solid
Analysis Batch: 237078

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Total Dissolved Solids	339	342		mg/L		101	80 - 120

Lab Sample ID: MB 180-237329/2
Matrix: Solid
Analysis Batch: 237329

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	<10		10		mg/L			02/19/18 15:41	1

Lab Sample ID: LCS 180-237329/1
Matrix: Solid
Analysis Batch: 237329

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Total Dissolved Solids	339	330		mg/L		97	80 - 120

Lab Sample ID: 180-74229-13 DU
Matrix: Solid
Analysis Batch: 236825

Client Sample ID: WEST POND - PH 13.0
Prep Type: Leach

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Total Dissolved Solids	14000		14200		mg/L		1	10

Lab Sample ID: 180-74229-19 DU
Matrix: Solid
Analysis Batch: 237077

Client Sample ID: WEST POND - PH 5.5
Prep Type: Leach

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Total Dissolved Solids	17000		17200		mg/L		2	10

Lab Sample ID: 180-74229-2 DU
Matrix: Solid
Analysis Batch: 237078

Client Sample ID: EAST POND - PH 13.0
Prep Type: Leach

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Total Dissolved Solids	14000		13400		mg/L		2	10

Method: SM 2580B - Reduction-Oxidation (REDOX) Potential

Lab Sample ID: LCS 180-236472/1
Matrix: Solid
Analysis Batch: 236472

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Oxidation Reduction Potential	475	467		millivolts		98	90 - 110

Lab Sample ID: LCS 180-236472/13
Matrix: Solid
Analysis Batch: 236472

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Oxidation Reduction Potential	475	465		millivolts		98	90 - 110

Lab Sample ID: LCS 180-236472/36
Matrix: Solid
Analysis Batch: 236472

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Oxidation Reduction Potential	475	463		millivolts		97	90 - 110

Lab Sample ID: LCS 180-237422/1
Matrix: Solid
Analysis Batch: 237422

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Oxidation Reduction Potential	475	466		millivolts		98	90 - 110

Lab Sample ID: LCS 180-237751/1
Matrix: Solid
Analysis Batch: 237751

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Oxidation Reduction Potential	475	467		millivolts		98	90 - 110

HPLC/IC

Leach Batch: 236165

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	1313	
180-74229-9	EAST POND - PH 4.0	Leach	Solid	1313	
180-74229-11	EAST POND - NATURAL	Leach	Solid	1313	
180-74229-13	WEST POND - PH 13.0	Leach	Solid	1313	
180-74229-20	WEST POND - PH 4.0	Leach	Solid	1313	
180-74229-22	WEST POND - NATURAL	Leach	Solid	1313	

Analysis Batch: 236373

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-11	EAST POND - NATURAL	Leach	Solid	EPA 9056A	236165
180-74229-22	WEST POND - NATURAL	Leach	Solid	EPA 9056A	236165
MB 180-236373/6	Method Blank	Total/NA	Solid	EPA 9056A	
LCS 180-236373/5	Lab Control Sample	Total/NA	Solid	EPA 9056A	

Analysis Batch: 236553

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	EPA 9056A	236165
180-74229-9	EAST POND - PH 4.0	Leach	Solid	EPA 9056A	236165
180-74229-13	WEST POND - PH 13.0	Leach	Solid	EPA 9056A	236165
180-74229-20	WEST POND - PH 4.0	Leach	Solid	EPA 9056A	236165
MB 180-236553/16	Method Blank	Total/NA	Solid	EPA 9056A	
LCS 180-236553/15	Lab Control Sample	Total/NA	Solid	EPA 9056A	

Leach Batch: 236722

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	1313	
180-74229-6	EAST POND - PH 8.0	Leach	Solid	1313	
180-74229-7	EAST POND - PH 7.0	Leach	Solid	1313	
180-74229-8	EAST POND - PH 5.5	Leach	Solid	1313	
180-74229-16	WEST POND - PH 9.0	Leach	Solid	1313	
180-74229-17	WEST POND - PH 8.0	Leach	Solid	1313	
180-74229-18	WEST POND - PH 7.0	Leach	Solid	1313	
180-74229-19	WEST POND - PH 5.5	Leach	Solid	1313	

Analysis Batch: 236732

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	EPA 9056A	236722
180-74229-6	EAST POND - PH 8.0	Leach	Solid	EPA 9056A	236722
MB 180-236732/6	Method Blank	Total/NA	Solid	EPA 9056A	
LCS 180-236732/5	Lab Control Sample	Total/NA	Solid	EPA 9056A	

Analysis Batch: 236891

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	EPA 9056A	236722
180-74229-6	EAST POND - PH 8.0	Leach	Solid	EPA 9056A	236722
MB 180-236891/6	Method Blank	Total/NA	Solid	EPA 9056A	
LCS 180-236891/5	Lab Control Sample	Total/NA	Solid	EPA 9056A	

Analysis Batch: 236997

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-7	EAST POND - PH 7.0	Leach	Solid	EPA 9056A	236722

HPLC/IC (Continued)

Analysis Batch: 236997 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-8	EAST POND - PH 5.5	Leach	Solid	EPA 9056A	236722
180-74229-16	WEST POND - PH 9.0	Leach	Solid	EPA 9056A	236722
180-74229-17	WEST POND - PH 8.0	Leach	Solid	EPA 9056A	236722
180-74229-18	WEST POND - PH 7.0	Leach	Solid	EPA 9056A	236722
180-74229-19	WEST POND - PH 5.5	Leach	Solid	EPA 9056A	236722
MB 180-236997/6	Method Blank	Total/NA	Solid	EPA 9056A	
LCS 180-236997/5	Lab Control Sample	Total/NA	Solid	EPA 9056A	

Analysis Batch: 237100

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-7	EAST POND - PH 7.0	Leach	Solid	EPA 9056A	236722
180-74229-8	EAST POND - PH 5.5	Leach	Solid	EPA 9056A	236722
180-74229-16	WEST POND - PH 9.0	Leach	Solid	EPA 9056A	236722
180-74229-17	WEST POND - PH 8.0	Leach	Solid	EPA 9056A	236722
180-74229-18	WEST POND - PH 7.0	Leach	Solid	EPA 9056A	236722
180-74229-19	WEST POND - PH 5.5	Leach	Solid	EPA 9056A	236722
MB 180-237100/6	Method Blank	Total/NA	Solid	EPA 9056A	
LCS 180-237100/5	Lab Control Sample	Total/NA	Solid	EPA 9056A	

Leach Batch: 237165

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	1313	
180-74229-10	EAST POND - PH 2.0	Leach	Solid	1313	
180-74229-14	WEST POND - PH 12.0	Leach	Solid	1313	
180-74229-21	WEST POND - PH 2.0	Leach	Solid	1313	

Analysis Batch: 237859

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	EPA 9056A	237165
180-74229-10	EAST POND - PH 2.0	Leach	Solid	EPA 9056A	237165
180-74229-14	WEST POND - PH 12.0	Leach	Solid	EPA 9056A	237165
180-74229-21	WEST POND - PH 2.0	Leach	Solid	EPA 9056A	237165
MB 180-237859/6	Method Blank	Total/NA	Solid	EPA 9056A	
LCS 180-237859/5	Lab Control Sample	Total/NA	Solid	EPA 9056A	

Metals

Leach Batch: 236165

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	1313	
180-74229-9	EAST POND - PH 4.0	Leach	Solid	1313	
180-74229-11	EAST POND - NATURAL	Leach	Solid	1313	
180-74229-13	WEST POND - PH 13.0	Leach	Solid	1313	
180-74229-20	WEST POND - PH 4.0	Leach	Solid	1313	
180-74229-22	WEST POND - NATURAL	Leach	Solid	1313	

Prep Batch: 236437

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-11	EAST POND - NATURAL	Leach	Solid	3010A	236165
180-74229-22	WEST POND - NATURAL	Leach	Solid	3010A	236165

Metals (Continued)

Prep Batch: 236437 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
MB 180-236437/1-A	Method Blank	Total/NA	Solid	3010A	
LCS 180-236437/2-A	Lab Control Sample	Total/NA	Solid	3010A	
LCSD 180-236437/3-A	Lab Control Sample Dup	Total/NA	Solid	3010A	

Prep Batch: 236440

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	3010A	236165
180-74229-9	EAST POND - PH 4.0	Leach	Solid	3010A	236165
180-74229-13	WEST POND - PH 13.0	Leach	Solid	3010A	236165
180-74229-20	WEST POND - PH 4.0	Leach	Solid	3010A	236165
MB 180-236440/1-A	Method Blank	Total/NA	Solid	3010A	
LCS 180-236440/2-A	Lab Control Sample	Total/NA	Solid	3010A	
LCSD 180-236440/3-A	Lab Control Sample Dup	Total/NA	Solid	3010A	

Leach Batch: 236722

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	1313	
180-74229-6	EAST POND - PH 8.0	Leach	Solid	1313	
180-74229-7	EAST POND - PH 7.0	Leach	Solid	1313	
180-74229-8	EAST POND - PH 5.5	Leach	Solid	1313	
180-74229-16	WEST POND - PH 9.0	Leach	Solid	1313	
180-74229-17	WEST POND - PH 8.0	Leach	Solid	1313	
180-74229-18	WEST POND - PH 7.0	Leach	Solid	1313	
180-74229-19	WEST POND - PH 5.5	Leach	Solid	1313	

Analysis Batch: 236729

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	EPA 6020A	236440
180-74229-11	EAST POND - NATURAL	Leach	Solid	EPA 6020A	236437
180-74229-13	WEST POND - PH 13.0	Leach	Solid	EPA 6020A	236440
180-74229-22	WEST POND - NATURAL	Leach	Solid	EPA 6020A	236437
MB 180-236437/1-A	Method Blank	Total/NA	Solid	EPA 6020A	236437
MB 180-236440/1-A	Method Blank	Total/NA	Solid	EPA 6020A	236440
LCS 180-236437/2-A	Lab Control Sample	Total/NA	Solid	EPA 6020A	236437
LCS 180-236440/2-A	Lab Control Sample	Total/NA	Solid	EPA 6020A	236440
LCSD 180-236437/3-A	Lab Control Sample Dup	Total/NA	Solid	EPA 6020A	236437
LCSD 180-236440/3-A	Lab Control Sample Dup	Total/NA	Solid	EPA 6020A	236440

Prep Batch: 236807

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	3010A	236722
180-74229-6	EAST POND - PH 8.0	Leach	Solid	3010A	236722
180-74229-7	EAST POND - PH 7.0	Leach	Solid	3010A	236722
180-74229-8	EAST POND - PH 5.5	Leach	Solid	3010A	236722
180-74229-16	WEST POND - PH 9.0	Leach	Solid	3010A	236722
180-74229-17	WEST POND - PH 8.0	Leach	Solid	3010A	236722
180-74229-18	WEST POND - PH 7.0	Leach	Solid	3010A	236722
180-74229-19	WEST POND - PH 5.5	Leach	Solid	3010A	236722
MB 180-236807/1-A	Method Blank	Total/NA	Solid	3010A	
LCS 180-236807/2-A	Lab Control Sample	Total/NA	Solid	3010A	
LCSD 180-236807/3-A	Lab Control Sample Dup	Total/NA	Solid	3010A	

Analysis Batch: 236828

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	EPA 6020A	236440
180-74229-9	EAST POND - PH 4.0	Leach	Solid	EPA 6020A	236440
180-74229-11	EAST POND - NATURAL	Leach	Solid	EPA 6020A	236437
180-74229-13	WEST POND - PH 13.0	Leach	Solid	EPA 6020A	236440
180-74229-20	WEST POND - PH 4.0	Leach	Solid	EPA 6020A	236440
180-74229-22	WEST POND - NATURAL	Leach	Solid	EPA 6020A	236437
MB 180-236437/1-A	Method Blank	Total/NA	Solid	EPA 6020A	236437
MB 180-236440/1-A	Method Blank	Total/NA	Solid	EPA 6020A	236440
LCS 180-236437/2-A	Lab Control Sample	Total/NA	Solid	EPA 6020A	236437
LCS 180-236440/2-A	Lab Control Sample	Total/NA	Solid	EPA 6020A	236440
LCSD 180-236437/3-A	Lab Control Sample Dup	Total/NA	Solid	EPA 6020A	236437
LCSD 180-236440/3-A	Lab Control Sample Dup	Total/NA	Solid	EPA 6020A	236440

Leach Batch: 237165

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	1313	
180-74229-10	EAST POND - PH 2.0	Leach	Solid	1313	
180-74229-14	WEST POND - PH 12.0	Leach	Solid	1313	
180-74229-21	WEST POND - PH 2.0	Leach	Solid	1313	

Analysis Batch: 237198

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	EPA 6020A	236807
180-74229-6	EAST POND - PH 8.0	Leach	Solid	EPA 6020A	236807
180-74229-16	WEST POND - PH 9.0	Leach	Solid	EPA 6020A	236807
180-74229-17	WEST POND - PH 8.0	Leach	Solid	EPA 6020A	236807
MB 180-236807/1-A	Method Blank	Total/NA	Solid	EPA 6020A	236807
LCS 180-236807/2-A	Lab Control Sample	Total/NA	Solid	EPA 6020A	236807
LCSD 180-236807/3-A	Lab Control Sample Dup	Total/NA	Solid	EPA 6020A	236807

Prep Batch: 237311

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	3010A	237165
180-74229-10	EAST POND - PH 2.0	Leach	Solid	3010A	237165
180-74229-14	WEST POND - PH 12.0	Leach	Solid	3010A	237165
180-74229-21	WEST POND - PH 2.0	Leach	Solid	3010A	237165
MB 180-237311/1-A	Method Blank	Total/NA	Solid	3010A	
LCS 180-237311/2-A	Lab Control Sample	Total/NA	Solid	3010A	
LCSD 180-237311/3-A	Lab Control Sample Dup	Total/NA	Solid	3010A	

Analysis Batch: 237323

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-7	EAST POND - PH 7.0	Leach	Solid	EPA 6020A	236807
180-74229-8	EAST POND - PH 5.5	Leach	Solid	EPA 6020A	236807
180-74229-18	WEST POND - PH 7.0	Leach	Solid	EPA 6020A	236807
180-74229-19	WEST POND - PH 5.5	Leach	Solid	EPA 6020A	236807

Analysis Batch: 237590

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	EPA 6020A	237311
180-74229-14	WEST POND - PH 12.0	Leach	Solid	EPA 6020A	237311
MB 180-237311/1-A	Method Blank	Total/NA	Solid	EPA 6020A	237311
LCS 180-237311/2-A	Lab Control Sample	Total/NA	Solid	EPA 6020A	237311

QC Association Summary

Metals (Continued)

Analysis Batch: 237590 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
LCSD 180-237311/3-A	Lab Control Sample Dup	Total/NA	Solid	EPA 6020A	237311

Analysis Batch: 237713

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	EPA 6020A	237311
180-74229-10	EAST POND - PH 2.0	Leach	Solid	EPA 6020A	237311
180-74229-14	WEST POND - PH 12.0	Leach	Solid	EPA 6020A	237311
180-74229-21	WEST POND - PH 2.0	Leach	Solid	EPA 6020A	237311
MB 180-237311/1-A	Method Blank	Total/NA	Solid	EPA 6020A	237311
LCS 180-237311/2-A	Lab Control Sample	Total/NA	Solid	EPA 6020A	237311
LCSD 180-237311/3-A	Lab Control Sample Dup	Total/NA	Solid	EPA 6020A	237311

General Chemistry

Analysis Batch: 234978

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-1	EAST POND - PRETEST	Total/NA	Solid	2540G	
180-74229-12	WEST POND - PRETEST	Total/NA	Solid	2540G	
180-74229-1 DU	EAST POND - PRETEST	Total/NA	Solid	2540G	

Analysis Batch: 235859

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-23	EAST POND - AIR DRIED	Total/NA	Solid	2540G	
180-74229-24	WEST POND - AIR DRIED	Total/NA	Solid	2540G	

Leach Batch: 236165

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	1313	
180-74229-9	EAST POND - PH 4.0	Leach	Solid	1313	
180-74229-11	EAST POND - NATURAL	Leach	Solid	1313	
180-74229-13	WEST POND - PH 13.0	Leach	Solid	1313	
180-74229-20	WEST POND - PH 4.0	Leach	Solid	1313	
180-74229-22	WEST POND - NATURAL	Leach	Solid	1313	
180-74229-2 DU	EAST POND - PH 13.0	Leach	Solid	1313	
180-74229-13 DU	WEST POND - PH 13.0	Leach	Solid	1313	

Analysis Batch: 236465

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	EPA 9040C	236165
180-74229-9	EAST POND - PH 4.0	Leach	Solid	EPA 9040C	236165
180-74229-11	EAST POND - NATURAL	Leach	Solid	EPA 9040C	236165
180-74229-13	WEST POND - PH 13.0	Leach	Solid	EPA 9040C	236165
180-74229-20	WEST POND - PH 4.0	Leach	Solid	EPA 9040C	236165
180-74229-22	WEST POND - NATURAL	Leach	Solid	EPA 9040C	236165
LCS 180-236465/1	Lab Control Sample	Total/NA	Solid	EPA 9040C	
LCS 180-236465/24	Lab Control Sample	Total/NA	Solid	EPA 9040C	
LCS 180-236465/47	Lab Control Sample	Total/NA	Solid	EPA 9040C	

QC Association Summary

General Chemistry (Continued)

Analysis Batch: 236472

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	SM 2580B	236165
180-74229-9	EAST POND - PH 4.0	Leach	Solid	SM 2580B	236165
180-74229-11	EAST POND - NATURAL	Leach	Solid	SM 2580B	236165
180-74229-13	WEST POND - PH 13.0	Leach	Solid	SM 2580B	236165
180-74229-20	WEST POND - PH 4.0	Leach	Solid	SM 2580B	236165
180-74229-22	WEST POND - NATURAL	Leach	Solid	SM 2580B	236165
LCS 180-236472/1	Lab Control Sample	Total/NA	Solid	SM 2580B	
LCS 180-236472/13	Lab Control Sample	Total/NA	Solid	SM 2580B	
LCS 180-236472/36	Lab Control Sample	Total/NA	Solid	SM 2580B	

Analysis Batch: 236475

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	SM 2510B	236165
180-74229-9	EAST POND - PH 4.0	Leach	Solid	SM 2510B	236165
180-74229-11	EAST POND - NATURAL	Leach	Solid	SM 2510B	236165
180-74229-13	WEST POND - PH 13.0	Leach	Solid	SM 2510B	236165
180-74229-20	WEST POND - PH 4.0	Leach	Solid	SM 2510B	236165
180-74229-22	WEST POND - NATURAL	Leach	Solid	SM 2510B	236165
MB 180-236475/17	Method Blank	Total/NA	Solid	SM 2510B	
MB 180-236475/2	Method Blank	Total/NA	Solid	SM 2510B	
MB 180-236475/43	Method Blank	Total/NA	Solid	SM 2510B	
LCS 180-236475/1	Lab Control Sample	Total/NA	Solid	SM 2510B	
LCS 180-236475/16	Lab Control Sample	Total/NA	Solid	SM 2510B	
LCS 180-236475/42	Lab Control Sample	Total/NA	Solid	SM 2510B	

Leach Batch: 236722

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	1313	
180-74229-6	EAST POND - PH 8.0	Leach	Solid	1313	
180-74229-7	EAST POND - PH 7.0	Leach	Solid	1313	
180-74229-8	EAST POND - PH 5.5	Leach	Solid	1313	
180-74229-16	WEST POND - PH 9.0	Leach	Solid	1313	
180-74229-17	WEST POND - PH 8.0	Leach	Solid	1313	
180-74229-18	WEST POND - PH 7.0	Leach	Solid	1313	
180-74229-19	WEST POND - PH 5.5	Leach	Solid	1313	
180-74229-19 DU	WEST POND - PH 5.5	Leach	Solid	1313	

Analysis Batch: 236785

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-22	WEST POND - NATURAL	Leach	Solid	SM 2540C	236165
MB 180-236785/2	Method Blank	Total/NA	Solid	SM 2540C	
LCS 180-236785/1	Lab Control Sample	Total/NA	Solid	SM 2540C	

Analysis Batch: 236825

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-9	EAST POND - PH 4.0	Leach	Solid	SM 2540C	236165
180-74229-11	EAST POND - NATURAL	Leach	Solid	SM 2540C	236165
180-74229-13	WEST POND - PH 13.0	Leach	Solid	SM 2540C	236165
180-74229-20	WEST POND - PH 4.0	Leach	Solid	SM 2540C	236165
MB 180-236825/2	Method Blank	Total/NA	Solid	SM 2540C	
LCS 180-236825/1	Lab Control Sample	Total/NA	Solid	SM 2540C	

General Chemistry (Continued)

Analysis Batch: 236825 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-13 DU	WEST POND - PH 13.0	Leach	Solid	SM 2540C	236165

Analysis Batch: 237077

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	SM 2540C	236722
180-74229-6	EAST POND - PH 8.0	Leach	Solid	SM 2540C	236722
180-74229-7	EAST POND - PH 7.0	Leach	Solid	SM 2540C	236722
180-74229-8	EAST POND - PH 5.5	Leach	Solid	SM 2540C	236722
180-74229-16	WEST POND - PH 9.0	Leach	Solid	SM 2540C	236722
180-74229-17	WEST POND - PH 8.0	Leach	Solid	SM 2540C	236722
180-74229-18	WEST POND - PH 7.0	Leach	Solid	SM 2540C	236722
180-74229-19	WEST POND - PH 5.5	Leach	Solid	SM 2540C	236722
MB 180-237077/2	Method Blank	Total/NA	Solid	SM 2540C	
LCS 180-237077/1	Lab Control Sample	Total/NA	Solid	SM 2540C	
180-74229-19 DU	WEST POND - PH 5.5	Leach	Solid	SM 2540C	236722

Analysis Batch: 237078

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-2	EAST POND - PH 13.0	Leach	Solid	SM 2540C	236165
MB 180-237078/2	Method Blank	Total/NA	Solid	SM 2540C	
LCS 180-237078/1	Lab Control Sample	Total/NA	Solid	SM 2540C	
180-74229-2 DU	EAST POND - PH 13.0	Leach	Solid	SM 2540C	236165

Leach Batch: 237107

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-1	EAST POND - PRETEST	Leach	Solid	1313	
180-74229-1	EAST POND - PRETEST	Leach	Solid	1313	
180-74229-12	WEST POND - PRETEST	Leach	Solid	1313	
180-74229-12	WEST POND - PRETEST	Leach	Solid	1313	

Leach Batch: 237165

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	1313	
180-74229-10	EAST POND - PH 2.0	Leach	Solid	1313	
180-74229-14	WEST POND - PH 12.0	Leach	Solid	1313	
180-74229-21	WEST POND - PH 2.0	Leach	Solid	1313	

Analysis Batch: 237329

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	SM 2540C	237165
180-74229-10	EAST POND - PH 2.0	Leach	Solid	SM 2540C	237165
180-74229-14	WEST POND - PH 12.0	Leach	Solid	SM 2540C	237165
180-74229-21	WEST POND - PH 2.0	Leach	Solid	SM 2540C	237165
MB 180-237329/2	Method Blank	Total/NA	Solid	SM 2540C	
LCS 180-237329/1	Lab Control Sample	Total/NA	Solid	SM 2540C	

Analysis Batch: 237380

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-1	EAST POND - PRETEST	Leach	Solid	EPA 9040C	237107
180-74229-1	EAST POND - PRETEST	Leach	Solid	EPA 9040C	237107
180-74229-5	EAST POND - PH 9.0	Leach	Solid	EPA 9040C	236722

General Chemistry (Continued)

Analysis Batch: 237380 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-6	EAST POND - PH 8.0	Leach	Solid	EPA 9040C	236722
180-74229-7	EAST POND - PH 7.0	Leach	Solid	EPA 9040C	236722
180-74229-8	EAST POND - PH 5.5	Leach	Solid	EPA 9040C	236722
180-74229-12	WEST POND - PRETEST	Leach	Solid	EPA 9040C	237107
180-74229-12	WEST POND - PRETEST	Leach	Solid	EPA 9040C	237107
180-74229-16	WEST POND - PH 9.0	Leach	Solid	EPA 9040C	236722
180-74229-17	WEST POND - PH 8.0	Leach	Solid	EPA 9040C	236722
180-74229-18	WEST POND - PH 7.0	Leach	Solid	EPA 9040C	236722
180-74229-19	WEST POND - PH 5.5	Leach	Solid	EPA 9040C	236722
LCS 180-237380/1	Lab Control Sample	Total/NA	Solid	EPA 9040C	

Analysis Batch: 237422

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	SM 2580B	236722
180-74229-6	EAST POND - PH 8.0	Leach	Solid	SM 2580B	236722
180-74229-7	EAST POND - PH 7.0	Leach	Solid	SM 2580B	236722
180-74229-8	EAST POND - PH 5.5	Leach	Solid	SM 2580B	236722
180-74229-16	WEST POND - PH 9.0	Leach	Solid	SM 2580B	236722
180-74229-17	WEST POND - PH 8.0	Leach	Solid	SM 2580B	236722
180-74229-18	WEST POND - PH 7.0	Leach	Solid	SM 2580B	236722
180-74229-19	WEST POND - PH 5.5	Leach	Solid	SM 2580B	236722
LCS 180-237422/1	Lab Control Sample	Total/NA	Solid	SM 2580B	

Analysis Batch: 237425

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-5	EAST POND - PH 9.0	Leach	Solid	SM 2510B	236722
180-74229-6	EAST POND - PH 8.0	Leach	Solid	SM 2510B	236722
180-74229-7	EAST POND - PH 7.0	Leach	Solid	SM 2510B	236722
180-74229-8	EAST POND - PH 5.5	Leach	Solid	SM 2510B	236722
180-74229-16	WEST POND - PH 9.0	Leach	Solid	SM 2510B	236722
180-74229-17	WEST POND - PH 8.0	Leach	Solid	SM 2510B	236722
180-74229-18	WEST POND - PH 7.0	Leach	Solid	SM 2510B	236722
180-74229-19	WEST POND - PH 5.5	Leach	Solid	SM 2510B	236722
MB 180-237425/2	Method Blank	Total/NA	Solid	SM 2510B	
LCS 180-237425/1	Lab Control Sample	Total/NA	Solid	SM 2510B	

Analysis Batch: 237737

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	EPA 9040C	237165
180-74229-10	EAST POND - PH 2.0	Leach	Solid	EPA 9040C	237165
180-74229-14	WEST POND - PH 12.0	Leach	Solid	EPA 9040C	237165
180-74229-21	WEST POND - PH 2.0	Leach	Solid	EPA 9040C	237165
LCS 180-237737/1	Lab Control Sample	Total/NA	Solid	EPA 9040C	

Analysis Batch: 237751

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	SM 2580B	237165
180-74229-10	EAST POND - PH 2.0	Leach	Solid	SM 2580B	237165
180-74229-14	WEST POND - PH 12.0	Leach	Solid	SM 2580B	237165
180-74229-21	WEST POND - PH 2.0	Leach	Solid	SM 2580B	237165
LCS 180-237751/1	Lab Control Sample	Total/NA	Solid	SM 2580B	

QC Association Summary

Analysis Batch: 237752

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
180-74229-3	EAST POND - PH 12.0	Leach	Solid	SM 2510B	237165
180-74229-10	EAST POND - PH 2.0	Leach	Solid	SM 2510B	237165
180-74229-14	WEST POND - PH 12.0	Leach	Solid	SM 2510B	237165
180-74229-21	WEST POND - PH 2.0	Leach	Solid	SM 2510B	237165
MB 180-237752/2	Method Blank	Total/NA	Solid	SM 2510B	
LCS 180-237752/1	Lab Control Sample	Total/NA	Solid	SM 2510B	

TestAmerica

THE LEADER IN ENVIRONMENTAL TESTING

2417 Bond Street, University Park, IL 60484
Phone: 708.534.5200 Fax: 708.534.5211

(optional)
Report To
Contact: ______
Company: ______
Address: ______
Address: ______
Phone: ______
Fax: ______
E-Mail: ______

(optional)
Bill To
Contact: ______
Company: ______
Address: ______
Address: ______
Phone: ______
Fax: ______
PO#/Reference# ______

Chain of Custody Record

Lab Job #: ______
Chain of Custody Number: ______
Page ______ of ______
Temperature °C of Cooler: ______

Client KPRG & Assoc.
Client Project # 23517
Project Name NRG
Project Location/State IL
Lab Project # ______
Sampler LR/MW
Lab PM ______

Preservative Key
1. HCL, Cool to 4°
2. H2SO4, Cool to 4°
3. HNO3, Cool to 4°
4. NaOH, Cool to 4°
5. NaOH/Zn, Cool to 4°
6. NaHSO4
7. Cool to 4°
8. None
9. Other

							Preservative	8									
							Parameter	LEAF Method 1313									
Lab ID	MS/MSD	Sample ID	Sampling Date	Sampling Time	# of Containers	Matrix											Comments
		East Pond	1/17/18	1018	2	SE		X									
		West Pond	1/17/18	1037	2	SE		X									

180-74229 Chain of Custody

Turnaround Time Required (Business Days)
___ 1 Day ___ 2 Days ___ 5 Days ___ 7 Days ___ 10 Days ___ 15 Days ______ Other
Requested Due Date ______

Sample Disposal
☐ Return to Client ☑ Disposal by Lab ☐ Archive for ______ Months (A fee may be assessed if samples are retained longer than 1 month)

Relinquished By	Company	Date	Time	Received By	Company	Date	Time
	KPRG	1/17/18	1325		TA	1-17-18	1325
	TA	1-17-18	1700	Danielle Wabint	TAPH	1-18-18	12:20

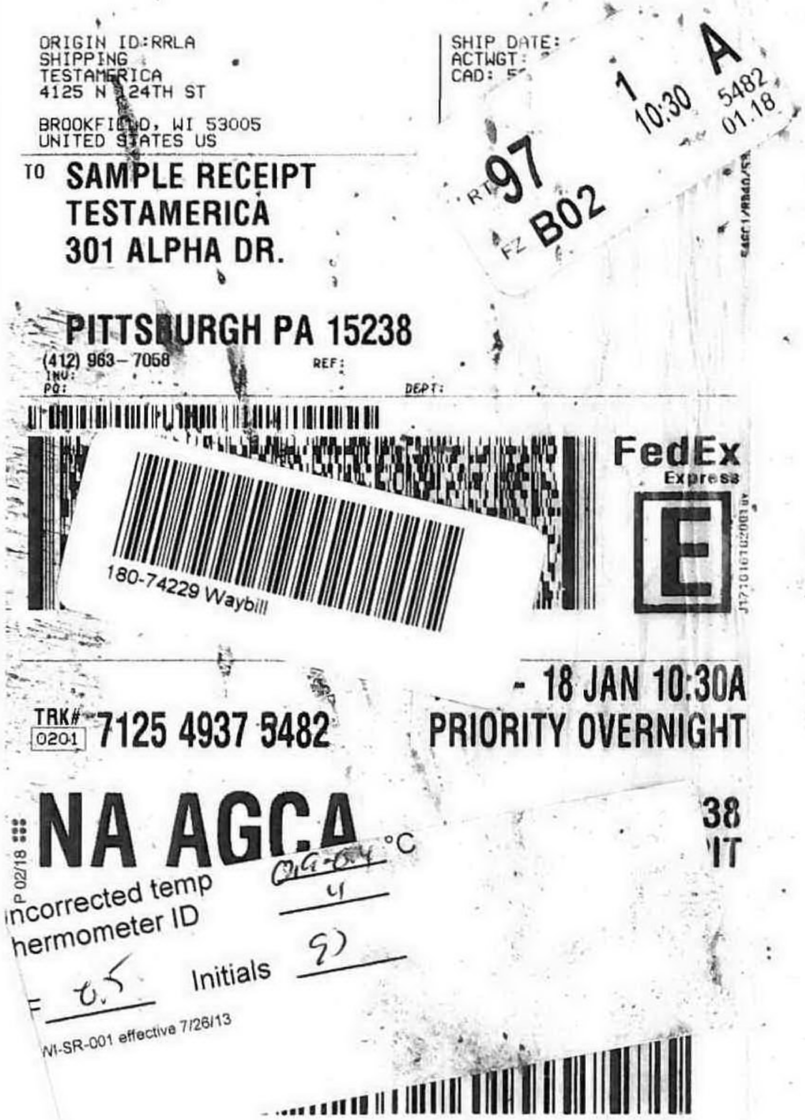
Lab Courier ☐
Shipped ☐
Hand Delivered ☐

Matrix Key
WW – Wastewater
W – Water
S – Soil
SL – Sludge
MS – Miscellaneous
OL – Oil
A – Air
SE – Sediment
SO – Soil
L – Leachate
WI – Wipe
DW – Drinking Water
O – Other

Client Comments
LEAF Method 1313 CCR Appendix 3
→ B, Ca, Cl, Fl, pH, SO4, TDS

Lab Comments:

TAL-4124-500 (1209)



ORIGIN ID:RRLA
SHIPPING
TESTAMERICA
4125 N 124TH ST

BROOKFIELD, WI 53005
UNITED STATES US

SHIP DATE:
ACTWGT:
CAD: 5

1 A
10:30 5482
01.18
RT 97
FZ B02

TO **SAMPLE RECEIPT**
TESTAMERICA
301 ALPHA DR.

PITTSBURGH PA 15238
(412) 963-7058 REF:
INV:
PO: DEPT:

180-74229 Waybill

FedEx
Express
E

J171016102001uv

18 JAN 10:30A
PRIORITY OVERNIGHT

TRK# 0201 **7125 4937 5482**

NA AGCA

38
IT

P 02/18
Uncorrected temp 0.6-0.4 °C
Thermometer ID 4
CF 0.5 Initials 9)
WI-SR-001 effective 7/26/13

Login Sample Receipt Checklist

Client: KPRG and Associates, Inc.

Job Number: 180-74229-1

Login Number: 74229

List Number: 1

Creator: Watson, Debbie

List Source: TestAmerica Pittsburgh

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	N/A	
The cooler's custody seal, if present, is intact.	True	
Sample custody seals, if present, are intact.	True	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	True	
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

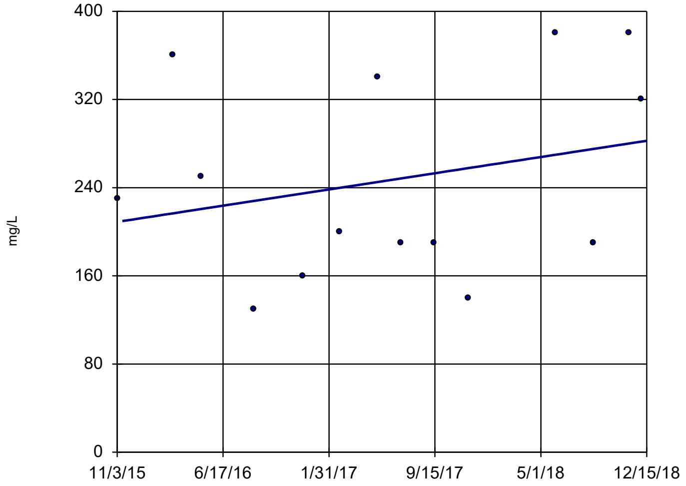
ATTACHMENT 3

Trend Analyses for Calcium, TDS and pH – MW-16

Sanitas™ v.9.6.09 Software licensed to KPRG and Associates, Inc. UG

Linear Regression

MW-16



n = 14

Slope = 23.61
units/year.

alpha = 0.02
t = 0.9418
critical = 2.303

No significant trend.

Normality test on residuals:
Shapiro Wilk @alpha
= 0.01, calculated
= 0.9186, critical
= 0.825.

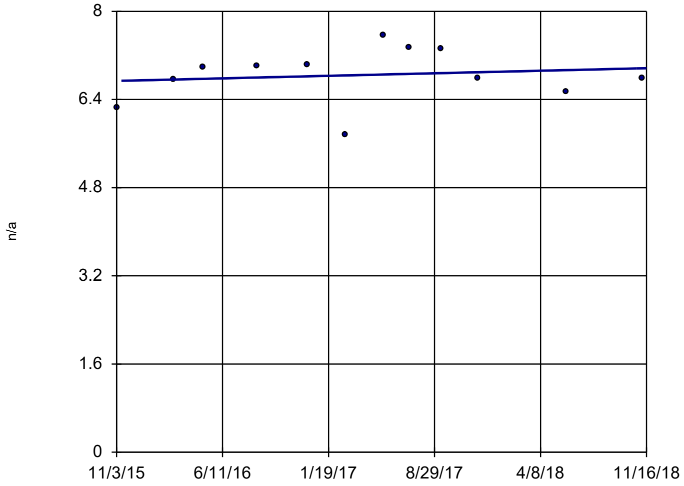
Constituent: Calcium Analysis Run 2/25/2019 11:46 AM

Waukegan Generating Station Client: NRG Data: Waukegan

Sanitas™ v.9.6.09 Software licensed to KPRG and Associates, Inc. UG

Linear Regression

MW-16



n = 12

Slope = 0.07597
units/year.

alpha = 0.02
t = 0.4404
critical = 2.359

No significant trend.

Normality test on residuals:
Shapiro Wilk @alpha
= 0.01, calculated
= 0.9584, critical
= 0.805.

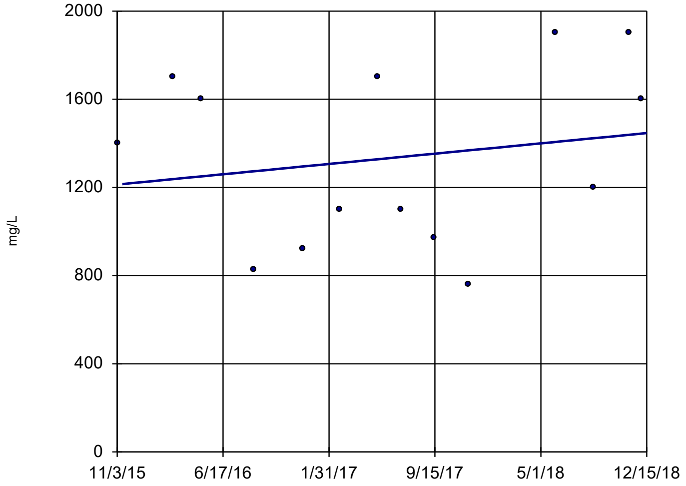
Constituent: pH Analysis Run 2/25/2019 11:46 AM

Waukegan Generating Station Client: NRG Data: Waukegan

Sanitas™ v.9.6.09 Software licensed to KPRG and Associates, Inc. UG

Linear Regression

MW-16



n = 14

Slope = 74.94
units/year.

alpha = 0.02
t = 0.6682
critical = 2.303

No significant trend.

Normality test on residuals:
Shapiro Wilk @alpha
= 0.01, calculated
= 0.8906, critical
= 0.825.

Constituent: Total Dissolved Solids Analysis Run 2/25/2019 11:46 AM

Waukegan Generating Station Client: NRG Data: Waukegan

Linear Regression

Constituent: Calcium, pH, Total Dissolved Solids Analysis Run 2/25/2019 11:48 AM

Waukegan Generating Station Client: NRG Data: Waukegan

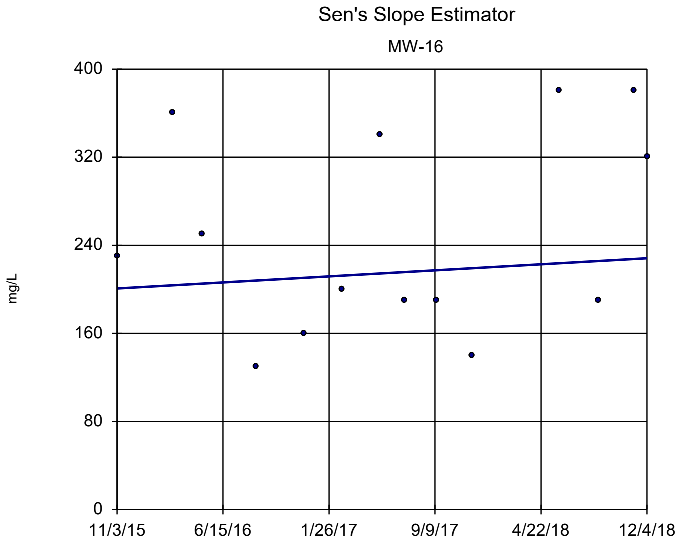
	MW-16	MW-16	MW-16
11/3/2015	230	6.24	1400
3/2/2016	360	6.76	1700
5/2/2016	250	6.99	1600
8/24/2016	130	7	830
12/5/2016	160	7.03	920
2/24/2017	200	5.76	1100
5/15/2017		7.57	
5/16/2017	340		1700
7/6/2017	190	7.35	1100
9/13/2017	190	7.33	970
11/27/2017	140	6.78	760
6/1/2018	380	6.53	1900
8/22/2018	190		1200
11/6/2018	380	6.78	1900
12/4/2018	320		1600

Trend Test MW-16 Ca, TDS, pH

Waukegan Generating Station   Client: NRG   Data: Waukegan   Printed 2/25/2019, 11:48 AM

Constituent	Well	Slope	Calc.	Critical	Sig.	N	%NDs	Normality	Xform	Alpha	Method
Calcium (mg/L)	MW-16	23.61	0.9418	2.303	No	14	0	Yes	no	0.02	Param.
pH (n/a)	MW-16	0.07597	0.4404	2.359	No	12	0	Yes	no	0.02	Param.
Total Dissolved Solids (mg/L)	MW-16	74.94	0.6682	2.303	No	14	0	Yes	no	0.02	Param.

Sanitas™ v.9.6.09 Software licensed to KPRG and Associates, Inc. UG



n = 14

Slope = 8.892
units per year.

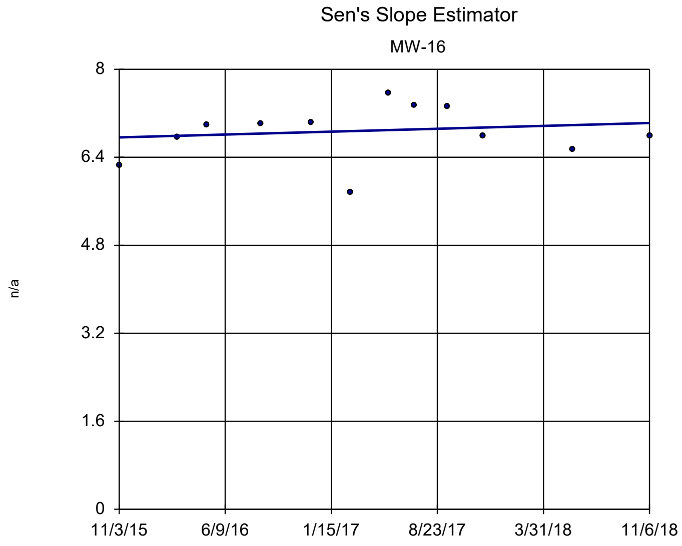
Mann-Kendall
statistic = 9
critical = 44

Trend not significant at 98%
confidence level
(α = 0.01 per
tail).

Constituent: Calcium Analysis Run 2/25/2019 11:49 AM

Waukegan Generating Station Client: NRG Data: Waukegan

Sanitas™ v.9.6.09 Software licensed to KPRG and Associates, Inc. UG



n = 12

Slope = 0.0868
units per year.

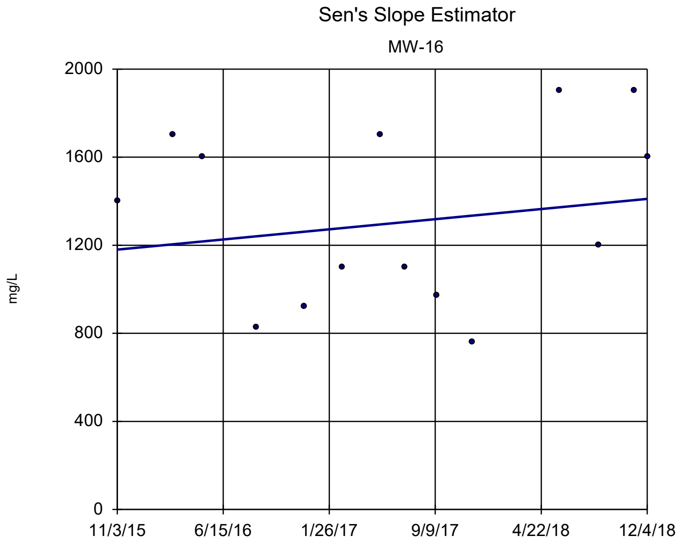
Mann-Kendall
statistic = 9
critical = 35

Trend not significant at 98%
confidence level
(α = 0.01 per
tail).

Constituent: pH Analysis Run 2/25/2019 11:49 AM

Waukegan Generating Station Client: NRG Data: Waukegan

Sanitas™ v.9.6.09 Software licensed to KPRG and Associates, Inc. UG



n = 14

Slope = 74.57
units per year.

Mann-Kendall
statistic = 11
critical = 44

Trend not significant at 98%
confidence level
(α = 0.01 per
tail).

Constituent: Total Dissolved Solids Analysis Run 2/25/2019 11:49 AM

Waukegan Generating Station Client: NRG Data: Waukegan

Sen's Slope Estimator

Constituent: Calcium, pH, Total Dissolved Solids Analysis Run 2/25/2019 11:50 AM

Waukegan Generating Station Client: NRG Data: Waukegan

	MW-16	MW-16	MW-16
11/3/2015	230	6.24	1400
3/2/2016	360	6.76	1700
5/2/2016	250	6.99	1600
8/24/2016	130	7	830
12/5/2016	160	7.03	920
2/24/2017	200	5.76	1100
5/15/2017		7.57	
5/16/2017	340		1700
7/6/2017	190	7.35	1100
9/13/2017	190	7.33	970
11/27/2017	140	6.78	760
6/1/2018	380	6.53	1900
8/22/2018	190		1200
11/6/2018	380	6.78	1900
12/4/2018	320		1600

Trend Test MW-16 Ca, TDS, pH

Waukegan Generating Station Client: NRG Data: Waukegan Printed 2/25/2019, 11:50 AM

Constituent	Well	Slope	Calc.	Critical	Sig.	N	%NDs	Normality	Xform	Alpha	Method
Calcium (mg/L)	MW-16	8.892	9	44	No	14	0	n/a	n/a	0.02	NP
pH (n/a)	MW-16	0.0868	9	35	No	12	0	n/a	n/a	0.02	NP
Total Dissolved Solids (mg/L)	MW-16	74.57	11	44	No	14	0	n/a	n/a	0.02	NP

EXHIBIT 16

Geosyntec consultants

16644 West Bernardo Drive, Suite 301
San Diego, CA 92127
Phone: 858.674.6559
Fax: 858.674.6586
www.geosyntec.com

CLOSURE PLAN
EAST AND WEST ASH BASINS
WAUKEGAN STATION
OCTOBER 2016

Pursuant to 40 CFR §257.102(b), Geosyntec Consultants prepared this Closure Plan for the East and West Ash Basins at the Waukegan Station (Site), operated by Midwest Generation, LLC. (Midwest Generation), in Waukegan, Illinois (Figure 1). This Closure Plan was developed to describe the steps necessary to close the coal combustion residual (CCR) units at any point during their active life in a manner that is consistent with recognized and generally accepted good engineering practices. Ms. Jane Soule, P.E., of Geosyntec Consultants, prepared this Closure Plan. Mr. Robert White reviewed this plan in accordance with Geosyntec's senior review policy.

The following addresses the information required by §257.102(b).

1. Narrative of Closure - §257.102(b)(1)(i)

The East and West Ash Basins will be closed through removal of CCR, and the closures will be performed in accordance with §257.102(c). CCR will be removed as described in the following section.

2. CCR Removal and Decontamination – §257.102(b)(1)(ii)

The same general process will be used to remove CCR from the East Ash Basin and the West Ash Basins. First, water contained in the basins will be drained using the existing outlet structures. Portable pumps may be used once the pool level is below the invert elevation of the outlet structures to pump water into the outlet structures. Next, heavy equipment will move CCR from one side of the basin to the other to further dewater the CCR solids. Once the material is dry enough to handle, CCR will be loaded into trucks and transported to a beneficial use facility or a permitted disposal facility. If the units will not be transitioned to store non-CCR process waters, the liner systems will be removed and transported to a permitted disposal facility. Otherwise, the liner systems will be properly decontaminated. Appurtenant structures such as inlet troughs, outlet structures, and piping will also be properly decontaminated or removed and transported to a permitted disposal facility depending on potential reuse opportunities for the structures identified at the time of closure. Decontamination procedures for the liner or appurtenant structures may consist of pressure washing, scrubbing, flushing, or other generally accepted decontamination procedures. In accordance with §257.102(c), CCR removal and decontamination will be complete when constituent concentrations throughout the CCR unit and areas that may have been affected by releases from these units have been removed and groundwater monitoring concentrations do not exceed the groundwater protection standard established pursuant to §257.95(h) for constituents listed in Appendix IV for two consecutive sampling events using the statistical procedures in §257.93(g). Decontamination may include removal of all CCR materials above the geomembrane liner to facilitate inspection of the liner for evidence of damage that may indicate a potential release of CCR. If evidence of a release is identified during closure, materials impacted by the release will be removed or remediated, as appropriate. Existing embankments may be breached to limit collection of stormwater if consistent with future proposed land use.

3. Final Cover Requirements – §257.102(b)(1)(iii)

CCR will be removed from the East and West Ash Basins in accordance with §257.102(c); therefore, no final cover system will be constructed for closure.

4. Maximum CCR Inventory - §257.102(b)(1)(iv)

Detailed records of the maximum inventory of CCR ever onsite and stored in the East and West Ash Basins are not available. For the purposes of this closure plan, the maximum CCR inventory for each basin was estimated to be the maximum quantity of CCR that could be reasonably stored in the basins. The table below presents the estimated maximum CCR inventory for the East and West Ash Basins.

Basin	**Estimated Maximum Quantity of CCR (cubic yards)**
West Ash Basin	137,200
East Ash Basin	127,600

5. Maximum Area Requiring Final Cover – §257.102(b)(1)(v)

CCR will be removed from the East and West Ash Basins in accordance with §257.102(c); therefore, no final cover system will be constructed for closure.

6. Closure Schedule – §257.102(b)(1)(vi)

Closure of the East and West Ash Basins is anticipated to begin in 2035 and be complete within five years of the commencement of closure in accordance with §257.102(f)(1)(ii). Prior to initiation of closure, a notice of intent to close will be prepared in accordance with §257.102(g).

Closure will assume to have been initiated when waste placement has ceased and any of the following actions are completed:

- Taken any steps to implement this written closure plan;
- Submitted a completed application for any required agency permit or permit modification; or
- Taken any steps to comply with any agency standards that are a prerequisite to initiating closure.

Closure design documents will be prepared to support applications for required local, state, and federal permits. Closure construction design documents may include construction drawings for closure, technical specifications, and adequate CCR removal confirmation procedures. The permits required for closure construction will be evaluated at the time of closure, but are anticipated to include permits from the Illinois Environmental Protection Agency (IEPA), Illinois Department of Natural Resources (IDNR), and Lake County. A preliminary schedule of anticipated closure activities and associated dates is included below.

Closure Activity	**Year**
Preparation of Closure Construction Design Documents	2033
Obtain Permits	2035
Last Receipt of CCR	2035
Begin Dewatering	2035
Removal of CCR	2035-2040
Decontamination of Appurtenant Structures	2035-2040
Completion of Closure	2040

In accordance with §257.102(e), closure activities will commence when one or more of the following conditions has occurred:

- No later than 30 days after the date on which the CCR unit received the known final receipt of CCR or non-CCR waste;
- No later than 30 days after the removal of the known final volume of CCR for the purpose of beneficial use;
- Within two years of the last receipt of waste for a unit that has not received CCR or non-CCR waste; or

- Within two years of the last removal of CCR material for the purposes of beneficial use.

In accordance with §257.102(h), notification of closure of a CCR unit will be made within 30 days of the completion of closure of the CCR unit. The notification will include certification from a qualified professional engineer, as required by §257.102(f)(3).

7. Closure Plan Amendments – §257.102(b)(3)

This Closure Plan will be amended in accordance with §257.102(b)(3) if a change in the operation of the East or West Ash Basins would substantially affect the content of this Closure Plan or if unanticipated events necessitate revision of the plan. If a change in operation requires amendment to the Closure Plan, the plan will be amended no later than 60 days prior to the change in operation being implemented. If an unexpected event occurs that requires amendment of the Closure Plan, the plan will be amended within 60 days of the unexpected event or within 30 days of the unexpected event if the event occurs after closure activities have commenced. Amendments to this Closure Plan will be certified by a professional engineer registered in the State of Illinois in accordance with §257.102(b)(4).

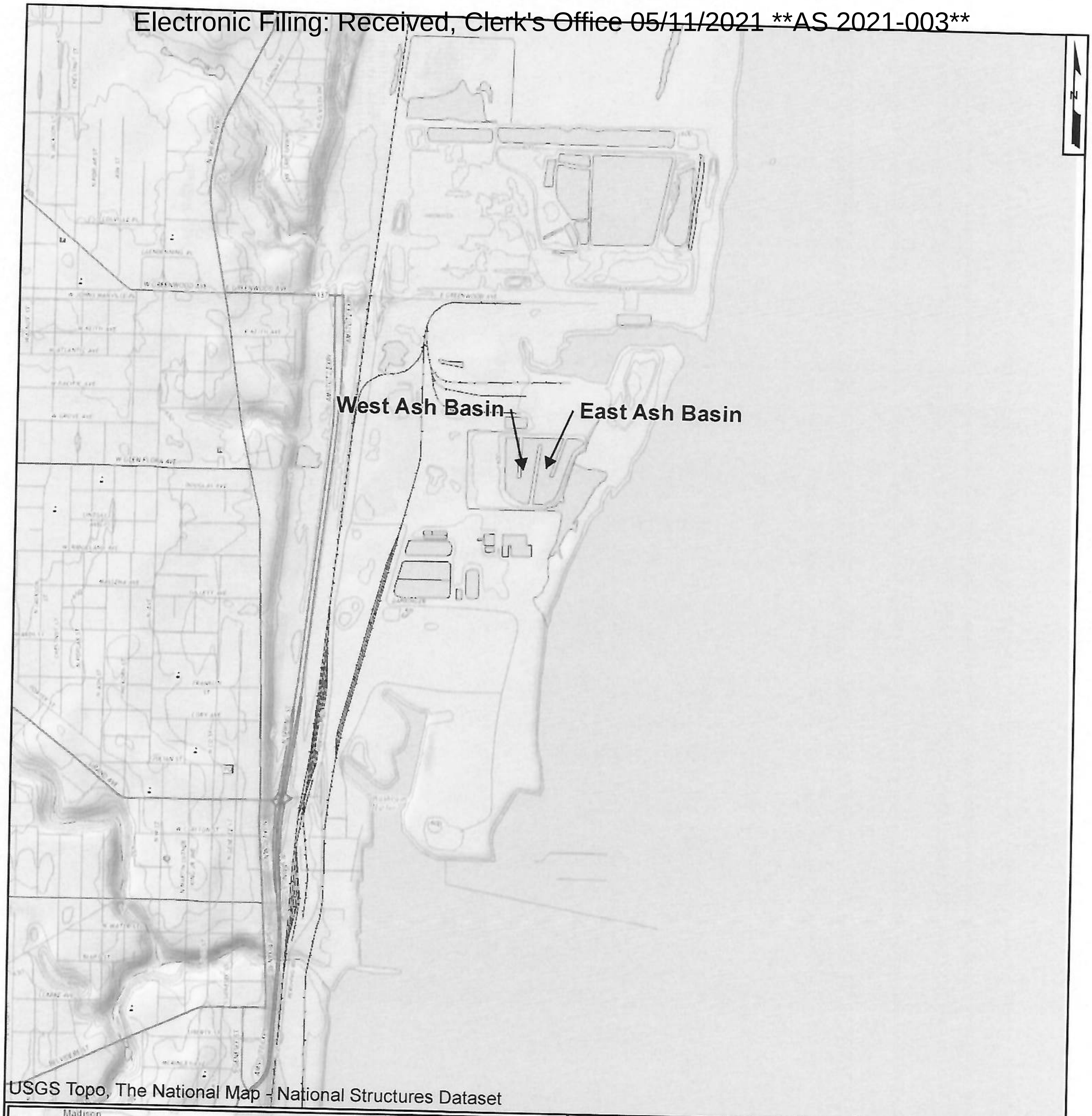
8. Certification – §257.102(b)(4)

This Closure Plan has been prepared to meet the requirements of 40 CFR §257.102(b) and was prepared under the direction of Ms. Jane Soule, P.E.

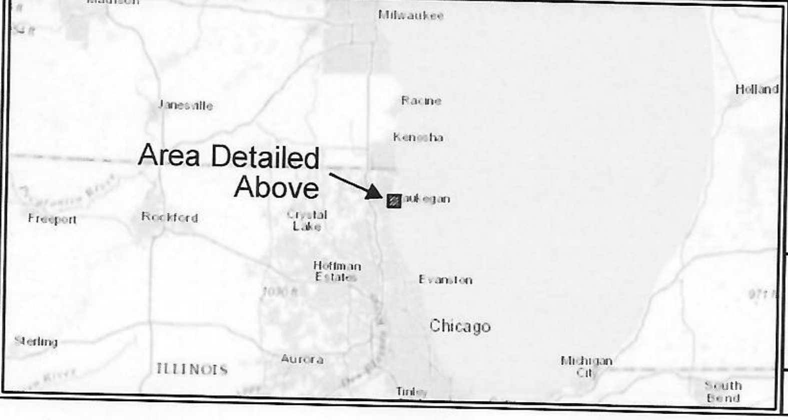
JANE W. SOULE
062-067766

Jane W. Soule

Jane W. Soule, P.E.
Illinois Professional Engineer No. 062-067766
Expiration Date: 11/30/2017



USGS Topo, The National Map - National Structures Dataset



2,000 1,000 0 2,000 Feet

Site Location

East and West Ash Basins
Waukegan Station
Waukegan, Illinois

Geosyntec
consultants

San Diego | October 2016

Figure
1

K:\GIS\WaukeganSiteLocation.mxd JGordon

EXHIBIT 17a

EXHIBIT 17b

EXHIBIT 18

LakeCounty GIS and Mapping

Enter an address Search

Play ☐ 1939 1946 1961 1974 1980 1993 1997 2000 2002 2004 2005 2006 2007 2008 2009 2010

EXHIBIT 19

Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

LakeCounty
GIS and Mapping

Enter an address

Search

Play

1939 1946 1961 1974 1980 1993 1997 2000 2002 2004 2005 2006 2007 2008 2009 2010

EXHIBIT 20

LakeCounty GIS and Mapping

Enter an address

Search

Play

1939 1946 1961 1974 1980 1993 1997 2000 2002 2004 2005 2006 2007 2008 2009 2010

EXHIBIT 21

LakeCounty
GIS and Mapping

Enter an address

Search

Play

1939 1946 1961 1974 1980 1993 1997 2000 2002 2004 2005 2006 2007 2008 2009 2010

Electronic Filing: Received, Clerk's Office 05/11/2021 **AS 2021-003**

LakeCounty
GIS and Mapping

Enter an address Search

Play

1939 1946 1961 1974 1980 1993 1997 2000 2002 2004 2005 2006 2007 2008 2009 2010

EXHIBIT 22

FOR EPA USE: Log # Received Permit Number Date

File Subject

STATE OF ILLINOIS
ENVIRONMENTAL PROTECTION AGENCY
Division of Water Pollution Control
Permit Section
Springfield, Illinois 62706

Richard B. Ogilvie
Governor

William L. Blaser
Director

RECEIVED
DEC 9 [illegible]
ENVIRONMENTAL PROTECTION AGENCY
STATE OF ILLINOIS

3603 72

APPLICATION FOR PERMIT
FOR
TREATMENT WORKS OR WASTEWATER SOURCES

(Read Instruction Booklet Before Completing)

PART II - APPLICATION FOR OPERATING PERMIT

SECTION I - General Information

1. Name of Facility WAUKEGAN GENERATING STATION
2. Owner's Name and Address COMMONWEALTH EDISON COMPANY
Name
P.O. BOX 767 CHICAGO, ILLINOIS 60690
Street City State Zip Code
3. Plant Mailing Address WAUKEGAN STATION, GREENWOOD & LAKE MICHIGAN 60085
Street WAUKEGAN, ILL. City State Zip Code
4. County LAKE
5. Engineer 27144
Name Illinois Registration Number

Firm SARGENT & LUNDY ENGINEERS

Address 140 SOUTH DEARBORN CHICAGO, ILLINOIS 60603
Street City State Zip Code

Telephone 312 FI-6-7600
Area Code Number

Electronic Filing: Received, Clerk's Office

6. Construction permit issued for the construction, additions, modifications, and upgrading of this treatment works or wastewater source. See list page 4.1, Part I

7. List previous operation permits issued for this facility after July 1, 1972.

NONE

8. Date that treatment works or wastewater source started operation, using all facilities currently at plant July 2, 1962 *

9. Name of certified operator in charge of this facility N/A

* This is the service date for the last generating unit installed (Unit #8) and does not apply to the treatment facilities constructed or modified after this date.

SECTION II – Effluent Data N/A

1. Approved Loadings (Design)

   a. Gallons Per Day ______________ GPD

   b. Pounds of BOD Per Day ______________ Lbs BOD/Day

   c. Pounds Suspended Solids Per Day ______________ Lbs SS/Day

   d. Population Equivalent (at .17 lb BOD/P.E. ______________ P.E.

2. Current Loadings N/A

   a. Gallons Per Day ______________ GPD

   b. Influent BOD Concentration ______________ mg/l

   c. Pounds of BOD Per Day ______________ Lbs BOD/Day

   d. Influent Suspended Solids Concentration ______________ mg/l

   e. Pounds Suspended Solids Per Day ______________ Lbs. SS/Day

   f. Population Equivalent (at .17 lb BOD/P.E. ______________ P.E.

3. History of Flows

   (a) N/A

Year	Flow
______________	______________ MGD
______________	______________ MGD
______________	______________ MGD
______________	______________ MGD

   (b) Graph of Flows (Last 12 Months)

4. Excess flows N/A

   a. Number of times which flow was bypassed to excess flow treatment or bypassed raw to the waters of the State for as long as data is available ______________ Times

   b. Length of time that above data covers ______________ Years ______________ Months

c. Average amount of flow bypassed each time N/A Million Gallons

d. Maximum amount of flow bypassed during single bypassing period N/A Million Gallons

5. i) Discharge #1 (main station cooling water discharge)

Chemical Constituents in mg/liter except pH	a	b	c Intake*	d Discharge **
Ammonia Nitrogen (as N)			.11	None Added
Arsenic (Total)		(3)	.04	"
Barium		(2)	.07	"
Boron (Total)		(3)	1.0	"
Cadmium (Total)		(3)	.003	"
Chloride			10	12
Carbon Chloroform Extract		Not	Sampled	***
Chromium (Total Hexavalent)		} TOTAL	.004	None Added
Chromium (Total Trivalent)				
Copper (Total)		(3)	.04	None Added
Cyanide		Not	Sampled	"
Flouride		Not	Sampled	"
Iron (Total)	All iron assumed dissolved		.420	"
Iron (Dissolved)			------------	------------
Lead (Total)		(3)	.026	None Added
Manganese (Total)		(2)	.008	"
Mercury (Total)		(3)	.0003	"
Nickel (Total)		(3)	.02	"
Oil (Hexane Soluables or Equivalent)		Not	Sampled	***
pH	Range		7.8-8.2	7.8-8.2
Phenols		Not	Sampled	None Added
Phosphorous (as P)			.2	.2
Selenium (Total)		(3)	< .03	None Added
Silver		(2)	< .001	"
Sulfate			21.5	24.2
Total Dissolved Solids			175	180
Zinc (Total)			.026	None Added
Dissolved Oxygen		Not	Sampled	No Significant Decrease expected

* Average of forty samples taken during typical operating days. The numbers in the parenthesis to the left of this column indicate the number of samples averaged when forty samples were not available.

** Calculated maximum concentrations. (See page 4 of the attached supplement for the average concentrations and details).

*** May be an incidental trace.

5. ii) Discharge #2 (slag field and settling basin discharge)

	a	b	c	d
Chemical Constituents in mg/liter except pH			Intake*	Discharge **
Ammonia Nitrogen (as N)			.11	.10
Arsenic (Total)		(3)	.04	< .05
Barium		(2)	.07	.21
Boron (Total)		(3)	7.0	4.0
Cadmium (Total)		(3)	.003	.009
Chloride			10	29†
Carbon Chloroform Extract		Not	Sampled	***
Chromium (Total Hexavalent)	}	TOTAL	.004	.008
Chromium (Total Trivalent)				
Copper (Total)		(3)	.061	.022
Cyanide		Not	Sampled	None Added
Flouride			.5	.5
Iron (Total)	Assume all iron dissolved		.420	1.1
Iron (Dissolved)			----------	----------
Lead (Total)		(3)	.02	.03
Manganese (Total)		(2)	.004	.17
Mercury (Total)		(3)	.0003	.0002
Nickel (Total)		(3)	.06	.05
Oil (Hexane Soluables or Equivalent)		Not	Sampled	***
pH (Range)			7.8-8.2	8.3†
Phenols		Not	Sampled	None Added
Phosphorous (as P)			.20	.04 †
Selenium (Total)		(3)	< .03	< .03
Silver		(3)	< .001	< .002
Sulfate			21.5	163 †
Total Dissolved Solids			175	408 †
Zinc (Total)			.026	.058
Dissolved Oxygen			10.9	7.0 (minimum)

* Average of forty samples taken during typical operating days. The numbers in the parenthesis to the left of this column indicate the number of samples averaged when forty samples were not available.

** Maximum of three samples taken during normal operation.

† Maximum of eleven monthly samples taken during normal operation for the period September 1971 through August 1972 (See page 6 of the attached supplement for the average concentrations and details).

*** May be an incidental trace.

SECTION III - Non-contact Cooling Water

1. Source of Water Intake Lake Michigan

2. Discharge Quantities (Average of Last Year)

Discharge #1

	Minimum	Average	Maximum
Flow (MGD)	161.3	1036.8	1036.8
Intake Temperature(°F)*	32	52	72
Discharge Temperature (°F)*	38	61	84

3. Does maximum discharge temperature normally occur at times of maximum discharge flow?
[✓ Yes] No (Circle) If no, explain.

*Intake and discharge temperatures are based on the plant record for December 1971 - November 1972 period. In our engineering judgement the discharge will meet the applicable thermal standards at the edge of the maximum allowable mixing zone, after the completion of the proposed alteration of the discharge structure (See page 2 of the attached supplement for details).

SECTION V - Signature by Engineer

I hereby certify to the best of my knowledge that the information contained in this application is true and correct.

Date 12/22/1972 Signature (Seal)

Certificate by Applicant

I hereby certify to the best of my knowledge that the information submitted is true and correct and the facility for which this permit is applied is being operated in compliance with all Standard and Special Conditions listed on the Construction Permit issued for this facility. I further agree that this Application for Permit shall not constitute a Permit until signed by the Manager of the Permit Section, Division of Water Pollution Control.

Commonwealth Edison Co.

Date 12/22/72 Signature of Applicant
L. F. Lischer

Title Vice President

Approval by Illinois Environmental Protection Agency

Permit Number

Date

This Permit Expires

Manager
Permit Section
Division of Water Pollution Control

Concentrations of Dissolved Iron in the Discharge from Slag Field (Settling Basin) and Station Intake

Waukegan Generating Station
Commonwealth Edison Company

Date	Dissolved Fe (mg/L) Slagfield Discharge	Station Intake
2-2-73	0.16	0.33
2-6-73	[illegible]	0.44
2-9-73	0.16	0.27
2-13-73	0.19	0.45
2-26-73	0.05	0.27
3-15-73	< 0.01	0.02
4-19-73	0.04	0.04
5-12-73	< 0.02	0.05
6-11-73	0.03	< 0.02
7-06-73	0.15	0.18
8-06-73	< 0.02	< 0.02
9-05-73	0.03	< 0.01
10-10-73	0.05	0.03
10-30-73	0.03	0.04
12-3-73	0.08	0.14
12-7-73	0.15	0.26

2020/05/06 15:51

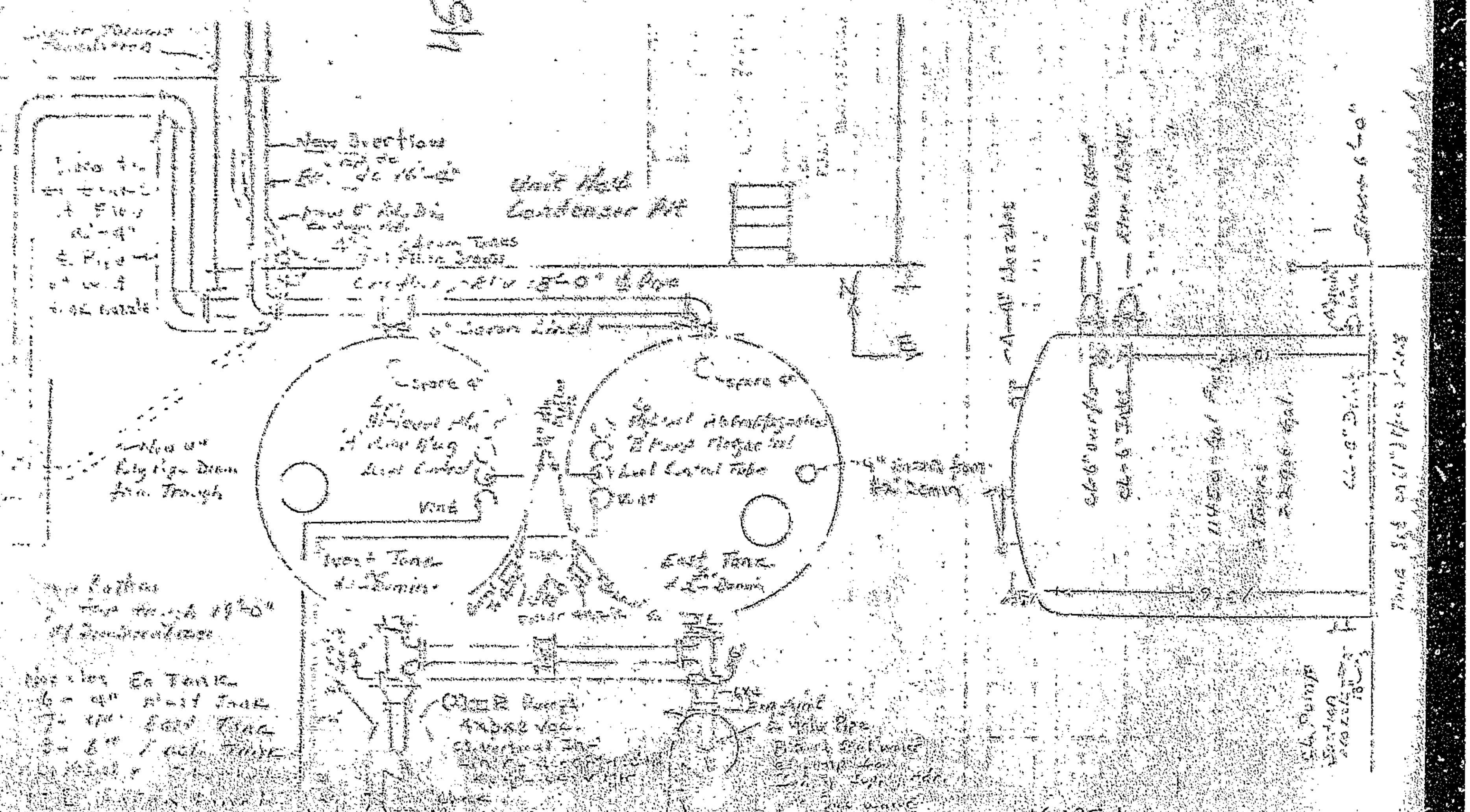
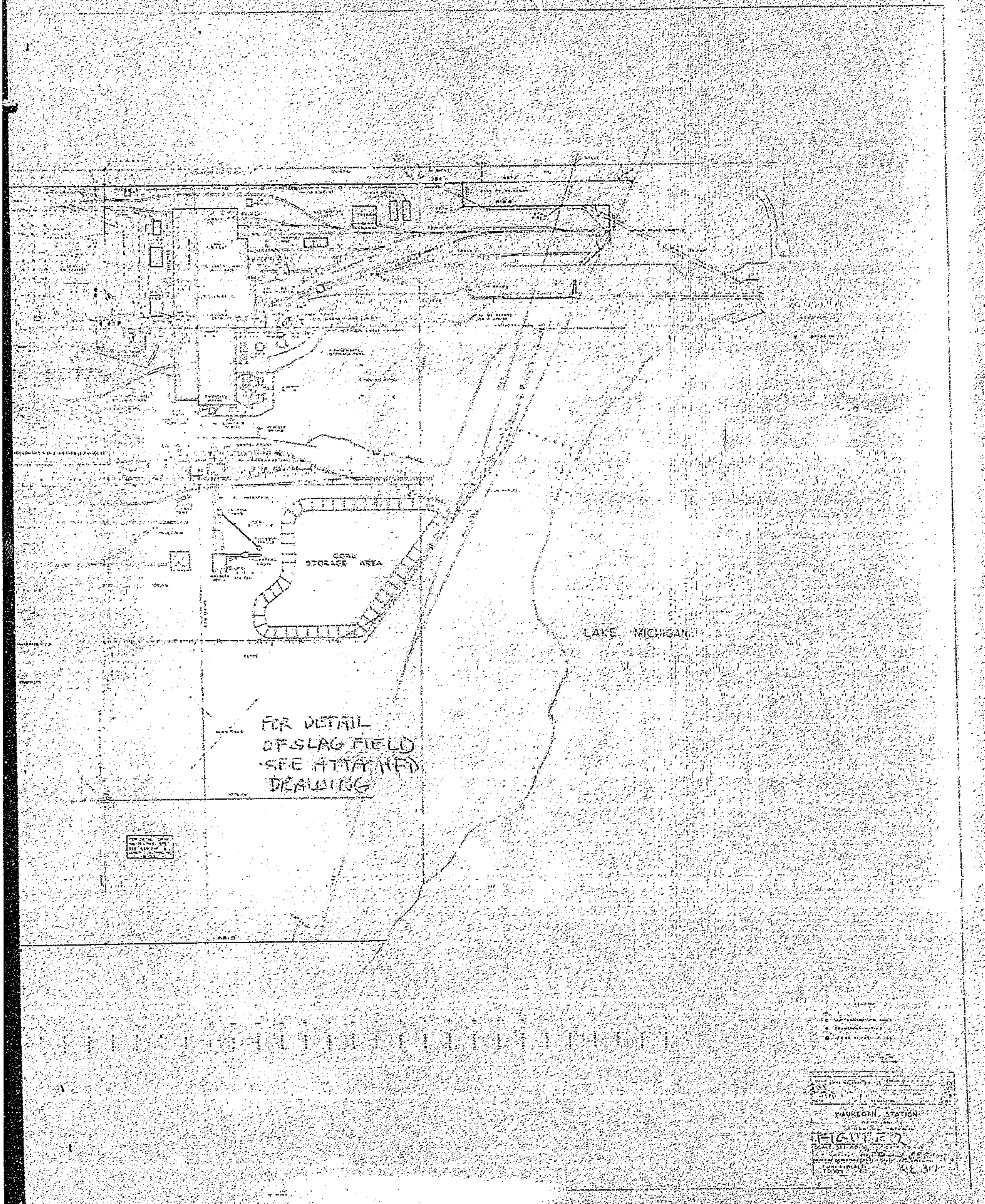
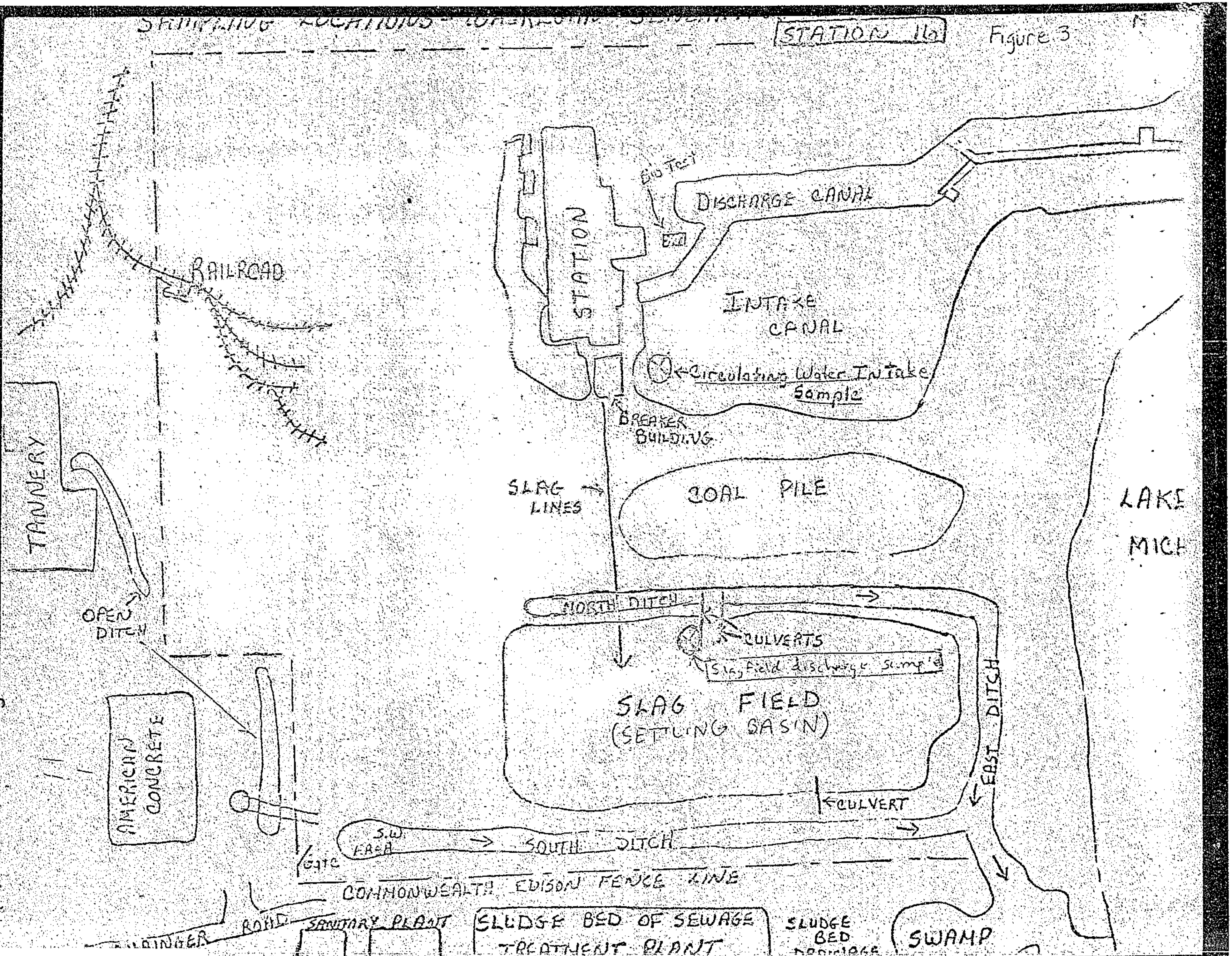


FIGURE 1
DEMINERALIZER WASTE WATER
CONTROL SYSTEM



FOR DETAIL OF SLAG FIELD SEE ATTACHED DRAWING



2020/05/06 15:53

EXHIBIT 23

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
WATER POLLUTION CONTROL PERMIT

PERMIT NUMBER: 1974-EB-346-OP

DATE ISSUED: March 14, 1974

PROJECT LOG NUMBERS: 3603-72, 562-73
4553-73

SUBJECT:
COMMONWEALTH EDISON COMPANY - Waukegan Generating Station
(Lake County) Operating Permit

154106

TO OWN AND OPERATE:
Commonwealth Edison Company
P.O. Box 767
Chicago, Illinois 60690

COPY-COPY-COPY

Permit is hereby granted to the above designated permittee to own and operate water pollution control facilities described as follows: slag field and settling basin which discharge an average of 4770 gpm to an unnamed ditch tributary to Lake Michigan.

The final plans, specifications and supporting documents approved by this permit were prepared by Sargent and Lundy and are identified in the records of the Illinois Environmental Protection Agency, Division of Water Pollution Control, Permit Section, by the log numbers designated in the subject heading above. This permit expires on February 28, 197[illegible].

The Standard Conditions of issuance of this permit are itemized below. Special Conditions applicable are itemized on the attached sheet.

READ ALL CONDITIONS CAREFULLY:

STANDARD CONDITIONS

Pertaining to both construction and operation permits:

1. If any statement or representation is found to be incorrect, this permit may be revoked and the permittee thereupon waives all rights thereunder.

2. During or after the construction or the installation of the sewage works, any agent duly authorized by the Environmental Protection Agency shall have the right to inspect such work and its operation.

3. The issuance of this permit (a) shall not be considered as in any manner affecting the title of the premises upon which the sewage works are to be located; (b) does not release the permittee from any liability for damage to person or property caused by or resulting from the installation, maintenance or operation of the proposed sewage works; (c) does not take into consideration the structural stability of any units or parts of the project; and (d) does not release the permittee from compliance with other applicable statutes of the State of Illinois, or with applicable local laws, regulations or ordinances.

4. Treatment works will be operated or supervised by a duly qualified sewage works operator certified under the Regulations of the Environmental Protection Agency.

5. The treatment works or wastewater source covered by this permit shall be constructed and operated in compliance with the provision of the Environmental Protection Act and Chapter 3 of the Rules and Regulations as adopted by the Illinois Pollution Control Board.

6. Plans, specifications and other documentation submitted shall constitute a part of the application and when approved shall constitute part of the permit.

7. This Permit may not be assigned or transferred without a new permit from the Illinois Environmental Protection Agency.

Pertaining only to construction permits:

1. There shall be no deviations from the approved plans and specifications unless revised plans, specifications, and application shall first have been submitted to the Environmental Protection Agency and a supplemental written permit issued.

2. The installation shall be made under the supervision of an inspector who is familiar with the approved plans and specifications provided by and approved by the owner, and said inspector shall require that construction complies with the plans and specifications approved by this Agency.

3. Unless otherwise stated by Special Condition, construction must be completed in three years for treatment works and two years for sewers and wastewater sources.

4. Unless otherwise stated by Special Condition, the issuance of this permit shall be a joint construction and operation permit provided that:

   a) All standard and Special Conditions are complied with.

   b) This Agency is notified within ten (10) days, respectively, of the start of construction and the date of testing and start-up of full operation.

   c) The submission of operating reports of the treatment works covered under this permit shall be at a frequency specified by this Agency.

   d) The operation permit shall expire one year from the date of start-up of operation.

   e) At least 90 days prior to the expiration date of the operation permit, the permittee shall apply for a renewal of the operation permit.

This permit is issued in accordance with the Illinois Environmental Protection Act of 1970 and the Chapter III Water Pollution Regulations adopted by the Illinois Pollution Control Board in March of 1972.

[illegible]

CC - EPA, Permit Section, Chicago
Lake County Health Department
Sargent and Lundy

DIVISION OF WATER POLLUTION CONTROL

William H. Busch

William H. Busch, P.E.

COMMONWEALTH EDISON COMPANY - Waukegan Generating Station
(Lake County) - Operating Permit
- Log #4553-75
- Permit #1974-EN-346-OP

SPECIAL CONDITION:

This Permit is for the slag field and settling basin discharge only and does not include the cooling water discharge.

5. (Treatment works only)

effluent standard are 4 mg/1 of BOD_5 and 5 mg/1 of suspended solids.

William H. Beach

Commonwealth Edison Co. - Waukegan Generating Station - OP
Log # 4553-73
Louis Kollias Date 2-22-73

Applicant: Commonwealth Edison Company
P.O. Box 767
Chicago, Illinois 60690

Engineer: Sargent and Lundy
140 S. Dearborn St.
Chicago, Illinois 60603

Documents Submitted: 8 Sheets of Plans
Application for Permit
Supplement to Application

Proposed: Discharge of the settling basin (slag field) whi consists of the ash sluice water from the boiler and associated ash handling equipment, the demineralizer regenerative waste water and the demineralizer filter backwash water.

Receiving Stream: Unnamed ditch tributary to Lake Mich

Meets the effluent and water quality standards very easily.

Will issue permit for 3 years.