BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	AS 2021-001
Petition of Midwest Generation	)	
for an Adjusted Standard from 845.740(a)	)	
and Finding of Inapplicability of Part 845	)	(Adjusted Standard)
(Joliet 29 Station)	)	

To: See attached service list.

NOTICE OF ELECTRONIC FILING

PLEASE TAKE NOTICE that I have today filed with the Office of the Clerk of the Pollution Control Board a RECOMMENDATION OF THE ILLINOIS ENVIRONMENTAL PROTECTION AGENCY, a copy of which is herewith served upon you.

Respectfully submitted,

Dated: February 4, 2022

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY,

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THIS FILING IS SUBMITTED ELECTRONICALLY

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RECOMMENDATION OF THE
ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

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(Joliet 29 Station)	)	

To: See attached service list.

RECOMMENDATION OF THE ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

The Illinois Environmental Protection Agency ("Illinois EPA" or "Agency"), by one of its attorneys, hereby files its Recommendation concerning the retention of existing liners in Pond 2 at Midwest Generation LLC's Joliet 29 Station in Joliet, Will County, Illinois, pursuant to Section 28.1 of the Illinois Environmental Protection Act ("Act"). 415 ILCS 5/28.1, 35 Ill. Adm. Code § 104.416. For the reasons stated below, Illinois EPA recommends that the Illinois Pollution Control Board ("Board") DENY Petitioner's request for an adjusted standard from 35 Ill. Adm. Code § 845.740(a). In support of its Recommendation, Illinois EPA states as follows:

I. INTRODUCTION

1. On April 15, 2021, the Board adopted new regulations providing standards for disposal of CCR in surface impoundments at 35 Ill. Adm. Code 845 ("Part 845"). *See* Board Docket R2020-019. The Part 845 rules became effective on April 21, 2021. 45 Ill. Reg. 5884 (May 7, 2021).

2. On May 11, 2021, Midwest Generation, LLC ("MWG") filed a petition for an adjusted standard from 35 Ill. Adm. Code §845.740(a) and a finding of inapplicability of Part 845 for certain impoundments located at its Joliet 29 Station ("Petition"), in which it requests a hearing on its petition.

3. The Petition concerns three surface impoundments, which Petitioner designates as Pond 1, Pond 2, and Pond 3.

4. Specifically, Petitioner is seeking the following adjusted standards from the requirements contained in Part 845:

a. Pond 2: MWG seeks an adjusted standard to allow the decontamination and retention of the existing liner rather than the liner's removal as required for closure by removal in Section 845.740(a).

b. Pond 1 and Pond 3: MWG asserts that Pond 1 and Pond 3 do not satisfy the regulatory definition of a coal combustion residuals ("CCR") surface impoundment and seeks an adjusted standard finding that Part 845 of the Board's regulations is inapplicable.

5. Illinois EPA must make a recommendation to the Board as to the disposition of the Petition within 45 days after the filing of the petition or at least 30 days before a hearing, unless otherwise ordered by the hearing officer or Board. 35 Ill. Adm. Code §104.416. Pursuant to Motions for Extension of Time, the Board ordered that the Agency file its Recommendation by August 22, 2021.

6. On August 22, 2021, Illinois EPA filed with the Board its Recommendation as to Petitioner's request for a finding of inapplicability of Part 845 to Pond 1 and Pond 3. Pursuant to Motions for Extension of Time, the Board has ordered the Agency file its Recommendation addressing Petitioner's request for an adjusted standard from Section 845.740(a) by February 4, 2022.

7. This Recommendation addresses MWG's petition for adjusted standard from Section 845.740(a) for Pond 2.

II. NOTICE AND ACCEPTANCE

8. A petitioner must "submit to the Board proof that, within 14 days after filing of the petition, it has published notice of the filing of the petition by advertisement in a newspaper of general circulation in the area likely to be affected by the petitioner's activity that is the subject of the adjusted standard proceeding." 415 ILCS 5/28.1; 35 Ill. Adm. Code § 104.408(a).

9. On June 2, 2021, MWG filed with the Board a certification of publication and a copy of the notice published on May 17, 2021, pursuant to 35 Ill. Adm. Code §§ 104.408(a), (b).

10. On June 3, 2021, the Board accepted MWG's petition for adjusted standard.

III. RECOMMENDATION REQUIREMENTS AND ANALYSIS OF REQUEST FOR ADJUSTED STANDARD

11. Illinois EPA's Recommendation must set forth the rationale for the Agency's position and may present any information which the Agency believes is relevant to the Board's consideration of the proposed adjusted standard. 35 Ill. Adm. Code § 104.416(a). At a minimum, the Agency must address and respond to the petition with respect to each issue raised by the requirements of Section 104.406(a) through (j). 35 Ill. Adm. Code § 104.416(b).

12. Illinois EPA hereby provides its analysis of MWG's request for an adjusted standard from Section 845.740(a) for Pond 2 at MWG's Joliet 29 Station in Joliet, Will County, Illinois:

a. **Standard from which the Adjusted Standard is Sought.**

Petitioner must include "[a] statement describing the standard from which an adjusted standard is sought. This must include the Illinois Administrative Code citation to the regulation of general applicability imposing the standard as well as the effective date of that regulation[.]" 35 Ill. Adm. Code § 104.406(a). MWG requests an adjusted standard from 35 Ill. Adm. Code § 845.740(a), which became effective on April 21, 2021, along with the rest of Part 845.

b. **Whether the regulation of general applicability was promulgated to implement, in whole or in part, the requirements of the CWA, Safe Drinking Water Act, Comprehensive Environmental Response, Compensation and Liability Act, CAA, or the State programs concerning RCRA, UIC, or NPDES.**

Petitioner must include "[a] statement that indicates whether the regulation of general applicability was promulgated to implement, in whole or in part, the requirements of the CWA (33 USC 1251 et seq.), Safe Drinking Water Act (42 USC 300(f) et seq.), Comprehensive Environmental Response, Compensation and Liability Act (42 USC 9601 et seq.), CAA (42 USC 7401 et seq.), or the State programs concerning RCRA, UIC, or NPDES (see 415 ILCS 5/28.1)[.]" 35 Ill. Adm. Code § 104.406(b). Illinois EPA does not take issue with Petitioner's comments on this topic. *See* Pet. at 16.

c. **The level of justification as well as other information or requirements necessary for an adjusted standard.**

Petitioner must include "[t]he level of justification as well as other information or requirements necessary for an adjusted standard as specified by the regulation of general applicability or a statement that the regulation of general applicability does not specify a level of justification or other requirements (see 415 ILCS 5/28.1 and Section 104.426 of this Part)[.]" 35 Ill. Adm. Code § 104.406(c). Illinois EPA agrees with Petitioner that since Part 845 does not specify a level of justification for an adjusted standard, the applicable level of justification are the factors identified in Section 28.1(c) of the Act, 415 ILCS 5/28.1(c) (2020). The Recommendation will address these factors in Paragraph 12(h) below.

d. **The nature of the petitioner's activity that is the subject of the proposed adjusted standard.**

Petitioner must include "[a] description of the nature of the petitioner's activity that is the subject of the proposed adjusted standard. The description must include the location of, and area affected by, the petitioner's activity. This description must also include the number of persons

employed by the petitioner's facility at issue, age of that facility, relevant pollution control equipment already in use, and the qualitative and quantitative description of the nature of emissions, discharges or releases currently generated by the petitioner's activity[.]" 35 Ill. Adm. Code § 104.406(d).

Petitioner states that all the CCR surface impoundments at the Joliet 29 Station were "built in 1978 with a poz-o-pac liner." Pet at. 6. MWG relined Pond 2 in 2008. According to Petitioner, from bottom to top, the Pond 2 liner system constructed in 2008 consists of: "the original poz-o-pac, a geotextile cushion, the HDPE liner, a geotextile cushion, a 12-inch thick sand cushion layer, and a six-inch limestone warning layer." *Id.* at 8, Pet. Ex. 10.

Illinois EPA has reviewed Pond 2's construction permit record, History of Construction, geotechnical data, aerial photographs, groundwater data, and other available documents. The Agency has not been able to locate a permit for the initial construction of Pond 2, but a review of aerial photographs confirms that the current location of Pond 2 was not present until it was initially constructed in 1978/1979. Ex. A and Ex. B. Upon review of the available materials, Illinois EPA maintains that (1) the "poz-o-pac" as placed and retained by MWG is a CCR material and potential source of groundwater contamination, and (2) Petitioner knowingly used CCR material, including coal ash (or "black silty gravel") as structural fill or foundational backfill in the 2008 construction of Pond 2's current HDPE liner system without meeting the Act's coal combustion byproduct ("CCB") requirements for beneficial reuse and, as such, it remains a coal combustion waste ("CCW") and a potential source of groundwater contamination. 415 ILCS 5/3.135.

i. <u>MWG's poz-o-pac is CCR material.</u>

According to the Federal Highway Administration ("FHWA"), pozzolan-stabilized base ("PSB"), or a poz-o-pac material/basic lime-fly ash-aggregate formulation, have been used to

provide stabilized base and subbase mixtures since the 1950's. Ex. C.[1] The History of Construction provides the following documented facts about MWG's poz-o-pac formulation during Pond 2's original 1978/1979 construction:

- The poz-o-pac consisted of 3% hydrated lime, 20% fly ash, and 77% boiler slag aggregate with density of 136.9 lbs. per cubic foot.
- The poz-o-pac was sealed with a bituminous seal coat. Curing of the bituminous seal coat was specified to include one week.

Ex. D, attach. 3, app. A-2.[2] CCR is defined as "fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated from burning coal for the purpose of generating electricity...." 415 ILCS 5/3.142; 35 Ill. Adm. Code § 845.120.[3] MWG's poz-o-pac formulation is primarily (97%) comprised of fly ash[4] and bottom ash and is therefore a CCR material. *See* Ex. D, attach. 3 and Ex. A.

ii. MWG retained Pond 2's poz-o-pac during the 2008 construction of the HDPE liner.

Illinois EPA issued state construction Permit 2007-EB-4091 on July 20, 2007. Pet. Ex. 13. This permit authorized the replacement of the poz-o-pac liners at Pond 1 and Pond 2 with a 60-mil high density polyethylene ("HDPE") geomembrane and a twelve-inch sand and limestone screenings warning layer. Ex. B. Appendix A-3 of the History of Construction for Pond 2 indicates ramp material from within the original CCR surface impoundment constructed in 1978/1979 was

[1]Coal Fly Ash User Guideline for Stabilized Base from "User Guidelines for Waste and Byproduct Materials in Pavement Construction," FHWA Publication No. FHWA-RD-97-148, can be found at https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/97148/020.cfm, last modified March 8, 2016. Illinois EPA has printed this portion of the publication from the FHWA website and provided it as Exhibit C.

[2] Drawing No. 5079C5019, Sheet 2 of 3, Rev. 2

[3] "Coal combustion waste" (or CCW) is similarly defined as "fly ash, bottom ash, slag or flue gas or fluid bed boiler desulfurization by-products generated as a result of the combustion of . . . coal, or . . . coal in combination with [other material].415 ILCS 5/3.140.

[4] Fly ash is often used as a component of stabilized base and subbase materials. Both bituminous (pozzolanic) or subbituminous or lignite (self-cementing) fly ashes can be used, but the Agency cannot find any statement of what kind of fly ash was used in MWG's poz-o-pac formulation. Ex. C at 1 and Ex. A.

placed under the HDPE liner as it lies along and under the ramp designed for access into the CCR surface impoundment. Ex. D, Attach. 3. Appendix A-3 also shows that the poz-o-pac was to be removed. *Id.* However, according to a December 2, 2021 MWG Letter to Illinois EPA, and its attachments, the ramp material was not excavated and the ramp and original poz-o-pac were retained during the 2008 construction.[5] Ex. D at 2.

Due to the poz-o-pac's nature and use conditions, it has likely been compromised by way of cracking or otherwise breaking down, resulting in material becoming unconsolidated or pulverized in certain areas. PSB is known to crack substantially over time and was likely compromised due to wear and tear during its original use, or during the construction and use currently with a HDPE liner installed. Ex. C at 8-9 and Ex. A.; *see also See Sierra Club, et. al v. Midwest Gen., LLC,* PCB No. 13-15, Interim Opinion and Order of the Board (June 20, 2019) ("Interim Board Order") at 26. The FHWA publication points out that crack control of PSBs is a continuing issue and that driving vehicles, addition of hydration, and freeze thaw activity over the PSB will cause cracks and breakdown of the PSB mixture. Ex. C at 8-9. The evidence of likely breakdown is the presence of the fine to coarse grained fill material used to smooth out the poz-o-pac creating flat, smooth subgrade on the bottom of the impoundment below the liner. Ex. A citing Ex. G, attach. 11. In *Sierra Club,* "after a careful review of the facts,"[6] the Board found that "both poz-o-pac and HDPE liners at Joliet 29 can and do crack or become damaged on occasions." Interim Board Order at 26. Unconsolidated or pulverized poz-o-pac material at Joliet 29 may leach because it is CCR material that is unlikely to have been rendered inert. Ex. A. Leaching occurs

[5] Since documents are not clear and sometimes appear to conflict, Illinois EPA is not confident regarding the quantity of poz-o-pac or other CCR materials left in place and/or reutilized during the 2008 construction. However, data provided by MWG suggests that the poz-o-pac was left in place on the bottom of Pond 2 but removed on the side slopes, along with up to three feet of material, and replaced and graded with onsite materials. Ex. A.

[6] Relevant facts included the investigation conducted by MWG's consultant, NRT, which rated the condition of the poz-o-pac liners as "poor" with "high potential for contamination" in 2005 and 2006. Interim Board Order at 25.

from the surface area of a material containing heavy metals. The more surface area exposures that occur because of cracking, the greater the leaching potential of the material. *Id*.

iii. The "black silty gravel" utilized as structural fill or foundational backfill is CCR.

The Joliet 29 History of Construction provides details on the engineering properties and construction plans for Pond 2. Ex. D, attach. 3. The engineering properties summarized show Pond 2's foundation is comprised of sand/gravel with a unit weight of 125 pounds per cubic foot ("pcf"). Ex. D, attach. 3, tbl. 2 at 3. The embankment properties are brown clay with a unit weight of 115 pcf and black silty gravel with a unit weight of 125 pcf. Ex. D, attach. 3, tbl. 3 at 5. According to the FHWA, dark gray to black soils represent organic material. Ex. F at 4-10. Organic materials do not make good structural base materials because of the potential for settlement. Ex. A. Additionally, gravels are typically derived from local sources which do not include black rock. Local quarried rock is Silurian Dolomite and Devonian Dolomite, which is typically white, tan or light gray in color. The Agency is not aware of any quarries or borrow sources within a reasonable distance to support economically shipping black inorganic source material from a natural source. Therefore, the black silty gravel is likely fly ash mixed with some crushed poz-o-pac or locally sourced limestone or dolomite gravel, or some combination of the two. Ex. A.

According to the 2005 Geotechnical Summary Letter, boring logs for Joliet 29 had some "minor amounts of ash/slag" at "some locations in the upper foot of material." Ex. E at 5. In response to Illinois EPA's inquiry into Pond 2's embankment construction, MWG provided a letter dated December 9, 2021 from its contractor, Sargent and Lundy. Ex. G. The letter acknowledges the presence of brown clay and black silty gravel material in multiple borings but does not provide any local source of geotechnically suitable black material that is not CCR. Ex. G at 3-4. The letter simply states that Pond 2's embankments "consist of a brown clay, black/gray silt and clay, and

brown/tan sand and gravel materials" and that these materials are a "combination of earthen materials obtained from on-site or off-site borrow sources." Neither the letter nor any other available documents provide any evidence of testing for organic content. Ex. A.

Attached to the December 9, 2021 letter is a picture of the 2008 construction shows the subgrade prepared and the geotextile and geomembrane being placed. Ex. G, attach. 11. The side slope of the impoundment subgrade is compacted black to dark brown silty gravel and the bottom is poz-o-pac smoothed over with fine to coarse grained material—potentially the aforementioned black silty gravel or unconsolidated poz-o-pac. Ex. G, attach. 11 and Ex. A. The black silty gravel, described in the History of Construction and shown in the picture of the construction of Pond 2's HDPE liner, likely contains fly ash and/or bottom ash to which MWG has not provided evidence to the contrary. Ex. A citing Ex. D, attach. 3 at 5 and Ex. G.

For the reasons provided above, Illinois EPA maintains that the poz-o-pac and black silty gravel material are CCR or CCR combined with other materials and are therefore a potential source of contamination in the groundwater.

iv. <u>MWG utilized CCR material that does not meet the definition of CCB as structural fill or foundational backfill during the 2008 construction of the HDPE liner.</u>

CCW is defined as "any fly ash, bottom ash, slag, or flue gas or fluid bed boiler desulfurization by-products generated as a result of the combustion of...coal...." Under the Act, CCW is considered CCB and not waste if it meets the beneficial use requirements of Section 3.135. 415 ILCS 5/3.135. To be used beneficially for structural fill, foundation backfill, antiskid material, soil stabilization, pavement, or mine subsidence, CCW (A) cannot be mixed with hazardous waste prior to use and (B) must be tested utilizing test method ASTM D3987-85 and cannot exceed Class

1 groundwater quality standards ("GWQS"). 415 ILCS 5/3.135(a-5)(A), (B).[7] It also must be "in an engineered application or combined with cement, sand, or water to produce a controlled strength fill material and covered with 12 inches of soil unless infiltration is prevented by the material itself or other cover material." 415 ILCS 5/3.135(a)(8).[8] Under Part 845, "beneficial use of CCR" means CCR that meets the definition of "coal combustion by-product" in Section 3.135 of the Act[9] and the definition of "beneficial use of CCR" in 40 CFR § 257.53,[10] incorporated by reference in Section 845.150. 35 Ill. Adm. Code § 845.120.

Available documents indicate that, as part of Pond 2's HDPE liner construction in 2008, MWG removed between one to three feet of the black silty gravel material and/or poz-o-pac along the internal side slopes of the embankment and then reused the black silty gravel material to rebuild the side slopes of the embankments. *See* Ex. D, attach. 3, app. A-3, sheet no. C020;[11] Ex. G, attach. 11; and Ex. A. For the CCR materials to meet the definition of CCB for beneficial reuse, MWG would have had to, at a minimum, test the material utilizing test method ASTM D3987-85, or the "shake test." Based on the 2005 Geotechnical Report and History of Construction, MWG had knowledge of the nature of the CCR material being reused prior to construction and knowingly

[7] In 2002, Public Act 92-0574 replaced former Section 3.94 of the Act with Section 3.135. The requirements of Section 3.135(a-5) are the same now as they were at the time of the 2008 construction.
[8] This requirement in Section 3.135(a)(8) is the same now as it was at the time of the 2008 construction. However, Section 3.135(a)(8) of the Act now also requires CCB to be designed and constructed "according to ASTM standard E2277-03" or "Illinois Department of Transportation specifications," which was not required at the time of the 2008 construction. 415 ILCS 5/3.135 (2020); *see* Public Act 97-510 (Aug. 23, 2011).
[9] Section 3.135 has also included varying notification requirements since 2002. Bureau of Land and Bureau of Water staff have completed a review of Agency records and were unable to locate any notifications made pursuant to Section 3.135 regarding the beneficial use or reuse of CCR materials at the Joliet 29 Station. Ex. A, B and H.
[10] Under Part 257, "*[b]eneficial use of CCR* means the CCR meet all of the following conditions . . . (3) The use of CCR must meet relevant product specifications, regulatory standards or design standards when available....".
[11] Attachment 6 to Exhibit G removes the topographic contours from the Pond 2 embankments that are shown in Appendix A-3 (Sheet C020) of the History of Construction, which illustrate the change in shape and grade during the construction. The geometry of the bottom of Pond 2 and the top of the embankment side slope did not change between the two documents. Ex. A.

reutilized the CCR materials for geotechnical applications, seemingly without testing for environmental suitability. *See* Ex. D, attach. 3, app. A-2 and A-3; Ex. E, attach. 4; and Ex. A.

Review of available documents does not indicate any shake test has been performed. Ex. A. None of the contractor notes on the drawings in the History of Construction (Ex. D, attach. 3) or the Construction Documentation Transmittal for Pond 1 and Pond 2 (Pet. Ex. 15) provide any evidence of any testing of subgrade materials for metals contamination. The documents focus on geotechnical and construction related quality control and do not account for or provide any details related to testing per ASTM D3987-85, which is a requirement of the Act for beneficial use of CCR that pertains to the environmental suitability of construction materials.[12] Ex. A. Without compliance with the CCB beneficial use requirements, the CCR materials utilized as structural fill or foundational backfill beneath the HDPE liner of Pond 2 remain "coal combustion waste" pursuant to the Act. *See, e.g., Sierra Club,* Interim Board Order at 89.

Petitioner asserts that Pond 2 and its HDPE liner can be fully decontaminated from CCR material without removal of the liner and its subsoils as required by Section 845.740(a). Illinois EPA's review of available information as provided above indicates that retention of the liner would necessarily include retention of CCR material as part of the CCR surface impoundment's containment structure components and contaminated subsoils. Without demonstration that the CCR material qualifies as CCB or has otherwise been tested for its leaching potential and environmental suitability, it remains a potential source of contamination and should be subject to the decontamination requirements of a closure by removal action. 35 Ill. Adm Code § 845.740(a), (e). For this reason, *inter alia,* Illinois EPA recommends that the Board deny Petitioner's request

[12] In *Sierra Club*, the Board found that CCR utilized as fill at four of MWG's facilities, including Joliet 29, had not been tested for compliance with the CCB beneficial use requirements and had not been demonstrated as compliant with IDOT specifications or ASTM standards as required by the Act. Interim Board Order at 89.

for adjusted standard from Section 845.740(a). Illinois EPA will address Petitioner's representations surrounding the available groundwater data and potential releases from Pond 2 in Paragraph 12(f) below.

e. **Efforts that would be necessary if the petitioner was to comply with the regulation of general applicability.**

Petitioner must include "[a] description of the efforts that would be necessary if the petitioner was to comply with the regulation of general applicability. All compliance alternatives, with the corresponding costs for each alternative, must be discussed. The discussion of costs must include the overall capital costs as well as the annualized capital and operating costs[.]" 35 Ill. Adm. Code §104.406(e).

Petitioner seeks adjusted standard from Section 845.740(a), which provides:

> Closure by Removal of CCR. An owner or operator may elect to close a CCR surface impoundment by removing all CCR 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 surface impoundment structures and ancillary equipment have been removed. Closure by removal must be completed before the completion of a groundwater corrective action under Subpart F.

To comply with the regulation of general applicability governing closure by removal, Petitioner would need to not only remove the HDPE liner, but also containment system components, including but not limited to contaminated subsoils. Following the completion of CCR removal and decontamination of the CCR surface impoundment under Section 845.740(a), Petitioner would need to submit to the Agency a completion of CCR removal and decontamination report and a certification from a qualified professional engineer that CCR removal and decontamination of the CCR surface impoundment has been completed, both of which are subject to Agency approval. 35 Ill. Adm. Code §§ 845.740(e) and 845.760(f).

Petitioner states that requiring compliance with the closure by removal requirements, including excavation of the HDPE liner, the poz-o-pac beneath, and "approximately six inches of soil below the liner" will cost $1,117,291. Additionally, replacement of the HDPE liner will cost approximately $160,772. Pet. at 16-17. Petitioner's estimate of removing "six inches of soil below the liner" is based on the assumption that only CCR released from inside the basin during the demolition and removal of the liner will be a source of contaminated subsoils, but does not account for further measures that will likely need to be taken to get the certification of decontamination under Section 845.740(e).

Petitioner's discussion of costs does not address the existence of CCR materials underneath the liner relevant to a closure by removal action under Part 845, or measures to remove or close with a final cover pursuant to Part 845 so as to include CCR material underlying the liner or in the embankments. Furthermore, Petitioner does not provide evidence that one or more of the embankments or the foundational backfill surrounding and underlying Pond 2 are not leaching metals into the groundwater. Illinois EPA maintains that a closure by removal action must require removal of all contaminated subsoils, and a final cover system would have to encapsulate the CCR materials placed under the liner or in the embankments of Pond 2, neither of which are accounted for in Petitioner's discussion of costs.

f. **Proposed Adjusted Standard and efforts necessary to achieve the Proposed Standard.**

Petitioner must include "[a] narrative description of the proposed adjusted standard as well as proposed language for a Board order that would impose the standard. Efforts necessary to achieve this proposed standard and the corresponding costs must also be presented[.]" 35 Ill. Adm. Code § 104.406(f). Petitioner proposes the following language for its requested adjusted standard:

> "MWG may close by removing and decontaminating all areas affected by releases from Pond 2 at the Joliet 29 Station. CCR removal and decontamination of the Pond 2 is complete when the CCR in Pond 2 and any areas affected by releases from the CCR surface impoundment have been removed. MWG must conduct visual inspection and analytical testing to demonstrate that the geomembrane liner in Pond 2 is not contaminated with CCR constituents. MWG must submit the results to Illinois EPA."

Pet at 19. Petitioner equates its proposed adjusted standard language to the language Illinois EPA originally proposed to the Board for closure by removal. *Id.* In support, Petitioner provides statements from its expert witness, Mr. Neilson, and the Board's opinion in the R20-19 regarding liner reuse for retrofit of a CCR surface impoundment. *Id.* However, Petitioner uses its expert's statements and the Board's opinion out of context while not fully considering the differences between the closure by removal standard initially proposed by the Agency and the closure by removal standard ultimately adopted by the Board in Section 845.740.

Proposed Section 845.740(a) required the following:

> Closure by removal of CCR. An owner or operator may elect to close a CCR surface impoundment 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.

Petitioner emphasizes removal of CCR and decontaminating the liner but does not address "…all areas affected by releases from the CCR surface impoundment." Contaminated groundwater is one such area where decontamination would have to be completed before closure is considered complete under Section 845.740(a) as originally proposed, current 40 CFR § 257.102(c), and as Petitioner has proposed its adjusted standard. 40 CFR § 257.102(c) makes it clear that closure is not complete unless the GWPS for Appendix IV constituents has been achieved. However, Part 257 does not assess fees for CCR surface impoundments. Therefore, delaying completion of closure until groundwater corrective actions are complete under Part 257 does not have the

economic disadvantage created by the fee system of Section 22.59(j) of the Act. 415 ILCS 5.22.58(j). To incentivize closure by removal yet remain as comprehensive and protective as Part 257, in its final comments, the Agency proposed, and the Board adopted, a closure by removal performance standard that separates a thorough and complete removal of the CCR surface impoundment's containment components and contaminated subsoils from the groundwater corrective action process that is required whenever the GWPS have been exceeded.

As adopted, Section 845.740(a) explicitly requires removal of the complete liner system, including the geomembrane and any structures or containment components, such as the poz-o-pac and other reused CCR materials for fill revealed by the Agency's geotechnical evaluation of Pond 2. Petitioner quotes the Board's statement in its Second Notice Order and Opinion that there is "no reason for requiring removal of these liners if they can be used as a supplement to the liner system required by this Part." Pet. at 21, citing R20-19 Feb 4, 2021 Board Order at 99. However, the Board's Opinion on the topic of liner decontamination and re-use during retrofit only discusses the decontamination of a synthetic liner, and does not address the additional requirement in Section 845.770(a)(1) to remove contaminated soils and sediments or the situation in which CCR has been used as structural and foundational fill of a CCR surface impoundment that is being closed.

Further, even if CCR is used as part of the structure of a CCR surface impoundment in a manner that qualifies it as CCB, retrofit occurs where a composite liner compliant with Part 845 is going to be installed over the top of the existing system. The installation of the composite liner creates a barrier over the existing synthetic liner and prevents any material underneath the pre-existing liner from being exposed to the contents of an impoundment.[13] Ex. A. A new composite

[13] Even if the CCR material used as structural fill or foundational backfill passes the "shake test" by demonstrating that the leaching potential of the material will not exceed Section 620.410, it is possible that the material could still cause exceedances of Section 845.600 GWPS for several parameters. Ex. A.

liner installed during a retrofit of Pond 2 that retained the HDPE liner system would isolate the surface water within the impoundment from the CCR materials used to construct the impoundment and the groundwater. Ex. A.

The composite liner installed during retrofit also prevents infiltration through damage or perforations in the existing liner from stress due to placement over a soil containing gravel. HDPE liners that overlie soils with gravel are likely to sustain perforations due to overburden stress. Ex. I and Ex. A. While a geotextile cushion was installed beneath the HDPE liner, there are other factors that may cause damage to the liner. In addition to overburden stress, liners installed in impoundments that are exposed to sunlight and weather conditions suffer degradation that buried HDPE liners do not. The exposure to the elements can also deteriorate and/or cause wear and tear on the liner that would not otherwise occur Ex. J[14] and Ex. A. According to MWG's inspection records for Joliet 29 Pond 2, the HDPE liner is exposed to the elements, as Pond 2 remains with zero to four feet of water in it. Ex. K at 4 and Ex. L.

Water from inside the impoundment that leaks through a damaged HDPE liner (whether it is operated as a CCR surface impoundment or another wastewater system), as well as stormwater from outside the liner, traverses through the CCR materials placed underneath the liner and in the embankments of Pond 2. The nature of the black silty gravel and broken poz-o-pac that has been reported to be left in place at Pond 2 has a higher hydraulic conductivity than the clay materials surrounding it. Ex. A. Thus, the CCR materials have primary or secondary permeability or

[14] "How Long Will My Liner Last? What is the Remaining Service Life of my HDPE Geomembrane?" by Ian D. Peggs, P.E, P.Eng., Ph.D. (October, 2008), is an Industrial Fabrics Association International (IFAI) Publication in Geosynthetics Magazine, and can be found at https://geosyntheticsmagazine.com/2008/10/01/how-long-will-my-liner-last/#. Illinois EPA has printed the publication from the FHWA website and provided it as Exhibit J for ease of reference.

hydraulic conductivities that constitute a primary flow path over the lower hydraulic conductivity clay. Ex. A.

Mr. Neilson recommends that visual inspections and wipe samples be performed to ensure decontamination is complete. Pet. at 20. While these tests may confirm that a synthetic liner is decontaminated, they don't necessarily ensure that the first requirement of Section 845.770(a)(4) for reuse of a synthetic liner during retrofit is met, which is that the synthetic liner is competent. Competence means the seals between sheets of the liner have not parted or otherwise become separated, the liner has not been damaged by the gravel underlying or overlying the liner, and exposure to the elements has not broken down the liner or the seals. *See* Ex. I, J and A. Visual inspections do not provide adequate verification of competence where the synthetic liner is the only barrier between the water within the impoundment and contaminated subsoils and groundwater. Ex. A. The liner must first be proven to be competent in accordance with Section 845.770(a)(4) before qualifying as a liner that may be proven sufficiently decontaminated for retrofit pursuant to that same Section.

The issue with keeping the liner in place and providing an adjusted standard for removal of contaminated subsoils is not only the extent to which a liner may leak, but also stormwater infiltrating through the embankments containing potential contaminants that can be leached and/or washed by gravity flow into the groundwater below. When compared to Section 620.410 groundwater quality standards ("GWQS") and Section 845.600 groundwater protection standards ("GWPS"), chloride sample results consistently exceed at downgradient and "upgradient" wells during the same quarterly sampling events in which rainfall has occurred or is occurring during sampling. Pet. Ex. 18, tbl. 4. Illinois EPA and MWG agreed in 2012 that the exceedances of Section 620.410 GWQS were likely due to road salts. Ex. M at 4. However, these exceedances

signify that storm water infiltration and recharge is occurring through the immediate vicinity of Pond 2, including the embankments. In other words, chlorides, which are presumably present in road salts applied on US Highway 6 and thus in the top-soils on the north side of the impoundment and extending into the US Highway Right-Of-Way storm water drainage system, are exhibiting that recharge is occurring at the site through the surface into the immediate groundwater through a material with a high hydraulic conductivity providing a rapid infiltration rate on the order of less than a week.[15] Storm water recharge through the shallow subsurface materials within the embankments and the permeability exhibited by the chloride transport demonstrate the potential for leaching of metals from the CCR materials placed under the liner at Pond 2. Ex A.

Petitioner states that "groundwater monitoring has not demonstrated that Pond 2 is a source of contamination to the groundwater." Pet at 9, citing Pet. Ex. 18. Cobalt is cited as a metal of primary interest in the USEPA Framework for Metals Risk Assessment and is recognized as possibly posing a toxic hazard to human health and ecosystems. Ex. N at 1-3. Illinois EPA has reviewed groundwater monitoring data available on Petitioner's Part 845 publicly available website. Ex. A. Currently, Section 845.600 contains the USEPA health-based value of 0.006 mg/L to evaluate groundwater contamination. *See* 40 CFR § 257, App. IV and 80 Fed. Reg. 36435, 36444 (July 30, 2018). Available groundwater monitoring results for cobalt indicate what would be exceedances of Section 845.600 GWPS for eight of the thirteen values reported in MWG's 2021 Q3 Data Summary Posting.[16] Ex. O, tbl 1. Additionally, MW-3 and MW-5 have each had cobalt detections.[17] Ex. O, tbl 1. Illinois EPA does not have knowledge of any evidence presented by

[15] *See* pp. 25-26 below for further discussion.
[16] Reporting of samples collected since Part 845 became effective (May 2021 and August 2021) are not representative of the aquifer because there are data quality issues associated with dissolved or field filtered samples and sampling methods used. *See* Ex. A.
[17] MW-3 had cobalt detections in May and August 2021. MW-5 had cobalt detections in October 2015 and February 2016. Because Exhibit O seems to include field filtered sample collection methods, the detections and potentially

Petitioner (such as a reactive transport model) showing that cobalt will resolve from the groundwater prior to corrective action being required under Part 845. The adjusted standard, as proposed by Petitioner, cannot be met until all areas affected by releases (which includes groundwater) have been decontaminated.

g. **Impact of the petitioner's activity on the environment if petitioner were to comply with the regulation of general applicability as compared to the impact on the environment if the petitioner were to comply with the proposed adjusted standard.**

Petitioner must include "[t}he quantitative and qualitative description of the impact of the petitioner's activity on the environment if the petitioner were to comply with the regulation of general applicability as compared to the quantitative and qualitative impact on the environment if the petitioner were to comply only with the proposed adjusted standard. To the extent applicable, cross-media impacts must be discussed. Also, the petitioner must compare the qualitative and quantitative nature of emissions, discharges or releases that would be expected from compliance with the regulation of general applicability as opposed to that which would be expected from compliance with the proposed adjusted standard[.]" 35 Ill. Adm. Code § 104.406(g).

If Petitioner complies with Section 845.740(a), as promulgated, it will have to remove not only the liner, but also other containment system components, such as contaminated subsoils, to attain a certification of decontamination. Additionally, Petitioner would have to obtain Agency approval of its closure report certifying to completion of CCR and decontamination. 35 Ill. Adm. Code §§ 845.740(e) and 845.760(e), (f). If the Board grants the requested adjusted standard, Petitioner can not only avoid removing the HDPE liner but also any contaminated subsoils or subgrade materials. If the liner and subsoils are not removed as part of Pond 2's closure as a CCR surface impoundment, then the materials will remain indefinitely, since future closure of Pond 2

some of the non-detections could have been greater if the total metals sample collection methods had been followed. Ex. A.

as a wastewater basin under Part 309 will not require certification of decontamination from a qualified professional engineer.

Petitioner maintains that reuse of the HDPE liner is "more environmentally beneficial than disposal of a plastic liner and its underlying soil, to be replaced with a virtually identical liner." Pet. at 23. However, Petitioner does not discuss the cross-media impacts that the materials used as CCR fill within the embankments or as structural fill or foundational backfill at Pond 2 may have on the environment. Furthermore, Petitioner does not discuss or provide evidence that the fill material used under the bottom of Pond 2 and in the embankments has been tested for its environmental suitability.

Illinois EPA reviewed the total metals results collected around Pond 2 from 2015 through 2021. When groundwater analytical results for MW-4 are compared to Section 845.600, there are exceedances in eight out of thirteen[18] quarters for cobalt. Ex. O, tbl 1. Samples collected on May 18, 2021 and August 30, 2021, after Part 845 became effective, seem to be field filtered, which is not in accordance with Section 845.640(i). Ex. A. Cobalt analytical results exceed what are now Section 845.600 GWPS at MW-04 as recently as October 22, 2020. Ex. O, tbl 1.

Illinois EPA agreed in 2012 that the presence of chloride at Joliet 29 was likely due to road salts infiltrating and migrating through the soil. Ex. M at 4. Joliet 29 Pond 2 groundwater consistently has chloride exceedances at the "upgradient" well, MW-10. However, given the topography of Pond 2's embankments and US Highway 6 and its associated storm water drainage, the chloride is likely moving from the road salts into the top soil of the Pond 2 embankment and the US Highway 6 storm water drainage ditch during the winter months and then infiltrating to the

[18] Cobalt results for May 2021 and August 2021 cannot be evaluated due to data quality issues associated with dissolved or field filtered samples.

groundwater beneath and to the north of Pond 2 directly during the springtime thaw of ice and snow and subsequent rain events. *See* pp. 22-23 above.

Illinois EPA inspected historic precipitation records[19] around the April 24, 2018 sampling event and the May 7, 2019 sampling event. In April 2018, there were rainfall events on the 14th (0.70-inches), 15th (0.74-inches), and 16th (0.35-inches) and less than 0.1-inch between April 17th and 24th recorded. Ex. A. Groundwater was sampled on April 24, 2018. Groundwater analytical results for chloride on April 24, 2018 ranged between 220 mg/L in MW-3 and 300 mg/L in MW-5. The upgradient well, MW-10, chloride groundwater analytical value is 260 mg/L. Ex. O, tbl. 1. Additionally, in May 2019, there were rainfall events on May 1st (2.04-inches), May 3rd (0.45-inches), and May 7th (0.35-inches). Groundwater was sampled on May 6 and 7, 2019. Groundwater analytical results for chloride on May 6 and 7, 2019 ranged between 280 mg/L in MW-3 and 500 mg/L in MW-5. The upgradient well, MW-10, chloride groundwater analytical value is 410 mg/L. *Id*.

In Paragraph 12(f), Illinois EPA summarized the pathways for stormwater infiltration to the groundwater at Pond 2 and hydraulic conductivities/permeabilities of the embankment materials, which provide a preferential flow path through CCR material and not the clay. Illinois EPA maintains that the stormwater recharge to the groundwater at Pond 2 requires additional investigation of leaching potential through shake tests using ASTM D 3987-85 and groundwater sampling of total metals pursuant to Subpart F.

[19] https://www.usclimatedata.com/climate/joliet/illinois/united-states/usil0592, last accessed on November 30, 2021. Historic precipitation values for Joliet, Illinois in April 2018 and May 2019 were viewed and summarized above.

h. **Justification of the proposed adjusted Standard.**

Petitioner must include "[a] statement that explains how the petitioner seeks to justify, under the applicable level of justification, the proposed adjusted standard[.]" 35 Ill. Adm. Code §104.406(h). Illinois EPA agrees with Petitioner that, because Part 845 does not specify a level of justification for an adjusted standard, the applicable level of justification are the factors identified in Section 28.1(c) of the Act, 415 ILCS 5/28.1(c) (2020), as set forth below:

"If a regulation of general applicability does not specify a level of justification required of a petitioner to qualify for an adjusted standard, the Board may grant individual adjusted standards whenever the Board determines, upon adequate proof by petitioner, that:

(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."

Illinois EPA maintains the following regarding Pond 2 and the aforementioned factors:

(1) The factors relating to Pond 2 have not been proven substantially and significantly different from the factors relied upon by the Board in adopting the Part 845 closure requirements applicable to Pond 2. The fact that CCR material (CCW) exists beneath the existing HDPE liner as part of the structure of the CCR surface impoundment

without demonstration of its environmental suitability provides even more support for requiring Petitioner to utilize Part 845 closure methods as adopted.

(2) Petitioner states that its proposed adjusted standard is justified because of the lack of environmental benefit in requiring removal of the HDPE liner in compliance with Section 845.740(a). Pet at. 23. Illinois EPA maintains that Petitioner's proposed adjusted standard is not justified because MWG performed construction and placed CCR materials as the structural and foundation backfill underlying the HDPE liner without first screening the materials for environmental suitability. The placement of CCR materials below the liner render the ability to leave the liner in place incongruent with a number of geotechnical and environmental factors, as summarized in Sections III(d) and III(f) above.

(3) As explained in Section III(g) above, the requested adjusted standard will result in environmental or health effects substantially more adverse than the effects addressed by the Board in adopting Part 845 closure requirements.

(4) As further explained in Section III(i) below, the requested adjusted standard is not consistent with or as protective as the federal CCR Rule (Part 257).

i. **Reasons the Board may grant the proposed adjusted standard consistent with federal law.**

Petitioner must include "[a] statement with supporting reasons that the Board may grant the proposed adjusted standard consistent with federal law. The petitioner must also inform the Board of all procedural requirements applicable to the Board's decision on the petition that are imposed by federal law and not required by this Subpart. Relevant regulatory and statutory authorities must be cited[.]" 35 Ill. Adm. Code § 104.406(i). Petitioner proposes the following language for its requested adjusted standard:

> "MWG may close by removing and decontaminating all areas affected by releases from Pond 2 at the Joliet 29 Station. CCR removal and decontamination of the Pond 2 is complete when the CCR in Pond 2 and any areas affected by releases from the CCR surface impoundment have been removed. MWG must conduct visual inspection and analytical testing to demonstrate that the geomembrane liner in Pond 2 is not contaminated with CCR constituents. MWG must submit the results to Illinois EPA."

Petitioner alleges that its proposed adjusted standard is consistent with federal law, stating that the applicable federal CCR rule and the USEPA's Part B proposal both allow for decontamination of a liner and do not require removal. Pet. at 24, 25. Illinois EPA maintains that Petitioner misrepresents the federal closure by removal requirements and that the proposed adjusted standard is not consistent with federal law.

First, the requested adjusted standard is not consistent with Part 257's closure by removal requirements, which explicitly require compliance with GWPS to complete closure by removal, as follows:

> "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."(Emphasis added).

Part 257 currently treats closure by removal and all associated corrective action as a single process, with closure not being considered complete until all corrective action, including groundwater remediation, has been completed. 40 CFR § 257.102(c). Second, Mr. Nielson's expert opinion testimony is correct that the federal rule does not explicitly require removal of decontaminated liners for a closure by removal action. Pet. Ex. 3 at 2-3, citing 40 CFR § 257.102(c). However, the 2015 Preamble indicates that USEPA intended for all CCR waste and the liner to be removed. In fact, "once a facility has removed waste and the liner, the presumption

is that the source of contamination has been removed as well." 85 Fed. Reg. at 12469. Furthermore, USEPA explains in the 2015 Preamble that part of attaining this performance standard is documentation that "any contaminants left in the subsoils (i.e. contaminated groundwater left in soils below the former landfill or impoundment) will not impact any environmental media including groundwater, surface water, or the atmosphere in excess of Agency-recommended limits or factors.... Once the facility has removed all the assessment monitoring constituents listed in Appendix IV down to background levels or MCLs, the groundwater is considered to be 'clean' and closure is complete." 80 Fed. Reg 21302, 21412 (Apr. 17, 2015).

In March 2020, USEPA proposed to divide closure by removal and corrective action requirements into two separate processes as part of a proposed rule known as "Part B." See proposed § 257.102(c). 85 Fed. Reg. 12456, 12477 (Mar. 3, 2020). USEPA cited new information posted to facility CCR websites, including the number of CCRSIs that are not lined with any type of composite liner system (such as Pond 2), as evidence that groundwater corrective action would be more complex than previously understood and should therefore be separated from the closure by removal process. 85 Fed. Reg. at 12469.[20] Proposed 40 CFR § 257.102(c) provides that closure by removal activities include "removing and 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." 85 Fed. Reg. at 12469, 12477. According to USEPA, for a complete demonstration that all CCR has been removed from the unit, "any containment system components such as a bottom liner, contaminated subsoils, and unit

[20] "Available information indicates more than 70 percent of all CCR surface impoundments subject to the CCR regulations currently have neither type of composite liner system. Given the number of unlined CCR units, many of which have already reported exceedances of the groundwater protection standards, it is now evident that many CCR units have released CCR constituents into the surrounding soils and groundwater. This means that the closure activity is simply not a matter of removing CCR from the unit, but instead will likely require significant undertaking to remediate impacted soil and groundwater in order to achieve the current CCR removal and decontamination standards."

structures and equipment . . . would have to be removed prior to closure of the unit." If an owner or operator does not demonstrate compliance with GWPS, an owner or operator could qualify to separate corrective action from closure if it has initiated corrective action, such that all components of the remedy are in place and operating as intended. See proposed 40 CFR 257.102(c)(2); 85 Fed. Reg. at 12469, 12477.

While the Part B proposal appears to require more than the current iteration of Part 257, USEPA states that Part B is not proposing any substantive change to Part 257 closure by removal requirements, but rather it is solely "proposing to present the current closure standard in a slightly revised format" for purposes of accommodating separation of groundwater corrective action from the rest of the requirements. 85 Fed. Reg. at 12469. USEPA's proposal to clarify the closure by removal requirements just reiterated its intention that the 2015 and current iteration of 40 CFR 257.102(c) requirements already include removal of unit liners and all contaminated CCR subsoils. Illinois EPA proposed, and the Board adopted, the requirements in USEPA's Part B proposal, so that a CCRSI can receive a certification of closure by removal well before groundwater exceedances are resolved. Pet. Ex. 7, citing 85 Fed. Reg. 12456 (Mar. 3, 2020).

Illinois EPA maintains that Part 845 is as protective as current Part 257, in part because: (1) Part 845 incorporates USEPA's proposed Part B revisions that explicitly require certification of removal of CCRSI components, including containment components such as liners and contaminated subsoils; (2) the reuse of a competent liner to supplement a composite liner allowed by subsection 845.770(a)(4) requires the owner or operator to provide analytical data for Agency review that will demonstrate that there are no contaminants left behind. This requirement supports the requirement in Section 745.770(a)(1) to remove all contaminated soils and sediments and precludes the reuse of a liner if CCR (or CCW), which does not meet the definition of CCB under

Section 3.135 and is therefore not considered "beneficial use of CCR" under Section 845.120, has been used as a structural component of a CCR surface impoundment; and (3) compliance with GWPS must still be demonstrated for three consecutive years prior to terminating groundwater corrective action and groundwater monitoring. Allowing Petitioner to certify as closed and decontaminated without removal of all the CCRSI components and contaminated subsoils, and before a consistent demonstration of compliance with GWPS exceedances has been made, would not be as protective as Part 257.

As explained above, Illinois EPA disputes Petitioner's interpretation of 40 CFR § 257.102(c)'s closure by removal requirements, which USEPA has made clear includes removal of the CCR surface impoundment's liner, contaminated subsoils and remediation of all GWPS exceedances. Even if Petitioner's interpretation of Part 257 allowing decontamination of the HDPE liner was accurate, its request to retain CCR material beneath the HDPE liner without demonstrating compliance with the GWPS would still be in contravention of the federal closure by removal requirements.

IV. RECOMMENDATION

WHEREFORE, for the above and foregoing reasons, Illinois EPA recommends that the Board DENY Petitioner's request for an adjusted standard from 35 Ill. Adm. Code § 845.740(a).

If the Board grants Petitioner's requested adjusted standard over Illinois EPA's objection, the Agency recommends that the Board only do so conditionally for a one-year period, during which Petitioner must conduct the ASTM D 3987-85 shake tests to evaluate the leaching potential of the CCR (CCW) materials underlying the HDPE liner within Pond 2's containment structures. Petitioner must collect a minimum of two samples in each of the four embankments at Pond 2 and three samples from the bottom of Pond 2 where the poz-o-pac was retained and utilized under the

HDPE liner. The shake test samples in the embankments must be collected in a black silty gravel material no deeper than 515 feet above mean sea level ("AMSL") (or one foot below the bottom elevation of the liner at Pond 2). The shake test samples of the PSB material from the bottom of Pond 2 must be crushed prior to conducting the shake test.

The shake test results must be compared to both 620.410 GWQS (which is required to be environmentally suitable as CCB) and 845.600 (which identifies GWPS that specifically apply to CCR surface impoundments) and accompanied by the chain of custody and laboratory reports. Minimum reporting limits must be at or below the GWQS or GWPS. For constituents with standards in both Section 620.410 and Section 845.600, the minimum reporting limits for all laboratory analyses conducted by Petitioner must be at or below the GWPS in Section 845.600.

If Petitioner's shake test results demonstrate that the leaching potential of the CCR materials underlying the HDPE liner does not exceed the lowest standard specified in either Section 620.410 and Section 845.600:[21]

a. Within the one-year interim adjusted standard period, MWG must conduct integrity testing of the seams and the HDPE liner where it may be perforated or damaged to determine the competency of the liner. The liner competency must be certified by a licensed professional engineer, which must include certification that (1) the seams are intact and sealed, and (2) that the liner is not perforated from previous use of gravel overlying or underlying the HDPE since installation in 2008 or otherwise damaged.
b. If the liner is found to not be certifiably competent, then the Board should only allow MWG to retain the HDPE liner through a permanent adjusted

[21] There are metals constituents in 620.410 that are required to demonstrate environmental suitability of CCB under Section 3.135, for which there are no GWPS in Section 845.600 (e.g., manganese and iron).

standard if it installs a new composite liner meeting the design criteria of Section 845.400 overlying the old liner, where the old liner will be considered part of the foundation of the new liner for purposes of Section 845.450(a)(1).

If Petitioner cannot demonstrate that the leaching potential of the CCR materials underlying the HDPE liner does not exceed the lowest of Section 620.410 and Section 845.600 at or below Section 845.600 GWPS, then Pond 2 must be closed pursuant to Part 845 without an adjusted standard.

Respectfully submitted,

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY,

Respondent,

Dated: February 4, 2022

BY: /s/ Christine Zeivel

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THIS FILING IS SUBMITTED ELECTRONICALLY

CERTIFICATE OF SERVICE

I, the undersigned, on affirmation certify the following:

That I have served the attached **RECOMMENDATION OF THE ILLINOIS ENVIRONMENTAL PROTECTION AGENCY** with supporting documents by e-mail upon Kristen L. Gale at the e-mail address of kg@nijmanfranzetti.com, upon Susan Franzetti at the e-mail address of sf@nijmanfranzetti.com, upon Molly Snittjer at the e-mail address of ms@nijmanfranzetti.com, upon Brad Halloran at the e-mail address of Brad.Halloran@illinois.gov, and upon Don Brown at the e-mail address of Don.Brown@illinois.gov.

That my e-mail address is Christine.Zeivel@Illinois.gov.

That the number of pages in the e-mail transmission is Two Thousand Fifty-Seven (2057).

That the e-mail transmission took place before 4:30 p.m. on the date of February 4, 2022.

/s/ Christine Zeivel
February 4, 2022

Exhibit List

Exhibit A – Affidavit of Lauren Martin.

Exhibit B – Affidavit of Derek Rompot.

Exhibit C – Federal Highway Administration, "Coal Fly Ash User Guideline for Stabilized Base," *User Guidelines for Waste and Byproduct Materials in Pavement Construction*, Publication No. FHWA-RD-97-148, *available at* https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/97148/020.cfm (last modified March 8, 2016).

Exhibit D – Sargent & Lundy Letter to Illinois EPA re: 2008 Reconstruction of Access Ramp for Pond 2 at Joliet 29 Generating Station, with attachments, dated December 2, 2021.

Exhibit E – KPRG & Associates, Inc. Letter Report re: Geotechnical Analysis of Soil Surrounding Basins/Ponds, dated October 13, 2005.

Exhibit F – Federal Highway Administration, "Soils and Foundations Reference Manual – Volume 1," Publication No. FHWA-NHI-06-088 (December 2006).

Exhibit G – Sargent & Lundy Letter to Illinois EPA re: Construction Chronology of Pond 2 at Joliet 29 Generating Station, with attachments, dated January 18, 2022.

Exhibit H – Affidavit of Thomas Hubbard.

Exhibit I – Patrick J. Fox et al., Technical Paper, *Geomembrane Damage Due to Static and Cyclic Shearing Over Compacted Gravelly Sand*, 18 Geosynthetics Int'l. 272 (2011).

Exhibit J – Ian D. Peggs, *How Long Will My Liner Last? What is the Remaining Service Life of my HDPE Geomembrane?*, Geosynthetics Mag. (October 1, 2008) *available at* https://geosyntheticsmagazine.com/2008/10/01/how-long-will-my-liner-last/#.

Exhibit K – MWG Weekly Inspection Report for Joliet 29 Station, October 13, 2021.

Exhibit L – MWG Annual Inspection Report for Joliet 29 Station, October 13, 2021.

Exhibit M – Nijman Franzetti, LLP letter to Illinois EPA, dated August 31, 2012.

Exhibit N – USEPA Framework for Metals Risk Assessment, March 2007.

Exhibit O – Part 845 MWG Joliet #29 Generating Station Q3 2021 Data Summary Posting.

Exhibit A

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	AS 2021-001
Petition of Midwest Generation	)	
for an Adjusted Standard from 845.740(a)	)	
and Finding of Inapplicability of Part 845	)	(Adjusted Standard)
(Joliet 29 Station)	)	

AFFIDAVIT OF LAUREN HUNT MARTIN

I, Lauren Martin, certify under penalty of perjury pursuant to Section 1-109 of the Illinois Code of Civil Procedure, 735 ILCS 5/1-109, that the statements set forth in this affidavit are true and correct, and further state that if called upon to testify in this matter, I would competently testify as follows:

1. I am employed by the Illinois Environmental Protection Agency ("Illinois EPA" or "Agency") as an Environmental Protection Geologist III in the Hydrogeology and Compliance Unit ("HCU") within the Groundwater Section of the Bureau of Water, and I am located in Springfield, Illinois. I have been employed by the Illinois EPA since February of 2020.

2. I have a Bachelor of Science degree in geology from Western Illinois University and a Master of Science in hydrogeology from Illinois State University. My curriculum vitae is attached (Attachment 1) for further detail about my training and experience.

3. As a Geologist in the HCU, my duties include: providing review of hydrogeologic assessments and reports, and providing technical input on the same as well as special projects requiring hydrogeologic and engineering geology expertise; providing construction, engineering geology, and hydrogeologic expertise to Bureau of Water permit programs (industrial, mines and municipal) and Public Water Supply permits; responding to questions from the regulated community, public and other governmental agencies about the provisions of the Illinois Environmental Protection Act ("Act"), Illinois Groundwater Protection Act (ILGPA), and Illinois

Pollution Control Board ("Board") rules adopted thereunder; project management of sites subject to corrective actions under the Act or Board rules; testifying before the Board on proposed rules and in various proceedings; and assisting in the implementation of source water protection programs.. As part of these duties, I served as a witness on behalf of the Groundwater Section in support of Illinois EPA's proposed Part 845 throughout the Illinois Pollution Control Board's rulemaking proceedings in R2020-019.

4. I have reviewed the Petition of Midwest Generation, LLC ("MWG") for an Adjusted Standard from Section 845.740(a) and Finding of Inapplicability of Part 845 for the Joliet 29 Station, along with its supporting documents ("the Petition").

5. I have personal knowledge of the facts set forth in Illinois EPA's Recommendation to the Board as stated below.

6. I have reviewed Pond 2's permit record, History of Construction, geotechnical data, aerial photographs, groundwater data, and other available documents.

7. A review of aerial photographs confirms that the current location of Pond 2 was not present until it was initially constructed in 1978/1979.

8. According to the History of Construction, MWG's poz-o-pac formulation is primarily (97%) comprised of fly ash and bottom ash and is therefore a CCR material. *See* Rec. Ex. D, attach. 3, app. A-2 (Drawing No. 5079C5019, Sheet 2 of 3, Rev. 2).

9. Fly ash is often used as a component of stabilized base and subbase materials. Both bituminous (pozzolanic) or subbituminous or lignite (self-cementing) fly ashes can be used, but after review of all available documents, I cannot find any statement of what kind of fly ash was used in MWG's poz-o-pac formulation. *See* Rec. Ex. C at 1.

10. Illinois EPA issued a state construction permit on July 20, 2007 authorizing the replacement of the poz-o-pac liners at Pond 1 and Pond 2 with a 60-mil high density polyethylene ("HDPE") geomembrane, attached to the Petition as Petitioner's Exhibit 13.

11. The History of Construction for Pond 2 indicates ramp material from within the original CCR surface impoundment constructed in 1978/1979 was placed under the HDPE liner as it lies along and under the ramp designed for access into the CCR surface impoundment. Appendix A-3 also shows that the poz-o-pac was to be removed. *See* Rec. Ex. D, attach. 3, app. A-3.

12. Following my review of the History of Construction and upon Agency inquiry about the material used beneath the HDPE liner, MWG provided Illinois EPA a December 2, 2021 letter with attached documents, including change requests and project invoices. According to MWG, the ramp material was not excavated and the ramp and original poz-o-pac were retained during the 2008 construction. *See* Rec. Ex. D.

13. I am not confident regarding the quantity of poz-o-pac or other CCR materials left in place and reutilized during the 2008 construction because documents are not clear and sometimes appear to conflict. However, data provided by MWG suggests that the poz-o-pac was left in place on the bottom of Pond 2 but removed from the side slopes, along with up to three feet of material, and replaced and graded with onsite materials.

14. MWG's pozzolan-stabilized base ("PSB"), or a poz-o-pac material/basic lime-fly ash-aggregate formulation consists of 3% hydrated lime, 20% fly ash, and 77% boiler slag aggregate. The poz-o-pac was sealed with a bituminous seal coat. Curing of the bituminous seal coat was specified to include one week. *See* Rec. Ex. D, attach. 3, app. A-2.

15. Due to the poz-o-pac's nature and use conditions, it has likely been compromised by way of cracking or otherwise breaking down, resulting in material becoming unconsolidated or pulverized in certain areas. PSB is known to crack substantially over time and was likely compromised due to wear and tear during its original use or during the construction and use currently with a HDPE liner installed. *See* Rec. Ex. C at 8-9. The evidence of likely breakdown is the presence of the fine to coarse grained fill material used to smooth out the poz-o-pac creating flat, smooth subgrade on the bottom of the impoundment below the liner. *See* Rec. Ex. G, attach. 11.

16. Unconsolidated or pulverized poz-o-pac material at Joliet 29 may leach because it is CCR material that is unlikely to have been rendered inert. Leaching occurs from the surface area of a material containing heavy metals. The more surface area exposures that occur because of cracking, the greater the leaching potential of the material.

17. The engineering properties summarized in Joliet 29's History of Construction show Pond 2's foundation is comprised of sand/gravel with a unit weight of 125 pounds per cubic foot (pcf). *See* Rec. Ex. D, attach. 3, tbl. 2 at 3. The embankment properties are brown clay with a unit weight of 115 pcf and black silty gravel with a unit weight of 125 pcf. *See* Rec. Ex. D, attach. 3, tbl. 3 at 5. According to the FHWA, dark gray to black soils represent organic material. *See* Rec. Ex. F at 4-10. Organic materials do not make good structural base materials because of the potential for settlement. Additionally, gravels are typically derived from local sources which do not include black rock. Local quarried rock is Silurian Dolomite and Devonian Dolomite, which is typically white, tan or light gray in color. I am not aware of any quarries or borrow sources within a reasonable distance to support economically shipping black inorganic source material from a

natural source. Therefore, the black silty gravel is likely fly ash mixed with some crushed poz-o-pac or locally sourced limestone or dolomite gravel, or some combination of the two.

18. MWG provided Illinois EPA a December 9, 2021 letter from its contractor, Sargent and Lundy. Rec. Ex. G. The letter acknowledges the presence of brown clay and black silty gravel material in multiple borings but does not provide any local source of geotechnically suitable black material that is not CCR. *See* Ex. G at 3-4. Neither the letter nor any other available documents provide any evidence of testing for organic content.

19. Attached to the December 9, 2021 letter is a picture of the 2008 construction that shows the subgrade prepared and the geotextile and geomembrane being placed. The side slope of the impoundment subgrade is compacted black to dark brown silty gravel and the bottom is poz-o-pac smoothed over with fine to coarse grained material—potentially the aforementioned black silty gravel or unconsolidated poz-o-pac. *See* Ex. G, attach. 11. The black silty gravel, described in the History of Construction and shown in the picture of the construction of Pond 2's HDPE liner, likely contains fly ash and/or bottom ash to which MWG has not provided evidence to the contrary. *See* Ex. D, attach. 3 at 5 and Ex. G, attach. 11.

20. Upon information and belief, the poz-o-pac and black silty gravel material are CCR or CCR combined with other materials and are therefore a potential source of contamination in the groundwater.

21. Available documents indicate that, as part of Pond 2's HDPE liner construction in 2008, MWG removed between one to three feet of the black silty gravel material and/or poz-o-pac along the internal side slopes of the embankment and then reused the black silty gravel material to rebuild the side slopes of the embankments. *See* Ex. D, attach. 3, app. A-3, sheet no. C020 and Ex. G, attach. 11.

22. The "Preliminary Draft" of sheet no. C020 attached to the December 9, 2021 letter removes the topographic contours from the Pond 2 embankments that are shown in Appendix A-3 (sheet C020) of the History of Construction, which illustrate the change in shape and grade during the construction. *See* Rec. Ex. G, attach. 6 and Rec. Ex. D, attach. 3. The geometry of the bottom of Pond 2 and the top of the embankment side slope did not change between the two documents.

23. Based on the 2005 Geotechnical Report and History of Construction, MWG had knowledge of the nature of the CCR material being reused prior to construction and knowingly reutilized the CCR materials for geotechnical applications, seemingly without testing for environmental suitability. *See* Rec. Ex. D, attach. 3, app. A-2 and A-3 and Rec. Ex. E, attach. 4.

24. I have reviewed all available documents and I have not found any indication that MWG or its contractors performed any testing utilizing ASTM D3987-85, otherwise known as the "shake test."

25. The shake test relates to the environmental suitability of construction materials. The History of Construction and the Construction Documentation Transmittal for Pond 1 and Pond 2 focus on geotechnical and construction related quality control and do not account for or provide any details related to testing per ASTM D3987-85. *See* Rec. Ex. D, Attach. 3 and Pet. Ex. 15.

26. The poz-o-pac and black silty gravel material are CCR or CCR combined with other materials and are therefore a potential source of contamination in the groundwater. Even if the CCR material used as structural fill or foundational backfill passes the "shake test" by demonstrating that the leaching potential of the material will not exceed Section 620.410, it is possible that the material could still cause exceedances of Section 845.600 GWPS for several parameters, such as cobalt, lithium, molybdenum, and radium 226 and 228 combined.

27. Retrofit of a CCR surface impoundment under Part 845 occurs where a composite liner compliant with Part 845 is going to be installed over the top of the existing system. In the case of retrofit, the composite liner creates a barrier over the existing synthetic liner and prevents any material underneath the pre-existing liner from being exposed to the contents of an impoundment. I am not a hydrologist and cannot testify as to hydraulic head from surface water sources; however, I can attest that, from a geologic or hydrogeologic perspective, a new composite liner installed during a retrofit of Pond 2 that retained the HDPE liner system would isolate the surface water within the impoundment from the CCR materials used to construct the impoundment and the groundwater below.

28. The composite liner installed during retrofit also prevents infiltration through damage or perforations in the existing liner from stress due to placement over a soil containing gravel.

29. HDPE liners that overlie soils with gravel are likely to sustain perforations due to overburden stress. *See* Rec. Ex. I

30. While a geotextile cushion was installed beneath the HDPE liner in Pond 2, there are other factors that may cause damage to the liner. In addition to overburden stress, liners installed in impoundments that are exposed to sunlight and weather conditions suffer degradation that buried HDPE liners do not. The exposure to the elements can also deteriorate and/or cause wear and tear on the liner that would not otherwise occur. *See* Rec. Ex. I and J.

31. Competence as it relates to synthetic liners means the seals between sheets of the liner have not parted or otherwise become separated, the liner has not been damaged by the gravel underlying or overlying the liner, and exposure to the elements has not broken down the liner or the seals. There are several destructive and non-destructive ASTM methods for testing the

competence of the seals of the liner. Additionally, there are methods presented in Recommendation Exhibits I and J that provide direction in methods on how to test for damage due to exposure or puncturing. *See* Rec. Ex. I and J.

32. Visual inspections do not provide adequate verification of competence where the synthetic liner is the only barrier between the water within the impoundment and contaminated subsoils and groundwater.

33. Stormwater infiltrates Pond 2's embankments, which contain CCR materials and potential contaminants that can be leached and/or washed by gravity flow into the groundwater below.

34. The stormwater infiltration is evidenced through the chloride data. When compared to Section 620.410 groundwater quality standards ("GWQS") and Section 845.600 groundwater protection standards ("GWPS"), chloride sample results consistently exceed at downgradient and "upgradient" wells during the same quarterly sampling events in which rainfall has occurred or is occurring during sampling. *See* Pet. Ex. 18, tbl. 4. Illinois EPA and MWG agreed in 2012 that the exceedances of Section 620.410 GWQS were likely due to road salts. *See* Rec. Ex. M at 4. However, these exceedances signify that storm water infiltration and recharge is occurring through the immediate vicinity of Pond 2, including the embankments.

35. Joliet 29 Pond 2 groundwater consistently has chloride exceedances at the "upgradient" well, MW-10. However, given the topography of Pond 2's embankments and US Highway 6 and its associated storm water drainage, the chloride is likely moving from the road salts into the top soil of the Pond 2 embankment and the US Highway 6 storm water drainage ditch during the winter months and then infiltrating to the groundwater beneath and to the north of Pond 2 directly during the springtime thaw of ice and snow and subsequent rain events.

36. I inspected historic precipitation records[1] around the April 24, 2018 sampling event and the May 7, 2019 sampling event. These events both had exceedances of cobalt and chlorides. In April 2018, there were rainfall events on the 14th (0.70-inches), 15th (0.74-inches), and 16th (0.35-inches) and less than 0.1-inch between April 17th and 24th recorded. Groundwater was sampled on April 24, 2018. Groundwater analytical results for chloride on April 24, 2018 ranged between 220 mg/L in MW-3 and 300 mg/L in MW-5. The upgradient well, MW-10, chloride groundwater analytical value is 260 mg/L. In May 2019, there were rainfall events on May 1st (2.04-inches), May 3rd (0.45-inches), and May 7th (0.35-inches). Groundwater was sampled on May 6 and 7, 2019. Groundwater analytical results for chloride on May 6 and 7, 2019 ranged between 280 mg/L in MW-3 and 500 mg/L in MW-5. The upgradient well, MW-10, chloride groundwater analytical value is 410 mg/L. *See* Rec. Ex. O, tbl. 1.

37. Be evaluating the data in Paragraph 35, I can conclude that chlorides, which are presumably present in road salts applied on US Highway 6 and thus in the top-soils on the north side of the impoundment and extending into the US Highway Right-Of-Way storm water drainage system, are exhibiting the recharge that is occurring at the site through the surface into the immediate groundwater through a material with a high hydraulic conductivity providing a rapid infiltration rate on the order of less than a week. Storm water recharge through the shallow subsurface materials within the embankments and the permeability exhibited by the chloride transport demonstrate the potential for leaching of metals from the CCR materials placed under the liner at Pond 2.

38. Water from inside the impoundment that leaks through a damaged HDPE liner (whether it is operated as a CCR surface impoundment or another wastewater system), as well as

[1] https://www.usclimatedata.com/climate/joliet/illinois/united-states/usil0592, last accessed on November 30, 2021.

stormwater from outside the liner, traverses through the CCR materials placed underneath the liner and in the embankments of Pond 2. The nature of the black silty gravel and broken poz-o-pac that has been reported to be left in place at Pond 2 has a higher hydraulic conductivity than the clay materials surrounding it. Thus, the CCR materials have primary or secondary permeability or hydraulic conductivities that constitute a primary flow path over the lower hydraulic conductivity clay.

39. I have reviewed groundwater monitoring data available on Petitioner's Part 845 publicly available website. Specifically, I reviewed the total metals results collected around Pond 2 from 2015 through 2021. Available groundwater monitoring results for cobalt indicate what would be exceedances of Section 845.600 GWPS at MW-4 for eight of the thirteen values reported in MWG's 2021 Q3 Data Summary Posting. Cobalt analytical results exceed what are now Section 845.600 GWPS at MW-04 as recently as October 22, 2020.

40. Reporting of samples collected since Part 845 became effective (May 2021 and August 2021) are not representative of the aquifer because there are data quality issues associated with dissolved or field filtered samples and sampling methods used. The Agency receives dissolved metals data and total metals data for the site. The dissolved metals results presented to the Agency were higher in value for some of the detections than the total metals results, suggesting that the sample bottles were switched in the field, all samples were field filtered, and/or some other sampling error occurred.

41. MW-3 and MW-5 have each had cobalt detections. MW-3 had cobalt detections in May and August 2021. MW-5 had cobalt detections in October 2015 and February 2016. Because MWG's 2021 Q3 Data Summary Posting seems to include field filtered sample collection methods, as explained in Paragraph 40 above, the detections and potentially some of the non-

detections could have been greater if the total metals sample collection methods had been followed. *See* Rec. Ex. O, tbl. 1.

42. I do not have knowledge of a reactive transport model showing that cobalt will resolve from the groundwater prior to corrective action being required under Part 845.

43. In order to demonstrate environment suitability of the CCR material underlying the HDPE liner and allow its retention, stormwater recharge to the groundwater at Pond 2 requires additional investigation of leaching potential through shake tests using ASTM D 3987-85 and groundwater sampling of total metals pursuant to Subpart F.

FURTHER AFFIANT SAYETH NOT

Lauren Hunt Martin
LAUREN HUNT MARTIN

2-4-22
DATE

State of Illinois
County of Sangamon

Subscribed and Sworn to before
me this 4th day of February 2022.

Dawn A. Hollis
Notary Public

OFFICIAL SEAL
DAWN A. HOLLIS
NOTARY PUBLIC, STATE OF ILLINOIS
MY COMMISSION EXPIRES 03-21-2025

Attachment 1

CURRICULUM VITAE

LAUREN HUNT MARTIN, M.S.

1021 N Grand Avenue East
Springfield, Illinois 62704
Illinois Environmental Protection Agency
Bureau of Water
Division of Public Water Supplies
Groundwater Section
Springfield, Illinois
Environmental Protection Geologist III
February 2020 to Present

Ms. Martin has been employed as an engineering geologist in the construction materials testing and geotechnical engineering consulting since 2001 and has been employed as a geologist and hydrogeologist in the environmental consulting industry since 2005. Ms. Martin started at the Illinois EPA in February 2020. During the short time that Ms. Martin has been at the Illinois EPA, Ms. Martin assisted in updates to the Part 845 regulations, implementation of Part 845, implementation of Part 620, and amendments to Part 620. Ms. Martin is involved as project manager for mines, industrial and municipal sites for ongoing support and decision making.

Professional History

Jacobs Engineering (Formerly CH2M)
Chicago, Illinois
Geologist
August 2005 to January 2020

Task Coordinator and Project Manager for H&S, Confidential Private Client, Cook and DuPage Counties, Illinois, 2012 to January 2020. Jacobs Engineering is the Design Corridor Manager for a premier transportation project for a confidential private client. Ms. Martin was the Task Coordinator various tasks including serving as the Project Manager for Safety, coordinated the combined geotechnical and environmental field investigation at O'Hare International Airport in

2014 and the follow up environmental field investigation in 2016 including evaluations of soils pursuant to 35 Ill. Admin. Code 1100. Ms. Martin was the task manager for combining the geotechnical and environmental field investigation for the borrow source material along and near the project right of way including identifying design needs and environmental testing needs to comply with 35 Ill. Admin. Code 1100. Coordination consisted of logistics for implementation of field work, work planning, and reporting including coordinating with the client and guiding internal team to ensure design needs were met. Work planning and reporting included coordination with geotechnical project lead and environmental project lead to implement an investigation that meets regulatory and design requirements.

Subject Matter Expert, Bedrock Geology, Confidential Federal Client, Iowa, August 2016 to January 2020. Jacobs Engineering is performing the site investigation for a Remedial Investigation for a large active military installation. Ms. Martin was subject matter expert for the investigation into bedrock. Ms. Martin also assisted in implementation of vegetation clearing, site safety management, site investigation management.

Task Coordinator and Technical Expert, Confidential State Client, Wisconsin, January 2017 to January 2020. Phase I Update for ongoing transportation design project. Ms. Martin wrote and consulted on the proposal and Phase I Update for the client deliverable.

Task Coordinator and Assistant Project Manager, LUST Site, Confidential Federal Client, Illinois, August 2017 to January 2020. Jacobs Engineering is performing the site investigation and corrective action for a LUST site in western Illinois at a former large military installation. Ms. Martin was the task coordinator and assistant project manager. In a technical role Ms.

Martin assisted in providing guidance in closing with monitored natural attenuation coupled with other possible closure alternatives.

Project Manager and Task Manager, Confidential Private Client, Illinois, February 2008-December 2016. Project site is a liquids terminal near Chicago, Illinois. Site has had many spills of various chemicals over the years around loading racks for railcars and semi-trucks and docks for loading barges. Ms. Martin managed tasks and projects including proposals, emergency environmental compliance response, site remediation, and site characterization. Emergency compliance response included overseeing emergency soil removal actions and subsequent reporting and regulatory agency coordination. Site remediation included emergency spill clean-up, construction of a geomembrane, and mentoring of junior staff on implementing construction plans. Site characterization included installing wells, drilling boreholes, gauging NAPL, and collecting groundwater data requiring mitigation of a multitude of gases, chemicals and subsequent safety hazards associated with chlorinated solvents, petroleum products and proprietary chemicals.

Assistant Project Manager, Site Superintendent, Construction Quality Manager, and Site Safety and Health Officer, Confidential Federal Client, Illinois, September 2014 to September 2016. The Project included the remediation of a railyard within a former military base for coal containing arsenic. Ms. Martin was the assistant project manager during work planning and reporting. During the construction phase, Ms. Martin was the site superintendent, construction quality manager, and site safety and health officer managing all site operations and contractors.

Technical Hydrogeology Lead, Confidential Federal Client, Illinois, August 2010 to July 2014. Project was a former Radar School for the military during WWII. Ms. Martin designed and

implemented the technical approach for closure of the site. Ms. Martin wrote and presented environmental data findings and proposed plan for closure to the public in the public meeting. The Site went to a No Further Action Record of Decision in 2013/2014.

Site Characterization Site Manager, Confidential Private Client, Middle East, January to July 2009. The Project involved the design of four new nuclear reactors and surrounding support structures at two proposed sites. Ms. Martin provided oversight for the field investigation and review of project documents for the site characterization during the field investigation and work planning for four new nuclear reactors at two proposed sites. The field investigation included geotechnical, hydrogeologic, geologic, biologic, geophysical and meteorological data collection and analyses for the purpose of design of the facility.

Geotechnical Field Investigation Lead, Confidential Private Client, Abu Dhabi, UAE, August to November 2008. The Programme was a $2+ billion Design/Build Tunneling Project for the City of Abu Dhabi in the United Arab Emirates. Ms. Martin led the field investigation including management of contractors from various countries of origin for the first one third section of the 25 mile long tunnel design on behalf of the programme ensuring that the field documentation and laboratory testing was completed as per the tunneling and geotechnical engineer's specifications.

Field Team Member, Field Team Leader, and Task Lead Assistant, Confidential Power Plant, Confidential Location, May-August 2006 and December 2006 to February 2007. The Project involved the design of two new nuclear reactors and surrounding support structures at an existing nuclear power plant. Ms. Martin actively participated in and led various tasks during

the Final Safety Analysis Report field work and reporting. Tasks included data collection, data validation, software validation, data analyses and task management.

Various other Geotechnical and Environmental projects. 2005 to 2019. Ms. Martin provided project support, field investigation leadership and implementation to a variety of geotechnical and environmental projects aside from the aforementioned, performing groundwater sampling, geotechnical field sampling and drilling, well installations, quality control and quality assurance field oversight.

Nicor 2004
Hudson Gas Storage Field, Hudson, Illinois
Reservoir Engineering Intern

Ms. Martin worked as a Reservoir Engineering Intern for the Summer of 2004 for Nicor. Ms. Martin's work tasks included supervising the seismic survey crew for her thesis, learning Geographix Software, reducing and analyzing data from the well logs for the various gas storage fields.

Whitney and Associates, Inc.
Peoria, Illinois
Engineering Geologist and Construction Inspector

Ms. Martin performed various concrete, soils, and asphalt quality assurance and quality control inspections at commercial and federal construction sites. Ms. Martin operated an IDOT and ASTM certified soils and concrete laboratory.

Education

Bachelor of Science, Geology, Western Illinois University

Master of Science, Hydrogeology, Illinois State University

Publications

Peterson, Eric, Lauren I. Martin, and David Malone. Identification of Potential Vertical Gas Migration Pathways Above Gas Storage Reservoirs, World of Engineering, 2015.

Certifications

OSHA 10-hour Construction Safety Awareness, 2005

OSHA 30-hour Construction Safety, 2015

USACE Construction Quality Manager, 2015-2020

WHMIS Certification (safety certification required for environmental site work in Canada), 2010

Additional Training

OSHA HAZWOPER 40-hour Training, 2005; 8-hour Refresher Training, Annually 2006 to 2019

First Aid/CPR Training, Annually or Biannually 2005 to 2019

Munitions Safety Awareness, 2011

Bloodborne Pathogens, 2018

Dangerous Goods Shipping, 2017

Fire Extinguisher Use Training, 2018

Arsenic, 2018

Asbestos, 2005

Behavior Based loss Prevention Systems Training, 2007

Benzene, 2013

Electrical Safety, 2017

Ergonomics Training, 2005

Excavation Safety Training, 2005

Fall Protection Safety Training, 2005

Field Awareness Safety Training, 2005

Global Harmonization Training, 2013

Hand Safety, 2018

Hazard Communication Training, 2005

Ladder Safety, 2005

Lead Safety, 2016

Manual Lifting Safety, 2016

Military Munitions Rule Training, 2018

Noise/Hearing Conservation, 2014

Personal Protective Equipment Training, 2018

Project Manager Health, Safety and Environment Training, 2013

Railroad Contractor Orientation Training, 2010

Railroad Education for Contractors (On-Track), 2010

Railroad Safety Online Training, 2013

Remediation Waste Management Training, 2018

Respirators-Level C, 2018

Various Site Safety Coordinator Trainings in accordance with 29 CFR 1920, every 3 years

2005-2018

Smith System Small Vehicle Backing and Forward Motion Trainings, 2012

Subcontractor Management Training, 2010

Traffic Control Training, 2013

Waste Management Training, 2018

Exhibit B

Electronic Filing: Received, Clerk's Office 2/04/2022

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	AS 2021-001
Petition of Midwest Generation	)	
for an Adjusted Standard from 845.740(a)	)	
and Finding of Inapplicability of Part 845	)	(Adjusted Standard)
(Joliet 29 Station)	)	

AFFIDAVIT OF DEREK ROMPOT

I, Derek Rompot, certify under penalty of perjury pursuant to Section 1-109 of the Illinois Code of Civil Procedure, 735 ILCS 5/1-109, that the statements set forth in this affidavit are true and correct, and further state that if called upon to testify in this matter, I would competently testify as follows:

1. I am employed by the Illinois Environmental Protection Agency ("Illinois EPA" or "Agency") as an Environmental Protection Engineer III in the Industrial Permits Section ("IPS") of the Bureau of Water, and I am located in Springfield, Illinois. Cumulatively, I have worked for the Illinois EPA for over 27 years in various sections within the Agency, including the Disposal Alternative Unit within Bureau of Land's Permit Section.

2. As a permit engineer in the IPS, my duties include timely review of National Pollution Discharge Elimination System ("NPDES") permit applications and State construction and operating permit applications, including those for coal combustion residual ("CCR") surface impoundments under 35 Ill. Adm. Code Part 845. I am the permit engineer assigned to the Midwest Generation, LLC ("MWG") Joliet 29 Station for all water pollution control permit activities.

3. I have personal knowledge of the facts set forth in Illinois EPA's Recommendation to the Board as to the Petition of MWG for an Adjusted Standard from Section 845.740(a) and Finding of Inapplicability of Part 845 for the Joliet 29 Station, as stated below.

4. I have reviewed the records of the Permit Section within the Bureau of Water, Division of Water Pollution Control, including the construction permit history for Pond 2 at the Joliet 29 Station.

5. I have not been able to locate a permit for the initial construction of Pond 2.

6. Illinois EPA issued state construction Permit 2007-EB-4091 on July 20, 2007, attached to the Petition as Petitioner's Exhibit 13. This permit authorized the replacement of the poz-o-pac liners at Pond 1 and Pond 2 with a 60-mil high density polyethylene ("HDPE") geomembrane and a twelve-inch sand and limestone screenings warning layer.

7. I have not been able to locate any records that indicate MWG provided the Agency notification of the beneficial use or reuse of CCR material at the Joliet 29 Station.

FURTHER AFFIANT SAYETH NOT

DEREK ROMPOT

Feb 4, 2022
DATE

State of Illinois
County of Sangamon
Subscribed and Sworn to before
me this 4th day of February 2022.

Notary Public

OFFICIAL SEAL
DAWN A. HOLLIS
NOTARY PUBLIC, STATE OF ILLINOIS
MY COMMISSION EXPIRES 03-21-2025

Exhibit C

Electronic Filing: Received, Clerk's Office 2/04/2022

Federal Highway Administration Research and Technology
Coordinating, Developing, and Delivering Highway Transportation Innovations



This report is an archived publication and may contain dated technical, contact, and link information

Publication Number: FHWA-RD-97-148

User Guidelines for Waste and Byproduct Materials in Pavement Construction

[Flowable Fill] [Material Description] [Asphalt Concrete] [Portland Cement Concrete] [Embankment or Fill]

COAL FLY ASH

User Guideline

Stabilized Base

INTRODUCTION

Fly ash is often used as a component of stabilized base and subbase mixtures. Both bituminous (pozzolanic) and subbituminous or lignite (self-cementing) fly ashes can be used in this application.

Bituminous fly ash is used with a chemical reagent or activator (usually lime, Portland cement, or kiln dust), aggregate, and water. For most coarse graded aggregates, the amount of fly ash used will normally be in the 8 to 20 percent range. For sandy aggregates, the amount of fly ash used may be in the 15 to 30 percent range.

Subbituminous or lignite fly ash, which is usually self-cementing, does not require a chemical reagent or activator. This ash is blended with aggregate and water, but, because of the flash setting properties of most sources, the amount of fly ash used may only be in the 5 to 15 percent range. There are instances where self-cementing fly ash is used by itself as the base course material without any aggregate.

The use of fly ash in stabilized base and subbase mixtures dates back to the 1950's, when a patented base course product known as Poz-o-Pac (consisting of a blend of lime, fly ash, and aggregate) was originally developed. Since the Poz-o-Pac patents expired during the early 1970's, numerous variations of the basic lime-fly ash-aggregate formulations have evolved. There have also been stabilized base mixtures containing Portland cement that have evolved from soil-cement. All of these mixtures contain fly ash and can be described under the general heading of pozzolan-stabilized base (PSB).

The major component of most stabilized base mixtures is the aggregate. Early Poz-o-Pac mixes used locally available high-quality crushed rock (such as limestone, trap rock, or granite), sand and gravel, or blast furnace slag, especially on high traffic volume roadways. However, many well-constructed PSB mixes have been placed within haul roads, residential streets, and local roadways using power plant aggregates (bottom ash or boiler slag), marginal aggregates (including some off-spec materials), coal refuse, and reclaimed paving materials. Such alternative aggregates are often available and economical in areas where high-quality aggregate materials may be in short supply.

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PERFORMANCE RECORD

The successful performance of PSB mixtures depends on the development of strength within the cementitious matrix formed by the pozzolanic reaction between the fly ash and the activator. This cementitious matrix acts as a binder that holds the aggregate particles together, similar in many respects to a low-strength concrete. However, unlike concrete, PSB mixtures are produced at a compactable consistency, not a plastic consistency, for placement at or near optimum moisture content and densification by roller compaction

According to a 1992 survey of state transportation agencies, at least 22 states have made some use of fly ash in stabilized base or subbase applications.[1] Table 5-5 is a summary of the use of fly ash in stabilized base mixtures in these states

Table 5-5. Summary of fly ash use in stabilized base and subbase applications throughout the United States.

State	Estimated Number of Projects	Time Period	Types of Projects	Remarks**
Alabama	Unknown	1955-1965	State roads	Used Class F fly ash
Arkansas*	At least 1	1982	State road	Test section w/100% Class C
Colorado	Unknown	Mid to late 1980's	Local roads	Used in Aurora, Denver suburb
Georgia	At least 1	1985	State road	EPRI fly ash demonstration
Illinois	More than 100	1955-1985	State and county roads	Class F & C ashes (Cook Cty)
Iowa	At least 1	Early to mid 1960's	County road	Class F ash used in Linn Cty
Kansas	At least 3	1987	County roads	EPRI fly ash demonstration
Kentucky*	At least 1	1984	State road	Used kiln dust and Class F ash
Maryland	At least 1	Early 1960's	Shoulders	Used for I-95 shoulders
Michigan*	At least 3	1959-1987	State and private roads	EPRI fly ash demonstration
Mississippi*	Unknown	1983	State roads	Used Class C fly ash
Missouri	At least 10	1970-1988	State and local roads	Class C ash used in Kansas City
Nebraska	At least 1	Unknown	State road	Used Class C ash in subbase
New Jersey*	At least 1	1984	State road	Used on portion of I-295
North Dakota	Several	1971 to mid 1980's	State road	Used lignite ash at I-94
Ohio	At least 10	1970-1985	State and local roads	Used mainly in Toledo
Oklahoma	At least 1	Early to mid 1980's	State road	Used Class C fly ash
Pennsylvania	Several dozen	1954-1985	State and local roads	Used mainly in S.E. PA
Tennessee*	At least 1	1982	State road	Used Class F fly ash
Texas	Unknown	1960-1990	State and local roads	Used Class C and Class F ash
Virginia*	At least 1	1982	State road	Dulles Airport extension road
Wyoming	Unknown	Early to mid 1980's	State roads	Used Class C fly ash

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*Participated in Federal Highway Administration (FHWA) Demonstration Program No. 59, "Fly Ash in Highway Construction."

**Note: Class F fly ash refers to the fly ash derived from the burning of bituminous coals. Class C fly ash refers to the fly ash derived from the burning of either lignite or subbituminous coals.

The three states in which PSB mixtures have been most frequently used are Illinois, Ohio, and Pennsylvania. It has been conservatively estimated that since the 1970's at least 25 to 30 million tons of PSB material have been produced and placed in the United States. One-third to one-half of all the PSB material placed prior to 1990 is thought to have been placed in the metropolitan Chicago area.(2)

Many of the stabilized base and subbase installations have been placed in low traffic areas. such as local streets or parking lots. These installations have not usually been well documented. There are, however, a number of PSB projects that have been well reported and have provided excellent performance. At least seven states installed PSB base courses as part of Federal Highway Administration Demonstration Project No. 59, Fly Ash Use in Highway Construction, during the mid 1980's. Nearly all of these projects have been documented in terms of design and installation, although in many cases, long-term performance data is not available.

During the mid to late 1980's, the Electric Power Research Institute (EPRI) funded three demonstration projects in Georgia, Kansas, and Michigan that involved the use of fly ash in stabilized road base compositions. For each project, EPRI contracted with the utility company supplying the ash to determine basic material properties, assess construction performance, and evaluate long-term pavement and environmental performance for 3 years.

In 1985, the Georgia Department of Transportation constructed a 2.6 km (1.6 mi) relocation of State Route 22 west of Crawfordville. A portion of the two-lane road included a 305 m (1,000 ft) section of cement stabilized pond ash base and a 244 m (800 ft) section of cement stabilized fly ash base. Each of these two base course sections was 215 mm (8 1/2 in) thick. One year after installation, the average strength of the pond ash section was 14,570 kPa (2,115 lb/in^2) and the average strength of the fly ash section was 5,990 kPa (870 lb/in^2).(3)

During 1987, three county gravel roads in Kansas were recycled in place using Class C fly ash. At each site, the existing road surface was pulverized, mixed, and redeposited in its original location. Fly ash was spread over the pulverized road material and mixed by a means of a pulvi-mixer. Following compaction, a seal coat surface was placed on all three of the roadways. Since the reconstruction of these first three locations, more than 44 km (400 mi) of pavement recycling using Class C fly ash have been accomplished in Kansas and Oklahoma.(4)

Also in 1987, the shoulders of a 460 m (1,500 ft) long section of relocated Michigan Route M-54 near Flint were constructed using 620 metric tons (690 tons) of a cement stabilized high carbon Class F fly ash base. A total of 915 m (3,000 ft) of shoulder material was placed at a width of 2.7 m (9 ft) and a compacted thickness of 250 mm (10 in). Core strengths after 270 days were variable, but reached as high as 6,890 kPa (1,000 lb/in^2). Although performance has been acceptable, some isolated areas of cracking were observed in both directions of the shoulder pavement after the first year of service.(5)

The largest single reported project in the United States involving the use of fly ash in PSB construction occurred during the early to mid 1970's with the building of runways, taxiways, and aprons at Newark International Airport, in Newark, New Jersey. A flexible pavement system using a base of lime, Portland cement, fly ash, and sand was designed to withstand the stresses from jumbo jet aircraft. The base course consisted of three layers, each with slight variations in the mix design. The lime and Portland cement combined ranged from 3 to 4 percent and the fly ash ranged from 10 to 12 percent. The PSB sections ranged in thickness from 610 to 914 mm (24 to 36 in). The ultimate strength of the 4 percent lime and Portland cement mix, which contains a blend of crushed stone and sand as the aggregate, was found to range from 13,780 to 17,910 kPa (2,000 to 2,600 lb/in^2).(6) After 20 or more years, the PSB pavements continue to perform satisfactorily.

PSB pavements have provided good to excellent performance over many years in numerous locations. In general, these mixtures have also been more economical than alternative base materials in many areas. Nonetheless, the major concern of highway engineers with stabilized-based materials, including soil-cement, is the development of cracks within the base course. These cracks, which are more often caused by shrinkage rather than fatigue, usually reflect up through the overlying asphalt pavement surface, resulting in increased long-term maintenance costs.

MATERIAL PROCESSING REQUIREMENTS

Moisture Control

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Aside from possible adjustments to moisture content, there is little to no processing required for using fly ash in PSB mixtures. For Class F fly ash, the moisture content is dictated by the type of equipment to be used in producing the base course material. If a central-mix concrete plant is used, the fly ash will most likely be fed from a silo in dry form. If a pugmill mixing plant is used, the fly ash will probably be fed from a storage bin in conditioned form. If PSB materials are to be mixed in place at the jobsite, Class F fly ash would also be placed and mixed in a conditioned form. Conditioned ash contains a minimal amount of water (usually 10 to 15 percent) to prevent dusting.

Activators (e.g., lime, Portland cement, kiln dust) are nearly always added to the mixture in a dry form. This means that the activators require no processing and will be delivered to the job site and stored in silos or tankers.

If Class C fly ash is used, it is likely to be self-cementing. For self-cementing fly ashes, there are two ways to offset the rapid hardening of base materials using such ashes. One is to initially condition the ash with relatively low amounts (in the range of 10 to 15 percent) of water, stockpile the partially hardened material for several weeks or more, then run the ash through a crusher to break down any agglomerations prior to use. The second is to use a commercial retarder (such as gypsum or borax) blended at a low percentage with the fly ash as a means of delaying the initial set.[7]

The aggregate(s) used in PSB mixtures should be in a saturated surface-dry condition during stockpiling. The moisture content of the aggregate(s) should be checked prior to mixing to ensure that excess moisture was not acquired while the aggregate(s) was being stockpiled.

ENGINEERING PROPERTIES

Some of the properties of fly ash that are of particular interest when fly ash is used in stabilized base applications include water solubility, moisture content, pozzolanic activity, fineness, and organic content.

Water Solubility: The physical requirements most frequently cited for the use of fly ash (Class F) in PSB mixtures are provided in ASTM C593[8], which specifies a maximum water soluble fraction of 10 percent.

Moisture Content: If conditioned fly ash is to be used, the moisture content of the conditioned ash must be determined prior to mixing in order to confirm that the moisture content is in the same range as the ash used for the mix design.

Pozzolanic Activity: One of the most important properties of fly ash, related to its use in PSB mixtures, is pozzolanic activity or reactivity. The pozzolanic reactivity is an indicator of the ability of a given source of fly ash to combine with calcium to form cementitious compounds. The pozzolanic reactivity of fly ash is influenced by its fineness, silica and alumina content, loss on ignition, and alkali content. Besides the gradation of the aggregate used, the pozzolanic reactivity of the fly ash is the major contributor to the strength of the base mix. Pozzolanic activity of fly ash with either lime or Portland cement can be determined using the test methods described in ASTM C311.[9]

Fineness: Fineness requirements in ASTM C593 specify that 98 percent of the fly ash should be finer than a 0.6 mm (No. 30) sieve and 70 percent finer than a 0.075 mm (No. 200) sieve. Most fly ash is capable of meeting these specifications. Minimum compressive strength requirements when fly ash is blended with lime at 7 and 21 days are also recommended in ASTM C593.[8]

Organic Content: Fly ash used in PSB mixtures does not have to meet the ASTM C618[10] requirements of fly ash that is used in Portland cement concrete. LOI is not a criterion for fly ash use in PSB mixtures.

Some of the properties of stabilized base mixes that are of particular interest when fly ash is incorporated include compressive strength, flexural strength, modulus of elasticity, bearing strength, autogeneous healing, fatigue, freeze-thaw durability, and permeability.

Compressive Strength: This is the most widely used criterion for the acceptability of PSB materials. Compressive strength testing of PSB mixtures is usually performed on Proctor-size specimens 10.2 cm (4 in) in diameter by 11.7 cm (4.6 in) in height, molded at or very close to the optimum moisture content of the mixture. Within limits, the higher the compressive strength, the better the quality of the stabilized material. For cement-stabilized base mixtures, the Portland Cement Association recommends a minimum 7-day compressive strength after curing at 23°C (73°F) of 3,100 kPa (450 lb/in^2).[11] Where lime or kiln dust is used as the activator, ASTM C593 specifies a minimum compressive strength, after 7 days of curing at 38°C (100°F), as 2,760 kPa (400 lb/in^2). The ultimate

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strength of PSB mixtures containing Class F fly ash is considerably higher than the 7-day strength. In many cases, long term compressive strength development of Class F fly ash mixes may be two to three times higher than the 7-day strength.

Actual compressive strength development of PSB mixtures in the field is time- and temperature- dependent. As the temperature increases, the rate of strength gain also increases. At or below 4°C (40°F), the pozzolanic reaction virtually ceases and the mixture no longer gains strength. However, once temperatures exceed 4<°C (40°F), the pozzolanic reaction resumes and further strength gains occur. In this way, PSB mixtures continue to show incremental gains in strength over many years.

Flexural Strength: Because hardened PSB material is a semi-rigid pavement layer, the flexural strength of PSB mixtures may be a better indicator of the effective strength of this material. Although flexural strength can be determined directly by testing, most transportation agencies estimate the flexural strength of these materials as a fraction of the material's compressive strength. An average value of 20 percent of the unconfined compressive strength is considered to be a fairly accurate estimate of the flexural strength of PSB mixtures.[12]

Modulus of Elasticity: The modulus of elasticity is a measure of the stiffness or bending resistance of a material. For semi-rigid materials such as PSB mixtures, the relationship between stress and strain is not linear and, therefore, the modulus of elasticity is not a constant value, but increases as the compressive strength of the material increases. The modulus of elasticity, as determined from flexural strength testing instead of compressive strength testing, is recommended for use in pavement design calculations. For most PSB mixtures, the modulus of elasticity is in the range of 9.6 x 10^6 kPa (1.4´ 10^6 lb/in^2) to 17.2 x 10^6 kPa (2.5´ 10^6 lb/in^2).[13]

Bearing Strength: The California Bearing Ratio (CBR) test[14] is often used as a way of measuring the bearing strength of soils used as subgrade materials for highway and airfield pavements. Due to the relatively high strength of compacted PSB mixtures, high CBR values (in excess of 100 percent) are not that unusual. Use of the CBR test is more applicable to subgrade soil stabilization with fly ash than in evaluating PSB mixtures.

Autogenous Healing: One of the unique characteristics of PSB compositions is their inherent ability to heal or re-cement cracks within the material by means of a self-activating mechanism. This mechanism is referred to as autogenous healing and it results from the continuation of the pozzolanic reaction between the activator and the fly ash in the PSB mixture. The extent to which autogenous healing occurs depends on the age of the pavement when cracking develops, the degree of contact of the fractured surfaces, curing conditions, the strength of the pozzolanic reaction, and available moisture.[12]

Fatigue Properties: All engineering materials are subject to potential failure caused by progressive fracture under the action of repeated wheel loadings. In pavement design analysis, the flexural fatigue properties of PSB materials are a very important consideration. The flexural strength of PSB mixtures, like the compressive strength, increases with time, while the stress level (the ratio of applied stress to the modulus of rupture) gradually decreases. Because of autogenous healing, PSB mixtures are even less susceptible to fatigue failure than other conventional paving materials.[15]

Freeze-Thaw Durability: Durability testing of PSB materials is performed using one of two established test procedures. For lime and lime-based activators (including kiln dusts), the durability test procedure specified in ASTM C593 is used. This is a vacuum saturation procedure that has been correlated to weight loss after 12 freeze-thaw cycles. The acceptance criterion for ASTM C593 durability testing is that test specimens must have at least 400 psi unconfined compressive strength following vacuum saturation testing. For cement-based activators, the durability test procedure specified in ASTM D560[16] is used. The acceptance criterion is a maximum 14 percent weight loss after 12 freeze-thaw cycles.[16]

The minimum strength required prior to the first freezing cycle, in order to provide sufficient durability against freeze-thaw damage, is dependent on the severity of the climate. The American Coal Ash Association (ACAA) recommends the minimum compressive strengths of 6,900, 5,500 and 4,100 kPa (1000, 800, and 600 lb/in^2), respectively, for severe, moderate, and mild freeze-thaw conditions.[7]

Permeability: The permeability of hardened PSB materials is very low, depending on aggregate gradation, particularly when compared with that of crushed stone or granular bases and subbases, or even with the permeability of asphaltic base courses. In most cases, as the compressive strength of the PSB material increases, the permeability decreases. Initial permeability readings for hardened PSB mixtures can be expected to range between 10^{-5} and 10^{-6} cm/sec, as measured by the falling head permeability test. As the pozzolanic reaction proceeds, PSB materials may have permeability values between 10^{-6} and 10^{-7} cm/sec.[15]

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DESIGN CONSIDERATIONS

Mix Design

A wide range of aggregate sizes can be accommodated in stabilized base and subbase mixtures. After determining the particle size distribution of the aggregate to be used in the PSB mixture, the initial step in determining the mix proportions is to find the optimum fines content. This is done by progressively increasing the quantity of fines (consisting of fly ash plus activator) and making density determinations for the blends of aggregate and fines. An estimated optimum moisture content is selected "by eye" and held constant for each blend. Each blend of aggregate and fines is compacted into a Proctor mold using standard compaction procedures. At least three such blends are required and five blends are recommended. Dry density versus fines content is plotted and this procedure is used to identify the percentage of fines (expressed as a percentage by dry weight of the total mixture) that results in the highest compacted dry density.

It is recommended that the optimum fines content selected by this procedure be 2 percent higher than the fines content at the maximum dry density. The optimum moisture content must then be determined for the mix design proportions selected by this procedure.

Once the fines content and optimum moisture have been determined, the ratio of activator to fly ash must also be determined. Using a series of trial mixtures, final mix proportions are selected on the basis of the results of both strength and durability testing according to ASTM C593 procedures.[8]

To determine the most suitable proportion of activator to fly ash, five different mix combinations should be evaluated at the optimum moisture content. The typical range of activator to fly ash ratios is 1:3 to 1:5 when using lime or Portland cement. The typical range of kiln dust to fly ash ratios is likely to be in the 1:1 to 1:2 range.

The ratio of fines (activator plus fly ash) to aggregate determines the amount of matrix available to fill the void spaces between aggregate particles. Normally, activator plus fly ash contents range from 12 to 30 percent by dry weight of the total mix, although fine-graded aggregates require a higher percentage for satisfactory strength development than well-graded aggregates.

In general, the trial mixture with the lowest ratio of activator to fly ash that satisfies both the strength and durability criteria is considered the most economical mixture. To ensure an adequate factor of safety for field placement, it is recommended that the PSB mixture used in the field have an activator content that is at least 0.5 percent higher (1.0 percent higher if kiln dust) than that of the most economical mixture identified in the laboratory tests.[7]

Structural Design

The design of pavements using PSB mixtures can be undertaken using AASHTO structural equivalency design methods.[17] The main factors influencing the variation in the structural layer coefficient for thickness design using the AASHTO method are the compressive strength and modulus of elasticity of the PSB material. The value of compressive strength most often used to determine the structural layer coefficient for PSB mixtures is the field design compressive strength. The field design compressive strength is simulated by the compressive strength determined in the laboratory after 56 days of moist curing at 23°C (73°F).[7] Other curing conditions may be required by various specifying agencies.

Based on the comparative performance of pozzolanic and crushed stone base materials from studies performed at the University of Illinois[15], and using a value for a_1 of 0.44 (representing a bituminous concrete wearing surface) and a value for a_3 of 0.15 (representing a crushed stone base), structural layer coefficients for PSB mixtures were recommended. Table 5-6 provides a listing of recommended coefficients based on the early strength development of the mixtures.

Structural layer coefficient values (a_2) of 0.30 to 0.35 have been recommended for bituminous or Portland cement stabilized bases.[17]

CONSTRUCTION PROCEDURES

Material Handling and Storage

If the fly ash to be used in a PSB mixture is to be mixed in a dry form, the fly ash must be stored in a silo or pneumatic tanker until it is ready for use. If conditioned fly ash (usually Class F fly ash) is to be used, then the conditioned fly ash can be stockpiled until it is ready to be used. If fly ash is stockpiled for an extended period in

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dry or windy weather conditions, the stockpile may need to periodically be moistened to prevent unwanted dusting.

Mixing, Placing, and Compacting

The blending or mixing of PSB materials can be accomplished either in a mixing plant or in place. Plant mixing is recommended because it provides greater control over the quantities of materials batched, and it also results in the production of a more uniform PSB mixture.

Table 5-6. Recommended structural coefficients for PSB mixtures.

Quality	Compressive Strength, kPa (lb/in^2) (7 days @ 38°C (100°F)	Recommended Structural Coefficient
High	Greater than 6,900 (1,000)	a_2 = 0.34
Average	4,500 to 6,900 (650 to 1,000)	a_2 = 0.28
Low	2,800 to 4,500 (400 to 650)	a_2 = 0.20

Blending of PSB ingredients in a mixing plant can occur in discrete batches or by continuous mixing. Pugmill mixing plants blend accurately controlled amounts of aggregate, fly ash, activator, and water in batches in a mixing chamber, usually for periods of 30 to 45 seconds. Pugmill mixing plants can also be used with properly calibrated field conveyors from bins or silos for a continuous mixing operation. Rotating drum mixers have also been successfully used for blending PSB materials in batches.(13)

An alternative to plant mixing is in-place mixing. Although the mix-in-place approach does not usually result in as accurate a proportioning of the mix components as plant mixing, it is still possible to produce a high-quality PSB material using this approach. The various components of the PSB mixture are delivered and spread on the road site, then mixed in place using a pulvi-mixer, a self-propelled rotating device with mixing pads capable of mixing to a depth of 300 to 450 mm (12 to 18 in).

Plant-mixed materials should not be stockpiled, but should be delivered to the job site as soon as possible after mixing. Compaction of PSB materials should be completed as quickly as possible after placement, especially with mixtures containing Class C (self-cementing) fly ash.

The delivery of PSB materials to the job site has been most frequently handled by covered end-dump hauling vehicles. The same equipment is basically used for spreading plant-mixed PSB material, as well as material to be mixed in place. Once the PSB material is dumped, spreading is usually accomplished by a bulldozer or a motor grader. However, plant-mixed material can also be spread to a more uniform and accurate loose thickness by a spreader box or a paving machine. The material must be as close as possible to optimum moisture content when placed.

During the in-place mixing operation, fly ash should be placed on the roadway first, either directly on a prepared subgrade, or above a layer of aggregate, if the PSB mixture contains aggregate. Fly ash is usually applied in a conditioned form to minimize dusting. The activator is then placed on top of the fly ash, usually in a dry condition, although lime has also been applied in a slurry form. The materials are then mixed together by means of a rotary mixer. Water is added as needed using a water truck with spray nozzles.

Equipment used for compaction is the same, regardless of whether PSB material is plant-mixed or mixed in place. For granular or more coarsely graded PSB materials, compaction requires the use of steel-wheeled, vibratory, or pneumatic rollers. For more fine-grained PSB materials, initial compaction often requires the use of a sheepsfoot roller, followed by a pneumatic roller.(7)

PSB materials should not be placed in layers that are less than 100 mm (4 in) or greater than 200 to 225 mm (8 to 9 in) in compacted thickness. The material should be spread in loose layers that are approximately 50 mm (2 in) greater in thickness prior to compaction than the desired compacted thickness. The top surface of an underlying layer should be scarified prior to placing the next layer.

Curing

After placing and compacting the PSB material, it must be properly cured to protect against drying and to assist in the development of in-place strength. If an asphalt concrete pavement is to be placed as an overlay, an asphalt emulsion seal coat should be applied to the top surface of the base or subbase within 24 hours of

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placement. The exact type of emulsion, rate of application, and temperature of the asphalt must be in compliance with applicable specifications.

The performance of pavement systems incorporating PSB material is dependent on the development of in-place strength following placement, compaction, and curing. Depending on the anticipated traffic loadings, it is necessary to analyze when traffic can be permitted to travel on the base material, while also avoiding potential fatigue damage due to early overloading.

Based on laboratory testing for strength development, it is usually possible to determine when the PSB material is likely to achieve an in-place compressive strength of 2,410 kPa (350 lb/in^2). Unless an asphalt surface or binder course has been placed over the PSB material, vehicles should not be permitted to use the PSB layer until it has achieved at least 2,410 kPa (350 lb/in^2) in place. Ordinarily, placement of asphalt paving over the PSB material is recommended within 7 days after the PSB material has been placed.[7] If a Portland cement concrete pavement is to be constructed over the PSB layer, a waiting period of 7 days is also recommended.

Special Considerations

Late Season Construction

Unless pozzolan stabilized materials are able to develop a certain level of strength prior to the first freeze-thaw cycle, these materials may be unable to withstand repeated freezing and thawing. Since strength development is time- and temperature-dependent, PSB material placed when the air temperature is too cold may not be able to develop the strength and durability needed for adequate freeze-thaw resistance. Normally, very little strength development occurs when the temperature within the PSB material is 5°C (40°F) or lower.

For northern states, state transportation agencies have previously established construction cutoff dates for PSB materials that range from September 15 to October 15, depending on location within state and/or ability to develop compressive strength in the laboratory.[18]

Self-Cementing Fly Ash

Self-cementing fly ash mixed with water alone usually results in a very rapid time of set. Delays between placement and compacting of PSB material containing self-cementing fly ash are accompanied by a significant decrease in the strength of the compacted base material, unless a retarder is used. Accordingly, PSB mixtures containing self-cementing fly ash should be compacted as soon as possible after mixing, with a recommended maximum elapsed time of no more than 2 hours between mixing and completion of compaction.[19]

Low percentages of water in the range of 10 to 25 percent by weight of ash, sufficient to retard dusting, can be added at the mixing plant, with added water that is required for proper compaction applied to the PSB material in place at the construction site before compaction.

A commercial retarder (such as gypsum, borax, or concrete retarding admixture) may be added in low percentages to the PSB material at the mixing plant. It has been found that the addition of 1 percent gypsum did not adversely affect the overall strength development of PSB material, but was effective in retarding rapid setting.[19,20]

Crack Control

Pavement base layers constructed with PSB materials are subject to shrinkage cracking. The development of cracks is related to the hydration reaction between the activator and fly ash and is more evident when Portland cement is used in the mix. Some cracks do reflect up through the overlying asphalt pavement, but are less likely to do so if a concrete pavement is used. If surface cracks are sealed to prevent the intrusion of water and subsequent damage due to freezing and thawing, the overall durability of the PSB layer should not be adversely affected.

Approaches for controlling or minimizing the potential effects of reflective cracking associated with PSB layers have been recommended by the ACAA.[7]

UNRESOLVED ISSUES

Crack control has long been considered by many state transportation agencies as a prime concern associated with the use of PSB mixtures. Although there have been a number of experimental projects related to joint placement for pozzolanic bases, there is still no universally accepted procedure for minimizing, or even possibly

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eliminating, shrinkage cracking in such mixtures. Addressing this issue may make possible greater acceptance and use of PSB mixtures by state transportation agencies.

Although the overwhelming majority of the PSB placed over the years has been with Class F fly ash, there has been an increasing usage of Class C fly ash in PSB mixtures. Because the handling characteristics of Class C fly ash are so different from Class F fly ash, more specific direction is needed on how to best handle Class C fly ash when used as an activator in PSB mixtures.

Information needed includes how to evaluate the extent of flash setting, how to select the proper conditioning technique for different degrees of reactivity, and when and how much retarder should be used.

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[**Flowable Fill**] [**Material Description**] [**Asphalt Concrete**] [**Portland Cement Concrete**] [**Embankment or Fill**]

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TRT Terms: research, facilities, transportation, highway facilities, roads, parts of roads, pavements, Waste products as road materials--Handbooks, manuals, etc, Pavements, Asphalt concrete--Design and construction--Handbooks, manuals, etc, Pavements, Concrete--Design and construction--Handbooks, manuals, etc, Pavements--Additives--Handbooks, manuals, etc, Fills (Earthwork)--Design and construction--Handbooks, manuals, etc, Roads--Base courses--Design and construction--Handbooks, manuals, etc, Wastes, Environmental impacts, Recycling
Scheduled Update: Archive - No Update needed

This page last modified on 03/08/2016

Exhibit D

Thomas J. Dehlin, P.E.
Project Engineer (Licensed in IL and WY)
(312) 269-6373
tdehlin@sargentlundy.com

December 2, 2021

Re: 2008 Reconstruction of Access Ramp for Pond 2 at Joliet 29 Generating Station

Ms. Christine Zeivel
Assistant Counsel
Division of Legal Counsel
Illinois Environmental Protection Agency
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62702

Dear Ms. Zeivel:

In response to the Illinois Environmental Protection Agency's request for additional information on the 2008 reconstruction of the access ramp into Pond 2 at Midwest Generation, LLC's ("MWG") Joliet 29 Generating Station ("Joliet 29") in connection with Illinois Pollution Control Board Case No. AS 2021-001, "Petition of Midwest Generation for an Adjusted Standard from 845.740(a) and Finding of Inapplicability of Part 845," MWG is transmitting the enclosed documents related to Pond 2's construction history for the Agency's review and consideration as the Agency prepares its recommendation to the Board. The enclosed documents contain design drawings, technical specifications, construction quality assurance (CQA) reports, and related correspondence for when the new geomembrane liner was installed in Pond 2 in 2008. These design documents and construction records are organized as follows:

- **Attachment 1 ("2008 Re-Lining Technical Specifications"):** Natural Resource Technology, Inc. *Technical Specifications for Ash Impoundment #2 Liner Replacement*. Joliet 29 Generation Station, 1800 Channahon Road, Joliet Illinois. Natural Resource Technology Project No. 1862. Dated August 3, 2007.
- **Attachment 2 ("2008 Re-Lining Construction Records"):** *Construction Documentation Transmittal, Ash Impoundment #1 and #2 Liner Replacement*. Letter from Ms. Heather M. Simon (Natural Resource Technology, Inc.) to Mr. Brian DelCorio (Midwest Generation, LLC). Dated December 23, 2008. The 2008 Re-Lining Construction Records were attached as Exhibit 15 to the original petition, and are attached here for convenience.

- **Attachment 3 ("2016 History of Construction"):** Geosyntec Consultants. *History of Construction, Ash Pond 2, Joliet 29 Station*. Dated October 2016.
- **Attachment 4 ("Field Change Request #5"):** Field change request submitted by Brieser Construction (the Contractor) working on the 2008 Pond 1 and Pond 2 re-lining projects.
- **Attachment 5 ("Project Invoices"):** Job Invoice Nos. 34735 and 34737 submitted by the Contractor to MWG.

Although the attached technical specifications are not the final technical specifications issued for construction, it may be inferred from the attached construction records, field change request, and project invoices that the specifications for the ramp reconstruction work referenced herein were finalized as proposed in the attached August 3, 2007 version or were finalized with minimal changes that did not impact how the Contractor was instructed to reconstruct the ramp (*e.g.*, editorial only).

Based on these design documents and construction records, no CCR or CCR residues were used to reconstruct Pond 2's ramp prior to or after installing the pond's new geomembrane liner in 2008. The original ramp surface material installed circa 1978, which may have contained CCR and/or CCR residues, was originally specified to be re-used as the surface material for the reconstructed ramp but was ultimately deemed unsuitable for this purpose. Instead, granular fill imported from an offsite borrow source was used to reconstruct the surface of the pond's access ramp. Moreover, these 2008 construction records indicate that Pond 2's geomembrane liner was installed above the pond's original Poz-o-Pac liner (with a 16-oz non-woven geotextile in between both liners). Therefore, the ramp subgrade is comprised of the original fill material placed when Pond 2 was constructed circa 1978.

To facilitate the Agency's review of the enclosed documents, I have prepared the following summary of the 2008 reconstruction of Pond 2's access ramp. This summary is predominately based on information provided in the enclosed construction records. Any assumptions or instances of engineering judgement made by S&L are stated otherwise.

Based on the enclosed design documents and construction records, the 2008 reconstruction of Pond 2's ramp may be summarized as follows:

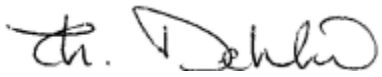
- Per Note 6 on Sheet C020 (Liner Subgrade Preparation) of Attachment 1, the Contractor was to "remove at least 18 inches of Existing Ramp Material for placement of subgrade layer and final layer of ramp."
    - Note 6 further states that the Contractor was to, subject to Owner approval, re-use the Excavated Ramp Material as the final layer of ramp.
    - "Excavated Ramp Material" was defined in Section 02300, Paragraph 2.01.E (Earthwork, General Soil Materials) as "[e]xcavated material from the existing ramp surface that does not require disposal and may be reused as backfill, subject to Owner's and/or Engineer's approval."
- Per Section 02300 (Earthwork), Paragraphs 1.01.C and 1.01.H of Attachment 1, the Contractor was to:
    - First, load and transport the Excavated Ramp Material to an onsite stockpile,
    - Then, after the new geomembrane liner was installed, load and transport the Excavated Ramp Material from the onsite stockpile area back to the ramp, and

  - Finally, place, grade, and compact the Excavated Ramp Material on the ramp above the new geomembrane liner.
- Per Section B on Sheet C031 (Ramp Section) of Attachment 1, the Excavated Ramp Material was to be used to create the 18-in.-thick layer of ramp surface material above the new geomembrane liner.
- Per Attachment B to the 2008 Re-Lining Construction Records (Attachment 2), the Engineer submitted Field Directive #1 on April 25, 2008, to the Owner with a revision to Section B on Sheet C031.
  - Per this field directive, the modifications to the layers placed above the geomembrane liner on the ramp were necessary due to "the presence and depth of the Poz-o-Pac liner on the access ramp."
    - The Poz-o-Pac liner refers to the original liner installed when Pond 2 was first constructed as shown on Sheets 2 and 3 of Drawing 5079-C-5019 in Appendix A-2 to the 2016 History of Construction (Attachment 3).
    - Per the "Access Ramp Detail" on Sheet 2 of Drawing 5079-C-5019, the Poz-o-Pac liner was to extend up and over the ramp subgrade, and the ramp surface was to be comprised of 9 inches of compacted limestone. Although this detail is specified for Pond 1 only, it is presumed that Pond 2's ramp was constructed in a similar manner given that Poz-o-Pac was encountered when excavating the existing ramp surface material prior to installing Pond 2's new geomembrane liner.
  - In lieu of excavating the existing Poz-o-Pac liner on Pond 2's ramp, the Engineer instructed the Contractor to "clean off the Poz-o-Pac surface to the extent practical to remove rocks that may pose a hazard to the geomembrane before placing the 16-ounce (oz) geotextile over the subgrade surface."
  - In addition, the Engineer noted that the Excavated Ramp Material was not sufficient to be re-used and therefore instructed the Contractor to "place 6 inches of limestone screenings (approved replacement material for the specified sand) over the geosynthetics and 6 inches of the warning layer material (IDOT CA-6) over the limestone screenings." This modification to Pond 2's new ramp surface is shown in the revised Section B on the version of Sheet C031 (dated April 25, 2008) attached to Field Directive #1.
- On April 28, 2008, the Contractor submitted Field Change Request #5 (Attachment 4) to MWG for supplying enough limestone screenings and IDOT CA-6 material to surface Pond 2's ramp instead of the 18 inches of Excavated Ramp Material originally specified. The Contractor estimates approximately 270 tons of limestone screenings and IDOT CA-6 material will be required. MWG approved the field change request on April 30, 2008.
- On May 7 and 8, 2008, the Contractor submitted Job Invoice Nos. 34735 and 34737 (Attachment 5), respectively, for approximately 150 tons of limestone screenings and 125 tons of IDOT CA-6 material from Lafarge Joliet Sand and Gravel for Pond 2's ramp.
- Per the as-built / record drawing of Sheet C031 (dated December 19, 2008) enclosed with Attachment 2, Section B shows the surface material installed above the geomembrane liner on Pond 2's ramp consists of one 6-inch cushion layer and one 6-inch warning layer. This detail matches the narrative and graphical representation of the modified ramp surface material specified by the Engineer in Field Directive #1 for Pond 2's ramp.

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Based on the preceding narrative and referenced construction documentation, the Excavated Ramp Material was not used to reconstruct Pond 2's ramp when a new geomembrane liner was installed therein in 2008. Instead the pond's original Poz-o-Pac liner was left in-place along the ramp and limestone screenings and IDOT CA-6 material were imported, placed, graded, and compacted to create the new ramp surface. Because the original Poz-o-Pac liner was left in-place, the ramp subgrade shown on the as-built Sheet C031 (dated December 19, 2008) enclosed with the 2008 Re-Lining Construction Records (Attachment 2) is comprised of the original fill material placed when Pond 2 was constructed in 1978.

Best Regards,



Thomas J. Dehlin
Project Engineer

Enclosures: Attachment 1 – 2008 Re-Lining Technical Specifications
Attachment 2 – 2008 Re-Lining Construction Records
Attachment 3 – 2016 History of Construction
Attachment 4 – Field Change Request #5
Attachment 5 – Project Invoices

Attachment 1

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ATTACHMENT 1
2008 RE-LINING TECHNICAL SPECIFICATIONS

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WATER-N6B1

NATURAL RESOURCE TECHNOLOGY

MIDWEST GENERATION

Technical Specifications for Ash Impoundment #2 Liner Replacement

Joliet 29 Generation Station
1800 Channanhon Road
Joliet, Illinois

August 3, 2007

Project No: 1862

MWG13-15_18654

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NATURAL RESOURCE TECHNOLOGY

MIDWEST GENERATION

Technical Specifications for Ash Impoundment #2 Liner Replacement

Joliet 29 Generation Station
1800 Channanhon Road
Joliet, Illinois

August 3, 2007

Project No: 1862

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NATURAL RESOURCE TECHNOLOGY

www.naturalrt.com

TRANSMITTAL

To:	**Midwest Generation, LLC**	**Date:**	**August 3, 2007**
	Joliet 29 Station	**Project #:**	**1862**
	1800 Channanhon Road	**From:**	**Eric Tlachac**
	Joliet, IL 60436		
Attn:	**Elsie Briette**	**Direct No:**	**262-522-1214**
Cc:	**Len Johnson, Midwest Generation**		
Re:	**Draft Specifications and Drawings for Ash Impoundment #2 Liner Replacement**		

For Your Files ____ **As Requested** ____ **For Review** X **Approve & Return** ____

Copies:	Description
1	Draft Technical Specifications for Ash Impoundment #2 Liner Replacement, Midwest Generation Joliet 29 Station, 1800 Channahon Road, Joliet, Illinois.

Message:

Please find enclosed draft technical specifications and drawings for the replacement liner for Ash Impoundment #2 at the Joliet 29 Station. Please review and contact me with your comments. Following receipt of your comments, we will finalize the technical specifications and drawings, and send you an adequate number of copies to include in your Request For Proposal for the project.

Thanks for the opportunity to provide continued support to Midwest Generation on this project.

EJT

23713 W. Paul Rd., Ste. D • Pewaukee, WI 53072 • Phone: 262.523.9000 • Fax: 262.523.9001 • www.naturalrt.com

[1862 EBriette Draft Specs trans 070803]

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NATURAL RESOURCE TECHNOLOGY

DRAFT

(DRAFT)
TECHNICAL SPECIFICATIONS FOR ASH IMPOUNDMENT #2 LINER REPLACEMENT

JOLIET 29 GENERATION STATION
1800 CHANNANHON ROAD
JOLIET, ILLINOIS

Project No. 1862

Prepared For:

Midwest Generation, LLC
1800 Channahon Road
Joliet, Illinois

Prepared By:

Natural Resource Technology, Inc.
23713 West Paul Road, Suite D
Pewaukee, WI 53072

August 3, 2007

_____	_____
Signature **(Seal)**	**Signature** **(Seal)**

MWG13-15_18657

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C030 Warning Layer Plan (D1862 C030-01)
C031 Details and Sections (D1743 C031-01)

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SECTION 00001
SPECIFICATION DATA SHEET

INTRODUCTORY PAGE

SPECIFICATION TITLE:	Ash Impoundment #2 Liner Replacement Midwest Generation, LLC Joliet 29 Generation Station Joliet, Illinois
REVISION NO.:	0
DATE:	August 1, 2007
MIDWEST GENERATION PROJECT MANAGER:	Elsie Briette– (815) 207-5489
NATURAL RESOURCE TECHNOLOGY, INC. (NRT) ENGINEERS:	Eric J. Tlachac, PE – Project Manager–(262) 522-1214 Heather M. Simon, PE – Project Engineer–(262) 522-1207

DESCRIPTION OF WORK SUMMARY:

Replacement of liner in Ash Impoundment #2 at Joliet 29 Generation Station in Joliet, Illinois. Site activities will consist of subgrade preparation, including minimal grading, excavation, transport, stockpiling and disposal, installation of marker posts, excavation of anchor trench, installation of white, 60-mil HDPE geomembrane and surrounding geotextile, placement of warning layer material, ramp reconstruction, and leak location survey of geomembrane.

END OF SECTION

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DIVISION 1

DIVISION 1

GENERAL REQUIREMENTS

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SECTION 01010
SUMMARY OF WORK

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Definitions

B. Location of Project

C. Existing Site Conditions and Uses

D. Work by Contractor

E. Work by Owner

F. Work by Others

1.02 DEFINITIONS

A. Owner: Midwest Generation, LLC.

B. Engineer: Natural Resource Technology, Inc. (NRT).

C. Contractor: The Contractor performing the Work described herein.

D. Contract Drawings: Set of construction drawings titled, "Ash Impoundment #2 Liner Replacement, Midwest Generation, Joliet Station No. 29, Joliet, Illinois."

E. Specifications: Exhibit A – Technical specifications of which this is the first Section.

F. Work: All labor, supplies, and materials for completing liner construction, as shown and specified.

1.03 LOCATION OF PROJECT

A. The project is located at Ash Impoundment #2 at the Joliet Station No. 29 in Joliet, Illinois.

B. Site is easily accessible by truck but security clearance is required for access. All contractor personnel must sign in at gate house.

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1.04 EXISTING SITE CONDITIONS AND USES

A. Ash Impoundments #1 and #2 both receive wastewater from the plant and individually discharge to Ash Impoundment #3 (east of the plant East Entrance, not shown on Contract Drawings). They operate in parallel to one another with only one impoundment in service at any given time. Currently, Ash Impoundment #1 is operating. Ash Impoundment #2 is not operating and undergoing fly ash removal. The condition of the current liner is unknown. The base of the impoundment is approximately 19 feet from the top bank. Ash fine deposits are distributed throughout the base of the impoundment. The total approximate volume of the impoundment is 14.5 million gallons.

B. The Illinois Environmental Protection Agency (IEPA) is reviewing the Water Pollution Control Construction Permit Application for the project.

C. Access to the Site will be provided at the Main Entrance.

D. Overhead and underground utilities are present at the site.

1.05 WORK BY CONTRACTOR:

A. The Contractor shall perform the following Work:

1. Furnish all labor, materials, services, equipment, and perform all necessary work for the excavating, loading, and hauling of brush and excess material from Ash Impoundment #2 to an approved recycling/disposal facility; construction of geomembrane anchor trench; installation of geomembrane liner; excavating, stockpiling, loading, and hauling ramp material to an Owner approved location; and transporting and placing imported soil at the site; quality control activities including leak location survey; documentation surveys; and completing site restoration activities as indicated on the Contract Drawings and as specified herein.

B. It shall be the Contractor's responsibility to obtain complete information as to the work involved in the project in order to submit a complete and comprehensive bid. Under no circumstances, shall the Contractor make any claims for any additional expenses incurred due to his failure to obtain a complete understanding of the complete and detailed scope of work involved during the bid period, after award, or after the Work is in progress. The summary of work described above is an overall summary of work to be performed and is the responsibility of the Contractor. It does not supersede specific requirements of other Contract Documents.

1.06 WORK BY OWNER

A. Work to be performed by the Owner or Owner's designated representatives is as follows:

1. Construction inspection and construction quality assurance (CQA) activities.

2. Public relations.

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3. Relocation of southern aboveground piping adjacent o Ash Impoundment #2.

4. Dredging of ash deposits from Ash Impoundment #2, and transportation of ash for disposal.

PART 2 - PRODUCTS **(NOT USED)**

PART 3 - EXECUTION **(NOT USED)**

END OF SECTION

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SECTION 01015
GENERAL REQUIREMENTS

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Abbreviations

B. Contractor's Responsibilities

C. Other's Responsibilities

D. Permits

E. Measurement and Payment

F. Estimates of Plan Quantities

G. Construction Limits

H. Work on Properties Owned by Others

1.02 ABBREVIATIONS

A. Abbreviations: ANSI – American National Standard Institute
ASTM – American Society for Testing and Materials
IDOT – Illinois Department of Transportation
IEPA – Illinois Environmental Protection Agency
NEC – National Electric Code; latest edition
NEMA – National Electrical Manufacturers Association
NPFA – National Fire Protection Association
OSHA – Occupational Safety and Health Administration

1.03 CONTRACTOR'S RESPONSIBILITIES

A. Become familiar with conditions relating to execution of Work. Neglect of this requirement will not be accepted as a basis for additional compensation.

B. Schedule operations to coordinate work of Contractor's forces, subcontractors, and suppliers to meet project schedule and completion date.

C. Obtain complete data of site and inspect areas scheduled to receive Work before proceeding with such Work.

D. Obtain any permits necessary to haul materials or equipment on public streets and highways. Obey load restrictions at all times.

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E. Take all precautions required to maintain the integrity and structural stability of the existing structures and utilities.

F. Maintain vehicle access on private roads for plant personnel.

G. Repair or clean public or private roads or driveways following damage or spillage.

H. Be solely responsible for obtaining and verifying accuracy of measurements and layout of Work.

I. Correct deficiencies, errors, or defects due to faulty measurements, information, layout, or due to failure to report discrepancies.

J. Immediately notify Owner and/or Engineer in writing in case of discrepancies between existing work and drawings or defects on such surfaces that are to receive work prior to commencing work. Failure to notify Owner and/or Engineer of such discrepancies and/or defects shall be done at expense of Contractor who applied work to defective surfaces.

K. Location of existing underground and aboveground utilities, structures, and other obstructions shown on Contract Drawings are taken from existing information and are approximate only. Obstructions not shown on the Drawings may exist and shall be exposed by Contractor without damage. Contractor shall be responsible for damage to existing facilities and utilities resulting from Contractor's operations and shall repair or replace damaged items to Owner's satisfaction.

1.04 OTHER'S RESPONSIBILITIES

A. Owner and/or Engineer shall be responsible for scheduling performance of Work by Owner or others.

B. Owner and/or Engineer shall be responsible to maintain daily contact with Contractor during progress of work.

1.05 PERMITS

A. Permits

1. Owner has obtained IEPA Water Pollution Control Construction Permit required for project.

2. Copies of permits and approvals provided by the Owner will be made available to the Contractor.

3. Copies of Permits obtained by the Contractor shall be provided to the Owner.

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1.06 ESTIMATES OF PLAN QUANTITIES

A. Quantities of materials provided in these plans and specifications are estimates and are to be verified by the Contractor prior to use in preparing the bid.

1.07 CONSTRUCTION LIMITS

A. Contractor shall restrict operations and storage of materials and equipment to the area within the project site as shown on the Contract Drawings unless otherwise approved by the Owner. Owner will further define the construction limits in the field when the Contractor believes it is appropriate or upon reasonable request of Contractor. Contractor shall restore all disturbed areas within the construction limits as necessary to match pre-existing conditions.

1.08 WORK ON PROPERTIES OWNED BY OTHERS

A. Contractor shall be familiar with property boundaries and those of the adjacent properties at the site where work is to be conducted.

B. Storage of materials or equipment on property owned by others is not allowed unless as authorized by the Owner.

C. Notify and receive advance approval of the Owner of need to remove or disturb materials not addressed by these documents.

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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SECTION 01040
PROJECT ADMINISTRATION

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Contractor Supervision and Subcontracted Work

B. Submittals

C. Project Meetings

D. Construction Schedule

E. Work Hours and Coordination

F. Reports

1.02 RELATED SECTIONS

A. Section 01050-Field Engineering and Surveying

B. Section 01300-Submittals

C. Section 01400-Quality Assurance and Control

1.03 CONTRACTOR SUPERVISION AND SUBCONTRACTED WORK

A. Assign one superintendent or foreman to be on site continuously during working hours from start to finish of project. Submit site superintendent/foreman's name and phone number prior to project start. The superintendent shall be the primary contact with the Owner and/or Engineer and shall be responsible for all negotiated change orders. If Contractor changes foreman assigned to site, Contractor shall make transition seamless to avoid lost work. In the event of a change in supervisory staff, the Owner shall be provided a minimum of two weeks notice prior to making the change.

B. Use an adequate number of skilled workers who are thoroughly trained and experienced and who are completely familiar with specified requirements and methods needed for performance of Work.

C. Use experienced professional personnel for that work which requires judgment, knowledge, and expertise of qualified professionals, and who are familiar with all aspects of Work.

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D. Contractor's superintendent/foreman shall maintain communication between subcontracted personnel and Contractor's personnel, and shall be on site when subcontractors are on site performing work.

E. Contractor shall direct and supervise all Subcontractors.

F. Contractor shall submit names of all Subcontractors who will be performing any work with bid.

1.04 SUBMITTALS

A. As required in accordance with this Section, Section 01300 and Table 2.

1.05 PROJECT MEETINGS

A. A pre-construction meeting will be conducted by the Owner and/or Engineer. Contractor shall submit all submittals required prior to the project start prior to the pre-construction meeting. Meeting shall be held at the site unless otherwise announced. At a minimum, the following personnel shall attend: Contractor, including site superintendent/foreman, geosynthetics installer's site superintendent / foreman, Owner and/or Engineer. The agenda for the meeting shall include, but not be limited to:

1. Review work scope.

2. Review status of submittals required to be transmitted prior to project commencement.

3. Discuss project administration prior to start of work.

4. Determine frequency and schedule for progress meetings.

5. Discuss the coordination and scheduling of each major element of the construction, including but not be limited to, site preparation, excavation and grading, anchor trench, geomembrane installation, backfilling, leak location survey, and site restoration.

6. Discuss Owner's emergency notification and operating practices for emergency situations.

B. The Owner and/or Engineer will conduct regular progress meetings for the purpose of coordinating and inspecting Work. All parties will agree upon the frequency and schedule for progress meetings at the pre-construction meeting. Contractor and subcontractors shall attend weekly progress meetings during the duration of each subcontractor's work.

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C. Owner and/or Engineer will conduct a final inspection meeting for purpose of confirming project is complete and consistent with Contract Documents. Meeting will be scheduled when Contractor has submitted written certification to Owner that the Contract Documents have been reviewed, Work has been inspected, and that Work is Substantially Complete in accordance with Contract Documents and ready for final inspection (Section 01700).

D. A principal member of Contractor's staff, authorized to make decisions on his behalf, shall represent Contractor at each meeting. Owner and/or Engineer may direct certain subcontractors to attend meetings as needed. Failure to attend a meeting does not relieve Contractor from acting on contents of meetings.

E. Owner and/or Engineer will record all pertinent topics discussed and any resulting action items in the minutes of the project meetings. Meeting minutes will be distributed prior to the next meeting to all parties in attendance and responsible for action items.

F. Special meetings may be called at discretion of the Owner and/or Engineer for the purpose of resolving problems or other purposes concerning Work. Attendance at special meetings is mandatory for Contractor and other parties requested by Owner and/or Engineer to attend.

1.06 CONSTRUCTION SCHEDULE

A. Overall work is to be completed as indicated in these Technical Specifications.

B. A Baseline Construction Schedule is required to be submitted with the Contractor's bid. Within 10 working days of date of contract award, Contractor shall submit to Company and/or Engineer for review one updated copy of the Baseline Construction Schedule. Schedule shall be time-scaled and show work activities, including sequence of performance and interdependency. Each activity shall be labeled and include an estimated duration in working days. Baseline Construction Schedule shall comply with required completion date stated in Contract Documents and any work restrictions, including restrictions on days or hours of work, stated in Technical Specifications. Baseline Construction Schedule shall be discussed at pre-construction meeting.

C. The Contractor shall update the Baseline Construction Schedule during Construction to indicate actual progress in percent completion for each activity and submit one updated copy to the Owner and/or Engineer one work day prior to the regularly scheduled progress meeting. This updated schedule is termed "Progress Schedule". In addition to indicating actual progress, the Progress Schedule shall also indicate any changes in completion times or dates for any of activities shown on previous version.

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D. Each Progress Schedule shall be submitted with a written narrative describing revisions, if any, from the previous version, the effects of these revisions upon remaining Work and schedule, and corrective actions taken or proposed by Contractor.

E. Owner and/or Engineer shall review the Contractor's Baseline Construction Schedule and Progress Schedules. Comments made by Owner and/or Engineer on Schedule, lack of such comments, rejection, or acceptance of Contractor's Schedule does not relieve Contractor from compliance with Contract Documents, nor create any responsibility or duty for scheduling owed from Owner and/or Engineer to Contractor. This review, whether accompanied by comments, rejection, or neither, is only for general conformance with information provided in the Contract Documents.

F. Any contingency within Schedule (i.e., a difference in time between project's early completion and required completion dates) will belong to Project and not any parties to Contract.

G. Contractor shall furnish material and labor at proper time and in sufficient quantities to correspond with actual job progress whether or not such actual progress is in conformance with subsequent Progress Schedules.

H. Should Contractor fail to adhere to the Baseline Construction Schedule or revised Progress Schedules, Contractor shall promptly take measures necessary to regain conformance with such schedules at no additional cost to Owner. Addition of equipment or construction forces, increase in working hours, or any other method, manner, or procedure to return to Schedule shall not be considered justification for a request for additional compensation or treated as an acceleration order. If, in opinion of the Owner, methods prove unsuccessful in compensating for lost time, Owner shall have right to pursue remedies, as described in Agreement and General Conditions of Contract Documents.

1.07 WORK HOURS AND COORDINATION

A. Contractor shall perform work during a regular workweek of ten hours per day, Monday through Friday. Working hours will be 7:00 a.m. to 5:00 p.m. Saturday work and hours shall be reviewed with the Owner on a case by case basis.

B. Contractor shall keep the Owner and/or Engineer informed, at reasonable time in advance or as required by specific sections of Technical Specifications, of times and places where work is to be done, so that any inspection or oversight deemed necessary may be done with minimum inconvenience to the Owner and/or Engineer.

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1.08 REPORTS

A. Contractor shall be responsible for submitting to the Owner and/or Engineer a progress report one work day prior to a regularly scheduled progress meeting. Progress report shall include following:

1. A brief description of work completed during the current reporting period.

2. Quantities and volumes of work completed during the current reporting period.

3. Contractor's summary of work completed and estimate of percentage of completion for each work item.

4. Erosion control inspection records, as necessary.

5. A list of work scheduled for the next reporting period.

6. Quantities and volumes of work anticipated for the next reporting period.

7. A list and number of supervision and craft people on site by craft.

8. A review of conditions affecting execution of work, including encountered or anticipated problem areas, including delays and causes.

B. Contractor shall be required to submit the following special reports:

1. Accident Reports

2. Work Stoppage/Dispute Records

3. Contractor's Invoices

4. Schedule of Values

5. Test Report Records

6. Equipment Check Reports

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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SECTION 01050
FIELD ENGINEERING AND SURVEYING

PART 1 – GENERAL

1.01 SECTION INCLUDES

A. Work by Contractor

B. Contractor's Responsibilities and Submittals

C. Survey Data for Construction Documentation

D. Construction Documentation Drawings

1.02 WORK BY CONTRACTOR: Contractor shall provide field engineering and surveying services as required for proper completion of work including:

A. Documenting location of anchor trench.

B. Documenting location and elevation of geomembrane panels.

C. Documenting location of marker posts.

D. Documenting topography of warning layer.

1.03 CONTRACTOR'S RESPONSIBILITIES AND SUBMITTALS

A. Upon commencement of construction work, become familiar with the location of existing benchmarks, control points, and other necessary reference points. Maintain their accuracy and prevent disturbance or destruction. Contractor is responsible for re-establishing control points and benchmarks if such items are damaged and/or destroyed at no cost to Owner.

B. Establish and verify grades, lines, levels, locations and dimensions as shown on Drawings and report any errors or inconsistencies to Owner and/or Engineer before commencing work.

C. Initial staking of discharge pipe and anchor trench.

D. Lay out own work and be responsible for all surveys, lines, elevations, and measurements of structures and other work executed under Contract. Exercise proper preparation to verify figures on Drawings within construction limits before laying out work. Any error resulting from failure to exercise such precautions or work done without being properly located may be removed at Owner's direction and corrected or replaced at Contractor's expense.

F. Contractor shall verify its own work with respect to required grades prior to documentation surveys. Areas deficient will be corrected and resurveyed at Contractor's expense.

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1.04 SURVEY DATA FOR CONSTRUCTION DOCUMENTATION

A. Survey work performed by Contractor shall be certified by a registered land surveyor (RLS), and will include items identified in Table 1.

B. Frequency of surveys for each item is summarized in Table 1 and relevant Sections of the Technical Specifications.

C. Survey data shall be supplied to Owner and/or Engineer in one of the following formats within two working days after completion of survey:

1. Topographic map (hard copy and electronic file compatible with AutoCAD).

2. Tabular (according to Table 1).

3. ASCII files (northing, easting, elevation).

D. Contractor will be notified by Owner and/or Engineer of areas to be adjusted or will be given written approval of surveyed area within two working days of receiving survey data.

E. Contractor shall obtain written approval from Owner and/or Engineer for each surveyed area prior to placement of any overlying materials.

1.05 CONSTRUCTION DOCUMENTATION DRAWINGS

A. Contractor shall distribute record drawings to Owner and/or Engineer based on results of documentation survey within four working days following completion of survey for a particular surface or set of features as supplied by the RLS.

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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SECTION 01300
SUBMITTALS

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. General Requirements

B. Submittal Format

C. Submittal Procedures

1.02 GENERAL REQUIREMENTS

A. Procedures and format for submittals required by the Technical Specifications that may include but are not limited to:

1. Soil and/or material test data
2. Survey data
3. Product test data
4. Progress reports
5. Shop drawings
6. Manufacturers instructions, certificates, guarantees and warranties
7. Management, staging and sequencing plans
8. Schedules

B. Refer to Technical Specifications and Table 2 for list of submittals.

1.03 SUBMITTAL FORMAT

A. All submittals shall be transmitted by Contractor with the following identified on the cover sheet:

1. Project name and contract number.
2. Applicable Technical Specification (Section) and submittal number.

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3. Date (or revision number).

4. Sequential page numbers.

B. Submittals shall be made in triplicate.

C. Stamp, sign, or initial submittal certifying products or field dimensions, whichever pertains, are in accordance with requirements of Work and Contract Documents.

1.04 SUBMITTAL PROCEDURES

A. Provide all submittals and information as identified in Technical Specifications to named parties in the time frames indicated in Table 2. Payments may be withheld, in whole or in part, at discretion of the Owner in the event that submittals are not made within times specified unless previously requested in writing by the Contractor (to Owner and/or Engineer) and approved in writing by Owner and/or Engineer.

B. Transmit submittals by appropriate means to expedite review of submittal. Submittals delivered by hand, facsimile, or mail service are acceptable. Business addresses of project representatives will be provided at the pre-construction meeting.

C. Submittals shall be made far enough in advance of the scheduled approval dates to allow adequate time for reviews, approvals, and revisions.

D. Submittals shall identify variations from Contract Documents and product or system limitations that may be detrimental to successful performance of completed work.

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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SECTION 01400
QUALITY ASSURANCE AND CONTROL

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Construction Quality Assurance

B. Contractor's Role

C. Engineer's Role

D. Owner's Role

1.02 CONSTRUCTION QUALITY ASSURANCE

A. Owner shall arrange for and inform Contractor of inspection and testing activities to confirm that the construction activities and completed Work complies with Technical Specifications and Contract Drawings.

B. Owner's inspection and testing activities shall consist of following activities:

1. Daily observation and record of Contractor activities.

2. Arrange for in-place soil compaction testing, as necessary.

3. Obtain material samples and transport samples to laboratory, as necessary.

4. On-site visual material inspection and testing.

5. Verifying compliance with Technical Specifications and Drawings.

1.03 CONTRACTOR'S ROLE

A. Perform work in strict accordance with Technical Specifications and Drawings, using necessary construction procedures and techniques. Coordinate, supervise, and oversee subcontractors as needed to perform construction activities.

B. Perform testing as deemed necessary to satisfy requirements of Technical Specifications related to off-site materials prior to delivery to site. Materials that do not meet specifications shall be removed from site at Contractor's expense.

C. Contractor shall replace and/or recompact material at Contractor's expense, if soil compaction not acceptable per compaction requirements.

D. Furnish material samples and provide assistance in on-site inspection and test activities.

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E. Provide submittals required by Contract Documents within times specified. Failure to do so will result in withholding of payment.

F. Perform or arrange survey and layout work to construct Work in accordance with Drawings and applicable sections of Technical Specifications.

G. If manufacturer's instructions and/or standard industry practice conflicts with Technical Specifications or Drawings request clarification from Owner and/or Engineer before proceeding.

H. Communicate any pertinent issues with the Owner and/or Engineer.

1.04 ENGINEER'S ROLE

A. Provide clarifications to Technical Specifications and Drawings, as well as any necessary design changes requested by the Owner.

B. Issue a Field Directive in cases where deviation from specified design, Technical Specifications and Drawings is necessary.

C. Communicate any pertinent issues with the Owner and/or Contractor.

D. Confirm construction compliance with Technical Specifications and Drawings by performing observations, inspections, verifications, and documentation activities, as directed by Owner.

E. Provide photo documentation and daily written reports documenting construction according to the Technical Specifications and Drawings, as directed by Owner.

F. Perform or observe soil and/or geosynthetic inspections and testing to confirm materials meet requirements herein, as directed by Owner.

1.05 OWNER'S ROLE

A. Perform Owner's engineering review and monitor construction progress, progress payment approval, and approval of field job orders.

B. Confirm construction compliance with Technical Specifications and Drawings by performing observations, inspections, verifications, and documentation activities, as necessary.

C. Perform Owner's administrative and managerial responsibilities. Owner has authority to accept/reject materials and workmanship, and for dispute resolution.

D. Communicate any pertinent issues with Contractor and/or Engineer. Maintain communication with IEPA, as necessary.

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PART 2 - PRODUCTS **(NOT USED)**

PART 3 - EXECUTION **(NOT USED)**

END OF SECTION

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SECTION 01500
CONSTRUCTION FACILITIES AND TEMPORARY CONTROLS

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Use of Site Facilities

B. Security

C. Parking

D. Telephone Service

E. Temporary Utilities

F. Sanitary Facilities

G. Equipment Storage Locations

H. Dust and Mud Controls

I. Fugitive Emissions Controls

J. Construction Noise

K. Water and Erosion Controls

L. Barriers and protection of installed work.

M. Site Progress Cleaning

N. Fuel Storage and Handling

O. Protection of the environment

P. Public Road Requirements

Q. Additional Requirements

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1.02 USE OF SITE FACILITIES

A. Use of Site

1. Contractor shall consult with the Owner and/or Engineer regarding locations for offices, trailers, material storage, access roads, fences, gates, and areas within construction limits for use by Contractor.

2. Contractor shall conduct construction activities in a manner to minimize interference with plant operations.

3. Confine equipment, storage of materials, and operations of workmen to areas designated by the Owner. Do not bring materials onto site until reasonably required for progress of work. No area outside of construction limit or staging area may be used for any purpose by Contractor or subcontractors unless expressly approved by the Owner in writing.

4. Store, place, and handle material and equipment to protect from any damage. Contractor shall move materials, sheds, or storage platforms, as necessary or when required for continuing construction at Contractor's expense.

5. Owner assumes no responsibility for project material or equipment stored on site or off site. Contractor assumes full responsibility for damage due to storage of materials.

6. Contractor is responsible to schedule work, storage of materials, etc., to minimize interference with construction activities.

7. Contractor is responsible for all snow removal as necessary during duration of project, as necessary.

8. Contractor is responsible for controlling sediment migration, reventing tracking of sediment onto site access roads and public roads along haul routes, and cleaning site access roads and public right-of-ways and streets daily or as deemed necessary by Owner with commercial street sweepers.

B. Contractor shall inspect site with Owner and/or Engineer prior to start of work to determine existing conditions in conjunction with preconstruction meeting (Section 01040).

1.03 SECURITY

A. Security is not provided by Owner for Contractor's property.

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B. Contractor is responsible for loss or injury to persons or property where his work is involved, and shall provide security and take precautionary measures as deemed necessary to protect Contractor's and Owner's interests.

1.04 ACCESS ROADS AND PARKING

A. Contractor shall maintain the service road accessing the construction areas and stockpile areas as necessary, or as directed by Owner and/or Engineer.

B. Parking areas on site shall be within the work area or area designated by Owner

1.05 TELEPHONE SERVICE

A. Contractor shall provide, maintain and pay for cellular phone service for Contractor's designated on-site superintendent or foreman. In addition, subcontractor's designated on-site personnel shall have cellular phones.

1.06 TEMPORARY UTILITIES

A. Electricity

1. Contractor shall arrange and pay for temporary electrical service as needed.

3. OSHA regulations require that employers shall use either ground fault circuit interrupters or an assured equipment grounding conductor program in addition to any other regulations for equipment grounding conductors.

4. Utilize and remove upon completion of project an electrical distribution system for temporary light and power during construction, if necessary.

B. Water

1. Water is not available on site.

2. Contractor shall provide clean water to be used for dust suppression in work areas. Dust suppression will be necessary for haul roads, stockpile areas, and within construction limits. Submit source of clean water to be used for dust suppression to Owner and/or Engineer for approval prior to project commencement.

3. Contractor shall provide potable water for Contractor's employees, as necessary.

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1.07 SANITARY FACILITIES

A. Contractor shall provide sanitary facilities on site conforming to state and local health and sanitation regulations in sufficient number for use of Contractor's employees.

B. Contractor shall maintain on-site facilities in sanitary condition at all times.

1.08 EQUIPMENT STORAGE LOCATIONS

A. Contractor shall park equipment and store materials only in areas proposed by Contractor and approved by Owner.

B. Restore disturbed areas to pre-construction condition upon project completion.

1.09 DUST AND MUD CONTROLS

A. Conduct operations and maintain site at all times to minimize creation and dispersion of dust and mud.

B. Provide equipment necessary to control dust generation resulting from wind effects on open stockpiles, excavations, and from Contractor's vehicle and equipment traffic at all times. Control dust by application of water to affected areas, such that surfaces are moistened to prevent dust from becoming a nuisance to public, neighbors, and concurrent performance of other work at site. Contractor shall prevent dusting 24 hours a day from project commencement to substantial completion of the work.

C. Control mud and tracking of mud on site access roads and public roads along haul routes. Maintain surfaces in proper condition to facilitate removal efficiency.

D. The Owner and/or Engineer shall monitor site conditions related to dust and mud generation on a daily basis and direct Contractor to take actions as necessary to address deficient practices or conditions deleterious to construction and/or public.

E. Clean public right-of-ways and streets as deemed necessary by Owner with commercial street sweepers.

1.10 CONSTRUCTION NOISE

A. The Owner shall decide on the adequacy of provision and maintenance of noise reduction equipment. When so instructed by the Owner, the Contractor shall immediately withdraw any item of plant or equipment from service and carry out all necessary additions, replacements, or repairs to the noise reduction equipment to the satisfaction of the Owner.

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1.11 WATER AND EROSION CONTROLS

A. Contractor shall install and maintain erosion control measures necessary to prevent runoff, tracking, or loss of soil materials by water or mechanical action from disturbed portions of the site or excavation areas(s).

B. No direct discharge shall be allowed into Ash Impoundment #1 without the approval from Owner.

1.12 BARRIERS AND PROTECTION OF INSTALLED WORK

A. Contractor shall protect installed work and provide special protection as needed.

B. Construction traffic shall be prohibited on completed and/or landscaped areas.

C. Protect existing facilities and adjacent properties from damage during construction operations.

1.13 SITE PROGRESS CLEANING

A. Maintain areas free of waste materials, debris, and rubbish. Site shall be maintained in clean and orderly condition.

B. Remove waste materials, debris, and rubbish from site weekly and dispose off-site at Contractor's expense and in accordance with federal, state and local regulations.

C. Contractor shall provide a dumpster on site for general waste materials and rubbish during site activities.

1.14 FUEL STORAGE

A. Store fuel according to local, state, and federal laws.

1.15 FUEL HANDLING

A. At no time shall overtopping fuel tanks or spillage to the ground surface be allowed.

1.16 PROTECTION OF THE ENVIRONMENT

A. Minimize air pollution by use of properly operating emission control devices on construction vehicles and equipment. Encourage shutdown of motorized equipment not in use.

B. Trash burning not permitted on site.

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C. All areas for handling and storage of fuels, oils, and other potentially hazardous liquids shall have spill containment or release prevention measures. Maintenance of equipment on site shall be with prior approval of the Owner and/or Engineer.

D. All waste materials shall be recycled, hauled to a licensed solid waste landfill, or otherwise disposed of in an environmentally sound manner and in compliance with all applicable local, state, and federal rules.

E. All hazardous waste shall be stored, handled, and disposed of in compliance with applicable local, state and federal rules.

F. Other measures shall be taken, as necessary, to maintain work site in an environmentally sound matter.

G. All spills or leaks of fuels, oil, or other IEPA-reportable liquids resulting from handling or equipment malfunctions shall be reported immediately to Owner and/or Engineer. Affected soils shall be properly removed from limits of construction and disposed in accordance with applicable local, state and federal rules at the sole expense of the Contractor and as agreed by the Owner and/or Engineer. Copies of manifests, if necessary, shall be provided to Owner and/or Engineer within five working days of disposal. Waste Generator Manifests shall not state Owner as Generator. Owner reserves right to order leaking equipment removed from site.

1.17 PUBLIC ROAD REQUIREMENTS

A. Contractor shall comply with Local Weight Limits. Local roads shall be cleaned daily, as necessary, to maintain their condition free of mud and dirt.

B. The Contractor shall conduct his operations on the site in a manner that will minimize interference with the normal operation of plant, adjoining public and private roads and parking lots, and shall implement all specified and other appropriate measures to ensure the safety of all users of the adjoining public and private roads and parking lots.

C. Contractor shall provide flag person(s) as necessary and at request of Owner and/or Engineer.

1.18 ADDITIONAL REQUIREMENTS

A. No cameras are allowed on the site without permission from the Owner.

B. No firearms or explosives are allowed on site.

C. Possession and/or use of intoxicating beverages and nonprescription drugs are prohibited at all times. Persons caught in possession or under the influence of drugs or alcohol will be immediately dismissed and removed from the site.

D. Smoking will be allowed in designated areas only.

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E. No horseplay is permitted on the job site.

F. Visitors or personnel not employed by the Contractor or his approved Subcontractors shall not be permitted on site without prior approval by the Owner.

G. Owner and/or Engineer reserve the right to require that any of the Contractor's personnel be excluded from work at the site at any time.

PART 2 – PRODUCTS (NOT USED)

PART 3 – EXECUTION (NOT USED)

END OF SECTION

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SECTION 01700
PROJECT CLOSEOUT

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Description of Work

B. Procedures

C. Record Documents

1.02 DESCRIPTION OF WORK

A. To provide an orderly and efficient transfer of the completed Work to the Owner.

1.03 PROCEDURES

A. Remove temporary above grade or buried utilities, equipment, materials, prior to final application or payment inspection, and clean and repair damage caused by installation or use of temporary facilities.

B. Substantial Completion: When all work described in the contract documents is completed:

1. Owner and/or Engineer will prepare and submit a list of items to be completed for Contractor review and completion.

2. Should the Owner and/or Engineer determine that the Work is not substantially complete; Contractor will remedy the deficiencies and notify the Owner and/or Engineer when ready for re-inspection.

C. Final Completion:

1. Remove waste and surplus materials, rubbish, and construction facilities from site.

2. Prepare and submit the notice that all Work is complete.

3. Certify in writing that the Work is complete and ready for final inspection.

4. Owner and/or Engineer will make a final inspection to verify status of completion.

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1.04 RECORD DOCUMENTS

A. Contractor will maintain on site one set of following record documents of all items of work; record actual revisions of all items of work:

1. Drawings.

2. Technical Specifications.

3. Change orders and other modifications to contract.

4. A copy of approvals of work performed.

5. Record documents.

B. Engineer, as directed by Owner, will record information concurrent with construction progress including changes made by addenda and modifications.

C. Contractor will maintain a Daily Field Log including work times, personnel on site, equipment used, and other essential information of the operation's progress.

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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DIVISION 2

DIVISION 2

SITE WORK

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SECTION 02300
EARTHWORK

PART 1 - GENERAL

1.01 WORK INCLUDES

A. Preparation of Ash Impoundment 2 liner subgrade by clearing and grubbing vegetation and removing rocks and other debris greater than 3 inches in diameter along side slopes and base of impoundment, and excavating at least 18 inches of existing ramp surface material.

B. Load and transport rocks and other debris removed from liner subgrade to an approved recycling or disposal facility.

C. Load and transport excavated ramp material to a stockpile area on site, as directed by Owner, for reuse at project completion.

D. Installation of marker posts along toe of the Ash Impoundment side slopes, as shown on Contract Drawings, prior to installation of geomembrane.

E. Trenching, backfilling, and compaction for anchoring geomembrane and geotextile including field verifying the location of discharge pipes, protection and maintenance of trench, and support of existing structures (i.e., aboveground piping, outlet and inlet).

F. Load and transport excess trench spoils to an approved recycling or disposal facility.

G. Placement, grading and compaction of sand material including weighting and transporting to site following installation of geomembrane.

H. Placement, grading and compaction of warning layer material including weighing and transporting to site following placement of sand material.

I. Placement of riprap at base of inlet apron.

J. Placement, grading, and compaction of excavated ramp material, including loading and transporting from on-site stockpile area to the ash impoundment ramp following installation of geomembrane.

1.02 RELATED SECTIONS

A. Section 01050 – Field Engineering and Surveying

B. Section 02600 – HDPE Geomembrane

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1.03 DEFINITIONS

A. Structures and Surface Features: Existing structures and surface features including buildings, signs, posts, utility poles, monitoring wells, fences, trees, shrubs, landscaped surface features, and other miscellaneous items.

B. Utilities: Existing gas mains, water mains, electric lines, storm sewers and conduits, telephone and other communication lines and conduits, sewer pipe, cable television, other utilities, and appurtenances.

C. Clearing and Grubbing: cutting, removal and disposal of trees, roots, brush, stumps, windfalls, logs, and other vegetation.

1.04 REFERENCES

A. ASTM D422-63 – Standard Test Method for Particle-Size Analysis of Soils.

B. ASTM D2487-93 – Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System).

C. ASTM D2940 – Standard Specifications for Graded Aggregate Material for Bases or Subbases for Highways or Airports

D. State of Illinois, Department of Transportation, Standard Specifications for Road and Bridge Construction, current edition.

E. OSHA 29 CFR Part 1926, Occupational Safety and Health Standards Excavations.

1.05 PERFORMANCE REQUIREMENTS

A. Excavation and grading shall be done without damage to adjacent property or structures and without interference to public and/or plant pedestrian and vehicular traffic.

B. Provide adequate backup systems to accomplish the excavation.

C. Complete Work to required grades as indicated in the Contract Drawings.

1.06 SUBMITTALS

A. In accordance with Section 01300.

B. Submit with bid a description of proposed Earthwork Plan, including but not limited to:

1. Methods and equipment.

2. Temporary staging facilities and stockpile locations.

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3. Methods of advancing and stabilizing anchor trenches.

4. Sequence of liner subgrade preparation, shoring, grading, material staging and replacement.

If changes occur, submittal shall be revised no later than five days prior to project start. Re-submittals shall be made during course of construction if plan is modified during construction.

C. Submit prior to start of construction the name and location of all sources that will be used to obtain the materials specified in this Section.

D. Provide Owner and/or Engineer written notice of construction start date at least five working days prior to beginning site activities.

E. Submit for documentation certificates and/or test results for one sample of each material obtained from off-site sources indicating compliance with Specifications prior to start of construction. Owner and/or Engineer may take random samples of the material upon delivery or placement to verify compliance with the Specifications.

F. Submit with bid name and location of the recycling and/or disposal facility that will be used to dispose of excess material specified in this Section.

PART 2 - PRODUCTS

2.01 GENERAL SOIL MATERIALS

A. Provide borrow soil materials when sufficient satisfactory soil materials are not available from excavations.

B. Satisfactory Soils: ASTM D2487 soil classification groups GW, GP, GM, SW, SP, and SM, or a combination of these group symbols; free of rock or gravel larger than 3 inches (75 mm) in any dimension, debris, waste, frozen materials, vegetation, and other deleterious matter.

C. Unsatisfactory Soils: ASTM D2487 soil classification groups GC, SC, MH, CH, OL, OH, and PT, or a combination of these group symbols.

1. Unsatisfactory soils also include satisfactory soils not maintained within 2 percent of optimum moisture content at time of compaction.

D. Unclassified Imported Fill: Satisfactory soil materials.

E. Excavated Ramp Material: Excavated material from the existing ramp surface that does not require disposal and may be reused as backfill, subject to Owner's and/or Engineer's approval.

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F. Anchor Trench Backfill: Trench spoils free of rock or gravel larger than 3 inches in any dimension, debris, waste, frozen materials, vegetation and other deleterious matter.

G. Riprap at Base of Inlet Apron: Riprap shall be durable field or quarry stone between 4 and 12 inches in diameter.

2.02 BASE COURSE MATERIAL (AS NEEDED)

A. Imported base course material shall be obtained from an off-site borrow source of the Contractor's choice and shall at a minimum satisfy the following specifications:

1. Naturally or artificially graded mixture of natural or crushed gravel, crushed stone, and natural or crushed sand; ASTM D 2940; with at least 95 percent passing a 1-1/2-inch sieve and not more than 8 percent passing a No. 200 sieve; and

2. Other materials with greater or equal bearing characteristics with the written approval of the Owner and/or Engineer. Verify the materials meet and/or exceed the materials specified in 2.02.A.1.

B. Contractor shall provide to Owner and/or Engineer a representative gradation (ASTM D422) and classification (ASTM D2487) for the base course material proposed for use in the project two weeks prior to delivery to site.

2.03 SAND MATERIAL

A. Conform to Section 1003.01, Fine Aggregates of Standard Specifications for Road and Bridge Construction:

a. Grade No. FA 1 or FA 2 shall be used; and

b. Other materials with greater or equal characteristics with the written approval of the Owner and/or Engineer.

B. Contractor shall provide Owner and/or Engineer a representative gradation (ASTM D422) and classification (ASTM D2487) for the sand layer two weeks prior to delivery to site.

2.04 WARNING LAYER MATERIAL

A. Imported Warning Layer Material shall be obtained from an off-site borrow source of the Contractor's choice and shall at a minimum satisfy the following specifications:

1. Conform to Section 1004.04, Coarse Aggregate for Stabilized Subbase of Standard Specifications for Road and Bridge Construction:

a. Grade No. CA 6 shall be used; and

b. Other materials with greater or equal characteristics with the written approval of the Owner and/or Engineer.

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B. Contractor shall provide Owner and/or Engineer a representative gradation (ASTM D422) and classification (ASTM D2487) for the warning layer two weeks prior to delivery to site.

PART 3 - EXECUTION

3.01 PROTECTION OF UTILITIES AND STRUCTURES

A. At least ten business days before beginning Work, coordinate utility locate with Owner and Owner's utility locator for locating Owner's private utilities near the ash impoundments.

B. Protect existing utilities not specified for removal against damage.

C. Locate existing underground utilities by hand excavation.

D. If unmarked utilities are encountered during excavation, stop work, place work in a safe condition, and notify Owner and/or Engineer.

E. Preserve and protect benchmarks and other structures. If damaged during construction, notify Owner and/or Engineer immediately. If determined by Owner and/or Engineer that the integrity of the structure is compromised, Contractor shall repair damaged benchmarks or other structures at Contractor's expense under observation of Owner and/or Engineer.

F. Protect, support, and maintain conduits, wires, pipes, or other utilities that are to remain in place during work as indicated in the Contract Drawings.

3.02 PREPARATION

A. Contractor shall perform, as necessary, additional survey and layout to establish location, line and grades for controlling the work.

B. Vicinity Controls

1. Surface Water: Contractor is responsible for management of surface water and maintaining adequate berms and drainage to control surface water run-on into the Ash Impoundment, as needed. Surface water and run-on water may be directed to Ash Impoundment 1, as needed to complete work and as approved by Owner.

2. Dust Controls: Dust shall be minimized at all times. Appropriate engineering controls shall be maintained that include using a light water spray with or without additives as approved by the Owner to minimize off-site migration of fugitive dust from stockpiles, truck routes, and other Contractor disturbed areas.

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3.03 ON-SITE MATERIAL GRADING, GENERAL

A. Uniformly grade all areas to a smooth surface, free from irregular surface changes. Provide a smooth transition between adjacent existing grades and new grades.

B. Comply with compaction requirements and grade to cross sections, lines, and elevations indicated.

C. Flatten or shore and brace slopes as required to maintain stability.

D. Removal of debris or other deleterious material encountered during excavations is to be managed as required under this Section.

E. Notify Owner and/or Engineer of unexpected subsurface conditions and discontinue work in affected area until notified to resume Work.

3.03 BACKFILLING, GENERAL

A. Material used to construct surface water diversion berms, as needed, may be reused for backfill as directed by the Owner and/or Engineer.

B. Imported backfill materials shall be pre-approved by the Owner and/or Engineer before delivery to the site in accordance with this Section.

C. Materials placed, which are not conforming to the Technical Specifications, shall be re-worked or removed. Replacement material and fill surfaces upon which it is placed shall conform to all requirements of this specification. All reworking or removal and replacement will be performed at Contractor's expense.

D. Mechanical tamping around structures shall be done in no greater than 6-inch lifts.

3.04 STOCKPILING, GENERAL

A. Stockpile materials on site at locations specified by Owner and consistent with the Contractor's Earthwork Plan.

B. Stockpile in sufficient quantities to meet project schedule and requirements.

C. Separate differing materials and stockpile separately to prevent mixing.

D. Direct surface water away from stockpiles to prevent erosion or deterioration of materials, as needed.

3.05 LINER SUBGRADE

A. Liner subgrade surface shall be graded to 3 horizontal to 1 vertical (3H:1V) along side slopes, or as approved by the Owner and/or Engineer. The base of the impoundment subgrade surface shall not exceed a 1% slope (to be relatively flat).

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B. Contractor shall prepare the liner subgrade by clearing and grubbing vegetation and removing rocks and other debris greater than 3 inches in diameter along side slopes and base of impoundment, and excavating at least 18 inches of existing ramp surface material.

C. Proof roll subgrade with smooth-drum compactor to identify soft pockets and areas of excess yielding. Do not proof roll wet or saturated subgrade.

D. Reconstruct liner subgrade damaged by freezing temperatures, frost, rain, accumulated water, or construction activities, as directed by the Owner and/or Engineer and Geomembrane Installer.

E. Cut out soft spots, fill low spots, and trim high spots to comply with required surface tolerances.

F. The surface of the subgrade shall be to the satisfaction of the Owner and/or Engineer and Geomembrane Installer, graded so it is free of irregularities, protrusions, loose soil, and abrupt changes in grade. Rocks with sharp protrusions and rocks or other debris grater than 3 inches in any dimension shall be removed.

G. Vegetation, rocks and other debris removed during subgrade preparation shall be loaded and transported to an approved recycling or disposal facility.

H. Excavated ramp material shall be loaded and transported to a stockpile area on-site, as directed by Owner.

I. Ramp subgrade shall be have a maximum 10% slope, and a minimum 1% slope toward the side slopes of the impoundment to divert water away from the outboard slopes of the ramp, as indicated on Contract Drawings.

3.06 ANCHOR TRENCH

A. Excavate to required alignment and grade. Where feasible, Contractor shall place anchor trench at least 4 feet from top of side slopes. If not feasible, Contractor shall provide Owner and/or Engineer with proposed alignment (i.e., 2 feet from top of side slope near the aboveground pipes) for approval.

B. Contractor shall not excavate more than the amount of anchor trench required for one day of geosynthetics deployment, unless otherwise specified by the Owner and/or Engineer. Rounded corners shall be provided in the trenches where the geosynthetics enter the trench to allow them to be uniformly supported by the subgrade and to avoid sharp bends. The geosynthetics shall not be supported by loose soils in anchor trenches.

C. Remove water which may accumulate in trench. Water shall be pumped to Ash Impoundment 1 (active impoundment), as directed by Owner and/or Engineer.

D. Owner and/or Engineer may limit amount of open trench where field conditions require.

E. Owner and/or Engineer may order additional excavation where unsuitable soil conditions are encountered.

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F. Excavations shall be filled with trench spoils, as directed by Owner and/or Engineer. Care shall be taken when backfilling to prevent any damage to Geomembrane or other geosynthetics that may be placed prior to backfilling.

G. Anchor Trench Backfill shall be mechanically compacted to a hard durable surface with no evidence of pumping or ponding of water. Backfill shall be compacted to the degree that no further appreciable consolidation is evident under the action of compaction equipment.

H. Anchoring, backfilling, and compaction of anchor trench will be observed by Owner and/or Engineer. .

3.07 INSTALLATION OF MARKER POSTS

A. Prior to deployment of the geomembrane liner, Contractor shall install marker posts along the toe of the impoundment side slopes, as shown on Contract Drawings.

B. Contractor shall construct 4 feet deep, 1 foot diameter holes. The hole shall be backfilled with concrete and 12 foot long steel poles.

C. Marks spaced every foot from the top of the subgrade layer shall be inscribed in the steel poles to the top of the pole, as indicated on the Contract Drawings.

3.08 PLACEMENT OF SAND AND WARNING LAYER MATERIALS

A. Prior to placement of the sand and warning layer materials, the Owner and/or Engineer and Geomembrane Installer shall verify the area of geomembrane completion and provide Contractor notification to proceed with placement of sand and warning layers.

B. Contractor shall place sand material to achieve 12-inch thickness over the 12-oz non woven geotextile within the Ash Impoundment, as indicated on Contract Drawings. The sand material shall be placed at least 4 feet along the impoundment's side slopes over the non woven geotextile.

C. Contractor shall place warning layer material to achieve 6-inch thickness over the sand material within the Ash Impoundment, as indicated on Contract Drawings. The warning layer material shall be placed at least 4 feet along the impoundment's side slopes over the sand material.

D. Sand and warning layer materials shall not be placed directly on geomembrane.

E. Place materials evenly on all sides of structures to required elevation,

F. Compact with tracked equipment to a hard, durable surface with no evidence of pumping or ponding of water. Materials shall be compacted to the degree that no further appreciable consolidation is evident under the action of compaction equipment.

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G. Apply following general criteria for covering of the 12-oz non woven geotextile and geomembrane liner:

1. Do not place soils on the geomembrane at an ambient temperature below 32 degrees F, (0 degrees C) nor above 104 degrees F (40 degrees C), unless otherwise specified.

2. Do not drive equipment used for placing soil directly on the geomembrane.

3. A minimum thickness of 1 foot of soil shall be between tracked equipment and the geomembrane.

4. Do not compact soils placed directly on geomembrane.

5. Damage to the geomembrane resulting from placement of cover soils shall be repaired in accordance with Part 3.07 by the Geomembrane Installer at the Contractor's expense.

6. Do not push soil downslope. Soil shall be placed over the geomembrane starting from base of the slope, up to top of the slope.

3.09 PLACEMENT OF RIPRAP

A. Place 18-inch thick layer of riprap at the base of the inlet apron over 12 oz non woven geotextile. The non woven geotextile shall cover the geomembrane batten bar attachment.

B. Riprap shall be placed cautiously to prevent damage to the batten bar attachment and geomembrane. Any damages to the batten bar or geomembrane shall be repaired at Contractor's expense.

3.11 RECONSTRUCTION OF RAMP

A. Following installation of the geomembrane and 12-oz non woven geotextile, Contractor shall load and transport excavated ramp material from stockpile area to the impoundment. Contractor shall place and compact excavated ramp material to achieve 18 inch thickness over the 12-oz non woven geotextile to construct final ramp surface.

B. The ramp final surface shall be a maximum 10% slope toward the base of the ramp, and a minimum 1% slope towards the 3H:1V side slopes, as indicated on Contract Drawings.

C. Compaction shall be conducted with tracked equipment only.

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3.12 MOISTURE CONTROL

A. Do not place backfill or fill material on surfaces that are muddy, frozen, or contain frost or ice.

B. Remove and replace, or scarify and air-dry, otherwise satisfactory soil material that is too wet to compact to specified dry unit weight.

3.10 GRADE TOLERANCE

A. Sand layer shall have minimum thickness of 12-inches, shall have a tolerance of 0 to +0.1 feet of design grade.

B. Warning layer shall have a minimum thickness of 6-inches, shall have a tolerance of 0 to +0.3 feet of design grade.

C. Top of ramp surface is to be a minimum thickness of 18-inches, shall have a tolerance of 0 to +0.1 feet of design grade.

D. Layer thickness shall be measured vertically. Minimum thickness shall be measured against previous layer grades.

3.11 PROTECTION

A. Protecting Graded Areas: Protect newly graded areas from traffic, freezing, and erosion. Keep free of trash and debris.

B. Repair and re-establish grades to specified tolerances where completed or partially completed surfaces become eroded, rutted, settled, or where they lose compaction due to subsequent construction operations or weather conditions.

1. Scarify or remove and replace soil material to depth as directed by Owner and/or Engineer, reshape and recompact.

C. Where settling occurs before Project correction period elapses, remove finished surfacing, backfill with additional soil material, compact, and reconstruct surfacing.

1. Restore appearance, quality, and condition of finished surfacing to match adjacent work, and eliminate evidence of restoration to the greatest extent possible.

3.13 SITE RESTORATION AND CLEANUP

A. Remove surplus soil and waste material, including unsatisfactory soil, trash, and debris, and transport off-site for disposal as directed by the Owner.

B. Restore pavement, base course, topsoil, landscaping, and utilities which are disturbed during the performance of the Work to preconstruction condition.

C. Temporary erosion control measures shall be removed.

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D. Contractor shall correct, at no expense to the Owner, any damage to buildings, telephone or other cables, overhead and underground utilities or their structures as a result of his construction, whether or not the item is shown on the Contract Drawings.

E. All Contractor equipment and materials shall be removed from the site.

END OF SECTION

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SECTION 02600
HIGH DENSITY POLYETHYLENE (HDPE) GEOMEMBRANE

PART 1 - GENERAL

1.01 WORK INCLUDES

A. Furnish all labor, materials, tools, supervision, transportation, and installation equipment necessary for installation of 60-mil High Density Polyethylene (HDPE) geomembrane, as specified herein, and as shown on Contract Drawings.

1.02 REFERENCE STANDARDS

A. ASTM D1004 – Test Method for Initial Tear Resistance of Plastic Film and Sheeting.

B. ASTM D1238 – Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.

C. ASTM D1505 – Test Method for Density of Plastics by the Density-Gradient Technique.

D. ASTM D1603 – Test Method for Carbon Black in Olefin Plastics.

E. ASTM D4833 – Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.

F. ASTM D5199 – Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

G. ASTM D5397 – Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test.

H. ASTM D5596 – Test Method for Microscopic Evaluation of Dispersion of Carbon Black in Polyolefin Geosynthetics.

I. ASTM D5994 Standard Test Method for Measuring Core Thickness of Textured Geomembranes.

J. ASTM D6392 –Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods.

K. ASTM D6693 Standard Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes.

L. ASTM D7007 Standard Practice for Locating Leaks in Geomembranes Covered with Water or Earthen Materials.

M. GRI Test Method, GM 13 - Test Methods, Test Properties and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes

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N. GRI Test Method, GM 14 – Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes.

O. GRI Test Method, GM 19 – Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes.

1.03 DEFINITIONS

A. Geomembrane Installer: hired by Contractor responsible for field handling, transporting, storing, deploying, seaming and testing of the geomembrane seams.

B. Geomembrane Manufacturer: hired by Geomembrane Installer to provide HDPE geomembrane.

C. Leak Location Contractor: hired by Contractor and responsible for locating potential holes in the installed geomembrane using electrical methods.

D. Geosynthetic Quality Assurance Laboratory (Testing Laboratory): Party, independent from the Owner, Manufacturer and Installer, responsible for conducting laboratory tests on samples of geosynthetics obtained at the site or during manufacturing, usually under the direction of the Owner.

E. Lot: A quantity of resin (usually the capacity of one rail car) used in the manufacture of geomembranes. Finished roll will be identified by a roll number traceable to the resin lot used.

F. Resin Supplier: selected by Geomembrane Manufacturer to provide resin used in manufacturing geomembrane.

G. Panel: Unit area of a geomembrane that will be seamed in the field that is larger than $100ft^2$.

H. Patch: Unit area of a geomembrane that will be seamed in the field that is less than $100ft^2$.

I. Subgrade Surface (Bedding Layer): Soil Layer surface which immediately underlies the geosynthetic material(s).

1.04 QUALITY ASSURANCE

A. Qualifications:

1. Geomembrane Installer:

a. 5 years of continuous experience in installation of HDPE geomembrane.

b. Experience totaling a minimum of 5,000,000 square feet of installed HDPE geomembrane on some combination of at least 10 completed facilities.

c. Personnel performing seaming operations qualified by experience or by successfully passing seaming tests. Master seamer shall have experience seaming a minimum of 3,000,000 square feet of geomembrane using same type of seaming apparatus to be used on this project.

2. Leak Location Contractor:

a. 3 years of continuous experience in performing leak location surveys using electrical methods.

b. Experience totaling a minimum of 2,000,000 square feet of geomembrane leak location surveys on some combination of at least 5 completed facilities.

c. Personnel performing survey qualified by experience with at least 2 years of geomembrane testing experience using the leak location survey electrical method.

d. Leak Location Contractors that are qualified and approved by Engineer are listed below:

i. Leak Location Services, Inc.
San Antonio, TX
210-408-1241

ii. The Hutchinson Group, Ltd.
Murrysville, Pennsylvania
724-325-3996

iii. Or other approved by Owner and/or Engineer.

B. Quality Assurance Program:

1. Geomembrane Manufacturer/Installer shall conform with requirements of these Technical Specifications.

2. The Owner and/or Engineer may document geomembrane installation including panel placement, seaming, pre-qualification seam testing, non-destructive seam and repair testing, repair size and locations, and weather conditions.

3. The Owner may engage and pay for the services of Engineer and QA Laboratory to monitor geomembrane installation.

1.05 SUBMITTALS

A. Prior to project start, submit the following to Owner and/or Engineer in accordance with Section 01300, Submittals:

1. Raw Materials:

a. Name of Resin Supplier, location of supplier's production plant(s), resin brand name and product number.

b. Source and nature of plasticizers, fillers, carbon black and any other additives along with their percent addition to geomembrane material.

c. Test results documenting conformance with the "index properties" of GRI Test Method, GM 13.

2. Geomembrane Manufacturer's Certification:

a. Written certification that Geomembrane Manufacturer's Quality Control Plan was fully implemented during production of geomembrane material supplied for this project. (Submittal shall be made within 5 working days of delivery to site).

3. Geomembrane Manufacturer Production Information:

a. Corporate background information indicating compliance with qualification requirements.

b. Quality control plan for manufacturing.

c. Copy of quality control certificates demonstrating compliance with the quality control plan for manufacturing and the test property requirements of GRI Test method, GM 13 (i.e., mill certificates).

4. Contractor shall provide the Engineer a certificate stating the name of the geotextile manufacturer, product name, chemical composition of the filaments and other pertinent information to fully describe the geotextile.

5. Geomembrane Installer's Seaming Personnel

a. Corporate background information indicating compliance with qualification requirements.

b. Training completed by personnel.

c. Seaming experience for each personnel.

6. Geomembrane Installer's Information:

a. Corporate background information indicating compliance with qualification requirements.

b. List of completed facilities, totaling 5,000,000 square feet minimum for which Geomembrane Installer has completed installation of a HDPE geomembrane. Include name and purpose of facility, location, date of installation, and quantity installed.

c. Resumes of personnel performing field seaming operation, along with pertinent experience information. Include documentation regarding which seamers are qualified to use thermal fusion welding apparatus.

d. Installation quality control plan.

7. Installation panel layout diagram identifying placement of geomembrane panels, seams, and any variance or additional details which deviate from Contract Drawings or Technical Specifications. Layout shall be drawn to scale and shall be adequate for use as a construction plan. Layout shall include dimensions and pertinent seam and anchorage details.

8. Installation Sequence and Schedule shall be included as part of Construction Progress Schedule.

9. Description of seaming apparatus to be used indicating compliance with specified requirements.

B. With bid, submit the following to Owner and/or Engineer in accordance with Section 01300, Submittals

1. Leak Location Contractor's Work Plan:

a. Corporate background information indicating compliance with qualification requirements.

b. List of completed facilities, totaling 2,000,000 square feet minimum of geomembrane leak location surveys on some combination of at least 5 completed facilities. Include name and purpose of facility, location, date of survey, survey method, and quantity surveyed.

c. Resumes of personnel performing leak location survey, along with pertinent experience information.

d. Leak Location Contractor quality control plan including description of the proposed survey methods and procedures, and field calibration procedures.

e. Leak Location Contractor's required site preparations to be completed to perform the proposed leak location survey, and estimated duration to complete the survey.

f. An example of a final report (per ASTM D 7007) provided by the Leak Location Contractor following the completion of the survey.

C. During installation, submit the following to the Owner and/or Engineer:

1. Daily records/logs prepared by Geomembrane Installer documenting work performed, personnel involved, general working conditions, and any problems encountered or anticipated on project. Submit on a weekly basis.

2. Copy of subgrade acceptance signed by Geomembrane Installer for areas to be covered with geomembrane each day.

D. Within 10 days of geomembrane installation completion, submit the following to Owner and/or Engineer:

1. Geomembrane installation certification that Work was performed under Geomembrane Installer's approved quality control plan and in substantial compliance with Technical Specifications and Contract Drawings.

2. As-built panel diagram identifying placement of geomembrane panels, seams, repairs, and destructive seam sample locations.

3. Copy of warranty for material (including factory seams) and installation covering both for a period of 2 years from the date of substantial completion.

E. The Owner and/or Engineer will review and inspect geomembrane installation upon completion of all Work specified in this Section. Deficiencies noted shall be corrected at no additional cost to the Owner.

F. The Owner and/or Engineer will provide written final acceptance of the geomembrane installation after completion of the leak location survey. Written conditional geomembrane installation acceptance can be provided to the Contractor prior to completion of the leak location survey when the following conditions are satisfied, if necessary, and requested by the Contractor:

1. The entire geomembrane installation is completed or any pre-determined subsection if the project is phased.

2. All installation quality assurance/control documentation has been completed and submitted to the Owner and/or Engineer.

3. Verification of the adequacy of all field seams, repairs and associated testing is complete.

G. Within 14 days of completion of the leak location survey, submit final written report (per ASTM D 7007) of the leak location survey provided by Leak Location Contractor.

1.06 DELIVERY, STORAGE, AND HANDLING

A. Transportation:

1. Geomembrane rolls shall be transported, unloaded and handled at the job site in accordance with manufacturer recommendations. Damaged material may be rejected by the Owner and/or Engineer. Manufacturer packaging shall be labeled in accordance with Section 02700, 2.02G.

B. On-site Storage:

1. Geomembrane rolls which have been delivered to job site shall be unloaded and stored in original, unopened packaging in a secure location, determined by Owner and/or Engineer.

2. Store geomembrane rolls to ensure adequate protection against exposure to the following:

   a. Equipment;

   b. Strong oxidizing chemicals, acids, or bases;

   c. Flames, including welding sparks;

   d. Temperatures in excess of 160 deg. F;

   e. Dust;

   f. Ultraviolet radiation (i.e. sunlight); and

   g. Inclement weather.

3. Whenever possible, provide a 6-inch minimum air space between rolls.

4. Containers/rolls shall not be stacked.

C. On-Site Handling:

1. Handle rolls per Geomembrane Manufacturer's recommendations and as necessary to prevent damage.

PART 2 - PRODUCTS

2.01 MATERIALS

A. Geotextile to be used for cushioning between subgrade and geomembrane shall be polyester or polypropylene, non-woven needlepunched fabric and shall conform to the following requirements:

GEOTEXTILE PROPERTIES

Property	Units	Value	Test	Criterion
Mass Per Unit Area	oz/yd^2	16	ASTM D5261	MARV
Puncture Strength	lb	170	ASTM D4833	MARV
Trapezoid Tear	lb	145	ASTM D4533	MARV
Grab Tensile Strength	lb	370	ASTM D4632	MARV
Grab Elongation	%	50	ASTM D4632	MARV
UV Resistance @500 hours	% retained	70	ASTM D4355	Minimum

B. Geotextile to be used for separation between geomembrane and sand material shall be polyester or polypropylene, non-woven needlepunched fabric and shall conform to the following requirements:

GEOTEXTILE PROPERTIES

Property	Units	Value	Test	Criterion
Mass Per Unit Area	oz/yd^2	12	ASTM D5261	MARV
Apparent Opening Size	US Sieve	100	ASTM D4751	MARV
Puncture Strength	lb	210	ASTM D4833	MARV
Trapezoid Tear	lb	125	ASTM D4533	MARV
Grab Tensile Strength	lb	320	ASTM D4632	MARV
Grab Elongation	%	50	ASTM D4632	MARV
UV Resistance @500 hours	% retained	70	ASTM D4355	Minimum

C. High Density Polyethylene (HDPE) White Textured Geomembrane

1. HDPE geomembrane shall be white, textured (both sides), 60-mil product approved by the Owner and/or Engineer.

2. The Contractor shall submit, with the bid, written certification from the proposed Geomembrane Manufacturer that geomembrane products proposed in the bid satisfy the following requirements:

   a. The proposed Geomembrane Manufacturer shall have a minimum of 5 years of continuous experience manufacturing HDPE geomembrane totaling 1,000,000 square feet.

   b. The proposed HDPE compound shall be comprised entirely of virgin materials. Compliance with this specification shall be documented in accordance with Geomembrane Manufacturer's quality control program and submitted to the Owner and/or Engineer with the written conformance certification.

   c. The proposed Geomembrane Manufacturer shall certify that any plasticizers, fillers and additives incorporated into the manufacturing process for the proposed HDPE geomembrane have demonstrated acceptable performance on past projects.

   d. The proposed geomembrane shall meet the requirements of Geosynthetic Research Institute's test method GM 13.

   e. The nominal thickness of proposed geomembrane shall be 60 mil., or as approved by the Owner and/or Engineer.

3. Geomembrane sheets shall be visually consistent in appearance and shall contain no holes, blisters, undisbursed raw materials or other signs of contamination by foreign material. Geomembrane must have no striations, roughness or bubbles on the surface.

B. Seaming Apparatus

1. Thermal fusion welding machines used for joining geomembrane surfaces may be either extrusion or hot wedge. These machines shall include sufficient temperature and rate-of-travel monitoring devices to allow continuous monitoring of operating conditions.

2. One spare, operable thermal fusion seaming device shall be maintained on site at all times.

C. Field Test Equipment

1. Field Tensiometer: the field tensiometer shall be calibrated within three months prior to project start date over the range of field test values.

2. Air Channel Test Equipment: air channel test equipment shall consist of hoses, fittings, valves and pressure gauge(s) needed to deliver and monitor the pressure of compressed air through an approved pressure feed device.

3. Air Compressor: the air compressor utilized for field testing shall be capable of producing and maintaining an operating pressure of at least 50 psi.

4. Vacuum Box: the vacuum box shall consist of a vacuum gage, valve, and a gasket around the edge of the open bottom needed to apply vacuum to a surface.

2.02. CONFORMANCE TESTING REQUIREMENTS

A. Geomembrane shipped to site shall undergo conformance testing. Manufacturer's roll certificates may be used for conformance evaluation at the option of the Owner and/or Engineer. Nonconforming material shall either be retested at the direction of the Owner and/or Engineer or removed from site and replaced at Contractor's expense.

B. Conformance Test Methods

1. Samples will be located and collected by the Owner and/or Engineer at a rate of one sample per 100,000 square feet of geomembrane delivered to site.

2. One sample will be obtained from each geomembrane production batch delivered to the site.

3 Samples shall be cut by Geomembrane Installer and be at least 45 square feet in size.

4. Samples shall be tested in accordance with Table 1 (Smooth) or Table 2 (Textured) specified in GRI Test Method GM13.

5. Geomembrane thickness shall be measured a minimum of three times per panel during deployment to verify conformance with GRI Test Method GM13.

C. Role of Testing Laboratories

1. The Owner and/or Engineer will be responsible for acquiring samples of the geomembrane for conformance testing. The Owner or Engineer will retain an independent, third party laboratory to perform conformance testing on samples of geomembrane.

2. Retesting of geomembrane panels by the Geomembrane Installer because of failure to meet any of the conformance specifications can only be authorized by the Owner and/or Engineer. Non-conforming panels may be retested in accordance with Subsection 2.03(B) and 2.03(D) under authorization of the Owner and/or Engineer.

3. The Geomembrane Manufacturer and/or Geomembrane Installer may perform independent tests in accordance with methods and procedures specified in Subsection 2.03(B). Results shall not be substituted for quality assurance testing described herein.

D. Procedures for Determining Conformance Test Failures

1. If conformance test results fail to meet specifications, the roll and/or batch may be retested using specimens from either the original roll sample or from another sample collected by the Owner and/or Engineer. Two additional tests (retests) shall be performed for each failed test procedure. Each retest shall consist of multiple specimen tests if multiple specimens are specified in the test procedure. If the results of both retests meet specifications, the roll and batch will be considered to have passed conformance testing.

2. Failure of any retest shall be cause for rejection of the entire roll or batch depending on the type of failing test. The Owner and/or Engineer reserves the right to collect samples from other roll of a particular batch for further conformance testing. The Owner and/or Engineer may choose to accept only a portion of the batch on the basis of the results of conformance testing of samples collected from other rolls.

3. If retesting does not result in conformance with the specifications as defined in preceding paragraph, or if there are any other nonconformities with the material specifications, the Contractor shall remove the rolls from use in project. The Contractor shall also be responsible for removal of rejected geomembrane from the site and replacement with acceptable geomembrane at no additional cost to the Owner.

PART 3 - EXECUTION

3.01 PRE-CONSTRUCTION MEETING

A. A Pre-Construction Meeting shall be held at the site in accordance with Section 01040, Project Administration, to discuss and plan the details of geomembrane installation. This meeting shall be attended by the Geomembrane Installer, Owner, Engineer and the Contractor.

B. The following topics relating to geomembrane installation shall be addressed:

1. Responsibilities of each party.
2. Lines of authority and communication.
3. Methods for documenting, reporting and distributing documents and reports.
4. Procedures for packaging and storing archive samples.
5. Review of the schedule for all installation and quality assurance testing, including third-party testing turnaround times.
6. Review of panel layout, access and numbering systems for panels and seams including details for marking on the HDPE geomembrane.
7. Procedures and responsibilities for preparation and submittal of as-built drawings.
8. Temperature and weather limitations, installation procedures for adverse weather conditions and defining acceptable subgrade or ambient moisture and temperature conditions for working during liner installation.
9. Subgrade conditions, dewatering responsibilities and subgrade maintenance plan.
10. Deployment techniques including allowable subgrade for geomembrane.
11. Procedures for covering of the geomembrane to prevent damage.
12. Plan for minimizing wrinkles in the geomembrane.
13. Measurement and payment schedules.
14. Site health and safety procedures/protocols.

3.02 SUBGRADE PREPARATION

A. The Geomembrane Installer shall visually inspect the subgrade immediately prior to geomembrane deployment. Inspection shall verify that there are no potentially harmful foreign objects present, such as sharp rocks and other deleterious debris. Any foreign objects encountered shall be removed by Geomembrane Installer or Contractor. All subgrade damaged by construction equipment and deemed unsuitable for geomembrane

deployment shall be repaired prior to geomembrane deployment. All repairs shall be approved by the Owner and/or Engineer and Geomembrane Installer. The responsibility for preparation, repairs, and maintenance of the subgrade shall be defined in the preconstruction meeting. The Geomembrane Installer shall provide the Owner and/or Engineer with written acceptance of subgrade surface over which 16 oz non woven geotextile and geomembrane is deployed (Part 1 .05B) for each day of deployment.

3.03 GEOMEMBRANE LINER DEPLOYMENT

A. Geomembrane Installer shall deploy 16-oz non woven geotextile following applicable certifications/quality control certificates listed in subsection 1.05 of this section and conformance testing in subsection 2.02 or this section are submitted and approved by the Owner and/or Engineer. Any 16-oz non woven geotextile placed prior to approval by the Owner and/or Engineer shall be at the sole risk of the Contractor. If geotextile installed prior to approval by the Owner and/or Engineer does not meet the requirements of this specification, it shall be removed from the site at no additional cost to the Owner.

B. Geomembrane will be deployed following installation of 16-oz non woven geotextile according to submitted panel layout drawing as approved by the Owner and/or Engineer. The Owner and/or Engineer is to be notified of and approve any revisions or modifications to the approved panel layout drawing prior to deploying geomembrane in the area of review.

C. Adequate temporary anchoring (sand bags, tires, etc.) that will not damage the geomembrane shall be placed on a deployed panel to prevent uplift by wind.

D. Geomembrane shall not be deployed if:

1. Ambient temperatures are below 41 degrees F (5 degrees C) or above 104 degrees F (40 degrees C) measured six inches above geomembrane surface unless approved by the Owner and/or Engineer.

2. Precipitation is expected or in the presence of excessive moisture or ponded water on the subgrade surface.

3. Winds are excessive as determined by Geomembrane Installer in agreement with the Owner and/or Engineer.

4. The Owner and/or Engineer will have the authority to suspend work during such conditions.

E. The Geomembrane Installer shall be responsible for conformance with the following requirements:

1. Equipment utilized for installation/quality assurance testing does not damage geomembrane. Such equipment shall have rubber tires and a ground pressure not exceeding 5 psi or total weight exceeding 750 lbs. Only equipment necessary for installation and quality assurance testing is allowed on the deployed geomembrane.

2. Personnel working on geomembrane do not damage geomembrane (activities such as smoking or wearing damaging clothing shall not be allowed).

3. Method of deployment does not damage geomembrane.

4. Method of deployment minimizes wrinkles.

5. Temporary loading or anchoring does not damage geomembrane.

6. Direct contact with geomembrane is minimized.

F. Geomembrane Installer shall place 12-oz non woven geotextile on the geomembrane at the base of the impoundment and at least 4 feet up side slopes, as indicated on Contract Drawings. Geomembrane Install shall cover the inlet apron batten bar attachment with the 12-oz non woven geotextile.

G. No vehicles shall be allowed on deployed geomembrane under any circumstances.

3.04 FIELD SEAMS

A. Seam Layout

1. In general, seams shall be oriented parallel to the line of the maximum slope. In corners and at other odd-shaped geometric intersections, number of seams should be minimized. If at all possible, seams shall not be located at low points in the subgrade unless geometry requires seaming to be done at these locations.

2. A seam numbering system compatible with the panel numbering system shall be agreed upon at the Pre-Construction Meeting.

B. Seaming Processes/Equipment

1. Approved processes for field seaming (panel to panel) are extrusion or hot wedge fusion-type seam methods. No other processes can be used without prior written authorization from the Owner and/or Engineer. Only equipment which has been specifically approved by make and model shall be used, if applicable.

3. The Geomembrane Installer will meet following requirements regarding use, availability, and cleaning of welding equipment at job site:

a. Intersecting hot wedge seams shall be patched using extrusion welding process.

b. Electric generator for equipment shall be placed on a smooth base such that no damage occurs to geomembrane. A smooth insulating plate or fabric shall be placed beneath hot equipment after usage.

3. The Geomembrane Installer shall keep records for performance and testing of all seams.

C. Seaming Requirements/Procedures

1. Weather Conditions - Range of weather conditions under which geomembrane seaming can be performed are as follows:

   a. Unless otherwise authorized in writing by Owner and/or Engineer, no seaming shall be attempted or performed at an ambient temperature below 41 degrees F (5 degrees C) or above 104 degrees F (40 degrees C).

   b. Between ambient temperatures of 32 degrees F (0 degrees C) and 41 degrees F (5 degrees C), seaming shall be performed only if geomembrane is preheated by either sun or a hot air device, provided there is no excessive ambient cooling resulting from high winds. Pre-qualification seams shall be produced under identical conditions.

   c. Above 41 degrees F (5 degrees C), no preheating of geomembrane will be required.

   d. Geomembrane shall be dry and protected from wind.

   e. Seaming shall not be performed during any precipitation event.

   f. Seaming shall not be performed in areas where ponded water has collected below surface of geomembrane.

2. If the Geomembrane Installer chooses to use methods which may allow seaming at ambient temperatures below 41 degrees F or above 104 degrees F, the Geomembrane Installer shall demonstrate and submit certification to Owner and/or Engineer that methods and techniques used to perform seaming produce seams that are equivalent to seams produced at temperatures above 41 degrees F and below 104 degrees F. The Owner and/or Engineer may deny approval for use of the proposed technique regardless of demonstration results.

3. Overlapping - Geomembrane panels shall have finished overlap as follows:

   a. Minimum of 6 inches for thermal fusion welding.

   b. Insufficient overlap will be considered a failed seam.

4. Pre-qualification tests for geomembrane fusion welding shall be conducted by a minimum of 2 pre-qualification seams conducted per day per welding machine by each seaming technician performing welding with that machine. At least one test shall be performed at the start of each work day, with tests at intervals of no greater than 5 hours and additional pre-qualification tests following work interruptions, weather changes, changes to machine settings, or as directed by the Owner and/or Engineer. Pre-qualification seams shall be made under the same conditions as the actual seams.

a. Pre-qualification seam samples shall be 5 feet long by 1-foot wide (minimum) after seaming, with seam centered along its length. Each pre-qualification seam shall be labeled with the date, geomembrane temperature, seaming unit identifier, seam number or test location, technician performing the test seam and description of testing results.

b. Seam overlap shall be in accordance with subsection 3.04(C)(3).

c. Pre-qualification seams shall be inspected for proper squeeze-out, footprint pressure, and general appearance.

d. Four specimens, each 1-inch in length, shall be cut from opposite ends of the pre-qualification seam sample by the Geomembrane Installer. The remainder of pre-qualification seam shall be retained by the Owner and/or Engineer and may be submitted for laboratory testing.

e. The Geomembrane Installer shall complete two shear tests and two peel tests.

f. Pre-qualification seams failed by inspection or testing may be retested at request of the Geomembrane Installer. If the second pre-qualification seam fails, then the seaming apparatus or seaming technique shall be disqualified from use until two consecutive, satisfactory pre-qualification seams are obtained.

5. Seam Preparation

a. Prior to seaming, seam area shall be clean and free of moisture, dust, dirt, debris of any kind, and foreign material.

b. Seams shall be aligned so as to minimize number of wrinkles and fishmouths.

6. General Seaming Procedures

a. Fishmouths or wrinkles at seam overlaps shall be cut along ridge of the wrinkle to achieve a flat overlap. Cut fishmouths or wrinkles shall be repaired, and/or patched in accordance with Part 3.07.

b. Seaming shall extend to the outside edge of geomembrane panels including material placed in anchor trenches.

c. For cross seams, the intersecting thermal fusion seams shall be patched using the extrusion welding process.

3.05 NON-DESTRUCTIVE TESTING

A. Each field seam shall be non-destructively tested over its entire length by the Installer. Testing shall be conducted as field seaming progresses, not at completion of all seams, unless specifically agreed to by the Owner and/or Engineer in writing.

B. Vacuum Testing – shall be performed in accordance with ASTM D5641, Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber.

C. Air Pressure Testing – shall be performed in accordance with ASTM D5820, Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes, and GRI GM 6, Pressurized Air Channel Test for Dual Seamed Geomembranes.

D. Each seam tested non-destructively shall be marked with the date of the test, name of the testing technician, length of the seam, test method and results. The same shall also be recorded by the Owner and/or Engineer on the appropriate CQA documentation.

E. Non-Destructive Seam Test Failures

1. Seams failing non-destructive testing shall be repaired by the Geomembrane Installer according to Part 3.07. Seams shall be non-destructively retested. If the seam defect cannot be located, the entire section of seams affected shall be repaired and retested.

3.06 ELECTRONIC LEAK LOCATION SURVEY

A. Leak Location Contractor shall identify actions required by Contractor to prepare the site for the leak location survey.

B. Contractor shall ensure that the sand and warning layers, and 12 oz non woven geotextile above and 16 oz non woven geotextile below the geomembrane contains sufficient moisture to conduct a leak location survey. Typically, a moisture content of earth materials of 1% to 2% by weight is sufficient to conduct the survey. If the moisture content of the sand layer, warning layer and subgrade is not sufficient per the requirements of the Leak Location Contractor, Contractor shall add sufficient water the layers, as required.

C. Contractor shall provide electrical isolation of the metal marker posts, batten bars, and concrete structures, as requested by Leak Location Contractor.

D. Leak Location Contractor shall inspect the site prior to commencing the survey to ensure all site preparations are completed and the site conditions are appropriate for conducting the leak location survey.

E. Any discrepancy in the required site preparation detailed in the Leak Location Contractor's Work Plan or site conditions shall be reported to the Contractor for corrective or appropriate action.

F. After the warning layer is placed, conduct a leak location survey on the warning layer material using the procedures for surveys with earth materials covering the Geomembrane as described in ASTM D 7007.

G. A leak detection sensitivity test using an artificial leak shall be conducted on the geomembrane for each set of equipment used before the equipment is used on for the leak location survey, as described in ASTM D 7007 to determine the detection distance for the survey.

H. The leak location survey shall be taken on survey lines or on a grid spaced no farther apart than twice the leak detection distance as determined in the leak detection sensitivity test.

I. The Leak Location Contractor shall inform the Owner and/or Engineer and mark the locations of all identified or indicated leaks with a flag or spray paint. The Geomembrane Installer shall repair the defect/hole as detailed in Part 3.08 of this Section.

3.07 DEFECTS AND REPAIRS

A. The geomembrane shall be examined by the Geomembrane Installer and the Owner and/or Engineer for defects, holes, blisters, undispersed raw materials, and any signs of contamination by foreign matter. The geomembrane surface shall be swept and/or washed by the Geomembrane Installer if the amount of dust or mud inhibits examination. The Contractor shall provide a water truck, an operator, clean water and hoses as reasonably necessary to assist the Geomembrane Installer in this activity.

B. Portions of geomembrane exhibiting flaws, or failing a non-destructive or destructive (if conducted) test, shall be repaired or replaced by the Geomembrane Installer. Repair procedures available include:

1. Patching - used to repair large holes, tears, undispersed raw materials, contamination by foreign matter, holes resulting from destructive sampling (if conducted), and locations where seam overlap is insufficient;

2. Capping - used to repair large lengths of failed seams; and

3. Additional Procedures - used upon recommendation of the Geomembrane Installer if agreed to by the Owner and/or Engineer.

C. Patches or caps.

1. Extend patch or cap 6 inches (minimum) beyond the edge of the defect.

2. Round corners of patch and/or cap (suggest 3-inch radius).

3. Repair procedures, equipment, materials, and techniques will be approved by the Owner and/or Engineer prior to repair.

4. Geomembrane below large caps shall be appropriately cut to avoid water or gas collection between two sheets.

D. The Geomembrane Installer shall mark on the geomembrane (using a non-puncturing writing utensil), repair date, time, and personnel involved.

E. Each repair shall be non-destructively tested in accordance with Part 3.05. Large caps may require destructive test sampling at the discretion of the Owner and/or Engineer (in accordance with Part 3.06).

F. Repairs which fail testing shall be redone and retested until a passing result is obtained. The Geomembrane Installer will perform non-destructive testing or repairs and will document retesting of repairs.

G. The Owner and/or Engineer will document repairs, repair testing, and retesting results.

H. The Geomembrane Installer shall cut and seam wrinkles which may adversely affect long-term integrity of the geomembrane, hinder subsequent construction of overlying layers, or impede drainage off of the geomembrane after it is covered by soil. Seaming shall be done in accordance with procedures described in Parts 3.04(B) and 3.04(C), and it shall be subject to test provisions of Parts 3.05 (non-destructive testing) and 3.06 (destructive testing – if conducted).

3.08 PROTRUSIONS AND CONNECTIONS TO GEOMEMBRANE

A. If required, the Geomembrane Installer shall install geomembrane around utility poles, guy wires, and other structures according to the Contract Drawings and the following requirements:

1. Use minimum 2-ft long membrane pipe boots and steel straps to seal the geomembrane around pole or structure.

2. Use standard welding procedures to seam the membrane boot to the geomembrane.

3. Seaming performed on and around penetrations, and other appurtenances shall be non-destructively tested using the vacuum testing method.

3.09 SURVEY DOCUMENTATION

A. Prior to covering the geomembrane, the Geomembrane Installer shall provide the Contractor , Owner and/or Engineer with 24-hour notification to conduct a survey. The Contractor shall survey the location of all seams (panel corners acceptable), and repairs. The Contractor shall provide survey data to the Owner and/or Engineer within one working day of survey completion and in accordance with Section 01050.

3.10 DAILY FIELD INSTALLATION REPORTS

A. At the beginning of each day, the Geomembrane Installer shall provide the Owner and/or Engineer with a report for all work completed the previous day.

B. The Daily Field Installation Report shall include the following:

1. The total amount and location of geomembrane placed.

2. The total length and location of seams completed, technician name and welding unit numbers.

3. A drawing or sketch depicting the geomembrane installed the previous day including the panel number, seam number and locations of non-destructive and destructive testing (if conducted).

4. Results of pre-qualification test seams, if available.

5. Results of non-destructive testing.

C. Destructive test results (if conducted) shall be reported within 48 hours or prior to covering the geomembrane, whichever is practical.

END OF SECTION

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FIGURES

Figure 1 Site Location Map (1862-A01C)

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Table 1 List of Documentation Surveys
Table 2 List of Submittals

SHEETS

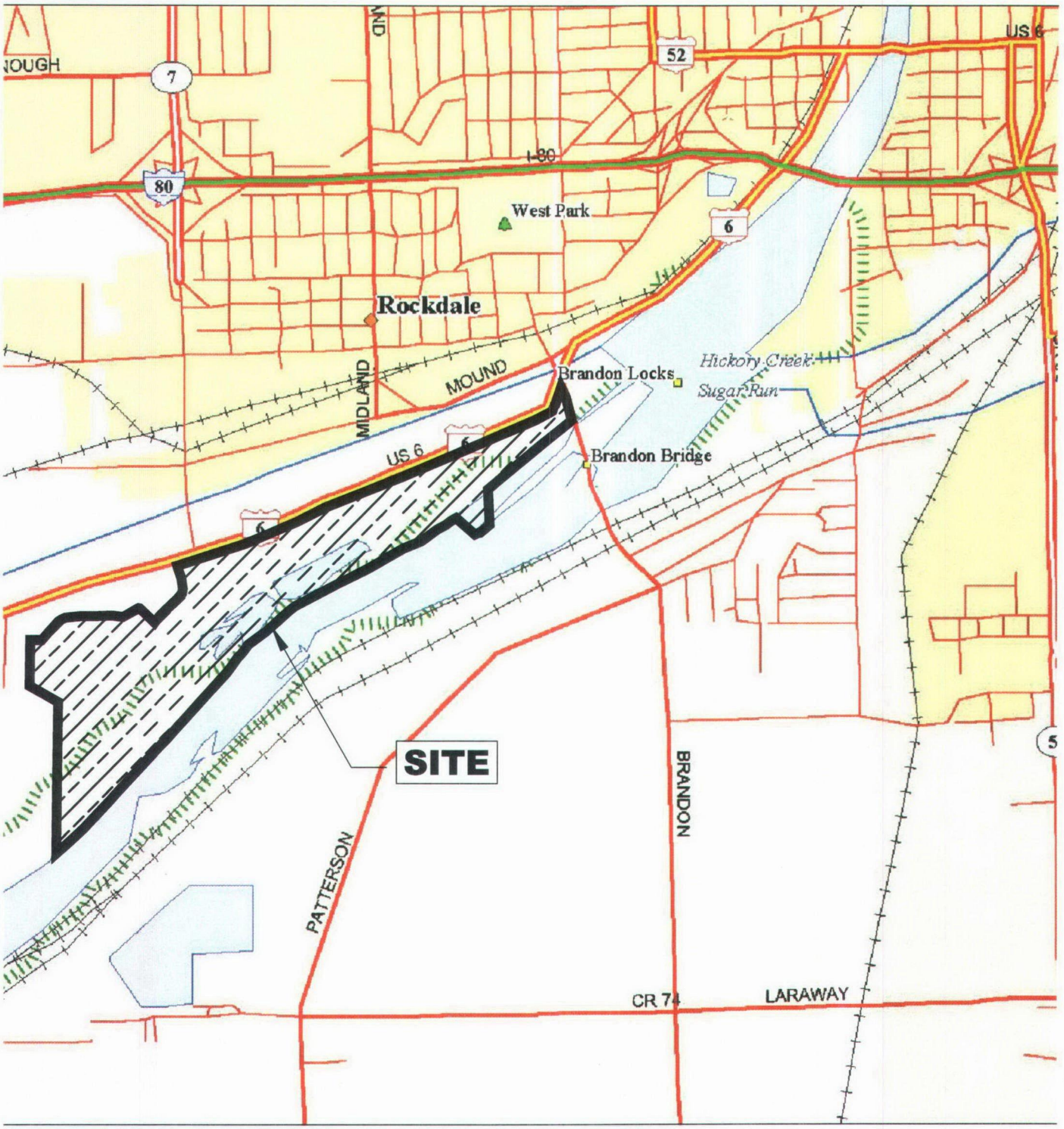
TS Title Sheet (D1862-TS-00)

C010 Existing Conditions (D1862 C010-01)
C020 Liner Subgrade Preparation (D1862 C020-01)
C030 Warning Layer Plan (D1862 C030-01)
C031 Details and Sections (D1743 C031-01)

MWG13-15_18721

FIGURES

FIGURE



SOURCE: DELORME MAP EXPERT (TM)
VERSION 2.0
COPYRIGHT 1993, DELORME MAPPING
JOLIET. DATED 1993.



QUADRANGLE LOCATION

N

0 2000 4000

SCALE IN FEET

SITE LOCATION MAP

MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

NATURAL RESOURCE TECHNOLOGY

DRAWN BY: BJK 05/08/07 APP'D BY: HMS DATE: 06/04/07

PROJECT NO. 1862

DRAWING NO. 1862–A01C

FIGURE NO. 1

MWG13-15_18724

Electronic Filing: Received, Clerk's Office 2/04/2022

TABLES

TABLES

Table 1. List of Documentation Surveys
Ash Impoundment #2 Liner Replacement Specifications
Midwest Generation – Joliet 29

Survey	Responsible Party	Frequency	Technical Specification Reference
Location of anchor trench alignment	Contractor	Every 25 ft intervals	Section 01050, 1.02B
Location and elevation geomembrane panels	Contractor	At panel corners and repairs, as necessary	Section 01050, 1.02C Section 02600, 1.05C, 3.10A
Location of marker post	Contractor	As necessary	Section 01050, 1.02E
Topographic survey of warning layer	Contractor	50 ft square grid and at grade changes	Section 01050, 1.02F

Notes
1. Contractor shall provide Owner and/or Engineer results of survey within 2 working days after completion.
2. Owner and/or Engineer acceptance or rejection will be provided within 2 working days following receipt of documentation survey.

MWG13-15_18727

Table 2 - List of Submittals
Ash Impoundment #2 Liner Replacement Specifications
Midwest Generation – Joliet 29

	Submittal	From	To	Time Frame	Reviewer	Technical Specification	
						Section	Part
1	Subcontractor List	Contractor	Owner and/or Engineer	**With bid documents**	Owner	01040	1.03F
2	Baseline Construction Schedule	Contractor	Owner and/or Engineer	**With bid documents** and update within 10 calendar days of the date of the Contract award	Owner and/or Engineer	01040	1.06B
3	Earthwork Plan	Contractor	Owner and/or Engineer	**With bid documents**	Owner and/or Engineer	02300	1.06B
4	Name and Location of Recycling / Disposal Facility	Contractor	Owner and/or Engineer	**With bid documents**	Owner and/or Engineer	02300	1.06E
5	Leak Location Contractor's Work Plan	Contractor	Owner and/or Engineer	**With bid documents**	Owner and/or Engineer	02600	1.05B
6	Construction Start Date	Contractor	Owner and/or Engineer	5 Working days prior to construction start	Owner and/or Engineer	02300	1.06D
7	IEPA Water Pollution Control Construciton Permit	Owner through Engineer	Contractor	Prior to project start	Contractor	01015	1.05A
8	Site Superintendant/Foreman's Name & Phone Number	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	01040	1.03A
9	Location of Off-site Fill Material Sources	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02300	1.06C
10	Off-site Fill Material Certificates/Test Results	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02300	1.06E
11	Resin Supplier, Address, Brand Name, Product Number and Test Results	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02600	1.05A
12	Source and nature of additives	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02600	1.05A
13	Geomembrane Installer's Information, Layout Diagram, Schedule, Seaming Equipment	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02600	1.05A

Table 2 - List of Submittals
Ash Impoundment #2 Liner Replacement Specifications
Midwest Generation – Joliet 29

	Submittal	From	To	Time Frame	Reviewer	Technical Specification	
						Section	Part
14	Progress Meeting Minutes	Owner and/or Engineer	Owner, Contractor, Engineer, and Subcontractors (as necessary)	Prior to subsequent progress meeting	Owner and/or Engineer	01040	1.05E
15	Progress Schedule	Contractor	Owner and/or Engineer	Weekly one working day prior to regular scheduled progess meeting	Owner and/or Engineer	01040	1.06C 1.06D
16	Progress Reports	Contractor	Owner and/or Engineer	Weekly one working day prior to regular scheduled progess meeting	Owner and/or Engineer	01040	1.08A
17	Accident Reports, Work Stoppage/Dispute Records, Contractor Invoices, Schedule of Values, Test Report Records, and Equipment Check Records	Contractor	Owner and/or Engineer	As Necessary	Owner and/or Engineer	01040	1.08B
18	Sand Material Representative Sample	Contractor	Owner and/or Engineer	Two weeks prior to delivery	Owner and/or Engineer	02300	2.03
19	Warning Layer Representative Sample	Contractor	Owner and/or Engineer	Two weeks prior to delivery	Owner and/or Engineer	02300	2.04
20	Geomembrane Manufacture's Certification-PGI Standards	Contractor	Owner and/or Engineer	5 working days prior to delivery to site	Owner and/or Engineer	02600	1.05A
21	Geotextile - Product Information	Contractor	Owner and/or Engineer	5 working days prior to delivery to site	Owner and/or Engineer	02600	1.05A
22	Geomembrane Manufacturer's Certification - Product Information	Contractor	Owner and/or Engineer	5 working days prior to delivery to site	Owner and/or Engineer	2600	1.05A
23	Certification of Geomembrane Manufacturer's Quality Control Plan	Contractor	Owner and/or Engineer	5 working days prior to delivery to site	Owner and/or Engineer	2600	1.05A

Table 2 - List of Submittals
Ash Impoundment #2 Liner Replacement Specifications
Midwest Generation – Joliet 29

	Submittal	From	To	Time Frame	Reviewer	Technical Specification	
						Section	Part
24	Geomembrane Installer's Daily Logs and Quality Control Documentation	Contractor	Owner and/or Engineer	During geomembrane installation	Owner and/or Engineer	02600	1.05C
25	Geomembrane Installer's Subgrade Acceptance	Contractor	Owner and/or Engineer	Each day prior to geomembrane installation	Owner and/or Engineer	02600	1.05C 3.02A
26	Geomembrane Installation Certificate, As-Builts, and Warranties	Contractor	Owner and/or Engineer	Within 10 working days of geomembrane installation completion	Owner and/or Engineer	02600	1.05D
27	Written Certification for Project	Contractor	Owner and/or Engineer	Upon completion of work	Owner and/or Engineer	01700	1.03B & C
28	Conditional and/or Final Geomembrane Installation Acceptance	Owner and/or Engineer	Contractor	Upon completion of geomembrane installation and submittals	Contractor	2600	1.05F
29	Record Documents	Contractor	Owner and/or Engineer	Prior to submittal of final invoice	Owner and/or Engineer	01700	1.04
30	Survey Data	Contractor	Owner and/or Engineer	Within 4 days following completion of survey	Owner and/or Engineer	01050	1.05
31	Final Leak Location Survey Report	Contractor	Owner and/or Engineer	Within 14 days following completion of leak location survey	Owner and/or Engineer	02600	1.05G

SHEETS

ASBUILT OF
MIDWEST GENERATION JOLIET 29 POWER PLANT
WEST-ASH IMPOUNDMENTS

GRAPHIC SCALE
40 0 40
(IN FEET)
1 inch = 40 ft.



LEGEND

meas.	MEASURED
rec.	RECORDED
calc.	CALCULATED
●	FOUND SURVEY MONUMENT
■	SET 5/8" REBAR UNLESS OTHERWISE NOTED
	6' HIGH CHAIN LINK FENCE
	UTILITY POLE
	LIGHT
	UNDERGROUND PIPELINE LOCATED BY OTHERS
XXX	EXISTING CONTOUR
XXX.XX	EXISTING ELEVATION
	OVERHEAD UTILITY LINES

ASBUILT NOTE:

THE POND ASBUILT EXTENDS TO THE OUTSIDE OF THE NEW LINER, AS SHOWN HEREON. AREAS OUTSIDE THE NEW LINER AND SHOWN HEREON HAVE NOT BEEN REVERIFIED

SITE BENCHMARK 1:

SET CONCRETE NAIL IN WESTERLY FACE OF UTILITY POLE, WEST SIDE OF EAST ENTRANCE ROAD, 4TH UTILITY POLE SOUTH OF U.S. ROUTE 6.

ELEVATION: 536.39 (NGVD 29)

SITE BENCHMARK 2:

SET REBAR 2' S & 2.5' E OF 6' HIGH CHAIN LINK FENCE CORNER AT SOUTHEAST CORNER OF MAIN ENTRANCE ROAD & U.S. ROUTE 6.

ELEVATION: 536.71 (NGVD 29)

BENCHMARK:

WILL COUNTY CONTROL MONUMENT STATION 6274 CUT SQUARE ON CENTERLINE OF SOUTH HEADWALL IN THE SOUTHEAST CORNER OF THE INTERSECTION OF BRANDON ROAD AND MEADOW AVENUE.

ELEVATION: 550.33 (NGVD 29)

FIELD VERIFY BENCHMARKS WITH BENCHMARK LIST.

STATE OF ILLINOIS)
)SS
COUNTY OF WILL)

RUETTIGER, TONELLI & ASSOCIATES, INC., ILLINOIS PROFESSIONAL DESIGN FIRM No. 184-001251, HEREBY CERTIFIES THAT IT HAS TOPOGRAPHICALLY SURVEYED THE POND AREA NOTED HEREON AND AS SHOWN ON THE ANNEXED PLAT, WHICH IS A TRUE AND CORRECT REPRESENTATION OF SAID TOPOGRAPHY.

SURVEY FIELD WORK COMPLETED 10/20/08

GIVEN UNDER MY HAND AND SEAL THIS 10th DAY OF MAY, 2008.

BY _____
ILLINOIS PROFESSIONAL LAND SURVEYOR (MY LICENSE EXPIRES 11-30-2008)

REVISIONS

No.	DATE	DESCRIPTION	BY
1	12/2/08	ADDED NEW ASBUILT INFORMATION	MJ

R&T Ruettiger, Tonelli & Associates, Inc.
Surveyors •Engineers •Planners •Landscape Architects •G.I.S. Consultants
2174 ONEIDA STREET, JOLIET, ILLINOIS 60435, PH. (815) 744-6600 FAX (815) 744-0101
2603 S. WASHINGTON STREET - SUITE 170, NAPERVILLE, ILLINOIS 60565, PH. (630) 420-7740 FAX (630) 420-7741

DATE: 6/9/08	SCALE: 1" = 40'	DRAWN BY: MJ	CHECKED BY: EC

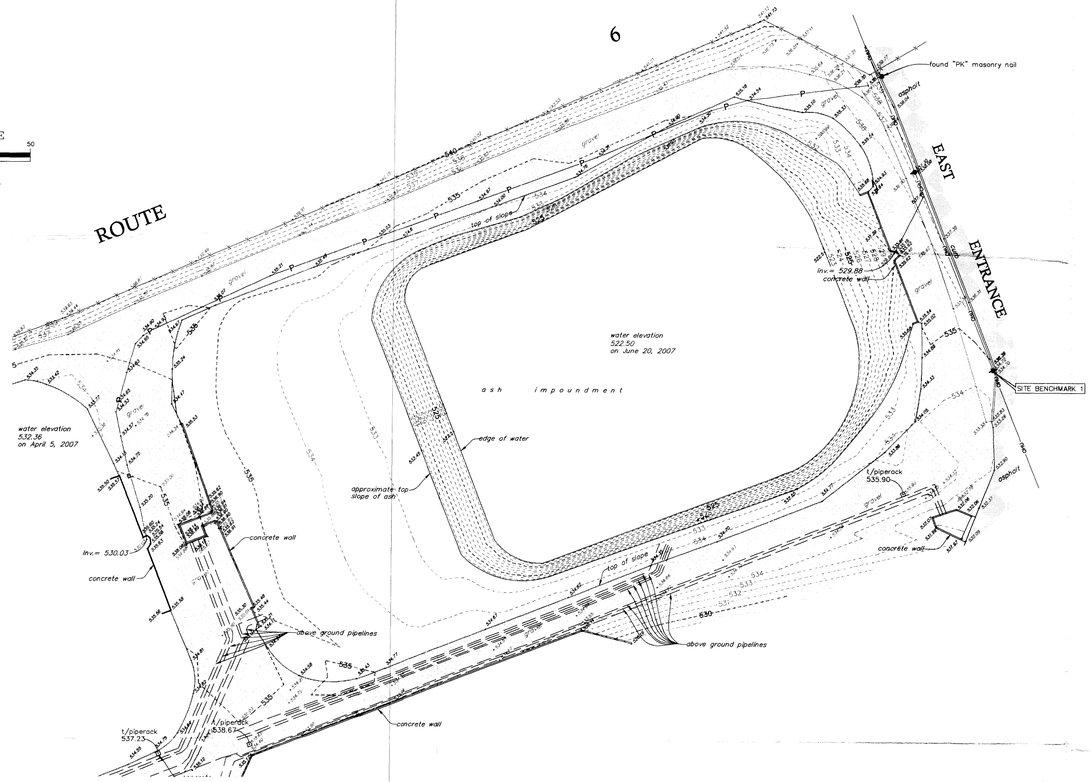
PREPARED FOR: BREISER CONSTRUCTION COMPANY
24101 S. MUNICIPAL DRIVE
CHANNAHON, IL

FIELD BOOK: MIDWEST GEN.
PAGE: 11-13

DRAWING No.:
308-0363 ASBUILT WEST-ASH IMP.

DRAWING TITLE: ASBUILT

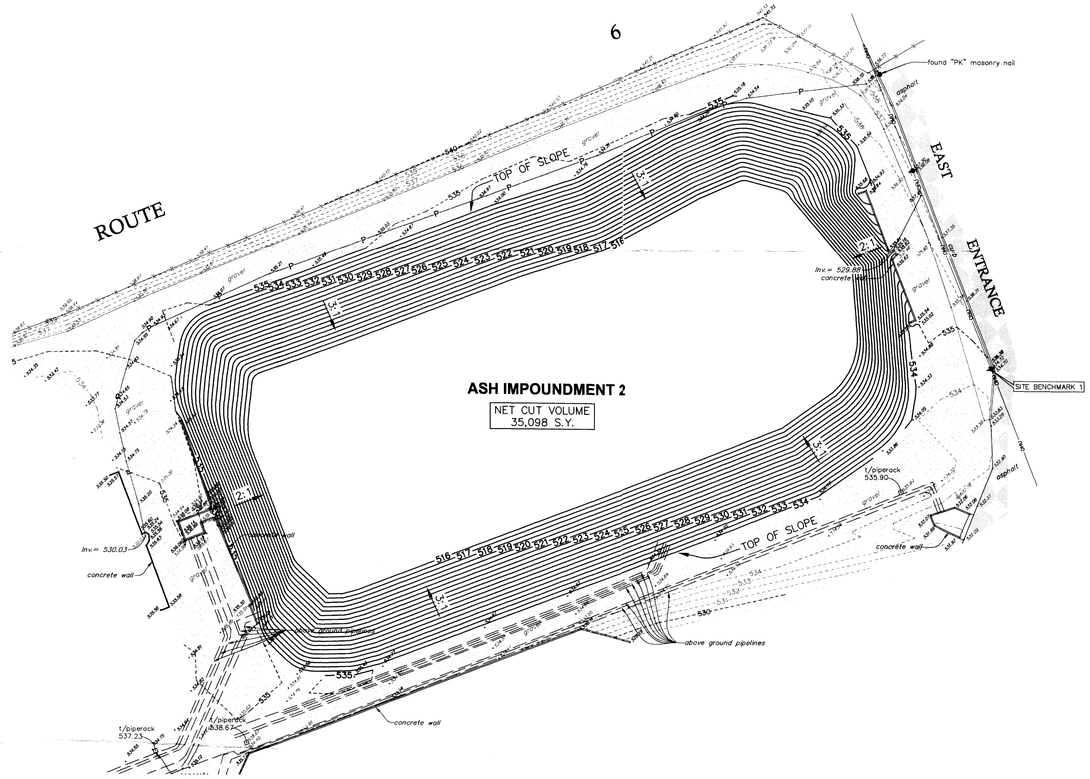
GRAPHIC SCALE
50 0 50
(IN FEET)
1 inch = 50 ft.



EXISTING CONDITONS

LEGEND

meas.	MEASURED
rec.	RECORDED
calc.	CALCULATED
●	FOUND SURVEY MONUMENT
■	SET 5/8" REBAR UNLESS OTHERWISE NOTED
x—x—x—x	6' HIGH CHAIN LINK FENCE
◆	UTILITY POLE
☼	LIGHT
—P—	UNDERGROUND PIPELINE LOCATED BY OTHERS
XXX	EXISTING CONTOUR
XXX.XX	EXISTING ELEVATION
OHU	OVERHEAD UTILITY LINES



ASH IMPOUNDMENT 2

NET CUT VOLUME
35,098 S.Y.

CONCEPTUAL DESIGN CONTOURS FOR PROPOSED EXCAVATION

NOTE: THIS DESIGN IS BASED UPON INFORMATION OBTAINED IN NATURAL RESOURCE TECHNOLOGY'S DRAWING No. D1862C010-00, DATED 05-04-07.

REVISIONS

No.	DATE	DESCRIPTION	BY	No.	DATE	DESCRIPTION	BY

DOCUMENTATION:
PROJECT No.: 20070648
DATE: 06-27-07
FIELD BOOK: MIDWEST GEN.
DRAWN BY: NW
CHECKED BY: JPH

R T & A
Ruettiger, Tonelli & Associates, Inc.
Surveyors • Engineers • Planners • Landscape Architects • G.I.S. Consultants
2174 ONEIDA STREET JOLIET, ILLINOIS 60435 PH. (815) 744-6600 FAX (815) 744-0101
2603 S. WASHINGTON STREET - SUITE 170 NAPERVILLE, ILLINOIS 60565 PH. (630) 420-7740 FAX (630) 420-7741

PROJECT TITLE:
MIDWEST GENERATION JOLIET STATION No. 29 ASH IMPOUNDMENT

DRAWING TITLE:
ASH REMOVAL EXHIBIT

DRAWING No. 307-0648-E1
SCALE: 1" = 50'
"DEPARTMENT"
SHEET 1 OF 1

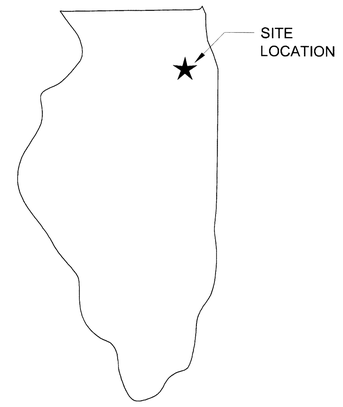
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MWG13-15_18733

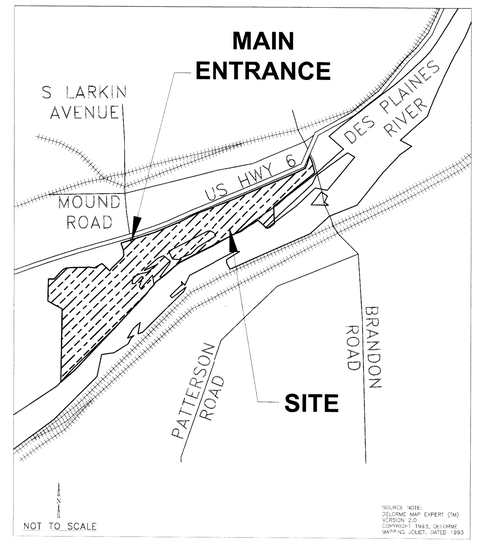
ASH IMPOUNDMENT DESIGN
JOLIET STATION NO. 29
MIDWEST GENERATION
JOLIET, WILL COUNTY, ILLINOIS

LIST OF DRAWINGS

SHEET NO.	TITLE	DRAWING NO.
TS	TITLE SHEET	D1862TS-00
C010	EXISTING CONDITIONS	D1862C010-01
C020	LINER SUBGRADE PREPARATION	D1862C020-01
C030	WARNING LAYER PLAN	D1862C030-01
C031	DETAILS AND SECTIONS	D1862C031-01



ILLINOIS



SITE VICINITY

NOT FOR CONSTRUCTION

TITLE SHEET

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

SHEET NO. TS

PROJECT NO. 1862/3.0
DRAWN BY: BJK 07/12/07
CHECKED BY: HMS 08/02/07
APPROVED BY:
DRAWING NO: D1862TS-00
REFERENCE: 1862/3/BID-CON/

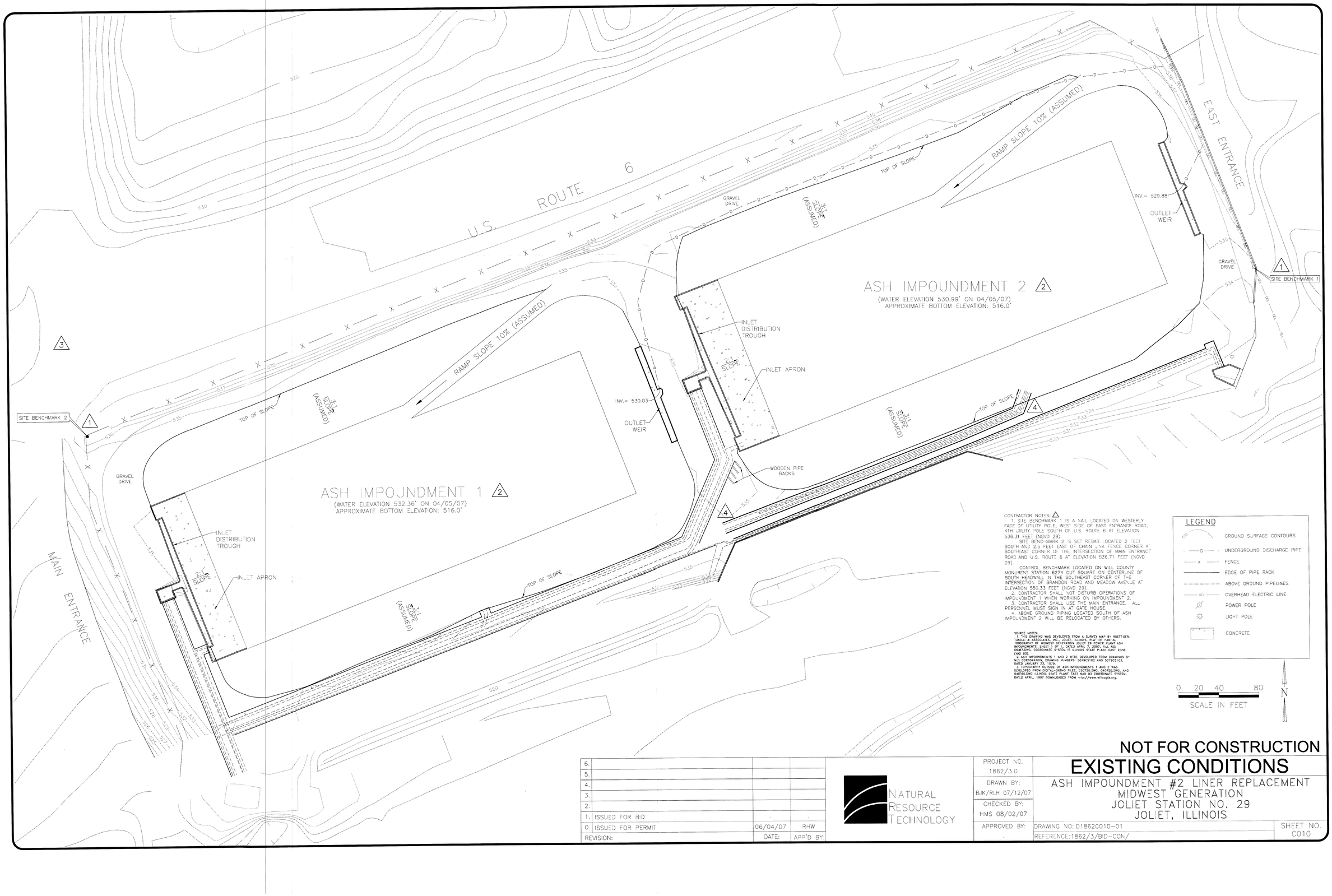
NATURAL RESOURCE TECHNOLOGY

NO.	REVISION:	DATE:	APP'D BY:
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AUGUST 2007

PREPARED FOR:

MIDWEST GENERATION, LLC
1800 CHANNAHON ROAD
JOLIET, ILLINOIS 60436



CONTRACTOR NOTES: △

1. SITE BENCHMARK 1 IS A NAIL LOCATED ON WESTERLY FACE OF UTILITY POLE, WEST SIDE OF EAST ENTRANCE ROAD, 41M UTILITY POLE SOUTH OF U.S. ROUTE 6 AT ELEVATION 536.39 FEET (NGVD 29).

SITE BENCH-MARK 2 IS SET REBAR LOCATED 2 FEET SOUTH AND 2.5 FEET EAST OF CHAIN LINK FENCE CORNER AT SOUTHEAST CORNER OF THE INTERSECTION OF MAIN ENTRANCE ROAD AND U.S. ROUTE 6 AT ELEVATION 536.71 FEET (NGVD 29).

CONTROL BENCHMARK LOCATED ON WILL COUNTY MONUMENT STATION 6274 CUT SQUARE ON CENTERLINE OF SOUTH HEADWALL IN THE SOUTHEAST CORNER OF THE INTERSECTION OF BRANDON ROAD AND MEADOW AVENUE AT ELEVATION 550.33 FEET (NGVD 29).

2. CONTRACTOR SHALL NOT DISTURB OPERATIONS OF IMPOUNDMENT 1 WHEN WORKING ON IMPOUNDMENT 2.

3. CONTRACTOR SHALL USE THE MAIN ENTRANCE. ALL PERSONNEL MUST SIGN IN AT GATE HOUSE.

4. ABOVE GROUND PIPING LOCATED SOUTH OF ASH IMPOUNDMENT 2 WILL BE RELOCATED BY OTHERS.

SOURCE NOTES:

1. THIS DRAWING WAS DEVELOPED FROM A SURVEY MAP BY: RUETT-GER, TONELLI & ASSOCIATES, INC., JOLIET, ILLINOIS, PLAT OF PARTIAL TOPOGRAPHY OF MIDWEST GENERATION JOLIET 29 POWER PLANT ASH IMPOUNDMENTS, SHEET 1 OF 1, DATED APRIL 7, 2007, FILE NO. D1862DWG. COORDINATE SYSTEM IS ILLINOIS STATE PLANE EAST ZONE, NAD 83.

2. ASH IMPOUNDMENTS 1 AND 2 WERE DEVELOPED FROM DRAWINGS BY NUS CORPORATION, DRAWING NUMBERS: 5079C5102 AND 5079C5103, DATED JANUARY 23, 1979.

3. TOPOGRAPHY OUTSIDE OF ASH IMPOUNDMENTS 1 AND 2 WAS DEVELOPED FROM DIGITAL-ORTHO FILES, D30750.DWG, D43750.DWG, AND D40760.DWG ILLINOIS STATE PLANE EAST NAD 83 COORDINATE SYSTEM, DATED APRIL, 1997 DOWNLOADED FROM http://www.wiliogis.org

LEGEND

- GROUND SURFACE CONTOURS
- UNDERGROUND DISCHARGE PIPE
- FENCE
- EDGE OF PIPE RACK
- ABOVE GROUND PIPELINES
- OVERHEAD ELECTRIC LINE
- POWER POLE
- LIGHT POLE
- CONCRETE

0 20 40 80
SCALE IN FEET

N

NOT FOR CONSTRUCTION

EXISTING CONDITIONS

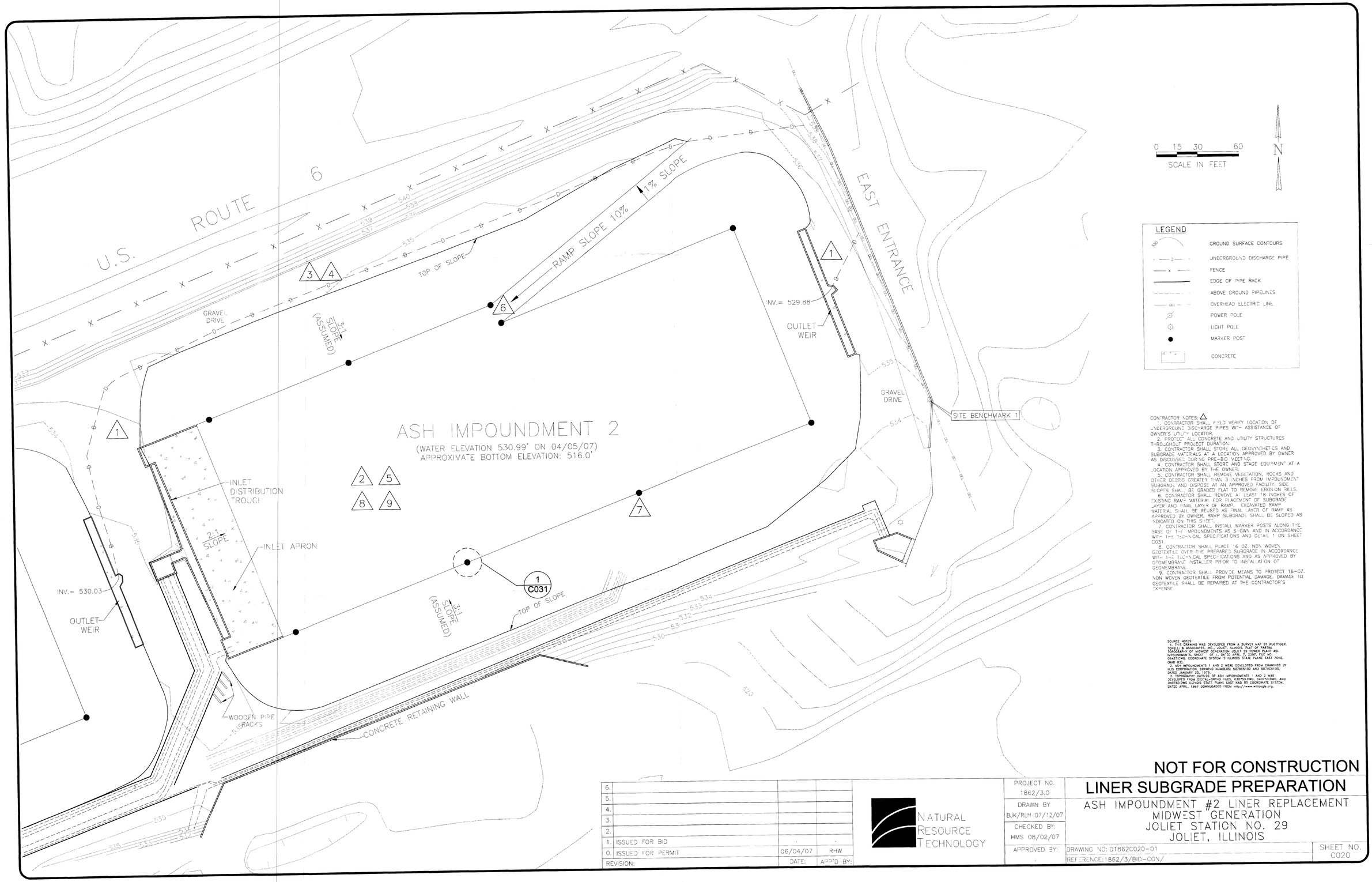
ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

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REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.	1862/3.0
DRAWN BY:	BJK/RLH 07/12/07
CHECKED BY:	HMS 08/02/07
APPROVED BY:	.
DRAWING NO:	D1862C010-01
REFERENCE:	1862/3/BID-CON/
SHEET NO.	C010

MWG13-15_18735



CONTRACTOR NOTES:
1. CONTRACTOR SHALL FIELD VERIFY LOCATION OF UNDERGROUND DISCHARGE PIPES WITH ASSISTANCE OF OWNER'S UTILITY LOCATOR.
2. PROTECT ALL CONCRETE AND UTILITY STRUCTURES THROUGHOUT PROJECT DURATION.
3. CONTRACTOR SHALL STORE ALL GEOSYNTHETICS AND SUBGRADE MATERIALS AT A LOCATION APPROVED BY OWNER AS DISCUSSED DURING PRE-BID MEETING.
4. CONTRACTOR SHALL STORE AND STAGE EQUIPMENT AT A LOCATION APPROVED BY THE OWNER.
5. CONTRACTOR SHALL REMOVE VEGETATION, ROCKS AND OTHER DEBRIS GREATER THAN 3 INCHES FROM IMPOUNDMENT SUBGRADE AND DISPOSE AT AN APPROVED FACILITY. SIDE SLOPES SHALL BE GRADED FLAT TO REMOVE EROSION RILLS.
6. CONTRACTOR SHALL REMOVE AT LEAST 18 INCHES OF EXISTING RAMP MATERIAL FOR PLACEMENT OF SUBGRADE LAYER AND FINAL LAYER OF RAMP. EXCAVATED RAMP MATERIAL SHALL BE REUSED AS FINAL LAYER OF RAMP AS APPROVED BY OWNER. RAMP SUBGRADE SHALL BE SLOPED AS INDICATED ON THIS SHEET.
7. CONTRACTOR SHALL INSTALL MARKER POSTS ALONG THE BASE OF THE IMPOUNDMENTS AS SHOWN AND IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS AND DETAIL 1 ON SHEET C031.
8. CONTRACTOR SHALL PLACE 16 OZ. NON WOVEN GEOTEXTILE OVER THE PREPARED SUBGRADE IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS AND AS APPROVED BY GEOMEMBRANE INSTALLER PRIOR TO INSTALLATION OF GEOMEMBRANE.
9. CONTRACTOR SHALL PROVIDE MEANS TO PROTECT 16-OZ. NON WOVEN GEOTEXTILE FROM POTENTIAL DAMAGE. DAMAGE TO GEOTEXTILE SHALL BE REPAIRED AT THE CONTRACTOR'S EXPENSE.

SOURCE NOTES:
1. THIS DRAWING WAS DEVELOPED FROM A SURVEY MAP BY RUETTIGER, TONELLI & ASSOCIATES, INC., JOLIET, ILLINOIS, TITLED BY PARTIAL TOPOGRAPHY OF MIDWEST GENERATION ASH IMPOUNDMENT #2 AND ADJACENT AREAS, SHEET 1 OF 1, DATED APRIL 23, 2007, FILE NO. D0607-TOPO. COORDINATE SYSTEM IS ILLINOIS STATE PLANE EAST ZONE, (NAD 83).
2. ASH IMPOUNDMENTS 1 AND 2 WERE DEVELOPED FROM DRAWINGS BY NUS CORPORATION, DRAWING NUMBERS: 5079C5103 AND 5079C5105, DATED JANUARY 23, 1979.
3. TOPOGRAPHY OUTSIDE OF ASH IMPOUNDMENTS 1 AND 2 WAS DEVELOPED FROM DIGITAL CONTOUR FILES, 530750.DWG, 540750.DWG, AND 540760.DWG, ILLINOIS STATE PLANE EAST NAD 83 COORDINATE SYSTEM, DATED APRIL, 1997 DOWNLOADED FROM http://www.willcogis.org.

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REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.	1862/3.0
DRAWN BY	BJK/RLH 07/12/07
CHECKED BY:	HMS 08/02/07
APPROVED BY:	.

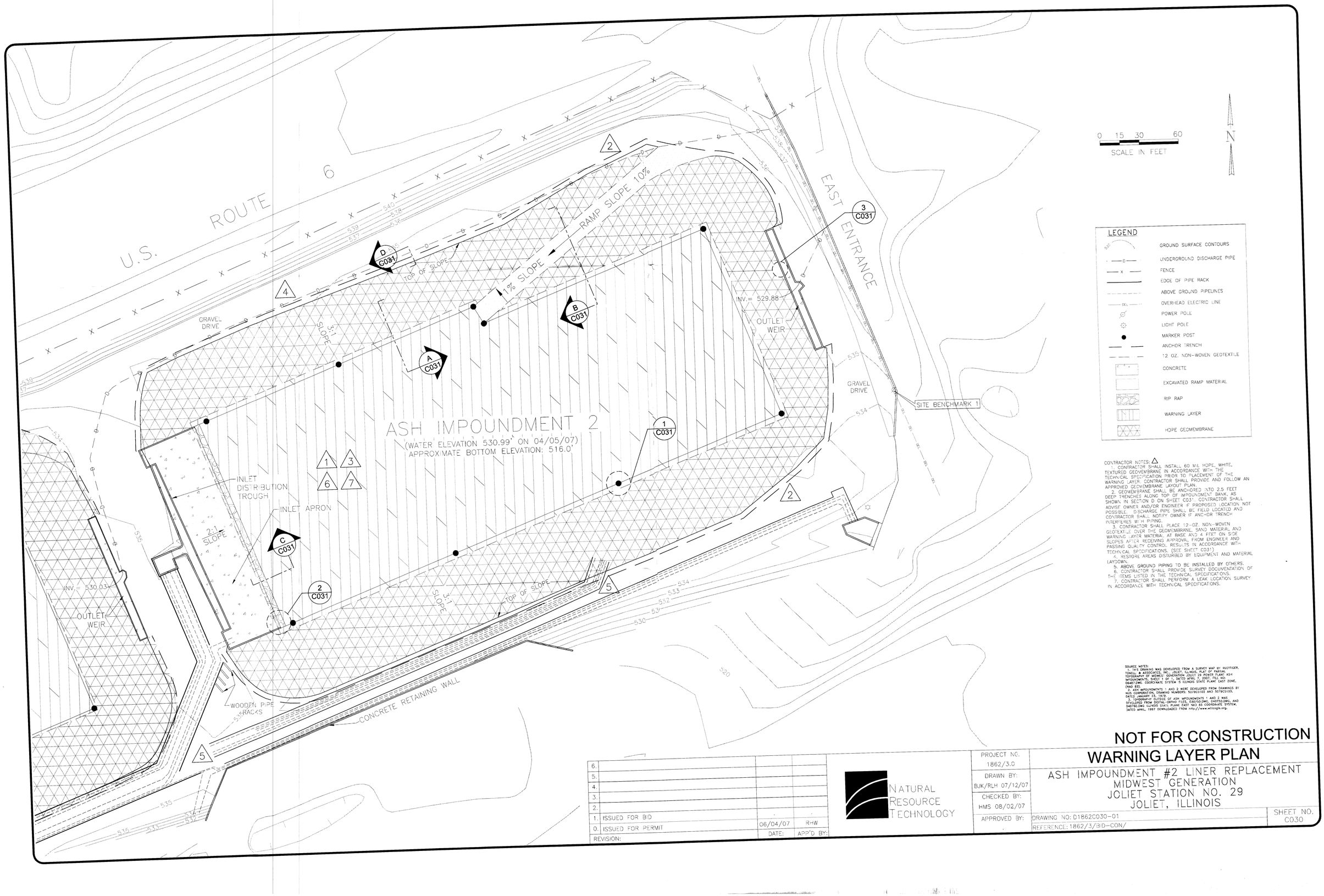
NOT FOR CONSTRUCTION

LINER SUBGRADE PREPARATION

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

DRAWING NO: D1862C020-01
REFERENCE:1862/3/BID-CON/

SHEET NO. C020



CONTRACTOR NOTES: △
1. CONTRACTOR SHALL INSTALL 60 MIL HDPE, WHITE, TEXTURED GEOMEMBRANE IN ACCORDANCE WITH THE TECHNICAL SPECIFICATION PRIOR TO PLACEMENT OF THE WARNING LAYER. CONTRACTOR SHALL PROVIDE AND FOLLOW AN APPROVED GEOMEMBRANE LAYOUT PLAN.
2. GEOMEMBRANE SHALL BE ANCHORED INTO 2.5 FEET DEEP TRENCHES ALONG TOP OF IMPOUNDMENT BANK, AS SHOWN IN SECTION D ON SHEET C031. CONTRACTOR SHALL ADVISE OWNER AND/OR ENGINEER IF PROPOSED LOCATION NOT POSSIBLE. DISCHARGE PIPE SHALL BE FIELD LOCATED AND CONTRACTOR SHALL NOTIFY OWNER IF AND/OR TRENCH INTERFERES WITH PIPING.
3. CONTRACTOR SHALL PLACE 12-OZ. NON-WOVEN GEOTEXTILE OVER THE GEOMEMBRANE, SAND MATERIAL AND WARNING LAYER MATERIAL AT BASE AND 4 FEET ON SIDE SLOPES AFTER RECEIVING APPROVAL FROM ENGINEER AND PASSING QUALITY CONTROL RESULTS IN ACCORDANCE WITH TECHNICAL SPECIFICATIONS. (SEE SHEET C031)
4. RESTORE AREAS DISTURBED BY EQUIPMENT AND MATERIAL LAYDOWN.
5. ABOVE GROUND PIPING TO BE INSTALLED BY OTHERS.
6. CONTRACTOR SHALL PROVIDE SURVEY DOCUMENTATION OF THE ITEMS LISTED IN THE TECHNICAL SPECIFICATIONS.
7. CONTRACTOR SHALL PERFORM A LEAK LOCATION SURVEY IN ACCORDANCE WITH TECHNICAL SPECIFICATIONS.

SOURCE NOTES:
1. THIS DRAWING WAS DEVELOPED FROM A SURVEY MAP BY KUETTIGER, TONELL & ASSOCIATES, INC., JOLIET, ILLINOIS, PLAT OF PARTIAL TOPOGRAPHY OF MIDWEST GENERATION JOLIET 29 POWER PLANT ASH IMPOUNDMENTS, SHEET 1 OF 1, DATED APRIL 7, 2007, T&L NO. 06487.DWG. COORDINATE SYSTEM IS ILLINOIS STATE PLANE EAST ZONE, (NAD 83).
2. ASH IMPOUNDMENTS 1 AND 2 WERE DEVELOPED FROM DRAWINGS BY NCR CORPORATION, DRAWING NUMBERS: 9023G102 AND 5079C3103, DATED JANUARY 23, 1978.
3. TOPOGRAPHY OUTSIDE OF ASH IMPOUNDMENTS 1 AND 2 WAS DEVELOPED FROM DIGITAL-ORTHO FILES, D80250.DWG, D40730.DWG, AND D40760.DWG ILLINOIS STATE PLANE EAST NAD 83 COORDINATE SYSTEM, DATED APRIL 1997 DOWNLOADED FROM http://www.ntlsonb.org.

NOT FOR CONSTRUCTION

WARNING LAYER PLAN

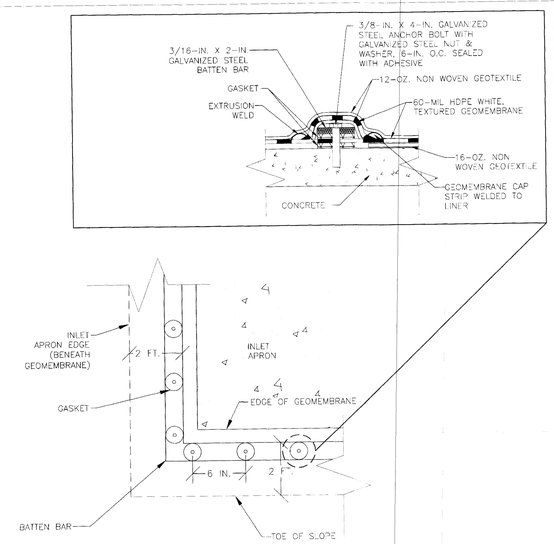
ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

REVISION:	DATE:	APP'D BY:
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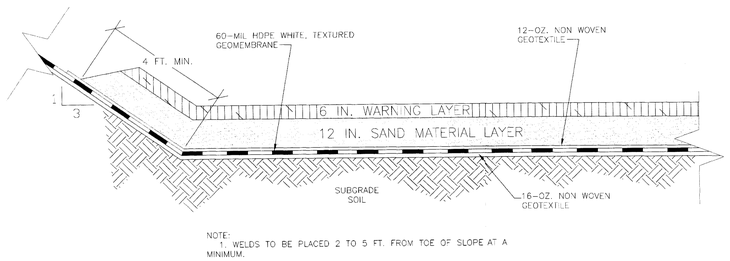
NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/3.0	
DRAWN BY: BJK/RLH 07/12/07	DRAWING NO: D1862C030-01
CHECKED BY: HMS 08/02/07	REFERENCE: 1862/3/3D-CON/
APPROVED BY:	SHEET NO. C030

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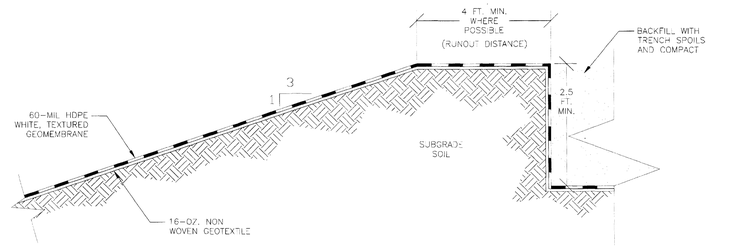


2 / C030 INLET APRON DETAIL PLAN
NOT TO SCALE

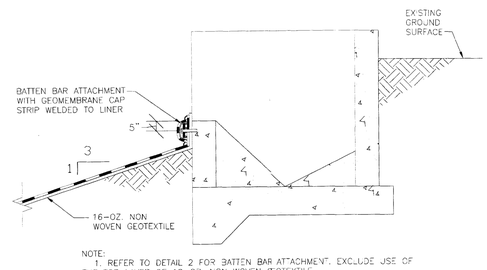


NOTE:
1. WELDS TO BE PLACED 2 TO 5 FT. FROM TOE OF SLOPE AT A MINIMUM.

A / C030 SLOPE TRANSITION SECTION
NOT TO SCALE

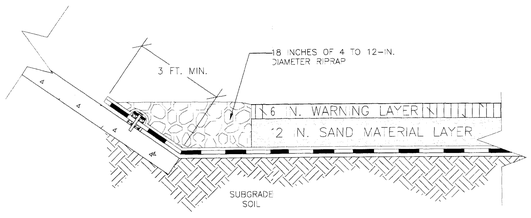


D / C030 ANCHOR TRENCH SECTION
NOT TO SCALE

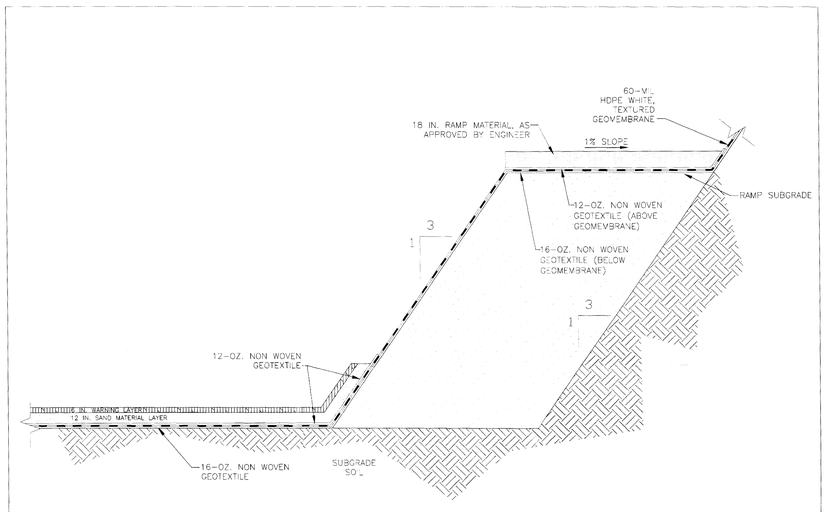


NOTE:
1. REFER TO DETAIL 2 FOR BATTEN BAR ATTACHMENT. EXCLUDE USE OF THE TOP LAYER OF 12-OZ. NON WOVEN GEOTEXTILE.

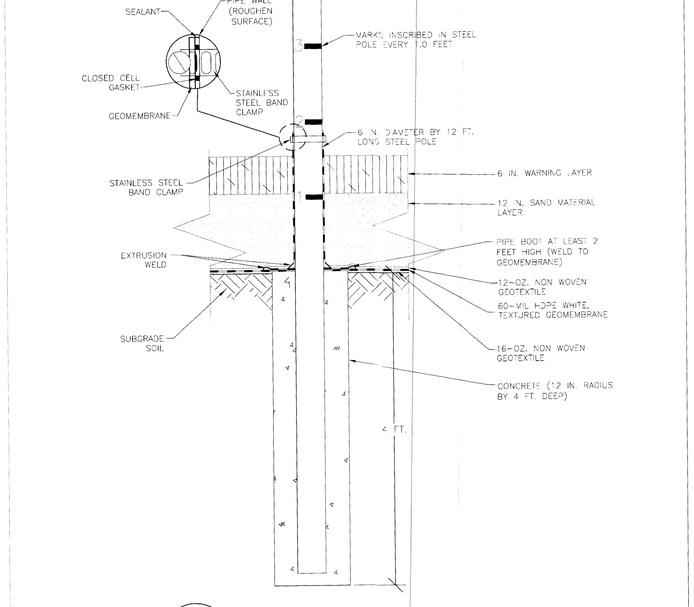
3 / C030 OUTLET WEIR DETAIL
NOT TO SCALE



C / -- INLET APRON SECTION
NOT TO SCALE



B / C030 RAMP SECTION
NOT TO SCALE



1 / C020 MARKER POST DETAIL
NOT TO SCALE

NOT FOR CONSTRUCTION

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NATURAL RESOURCE TECHNOLOGY

DETAILS AND SECTIONS

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

PROJECT NO. 1862/3.0		
DRAWN BY: BJK/RLH 07/12/07		
CHECKED BY: HMS 08/02/07		
APPROVED BY: -	DRAWING NO: D1862C031-01	SHEET NO. C031
	REFERENCE: 1862/3/BID-CON/	

Attachment 2

Electronic Filing: Received, Clerk's Office 2/04/2022

ATTACHMENT 2
2008 RE-LINING CONSTRUCTION RECORDS

Electronic Filing: Received, Clerk's Office 2/04/2022

NATURAL RESOURCE TECHNOLOGY

Mr. Brian Delcorio
Midwest Generation, LLC
Joliet Generating Station, Units 7/8
1800 Channahon Road
Joliet, IL 60436

December 23, 2008
(1862)

RE: Construction Documentation Transmittal
Ash Impoundment #1 and #2 Liner Replacement

Dear Mr. Delcorio:

Enclosed with this correspondence are construction record documents related to replacement of the liners in Ash Impoundments #1 and #2 at Joliet 29. Construction began on Impoundment #2 in early April 2008. Following Impoundment #2 construction, Impoundment #1 was dewatered and dredged. Liner replacement construction on Impoundment #1 began in late August 2008. The following information is enclosed:

- Select submittals from Contractor;

Attachment	Submittal Item # on Table 2[1]	Submittal Description
A1	10	Warning Layer and Cushion Layer Gradation Reports
A2	11	Geomembrane Resin Test Results
A3	21	Geosynthetic Product Information
A4	24	Geomembrane Installer's Daily Logs and QC Documentation (Impoundment #1 and #2)
A5	25	Geomembrane Installer's Subgrade Acceptance (Impoundment #1 and #2)
A6	26	Geomembrane Installation Certificate (Impoundment #1 and #2)
A7	26	Geomembrane Installation Warranties
A8	26	Geomembrane As-Built Panel Layout (Impoundment #1 and #2)
A9	31	Leak Location Survey Report (Impoundment #1and #2)

- Field Directives #1 and #2 (Attachment B);
- Drawings for both impoundments updated to reflect Contractor's documentation survey of the location of anchor trench alignment and marker posts, and topography of the warning layer (Attachment C);
- Natural Resource Technology, Inc. (NRT) Construction Quality Assurance (CQA) Daily Field Reports (Attachment D); and
- Record drawing containing liner details and sections (Sheet C031).

[1] Refer to Table 2 – List of Submittals from Specification No. 20007575

Electronic Filing: Received, Clerk's Office 2/04/2022

If you have any questions or comments pertaining to this transmittal, please feel free to contact us. It has been a pleasure working with you on this project, and we look forward to working with you again in the future.

Sincerely,

NATURAL RESOURCE TECHNOLOGY, INC.

Heather M. Simon, PE
Project Engineer

Eric J. Tlachac, PE
Project Manager

Encls.: Attachment A: Contractor Submittals
Attachment B: Field Directives Attachment C: Ash Impoundment #1 and #2 Documentation Survey
Attachment D: NRT CQA Daily Field Reports
Sheet C031 – Details and Sections

cc: Ms. Maria Race (w/o attachments)

[1862 Construction Documentation 081223.doc]

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ATTACHMENT A

CONTRACTOR SUBMITTALS

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ATTACHMENT A1

WARNING LAYER AND CUSHION LAYER GRADATION REPORTS

LAFARGE AGGREGATES & CONCRETE

Quality Test Report

Plant 30260-Joliet
Product CA-6-042CM06
Specification IDOT MODIFIED CM06 Spec

1641306362

Sample Information

Sample No 1641306362
Date Sampled 03/26/2008 10:30
Date Completed 03/27/2008 10:30
Sampled By Ken Sierzega
Tested By Ken Sierzega
Type Shipping
Method Bucket Blend/Sam Pad
Location
Process MAIN IDOT
Ledge Underground Bench
Other

Weather
Temp
Split Sample ☐ **Sequence**
Resample ☐ **Code**
Borehole
Depth Top/Bottom

Test Note

Gradation Results

Unit	Moist Mass	Dry Mass	Wash Mass	Moisture %	Wash Loss %	Procedure
g	6317.00	6203.00	5643.00	1.8	9.0	

Sieve	Mass Retained	Cum Mass Retained	Ind % Retained	% Retained	% Passing	Target	Specification	Comment
1 1/2" (37.5mm)	0.0	0.0	0	0	100		100-100	
1" (25mm)	528.0	528.0	8	8	92		90-100	
3/4" (19mm)	619.0	1147.0	10	18	82			
5/8" (16mm)	520.0	1667.0	8	27	73			
1/2" (12.5mm)	475.0	2142.0	8	35	65		60-90	
3/8" (9.5mm)	496.0	2638.0	8	43	57			
1/4" (6.3mm)	517.0	3155.0	8	51	49			
#4 (4.75mm)	284.0	3439.0	5	55	45		30-56	
#8 (2.36mm)	669.0	4108.0	11	66	34			
#16 (1.18mm)	473.0	4581.0	8	74	26		10-40	
#40 (0.425mm)	419.0	5000.0	7	81	19			
#200 (75um)	593.0	5593.0	9.6	90.2	9.8		4-12	
PAN (0um)	45.0	5638.0	9.8	100.0	0.0			

Other Test Results

Test Name	Date / Procedure	Result / Lab	Unit	Target	Specification / Tested By	Comment
FM	03/27/2008 10:30	5.57 Joliet			Ken Sierzega	
Grad Loss %	03/27/2008 10:30	0.081 Joliet	%		Ken Sierzega	
Wash Loss %	03/27/2008 10:30	9.0 Joliet	%		Ken Sierzega	

Electronic Filing: Received, Clerk's Office 2/04/2022

LAFARGE AGGREGATES & CONCRETE

Quality Test Report

Plant 30260-Joliet
Product Stone Sand-013FM05
Specification 013FM05

1635349963

Sample Information

Sample No	1635349963	Weather	
Date Sampled	03/26/2008 08:29	Temp	
Date Completed	03/27/2008 08:29	Split Sample ☐	Sequence
Sampled By	Ken Sierzega	Resample ☐	Code
Tested By	Ken Sierzega	Borehole	
Type	Shipping	Depth Top/Bottom	
Method	Bucket Blend/Sam Pad	Test Note	
Location			
Process	MAIN IDOT		
Ledge	Underground Bench		
Other			

Gradation Results

Unit	Moist Mass	Dry Mass	Wash Mass	Moisture %	Wash Loss %	Procedure
g	805.30	769.70	640.20	4.6	16.8	

Sieve	Mass Retained	Cum Mass Retained	Ind % Retained	% Retained	% Passing	Target	Specification	Comment
3/8" (9.5mm)	0.0	0.0	0	0	100		100	
#4 (4.75mm)	18.5	18.5	2	2	98		84-100	
#8 (2.36mm)	142.3	160.8	19	21	79			
#16 (1.18mm)	181.1	341.9	24	45	55			
#30 (0.6mm)	116.1	458.0	15	60	40			
#50 (0.3mm)	77.2	535.2	10	70	30			
#100 (0.15mm)	50.6	585.8	7	76	24		0-40	
#200 (75um)	41.2	627.0	5.4	81.7	18.3		0-30	
PAN (0um)	11.5	638.5	18.3	100.0	0.0			

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ATTACHMENT A2

GEOMEMBRANE RESIN TEST RESULTS

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips Chemical Company LP

CoA Date: 08/23/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87473726
PO #: 40932
Weight: 188900 LB
Ship Date: 08/23/2007
Package: BULK
Mode: Hopper Car
Car #: PSPX009173
Seal No: 235847

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271106

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	9.8	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/22/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips Chemical Company LP

CoA Date: 08/23/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87473728
PO #: 40932
Weight: 192500 LB
Ship Date: 08/23/2007
Package: BULK
Mode: Hopper Car
Car #: PSPX005936
Seal No: 235760

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271118

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	12.9	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/25/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips Chemical Company LP

CoA Date: 08/23/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87473728
PO #: 40932
Weight: 192500 LB
Ship Date: 08/23/2007
Package: BULK
Mode: Hopper Car
Car #: PSPX005936
Seal No: 235760

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271118

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	12.9	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/25/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips

CoA Date: 08/27/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC 19103 GUNDLE ROAD WESTFIELD TX 77090 USA	CPC Delivery #: 87476502 PO #: 40931 Weight: 191700 LB Ship Date: 08/27/2007 Package: BULK
Recipient: Phouangsavanh Fax:	Mode: Hopper Car Car #: PSPX002351 Seal No: 235617

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271154

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	11.9	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/31/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips Chemical Company LP

CoA Date: 08/27/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87476504
PO #: 40931
Weight: 192500 LB
Ship Date: 08/27/2007
Package: BULK
Mode: Hopper Car
Car #: CHVX896642
Seal No: 235619

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271157

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	12.4	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/31/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Chevron Phillips Chemical Company LP

CoA Date: 08/29/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87477809
PO #: 40931
Weight: 190000 LB
Ship Date: 08/29/2007
Package: BULK
Mode: Hopper Car
Car #: GOCX058423
Seal No: 235771

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271162

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	12.1	g/10mi
Density	ASTM D1505	0.936	g/cm3
Production Date		08/02/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

CoA Date: 11/20/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87535160
PO #: 40931
Weight: 188700 LB
Ship Date: 11/20/2007
Package: BULK
Mode: Hopper Car
Car #: CHVX893140
Seal No: 246044

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271744

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	10.7	g/10mi
Density	ASTM D1505	0.936	g/cm3
Production Date		11/18/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

CoA Date: 11/20/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87535163
PO #: 40931
Weight: 192400 LB
Ship Date: 11/20/2007
Package: BULK
Mode: Hopper Car
Car #: PSPX003065
Seal No: 245929

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271747

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	11.2	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		11/19/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

GSE Roll Allocation

Order 53376
Customer CAAWS
Site Midwest Generation LLC

Roll#	*Resin Lot*	*Product Code*	*Description*	*Mfg. Date*	*Length*
104137147	8271106	HDT060A010	HDT060A010	8/31/2007	520
104137238	8271118	HDT060A010	HDT060A010	9/6/2007	520
104137263	8271154	HDT060A010	HDT060A010	9/8/2007	520
104137264	8271154	HDT060A010	HDT060A010	9/8/2007	520
104137340	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137341	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137342	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137343	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137344	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137406	8271162	HDT060A010	HDT060A010	9/17/2007	520
104137407	8271162	HDT060A010	HDT060A010	9/17/2007	520
105136345	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136346	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136347	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136353	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136354	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136356	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136357	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136358	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136359	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136360	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136361	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136362	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136363	8271747	HDT060A010	HDT060A010	12/5/2007	520
105136364	8271747	HDT060A010	HDT060A010	12/5/2007	520
105136365	8271747	HDT060A010	HDT060A010	12/5/2007	520
105136367	8271747	HDT060A010	HDT060A010	12/5/2007	520
105136368	8271747	HDT060A010	HDT060A010	12/5/2007	520

Electronic Filing: Received, Clerk's Office 2/04/2022

ATTACHMENT A3

GEOSYNTHETIC PRODUCT INFORMATION

Electronic Filing: Received, Clerk's Office 2/04/2022

Submittal #20

GSE Lining Technology, Inc.

19103 Gundle Road
Houston, Texas 77073
800-435-2008
281.230.6747

February 18, 2008

Matt Albert
Clean Air and Water Systems, LLC
123 Elm Street
Dousman, WI 53118

RE: Midwest Generation
Project No. 524244

Certification of Compliance

The undersigned, being qualified and authorized to do so, hereby certifies that GSE Lining Technologies Manufacturing Quality Assurance plan was fully implemented during production of the geosynthetic materials for the aforementioned project.

Sincerely,

Daniel Semanisin
GSE Technical Support Specialist

cc: Karen Dennison, GSE Lining Technology Inc.

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE®

GSE Lining Technology, Inc.

LETTER OF TRANSMITTAL

Brian McKeown
Clean Air and Water Systems, LLC.
123 Elm Street
Dousman, WI 53118-0337

DATE: December 11, 2007
JOB NO: SO 53376
JOB NAME: Midwest Generation, LLC
RE: QC/QA Certificate

COPIES	DESCRIPTION
1	QC/QA Documentation as per Bill of Lading # 72674 & 72671

TRANSMIT VIA:

U.S. Mail

If enclosures are not as noted kindly notify us at once.

SIGNED: Janet M Valadez
DATE: December 11, 2007

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at HOUSTON, TEXAS

Shippers No. 72671

Received at Houston, Texas from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Roll Certifications Included

Date: 12/10/07

Branch Plant: 1500

Shipping Instructions: Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order 53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	FREIGHTSHT001 DOM. SHIPPING CHARGE DOMESTIC SHEET NON TAXABLE	
2	105136353	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,973.00
3	105136356	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,920.00
4	105136357	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,930.00
5	105136358	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,920.00
6	105136359	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,920.00
7	105136360	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,920.00
8	105136362	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,980.00
9	105136363	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,922.00
10	105136364	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,940.00
11	105136365	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,970.00
12	105136367	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,990.00
13	105136368	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,004.00

Deliver on 12/12/07

Total Quantity 140,401 **Total Weight:** 47,389.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up # 18406RR

Seal #

Truckers P.O. # PO183780

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (281) 230-6781 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: BENNETT

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Lining Technology, Inc

Roll Test Data Report

Bill of Lading: 72671

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	HDT060A010	12/10/2007

GSE QC APPROVED

*Modified

	ASTM D 5994		ASTM D638, Type IV / D6693								ASTM D 1004		ASTM D 4833	ASTM D 1505	ASTM D 4218/1603	ASTM D 5596	GRI GM 12	
	Average Thickness	Minimum Thickness	TD Strength @ Yield	MD Strength @ Yield	TD Strength @ Break	MD Strength @ Break	TD Elongation @ Yield	MD Elongation @ Yield	TD Elongation @ Break	MD Elongation @ Break	TD Tear Resistance	MD Tear Resistance	Puncture Resistance	Density	Carbon Black Content	Carbon Black Dispersion	Asperity Height Side A	Asperity Height Side B
	(mils)	(mils)	(ppi)	(ppi)	(ppi)	(ppi)	(%)	(%)	(%)	(%)	(lbs)	(lbs)	(lbs)	(g/cc)	(%)	Views in Cat1 - Cat2	(mils)	(mils)
Roll No.	every roll		every 4th								every 4th		every 4th	every 4th	every 4th	every 4th	every 2nd	
105136353	62	59	165	161	184	218	17	18	440	554	53	55	151	0.945	2.59	10	32	18
105136356	62	60	162	159	176	205	15	18	448	518	51	54	147	0.944	2.59	10	24	22
105136357	62	60	162	159	176	205	15	18	448	518	51	54	147	0.944	2.59	10	24	22
105136358	63	60	168	161	172	213	15	17	417	545	51	53	142	0.945	2.66	10	24	19
105136359	62	60	168	161	172	213	15	17	417	545	51	53	142	0.945	2.66	10	24	19
105136360	62	58	168	161	172	213	15	17	417	545	51	53	142	0.945	2.66	10	23	24
105136362	61	57	170	166	184	214	16	18	436	541	53	57	156	0.945	2.56	10	23	21
105136363	61	58	170	166	184	214	16	18	436	541	53	57	156	0.945	2.56	10	23	21
105136364	62	59	170	166	184	214	16	18	436	541	53	57	156	0.945	2.56	10	24	19
105136365	62	57	170	166	184	214	16	18	436	541	53	57	156	0.945	2.56	10	24	19
105136367	61	59	162	160	214	202	18	18	588	553	51	55	152	0.944	2.75	10	24	23
105136368	63	61	162	160	214	202	18	18	588	553	51	55	152	0.944	2.75	10	24	23

Approved By:

This test report shall not be reproduced, except in full, without written approval of the laboratory.

GSE-8.2.4-029 Rev - - 03/05

19103 Gundle Road - Houston, Texas 77073

Dec 10 07 03:31p Lab 2812336797 P.1

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at HOUSTON, TEXAS

Shippers No. 72674

Received at Houston, Texas from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Roll Certifications Included

Date: 12/10/07

Branch Plant: 1500

Shipping Instructions:

Call 24 hours before delivery

Tedd Mills @ 815-521-0900

Sales Order 53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	**FREIGHTSHT001** DOM. SHIPPING CHARGE DOMESTIC SHEET NON TAXABLE	
2	104137263	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,000.00
3	104137264	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,972.00
4	104137340	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,932.00
5	104137341	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,952.00
6	104137342	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,940.00
7	104137343	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,932.00
8	104137344	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,936.00
9	105136345	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,028.00
10	105136346	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,078.00
11	105136347	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,000.00
12	105136354	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,976.00
13	105136361	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,934.00

Deliver on 12/12/07

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up # 18407RR

Seal #

Truckers P.O. # PO176633

Total Quantity 140,401 Total Weight: 47,880.00

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (281) 230-6781 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: TMC

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Lining Technology, Inc

Roll Test Data Report

Bill of Lading: 72674

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	HDT060A010	12/10/2007 *Modified

GSE QC APPROVED

	ASTM D 5994		ASTM D638,Type IV / D6693								ASTM D 1004		ASTM D 4833	ASTM D 1505	ASTM D 4218/1603	ASTM D 5596	GRI GM 12	
	Average Thickness (mils)	Minimum Thickness (mils)	TD Strength @ Yield (ppi)	MD Strength @ Yield (ppi)	TD Strength @ Break (ppi)	MD Strength @ Break (ppi)	TD Elongation @ Yield (%)	MD Elongation @ Yield (%)	TD Elongation @ Break (%)	MD Elongation @ Break (%)	TD Tear Resistance (lbs)	MD Tear Resistance (lbs)	Puncture Resistance (lbs)	Density (g/cc)	Carbon Black Content (%)	Carbon Black Dispersion Views in Cat1 - Cat2	Asperity Height Side A (mils)	Asperity Height Side B (mils)
Roll No.	every roll		every 4th								every 4th		every 4th	every 4th	every 4th	every 4th	every 2nd	
104137263	61	58	128	134	155	175	16	17	494	535	47	45	137	0.946	2.51	10	29	21
104137264	61	57	153	165	210	200	18	17	565	518	54	54	151	0.946	2.52	10	29	21
104137340	61	58	161	148	198	240	16	18	531	622	51	55	153	0.947	2.44	10	18	22
104137341	62	56	162	158	189	229	18	17	552	634	51	55	153	0.947	2.41	10	18	22
104137342	61	57	162	158	189	229	16	17	552	634	51	55	153	0.947	2.41	10	17	21
104137343	61	58	162	158	189	229	16	17	552	634	51	55	153	0.947	2.41	10	17	21
104137344	61	58	162	158	189	229	16	17	552	634	51	55	153	0.947	2.41	10	22	22
105136345	63	59	168	170	207	208	15	16	549	519	54	57	148	0.946	2.59	10	26	18
105136346	60	55	163	155	205	212	16	18	559	538	53	55	151	0.946	2.58	10	26	21
105136347	62	59	163	155	205	212	16	18	559	538	53	55	151	0.946	2.58	10	23	21
105136354	61	58	162	159	176	205	15	18	448	518	51	54	147	0.944	2.59	10	24	21
105136361	61	58	168	161	172	213	15	17	417	545	51	53	142	0.945	2.66	10	23	24

Approved By:

This test report shall not be reproduced, except in full, without written approval of the laboratory.

19103 Gundle Road - Houston, Texas 77073

Dec 10 07 04:14p Lab 2812306787 p.1

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE®

GSE Lining Technology, Inc.

LETTER OF TRANSMITTAL

Brian McKeown
Clean Air and Water Systems, LLC.
123 Elm Street
Dousman, WI 53118-0337

DATE: December 12, 2007
JOB NO: SO 53376
JOB NAME: Midwest Generation, LLC
RE: QC/QA Certificate

COPIES	DESCRIPTION
1	QC/QA Documentation as per Bill of Lading # 72695

TRANSMIT VIA:

U.S. Mail

If enclosures are not as noted kindly notify us at once.

SIGNED: Janet M Valadez
DATE: December 12, 2007

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at HOUSTON, TEXAS

Shippers No. 72695

Received at Houston, Texas from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Roll Certifications Included

Date: 12/11/07

Branch Plant: 1500

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order: 53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	**FREIGHTSHT001** DOM. SHIPPING CHARGE DOMESTIC SHEET NON TAXABLE	
2	104137147	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,994.00
3	104137238	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,934.00
4	104137406	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,978.00
5	104137407	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,964.00

Del. 12/13/07

Total Quantity 46,801 — Total Weight: 15,870.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Signature of Consignor

Local Verification Signed:

X

Pick Up # 18408RR

Seal #

Truckers P.O. # P0187869

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (281) 230-6781 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: IIE

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Lining Technology, Inc

Roll Test Data Report

Bill of Lading: 72695

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	HDT060A010	12/11/2007 *Modified

GSE QC APPROVED

	ASTM D 5994		ASTM D638,Type IV / D6693								ASTM D 1004		ASTM D 4833	ASTM D 1505	ASTM D 4218/1603	ASTM D 5596	GRI GM 12	
	Average Thickness (mils)	Minimum Thickness (mils)	TD Strength @ Yield (ppi)	MD Strength @ Yield (ppi)	TD Strength @ Break (ppi)	MD Strength @ Break (ppi)	TD Elongation @ Yield (%)	MD Elongation @ Yield (%)	TD Elongation @ Break (%)	MD Elongation @ Break (%)	TD Tear Resistance (lbs)	MD Tear Resistance (lbs)	Puncture Resistance (lbs)	Density (g/cc)	Carbon Black Content (%)	Carbon Black Dispersion Views in Cat1 - Cat2	Asperity Height Side A (mils)	Asperity Height Side B (mils)
Roll No.	every roll		every 4th								every 4th		every 4th	every 4th	every 4th	every 4th	every 2nd	
104137147	62	59	154	147	209	221	16	18	561	558	51	54	143	0.945	2.54	10	23	23
104137238	60	57	156	147	181	226	16	18	469	616	52	55	150	0.946	2.52	10	24	23
104137406	62	55	161	153	188	209	15	17	502	548	52	55	124	0.946	2.31	10	29	22
104137407	61	57	161	153	188	209	15	17	502	548	52	55	124	0.946	2.31	10	28	25

Approved By: Jane Allan

This test report shall not be reproduced, except in full, without written approval of the laboratory.

19103 Gundle Road - Houston, Texas 77073

Dec 11 07 01:29p Lab 2812306787 p.2

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE® GSE Lining Technology, Inc.

LETTER OF TRANSMITTAL

Brian McKeown
Clean Air and Water Systems, LLC.
123 Elm Street
Dousman, WI 53118-0337

DATE: January 2, 2008
JOB NO: SO 53376
JOB NAME: Midwest Generation, LLC
RE: QC/QA Certificate

COPIES	DESCRIPTION
1	QC/QA Documentation as per Bill of Lading # 72947

TRANSMIT VIA:

U.S. Mail

If enclosures are not as noted kindly notify us at once.

SIGNED: Janet M Valadez
DATE: January 2, 2008

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72947

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/27/07

Branch Plant: 1503

Shipping Instructions: ETA 12-31-07

Call 24 hours before delivery

Tedd Mills @ 815-521-0900

Sales Order 53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	FREIGHTGEO001 DOM. SHIPPING CHARGE DOMESTIC GEOTEXTILE NONTAXABLE	
2	130288407	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
3	130288408	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	398.00
4	130288410	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	398.00
5	130288411	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	400.00
6	130288412	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
7	130288413	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
8	130288414	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	389.00
9	130288415	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	392.00
10	130288416	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	400.00
11	130288417	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	403.00
12	130288418	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	401.00
13	130288419	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	399.00
14	130288420	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
15	130288421	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	401.00
16	130288422	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	403.00
17	130288423	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	399.00
	19,001			*Continued on next page.....*	15,037.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Signature of Consignor

Local Verification Signed:

Pick Up # 10937KS

Seal #

Truckers P.O. #

Driver Requirements: TRL# 53205

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: Landstar

Carrier Signature:

Date: 12-27-07

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72947

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/27/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery

Tedd Mills @ 815-521-0900

Sales Order
53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
18	130288424	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	398.00
19	130288425	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	392.00
20	130288426	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
21	130288427	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
22	130288428	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
23	130288429	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	392.00
24	130288430	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	393.00
25	130288431	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	393.00
26	130288432	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	397.00
27	130288433	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	392.00
28	130288434	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
29	130288435	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	390.00
30	130288436	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	393.00
31	130288437	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
32	130288438	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
33	130288439	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
34	130288440	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
	19,001			*Continued on next page.....*	15,037.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number:
1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72947

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/27/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order

53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
35	130288441	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
36	130288442	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
37	130288443	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
38	130288444	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
39	130288445	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00

Total Quantity 19,001 Total Weight: 15,037.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72947

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1208002	12/27/2007

GSE QC APPROVED

*Modified

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallon-min/ft2)	Water permeability (cm sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength (D) (lbs)	Trap Tear Strength (MD) (lbs)	Grab Elongation (D) (%)	Grab Elongation (MD) (%)	Grab Strength (D) (lbs)	Grab Strength (MD) (lbs)	Thickness (mils)	Mass per Unit Area (oz./yd2)
Roll No.	every 60th			every roll	every 20th	every 20th	every 20th		every 20th				every 20th	every 20th
130288407	115	0.80	1.6	0.150	718	236	395	252	122	109	451	364	186	13.6
130288408	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288410	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288411	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288412	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288413	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288414	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288415	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288416	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288417	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288418	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288419	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288420	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288421	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288422	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288423	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288424	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288425	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288426	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288427	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288428	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288429	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288430	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7

Approved By: Nate T. Dawson

This test report shall not be reproduced, except in full, without written approval of the laboratory.

Roll Test Data Report

Bill of Lading: 72947

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1208002	12/27/2007 *Modified

GSE OC APPROVED

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallon/min/ft2)	Water permeability (cm/sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength (CD) (lbs)	Trap Tear Strength (MD) (lbs)	Grab Elongation (CD) (%)	Grab Elongation (MD) (%)	Grab Strength (CD) (lbs)	Grab Strength (MD) (lbs)	Thickness (mils)	Mass per Unit Area (oz/yd2)
Roll No.	every 80th			every roll	every 20th	every 20th	every 20th		every 20th				every 20th	every 20th
130288431	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288432	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288433	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288434	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288435	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288436	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288437	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288438	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288439	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288440	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288441	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288442	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288443	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288444	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288445	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7

Approved By: Nicole T. Dawson

This test report shall not be reproduced, except in full, without written approval of the laboratory.

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE®

GSE Lining Technology, Inc.

LETTER OF TRANSMITTAL

Brian McKeown
Clean Air and Water Systems, LLC.
123 Elm Street
Dousman, WI 53118-0337

DATE: January 2, 2008
JOB NO: SO 53376
JOB NAME: Midwest Generation, LLC
RE: QC/QA Certificate

COPIES	DESCRIPTION
1	QC/QA Documentation as per Bill of Lading # 72923 & 72926

TRANSMIT VIA:

U.S. Mail

If enclosures are not as noted kindly notify us at once.

SIGNED: Janet M Valadez
DATE: January 2, 2008

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72926

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions: ETA 12-28-07
Call 24 hours before delivery
Tedd Mills @ 815-521-0900

Sales Order
53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	FREIGHTGEO001 DOM. SHIPPING CHARGE DOMESTIC GEOTEXTILE NONTAXABLE	
2	130288335	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	506.00
3	130288336	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
4	130288337	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
5	130288338	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
6	130288339	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
7	130288340	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	506.00
8	130288341	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	506.00
9	130288342	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
10	130288343	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
11	130288344	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
12	130288345	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
13	130288346	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
14	130288347	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
15	130288348	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
16	130288349	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
17	130288350	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	507.00
		17,501			17,721.00

Continued on next page.....

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number:
1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Wendy Kessler
Signature of Consignor

Local Verification Signed:

X

Pick Up # 10939KS

Seal #

Truckers P.O. #

Driver Requirements:

TRL# 76607

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: RGT

Carrier Signature:

Date: 12-28-07

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72926

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order

53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
18	130288351	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
19	130288352	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
20	130288353	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
21	130288354	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	507.00
22	130288355	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
23	130288356	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
24	130288357	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
25	130288359	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	506.00
26	130288360	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
27	130288361	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
28	130288362	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	507.00
29	130288363	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
30	130288364	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
31	130288365	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
32	130288366	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	507.00
33	130288367	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
34	130288369	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	514.00
		17,501		*Continued on next page.....*	17,721.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72926

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order

53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
35	130288404	500	SY	**GEO1608002** Geotextile 16 oz/yd2 MARV	505.00
36	130288405	500	SY	**GEO1608002** Geotextile 16 oz/yd2 MARV	509.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Signature of Consignor

Local Verification Signed:

X

Pick Up #

Seal #

Truckers P.O. #

Total Quantity 17,501 Total Weight: 17,721.00

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72926

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1608002	12/21/2007 *Modified

GSE QC APPROVED

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallon/min/ft2)	Water permeability (cm/sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength CD (lbs)	Trap Tear Strength MD (lbs)	Grab Elongation CD (%)	Grab Elongation MD (%)	Grab Strength CD (lbs)	Grab Strength MD (lbs)	Thickness (mils)	Mass per Unit Area (oz/yd2)
Roll No.		every 20th		every roll	every 11th	every 11th	every 11th			every 11th			every 11th	every 11th
130288335	87	0.60	1.2	0.150	822	304	446	226	121	121	517	411	196	16.1
130288336	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288337	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288338	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288339	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288340	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288341	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288342	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288343	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288344	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288345	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288346	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288347	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288348	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288349	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288350	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288351	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288352	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288353	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288354	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288355	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288356	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288357	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8

Approved By: Vicky T. Parrott

This test report shall not be reproduced, except in full, without written approval of the laboratory.

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72926

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1608002	12/21/2007 "Modified

GSE QC APPROVED

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallmin/sq ft)	Water permeability (cm/sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength CD (lbs)	Trap Tear Strength MD (lbs)	Grab Elongation CD (%)	Grab Elongation MD (%)	Grab Strength CD (lbs)	Grab Strength MD (lbs)	Thickness (mils)	Mass per Unit Area (oz/sq.yd)
Roll No.	every 20th			every roll	every 11th	every 11th	every 11th		every 11th				every 11th	every 11th
130288359	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288360	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288361	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288362	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288363	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288364	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288365	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288366	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288367	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288369	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288404	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288405	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0

Approved By: Vicky T. Powell

This test report shall not be reproduced, except in full, without written approval of the laboratory.

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72923

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:
Call 24 hours before delivery

ETA 12-28-07
Tedd Mills @ 815-521-0900

Sales Order
53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	FREIGHTGEO001 DOM. SHIPPING CHARGE DOMESTIC GEOTEXTILE NONTAXABLE	
2	130288368	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
3	130288370	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	515.00
4	130288371	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	515.00
5	130288372	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	513.00
6	130288373	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	512.00
7	130288374	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	511.00
8	130288375	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
9	130288376	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
10	130288377	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
11	130288378	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
12	130288379	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
13	130288380	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
14	130288381	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
15	130288382	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
16	130288383	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	539.00
17	130288384	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	531.00
		17,501			17,747.00

Continued on next page.....

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number:
1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Signature of Consignor

Local Verification Signed:

Pick Up # 10938KS

Seal #

Truckers P.O. #

Driver Requirements:
TRL# 74608
1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: RGT
Carrier Signature:
Date: 12-21-07

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72923

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order

53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
18	130288385	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	539.00
19	130288386	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
20	130288387	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	502.00
21	130288388	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
22	130288389	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
23	130288390	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
24	130288391	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
25	130288392	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
26	130288393	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	502.00
27	130288394	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
28	130288395	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
29	130288396	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
30	130288397	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
31	130288398	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	502.00
32	130288399	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
33	130288400	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
34	130288401	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
	17,501			*Continued on next page.....*	17,747.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC Shippers No. 72923

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery Tedd Mills @ 815-521-0900

Sales Order
53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
35	130288402	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
36	130288403	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00

Total Quantity 17,501 Total Weight: 17,747.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number:
1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Signature of Consignor

Local Verification Signed:

X

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72923

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1608002	12/21/2007

GSE QC APPROVED

*Modified

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate	Water permeability	Permittivity	Apparent Opening Size	Mullen Burst Strength	Puncture Resistance	Trap Tear Strength CD	Trap Tear Strength MD	Grab Elongation CD	Grab Elongation MD	Grab Strength CD	Grab Strength MD	Thickness	Mass per Unit Area
	(gallon/min/ft2)	(cm/sec)	(Sec-1)	(mm)	(psi)	(lbs)	(lbs)	(lbs)	(%)	(%)	(lbs)	(lbs)	(mils)	(oz./yd2)
Roll No.	every 20th			every roll	every 11th	every 11th	every 11th		every 11th				every 11th	every 11th
130288368	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288370	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288371	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288372	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288373	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288374	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288375	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288376	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288377	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288378	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288379	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288380	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288381	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288382	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288383	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288384	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288385	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288386	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288387	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288388	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288389	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288390	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288391	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8

Approved By: Vicky T. Parrott

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GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72923

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1608002	12/21/2007 *Modified

GSE QC APPROVED

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallons/min/ft2)	Water permeability (cm/sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength (T) (lbs)	Trap Tear Strength (MD) (lbs)	Grab Elongation (T) (%)	Grab Elongation (MD) (%)	Grab Strength (T) (lbs)	Grab Strength (MD) (lbs)	Thickness (mils)	Mass per Unit Area (oz/yd2)
Roll No.	every 20th			every roll	every 11th	every 11th	every 11th		every 11th				every 11th	every 11th
130288392	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288393	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288394	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288395	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288396	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288397	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288398	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288399	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288400	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288401	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288402	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288403	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0

Approved By: Vicky T. Parrott

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ATTACHMENT A4

GEOMEMBRANE INSTALLER'S DAILY LOGS AND QC DOCUMENTATION (IMPOUNDMENT #1 AND #2)

A4

IMPOUNDMENT #1

Electronic Filing: Received, Clerk's Office 2/04/2022 Submittal #24

CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	Q.C. NAME:
PROJECT NAME: Midwest Gen Ash Pond 1	MAT. TYPE:
PROJECT NUMBER: 0	TRUCK NUMBER:
LOCATION Joliet, IL	BILL OF LADING #

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
365	22.50 x 520	11,700	
357	22.50 x 520	11,700	
362	22.50 x 520	11,700	
359	22.50 x 520	11,700	
356	22.50 x 520	11,700	
360	22.50 x 520	11,700	
368	22.50 x 520	11,700	
353	22.50 x 520	11,700	
367	22.50 x 520	11,700	
344	22.50 x 520	11,700	
364	22.50 x 520	11,700	
134	x		partial
116	x		partial
346	22.50 x 520	11,700	
356	x		partial
357	x		partial
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	TOTAL =	140,400	

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Submittal

GAAWP Systems

TRIAL WELD TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB NUMBER:	0	MAT'L TYPE:

TENSIOMETER ID:	0

DATE	SAMPLE I.D. (TW#)	TIME	AMB. TEMP (ºF)	WEATHER (CLOUDY/ SUNNY)	QC INT	MACH NO.	SEAMER INT	EXTRUSION BARREL/ PREHEAT	FUSION WEDGE/ SET SPEED	FIELD WELD VALUES PEEL (PPI)					SHEAR (PPI)			P/F	Comments
10/1/2008	1	08:27	54	cloudy	ss	138	hn	B:	W: 850	167	162	155			184	188	183	P	
								P:	S: 350	162	151	154							
10/1/2008	2	08:25	54	cloudy	ss	427	kk	B:	W: 850	152	147	158			179	183	188	P	
								P:	S: 350	164	156	155							
10/1/2008	3	13:30	68	cloudy	ss	427	kk	B:	W: 850	130	133	126			164	166	160	P	
								P:	S: 350	128	124	124							
10/1/2008	4	13:00	68	cloudy	ss	138	hn	B:	W: 850	130	140	133			160	158	155	P	
								P:	S: 350	129	132	129							
10/2/2008	1	08:05	58	cloudy	ss	138	hn	B:	W: 850	142	154	157			178	172	183	P	
								P:	S: 350	133	148	149							
10/2/2008	2	08:00	58	cloudy	ss	427	kk	B:	W: 850	151	143	148			181	167	188	P	
								P:	S: 350	156	164	155							
10/2/2008	3	08:45	65	cloudy	ss	175	vk	B: 545	W:	134	138	142			189	182	190	P	
								P: 245	S:										
10/2/2008	4	13:05	65	cloudy	ss	175	vk	B: 545	W:	128	136	132			174	180	177	P	
								P: 245	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

TRIAL WELD TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB NUMBER:	0	MAT'L TYPE:

TENSIOMETER ID:	0	EXTRUSION	FUSION	FIELD WELD VALUES										
DATE	SAMPLE I.D. (TW#)	TIME	AMB. TEMP (ºF)	WEATHER (CLOUDY/ SUNNY)	QC INT	MACH NO.	SEAMER INT	BARREL/ PREHEAT	WEDGE/ SET SPEED	PEEL (PPI)				SHEAR (PPI)			P/F	Comments
10/3/2008	1	07:20	57	cloudy	ss	175	vk	B: 545	W:	129	130	140		168	163	170	P	
								P: 245	S:									
10/3/2008	2	10:30	57	cloudy	ss	427	kk	B:	W: 850	128	128	140		175	157	168	P	
								P:	S: 350	145	130	147						
10/3/2008	3	10:27	57	cloudy	ss	138	hn	B:	W: 850	145	153	139		173	171	170	P	
								P:	S: 350	153	142	145						
10/3/2008	4	13:20	64	cloudy	ss	427	kk	B:	W: 850	139	144	128		160	159	159	P	
								P:	S: 350	142	132	126						
10/3/2008	5	13:19	64	cloudy	ss	138	hn	B:	W: 850	136	125	133		165	157	163	P	
								P:	S: 350	145	143	136						
10/3/2008	6	13:35	64	cloudy	ss	175	vk	B: 515	W:	115	102	123		165	162	151	P	
								P: 235	S:									
10/4/2008	1	07:03	41	sunny	ss	138	hn	B:	W: 850	151	170	158		198	191	190	P	
								P:	S: 350	148	164	163						
10/4/2008	2	07:30	41	sunny	ss	427	kk	B:	W: 850	167	184	167		188	190	185	P	
								P:	S: 350	173	190	163						
10/4/2008	3	07:35	41	sunny	ss	175	vk	B: 545	W:	162	154	171		201	200	198	P	
								P: 245	S:									
10/4/2008	4	13:05	69	sunny	ss	175	vk	B: 515	W:	148	132	137		154	150	163	P	
								P: 215	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									

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Submitted 2/2

GeoSynthetics

PANEL PLACEMENT FORM

PROJECT NAME:			Midwest Gen Ash Pond 1			JOB NUMBER: 0	Material Type:
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
10/1/2008		P1	58	22.00	1,276	365	
10/1/2008		P2	58	22.00	1,276	365	
10/1/2008		P3	58	22.00	1,276	365	
10/1/2008		P4	58	22.00	1,276	365	
10/1/2008		P5	58	22.00	1,276	365	
10/1/2008		P6	58	22.00	1,276	365	
10/1/2008		P7	58	22.00	1,276	365	
10/1/2008		P8	58	22.00	1,276	365	
10/1/2008		P9	58	22.00	1,276	357	
10/1/2008		P10	58	22.00	1,276	357	
10/1/2008		P11	58	22.00	1,276	357	
10/1/2008		P12	58	22.00	1,276	357	
10/1/2008		P13	58	22.00	1,276	357	
10/1/2008		P14	58	22.00	1,276	357	
10/1/2008		P15	58	22.00	1,276	357	
10/1/2008		P16	58	22.00	1,276	357	
10/1/2008		P17	58	22.00	1,276	362	
10/1/2008		P18	58	22.00	1,276	362	
10/1/2008		P19	52	22.00	1,144	362	
10/1/2008		P20	52	22.00	1,144	362	
10/1/2008		P21	17	17.00	145	362	
10/1/2008		P22	52	22.00	1,144	362	
10/1/2008		P23	76	22.00	1,518	362	
10/1/2008		P24	76	22.00	1,672	362	
				Total Area (SF) This Page Only =	29,735		

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C a a W Systems

PANEL PLACEMENT FORM

PROJECT NAME:		Midwest Gen Ash Pond 1				JOB NUMBER: 0	Material Type:
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
10/1/2008		P25	58	22.00	968	362	
10/1/2008		P26	30	15.00	225	362	
10/1/2008		P27	35	22.00	385	359	
10/1/2008		P28	53	22.00	968	359	
10/1/2008		P29	417	22.00	9,174	359	
10/2/2008		P30	470	22.00	10,340	356	
10/2/2008		P31	478	22.00	10,516	360	
10/2/2008		P32	478	22.00	10,516	362	
10/2/2008		P33	478	22.00	10,516	368	
10/2/2008		P34	478	22.00	10,516	353	
10/3/2008		P35	55	22.00	1,210	367	
10/3/2008		P36	26	18.00	234	367	
10/3/2008		P37	26	16.00	208	367	
10/3/2008		P38	58	22.00	792	367	
10/3/2008		P39	113	22.00	2,486	367	
10/3/2008		P40	50	22.00	1,100	367	
10/3/2008		P41	113	22.00	2,486	344	
10/3/2008		P42	113	22.00	2,486	344	
10/3/2008		P43	113	22.00	2,486	344	
10/3/2008		P44	113	22.00	2,486	344	
10/3/2008		P45	113	22.00	2,486	344	
10/3/2008		P46	65	22.00	1,430	344	
10/3/2008		P47	48	22.00	1,056	364	
10/3/2008		P48	113	22.00	2,486	364	
				Total Area (SF) This Page Only =	87,556		

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CAAW Systems

PANEL PLACEMENT FORM

PROJECT NAME:			Midwest Gen Ash Pond 1			JOB NUMBER: 0	Material Type:
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
10/3/2008		P49	113	22.00	2,486	364	
10/3/2008		P50	113	22.00	2,486	364	
10/3/2008		P51	113	22.00	2,486	364	
10/3/2008		P52	113	22.00	2,486	134	
10/4/2008		P53	113	22.00	2,486	134	
10/4/2008		P54	51	22.00	1,122	134	
10/4/2008		P55	62	22.00	1,364	116	
10/4/2008		P56	113	22.00	2,486	116	
10/4/2008		P57	100	22.00	2,200	346	
10/4/2008		P58	100	22.00	2,200	346	
10/4/2008		P59	100	22.00	2,200	346	
10/4/2008		P60	100	22.00	2,200	346	
10/4/2008		P61	100	22.00	1,529	346	
10/4/2008		P62	44	22.00	484	344	
10/4/2008		P63	27	13.00	176	344	
10/4/2008		P64	54	13.00	351	346	
10/4/2008		P65	51	22.00	1,122	346	
10/4/2008		P66	47	22.00	1,034	356	
10/4/2008		P67	50	22.00	1,100	357	
				Total Area (SF) This Page Only =	31,998		

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Submittal #24

CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/1/2008	08:40	P1/P2	58	kk	850	350	427	10MPH/54		
10/1/2008	08:38	P2/P3	58	hn	850	350	138	10MPH/54		
10/1/2008	08:50	P3/P4	58	kk	850	350	427	10MPH/54		
10/1/2008	08:56	P4/P5	58	hn	850	350	138	10MPH/54		
10/1/2008	09:10	P6/P7	58	kk	850	350	427	10MPH/54		
10/1/2008	09:13	P7/P8	58	hn	850	350	138	10MPH/54		
10/1/2008	09:45	P9/P10	58	kk	850	350	427	10MPH/54		
10/1/2008	09:51	P10/P11	58	hn	850	350	138	10MPH/54		
10/1/2008	10:00	P11/P12	58	kk	850	350	427	10MPH/54		
10/1/2008	10:08	P12/P13	58	hn	850	350	138	10MPH/54		
10/1/2008	10:27	P14/P15	58	hn	850	350	138	10MPH/54		
10/1/2008	10:30	P15/P16	58	kk	850	350	427	10MPH/54		
10/1/2008	09:35	P8/P9	58	hn	850	350	138	10MPH/54		
10/1/2008	09:14	P5/P6	58	hn	850	350	138	10MPH/54		
10/1/2008	10:15	P13/P14	58	kk	850	350	427	10MPH/54		
10/1/2008	10:53	P16/P17	58	hn	850	350	138	10MPH/54		
10/1/2008	11:00	P17/P18	58	kk	850	350	427	10MPH/54		
10/1/2008	11:10	P18/P19	58	hn	850	350	138	10MPH/54		
10/1/2008	12:10	P19/P20	52	kk	850	350	427	10MPH/54		
10/1/2008	11:27	P20/P21	17	hn	850	350	138	10MPH/54		
10/1/2008	11:58	P21/P22	17	hn	850	350	138	10MPH/54		
10/1/2008	12:00	P22/P23	52	kk	850	350	427	10MPH/54		
10/1/2008	11:44	P23/P24	69	hn	850	350	138	10MPH/54		
10/1/2008	12:26	P20/P22	28	kk	850	350		10MPH/54		

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CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/1/2008	14:10	P25/P28	21	kk	850	350	427	10MPH/54		
10/1/2008	14:10	P25/P27	5	hn	850	350	138	10MPH/54		
10/1/2008	13:35	P1/P25	58	kk	850	350	427	10MPH/54		
10/1/2008	13:48	P25/P26	30	hn	850	350	138	10MPH/54		
10/1/2008	14:10	P26/P27	29	hn	850	350	138	10MPH/54		
10/1/2008	14:00	P27/P28	35	kk	850	350	427	10MPH/54		
10/1/2008	14:50	P29/P25	10	kk	850	350	427	10MPH/54		
10/1/2008	14:25	P29/P30	417	hn	850	350	138	10MPH/54		
10/1/2008	15:05	P29/P1	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P2	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P3	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P4	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P5	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P6	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P7	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P8	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P9	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P10	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P12	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P13	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P14	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P15	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P16	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P17	22	kk	850	350	427	10MPH/54		

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CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/1/2008	15:05	P29/P18	22	kk	850	350	427	10MPH/54		
10/2/2008	08:40	P31/P30	470	kk	850	350	427	10MPH/54		
10/2/2008	08:47	P31/P32	470	hn	850	350	138	10MPH/54		
10/2/2008	09:02	P32/P33	470	kk	850	350	427	10MPH/54		
10/2/2008	10:34	P33/P34	470	hn	850	350	138	10MPH/54		
10/2/2008	09:25	P31/P24	58	kk	850	350	427	10MPH/54		
10/3/2008	13:35	P40/P35	13	hn	850	350	138	10MPH/68		
10/3/2008	11:37	P38/P37	24	hn	850	350	138	10MPH/68		
10/3/2008	11:37	P38/P36	8	hn	850	350	138	10MPH/68		
10/3/2008	11:37	P38/P35	24	hn	850	350	138	10MPH/68		
10/3/2008	11:03	P38/P39	58	hn	850	350	138	10MPH/68		
10/3/2008	11:37	P39/P40	50	hn	850	350	138	10MPH/68		
10/3/2008	11:25	P36/P37	26	hn	850	350	138	10MPH/68		
10/3/2008	11:25	P36/P35	37	kk	850	350	427	10MPH/68		
10/3/2008	11:30	P39/P41	108	kk	850	350	427	10MPH/68		
10/3/2008	13:30	P41/P42	108	kk	850	350	427	10MPH/68		
10/3/2008	14:05	P43/P42	108	hn	850	350	138	10MPH/68		
10/3/2008	14:00	P43/P44	108	kk	850	350	427	10MPH/68		
10/3/2008	14:42	P44/P45	108	hn	850	350	138	10MPH/68		
10/3/2008	15:00	P45/P46	60	kk	850	350	427	10MPH/68		
10/3/2008	15:00	P45/P47	48	kk	850	350	427	10MPH/68		
10/3/2008	15:00	P46/P47	22	hn	850	350	138	10MPH/68		
10/3/2008	15:07	P46/P48	60	hn	850	350	138	10MPH/68		
10/3/2008	15:07	P47/P48	48	hn	850	350	138	10MPH/68		

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CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/3/2008	15:25	P48/P49	108	kk	850	350	427	10MPH/68		
10/3/2008	15:41	P49/P50	108	hn	850	350	138	10MPH/68		
10/3/2008	15:50	P50/P51	108	kk	850	350	427	10MPH/68		
10/3/2008	16:15	P51/P52	108	kk	850	350	427	10MPH/68		
10/3/2008	16:19	P52/P53	108	hn	850	350	138	10MPH/68		
10/3/2008	16:42	P53/P54	46	hn	850	350	138	10MPH/68		
10/3/2008	16:42	P53/P55	62	hn	850	350	138	10MPH/68		
10/3/2008	16:40	P55/P54	22	kk	850	350	427	10MPH/68		
10/3/2008	16:45	P54/P56	46	kk	850	350	427	10MPH/68		
10/3/2008	16:45	P55/P56	62	kk	850	350	427	10MPH/68		
10/4/2008	07:40	P67/P56	22	hn	850	350	138	10MPH/68		
10/4/2008	07:52	P56/P57	95	hn	850	350	138	10MPH/68		
10/4/2008	08:10	P57/P58	95	hn	850	350	138	10MPH/68		
10/4/2008	08:20	P58/P59	95	kk	850	350	427	10MPH/68		
10/4/2008	08:35	P59/P60	95	hn	850	350	138	10MPH/68		
10/4/2008	08:50	P60/P61	95	kk	850	350	427	10MPH/68		
10/4/2008	09:40	P61/P62	44	kk	850	350	427	10MPH/68		
10/4/2008	10:15	P62/P63	27	kk	850	350	427	10MPH/68		
10/4/2008	10:25	P63/P64	13	kk	850	350	427	10MPH/68		
10/4/2008	10:25	P64/P62	22	kk	850	350	427	10MPH/68		
10/4/2008	09:30	P64/P65	54	kk	850	350	427	10MPH/68		
10/4/2008	10:25	P61/P64	27	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P61/P66	9	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P60/P66	22	kk	850	350	427	10MPH/68		

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/4/2008	10:50	P59/P66	16	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P59/P67	6	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P58/P67	22	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P57/P67	22	kk	850	350	427	10MPH/68		
10/4/2008	07:40	P67/P66	22	kk	850	350	427	10MPH/68		
10/4/2008	08:00	P34/P67	50	kk	850	350	427	10MPH/68		
10/4/2008	08:00	P34/P66	47	hn	850	350	138	10MPH/68		
10/4/2008	10:15	P66/P65	22	hn	850	350	138	10MPH/68		
10/4/2008	10:00	P45/P65	43	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P40/P34	10	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P39	11	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P41	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P42	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P43	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P44	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P45	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P47	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P48	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P49	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P50	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P51	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P52	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P53	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P55	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P56	22	kk	850	350	427	10MPH/68		

Submittal #21

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PAGE NO.: 1

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/1/2008	58	P1/P2	ss	11:01	11:06	30	30	P		
10/1/2008	58	P2/P3	ss	11:02	11:07	30	30	P		
10/1/2008	58	P3/P4	ss	11:04	11:09	30	29	P		
10/1/2008	58	P4/P5	ss	11:05	11:10	30	30	P		
10/1/2008	58	P6/P7	ss	11:13	11:18	30	30	P		
10/1/2008	58	P7/P8	ss	11:14	11:19	30	29	P		
10/1/2008	58	P9/P10	ss	11:15	11:20	30	30	P		
10/1/2008	58	P10/P11	ss	11:16	11:21	30	30	P		
10/1/2008	58	P11/P12	ss	11:18	11:23	30	30	P		
10/1/2008	58	P12/P13	ss	11:30	11:35	30	30	P		
10/1/2008	58	P14/P15	ss	11:31	11:36	30	30	P		
10/1/2008	58	P15/P16	ss	11:32	11:37	30	29	P		
10/1/2008	58	P8/P9	ss	11:33	11:38	30	30	P		
10/1/2008	58	P5/P6	ss	11:37	11:42	30	28	P		
10/1/2008	58	P13/P14	ss	11:39	11:44	30	30	P		
10/1/2008	58	P16/P17	ss	11:41	11:46	30	30	P		
10/1/2008	58	P17/P18	ss	11:43	11:48	30	29	P		
10/1/2008	58	P18/P19	ss	11:52	11:57	30	30	P		
10/1/2008	52	P19/P20	ss	12:02	12:07	30	30	P		
10/1/2008	17	P20/P21	ss	13:03	13:08	30	29	P		
10/1/2008	17	P21/P22	ss	13:04	13:09	30	30	P		
10/1/2008	52	P22/P23	ss	13:05	13:10	30	28	P		
10/1/2008	69	P23/P24	ss	13:06	13:11	30	29	P		
10/1/2008	28	P20/P22	ss	13:08	13:13	30	30	P		

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CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/2/2008	21	P25/P28	ss	7:02	7:07	30	29	P		
10/2/2008	5	P25/P27	ss	07:03	7:08	30	30	P		
10/2/2008	58	P1/P25	ss	07:04	7:09	30	30	P		
10/2/2008	30	P25/P26	ss	07:06	7:11	30	30	P		
10/2/2008	29	P26/P27	ss	07:10	7:15	30	30	P		
10/2/2008	35	P27/P28	ss	07:11	7:16	30	29	P		
10/2/2008	10	P29/P25	ss	07:12	7:17	30	30	P		
10/2/2008	417	P29/P30	ss	07:15	7:20	30	30	P		
10/2/2008	22	P29/P1	ss	07:21	7:26	30	29	P		
10/2/2008	22	P29/P2	ss	07:22	7:27	30	28	P		
10/2/2008	22	P29/P3	ss	07:23	7:28	30	30	P		
10/2/2008	22	P29/P4	ss	07:24	7:29	30	30	P		
10/2/2008	22	P29/P5	ss	07:33	7:38	30	29	P		
10/2/2008	22	P29/P6	ss	07:34	7:39	30	30	P		
10/2/2008	22	P29/P7	ss	07:35	7:40	30	28	P		
10/2/2008	22	P29/P8	ss	07:36	7:41	30	30	P		
10/2/2008	22	P29/P9	ss	07:37	7:42	30	29	P		
10/2/2008	22	P29/P10	ss	08:02	8:07	30	30	P		
10/2/2008	22	P29/P12	ss	08:03	8:08	30	28	P		
10/2/2008	22	P29/P13	ss	08:05	8:10	30	29	P		
10/2/2008	22	P29/P14	ss	08:07	8:12	30	30	P		
10/2/2008	22	P29/P15	ss	08:09	8:14	30	28	P		
10/2/2008	22	P29/P16	ss	08:10	8:15	30	30	P		
10/2/2008	22	P29/P17	ss	08:11	8:16	30	30	P		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/4/2008	22	P29/P18	ss	7:00	7:05	30	29	P		
10/4/2008	470	P31/P30	ss	07:01	7:06	30	30	P		
10/4/2008	470	P31/P32	ss	07:03	7:08	30	29	P		
10/4/2008	470	P32/P33	ss	07:05	7:10	30	30	P		
10/4/2008	470	P33/P34	ss	07:06	7:11	30	30	P		
10/4/2008	58	P31/P24	ss	07:07	7:12	30	29	P		
10/4/2008	13	P40/P35	ss	07:13	7:18	30	28	P		
10/4/2008	24	P38/P37	ss	07:14	7:19	30		F	P	ext welded
10/4/2008	8	P38/P36	ss	07:15	7:20	30		F	P	ext welded
10/4/2008	24	P38/P35	ss	07:16	7:21	30		F	P	ext welded
10/4/2008	58	P38/P39	ss	07:17	7:22	30	30	P		
10/4/2008	50	P39/P40	ss	07:24	7:29	30	29	P		
10/4/2008	26	P36/P37	ss	07:25	7:30	30	28	P		
10/4/2008	37	P36/P35	ss	07:28	7:33	30	30	P		
10/4/2008	108	P39/P41	ss	07:29	7:24	30	30	P		
10/4/2008	108	P41/P42	ss	07:30	7:35	30	30	P		
10/4/2008	108	P43/P42	ss	07:33	7:38	30	30	P		
10/4/2008	108	P43/P44	ss	07:35	7:40	30	28	P		
10/4/2008	108	P44/P45	ss	07:36	7:41	30	30	P		
10/4/2008	60	P45/P46	ss	07:44	7:49	30	29	P		
10/4/2008	48	P45/P47	ss	07:45	7:50	30	29	P		
10/4/2008	22	P46/P47	ss	07:46	7:51	30	30	P		
10/4/2008	60	P46/P48	ss	07:47	7:48	30	30	P		
10/4/2008	48	P47/P48	ss	07:50	7:55	30	29	P		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/4/2008	108	P48/P49	ss	8:04	8:09	30	30	P		
10/4/2008	108	P49/P50	ss	08:05	8:10	30	30	P		
10/4/2008	108	P50/P51	ss	08:06	8:11	30	30	P		
10/4/2008	108	P51/P52	ss	08:15	8:20	30	29	P		
10/4/2008	108	P52/P53	ss	08:16	8:21	30	30	P		
10/4/2008	46	P53/P54	ss	08:18	8:23	30	30	P		
10/4/2008	62	P53/P55	ss	08:20	8:25	30	30	P		
10/4/2008	22	P55/P54	ss	08:22	8:27	30	29	P		
10/4/2008	46	P54/P56	ss	08:23	8:28	30	30	P		
10/4/2008	62	P55/P56	ss	08:30	8:35	30	29	P		
10/4/2008	22	P67/P56	ss	14:02	14:07	30	30	P		
10/4/2008	95	P56/P57	ss	14:03	14:08	30	30	P		
10/4/2008	95	P57/P58	ss	14:04	14:09	30	30	P		
10/4/2008	95	P58/P59	ss	14:20	14:25	30	30	P		
10/4/2008	95	P59/P60	ss	14:24	14:29	30	30	P		
10/4/2008	95	P60/P61	ss	14:26	14:31	30	30	P		
10/4/2008	44	P61/P62	ss	14:28	14:33	30	30	P		
10/4/2008	27	P62/P63	ss	14:30	14:35	30	30	P		
10/4/2008	13	P63/P64	ss	14:40	14:45	30	30	P		
10/4/2008	22	P64/P62	ss	14:41	14:46	30	30	P		
10/4/2008	54	P64/P65	ss	14:42	14:47	30	30	P		
10/4/2008	27	P61/P64	ss	14:43	14:48	30	30	P		
10/4/2008	9	P61/P66	ss	14:48	14:53	30	29	P		
10/4/2008	22	P60/P66	ss	14:49	14:54	30	30	P		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/4/2008	16	P59/P66	ss	15:02	15:07	30	30	P		
10/4/2008	6	P59/P67	ss	15:03	15:08	30	30	P		
10/4/2008	22	P58/P67	ss	15:04	15:09	30	30	P		
10/4/2008	22	P57/P67	ss	15:05	15:10	30	30	P		
10/4/2008	22	P67/P66	ss	15:12	15:17	30	30	P		
10/4/2008	50	P34/P67	ss	15:13	15:18	30	29	P		
10/4/2008	47	P34/P66	ss	15:15	15:20	30	28	P		
10/4/2008	22	P66/P65	ss	15:22	15:27	30	30	P		
10/4/2008	43	P45/P65	ss	15:23	15:28	30	29	P		
10/4/2008	10	P40/P34	ss	15:24	15:29	30	30	P		
10/4/2008	11	P34/P39	ss	15:32	15:37	30	30	P		
10/4/2008	22	P34/P41	ss	15:33	15:38	30	30	P		
10/4/2008	22	P34/P42	ss	15:34	15:39	30	30	P		
10/4/2008	22	P34/P43	ss	15:35	15:40	30	28	P		
10/4/2008	22	P34/P44	ss	15:36	15:41	30	30	P		
10/4/2008	22	P34/P45	ss	15:43	15:48	30	30	P		
10/4/2008	22	P34/P47	ss	15:44	15:49	30	29	P		
10/4/2008	22	P34/P48	ss	15:45	15:50	30	30	P		
10/4/2008	22	P34/P49	ss	15:46	15:51	30	30	P		
10/4/2008	22	P34/P50	ss	15:54	15:59	30	30	P		
10/4/2008	22	P34/P51	ss	15:55	16:00	30	28	P		
10/4/2008	22	P34/P52	ss	15:56	16:01	30	30	P		
10/4/2008	22	P34/P53	ss	15:58	16:03	30	29	P		
10/4/2008	22	P35/P55	ss	16:05	16:10	30	30	P		
10/4/2008	22	P34/P56	ss	16:06	16:11	30	29	P		

Electronic Filing: Received, Clerk's Office 2/04/2022

Submittal #24

GAAW Systems

DESTRUCTIVE TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB NUMBER:	0	MATERIAL TYPE:

TENSIOMETER ID:	0	EXTRUSION	FUSION	FIELD WELD VALUES										
SAMPLE I.D. (DT#)	SEAM NO.	QC INT	MACH NO.	SEAMER INT	BARREL/ PREHEAT	WEDGE/ SET SPEED	PEEL (PPI)					SHEAR (PPI)			P/F	LOCATION OF DESTRUCTIVE TEST
DS1	P16/P17	ss	138	hn	B:	W: 850	135	141	137			178	180	172	P	neos 0'->3'
					P:	S: 350	128	146	144							
DS2	P17.P18	ss	427	kk	B:	W: 850	133	139	129			189	172	180	P	neos 0'->3'
					P:	S: 350	127	148	134							
DS3	P15/P29	ss	427	kk	B:	W: 850	141	142	127			169	173	177	P	weos 0'->5'
					P:	S: 350	123	130	138							
DS4	P29/P30	ss	138	hn	B:	W: 850	138	131	125			163	168	170	P	weos 0'->50'
					P:	S: 350	122	135	127							
DS5	P31/P30	ss	427	kk	B:	W: 850	136	122	138			172	163	169	P	weos 0'->150'
					P:	S: 350	129	126	122							
DS6	P31/P32	ss	138	hn	B:	W: 850	145	134	142			162	173	174	P	weos 0'->150'
					P:	S: 350	129	141	127							
DS7	P32/P33	ss	427	kk	B:	W: 850	137	135	139			167	169	172	P	weos 0'->200'
					P:	S: 350	131	127	124							
DS8	P33/P34	ss	138	hn	B:	W: 850	145	116	131			157	164	162	P	weos 0'->200'
					P:	S: 350	128	122	125							
DS9	P48/P49	ss	427	kk	B:	W: 850	133	128	132			167	162	169	P	neos 0'-76'
					P:	S: 350	127	123	127							
DS10	P49/P50	ss	138	hn	B:	W: 850	136	144	120			161	168	171	P	neos 0'->84'
					P:	S: 350	130	139	132							
DS11	P56/P34	ss	427	kk	B:	W: 850	121	134	125			158	166	165	P	weos 0'->8'
					P:	S: 350	122	128	134							
DS12	P58/P59	ss	427	kk	B:	W: 850	136	140	121			162	178	172	P	neos 0'->90'
					P:	S: 350	138	144	138							
DS13	P59/P60	ss	138	hn	B:	W: 850	126	137	131			167	173	165	P	neos 0'->90'
					P:	S: 350	134	127	130							

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Submittal #2

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P21/P20		R1	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P20-P21-P22	P
P19/P20		R2	vk	175	sv	10/2/2008	patch 2x4	10/2/2008	int of P19-P20-P23	P
P20/P23		R3	vk	175	sv	10/2/2008	ext weld 4'	10/2/2008	eeos 0'->4'	P
P23/P22		R4	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P22-P23-P19	P
	P23	R5	vk	175	sv	10/2/2008	Boot patch 24"/ 3x5	10/2/2008	weop 0'->5' / neop 0'->14'	P
P23/P29		R6	vk	175	sv	10/2/2008	patch 3x8	10/2/2008	int of P29-P23-P19	P
P29/P30		R7	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P30-P29-P23-P24	P
P19/P18		R8	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P19-P18-P29	P
P18/P17		R9	vk	175	sv	10/2/2008	patch 2x3	10/2/2008	neos 0'->3' DS-2	P
P18/P17		R10	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P18-P17-P29	P
P17/P16		R11	vk	175	sv	10/2/2008	patch 2x3	10/2/2008	neos 0'->3' DS-1	P
P17/P16		R12	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P16-P17-P29	P
P16/P15		R13	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P16-P15-P29	P
P15/P29		R14	vk	175	sv	10/2/2008	patch 2x3	10/2/2008	weos 0'->5' DS-3	P
P15/P14		R15	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P15-P14-P29	P
P14/P13		R16	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P14/P13-P29	P
	P13	R17	vk	175	sv	10/2/2008	Boot patch 24"/ 3x9	10/2/2008	neop 0'->8' / weop 0'->6'	P
P13/P12		R18	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P13-P12-P29	P
P12/P11		R19	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P12-P11-P29	P
P12/P11		R20	vk	175	sv	10/2/2008	patch 2x2	10/2/2008	seos 0'-6"	P
P11/P10		R21	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P11-P10-P29	P
P10/P9		R22	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P10-P9-P29	P
P9/P8		R23	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P9-P8-P29	P
P9/P8		R24	vk	175	sv	10/2/2008	ext weld 5"	10/2/2008	neos 0'->30'	P
P8/P7		R25	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P8-P7-P29	P

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GEOMEMBRANE REPAIR REPORT

PROJECT NAME:		Midwest Gen Ash Pond 1					JOB #: 0		MATERIAL TYPE:	
FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P7/P6		R26	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P7-P6-P29	P
P7/P6		R27	vk	175	sv	10/2/2008	paych boot 24" 3x4	10/2/2008	neos 0'->8'	P
P6/P5		R28	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P6-P5-P29	P
P5/P4		R29	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P5-P4-P29	P
P4/P3		R30	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P4-P3-P29	P
P3/P2		R31	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P3-P2-P29	P
P2/P1		R32	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P2-P1-P29	P
	P25	R33	vk	175	sv	10/3/2008	patch boot 24" 3x7	10/3/2008	neop 0'->5' / eeop 0'->75'	P
P1/P25		R34	vk	175	sv	10/3/2008	t-weld	10/3/2008	int of P25-P1-P29	P
P25/P26		R35	vk	175	sv	10/3/2008	patch 2x4	10/3/2008	int of P25-P26-P27-P28	P
P25/P28		R36	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	int of P25-P28-P29	P
P24/P31		R37	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	int of P24-P20-P31	P
P31/P32		R38	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	eeos 0'-45'	P
P31/P32		R39	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	eeos 0'->72'	P
P30/P31		R40	vk	175	sv	10/3/2008	ext weld 2'	10/3/2008	weos 0'->129'	P
P33/P34		R41	vk	175	sv	10/3/2008	patch 2x2	10/3/2008	weos 0'->31'	P
P35/P38		R42	vk	175	sv	10/3/2008	ext weld 24'	10/3/2008	seos 0'->24' (ext whole seam)	P
P35/P36		R43	vk	175	sv	10/3/2008	patch 2x2	10/3/2008	int of P35-P36-P38	P
P36/P38		R44	vk	175	sv	10/3/2008	ext weld 8'	10/3/2008	seos 0'->8' (ext whole seam)	P
P37/P38		R45	vk	175	sv	10/3/2008	ext weld 24'	10/3/2008	seos 0'->24' (ext whole seam)	P
P38/P39		R46	vk	175	sv	10/3/2008	patch boot 24"3x5	10/3/2008	neos 0'->58'	P
P39/P41		R47	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	int of P34-P39-P41	P
P42/P43		R48	vk	175	sv	10/3/2008	patch 2x5	10/3/2008	neos 0'->37'	P
P43/P44		R49	vk	175	sv	10/3/2008	patch 2x2	10/3/2008	neos 0'->55'	P
P44/P45		R50	vk	175	sv	10/3/2008	patch 2x2	10/3/2008	neos 0'->55'	P

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GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
	P44	R51	vk	175	10/4/2008	sv	patch boot 24"/ 3x3	10/4/2008	neop 0'->55' / weop 0'->10'	P
P45/P46		R52	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	int of P45-P46-P47	P
P48/P49		R53	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->44'	P
P48/P49		R54	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->76' DS-9	P
P48/P47		R55	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->55'	P
	P48	R56	vk	175	10/4/2008	sv	patch boot 24"/3x4	10/4/2008	neop 0'->55' / weop 0'->11'	P
P49/P50		R57	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->55'	P
P49/P50		R58	vk	175	10/4/2008	sv	patch boot 24"/3x3	10/4/2008	neos 0'-72'	P
P49/P50		R59	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->84' DS-10	P
P50/P51		R60	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->78'	P
P54/P53		R61	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	int of P53-P54-P55	P
P54/P56		R62	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	int ofP54-P55-P56	P
P56/P34		R63	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	weos 0'->8' DS-11	P
P67/P56		R64	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	int of P67-P34-P56	P
P57/P67		R65	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	int of P67-P57-P56	P
P56/P57		R66	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->29'	P
P56/P57		R67	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->51'	P
P58/P59		R68	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->90' DS-12	P
P59/P60		R69	vk	175	10/4/2008	sv	patch 3x3	10/4/2008	neos 0'->62'	P
P59/P60		R70	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->73'	P
P59/P60		R71	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->90' DS-13	P
P62/P61		R72	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->21'	P
P62/P63		R73	vk	175	10/4/2008	sv	patch 6x3	10/4/2008	neos 0'->6'	P
P64/P63		R74	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	eeos 0'->6'	P
P64/P63		R75	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P64-P63-P62	P

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Submittal =

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:		Midwest Gen Ash Pond 1			JOB #: 0				MATERIAL TYPE:	
FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P64/P62		R76	vk	175	10/4/2008	sv	patch 3x3	10/4/2008	int of P64-P62-P61	P
P64/P65		R77	vk	175	10/4/2008	sv	patch 2x4	10/4/2008	eeos 0'->6'	P
P64/P65		R78	vk	175	10/4/2008	sv	patch 3x5	10/4/2008	int of P65-P64-P66-P61	P
P64/P61		R79	vk	175	10/4/2008	sv	patch boot 24"/3x4	10/4/2008	seos 0'->7'	P
P61/P60		R80	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P60-P61-P66	P
P59/P60		R81	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P59-P60-P66	P
P66/P67		R82	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P66-P67-P59	P
P59/P58		R83	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P58-P59-P67	P
P58/P57		R84	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P57-P58-P67	P
P67/P34		R85	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P67-P66-P34	P
P15/P29		R86	vk	175	10/2/2008	sv	patch 2x3	10/2/2008	weos 0'->5' DS-3	P
P29/P30		R87	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'->50' DS-4	P
P31/P30		R88	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'->150' DS-5	P
P31/P32		R89	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'->150' DS-6	P
P32/P33		R90	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'->200' DS-7	P
P33/P34		R91	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'-.200' DS-8	P

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A4

IMPOUNDMENT #2

Electronic Filing: Received, Clerk's Office 2/04/2022 Submittal # 2

CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	4/29/2008	**Q.C. NAME:**	Sengratana Sengsay
PROJECT NAME:	Midwest Gen Station - Pond #2	**MAT. TYPE:**	60 Mil. HDPE Texture
PROJECT NUMBER:	200754	**TRUCK NUMBER:**	
LOCATION	Joliet, IL	**BILL OF LADING #**	

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
105136361	22.50 x 520	11,700	
105136347	22.50 x 520	11,700	
104137238	22.50 x 520	11,700	
104137340	22.50 x 520	11,700	
105136345	22.50 x 520	11,700	
104137407	22.50 x 520	11,700	
104137341	22.50 x 520	11,700	
104137342	22.50 x 520	11,700	
104137406	22.50 x 520	11,700	
104137147	22.50 x 520	11,700	
105136354	22.50 x 520	11,700	
105136346	22.50 x 520	11,700	
104137343	22.50 x 520	11,700	
184137263	22.50 x 520	11,700	
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	TOTAL =	163,800	

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CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	4/29/2008	**Q.C. NAME:**	Sengratana Sengsay
PROJECT NAME:	Midwest Gen Station - Pond #2	**MAT. TYPE:**	16 oz. Geotextile
PROJECT NUMBER:	200754	**TRUCK NUMBER:**	
LOCATION	Joliet, IL	**BILL OF LADING #**	

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
130288393	15.00 x 300	4,500	
130288390	15.00 x 300	4,500	
130288351	15.00 x 300	4,500	
130288383	15.00 x 300	4,500	
130288370	15.00 x 300	4,500	
130288381	15.00 x 300	4,500	
130288391	15.00 x 300	4,500	
130288397	15.00 x 300	4,500	
130288399	15.00 x 300	4,500	
130288389	15.00 x 300	4,500	
130288384	15.00 x 300	4,500	
130288395	15.00 x 300	4,500	
130288387	15.00 x 300	4,500	
130288401	15.00 x 300	4,500	
130288392	15.00 x 300	4,500	
130288372	15.00 x 300	4,500	
130288382	15.00 x 300	4,500	
130288373	15.00 x 300	4,500	
130288402	15.00 x 300	4,500	
130288386	15.00 x 300	4,500	
130288398	15.00 x 300	4,500	
130288352	15.00 x 300	4,500	
130288377	15.00 x 300	4,500	
130288379	15.00 x 300	4,500	
130288376	15.00 x 300	4,500	
130288394	15.00 x 300	4,500	
130288363	15.00 x 300	4,500	
130288400	15.00 x 300	4,500	
130288385	15.00 x 300	4,500	
130288365	15.00 x 300	4,500	
130288403	15.00 x 300	4,500	
	TOTAL =	139,500	

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	4/29/2008	Q.C. NAME:	Sengratana Sengsay
PROJECT NAME:	Midwest Gen Station - Pond #2	MAT. TYPE:	16 oz. Geotextile
PROJECT NUMBER:	200754	TRUCK NUMBER:	
LOCATION	Joliet, IL	BILL OF LADING #	

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
130288380	15.00 x 300	4,500	
130288369	15.00 x 300	4,500	
130288388	15.00 x 300	4,500	
130288396	15.00 x 300	4,500	
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	TOTAL =	18,000	

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CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	4/29/2008	**Q.C. NAME:**	Sengratana Sengsay
PROJECT NAME:	Midwest Gen Station - Pond #2	**MAT. TYPE:**	12 oz. Geotextile
PROJECT NUMBER:	200754	**TRUCK NUMBER:**	
LOCATION	Joliet, IL	**BILL OF LADING #**	

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
130288410	15.00 x 300	4,500	
130288449	15.00 x 300	4,500	
130288429	15.00 x 300	4,500	
130288424	15.00 x 300	4,500	
130288430	15.00 x 300	4,500	
130288439	15.00 x 300	4,500	
130288418	15.00 x 300	4,500	
130288426	15.00 x 300	4,500	
130288428	15.00 x 300	4,500	
130288440	15.00 x 300	4,500	
130288421	15.00 x 300	4,500	
130288412	15.00 x 300	4,500	
130288425	15.00 x 300	4,500	
130288422	15.00 x 300	4,500	
130288423	15.00 x 300	4,500	
130288427	15.00 x 300	4,500	
130288420	15.00 x 300	4,500	
130288416	15.00 x 300	4,500	
130288438	15.00 x 300	4,500	
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	TOTAL =	85,500	

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Submitted PC 1

GAW Systems

TRIAL WELD TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB NUMBER:	200754	MAT'L TYPE:	60 Mil. HDPE
TENSIOMETER ID:	T-062/06				

DATE	SAMPLE I.D. (TW#)	TIME	AMB. TEMP (ºF)	WEATHER (CLOUDY/ SUNNY)	QC INT	MACH NO.	SEAMER INT	EXTRUSION BARREL/ PREHEAT	FUSION WEDGE/ SET SPEED	FIELD WELD VALUES PEEL (PPI)					SHEAR (PPI)			P/F	Comments
4/30/2008	1	09:30	58	sunny	ss	428	ck	B:	W: 850	168	167	162			165	169		P	
								P:	S: 400	154	164	166							
4/30/2008	2	09:28	58	sunny	ss	138	vp	B:	W: 850	161	154	169			172	163		P	
								P:	S: 400	159	160	155							
4/30/2008	3	13:10	58	sunny	ss	428	ck	B:	W: 850	143	137	144			169	161		P	
								P:	S: 400	138	142	148							
4/30/2008	4	13:15	58	sunny	ss	138	vp	B:	W: 850	137	134	140			166	162		P	
								P:	S: 400	139	138	133							
5/1/2008	1	07:45	58	sunny	ss	428	ck	B:	W: 850	134	126	135			162	166		P	
								P:	S: 450	145	130	133							
5/1/2008	2	07:43	58	sunny	ss	138	vp	B:	W: 850	144	138	141			171	168		P	
								P:	S: 450	142	135	136							
5/1/2008	3	12:45	64	cloudy	ss	428	ck	B:	W: 850	137	141	144			167	162		P	
								P:	S: 450	154	135	138							
5/1/2008	4	12:40	64	cloudy	ss	138	vp	B:	W: 850	138	128	136			166	169		P	
								P:	S: 450	137	134	138							
5/2/2008	1	07:40	63	cloudy	ss	138	vp	B:	W: 850	136	144	137			161	157		P	
								P:	S: 450	148	139	142							
5/2/2008	2	07:42	63	cloudy	ss	428	ck	B:	W: 850	152	137	136			160	158		P	
								P:	S: 450	144	139	142							
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										

Electronic Filing: Received, Clerk's Office 2/04/2022

GAI Systems

TRIAL WELD TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB NUMBER:	200754	MAT'L TYPE:

TENSIOMETER ID:	T-062/06	EXTRUSION	FUSION	FIELD WELD VALUES										
DATE	SAMPLE I.D. (TW#)	TIME	AMB. TEMP (ºF)	WEATHER (CLOUDY/ SUNNY)	QC INT	MACH NO.	SEAMER INT	BARREL/ PREHEAT	WEDGE/ SET SPEED	PEEL (PPI)				SHEAR (PPI)			P/F	Comments
5/5/2008	1	08:40	67	Sunny	ss	428	ck	B:	W: 850	158	138	141		181	178		P	
								P:	S: 400	168	155	150						
5/5/2008	2	09:00	67	Sunny	ss	138	vp	B:	W: 850	135	137	133		183	180		P	
								P:	S: 400	130	130	140						
5/5/2008	3	13:05	67	Sunny	ss	428	ck	B:	W: 850	139	143	136		176	180		P	
								P:	S: 400	138	139	134						
5/5/2008	4	13:03	67	Sunny	ss	138	vp	B:	W: 850	144	137	141		188	183		P	
								P:	S: 400	139	134	138						
5/6/2008	1	07:07	58	Sunny	ss	428	ck	B:	W: 850	143	139	138		169	174		P	
								P:	S: 400	140	142	144						
5/6/2008	2	07:55	58	Sunny	ss	138	vp	B:	W: 850	152	138	139		178	174		P	
								P:	S: 400	139	144	145						
5/6/2008	3	08:00	58	Sunny	ss	175	vk	B: 550	W:	166	169	164		204	207		P	
								P: 350	S:									
5/6/2008	4	08:02	58	Sunny	ss	88	vp	B: 550	W:	165	173	167		198	203		P	
								P: 250	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									

Electronic Filing: Received, Clerk's Office 2/04/2022

Submittal #24

GAAW Systems

PANEL PLACEMENT FORM

PROJECT NAME:		Midwest Gen Station - Pond #2				JOB NUMBER: 200754	Material Type: 60 Mil. HDPE
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
4/30/2008		P1	72	22.00	1,584	105136347	
4/30/2008		P2	75	22.00	1,650	105136347	
4/30/2008		P3	77	22.00	1,694	105136347	
4/30/2008		P4	77	22.00	1,694	105136347	
4/30/2008		P5	73	22.00	1,606	105136347	
4/30/2008		P6	75	22.00	1,650	105136347	
4/30/2008		P7	74	22.00	1,628	104137263	
4/30/2008		P8	71	22.00	1,562	104137263	
4/30/2008		P9	73	22.00	1,606	104137263	
4/30/2008		P10	75	22.00	1,650	104137263	
4/30/2008		P11	77	22.00	1,694	104137263	
4/30/2008		P12	75	22.00	1,650	104137263	
4/30/2008		P13	74	22.00	1,628	105136361	
4/30/2008		P14	74	22.00	1,628	105136361	
4/30/2008		P15	76	22.00	1,672	105136361	
4/30/2008		P16	75	22.00	1,650	105136361	
4/30/2008		P17	75	22.00	1,650	105136361	
4/30/2008		P18	72	22.00	1,584	105136361	
4/30/2008		P19	48	22.00	720	105136361	
4/30/2008		P20	24	22.00	192	105136361	
4/30/2008		P21	46	22.00	1,012	105136347	
4/30/2008		P22	72	22.00	1,584	104137407	
4/30/2008		P23	72	22.00	1,584	104137407	
4/30/2008		P24	24	22.00	264	104137407	
				Total Area (SF) This Page Only =	34,836		

Electronic Filing: Received, Clerk's Office 2/04/2022

PANEL PLACEMENT FORM

PROJECT NAME:		Midwest Gen Station - Pond #2				JOB NUMBER: 200754	Material Type: 60 Mil. HDPE
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
4/30/2008		P25	40	22.00	880	104137407	
4/30/2008		P26	65	22.00	1,430	104137407	
4/30/2008		P27	66	22.00	1,452	104137407	
5/1/2008		P28	58	22.00	1,276	104137407	
5/1/2008		P29	59	22.00	1,298	104137407	
5/1/2008		P30	61	22.00	1,342	105136345	
5/1/2008		P31	63	22.00	1,386	105136345	
5/1/2008		P32	62	22.00	1,364	105136345	
5/1/2008		P33	72	22.00	1,584	105136345	
5/1/2008		P34	60	22.00	1,034	105136345	
5/1/2008		P35	34	22.00	391	105136345	
5/1/2008		P36	74	22.00	1,628	105136345	
5/1/2008		P37	75	22.00	1,650	105136345	
5/1/2008		P38	76	22.00	1,672	104137341	
5/1/2008		P39	77	22.00	1,694	104137341	
5/1/2008		P40	76	22.00	1,672	104137341	
5/1/2008		P41	75	22.00	1,650	104137341	
5/1/2008		P42	76	22.00	1,672	104137341	
5/1/2008		P43	75	22.00	1,650	104137341	
5/1/2008		P44	75	22.00	1,650	104137104	
5/1/2008		P45	61	22.00	891	104137147	
5/1/2008		P46	20	22.00	220	104137147	
5/1/2008		P47	54	22.00	1,188	104137341	
5/1/2008		P48	55	22.00	1,210	104137342	
				Total Area (SF) This Page Only =	31,884		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

PANEL PLACEMENT FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB NUMBER: 200754	Material Type: 60 Mil. HDPE

DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
5/1/2008		P49	53	22.00	1,166	104137342	
5/1/2008		P50	53	22.00	1,166	104137342	
5/1/2008		P51	53	22.00	1,166	104137342	
5/1/2008		P52	53	22.00	1,166	104137342	
5/1/2008		P53	53	22.00	1,166	104137342	
5/1/2008		P54	53	22.00	1,166	104137342	
5/1/2008		P55	53	22.00	1,166	104137342	
5/2/2008		P56	405	22.00	8,910	104137340	
5/5/2008		P57	405	22.00	8,910	104137238	
5/5/2008		P58	108	22.00	2,376	104137264	
5/5/2008		P59	297	22.00	6,534	104137264	
5/5/2008		P60	202	22.00	4,444	104137264	
5/5/2008		P61	203	22.00	4,466	104137406	
5/5/2008		P62	303	22.00	6,666	104137406	
5/5/2008		P63	102	22.00	2,244	104137340	
5/5/2008		P64	405	22.00	8,910	105136346	
5/5/2008		P65	115	22.00	2,530	105136346	
5/5/2008		P66	67	22.00	1,474	184137263	
5/5/2008		P67	96	22.00	2,112	105136354	
5/5/2008		P68	96	22.00	2,112	105136354	
5/5/2008		P69	95	22.00	2,090	105136354	
5/5/2008		P70	96	22.00	2,112	105136354	
5/5/2008		P71	98	22.00	2,156	105136354	
5/5/2008		P72	98	22.00	2,156	104137343	
				Total Area (SF) This Page Only =	78,364		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAMP Systems

PANEL PLACEMENT FORM

PROJECT NAME:		Midwest Gen Station - Pond #2				JOB NUMBER: 200754	Material Type:
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
5/5/2008		P73	98	22.00	2,156	104137343	
5/5/2008		P74	98	22.00	2,156	104137343	
5/5/2008		P75	98	22.00	2,156	104137343	
5/6/2008		P76	92	22.00	2,024	104137343	
5/6/2008		P77	71	22.00	1,562	104137343	
5/6/2008		P78	32	24.00	384	104137343	
				Total Area (SF) This Page Only =	10,438		

Electronic Filing: Received, Clerk's Office 2/04/2022

Submitted #24

CQA-w Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
4/30/2008	09:50	P1/P2	72	VP	850	400	148	10-15 MPH/58		
4/30/2008	10:05	P2/P3	75	CK	850	400	428	10-15 MPH/58		
4/30/2008	10:04	P3/P4	76	VP	850	400	148	10-15 MPH/58		
4/30/2008	10:24	P4/P5	73	CK	850	400	428	10-15 MPH/58		
4/30/2008	10:38	P5/P6	74	VP	850	400	148	10-15 MPH/58		
4/30/2008	10:43	P6/P7	73	CK	850	400	428	10-15 MPH/58		
4/30/2008	10:58	P7/P8	71	VP	850	400	148	10-15 MPH/58		
4/30/2008	11:14	P8/P9	71	CK	850	400	428	10-15 MPH/58		
4/30/2008	11:19	P9/P10	72	VP	850	400	148	10-15 MPH/58		
4/30/2008	11:31	P10/P11	75	CK	850	400	428	10-15 MPH/58		
4/30/2008	11:36	P11/P12	75	VP	850	400	148	10-15 MPH/58		
4/30/2008	13:20	P12/P13	74	CK	850	400	428	10-15 MPH/58		
4/30/2008	13:28	P13/P14	74	VP	850	400	148	10-15 MPH/58		
4/30/2008	13:35	P14/P15	74	CK	850	400	428	10-15 MPH/58		
4/30/2008	13:47	P15/P16	75	VP	850	400	148	10-15 MPH/58		
4/30/2008	13:48	P16/P17	75	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:04	P17/P18	72	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:18	P18/P19	48	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:28	P19/P20	24	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:40	P20/P21	16	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:49	P21/P19	27	CK	850	400	428	10-15 MPH/58		
4/30/2008	15:00	P18/P21	13	CK	850	400	428	10-15 MPH/58		
4/30/2008	17:01	P1/P22	69	CK	850	400	428	10-15 MPH/58		
4/30/2008	17:05	P22/P23	72	VP	850	400	138	10-15 MPH/58		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAMP Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
4/30/2008	17:16	P26/P27	64	CK	850	400	428	10-15 MPH/58		
4/30/2008	17:20	P26/P25	40	VP	850	400	138	10-15 MPH/58		
4/30/2008	17:23	P24/P25	23	CK	850	400	428	10-15 MPH/58		
4/30/2008	17:26	P24/P23	24	VP	850	400	138	10-15 MPH/58		
4/30/2008	17:31	P23/P25	22	VP	850	400	138	10-15 MPH/58		
4/30/2008	17:36	P23/P26	27	VP	850	400	138	10-15 MPH/58		
5/1/2008	08:17	P27/P28	56	CK	850	450	428	10-15 MPH/68		
5/1/2008	08:30	P28/P29	59	CK	850	450	428	10-15 MPH/68		
5/1/2008	08:47	P29/P30	58	CK	850	450	428	10-15 MPH/68		
5/1/2008	08:57	P30/P31	62	CK	850	450	428	10-15 MPH/68		
5/1/2008	09:07	P31/P32	62	CK	850	450	428	10-15 MPH/68		
5/1/2008	09:17	P32/P33	63	CK	850	450	428	10-15 MPH/68		
5/1/2008	09:33	P33/P34	60	CK	850	450	428	10-15 MPH/68		
5/1/2008	09:44	P34/P35	34	CK	850	450	428	10-15 MPH/68		
5/1/2008	12:51	P36/P37	74	CK	850	450	428	10-15 MPH/68		
5/1/2008	13:10	P37/P38	75	CK	850	450	428	10-15 MPH/68		
5/1/2008	13:23	P38/P39	76	CK	850	450	428	10-15 MPH/68		
5/1/2008	13:40	P39/P40	75	VP	850	450	138	10-15 MPH/68		
5/1/2008	13:43	P40/P41	75	CK	850	450	428	10-15 MPH/68		
5/1/2008	13:55	P41/P42	76	VP	850	450	138	10-15 MPH/68		
5/1/2008	14:00	P42/P43	76	CK	850	450	428	10-15 MPH/68		
5/1/2008	14:20	P43/P44	75	VP	850	450	138	10-15 MPH/68		
5/1/2008	14:30	P44/P45	61	CK	850	450	428	10-15 MPH/68		
5/1/2008	14:35	P45/P46	20	VP	850	450	138	10-15 MPH/68		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAMWS Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/1/2008	14:57	P47/P46	22	CK	850	450	428	10-15 MPH/68		
5/1/2008	14:57	P47/P45	33	CK	850	450	428	10-15 MPH/68		
5/1/2008	16:18	P48/P21	42	CK	850	450	428	10-15 MPH/68		
5/1/2008	16:20	P48/P49	53	CK	850	450	428	10-15 MPH/68		
5/1/2008	16:18	P18/P48	16	CK	850	450	428	10-15 MPH/68		
5/1/2008	16:55	P49/P50	53	VP	850	450	138	10-15 MPH/68		
5/1/2008	17:03	P50/P51	53	CK	850	450	428	10-15 MPH/68		
5/1/2008	17:10	P51/P52	53	VP	850	450	138	10-15 MPH/68		
5/1/2008	17:20	P52/P53	53	CK	850	450	428	10-15 MPH/68		
5/1/2008	17:33	P53/P54	53	VP	850	450	138	10-15 MPH/68		
5/1/2008	17:50	P54/P55	53	CK	850	450	428	10-15 MPH/68		
5/1/2008	17:48	P55/P47	53	VP	850	450	138	10-15 MPH/68		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2			JOB #:	200754		MATERIAL TYPE:		
DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/2/2008	08:00	P56/P18	9	VP	850	450	138	10 MPH/65		
5/2/2008	08:04	P48/P56	12	VP	850	450	138	10 MPH/65		
5/2/2008	08:09	P49/P56	9	VP	850	450	138	10 MPH/65		
5/2/2008	08:13	P17/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:17	P16/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:21	P15/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:25	P14/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:29	P13/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:33	P12/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:37	P11/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:41	P10/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:45	P9/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:49	P8/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:53	P7/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:57	P6/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:01	P5/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:05	P4/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:09	P3/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:13	P2/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:17	P1/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:21	P22/P56	22	VP	850	450	138	10 MPH/65		

Electronic Filing: Received, Clerk's Office 2/04/2022

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/5/2008	08:47	P56/P57	405	CK	850	400	428	5-10 MPH / 59		
5/5/2008	09:30	P57/P58	108	VP	850	400	138	5-10 MPH / 59		
5/5/2008	09:44	P58/P59	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	09:46	P59/P57	297	VP	850	400	138	5-10 MPH / 59		
5/5/2008	10:48	P60/P61	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	10:33	P61/P59	311	CK	850	400	428	5-10 MPH / 59		
5/5/2008	11:16	P59/P60	94	CK	850	400	428	5-10 MPH / 59		
5/5/2008	11:25	P60/P62	202	VP	850	400	138	5-10 MPH / 59		
5/5/2008	11:40	P61/P62	101	VP	850	400	138	5-10 MPH / 59		
5/5/2008	11:35	P60/P58	108	CK	850	400	428	5-10 MPH / 59		
5/5/2008	13:10	P63/P61	102	VP	850	400	138	5-10 MPH / 59		
5/5/2008	13:11	P63/P64	102	CK	850	400	428	5-10 MPH / 59		
5/5/2008	13:26	P62/P64	303	CK	850	400	428	5-10 MPH / 59		
5/5/2008	14:00	P64/P66	67	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:15	P64/P65	115	VP	850	400	138	5-10 MPH / 59		
5/5/2008	13:45	P65/P66	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P65/P55	5	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P65/P54	13	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P64/P54	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P64/P53	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P62/P53	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P62/P52	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P60/P52	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P60/P51	12	VP	850	400	138	5-10 MPH / 59		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAVU Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/5/2008	14:40	P58/P51	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P58/P50	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P57/P50	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P57/P49	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P56/P49	10	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P56/P48	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	15:11	P67/P36	76	CK	850	400	428	5-10 MPH / 59		
5/5/2008	15:33	P67/P68	95	CK	850	400	428	5-10 MPH / 59		
5/5/2008	16:00	P68/P69	95	CK	850	400	428	5-10 MPH / 59		
5/5/2008	16:26	P69/P70	95	CK	850	400	428	5-10 MPH / 59		
5/5/2008	16:26	P66/P36	15	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P66/P37	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P66/P38	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P66/P39	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P40	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P41	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P42	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P43	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P44	15	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:40	P70/P71	95	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:40	P71/P72	96	CK	850	400	428	5-10 MPH / 59		
5/5/2008	16:58	P72/P73	96	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:59	P73/P74	97	CK	850	400	428	5-10 MPH / 59		
5/5/2008	17:05	P74/P75	97	VP	850	400	138	5-10 MPH / 59		

Electronic Filing: Received, Clerk's Office 2/04/2022

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/6/2008	07:57	P75/P76	92	CK	850	400	428	5-10 MPH / 59		
5/6/2008	08:18	P76/P77	71	VP	850	400	138	5-10 MPH / 59		
5/6/2008	08:22	P77/P78	32	CK	850	400	428	5-10 MPH / 59		
5/6/2008	08:40	P78/P35	24	CK	850	400	428	5-10 MPH / 59		
5/6/2008	08:50	P77/P34	27	CK	850	400	428	5-10 MPH / 59		
5/6/2008	09:04	P77/P33	6	CK	850	400	428	5-10 MPH / 59		
5/6/2008	09:10	P76/P33	9	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P67/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P68/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P69/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P70/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P71/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P72/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P73/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P74/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P75/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P76/P64	22	CK	850	400	428	5-10 MPH / 59		

Electronic Filing: Received, Clerk's Office 2/04/2022

Submittal #24

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
4/30/2008	72	P1/P2	ss	14:11	14:16	30	30	P	P	
4/30/2008	75	P2/P3	ss	14:12	14:17	30	28	P	P	
4/30/2008	76	P3/P4	ss	14:18	14:23	30	29	P	P	
4/30/2008	73	P4/P5	ss	14:19	14:24	30	28	P	P	
4/30/2008	65	P5/P6	ss	14:25	14:30	30	28	P	P	
4/30/2008	9	P5/P6	ss	14:24	14:29	30	28	P	P	
4/30/2008	73	P6/P7	ss	14:26	14:31	30	30	P	P	
4/30/2008	65	P7/P8	ss	14:28	14:33	30	30	P	P	
4/30/2008	9	P8/P9	ss	14:34	14:39	30	29	P	P	
4/30/2008	73	P9/P10	ss	14:40	14:45	30	30	P	P	
4/30/2008	71	P10/P11	ss	14:41	14:46	30	29	P	P	
4/30/2008	71	P11/P12	ss	14:43	14:48	30	30	P	P	
4/30/2008	72	P12/P13	ss	15:08	15:13	30	28	P	P	
4/30/2008	75	P12/P13	ss	15:09	15:14	30	29	P	P	
4/30/2008	75	P21/P20	ss	16:20	16:25	30	30	P	P	
4/30/2008	23	P21/P19	ss	16:21	16:26	30	28	P	P	
4/30/2008	50	P21/P18	ss	16:22	16:27	30	29	P	P	
4/30/2008	24	P19/P20	ss	16:33	16:38	30	30	P	P	
4/30/2008	48	P19/P18	ss	16:34	16:39	30	28	P	P	
4/30/2008	10	P18/P17	ss	16:36	16:41	30	30	P	P	
4/30/2008	62	P18/P17	ss	16:44	16:49	30	30	P	P	
4/30/2008	75	P17/P16	ss	16:50	16:55	30	29	P	P	
4/30/2008	75	P16/P15	ss	16:52	16:57	30	20	P	P	
4/30/2008	74	P15/P14	ss	16:54	16:59	30	28	P	P	
4/30/2008	74	P14/P13	ss	17:04	17:09	30	30	P	P	
5/1/2008	72	P1/P22	ss	07:40	7:45	30	30	P	P	
5/1/2008	72	P22/P23	ss	07:41	7:46	30	29	P	P	
5/1/2008	22	P23/P24	ss	07:42	7:47	30	28	P	P	
5/1/2008	24	P24/P25	ss	07:48	7:53	30	29	P	P	
5/1/2008	40	P25/P26	ss	07:49	7:54	30	30	P	P	
5/1/2008	65	P26/P27	ss	07:51	7:56	30	28	P	P	
5/1/2008	37	P26/P23	ss	08:00	8:05	30	29	P	P	
5/1/2008	22	P25/P23	ss	08:08	8:13	30	29	P	P	

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
5/1/2008	56	P27/P28	ss	8:46	8:51	30	30	P	P	
5/1/2008	59	P28/P29	ss	08:47	8:52	30	30	P	P	
5/1/2008	58	P29/P30	ss	09:06	9:11	30	28	P	P	
5/1/2008	62	P30/P31	ss	09:10	9:15	30	30	P	P	
5/1/2008	62	P31/P32	ss	09:48	9:53	30	30	P	P	
5/1/2008	63	P32/P33	ss	09:49	9:54	30	28	P	P	
5/1/2008	60	P33/P34	ss	10:01	10:06	30	30	P	P	
5/1/2008	34	P34/P35	ss	10:03	10:08	30	29	P	P	
5/1/2008	74	P36/P37	ss	13:22	13:27	30	28	P	P	
5/1/2008	75	P37/P38	ss	13:28	13:33	30	30	P	P	
5/1/2008	76	P38/P39	ss	13:45	13:50	30	29	P	P	
5/1/2008	75	P39/P40	ss	14:00	14:05	30	30	P	P	
5/1/2008	75	P40/P41	ss	14:04	14:09	30	28	P	P	
5/1/2008	76	P41/P42	ss	14:20	14:25	30	30	P	P	
5/1/2008	76	P42/P43	ss	14:24	14:29	30	30	P	P	
5/1/2008	75	P43/P44	ss	15:00	15:05	30	29	P	P	
5/1/2008	61	P44/P45	ss	15:04	15:09	30	30	P	P	
5/1/2008	20	P45/P46	ss	15:15	15:20	30	30	P	P	
5/1/2008	22	P46/P47	ss	16:02	16:07	30	28	P	P	
5/1/2008	33	P47/P45	ss	16:04	16:09	30	30	P	P	
5/1/2008	42	P21/P48	ss	16:10	16:15	30	3O	P	P	
5/1/2008	16	P18/P48	ss	16:20	16:25	30	28	P	P	
5/2/2008	53	P48/P49	ss	07:45	7:50	30	29	P	P	
5/2/2008	53	P49/P50	ss	07:47	7:52	30	30	P	P	
5/2/2008	53	P50/P51	ss	07:54	7:59	30	30	P	P	
5/2/2008	53	P51/P52	ss	07:55	8:00	30	29	P	P	
5/2/2008	53	P52/P53	ss	08:10	8:15	30	30	P	P	
5/2/2008	53	P53/P54	ss	08:11	8:16	30	29	P	P	
5/2/2008	53	P54/P55	ss	08:18	8:23	30	28	P	P	
5/2/2008	53	P55/P47	ss	08:31	8:36	30	30	P	P	

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
5/5/2008	9	P18/P56	SS	8:01	8:06	30	30	P	P	
5/5/2008	22	P17/P56	SS	08:02	8:07	30	28	P	P	
5/5/2008	22	P16/P56	SS	08:09	8:14	30	30	P	P	
5/5/2008	22	P15/P56	SS	08:11	8:16	30	29	P	P	
5/5/2008	22	P14/P56	SS	08:13	8:18	30	28	P	P	
5/5/2008	22	P13/P56	SS	08:19	8:24	30	30	P	P	
5/5/2008	22	P12/P56	SS	08:20	8:25	30	29	P	P	
5/5/2008	22	P11/P56	SS	08:26	8:31	30	29	P	P	
5/5/2008	22	P10/P56	SS	08:28	8:33	30	30	P	P	
5/5/2008	22	P9/P56	SS	08:34	8:39	30	28	P	P	
5/5/2008	22	P8/P56	SS	08:35	8:40	30	28	P	P	
5/5/2008	22	P7/P56	SS	08:41	8:46	30	30	P	P	
5/5/2008	22	P6/P56	SS	08:42	8:47	30	30	P	P	
5/5/2008	22	P5/P56	SS	08:48	8:53	30	30	P	P	
5/5/2008	22	P4/P56	SS	08:47	8:52	30	29	P	P	
5/5/2008	22	P3/P56	SS	08:58	9:03	30	30	P	P	
5/5/2008	22	P2/P56	SS	08:59	9:54	30	29	P	P	
5/5/2008	22	P1/P56	SS	09:10	9:15	30	30	P	P	
5/5/2008	22	P22/P56	SS	09:11	9:16	30	28	P	P	
5/5/2008	22	P48/P56	SS	09:20	9:25	30	28	P	P	
5/5/2008	22	P49/P56	SS	09:21	9:26	30	30	P	P	

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
5/5/2008	405	P56/P57	SS	10:48	10:53	30	28	P	P	
5/5/2008	108	P57/P58	SS	10:49	10:54	30	30	P	P	
5/5/2008	22	P58/P59	SS	14:02	14:07	30	30	P	P	
5/5/2008	297	P59/P57	SS	16:20	16:25	30	29	P	P	
5/5/2008	108	P58/P60	SS	16:21	16:26	30	30	P	P	
5/5/2008	94	P60/P59	SS	16:27	16:32	30	30	P	P	
5/5/2008	22	P60/P61	SS	16:28	16:33	30	29	P	P	
5/5/2008	203	P61/P59	SS	16:29	16:34	30	28	P	P	
5/5/2008	202	P60/P62	SS	16:35	16:40	30	30	P	P	
5/5/2008	101	P61/P62	SS	16:36	16:41	30	29	P	P	
5/5/2008	102	P61/P63	SS	16:42	16:47	30	30	P	P	
5/5/2008	22	P62/P63	SS	16:43	16:48	30	30	P	P	
5/5/2008	303	P64/P62	SS	16:49	16:54	30	29	P	P	
5/5/2008	102	P64/P63	SS	16:50	16:55	30	30	P	P	
5/5/2008	115	P64/P65	SS	16:56	17:01	30	29	P	P	
5/5/2008	67	P66/P64	SS	16:57	17:02	30	30	P	P	
5/5/2008	15	P66/P36	SS	16:58	17:53	30	28	P	P	
5/5/2008	22	P66/P37	SS	17:10	17:15	30	30	P	P	
5/5/2008	22	P66/P38	SS	17:11	17:16	30	29	P	P	
5/5/2008	9	P66/P39	SS	17:12	17:17	30	30	P	P	
5/5/2008	12	P65/P40	SS	17:13	17:18	30	29	P	P	
5/5/2008	22	P65/P41	SS	17:18	17:23	30	28	P	P	
5/5/2008	22	P65/P42	SS	17:25	17:30	30	30	P	P	
5/5/2008	22	P65/P43	SS	17:26	17:31	30	30	P	P	
5/5/2008	15	P65/P44	SS	17:33	17:38	30	29	P	P	
5/5/2008	95	P67/P68	SS	17:34	17:39	30	30	P	P	
5/5/2008	95	P68/P69	SS	17:41	17:46	30	28	P	P	
5/5/2008	96	P69/P70	SS	17:42	17:47	30	30	P	P	
5/5/2008	96	P70/P71	SS	17:49	17:54	30	28	P	P	
5/5/2008	96	P71/P72	SS	17:50	17:55	30	30	P	P	
5/5/2008	96	P72/P73	SS	17:56	18:01	30	29	P	P	
5/5/2008	96	P73/P74	SS	17:58	18:53	30	30	P	P	
5/5/2008	97	P74/P75	SS	18:10	18:15	30	29	P	P	

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
5/6/2008	22	P64/P75	SS	9:08	9:13	30	30	P	P	
5/6/2008	22	P64/P74	SS	09:09	9:14	30	28	P	P	
5/6/2008	22	P64/P73	SS	09:15	9:20	30	29	P	P	
5/6/2008	22	P64/P72	SS	09:16	9:21	30	30	P	P	
5/6/2008	22	P64/P71	SS	09:17	9:22	30	30	P	P	
5/6/2008	22	P64/P70	SS	09:23	9:28	30	29	P	P	
5/6/2008	22	P64/P69	SS	09:24	9:29	30	28	P	P	
5/6/2008	22	P64/P68	SS	09:25	9:30	30	30	P	P	
5/6/2008	22	P64/P67	SS	09:31	9:36	30	30	P	P	
5/6/2008	13	P56/P27	SS	09:32	9:37	30	29	P	P	
5/6/2008	8	P57/P27	SS	09:33	9:38	30	30	P	P	
5/6/2008	12	P57/P28	SS	09:39	9:44	30	29	P	P	
5/6/2008	9	P59/P28	SS	09:47	9:52	30	30	P	P	
5/6/2008	12	P59/P29	SS	09:48	9:53	30	28	P	P	
5/6/2008	9	P61/P29	SS	09:56	10:01	30	30	P	P	
5/6/2008	12	P61/P30	SS	09:57	10:02	30	29	P	P	
5/6/2008	9	P63/P30	SS	10:08	10:13	30	30	P	P	
5/6/2008	12	P63/P31	SS	10:11	10:16	30	28	P	P	
5/6/2008	9	P64/P31	SS	10:12	10:17	30	30	P	P	
5/6/2008	12	P64/P32	SS	10:25	10:30	30	30	P	P	
5/6/2008	95	P67/P64	SS	10:35	10:40	30	30	P	P	
5/6/2008	95	P68/P64	SS	10:36	10:41	30	28	P	P	
5/6/2008	96	P69/P64	SS	10:42	10:47	30	29	P	P	
5/6/2008	95	P70/P64	SS	10:43	10:48	30	30	P	P	
5/6/2008	96	P71/P64	SS	10:45	10:50	30	29	P	P	
5/6/2008	95	P72/P64	SS	10:53	10:58	30	30	P	P	
5/6/2008	95	P73/P64	SS	10:55	11:00	30	28	P	P	
5/6/2008	96	P74/P64	SS	11:12	11:17	30	30	P	P	
5/6/2008	96	P75/P64	SS	11:15	11:20	30	30	P	P	
5/6/2008	96	P76/P74	SS	11:20	11:25	30	30	P	P	
5/6/2008	92	P75/P76	SS	11:21	11:26	30	30	P	P	
5/6/2008	71	P76/P77	SS	11:27	11:32	30	28	P	P	
5/6/2008	32	P77/P78	SS	11:28	11:33	30	29	P	P	
5/6/2008	24	P78/P35	SS	11:29	11:34	30	30	P	P	

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
5/6/2008	27	P77/P34	SS	11:35	11:40	30	30	P	P	
5/6/2008	6	P77/P33	SS	11:41	11:46	30	29	P	P	
5/6/2008	9	P76/P33	SS	11:43	11:48	30	28	P	P	

Electronic Filing: Received, Clerk's Office 2/04/2022

Submitted '24

DESTRUCTIVE TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB NUMBER:	200754	MATERIAL TYPE:	60 Mil. HDPE

TENSIOMETER ID:	T-062/06	EXTRUSION	FUSION	FIELD WELD VALUES											
SAMPLE I.D. (DT#)	SEAM NO.	QC INT	MACH NO.	SEAMER INT	BARREL/ PREHEAT	WEDGE/ SET SPEED	PEEL (PPI)					SHEAR (PPI)			P/F	LOCATION OF DESTRUCTIVE TEST
DS1	P13/P14	ss	138	vp	B:	W: 850	146	151	138			165	162		P	NEOS 0'->14'
					P:	S: 400	140	139	137							
DS2	P14/P15	ss	428	ck	B:	W: 850	133	139	134			166	169		P	NEOS 0'->33'
					P:	S: 400	136	140	153							
DS3	P27/P28	ss	428	ck	B:	W: 850	138	135	131			169	168		P	WEOS 0'->10'
					P:	S: 450	140	134	137							
DS4	P37/P38	ss	428	ck	B:	W: 850	139	151	140			169	164		P	SEOS 0'->25'
					P:	S: 450	143	138	145							
DS5	P43/P44	ss	138	vp	B:	W: 850	132	136	138			171	168		P	SEOS 0'->20'
					P:	S: 450	142	144	135							
DS6	P50/P51	ss	428	ck	B:	W: 850	146	139	142			166	167		P	EEOS 0'->8'
					P:	S: 450	154	138	151							
DS7	P7/P56	ss	138	vp	B:	W: 850	138	137	134			180	165		P	WEOS 0'->10'
					P:	S: 450	132	139	132							
DS8	P56/P57	ss	428	ck	B:	W: 850	139	135	137			167	183		P	EEOS 0'->11'
					P:	S: 450	142	138	146							
DS9	P57/P59	ss	138	vp	B:	W: 850	138	138	132			165	174		P	EEOS 0'->102'
					P:	S: 450	136	132	143							
DS10	P60/P58	ss	428	ck	B:	W: 850	143	132	133			177	173		P	EEOS 0'->24'
					P:	S: 450	139	139	147							
DS11	P63/P61	ss	138	vp	B:	W: 850	133	135	132			171	179		P	EEOS 0'->5'
					P:	S: 450	137	133	136							
DS12	P63/P64	ss	428	ck	B:	W: 850	139	132	143			177	175		P	EEOS 0'->25'
					P:	S: 450	135	138	144							
DS13	P65/P43	ss	138	vp	B:	W: 850	143	146	137			172	178		P	EEOS 0'->10'
					P:	S: 450	138	133	139							

Electronic Filing: Received, Clerk's Office 2/04/2022

Submitted #21

CAAW Systems

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P17/P56		R1	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P16/P56		R2	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P15/P56		R3	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P14/P56		R4	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P13/P56		R5	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P12/P56		R6	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P11/P56		R7	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P10/P56		R8	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P9/P56		R9	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P8/P56		R10	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P7/P56		R11	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P6/P56		R12	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P5/P56		R13	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P4/P56		R14	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P3/P56		R15	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P2/P56		R16	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P1/P56		R17	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P22/P56		R18	VK	175	5/6/2008	CK	patch 3x3	5/6/2008	NEOS 0'	P
P65/P55		R19	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P65/P54		R20	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P64/P54		R21	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P64/P53		R22	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P62/P53		R23	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P62/P52		R24	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P60/P52		R25	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P

Electronic Filing: Received, Clerk's Office 2/04/2022

CQA Systems

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:		Midwest Gen Station - Pond #2			JOB #: 200754			MATERIAL TYPE:		
FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P60/P51		R26	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P58/P51		R27	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P58/P50		R28	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P57/P50		R29	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P57/P49		R30	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P56/P49		R31	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P56/P48		R32	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P66/P36		R33	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P66/P37		R34	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P66/P38		R35	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P66/P39		R36	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P40		R37	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P41		R38	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P42		R39	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P43		R40	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P44		R41	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P67/P64		R42	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	SEOS 0'	P
P68/P64		R43	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P69/P64		R44	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P70/P64		R45	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P71/P64		R46	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	SEOS 0'	P
P72/P64		R47	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P73/P64		R48	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P74/P64		R49	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P75/P64		R50	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	SEOS 0'	P

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GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P76/P64		R51	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	SEOS 0'	P
P58/P57		R52	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P60/P58		R53	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P60/P59		R54	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P60/P62		R55	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P61/P62		R56	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P64/P62		R57	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P65/P64		R58	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P26/P25		R59	VK	175	5/6/2008	CK	ext weld	5/6/2008	anchor	P
P14/P13		R60	VK	175	5/6/2008	CK	bead	5/6/2008	anchor	P
P20/P21		R61	VK	175	5/6/2008	CK	patch 6x3	5/6/2008	anchor	P
P48/P21		R62	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	WEOS 0'	P
P18/P19		R63	VK	175	5/6/2008	CK	patch 1x1	5/6/2008	NEOS 0'	P
P50/P51		R64	VK	175	5/6/2008	CK	ext weld	5/6/2008	WEOS 0'	P
P51/P52		R65	VK	175	5/6/2008	CK	patch 1x1	5/6/2008	WEOS 0'	P
P55/P54		R66	VK	175	5/6/2008	CK	patch 1x1	5/6/2008	WEOS 0'	P
P47/P55		R67	VP	88	5/6/2008	CK	patch 6x8	5/6/2008	WEOS 0'	P
P46/P45		R68	VP	88	5/6/2008	CK	patch 1x1	5/6/2008	SEOS 0'	P
P45/P44		R69	VP	88	5/6/2008	CK	patch 3x3	5/6/2008	SEOS 0'	P
P42/P43		R70	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'->5'	P
P40/P41		R71	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'->27'	P
P35/P34		R72	VP	88	5/6/2008	CK	patch 3x3	5/6/2008	WEOS 0'	P
P34/P33		R73	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	WEOS 0'	P
P33/P32		R74	VK	175	5/6/2008	CK	patch 10x10	5/6/2008	EEOS 0'->5'	P
	P32	R75	VK	175	5/6/2008	CK	patch 1x1	5/6/2008	EEOP 0'->10'	P

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CAAW Systems

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
	P28	R76	VK	175	5/6/2008	CK	bead	5/6/2008	EEOP 0'->10'	P
	P28	R77	VK	175	5/6/2008	CK	bead	5/6/2008	EEOP 0'->12'	P
P27/P28		R78	VK	175	5/6/2008	CK	patch 6x12	5/6/2008	EEOS 0'->15'	P
P13/P14		R79	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	NEOS 0'->14'(DS1)	P
P14/P15		R80	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	NEOS 0'->33'(DS2)	P
P27/P28		R81	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	WEOS 0'->10'(DS3)	P
P37/P38		R82	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	SEOS 0'->25'(DS4)	P
P43/P44		R83	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	SEOS 0'->20'(DS5)	P
P50/P51		R84	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->8'(DS6)	P
P7/P56		R85	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	WEOS 0'->10'(DS7)	P
P56/P57		R86	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->11'(DS8)	P
P57/P59		R87	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->102'(DS9)	P
P60/P58		R88	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->24'(DS10)	P
P63/P61		R89	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->5'(DS11)	P
P63/P64		R90	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->25'(DS12)	P
P65/P43		R91	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->10'(DS13)	P
	P77	R92	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P69	R93	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P68	R94	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P39	R95	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P44	R96	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P22	R97	VK	175	5/6/2008	CK	patch 3x3; pipe boot		NEOP	P
	P5	R98	VK	175	5/6/2008	CK	patch 3x3; pipe boot		NEOP	P
	P11	R99	VK	175	5/6/2008	CK	patch 3x3; pipe boot		NEOP	P
	P18	R100	VK	175	5/6/2008	CK	patch 3x3; pipe boot		NEOP	P

Electronic Filing: Received, Clerk's Office 2/04/2022

ATTACHMENT A5

GEOMEMBRANE INSTALLER'S SUBGRADE ACCEPTANCE (IMPOUNDMENT #1 AND #2)

Electronic Filing: Received, Clerk's Office 2/04/2022

CERTIFICATE OF ACCEPTANCE OF SUBGRADE SURFACE PREPARATION FOR GEOMEMBRANE INSTALLATION

PROJECT NAME: Midwest Generation Joliet Station Ash Pond 1

LOCATION: Joliet, IL

JOB NUMBER: 200754 CLIENT: Brieser Construction Company

AREA ACCEPTED: Entire area to be lined under panels P1 to P67

COMMENTS:

INSTALLER: The undersigned authorized representative of CAAW Systems certifies that he or she has visually inspected the subgrade surface of the area described above and has found the surface to be acceptable for installation of the geosynthetic materials.

CAAW Systems shall be responsible for the integrity of finished geosynthetic material until completion of the installation or demobilization from site.

This certification is based on observations of the subgrade surface conditions only. CAAW Systems has made no subterrain inspections or tests and makes no representations or warranties as to the conditions that may exist below the surface of the subgrade.

CERTIFICATE APPROVED BY:

Installers Acceptance		Inspectors Acceptance	
Company:	Clean Air And Water Systems, LLC	Company:	Brieser Construction Company
By:	Thong Ingels	By:	Mike Schmidt
Title:	Superintendent	Title:	Superintendent
Date:	10-6-08	Date:	10-6-08

Electronic Filing: Received, Clerk's Office 2/04/2022 Submittal #25

CERTIFICATE OF ACCEPTANCE OF SUBGRADE SURFACE PREPARATION FOR GEOMEMBRANE INSTALLATION

PROJECT NAME: Midwest Generation Joliet Station Ash Pond 2

LOCATION: Joliet, IL

JOB NUMBER: 200754 CLIENT: Brieser Construction Company

AREA ACCEPTED: Entire area to be lined under panels P1 to P78

COMMENTS:

INSTALLER: The undersigned authorized representative of CAAW Systems certifies that he or she has visually inspected the subgrade surface of the area described above and has found the surface to be acceptable for installation of the geosynthetic materials.

CAAW Systems shall be responsible for the integrity of finished geosynthetic material until completion of the installation or demobilization from site.

This certification is based on observations of the subgrade surface conditions only. CAAW Systems has made no subterrain inspections or tests and makes no representations or warranties as to the conditions that may exist below the surface of the subgrade.

CERTIFICATE APPROVED BY:

Installers Acceptance		Inspectors Acceptance	
Company:	Clean Air And Water Systems, LLC	Company:	Brieser Construction Company
By:	Thong Ingels	By:	Mike Schmidt
Title:	Superintendent	Title:	Superintendent
Date:	5-6-08	Date:	5-6-08

Electronic Filing: Received, Clerk's Office 2/04/2022

ATTACHMENT A6

GEOMEMBRANE INSTALLATION CERTIFICATE (IMPOUNDMENT #1 AND #2)

Electronic Filing: Received, Clerk's Office 2/04/2022

November 17, 2008

Tedd Mills
Brieser Construction Company
24101 S. Municipal Drive
Channahon, IL 60410

RE: Midwest Generation Joliet Station – Installation Certification for Ash Pond 1

To Whom It May Concern,

This letter shall act as a certification to the geomembrane and geotextile installation at the above referenced project. The HDPE geomembrane and geotextiles installed in Ash Pond 1 were installed in accordance with the project specifications.

Sincerely,

Brian McKeown
Member
Clean Air And Water Systems, LLC

Corporate Office
123 Elm Street
P.O. Box 337
Dousman, WI. 53118-0337
(262) 965-4366 Fax (262) 965-4369

www.caawsystem.com

Regional Office
2727 W. 2nd St., Ste 235
Hastings, NE 68901
(402) 463-0857 Fax (402) 463-0858

July 10, 2008

Tedd Mills
Brieser Construction Company
24101 S. Municipal Drive
Channahon, IL 60410

RE: Midwest Generation Joliet Station – Installation Certification for Ash Pond 2

To Whom It May Concern,

This letter shall act as a certification to the geomembrane and geotextile installation at the above referenced project. The HDPE geomembrane and geotextiles installed in Ash Pond 2 were installed in accordance with the project specifications.

Sincerely,

Brian McKeown
Member
Clean Air And Water Systems, LLC

Corporate Office
123 Elm Street
P.O. Box 337
Dousman, WI. 53118-0337
(262) 965-4366 Fax (262) 965-4369

www.caawsystem.com

Regional Office
2727 W. 2nd St., Ste 235
Hastings, NE 68901
(402) 463-0857 Fax (402) 463-0858

Electronic Filing: Received, Clerk's Office 2/04/2022

ATTACHMENT A7

GEOMEMBRANE WARRANTIES

Electronic Filing: Received, Clerk's Office 2/04/2022

INSTALLATION WARRANTY- GEOMEMBRANE LINERS

PROJECT NAME: Midwest Generation – Joliet Station

Subject to the terms and conditions set forth below, Clean Air And Water Systems, LLC warrants to Purchaser, Brieser Construction, that the 60 mil HDPE white liner installed at the Midwest Generation – Joliet Station, was installed by Clean Air And Water Systems, LLC, in accordance with specifications in a good and workmanlike manner and that the installation of the liner is free from defects in workmanship for a period of two (2) years from the date upon which the material was installed.

This warranty covers only defects in workmanship occurring during the installation of the liner. This warranty does not cover ay damage to, or defects in the liner found to have been a result of misuse, abuse or conditions existing after it was installed, including, but not limited to, rough handling; malicious mischief; vandalism; sabotage; fire; acts of God; acts of the public enemy; acts of war, public rebellion, severe weather conditions of all types; damage due to ice; excessive stress from any source; floating debris; damage due to machinery; foreign objects or animals. Nor does this warranty cover any defects which are found to have been a result of improper or defective design or engineering unless the design or engineering was performed by Clean Air And Water Systems, LLC. In the event circumstances are found to exist which purchaser believes may give rise to a claim under this warranty, the following procedure shall be followed:

a) Purchaser shall give Clean Air And Water Systems, LLC written notice of the facts and circumstances of said claim within ten (10) days of becoming aware of said facts and circumstances. Said notice shall be by registered or certified mail, return receipt requested, postage prepaid, addressed to Member, Clean Air And Water Systems, LLC, 123 Elm Street, PO Box 337, Dousman, Wisconsin 53118. The words "WARRANTY CLAIM" shall be clearly marked on the face of envelope in the lower right hand corner. Said notice shall contain, at a minimum, the name and address of the owner, the name and address of the installation, the name and address of the installer, the date upon which the material was purchased and the facts known to Purchaser upon which the claim is based. Failure to strictly comply with all the requirements of this paragraph shall void this warranty.

b) Within twenty days after receipt of the notice described in paragraph a., above, Clean Air And Water Systems, LLC shall notify Purchaser either that it will send a representative to inspect the allegedly defective liner or that it does not wish to do so. Purchaser shall pay the expenses incurred by Clean Air And Water Systems, LLC in making the inspection, including current per diem rates for personnel involved in making the inspection, in the event Clean Air And Water Systems, LLC determines that the claim is not covered by this warranty.

c) Purchaser SHALL NOT REPAIR, REPLACE, REMOVE, ALTER OR DISTURB ANY LINER, NOR SHALL Purchaser ALLOW ANYONE ELSE TO REPAIR, REPLACE, REMOVE, ALTER, OR DISTURB ANY LINER PRIOR TO SUCH INSPECTION OR RECEIPT OF CLEAN AIR AND WATER SYSTEMS, LLC.'S NOTICE THAT IT ELECTS NOT TO INSPECT. A FAILURE TO STRICTLY COMPLY WITH THIS PARAGRAPH SHALL VOID THIS WARRANTY OR MAY LEAD TO A DETERMINATION THAT THE ALLEGED DEFECTS ARE NOT WITHIN THE SCOPE OF THIS WARRANTY.

d) If Clean Air And Water Systems, LLC determines that the alleged defects are covered by this warranty, Clean Air And Water Systems, LLC shall, in its sole discretion, either repair the defective liner or provide Purchaser with replacement liner. THE REMEDIES PROVIDED HEREIN ARE THE EXCLUSIVE REMEDIES AVAILABLE UNDER THIS WARRANTY. Any determination as to whether a particular

defect is covered by this warranty will be made by Clean Air And Water Systems, LLC in its sole and complete discretion.

e) Purchaser agrees that it shall provide Clean Air And Water Systems, LLC with clean, dry and unobstructed access to the liner in order for Clean Air And Water Systems, LLC to perform the inspections and warranty work which may be required pursuant to this warranty.

THE REMEDIES PROVIDED TO Purchaser HEREIN ARE THE EXCLUSIVE REMEDIES AVAILABLE UNDER THIS WARRANTY AND ARE INTENDED FOR THE SOLE BENEFIT OF Purchaser. NEITHER THIS WARRANTY NOR ANY RIGHTS HEREUNDER SHALL BE ASSIGNABLE. CLEAN AIR AND WATER SYSTEMS, LLC SHALL HAVE NO LIABILITY UNDER THIS WARRANTY TO THIRD PARTIES OR STRANGERS TO THIS AGREEMENT. THE WARRANTY SET FORTH ABOVE IS THE ONLY WARRANTY APPLICABLE TO THE LINER AND ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL CLEAN AIR AND WATER SYSTEMS, LLC BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL OR CONSEQUENTIAL DAMAGES FOR, RESULTING FROM, OR IN CONNECTION WITH, ANY LOSS RESULTING FROM THE USE OF THE LINER. IN THE EVENT THE EXCLUSIVE REMEDY PROVIDED HEREIN FAILS IN ITS ESSENTIAL PURPOSE, AND IN THAT EVENT ONLY, Purchaser SHALL BE ENTITLED TO RETURN OF THE PURCHASE PRICE FOR SO MUCH OF THE MATERIAL AS CLEAN AIR AND WATER SYSTEMS, LLC DETERMINES IN ITS SOLE DISCRETION, TO HAVE VIOLATED THE WARRANTY PROVIDED HEREIN. EXCEPT FOR THE WARRANTY SET FORTH ABOVE, NO REPRESENTATION OR WARRANTY MADE BY ANY SALES OR OTHER REPRESENTATIVE CLEAN AIR AND WATER SYSTEMS, LLC, OR ANY OTHER PERSON, CONCERNING THE LINER SHALL BE BINDING UPON CLEAN AIR AND WATER SYSTEMS, LLC.

Any waiver of the terms and conditions of this warranty shall be in writing signed by CLEAN AIR AND WATER SYSTEMS, LLC the failure to insist upon strict compliance with any of the terms and conditions contained herein shall not act as a waiver of strict compliance with all of the remaining terms and conditions or this warranty and shall not operate as a waiver as to any of the terms and conditions of this warranty as to future claims under this warranty.

CLEAN AIR AND WATER SYSTEMS, LLC

BY: Brian McKeown, member

Brian K. McKeown/ Member

I have read and agree to be bound by the terms and conditions of the foregoing warranty.

By: Todd McC

Title: Vice President

Company: Bricar Construction

Date: 12-8-08

Electronic Filing: Received, Clerk's Office 2/04/2022

PRO RATA LIMITED MATERIAL WARRANTY
FOR GSE LINING TECHNOLOGY, INC.
Geomembrane Products
(U.S.A.)

Date:	11/19/2008	Warranty No.:	**524244**
Purchaser Name:	Midwest Generation	Project No.:	524244
Address:	1800 Channahon Rd.	Effective Date:	10/6/2008
City, State:	Joliet, IL 60436	Project Name:	Midwest Generation
Product Type/Description:	GSE HDT Geomembrane	Project Address:	1800 Channahon Rd., Joliet, IL 60436

GSE Lining Technology, Inc. ("GSE") warrants each GSE product described above to be free from material manufacturing defects (as described by the contract's material specifications) and to be able to withstand normal weathering for a period of **two (2) years** from the date of sale. This limited warranty does not include damages or defects in the GSE product resulting from acts of God, casualty or catastrophe, including but not limited to: earthquakes, floods, piercing hail, tornadoes or force majeure. The term "normal use" does not include, among other things, the exposure of GSE's product to harmful chemicals, abuse by machinery, equipment or people; improper site preparation or placement of cover materials; excessive pressures or stresses from any source. This warranty is intended for commercial use only and is not in effect for the consumer as defined in the Magnuson-Moss Warranty Act.

Should defects or premature loss of use within the scope of this warranty occur, GSE will, at its option, repair or replace the GSE product on a pro rata basis at the current price in such manner as to charge the Purchaser only for that portion of the warranted life which has elapsed since the purchase of the product. GSE shall have the right to inspect and determine the cause of the alleged defect in the product and to take appropriate steps to repair or replace the product if a defect exists that is covered under this warranty.

Any claim for any alleged breach of this warranty must be made in writing, by certified mail or courier, to GSE Lining Technology Co., 19103 Gundle Road, Houston, TX 77073, with the words "Warranty Claim" clearly marked on the face of the envelope, within ten (10) days of Purchaser becoming aware of the alleged defect. Should the required notice not be given, the defect and all warranties are waived by the Purchaser, and Purchaser shall not have rights under this warranty. GSE shall not be obligated to perform any inspection or obligated to perform any repair or replacement under this warranty until the area is made available free from all obstructions, water, dirt, sludge, residuals and liquids of any kind. If after inspection it is determined that there is no claim under this warranty, Purchaser shall reimburse GSE for its costs associated with the site inspection.

In the event the exclusive remedy provided herein fails in its essential purpose, and in that event only, the Purchaser shall be entitled to a return of the purchase price for so much of the product as GSE determines to have violated the warranty provided herein. GSE shall not be liable for direct, indirect, special, consequential or incidental damages resulting from a breach of this warranty including, but not limited to: damages for loss of production, lost profits, personal injury or property damage. GSE shall not be obligated to reimburse Purchaser for any repairs, replacement, modifications or alterations made by Purchaser to GSE's product, unless GSE specifically authorized, in writing, said repairs, replacements, modifications or alterations in advance. GSE liability under this warranty shall in no event exceed the replacement cost of the product sold to the Purchaser for the particular installation in which it failed.

GSE neither assumes nor authorizes any person other than an officer of GSE to assume for it any other or additional liability in connection with the GSE product made on the basis of the Limited Warranty. **GSE MAKES NO WARRANTY OF ANY KIND OTHER THAN THAT GIVEN HEREIN AND HEREBY DISCLAIMS ALL WARRANTIES, INCLUDING BOTH EXPRESS OR IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, AND BY ACCEPTING DELIVERY OF THE PRODUCT, PURCHASER WAIVES ALL OTHER POSSIBLE WARRANTIES. GSE's WARRANTY BECOMES AN OBLIGATION OF GSE TO PERFORM UNDER THE WARRANTY ONLY UPON RECEIPT OF FINAL PAYMENT.**

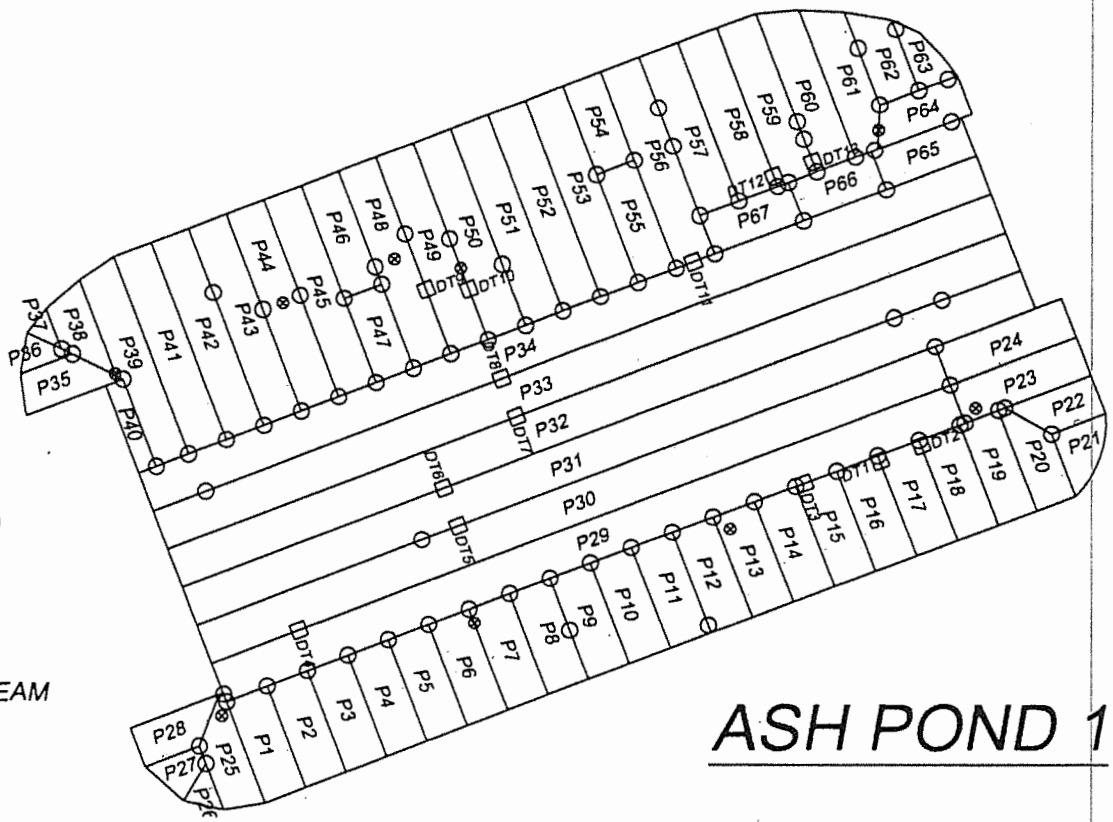
This warranty is extended to the Purchaser and is non-transferable and non-assignable, i.e. there are no third-party beneficiaries to this warranty.

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ATTACHMENT A8

GEOMEMBRANE AS-BUILT PANEL LAYOUT (IMPOUNDMENT #1 AND #2)

NORTH



ASH POND 1

LEGEND

○	PATCH / REPAIR WELD
□DT#	DESTRUCTIVE TEST
P#	PANEL NUMBER
⊗	PIPE BOOT
———	PANEL EDGE / FIELD SEAM

SCALE

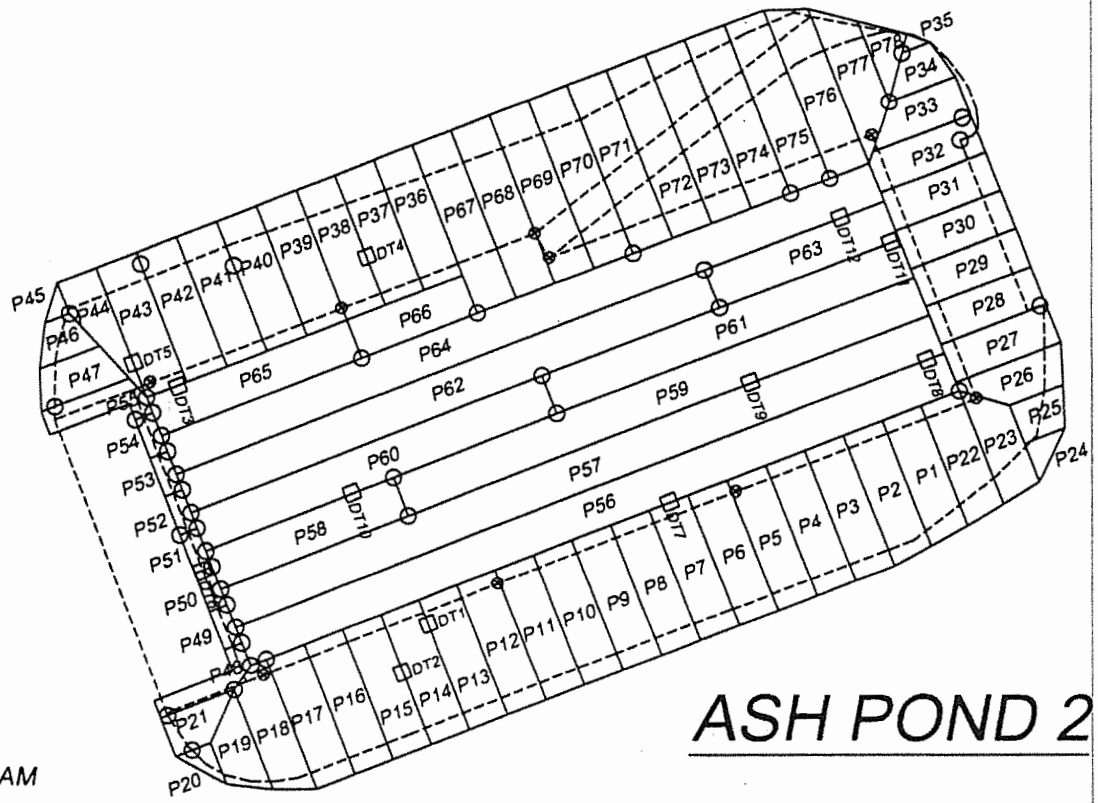
0 50 100

DRAWN BY M.A.		PROJECT NAME: MIDWEST GENERATION - JOLIET STATION #29 ASH IMPOUNDMENT CONSTRUCTION	
SCALE 1"=100'		DRAWING NAME: AS BUILT HDPE PANEL LAYOUT FOR ASH POND 1	
JOB #		LOCATION: JOLIET, IL	DRAWING NUMBER: ABPOND1
DATE 10-24-08			FILENAME: MIDWEST GENERATION

caawsystems.com
Clean Air And Water Systems, LLC
"You create it, we'll contain it"
123 ELM STREET
PO BOX 337
DOUSMAN, WI 53118
262-965-4366
FAX: 262-965-4369

Submittal # 26

NORTH



ASH POND 2

LEGEND

○	PATCH
□DT#	DESTRUCTIVE TEST
P#	PANEL NUMBER
⊗	PIPE BOOT
———	PANEL EDGE / FIELD SEAM

SCALE

0 50 100

DRAWN BY M.A.	PROJECT NAME: MIDWEST GENERATION - JOLIET STATION #29 ASH IMPOUNDMENT CONSTRUCTION	
SCALE 1"=100'	DRAWING NAME: AS BUILT HDPE PANEL LAYOUT FOR ASH POND 2	
JOB #	LOCATION: JOLIET, IL	DRAWING NUMBER: ABPOND2
DATE 6-6-08		FILENAME: MIDWEST GENERATION

caawsystems.com
Clean Air And Water Systems, LLC
"You create it, we'll contain it"
123 ELM STREET
PO BOX 337
DOUSMAN, WI 53118
· 262-965-4366
FAX: 262-965-4369

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ATTACHMENT A9

LEAK LOCATION SURVEY REPORT (IMPOUNDMENT #1 AND #2)

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LEAK LOCATION SERVICES, INC.

16124 UNIVERSITY OAK • SAN ANTONIO, TEXAS 78249 • (210) 408-1241 / FAX (210) 408-1242

October 23, 2008

Mr. Tedd Mills
Brieser Construction Company
24101 S. Municipal Drive
Channahon, IL 60410

Fax: (815) 521-0999

Subject: Report for "Geomembrane Leak Location Survey of a pond Located at the Midwest Generation Joliet Station"
LLSI Project 1165

Dear Mr. Mills:

On October 20 and 21, 2008, Martin Morales of Leak Location Services, Inc. (LLSI) conducted a leak location survey of the subject pond. The pond has an area of approximately 2 acres and has a geotextile under a single 60-mil HDPE geomembrane. The geomembrane is covered with a non-woven geotextile, a 12-inch sand layer and a 5-inch warming layer. This report documents the report of the survey.

I. SURVEY

A Results

No leaks were found in the primary geomembrane liner of the pond. The leak location equipment was tested for sensitivity and proper operation. A 0.25-inch diameter artificial leak was buried in the soil and leak location survey lines were run along both sides of the artificial leak.

Leak location survey measurements were collected to determine the maximum distance that the simulated leak could be reliably detected. This detection distance was approximately 7.5 feet. Figure 1 shows the artificial leak data for the instrument that was used.

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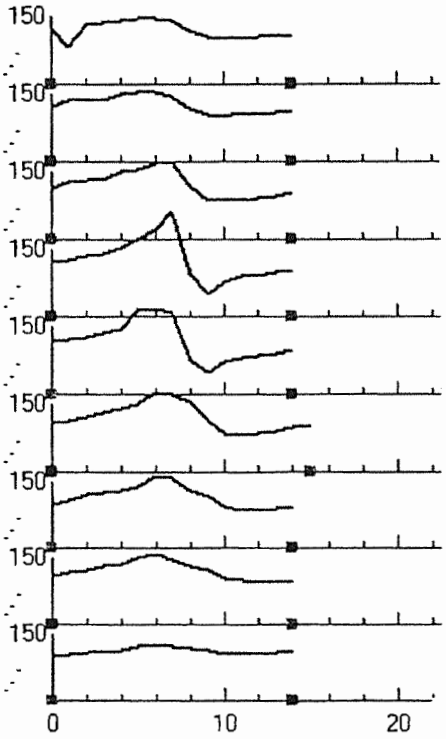


FIGURE 1. ARTIFICIAL LEAK DATA PLOT

II. TECHNIQUE

A. Principles of the Electrical Leak Location Method

The principle of the electrical survey method for geomembrane liners is to impress a high DC voltage across the liner and measure the resulting potential gradients on or in the conducting material on the liner. If any holes are present, characteristic anomalies in the potential measurements caused by electrical current flowing through the holes indicate their location.

B. Soil Covered Survey

A high voltage isolated DC power supply was used to impress a voltage across the liner using one electrode placed in the operations layer located on top of the primary liner and a second electrode placed in the electrically conducting material located beneath the liner. Therefore, the geomembrane liner provides an electrical barrier between the electrodes except where there are holes in the geomembrane liner. Electrical current flowing through the holes in the geomembrane liner produces localized anomalous areas of high current density near the holes. This electrical current path is provided by electrically conducting material such as water, sand, or soil.

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The survey of the pond was conducted by making potential gradient measurements on the moist warming layer with measurement electrodes spaced approximately 3 feet apart. These measurements were made approximately every 3 feet along numbered survey lines that were spaced approximately 5 feet apart. A portable digital data logger was used to collect the data. The data was then down-loaded into a portable computer for display, plotting, and analysis.

If there are any questions regarding the electrical surveys or this report, please contact us at (210) 408-1241. We appreciate the opportunity to have been of service to Brieser Construction Company.

Very truly yours,

John Ortiz
Project Manager

Approved by:

Daren L. Laine
President

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LEAK LOCATION SERVICES, INC.

16124 UNIVERSITY OAK • SAN ANTONIO, TEXAS 78249 • (210) 408-1241 / FAX (210) 408-1242

June 2, 2008

RECEIVED
JUN 10 2008
By

Ted Mills
Brieser Construction Company
24101 S. Municipal Drive
Channahon, IL 60410

Fax: 815-521-0999

Subject: Report for "Electronic Leak Location Survey for Ash Impoundment 2 at the Midwest Generation Joliet Station"
LLSI Project 1007

Dear Mr. Wells:

On May 22 and 23, 2008, Martin Morales of Leak Location Services, Inc. (LLSI) conducted the subject geomembrane leak location survey. The impoundment has an area of 3 acres and has a geotextile under a single 60-mil HDPE geomembrane. The geomembrane was covered with a non-woven geotextile, 12-inch sand layer and 5-inch warning layer. The geomembrane leak location survey was conducted after the warning layer was installed. This report documents the results of the leak location survey.

I. RESULTS

One leak was found. Figure 1 shows the approximate location of the leak. The leak was excavated and found to be an 8-inch by 4-inch tear. The leak was about 21 feet from the northwest edge of the floor and 245 feet from the northeast edge of the floor.

A 0.23-inch artificial leak was used to document the leak detection sensitivity. The artificial leak was a 0.23-inch electrode connected to an insulated wire. The other end of the wire was grounded. Leak location scans were made to determine the maximum distance that the artificial leak could be reliably detected. That distance was 10 feet.

II. TECHNIQUE

The electrical leak location method detects electrical paths through the liner caused by water or moisture in the leaks. A voltage is connected to one electrode in the material covering the liner and to an electrode connected to earth ground. Electrical current flowing through the leaks in the liner produces localized anomalous areas of high current density near the leaks. These areas are located by making electrical potential measurement scans on the material on the geomembrane liner.

Surveys with material covering the liner are conducted by making point-by-point potential measurements using special electrodes and a portable digital data acquisition system. The potential readings are made along survey lines with a fixed measurement electrode separation. The data is downloaded to a computer for storage and plotting. When a suspect area is located, manual measurements are made to further isolate the leak.

A systematic survey was conducted on the warning layer. Data was taken every 3 feet using a measurement electrode separation of 3 feet along survey lines spaced 5 feet apart. The data was

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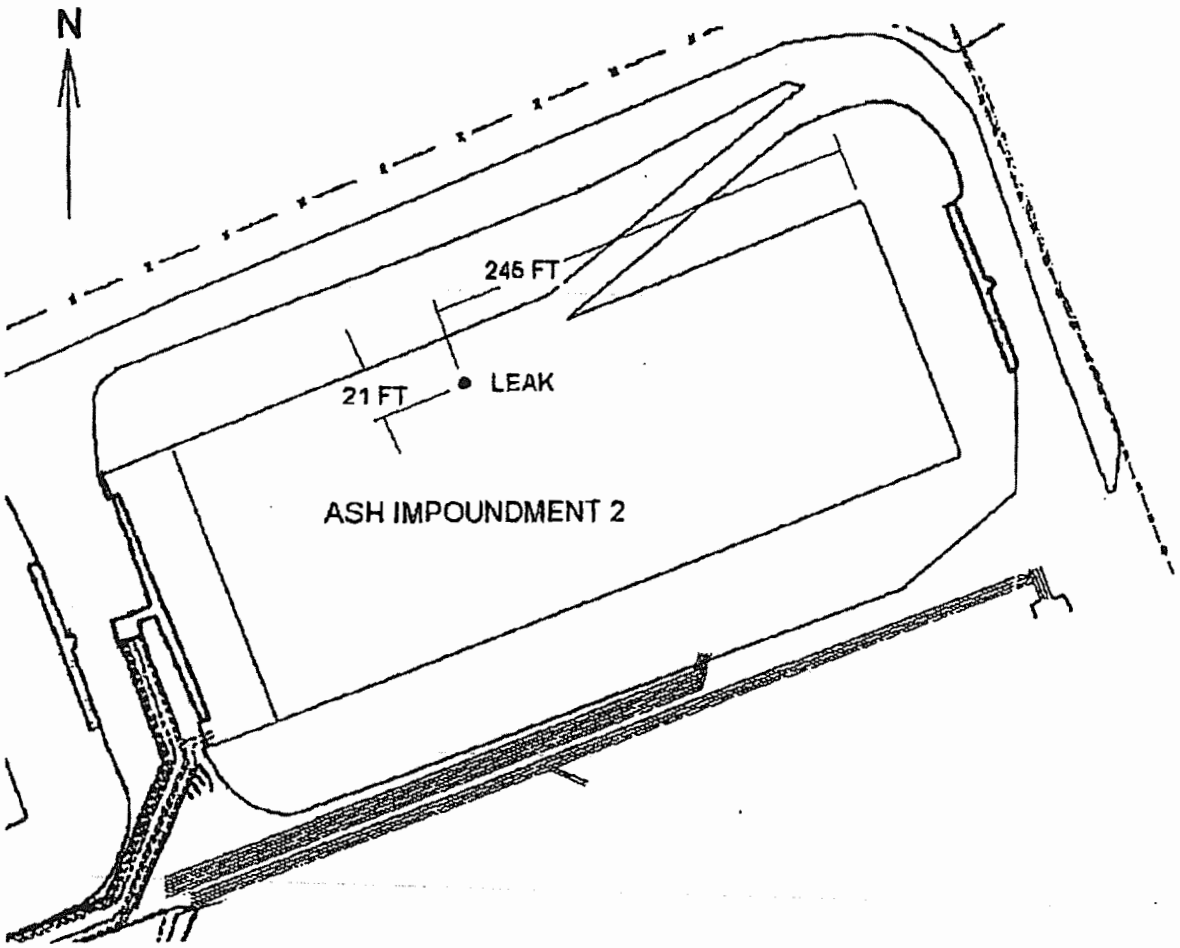


FIGURE 1. APPROXIMATE LOCATION OF THE LEAK

periodically downloaded to a computer for storage, plotting, and analysis for leak signals. Manual measurements were made to isolate the leak locations for excavation while the survey crew was on site. The leak was excavated and isolated from the materials on the geomembrane. Additional measurements were made to determine that there were no additional leaks in the area of the leak.

If there are any questions regarding the leak location survey or this report, please contact us at (210) 408-1241. We appreciate this opportunity to have been of service to Brieser Construction on this important service requirement.

Very truly yours,

Glenn T. Darilek

Glenn T. Darilek
Principal Engineer

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ATTACHMENT B

FIELD DIRECTIVES

Electronic Filing: Received, Clerk's Office 2/04/2022

NATURAL RESOURCE TECHNOLOGY

FIELD DIRECTIVE: NO. 1

DATE: April 25, 2008

TO: Brian Delcorio, Midwest Generation, LLC

FROM: Eric J. Tlachac, Natural Resource Technology, Inc.

SUBJECT: **Modifications to Section B, Sheet C031 (Access Ramp)**
Ash Impoundment #2 Liner Replacement, Joliet 29 Station

Due to existing site conditions with regard to the presence and depth of the Poz-o-Pac liner on the access ramp of Ash Impoundment #2, modifications are required to the layers of materials that will be placed above the geomembrane, as depicted in Section B on Sheet C031. A revised version of Sheet C031 (Rev. 2) is included as part of this field directive.

The contractor shall clean off the Poz-o-Pac surface to the extent practical to remove rocks that may pose a hazard to the geomembrane before placing the 16-ounce (oz) geotextile over the subgrade surface. The contractor shall also place 2 layers of the 12-oz geotextile over the geomembrane liner on the ramp, rather than the single layer originally specified. If sand bags are not adequate to hold the top layer of geotextile in place until it is covered, the contractor may heat bond the upper layer to the lower layer of geotextile with adequate precautions to avoid adversely affecting the underlying geomembrane.

Regarding the cover material on the ramp, the existing ramp material is not sufficient to be re-used, and there is question whether there is sufficient quantity, so the contractor shall place 6 inches of limestone screenings (approved replacement material for the specified sand) over the geosynthetics and 6 inches of the warning layer material (IDOT CA-6) over the limestone screenings. These layers will likely need to be blended into a smooth grade transition at the top of the ramp. If the ramp material needs to be thinned to 6 inches or less, the cover should be completely comprised of limestone screenings.

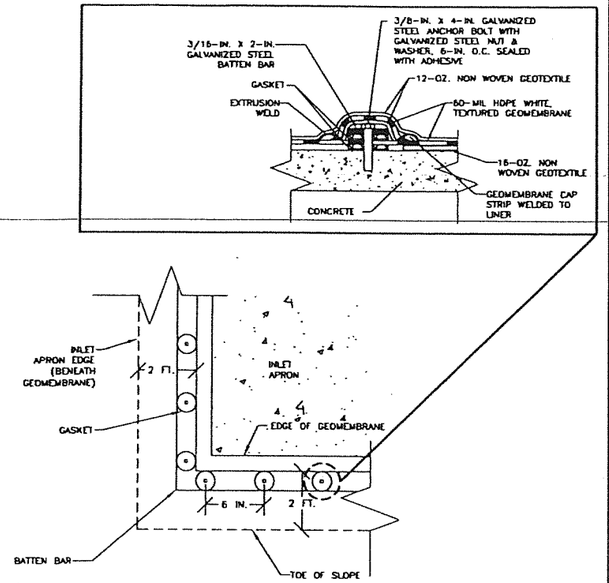
Minor modifications have also been made to Section C on Sheet C031 (Inlet Apron Section) to reflect discussion at the Job Start Meeting on March 28, 2008 regarding concerns about the "flap" of geomembrane that extends beyond the batten strip on the concrete inlet apron. As you may recall, there was concern that this "flap" will accumulate ash and other sediment if too long, and possibly cause uplift of the batten strip. Section C has been modified to remove the specified dimension for this flap so that it may be completed at the installer's discretion in the field.

As always, contractor comments are welcome and should be discussed / approved with the field construction quality assurance (CQA) engineer on site prior to modifying the approach described above. Should the field CQA engineer not be on site when concerns arise, please contact me at 262-522-1214.

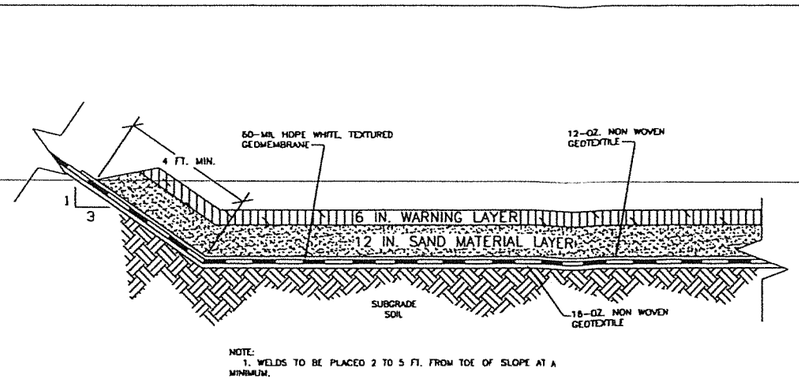
Enclosure: Sheet C031, Details and Sections, Rev. 2

23713 W. Paul Rd., Ste. D • Pewaukee, WI 53072 • Phone: 262.523.9000 • Fax: 262.523.9001 • www.naturalrt.com

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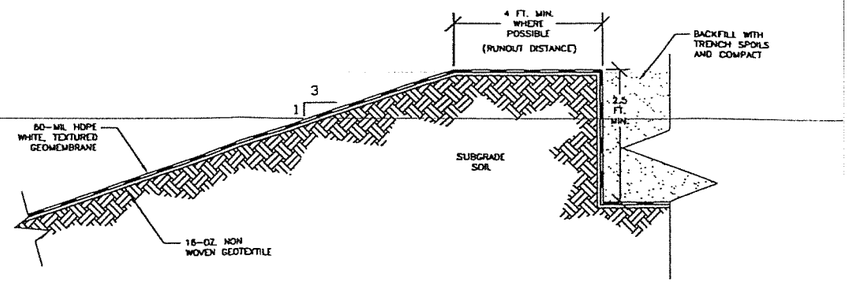


2 / C030 INLET APRON DETAIL PLAN
NOT TO SCALE

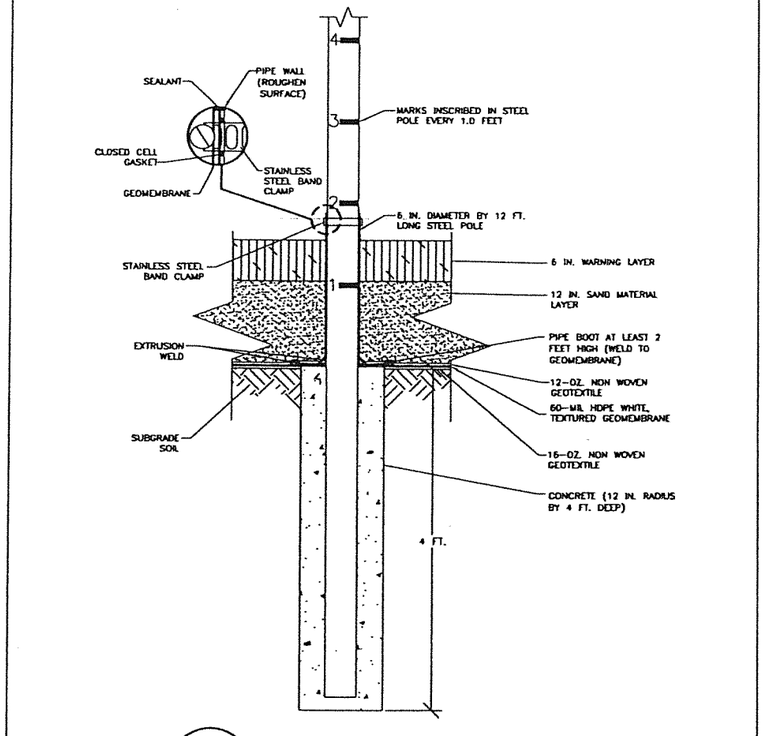


NOTE:
1. WELDS TO BE PLACED 2 TO 5 FT. FROM TOE OF SLOPE AT A MINIMUM.

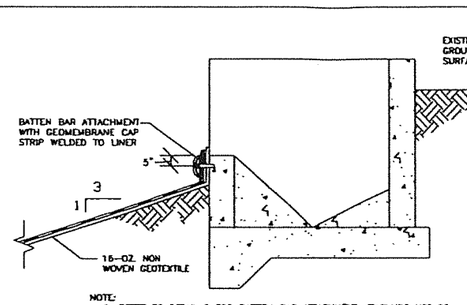
A / C030 SLOPE TRANSITION SECTION
NOT TO SCALE



D / C030 ANCHOR TRENCH SECTION
NOT TO SCALE

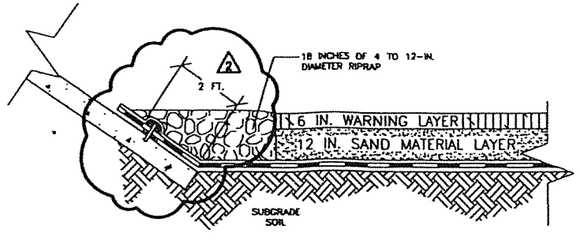


1 / C020 MARKER POST DETAIL
NOT TO SCALE

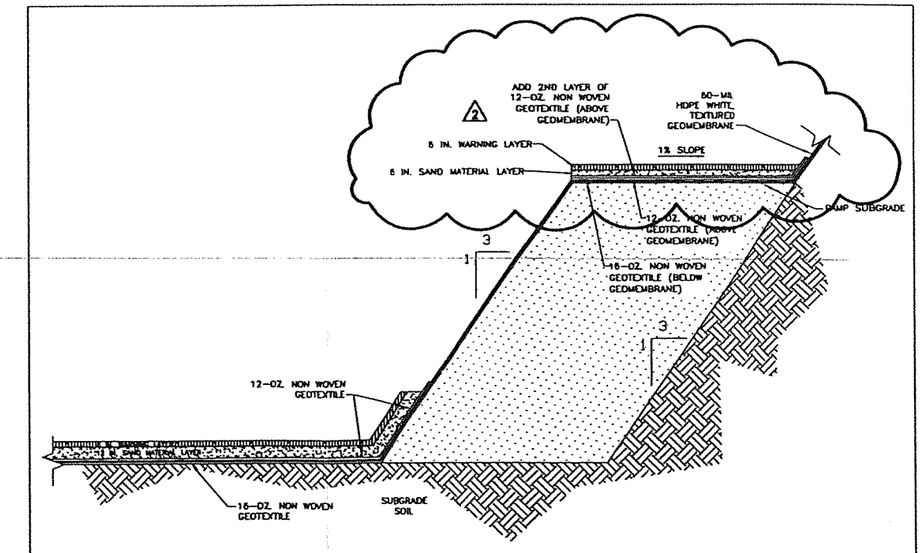


NOTE:
1. REFER TO DETAIL 2 FOR BATTEN BAR ATTACHMENT. EXCLUDE USE OF THE TOP LAYER OF 12-OZ. NON WOVEN GEOTEXTILE.

3 / C030 OUTLET WEIR DETAIL
NOT TO SCALE



C / -- INLET APRON SECTION
NOT TO SCALE



B / C030 RAMP SECTION
NOT TO SCALE

NOT FOR CONSTRUCTION

6.			
5.			
4.			
3.			
2.	ISSUED FOR FIELD DIRECTIVE #1	04/25/08	EJT
1.	ISSUED FOR BID	09/05/07	EJT
0.	ISSUED FOR PERMIT	06/04/07	RHW
REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/3.0	DETAILS AND SECTIONS
DRAWN BY: BJK/RLH 07/12/07	ASH IMPOUNDMENT #2 LINER REPLACEMENT MIDWEST GENERATION JOLIET STATION NO. 29 JOLIET, ILLINOIS
CHECKED BY: HMS 08/02/07	
APPROVED BY: EJT 09/05/07	DRAWING NO: D1862C031-02
	REFERENCE: 1862/3/BID-CON/
	SHEET NO C031

Electronic Filing: Received, Clerk's Office 2/04/2022

NATURAL RESOURCE TECHNOLOGY

FIELD DIRECTIVE: NO. 2

DATE: September 10, 2008

TO: Brian Delcorio, Midwest Generation, LLC

FROM: Heather M. Simon, Natural Resource Technology, Inc.

SUBJECT: **Modifications to Geomembrane Anchor Trench**
Ash Impoundment # 1 Liner Replacement, Joliet 29 Station

Due to existing site conditions with regards to limited access and the presence of large stones along the south bank top of slope of Ash Impoundment #1, modifications are required to the anchor trench depicted in Section D, Sheet C031.

The contractor shall construct the anchor trench at the top of slope along the south bank, despite the fact that there will be less than 4 feet of horizontal runout distance for the geosynthetics. The contractor shall remove the large stones at the top of the slope to approximately 2 feet below the current ground surface in this area. The contractor shall construct berms at the top of slope using limestone screenings to create a minimum 2-foot deep anchor trench along the south bank. The limestone screenings shall be compacted in 12-inch lifts. Limestone screenings shall be compacted to a hard durable surface that exhibits no further noticeable consolidation under the action of compaction equipment and no evidence of pumping or ponding of water. Engineer will inspect compaction every 25 feet along the length of the anchor trench. The contractor shall place the geosynthetics in the constructed trench, as depicted on in Section D, Sheet C031. Limestone screenings shall be placed and compacted in the anchor trench following placement of the geosynthetics.

Areas where large stones are removed from the anchor trench along the east, west or north banks shall be backfilled with limestone screenings and compacted. Compaction requirements, as stated above. Contractor shall remove stones that protrude from the sides of the trench and may pose a hazard to the geomembrane. The large stones removed from the trench shall be disposed at MWG's direction.

As always, contractor comments are welcome and should be discussed / approved with the field engineer on site prior to modifying the approach described above. Should the field engineer not be on site when concerns arise, please contact me at 262-522-1207.

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ATTACHMENT C

ASH IMPOUNDMENT #1 AND #2
DOCUMENTATION SURVEY

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ASBUILT OF
MIDWEST GENERATION JOLIET 29 POWER PLANT
WEST-ASH IMPOUNDMENTS

GRAPHIC SCALE
(IN FEET)
1 inch = 40 ft.


6
U.S. ROUTE
EAST ENTRANCE
MAIN ENTRANCE
AS-BUILT AREA
SITE BENCHMARK 1
SITE BENCHMARK 2
found "PK" masonry nail
CUT CROSS @ ELEV.= 535.02 (NGVD 29)
CUT CROSS @ ELEV.= 536.30 (NGVD 29)
CUT CROSS @ ELEV.= 536.68 (NGVD 29)
concrete wall
above ground pipelines
edge of liner
edge of liner over concrete
edge of liner over geotextile
edge of liner over soil
edge of liner over riprap
edge of liner over gravel
edge of liner over asphalt
ridge of liner over concrete
ridge of liner over geotextile
ridge of liner over soil
ridge of liner over riprap
ridge of liner over gravel
ridge of liner over asphalt
concrete post (typ.)
metal post (typ.)
wood post (typ.)
metal rail (typ.)
concrete rail (typ.)
wood rail (typ.)
concrete pad (typ.)
asphalt
concrete
gravel
riprap
soil
geotextile
Electrical Manhole
Electrical Manhole
Electrical Manhole

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ATTACHMENT D

NRT CQA DAILY FIELD REPORTS

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.1
Project Names: Impoundment #2 liner replacement

Date:	April 28, 2008
Work Scope:	Subgrade Inspection and roll QC – Impoundment #2
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction and Clean Air and Water
Weather:	Rain and windy, low 40's (°F)
Equipment:	Digital camera
Field Comments:	• I arrive on site around 0800, checked in at gate house. • Gate house called Brian Delcorio to let him know I was here. • I went up to Brian's office and received the site specific training. • After meeting with Brian, I went over to pond #2 and walked the base and side slopes to inspect the subgrade (see photo). • The subgrade looked good, except one spot on the slope had a foot wide hole. I notified Brian and Brieser, Brieser said that they would fill it in. • Talked with Thong Ingels (Clean Air) and he said that the subgrade was fine just needed to get it dry. • Before leaving, I recorded the roll numbers for the geotextile and geomembrane (see photo). • Offsite around 1030, arrived at office 1330
Scope Changes: (Problems, Additional Hours, etc…)	• None
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	• Wet from Rain
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: _____ Date: 4-28-8
Ricky J. Guenther Jr.



Subgrade looking southwest



Rolls of HDPE liner

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.1
Project Names: Impoundment #2 liner replacement

Date:	April 30, 2008
Work Scope:	Discuss liner batten location on concrete inlet with Clean Air and Water and Brian Delcorio – Impoundment #2
NRT Staff:	Glenn Luke
Contractors:	Brieser Construction and Clean Air and Water
Weather:	Sunny, low 50's (°F)
Equipment:	Digital Camera
Field Comments:	• Arrived onsite at approximately 9:30 a.m. Had safety training and inspection at the Gate House. • Met with Brian for additional safety training in the Administrative building. • Met with Thong Ingels (Clean Air), Mike Schmidt (Brieser), and Brian regarding the batten on Pond #2 concrete inlet. • It was decided that the batten would be installed on the top of the concrete inlet on the flat section directly outside of the weir (see photos). Brieser, Clean Air, and Midwest Generation were all comfortable with this alignment for the batten. The liner will be carried to the top of the concrete for battening. The liner (and 16 oz. fabric) will be carried continuously over the curb on the edges of the concrete. The contractor (Brieser) indicated that they would put an extra strip of 16 oz. over the curb for added protection. • Brieser also expressed concern about placing the rip rap directly on the liner (and fabric). They asked if they could place a 4-6 inch layer of screenings prior to the rip rap, I discussed with Eric Tlachac and we agreed that this would be fine. • Obtained Mike Schmidt's (Brieser on-site supervisor) contact info so that he could contact Eric Tlachac directly to discuss overall liner installation procedures, etc. Mike Schmidt Phone: 815-693-3337. • Took photos of pond #1 as it was receiving water/bottom ash. • Contractor was installing 16 oz. fabric and 60 mil liner on the slopes. • Offsite approximately 13:00.
Scope Changes: (Problems, Additional Hours, etc…)	• Liner to be installed to the top of slope below the weir on the concrete inlet. Batten installed directly outside of the weir and to the top edge of concrete on the end wings. The liner will be carried over the curbs on the edge of the concrete. The contractor indicated that they would place and extra section of 16 oz. fabric over the curb for added protection. The contractor will place a 4-6 inch layer of screening beneath the rip rap.
Site Conditions: (Needed repairs, system condition, etc…)	• Subgrade at pond bottom improving.

Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: _____ Date: April 30, 2008

Glenn R. Luke.

Signature: _____ Date: _____



Inlet weir



Installation of liner at SE corner of Impoundment #2

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2

Project Names: Midwest Generation (MWG) Joliet 29 Ash Impoundment #2 Liner Replacement

Date:	May 6, 2008 (Tuesday)
Work Scope:	Site visit to observe / document geomembrane (GM) installation
NRT Staff:	Eric Tlachac
Contractors:	Brieser Construction (General Contractor) and Clean Air & Water Systems, LLC (CAAWS, subcontracted GM installer)
Weather:	Sunny, light winds, temps in the 70s (°F)
Equipment:	Digital Camera
Field Comments:	10:30 - Arrived at site at (following 3 hrs travel)

- CAAWS performing detail work (marker post boots, seam intersections, destructive sample patches), production seaming appears to be complete and tested
- Brieser loading out anchor trench spoils, backfilling anchor trench on north side of pond with limestone screenings utilizing Bobcat T300 skidsteer loader equipped with rubber tracks, and compacting with Bomag BMP-851 walk-behind sheepsfoot compactor
- Mike Schmidt (Brieser foreman) advised that he tentatively planned (weather dependent – rain forecasted for tonight / tomorrow) to begin placing limestone screenings on ramp tomorrow and will hold in place with sandbags from GM installation
- Other contractor equipment on site:
  - Brieser
    - CAT 420E-IT rubber-tired backhoe (for excavating anchor trench)
    - Airman PDS-185S air compressor (for drilling marker post holes)
  - CAAWS
    - Geomembrane seaming devices (wedge and extrusion welders), rubber-tired All Terrain Vehicle (for GM deployment), 5-kW portable generators
    - CAT TL943 forklift (for GM deployment)

12:45 - Met with Brian Delcorio (MWG PM) at his office to discuss project status and went out to pond to meet with Thong Ingels (CAAWS foreman), but Thong was off site to pick up additional sealant for boots and batten bar connections

	15:00 - Discussed GM connection to concrete inlet structure with Brian Delcorio, Mike Schmidt, and Thong Ingels o Design was modified last week to move GM connection from bottom of concrete inlet apron to top due to concerns expressed by CAAWS regarding quality of GM connection on rough concrete surface below water line. This change was mutually agreed to by CAAWS, Brieser, NRT, and MWG. MWG reported incurring a change order for this valued at approximately $10,000 for 1 additional roll of GM to cover the inlet apron. o MWG and NRT now concerned about ability of exposed GM to withstand inlet flows on apron before bottom ash accumulates. Both observed flows at Pond 1 (currently in service). NRT photographed same. o NRT continued discussions with Brieser and CAAWS regarding GM connection at inlet 17:45 – Leave site
Scope Changes: (Problems, Additional Hours, etc…)	None yet, but MWG has concerns over stability of GM against inlet flows, another design modification may be forthcoming
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	GM installed appears in good condition, CAAWS unable to produce quality control records (claimed they were left at hotel)
Soil/Water Stored On-site: (Prior & newly generated) (containers – conditions, labeling, location)	None – Brieser loading out anchor trench spoils and transporting to MWG disposal site (Lincoln Quarry)
Summary of Forms Attached:	Photos

Signature: Eric J. Tlachac Date: May 6, 2008

Eric J. Tlachac



Completed GM looking west



Completed marker posts (foreground) and anchor trench backfill (background)



GM inlet connection

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FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2

Project Names: Midwest Generation (MWG) Joliet 29 Ash Impoundment #2 Liner Replacement

Date:	May 8, 2008 (Thursday)
Work Scope:	Site visit to observe / document geomembrane (GM) installation and cushion layer placement
NRT Staff:	Eric Tlachac
Contractors:	Brieser Construction (General Contractor) and Clean Air & Water Systems, LLC (CAAWS, subcontracted GM installer)
Weather:	Cloudy, temps in the 50s (°F), NE winds 15-25 mph
Equipment:	Digital Camera
Field Comments:	7:45 - Arrived at site at (following 2.5 hrs travel) o Brieser pumping water from bottom of pond to facilitate placement of geotextile (GT). No work performed yesterday due to rain event. Also placing / compacting limestone screenings and dense-graded aggregate on ramp over double-layer of GT utilizing Bobcat T300 skidsteer loader equipped with rubber tracks and Case SV210 smooth-drum compactor o CAAWS continuing detail work (marker post boots, GM connection to outlet structure, re-working GM connection to inlet structure) and installing GT portion of cushion layer ▪ MWG decided yesterday to move GM connection from top of concrete inlet apron to back to bottom (as originally designed) due to concerns regarding ability of exposed GM to withstand inlet flows on apron before bottom ash accumulates. MWG reported incurring a change order for this to cover additional labor associated with re-working the batten bar. ▪ Observed gaps in batten bar on outlet structure, informed Thong Ingels (CAAWS foreman) and batten bars were re-positioned to minimize gaps 12:45 - Met with Brian Delcorio (MWG PM) at his office to discuss project status. Brian indicated that Brieser may seek a change order for additional limestone screenings due to the fact that the bottom of the pond is uneven (thus requiring additional material to construct a flat warning layer surface and meet minimum thickness requirements). In order to quantify the amount of limestone screenings included in Brieser's lump sum bid, Brian and I measured the dimensions of Pond 2 utilizing a measuring wheel provided by CAAWS, and I calculated the tonnage in a 1-ft layer of limestone screenings assuming a conversion of 1.8 tons / cubic yard (see attached calc). The result was approximately 5,000 tons. Brian then utilized this value in negotiations with Brieser, which resulted in the instruction to place the limestone screenings to the specified thickness regardless of the final pond elevation.

	Brieser expressed concern over the difficulty of executing this instruction given the variability in the bottom surface of the pond, and believed that, even with diligent grade control, they would still wind up placing more limestone screenings than allowed for in their bid. 14:30 – Mutually decided with CAAWS to attach the GM to the south side of the inlet apron approximately 10-12 ft north of (in from) the edge to avoid the large "pit" located at the south edge of the apron beneath an 18-inch pipe that discharges vertically onto the apron. This will require relocation of the pipe so that it does not discharge onto the GM. Advised Brian Delcorio accordingly, and he concurred with the modifications to the GM attachment and discharge pipe. Brian will arrange internally to have the discharge pipe relocated. 16:00 – observe / photograph completion of GM connection on inlet apron, placement of GT portion of cushion layer, and placement of limestone screenings at bottom of ramp. Discuss placement of limestone screenings with Mike Addenall (Brieser superintendant?). Traffic cones will be utilized to mark 12-inch thickness to aide the operator spreading the screenings with the skidsteer. I requested that trucks transporting screenings back down the ramp to dump to minimize turning on the GM. Mike Addenall and Mike Schmidt agreed. 18:45 – Leave site.
Scope Changes: (Problems, Additional Hours, etc…)	GM connection on concrete inlet apron was moved from top of apron back to the bottom of the apron (as originally designed) due to MWG concerns regarding ability of exposed GM to withstand inlet flows on apron before bottom ash accumulates.
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	Bolts from former batten bar attachment at top of concrete inlet apron need to be cut flush with the apron. Informed Brian Delcorio (MWG) via phone on 5/9.
Soil/Water Stored On-site: (Prior & newly generated) (containers – conditions, labeling, location)	None
Summary of Forms Attached:	Photos

Signature: Eric J. Tlachac Date: May 8, 2008

Eric J. Tlachac



GM attachment to outlet structure



Placement of limestone screenings on ramp



GM attachment to inlet structure

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.1
Project Names: Impoundment #2 liner replacement

Date:	May 22, 2008, May 23, 2008
Work Scope:	Leak detection survey and leak repair oversight – Impoundment #2
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction and Clean Air and Water
Weather:	Sunny, low 60's (°F) and Sunny, low 50's (°F)
Equipment:	Digital camera
Field Comments:	5/22 Leak Detection Survey • I arrive on site around 0800, checked in at gate house. • Talked with Brian (MWG), Mike (Brieser), and leak location surveyor at the pond. • Setup transects every 10 feet across the length of the pond. • The machine was calibrated to a ¼ inch hole. • The leak location surveyor walked transects at each line and at the half way point. Every hundred or fifty feet he downloaded the data to the laptop and checked for leaks. • One hole was found around 245 feet from the discharge weir. • Brieser and I dug out the leak after it was more precisely marked by the surveyor. It appeared that the liner was punctured by the construction equipment when placing the cushion layer/limestone screenings. • There was one other hole in the southeast corner of the pond where an operator hit the side slope with the construction equipment. • Offsite around 1530 5/23 Leak Repairs • I arrived on site around 0900, checked in at gate house. • Took a couple more photos of the two holes prior to Clean Air and Water arriving. • Clean Air and Water placed a patch on each location. • Offsite 1030
Scope Changes: (Problems, Additional Hours, etc…)	• None
Site Conditions: (Needed repairs, system condition, etc…)	• Good
Soil/Water Stored On-site:	• None
Summary of	• None

Summary of Forms Attached:

- None

Signature: Ricky J. Guenther Jr. Date: 5.23.8



Marker post



Warning layer looking west at inlet



Leak location surveyor and equipment

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Impoundment #1 liner replacement

Date:	September 12, 2008
Work Scope:	Subgrade Inspection – Impoundment #1
NRT Staff:	Rick Guenther
Contractors:	Brieser -Bill
Weather:	Rain and windy, low 70's (°F)
Equipment:	Digital camera
Field Comments:	• I arrive on site around 0930, checked in at gate house. • Gate house called Elsie to let her know I was here. • I went over to pond #1 and walked the base and side slopes to inspect the subgrade. • The subgrade was not complete at this time. • I talked with Bill (Brieser) and he said that he had stopped work until they could talk to us about the subgrade. He notified me that the material was wet under the top couple inches and equipment was sinking in when moving material around. He wanted to see if we had any suggestions or comments about the bottom being soft. Brieser doesn't want to be responsible if the liner gets ripped if the equipment hits a soft spot when placing the limestone screenings. • Offsite around 1100
Scope Changes: (Problems, Additional Hours, etc...)	• Brieser wanted to discuss wet material on subgrade not to do the subgrade inspection for approval.
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc...)	• Wet from Rain
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: _____ Date: 9.12.8

Ricky J. Guenther Jr.



Subgrade looking southwest



North side slope looking east

Electronic Filing: Received, Clerk's Office 2/04/2022

.FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Impoundment #1 liner replacement

Date:	September 25, 2008
Work Scope:	Subgrade Inspection – Impoundment #1
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction -Bill
Weather:	Rain and windy, low 70's (°F)
Equipment:	Digital camera
Field Comments:	• I arrive on site around 1100, checked in at gate house. • Walked the base and side slopes of pond #1 to inspect the subgrade. • Brieser was working on the anchor trench on the north side of the pond and working on the berm on the south end of the pond. • I talked with Bill (Brieser) and he said that they would be ready by Monday for the liner crew. • They will finish the anchor trench on the north side today and have the berm compacted and complete by Monday. • Once the berm is complete they will continue compaction of the bottom of the pond. • They will also be walking the site to remove large rocks. • I told him that they needed to fix the slope transition from the side slope to the bottom of the pond so the liner can lay down smooth. • Told him that they are responsible for completing the marker posts. • They will also be fixing some washouts in the NE corner side slopes. • Subgrade is looking good, mostly clean up and finish work left. • Offsite around 1530
Scope Changes: (Problems, Additional Hours, etc…)	• none
Site Conditions: (Needed repairs, system condition, etc…)	• In good condition, working on finishing up.
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: Rick J. Guenther Jr. Date: 9-25-8



Placement of anchor trench berm along top of south bank



North anchor trench



Prepared subgrade looking west

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Joliet 29 Impoundment #1 liner replacement

Date:	October 1 and 2, 2008
Work Scope:	Liner Installation Inspection – Impoundment #1
NRT Staff:	Heather Simon
Contractors:	Brieser Construction -Bill
Weather:	Partly Sunny 60s degree F
Equipment:	Digital camera
Field Comments:	10/1 • I arrive on site around 1100, checked in at gate house. • I went over to pond #1 to observe deployment of the liner on the southeast corner. • Liner installation was completed along the entire length of south bank today. At the end of day, liner was deployed at base of pond along southern edge up to the outlet. • Field seam tests were conducted. • Began installation of pipe boots. • Batten bars deployed along base of inlet apron. • Left site at 1600 10/2 • I arrive on site around 700 • Brieser backfilling south anchor trench with conveyor system. • I talked with Bill (Brieser) about compaction of the anchor trench backfill. • Crew deploying liner at base of pond. Left site at 1030
Scope Changes: (Problems, Additional Hours, etc…)	• None
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	• In good condition, compaction of anchor trench backfill required
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: Heather M Simon Date: 10/3/08
Heather Simon



Install of HDPE liner looking southwest



Thermal fusion welding apparatus

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Midwest Generation (MWG)
Joliet 29 Ash Impoundment #1
Liner Replacement

Date:	October 3, 2008 (Friday)
Work Scope:	Site visit to observe / document geomembrane (GM) installation and cushion layer placement
NRT Staff:	Eric Tlachac
Contractors:	Brieser Construction (General Contractor) and Clean Air & Water Systems, LLC (CAAWS, subcontracted GM installer)
Weather:	Partly cloudy, temps in the 50s (°F), E winds 5-10 mph
Equipment:	Digital Camera
Field Comments:	8:30 - Arrived at site at (following 3 hrs travel) , required to watch safety video by site security o Brieser excavating anchor trench at top of ramp with New Holland E150LC hydraulic excavator; later in day, Brieser assists CAAWS with GM and GT deployment and backfill of anchor trench on north side of pond ▪ Limestone screenings backfill in anchor trench on south side of pond not compacted. Advised Billy (Brieser foreman) that anchor trench backfill needed to be compacted. o CAAWS deploying geotextile (GT) portion of cushion layer and completing GM connections to outlet and inlet structures; later in day CAAWS deploys remaining GM on north side slopes ▪ Lower subgrade GT deployed on ramp following anchor trench excavation ▪ Observed edge of GM exposed at top of slope near inlet structure, advised Thong Ingels (CAAWS foreman) that edge of GM needs to be tucked into anchor trench ▪ AM and PM trial welds meet project specifications ▪ Several production seam air channel tests failed in NW corner of pond – much of the seams in this area extrusion welded. Seaming equipment adjusted accordingly. o Safety inspection conducted by Tim (Brieser safety officer) – CAAWS reprimanded for housekeeping o Discussed status with Brian Delcorio 17:15 – Leave site – GM deployed to NE corner of pond (ramp).
Scope Changes:	None

(Problems, Additional Hours, etc…)	
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	None
Soil/Water Stored On-site: (Prior & newly generated) (containers – conditions, labeling, location)	None
Summary of Forms Attached:	Photos

Signature: _____ Date: October 3, 2008

Eric J. Tlachac



Liner construction status upon arrival



Production seaming



GM deployment



Anchor trench backfill

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FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Impoundment #1 liner replacement

Date:	October 6, 2008
Work Scope:	Limestone screenings placement – Impoundment #1
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction-Bill
Weather:	Partly Cloudy, high 60's (°F)
Equipment:	Digital camera
Field Comments:	• I arrive on site around 1130, checked in at gate house. • I went over to pond #1 and verified that liner was complete and geotextile was installed. • Brieser was placing screens on the ramp using the rubber tracked skidster. • I instructed Bill that the warning layer needed to be placed on the ramp before any trucks drive on the ramp. • We also went over things that needed to be completed 1) place riprap at base of apron 2) cover up liner at inlet and discharge corners 3) place screenings 4 feet up side slope 4) compact north anchor trench 5) paint marker poles • Called Brian DelCorio. (MWG) before leaving to let him know what was left to be completed. • Offsite around 1400.
Scope Changes:	• none
Site Conditions: (Needed Well repairs,	• In good condition.
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: Ricky J. Guenther Jr. Date: 10.6.8



Placement of limestone screening on ramp



Top of southwest corner along anchor trench

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FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Impoundment #1 liner replacement

Date:	October 21, 2008
Work Scope:	Leak detection survey – Impoundment #1
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction-Billy
Weather:	Partly Sunny 60s degree F
Equipment:	none
Field Comments:	• I arrive on site around 0845, checked in at gate house. • I went over to pond #1 to observe the leak detection survey already in progress. • The survey was completed with one possible leak detection. Brieser removed the limestone screenings and visually inspected the linear, a hole was not detected. • The area was buried again and survyed again with and without an artificaial leak. The artificial leak was more visible with the software and it was ruled that there was no leak at this location. One possible cause for the intial leak signal is that the area below the screenings was very dry. • Brieser began final cleanup of the site. • Left site at 1115
Scope Changes: (Problems, Additional Hours, etc…)	• None
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	• Looks good
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

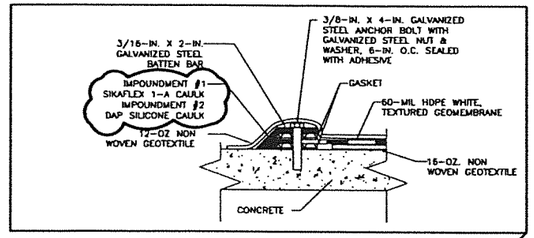
Signature: R. T. Guenther Jr. Date: 10·21·8

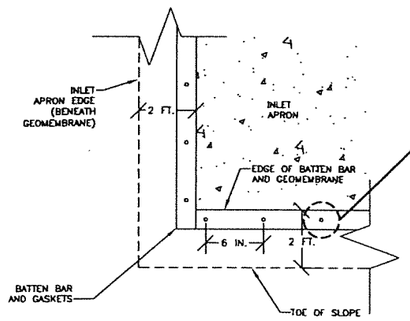
Rick Guenther

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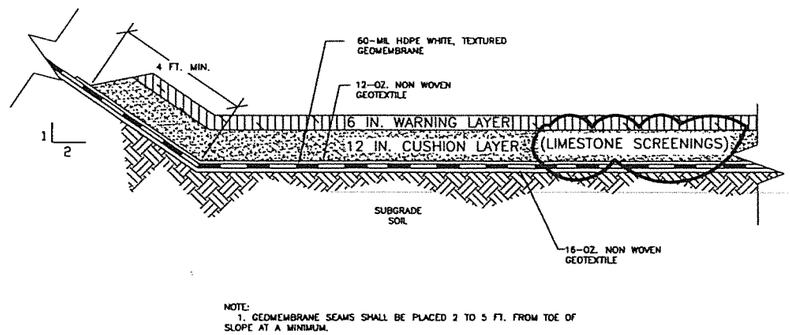
SHEETS

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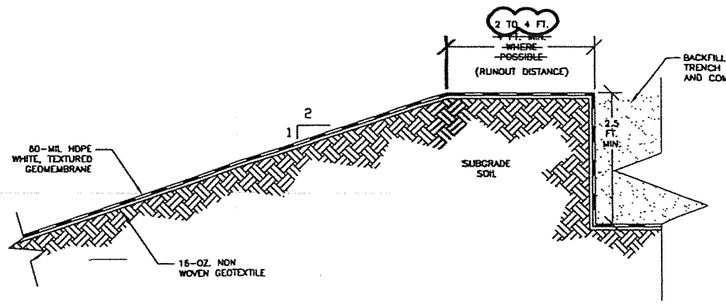


2 / C030 INLET APRON DETAIL PLAN
NOT TO SCALE

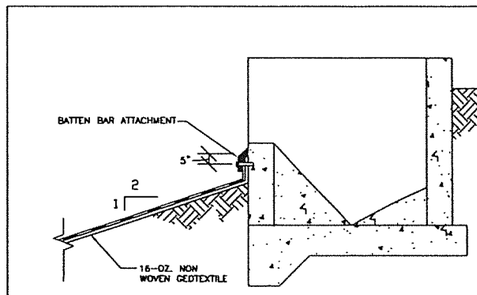


NOTE:
1. GEOMEMBRANE SEAMS SHALL BE PLACED 2 TO 5 FT. FROM TOE OF SLOPE AT A MINIMUM.

A / C030 SLOPE TRANSITION SECTION
NOT TO SCALE

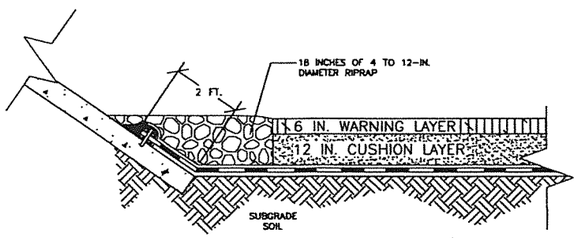


D / C030 ANCHOR TRENCH SECTION
NOT TO SCALE



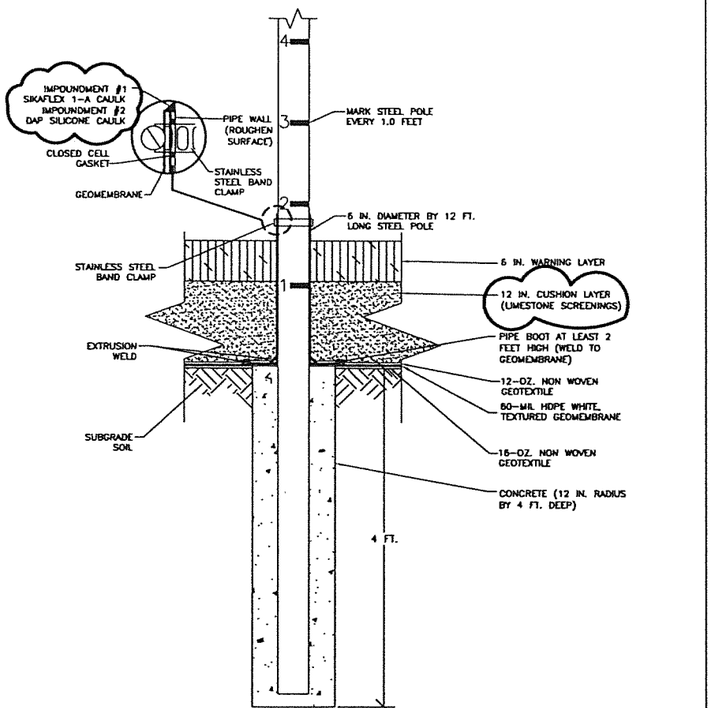
NOTE:
1. REFER TO DETAIL 2 FOR BATTEN BAR ATTACHMENT. EXCLUDE USE OF THE TOP LAYER OF 12-OZ. NON WOVEN GEOTEXTILE.

3 / C030 OUTLET WEIR DETAIL
NOT TO SCALE

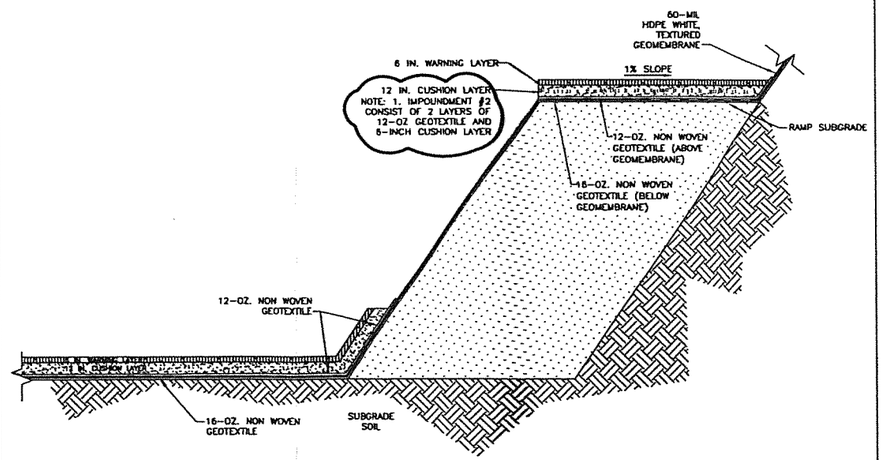


NOTE:
1. REFER TO DETAIL 2 FOR BATTEN BAR ATTACHMENT.

C / -- INLET APRON SECTION
NOT TO SCALE



1 / C020 MARKER POST DETAIL
NOT TO SCALE



B / C030 RAMP SECTION
NOT TO SCALE

6.			
5.			
4.			
3.			
2.			
1.			
0.	RECORD DRAWING	12/19/08	HMS
REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/5.2	DETAILS AND SECTIONS
DRAWN BY: KNW 12/19/08	ASH IMPOUNDMENT #1 AND #2 LINER REPLACEMENT MIDWEST GENERATION, LLC JOLIET STATION NO. 29 JOLIET, ILLINOIS
CHECKED BY: HMS 12/19/08	
APPROVED BY: HMS 12/19/08	DRAWING NO: D1862C031-00 / REFERENCE:1862/RECORD DWGS/
	SHEET NO. C031

Attachment 3

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Geosyntec consultants

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Phone: 858.674.6559
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HISTORY OF CONSTRUCTION
ASH POND 2
JOLIET 29 STATION
OCTOBER 2016

Geosyntec Consultants (Geosyntec) prepared this history of construction report for Ash Pond 2 located at the Joliet 29 Station (Site) in Joliet, Illinois, which is owned and operated by Midwest Generation, LLC (Midwest Generation). This history of construction report addresses the requirements of the Coal Combustion Residuals (CCR) Rule codified in the Code of Federal Regulations Title 40, Part 257, Subpart D. These regulations were published in the Federal Register on 17 April 2015 and became effective on 19 October 2015. This report identifies and addresses the specific requirements of §257.73(c) of the CCR Rule regarding preparing a history of construction report for CCR surface impoundments. Specifically, this report provides the history of construction through 17 October 2016 for Ash Pond 2.

This report was prepared under the direction of Ms. Jane Soule, P.E., and was reviewed in accordance with Geosyntec's internal review policy by Mr. Robert White of Geosyntec.

1. CCR Rule Requirements for History of Construction

History of construction requirements for existing CCR surface impoundments are included in the structural integrity criteria presented in §257.73 of the CCR Rule. The preamble of the CCR Rule (Page 21380) states that the history of construction for an existing CCR impoundment (in this case, Ash Pond 2) is required to include information only to the extent available and that only factual documentation, not anecdotal or speculative information, is to be included. Additionally, the preamble states that no new information should be generated to satisfy the requirements of §257.73(c).

2. History of Construction

2.1 Owner and Unit Identification - §257.73 (c)(1)(i)

Owner and unit identification for Ash Pond 2 is presented in Table 1 below.

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Table 1: Owner and Unit Identification

UNIT NAME	OWNER/OPERATOR	IDENTIFICATION NUMBER
Ash Pond 2	Midwest Generation 804 Carnegie Center Princeton, NJ 08540	IL0064254

2.2 Unit Location on USGS Map – §257.73 (c)(1)(ii)

The Site is located approximately 35 miles southwest of Lake Michigan on the Des Plaines River in Joliet, Illinois. Figure 1 presents the location of Ash Pond 2 on a 7.5-minute United States Geological Survey (USGS) topographic quadrangle map.

2.3 Purpose of the CCR Units – §257.73 (c)(1)(iii)

Ash Pond 2 served as a settling pond for sluiced CCR and other process waters related to electrical power generation at the Site. While CCR is present in the pond, CCR is no longer sluiced to Ash Pond 2.

2.4 Name and Size of the Watershed – §257.73 (c)(1)(iv)

Ash Pond 2 is located in the Des Plaines River watershed (HUC 071200040905), which is approximately 23,808 acres in size (USGS, 2015). However, Ash Pond 2 was constructed with elevated embankments on the south, east and west perimeters, and surface water run-on to the pond is limited to the area within the embankment crests and the access road located north of the pond.

2.5 Description of Foundation– §257.73 (c)(1)(v)

Site observations and construction documents show Ash Pond 2 is surrounded by embankments on the south, east, and west. There are no embankments on the north side of the pond where existing ground elevations generally increase to the north; however, Site investigations indicate that fill material may be present along the northern boundary. For engineering purposes, material located along the northern embankment is considered consistent with embankment fill. Native materials do not provide any lateral support for the embankments and therefore the pond does not contain abutments. The remainder of this section addresses the foundation materials for the pond's embankments.

2.5.1 Physical Properties of Foundation Materials

Information on the physical properties of the foundation materials for Ash Pond 2 is based on published geologic information and field investigations performed at the Site by KPRG in 2005, Patrick Engineering in 2011, and Geosyntec in 2015. Detailed descriptions of these investigations and the regional geology at the Site are included in Geosyntec (2016).

Foundation materials in the vicinity of Ash Pond 2 vary from clay to sand and gravel with Silurian Dolomite as a bedrock layer at approximately 40 feet below the embankment crests.

2.5.2 Engineering Properties of Foundation

Table 2 presents engineering properties for the foundation materials at the Site developed for the periodic structural stability and safety factor assessments (Geosyntec, 2016). These engineering properties are based on investigations performed at the Site, published correlations, and laboratory testing of samples collected from foundation soils during the Site investigations. Engineering properties were not developed for the Silurian Dolomite bedrock layer due to its very dense consistency, relative depth below the ground surface, and negligible contribution to the slope stability analyses.

Table 2: Foundation Material Engineering Properties

MATERIAL	UNIT WEIGHT (PCF)	DRAINED FRICTION ANGLE (DEGREES)	EFFECTIVE COHESION (PSF)
Sand/Gravel	125	38	25

2.6 Description of the Materials, Methods, and Dates of Construction - §257.73 (c)(1)(vi)

The following sections describe the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of Ash Pond 2, the method of site preparation and construction of each zone of the unit, and the approximate dates of construction of each successive stage of construction of the unit, to the extent the information is available.

Information presented in the following sections is based on available construction drawings (NUS, 1978, NUS, 1979), liner replacement construction drawings (NRT, 2007; NRT, 2008) and subsequent investigations at the Site. No as-built construction drawings or construction completion reports detailing the actual materials and methods used for the original construction of the pond was available for this report; however, some as-built data was available for the liner replacement project.

Based on available construction drawings (NUS, 1978), excavation was required to construct Ash Pond 2 because the original ground surface is indicated at approximately the design embankment crest elevation.

Construction drawings for Ash Pond 2 do not indicate that it was constructed with engineered zones of different soil types typical of large earthen dams; therefore, the size and range of each zone or stage of construction is not applicable.

Interior embankments were designed at an inclination of 3H:1V (horizontal:vertical), with the exception of the concrete-lined inlet apron area on the western inboard slope, which is inclined at 2H:1V (NUS, 1978). Exterior embankment slopes were shown on the available construction drawings to be inclined at 3H:1V or flatter. The interior slopes and pond bottom, except the concrete-lined inlet apron, were originally designed with a 1 foot thick Poz-o-Pac ™ liner system (NUS, 1978). The construction drawings also include site preparation requirements (NUS, 1978).

The available construction drawings also provide the design of a reinforced concrete retaining wall located south of the western half of Ash Pond 2 and north of the silo building. The retaining wall has a maximum retained height of approximately 17 feet and is approximately 250 feet in length with approximately 75-foot long wing walls extending southward at each end of the wall.

In 2009, the original Poz-o-Pac™ liner system was replaced with the existing high-density polyethylene (HDPE) geomembrane liner system. As-built drawings developed as part of the liner replacement project show that the southern, northern, and eastern interior slopes of the pond range from 2H:1V to 3H:1V (Ruettiger, Tonelli & Associates, Inc., 2009). Site surveys show that downstream slope inclinations are approximately 3H:1V or flatter on the slope south of the eastern half of Ash Pond 2 and the slope on the southern half of the eastern perimeter toward the clarifier (Aero-Metric, 2008). The interior slope of the east embankment for Pond 1 (the downstream slope of the west embankment for Ash Pond 2) was originally designed at 3H:1V; however, design drawings for the liner replacement of Pond 1 show this slope re-designed at 2H:1V (NRT, 2008). No as-built records were available for the Pond 1 liner replacement project.

In September 2016, approximately 100 cubic yards of engineered fill was placed on the Ash Pond 2 embankment crest in the southeast corner of the pond to provide additional freeboard for the pond. A drawing indicating the fill location and compaction requirements is included in Appendix A-1.

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2.6.1 Engineering Properties

Engineering properties used for the design and construction of the Ash Pond 2 embankment materials were not available at the time of this report. However, engineering properties were estimated for use in the factor of safety assessment performed for the pond in accordance with the CCR Rule. The estimated engineering properties were based on investigations performed at the Site, published correlations, and laboratory testing of embankment materials and are presented in Geosyntec (2016) and reproduced in Table 3. For engineering analyses, two different materials were identified in the embankments for Ash Pond 2: stiff brown clay and black silty gravel. Observed depths of these two materials varied around Ash Pond 2.

Table 3: Embankment Fill Engineering Properties

MATERIAL	UNIT WEIGHT (PCF)	DRAINED FRICTION ANGLE (DEGREES)	EFFECTIVE COHESION (PSF)
Brown Clay	115	30	25
Silty Gravel	125	32	25

2.6.2 Construction Dates

Available construction dates for Ash Pond 2 are unknown; however, available construction drawings were approved for construction in 1977 and 1978 (NUS, 1977; NUS, 1978). Replacement of the original Poz-o-Pac™ liner system with the HDPE liner system was completed in 2009.

2.7 Drawings - §257.73 (c)(1)(vii)

Available construction drawings relevant to the design, construction, operation, and maintenance of Ash Pond 2[1] are included in Appendix A. Appendix A-2 includes available construction drawings (NUS, 1978; NUS, 1979), Appendix A-3 includes drawings from the liner replacement performed in 2009 for Ash Pond 2 (NRT, 2007), Appendix A-4 includes an as-built drawing from the Ash Pond 2 liner replacement project (Ruettiger, Tonelli & Associates, Inc., 2009), and

[1] Ash Pond 2 is also referred to as Ash Impoundment 2 in drawings prepared by NRT (2007).

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Appendix A-5 includes relevant construction drawings from the liner replacement performed for Pond 1 (NRT, 2008)[2] as they relate to western boundary of Ash Pond 2.

2.8 Instrumentation - §257.73 (c)(1)(viii)

There is no instrumentation related to Ash Pond 2; thus, there are no records of instrumentation associated with hydraulic structures, embankments or slope performance related to Ash Pond 2.

2.9 Area-Capacity Curve - §257.73 (c)(1)(ix)

An area-capacity curve for Ash Pond 2 is included as Figure 2.

2.10 Spillway Description and Calculations - §257.73 (c)(1)(x)

Ash Pond 2 does not include a spillway.

2.11 Construction Specifications and Provisions for Surveillance, Maintenance and Repair - §257.73 (c)(1)(xi)

The only construction specification available for this report is an HDPE geomembrane specification for the liner replacement project performed in 2009. The specification was included in a draft application for construction permit approval and is marked "not for construction." Generally, the HDPE geomembrane specification identifies that an HDPE, white, 60-mil, textured geomembrane be used for the project. It also identifies deployment and seaming requirements, quality control procedures, and requirements for materials placed above the geomembrane. The geomembrane specification is included in Appendix B.

As part of the 2009 liner replacement project, warning posts were installed at the toe of interior basin slopes above the geomembrane liner system. These posts are utilized as a visual guide to identify the toe of slope during CCR removal operations to limit potential damage to the liner system.

2.12 Record of Any Structural Instability - §257.73 (c)(1)(xii)

Based on discussions with Site staff and review of available information, there are no records or knowledge of structural instability for Ash Pond 2.

[2] Liner replacement drawings are based on the North American Vertical Datum of 1929 (NAVD29). The NUS construction drawings do not provide a referenced datum, however, elevations are generally consistent with those in the liner replacement drawings.

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3. References

Aero-Metric, 2008. Topographic Mapping of Joliet 29 Station, prepared for Midwest Generation, LLC., (AutoCAD file)

Geosyntec, 2016. Soil Properties Calculations, Joliet 29 Station, October.

KPRG and Associates, Inc., 2005. Geotechnical Analysis of Soil Surrounding Settling Basins/Ponds, KPRG Project No. 15805, October.

Natural Resource Technology (NRT), 2007. Ash Impoundment #2 Liner Replacement, Midwest Generation, LLC, Joliet Station No. 29:

Title Sheet, Sheet No. TS
Existing Conditions, Sheet C010
Liner Subgrade Preparation, Sheet C020
Warning Layer Plan, Sheet No. C030
Details and Sections, Sheet No. C031

Natural Resource Technology (NRT), 2008. Ash Impoundment #1 Liner Replacement, Midwest Generation, LLC, Joliet Station No. 29:

Warning Layer Plan, Sheet No. C030
Details and Sections, Sheet No. C031

NUS Corporation, 1978. Waste Water Treatment Facilities Joliet 7-8:

Location Plot and Plan, Sheet No. 5079 C 5100.
Ponds & Basins Profiles, Sections & Details, Sheet No. 5079 C 5019, Sheet 2 of 3.
Ponds & Basins Profiles, Sections & Details, Sheet No. 5079 C 5019, Sheet 3 of 3.
Detail Plan – Ash Silo Area, Sheet No. 5079 C 51.
Ash Pond 1 & 2 – Outlet Weirs, Sheet No. 5079 C 5503.
Retaining Wall at Silos – Plan, Sections & Elevations, Sheet 5079 C 5507

NUS Corporation, 1979. Waste Water Treatment Facilities Joliet 7-8:

Site Plan – East Yard Area, Sheet No. 5079 C 5103.
Pipe Support Plan and Details – PS 834, 836 thru 846, Sheet 5079 C 5743

Patrick Engineering, 2011. Hydrogeological Assessment Report, Joliet 29 Generating Station, Joliet, Illinois, Patrick Project No. 21053.070, February.

Ruettiger, Tonelli & Associates, Inc., 2009. Midwest Generation Joliet 29 Power Plant, Ash Impoundments, Ash Pond 2 Subgrade As-Built.

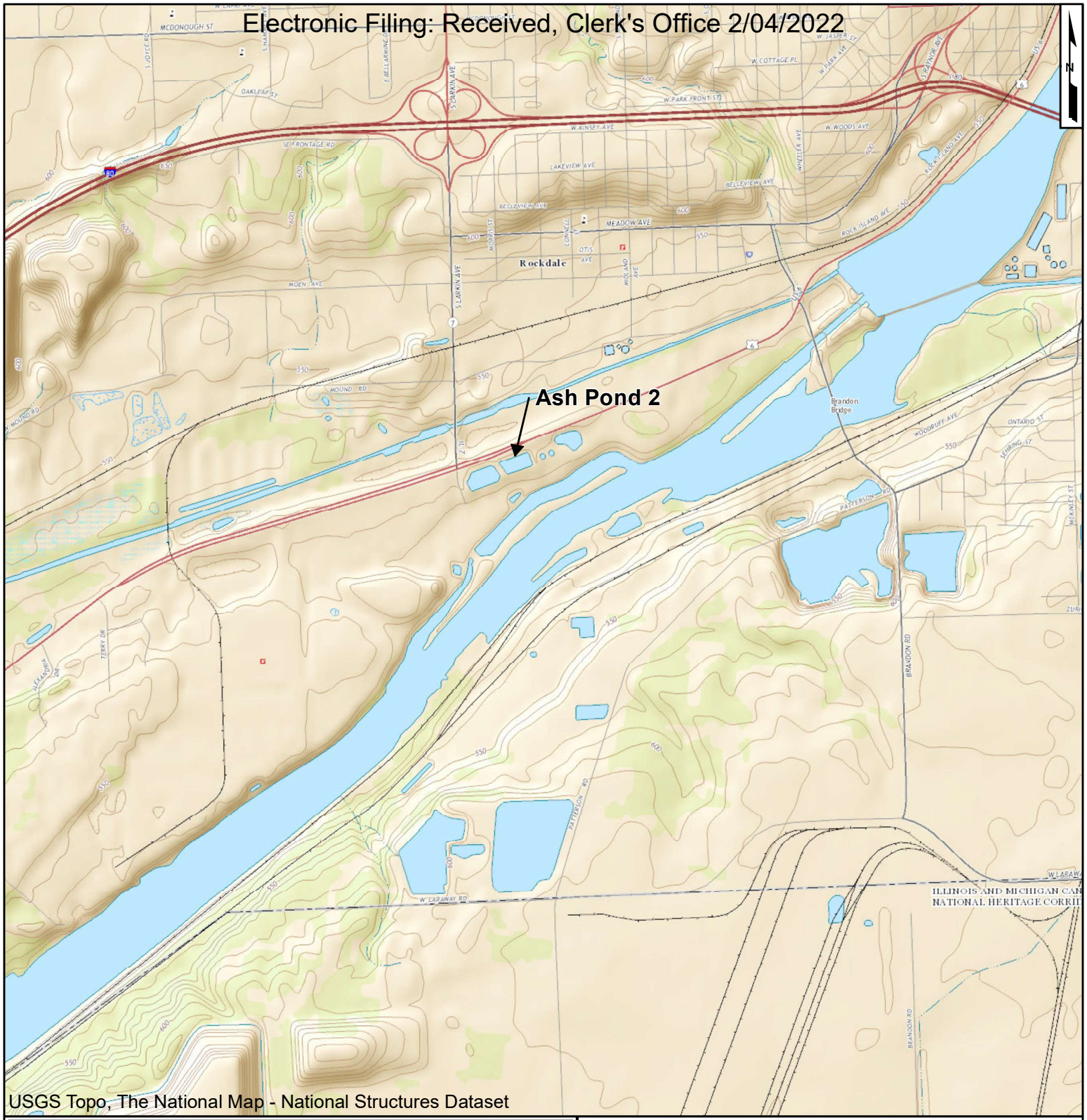
USGS, 2015. "Watershed Boundary Dataset," accessed via The National Map, accessed 1 February 2016.

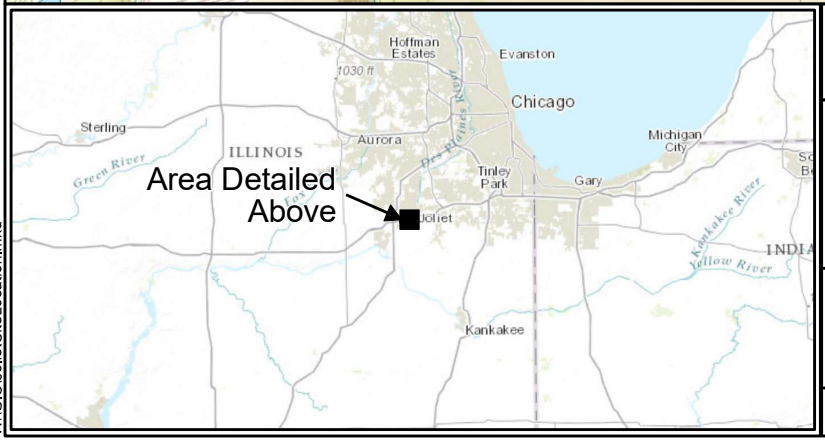
Attachments

Figure 1:	Vicinity Map
Figure 2:	Area-Capacity Curves
Appendix A:	Construction Drawings
Appendix A-1	2016 Additional Fill Drawing
Appendix A-2	NUS Construction Drawings
Appendix A-3	Liner Replacement Construction Drawings
Appendix A-4	Ash Pond 2 Liner Replacement As-Built
Appendix A-5	Pond 1 Liner Replacement Construction Drawings
Appendix B	Technical Specifications

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2,000 1,000 0 2,000 Feet

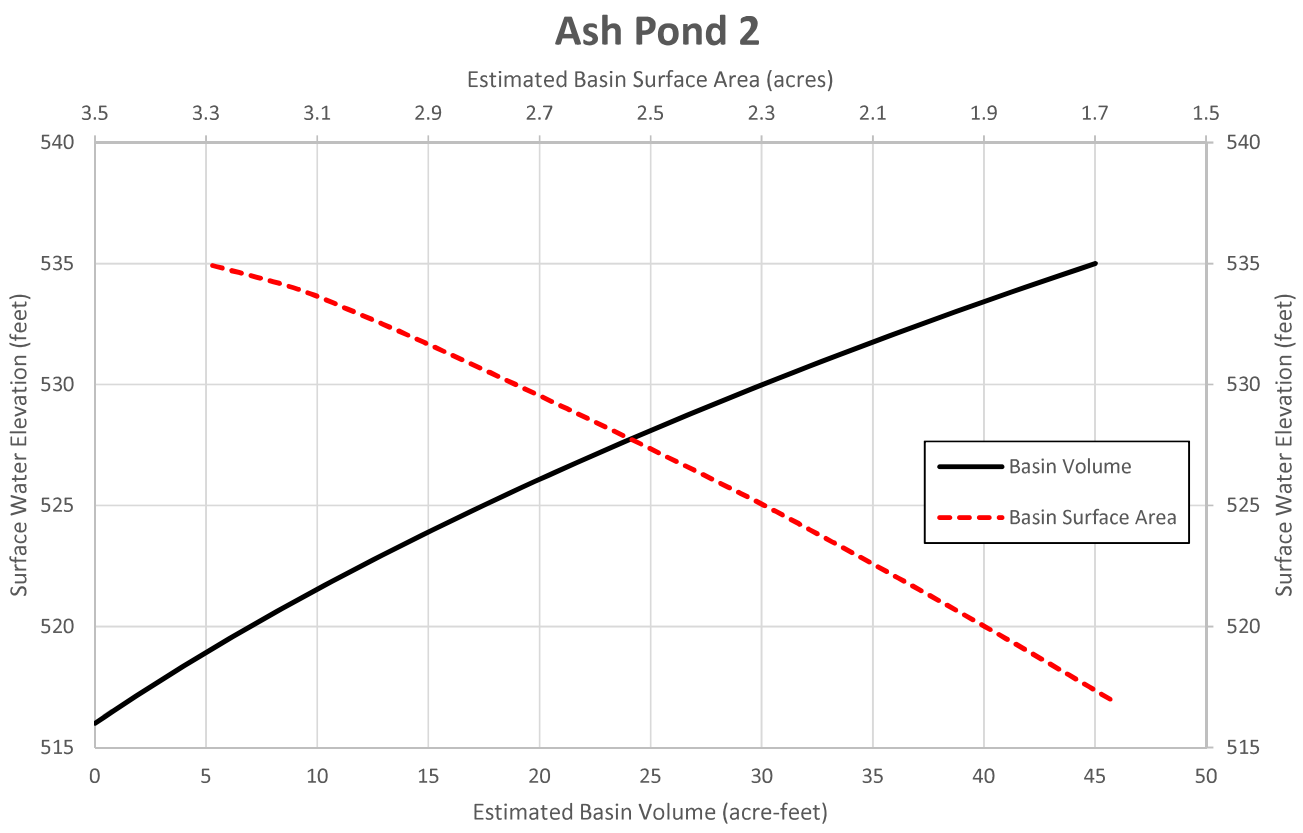
Site Location

Ash Pond 2
Joliet 29 Station
Joliet, Illinois

Geosyntec consultants

San Diego	October 2016	Figure 1

W:\GIS\JolietSiteLocation.mxd



Notes:
(1) Surface water elevations are NAVD88.
(2) Basin volumes are estimated based on as-built information and 2008 site topography.

Geosyntec consultants	AREA-CAPACITY CURVE ASH POND 2 JOLIET 29 STATION JOLIET, ILLINOIS	**FIGURE 2**
OCTOBER 2016		
SW0251-05		

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APPENDIX A

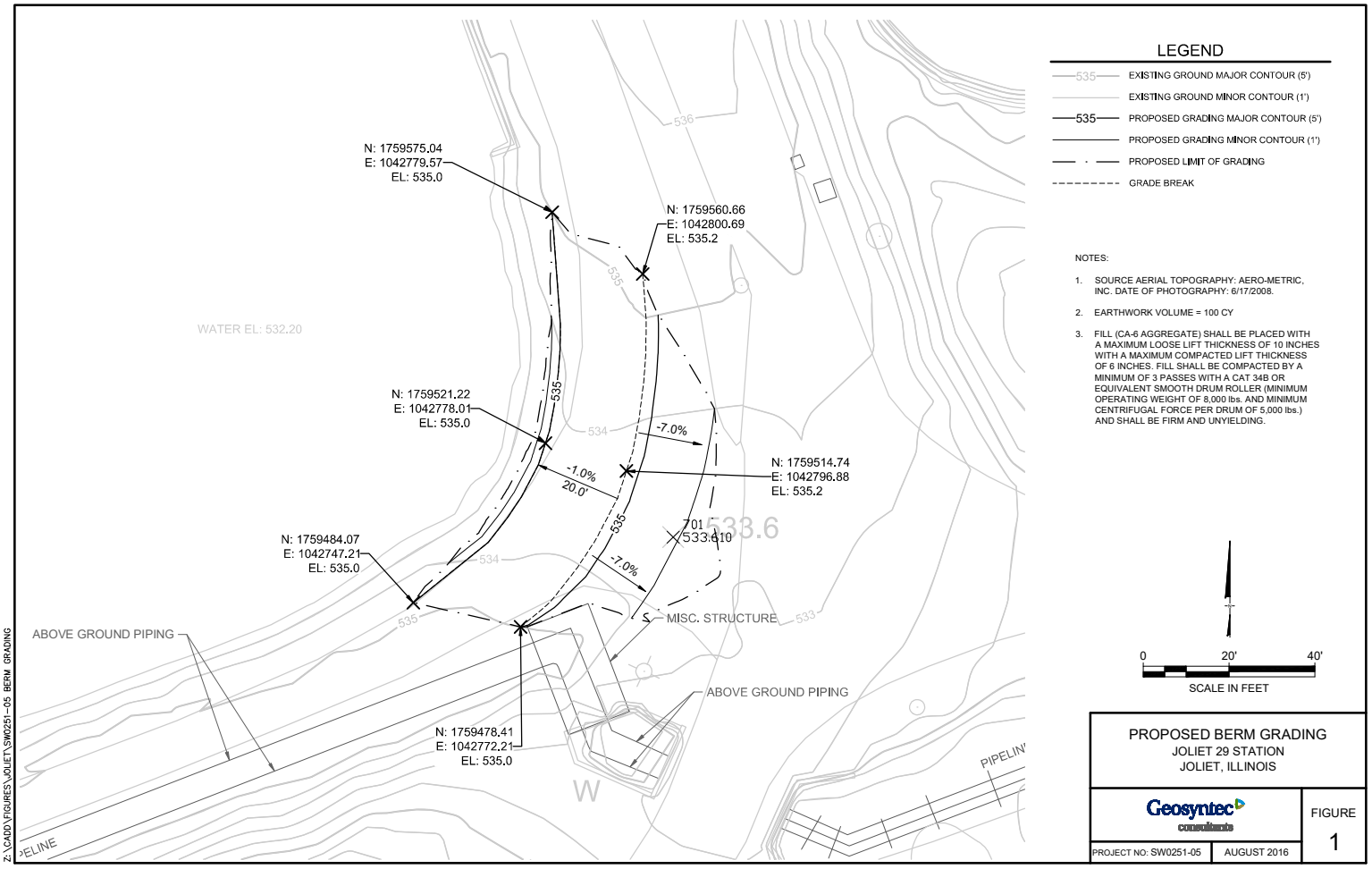
Construction Drawings

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APPENDIX A-1

2016 Additional Fill Drawing

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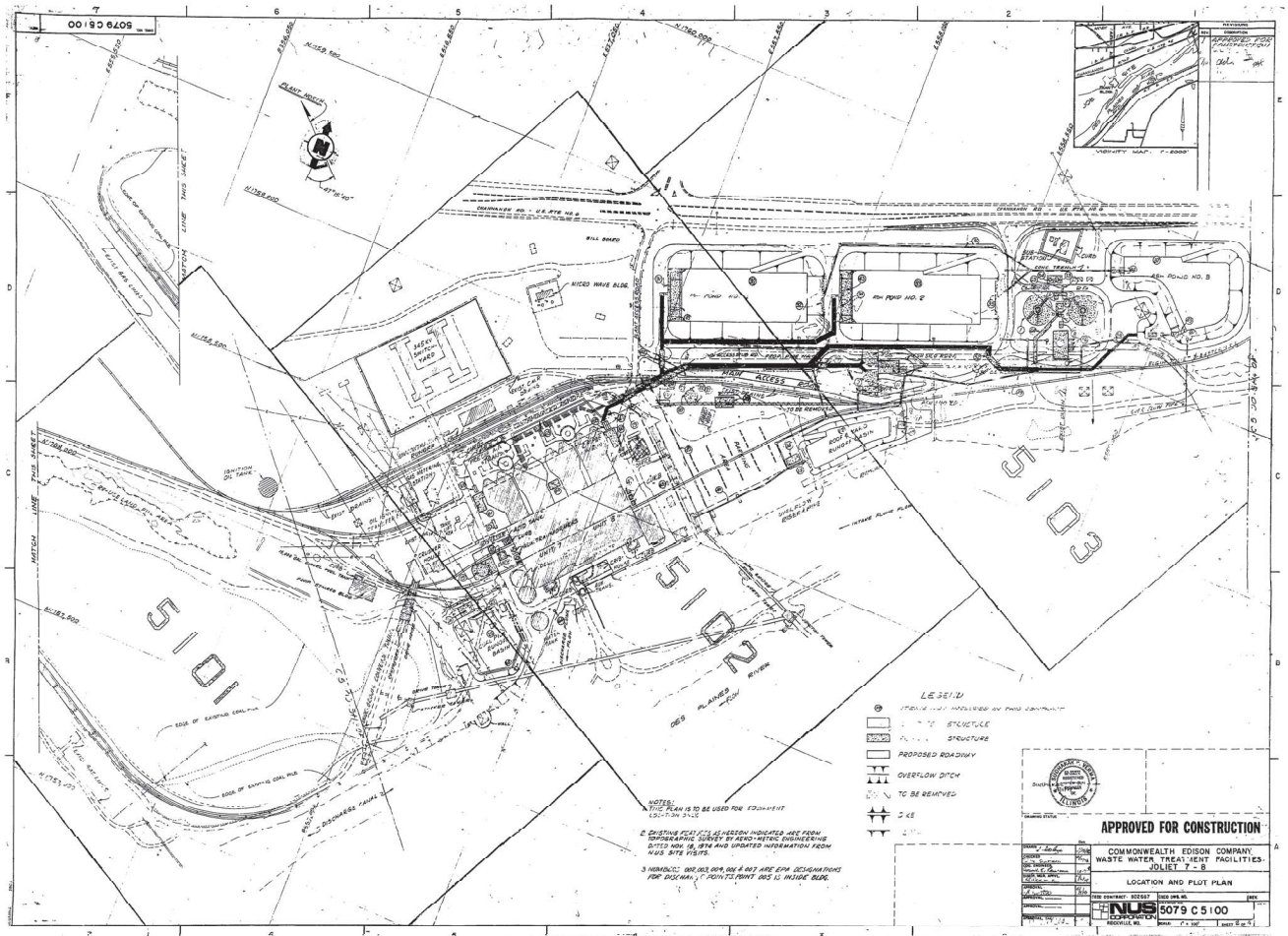


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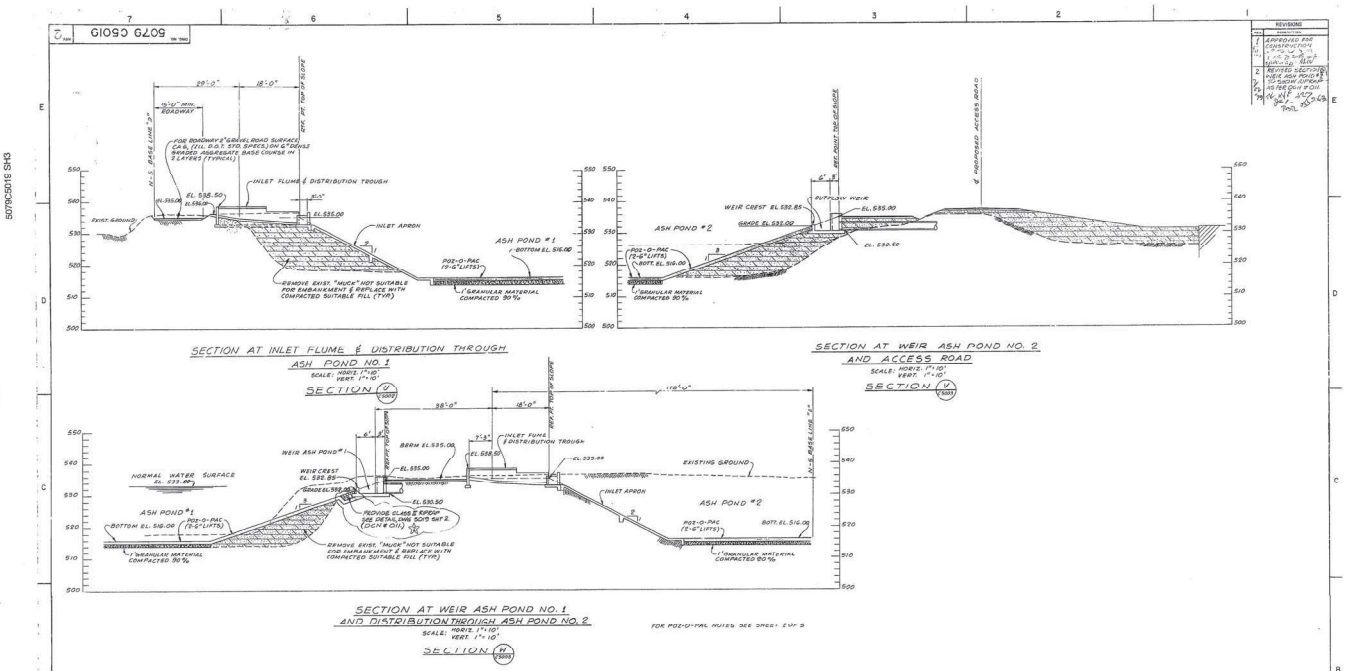
APPENDIX A-2

NUS Construction Drawings

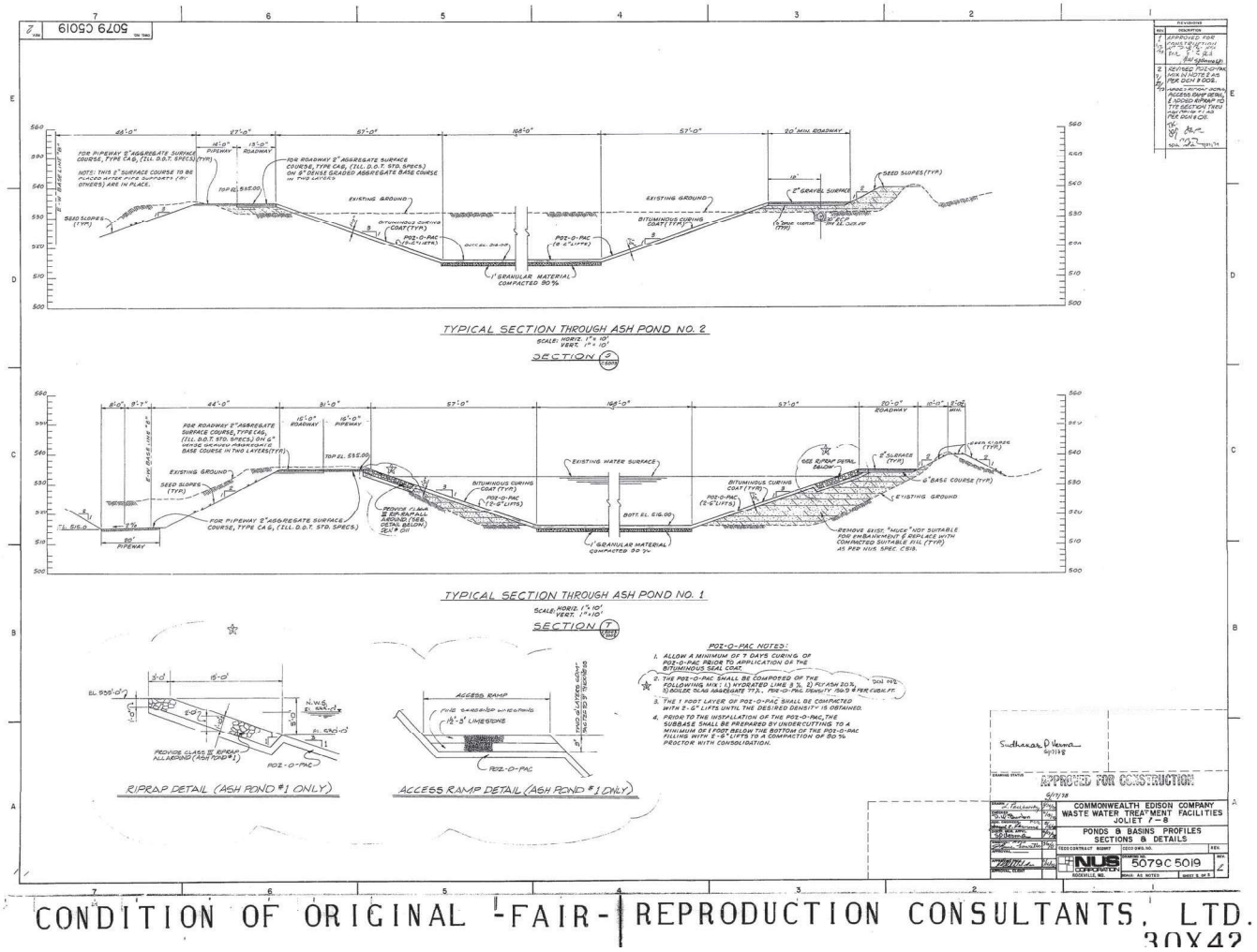
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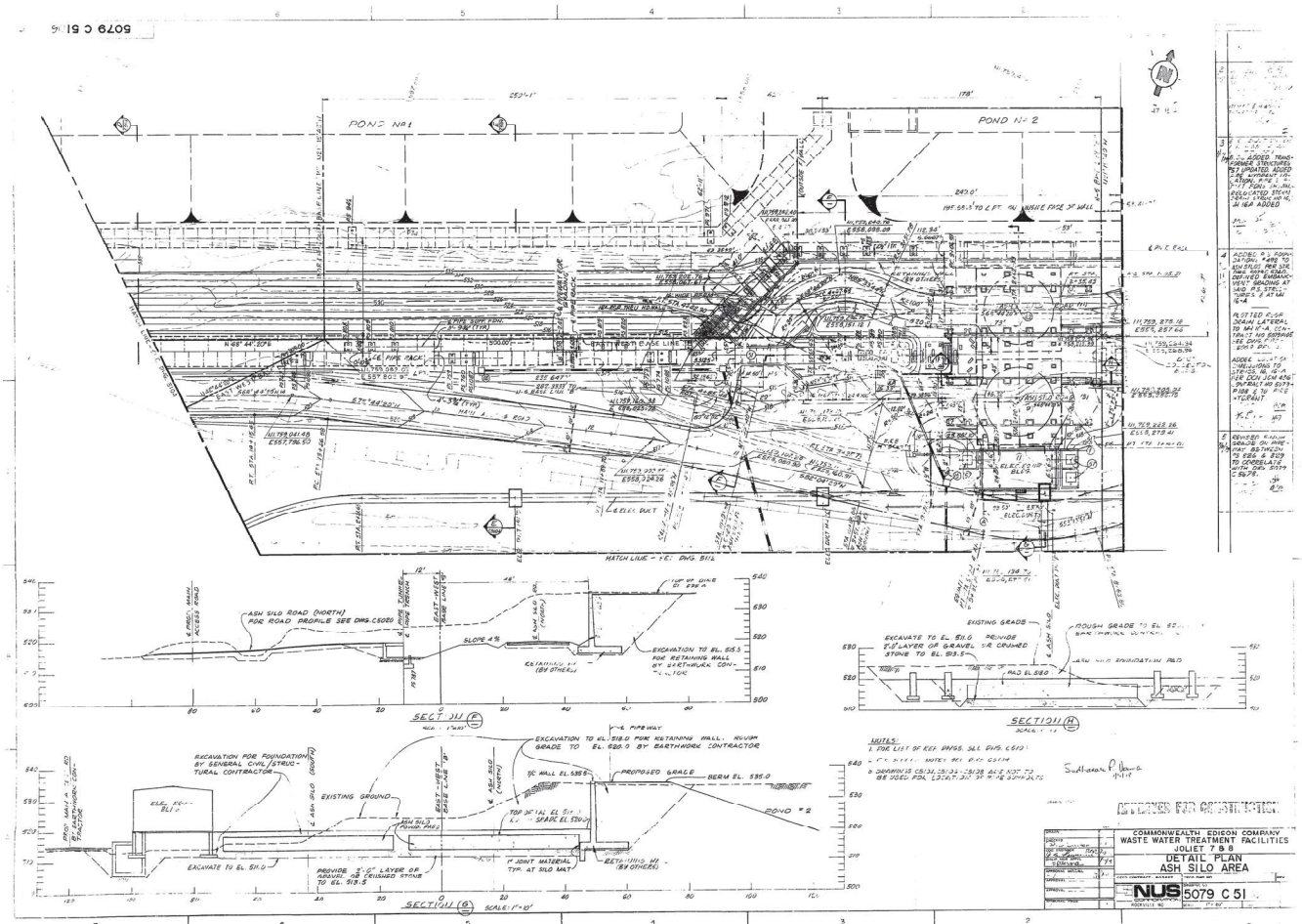
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- BLUELINE PRINT -
30X42



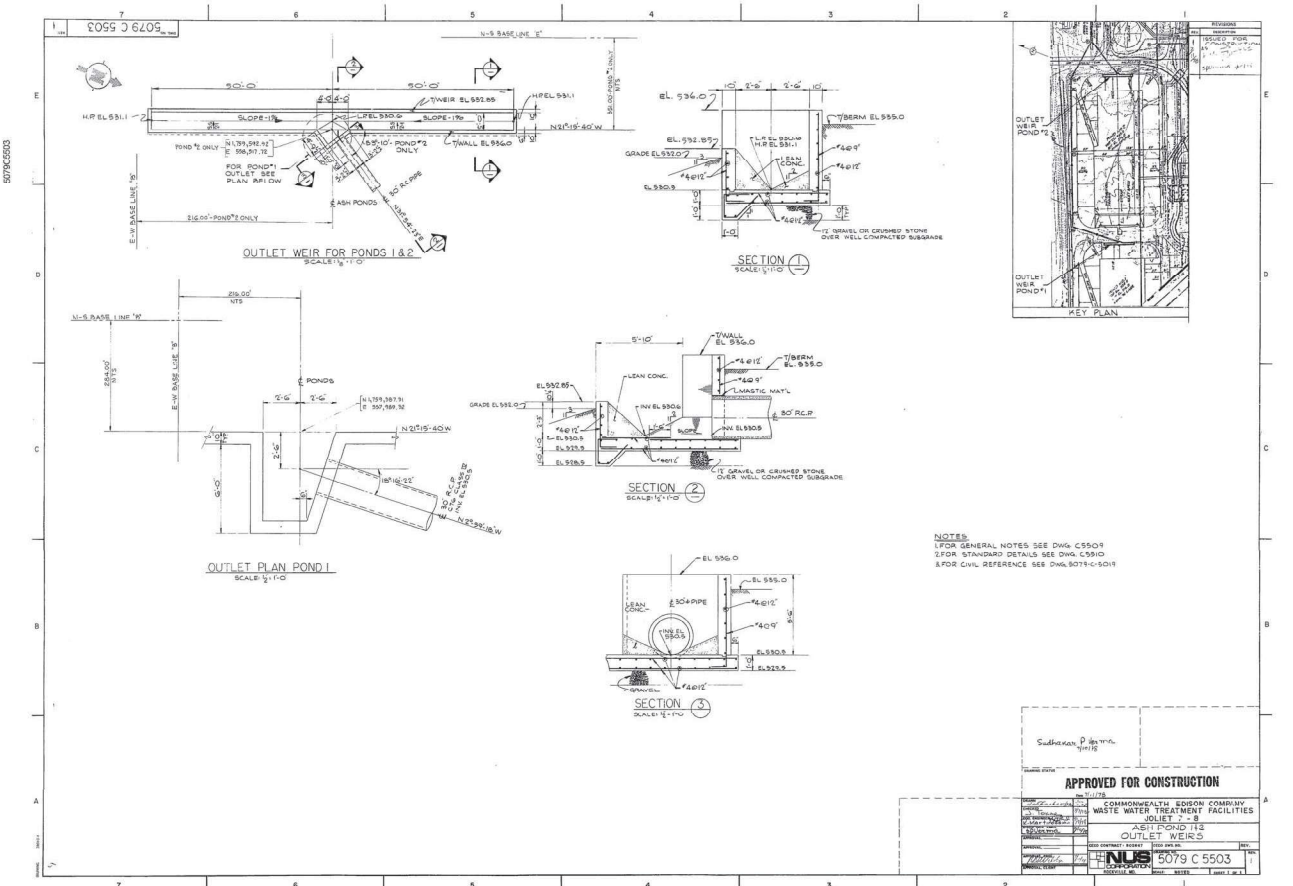
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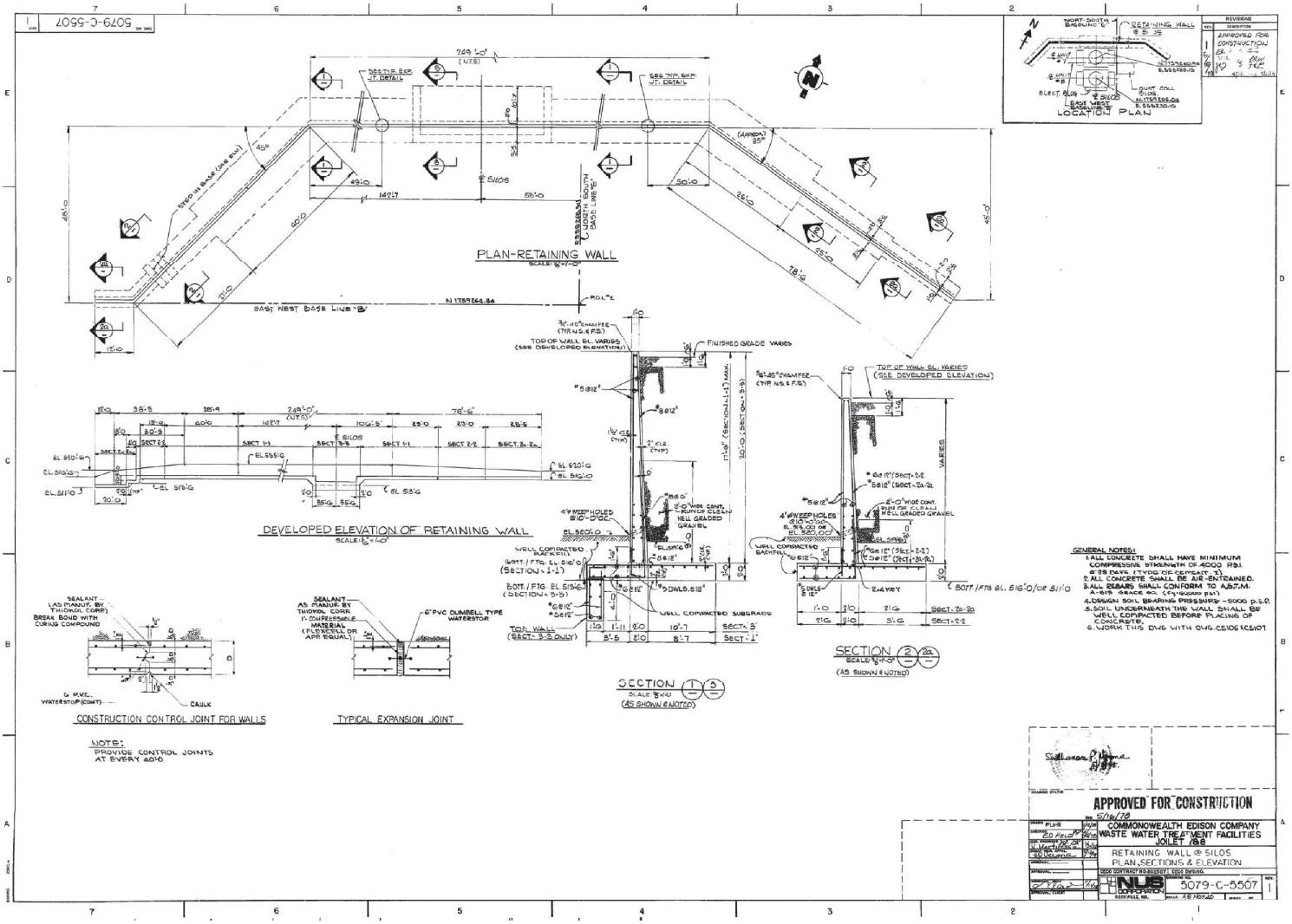
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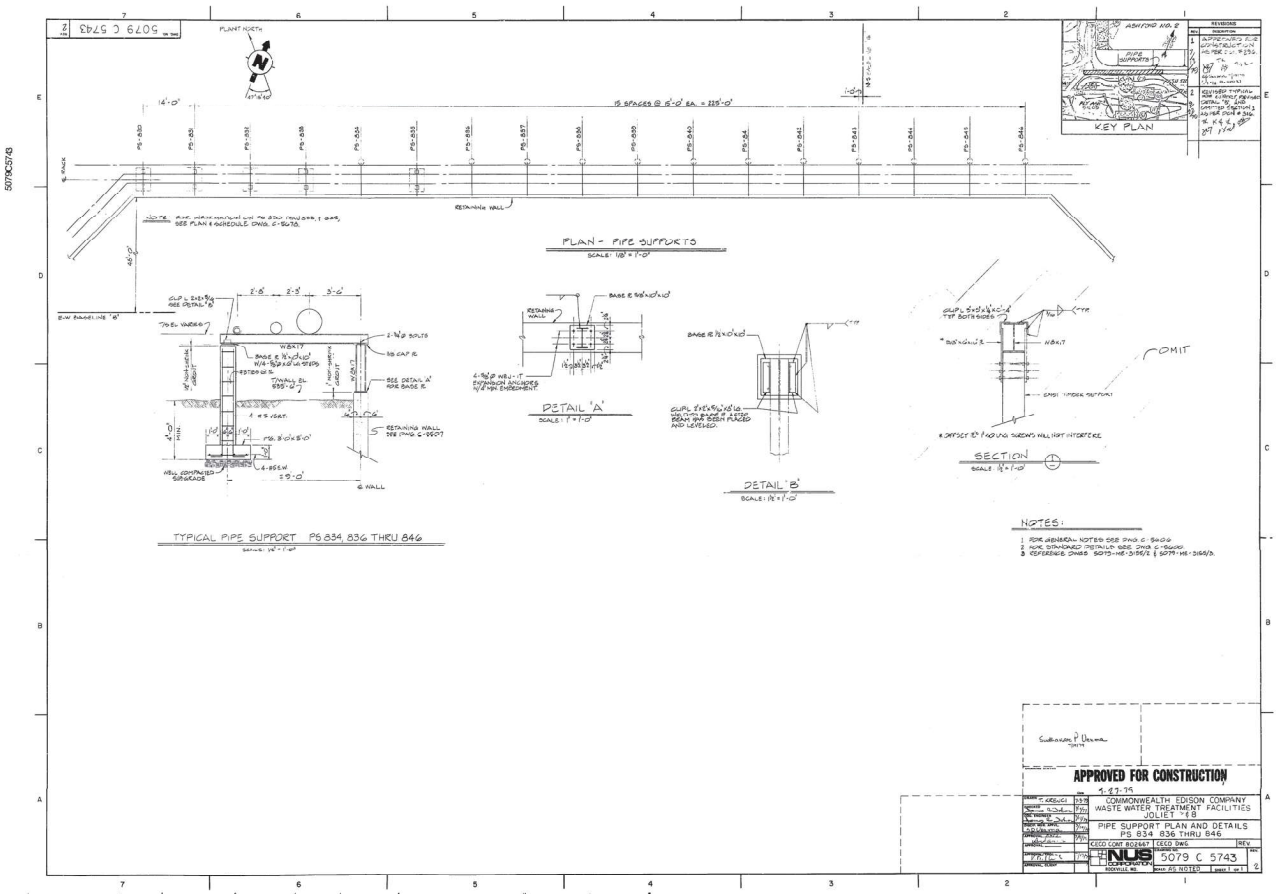
CONDITION OF ORIGINAL "-FAIR-" REPRODUCTION CONSULTANTS, LTD.
30X42


PLAN-RETAINING WALL
SCALE: 1/8"=1'-0"
DEVELOPED ELEVATION OF RETAINING WALL
SCALE: 1/8"=1'-0"
SECTION
SCALE: 1/4"=1'-0"
(AS SHOWN & NOTED)
SECTION
SCALE: 1/4"=1'-0"
(AS SHOWN & NOTED)
LOCATION PLAN
CONSTRUCTION CONTROL JOINT FOR WALLS
TYPICAL EXPANSION JOINT
NOTE:
PROVIDE CONTROL JOINTS AT EVERY 40'-0
GENERAL NOTES:
1. ALL CONCRETE SHALL HAVE MINIMUM COMPRESSIVE STRENGTH OF 4000 PSI. @ 28 DAYS. (TYPE OR CEMENT 2)
2. ALL CONCRETE SHALL BE AIR-ENTRAINED.
3. ALL REBARS SHALL CONFORM TO A.S.T.M. A-615 GRADE 60. (fy=60000 psi)
4. DESIGN SOIL BEARING PRESSURE - 5000 P.S.F.
5. SOIL UNDERNEATH THE WALL SHALL BE WELL COMPACTED BEFORE PLACING OF CONCRETE.
6. WORK THIS DWG WITH DWG. CS106 RCS101
APPROVED FOR CONSTRUCTION
5/16/78
COMMONWEALTH EDISON COMPANY
WASTE WATER TREATMENT FACILITIES
JOLIET #6
RETAINING WALL @ SILOS
PLAN, SECTIONS & ELEVATION
NUS CORPORATION
ROCKVILLE, MD.
5079-C-5507

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CONDITION OF ORIGINAL -FAIR- | REPRODUCTION CONSULTANTS, LTD.
30X42



CONDITION OF ORIGINAL - FAIR - | REPRODUCTION CONSULTANTS. LTD.
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APPENDIX A-3

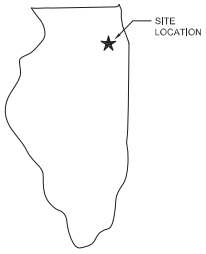
Liner Replacement Construction Drawings

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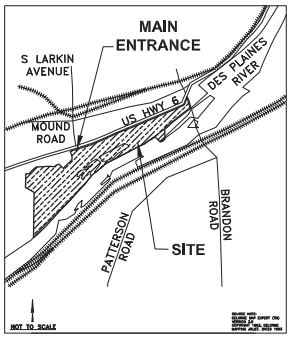
ASH IMPOUNDMENT DESIGN
JOLIET STATION NO. 29
MIDWEST GENERATION
JOLIET, WILL COUNTY, ILLINOIS

LIST OF DRAWINGS

SHEET NO.	TITLE	DRAWING NO.
TS	TITLE SHEET	D1862TS-00
C010	EXISTING CONDITIONS	D1862C010-01
C020	LINER SUBGRADE PREPARATION	D1862C020-01
C030	WARNING LAYER PLAN	D1862C030-01
C031	DETAILS AND SECTIONS	D1862C031-01



ILLINOIS



SITE VICINITY

PREPARED FOR:

MIDWEST GENERATION, LLC
1800 CHANNAHON ROAD
JOLIET, ILLINOIS 60436

NOT FOR CONSTRUCTION

SEPTEMBER 2007

TITLE SHEET

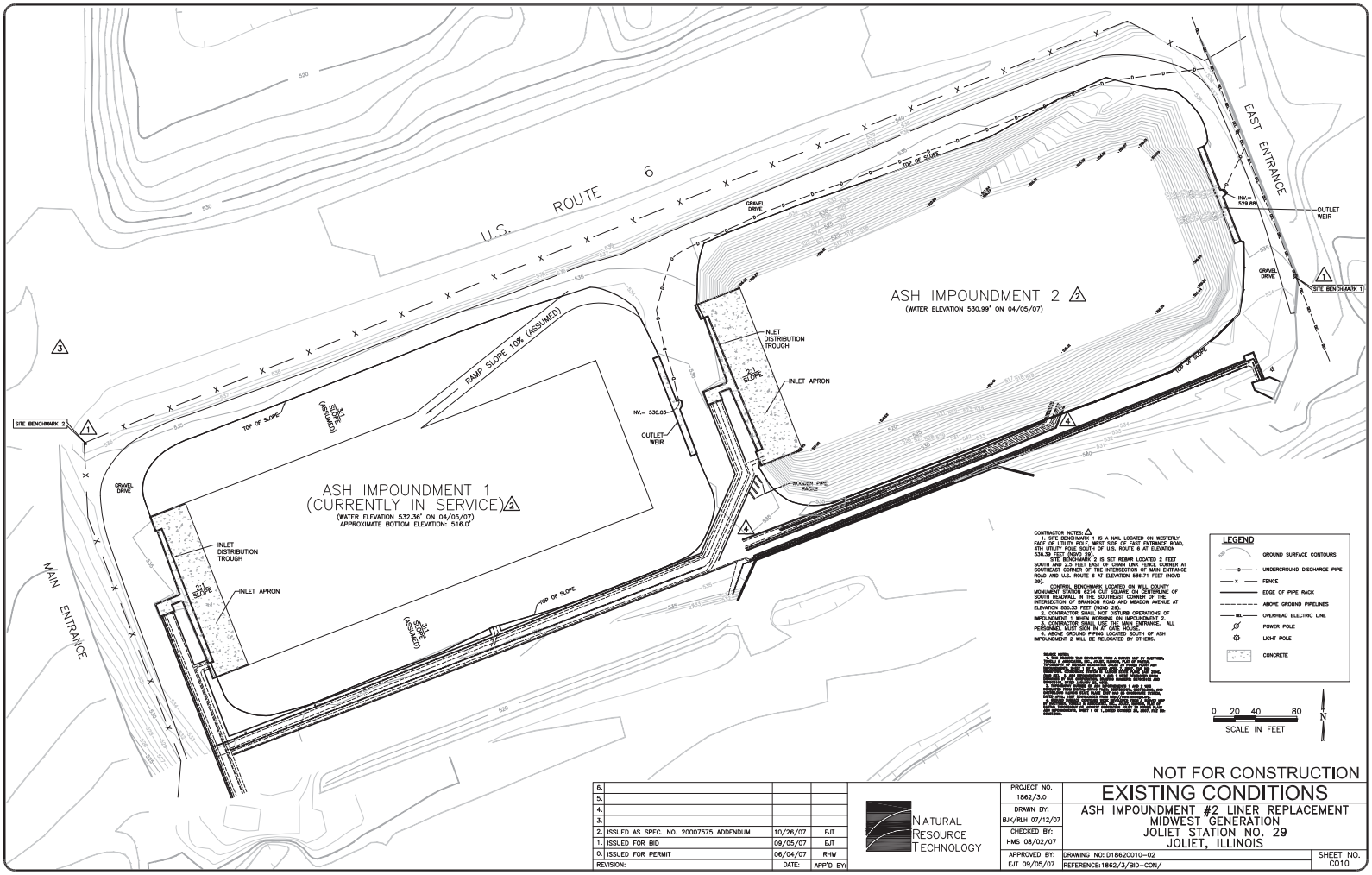
ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

SHEET NO. TS

PROJECT NO. 1862.3.01
DRAWN BY: BJK 07/12/07
CHECKED BY: HMS 09/02/07
APPROVED BY: EJT 09/05/07
DRAWING NO: D1862TS-00
REFERENCE: 1862.3/BID-CON/

NATURAL RESOURCE TECHNOLOGY

REVISION:	DATE:	APP'D BY:
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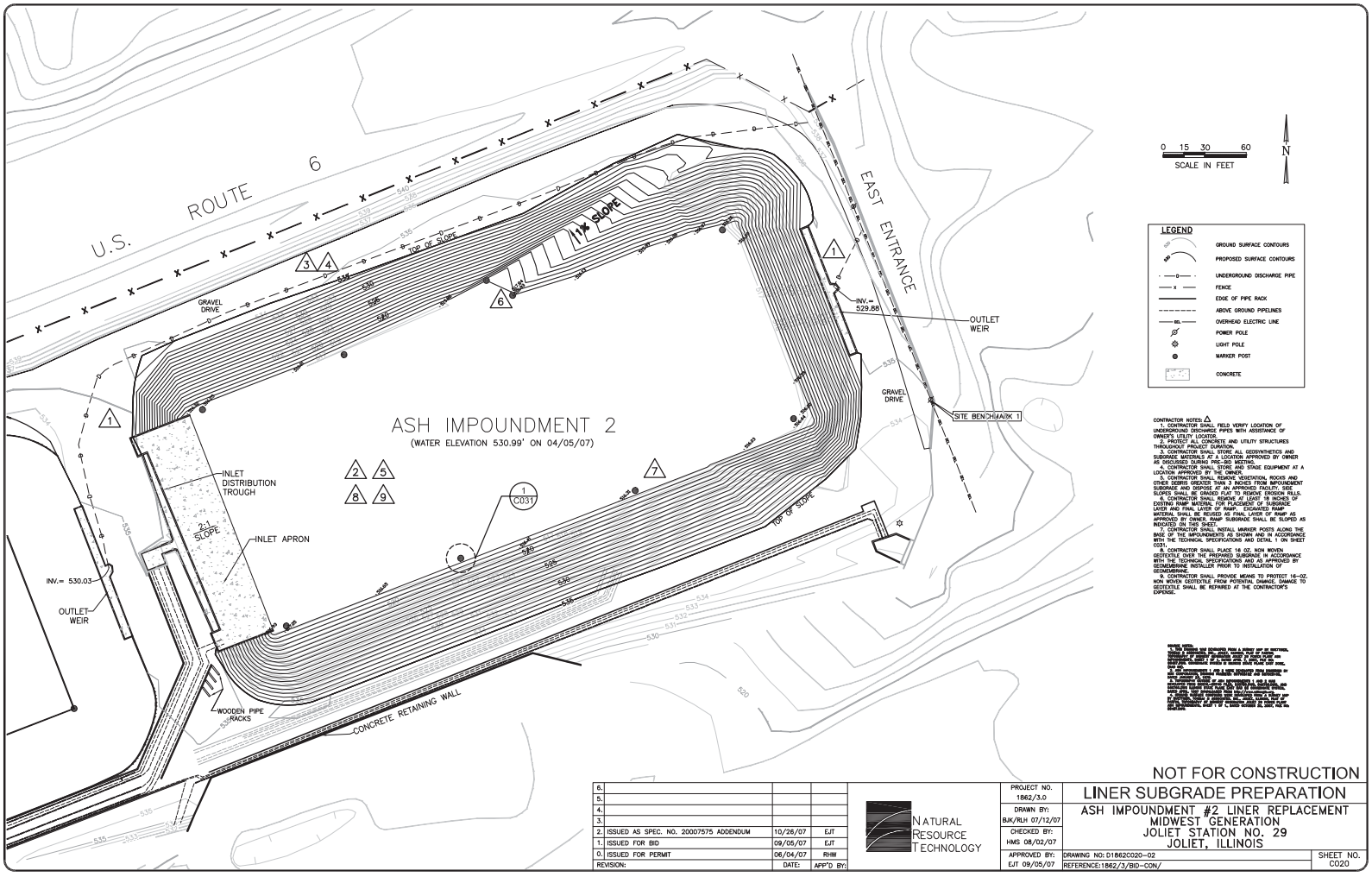
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1. ISSUED FOR BID	09/05/07	EJT
0. ISSUED FOR PERMIT	06/04/07	RHW

NATURAL RESOURCE TECHNOLOGY

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DRAWN BY:	BJK/RLH 07/12/07
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DRAWING NO:	D1862C010-02
REFERENCE:	1862/3/BID-CON/
SHEET NO.	C010

EXISTING CONDITIONS

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS



CONTRACTOR NOTES:

1. CONTRACTOR SHALL FIELD VERIFY LOCATION OF UNDERGROUND DISCHARGE PIPES WITH ASSISTANCE OF OWNER'S UTILITY LOCATOR.
2. PROTECT ALL CONCRETE AND UTILITY STRUCTURES THROUGHOUT PROJECT DURATION.
3. CONTRACTOR SHALL STORE ALL GEOSYNTHETICS AND SUBGRADE SOILS AT A PRE-LOCATION APPROVED BY OWNER AT A DISTANCE NOT TO EXCEED 1 MILE FROM EXISTING.
4. CONTRACTOR SHALL STORE AND STAGE EQUIPMENT AT A LOCATION APPROVED BY THE OWNER.
5. CONTRACTOR SHALL REMOVE VEGETATION, ROCKS AND OTHER DEBRIS GREATER THAN 3 INCHES FROM IMPOUNDMENT SUBGRADE AND DISPOSE AT AN APPROVED FACILITY. SITE SLOPE CONTRACTOR SHALL REMOVE ALL LOOSE, ERODED FILLS.
6. CONTRACTOR SHALL REMOVE A MINIMUM 6" OF EXISTING RAMP MATERIAL FOR PLACEMENT OF SUBGRADE LAYER AND FINAL LAYER OF RAMP. EXCAVATED RAMP MATERIAL SHALL BE REUSED AS FINAL LAYER OF RAMP AS APPROVED BY OWNER. RAMP SUBGRADE SHALL BE SLOPED AS INDICATED ON THIS SHEET.
7. CONTRACTOR SHALL INSTALL MARKER POSTS ALONG THE BASE OF THE IMPOUNDMENTS AS SHOWN AND IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS AND DETAIL 1 ON SHEET C031.
8. CONTRACTOR SHALL PLACE 16 OZ. NON WOVEN GEOTEXTILE OVER THE PREPARED SUBGRADE IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS AND AS APPROVED BY GEOMEMBRANE INSTALLER PRIOR TO INSTALLATION OF GEOMEMBRANE.
9. CONTRACTOR SHALL PROVIDE MEANS TO PROTECT 16-OZ. NON WOVEN GEOTEXTILE FROM POTENTIAL DAMAGE. DAMAGE TO GEOTEXTILE SHALL BE REPAIRED AT THE CONTRACTOR'S EXPENSE.

REVISION:	DATE:	APP'D BY:
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2. ISSUED AS SPEC. NO. 20007575 ADDENDUM	10/26/07	EJT
1. ISSUED FOR BID	09/05/07	EJT
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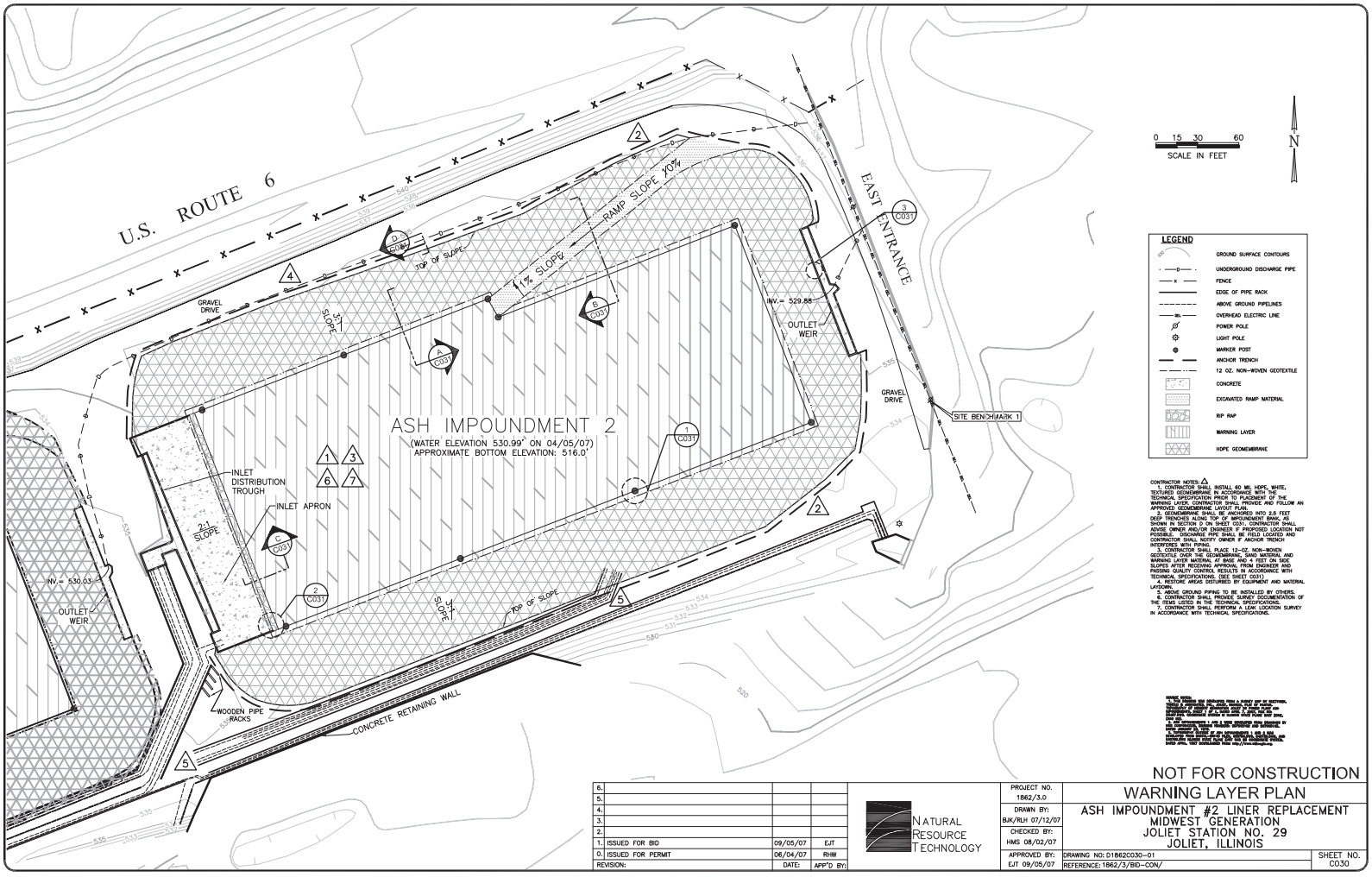
NOT FOR CONSTRUCTION

LINER SUBGRADE PREPARATION

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

DRAWING NO: D1862C020-02
REFERENCE:1862/3/BID-CON/

SHEET NO. C020



CONTRACTOR NOTES:
1. CONTRACTOR SHALL INSTALL 60 MIL HDPE, WHITE, TEXTURED GEOMEMBRANE IN ACCORDANCE WITH THE TECHNICAL SPECIFICATION PRIOR TO PLACEMENT OF THE WARNING LAYER. CONTRACTOR SHALL PROVIDE AND FOLLOW AN APPROVED GEOMEMBRANE LAYOUT PLAN.
2. GEOMEMBRANE SHALL BE ANCHORED INTO 2.5 FEET DEEP TRENCHES ALONG TOP OF IMPOUNDMENT BANK AS SHOWN IN SECTIONS A ON SHEET C031. CONTRACTOR SHALL MINIMIZE WRINKLES IN GEOMEMBRANE TO THE EXTENT NOT POSSIBLE. DISCHARGE PIPE SHALL BE FIELD LOCATED AND CONTRACTOR SHALL NOTIFY OWNER IF ANCHOR TRENCH INTERFERES WITH PIPING.
3. CONTRACTOR SHALL PLACE 12-OZ. NON-WOVEN GEOTEXTILE OVER THE GEOMEMBRANE, SAND MATERIAL AND WARNING LAYER MATERIAL AT BASE AND 4 FEET ON SIDE SLOPES. CONTRACTOR SHALL PERFORM AS REQUIRED AND PASSING QUALITY CONTROL RESULTS IN ACCORDANCE WITH TECHNICAL SPECIFICATIONS, CSEI SHEET C031.
4. RESTORE AREAS DISTURBED BY EQUIPMENT AND MATERIAL LAYDOWN.
5. ABOVE GROUND PIPING TO BE INSTALLED BY OTHERS.
6. CONTRACTOR SHALL PROVIDE SURVEY DOCUMENTATION OF THE ITEMS LISTED IN THE TECHNICAL SPECIFICATIONS.
7. CONTRACTOR SHALL PERFORM A LEAK LOCATION SURVEY IN ACCORDANCE WITH TECHNICAL SPECIFICATIONS.

NOTICE TO CONTRACTOR
1. THE LOCATIONS AND DESCRIPTIONS OF UTILITIES SHOWN ON THESE PLANS ARE APPROXIMATE ONLY AND ARE BASED ON THE RECORDS OF THE VARIOUS UTILITY COMPANIES AND OTHER SOURCES. THE CONTRACTOR SHALL NOTIFY ALL UTILITY COMPANIES AND OTHERS POSSESSING UNDERGROUND FACILITIES IN THE AREA OF THE WORK AT LEAST 48 HOURS BEFORE BEGINNING EXCAVATION. THE CONTRACTOR SHALL ALSO CONTACT THE ILLINOIS ONE CALL SYSTEM, INC. AT 1-800-892-0123 AT LEAST 48 HOURS BEFORE BEGINNING EXCAVATION.

NOT FOR CONSTRUCTION

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REVISION:	DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

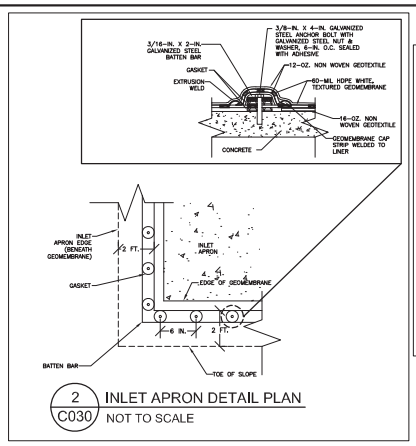
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APPROVED BY:	EJT 09/05/07

WARNING LAYER PLAN

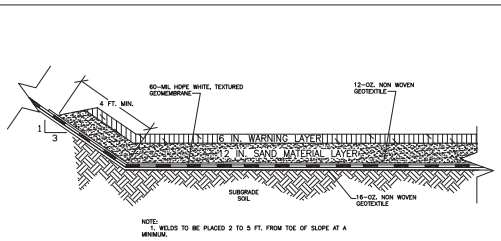
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MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

DRAWING NO: D1862C030-01
REFERENCE: 1862/3/BID-CON/

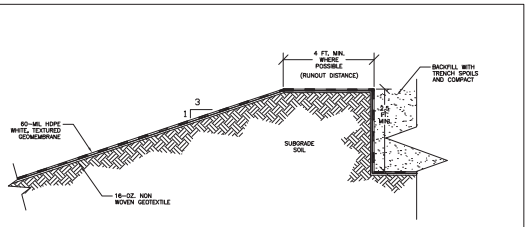
SHEET NO. C030



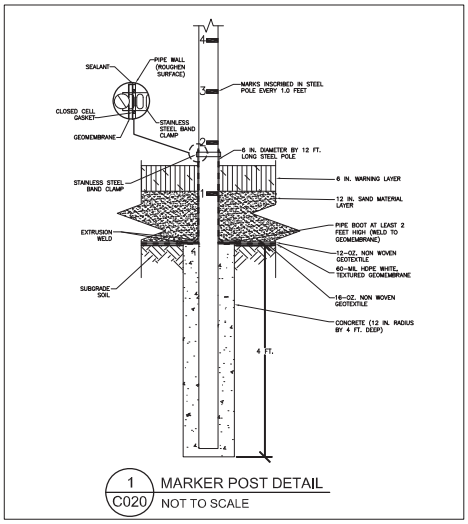
2 C030 INLET APRON DETAIL PLAN
NOT TO SCALE



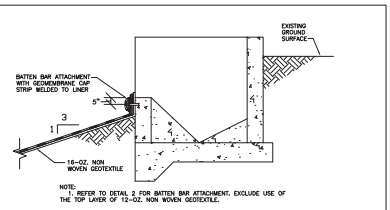
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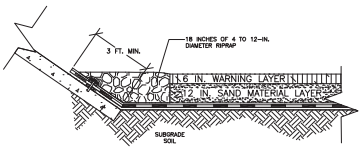
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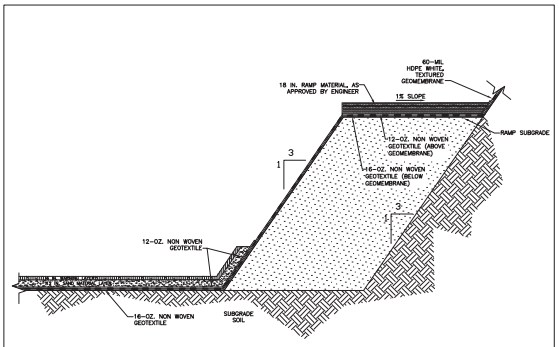
1 C020 MARKER POST DETAIL
NOT TO SCALE



3 C030 OUTLET WEIR DETAIL
NOT TO SCALE



C — INLET APRON SECTION
NOT TO SCALE



B C030 RAMP SECTION
NOT TO SCALE

NOT FOR CONSTRUCTION

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1. ISSUED FOR BID	09/05/07	EJT	
0. ISSUED FOR PERMIT	06/04/07	RHW	
REVISION:	DATE:	APP'D BY:	

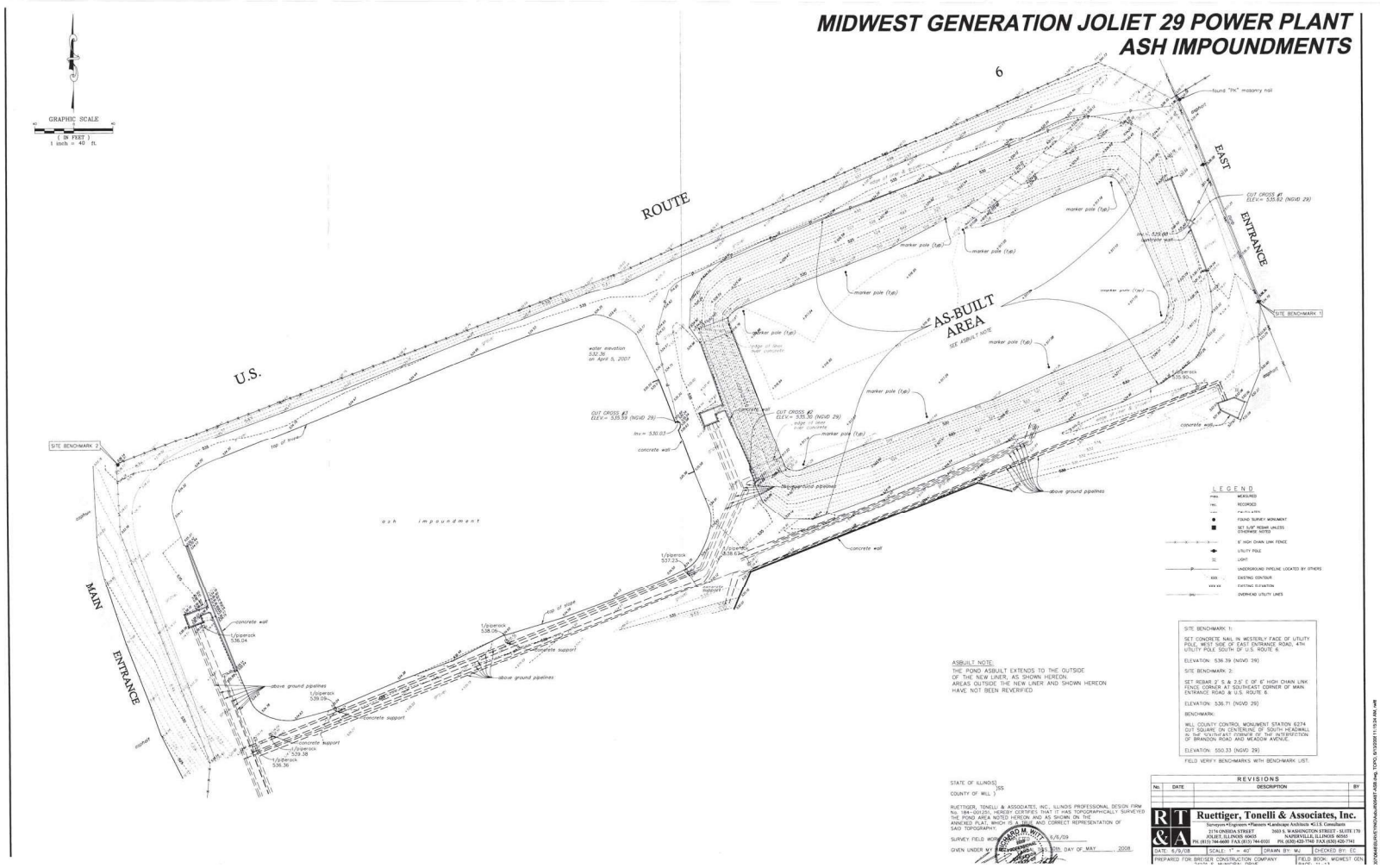
NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/3.0	DETAILS AND SECTIONS
DRAWN BY: BJK/RLH 07/12/07	ASH IMPOUNDMENT #2 LINER REPLACEMENT
CHECKED BY: HMS 08/02/07	MIDWEST GENERATION
	JOLIET STATION NO. 29
	JOLIET, ILLINOIS
APPROVED BY: EJT 09/05/07	DRAWING NO: D1862C031-01
	REFERENCE:1862/3/BID-CON/
	SHEET NO. C031

Electronic Filing: Received, Clerk's Office 2/04/2022

APPENDIX A-4

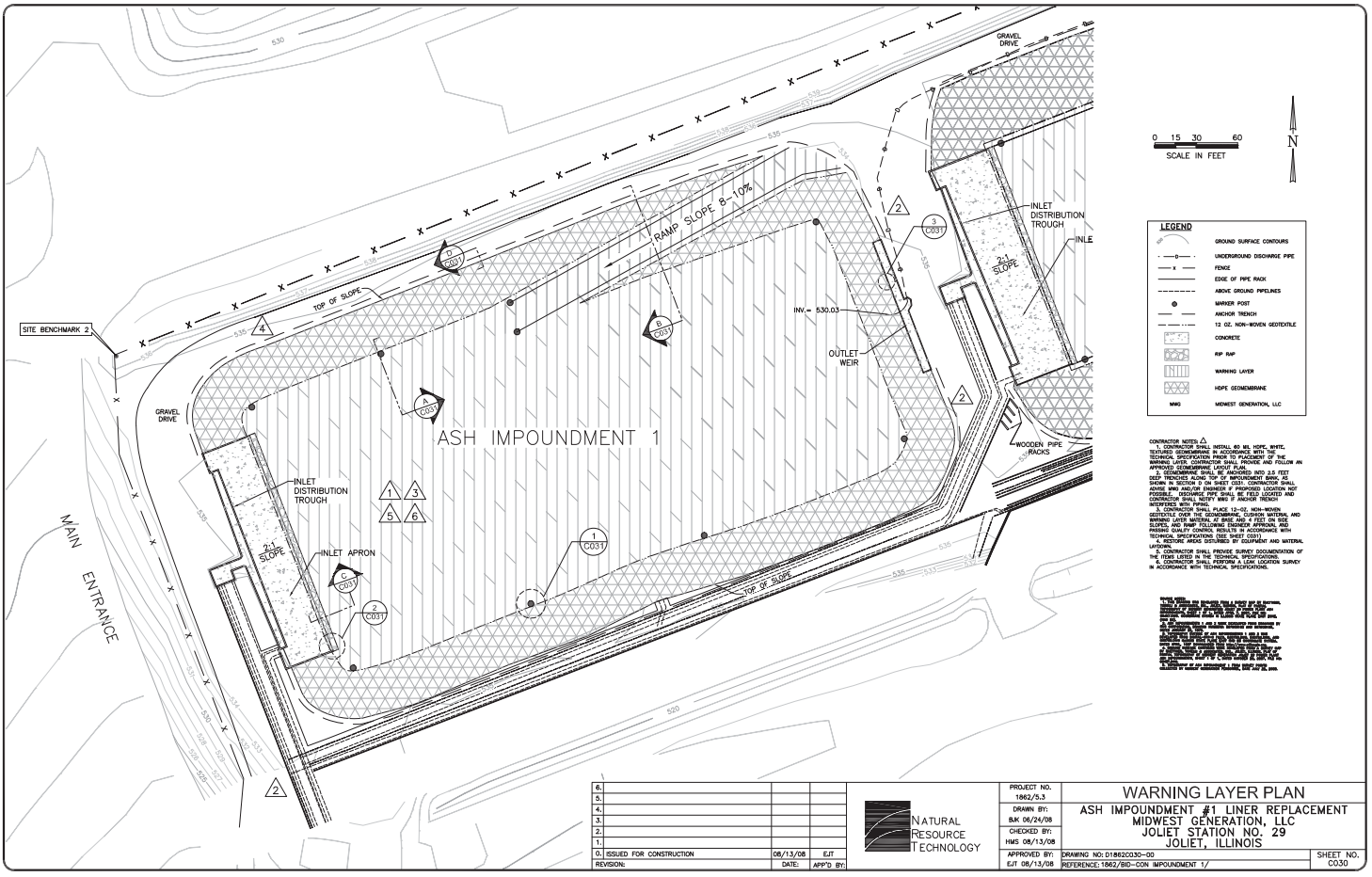
Ash Pond 2 Liner Replacement As-Built


MIDWEST GENERATION JOLIET 29 POWER PLANT
ASH IMPOUNDMENTS
GRAPHIC SCALE
(IN FEET)
1 inch = 40 ft.
ROUTE
U.S.
6
EAST
ENTRANCE
MAIN
ENTRANCE
AS-BUILT
AREA
SEE ASBUILT NOTE
ash impoundment
SITE BENCHMARK 1
SITE BENCHMARK 2
found "PK" masonry nail
CUT CROSS
ELEV.= 535.82 (NGVD 29)
CUT CROSS
ELEV.= 535.59 (NGVD 29)
CUT CROSS
ELEV.= 535.50 (NGVD 29)
water elevation
532.76
on April 5, 2007
concrete wall
above ground pipelines
concrete support
marker pole (typ)
LEGEND
MEASURED
RECORDED
FOUND SURVEY MONUMENT
SET 5/8" REBAR UNLESS
OTHERWISE NOTED
6' HIGH CHAIN LINK FENCE
UTILITY POLE
LIGHT
UNDERGROUND PIPELINE LOCATED BY OTHERS
EXISTING CONTOUR
EXISTING ELEVATION
OVERHEAD UTILITY LINES
ASBUILT NOTE:
THE POND ASBUILT EXTENDS TO THE OUTSIDE OF THE NEW LINER, AS SHOWN HEREON. AREAS OUTSIDE THE NEW LINER AND SHOWN HEREON HAVE NOT BEEN REVERIFIED.
SITE BENCHMARK 1:
SET CONCRETE NAIL IN WESTERLY FACE OF UTILITY POLE, WEST SIDE OF EAST ENTRANCE ROAD, 4TH UTILITY POLE SOUTH OF U.S. ROUTE 6.
ELEVATION: 536.39 (NGVD 29)
SITE BENCHMARK 2:
SET REBAR 2' S. & 2.5' E. OF 6' HIGH CHAIN LINK FENCE CORNER AT SOUTHEAST CORNER OF MAIN ENTRANCE ROAD & U.S. ROUTE 6.
ELEVATION: 536.71 (NGVD 29)
BENCHMARK:
WILL COUNTY CONTROL MONUMENT STATION 6274
CUT SQUARE ON CENTERLINE OF SOUTH HEADWALL IN THE SOUTHEAST CORNER OF THE INTERSECTION OF BRANDON ROAD AND MEADOW AVENUE.
ELEVATION: 550.33 (NGVD 29)
FIELD VERIFY BENCHMARKS WITH BENCHMARK LIST.
STATE OF ILLINOIS }
COUNTY OF WILL } SS
RUETTIGER, TONELLI & ASSOCIATES, INC., ILLINOIS PROFESSIONAL DESIGN FIRM No. 184-001251, HEREBY CERTIFIES THAT IT HAS TOPOGRAPHICALLY SURVEYED THE POND AREA NOTED HEREON AND AS SHOWN ON THE ANNEXED PLAT, WHICH IS A TRUE AND CORRECT REPRESENTATION OF SAID TOPOGRAPHY.
SURVEY FIELD WORK COMPLETED 6/5/09
GIVEN UNDER MY HAND AND SEAL THIS 5th DAY OF MAY, 2008.
REVISIONS
No. DATE DESCRIPTION BY
Ruettiger, Tonelli & Associates, Inc.
Surveyors • Engineers • Planners • Landscape Architects • G.I.S. Consultants
219 ONEIDA STREET JOLIET, ILLINOIS 60435 PH. (815) 744-6600 FAX (815) 744-6100
3600 S. WASHINGTON STREET - SUITE 170 NAPERVILLE, ILLINOIS 60565 PH. (630) 420-7740 FAX (630) 420-7741
DATE: 6/8/08 SCALE: 1" = 40' DRAWN BY: MJ CHECKED BY: EC
PREPARED FOR: BREISER CONSTRUCTION COMPANY FIELD BOOK: MIDWEST GEN

Electronic Filing: Received, Clerk's Office 2/04/2022

APPENDIX A-5

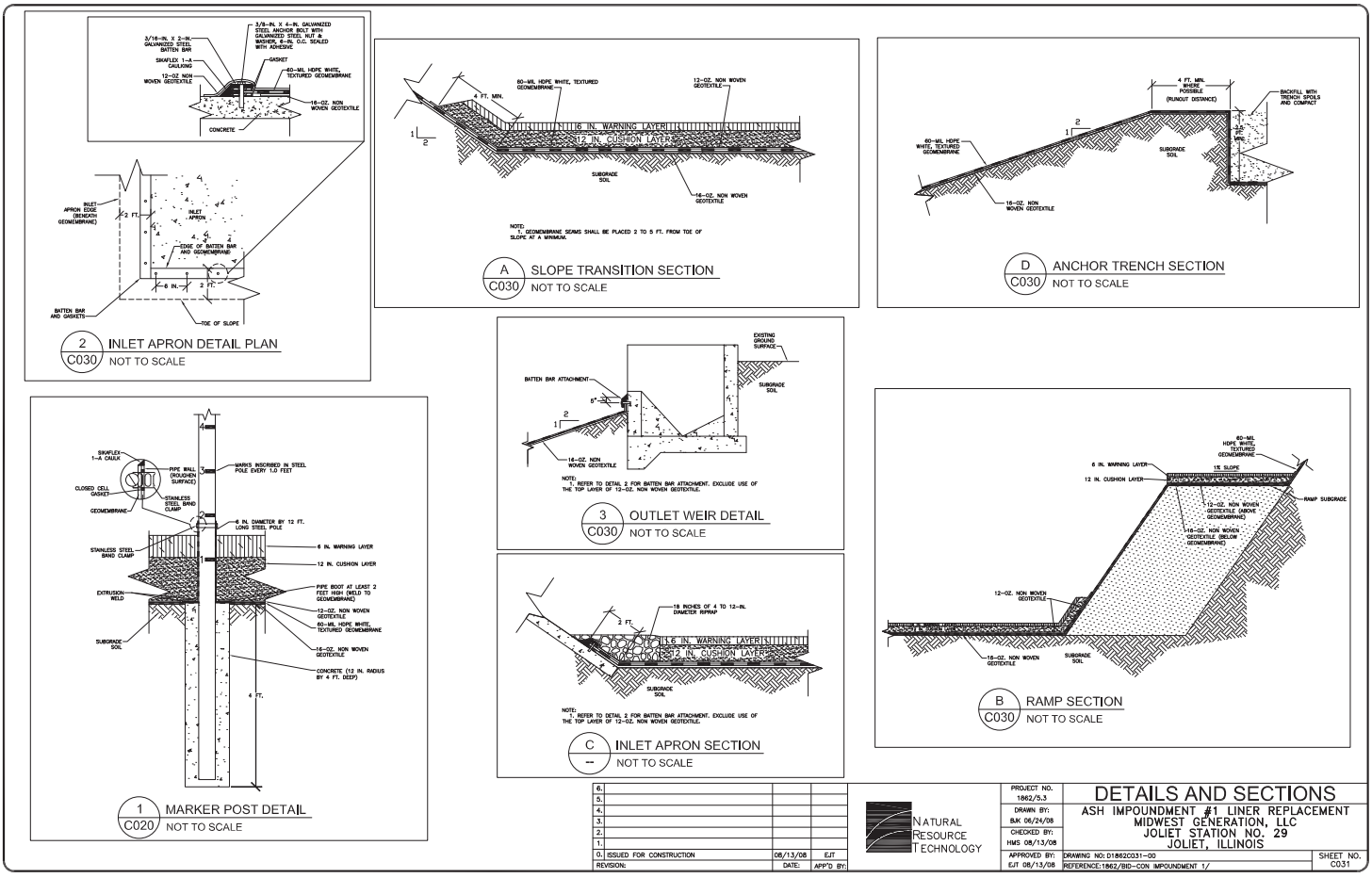
Pond 1 Liner Replacement Construction Drawings



6.			
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0.	ISSUED FOR CONSTRUCTION	08/13/08	EJT
REVISION:		DATE:	APP'D. BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/5.3	WARNING LAYER PLAN
DRAWN BY: BJK 06/24/08	ASH IMPOUNDMENT #1 LINER REPLACEMENT MIDWEST GENERATION, LLC JOLIET STATION NO. 29 JOLIET, ILLINOIS
CHECKED BY: HMS 08/13/08	
APPROVED BY: EJT 08/13/08	DRAWING NO: D1862C030-00
	REFERENCE: 1862/BID-CON IMPOUNDMENT 1/
	SHEET NO. C030



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0.	ISSUED FOR CONSTRUCTION	08/13/08	EJT
REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.	1862/5.3
DRAWN BY:	BJK 06/24/08
CHECKED BY:	HMS 08/13/08
APPROVED BY:	EJT 08/13/08

DETAILS AND SECTIONS

ASH IMPOUNDMENT #1 LINER REPLACEMENT
MIDWEST GENERATION, LLC
JOLIET STATION NO. 29
JOLIET, ILLINOIS

DRAWING NO: D1862C031-00
REFERENCE: 1862/BID-CON IMPOUNDMENT 1/

SHEET NO. C031

Electronic Filing: Received, Clerk's Office 2/04/2022

APPENDIX B

Technical Specifications

Electronic Filing: Received, Clerk's Office 2/04/2022

SECTION 02600
HIGH DENSITY POLYETHYLENE (HDPE) GEOMEMBRANE

PART 1 - GENERAL

1.01 WORK INCLUDES

A. Furnish all labor, materials, tools, supervision, transportation, and installation equipment necessary for installation of 60-mil High Density Polyethylene (HDPE) geomembrane, as specified herein, and as shown on Contract Drawings.

1.02 REFERENCE STANDARDS

A. ASTM D1004 – Test Method for Initial Tear Resistance of Plastic Film and Sheeting.

B. ASTM D1238 – Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.

C. ASTM D1505 – Test Method for Density of Plastics by the Density-Gradient Technique.

D. ASTM D1603 – Test Method for Carbon Black in Olefin Plastics.

E. ASTM D4833 – Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.

F. ASTM D5199 – Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

G. ASTM D5397 – Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test.

H. ASTM D5596 – Test Method for Microscopic Evaluation of Dispersion of Carbon Black in Polyolefin Geosynthetics.

I. ASTM D5994 Standard Test Method for Measuring Core Thickness of Textured Geomembranes.

J. ASTM D6392 –Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods.

K. ASTM D6693 Standard Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes.

L. GRI Test Method, GM 13 - Test Methods, Test Properties and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes

M. GRI Test Method, GM 14 – Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes.

N. GRI Test Method, GM 19 – Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes.

1.03 DEFINITIONS

A. Geomembrane Installer: hired by Contractor or Owner responsible for field handling, transporting, storing, deploying, seaming and testing of the geomembrane seams.

B. Geomembrane Manufacturer: hired by Geomembrane Installer to provide HDPE geomembrane.

C. Geosynthetic Quality Assurance Consultant: Consultant, independent from the Owner, Manufacturer, and Installer, responsible for field oversight of geosynthetics installation, and related testing, usually under the direction of the Owner.

D. Geosynthetic Quality Assurance Laboratory (Testing Laboratory): Party, independent from the Owner, Manufacturer and Installer, responsible for conducting laboratory tests on samples of geosynthetics obtained at the site or during manufacturing, usually under the direction of the Owner.

D. Lot: A quantity of resin (usually the capacity of one rail car) used in the manufacture of geomembranes. Finished roll will be identified by a roll number traceable to the resin lot used.

E. Resin Supplier: selected by Geomembrane Manufacturer to provide resin used in manufacturing geomembrane.

F. Panel: Unit area of a geomembrane that will be seamed in the field that is larger than $100ft^2$.

G. Patch: Unit area of a geomembrane that will be seamed in the field that is less than $100ft^2$.

H. Subgrade Surface (Bedding Layer): Soil Layer surface which immediately underlies the geosynthetic material(s).

1.04 QUALITY ASSURANCE

A. Qualifications:

1. Geomembrane Installer:

a. 5 years of continuous experience in installation of HDPE geomembrane.

b. Experience totaling a minimum of 5,000,000 square feet of installed HDPE geomembrane on some combination of at least 10 completed facilities.

c. Personnel performing seaming operations qualified by experience or by successfully passing seaming tests. Master seamer shall have experience

seaming a minimum of 3,000,000 square feet of geomembrane using same type of seaming apparatus to be used on this project.

B. Quality Assurance Program:

1. Geomembrane Manufacturer/Installer shall conform with requirements of these Technical Specifications.

2. The Engineer will document geomembrane installation including panel placement, seaming, pre-qualification seam testing, non-destructive seam and repair testing, repair size and locations, weather conditions.

3. The Owner will engage and pay for the services of a Geosynthetic Quality Assurance Consultant and Laboratory to monitor geomembrane installation.

1.05 SUBMITTALS

A. Prior to project start, submit the following to Geosynthetic Quality Assurance Consultant in accordance with Section 01300, Submittals:

1. Raw Materials:

a. Name of Resin Supplier, location of supplier's production plant(s), resin brand name and product number.

b. Source and nature of plasticizers, fillers, carbon black and any other additives along with their percent addition to geomembrane material.

c. Test results documenting conformance with the "index properties" of GRI Test Method, GM 13.

2. Geomembrane Manufacturer's Certification:

a. Written certification that Geomembrane Manufacturer's Quality Control Plan was fully implemented during production of geomembrane material supplied for this project. (Submittal shall be made within 5 working days of delivery to site).

3. Geomembrane Installer's Seaming Personnel

a. Corporate background information indicating compliance with qualification requirements.

b. Training completed by personnel.

c. Seaming experience for each personnel.

4. Geomembrane Manufacturer Production Information:

a. Corporate background information indicating compliance with qualification requirements.

b. Quality control plan for manufacturing.

c. Copy of quality control certificates demonstrating compliance with the quality control plan for manufacturing and the test property requirements of GRI Test method, GM 13 (i.e. mill certificates).

5. Geomembrane Installer's Information:

a. Corporate background information indicating compliance with qualification requirements.

b. List of completed facilities, totaling 5,000,000 square feet minimum for which Geomembrane Installer has completed installation of a HDPE geomembrane. Include name and purpose of facility, location, date of installation, and quantity installed.

c. Resumes of personnel performing field seaming operation, along with pertinent experience information. Include documentation regarding which seamers are qualified to use thermal fusion welding apparatus.

d. Installation quality control plan.

6. Installation panel layout diagram identifying placement of geomembrane panels, seams, and any variance or additional details which deviate from Contract Drawings or Technical Specifications. Layout shall be drawn to scale and shall be adequate for use as a construction plan. Layout shall include dimensions and pertinent seam and anchorage details.

7. Installation Sequence and Schedule shall be included as part of Construction Progress Schedule.

8. Description of seaming apparatus to be used indicating compliance with specified requirements.

B. During installation, submit the following to the Geosynthetic Quality Assurance Consultant:

1. Daily records/logs prepared by Geomembrane Installer documenting work performed, personnel involved, general working conditions, and any problems encountered or anticipated on project. Submit on a weekly basis.

2. Copy of subgrade acceptance signed by Geomembrane Installer for areas to be covered with geomembrane each day.

C. Within 10 days of geomembrane installation completion, submit the following to Geosynthetic Quality Assurance Consultant:

1. Geomembrane installation certification that Work was performed under Geomembrane Installer's approved quality control plan and in substantial compliance with Technical Specifications and Contract Drawings.

2. As-built panel diagram identifying placement of geomembrane panels, seams, repairs, and destructive seam sample locations.

3. Copy of warranty for material (including factory seams) and installation covering both for a period of 2 years from the date of substantial completion.

D. The Geosynthetic Quality Assurance Consultant will review and inspect HDPE geomembrane installation upon completion of all Work specified in this Section. Deficiencies noted shall be corrected at no additional cost to the Owner.

E. The Geosynthetic Quality Assurance Consultant will provide written final acceptance of the geomembrane installation after completion of material placement above geomembrane. Written conditional geomembrane installation acceptance can be provided to the Contractor prior to completion of material placement above geomembrane when the following conditions are satisfied, if necessary, and requested by the Contractor:

1. The entire geomembrane installation is completed or any pre-determined subsection if the project is phased.

2. All installation quality assurance/control documentation has been completed and submitted to the Geosynthetic Quality Assurance Consultant or Owner.

3. Verification of the adequacy of all field seams, repairs and associated testing is complete.

1.06 DELIVERY, STORAGE, AND HANDLING

A. Transportation:

1. Geomembrane rolls shall be transported, unloaded and handled at the job site in accordance with manufacturer recommendations. Damaged material may be rejected by the Geosynthetic Quality Assurance Consultant. Manufacturer packaging shall be labeled in accordance with Section 02700, 2.02G.

B. On-site Storage:

1. Geomembrane rolls which have been delivered to job site shall be unloaded and stored in original, unopened packaging in a secure location, determined by Owner and/or Geosynthetic Quality Assurance Consultant.

2. Store geomembrane rolls to ensure adequate protection against exposure to the following:

a. Equipment;

b. Strong oxidizing chemicals, acids, or bases;

c. Flames, including welding sparks;

d. Temperatures in excess of 160 deg. F;

e. Dust;

f. Ultraviolet radiation (i.e. sunlight); and

g. Inclement weather.

3. Whenever possible, provide a 6-inch minimum air space between rolls.

4. Containers/rolls shall not be stacked.

C. On-Site Handling:

1. Handle rolls per Geomembrane Manufacturer's recommendations and as necessary to prevent damage.

PART 2 - PRODUCTS

2.01 MATERIALS

A. High Density Polyethylene (HDPE) White Textured Geomembrane.

1. HDPE geomembrane shall be white, textured, 60-mil product approved by the Engineer and/or Geosynthetic Quality Assurance Consultant.

2. The Contractor shall submit, with the bid, written certification from the proposed Geomembrane Manufacturer that geomembrane products proposed in the bid satisfy the following requirements:

a. The proposed Geomembrane Manufacturer shall have a minimum of 5 years of continuous experience manufacturing HDPE geomembrane totaling 1,000,000 square feet.

b. The proposed HDPE compound shall be comprised entirely of virgin materials. Compliance with this specification shall be documented in accordance with Geomembrane Manufacturer's quality control program and submitted to the Geosynthetic Quality Assurance Consultant with the written conformance certification.

c. The proposed Geomembrane Manufacturer shall certify that any plasticizers, fillers and additives incorporated into the manufacturing process for the proposed HDPE geomembrane have demonstrated acceptable performance on past projects.

d. The proposed geomembrane shall meet the requirements of Geosynthetic Research Institute's test method GM 13.

e. The nominal thickness of proposed geomembrane shall be 60 mil., or as approved by the Engineer and/or Geosynthetic Quality Assurance Consultant.

3. Geomembrane sheets shall be visually consistent in appearance and shall contain no holes, blisters, undisbursed raw materials or other signs of contamination by foreign material. Geomembrane must have no striations, roughness or bubbles on the surface.

B. Seaming Apparatus

1. Thermal fusion welding machines used for joining geomembrane surfaces may be either extrusion or hot wedge. These machines shall include sufficient temperature and rate-of-travel monitoring devices to allow continuous monitoring of operating conditions.

2. One spare, operable thermal fusion seaming device shall be maintained on site at all times.

C. Field Test Equipment

1. Field Tensiometer: the field tensiometer shall be calibrated within three months prior to project start date over the range of field test values.

2. Air Channel Test Equipment: air channel test equipment shall consist of hoses, fittings, valves and pressure gauge(s) needed to deliver and monitor the pressure of compressed air through an approved pressure feed device.

3. Air Compressor: the air compressor utilized for field testing shall be capable of producing and maintaining an operating pressure of at least 50 psi.

4. Vacuum Box: the vacuum box shall consist of a vacuum gage, valve, and a gasket around the edge of the open bottom needed to apply vacuum to a surface.

2.02. CONFORMANCE TESTING REQUIREMENTS

A. Geomembrane shipped to site shall undergo conformance testing. Manufacturer's roll certificates may be used for conformance evaluation at the option of the Geosynthetic Assurance Consultant. Nonconforming material shall either be retested at the direction of the Geosynthetic Quality Assurance Consultant or removed from site and replaced at Contractor's expense.

B. Conformance Test Methods

1. Samples will be located and collected by the Geosynthetic Quality Assurance Consultant at a rate of one sample per 100,000 square feet of geomembrane delivered to site.

2. One sample will be obtained from each geomembrane production batch delivered to the site.

3 Samples shall be cut by Geomembrane Installer and be at least 45 square feet in size.

4. Samples shall be tested in accordance with Table 1 (Smooth) or Table 2 (Textured) specified in GRI Test Method GM13.

5. Geomembrane thickness shall be measured a minimum of three times per panel during deployment to verify conformance with GRI Test Method GM13.

C. Role of Testing Laboratories

1. The Geosynthetic Quality Assurance Consultant will be responsible for acquiring samples of the geomembrane for conformance testing. The Owner or Geosynthetic Quality Assurance Consultant will retain an independent, third party laboratory to perform conformance testing on samples of geomembrane.

2. Retesting of geomembrane panels by the Geomembrane Installer because of failure to meet any of the conformance specifications can only be authorized by the Geosynthetic Quality Assurance Consultant. Non-conforming panels may be retested in accordance with Subsection 2.03(B) and 2.03(D) under authorization of the Geosynthetic Quality Assurance Consultant only.

3. The Geomembrane Manufacturer and/or Geomembrane Installer may perform independent tests in accordance with methods and procedures specified in Subsection 2.03(B). Results shall not be substituted for quality assurance testing described herein.

D. Procedures for Determining Conformance Test Failures

1. If conformance test results fail to meet specifications, the roll and/or batch may be retested using specimens from either the original roll sample or from another sample collected by the Geosynthetic Quality Assurance Consultant. Two additional tests (retests) shall be performed for each failed test procedure. Each retest shall consist of multiple specimen tests if multiple specimens are specified in the test procedure. If the results of both retests meet specifications, the roll and batch will be considered to have passed conformance testing.

2. Failure of any retest shall be cause for rejection of the entire roll or batch depending on the type of failing test. The Geosynthetic Quality Assurance Consultant reserves the right to collect samples from other roll of a particular batch for further conformance testing. The Geosynthetic Quality Assurance Consultant may choose to accept only a portion of the batch on the basis of the results of conformance testing of samples collected from other rolls.

3. If retesting does not result in conformance with the specifications as defined in preceding paragraph, or if there are any other nonconformities with the material

specifications, the Contractor shall remove the rolls from use in project. The Contractor shall also be responsible for removal of rejected geomembrane from the site and replacement with acceptable geomembrane at no additional cost to the Owner.

PART 3 - EXECUTION

3.01 PRE-CONSTRUCTION MEETING

A. A Pre-Construction Meeting shall be held at the site in accordance with Section 01040, Project Administration, to discuss and plan the details of geomembrane installation. This meeting shall be attended by the Geomembrane Installer, Owner, Geosynthetic Quality Assurance Consultant and the General Contractor.

B. The following topics relating to geomembrane installation shall be addressed:

1. Responsibilities of each party.

2. Lines of authority and communication.

3. Methods for documenting, reporting and distributing documents and reports.

4. Procedures for packaging and storing archive samples.

5. Review of the schedule for all installation and quality assurance testing, including third-party testing turnaround times.

6. Review of panel layout, access and numbering systems for panels and seams including details for marking on the HDPE geomembrane.

7. Procedures and responsibilities for preparation and submittal of as-built drawings.

8. Temperature and weather limitations, installation procedures for adverse weather conditions and defining acceptable subgrade or ambient moisture and temperature conditions for working during liner installation.

9. Subgrade conditions, dewatering responsibilities and subgrade maintenance plan.

10. Deployment techniques including allowable subgrade for geomembrane.

11. Procedures for covering of the geomembrane to prevent damage.

12. Plan for minimizing wrinkles in the geomembrane.

13. Measurement and payment schedules.

14. Site health and safety procedures/protocols.

3.02 SUBGRADE PREPARATION

A. Contractor shall prepare a subgrade surface in accordance with Section 02243, Subgrade Layer Preparation, and excavate and backfill in accordance with Section 02222, Anchor Trenching, Backfilling and Compaction.

B. The Contractor shall not excavate more than the amount of anchor trench required for one day of geosynthetics deployment, unless otherwise specified by the Geosynthetic Quality Assurance Consultant. Rounded corners shall be provided in the trenches where the geosynthetics enter the trench to allow them to be uniformly supported by the subgrade and to avoid sharp bends. The geosynthetics shall not be supported by loose soils in anchor trenches.

C. The Geomembrane Installer shall visually inspect the subgrade immediately prior to geomembrane deployment. Inspection shall verify that there are no potentially harmful foreign objects present, such as sharp rocks and other deleterious debris. Any foreign objects encountered shall be removed by Geomembrane Installer or Contractor. All subgrade damaged by construction equipment and deemed unsuitable for geomembrane deployment shall be repaired prior to geomembrane deployment. All repairs shall be approved by the Geosynthetic Quality Assurance Consultant and Geomembrane Installer. The responsibility for preparation, repairs, and maintenance of the subgrade shall be defined in the preconstruction meeting. The Geomembrane Installer shall provide the Geosynthetic Quality Assurance Consultant with written acceptance of subgrade surface over which geomembrane is deployed (Part 1 .05B*)* for each day of deployment.

3.03 GEOMEMBRANE DEPLOYMENT

A. Geomembrane shall not be deployed until all applicable certifications/quality control certificates listed in subsection 1.05 of this section and conformance testing listed in subsection 2.03 of this section are submitted and approved by the Geosynthetic Quality Assurance Consultant. Any geomembrane deployed prior to approval by the Geosynthetic Quality Assurance Consultant shall be at the sole risk of the Geomembrane Installer and/or Contractor. If material installed prior to approval by the Geosynthetic Quality Assurance Consultant does not meet the requirements of this specification, it shall be removed from the site at no additional cost to the Owner.

B. Geomembrane will be deployed according to submitted panel layout drawing as approved by the Geosynthetic Quality Assurance Consultant. The Geosynthetic Quality Assurance Consultant is to be notified of and approve any revisions or modifications to the approved panel layout drawing prior to deploying geomembrane in the area of review.

C. Adequate temporary anchoring (sand bags, tires, etc.) that will not damage the geomembrane shall be placed on a deployed panel to prevent uplift by wind.

D. Geomembrane shall not be deployed if:

1. Ambient temperatures are below 41 degrees F (5 degrees C) or above 104 degrees F (40 degrees C) measured six inches above geomembrane surface unless approved by the Geosynthetic Quality Assurance Consultant.

2. Precipitation is expected or in the presence of excessive moisture or ponded water on the subgrade surface.

3. Winds are excessive as determined by Geomembrane Installer in agreement with the Geosynthetic Quality Assurance Consultant.

4. The Geosynthetic Quality Assurance Consultant will have the authority to suspend work during such conditions.

E. The Geomembrane Installer shall be responsible for conformance with the following requirements:

1. Equipment utilized for installation/quality assurance testing does not damage geomembrane. Such equipment shall have rubber tires and a ground pressure not exceeding 5 psi or total weight exceeding 750 lbs. Only equipment necessary for installation and quality assurance testing is allowed on the deployed geomembrane.

2. Personnel working on geomembrane do not damage geomembrane (activities such as smoking or wearing damaging clothing shall not be allowed).

3. Method of deployment does not damage geomembrane.

4. Method of deployment minimizes wrinkles.

5. Temporary loading or anchoring does not damage geomembrane.

6. Direct contact with geomembrane is minimized.

F. No vehicles shall be allowed on deployed geomembrane under any circumstances.

3.04 FIELD SEAMS

A. Seam Layout

1. In general, seams shall be oriented parallel to the line of the maximum slope. In corners and at other odd-shaped geometric intersections, number of seams should be minimized. If at all possible, seams shall not be located at low points in the subgrade unless geometry requires seaming to be done at these locations.

2. A seam numbering system compatible with the panel numbering system shall be agreed upon at the Pre-Construction Meeting.

B. Seaming Processes/Equipment

1. Approved processes for field seaming (panel to panel) are extrusion or hot wedge fusion-type seam methods. No other processes can be used without prior written authorization from the Geosynthetic Quality Assurance Consultant. Only equipment which has been specifically approved by make and model shall be used, if applicable.

2. The Geomembrane Installer will meet following requirements regarding use, availability, and cleaning of welding equipment at job site:

a. Intersecting hot wedge seams shall be patched using extrusion welding process.

b. Electric generator for equipment shall be placed on a smooth base such that no damage occurs to geomembrane. A smooth insulating plate or fabric shall be placed beneath hot equipment after usage.

3. The Geomembrane Installer shall keep records for performance and testing of all seams.

C. Seaming Requirements/Procedures

1. Weather Conditions - Range of weather conditions under which geomembrane seaming can be performed are as follows:

a. Unless otherwise authorized in writing by Geosynthetic Quality Assurance Consultant, no seaming shall be attempted or performed at an ambient temperature below 41 degrees F (5 degrees C) or above 104 degrees F (40 degrees C).

b. Between ambient temperatures of 32 degrees F (0 degrees C) and 41 degrees F (5 degrees C), seaming shall be performed only if geomembrane is preheated by either sun or a hot air device, provided there is no excessive ambient cooling resulting from high winds. Pre-qualification seams shall be produced under identical conditions.

c. Above 41 degrees F (5 degrees C), no preheating of geomembrane will be required.

d. Geomembrane shall be dry and protected from wind.

e. Seaming shall not be performed during any precipitation event.

f. Seaming shall not be performed in areas where ponded water has collected below surface of geomembrane.

2. If the Geomembrane Installer chooses to use methods which may allow seaming at ambient temperatures below 41 degrees F or above 104 degrees F, the Geomembrane Installer shall demonstrate and submit certification to Geosynthetic Quality Assurance Consultant that methods and techniques used to perform seaming produce seams that are equivalent to seams produced at temperatures above 41 degrees F and below 104 degrees F. The Geosynthetic Quality Assurance Consultant may deny approval for use of the proposed technique regardless of demonstration results.

3. Overlapping - Geomembrane panels shall have finished overlap as follows:

a. Minimum of 6 inches for thermal fusion welding.

b. Insufficient overlap will be considered a failed seam.

4. Pre-qualification tests for geomembrane fusion welding shall be conducted by a minimum of 2 pre-qualification seams conducted per day per welding machine by each seaming technician performing welding with that machine. At least one test shall be performed at the start of each work day, with tests at intervals of no greater than 5 hours and additional pre-qualification tests following work interruptions, weather changes, changes to machine settings, or as directed by the Geosynthetic Quality Assurance Consultant. Pre-qualification seams shall be made under the same conditions as the actual seams.

    a. Pre-qualification seam samples shall be 5 feet long by 1-foot wide (minimum) after seaming, with seam centered along its length. Each pre-qualification seam shall be labeled with the date, geomembrane temperature, seaming unit identifier, seam number or test location, technician performing the test seam and description of testing results.

    b. Seam overlap shall be in accordance with subsection 3.04(C)(3).

    c. Pre-qualification seams shall be inspected for proper squeeze-out, footprint pressure, and general appearance.

    d. Four specimens, each 1-inch in length, shall be cut from opposite ends of the pre-qualification seam sample by the Geomembrane Installer. The remainder of pre-qualification seam shall be retained by the Geosynthetic Quality Assurance Consultant and may be submitted for laboratory testing.

    e. The Geomembrane Installer shall complete two shear tests and two peel tests.

    f. Pre-qualification seams failed by inspection or testing may be retested at request of the Geomembrane Installer. If the second pre-qualification seam fails, then the seaming apparatus or seaming technique shall be disqualified from use until two consecutive, satisfactory pre-qualification seams are obtained.

5. Seam Preparation

    a. Prior to seaming, seam area shall be clean and free of moisture, dust, dirt, debris of any kind, and foreign material.

    b. Seams shall be aligned so as to minimize number of wrinkles and fishmouths.

6. General Seaming Procedures

    a. Fishmouths or wrinkles at seam overlaps shall be cut along ridge of the wrinkle to achieve a flat overlap. Cut fishmouths or wrinkles shall be repaired, and/or patched in accordance with Part 3.07.

    b. Seaming shall extend to the outside edge of geomembrane panels including material placed in anchor trenches.

c. For cross seams, the intersecting thermal fusion seams shall be patched using the extrusion welding process.

3.05 NON-DESTRUCTIVE TESTING

A. Each field seam shall be non-destructively tested over its entire length by the Installer. Testing shall be conducted as field seaming progresses, not at completion of all seams, unless specifically agreed to by the Geosynthetic Quality Assurance Consultant in writing.

B. Vacuum Testing – shall be performed in accordance with ASTM D5641, Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber.

C. Air Pressure Testing – shall be performed in accordance with ASTM D5820, Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes, and GRI GM 6, Pressurized Air Channel Test for Dual Seamed Geomembranes.

D. Each seam tested non-destructively shall be marked with the date of the test, name of the testing technician, length of the seam, test method and results. The same shall also be recorded by the Geosynthetic Quality Assurance Consultant on the appropriate CQA documentation.

E. Non-Destructive Seam Test Failures

1. Seams failing non-destructive testing shall be repaired by the Geomembrane Installer according to Part 3.07. Seams shall be non-destructively retested. If the seam defect cannot be located, the entire section of seams affected shall be repaired and retested.

3.06 DESTRUCTIVE TESTING

A. The Owner shall have the option to conduct destructive testing of geomembrane panel seams completed in the field. Destructive seam sampling and testing shall be performed by the Geomembrane Installer under the observation of the Geosynthetic Quality Assurance Consultant.

B. Sampling Procedure

1. For each sample location, the Geosynthetic Quality Assurance Consultant will:

a. Assign a sample number and mark the sample accordingly.

b. Record the sample location on the as-built layout drawing.

c. By sample number, record reason for collecting sample (e.g., as part of statistical testing program, suspicious seam, retest, etc.).

d. Record pertinent information, including date, time, seam number, number of seaming unit, and name of seamer, on both the seam sample and CQA documentation.

2. Each destructive sample shall be at least 12 inches wide (at least 6 inches on each side of seam) by 54 inches long. Samples will be cut by the Geomembrane Installer into three parts and distributed as follows:

a. A 12-inch by 12-inch portion shall be cut and tested in accordance with subsection 3.06(C) by the Geomembrane Installer.

b. A 12-inch by 12-inch portion shall be cut and retained by the Geomembrane Installer. The Geomembrane Installer may elect to omit this requirement.

c. A 12-inch by 12-inch portion shall be cut and retained by the Geosynthetic Quality Assurance Consultant as an archive sample.

d. A 12-inch by 18-inch portion shall be submitted by the Geosynthetic Quality Assurance Consultant for laboratory testing as described in Part 3.06(D).

3. Ten specimens, each 1 inch wide by 12 inches long with seam centered perpendicular to width, shall be collected and field tested by the Geomembrane Installer prior to shipping the sample to the laboratory. If all samples pass field tensiometer test described in Part 3.06(C), then the laboratory sample shall be collected according to procedure described in Part 3.06(B)(2)(d).

4. Holes cut into geomembrane resulting from destructive seam sampling shall be immediately repaired by Geomembrane Installer in accordance with repair procedures described in Part 3.07.

C. Field Test Methods

1. Ten 1-inch-wide samples described above under Part 3.06(B)(3) shall be field tested for peel (5 samples) and shear (5 samples).

2. One end of seam sample shall be field tested for peel and shear at end of each continuous field seam 100 feet long or greater.

3. Testing shall be performed in accordance to with ASTM D6392 using a field tensiometer or equivalent device to qualitatively and quantitatively determine mode of failure.

4. Seam shall be considered passing if failure in both peel and shear meet criteria listed in GRI GM 19, Table 2.

5. The procedures specified in Subsection 3.06(D) shall be implemented when sample passes field tensiometer test.

D. Laboratory Test Methods

1. Laboratory testing of seam samples shall be conducted by the Geosynthetic Quality Asssurance Laboratory under contract with the Geosynthetic Quality Assurance Consultant or Owner. Five specimens shall be tested in shear and five in peel.

2. Laboratory testing shall be conducted in accordance with ASTM D6392.

3. For both seam shear and peel tension tests, an indication will be given for each specimen tested which defines locus of failure.

4. For shear tests, the following values, along with the mean and standard deviation where appropriate, will be reported for each specimen tested:

   a. Maximum tension in pounds per square inch.

   b. Elongation at break (up to a tested maximum of 100 percent).

   c. Locus of failure using ASTM designations.

5. For peel tests, the following values, along with the mean and standard deviation where appropriate, will be reported for each specimen tested:

   a. Maximum tension in pounds per square inch.

   b. Seam separation (expressed as percent of original seam area).

   c. Locus of failure.

4. Retesting of seams due to nonconformance with specifications may be performed at the discretion of the Geosynthetic Quality Assurance Consultant.

E. Destructive Seam Test Failure

1. Shear and peel test results derived from testing described in Parts 3.06(C) and 3.06(D) shall comply with GRI GM 19, Table 2 for seam to be considered acceptable.

2. The Geomembrane Installer has two options in determining the repair boundary whenever a seam has failed destructive testing:

a. The seam can be reconstructed between the two previously tested and passed destructive sample locations; or,

b. The Geomembrane Installer can trace the welding path to an intermediate location at least ten feet from point of failed test in each direction and obtain destructive test samples collected from these locations. If destructive tests on these samples are acceptable, then the seam shall be reconstructed between the intermediate locations. If either sample fails, the process may be repeated until an acceptable seam test has been performed on both sides of the original failed sample. If a passing sample is not realized on one (or both) side of the original failed sample, then seam repair must extend to the end(s) of the seam. Retesting of seams according to this procedure shall utilize the sampling methodology described in Part 3.06(B). The Owner reserves the right to terminate this process, at the discretion of the Geosynthetic Quality Assurance Consultant, after the second retesting. An additional sample taken from the reconstructed zone must pass destructive seam testing, if destructive sample failure(s) causes reconstruction.

3. The Geosynthetic Quality Assurance Consultant shall be responsible for documenting all actions taken in repairing seams. The Geomembrane Installer will be responsible for keeping the Geosynthetic Quality Assurance Consultant informed of seaming progress.

3. Additional fees for destructive seam test failures shall be assessed to the Contractor and deducted from payment. This fee shall be assessed only if the failing sample is a laboratory sample.

3.07 DEFECTS AND REPAIRS

A. The geomembrane shall be examined by the Geomembrane Installer and the Engineer for defects, holes, blisters, undispersed raw materials, and any signs of contamination by foreign matter. The geomembrane surface shall be swept and/or washed by the Geomembrane Installer if the amount of dust or mud inhibits examination. The Contractor shall provide a water truck, an operator, clean water and hoses as reasonably necessary to assist the Geomembrane Installer in this activity.

B. Portions of geomembrane exhibiting flaws, or failing a non-destructive or destructive (if conducted) test, shall be repaired or replaced by the Geomembrane Installer. Repair procedures available include:

1. Patching - used to repair large holes, tears, undispersed raw materials, contamination by foreign matter, holes resulting from destructive sampling (if conducted), and locations where seam overlap is insufficient;

2. Capping - used to repair large lengths of failed seams; and

3. Additional Procedures - used upon recommendation of the Geomembrane Installer if agreed to by the Engineer.

C. Patches or caps.

1. Extend patch or cap 6 inches (minimum) beyond the edge of the defect.

2. Round corners of patch and/or cap (suggest 3-inch radius).

3. Repair procedures, equipment, materials, and techniques will be approved by the Geosynthetic Quality Assurance Consultant prior to repair.

4. Geomembrane below large caps shall be appropriately cut to avoid water or gas collection between two sheets.

D. The Geomembrane Installer shall mark on the geomembrane (using a non-puncturing writing utensil), repair date, time, and personnel involved.

E. Each repair shall be non-destructively tested in accordance with Part 3.05. Large caps may require destructive test sampling at the discretion of the Geosynthetic Quality Assurance Consultant (in accordance with Part 3.06).

F. Repairs which fail testing shall be redone and retested until a passing result is obtained. The Geomembrane Installer will perform non-destructive testing or repairs and will document retesting of repairs.

G. The Geosynthetic Quality Assurance Consultant will document repairs, repair testing, and retesting results.

H. The Geomembrane Installer shall cut and seam wrinkles which may adversely affect long-term integrity of the geomembrane, hinder subsequent construction of overlying layers, or impede drainage off of the geomembrane after it is covered by soil. Seaming shall be done in accordance with procedures described in Parts 3.04(B) and 3.04(C), and it shall be subject to test provisions of Parts 3.05 (non-destructive testing) and 3.06 (destructive testing – if conducted).

3.08 PROTRUSIONS AND CONNECTIONS TO GEOMEMBRANE

A. If required, the Geomembrane Installer shall install geomembrane around utility poles, guy wires, and other structures according to the Contract Drawings and the following requirements:

1. Use minimum 1-ft long membrane pipe boots and steel straps to seal the geomembrane around pole or structure.

2. Use standard welding procedures to seam the membrane boot to the geomembrane.

3. Seaming performed on and around penetrations, and other appurtenances shall be non-destructively tested using the vacuum testing method.

3.09 SURVEY DOCUMENTATION

A. The Geomembrane Installer shall survey the completed geomembrane prior to covering and provide the Geosynthetic Quality Assurance Consultant with 24-hour notification of survey. The Contractor shall document the location of all seams (panel corners acceptable), destructive test samples (if conducted) and repairs. The Contractor shall provide survey data to the Geosynthetic Quality Assurance Consultant within one working day of survey completion and in accordance with Section 01050.

3.10 DAILY FIELD INSTALLATION REPORTS

A. At the beginning of each day, the Geomembrane Installer shall provide the Geosynthetic Quality Assurance Consultant with a report for all work completed the previous day.

B. The Daily Field Installation Report shall include the following:

1. The total amount and location of geomembrane placed.

2. The total length and location of seams completed, technician name and welding unit numbers.

3. A drawing or sketch depicting the geomembrane installed the previous day including the panel number, seam number and locations of non-destructive and destructive testing (if conducted).

4. Results of pre-qualification test seams, if available.

5. Results of non-destructive testing.

C. Destructive test results (if conducted) shall be reported within 48 hours or prior to covering the geomembrane, whichever is practical.

3.10 MATERIAL ABOVE GEOMEMBRANE

A. The Geosynthetic Quality Assurance Consultant and Geomembrane Installer shall verify the area of geomembrane completion prior to placement of material over the geomembrane.

B. Soils - Requirements for placement of general fill are described in Sections 02221 and 02222. Apply following general criteria for covering of the geomembrane:

1. Do not place soils on the geomembrane at an ambient temperature below 32 degrees F, (0 degrees C) nor above 104 degrees F (40 degrees C), unless otherwise specified.

2. Do not drive equipment used for placing soil directly on the geomembrane.

3. A minimum thickness of 1 foot of soil is specified between a low ground pressure dozer (maximum contact pressure of 5 lb/sq. inch) and the geomembrane.

4. A minimum thickness of 2 feet of soil is required between rubber-tired vehicles and the geomembrane.

5. Do not compact soils placed directly on geomembrane.

6. Damage to the geomembrane resulting from placement of cover soils shall be repaired in accordance with Part 3.07 by the Geomembrane Installer at the Contractor's expense.

7. Do not push soil downslope. Soil shall be placed over the geomembrane starting from base of the slope, up to top of the slope.

END OF SECTION

Attachment 4

ATTACHMENT 4
FIELD CHANGE REQUEST #5

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04/27/2008 19:53 8155210999 BR1ESER CONSTRUCTION PAGE 02

MIDWEST GENERATION EME, LLC
An EDISON INTERNATIONAL℠ Company

FCR # 5

Field Change Request (FCR)

Contractor: Brieser Construction MWGen PO # 4500007560

Description of Change/Information Requested: Supply screenings + CA-6 in lieu of using existing soil to backfill ramp Approximately 270 ton required

Affected Design/Contract Documents:

Reason for Change: Existing soil is not suitable for backfill

Requested by: Todd Mills Date: 4-28-08

MWGen Response:

Response by: Date:

Does this Request require a contract change? ☒ YES ☐ NO
If YES, complete the following:

Requisition Number: PO # / Line Item: 4500007560

Cost of Change: $3,100.00
Cost Basis: ☐ Firm Lump Sum Quote ☒ T&M estimate ☐ T&M estimate not to exceed

Schedule Impact: None

Change Approved by: Authorized MWGen Signature 4-30-08 Approval Date

Change Approved by: Authorized Contractor Signature 5-1-08 Approval Date

FCR Form Revision 0, dated 8/4/00

Attachment 5

ATTACHMENT 5
PROJECT INVOICES

Electronic Filing: Received, Clerk's Office

Brieser Construction Co.
24101 S. Municipal Drive
Channahon, IL 60410
(815) 521-0900
FAX (815) 521-0999

JOB INVOICE
34735

☐ DAY WORK ☐ CONTRACT ☒ EXTRA

Job Name: Pond Liner #2
(material for ramp)

To: Midwest Generation

Order #:

Job Number: 87188-phase 1703 Date: 5-7-08

DESCRIPTION OF WORK

Hauled in screenings for ramp

EQUIPMENT CHARGES	HRS.	RATE	AMOUNT
TOTAL EQUIPMENT			

QTY.	MAT/SUBCONTRACTOR	PRICE	AMOUNT
-	Ksb trucking		
	(No ticket #)		
100.19 ton	Lafarge-Joliet sand + gravel		
	(4 tickets - 100.19 ton)		
TOTAL MAT/SUBS			

NAME	CLASS	HOURS	RATE	AMOUNT
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TOTAL LABOR				

TOTAL MAT/SUBS	
TOTAL EQUIPMENT	
TOTAL	

WORK ORDERED BY

SIGNATURE Brian Dalton

CUSTOMER COPY

MWG13-15_18524

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Brieser Construction Co.
24101 S. Municipal Drive
Channahon, IL 60410
(815) 521-0900
FAX (815) 521-0999

JOB INVOICE

34737

☐ DAY WORK ☐ CONTRACT ☒ EXTRA

To: Midwest Generation

Order #:

Job Name: Pond liner #2 (Build ramp)

Job Number: 87188-phase 1703 Date: 5-8-08

DESCRIPTION OF WORK

Finish building ramp w/ screenings & CA6 stone.

EQUIPMENT CHARGES	HRS.	RATE	AMOUNT
TOTAL EQUIPMENT			

QTY.	MAT/SUBCONTRACTOR	PRICE	AMOUNT
	KSB trucking		
	(No ticket #)		
50.66 ton (screenings)	Lafarge Joliet sand & gravel		
	(2 tickets - 50.66 ton)		
125.86 ton (grade 8)	Lafarge Joliet sand & gravel		
	(5 tickets - 125.86 ton)		
TOTAL MAT/SUBS			

NAME	CLASS	HOURS	RATE	AMOUNT
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TOTAL LABOR				

TOTAL MAT/SUBS	
TOTAL EQUIPMENT	
TOTAL	

WORK ORDERED BY

SIGNATURE

CUSTOMER COPY

MWG13-15_18523

Exhibit E

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SUMMARY LETTER

October 13, 2005

Ms. Maria L. Race
Midwest Generation EME, LLC
One Financial Place
440 South LaSalle Street, Suite 3500
Chicago, Illinois 60605

VIA FEDERAL EXPRESS

KPRG Project No. 15805

Re: Geotechnical Analysis of Soil Surrounding Settling Basins/Ponds

Dear Ms. Race:

KPRG and Associates, Inc. (KPRG) has recently received the geotechnical testing results from the soil boring program implemented in the vicinity of various ponds located at six of the Midwest Generation stations. Specifically, these stations and the number of borings advanced at each were:

- Waukegan Station (5 borings)
-
- Will County Station (5 borings)
- Joliet #29 Station (6 borings)
- Joliet #9 Station (3 borings)
- Powerton Station (9 borings)

This letter report provides a project objective, documents the field procedures, identifies the geotechnical laboratory specifications and summarizes the geotechnical testing results. Each item is discussed separately below.

PROJECT OBJECTIVE

Based on discussions with Midwest Generation, the objective of the project was to obtain stratigraphic and geotechnical data from the vicinity of specific ponds at the various station locations. The results of the investigation would provide a physical characteristic data base for subsequent engineering evaluations, planning and decision analysis. The soil sample collection for geotechnical analysis was targeted for the approximate equivalent base elevation of each pond as specified by Midwest Generation.

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FIELD PROCEDURES

Prior to mobilizing for drilling activities, Midwest Generation contracted Lucky Locators, Inc. to provide utility clearance at each pre-established drilling location. Once the utility clearance was provided, KPRG mobilized a geoprobe rig which utilizes a direct hydraulic push technology for collecting soil cores. Continuous 5-foot core samples were collected during drilling at each location. The core samples were screened in the filed for total organic vapors with a photoionization detector (PID) and where appropriate, compressive strength readings were taken using a hand penetrometer. At the approximate base elevation of the adjoining pond, an attempt was made to push a Shelby Tube for collection of an undisturbed sample for subsequent geotechnical analysis. If the subsurface conditions did not allow for sample collection by pushing a Shelby Tube, an acetate core sample was collected for submittal for geotechnical analysis. If the targeted interval consisted of sufficiently coarse material that would not allow for either proper Shelby Tube or acetate core sampling, a representative volume of retrieved sample was placed into a plastic baggie for submittal for geotechnical analysis. Table 1 summarizes the overall results of the geotechnical sampling effort relative to station, sample identification number, sample collection type and depth.

Upon completion of sampling at each location, the boring was abandoned by placing unsampled core material back into the hole and filling the remainder of the boring with granular bentonite. A surface patch was then placed to match the surrounding surficial material.

GEOTECHNICAL LABORATORY SPECIFICATIONS

KPRG subcontracted Terracon Consulting Engineers (Terracon) to perform the geotechnical laboratory analyses. The following geotechnical testing methods were run by Terracon:

- Grain Size with Hydrometer (ASTM Method D 422)
- Atterberg Limits (ASTM Method D 4318)
- Bulk Density (ASTM Method D 2937)
- Specific Gravity (ASTM Method D 854)
- Moisture Content (ASTM Method D 2216)
- Permeability (ASTM Method D 5084)
- USCS Soil Classification

In accordance with KPRG's proposal, Terracon was instructed to first run the Grain Size Distribution and Atterberg Limits testing. Based on these results, permeability testing was only performed if the Plasticity Index (PI) was less than 11 or if there was less than a 30% fraction passing the 200 mesh sieve. If both of these criteria were met (i.e., a PI of greater than 11 and greater than 30% fraction passing the 200 mesh sieve), the material should have a permeability in the order of 10^{-7} cm/sec which should provide sufficient

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information for most desk-top engineering evaluations. As noted further below, only a few of the samples actually met these criteria.

It is noted that geoprobe acetate tube and/or baggie samples are not considered "undisturbed" samples and that some remolding/recompaction was required for completing permeability tests.

RESULTS

Table 1 summarizes the various samples collected for geotechnical analysis by station location and depth interval. The table notes whether the sample sent to the laboratory was a Shelby Tube, acetate tube or baggie sample.

The results of the geotechnical investigation program are organized separately for specific stations and provided in Attachments 1 through 6 along with sample location maps. A brief summary for each station is provided below. The complete geotechnical laboratory report is provided in Attachment 7.

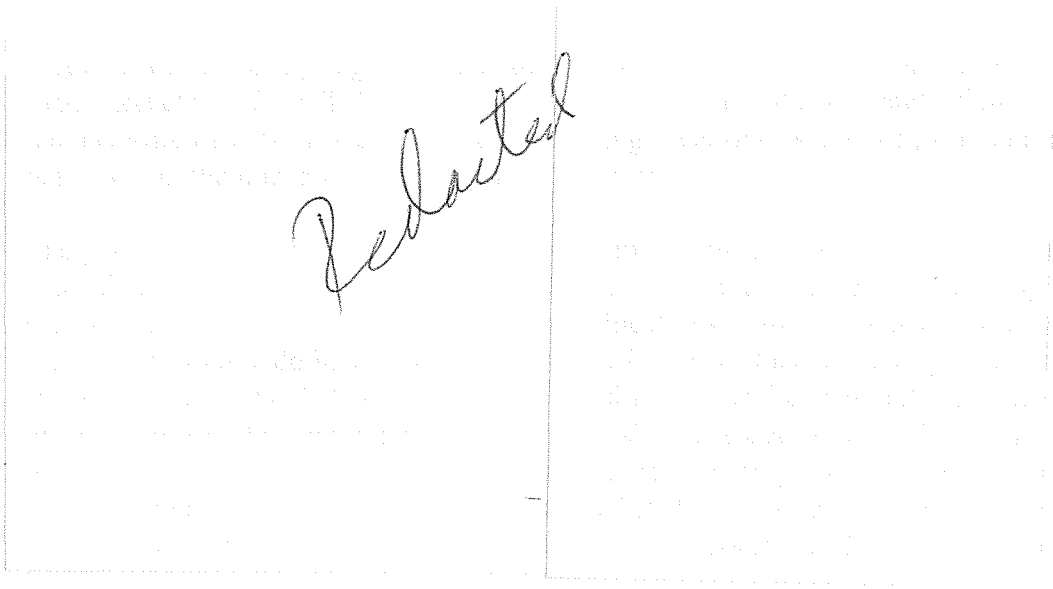
Waukegan Station

A total of five borings were drilled and sampled at the Waukegan Station (WS-GT-1 through WS-GT-5). The approximate sample locations are provided on Figure 1-1 in Attachment 1 along with the results of the geotechnical testing in Table 1-1 and the associated soil boring logs.

A review of the boring logs indicates that the subsurface materials were generally sandy with some gravel and/or silts and clays. Some areas were noted to containing fill material generally consisting of ash/slag.

The geotechnical data in Table 1-1 from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) also document these materials to be classified as sands with some gravel, silt and/or clay. Permeabilities were found to range from 1.0×10^{-3} cm/sec to 2.3×10^{-2} cm/sec. These permeabilities are consistent with sandy/gravelly materials.

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Will County Station

A total of five borings were drilled and sampled at the Will County Station (WC-GT-1 through WC-GT-5). The approximate sample locations are provided on Figure 3-1 in Attachment 3 along with the results of the geotechnical testing in Table 3-1 and the associated soil boring logs.

A review of the boring logs indicates that the subsurface stratigraphy varied across the site. The northern most boring (WC-GT-1) has a sandy/gravelly unit overlying a clay unit with weathered bedrock being encountered between 4.5 and 5 feet below ground surface (bgs). Borings WC-GT-2 through WC-GT-4 located on the west central portion of the property generally had a 1.5 to 2.5 foot thick fill layer with ash/slag and underlying sandy and gravelly units. Bedrock was generally encountered at around 10 feet bgs. The southern most boring (WC-GT-5) had a silty/sandy/gravelly layer overlaying weathered bedrock which was encountered at about 2.5 feet bgs.

The geotechnical data in Table 3-1 from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) also document these materials to be classified as sands with some gravel or silts/clays. Permeabilities for the clayey and silty materials at borings WC-GT-4 and WC-GT-3 were estimated to range from 3.65×10^{-7} cm/sec to 1.86×10^{-6} cm/sec, respectively. It is noted, however, that the remolding for these samples could not meet the analytical method standard requirements due to the coarse fractions and that the values provided a verbal estimates. The true values could not be quantified due to the noted remolding issue and, therefore, are not included in the formal quantified results table provided by the geotechnical laboratory in Attachment 7. The coarser sandy and/or gravelly materials at locations WC-GT-2 and WC-GT-1 showed permeabilities at 4.02×10^{-3} and 1.35×10^{-1} cm/sec, respectively. The permeability for sample WC-GT-5 could not be run due to the relative amount of gravel which precluded being able to properly

remold a sample for the permeability analysis. This of itself suggests a relatively high permeability layer.

Joliet Station #29

A total of six borings were drilled and sampled at Joliet Station #29 (JS29-GT-1, through JS29-GT-6). The approximate sample locations are provided on Figure 4-1 in Attachment 4 along with the results of the geotechnical testing in Table 4-1 and the associated soil boring logs.

A review of the boring logs indicates that the subsurface stratigraphy varied across the site from primarily sand/gravel at location JS29-GT-1 to primarily clay at locations JS29-GT-3, JS29-GT-5 and JS29-GT-6. The boring logs for the remaining locations indicate an interlayering of the coarse and fine materials. Some minor amounts of ash/slag were noted at some locations within the upper foot of material. Bedrock was definitively encountered only at location JS29-GT-6 at a depth of approximately 15 feet bgs.

The geotechnical data in Table 4-1 from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) indicates that the sample from location JS29-GT-6 met the previously defined criteria of a high PI (greater than 11) and greater than a 30% fraction passing the 200 mesh sieve. Therefore, it can be generally assumed that the materials are of low permeability as previously discussed and no further permeability testing was performed on this sample. The results of the permeability tests for locations JS29-GT-1, JS29-GT-3 and JS29-GT-5 ranged from 4.7×10^{-4} to 2.96×10^{-2} cm/sec. The permeabilities for samples JS29-GT-2 and JS29-GT-4 could not be run due to the relative amount of gravel which precluded being able to properly remold a sample for the permeability analysis. This of itself suggests relatively high permeability layers at those locations.

Joliet Station #9

A total of three borings were drilled and sampled at Joliet Station #9 (JS9-GT-1, through JS9-GT-3). The approximate sample locations are provided on Figure 5-1 in Attachment 5 along with the results of the geotechnical testing in Table 5-1 and the associated soil boring logs.

A review of the boring logs indicates that the subsurface stratigraphy varied across the site. Location JS9-GT-1 showed interlayerd gravel/sand and clay with the bottom three feet of the boring being silty sand. Location JS9-GT-2 showed primarily silty and silty sand material with some gravel. A peat layer was also encountered in the bottom three feet of the boring. Location JS9-GT-3 had primarily sandy and gravelly materials to its total depth of 15 feet bgs. A slag layer was logged between approximately 4 and 6 feet bgs.

The geotechnical data in Table 5-1 from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) also document these materials to be rather coarse with high permeabilities.

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The permeability for location JS9-GT-2 was determined to be 2.73 X 10^{-2} cm/sec. The permeabilities for samples JS9-GT-1 and JS9-GT-3 could not be run due to the relative amount of gravel which precluded being able to properly remold a sample for the permeability analysis. This of itself suggests relatively high permeability layers at those locations.

Powerton Station

A total of nine borings were drilled and sampled at Powerton Station (PS-GT-1, through PS-GT-9). The approximate sample locations are provided on Figure 6-1 in Attachment 6 along with the results of the geotechnical testing in Table 6-1 and the associated soil boring logs.

A review of the boring logs indicates a varied stratigraphy from primarily clayey at locations PS-GT-1 and PS-GT-5 to an interlayering of sandy and clayey units at the other locations. It is noted that at locations PS-GT-7 through PS-GT-9, a slag/ash unit was logged starting at between 2 and 3 feet bgs and extending to approximately 15 feet bgs. A two foot ash layer was also logged between 2 and 4 feet bgs at location PS-GT-5.

The geotechnical data from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) indicates that the sample from location PS-GT-5 met the previously defined criteria of a high PI (greater than 11) and greater than a 30% fraction passing the 200 mesh sieve. Therefore, it can be generally assumed that the materials are of low permeability as previously discussed and no further permeability testing was performed on this sample. The remaining permeabilities ranged from 1.6 X 10^{-7} cm/sec to 2.31 X 10^{-2} cm/sec; the lower permeabilities associated with clayey and silty soils and the higher values associated with sandier soils.

KPRG appreciates the opportunity for providing our technical services to Midwest Generation on this project. If there are any questions, please contact me at 262-781-0475.

Sincerely,
KPRG and Associates, Inc.

Richard R. Gnat

Richard R. Gnat, P.G.
Principal

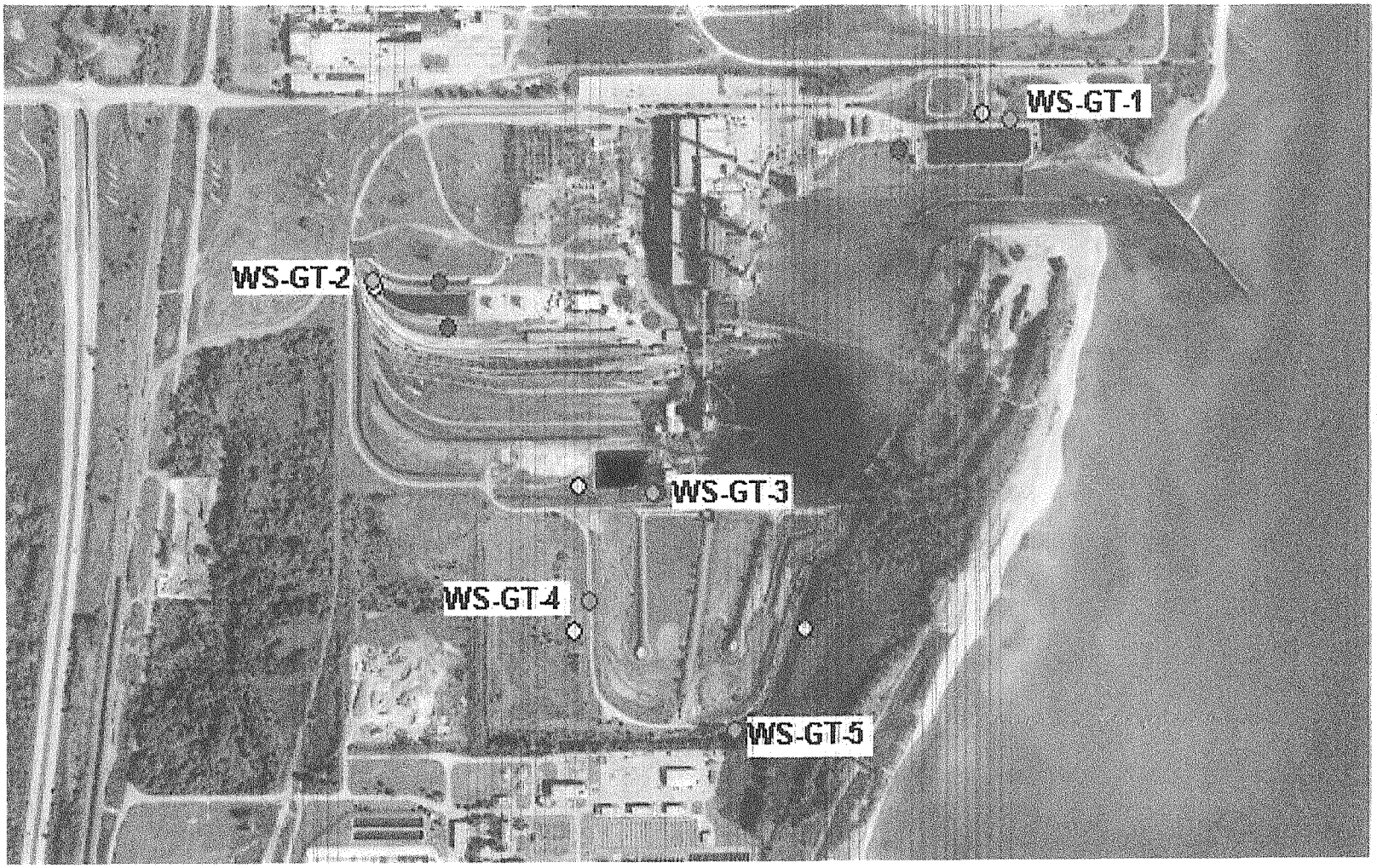
TABLE

Table 1. Summary of Samples Collected for Geotechnical Analysis

STATION	BORING ID	SHELBY TUBE (Depth Ft)	GEOPROBE TUBE (Depth Ft)	BAGGIE SAMPLE
Waukegan	WS-GT-1		5-10	
	WS-GT-2	7.5-10	5-10	
	WS-GT-3		5-10	
	WS-GT-4		22-27	
	WS-GT-5		22-27	
Will County	WC-GT-1		5-10	
	WC-GT-2		5-10	
	WC-GT-3		3-8	3-8
	WC-GT-4		5-10	
	WC-GT-5		5-9	5-9
Joliet #29	JS29-GT-1		19-24	15-19
	JS29-GT-2		19-24	
	JS29-GT-3		19-24	17-19
	JS29-GT-4		17-22	
	JS29-GT-5		9-14	
	JS29-GT-6		11-14	11-14
Joliet #9	JS9-GT-1		7-12	7-10
	JS9-GT-2		7-11.5	7-10
	JS9-GT-3		8-13	8-11
Powerton	PS-GT-4	10-11.5		
	PS-GT-5	17-19		
	PS-GT-6		15-20	
	PS-GT-7		10-15	
	PS-GT-8		10-13	
	PS-GT-9		13-18	

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ATTACHMENT 1
Waukegan Station Geotechnical Study Results





Suggested

Possible Alternate

Soil Sample Sites cleared by Lucky Locators Inc.

Figure 1-1

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Table 1-1. Soil Sample Geotechnical Data - Midwest Generation, Waukegan Station, Waukegan, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
WS-GT-1	5 to 10'	Sand with trace gravel	5.6	114	NP	NP	94	1	2.63	1.05x10-2
WS-GT-2	7.5'-10'	Silty Sand, trace gravel, dark brown	15.2	107	NP	NP	79	7	2.44	1.52x10-2
			18.1							
WS-GT-3	5 to 10'	Sand with trace gravel	11.2	99	NP	NP	86	0	2.65	2.3x10-2
WS-GT-4	22-27'	Sand with trace gravel	5.4	114	NP	NP	53	2	2.64	2.16x10-2
WS-GT-5	22-27'	Sand, trace gravel, black	4.4	96	NP	NP	15	0	2.73	1.0x10-3
		(Bottom Ash?)								

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
NA - Not Analyzed
NP - Not Plastic

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LOG OF BORING WS-GT-1

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND and GRAVEL, gray and orange brown. Dry.	1	0.0		
1–3	SP		SLAG, black, medium to coarse sand and gravel, some bottom ash. Dry.	2	0.0	80	
3–5	SP		SAND, fine to medium, light brown, trace silt. Slightly Moist.				
5–10			Push Geoprobe Tube 5 to 10.				
10			End of boring at 10 feet.				

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LOG OF BORING WS-GT-2

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0	GW		SAND and GRAVEL, brown and black. Dry.	1	0.0		
1	SP		SAND, fine to medium, brown, trace silt and gravel. Slightly Moist.				
2							
3			- wet	2	0.0	80	
4	SP		SAND, fine to medium, little silt. Very Moist.				
5							
6			Push Geoprobe Tube 5 to 10.				
7			Pushed Shelby tube in new boring 5 to 10 feet. 18" recovery.				
8							
9							
10			End of boring at 10 feet.				
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

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LOG OF BORING WS-GT-3

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND and GRAVEL, dark brown. Dry.	1	0.0		
2	SP		Bottom Ash, black and gray, fine, some sand and gravel. Dry.				
3	CO		COAL, black, some gray clayey bottom ash. Moist.	2	0.0	80	
4	SP		SAND, fine to medium, black and brown, little silt. Moist.				
5–10			Push Geoprobe Tube 5 to 10. Full recovery.				
10			End of boring at 10 feet.				

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LOG OF BORING WS-GT-4

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND and GRAVEL, brown. Dry.	1	0.0		
1–3	GW		Bottom Ash and SAND and GRAVEL Mixture. Very Moist.	2	0.0	100	
3–10	GW		Bottom Ash, black, medium to coarse sand and gravel, some fines. Slightly Moist.	3	0.0		
				4	0.0	80	
			- wet, some organics				
11–13	SP		SAND, fine to medium, some silt and clay, brown, organics. Slightly Moist.	5	0.0		
13–19	SP		Bottom Ash, black, granular, medium to coarse sand and gravel. Slightly Moist.	6	0.0	70	
				7	0.0		
20–22	SP		SAND, gray, fine to medium, trace silt.	8	0.0		
22–27			Push Geoprobe Tube 22 to 27 feet. Full Recovery				
27			End of boring at 27 feet.				

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LOG OF BORING WS-GT-5

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND and GRAVEL, brown, grass. Dry.	1	0.0		
1–4	SM		Bottom Ash, light gray, fine sand and silt powder. Dry.	2	0.0	80	
			- 3" light brown SAND, fine to medium. Dry.	3	0.0		
4–9	SM		Bottom Ash, fine to medium sand and silt, brown some gray, some slag. Slightly Moist.	4	0.0	100	
9–22	SP		Bottom Ash, black, granular, medium to coarse sand and gravel. Slightly Moist.	5	0.0		
				6	0.0	60	
				7	0.0	80	
				8	0.0	100	
22–27			Push Geoprobe Tube 22 to 27 feet. 24" Recovery.				
27			End of boring at 27 feet.				

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ATTACHMENT 3
Will County Station Geotechnical Study Results

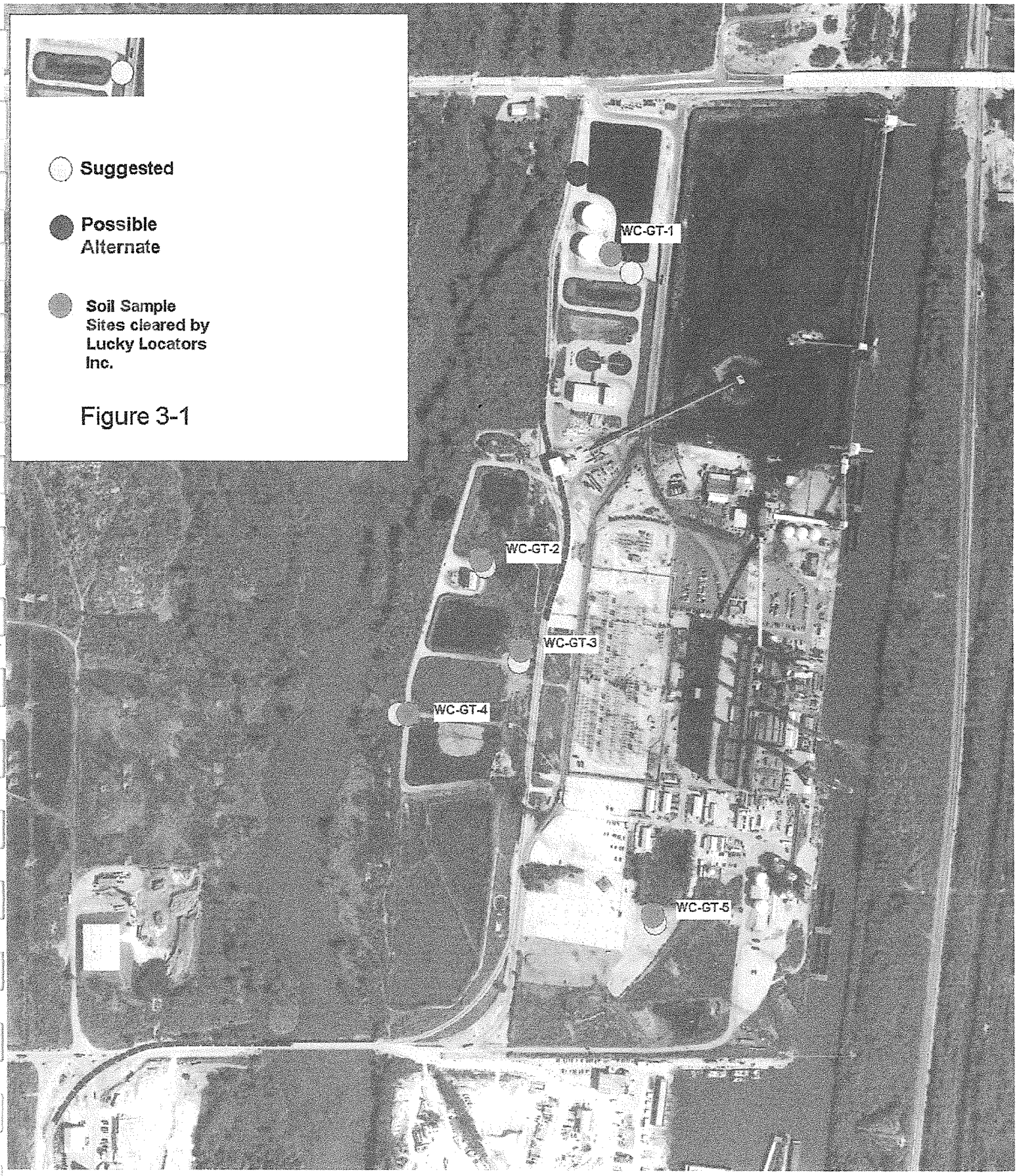

Suggested
Possible Alternate
Soil Sample Sites cleared by Lucky Locators Inc.
WC-GT-1
WC-GT-2
WC-GT-3
WC-GT-4
WC-GT-5

Figure 3-1

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Table 3-1. Soil Sample Geotechnical Data - Midwest Generation, Will County Station, Romeoville, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
WC-GT-1	5 to 10'	Clayey Sand, dark brown to tan	3.4	118	31	15	25.1	11.4	2.66	1.35x10-1
WC-GT-2	5 to 10'	Sand with gravel, dark brown	18.1	92	NP	NP	35.1	11.9	2.65	4.02x10-3
WC-GT-3	3 to 8'	Lean Clay, dark brown	10.0	103	35	12	25.6	19.7	2.71	1.86x10-6***
WC-GT-4	5 to10'	Silty Clay, dark brown	9.5	128	25	7	35.4	23.3	2.7	3.65x10-7***
WC-GT-5	5-9'	Sandy Clay with Gravel	4.2	119	NP	NP	39	35	2.65	*

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
***Verbal estimate provided by geotechnical lab. The data package in Attachment 7 indicates that due to the coarse fraction the samples could not be ideally remolded. The above verbal estimate is not a quantitaive number due to the remolding issue and is therefore not reported as such in Attachment 7.
NA - Not Analyzed
NP - Not Plastic

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LOG OF BORING WC-GT-1

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed	: 08/09/05
Drilling Method	: Direct-Push
Drilling Company	: CABENO Env. Field Services
Operator	: D. Joyce
Logged By	: P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	GW		GRAVEL and SAND, light brown / gray, trace silt and clay. Dry.	1	0.0		
2–4	CL		CLAY, dark brown, some sand and gravel. Dry.	2	3.0	80	>4.5
4–5	GW		SLAG and Bottom Ash, black and dark gray, medium to coarse sand, little silt. Dry to Slightly Moist.	3	25		
5			- clayey weathered bedrock, gray, moist				

End of Boring at 5 feet.
Push geoprobe tube 0 to 5 feet in new boring.

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LOG OF BORING WC-GT-2

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed : 08/09/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	ML		Bottom Ash, brown and black, fine, little gravel. Dry. - increase gravel	1	0.0		
3–4	SP		SAND, fine to medium, dark brown to brown, little silt. Slightly Moist to Moist.	2	0.0	80	
5–6	SP			3	0.0		
7–9	SP		- very moist	4	0.0	80	
10			End of Boring at 10 feet. Push geoprobe tube 5 to 10 feet in new boring.				

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LOG OF BORING WC-GT-3

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed : 08/09/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SP		Bottom Ash and Coal, black, fine to medium, little gravel. Slightly Moist.	1	0.0		
2	GW		SAND-SILT-GRAVEL mixture, with crushed limestone, Slightly Moist.				
3–4	CL/GW		CLAY and GRAVEL, dark brown. Slightly Moist.	2	0.0	70	
5			- layer orange brown sand and gravel				
6–7				3	0.0		
8–9	GW		SLAG, black, fine to medium sand with fine gravel. Moist.	4	0.0	40	
			- clayey weathered bedrock, gray				
10			End of Boring at 9.5 feet.				
11			Attempt push Shelby Tube, colapsed.				
12			Push geoprobe tube 3 to 8 feet in new boring. 28 " recovery.				
13–20							

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LOG OF BORING WC-GT-4

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed : 08/09/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SP		Bottom Ash, sand and gravel. Dry. - black silt and fine sand, trace gravel. Dry. - gray	1	0.0		
2	CL/GW		CLAY and GRAVEL, some sand, dark brown. Dry.				
3–4	GW		SAND and GRAVEL, light brown. Dry.	2	0.0	100	
5–6			Pushed Geoprobe Tube 5 to 10. 41" recovery.	3	0.0		
7–9				4	0.0	70	
10			End of Boring at 10 feet.				
11–20							

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LOG OF BORING WC-GT-5

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed : 08/09/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

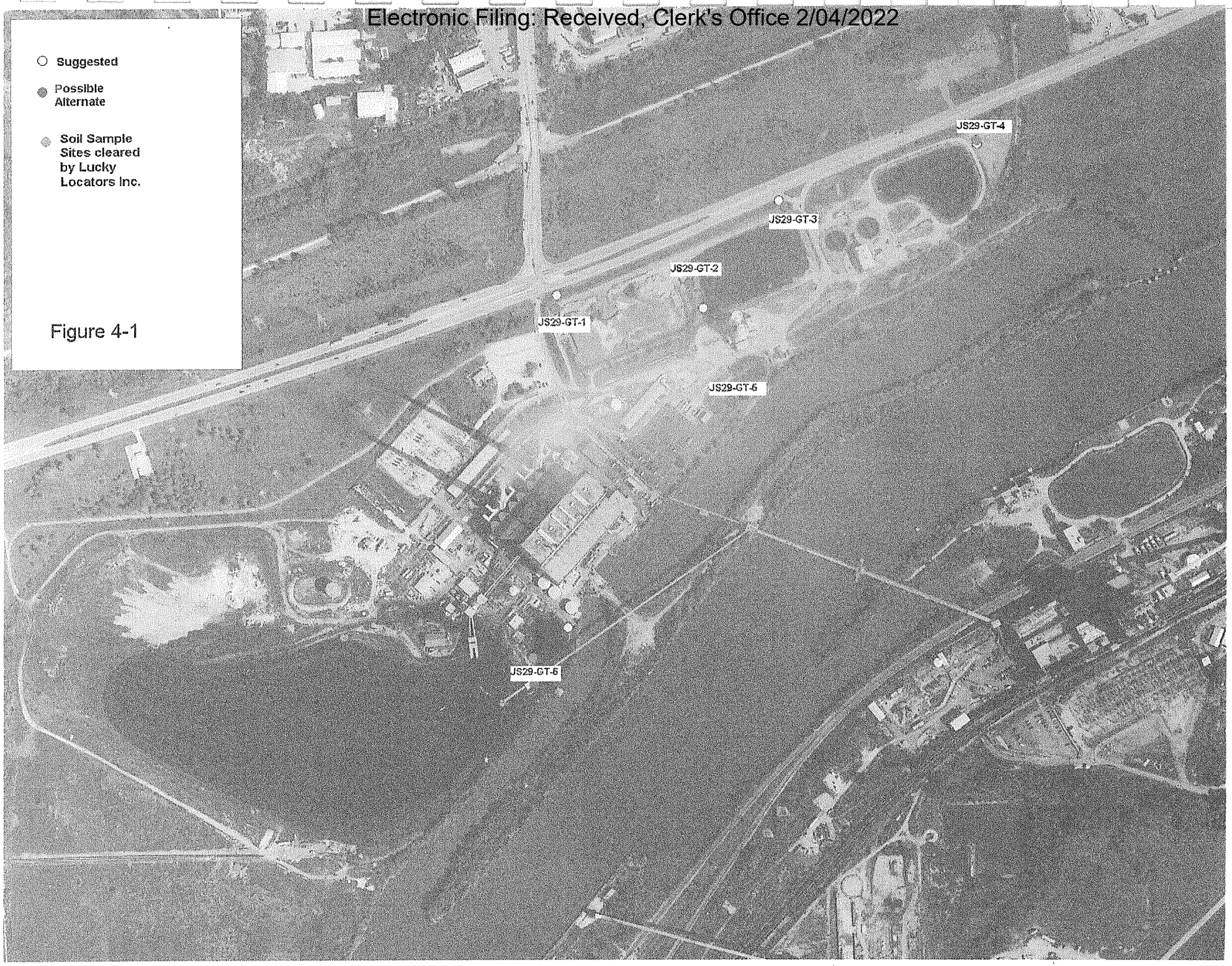
Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND-SILT-GRAVEL Mixture, brown, black, white, orange/brown. Dry to Slightly Moist.	1	0.0		
1–2	WBR		Weathered Bedrock, limestone. Moist.	2	0.0	100	

End of Boring at 2.5 feet.

Repeated boring for sample volume. Bagged.

ATTACHMENT 4
Joliet Station #29 Geotechnical Study Results

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Table 4-1. Soil Sample Geotechnical Data - Midwest Generation, Joliet Station #29, Joliet, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
JS-29-GT-1	19-24'	Sand, fine grained, trace clay and gravel, dark yellow	5.3	120	NP	NP	13.9	8.7	2.62	2.96x10-2
JS-29-GT-2	19-24	Gravelly sand, brown	10.0	87.0	NP	NP	21	14	2.66	*
		Gravelly sand, trace clay, dark brown	6.0							
JS-29-GT-3	19-24	Sand, with gravel, trace clay, brown	8.6	121**	NP	NP	13	9	2.64	2.51x10-2
		Lean clay, gray	7.3							
JS-29-GT-4	17-22	Limestone with fine to coarse sand	4.1	124.0	NP	NP	11	7	2.7	*
JS29-GT-5	5-14'	Clayey gravel with sand, dark gray	26.0	94.0	34	11	32	18.7	2.56	4.7x10-4
JS-29-GT-6	11-14'	Organic clay, dark gray, black	74.6	53.0	78	17	88.9	65.4	2.41	NA

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
NA - Not Analyzed
NP - Not Plastic

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LOG OF BORING JS29-GT-1

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0	GW		Bottom Ash and GRAVEL, dark gray. Dry.	1	0.0		
1	GW		Crushed Limestone, gravel and sand, clayey at 1.5 to 2 feet. Slightly Moist.	2	0.0	80	
2							
3			SAND and GRAVEL, orange brown, little silt, very stiff. Dry to Slightly Moist.	3	0.0		
4				4	0.0	70	
5				5	0.0		
6							
7				6	0.0	60	
8	GW						
9				7	0.0		
10							
11				8	0.0	50	
12							
13			- 10 "clayey	9	0.0		
14							
15							
16							
17							
18							
19							
20	GW		Push Geoprobe Tube 19 to 24. 33" recovery.				
21							
22							
23							
24							
25			End of Boring at 24 feet.				
26							
27							
28							
29							
30							

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LOG OF BORING JS29-GT-2

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SM		SAND and SILT, fine to medium, dark brown, some slag. Dry.	1	0.0		
1–2	GW		Crushed Limestone, sand and gravel. Dry.				
2–10	GW/CL		CLAY and GRAVEL, dark brown, black, some sand and silt. Slightly Moist.	2	0.0	60	
			- 6" clayey, black, soft	3	0.0	40	
			- 6" coarse gravel and cobbles	4	0.0		
10–15	CL		SILT and CLAY, black, some sand and gravel, soft, organic odor. Moist.	5	0.0	40	1.0
			- some limestone gravel	6	0.0		1.0
15–22			Push Geoprobe Tube 15 to 19. 19" recovery. Push Geoprobe Tube 19 to 22. 22" recovery.				
22			End of Boring at 22 feet.				

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LOG OF BORING JS29-GT-3

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	CL		Bottom Ash, dark brown, clay, little gravel. Dry.	1	0.0		
	GW		Crushed Limestone, sand and gravel. Dry.				
3–4	CL		CLAY, dark brown, brown, some sand and silt, trace gravel. Slightly Moist.	2	0.0	100	4.0 - >4.5
5–6			- mostly brown, slightly moist	3	0.0	100	4.0 - >4.5
7–8			- 1" black layer	4	0.0		4.0 - >4.5
9–11			- trace gray silt	5	0.0	100	4.0 - >4.5
12–14			- softer	6	0.0		1.0 - 1.5
15	CL		CLAY, brown, little to trace sand and silt, trace gravel. Slightly Moist.				
16	CL		CLAY, brown, with gray silt, some dark. Moist.				
17–18	CL		CLAY, dark brown, some silt, sand and gravel. Moist.	7	0.0	100	1.0 - 4.0
			- vug of dark gray fine sand, wet.				
19–24			Push Geoprobe Tube 19 to 24. 30" recovery.				
25			End of Boring at 24 feet.				

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LOG OF BORING JS29-GT-4

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–5	CL/GP		GRAVEL CLAY and GRAVEL, coarse, dark brown, some sand and silt, stiff. Dry. - some brown and orange brown	1 2	0.0 0.0	60	
5–6	CL		SILT and CLAY, dark brown and black, close to peat. Moist.	3	0.0		1.5
6–17	GW		SAND and GRAVEL, orange brown, some coarse gravel, trace silt. Dry.	4 5 6 7 8	0.0 0.0 0.0 0.0 0.0	60 50 50	
17–22			Push Geoprobe Tube 17 to 22. 33" recovery.				
22			End of Boring at 22 feet.				

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LOG OF BORING JS29-GT-5

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0-1	TS		Top Soil, black, clayey, some gravel. Slightly Moist. GRAVEL, brown, some sand and silt. Dry.	1	0.0		
2-4	CL		CLAY, dark brown and black, some silt, little sand and gravel, moderately soft. Slightly Moist. - cobble	2	0.0	80	1.5 - 2.0
5-7				3	0.0	75	
8-9			- cobble	4	0.0		
10-12				5	0.0	50	
13-14			- wet gravel	6	0.0		

End of Boring at 14 feet.

Attempted Shelby Tube, colapsed then refusal.

Retained Geoprobe Tube 5 to 9. 34" recovery.
Retained Geoprobe Tube 9 to 14. 22" recovery.

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LOG OF BORING JS29-GT-6

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	ML		Bottom Ash, silt, black, some gravel. Dry.				
1–2	GW		Crushed Limestone, sand and gravel. Dry.	1	0.0		
2–3	CL		CLAY, black, some sand and gravel and bottom ash. Dry.				
3–4	GW		SAND and GRAVEL, orange brown, some silt and clay. Dry.	2	0.0	70	
4–5							
5–6				3	0.0		
6–7	CL		CLAY, black, with sand and gravel. Slightly Moist.				
7–8			- orange brown, dry	4	0.0	70	
8–9							
9–10	CG		GRAVEL, black, some silt and clay. Wet.	5	0.0		
10–11	PT		PEAT, blalck, soft. Slightly Moist to Moist.				
11–12							
12–13				6	0.0	100	1.0 - 1.5
13–14			- wet				
14–15			- weathered bedrock				
15–16			End of Boring at 15 feet.				
16–17			Bagged 11 to 14 feet. Also from new hole 11 to 14 feet.				
17–18							
18–19							
19–20							
20–21							
21–22							
22–23							
23–24							
24–25							
25–26							
26–27							
27–28							
28–29							
29–30							

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ATTACHMENT 5
Joliet Station #9 Geotechnical Study Results

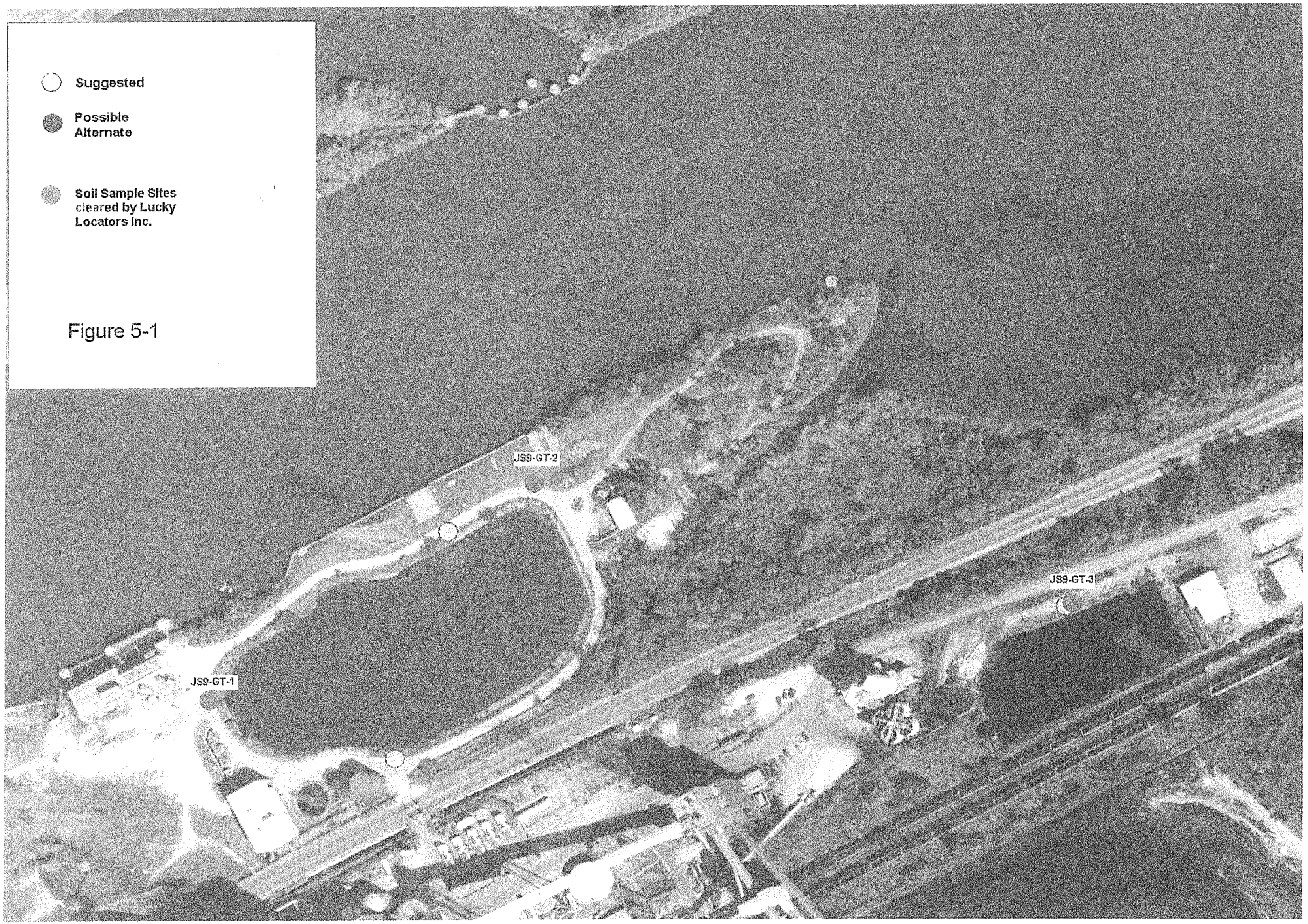

Suggested
Possible Alternate
Soil Sample Sites cleared by Lucky Locators Inc.
JS9-GT-1
JS9-GT-2
JS9-GT-3

Figure 5-1

Electronic Filing: Received, Clerk's Office 2/04/2022

Table 5-1. Soil Sample Geotechnical Data - Midwest Generation, Joliet Station #9, Joliet, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
JS-9-GT-1	7-12'	Sand, with gravel, gray	4	110	16	NP	32	23	2.63	*
		Organic clay, with gravel	20.0							
JS-9-GT-2	7-11.5'	Clayey sand, with organics, trace gravel, dark brown	23.7	91.0	NP	NP	51	21		2.73x10-2
		Organic clay, occasional shells and peat, trace gravel, black, dark brown	56.3							
JS-9-GT-3	8-13'	Sand, with gravel, gray	5.5	86	NP	NP	11	7	2.66	*

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
NA - Not Analyzed
NP - Not Plastic

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LOG OF BORING JS9-GT-1

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0	GW		Crushed Limestone and SILT, gray and black. Dry.	1	0.0		
1	CL		CLAY, dark brown, with gravel, little silt and fine to medium sand. Slightly Moist.	2	0.0	100	
2							
3			- 3" crushed limestone gravel	3	0.0		
4							
5			- 3" crushed limestone gravel				
6	GW		SAND-SILT-GRAVEL Mixture, black, moderately stiff. Moist. - gravel	4	0.0	60	
7							
8	SM		SILT and fine SAND, black, some clay. little gravel. Moist.	5	0.0		
9			- 3" gravel				
10							
11			End of Boring at 10 feet.				
12			Push Geoprobe Tube in new boring 7 to 12 feet. 26" Recovery.				
13							
14							
15							
16							
17							
18							
19							
20							

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LOG OF BORING JS9-GT-2

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	ML		SILT, gray, with fine sand and gravel. Moist.	1	0.0		
1–2	CL/GW		CLAY and GRAVEL, dark brown, some silt and fine to medium sand. Moist.	2	0.0	90	
2–5	SM		SAND-SILT-CLAY Mixture, black, little gravel. Moist.	3	0.0		
5–7	SM		SAND-SILT-CLAY Mixture, black, little gravel. Moist.	4	0.0	30	
7–10	PT		PEAT, black/dark brown, trace shells. Moist.	5	0.0		<1.0

End of Boring at 10 feet.

Push Geoprobe Tube in new boring 7 to 11.5 feet.
Refusal. 35" Recovery.

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LOG OF BORING JS9-GT-3

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SM		SILT and fine SAND, organics, black. Moist.	1	0.0		
1–2	SM		SAND-SILT-CLAY Mixture, black, trace coarse gravel. Slightly Moist.	2	0.0	50	
2–3	GW		Crushed Limestone GRAVEL. Slightly Moist.	3	0.0		
3–4	SM		SLAG, black, granular, sand and gravel. Slightly Moist.	4	0.0		
4–5	GW		SAND and GRAVEL, red, little clay and silt. Very Moist.	5	0.0	30	
5–6	GW		Crushed Limestone GRAVEL, tan, with gray and black fine sand and silt. Very Moist.	6	0.0		
6–7	GW			7	0.0	30	
7–8							
8–9							
9–10							
10–11							
11–12							
12–13							
13–14							
14–15							
15–16			End of Boring at 15 feet.				
16–17			Push Geoprobe Tube in new boring 8 to 13 feet. 18" Recovery.				
17–18							
18–19							
19–20							

ATTACHMENT 6
Powerton Station Geotechnical Study Results

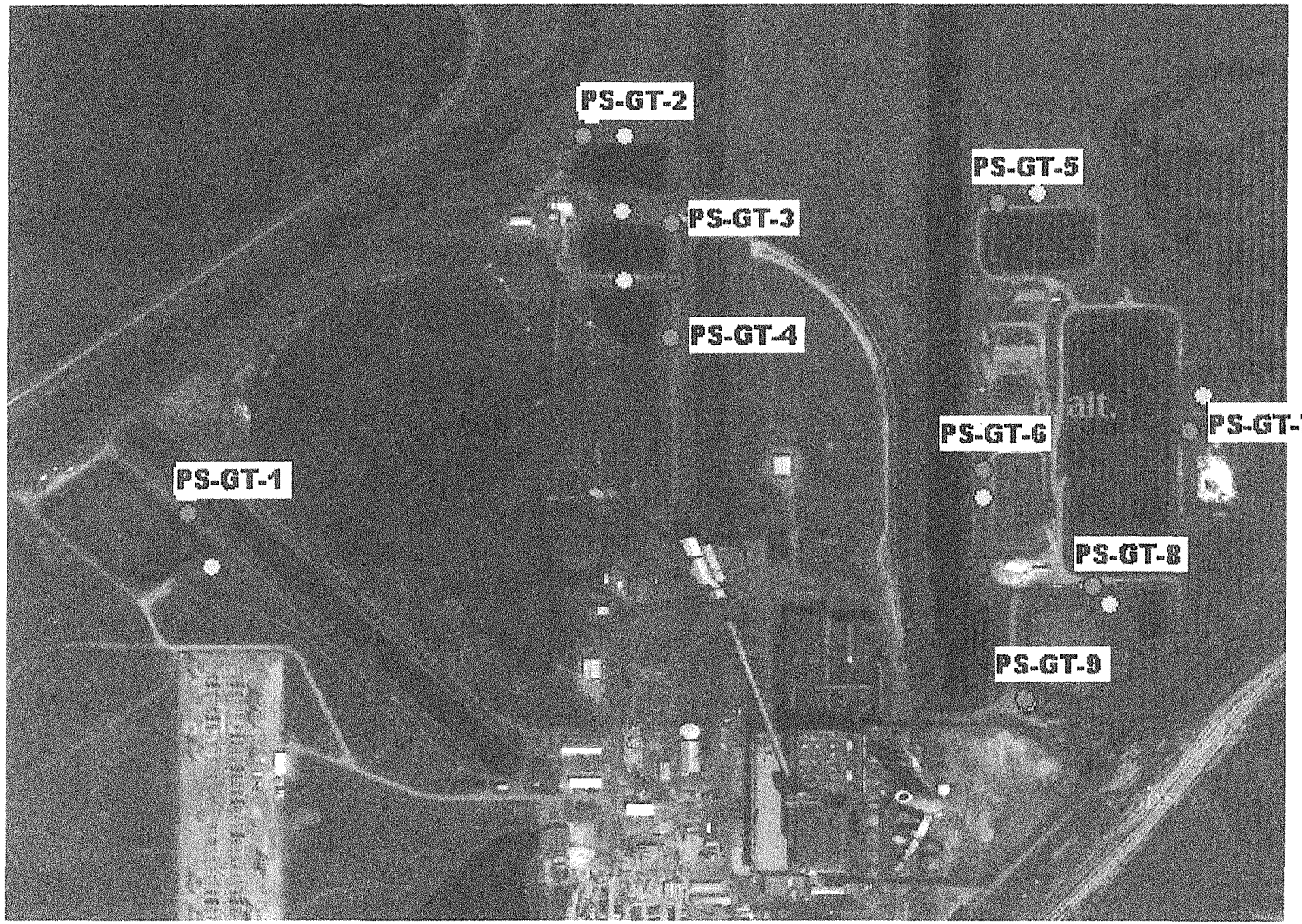

PS-GT-2
PS-GT-5
PS-GT-3
PS-GT-4
PS-GT-6
PS-GT-7
PS-GT-1
PS-GT-8
PS-GT-9
Suggested
Possible Alternate
Soil sample sites, cleared by Lucky Locators Inc.

Figure 6-1

Table 6-1. Soil Sample Geotechnical Data - Midwest Generation, Powerton Station, Pekin, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
PS-GT-1	10'-12'	Clayey Sand/Sandy Clay, with gravel, dark brown	7.8	115	NP	NP	83	17	2.7	6.2x10-5
			9.7		22	NP	79	48	2.56	
PS-GT-2	7-8.5	Sand, trace clay and gravel, medium to coarse grained, brown	9.5	126.7	22	NP	79	48	2.7	1.1x10-4
PS-GT-3	7'-9'	Topsoil, with gravel, dark brown (possible cave-in)	12.9	112					2.7	
		Sandy Lean Clay, trace gravel and organics, dark brown	28.0	110	31	15	58	17	2.68	2x10-4
PS-GT-4	10'-11.5'	Sand, with clay and gravel, trace organics fine to coarse grained, dark brown	7.9	116	NP	NP	33	16	2.77	1.6x10-7
PS-GT-5	17-19	Clayey Sand, with gravel, dark brown	16.0							
		Lean Clay, trace sand	38.5	93	53	27	63	44	2.44	NA
PS-GT-6	1'	Fill: Sand, fine to medium coarse, trace gravel, dark brown	4.9	113.5	NP	NP	33	5	2.52	8.37x10-3
PS-GT-7	10-13'	Sand, with silt and gravel, dark brown, black	7.6	118.0	21	3	44	17	2.63	2.2x10-3
PS-GT-8	10-15'	Fill: cinders, metal shavings, glass, black	9.0	86**	NP	NP	14	4		
		Silty sand, trace clay, dark gray	12.0	115.0	NP	NP	34	14	2.61	2.31x10-2
PS-GT-9	15-20'	Fill: Sand, trace clay and gravel, dark brown	7.9	113.0	NP	NP	30	21	2.64	1.7x10-3
		Clayey sand, with gravel, brown and gray	9.8							

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
NA - Not Analyzed
NP - Not Plastic

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KPRG and Associates, Inc.

LOG OF BORING PS-GT-1

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	SC		CLAY top soil, brown, with sand-silt-gravel mixture, organics. Slightly Moist to Dry. - less clay	1	0.0		
3–4	CL		CLAY, brown, some silt, little sand, trace gravel. Slightly Moist.	2	0.0	90	4.0 to >4.5
5–6				3	0.0		2.0 to 2.5
6–9			- darker (dark brown) - increase gravel	4	0.0	60	
10–11			Push Shelby Tube 10-12. 19 " recovery.				
12			End of Boring at 18 feet.				
13–20							

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LOG OF BORING PS-GT-2

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SC		CLAY top soil, brown and light brown, organics. Dry.	1	0.0		
1–5	CL		CLAY, brown, some silt and fine sand, trace gravel. Dry.	2	0.0	70	>4.5
5–11	SP		SAND, fine, brown and orange brown, some silt. Slightly Moist to Dry. - dark brown - some clayey layers	3 4	0.0 0.0	100 100	
11–12	CL		CLAY, gray, little medium sand and fine gravel, soft. Moist. (Native)	5	0.0		1.0

End of Boring at 12 feet.

Push Shelby Tube in new boring 7 to 8.5 feet. 27" recovery.

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LOG OF BORING PS-GT-3

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		Bottom Ash, black, fine, and GRAVEL, fine to medium, limestone. Dry.	1	0.0		
1–2	CL		CLAY, dark brown, some silt and fine sand, trace gravel. Dry.	2	0.0	100	>4.5
2–5	GW		SAND and GRAVEL, brown and orange brown, some clay in layers. Slightly Moist.	3	0.0		
5–6	CL		CLAY, brown and dark brown, some fine sand and silt, trace gravel, Moist.	4	0.0		1.0
6–7	CL		- fine sand and silt seam, brwon	5	0.0	100	4.0
7–9			Push Shelby Tube 7 to 9 feet. 21.5" recovery.				
9			End of Boring at 9 feet.				
10–20							

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(DRAFT) LOG OF BORING PS-GT-4

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		GRAVEL and SILT, gray and black. Dry.	1	0.0		
1–3	GW		CLAY-SAND-GRAVEL Mixture, brown some dark brown and black. Slightly Moist.	2	0.0	100	
4–7	SM		SAND and SILT, brown, fine, little gravel. Slightly Moist. - gray and light brown	3	0.0		
8–9	CL		CLAY, dark gray to black, little medium sand, trace gravel. Slightly Moist to Moist.	4	0.0	90	1.0
9–10	CL		CLAY, dark gray to black, little medium sand, trace gravel. Slightly Moist to Moist.	5	0.0		4.0
10–11			Push Shelby Tube 10-11.5. Refusal. 21.5" recovery.				
12			End of Boring at 11.5 feet.				

13 14 15 16 17 18 19 20

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LOG OF BORING PS-GT-5

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	GW		Top Soil, clayey, brown, some sand and gravel. Dry.	1	0.0		
2–4	SM		Bottom Ash, brown, sand and silt. Dry.	2	0.0	80	
4			- grade to dark brown and black				
4–16	CL		CLAY and SILT, brown and gray, some slag, medium to coarse sand and fine gravel. Moist.	3	0.0		
				4	0.0	80	
				5	0.0		
			12-14 - granular, little fines	6	0.0	80	
16–17	CL		PEAT, brown, moderately soft. Moist.	7	0.0	50	
17–19			Push Shelby Tube 17-19. 22" recovery.				
19–20			End of Boring at 19 feet.				

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LOG OF BORING PS-GT-6

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SC		CLAY, brown, and Bottom Ash, brown, and Slag, sand, stiff. Dry.	1	0.0		
1–6	GW		SLAG and Bottom Ash, black, fine to medium sand and silt. Dry. - mixed with orange/brown clay and gravel.	2 3	0.0 0.0	100	
6–8	CL		CLAY, dark brown and black, some silt, trace gravel. Moist.	4	0.0	90	4.0
8–13	CL		CLAY-SAND-GRAVEL Mixture, brown. Slightly Moist. - 3" light brown silt and fine sand seam - darker	5 6	0.0 0.0		1.0
13–18			Attempt to Push Shelby Tube 13-15. Refusal. Push geoprobe tube 13-18. 40 " recovery.				
18			End of Boring at 18 feet.				

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LOG OF BORING PS-GT-7

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	CL		CLAY and SILT, organics, light brown, some sand and gravel . Dry. - transistion (mixed layer)	1	0.0		
2–13	SM		SLAG and Bottom Ash, black and dark brown, some medium to coarse sand and silt. Dry. - clayey, brown, very stiff	2	0.0	100	
				3	0.0		
				4	0.0	100	
				5	0.0	100	

End of Boring at 13 feet. Refusal.

Push geoprobe tube in seperate boring 8 to 13.

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LOG OF BORING PS-GT-8

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	SP		SAND, fine to medium, brown and dark brown, little silt, trace gravel, very stiff. Dry.	1	0.0		
3–15	SM		SLAG and Bottom Ash, black and dark gray, fine to medium sand, some silt and clay, very stiff. Dry.	2	0.0	100	
			- clayey, brown				
			- granular, medium to coarse sand	3	0.0		
				4	0.0	100	
			- a few clayey layers, slightly moist				
				5	0.0	100	
15–20			Push geoprobe tube 15 to 20 feet. 44" recovery.				

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LOG OF BORING PS-GT-9

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		Crushed Limestone, silt, sand and gravel. Dry.				
1–3	GW		CLAY and GRAVEL, brown, stiff. Dry.	1	0.0		
3–5	SM		SLAG and Bottom Ash, black and dark gray, medium to coarse sand, little silt. Dry to Slightly Moist.	2	0.0	100	
5–7	SM		- 6" gray clay with medium to coarse sand	3	0.0		>4.5
7–9	SM			4	0.0	100	>4.5
9–12	SM			5	0.0	100	
12–14	SM						
14–15	CL		CLAY, gray, trace silt, black ribbon. Moist.	6	0.0		1.5
15–20			Could not anchor to attempt Shelby Tube. Push geoprobe tube 15 to 20 feet. 44" recovery.				

ATTACHMENT 7
Geotechnical Laboratory Report

Electronic Filing: Received, Clerk's Office 2/04/2022

KPRG Project No. 15805 Laboratory Results
Terracon Project No. 58055075
October 11, 2005

Sample	Depth	Soil Description	Moisture (%)	Dry Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Coefficient of Permeability (cm/s)
					LL (%)	PI (%)				
CS-GT-1	5-10'	Sand, fine to coarse, trace gravel and silt, brown, dark brown, black	10.4	117**	NP	NP	24	12	2.71	2.2x10-3
CS-GT-2	10'-12'	Sand, fine to coarse grained, gray (crushed limestone) (top)	1.7		NP	NP	24	14	2.68	*
CS-GT-2	10'-12'	Lean Clay, trace sand, gray (bottom)	15.9	117	36	18	94	88		N/A
		(2nd test)	16.2		36	19				
CS-GT-4	5'-7'	Sand, with gravel, fine to medium, gray (crushed concrete)	2.2		NP	NP			2.65	*
CS-GT-4	5'-7'	Lean Clay, trace sand and gravel, gray	22.2	110	38	19	72	65	2.69	N/A
CS-GT-5	5'-7.5'	Sand, with gravel and clay, dark brown (possible cave-in)	7.3		NP	NP			2.5	
		Lean Clay, with sand, brown and gray	22.0	112	27	19	37	33	2.7	2.3x10-8
CS-GT-6	10-12.5'	Sandy Lean Clay, with gravel, brown and dark brown	6.3	118**	31	13	77	62	2.58	N/A
WS-GT-1	5 to 10'	Sand with trace gravel	5.6	114	NP	NP	94	1	2.63	1.05x10-2
WS-GT-2	7.5'-10'	Silty Sand, trace gravel, dark brown	15.2	107	NP	NP	79	18	2.44	1.52x10-2
			18.1							
WS-GT-3	5 to 10'	Sand with trace gravel	11.2	99	NP	NP	86	0	2.65	2.3x10-2
WS-GT-4	22-27'	Sand with trace gravel	5.4	114	NP	NP	53	2	2.64	2.16x10-2
WS-GT-5	22-27'	Sand, trace gravel, black	4.4	96	NP	NP	15	0	2.73	1.21x10-2
		(Bottom Ash?)								
WC-GT-1	5 to 10'	Clayey Sand, dark brown to tan	3.4	118	NP	NP	26	17	2.66	1.35x10-1
WC-GT-2	5 to 10'	Sand with gravel, dark brown	18.1	92	NP	NP	35	12	2.65	4.02x10-3
WC-GT-3	3 to 8'	Lean Clay, dark brown	10.0	103	35	12	26	20	2.71	***
WC-GT-4	5 to10' (btm)	Silty Clay, dark brown	9.5	128	25	7			2.7	***
WC-GT-4	5 to 10'	Sandy Gravel, with clay					35	23		
WC-GT-5	5-9'	Sandy Clay with Gravel	4.2	119	NP	NP	39	35	2.65	*

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KPRG Project No. 15805 Laboratory Results
Terracon Project No. 58055075
October 11, 2005

Sample	Depth	Soil Description	Moisture (%)	Dry Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Coefficient of Permeability (cm/s)
					LL (%)	PI (%)				
PS-GT-1	10'-12'	Clayey Sand, with gravel, dark brown	7.8	115	NP	NP	83	34	2.7	6.2x10-5
PS-GT-1	10'-12'	Sandy Clay, with gravel, dark brown	9.7		22	NP	79	48	2.56	
PS-GT-2	7-8.5	Clayey Sand, trace gravel, medium to coarse grained, brown	9.5	126.7	22	NP	79	48	2.7	1.1x10-4
PS-GT-3	7'-9'	Topsoil, with gravel, dark brown (possible cave-in)	12.9	112					2.7	
PS-GT-3	7'-9'	Sand, trace clay, gravel and organics, dark brown	28.0	110	31	15	58	17	2.68	2x10-4
PS-GT-4	10'-11.5'	Sand, with clay and gravel, trace organics fine to coarse grained, dark brown	7.9	116	NP	NP	33	16	2.77	1.6x10-7
PS-GT-5	17-19	Clayey Sand, with gravel, dark brown	16.0							
PS-GT-5	17-19	Sandy Lean Clay, trace gravel, brown	38.5	93	53	27	63	44	2.44	N/A
PS-GT-6	15-20'	Fill: Sand, fine to medium coarse, trace gravel, dark brown	4.9	113.5	NP	NP	33	5	2.52	8.37x10-3
PS-GT-7	10-13'	Sand, with silt and gravel, dark brown, black	7.6	118.0	21	3	44	17	2.63	2.2x10-3
PS-GT-8	10-15'	Fill: cinders, metal shavings, glass, black	9.0	86**	NP	NP	14	4		
PS-GT-8	10-15'	Silty sand, trace clay, dark gray	12.0	115.0	NP	NP	34	14	2.61	2.31x10-2
PS-GT-9	15-20' (top)	Silty Sand, dark gray	9.8		22	3	30	14		
PS-GT-9	15-20' (mid)	Gravel, with silt and sand, dark brown					12	7		
PS-GT-9	15-20' (btm)	Sand, trace clay and gravel, dark brown	7.9	113.0	24	3	30	21	2.64	1.7x10-3

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KPRG Project No. 15805 Laboratory Results
Terracon Project No. 58055075
October 11, 2005

Sample	Depth	Soil Description	Moisture (%)	Dry Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Coefficient of Permeability (cm/s)
					LL (%)	PI (%)				
JS-9-GT-1	7-12'	Sand, with gravel, gray	4	110	16	NP	32	23	2.63	*
JS-9-GT-1	7-12'	Organic Clay, with gravel	20.0							
JS-9-GT-2	7-11.5'	Clayey Sand, with organics, trace gravel, dark brown	23.7	91.0	NP	NP	51	21		2.73x10-2
JS-9-GT-2	7-11.5'	Organic Clay, occasional shells and peat, trace gravel, black, dark brown	56.3							
JS-9-GT-3	8-13'	Sand, with gravel, gray	5.5	86	NP	NP	11	7	2.66	*
JS-29-GT-1	19-24'	Sandy Gravel, trace clay, dark yellow	5.3	120	16	NP	14	9	2.62	2.96x10-2
JS-29-GT-2	19-24	Gravelly Sand, brown	10.0	87.0	NP	NP	21	14	2.66	*
JS-29-GT-2	19-24	Gravelly Sand, trace clay, dark brown	6.0		NP	NP				
JS-29-GT-3	19-24	Poorly graded gravel with clay and sand, brown	8.6	121**	NP	NP	13	9	2.64	2.51x10-2
JS-29-GT-3	19-24	Lean clay, gray	7.3							
JS-29-GT-4	17-22	Limestone with fine to coarse sand	4.1	124.0	NP	NP	11	7	2.7	*
JS29-GT-5	5-9'	Clayey Gravel with sand, dark gray	26.0	94.0	34	11	32	19	2.56	4.7x10-4
	9-14' (top)	Gravel, with silt and sand, dark gray			NP	NP	16	10		
	9-14' (btm)	Silty Gravel			21	NP	23	16		
JS-29-GT-6	11-14'	Organic Silt, dark gray, black	74.6	53.0	78	17	89	65	2.41	N/A

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
***Unable to properly remold sample, too much large aggregate
NP=Non Plastic Soil

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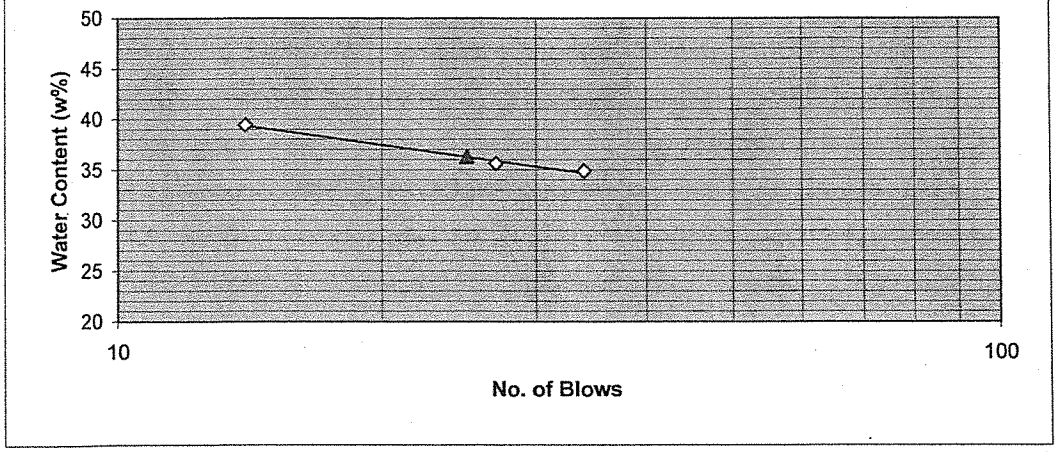
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
			CS-GT-2		
Location of project:		Boring No:	(top)	Sample Depth:	10'-12'
Description of Soil:	Sand, fine to coarse grained, gray	Tested By:	KF		

Liquid Limit Determination:

Can no.	49	115	119	
Mass of wet soil + can, gm	46.68	45.43	55.20	
Mass of dry soil + can, gm	42.72	41.78	48.39	
Mass of Can, gm	31.36	31.53	31.12	
Mass of dry soil, gm	11.36	10.25	17.27	
Mass of moisture, gm	3.96	3.65	6.81	
Water Content, w%	34.86	35.61	39.43	
No. of Blows	34	27	14	
Notes				



Plastic Limit Determination:

Can no.	400	109		
Mass of wet soil + can, gm	46.90	49.62		
Mass of dry soil + can, gm	44.49	46.83		
Mass of Can, gm	31.25	31.21		
Mass of dry soil, gm	13.24	15.62		
Mass of moisture, gm	2.41	2.79		
Water Content, w%	18.20	17.86		

Liquid Limit	36
Plastic Limit	18
Plasticity Index	18

By: TK

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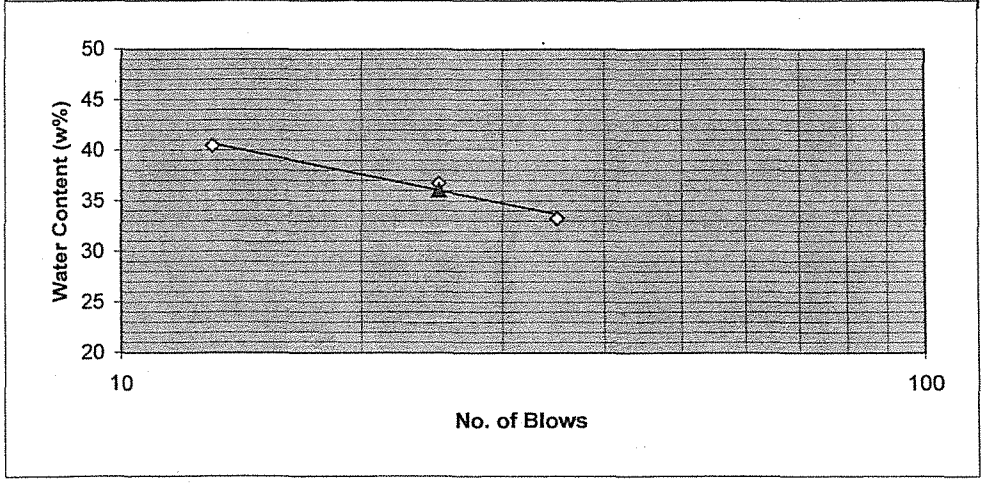
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	CS-GT-2 (Bottom)	Sample Depth:	10'-12'
Description of Soil:	Lean Clay, trace sand, gray	Tested By:	KF		

Liquid Limit Determination:

Can no.	456	400D	52A	
Mass of wet soil + can, gm	50.10	54.66	57.12	
Mass of dry soil + can, gm	45.51	48.37	49.64	
Mass of Can, gm	31.71	31.24	31.14	
Mass of dry soil, gm	13.80	17.13	18.50	
Mass of moisture, gm	4.59	6.29	7.48	
Water Content, w%	33.26	36.72	40.43	
No. of Blows	35	25	13	
Notes				



Plastic Limit Determination:

Can no.	109	115		
Mass of wet soil + can, gm	40.97	39.71		
Mass of dry soil + can, gm	39.51	38.49		
Mass of Can, gm	31.21	31.53		
Mass of dry soil, gm	8.30	6.96		
Mass of moisture, gm	1.46	1.22		
Water Content, w%	17.59	17.53		

Liquid Limit	**36**
Plastic Limit	**18**
Plasticity Index	**19**

By: TK

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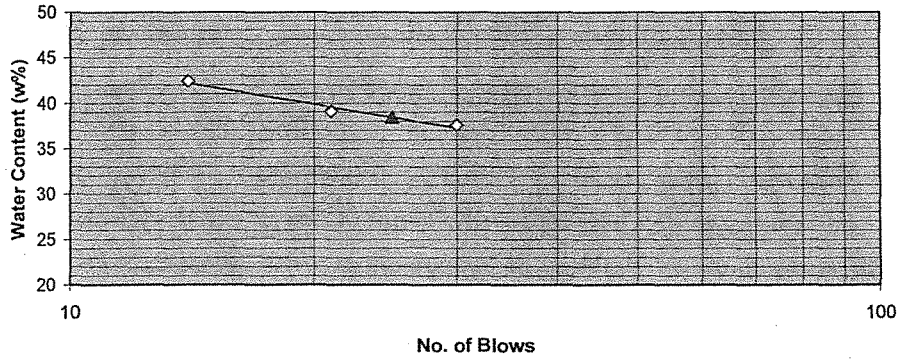
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Laboratory Test Results of
Atterberg Limits
ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	CS-GT-4	Sample Depth:	5'-7'
Description of Soil:	Lean Clay, trace sand and gravel, gray	Tested By:	KF		

Liquid Limit Determination:

Can no.	BJ	DE	CC	
Mass of wet soil + can, gm	41.32	44.93	43.45	
Mass of dry soil + can, gm	35.78	38.32	36.70	
Mass of Can, gm	21.03	21.40	20.79	
Mass of dry soil, gm	14.75	16.92	15.91	
Mass of moisture, gm	5.54	6.61	6.75	
Water Content, w%	37.56	39.07	42.43	
No. of Blows	30	21	14	
Notes				



Plastic Limit Determination:

Can no.	DW	456		
Mass of wet soil + can, gm	29.94	42.32		
Mass of dry soil + can, gm	28.48	40.56		
Mass of Can, gm	21.15	31.74		
Mass of dry soil, gm	7.33	8.82		
Mass of moisture, gm	1.46	1.76		
Water Content, w%	19.92	19.95		

Liquid Limit	38
Plastic Limit	20
Plasticity Index	19

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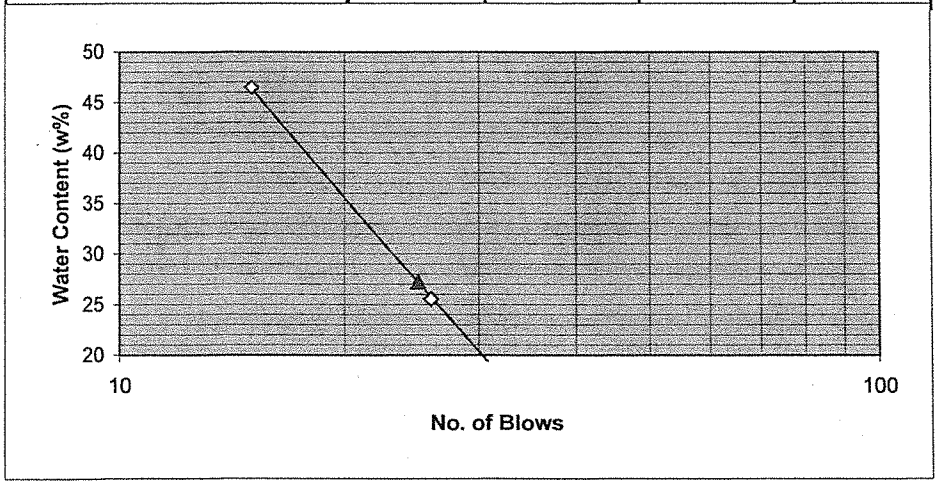
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	CS-GT-5	Sample Depth:	5'-7.5'
Description of Soil:	Lean Clay, with sand, brown and gray	Tested By:	KF		

Liquid Limit Determination:

Can no.	33	DR	BC	
Mass of wet soil + can, gm	47.30	45.06	43.52	
Mass of dry soil + can, gm	45.27	40.13	36.29	
Mass of Can, gm	32.45	20.82	20.73	
Mass of dry soil, gm	12.82	19.31	15.56	
Mass of moisture, gm	2.03	4.93	7.23	
Water Content, w%	15.83	25.53	46.47	
No. of Blows	34	26	15	
Notes				



Plastic Limit Determination:

Can no.	400-A	52-A		
Mass of wet soil + can, gm	41.20	39.92		
Mass of dry soil + can, gm	39.83	39.90		
Mass of Can, gm	31.87	28.06		
Mass of dry soil, gm	7.96	11.84		
Mass of moisture, gm	1.37	0.02		
Water Content, w%	17.21	0.17		

Liquid Limit	27
Plastic Limit	9
Plasticity Index	19

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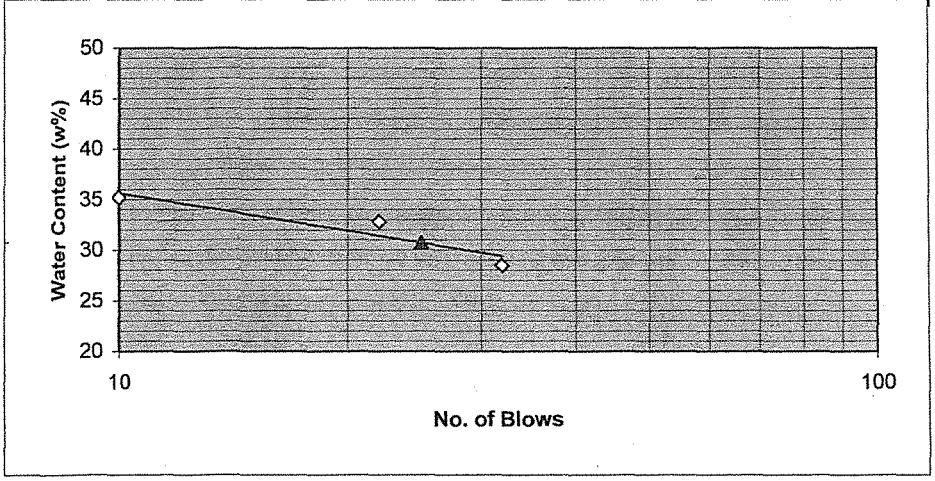
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	CS-GT-6	Sample Depth:	10'-12.5'
Description of Soil:	Sandy Lean Clay, with gravel, brown and dark	Tested By:	KF		

Liquid Limit Determination:

Can no.	AC	49	119	
Mass of wet soil + can, gm	48.64	57.98	54.65	
Mass of dry soil + can, gm	42.52	51.40	48.55	
Mass of Can, gm	21.03	31.34	31.22	
Mass of dry soil, gm	21.49	20.06	17.33	
Mass of moisture, gm	6.12	6.58	6.10	
Water Content, w%	28.48	32.80	35.20	
No. of Blows	32	22	10	
Notes				



Plastic Limit Determination:

Can no.	59	131		
Mass of wet soil + can, gm	39.33	37.76		
Mass of dry soil + can, gm	38.07	36.78		
Mass of Can, gm	31.24	31.13		
Mass of dry soil, gm	6.83	5.65		
Mass of moisture, gm	1.26	0.98		
Water Content, w%	18.45	17.35		

Liquid Limit	**31**
Plastic Limit	**18**
Plasticity Index	**13**

By: TK

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3 pt. ATTERBERG

LIQUID LIMIT DETERMINATION

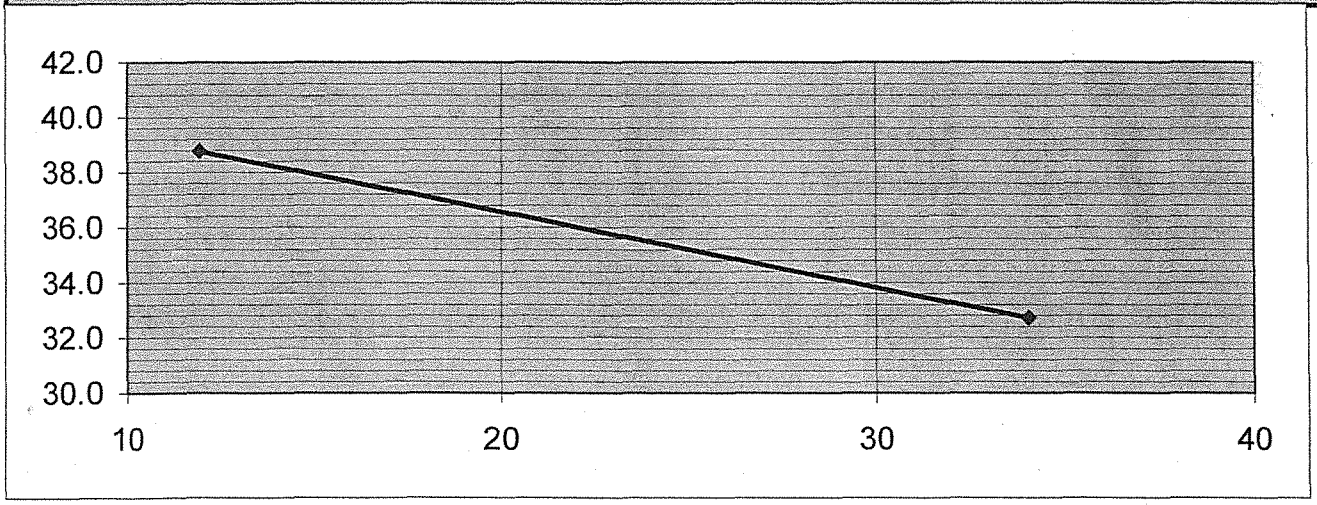
POINT No.	POINT 1	POINT 2	POINT 3	POINT 4
WET SOIL + TARE	9.92	13.87	13.87	
DRY SOIL + TARE	7.79	10.35	10.35	
TARE	1.28	1.27	1.27	
No. OF BLOWS	34	12	12	
MOISTURE %	**32.7**	**38.8**	**38.8**	**#DIV/0!**
CORECTION FACT.	1.000	1.000	1.000	1.000
MOISTURE @ 25	**32.7**	**38.8**	**38.8**	**#DIV/0!**

PLASTIC LIMIT DETERMINATION

POINT No.	POINT 1	POINT 2
WET SOIL + TARE	11.32	10.51
DRY SOIL + TARE	9.42	8.81
TARE	1.26	1.29
MOISTURE %	**23.3**	**22.6**

For 3 pts.		
LL	PL	PI
34.5	**22.9**	**11.6**

For 4 pts.		
LL	PL	PI
#VALUE!	**23**	**#VALUE!**



Project : KPRG Laboratory Testing
Project No. : 58055075
Location : WCGT-3, 3 to 8' Top of Sample
Description : Lean Clay, dark brown

TK

3 pt. ATTERBERG

LIQUID LIMIT DETERMINATION

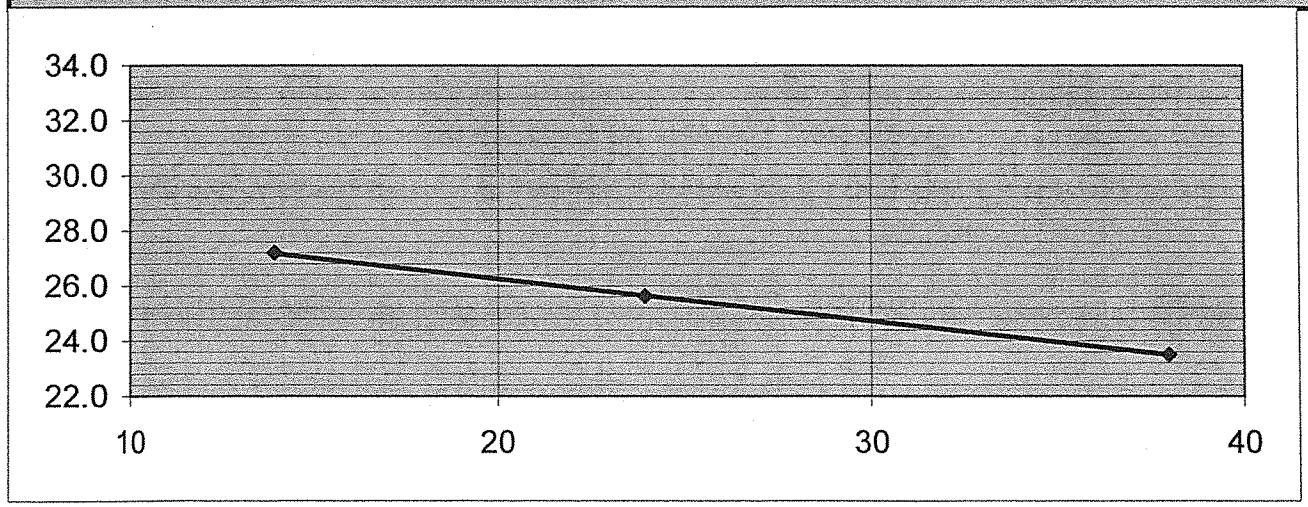
POINT No.	POINT 1	POINT 2	POINT 3	POINT 4
WET SOIL + TARE	19.50	21.32	24.54	
DRY SOIL + TARE	17.37	18.86	21.29	
TARE	8.31	9.26	9.34	
No. OF BLOWS	38	24	14	
MOISTURE %	**23.5**	**25.6**	**27.2**	**#DIV/0!**
CORECTION FACT.	1.000	1.000	1.000	1.000
MOISTURE @ 25	**23.5**	**25.6**	**27.2**	**#DIV/0!**

PLASTIC LIMIT DETERMINATION

POINT No.	POINT 1	POINT 2
WET SOIL + TARE	25.62	28.26
DRY SOIL + TARE	23.04	25.27
TARE	9.07	9.35
MOISTURE %	**18.5**	**18.8**

For 3 pts.		
L.L.	P.L.	P.I.
25.2	**18.6**	**6.6**

For 4 pts.		
L.L.	P.L.	P.I.
#VALUE!	**19**	**#VALUE!**



Project : KPRG Laboratory Testing
Project No. : 58055075
Location : WCGT-4, Btm of Sample From 5 to 10'
Description : Silty Clay, dark brown

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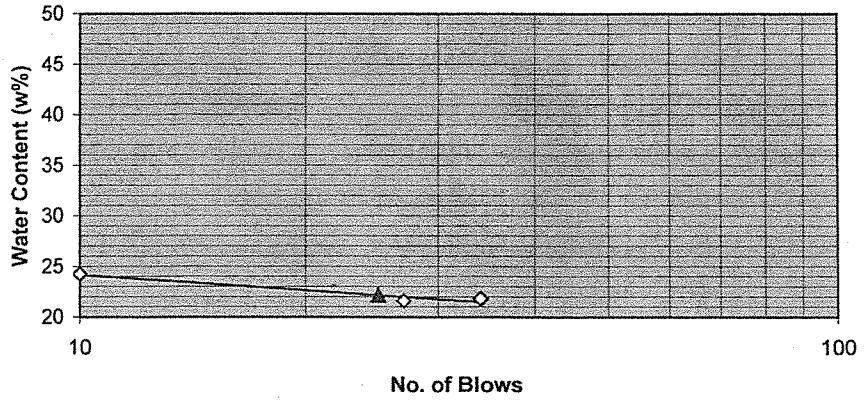
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	PS-GT-2	Sample Depth:	7'-8.5'
Description of Soil:	Clayey Sand, trace gravel, medium to coarse grained, brown	Tested By:	KF		

Liquid Limit Determination:

Can no.	59	BQ	1Q	
Mass of wet soil + can, gm	55.18	52.21	59.59	
Mass of dry soil + can, gm	50.89	46.74	54.11	
Mass of Can, gm	31.22	21.40	31.50	
Mass of dry soil, gm	19.67	25.34	22.61	
Mass of moisture, gm	4.29	5.47	5.48	
Water Content, w%	21.81	21.59	24.24	
No. of Blows	34	27	10	
Notes				



Plastic Limit Determination: **Unable to perform, too sandy**

Can no.				
Mass of wet soil + can, gm				
Mass of dry soil + can, gm				
Mass of Can, gm				
Mass of dry soil, gm				
Mass of moisture, gm				
Water Content, w%				

Liquid Limit	22
Plastic Limit	N/A
Plasticity Index	N/A

By: TLS

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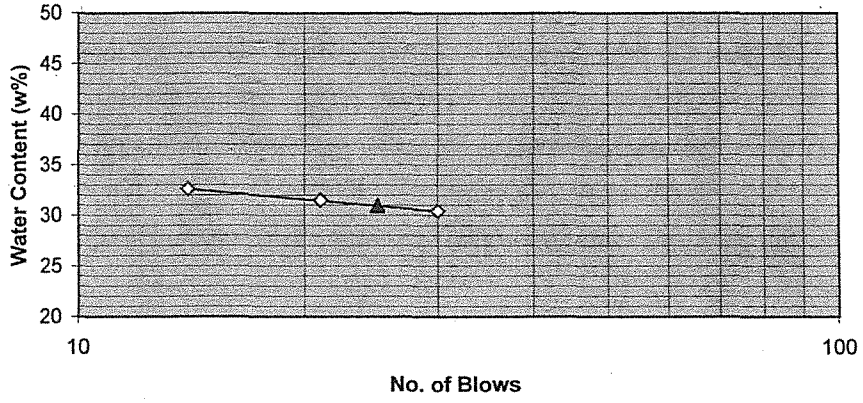
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	PS-GT-3	Sample Depth:	7'-9'
Description of Soil:	Sand, trace clay, organics, and gravel, dark brown	Tested By:	KF		

Liquid Limit Determination:

Can no.	FP	EK	BA	
Mass of wet soil + can, gm	42.58	43.90	46.56	
Mass of dry soil + can, gm	37.67	38.51	40.43	
Mass of Can, gm	21.52	21.39	21.61	
Mass of dry soil, gm	16.15	17.12	18.82	
Mass of moisture, gm	4.91	5.39	6.13	
Water Content, w%	30.40	31.48	32.57	
No. of Blows	30	21	14	
Notes				



Plastic Limit Determination:

Can no.	BN	46		
Mass of wet soil + can, gm	30.73	39.43		
Mass of dry soil + can, gm	29.37	38.28		
Mass of Can, gm	21.36	31.01		
Mass of dry soil, gm	8.01	7.27		
Mass of moisture, gm	1.36	1.15		
Water Content, w%	16.98	15.82		

Liquid Limit	**31**
Plastic Limit	**16**
Plasticity Index	**15**

By: TK

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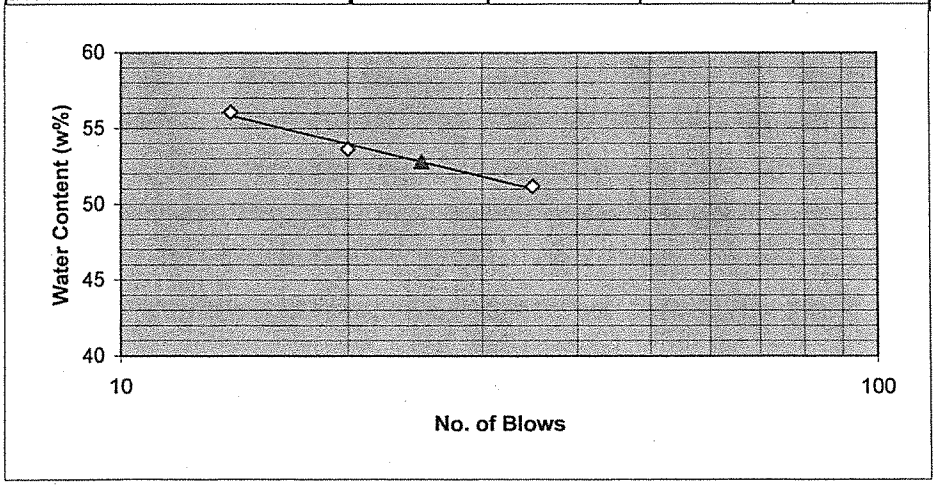
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	PS-GT-5	Sample Depth:	17'-19'
Description of Soil:	Sandy Lean Clay, trace gravel, dark brown	Tested By:	KF		

Liquid Limit Determination:

Can no.	AU	AC	EB	
Mass of wet soil + can, gm	38.74	47.26	41.01	
Mass of dry soil + can, gm	32.78	38.09	34.09	
Mass of Can, gm	21.13	20.99	21.75	
Mass of dry soil, gm	11.65	17.10	12.34	
Mass of moisture, gm	5.96	9.17	6.92	
Water Content, w%	51.16	53.63	56.08	
No. of Blows	35	20	14	
Notes				



Plastic Limit Determination:

Can no.	BM	AN		
Mass of wet soil + can, gm	31.90	29.18		
Mass of dry soil + can, gm	29.70	27.60		
Mass of Can, gm	21.12	21.52		
Mass of dry soil, gm	8.58	6.08		
Mass of moisture, gm	2.20	1.58		
Water Content, w%	25.64	25.99		

Liquid Limit	53
Plastic Limit	26
Plasticity Index	27

By: TK

Terracon Consultants

1pt. ATTERBERG

LIQUID LIMIT DETERMINATION

POINT No.	POINT 1	POINT 2
WET SOIL + TARE	18.67	15.48
DRY SOIL + TARE	16.27	13.52
TARE	1.28	1.30
No. OF BLOWS	19	16
MOISTURE %	**16.0**	**16.0**
CORECTION FACT.	0.967	0.947
MOISTURE @ 25	**15.5**	**15.2**

PLASTIC LIMIT DETERMINATION

POINT No.	POINT 1	POINT 2
WET SOIL + TARE	15.45	12.46
DRY SOIL + TARE	13.58	10.99
TARE	1.35	1.30
MOISTURE %	**15.3**	**15.2**

L.L.	**16**	**16**
L.L. @ 25 BLOWS	**15**	**15**
PLASTIC LIMITS	**15**	**15**
PLASTIC INDEX	**0**	**0**

Project : KPRG Laboratory Testing
Project No. : 58055075
Location : JS29GT-1
Description : Sandy Gravel, trace clay, dark yellow

TK

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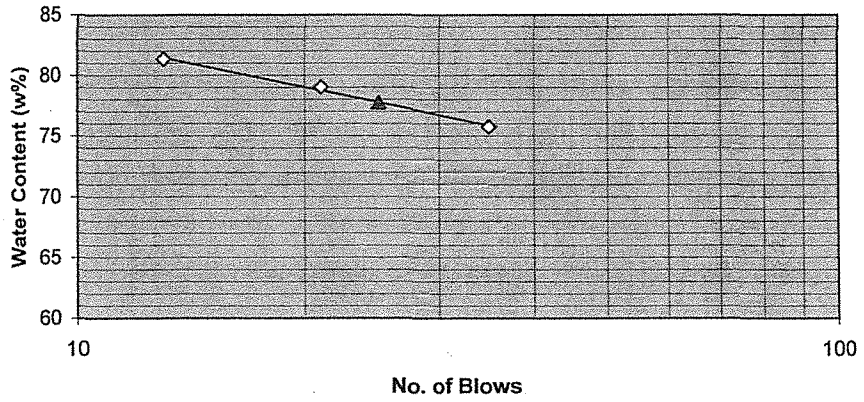
Terracon

Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing	Job No:	58055075
Location of project:		Boring No:	JS-29-GT-6 Sample Depth: 11-14'
Description of Soil:	Organic Silt, dark gray and black	Tested By:	MZ

Liquid Limit Determination:

Can no.	131	CE	400C	
Mass of wet soil + can, gm	35.84	25.29	35.20	
Mass of dry soil + can, gm	33.81	23.48	33.37	
Mass of Can, gm	31.13	21.19	31.12	
Mass of dry soil, gm	2.68	2.29	2.25	
Mass of moisture, gm	2.03	1.81	1.83	
Water Content, w%	75.75	79.04	81.33	
No. of Blows	35	21	13	
Notes				



Plastic Limit Determination:

Can no.	119	DU		
Mass of wet soil + can, gm	37.16	29.96		
Mass of dry soil + can, gm	35.31	26.24		
Mass of Can, gm	31.26	21.33		
Mass of dry soil, gm	4.05	4.91		
Mass of moisture, gm	1.85	3.72		
Water Content, w%	45.68	75.76		

Liquid Limit	78
Plastic Limit	61
Plasticity Index	17

By: TK
Terracon Consultants

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 10/7/2005

SAMPLE ID: CS-GT-1 5-7' -#4 MATERIAL
DESCR.: Sand, fine to coarse grained, trace gravel and silt, brown, dark brown and black

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	88.50	WET WT, g	195.8		
D & T, g	82.00	DIA, in	1.94	4.93	cm
T, g	19.37	HT, in	1.96	4.98	cm
		AREA		19.05	cm^2
MOIST-		DENSITY:	128.9	PCF WET	
URE, %	**10.4**	DENSITY:	**116.8**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	30.7	PROCTOR:	NA
SATURATION, %:	63.3	OPTIMUM:	NA
VOID RATIO:	0.44	COMPACTION, %:	#VALUE!
		OVER OPTIMUM, %:	#VALUE!

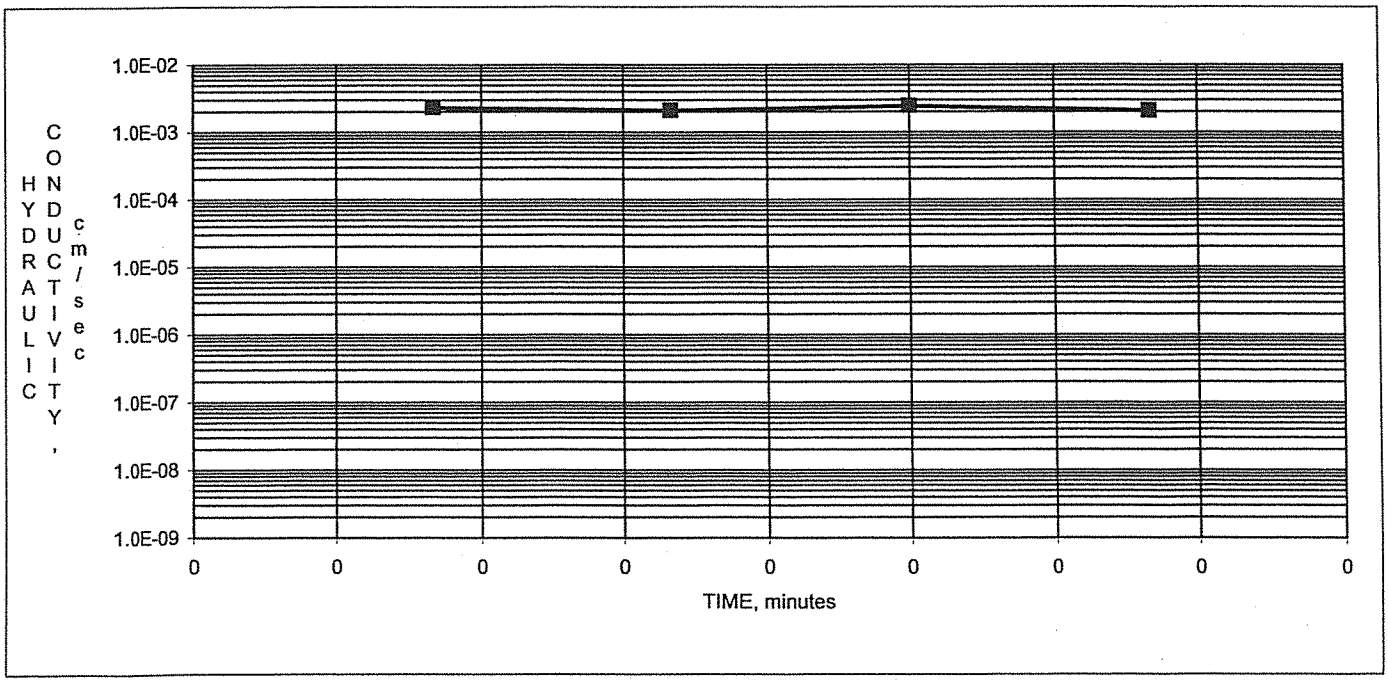
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
20.8	30.1	0	9.3									
21.8	28.8	0	7.0	0.284104	2.31E-03	1.0	1.3	0.77	1.4	3	21	0.980
22.6	28.0	0	5.4	0.259511	2.11E-03	0.8	0.8	1.00	1.1	6	21	0.980
23.2	27.2	0	4.0	0.300105	2.44E-03	0.6	0.8	0.75	0.8	9	21	0.980
23.8	26.9	0	3.1	0.254892	2.07E-03	0.6	0.3	2.00	0.6	7	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 2.2E-03 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0327



Terracon

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MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE
ID: CS-GT-5 5.0' - 7.5'
DESCR.: SILTY CLAY, WITH SAND, BROWN & GRAY

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	79.26	WET WT, g	229.7		
D & T, g	68.61	DIA, in	2.00	5.09	cm
T, g	20.38	HT, in	2.19	5.56	cm
		AREA		20.36	cm^2
MOIST-		DENSITY:	126.6	PCF WET	
URE, %	**22.1**	DENSITY:	**103.7**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	38.5	PROCTOR:	112.4
SATURATION, %:	95.3	OPTIMUM:	22.0
VOID RATIO:	0.63	COMPACTION, %:	92.3
		OVER OPTIMUM, %:	0.1

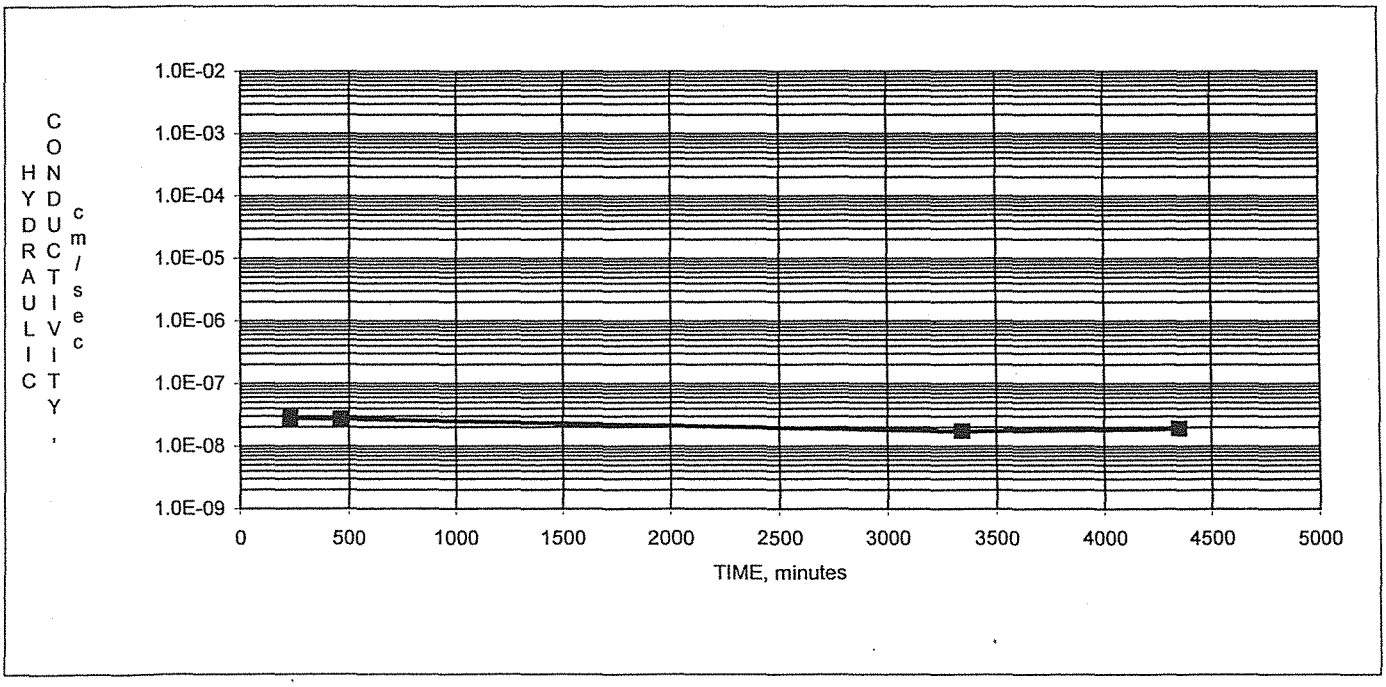
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER:	100.0	psi
				BIAS PRESSURE (=LOWER-UPPER)		0.0	psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
4.1	70.2	0	66.1									
4.4	69.9	229	65.5	0.009119	2.75E-08	0.3	0.3	1.00	11.8	21	22	0.956
4.7	69.6	461	64.9	0.009203	2.74E-08	0.3	0.3	1.00	11.7	20	22	0.956
6.7	67.2	3345	60.5	0.070204	1.72E-08	2.0	2.4	0.83	10.9	24	21	0.980
7.5	66.4	4351	58.9	0.026802	1.88E-08	0.8	0.8	1.00	10.6	17	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 2.3E-08 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0247



Terracon

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/14/2005

Location of Sample WSGT-1 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 5 to 10'

Description of Soil Sand, fine, trace gravel, light brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.62 Wt. Soil (lb.) 1.170

Area, A, cm^2 45.60 Moisture Content _____

Length, L, cm 6.350000 Volume (ft^3) 0.01023

Dry Density 114.4

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	7	20	38.5	127	12290.2	0.01139	1.10236	20	1.000	1.03E-02
2	17.2	20	15.5	127	12157.9	0.02829	2.70866	20	1.000	1.04E-02
3	24.3	20	11	127	12189.9	0.03987	3.82677	20	1.000	1.04E-02
4	29.8	20	9	127	12230.9	0.04873	4.69291	20	1.000	1.04E-02
5	33.2	20	8.2	127	12415.1	0.05348	5.22835	20	1.000	1.02E-02
6	37.5	20	6.8	127	11628.9	0.06449	5.90551	20	1.000	1.09E-02
7	40.9	20	6.5	127	12123.7	0.06747	6.44094	20	1.000	1.05E-02
8									Avg	1.05E-02
9										
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WS-GT-2 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 7.5-10

Description of Soil Silty Sand, trace gravel, light brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 6.23 Wt. Soil (lb.) 0.798

Area, A, cm^2 30.48 Moisture Content 8.9

Length, L, cm 6.350000 Volume (ft^3) 0.00685

Dry Density 107.0

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	13.2	20	19.08	127	7677.47	0.03439	2.07874	20	1.000	1.65E-02
2	19.5	20	12.8	127	7608.7	0.05126	3.07087	20	1.000	1.67E-02
3	27.8	20	10.2	127	8643.92	0.06432	4.37795	20	1.000	1.47E-02
4	32.2	20	8.87	127	8706.53	0.07397	5.07087	20	1.000	1.46E-02
5	35	20	8.17	127	8716.77	0.0803	5.51181	20	1.000	1.46E-02
6	36.7	20	7.52	127	8412.97	0.08725	5.77953	20	1.000	1.51E-02
7	39.6	20	7.24	127	8739.76	0.09062	6.23622	20	1.000	1.45E-02
8	41	20	6.95	127	8686.29	0.0944	6.45669	20	1.000	1.46E-02
9									AVG	1.52E-02
10										
11										
12										

Note:

Tested by: _____ Checked by: TK

Rowdy Miller Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WS-GT-3 Sampled _____ Report _____

Boring- _____ Sample- Bottom Depth- 5 to 10'

Description of Soil Sand, fine, trace gravel, light brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.62 Wt. Soil (lb.) 1.120

Area, A, cm^2 45.60 Moisture Content 11.2

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 98.6

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	3.3	20	31.5	127	4740.5	0.01392	0.51969	20	1.000	2.68E-02
2	8.7	20	14	127	5554.52	0.03133	1.37008	20	1.000	2.29E-02
3	13.5	20	9.5	127	5848.67	0.04616	2.12598	20	1.000	2.17E-02
4	17.2	20	7	127	5490.68	0.06265	2.70866	20	1.000	2.31E-02
5	21.5	20	5.5	127	5392.63	0.07974	3.38583	20	1.000	2.36E-02
6	24.3	20	5	127	5540.84	0.08771	3.82677	20	1.000	2.29E-02
7	32.3	20	4	127	5891.99	0.10964	5.08661	20	1.000	2.16E-02
8	32.3	20	4	127	5891.99	0.10964	5.08661	20	1.000	2.16E-02
9									AVG	2.30E-02
10										
11										
12										

Note:

Tested by: _____ Checked by: TK

Rowdy Miller Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WSGT-4 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 22 to 27'

Description of Soil Fine Sand Grading to a Fine To Coarse Sand With Gravel

Materials Used: Fine Sand @ Top of Sample.

Unit Weight Determination:

Diameter, D, cm 6.23 Wt. Soil (lb.) 0.822

Area, A, cm^2 30.48 Moisture Content 5.4

Length, L, cm 6.350000 Volume (ft^3) 0.00685

Dry Density 113.9

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	5.4	20	41.15	127	6773.75	0.01594	0.85039	22	0.953	1.79E-02
2	14.7	20	11.08	127	4965.04	0.05921	2.31496	22	0.953	2.44E-02
3	20.3	20	9.02	127	5581.72	0.07274	3.19685	22	0.953	2.17E-02
4	23.5	20	7.49	127	5365.56	0.0876	3.70079	22	0.953	2.26E-02
5	25.5	20	7.08	127	5503.5	0.09267	4.01575	22	0.953	2.20E-02
6	27.5	20	6.89	127	5775.87	0.09522	4.33071	22	0.953	2.10E-02
7	28	20	6.46	127	5513.87	0.10156	4.40945	22	0.953	2.20E-02
8									AVG	2.16E-02
9										
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WS-GT-5 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 22-27

Description of Soil Sand, Fine to Coarse Grained, Trace Gravel, Black

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 5.08 Wt. Soil (lb.) 0.619

Area, A, cm^2 20.27 Moisture Content 4.4

Length, L, cm 8.260000 Volume (ft^3) 0.00591

Dry Density 100.3

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	210.9	2.01	1	99.6156	4274.58	0.09917	25.5327	20	1.000	2.33E-02
2	210.9	2.01	150	579.431	641187	0.00066	25.5327	20	1.000	9.04E-04
3										
4										
5										
6										
7										
8										
9									AVG	1.21E-02
10										
11										
12										

Note:

Tested by: _____ Checked by: TK

Rowdy Miller Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/29/2005

Location of Sample WC-GT-1 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 5 to 10'

Description of Soil Clayey Sand, dark brown to tan

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 6.35 Dry Density 115.000

Area, A, cm^2 31.67 Moisture Content 3.4

Length, L, cm 6.350000

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	1.2	20	24	127	912.073	0.02631	0.18898	22	0.953	1.33E-01
2	2.6	20	14	127	1152.76	0.04511	0.40945	22	0.953	1.05E-01
3	4.1	20	10	127	1298.44	0.06315	0.64567	22	0.953	9.32E-02
4	5	20	8	127	1266.77	0.07894	0.7874	22	0.953	9.55E-02
5	5.3	20	8	127	1342.77	0.07894	0.83465	22	0.953	9.01E-02
6	5.5	20	8	127	1393.44	0.07894	0.86614	22	0.953	8.69E-02
7	6	20	8	127	1520.12	0.07894	0.94488	22	0.953	7.96E-02
8	6.8	20	7	127	302.26	0.44994	1.07087	22	0.953	4.00E-01
9									AVG	1.35E-01
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WC-GT-2 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 5 to 10'

Description of Soil Sand, with gravel, dark brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.60 Dry Density 90.900

Area, A, cm^2 45.36 Moisture Content 18.1

Length, L, cm 6.350000

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	9.8	20	32.3	127	14359.7	0.01365	1.54331	20	1.000	8.84E-03
2	63	20	18.4	127	52586.6	0.02396	9.92126	20	1.000	2.42E-03
3	65	20	17.3	127	51012.4	0.02548	10.2362	20	1.000	2.49E-03
4	71	20	17.05	127	54916.1	0.02586	11.1811	20	1.000	2.31E-03
									AVG	4.02E-03

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE
ID: PS-GT-1 10.0'-12.0'
DESCR.: CLAYEY SAND/SANDY CLAY,WITH GRAVEL, DARK BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	68.74	WET WT, g	208.6		
D & T, g	65.16	DIA, in	2.00	5.08	cm
T, g	19.41	HT, in	2.04	5.19	cm
		AREA		20.29	cm^2
MOIST-		DENSITY:	123.6	PCF WET	
URE, %	7.8	DENSITY:	**114.6**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	32.0	PROCTOR:	115.0
SATURATION, %:	44.9	OPTIMUM:	7.8
VOID RATIO:	0.47	COMPACTION, %:	99.7
		OVER OPTIMUM, %:	0.0

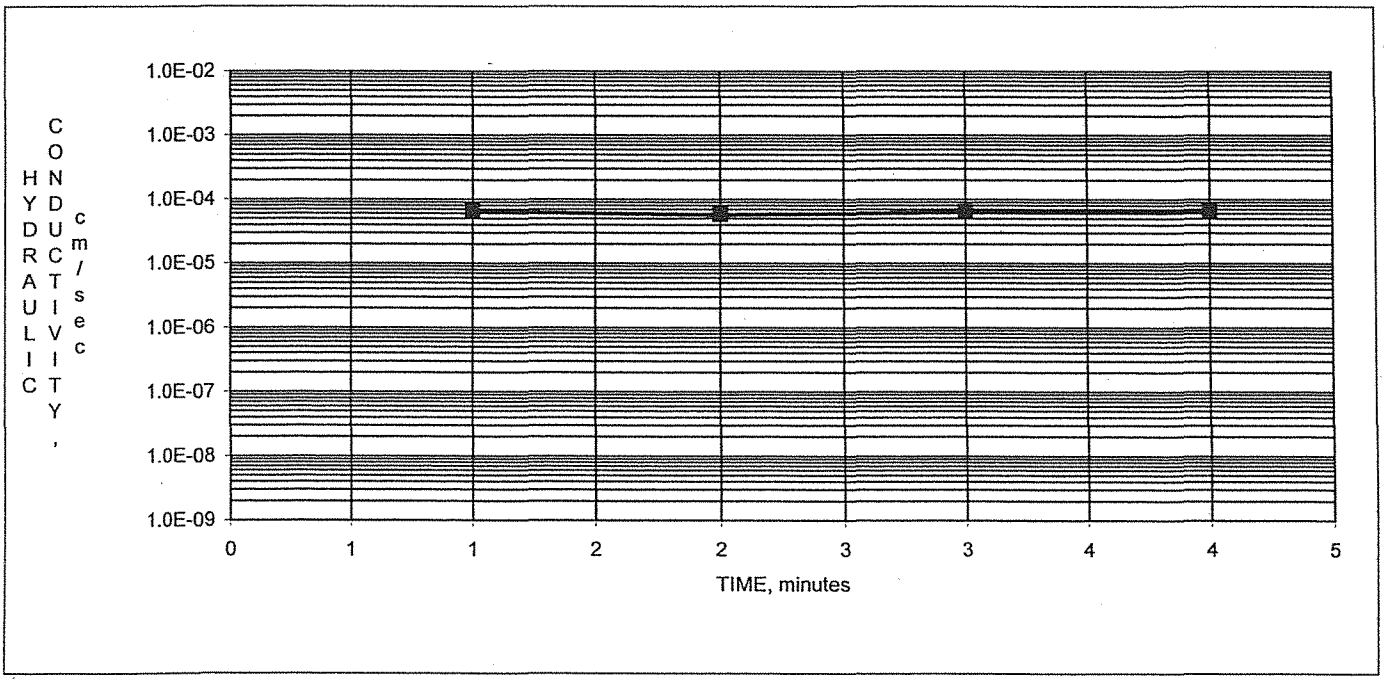
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TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER:	100.0	psi
				BIAS PRESSURE (=LOWER-UPPER)		0.0	psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
24.7	43.2	0	18.5									
25.5	42.3	1	16.8	0.096392	6.39E-05	0.8	0.9	0.89	3.2	2	21	0.980
26.2	41.6	2	15.4	0.087011	5.76E-05	0.7	0.7	1.00	3.0	7	21	0.980
26.9	40.9	3	14.0	0.095310	6.31E-05	0.7	0.7	1.00	2.7	1	21	0.980
27.5	40.2	4	12.7	0.097455	6.46E-05	0.6	0.7	0.86	2.4	4	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 6.2E-05 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0263



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Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE
ID: PS-GT-2 7.0' TO8.5'
DESCR.: CLAYEY SAND, TRACE GRAVEL, MEDIUM COURSE, BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	74.82	WET WT, g	230.3		
D & T, g	70.08	DIA, in	1.99	5.06	cm
T, g	20.32	HT, in	2.03	5.16	cm
		AREA		20.09	cm^2
MOIST-		DENSITY:	138.7	PCF WET	
URE, %	9.5	DENSITY:	126.7	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	24.8	PROCTOR:	125.0
SATURATION, %:	77.8	OPTIMUM:	9.7
VOID RATIO:	0.33	COMPACTION, %:	101.3
		OVER OPTIMUM, %:	-0.2

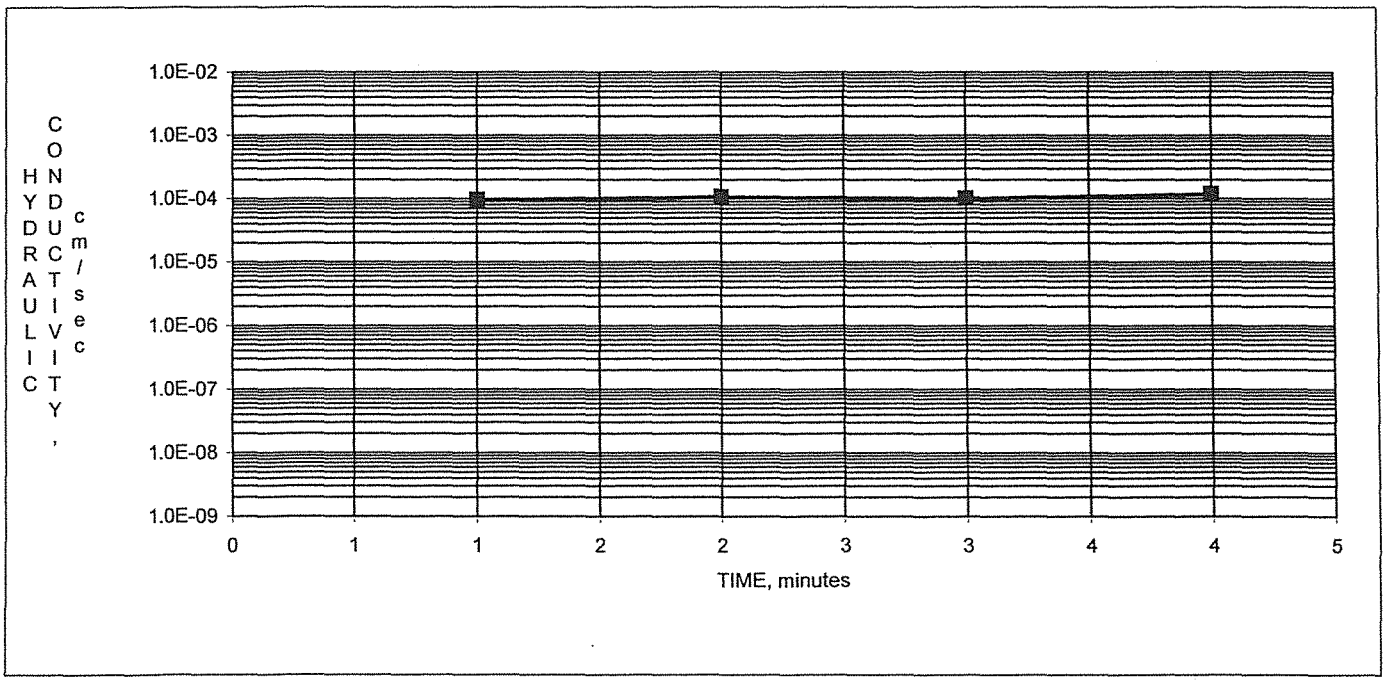
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
20.8	37.2	0	16.4									
21.8	36.0	1	14.2	0.144039	9.58E-05	1.0	1.2	0.83	2.8	9	21	0.980
22.8	34.9	2	12.1	0.160037	1.06E-04	1.0	1.1	0.91	2.3	1	21	0.980
23.6	34.0	3	10.4	0.151400	1.01E-04	0.8	0.9	0.89	2.0	4	21	0.980
24.4	33.1	4	8.7	0.178483	1.19E-04	0.8	0.9	0.89	1.7	13	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 1.1E-04 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0443



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MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE
ID: PS-GT-3 7.0'-9.0'
DESCR.: SAND, WITH CLAY, TRACE GRAVEL & ORGANICS, DARK BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	79.03	WET WT, g	208.3		
D & T, g	72.30	DIA, in	1.99	5.06	cm
T, g	20.26	HT, in	2.02	5.12	cm
		AREA		20.13	cm^2
MOIST-		DENSITY:	126.2	PCF WET	
URE, %	**12.9**	DENSITY:	**111.8**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	33.7	PROCTOR:	115.0
SATURATION, %:	68.7	OPTIMUM:	12.9
VOID RATIO:	0.51	COMPACTION, %:	97.2
		OVER OPTIMUM, %:	0.0

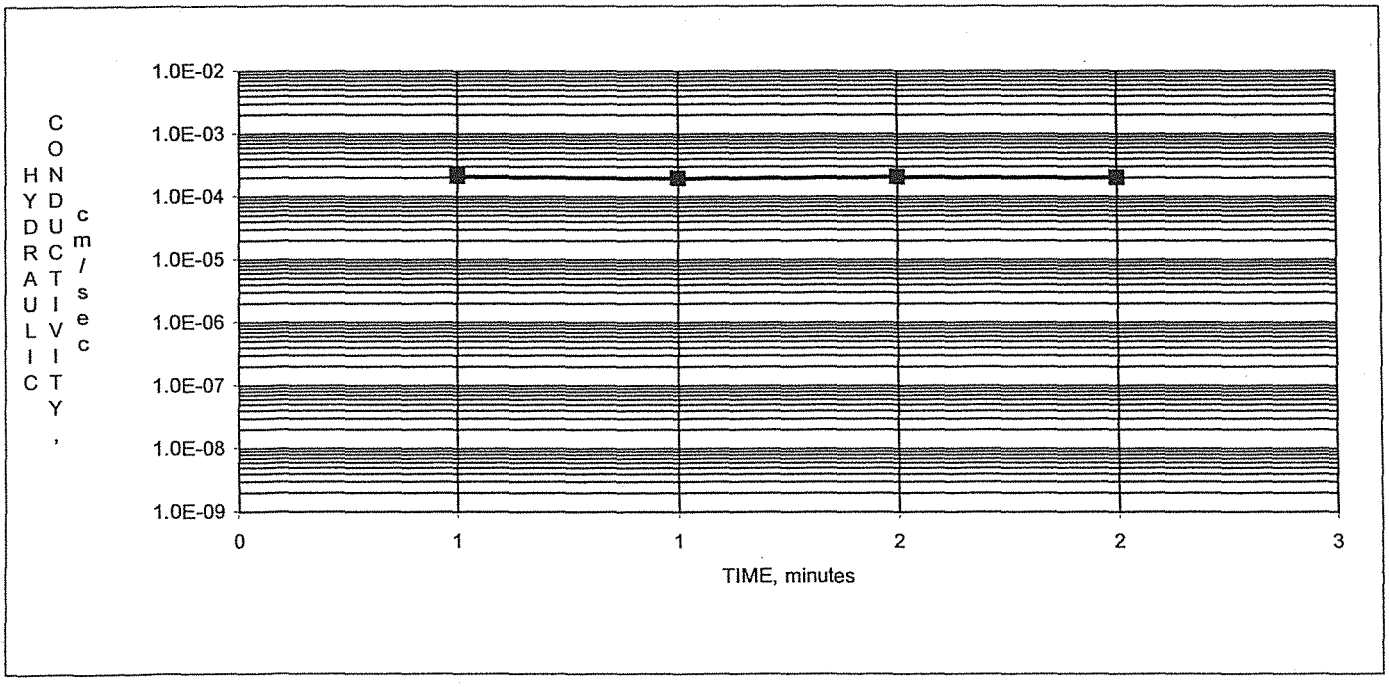
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
22.1	39.1	0	17.0									
23.3	37.8	0	14.5	0.159065	2.09E-04	1.2	1.3	0.92	2.8	4	21	0.980
24.3	36.8	1	12.5	0.148420	1.95E-04	1.0	1.0	1.00	2.4	3	21	0.980
25.2	35.9	1	10.7	0.155485	2.05E-04	0.9	0.9	1.00	2.1	1	21	0.980
26.0	35.2	2	9.2	0.151040	1.99E-04	0.8	0.7	1.14	1.8	2	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 2.0E-04 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0356



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Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE ID: PS-GT-4
DESCR.: SAND, WITH CLAY & GRAVEL, TRACE ORGANICS, FINE TO COURSE GRAINED, DARK BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	66.57	WET WT, g	223.0		
D & T, g	60.35	DIA, in	1.97	5.00	cm
T, g	20.37	HT, in	2.08	5.29	cm
		AREA		19.66	cm^2
MOIST-		DENSITY:	133.9	PCF WET	
URE, %	**15.6**	DENSITY:	**115.9**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	31.2	PROCTOR:	115.0
SATURATION, %:	92.5	OPTIMUM:	15.7
VOID RATIO:	0.45	COMPACTION, %:	100.8
		OVER OPTIMUM, %:	-0.1

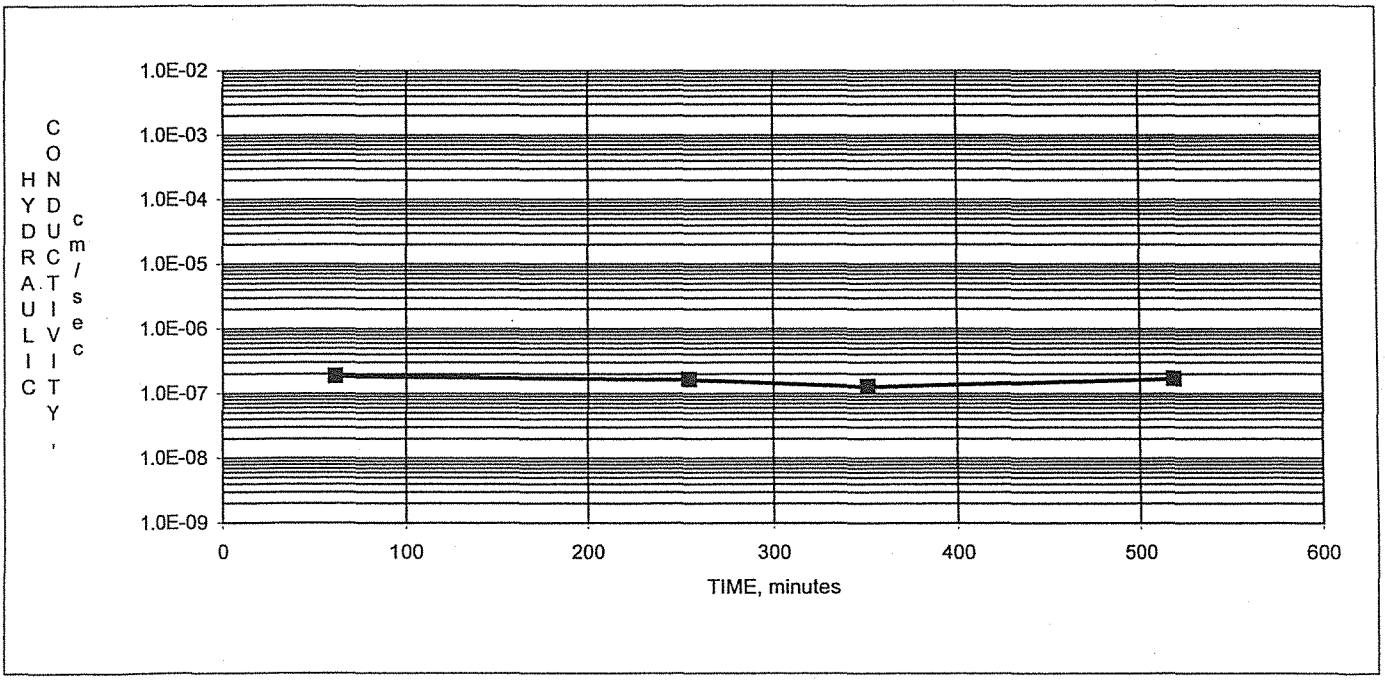
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
4.1	71.3	0	67.2									
4.6	70.7	62	66.1	0.016505	1.85E-07	0.5	0.6	0.83	12.5	16	21	0.980
5.9	69.1	254	63.2	0.044864	1.63E-07	1.3	1.6	0.81	12.0	1	21	0.980
6.4	68.5	351	62.1	0.017558	1.26E-07	0.5	0.6	0.83	11.7	21	21	0.980
7.5	67.2	519	59.7	0.039414	1.67E-07	1.1	1.3	0.85	11.3	4	20	1.005

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 1.6E-07 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0332



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PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 10/1/2005

Location of Sample PS-GT-6 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 13 to 18'

Description of Soil Sand, fine to coarse, trace gravel, trace rubble, dark brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 6.23 Dry Density 107.000

Area, A, cm^2 30.48 Moisture Content 4.3

Length, L, cm 6.350000

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	17.6	20	25.1	127	13466.4	0.02614	2.77165	22	0.953	8.99E-03
2	31.8	20	14.7	127	14249.8	0.04463	5.00787	22	0.953	8.49E-03
3	36.8	20	13	127	14583.3	0.05047	5.79528	22	0.953	8.30E-03
4	38.8	20	12.6	127	14902.8	0.05207	6.11024	22	0.953	8.12E-03
5	40.8	20	12.2	127	15173.5	0.05378	6.4252	22	0.953	7.98E-03
6	42.7	20	11.4	127	14838.8	0.05755	6.72441	22	0.953	8.16E-03
7	47.8	20	9.7	127	14134	0.06764	7.52756	22	0.953	8.56E-03
									AVG	8.37E-03

Note:

Tested by: _____ Checked by: TK
Rowdy Miller Trevor Kauffeld

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 10/7/2005

SAMPLE
ID: PS-GT-7 10.0'-13.0' -#4 MATERIAL
DESCR.: SAND WITH SILT and GRAVEL (SW-SM), DARK GRAY

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	88.50	WET WT, g	191.6		
D & T, g	83.87	DIA, in	1.94	4.93	cm
T, g	19.37	HT, in	1.96	4.98	cm
		AREA		19.05	cm^2
MOIST-		DENSITY:	126.2	PCF WET	
URE, %	7.2	DENSITY:	**117.7**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	30.1	PROCTOR:	NA
SATURATION, %:	44.9	OPTIMUM:	NA
VOID RATIO:	0.43	COMPACTION, %:	#VALUE!
		OVER OPTIMUM, %:	#VALUE!

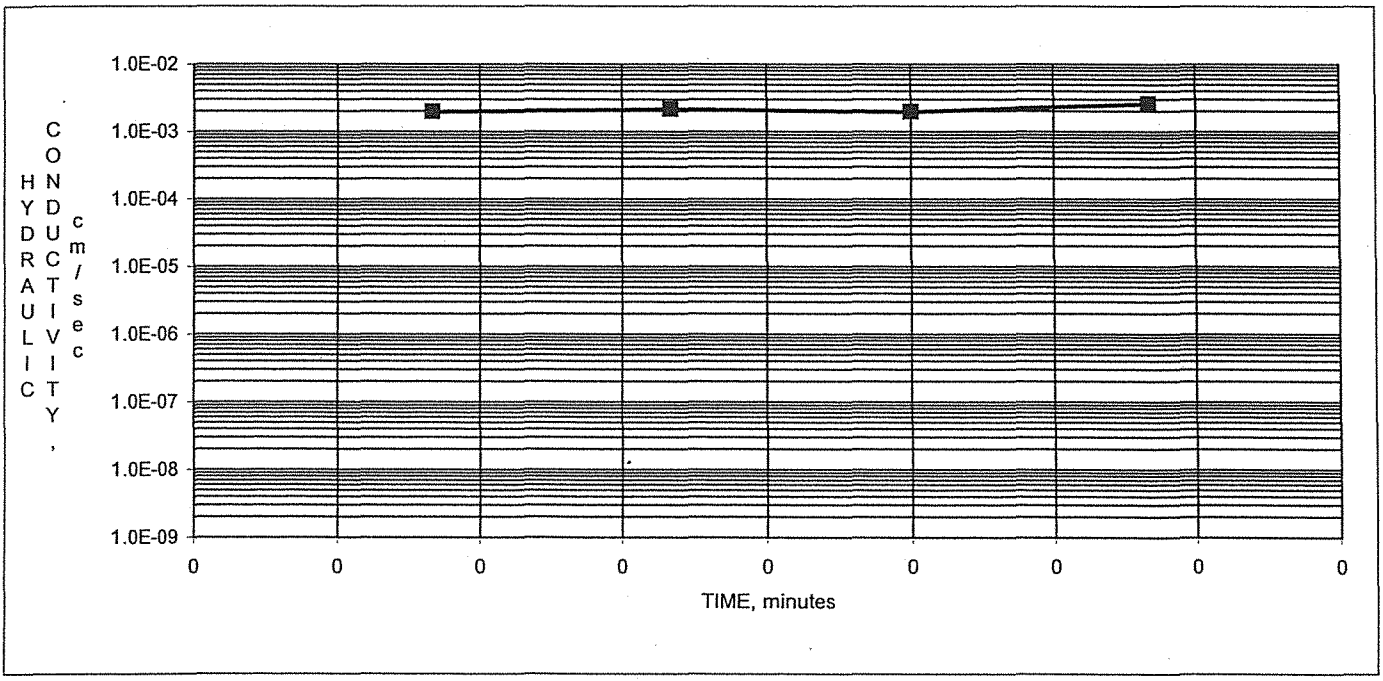
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
20.8	30.1	0	9.3									
21.8	29.1	0	7.3	0.242140	1.96E-03	1.0	1.0	1.00	1.5	9	21	0.980
22.6	28.2	0	5.6	0.265108	2.15E-03	0.8	0.9	0.89	1.1	1	21	0.980
23.2	27.6	0	4.4	0.241162	1.96E-03	0.6	0.6	1.00	0.9	10	21	0.980
23.8	27.0	0	3.2	0.318454	2.58E-03	0.6	0.6	1.00	0.6	19	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 2.2E-03 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0333



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PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/18/2005

Location of Sample PS-GT-8 Sampled _____ Report _____

Boring- _____ Sample- Bottom Depth- 10 to 15'

Description of Soil Silty Sand, trace clay, dark gray

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.62 Wt. Soil (lb.) 1.320

Area, A, cm^2 45.60 Moisture Content 12.0

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 115.3

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	3.3	20	31.5	127	4740.5	0.01392	0.51969	20	1.000	2.68E-02
2	8.7	20	14	127	5554.52	0.03133	1.37008	20	1.000	2.29E-02
3	13.5	20	9.2	127	5663.97	0.04767	2.12598	20	1.000	2.24E-02
4	17.2	20	7	127	5490.68	0.06265	2.70866	20	1.000	2.31E-02
5	21.5	20	5.5	127	5392.63	0.07974	3.38583	20	1.000	2.36E-02
6	24.3	20	5	127	5540.84	0.08771	3.82677	20	1.000	2.29E-02
7	32.3	20	4	127	5891.99	0.10964	5.08661	20	1.000	2.16E-02
8	32.3	20	4	127	5891.99	0.10964	5.08661	20	1.000	2.16E-02
9									AVG	2.31E-02
10										
11										
12										

Note:

Tested by: _____ Checked by: TK

Rowdy Miller Trevor Kauffeld

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 10/7/2005

SAMPLE ID: PS-GT-9 15.0'-20.0' #4 MATERIAL
DESCR.: SAND WITH GRAVEL & SILT, DARK YELLOWISH BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	51.97	WET WT, g	183.1		
D & T, g	50.15	DIA, in	1.94	4.94	cm
T, g	20.20	HT, in	1.95	4.96	cm
		AREA		19.15	cm^2
MOIST-		DENSITY:	120.3	PCF WET	
URE, %	6.1	DENSITY:	**113.4**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	32.7	PROCTOR:	NA
SATURATION, %:	33.7	OPTIMUM:	NA
VOID RATIO:	0.49	COMPACTION, %:	#VALUE!
		OVER OPTIMUM, %:	#VALUE!

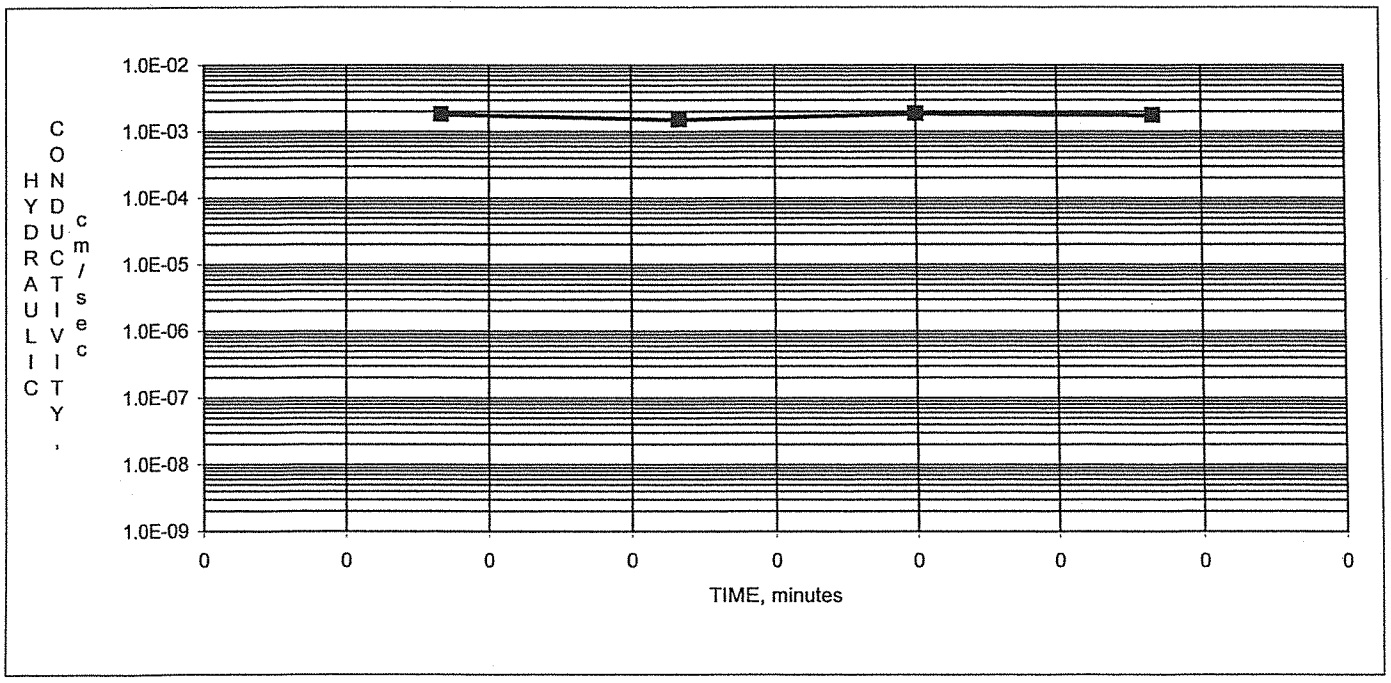
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER:	100.0	psi
				BIAS PRESSURE (=LOWER-UPPER)		0.0	psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
10.5	16.3	0	5.8									
11.1	15.7	0	4.6	0.231802	1.82E-03	0.6	0.6	1.00	0.9	5	22	0.956
11.5	15.3	0	3.8	0.191055	1.50E-03	0.4	0.4	1.00	0.8	13	22	0.956
11.9	14.9	0	3.0	0.236389	1.85E-03	0.4	0.4	1.00	0.6	7	22	0.956
12.2	14.6	0	2.4	0.223144	1.75E-03	0.3	0.3	1.00	0.5	1	22	0.956

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 1.7E-03 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0173



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PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/16/2005

Location of Sample JS-29-GT-1 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 19 to 24'

Description of Soil Sand, fine grained, trace clay and gravel, dark yellow

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.58 Wt. Soil (lb.) 1.290

Area, A, cm^2 45.13 Moisture Content 5.3

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 119.9

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	2.5	20	31.5	127	3553.68	0.01407	0.3937	20	1.000	3.57E-02
2	7.1	20	14	127	4485.54	0.03166	1.11811	20	1.000	2.83E-02
3	11.2	20	9.5	127	4801.42	0.04665	1.76378	20	1.000	2.65E-02
4	14	20	7	127	4422.36	0.06331	2.20472	20	1.000	2.87E-02
5	17.6	20	5.5	127	4368.21	0.08058	2.77165	20	1.000	2.91E-02
6	18.8	20	5	127	4241.85	0.08864	2.96063	20	1.000	2.99E-02
7	24	20	4	127	4332.11	0.1108	3.77953	20	1.000	2.93E-02
8	24	20	4	127	4332.11	0.1108	3.77953	20	1.000	2.93E-02
9									AVG	2.96E-02
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/12/2005

Location of Sample JS-9-GT-2 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 7 to 11.5'

Description of Soil Clayey Sand, with organics, trace gravel, dark brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.62 Wt. Soil (lb.) 1.150

Area, A, cm^2 45.60 Moisture Content 23.7

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 91.0

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	3	20	31.5	127	4309.54	0.01392	0.47244	20	1.000	2.95E-02
2	7.1	20	14	127	4533	0.03133	1.11811	20	1.000	2.80E-02
3	11.9	20	9.5	127	5155.49	0.04616	1.87402	20	1.000	2.46E-02
4	13.3	20	7	127	4245.7	0.06265	2.09449	20	1.000	2.99E-02
5	18.2	20	5.5	127	4564.92	0.07974	2.86614	20	1.000	2.78E-02
6	20.8	20	5	127	4742.78	0.08771	3.27559	20	1.000	2.68E-02
7	27	20	4	127	4925.19	0.10964	4.25197	20	1.000	2.58E-02
8	27	20	4	127	4925.19	0.10964	4.25197	20	1.000	2.58E-02
9									AVG	2.73E-02
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/15/2005

Location of Sample JS-29-GT-3 Sampled _____ Report _____

Boring- _____ Sample- Bottom Depth- 19 to 24'

Description of Soil Sand, with gravel, trace clay, brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.59 Wt. Soil (lb.) 1.340

Area, A, cm^2 45.25 Moisture Content 8.6

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 120.7

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	2.9	20	31.5	127	4133.15	0.01403	0.45669	20	1.000	3.07E-02
2	7.3	20	14	127	4624.07	0.03157	1.14961	20	1.000	2.75E-02
3	11.3	20	9.5	127	4857.08	0.04653	1.77953	20	1.000	2.61E-02
4	16.4	20	7	127	5194.16	0.06315	2.58268	20	1.000	2.45E-02
5	21.7	20	5.5	127	5400.02	0.08037	3.41732	20	1.000	2.35E-02
6	23.9	20	5	127	5406.81	0.08841	3.76378	20	1.000	2.35E-02
7	31	20	4	127	5610.41	0.11051	4.88189	20	1.000	2.26E-02
8	31	20	4	127	5610.41	0.11051	4.88189	20	1.000	2.26E-02
9									AVG	2.51E-02
10										
11										
12										

Note:

Tested by: _____ Checked by: TK

Rowdy Miller Trevor Kauffeld

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING — TERRACON JOB #: 58055075 — DATE: 10/7/2005

SAMPLE ID: JS 29-GT-5 — 5.0' - 9.0' — Top 8" — #4 MATERIAL

DESCR.: CLAYEY GRAVEL WITH SAND (GC), DARK GRAY WITH YELLOWISH BROWN

Durham Perm Cell — BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	48.02	WET WT, g	172.0		
D & T, g	44.14	DIA, in	1.94	4.93	cm
T, g	20.33	HT, in	1.96	4.98	cm
		AREA		19.05	cm^2
MOIST-		DENSITY:	113.3	PCF WET	
URE, %	16.3	DENSITY:	97.4	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	42.2	PROCTOR:	NA
SATURATION, %:	60.2	OPTIMUM:	NA
VOID RATIO:	0.73	COMPACTION, %:	#VALUE!
		OVER OPTIMUM, %:	#VALUE!

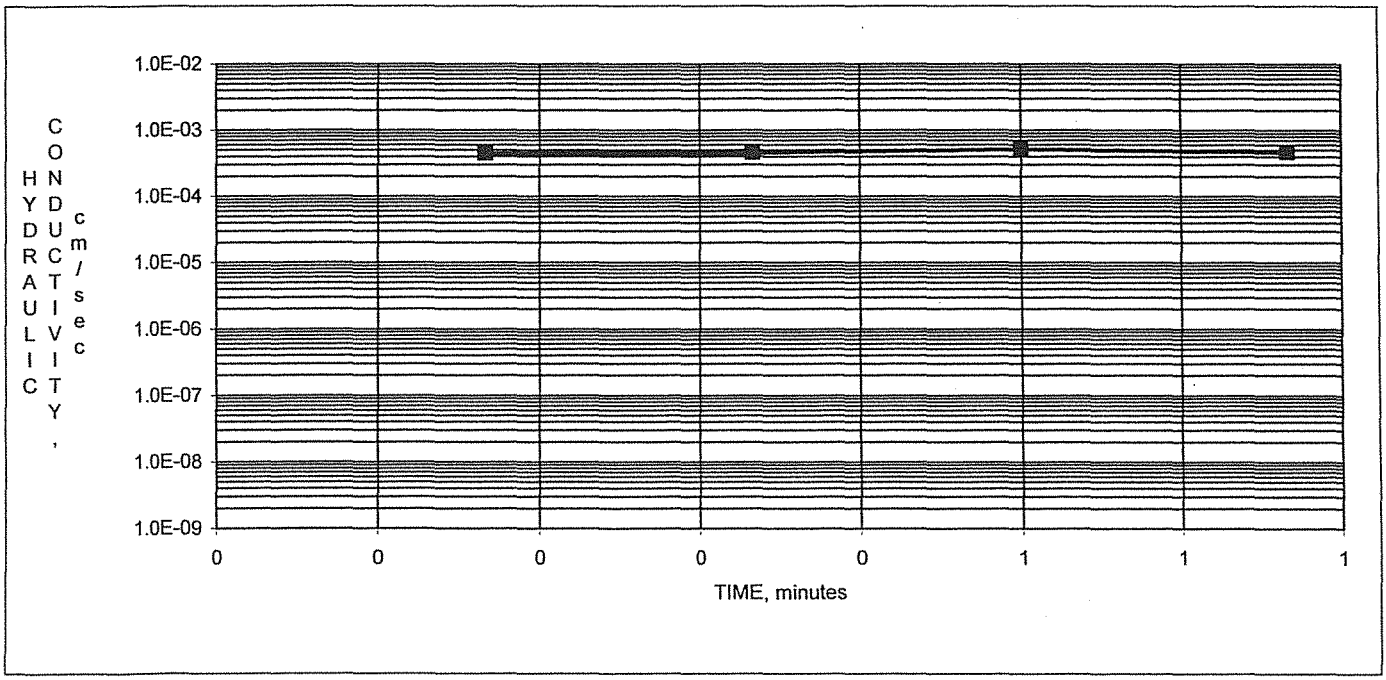
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
10.6	20.9	0	10.3									
11.2	20.4	0	9.2	0.112940	4.47E-04	0.6	0.5	1.20	1.8	5	22	0.956
11.7	19.9	0	8.2	0.115069	4.55E-04	0.5	0.5	1.00	1.6	3	22	0.956
12.2	19.4	1	7.2	0.130053	5.14E-04	0.5	0.5	1.00	1.4	9	22	0.956
12.6	19.0	1	6.4	0.117783	4.66E-04	0.4	0.4	1.00	1.3	1	22	0.956

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 4.7E-04 cm/sec

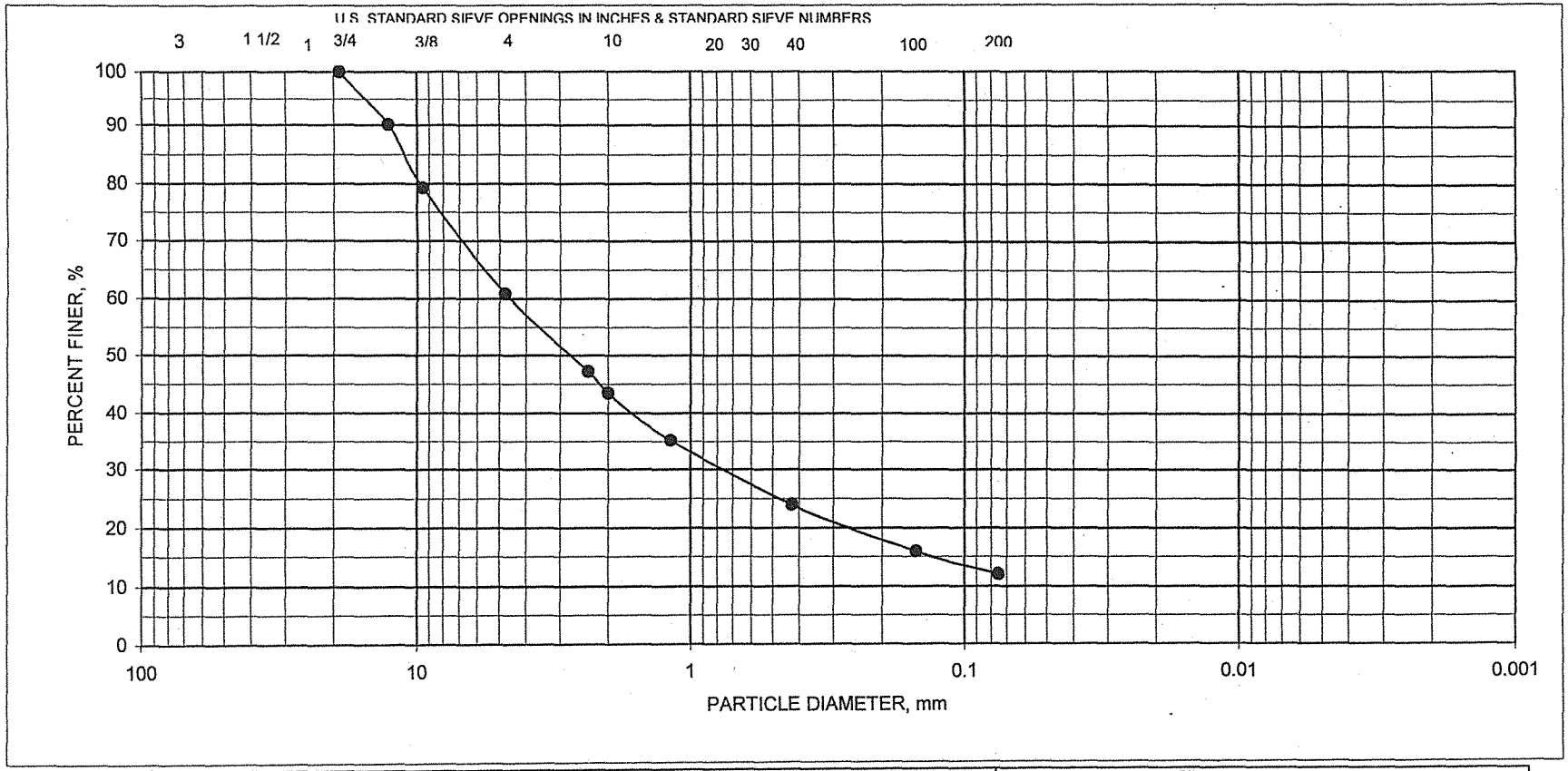
MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0158



Terracon

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
CS-GT-1		5 to 10'	Sand, fine to coarse grained, trace gravel and silt, brown, dark brown, blac	SP				

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Sieve CS-GT-1.xls

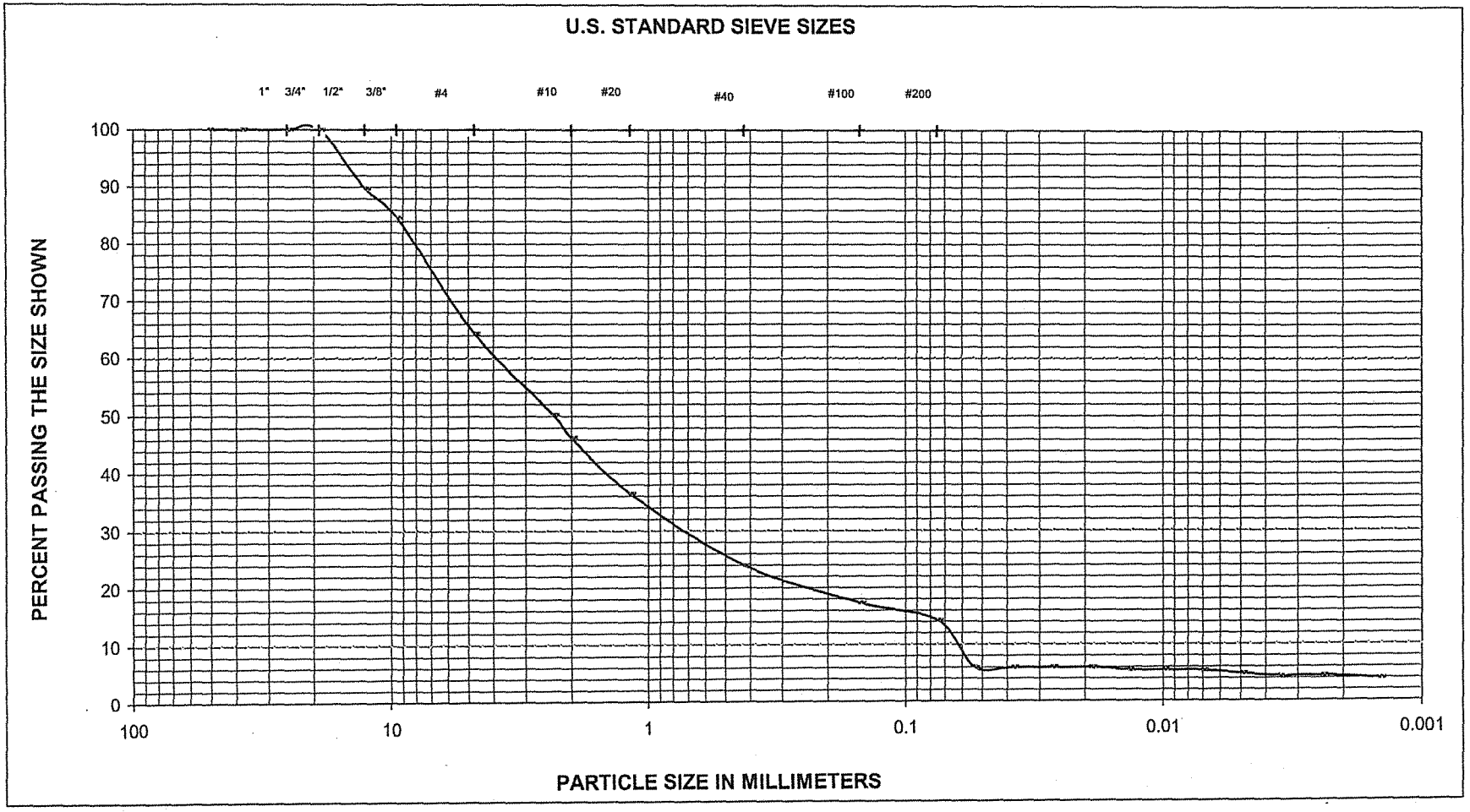
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing | Boring Number: CS-GT-2 | Date: 8/29/2005

Terracon Project #: 58055075 | Sample No.: 10-12' (top) | Sample type.:

Sample Description: Sand, fine to coarse grained, with gravel, gray (crushed limestone)



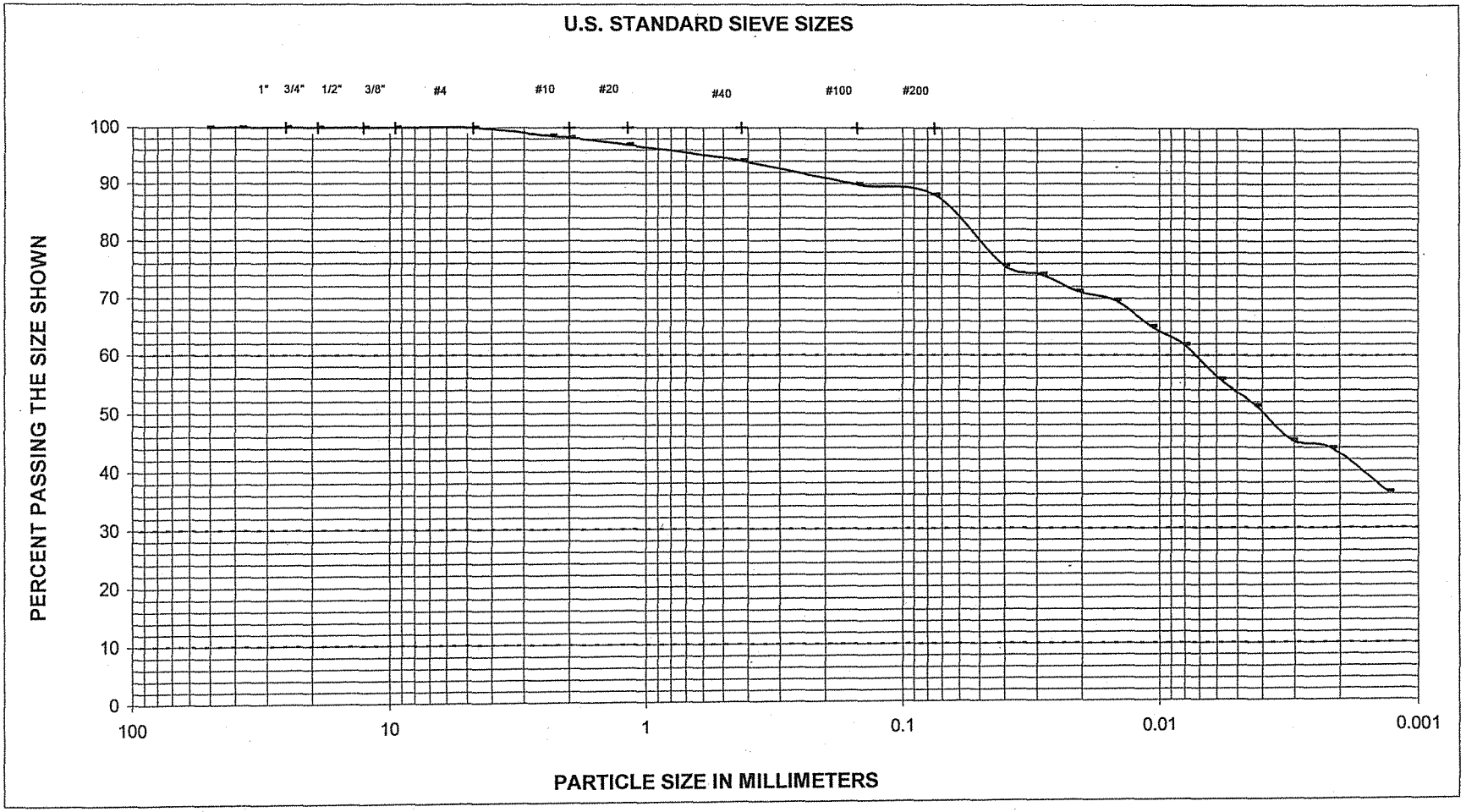
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing | Boring Number: CS-GT-2 | Date: 8/29/2005

Terracon Project #: 58055075 | Sample No.: bottom | Sample type.:

Sample Description: Lean clay, trace sand, gray



Electronic Filing: Received, Clerk's Office 2/04/2022

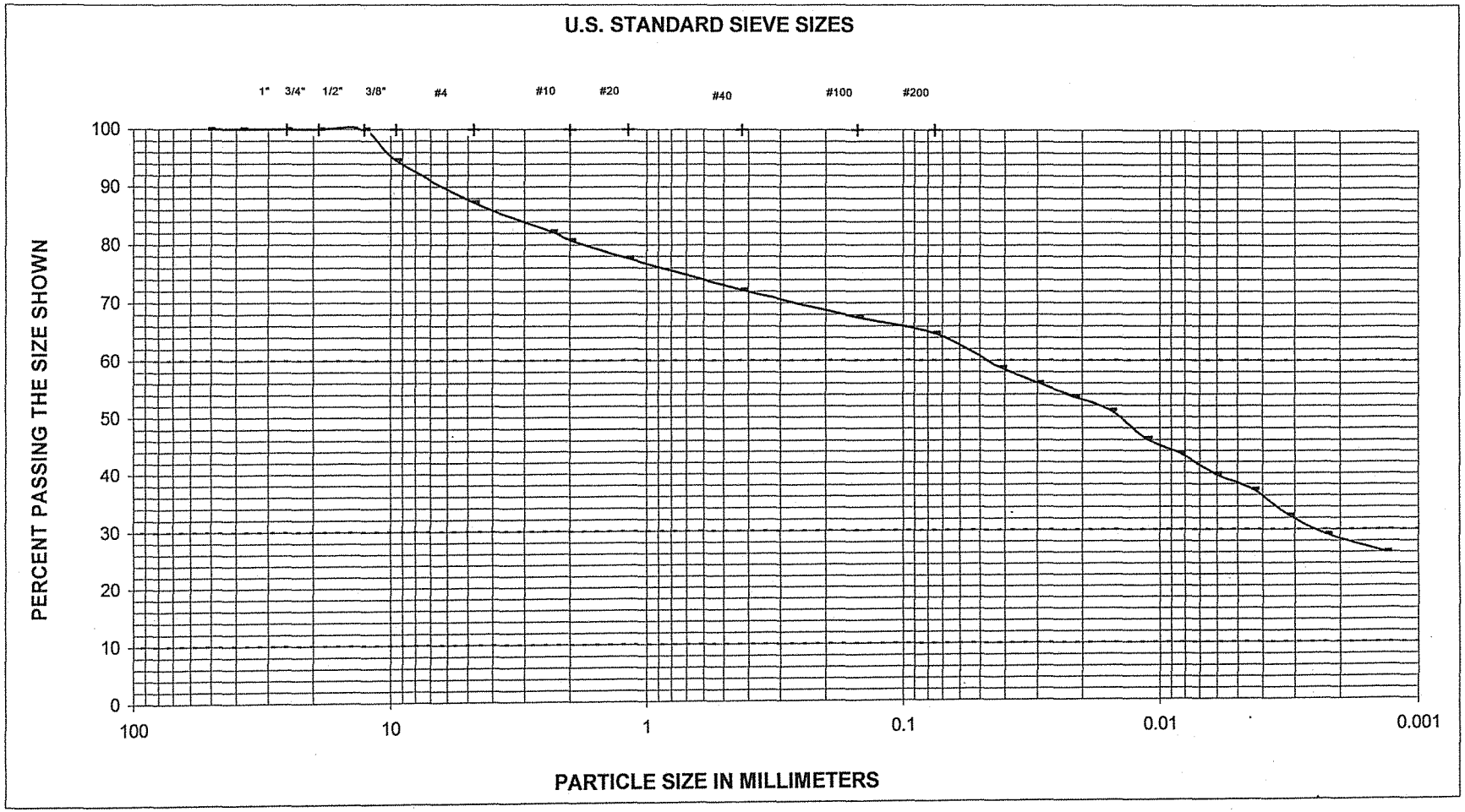
Terracon

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing | Boring Number: CS-GT-4 | Date: 8/25/2005

Terracon Project #: 58055075 | Sample No.: | Sample type.:

Sample Description: Lean Clay, Trace Sand and Gravel, Gray



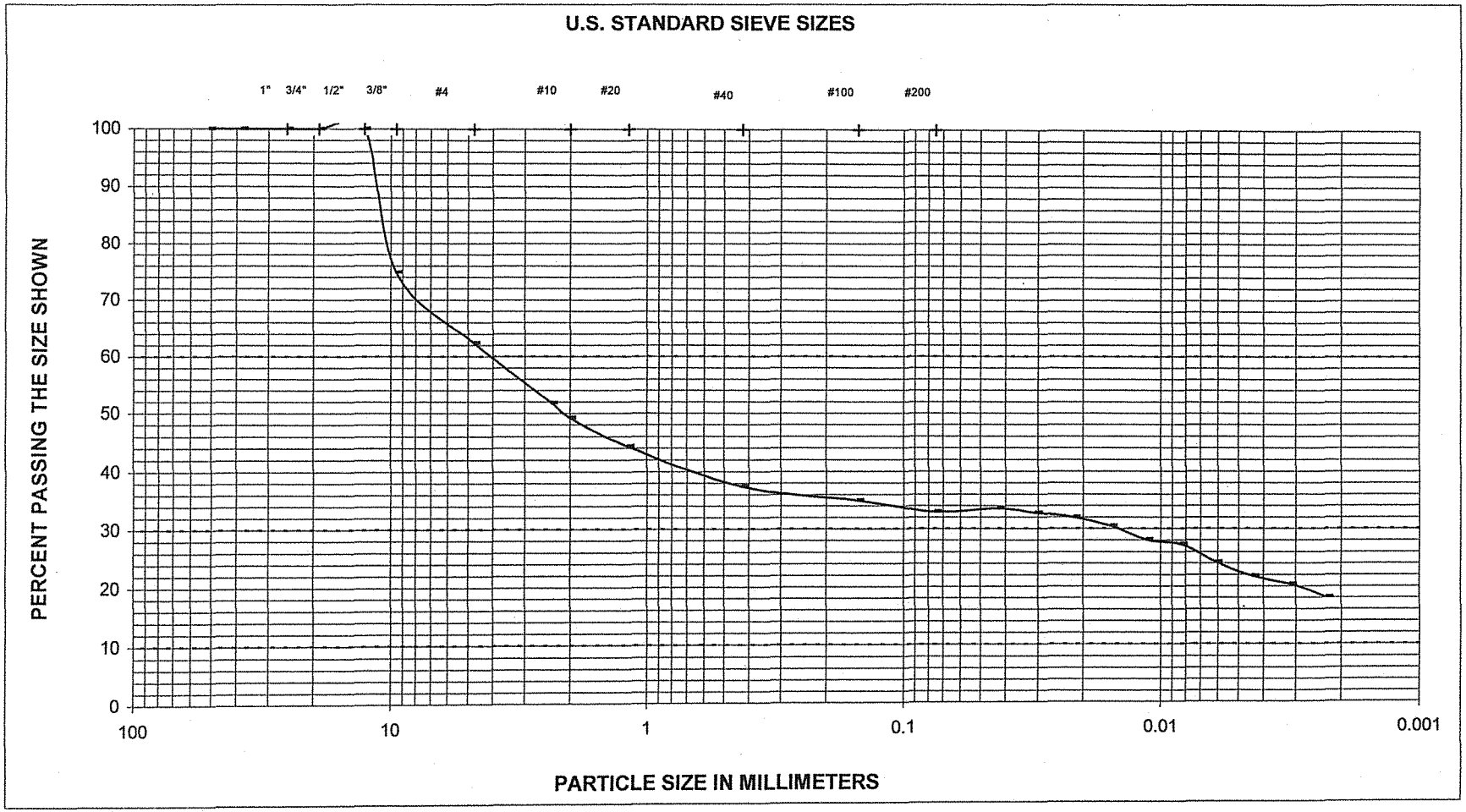
Electronic Filing: Received, Terracon 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing | Boring Number: CS-GT-5 | Date: 8/25/2005

Terracon Project #: 58055075 | Sample No.: | Sample type.:

Sample Description: Silty clay, with sand, brown and gray



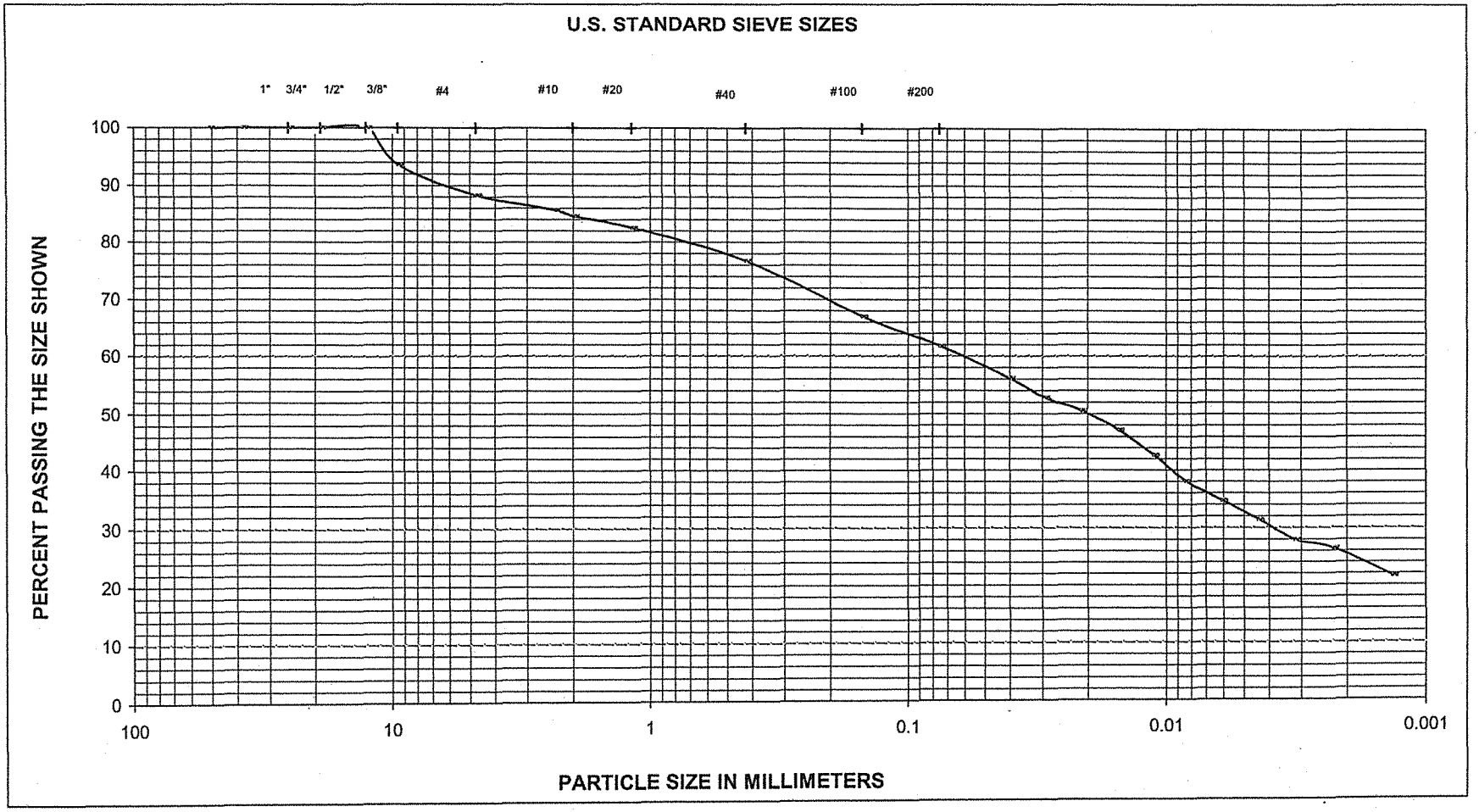
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

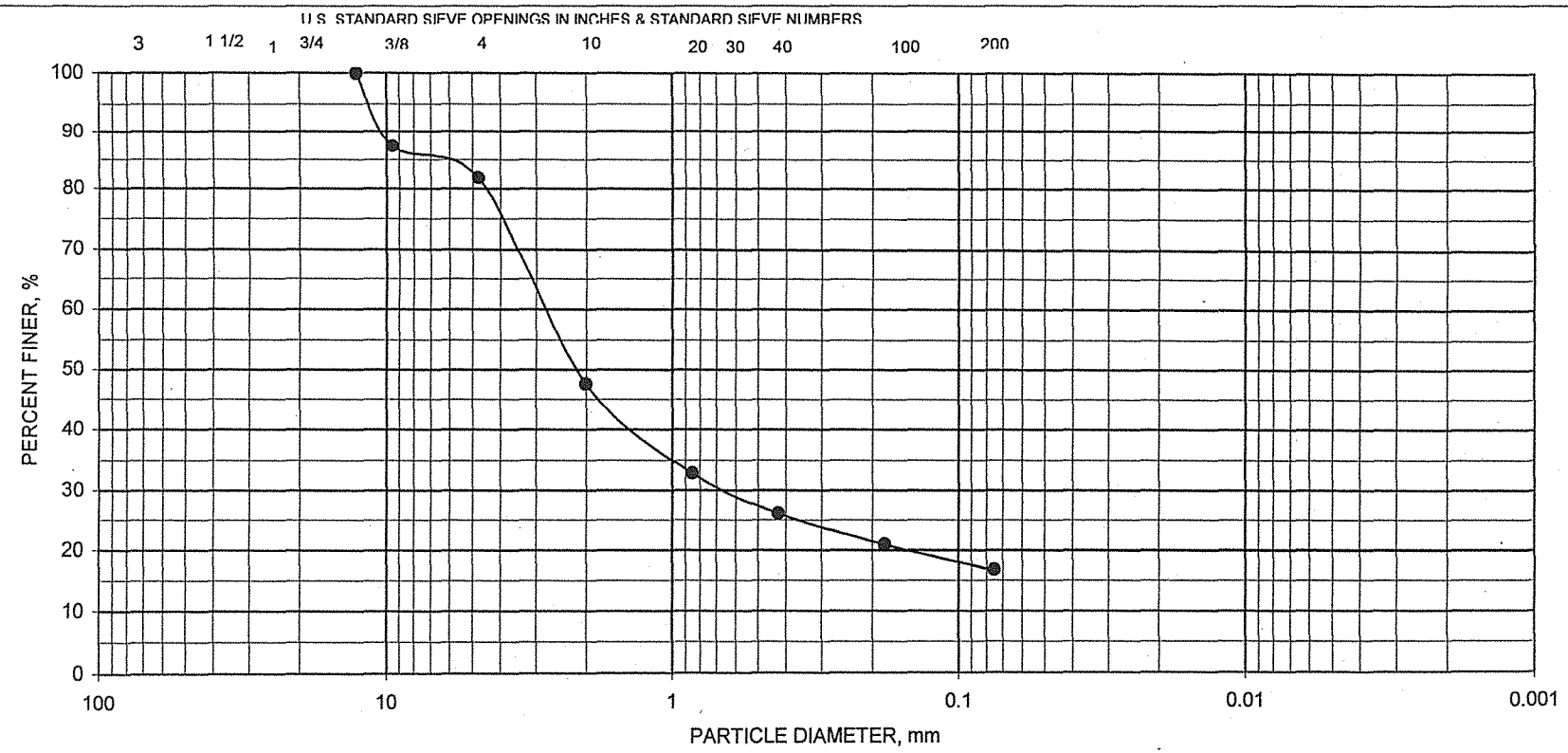
Project Name: KPRG Labarotory Testing Boring Number CS-GT-6 Date: 8/29/2005

Terracon Project #: 58055075 Sample No.: Sample type.:

Sample Description: Sandy Lean Clay, with gravel, brown and dark brown



Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-1		5 to 10'-Top	Clayey Gravelly Sand	SC				

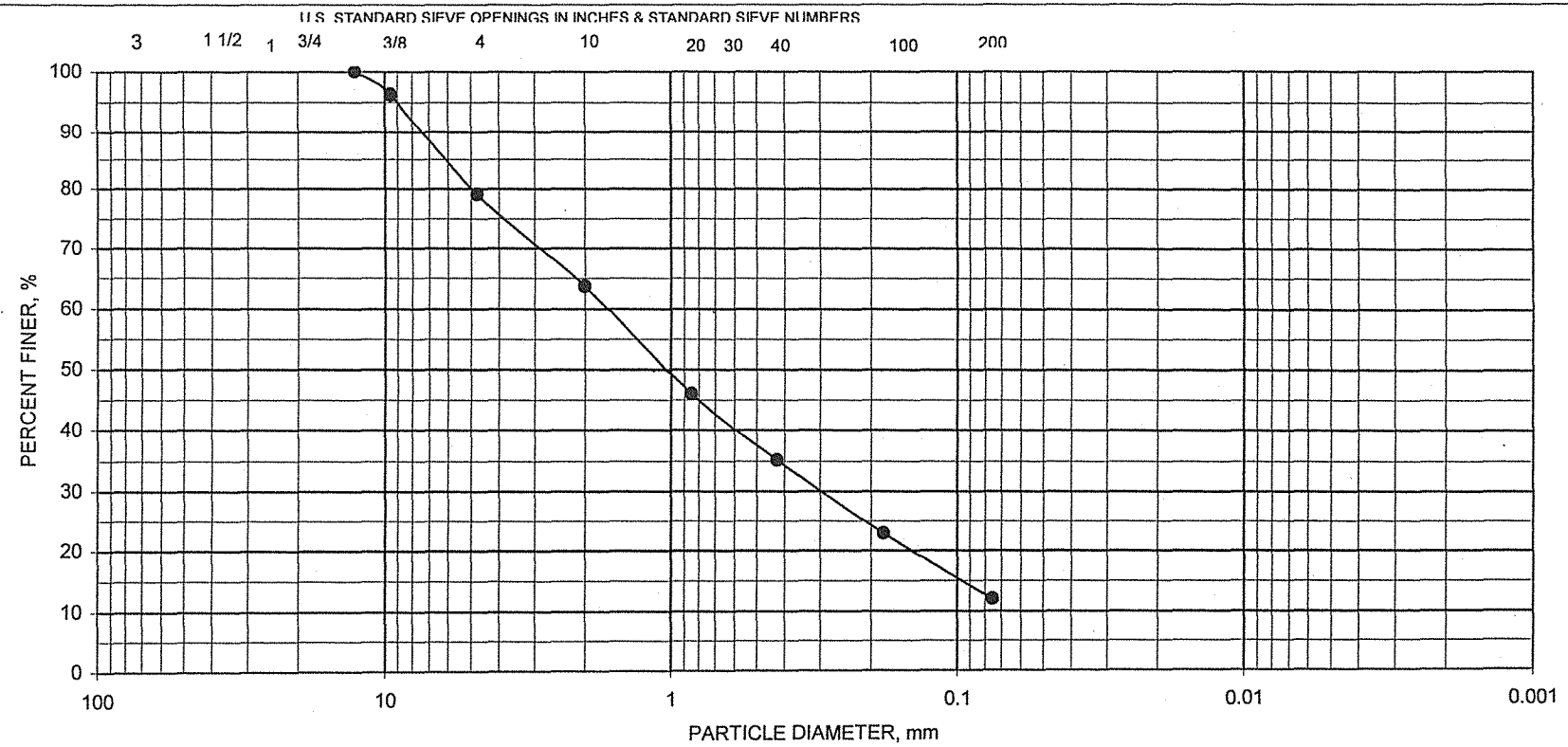
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 10/1/2005

Terracon

Sieve WCGT-1.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-2		5 to 10' BTM	VeryDark Brown Fine To Coarse Sand With Gravel, Trace Clay and Glass Slag	SC				

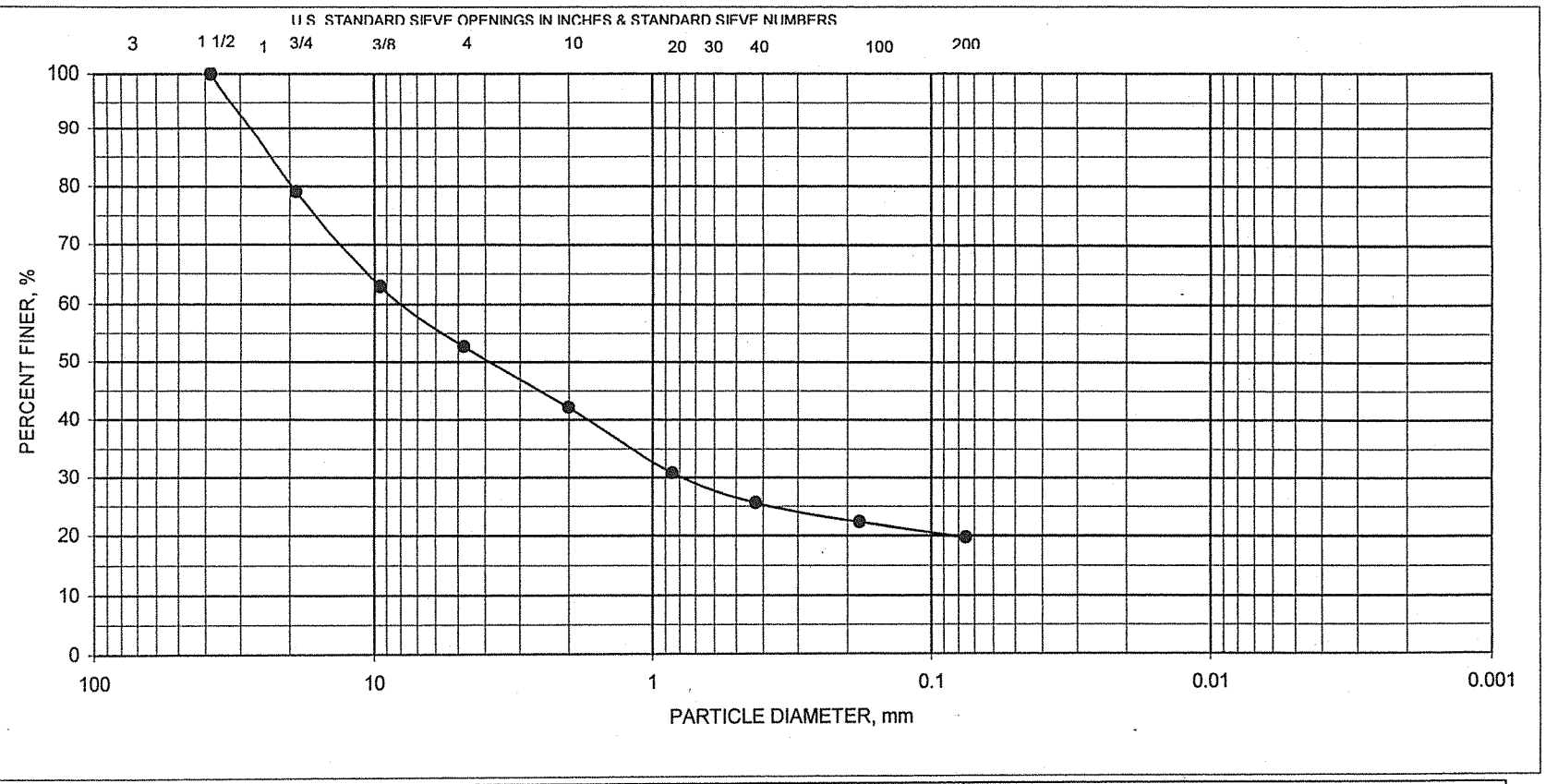
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/30/2005

Terracon

Sieve WCGT-2.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-3		3 to 8' (Top)	Clayey Gravelly Fine To Coarse Sand	SC				

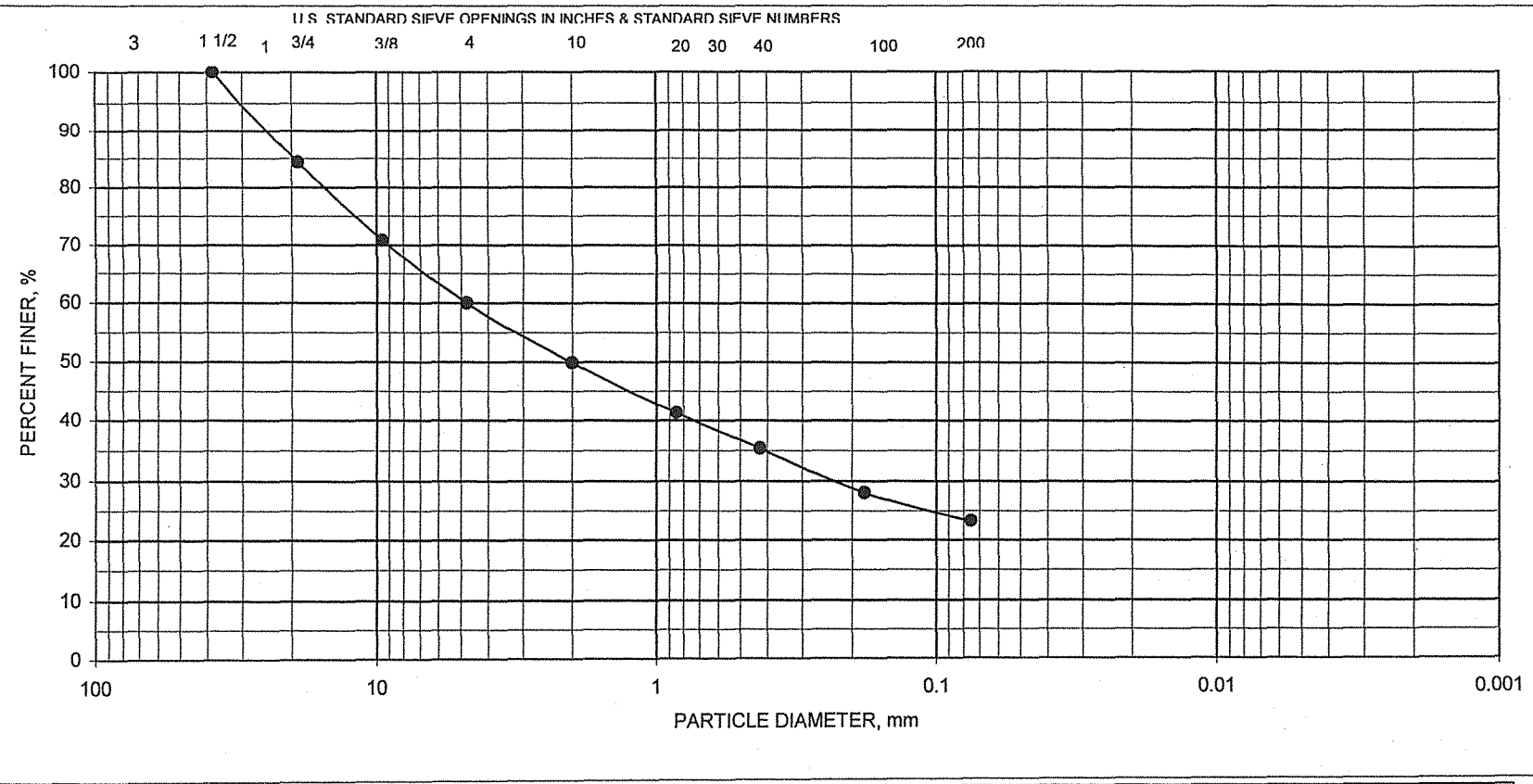
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 10/4/2005

Terracon

Sieve WCGT-3.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-4		5 to 10'-Bottom of Sample	Sandy Fine To Coarse Gravel With Clay	GC				

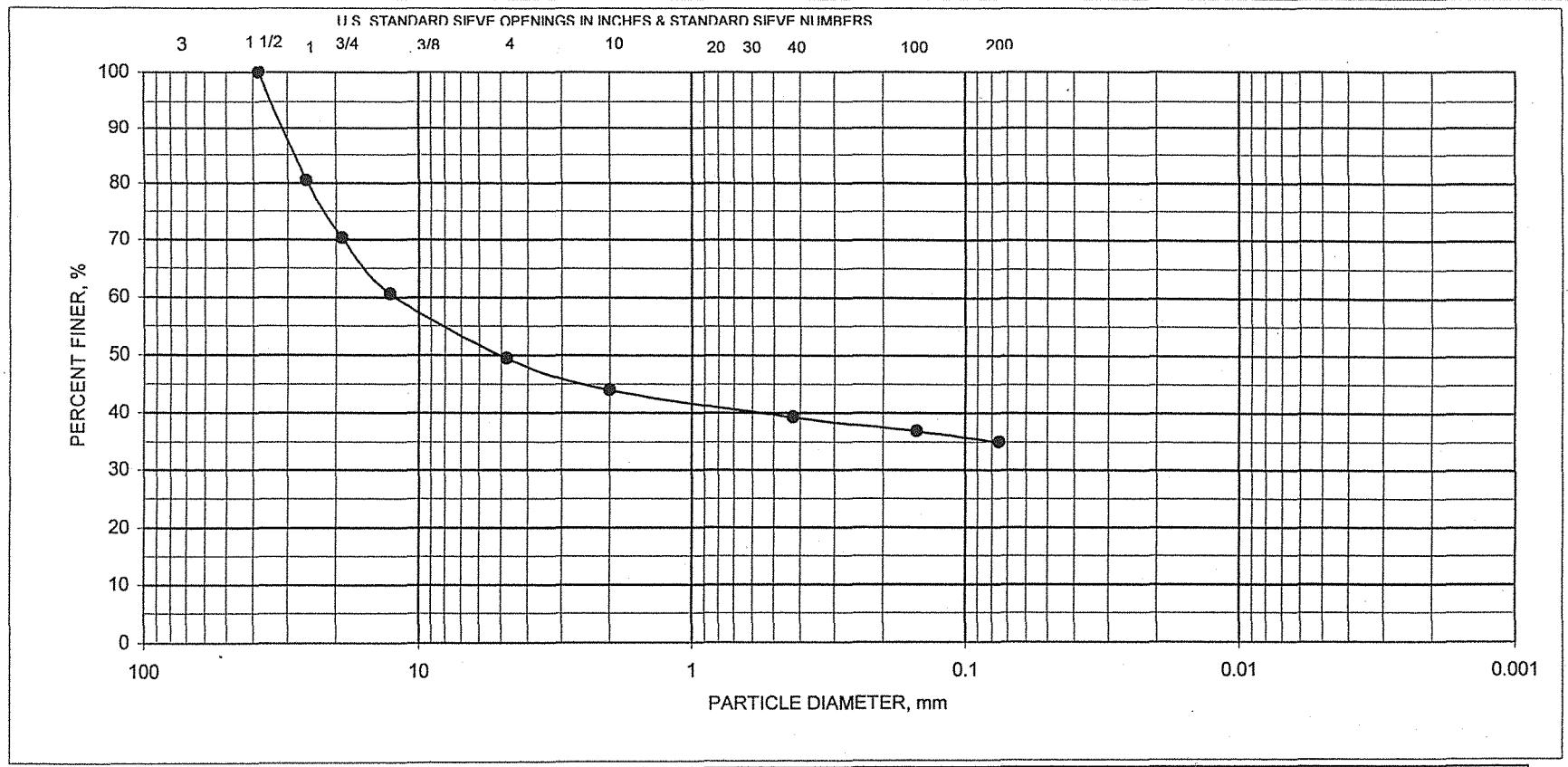
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/24/2005

Terracon

Sieve WCGT-4.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

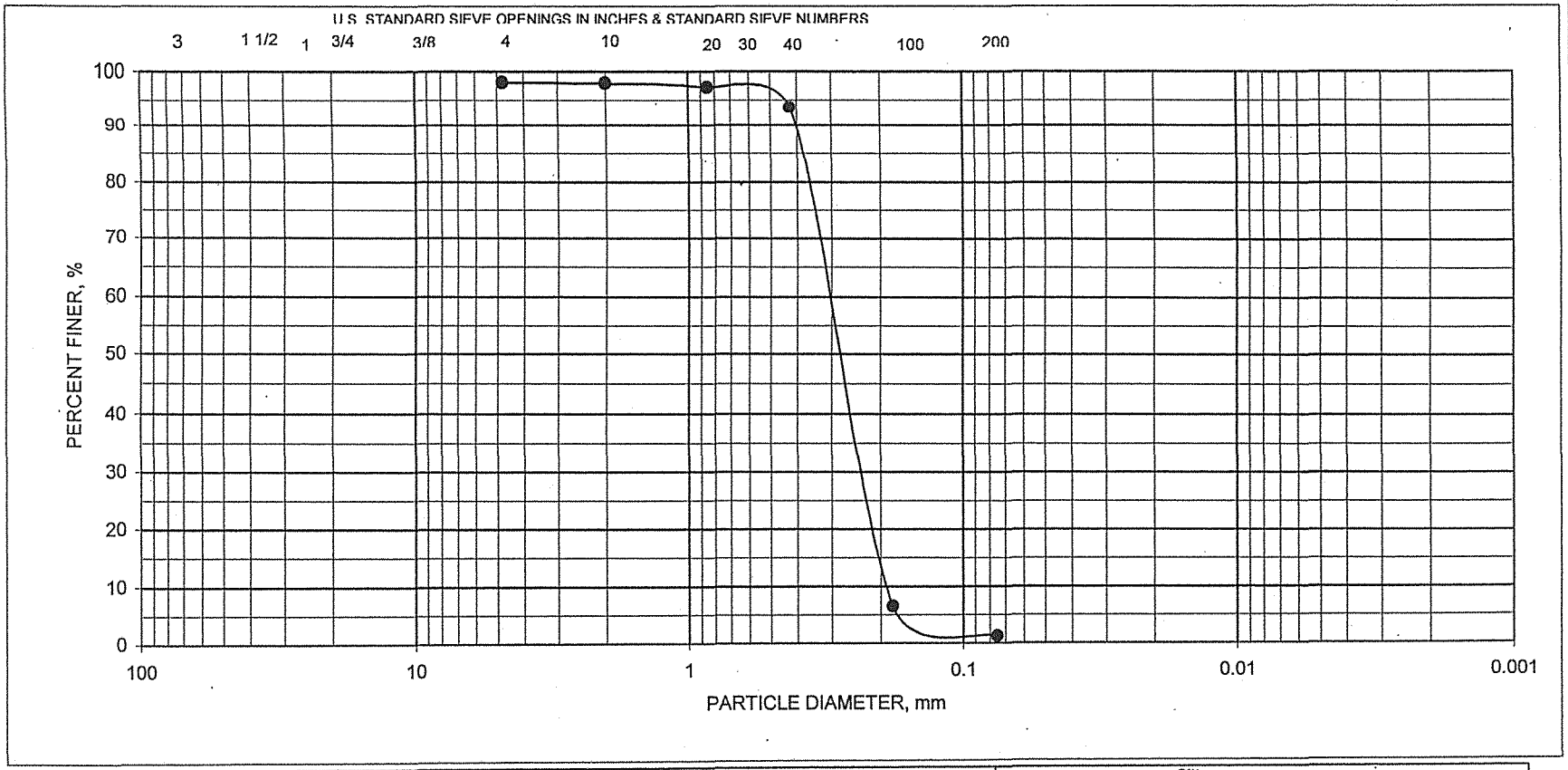
BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-5		5 to 9'-Bottom of Sample	Sandy clay with gravel	CL				

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/29/2005

Terracon

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WSGT-1		5 to 10'	Fine Sand, Trace Gravel & Silt	SP	14	NP	NP	NP

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/21/2005

Terracon

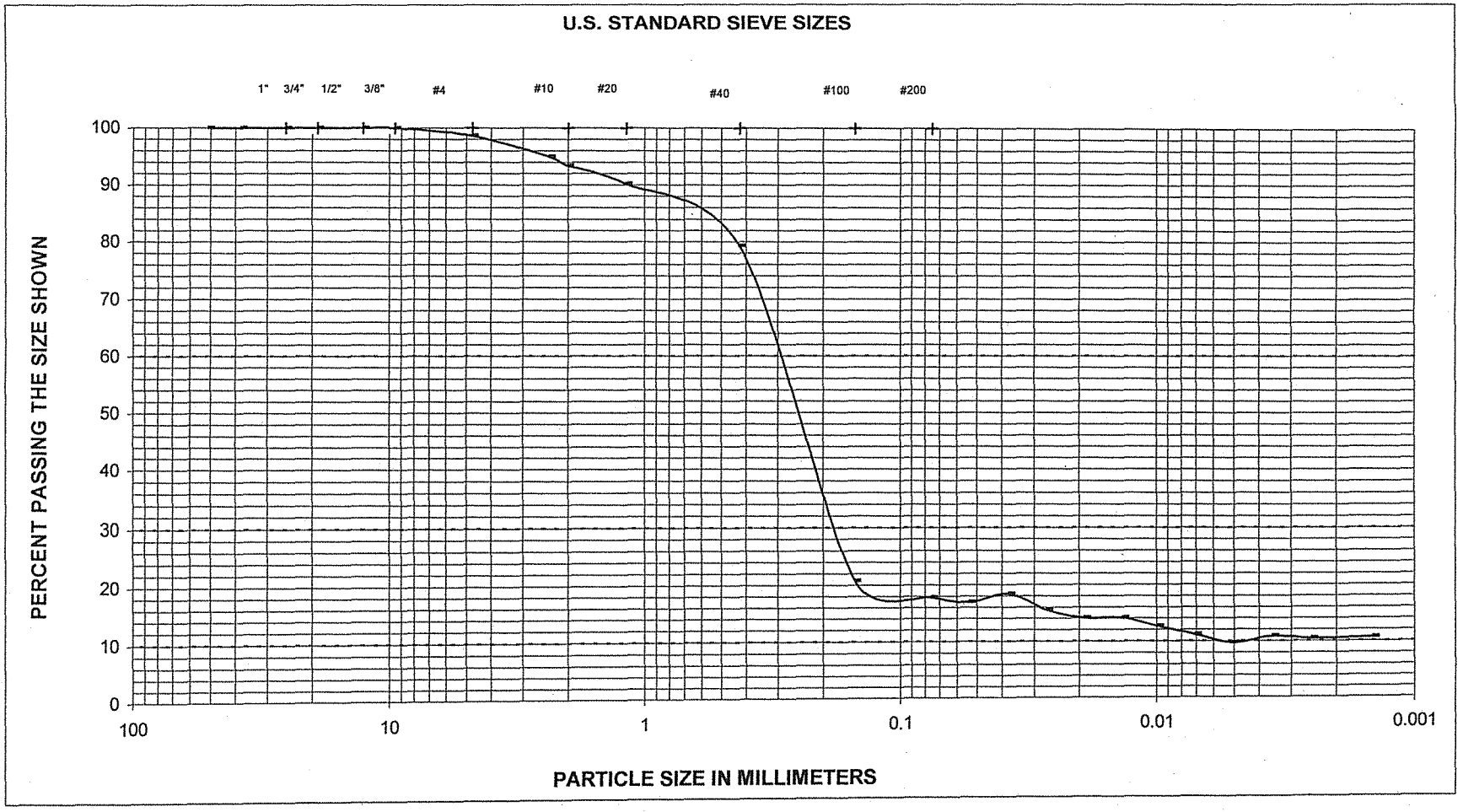
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

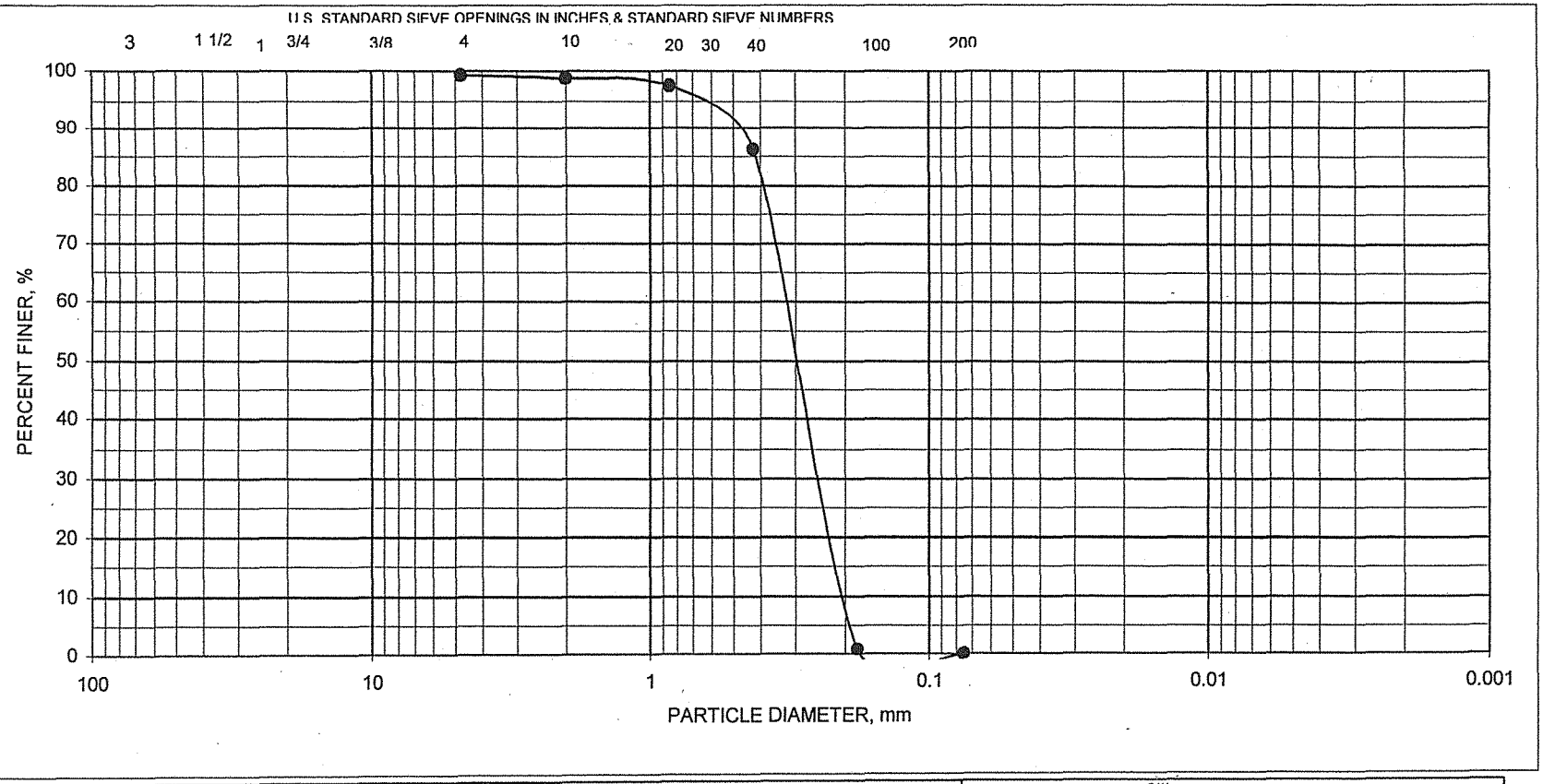
Project Name: KPRG Laboratory Testing Boring Number WS-GT-2 Date: 8/26/2005

Terracon Project #: 58055075 Sample No.: Sample type.:

Sample Description: Silty sand, trace gravel, dark brown



Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

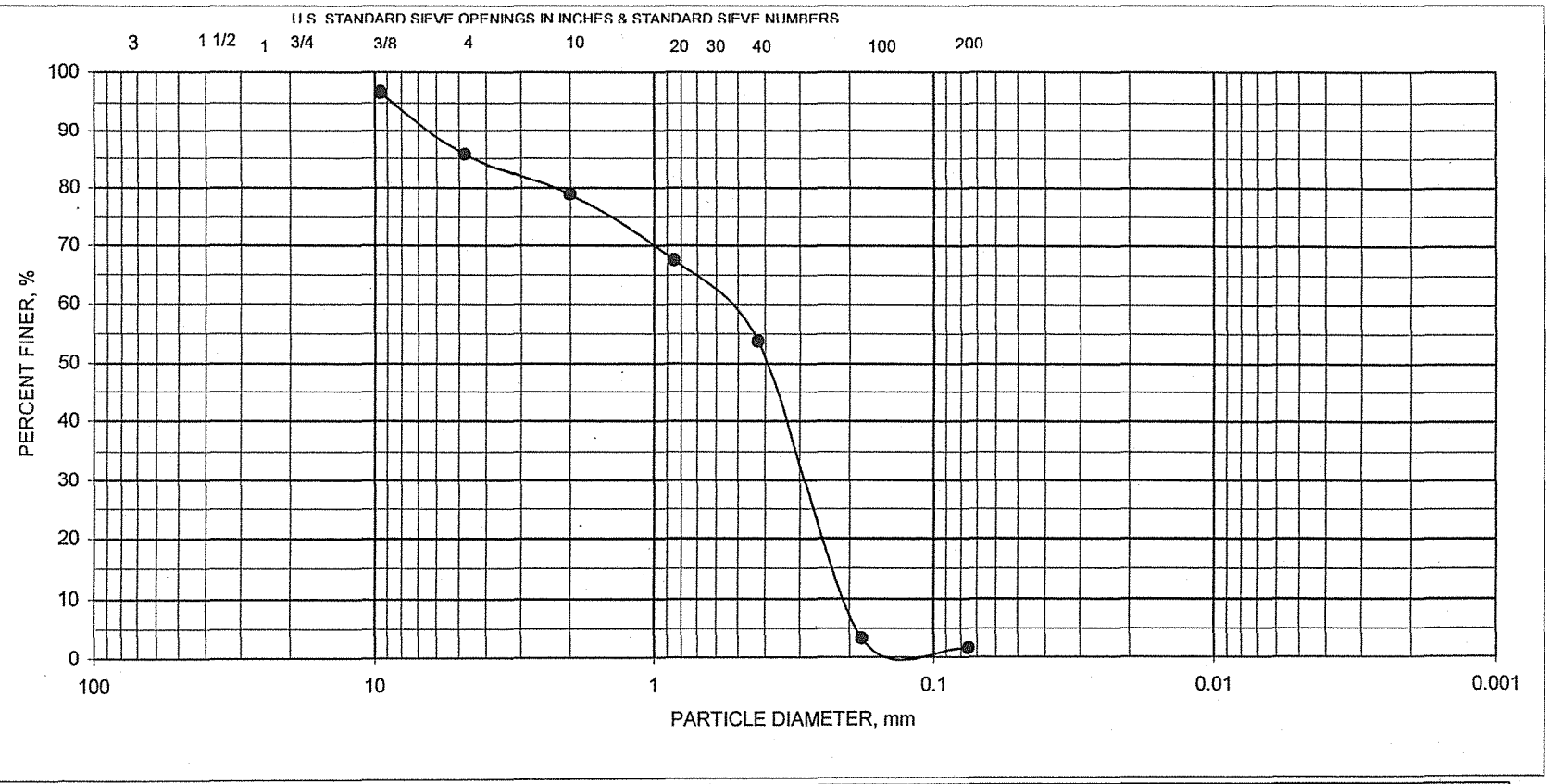
BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WSGT-3			Fine Sand, Trace Silt	SP	11.2	NP	NP	NP

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/22/2005

Terracon

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

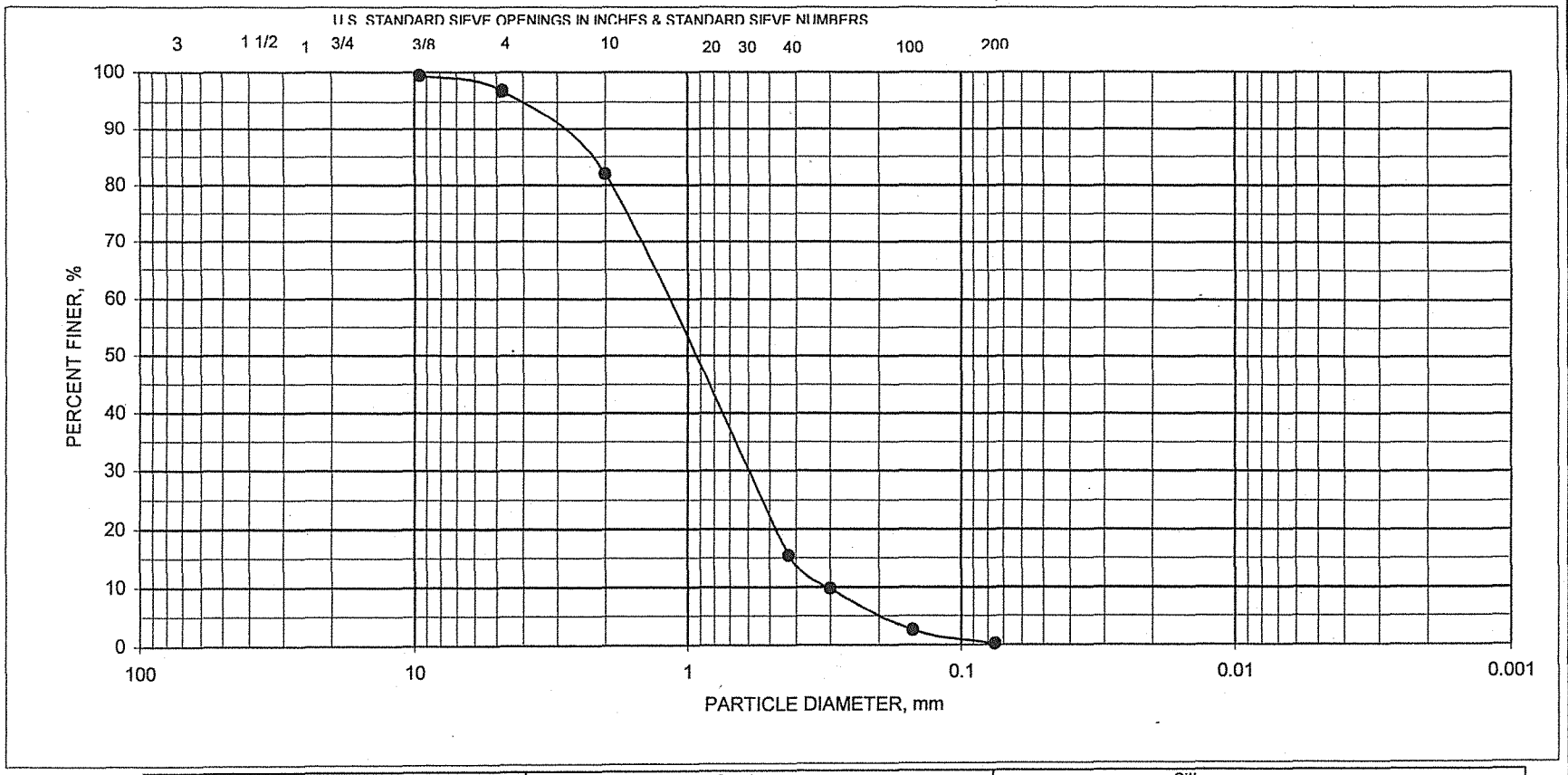
BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WSGT-4		5 to 10'-Bottom of Sample	Fine to Medium Sand With Gravel	SP	9.5	NP	NP	NP

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/22/2005

Terracon

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WSGT-5		22 to 27'	Sand, trace gravel, black	SP	9.5	NP	NP	NP

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/28/2005

Terracon

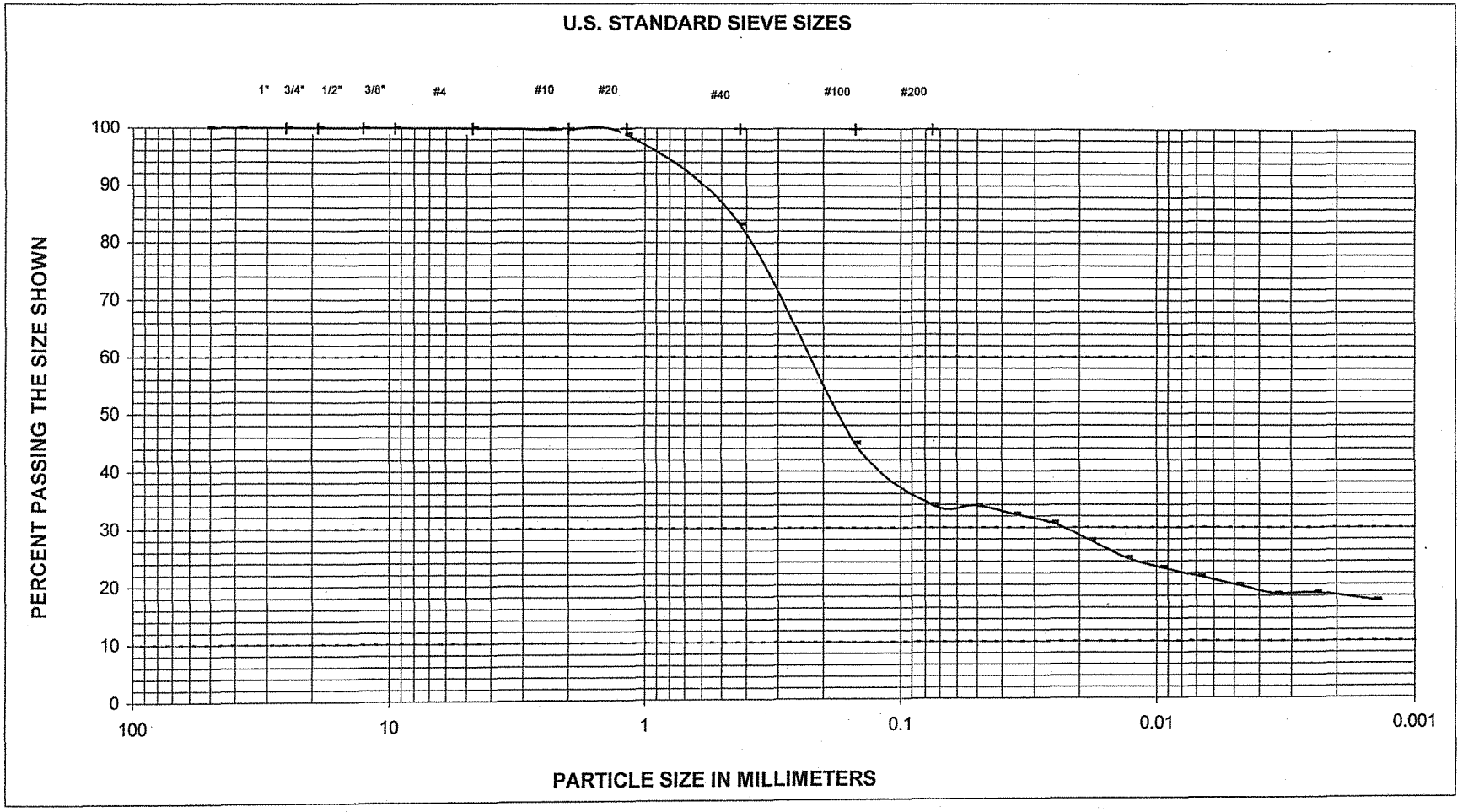
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing Boring Number PS-GT-1 Date: 8/29/2005

Terracon Project #: 58055075 Sample No.: Sample type.:

Sample Description: Clayey sand, dark brown



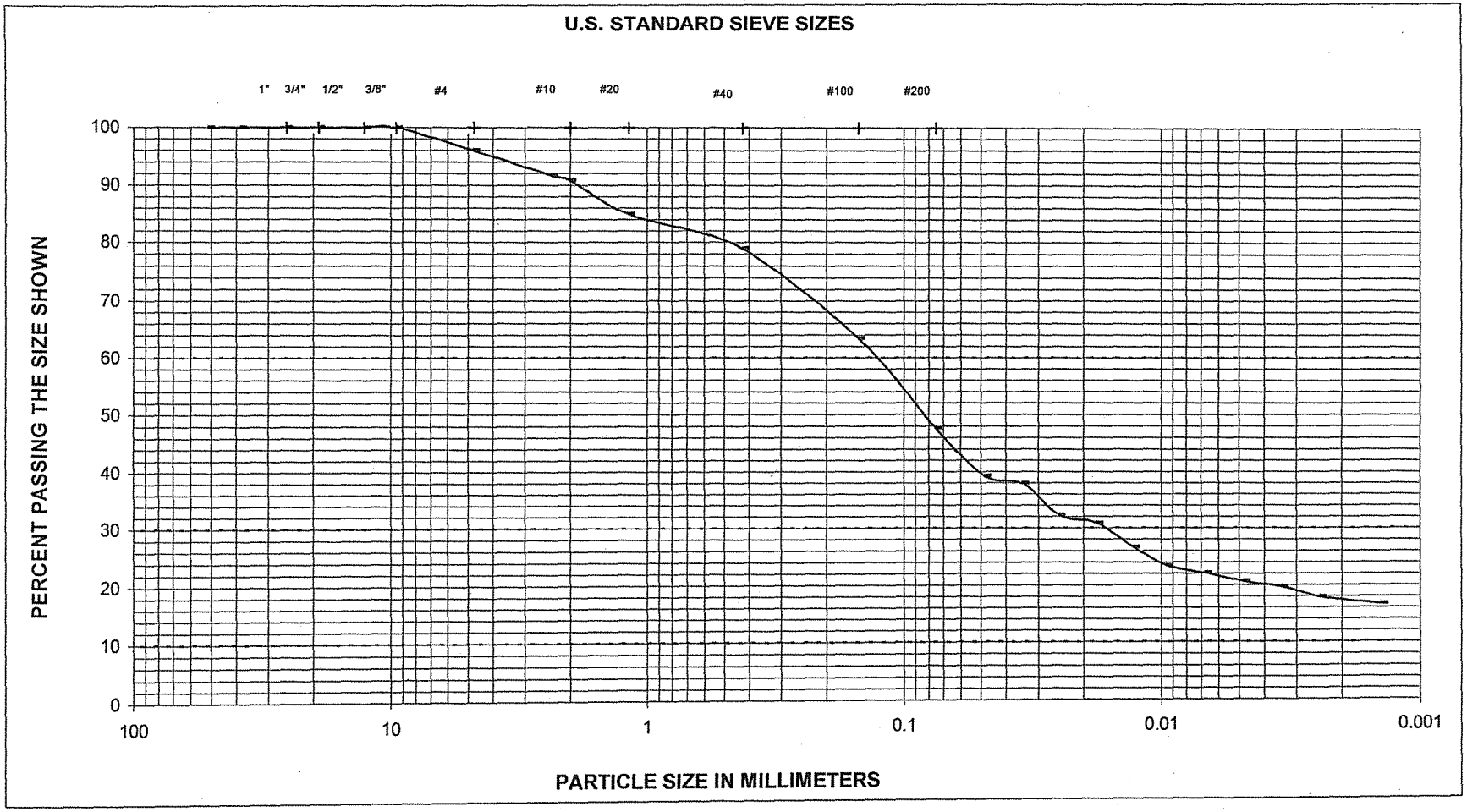
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing Boring Number PS-GT-2 Date: 8/25/2005

Terracon Project #: 58055074 Sample No.: Sample type.:

Sample Description: Clayey sand, trace gravel, medium to coarse grained, brown



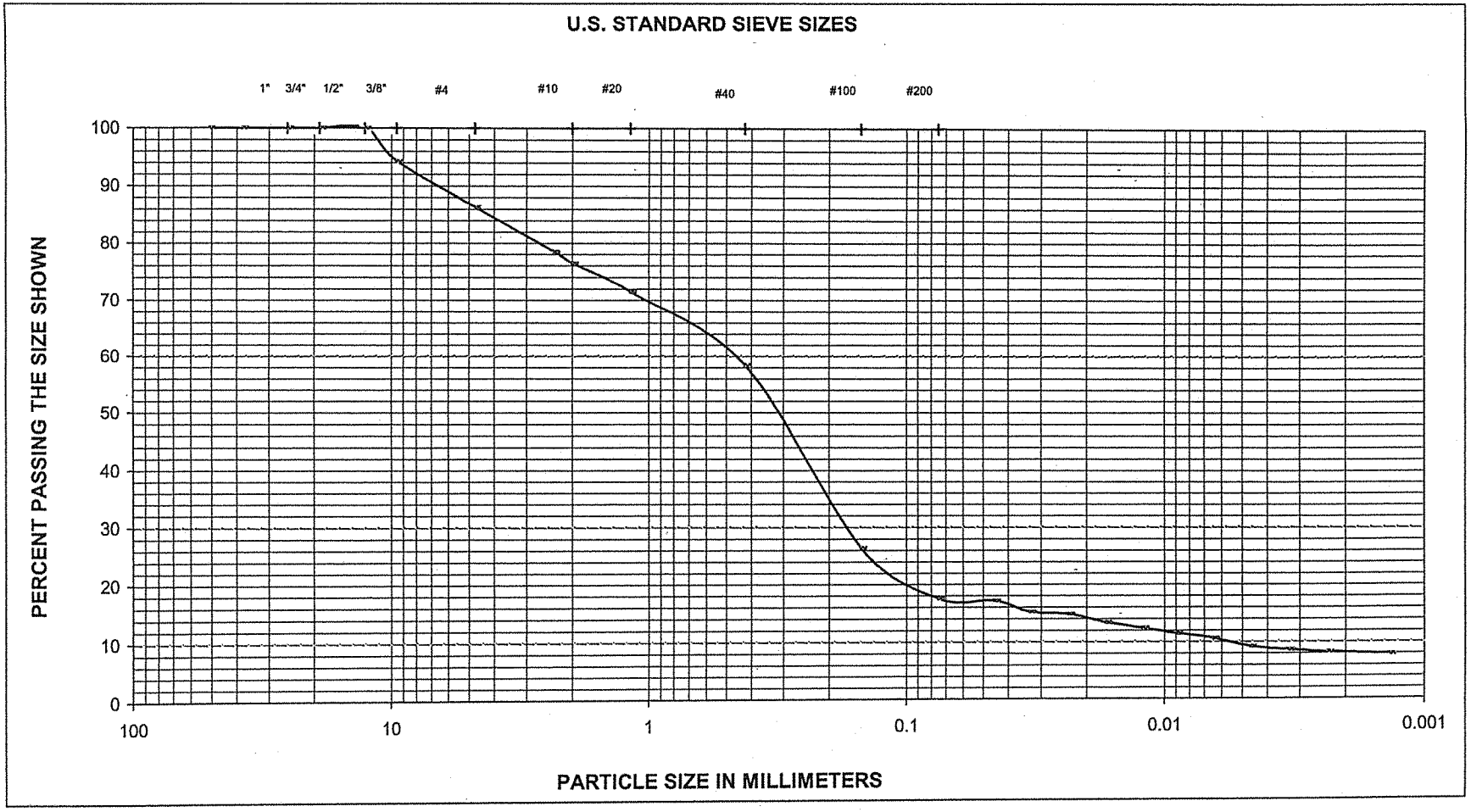
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing | Boring Number PS-GT-3 | Date: 8/26/2005

Terracon Project #: 58055075 | Sample No.: 7-9' | Sample type.:

Sample Description: Sand, trace clay, gravel and organics, dark brown



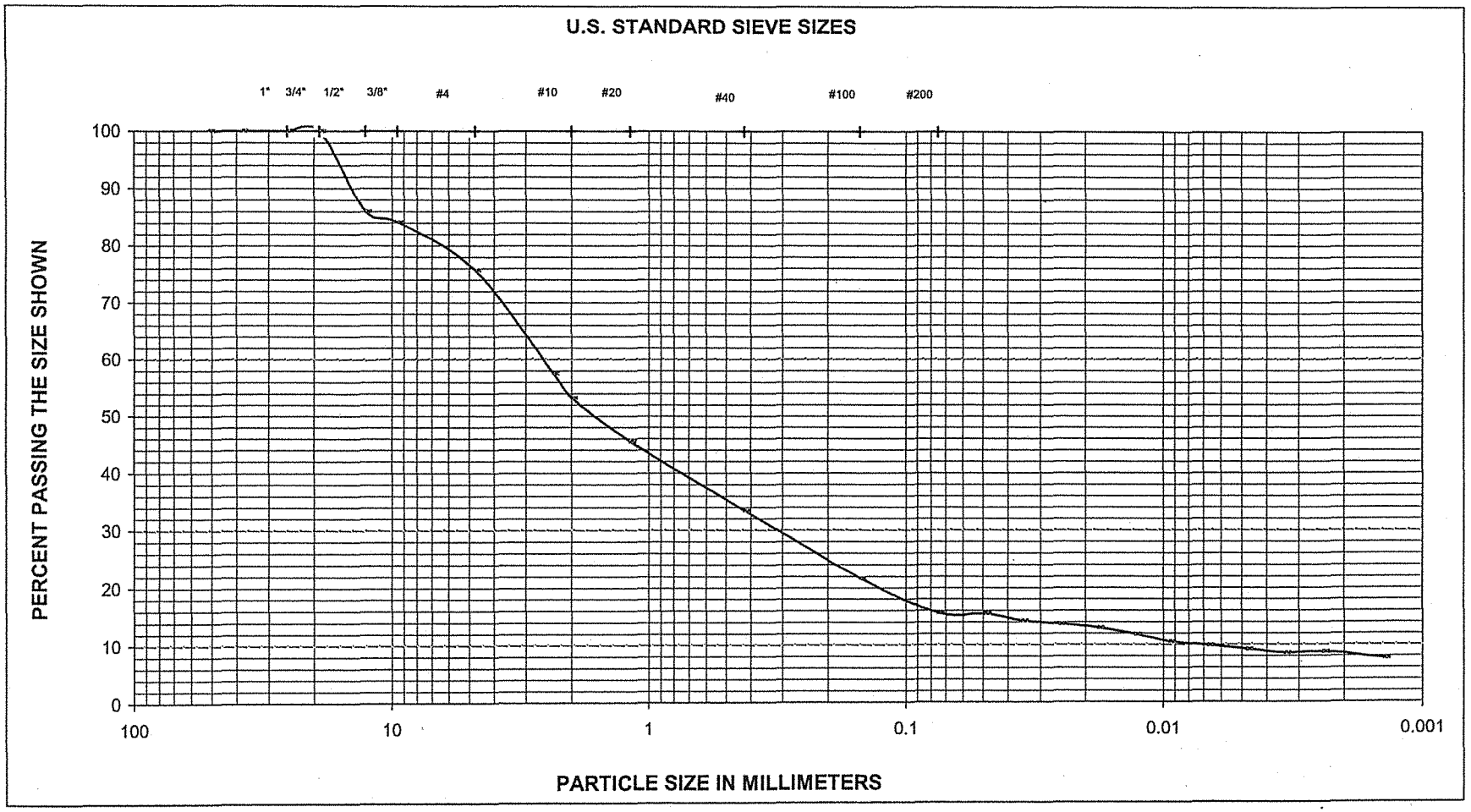
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing Boring Number PS-GT-4 Date: 8/29/2005

Terracon Project #: 58055075 Sample No.: Sample type.:

Sample Description: Sand, with clay and gravel, trace organics, fine to coarse grained, dark brown



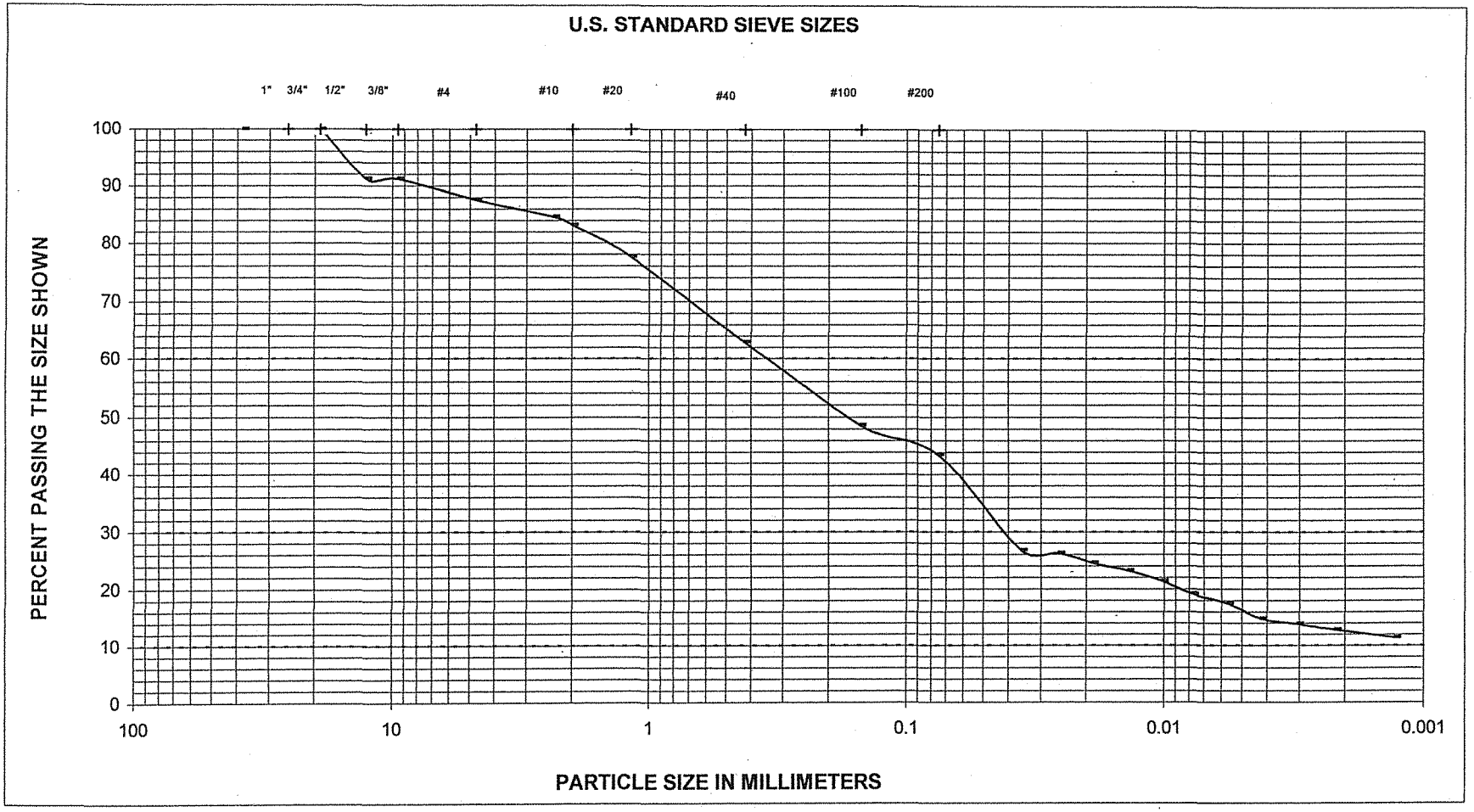
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GRAIN SIZE DISTRIBUTION CURVE

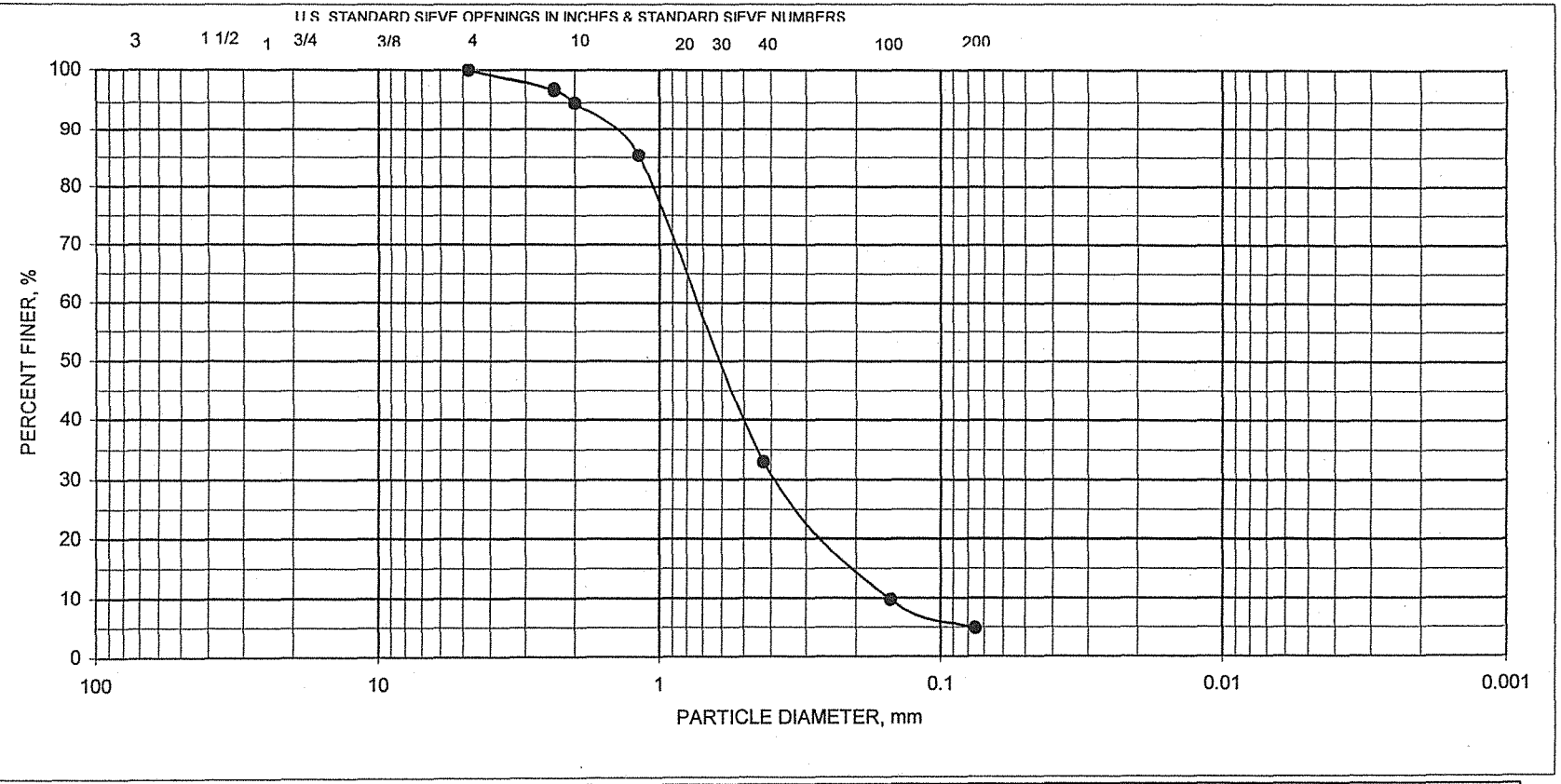
Project Name: KPRG Laboratory Testing Boring Number PS-GT-5 Date: 8/26/2005

Terracon Project #: 58055075 Sample No.: Sample type.:

Sample Description: Clayey Sand, trace gravel, brown



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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-6		15-20'	Fill: Sand, fine to medium coarse, trace gravel, dark brown	SP				

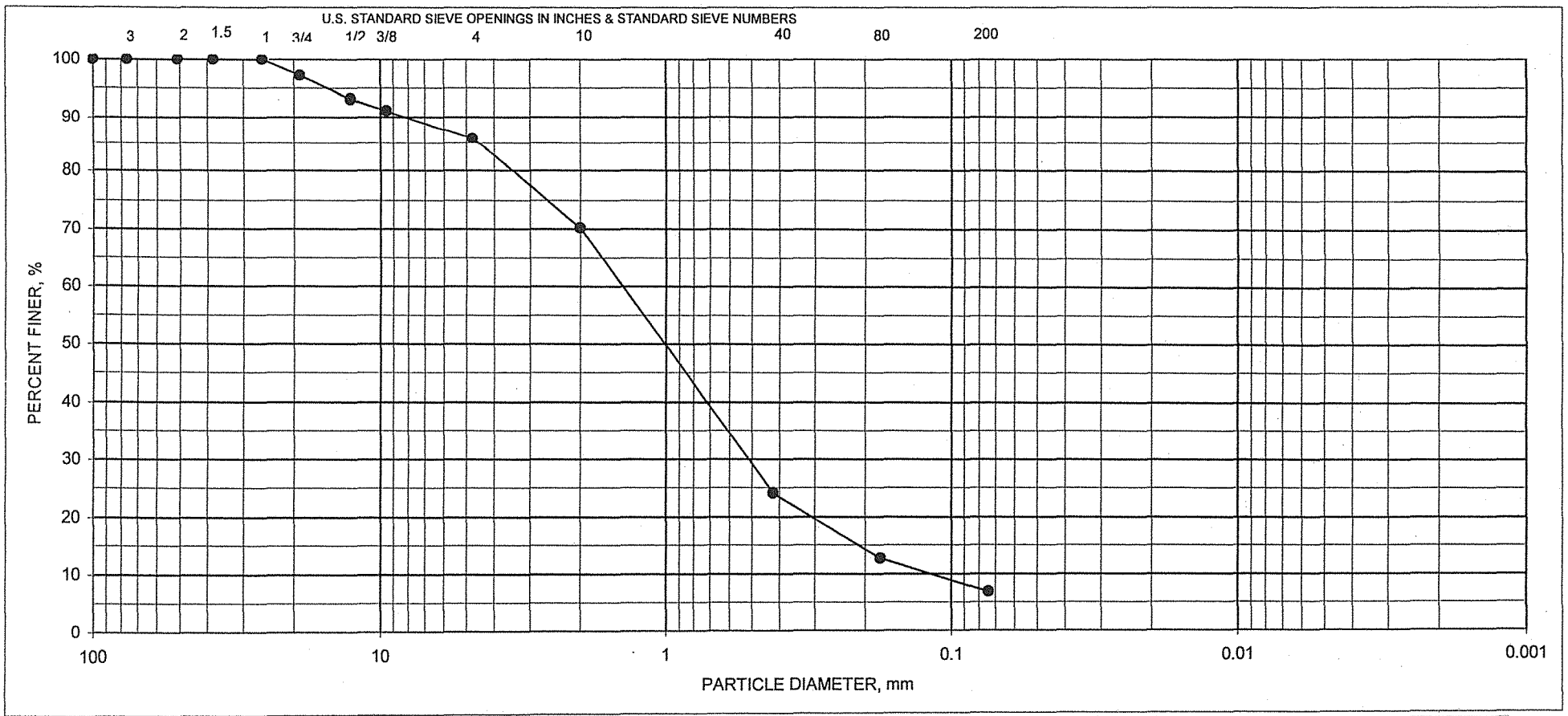
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Grad PS-GT-6.xls

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-7		10.0 TO 13.0	WELL GRADED SAND WITH SILT, DARK GRAY	SW-SM	7.0	21	18	3

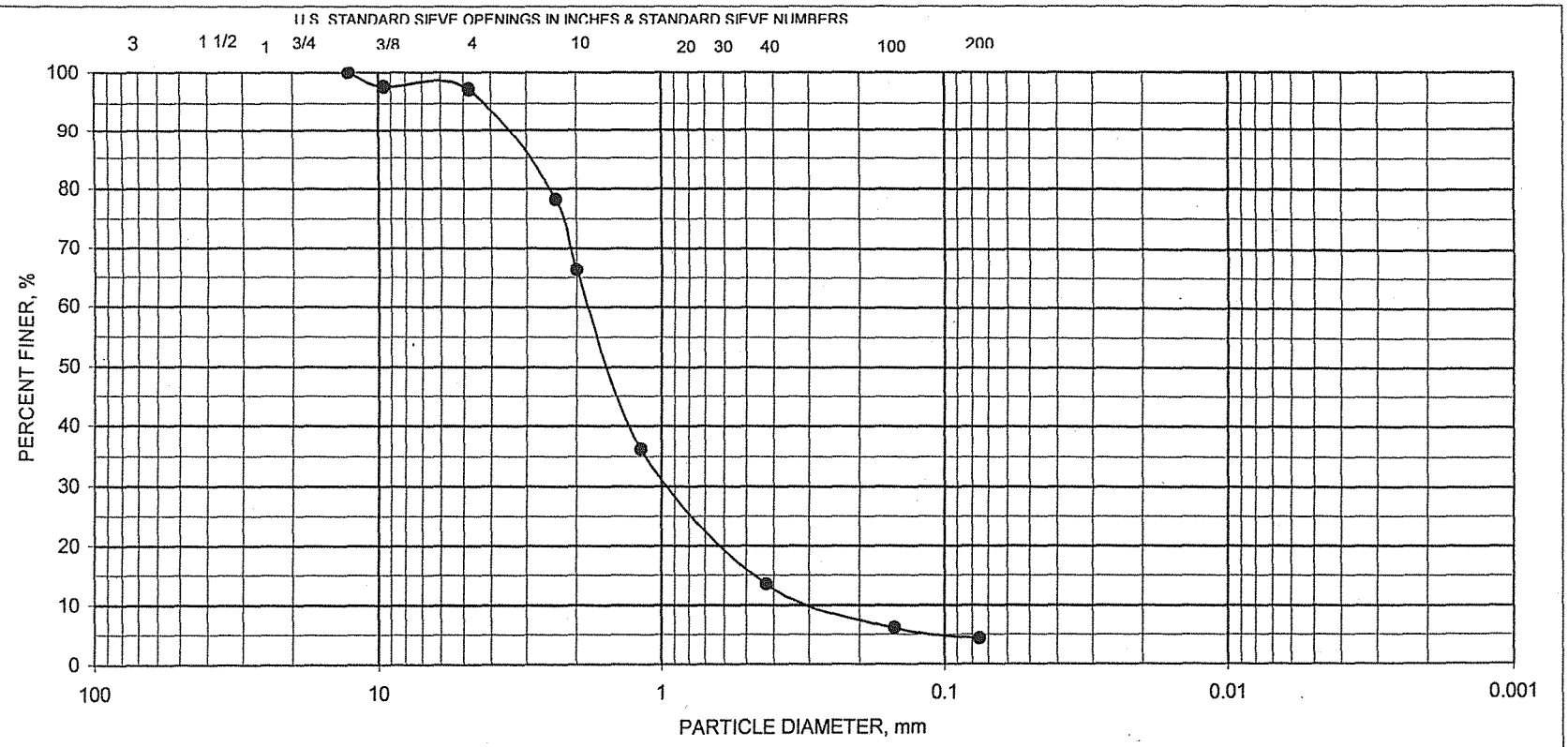
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Terracon

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-8 (top)		10 to 15'	Cinders, metal shavings, glass, black					

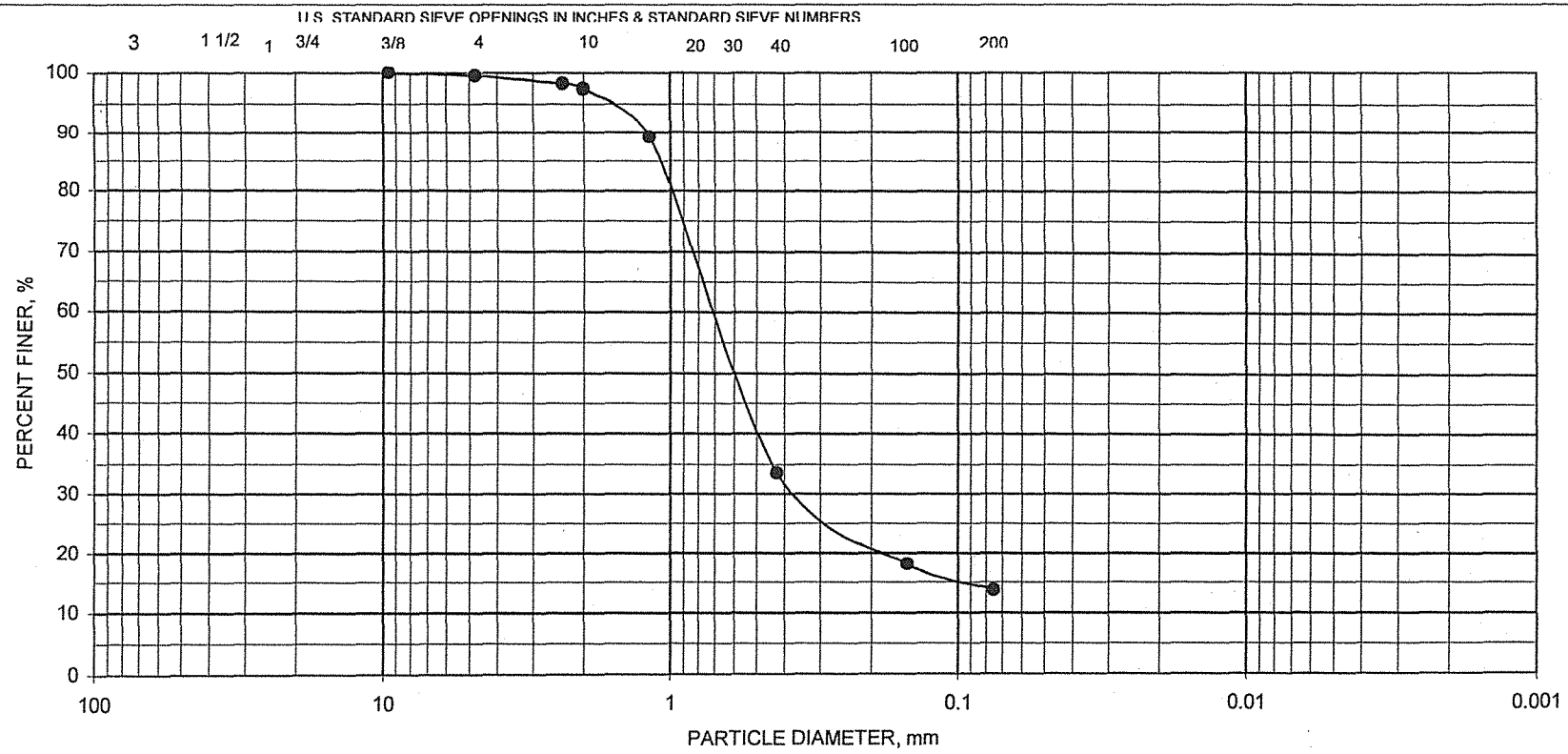
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Sieve PS-GT-8

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-8 (bottom)		10 to 15'	Silty Sand, trace clay, dark gray	SM				

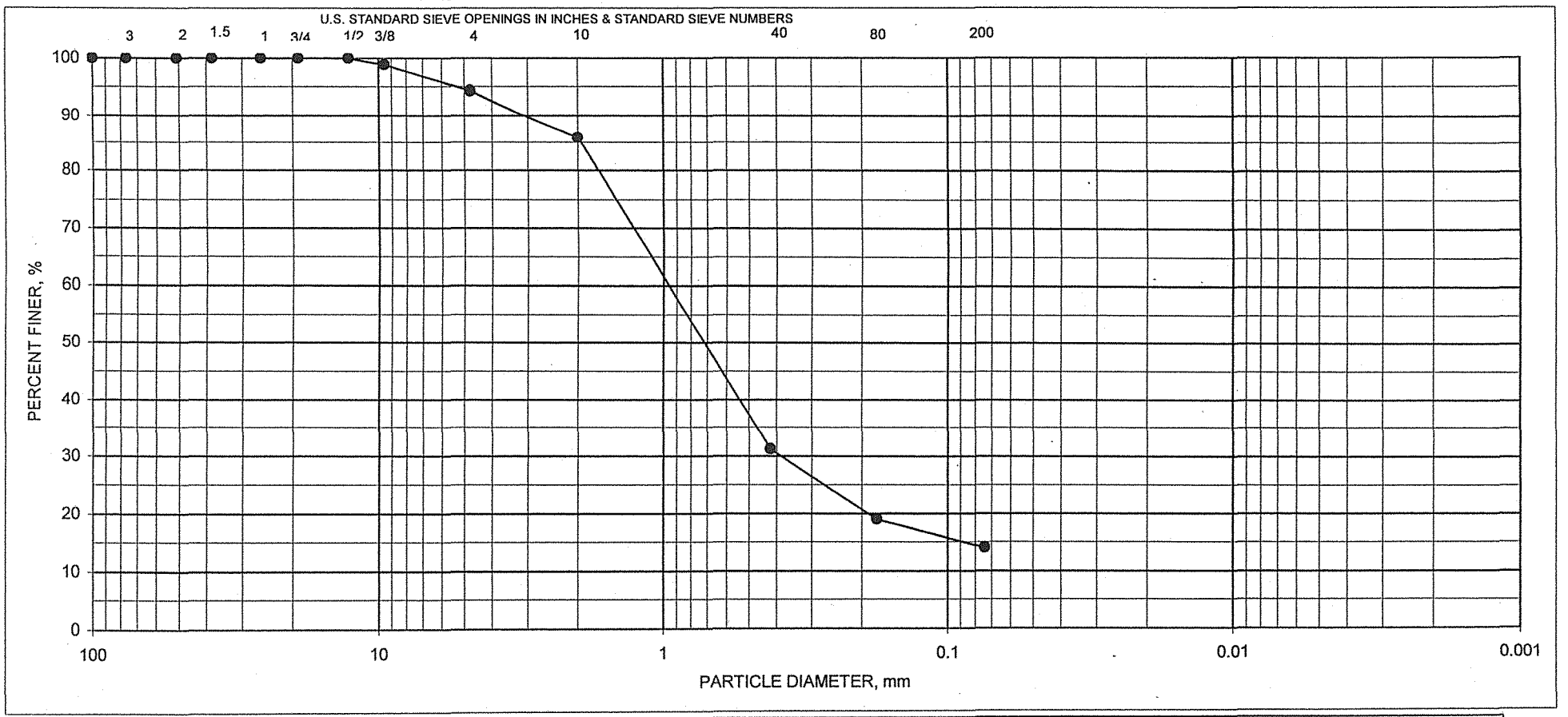
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Sieve PS-GT-8 (bottom).xls

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-9	TOP 16"	15.0 TO 20.0	SILTY SAND, DARK GRAY	SM	8.9	22	19	3

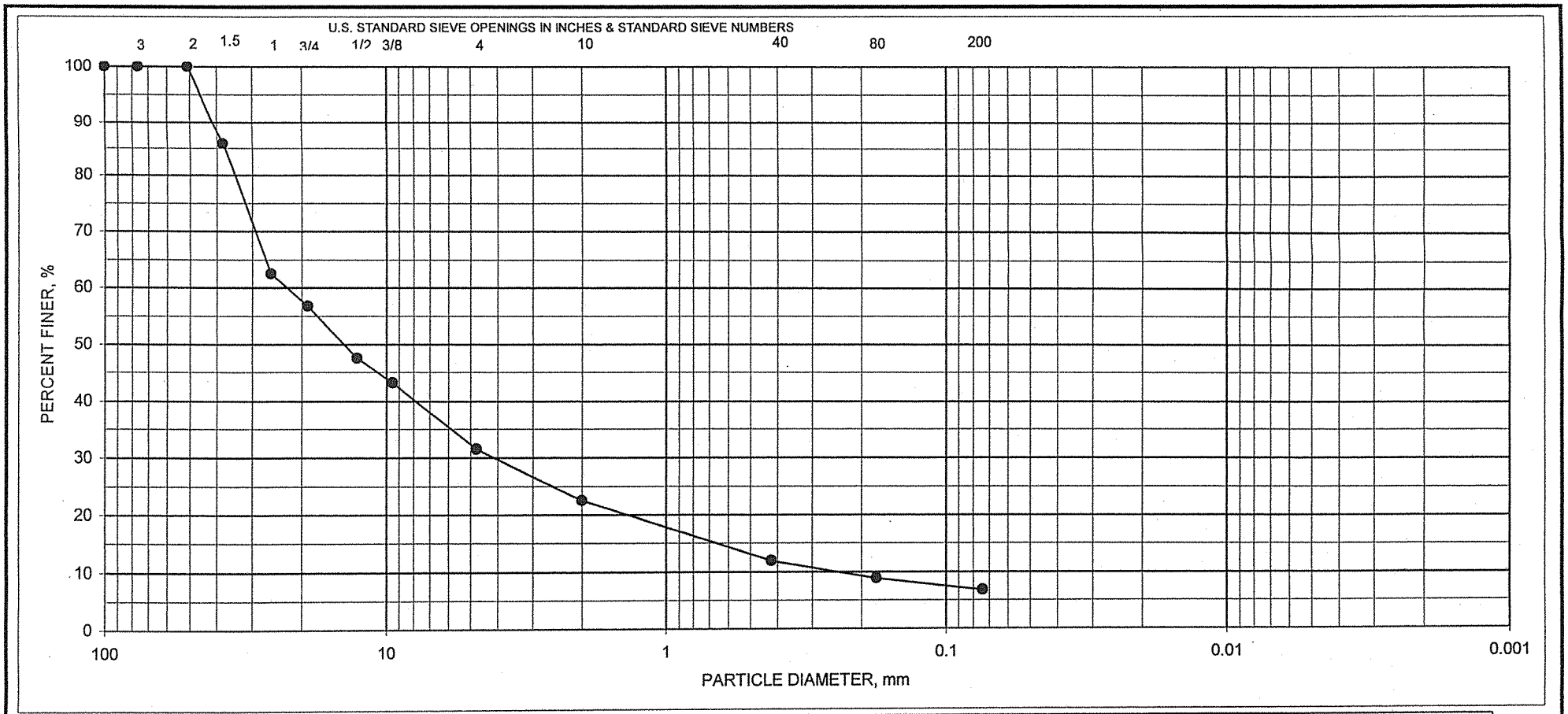
PROJECT KPRG LABORATORY TESTING

JOB NO. 58055075 DATE 10/7/2005

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-9	MIDDLE 8"	15.0 TO 20.0	POORLY GRADED GRAVEL WITH SILT & SAND, DARK YELLOWISH BROWN	GP-GM	3.3			

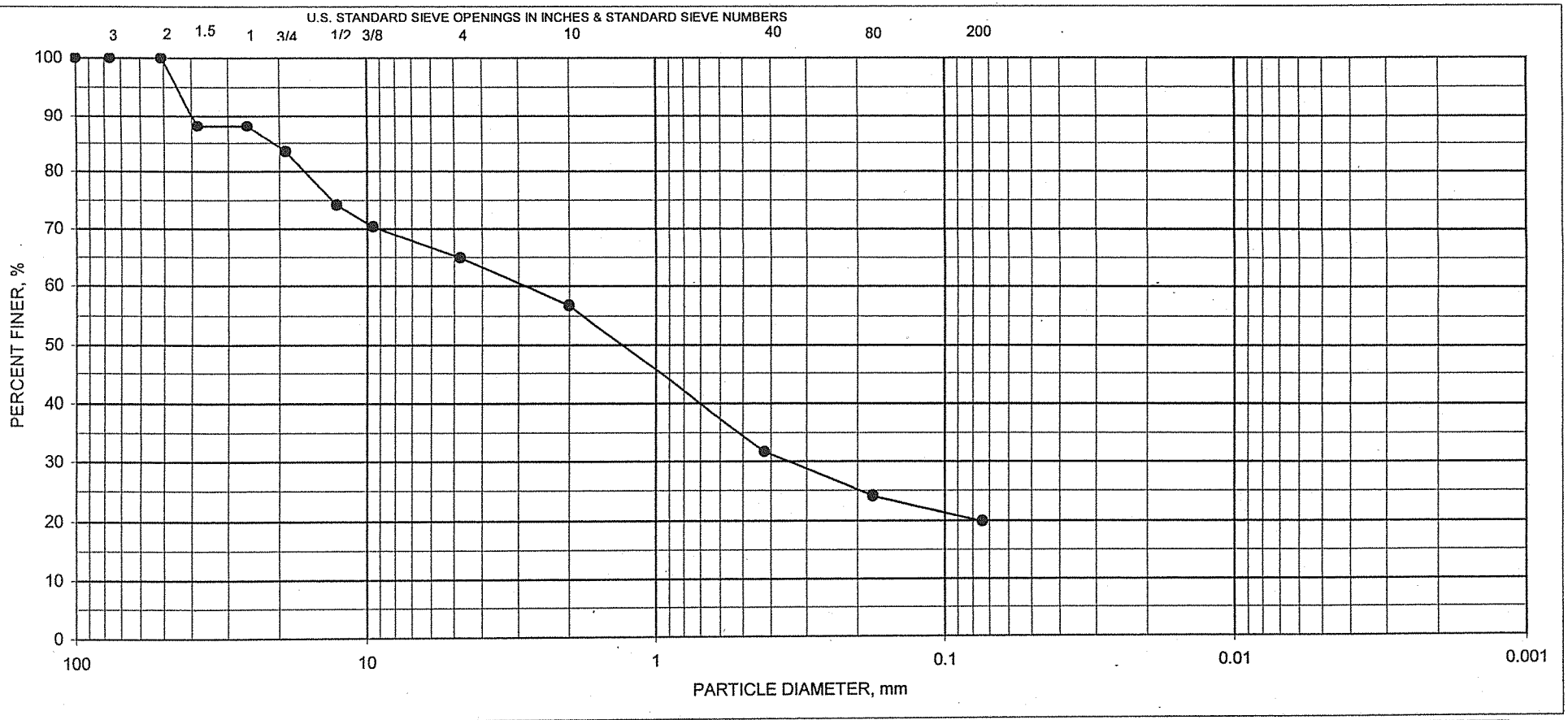
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JOB NO. 58055075 DATE 10/7/2005

Terracon

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-9	BOTTOM 8"	15.0 TO 20.0	SILTY SAND WITH GRAVEL, DARK GRAY TRACE LIGHT GRAY	SM	16.4	24	21	3

PROJECT KPRG LABORATORY TESTING

JOB NO. 58055075 DATE 10/7/2005

Terracon

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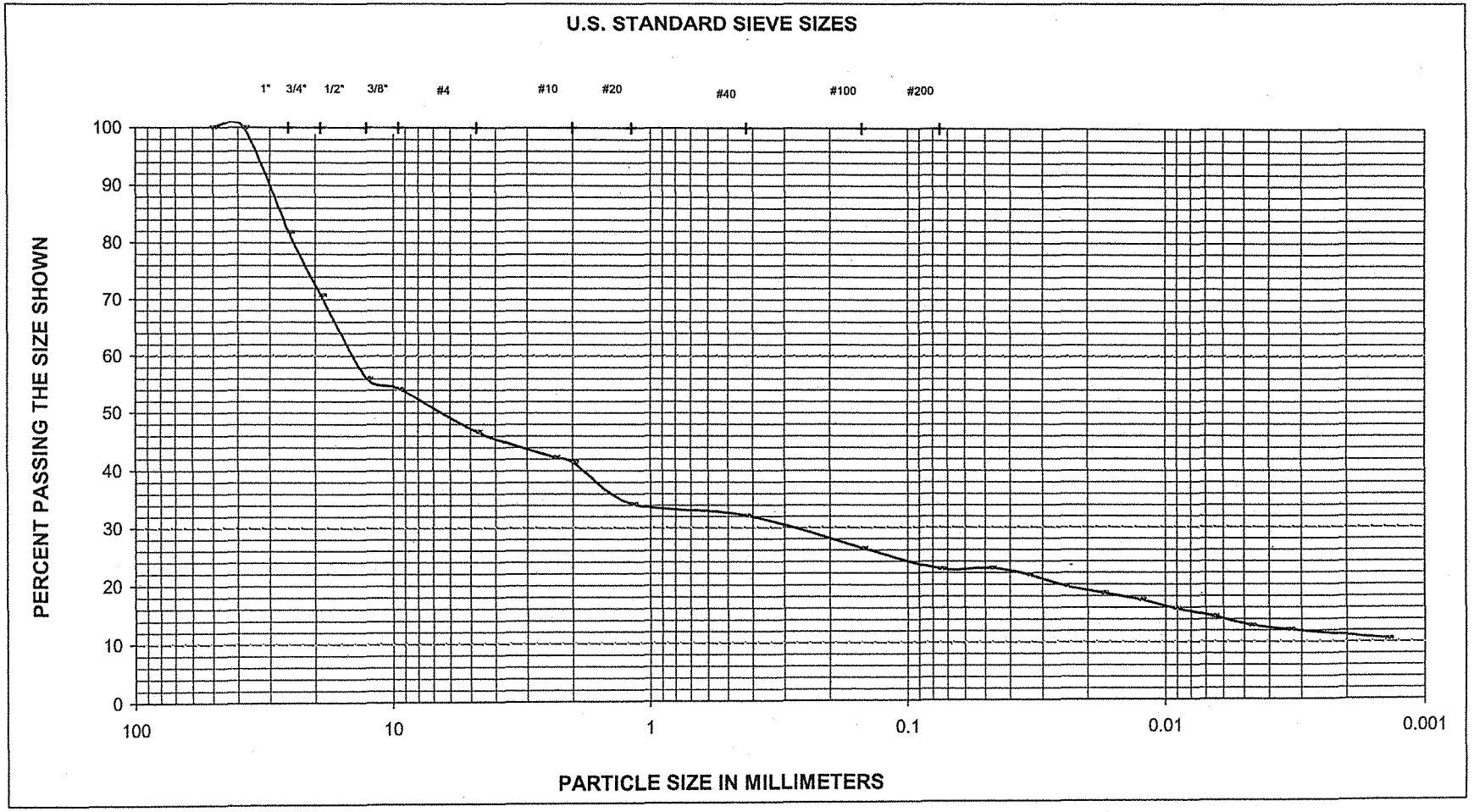
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GRAIN SIZE DISTRIBUTION CURVE

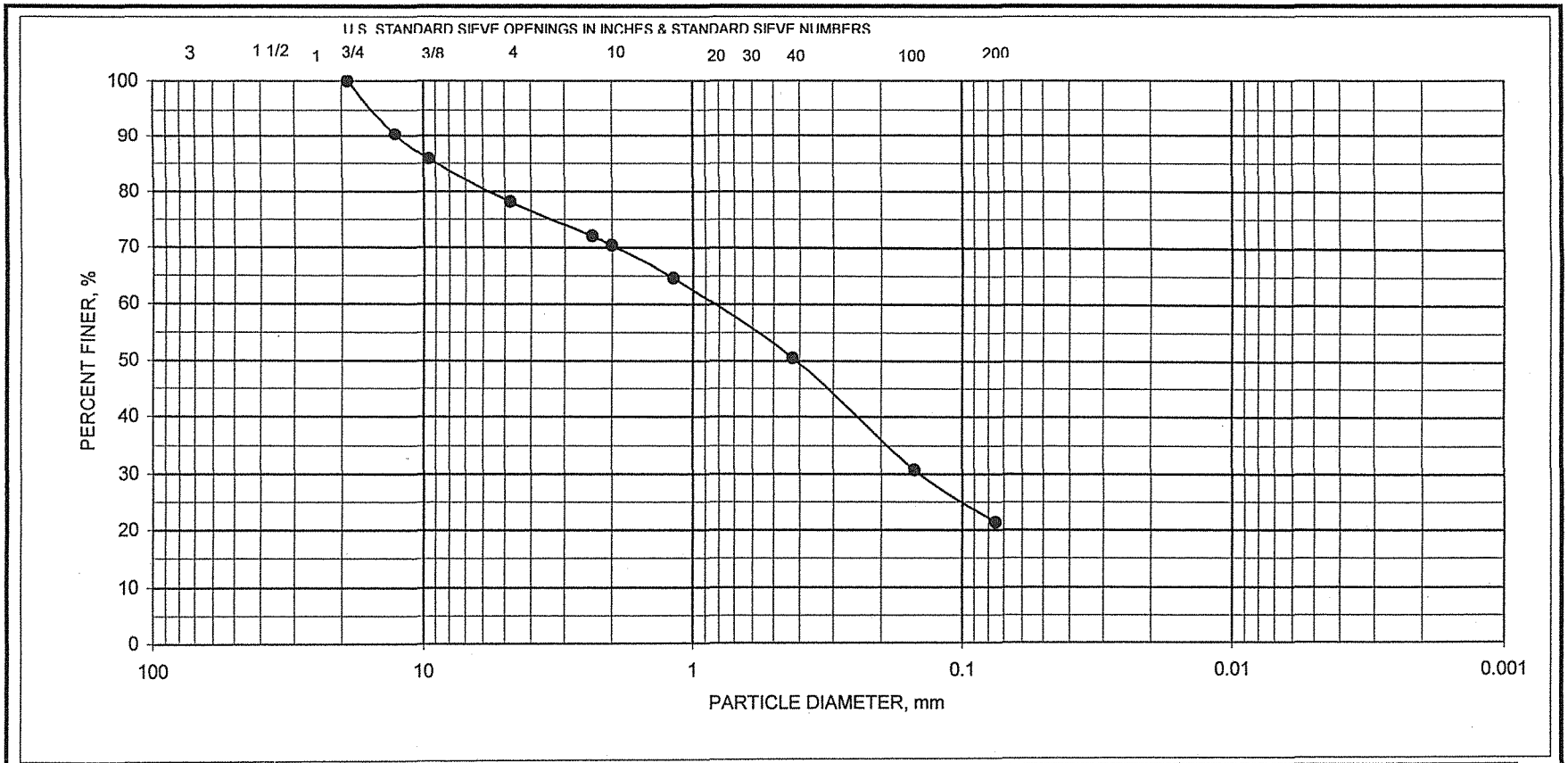
Project Name: KPRG Laboratory Testing | Boring Number JS-9-GT-1 | Date: 9/26/2005

Terracon Project #: 58055075 | Sample No.: 7-12' | Sample type.:

Sample Description: Sand, with gravel, gray



Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS-9-GT-2		7 to 11.5'	Clayey Sand, with organics, with gravel, dark brown	SC				

PROJECT KPRG Laboratory Testing

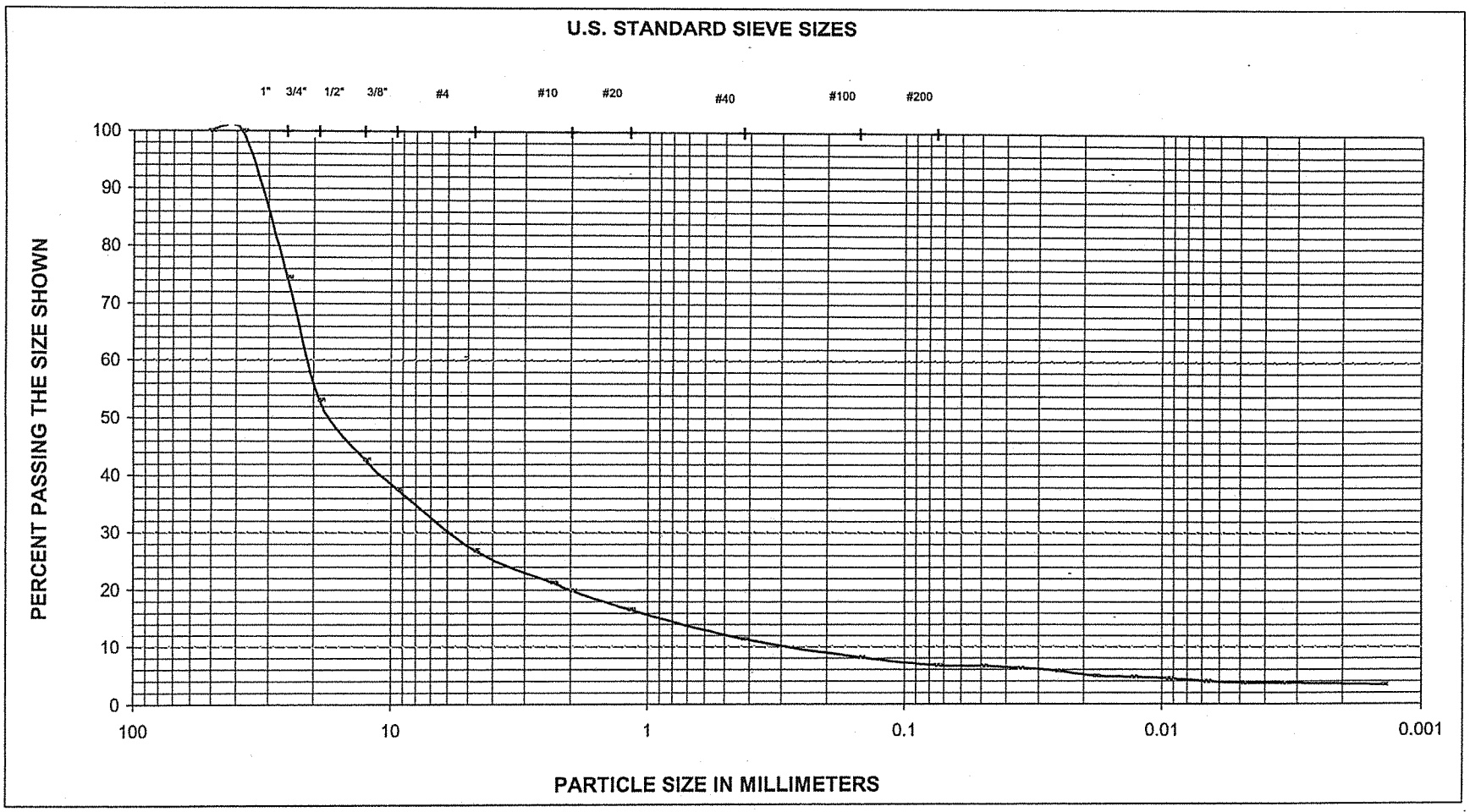
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Terracon

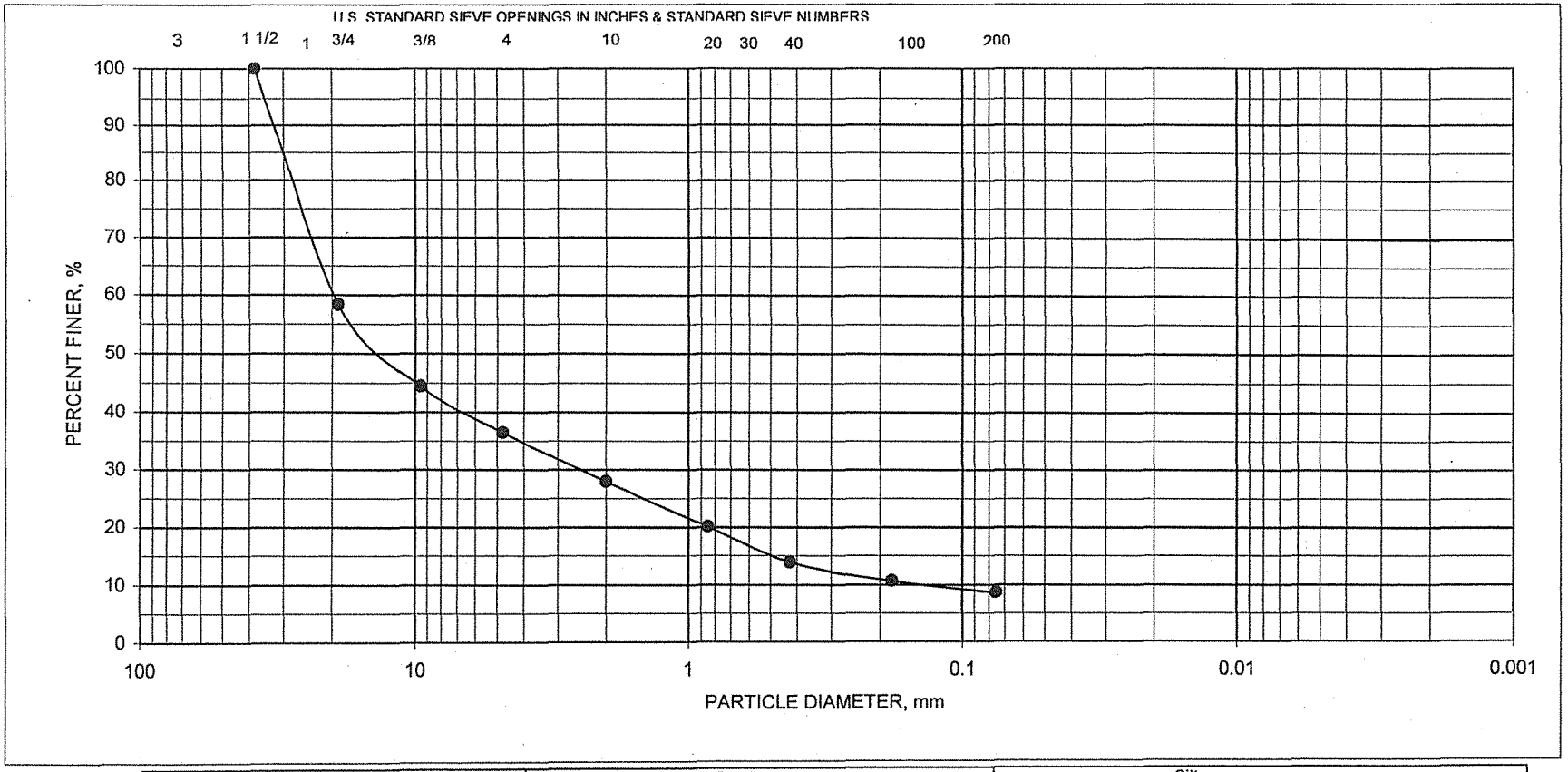
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GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing
Boring Number JS-9-GT-3
Date: 9/26/2005
Terracon Project #: 58055075
Sample No.: 8-13'
Sample type.:
Sample Description: Sand, with gravel, gray



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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS29GT-1		19 to 24'	Sandy Gravel, Trace Clay	GW		NP	NP	NP

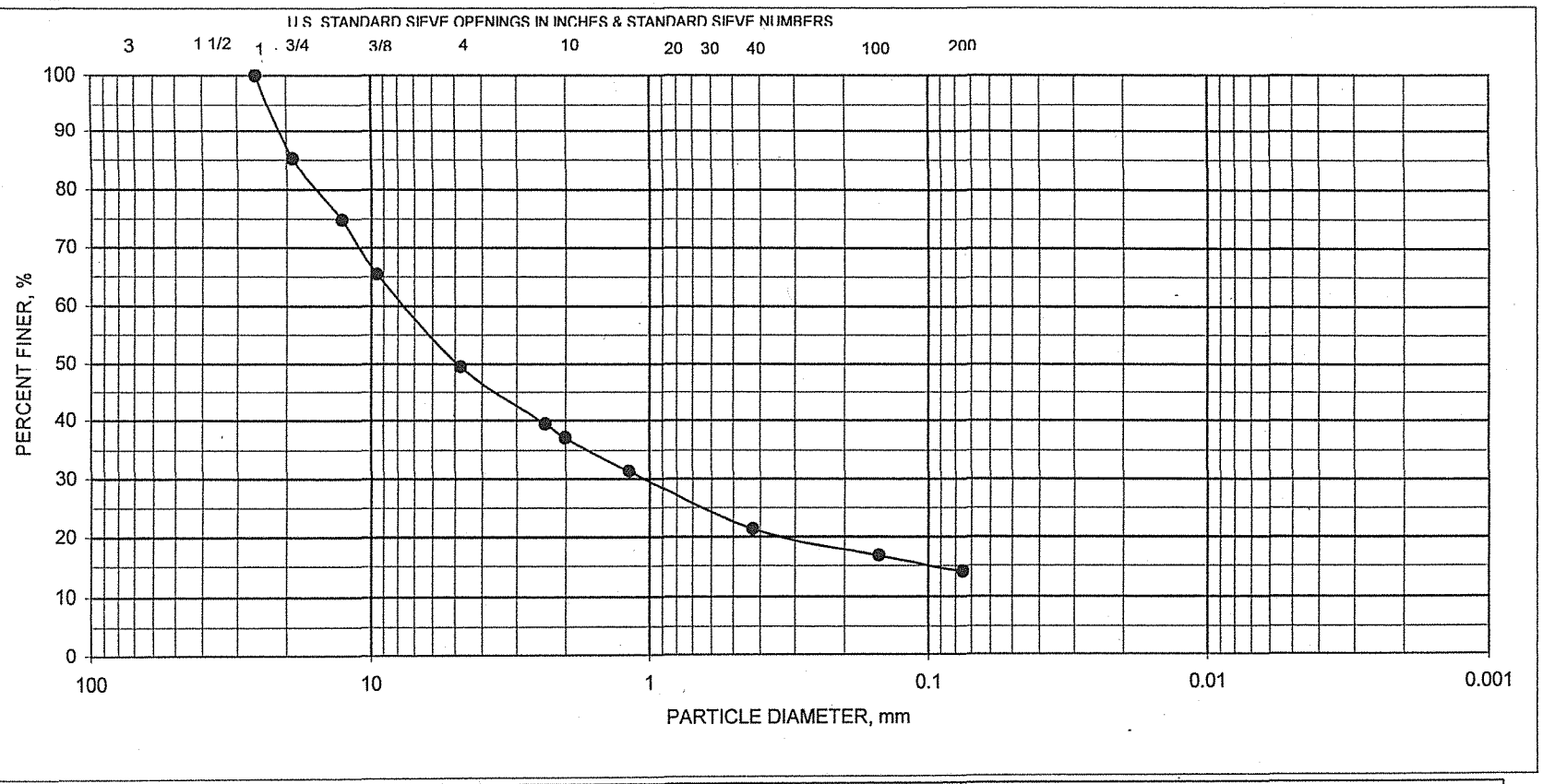
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/21/2005

Terracon

Sieve JS29GT-1.xls

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS-29-GT-2		19 to 24'	Clayey Gravel, brown	GC				

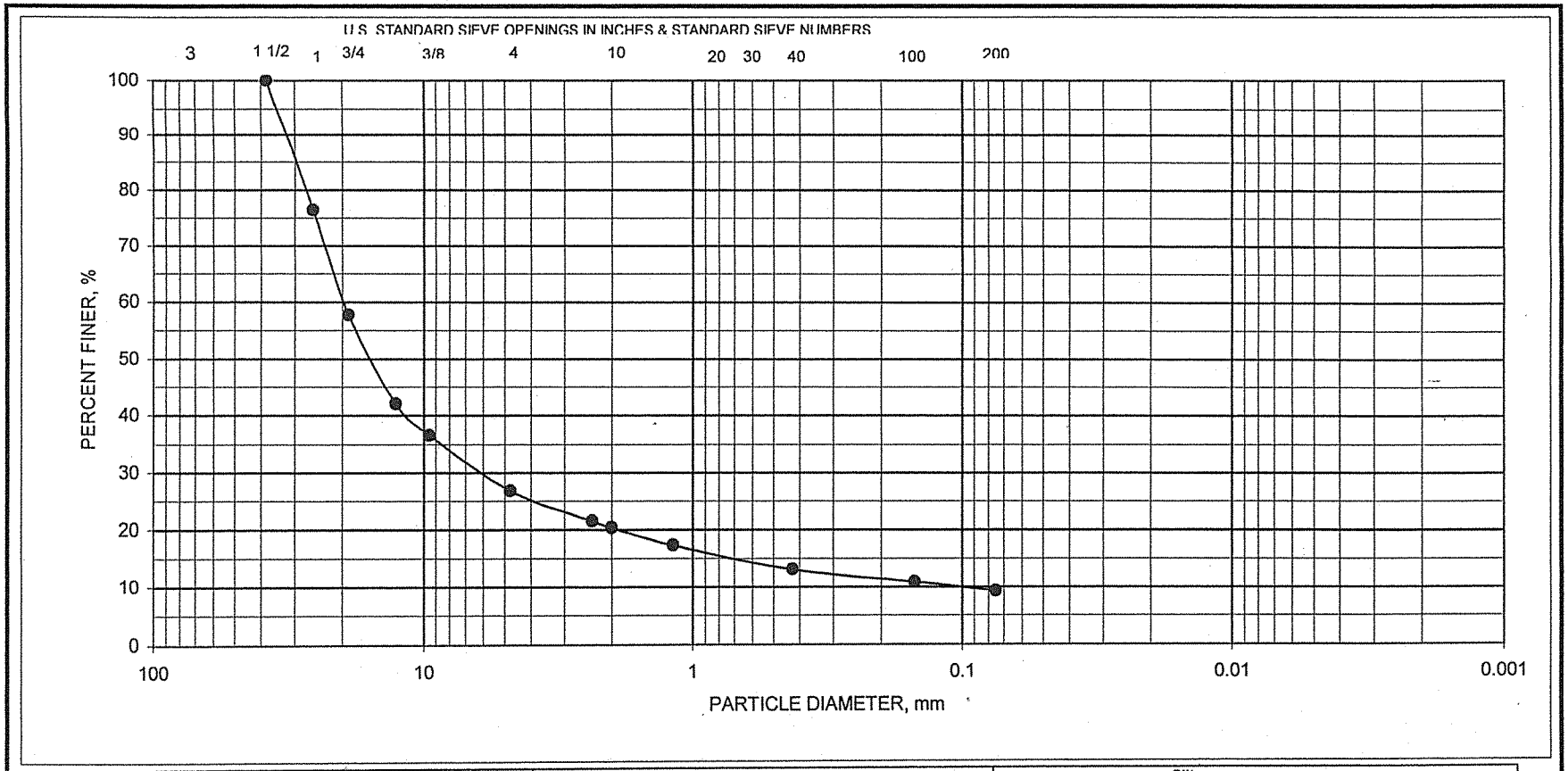
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Sieve JS-29-GT-2.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS-29-GT-3		19-24'	Poorly graded gravel with clay and sand, gray	GP-GC				

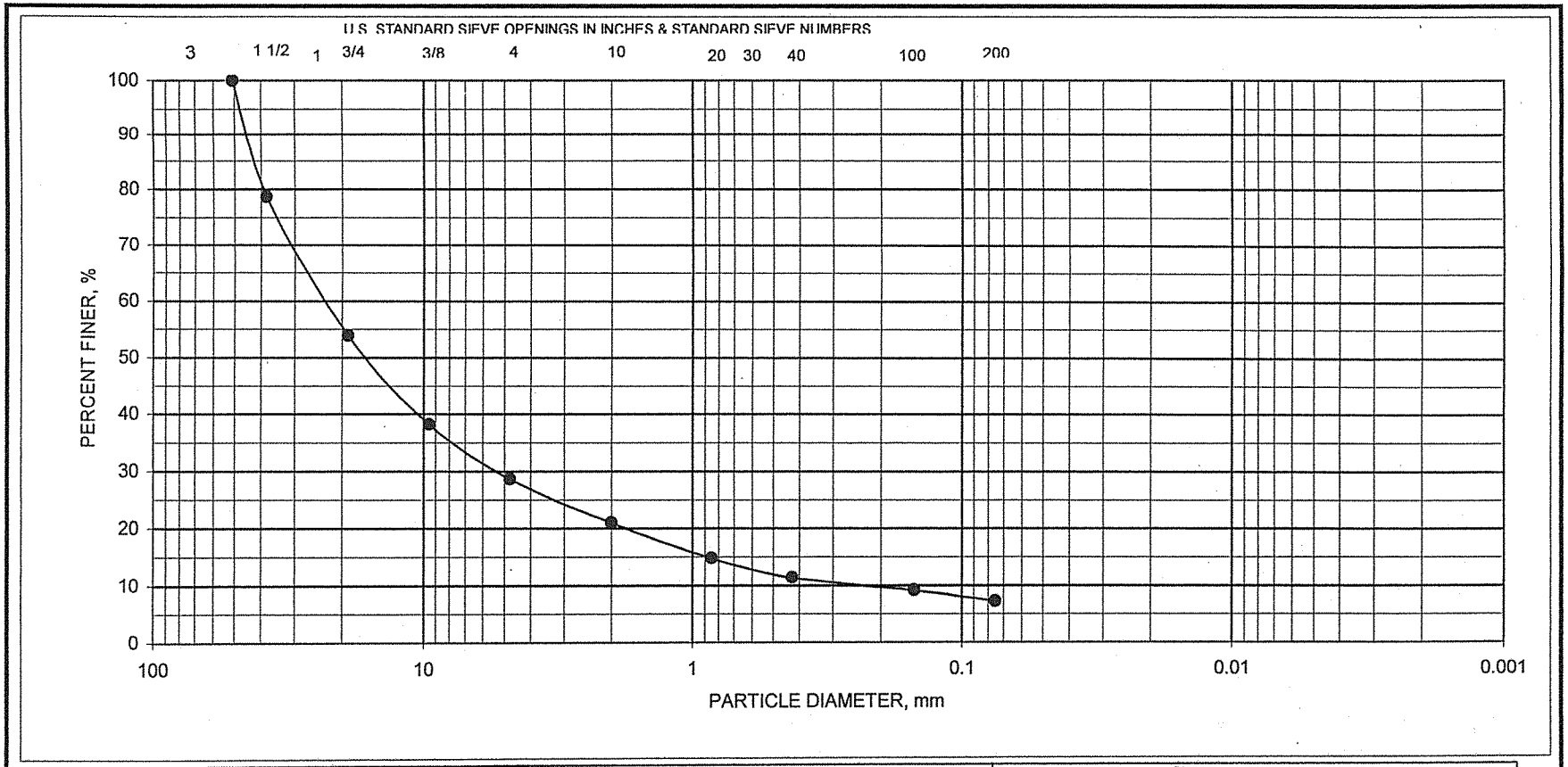
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Grad JS-29-GT-3.xls

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

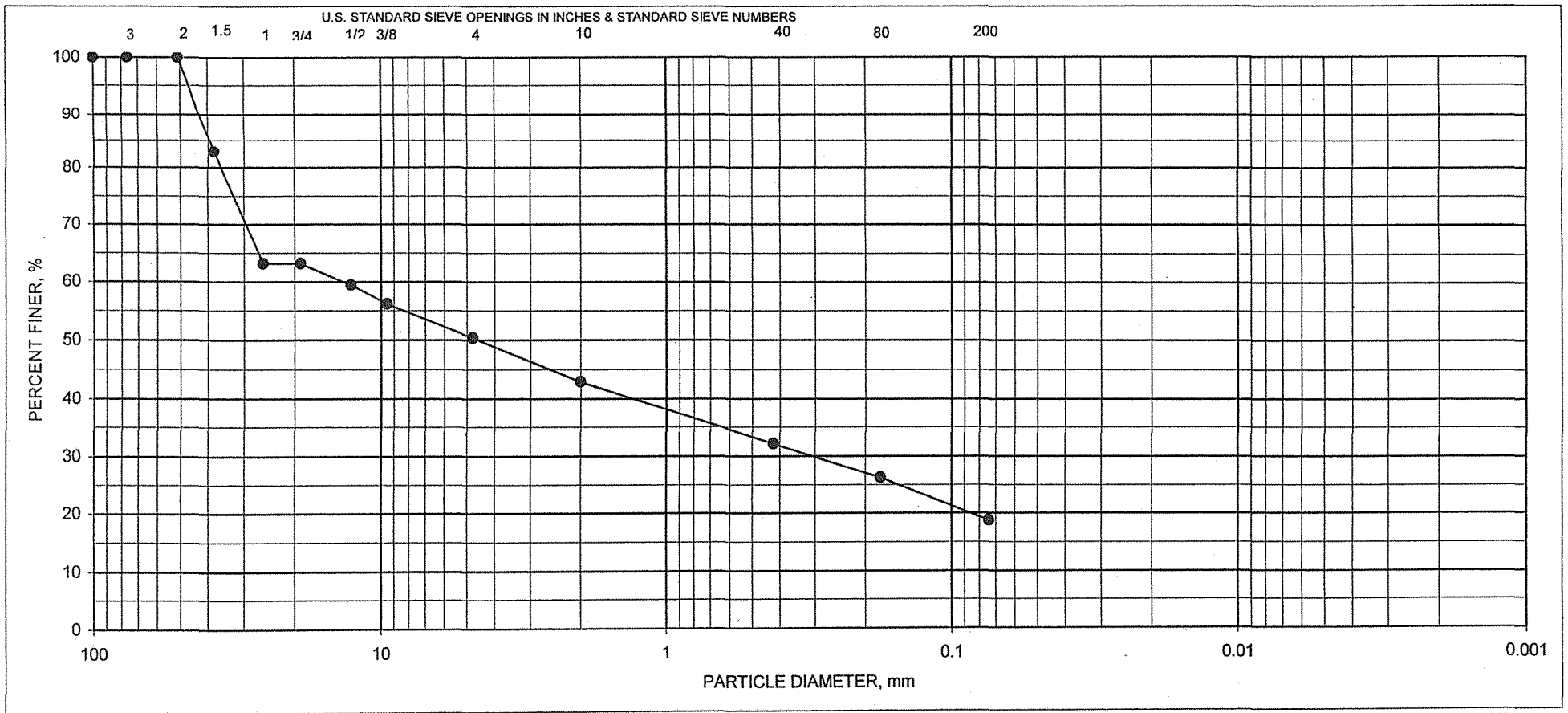
BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS29GT-4		17 to 22'	Dolomitic Limestone With Fine To Coarse Sand	GP				

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JOB NO. 58055075 DATE 10/6/2005

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS 29-GT-5	TOP 8"	5.0 TO 9.0	CLAYEY GRAVEL WITH SAND, DARK GRAY WITH YELLOWISH BROWN	GC	26.0	34	23	11

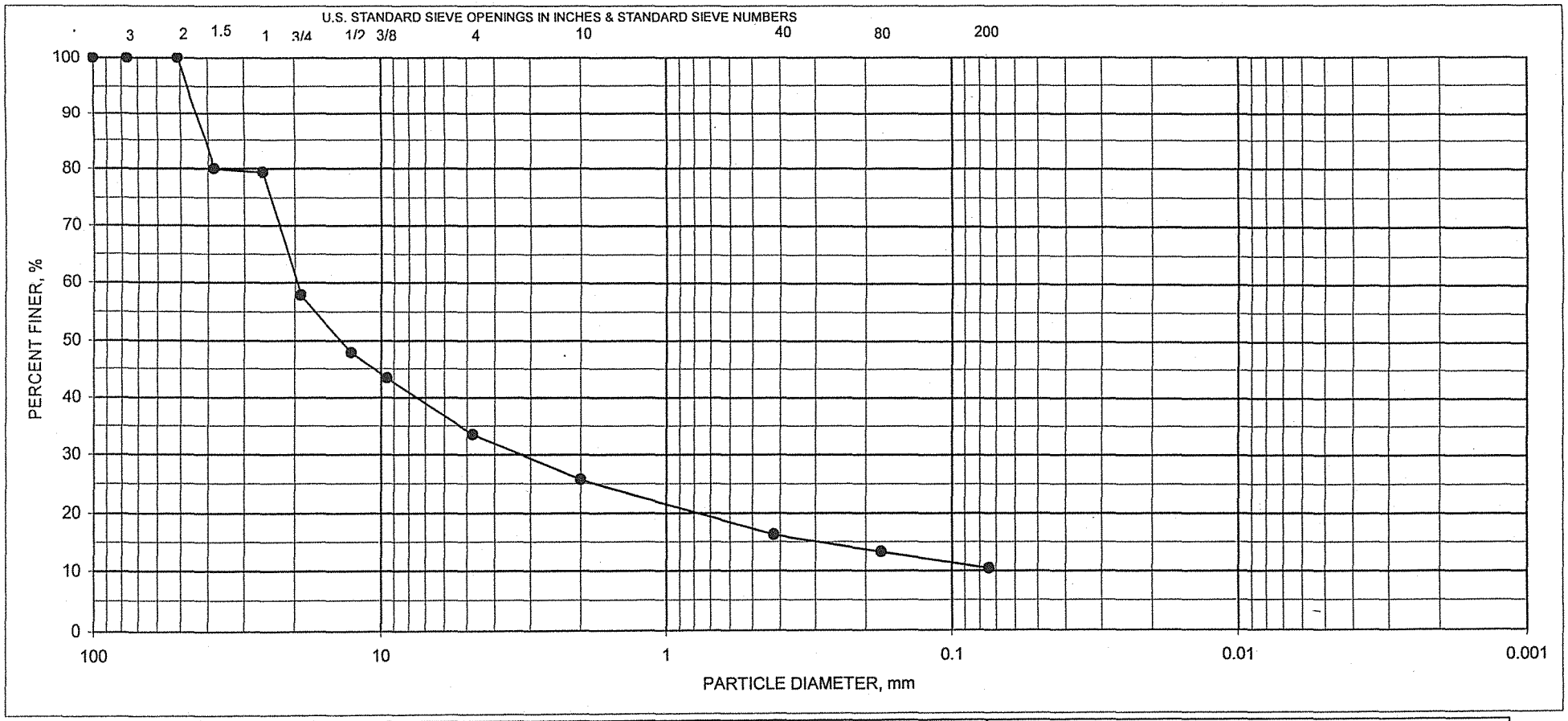
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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS 29-GT-5	TOP 7"	9.0 TO 14.0	POORLY GRADED GRAVEL WITH SILT & SAND, DARK GRAY	GP-GM	8.5			

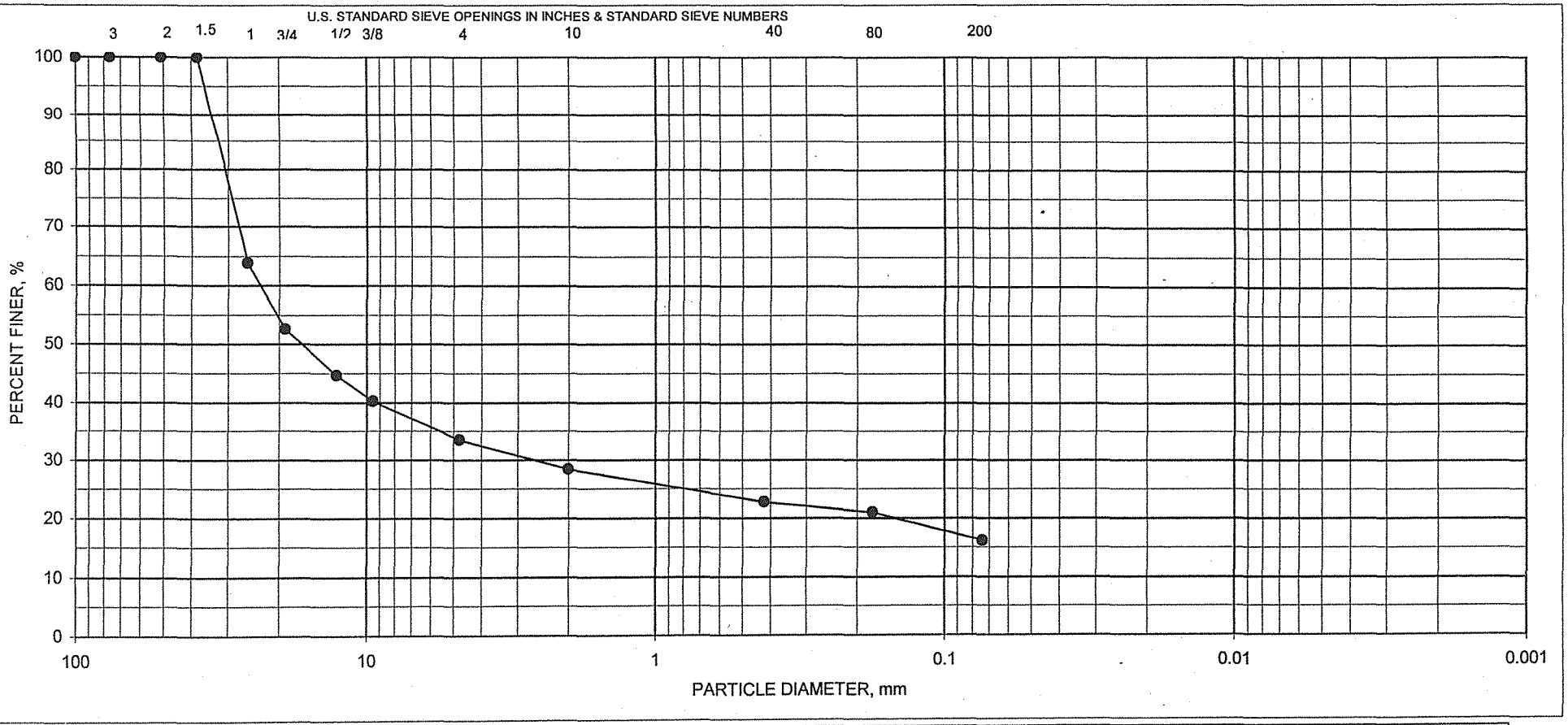
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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS 29-GT-5	BOTTOM 10"	9.0 TO 14.0	SILTY GRAVEL WITH SAND, DARK GRAY	GM	8.9	21	21	NP

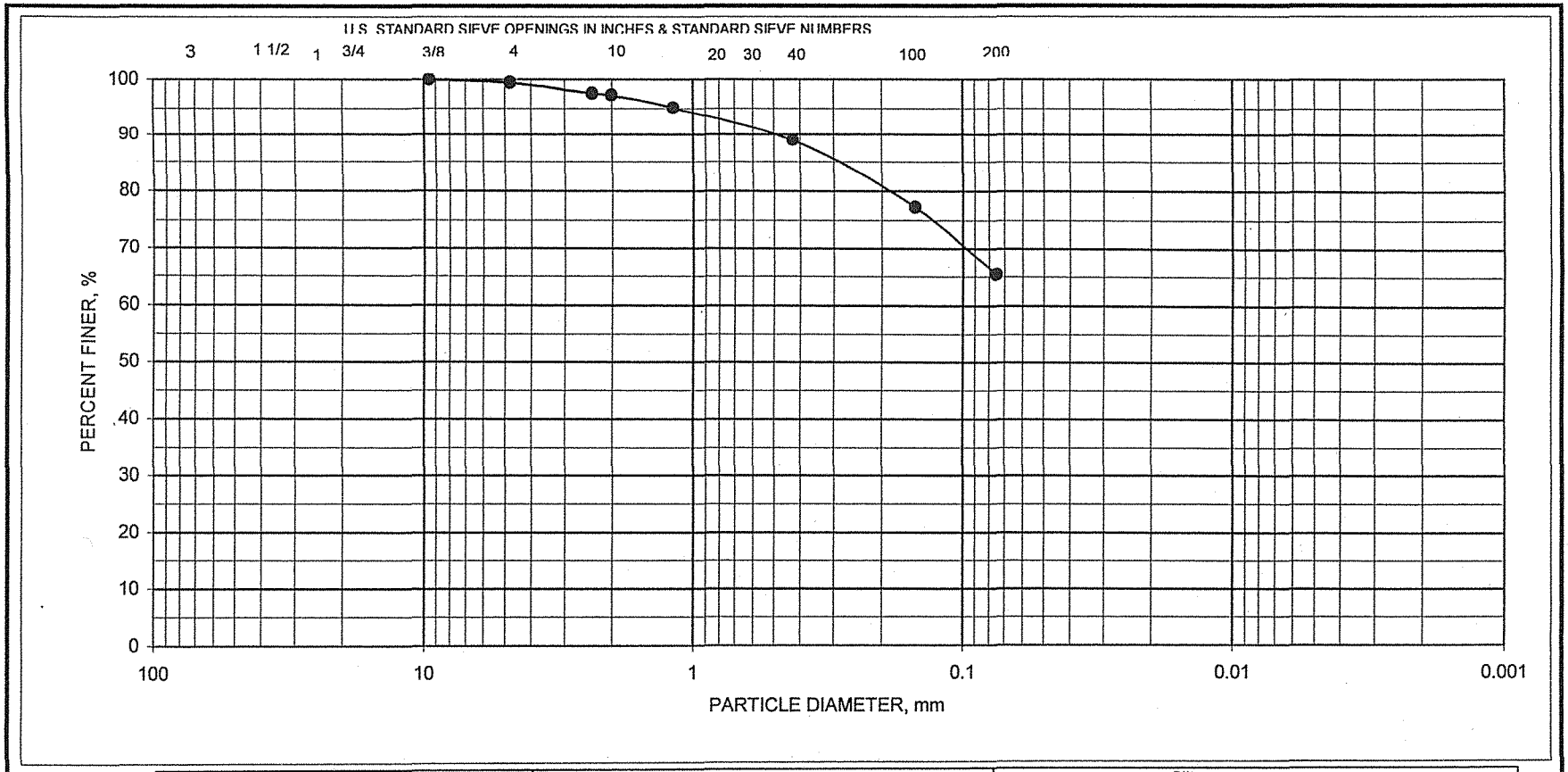
PROJECT KPRG LABORATORY TESTING

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS-29-GT-6		11 to 14'	Organic Silt, dark gray, black	OH				

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Exhibit F

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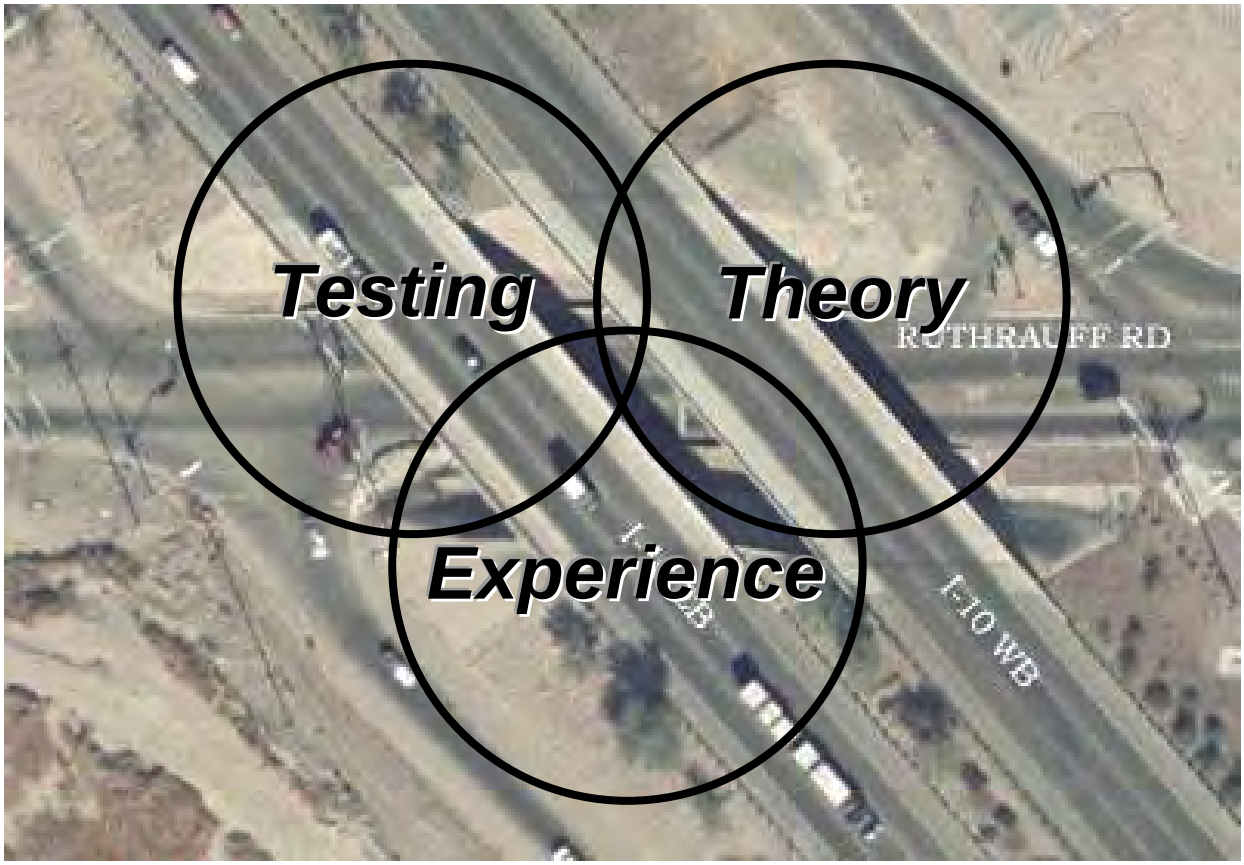
U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA NHI-06-088
December 2006

NHI Course No. 132012

SOILS AND FOUNDATIONS

Reference Manual – Volume I



National Highway Institute

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Naresh C. Samtani*, PE, PhD and Edward A. Nowatzki*, PE, PhD	
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15. Supplementary Notes

FHWA COTR – Larry Jones

FHWA Technical Review – Jerry A. DiMaggio, PE; Silas Nichols, PE; Richard Cheney, PE; Benjamin Rivers, PE; Justin Henwood, PE.

Contractor Technical Review – Ryan R. Berg, PE; Robert C. Bachus, PhD, PE; Barry R. Christopher, PhD, PE

This manual is an update of the 3rd Edition prepared by Parsons Brinckerhoff Quade & Douglas, Inc, in 2000. Author: Richard Cheney, PE. The authors of the 1st and 2nd editions prepared by the FHWA in 1982 and 1993, respectively, were Richard Cheney, PE and Ronald Chassie, PE.

16. Abstract

The Reference Manual for Soils and Foundations course is intended for design and construction professionals involved with the selection, design and construction of geotechnical features for surface transportation facilities. The manual is geared towards practitioners who routinely deal with soils and foundations issues but who may have little theoretical background in soil mechanics or foundation engineering. The manual's content follows a project-oriented approach where the geotechnical aspects of a project are traced from preparation of the boring request through design computation of settlement, allowable footing pressure, etc., to the construction of approach embankments and foundations. Appendix A includes an example bridge project where such an approach is demonstrated. Recommendations are presented on how to layout borings efficiently, how to minimize approach embankment settlement, how to design the most cost-effective pier and abutment foundations, and how to transmit design information properly through plans, specifications, and/or contact with the project engineer so that the project can be constructed efficiently.

The objective of this manual is to present recommended methods for the safe, cost-effective design and construction of geotechnical features. Coordination between geotechnical specialists and project team members at all phases of a project is stressed. Readers are encouraged to develop an appreciation of geotechnical activities in all project phases that influence or are influenced by their work.

17. Key Words	18. Distribution Statement
Subsurface exploration, testing, slope stability, embankments, cut slopes, shallow foundations, driven piles, drilled shafts, earth retaining structures, construction.	No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	462	

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PREFACE

This update to the Reference Manual for the Soils and Foundations course was developed to incorporate the guidance available from the FHWA in various recent manuals and Geotechnical Engineering Circulars (GECs). The update has evolved from its first two versions prepared by Richard Cheney and Ronald Chassie in 1982 and 1993, and the third version prepared by Richard Cheney in 2000.

The updated edition of the FHWA Soils and Foundations manual contains an enormous amount of information ranging from methods for theoretically based analyses to "rules of thumb" solutions for a wide range of geotechnical and foundation design and construction issues. It is likely that this manual will be used nationwide for years to come by civil engineering generalists, geotechnical and foundation specialists, and others involved in transportation facilities. That being the case, the authors wish to caution against indiscriminate use of the manual's guidance and recommendations. The manual should be considered to represent the minimum standard of practice. The user must realize that there is no possible way to cover all the intricate aspects of any given project. Even though the material presented is theoretically correct and represents the current state-of-the-practice, engineering judgment based on local conditions and knowledge must be applied. This is true of most engineering disciplines, but it is especially true in the area of soils and foundation engineering and construction. For example, the theoretical and empirical concepts in the manual relating to the analysis and design of deep foundations apply to piles installed in the glacial tills of the northeast as well as to drilled shafts installed in the cemented soils of the southwest. The most important thing in both applications is that the values for the parameters to be used in the analysis and design be selected by a geotechnical specialist who is intimately familiar with the type of soil in that region and intimately knowledgeable about the regional construction procedures that are required for the proper installation of such foundations in local soils.

General conventions used in the manual

This manual addresses topics ranging from fundamental concepts in soil mechanics to the practical design of various geotechnical features ranging from earthworks (e.g., slopes) to foundations (e.g., spread footings, driven piles, drilled shafts and earth retaining structures). In the literature each of these topics has developed its own identity in terms of the terminology and symbols. Since most of the information presented in this manual appears in other FHWA publications, textbooks and publications, the authors faced a dilemma on the regarding terminology and symbols as well as other issues. Following is a brief discussion on such issues.

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- **Pressure versus Stress**

  The terms “pressure” and “stress” both have units of force per unit area (e.g., pounds per square foot). In soil mechanics “pressure” generally refers to an applied load distributed over an area or to the pressure due to the self-weight of the soil mass. “Stress,” on the other hand, generally refers to the condition induced at a point within the soil mass by the application of an external load or pressure. For example, “overburden pressure,” which is due to the self weight of the soil, induces “geostatic stresses” within the soil mass. Induced stresses cause strains which ultimately result in measurable deformations that may affect the behavior of the structural element that is applying the load or pressure. For example, in the case of a shallow foundation, depending upon the magnitude and direction of the applied loading and the geometry of the footing, the pressure distribution at the base of the footing can be uniform, linearly varying, or non-linearly varying. In order to avoid confusion, the terms “pressure” and “stress” will be used interchangeably in this manual. In cases where the distinction is important, clarification will be provided by use of the terms “applied” or “induced.”

- **Symbols**

  Some symbols represent more than one geotechnical parameter. For example, the symbol C_c is commonly used to identify the coefficient of curvature of a grain size distribution curve as well as the compression index derived from consolidation test results. Alternative symbols may be chosen, but then there is a risk of confusion and possible mistakes. To avoid the potential for confusion or mistakes, the Table of Contents contains a list of symbols for each chapter.

- **Units**

  English units are the primary units in this manual. SI units are included in parenthesis in the text, except for equations whose constants have values based on a specific set of units, English or SI. In a few cases, where measurements are conventionally reported in SI units (e.g., aperture sizes in rock mapping), only SI units are reported. English units are used in example problems. Except where the units are related to equipment sizes (e.g., drill rods), all unit conversions are “soft,” i.e., approximate. Thus, 10 ft is converted to 3 m rather than 3.05 m. The soft conversion for length in feet is rounded to the nearest 0.5 m. Thus, 15 ft is converted to 4.5 m not 4.57 m.

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- **Theoretical Details**

  Since the primary purpose of this manual is to provide a concise treatment of the fundamental concepts in soil mechanics and an introduction to the practical design of various geotechnical features related to highway construction, the details of the theory underlying the methods of analysis have been largely omitted in favor of discussions on the application of those theories to geotechnical problems. Some exceptions to this general approach were made. For example, the concepts of lateral earth pressure and bearing capacity rely too heavily on a basic understanding of the Mohr's circle for stress for a detailed presentation of the Mohr's circle theory to be omitted. However, so as not to encumber the text, the basic theory of the Mohr's circle is presented in Appendix B for the reader's convenience and as an aid for the deeper understanding of the concepts of earth pressure and bearing capacity.

- **Standard Penetration Test (SPT) N-values**

  The SPT is described in Chapter 3 of this manual. The geotechnical engineering literature is replete with correlations based on SPT N-values. Many of the published correlations were developed based on SPT N-values obtained with cathead and drop hammer methods. The SPT N-values used in these correlations do not take in account the effect of equipment features that might influence the actual amount of energy imparted during the SPT. The cathead and drop hammer systems typically deliver energy at an estimated average efficiency of 60%. Today's automatic hammers deliver energy at a significantly higher efficiency (up to 90%). When published correlations based on SPT N-values are presented in this manual, they are noted as N_{60}-values and the measured SPT N-values should be corrected for energy before using the correlations.

  Some researchers developed correction factors for use with their SPT N-value correlations to address the effects of overburden pressure. When published correlations presented in this manual are based upon values corrected for overburden they are noted as $N1_{60}$. Guidelines are provided as to when the N_{60}-values should be corrected for overburden.

- **Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD) Methods**

  The design methods to be used in the transportation industry are currently (2006) in a state of transition from ASD to LRFD. The FHWA recognizes this transition and has developed separate comprehensive training courses for this purpose. Regardless of whether the ASD or LRFD is used, it is important to realize that the fundamentals of soil mechanics, such as the

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determination of the strength and deformation of geomaterials do not change. The only difference between the two methods is the way in which the uncertainties in loads and resistances are accounted for in design. Since this manual is geared towards the fundamental understanding of the behavior of soils and the design of foundations, ASD has been used because at this time most practitioners are familiar with that method of design. However, for those readers who are interested in the nuances of both design methods Appendix C provides a brief discussion on the background and application of the ASD and LRFD methods.

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SI CONVERSION FACTORS				
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0,0015	square inches	in^2
m^2	square meters	10.758	square feet	ft^2
m^2	square meters	1.188	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.29	cubic feet	ft^3
m^3	cubic meters	1.295	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
tonnes	tonnes	1.103	US short tons	tons
TEMPERATURE				
ºC	Celsius	1.8ºC + 32	Fahrenheit	ºF
WEIGHT DENSITY				
kN/m^3	kilonewtons / cubic meter	6.36	Pound force / cubic foot	pcf
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	pound force	lbf
kN	kilonewtons	225	pound force	lbf
kPa	kilopascals	0.145	pound force / square inch	psi
kPa	kilopascals	20.88	pound force / square foot	psf
PERMEABILITY (VELOCITY)				
cm/sec	centimeter/second	1.9685	feet/minute	ft/min

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SOILS AND FOUNDATIONS
VOLUME I

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LIST OF SYMBOLS

Chapter 1

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphaltic concrete
CMAR	Construction manager at risk
D-B	Design-build
FHWA	Federal Highway Administration
MSE	Mechanically stabilized earth
NHI	National Highway Institute
NMDOT	New Mexico Department of Transportation
PCC	Portland cement concrete
RCC	Reinforced cement concrete
RSS	Reinforced soil slope(s)
USDA	United States Department of Agriculture
USGS	Unites States Geological Survey

Chapter 2

A	Overall contact area
AASHTO	American Association of State Highway and Transportation Officials
B	Width
c	Cohesion
c'	Effective cohesion
D_r	Relative density
D_s, DOSI	Depth of significant influence
e	Void ratio
e_{max}	Maximum void ratio
e_{min}	Minimum void ratio
F_a	Tangential force
F_r	Shearing resistance
G	Specific gravity
G_s	Specific gravity of the solid phase
h	Embankment height
h_w	Depth to water table
K	Value of proportionality constant; coefficient of lateral earth pressure
K_a	Coefficient of active earth pressure
K_o	Coefficient of lateral earth pressure “at rest”
K_p	Coefficient of passive earth pressure
K_w	Coefficient of lateral earth pressure for water
L	Length
LI	Liquidity index
LL	Liquid limit
n	Porosity
P	Load applied
p_a	Active lateral pressure

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p_f	Final stress = effective overburden pressure + pressure increment due to external loads
p_h	Lateral stress
PI	Plasticity index
PL	Plastic limit
P_n	Normal force
p_o	Effective overburden pressure
p_p	Passive lateral pressure
p_t	Total overburden pressure
Q	Load
q, q_o	Unit load of embankment
S	Degree of saturation
SI	Shrinking index
SL	Shrinkage limit
t	time
u	Porewater pressure
USCS	Unified Soil Classification System
V	Volume of the total soils mass
V_a	Volume of air phase
V_s	Volume of solid phase
V_v	Volume of total voids
V_w	Volume of water phase
w	Gravimetric water or moisture content
W	Weight of the total soil mass
W_a	Weight of air phase
W_s	Weight of solid phase
W_v	Weight of total voids
W_w	Weight of water phase
z	Depth
z_w	Depth below water table
δ	Angle of interface friction
δ_a	active translation
δ_b	passive translation
Δp	Pressure due to external loads
Δu	Excess pore water pressure
γ	Total unit weight
γ'	Effective unit weight
γ_b	Buoyant unit weight (same as effective unit weight)
γ_d	Dry unit weight
γ_s	Unit weight of the solid phase
γ_{sat}	Saturated unit weight
γ_T or γ_t	Total unit weight
γ_w	Unit weight of water
ϕ	Angle of friction
ϕ'	Effective angle of internal friction

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ν	Poisson's ratio
θ	Angle of obliquity
θ_m	Maximum angle of obliquity
σ	Total stress
σ'	Effective stress
σ_n	Normal stress
σ_n'	Effective normal stress
τ	Shearing strength
τ'	Effective shear stress (strength)

Chapter 3

AASHTO	American Association of State Highway and Transportation Officials
AR	Area ratio
ASTM	American Society for Testing and Materials
BPT	Becker (Hammer) penetration test
C_N	Overburden correction factor or stress normalization parameter
CPT	Cone penetration test
CPTu, PCPT	Piezocone penetration test
d	Displacement
DC	Direct current
D_e	Diameter of sampler cutting tip
D_i	Inside diameter of the sampling tube
DMT	Flat plate dilatometer
D_o	Outside diameter of the sampling tube
DOT	Department of Transportation
E_f	Energy efficiency
ER	Energy ratio
F	Force
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
f_s	Sleeve friction
g	Gravitational constant
GPR	Ground penetrating radar
h	Drop height
i	Inclination
ICR	Inside clearance ratio
ID	Inside Diameter
ISRM	International Society of Rock Mechanics
KE	Kinetic energy
LPT	Large penetration test
m	Mass
N	SPT blows per foot
$N1_{60}$	Overburden-normalized energy-corrected blowcount
N_{60}	Energy-corrected SPT-N value adjusted to 60% efficiency
NAVFAC	Naval Facilities Engineering Command
NCR	No core recovery

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N_{meas}	N-Value measured in the field
OD	Outside diameter
PE	Potential energy
PMT	Pressuremeter test
p_o	Vertical effective pressure at the depth where the SPT is performed
PVC	Polyvinyl chloride
q_c	Cone tip resistance
q_t	Tip resistance
R_f	Friction ratio
RQD	Rock quality designation
S_t	Sensitivity
SASW	Spectral analysis of surface waves
SBT	Soil behavioral type
SCPTu	Seismic cone piezocone penetration test
SPT	Standard Penetration Test
SWPPP	Storm Water Pollution Prevention Plan
t_s	Shear wave time
u_m	Pore water pressure
USCS	Unified Soil Classification System
USEPA	United States Environmental Protection Agency
USGS	Unites States Geological Survey
v	Impact velocity
VST	Vane shear test
W	Work

Chapter 4

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
C_c	Coefficient of curvature
C_u	Coefficient of uniformity
D_{10}	Diameter of soil particles of which 10% of the soil is finer
D_{30}	Diameter of soil particles of which 30% of the soil is finer
D_{60}	Diameter of soil particles of which 60% of the soil is finer
DOT	Department of Transportation
EGS	Effective grain size
F	Percent passing No. 200 sieve
FHWA	Federal Highway Administration
GI	Group index
GIS	Geographic information system
GSD	Grain size distribution
IGM	Intermediate geomaterial
I_s	Point load index
ISRM	International Society of Rock Mechanics
LI	Liquid index
LL	Liquid limit
N	SPT blows per foot

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N_{60}	Energy-corrected SPT-N value adjusted to 60% efficiency
NAVFAC	Naval Facilities Engineering Command
PI	Plasticity index
PL	Plastic limit
RMR	Rock mass rating
RQD	Rock quality designation
SPT	Standard penetration test
U.S.	United States
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture

Chapter 5

A	Activity index
A	Area
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
B	Bulk modulus
c	Cohesion
C	Permeability coefficient
C_α	Coefficient of secondary compression
c'	Effective stress cohesion intercept
c'_{cu}	Effective stress cohesion from CU test
CBR	California Bearing Ratio
C_c	Compression index
$C_{c\varepsilon}$	Modified compression index
CD	Consolidated drained triaxial test
CF	Clay fraction
c_h	Coefficient of horizontal consolidation
c_o	Compacted cohesion
CP	Collapse potential
C_r	Recompression index
$C_{r\varepsilon}$	Modified recompression index
c_{sat}	Saturated cohesion
CU	Consolidated undrained triaxial test
c_u	Apparent cohesion
c_v	Coefficient of consolidation
c_v	Coefficient of vertical consolidation
C_α	Secondary compression index
$C_{\alpha\varepsilon}$	Modified secondary compression index
D	Distance between contact points of platens
D	Vane diameter
D_{10}	Diameter of soil particles of which 10% of the soil is finer
D_{60}	Diameter of soil particles of which 60% of the soil is finer
D_e	Equivalent core diameter
D_{max}	Maximum diameter of soil particle
D_{min}	Minimum diameter soil particles

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D_r	Relative density
d_s	Equivalent diameter
e	Void ratio
e_{max}	Maximum void ratio
e_{min}	Minimum void ratio
E	Young modulus
E_i	Elastic modulus of intact rock
E_m	Elastic modulus of rock mass
e_{max}	Maximum void ratio
e_{min}	Minimum void ratio
e_o	Initial void ratio
E or E_s	Elastic modulus
FHWA	Federal Highway Administration
g	Gravitational constant
G	Shear modulus
G_S	Specific gravity
H	Height of vane
H	Soil layer thickness
H/D	Height to diameter ratio
H_o	Initial height of specimen
i_B	Angle of taper at the bottom of the vane
IL	Incremental load
I_s	Point load strength index
$I_{s(50)}$	Size-corrected point load strength index
i_T	Angle of taper at the top of the vane
k	Hydraulic conductivity
k_{PLT}	Size correction factor
LI	Liquid index
LIR	Load increment ratio
LL	Liquid limit
LVDT	Linear variable differential transducer
md	Man-days
MPC	Modified Proctor compaction
M_s	Mass of solid component of sample
M_t	Total mass
N	Normal stress
N	SPT blows per foot
$N1_{60}$	Overburden-normalized energy-corrected blowcount
N_{60}	Energy-corrected SPT-N value adjusted to 60% efficiency
NAVFAC	Naval Facilities Engineering Command
NC	Normally consolidated
n_h	Rate of increase of soil modulus with depth
OC	Over consolidated
OCR	Overconsolidation ratio
OMC	Optimum moisture content
P	Breaking load

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p_c	Maximum past effective stress
p_c	Preconsolidation pressure
PI	Plasticity index
PL	Plastic limit
p_o	Effective overburden pressure
p_t	Total vertical stress
q_c	Cone tip resistance
q_u	Unconfined compression stress
RC	Relative compaction
RMR	Rock mass rating
RQD	Rock quality designation
S	Degree of saturation
S, S_t	Sensitivity
$s_{collapse}$	Collapse settlement
SL	Shrinkage limit
SPC	Standard Proctor compaction
SPT	Standard penetration test
$s_{r, VST}$	Remolded undrained shear strength (obtained by using VST data)
$s_{t, VST}$	Sensitivity (obtained by using VST data)
s_u	Undrained shear strength
$s_{u, VST}$	Undrained shear strength (obtained by using VST data)
s_u/p_o	Undrained strength ratio
T	Tangential (shear) force
T	Torque (related to VST)
t	Vane edge thickness
t_{100}	Time corresponding to 100% of primary consolidation
T_{max}	Maximum torque (related to VST)
T_{net}	Difference between T_{max} and T_{rod}
T_{rod}	Rod friction (related to VST)
u	Pore water pressure
UC	Unconfined compression test
U.S.	United States
USBR	United States Bureau of Reclamation
USCS	Unified Soil Classification System
UU	Unconsolidated undrained triaxial test
V	Coefficient of variation
V_s	Volume of soil solids
VST	Vane shear test
V_t	Total volume
W	Specimen width
w	Water content
w_n	Natural moisture content
w_{opt}	Optimum moisture content
W_s	Weight of solid component of soil
W_t	Total weight
Z	Depth below ground surface

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Δe	Change in void ratio
ΔH_c	Change in height upon wetting
$\Delta\sigma$	Incremental stress
ε	Strain
γ	Unit weight
γ'	Effective unit weight
γ_b	Buoyant unit weight (same as effective unit weight)
$\gamma_{d\ field}$	Field dry unit weight
γ_d or γ_{dry}	Dry unit weight
$\gamma_{d\text{-}max}$	Maximum dry unit weight
γ_s	Unit weight of solid particles in the soil mass
γ_{sat}	Saturated unit weight
γ_t or γ_{tot}	Total unit weight
γ_t	Moist unit weight of compacted soil
γ_w	Unit weight of water
ϕ	Angle of internal friction
ϕ'	Effective friction angle
ϕ	Friction
ϕ'	Peak effective stress friction angle
ϕ'_{cu}	Effective friction angle from CU test
ϕ'_r	Residual effective stress friction angle
μ	Coefficient of friction
ν	Poisson ratio
ρ	Density
ρ_d or ρ_{dry}	Dry mass density
ρ_t or ρ_{tot}	Total mass density
ρ_t	Moist (total) mass density
σ'	Effective normal stress
σ_c	Uniaxial compressive strength
σ_n	Normal stress
σ'_p	Preconsolidation stress
σ_{vo}	Total vertical stress
τ	Shear stress
%C	Percent collapse

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Chapter 6

AASHTO	American Association of State Highway and Transportation Officials
b	Unit width
b	Width of slice
c	Cohesion
c	Cohesion component of shear strength
c	Unit cohesion
c'	Effective cohesion
CD	Consolidated drained triaxial test
c_d	Developed cohesion
CU	Consolidated undrained triaxial test
d	Depth factor
D	Depth ratio
F_c	Average factor of safety with respect to cohesion
FHWA	Federal Highway Administration
FS or FOS	Factor of safety
F_ϕ	Average factor of safety with respect to friction angle
h	Depth less than or equal to the depth of saturation
H	Height
H	Height of soil layer in active wedge
h	Slope depth
H	Slope height
H'_w	Height of water within the slope
H_{Fill}	Fill height
h_i	Height of layer at center of slice
H_t	Tension crack height
h_w	Depth from groundwater surface to the centroid point on the circle
H_w	Depth of water outside the slope
H_{zone}	Height of zone
I_N	Interslice normal (horizontal) force
I_S	Interslice shear (vertical) force
K_a	Coefficient of active earth pressure
K_p	Coefficient of passive earth pressure
l	Arc length of slice base
L_s	Radius of circle
L_w	Level arm distance to the center of rotation
N	Normal force component or total normal force
N	Number of reinforcement layers
N'	Effective normal force component
N_{cf}	Critical stability number
N_o	Stability number
N_s	Stability number
P_a	Active force (driving)
p_o	In-situ vertical effective overburden pressure
P_p	Passive force (resisting)
q	Surcharge load

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R	Moment arm
R_c	Coverage ratio of the reinforcement
RSS	Reinforced soil slope
S	Frictional force along failure plane
S	Shear strength along failure plane
SPT	Standard penetration test
S_v	Vertical spacing of reinforcement
T	Tangential force component
T_a	Sum of available tensile force per width of reinforcement for all reinforcement layers
tan ϕ	Coefficient of friction along failure surface
T_{MAX}	Maximum design tension
$T_{S\text{-}MAX}$	Maximum tensile force
T_{zone}	Maximum reinforced tension required for each zone
U	Pore water force
u	Water pressure on slice base
u	Water uplift pressure against failure surface
UU	Unconsolidated undrained triaxial test
W	Weight of slice
W_i	Partial weight
W_T	Total slice weight
α	Angle between vertical and line drawn from circle center to midpoint of slice base
α_w	Slope of water table from horizontal
γ_{Fill}	Fill soil unit weight
μ'_w	Seepage correction factor
μ_q	Surcharge correction factor
μ_t	Tension crack correction factor
μ_w	Submergence correction factor
σ	The total normal stress against the failure surface slice base due to the weight of soil and water above the failure surface
ΣW_i	Total weight of slice
β	Angle of slope
β	Inclination of the slope
ϕ	Angle of internal friction
ϕ'	Effective angle of internal friction
ϕ_d	Developed angle of internal friction
γ	Unit weight of soil
γ	Unit weight of soil in the active wedge
γ_i	Unit weight of layer i
γ	Effective unit weight
γ_m	Moist unit weight
γ_{sat}	Saturated unit weight
γ_t	Total soil unit weight
γ_w	Unit weight of water

σ'_n	Effective stress between soil grains
τ	Frictional shearing resistance
τ	Total shear strength
τ_d	Developed shear strength

Chapter 7

AASHTO	American Association of State Highway and Transportation Officials
C′	Bearing capacity index
C_c	Compression index
$C_{c\varepsilon}$	Modified compression index
C_r	Mean slope of the rebound laboratory curve
$C_{r\varepsilon}$	Modified recompression index
c_v	Coefficient of consolidation
C_α	Coefficient of secondary consolidation (determined from lab consolidation test)
$C_{\alpha\varepsilon}$	Modified secondary compression index
D_S	Depth of soft soil beneath the toe of the end slope of the embankment
e	Void ratio
e_o	Initial void ratio at p_o
FHWA	Federal Highway Administration
FS_{SQ}	Safety factor against failure by squeezing
H	Height of the fill
H	Thickness of soil layer considered
H_d	Distance to the drainage boundary
h_f	Fill height
H_o	Layer thickness
ID	Inner Diameter
$N1_{60}$	Number of blows per foot corrected for overburden and hammer efficiency
NCHRP	National Cooperative of Highway Research Program
OCR	Over consolidation ratio
p_c	Maximum past effective stress
p_c	Maximum past vertical pressure (preconsolidation)
p_f	Final effective vertical stress at the center of layer n
p_f	Final pressure applied to the foundation subsoil
p_f	Final stress
p_f	Total embanklment pressure
PI	Plasticity index
p_o	Effective overburden pressure
p_o	Existing effective overburden pressure
p_o	Initial effective vertical stress at the center of layer n
RSS	Reinforced soil slope
S	Degree of saturation
S	Settlement
S_c	Settlement due to primary consolidation
SPT N	Number of blows per foot (blow/0.3m)
SPT	Standard penetration test

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S_s	Settlement due to secondary compression
S_t	Settlement at time t
s_u	Undrained shear strength of soft soil beneath embankment
$S_{ultimate}$	Settlement at end of primary consolidation
t	Time
$t_{1\ lab}$	Time when secondary compression begins
t_1	Time when approximately 90% of primary compression has occurred
t_{100}	Time for 100%of primary consolidation
$t_{2\ lab}$	Arbitrary time on the curve
t_2	The service life of the structure or any time of interest
t_{90}	Time for 90%of primary consolidation
T_v	Time factor
U	Average degree of consolidation
u_s	Hydrostatic pore water pressure at any depth
u_s	Initial hydrostatic pore water pressure
USACE	United States Army Corps of Engineers
u_{sb}	Hydrostatic pore water pressure at bottom of layer
u_{st}	Hydrostatic pore water pressure at top of layer
u_t	Total pore water pressure at any depth after time t
Z_I	Zone of influence
Δe	Change in void ratio
ΔH	Settlement
Δp	Distributed embankment pressure
Δp	Load increment
Δp	Stress increase
Δp_o	Effective vertical stress increment
Δp_t	Applied vertical stress increment
Δu	Excess pore water pressure at any depth after time t
Δu_i	Initial excess pore water pressure
ε_v	Vertical strain
γ	Unit weight of fill
γ'	Effective unit weight
γ_b	Buoyant unit weight (same as effective unit weight)
γ_f	Fill unit weight
θ	Angle of slope

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CHAPTER 1.0
INTRODUCTION

1.1 PURPOSE AND SCOPE

The Soils and Foundations course is sponsored by the National Highway Institute (NHI) to provide practical knowledge in geotechnical and foundation engineering for both civil engineering generalists and geotechnical and foundation specialists. The course is developed around the design and construction aspects of a highway project that includes bridges, earthworks and earth retaining structures. Bridges can range from single span bridges to multi-span bridges as part of a stack interchange. Bridges may be constructed over land, in which case they are known as viaducts, or over water. Examples of transportation facilities that include bridge structures are shown in Figures 1-1 to 1-4. Not all highway projects include bridge structures. Figure 1-5 shows an example of a highway corridor without bridges and in an environmentally sensitive area.



Figure 1-1. Aerial view of a pair of 3-span Interstate 10 (I-10) bridges over a local roadway in Tucson, Arizona.

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Figure 1-2. Example of 3-span roadway bridges over another roadway.

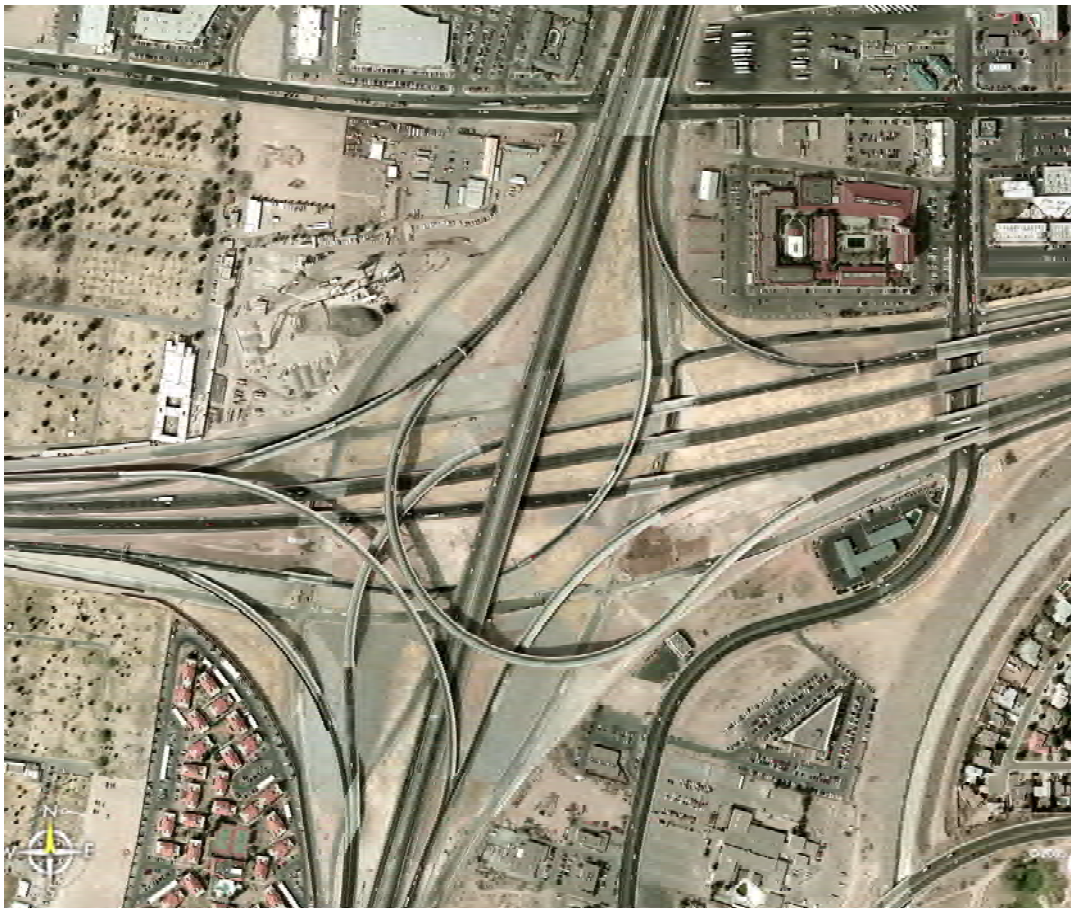


Figure 1-3. The "BIG I" stack interchange at the intersection of I-40 and I-25 in Albuquerque, New Mexico (Photo: Courtesy of Bob Meyers, NMDOT) (Note: A stack interchange is a free-flowing junction between two or more roadways that allows turning in all directions).

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Figure 1-4. A major multi-span bridge structure over water (George P. Coleman Bridge over the York River in Yorktown, Virginia).

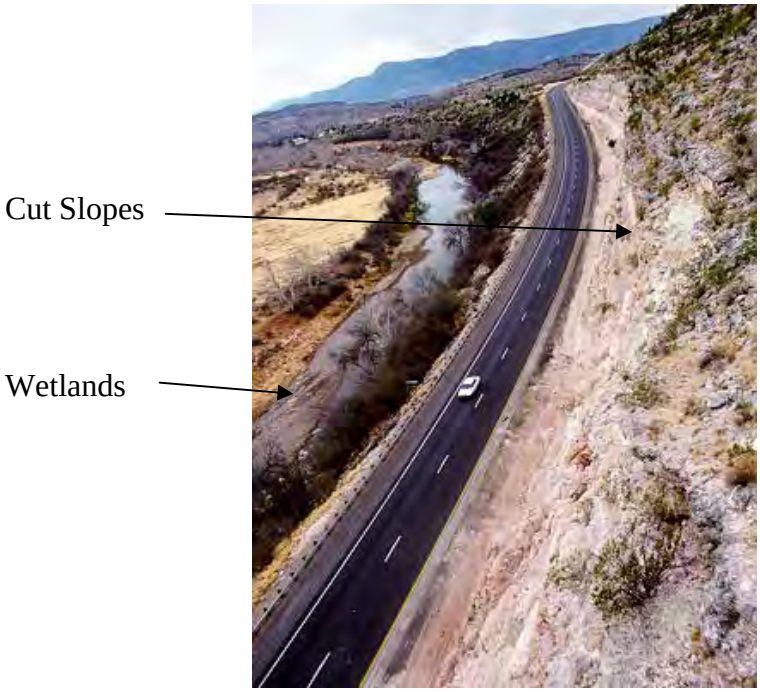


Figure 1-5. Example of a roadway bounded by cut slopes and wetlands in an environmentally sensitive area.

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Highway projects can involve a full range of geotechnical engineering assessments and alternatives depending on the complexity of the project. For example, the foundations for the bridge piers and abutments may be shallow foundations, or deep foundations such as driven piles and/or drilled shafts. The approach embankments may be unreinforced slopes or reinforced soil slopes (RSS). Cut slopes may be in rocks and/or soils. Retaining walls may be used at abutments and/or along approaches and may consist of cantilevered walls or mechanically stabilized earth (MSE) walls. The ground under the bridge may be soft and require improvement. Similarly, the transportation corridor may traverse wetlands and special ground improvement measures may be required. Pavements seen in Figures 1-1 to 1-3 and 1-5 may be constructed of asphaltic concrete (AC), Portland cement concrete (PCC) or reinforced cement concrete (RCC) on a variety of subgrade materials[1].

Recognizing the need for consistent guidance for practitioners involved in the planning, design and construction of transportation facilities that include bridges and associated structures, the Federal Highway Administration (FHWA) developed the first version of this manual in 1982. Subsequently, the manual was revised in 1993 and in 2000. The present reference manual, which is the fourth edition, represents a significant update and supersedes earlier editions of the manual. In particular, this manual has been updated to reflect the current standard of geotechnical practice in the planning, design and construction of transportation facilities. As part of this effort, this edition provides guidance consistent with that found in the latest FHWA manuals and courses.

This edition of the manual, like the earlier editions, is geared towards the practicing engineer who routinely deals with soils and foundations problems on highway projects but who may not have a thorough theoretical background of soil mechanics or foundation engineering. The overall goals of this manual are: (i) to explain geotechnical engineering principles, and (ii) to provide sound methods and recommendations related to safe, cost-effective design and construction of geotechnical features. The reader is encouraged to develop an appreciation for the design and construction of geotechnical features in all phases of a project that may influence or could be influenced by his/her work (cost, quality, time, and performance). Coordination among generalists and specialists in all project phases is stressed.

The manual contains an appendix (Appendix A) wherein the geotechnical engineering input to a bridge project is traced from conception (scoping) to completion (post construction) in a serialized illustrative problem that incorporates many of the technical concepts presented in the course. The bridge project used in Appendix A is based on an actual project in the State of New York.

[1] Pavement structures are not addressed in this manual.

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1.2 SOILS AND FOUNDATIONS FOR HIGHWAY FACILITIES

Civilization's earliest attempts at construction probably involved soil; however, the understanding of the role of soil as a foundation or building material developed by trial and error. Since the early 20th century, an improved understanding of soil behavior has been achieved by applying the principles of physics, solid mechanics, fluid mechanics, strength of materials, and structural engineering to define soil behavior. The body of knowledge developed by analyzing soil behavior on a theoretically sound basis is called "**soil mechanics**" and its application to solution of actual problems is called "**geotechnical engineering**." Soil is a complex three-phase medium that contains various amounts of water and/or air surrounding the solid particles. It is not a solid mass, i.e., a continuum, as many of the theories of solid mechanics require. Therefore, an entirely theoretical solution of the most commonly encountered soil problems is not practical. The most practical solution to soil problems can be reached by a combination of the sources of information as illustrated in Figure 1-6.

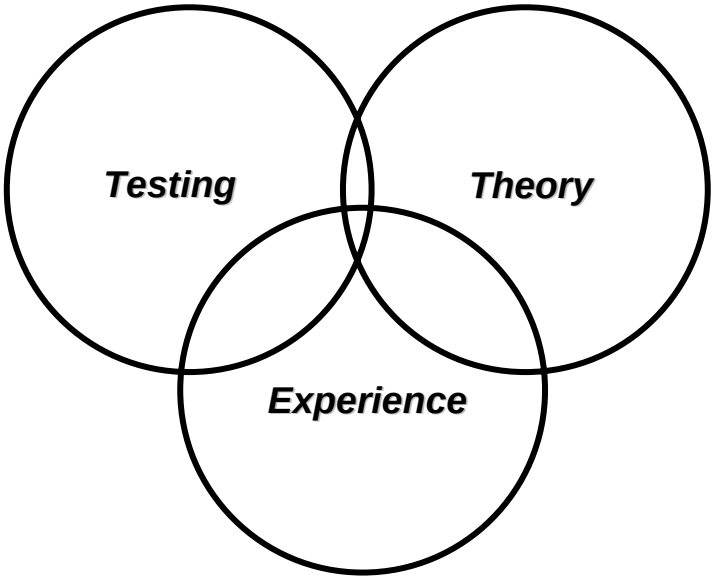


Figure 1-6. Combinations of sources of information required to solve geotechnical engineering issues.

1. **Experience** obtained from previous projects can be developed into the empirical or "rule of thumb" procedures followed by some engineers/specialists today. Often some geotechnical designers rely almost exclusively on experience. The weakness of using this approach exclusively is that experience does not always recognize the factors that cause differences in the engineering properties of soils. What works well at one location may not succeed with the same type of soil at another location because of a change in conditions, such as water content. The current state of the practice

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requires the geotechnical specialist to rely on testing and theory in addition to experience or rules of thumb.

2. **Testing** of representative samples of soil in the field and laboratory is required to obtain information on the engineering properties and the characteristics of soils. The results of subsequent engineering analyses will be only as good as the soils data used as input.

3. **Theory** based on principles from various fields of engineering and science tempered by assumptions to fit reality is used to explain or predict the behavior of soils under various conditions.

The engineering analysis of soils is often more complex than the analysis of other construction materials because soil is not a continuum. Therefore, soil typically does not strictly meet the assumptions of the theories of solid mechanics and strength of materials. By contrast, steel and concrete are relatively uniform solids that have predictable properties. For example, the strength of steel is predictable within the elastic range of loading. Even though the strength of steel and concrete may be "ordered," that strength will be essentially constant under a wide range of climatic conditions. Structures can then be built of these materials with a high degree of confidence regarding the material strength.

The engineering properties of the soils, on the other hand, can vary widely over time and space so that their physical properties cannot be defined accurately at all locations for all conditions. Since soils are composed of a mixture of three dissimilar materials - soil solids, liquid fluids (usually water), and gaseous fluids (usually air) - their properties are influenced by the interaction of these three phases in the soil mass. Some of the factors that influence the behavior of soil are:

1. size, shape, and distribution of soil particles,
2. mineralogy,
3. degree of packing of soil particles,
4. amount of water in the soil,
5. climatic conditions, and
6. degree of confinement (i.e., depth).

In short, engineers should understand that the engineering properties of soils can be significantly influenced by many factors.

The success or failure of a geotechnical feature is often decided in the early stages of a project. Geotechnical engineering is a specialized field. Therefore, to assure success of a

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project, the input of a qualified and experienced geotechnical specialist should begin at project inception and continue until completion of construction. Geotechnical designs are based upon soil properties that are generally defined from a subsurface exploration and laboratory testing of a very minute physical sampling of the soils. The volume of site soils excavated and exposed during construction is many orders of magnitude greater than that from the subsurface explorations. Thus, a great deal of geotechnical information can and should be gathered during the construction phase of a project to validate or revise the geotechnical design parameters. **A geotechnical design should not be considered complete until construction has been successfully completed.** A geotechnical specialist should also be involved during post-construction activities such as instrumentation monitoring, participating in resolution of contractor disputes and claims activities, and documenting lessons learnt on the project.

Based on the above considerations, early interactions at a project's scoping phase among the geotechnical specialist, other engineers/specialists, the project manager and the contractor will prevent the design of a project element, or even worse the construction of an element, such as alignment or grade, that may require costly foundation treatment later. **It is imperative that good communication and interaction exist among the geotechnical specialist, structural specialist, construction specialist, project manager and contractor throughout the design and the construction process**. Such interactions and involvement are required to insure a cost-effective design and to minimize change orders and contract disputes resulting from design deficiencies and/or misunderstandings during construction. **The importance of communication and interaction is stressed throughout this manual and cannot be overemphasized**.

The flow chart in Figure 1-7 and the six phases identified in Table 1-1 describe the details of geotechnical involvement in a typical project using the design-bid-build (D-B-B) procurement process where the geotechnical specialist interacts with the owner to provide information to the contractor. There are several other procurement processes such as the design-build (D-B) process and the Construction Manager at Risk (CMAR) process. In each such alternative process, the geotechnical specialist is concurrently dealing with both the owners and the contractors, with the geotechnical specialist's direct client being the contractor. Even though the geotechnical involvement is somewhat different in each of these types of procurement processes, it is important to realize that all the items listed in Figure 1-7 as well as in Table 1-1 must be addressed to achieve a successful project.

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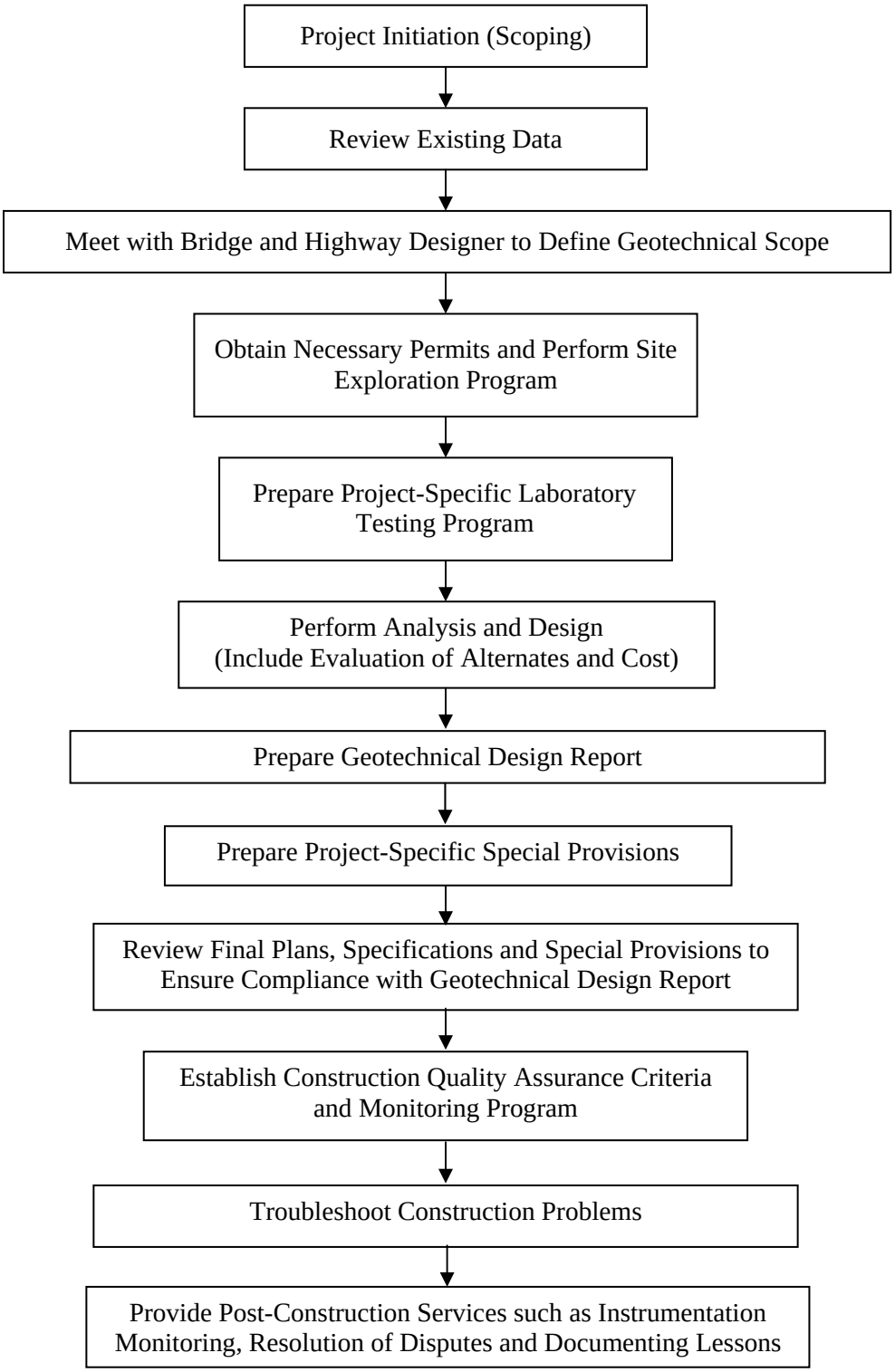


Figure 1-7. Geotechnical activity flow chart for a typical project using design-bid-build procurement process.

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Table 1-1
Geotechnical involvement in project phases

Phase	Function
PHASE 1 Planning	1. Study project information, scope and existing data. (a) USGS topographic sheets. (b) USDA soil maps. (c) groundwater bulletins. (d) air photos. 2. Conduct site inspection with project manager. (a) inspect nearby structures for settlement, scour, etc. (b) assess site conditions. 3. Prepare terrain reconnaissance report for planning engineer. Include: (a) anticipated soil, rock and water conditions. (b) major problems or costs that will hinder or preclude construction of the facility. (c) right-of-way required for possible special geotechnical treatment. (d) beneficial shifts in alignment.
PHASE 2 Design Alternatives	1. Assess facility locations with regard to major soil issues. 2. Provide input for specific uses, e.g., soil/rock scour. 3. Implement subsurface exploration and laboratory testing programs after design approval.
PHASE 3 Prepare Detail Plans	1. Review and interpret subsurface information from field and laboratory work. 2. Provide preliminary input to bridge/roadway engineer. 3. Submit report to bridge and roadway engineer summarizing the investigations along with recommendations. Include: (a) coordination with roadway construction. (b) alternate foundation design. (c) subsurface profile. (d) special provisions and specifications.
PHASE 4 Final Design	1. Review final plans 2. Make appropriate adjustments to geotechnical information if necessary
PHASE 5 Construction	1. Provide geotechnical support to the resident engineer during construction. Examples are as follows: (A) *Driven Piles*: (a) submit wave equation analysis to bridge engineer. (b) hammer approval. (c) stress analysis. (d) required blow count. (e) special effects, etc. (B) *Drilled Shafts*: (a) shaft excavation information, e.g., need for casing or slurry. (b) steel placement tolerances. (c) tube placement for integrity testing. (d) concreting requirements. (e) post-installation integrity tests, etc. (C) *Spread footings*: (a) evaluation criteria of stiffness of soils at base of footing excavation, etc. (D) *Retaining Walls*: (a) construction process based on whether wall is top-down or bottom-up construction. (b) backfill compaction requirements, etc. (E) *Slopes/Embankments*: (a) backfill compaction requirements. (b) final grading of a slope, etc. 2. Attend preconstruction meeting with resident engineer and foundation inspector. Explain various important geotechnical issues: (a) general geologic profile. (b) design basis. (c) wave equation analysis for driven piles. (d) end and skin resistance values taking into account strain compatibility for drilled shafts. (e) possible geotechnical problems. 3. Troubleshoot soils-related problems as required. 4. Assist with structural foundation load tests as required.
PHASE 6 Post Construction	1. Review actual pile results versus predicted. Include: (a) blow count for driven piles. (b) installation methods for drilled shafts. (c) length. (d) field problems. (e) load test capacity. 2. Participate in contractor disputes and claims activities.

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1.3 ORGANIZATION OF MANUAL

The organization of this manual follows a project-oriented approach whereby a typical bridge project is traced from scoping stage through design computation of settlement, allowable footing pressure, selection of earth retaining structure, to the construction of approach embankments, pile driving or shaft drilling operations, etc. Recommendations are presented on how to layout borings efficiently, how to minimize approach embankment settlement and eliminate the bump at the end of-the bridge, how to design the most cost-effective deep foundation, and how to transmit design information properly to contractors directly through plans, specifications, and special provisions and/or indirectly through contact with the project engineer.

The concepts presented in various chapters are concise and specifically directed at a particular operation in the geotechnical design and construction process. Basic example problems are included in several sections to illustrate how concepts are used and for hands-on knowledge. Continuity between chapters is achieved by sequencing the information in the normal progression of a geotechnical project. In addition, the manual contains an appendix (Appendix A) with the solution to geotechnical issues, in a serialized format, for a highway project involving a bridge and approach embankment over soft ground. In each phase of the fictitious project the geotechnical concepts are developed into specific designs or recommendations for that segment of the problem.

The organization of the manual and a summary of the material presented in each chapter follow.

- Chapter 1 – this chapter (Introduction) presents the purpose and scope of NHI's Soils and Foundation course and provides introductory material about geotechnical activities related to the design and construction aspects of a highway project.

- Chapter 2 (Stress and Strain in Soils) presents basic phase (weight-volume) relationships, effective stress principles, computation of overburden pressures, estimating vertical and horizontal stresses in soils due to external (superimposed) loads on geomaterials.

- Chapter 3 (Subsurface Explorations) presents basic information on subsurface exploration procedures including terrain reconnaissance, subsurface investigation methods, standard penetration test procedures, undisturbed soil sampling, and guidelines for the geotechnical investigation of both roadway and structure sites.

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- Chapter 4 (Engineering Description, Classification and Characteristics of Soils and Rocks) discusses the basic engineering characteristics of the main soil and rock groups, and presents procedures for describing and classifying soils and rocks, and for developing a subsurface profile.

- Chapter 5 (Laboratory Testing for Geotechnical Design and Construction) presents several commonly used laboratory tests for soils and rocks including soil classification, basic consolidation and strength testing concepts. This chapter also includes guidelines for laboratory testing on a typical highway project, and a procedure for summarizing and choosing design values from laboratory tests.

- Chapter 6 (Slope Stability) presents the general procedures for the stability analysis of embankments and cut slopes. Basic methods of analysis are shown and explained with emphasis on practical application to highway embankments. Stability charts are presented for a rapid preliminary evaluation of slope stability. Remedial methods are discussed for stability problems.

- Chapter 7 (Approach Roadway Deformations) distinguishes between internal and external settlement within and below embankment fills. Recommendations are provided for select fill and compaction control for soils placed near abutments. Immediate (i.e., short-term) and consolidation (i.e., long-term) settlement, and lateral squeeze are discussed and methods of analysis are presented.

- Chapter 8 (Shallow Foundations) presents the FHWA-recommended foundation design procedure for shallow foundations in soils and rocks. The analysis for both bearing capacity and settlement are discussed and the application of results is presented. Economic considerations of shallow versus deep foundations are discussed.

- Chapter 9 (Deep Foundations) discusses basic concepts in the selection and design of both driven piles and drilled shafts in soils and rocks. Analyses for skin friction and end bearing are addressed for cohesive soil, cohesionless soils and rocks. Foundation installation effects on design are discussed as well as group effects, negative skin friction and deep foundation settlement. The components of pile driving equipment are presented. The use of driving formulae and the wave equation analysis in construction is introduced monitoring. Generic information is presented on the use of load testing. Construction considerations for drilled shafts are also presented.

- Chapter 10 (Earth Retaining Structures) presents the basic lateral earth pressure theories, briefly introduces various wall types, presents a wall classification system, and presents the external stability analysis for a typical fill wall.

- Chapter 11 (Geotechnical Reports) presents outlines for various types of geotechnical reports, discussions on subsurface profiles, guidelines on the use of disclaimers, and suggestions for how to incorporate geotechnical information into contract documents.

1.4 REFERENCES

A detailed list of references is provided in Chapter 12. However, certain primary references were used to develop materials for many sections in this document. In addition, FHWA has either developed or is in the process of developing detailed guidance in the topic areas covered in this document. Most of those documents are reference manuals for geotechnical courses developed for the National Highway Institute. Both the FHWA and other primary references are listed below. The reader is directed to the web site for the FHWA National Geotechnical Team (NGT), http://www.fhwa.dot.gov/engineering/geotech/index.cfm, to obtain information on all geotechnical publications and software that have been developed by FHWA. The NAVFAC manuals and many other public domain manuals can be downloaded from http://www.geotechlinks.com.

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1.4.2 Other Primary References

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CHAPTER 2.0
STRESS AND STRAIN IN SOILS

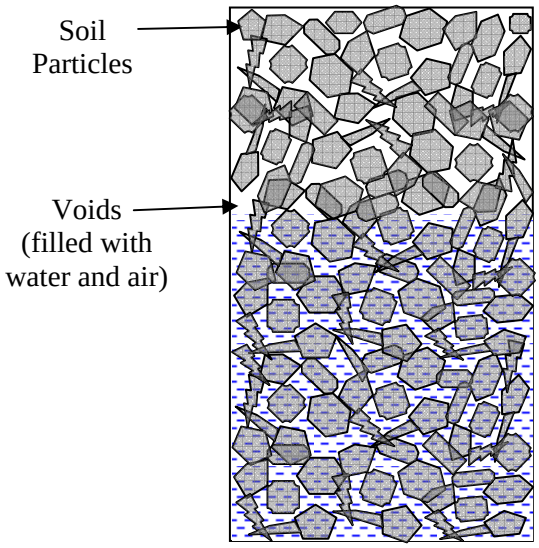
Soil mass is generally a three phase system that consists of solid particles, liquid and gas. The liquid and gas phases occupy the voids between the solid particles as shown in Figure 2-1a. For practical purposes, the liquid may be considered to be water (although in some cases the water may contain some dissolved salts or pollutants) and the gas as air. Soil behavior is controlled by the interaction of these three phases. Due to the three phase composition of soils, complex states of stresses and strains may exist in a soil mass. Proper quantification of these states of stress, and their corresponding strains, is a key factor in the design and construction of transportation facilities.

The first step in quantification of the stresses and strains in soils is to characterize the distribution of the three phases of the soil mass and determine their inter-relationships. The inter-relationships of the weights and volumes of the different phases are important since they not only help define the physical make-up of a soil but also help determine the in-situ geostatic stresses, i.e., the states of stress in the soil mass due only to the soil's self-weight. The volumes and weights of the different phases of matter in a soil mass shown in Figure 2-1a can be represented by the block diagram shown in Figure 2-1b. Such a diagram is also known as a phase diagram. A block of unit cross sectional area is considered. The symbols for the volumes and weights of the different phases are shown on the left and right sides of the block, respectively. The symbols for the volumes and weights of the three phases are defined as follows:

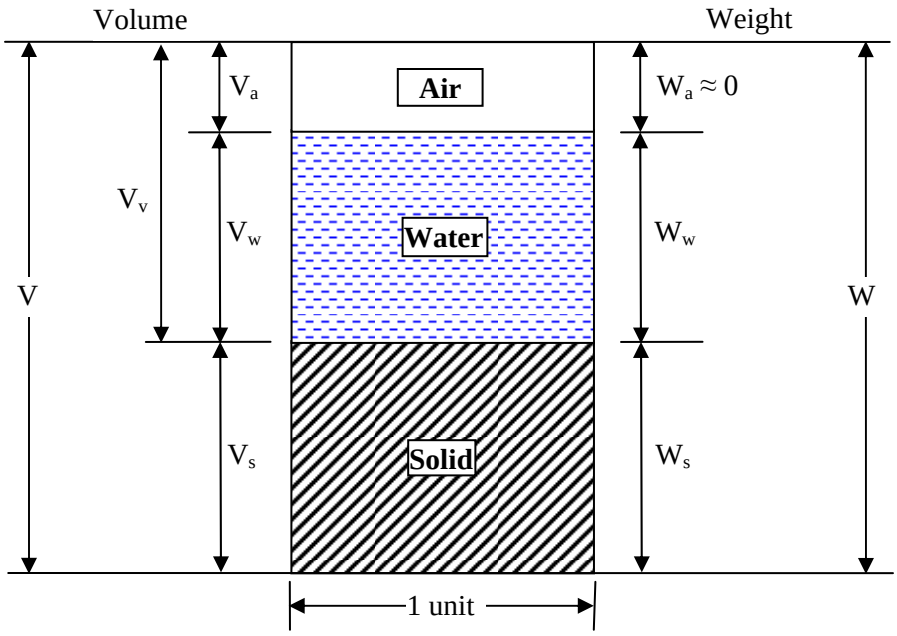
V_a, W_a : volume, weight of air phase. For practical purposes, $W_a = 0$.
V_w, W_w: volume, weight of water phase.
V_v, W_v : volume, weight of total voids. For practical purposes, $W_v = W_w$ as $W_a = 0$.
V_s, W_s : volume, weight of solid phase.
V, W : volume, weight of the total soil mass .

Although $W_a = 0$ so that $W_v = W_w$, V_a is generally > 0 and must always be taken into account. Since the relationship between V_a and V_w usually changes with groundwater conditions as well as under imposed loads, it is convenient to designate all the volume not occupied by the solid phase as void space, V_v. Thus, $V_v = V_a + V_w$. Use of the terms illustrated in Figure 2-1b, allows a number of basic phase relationships to be defined and/or derived as discussed next.

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(a)



(b)

Figure 2-1. A unit of soil mass and its idealization.

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2.1 BASIC WEIGHT-VOLUME RELATIONSHIPS

Various volume change phenomena encountered in geotechnical engineering, e.g., compression, consolidation, collapse, compaction, expansion, etc. can be described by expressing the various volumes illustrated in Figure 2-1b as a function of each other. Similarly, the in-situ stress in a soil mass is a function of depth and the weights of the different soil elements within that depth. This in-situ stress, also known as overburden stress (see Section 2.3), can be computed by expressing the various weights illustrated in Figure 2-1b as a function of each other. This section describes the basic inter-relationships among the various quantities shown in Figure 2-1b.

2.1.1 Volume Ratios

A parameter used to express of the volume of the voids in a given soil mass can be obtained from the ratio of the volume of voids, V_v, to the total volume, V. This ratio is referred to as **porosity, n,** and is expressed as a percentage as follows:

$$n = \frac{V_v}{V} x100 \qquad 2\text{-}1$$

Obviously, the porosity can never be greater than 100%. As a soil mass is compressed, the volume of voids, V_v, and the total volume, V, decrease. Thus, the value of the porosity changes. Since both the numerator and denominator in Equation 2-1 change at the same time, it is difficult to quantify soil compression, e.g., settlement or consolidation, as a function of porosity. Therefore, in soil mechanics the volume of voids, V_v, is expressed in relation to a quantity, such as the volume of solids, V_s, that remains unchanging during consolidation or compression. This is done by the introduction of a quantity known as **void ratio, e,** which is expressed in decimal form as follows:

$$e = \frac{V_v}{V_s} \qquad 2\text{-}2$$

Unlike the porosity, the void ratio can have values greater than 1. That would mean that the soil has more void volume than solids volume, which would suggest that the soil is “loose” or “soft.” Therefore, in general, the smaller the value of the void ratio, the denser the soil. As a practicality, for a given type of coarse-grained soil, such as sand, there is a minimum and maximum void ratio. These values can be used to evaluate the **relative density, D_r (%),** of that soil at any intermediate void ratio as follows:

$$D_r = \frac{(e_{max} - e)}{(e_{max} - e_{min})} x100 \qquad 2\text{-}2a$$

At $e = e_{max}$ the soil is as loose as it can get and the relative density equals zero. At $e = e_{min}$ the soil is as dense as it can get and the relative density equals 100%. Relative density and void ratio are particularly useful index properties since they are general indicators of the relative strength and compressibility of the soil sample, i.e., high relative densities and low void ratios generally indicate strong or incompressible soils; low relative densities and high void ratios may indicate weak or compressible soils.

While the expressions for porosity and void ratio indicate the relative volume of voids, they do not indicate how much of the void space, V_v, is occupied by air or water. In the case of a saturated soil, all the voids (i.e., soil pore spaces) are filled with water, $V_v = V_w$. While this condition is true for many soils below the ground water table or below standing bodies of water such as rivers, lakes, or oceans, and for some fine-grained soils above the ground water table due to capillary action, the condition of most soils above the ground water table is better represented by consideration of all three phases where voids are occupied by both air and water. To express the amount of void space occupied by water as a percentage of the total volume of voids, the term **degree of saturation, S,** is used as follows:

$$S = \frac{V_w}{V_v} x100 \qquad 2\text{-}3$$

Obviously, the degree of saturation can never be greater than 100%. When S = 100%, all the void space is filled with water and the soil is considered to be **saturated**. When S = 0%, there is no water in the voids and the soil is considered to be **dry**.

2.1.2 Weight Ratios

While the expressions of the distribution of voids in terms of volumes are convenient for theoretical expressions, it is difficult to measure these volumes accurately on a routine basis. Therefore, in soil mechanics it is convenient to express the void space in gravimetric, i.e., weight, terms. Since, for practical purposes, the weight of air, W_a, is zero, a measure of the void space in a soil mass occupied by water can be obtained through an index property known as the ***gravimetric*** **water or moisture content, w,** expressed as a percentage as follows:

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$$w = \frac{W_w}{W_s} x100 \qquad 2\text{-}4$$

The word “gravimetric” denotes the use of weight as the basis of the ratio to compute water content as opposed to volume, which is often used in hydrology and the environmental sciences to express water content. Since water content is understood to be a weight ratio in geotechnical engineering practice, the word “gravimetric” is generally omitted. Obviously, the water content can be greater than 100%. This occurs when the weight of the water in the soil mass is greater than the weight of the solids. In such cases the void ratio of the soil is generally greater than 1 since there must be enough void volume available for the water so that its weight is greater than the weight of the solids. However, even if the water content is greater than 100%, the degree of saturation may not be 100% because the water content is a weight ratio while saturation is a volume ratio.

For a given amount of soil, the total weight of soil, W, is equal to $W_s + W_w$, since the weight of air, W_a, is practically zero. The water content, w, can be easily measured by oven-drying a given quantity of soil to a high enough temperature so that the amount of water evaporates and only the solids remain. By measuring the weight of a soil sample before and after it ahs been oven dried, both W and W_s, can be determined. The water content, w, can be determined as follows since $W_a = 0$:

$$w = \frac{W - W_s}{W_s} = \frac{W_w}{W_s} x100 \qquad 2\text{-}4a$$

Most soil moisture is released at a temperature between 220 and 230^{o}F (105 and 110^{o}C). Therefore, to compare reported water contents on an equal basis between various soils and projects, this range of temperature is considered to be a standard range.

2.1.3 Weight-Volume Ratios (Unit Weights) and Specific Gravity

The simplest relationship between the weight and volume of a soil mass (refer to Figure 2-1b) is known as the **total unit weight, γ_t,** and is expressed as follows:

$$\gamma_t = \frac{W}{V} = \frac{W_w + W_s}{V} \qquad 2\text{-}5$$

The total unit weight of a soil mass is a useful quantity for computations of vertical in-situ stresses. For a constant volume of soil, the total unit weight can vary since it does not

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account for the distribution of the three phases in the soil mass. Therefore the value of the total unit weight for a given soil can vary from its maximum value when all of the voids are filled with water (S=100%) to its minimum value when there is no water in the voids (S=0%). The former value is called the **saturated unit weight, γ_{sat}**; the latter value is referred to as the **dry unit weight**, γ_d. In terms of the basic quantities shown in Figure 2-1b and with reference to Equation 2-5, when $W_w = 0$ the **dry unit weight, γ_d,** can be expressed as follows:

$$\gamma_d = \frac{W_s}{V} \qquad 2\text{-}6$$

For computations involving soils below the water table, the buoyant unit weight is frequently used where:

$$\gamma_b = \gamma_{sat} - \gamma_w \qquad 2\text{-}7$$

where, γ_w equals the unit weight of water and is defined as follows:

$$\gamma_w = \frac{W_w}{V_w} \qquad 2\text{-}8$$

In the geotechnical literature, the buoyant unit weight, γ_b, is also known as the effective unit weight, γ', or submerged unit weight, γ_{sub}. Unless there is a high concentration of dissolved salts, e.g., in sea water, the unit weight of water, γ_w, can be reasonably assumed to be 62.4 lb/ft^3 (9.81 kN/m^3).

To compare the properties of various soils, it is often instructive and preferable to index the various weights and volumes to unchanging quantities, which are the volume of solids, V_s, and the weight of solids, W_s. A ratio of W_s to V_s, is known as the unit weight of the solid phase, γ_s, and is expressed as follows:

$$\gamma_S = \frac{W_S}{V_S} \qquad 2\text{-}9$$

The unit weight of the solid phase, γ_s, should not be confused with the dry unit weight of the soil mass, γ_d, which is defined in Equation 2-6 as the total unit weight of the soil mass when there is no water in the voids, i.e., at S = 0%. The distinction between γ_s and γ_d is very subtle,

but it is very important and should not be overlooked. For example, for a solid piece of rock (i.e., no voids) the total unit weight is γ_s while the total unit weight of a soil whose voids are dry is γ_d. In geotechnical engineering, γ_d is more commonly of interest than γ_s.

Since the value of γ_w is reasonably well known, the unit weight of solids, γ_s, can be expressed in terms of γ_w. The concept of **Specific Gravity, G,** is used to achieve this goal. In physics textbooks, G is defined as the ratio between the mass density of a substance and the mass density of some reference substance. Since unit weight is equal to mass density times the gravitational constant, G can also be expressed as the ratio between the unit weight of a substance and the unit weight of some reference substance. In the case of soils, the most convenient reference substance is water since it is one of the three phases of the soil and its unit weight is reasonably constant. Using this logic, the **specific gravity of the soil solids**, G_s, can be expressed as follows:

$$G_S = \frac{\gamma_S}{\gamma_w} \qquad 2\text{-}10$$

The **bulk specific gravity of a soil** is equal to γ_t / γ_w. The "bulk specific gravity" is not the same as G_s and is not very useful in practice since the γ_t of a soil can change easily with changes in void ratio and/or degree of saturation. Therefore, the bulk specific gravity is almost never used in geotechnical engineering computations.

The value of G_s can be determined in the laboratory, but it can usually be estimated with sufficient accuracy for various types of soil solids. For routine computations, the value of G_s for sands composed primarily of quartz particles may be taken as 2.65. Tests on a large number of clay soils indicate that the value of G_s for clays usually ranges from 2.5 to 2.9 with an average value of 2.7.

2.1.4 Determination and Use of Basic Weight-Volume Relations

The five relationships, n, e, w, γ_t and G_s, represent the basic weight-volume properties of soils and are used in the classification of soils and for the development of other soil properties. These properties and how they are obtained and applied in geotechnical engineering are summarized in Table 2-1. A summary of commonly used weight-volume (unit weight) relations that incorporate these terms is presented in Table 2-2.

Table 2-1
Summary of index properties and their application

Property	Symbol	Units[1]	How Obtained (AASHTO/ASTM)	Comments and Direct Applications
Porosity	n	Dim	From weight-volume relations	Defines relative volume of voids to total volume of soil
Void Ratio	e	Dim	From weight-volume relations	Volume change computations
Moisture Content	w	Dim	By measurement (T 265/ D 4959)	Classification and in weight-volume relations
Total unit weight [2]	γ_t	FL^{-3}	By measurement or from weight-volume relations	Classification and for pressure computations
Specific Gravity	G_s	Dim	By measurement (T 100/D 854)	Volume computations

NOTES:
1 F=Force or weight; L = Length; Dim = Dimensionless. Although by definition, moisture content is a dimensionless decimal (ratio of weight of water to weight of solids) and used as such in most geotechnical computations, it is commonly reported in percent by multiplying the decimal by 100.
2 Total unit weight for the same soil can vary from "saturated" (S=100%) to "dry" (S=0%).

Table 2-2
Weight-volume relations (after Das, 1990)

Unit-Weight Relationship	Dry Unit Weight (No Water)	Saturated Unit Weight (No Air)
$\gamma_t = \frac{(1+w)G_s\gamma_w}{1+e}$ $\gamma_t = \frac{(G_s+Se)\gamma_w}{1+e}$ $\gamma_t = \frac{(1+w)G_s\gamma_w}{1+\frac{wG_s}{S}}$ $\gamma_t = G_s\gamma_w(1-n)(1+w)$	$\gamma_d = \frac{\gamma_t}{1+w}$ $\gamma_d = \frac{G_s\gamma_w}{1+e}$ $\gamma_d = G_s\gamma_w(1-n)$ $\gamma_d = \frac{G_s\gamma_w}{1+\frac{wG_s}{S}}$ $\gamma_d = \frac{eS\gamma_w}{(1+e)w}$ $\gamma_d = \gamma_{sat} - n\gamma_w$ $\gamma_d = \gamma_{sat} - \left(\frac{e}{1+e}\right)\gamma_w$	$\gamma_{sat} = \frac{(G_s+e)\gamma_w}{1+e}$ $\gamma_{sat} = [(1-n)G_s+n]\gamma_w$ $\gamma_{sat} = \left(\frac{1+w}{1+wG_s}\right)G_s\gamma_w$ $\gamma_{sat} = \left(\frac{e}{w}\right)\left(\frac{1+w}{1+e}\right)\gamma_w$ $\gamma_{sat} = \gamma_d + n\gamma_w$ $\gamma_{sat} = \gamma_d + \left(\frac{e}{1+e}\right)\gamma_w$

In above relations, γ_w refers to the unit weight of water, 62.4 pcf (=9.81 kN/m^3).

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2.1.5 Size of Grains in the Solid Phase

As indicated in Figure 2-1a, the solid phase is composed of soil grains. One of the major factors that affect the behavior of the soil mass is the size of the grains. The size of the grains may range from the coarsest (e.g., boulders, which can be 12- or more inches [300 mm] in diameter) to the finest (e.g., colloids, which can be smaller than 0.0002–inches [0.005 mm]). Since soil particles come in a variety of different shapes, the size of the grains is defined in terms of an effective grain diameter. The distribution of grain sizes in a soil mass is determined by shaking air-dried material through a stack of sieves having decreasing opening sizes. Table 2-3 shows U.S. standard sieve sizes and associated opening sizes. **Sieves with opening size 0.25 in (6.35 mm) or less are identified by a sieve number which corresponds to the approximate number of square openings per linear inch of the sieve (ASTM E 11).**

To determine the grain size distribution, the soil is sieved through a stack of sieves with each successive screen in the stack from top to bottom having a smaller (approximately half of the upper sieve) opening to capture progressively smaller particles. Figure 2-2 shows a selection of some sieves and starting from right to left soil particles retained on each sieve, except for the powdery particles shown on the far left, which are those that passed through the last sieve on the stack. The amount retained on each sieve is collected, dried and weighed to determine the amount of material passing that sieve size as a percentage of the total sample being sieved. Since electro-static forces impede the passage of finer-grained particles through sieves, testing of such particles is accomplished by suspending the chemically dispersed particles in a water column and measuring the change in specific gravity of the liquid as the particles fall from suspension. The change in specific gravity is related to the fall velocities of specific particle sizes in the liquid. This part of the test is commonly referred to as a hydrometer analysis. Because of the strong influence of electro-chemical forces on their behavior, colloidal sized particles may remain in suspension indefinitely (particles with sizes from 10^{-3} mm to 10^{-6} mm are termed "**colloidal**.") Sample grain size distribution curves are shown in Figure 2-3. The nomenclature associated with various grain sizes (cobble, gravel, sand, silt or clay) is also shown in Figure 2-3. Particles having sizes larger than the No. 200 sieve (0.075 mm) are termed "**coarse-grained**" while those with sizes finer than the No. 200 sieve are termed "**fine-grained**."

The results of the sieve and hydrometer tests are represented graphically on a grain size distribution curve or gradation curve. As shown in Figure 2-3, an arithmetic scale is used on the ordinate (Y-axis) to plot the percent finer by weight and a logarithmic scale is used on the abscissa (X-axis) for plotting particle (grain) size, which is typically expressed in millimeters.

Table 2-3

U.S. standard sieve sizes and corresponding opening dimension

U.S. Standard Sieve No.[1]	Sieve Opening (in)	Sieve Opening (mm)	Comment (Based on the Unified Soil Classification System (USCS) discussed in Chapter 4)
3	0.2500	6.35	
4	0.1870	4.75	• Breakpoint between fine gravels and coarse sands • Soil passing this sieve is used for compaction test
6	0.1320	3.35	
8	0.0937	2.36	
10	0.0787	2.00	• Breakpoint between coarse and medium sands
12	0.0661	1.70	
16	0.0469	1.18	
20	0.0331	0.850	
30	0.0234	0.600	
40	0.0165	0.425	• Breakpoint between medium and fine sands • Soil passing this sieve is used for Atterberg limits
50	0.0117	0.300	
60	0.0098	0.250	
70	0.0083	0.212	
100	0.0059	0.150	
140	0.0041	0.106	
200	0.0029	0.075	• Breakpoint between fine sand and silt or clay
270	0.0021	0.053	
400	0.0015	0.038	

Note:

1. The sieve opening sizes for various sieve numbers listed above are based on Table 1 from ASTM E 11. Sieves with opening size greater than No. 3 are identified by their opening size. Some of these sieves are as follows:

4.0 in	(101.6 mm)	1-1/2 in	(38.1 mm)	½ in	(12.7 mm)
3.0 in	(76.1 mm)*	1-1/4 in	(32.0 mm)	3/8 in	(9.5 mm)
2-1/2 in	(64.0 mm)	1.0 in	(25.4 mm)	5/16 in	(8.0 mm)
2.0 in	(50.8 mm)	¾ in	(19.0 mm)**		
1-3/4 in	(45.3 mm)	5/8 in	(16.0 mm)		

* The 3 in (76.1 mm) sieve size differentiates between cobbles and coarse gravels.
**The ¾ in (19 mm) sieve differentiates between coarse and fine gravels.

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Figure 2-2. Example of laboratory sieves for mechanical analysis for grain size distributions. Shown (right to left) are sieve nos. 3/8-in (9.5-mm), No. 10 (2.0-mm), No. 40 (0.425 mm) and No. 200 (0.075 mm). Example soil particle sizes shown at the bottom of the photo include (right to left): medium gravel, fine gravel, medium-coarse sand, silt, and clay (kaolin) (FHWA, 2002b).

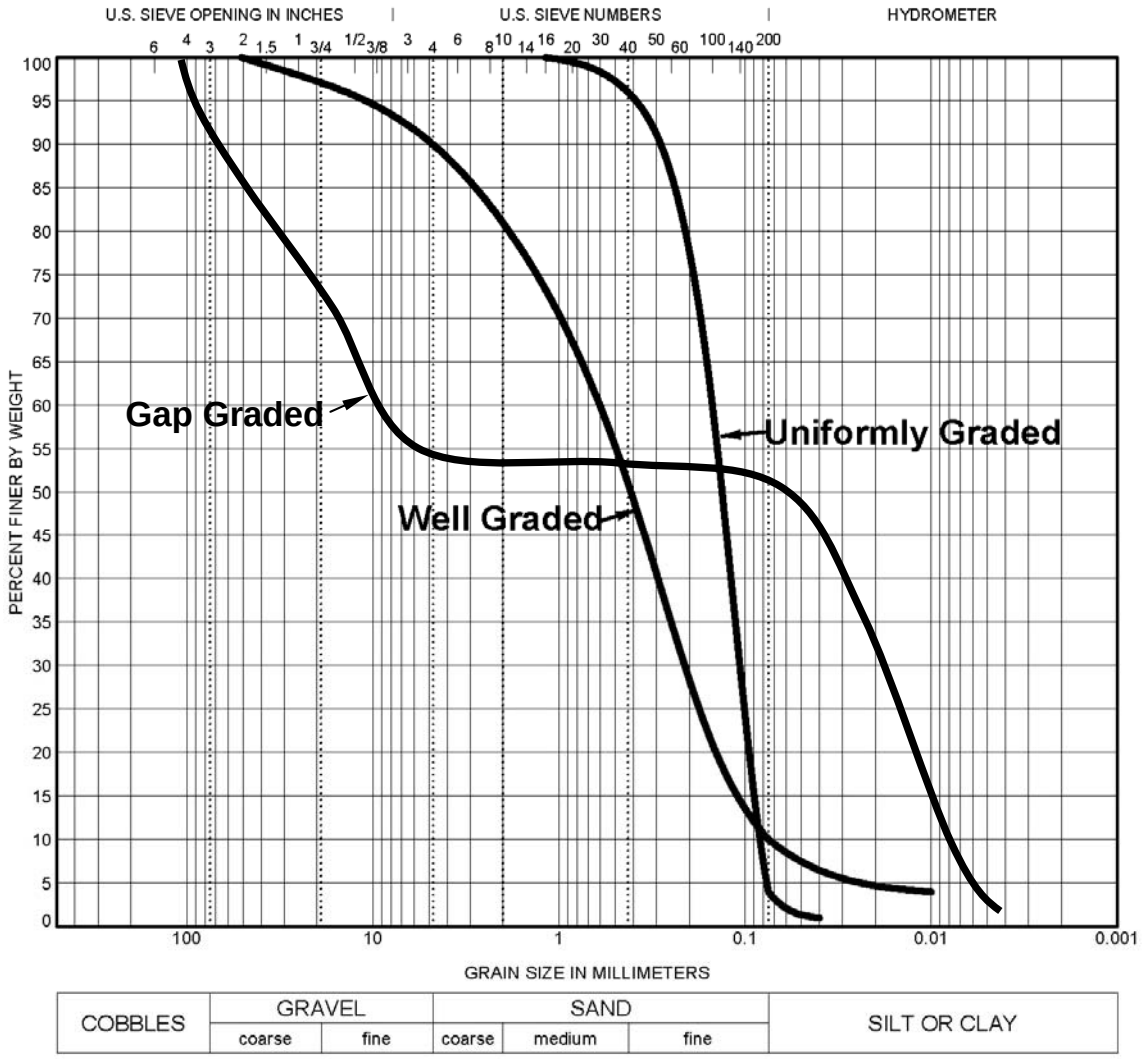


Figure 2-3. Sample grain size distribution curves.

The logarithmic scale permits a wide range of particle sizes to be shown on a single plot. More importantly it extends the scale, thus giving all the grains sizes an approximately equal amount of separation on the X-axis. For example, a grain-size range of 4.75 mm (No.4 sieve) to 0.075 mm (No. 200 sieve) when plotted on an arithmetic scale, will have the 0.075 mm (No. 200 sieve), 0.105 mm (No. 140 sieve), and 0.150 mm (No. 100) particle size plot very close to each other. The logarithmic scale permits separation of grain sizes that makes it easier to compare the grain size distribution of various soils.

The shape of the grain size distribution curve is somewhat indicative of the particle size distribution as shown in Figure 2-3. For example,

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- A smooth curve covering a wide range of sizes represents a *well-graded* or *non-uniform* soil.

- A vertical or near vertical slope over a relatively narrow range of particle sizes indicates that the soil consists predominantly of the particle sizes within that range of particle sizes. A soil consisting of particles having only a few sizes is called a *poorly-graded* or *uniform* soil.

- A curve that contains a horizontal or nearly horizontal portion indicates that the soil is deficient in the grain sizes in the region of the horizontal slope. Such a soil is called a *gap-graded* soil.

Well-graded soils are generally produced by bulk transport processes (e.g., glacial till). Poorly graded soils are usually sorted by the transporting medium e.g., beach sands by water; loess by wind. Gap-graded soils are also generally sorted by water, but certain sizes were not transported.

2.1.6 Shape of Grains in Solid Phase

The shape of individual grains in a soil mass plays an important role in the engineering characteristics (strength and stability) of the soil. Two general shapes are normally recognized, bulky and platy.

2.1.6.1 Bulky Shape

Cobbles, gravel, sand and some silt particles cover a large range of sizes as shown in Figure 2-2; however, they are all bulky in shape. The term bulky is confined to particles that are relatively large in all three dimensions, as contrasted to platy particles, in which one dimension is small as compared to the other two, see Figure 2-4. The bulky shape has five subdivisions listed in descending order of desirability for construction

- *Angular* particles are those that have been freshly broken up and are characterized by jagged projections, sharp ridges, and flat surfaces. Angular gravels and sands are generally the best materials for construction because of their interlocking characteristics. Such particles are seldom found in nature, however, because physical and chemical weathering processes usually wear off the sharp ridges in a relatively short period time. Angular material is usually produced artificially, by crushing.

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- *Subangular* particles are those that have been weathered to the extent that the sharper points and ridges have been worn off.

- *Subrounded* particles are those that have been weathered to a further degree than subangular particles. They are still somewhat irregular in shape but have no sharp corners and few flat areas. Materials with this shape are frequently found in stream beds. If composed of hard, durable particles, subrounded material is adequate for most construction needs.

- *Rounded* particles are those on which all projections have been removed, with few irregularities in shape remaining. The particles resemble spheres and are of varying sizes. Rounded particles are usually found in or near stream beds or beaches.

- *Well rounded* particles are rounded particles in which the few remaining irregularities have been removed. Like rounded particles, well rounded particles are also usually found in or near stream beds or beaches.

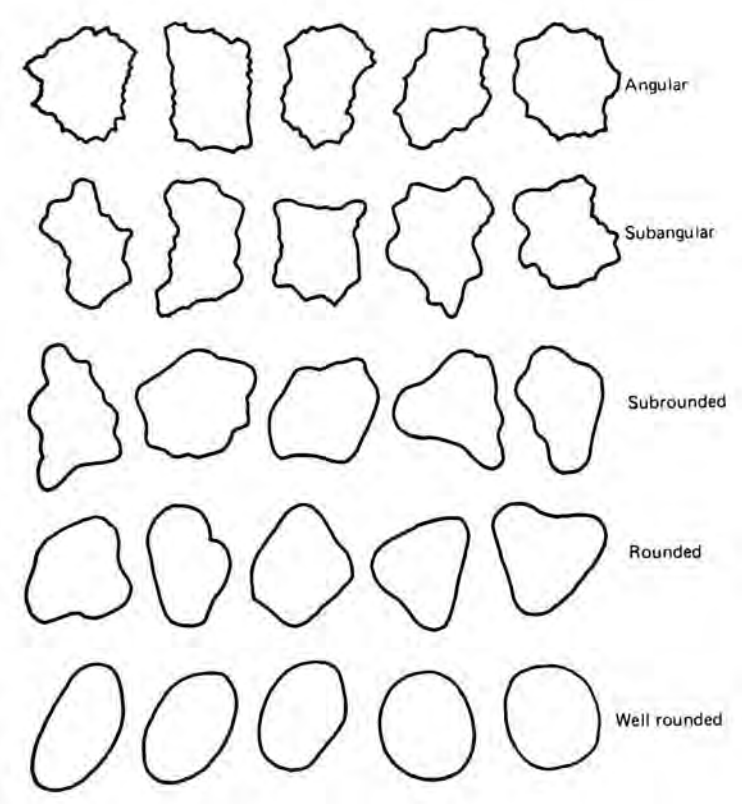


Figure 2-4. Terminology used to describe shape of coarse-grained soils (Mitchell, 1976).

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2.1.6.2 Platy Shape

Platy, or flaky, particles are those that have flat, plate like grains. Clay and some silts are common examples. Because of their shape, flaky particles have a greater surface area than bulky particles, assuming that the weights and volumes of the two are the same. For example, 1 gram of bentonite (commercial name for montmorillonite clay) has a surface area of approximately 950 yd^2 (800 m^2) compared to a surface area of approximately 0.035 yd^2 (0.03 m^2) of 1 gram of sand. Because of their mineralogical composition and greater specific surface area, most flaky particles also have a greater affinity for water than bulky particles. Due to the high affinity of such soils for water, the physical states of such fine-grained soils change with the amount of water in these soils. The effect of water on the physical states of fine grained soils is discussed next.

2.1.7 Effect of Water on Physical States of Soils

For practical purposes, the two most dominant phases are the solid phase and the water phase. It is intuitive that as the water content increases, the contacts between the particles comprising the solid phase will be "lubricated." If the solid phase is comprised of coarse particles, e.g. coarse sand or gravels, then water will start flowing between the particles of the solid phase. If the solid phase is comprised of fine-grained particles, e.g., clay or silt, then water cannot flow as freely as in the coarse-grained solid phase because pore spaces are smaller and solids react with water. However, as the water content increases even the fine-grained solid phase will conduct water and under certain conditions the solid phase itself will start deforming like a viscous fluid, e.g., like a milk shake or a lava flow. The mechanical transformation of the fine-grained soils from a solid phase into a viscous phase is a very important concept in geotechnical engineering since it is directly related to the load carrying capacity of soils. It is obvious that the load carrying capacity of a solid is greater than that of water. Since water is contained in the void space, the effect of water on the physical states of fine-grained soils is important. Some of the basic index properties related to the effect of water are described next.

The physical and mechanical behavior of fine-grained-soils is linked to four distinct states: solid, semi-solid, plastic and viscous liquid in order of increasing water content. Consider a soil initially in a viscous liquid state that is allowed to dry uniformly. This state is shown as Point A in Figure 2-5, which shows a plot of total volume versus water content. As the soil dries, its water content reduces and consequently so does its total volume as the solid particles move closer to each other. As the water content reduces, the soil can no longer flow like a viscous liquid. Let us identify this state by Point B in Figure 2-5. The water content at Point B is known as the "Liquid Limit" in geotechnical engineering and is denoted by LL.

As the water content continues to reduce due to drying, there is a range of water content at which the soil can be molded into any desired shape without rupture. In this range of water content, the soil is considered to be "plastic."

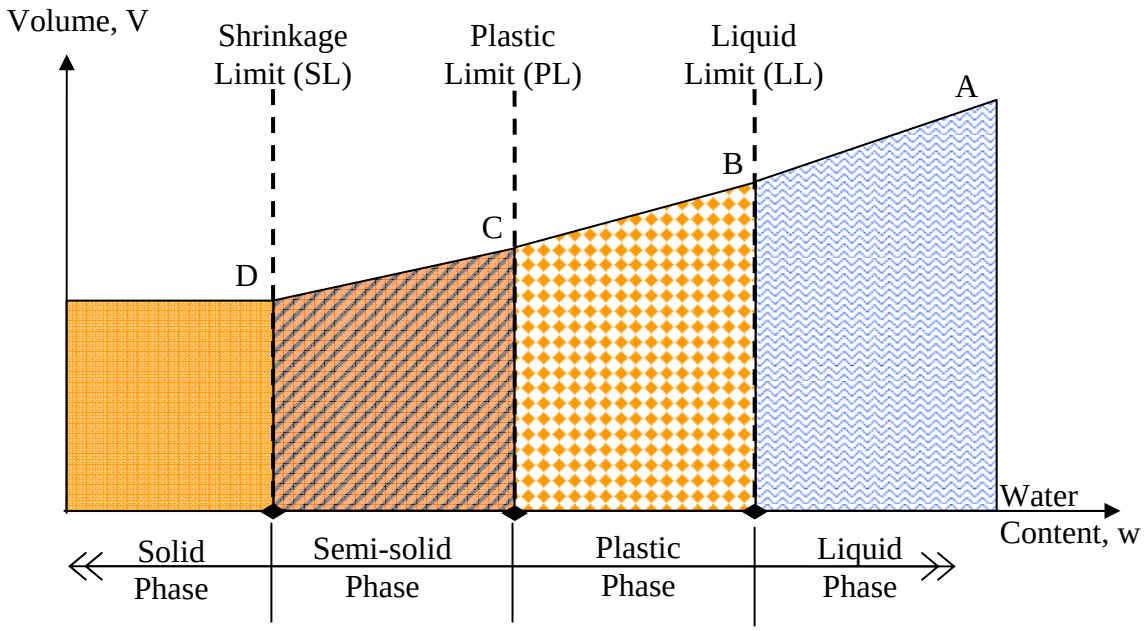


Figure 2-5. Conceptual changes in soil phases as a function of water content.

If the soil is allowed to dry beyond the plastic state, the soil cannot be molded into any shape without showing cracks, i.e., signs of rupture. The soil is then in a semi-solid state. The water content at which cracks start appearing when the soil is molded is known as the "Plastic Limit." This moisture content is shown at Point C in Figure 2-5 and is denoted by PL. The difference in water content between the Liquid Limit and Plastic Limit, is known as the **Plasticity Index**, PI, and is expressed as follows:

$$PI = LL - PL \qquad 2\text{-}11$$

Since PI is the difference between the LL and PL, it denotes the range in water content over which the soil acts as a plastic material as shown in Figure 2-5.

As the soil continues to dry, it will be reduced to its basic solid phase. The water content at which the soil changes from a semi-solid state to a solid state is called the **Shrinkage Limit**, SL. No significant change in volume will occur with additional drying below the shrinkage limit. The shrinkage limit is useful for the determination of the swelling and shrinkage characteristics of soils.

The liquid limit, plastic limit and shrinkage limit are called Atterberg limits after A. Atterberg (1911), the Swedish soil scientist who first proposed them for agricultural applications.

For foundation design, engineers are most interested in the load carrying capacity, i.e., strength, of the soil and its associated deformation. The soil has virtually no strength at the LL, while at water contents lower than the PL (and certainly below the SL) the soil may have considerable strength. Correspondingly, soil strength increases and soil deformation decreases as the water content of the soil reduces from the LL to the SL. Since the Atterberg limits are determined for a soil that is remolded, a connection needs to be made between these limits and the in-situ moisture content, w, of the soil for the limits to be useful in practical applications in foundation design. One way to quantify this connection is through the **Liquidity Index**, LI, that is given by:

$$LI = \frac{w - PL}{PI} \qquad 2\text{-}12$$

The liquidity index is the ratio of the difference between the soil's in-situ water content and plastic limit to the soil's plasticity index. The various phases shown in Figure 2-5 and anticipated deformation behavior can now be conveniently expressed in terms of LI as shown in Table 2-4.

Table 2-4
Concept of soil phase, soil strength and soil deformation based on Liquidity Index

Liquidity Index, LI	Soil Phase	Soil Strength (Soil Deformation)
$LI \geq 1$	Liquid	Low strength (Soil deforms like a viscous fluid)
$0 < LI < 1$	Plastic	Intermediate strength • at $w \approx LL$, the soil is considered soft and very compressible • at $w \approx PL$, the soil is considered stiff (Soil deforms like a plastic material)
$LI \leq 0$	Semi-solid to Solid	High strength (Soil deforms as a brittle material, i.e., sudden, fracture of material)

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Another valuable tool in assessing the characteristics of a fine-grained soil is to compare the LL and PI of various soils. Each fine-grained soil has a relatively unique value of LL and PI. A plot of PI versus LL is known as the **Plasticity Chart** (see Figure 2-6). Arthur Casagrande, who developed the concept of the Plasticity Chart, had noted the following during the First Pan American Conference on Soil Mechanics and Foundation Engineering (Casagrande, 1959).

> *I consider it essential that an experienced soils engineer should be able to judge the position of soils, from his territory, on a plasticity chart merely on the basis of his visual and manual examination of the soils. And more than that, the plasticity chart should be for him like a map of the world. At least for certain areas of the chart, that are significant for his activities, he should be well familiar. The position of soils within these areas should quickly convey to him a picture of the significant engineering properties that he should expect.*

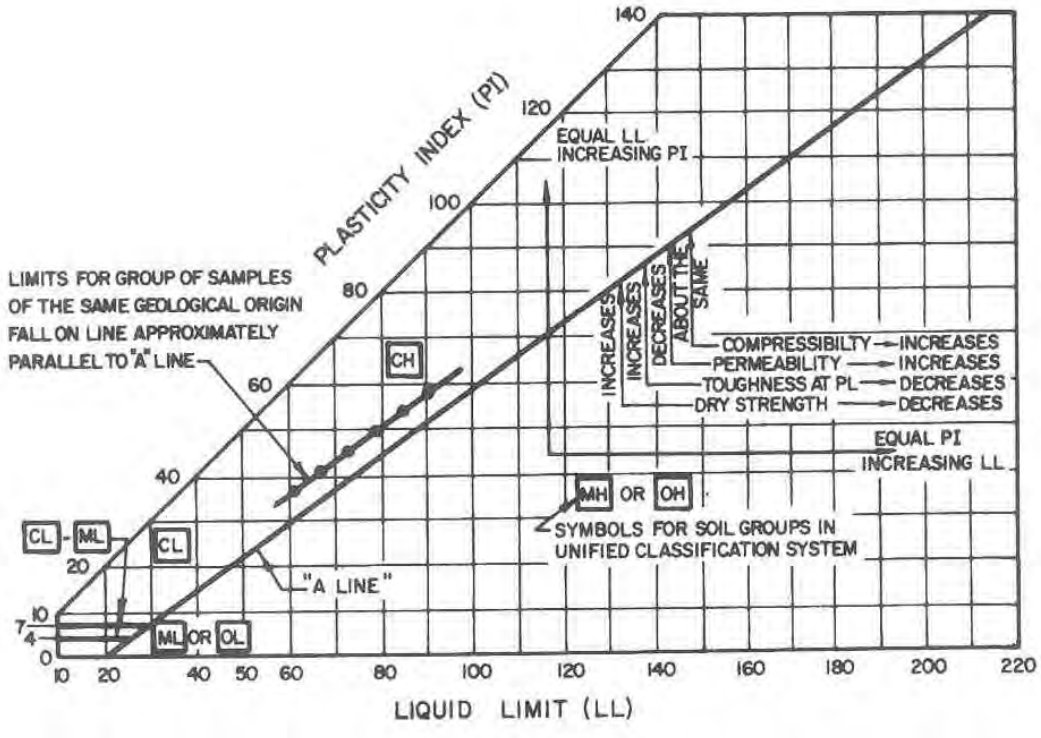


Figure 2-6. Plasticity chart and significance of Atterberg Limits (NAVFAC, 1986a).

Casagrande proposed the inclusion of the A-line on the plasticity chart as a boundary between clay (above the A-line) and silt (below the A-line) to help assess the engineering characteristics of fine-grained soils. Once PI and LL are determined for a fine-grained soil at a specific site, a point can be plotted on the plasticity chart that will allow the engineer to develop a feel for the general engineering characteristics of that particular soil. The plasticity

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chart also permits the engineer to compare different soils across the project site and even between different project sites. (The symbols for soil groups such as CL and CH are discussed later in this manual.) The plasticity chart, including the laboratory determination of the various limits (LL, PL and SL), are discussed further in Chapters 4 and 5. Additional useful terms such as "Activity Ratio" that relate the PI to clay fraction are also introduced in Chapter 5.

2.2 PRINCIPLE OF EFFECTIVE STRESS

The contacts between soil grains are effective in resisting applied stresses in a soil mass. Under an applied load, the total stress in a saturated soil sample is composed of the intergranular stress and the pore water pressure. When pore water drains from a soil, the contact between the soil grains increases, which increases the level of intergranular stress. This intergranular contact stress is called the **effective stress**. **The effective stress, p_o, within a soil mass is the difference between the total stress, p_t, and pore water pressure, u**. The **principle of effective stress** is a fundamental aspect of geotechnical engineering and is written as follows:

$$p_o = p_t - u \qquad 2\text{-}13$$

In general, soil deposits below the ground water table will be considered saturated and the ambient pore water pressure at any depth may be computed by multiplying the unit weight of water, γ_w, by the height of water above that depth. The total stress at that depth may be found by multiplying the total unit weight of the soil by the depth. The effective stress is the total stress minus the pore water pressure. This concept is used to construct the profile of pressure in the ground as a function of depth and is discussed next.

2.3 OVERBURDEN PRESSURE

Soils existing at a distance below ground are affected by the weight of the soil above that depth. The influence of this weight, known generally as **overburden**, causes a state of stress to exist, which is unique at that depth, for that soil. This state of stress is commonly referred to as the **overburden** or **in-situ** or **geostatic state of stress**. When a soil sample is removed from the ground, as during the field exploration phase of a project, that in-situ state of stress is relieved as all confinement of the sample has been removed. In laboratory testing, it is important to reestablish the in-situ stress conditions and to study changes in soil properties when additional stresses representing the expected design loading are applied. The stresses

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to be used during laboratory testing of soil samples are estimated from either the total or effective overburden pressure. The engineer's first task is determining the total and effective overburden pressure variation with depth. This relatively simple task involves estimating the average total unit weight for each soil layer in the soil profile, and determining the depth of the water table. Unit weight may be reasonably well estimated from tests on undisturbed samples or from standard penetration N-values and visual soil identification. The water table depth, which is typically recorded on boring logs, can be used to compute the hydrostatic pore water pressure at any depth. The **total overburden pressure, p_t,** is found by multiplying the total unit weight of each soil layer by the corresponding layer thickness and continuously summing the results with depth. The **effective overburden pressure, p_o,** at any depth is determined by accumulating the weights of all layers above that depth with consideration of the water level conditions at the site as follows:

Soils above the water table

- Multiply the total unit weight by the thickness of each respective soil layer above the desired depth, i.e., $p_o = p_t$.

Soils below the ground water table

- Compute pore water pressure u as $z_w \gamma_w$ where z_w is the depth below ground water table and γ_w is the unit weight of water
- To obtain effective overburden pressure, p_o, subtract pore water pressure, u, from p_t
- For soils below the ground water table, p_t is generally assumed to be equal to p_{sat}

Alternatively, the following approach can be used:

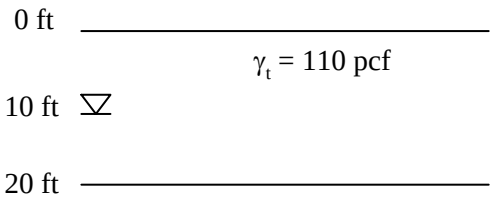
- Reduce the total unit weights of soils below the ground water table by the unit weight of water (62.4 pcf (9.8 kN/m^3)), i.e., use effective unit weights, γ', and multiply by the thickness of each respective soil layer between the water table and the desired depth below the ground water table, i.e., $p_o = (\gamma_t - \gamma_w)$ (depth), or γ' (depth).

In the geotechnical literature, the effective unit weight, γ', is also known as the buoyant unit weight or submerged unit weight and symbols, γ_b or γ_{sub}, respectively are used.

An example is solved in Figure 2-7.

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Example 2-1: Find p_o at 20 ft below ground in a sand deposit with a total unit weight of 110 pcf and the water table 10 ft below ground. Assume $\gamma_t = \gamma_{sat}$. Plot p_t and p_o versus depth from 0 ft – 20 ft.



Solution:

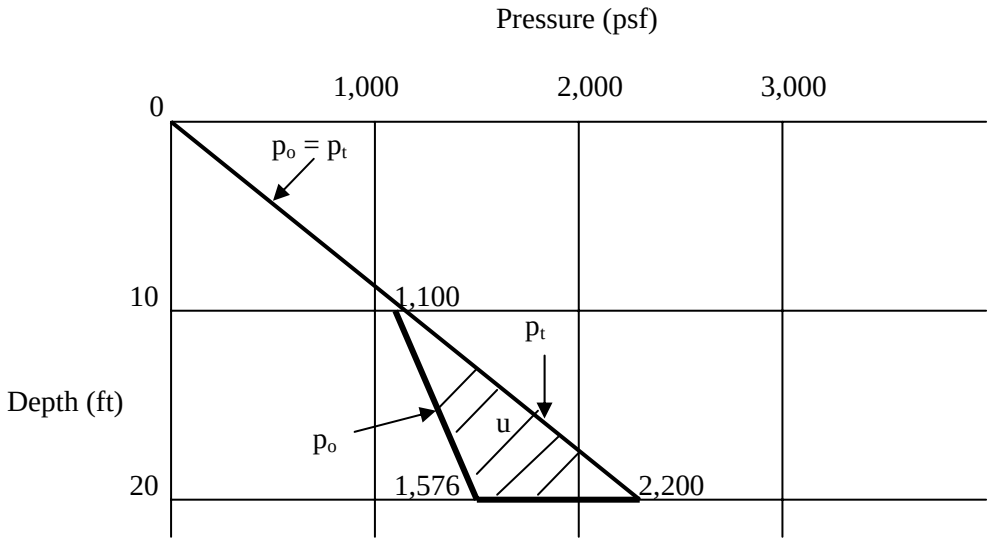
From Equation 2-13, $p_o = p_t - u$

p_t @ 10 ft = p_o @ 10 ft = 10 ft × 110 pcf = 1,100 psf

p_t @ 20 ft = p_t @ 10 ft + (10 ft × 110 pcf) = 2,200 psf

u @ 20 ft = 10 ft × 62.4 pcf = 624 psf

p_o @ 20 ft = p_t @ 20 ft - u @ 20 ft = 2,200 psf – 624 psf = 1,576 psf



Pressure Diagram

A plot of effective overburden pressure versus depth is called a "p_o – diagram" and is used throughout all aspects of geotechnical testing and analysis.

Figure 2-7. Example calculation of a p_o-diagram.

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2.4 VERTICAL STRESS DISTRIBUTION IN SOIL DUE TO EXTERNAL LOADINGS

When a load is applied to the soil surface, it increases the vertical and lateral stresses within the soil mass. The increased stresses are greatest directly under the loaded area and dissipate within the soil mass as a function of distance away from the loaded area. This is commonly called spatial attenuation of applied loads. A schematic of the vertical stress distribution with depth along the centerline under an embankment of height, h, constructed with a soil having total unit weight, γ_t, is shown in Figure 2-8.

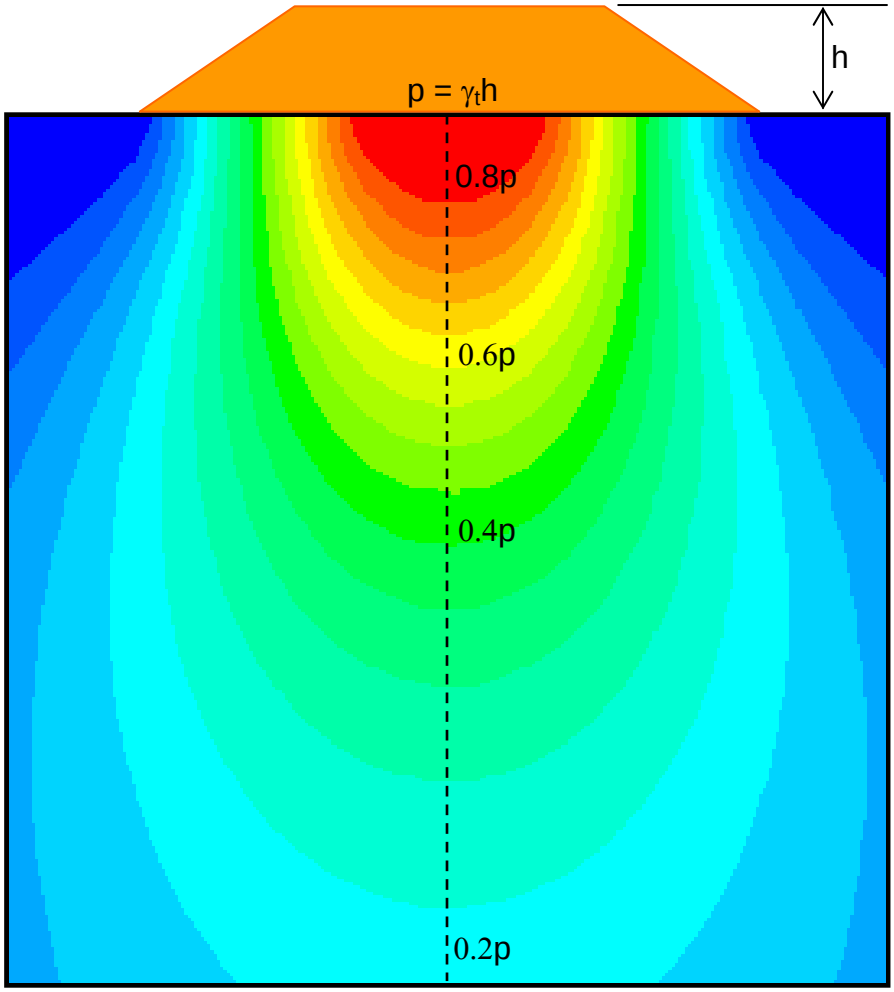


Figure 2-8. Schematic of vertical stress distribution under embankment loading. Graphic generated by FoSSA (2003) program.

(Note: Version 1.0 of FoSSA program is licensed to FHWA. See Appendix E for a brief overview of the FoSSA program).

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Estimation of vertical stresses at any point in a soil mass due to external loadings are of great significance in the prediction of volume change of soils (e.g., settlement) under buildings, bridges, embankments and many other structures. The computation of the total vertical stress change induced by an external loading will depend on the configuration of the external loads. Common examples of the external loads are as follows:

- Uniform strip loads such as the load on a long wall footing of sufficient width,

- Uniformly loaded square, rectangular or circular footings such as column footings of buildings, pier footings, footings for water tanks, mats, etc., and

- Triangular and/or trapezoidal strip loads such as the loads of long earth embankments.

The theory of elasticity is often used to compute the stresses induced within a soil mass by external loadings. The most widely used elastic formulae were first developed by Boussinesq (1885) for point loads acting at the surface of a semi-infinite elastic half-space. These formulae, often known as **Boussinesq solutions**, can be integrated to give stresses below external loadings acting on a finite area. The basic assumptions in these formulae are (a) the stress is proportional to strain, (b) the soil is homogeneous (i.e., the properties are constant throughout the soil mass), and (c) the soil is isotropic (i.e., the properties are the same in all directions through a point). Westergaard (1938) modified the Boussinesq solutions by assuming that the semi-infinite elastic half-space is interspersed with infinitely thin but perfectly rigid layers that allow vertical movement but no lateral movement. In reality, a soil mass never fulfills the assumptions of either of these idealized solutions. Nevertheless, these elastic solutions, with appropriate modifications and judgment, have been found to yield acceptable approximate estimates of stresses in the soil mass and are widely used in geotechnical engineering practice. The Boussinesq solutions are generally used in most situations, even those where layered soils are encountered provided the thickness of the layers is on the order of a few feet or more. On the other hand, the Westergaard solutions are usually used for varved clays where the predominant soil mass is clay interspersed with thin layers of sand whose thickness is on the order of inches.

The derivations of the equations for various common loadings cited above are tedious. They are omitted in this manual so that the reader can concentrate on the use of published solutions, generally in the form of charts. The following sections contain the chart solutions for some of the loadings most commonly encountered in practice. Caution in the use of these charts is advised since they all pertain to **stress increments** at very well-defined points within the soil mass due to the applied pressures indicated. **The total stress acting at a point of interest is equal to the stress increment at that point due to the newly applied**

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load plus existing stresses at that point due to the geostatic stress and stresses due to other external loads applied previously.

2.4.1 Uniformly Loaded Continuous (Strip) and Square Footings

A loaded area is considered to be infinitely long when its length, L, to width, B, ratio is greater than or equal to 10, i.e., $L/B \geq 10$. The load on such an area is commonly known as a strip load. Figure 2-9 presents vertical pressure isobars under strip and square footings based on Boussinesq's theory. An **isobar** is a line that connects all points of equal stress increment below the ground surface. In other words, an isobar is a stress increment contour.

Each isobar represents a fraction of the stress applied at the surface and delineates the zone of influence of the footing such that the area contained within two adjacent isobars experiences stresses greater than the lower isobar and less than the upper isobar. Since these isobars form closed figures that resemble the form of a bulb, they are also termed **bulbs of pressure** or simply the **pressure bulbs**. The pressure bulb concept gives the user a feel for the spread of the stresses through a soil mass.

According to linear elastic theory, the size of the pressure bulb is proportional to the size of the loaded area. This is a key concept in geotechnical engineering that is used to evaluate the **depth of significant influence, DOSI**, denoted by D_S of an applied surface load. The depth D_S is a finite depth below which there are no significant strains in the soil mass due to the loads imposed at the surface. Typically, strains are not significant once the stresses have attenuated to a value of 10 to 15% of those at the surface. For example, Figure 2-9a shows that for "infinitely long" strip footings, D_S = 4 to 6B, while for square footings, Figure 2-9b shows that D_S = 1.5 to 2B. The depths corresponding to this 10 to 15% criterion can be used to determine the minimum depth of field exploration for proposed strip or square footings to ensure that the anticipated significant depth is explored.

It may be seen from Figure 2-9 that the effect of the vertical stresses extends laterally beyond the width of the loaded area, B. This observation is very useful in assessing the influence of one loaded area on the other. Alternatively, this observation can be used to determine an adequate spacing between adjacent loaded areas. It also indicates that the effect of construction activities may be felt beyond a specific site. Such effects should be evaluated before construction so that mitigation measures can be taken to avoid legal implications.

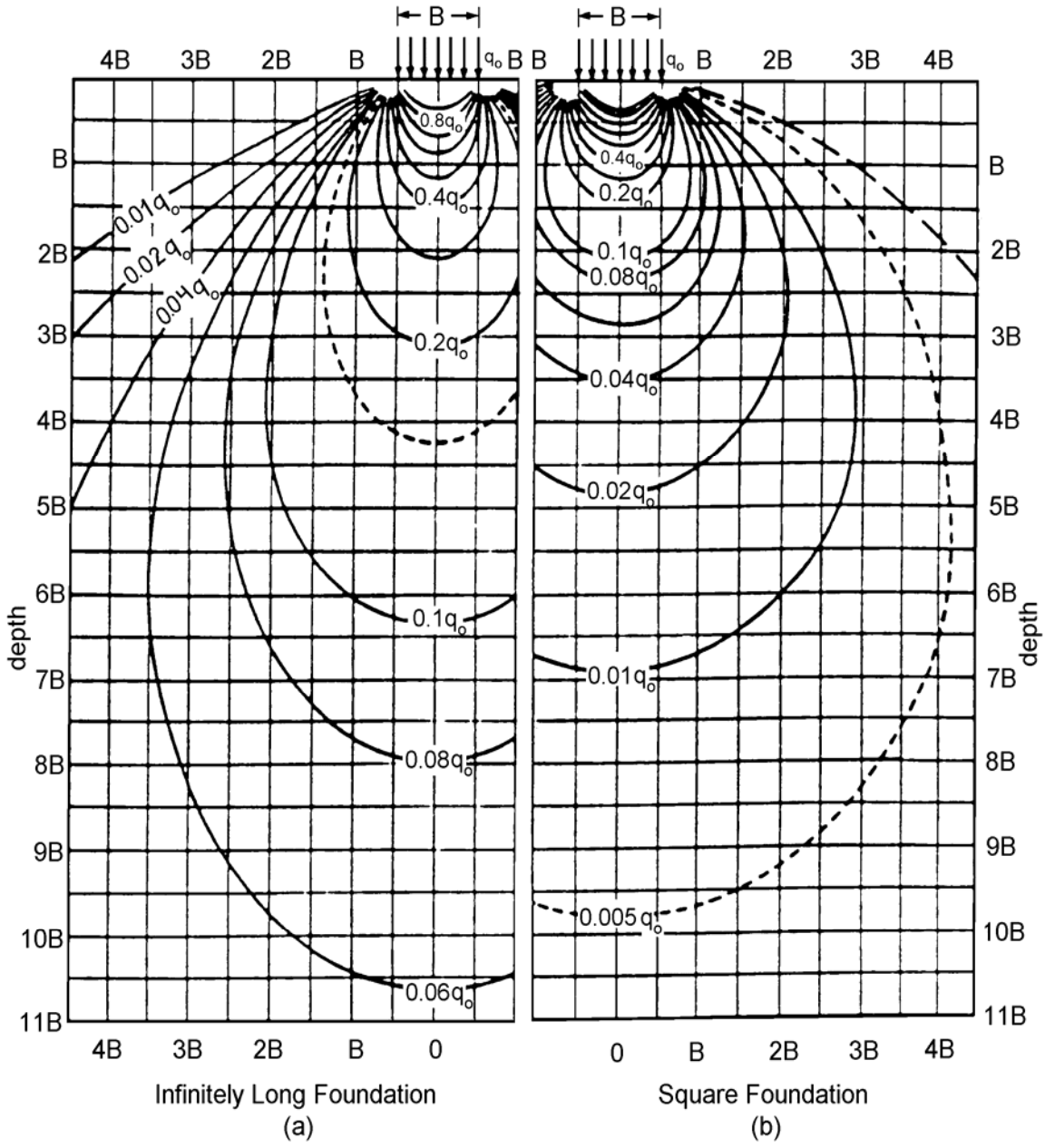


Figure 2-9. Vertical stress contours (isobars) based on Boussinesq's theory for continuous and square footings (modified after Sowers, 1979; AASHTO, 2002).

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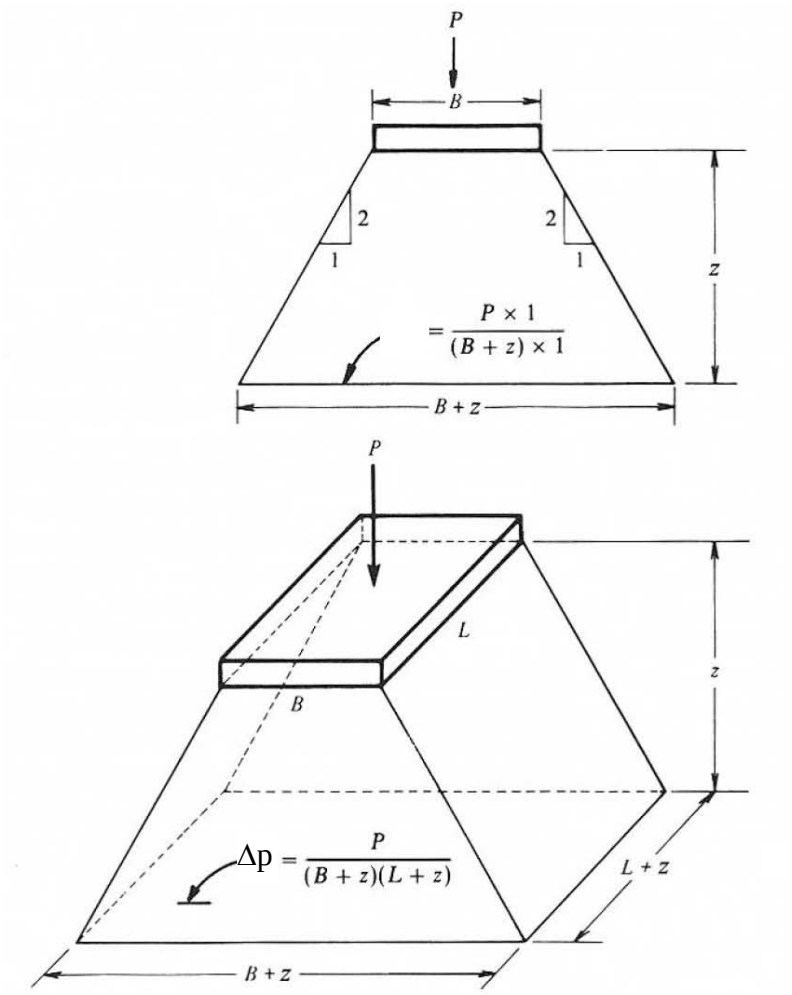
2.4.2 Approximate (2:1) Stress Distribution Concept

As an approximation to the exact solution given by the Boussinesq charts, the total load at the surface of the soil mass may be distributed over an area of the same shape as the loaded area on the surface, but with dimensions that increase with depth at a rate of one horizontal unit for every two vertical units. This is illustrated in Figure 2-10, which shows a rectangular area of dimensions B x L at the surface. At a depth, z, the total load is assumed to be uniformly distributed over an area (B+z) by (L+z). Since the stress is distributed at the rate of 2:1 (vertical:horizontal), this approximation method it is commonly known as the "**2:1 stress distribution**" method.

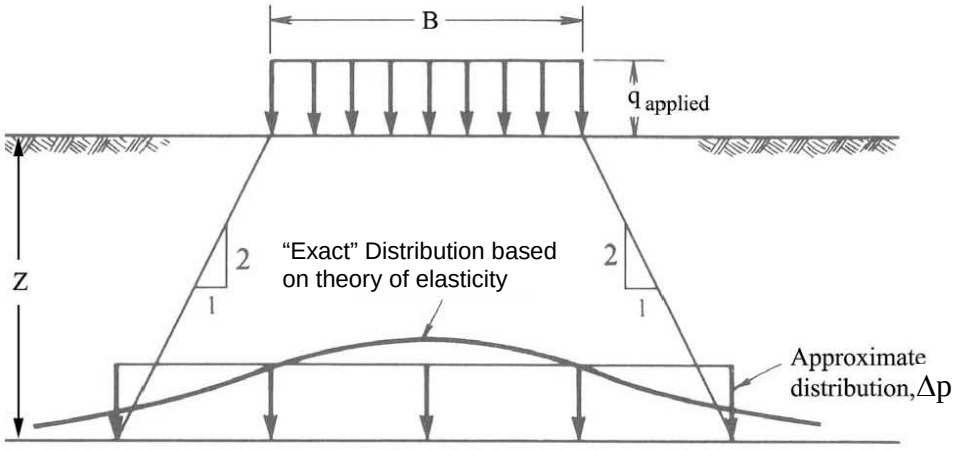
The relationship between the approximate distribution of stress determined by this method and the exact distribution is illustrated in Figure 2-10. In this figure, the vertical stress distribution at a depth B below a uniformly loaded square area of width B is shown along a horizontal line that passes beneath the center of the area and extends beyond the edges of the loaded area. Also shown is the approximate uniform distribution at depth B determined by the 2:1 stress distribution method described above. The discrepancy between the two methods decreases as the ratio of the depth considered to the size of the loaded area increases (Perloff and Baron, 1976).

2.5 REPRESENTATION OF IMPOSED PRESSURES ON THE p_o DIAGRAM

The pressure distributions computed by using the charts in Section 2.4, can be shown superimposed on the p_o diagram as shown in Figure 2-7. As discussed in the previous sections, an applied pressure at the surface causes stress increments within the soil mass that decrease with depth due to spatial attenuation. This is shown in Figure 2-11 where Δp is plotted with respect to the p_o line that represents the existing geostatic stress distribution. As can been seen in Figure 2-11, Δp approaches the p_o line, which indicates that at a sufficient depth the effect of the externally imposed loads reduces significantly. In other words, this means that most of the strain due to the increased stress from the applied load will be experienced at relatively shallow depths below the load. As noted earlier, this depth is known as the **depth of significant influence (DOSI)**, D_S. Also, as indicated previously, D_S depends on the load and load configuration as demonstrated by the pressure distribution charts in Section 2.4. Figure 2-11 also shows that that the **final stress, p_f, in the soil mass at any depth is equal to $p_o + \Delta p$**.



(a)



(b)

Figure 2-10. Distribution of vertical stress by the 2:1 method (after Perloff and Baron, 1976).

A chart such as that shown in Figure 2-11 is even more useful when the soil stratigraphy is plotted on it. Then the stress levels in various layers will be clearly identified, which can help the engineer determine depth of borings to collect subsurface information within DOSI as well as perform proper analysis.

Example 2-2 illustrates these concepts by providing calculations of p_f with depth due to stress increments from a strip load and presenting the results of the calculations on a p_o-diagram.

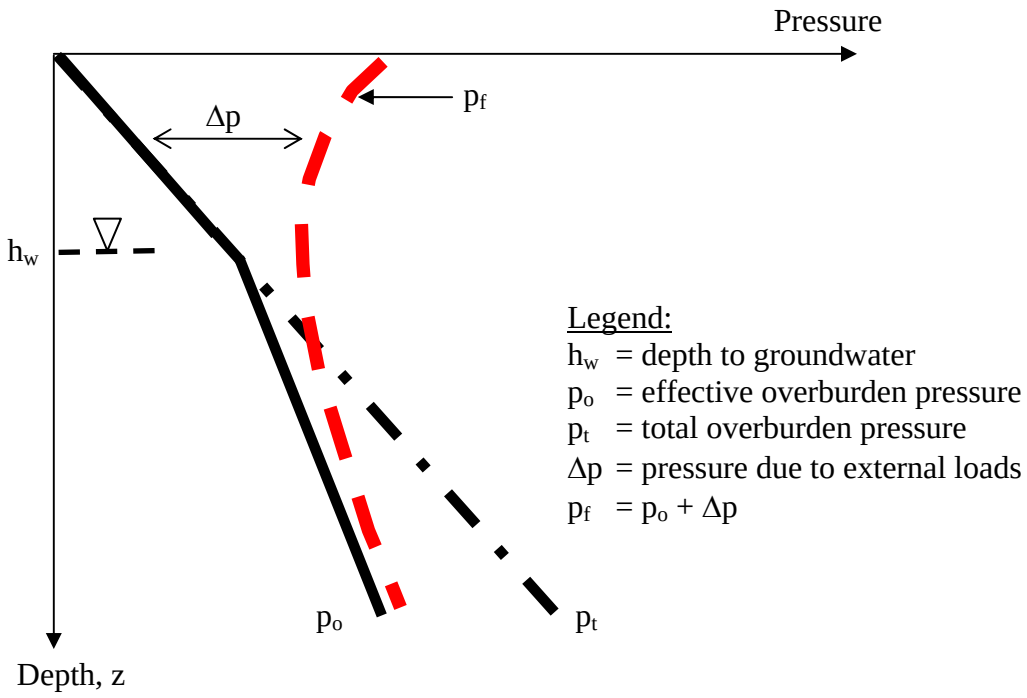
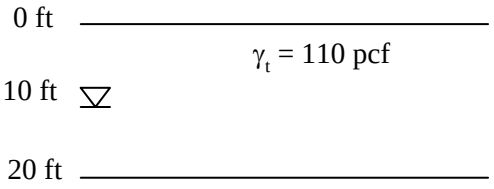


Figure 2-11. Combined plot of overburden pressures (total and effective) and pressure due to imposed loads.

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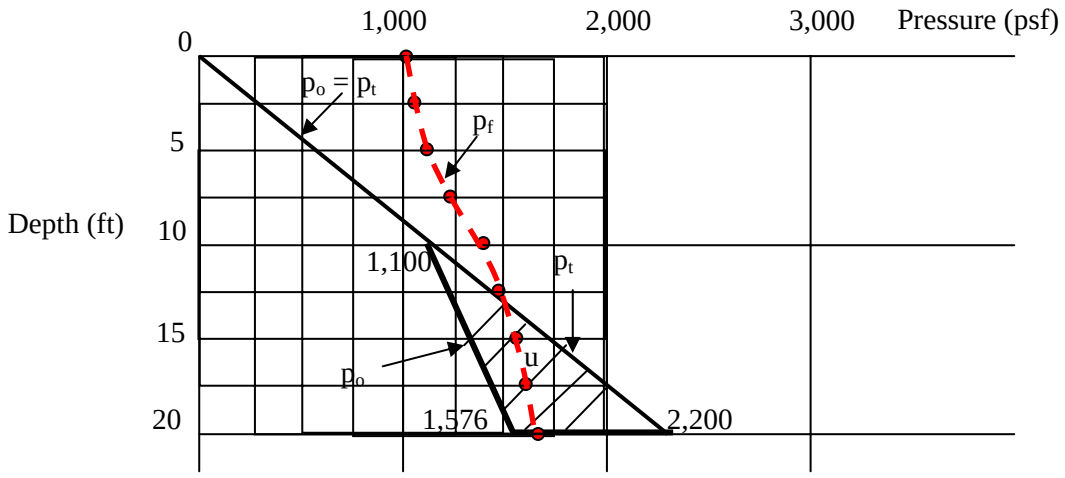
Example 2-2: For the Example 2-1 shown in Figure 2-7, assume that a 5 ft wide strip footing with a loading intensity of 1,000 psf is located on the ground surface. Compute the stress increments, Δp, under the centerline of the footing and plot them on the p_o diagram shown in Figure 2-7 down to a depth of 20 ft.



Solution:

For the strip footing, use the left chart in Figure 2-9. As per the terminology of the chart in Figure 2-9, B = 5 ft and q_o= 1,000 psf. Compile a table of stresses for various depths and plot as follows:

Depth z, ft	z/B	Isobar Value, x	Stress, $\Delta p = x(q_o)$, psf	p_o, psf	$p_f = p_o + \Delta p$ psf
2.5	0.5	0.80	800	(110)(2.5)=275	1,075
5.0	1.0	0.55	550	(110)(5.0)=550	1,100
7.5	1.5	0.40	400	(110)(7.5)=825	1,225
10.0	2.0	0.32	320	(110)(10.0)=1,100	1,420
12.5	2.5	0.25	250	1,100+(12.5-10.0)(110-62.4)=1,219	1,469
15.0	3.0	0.20	200	1,100+(15.0-10.0)(110-62.4)=1,338	1,538
17.5	3.5	0.18	180	1,100+(17.5-10.0)(110-62.4)=1,457	1,637
20.0	4.0	0.16	160	1,100+(20.0-10.0)(110-62.4)=1,576	1,736



Pressure Diagram

Figure 2-12. Example calculation of p_f with stress increments from strip load on p_o-diagram.

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2.6 LOAD-DEFORMATION PROCESS IN SOILS

When subjected to static and/or dynamic loads, soils deform mainly because of a change in void volume rather than through deformation of the soil solids. When the void volume decreases the soil is said to compress, consolidate, collapse or compact. There is an important distinction between these four mechanisms although conceptually they appear to be the same since each pertains to a reduction in volume.

- ***Compression***: Compression is defined as a relatively rapid decrease in void volume that partially saturated (unsaturated) soils undergo as air is expelled from the voids during loading.

- ***Consolidation:*** Consolidation is generally defined as a time-dependent decrease in void volume that saturated and near-saturated soils undergo as water is expelled from the voids during loading. The conceptual process of consolidation is discussed in Section 2.6.1.

- ***Collapse:*** Collapse is primarily related to soil structure and its response to an increase in water content that results in a rapid decrease in void volume. Collapse-susceptible soils characteristically have dry densities less than approximately 100 pcf (16 kN/m^3) that suggest high void ratios. Their structure is like a honeycomb with fine-grained "bridges" connecting coarser-grained particles. When dry, these soils are able to sustain externally applied loads with very little deformation. However, upon being wetted they tend to undergo a rapid decrease in void volume as the fine-grained "bridges" lose strength and the entire structure collapses. The magnitude of the potential collapse increases with increasing load. One of the important things to note is that full saturation (S=100%) is not required for these types of soils to collapse. Often collapse occurs at a degree of saturation of 50 to 70%. Collapse-susceptible soils are very common in the southwest and midwest of the United States and in many other parts of the world.

- ***Compaction***: Compaction is the name given to the compression that takes place generally under an impact-type loading (e.g., modified and standard Proctor), a static loading (e.g., rubber-tired or steel drum rollers) or kneading-type loading (e.g., sheepsfoot roller). Most commonly, the compaction processes are deliberate and intended to achieve a dense packing of soil particles. Regardless of the type of loading, the moisture content of the soil being compacted is far enough below the saturation moisture content that the compaction mechanism is considered to be related to compression (i.e., expulsion of air) rather than consolidation (i.e., expulsion

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of water) from the voids. Typically, the desired moisture content in the case of compaction is slightly above or below the PL. If the moisture content of the soil being compacted gets to be too close to the saturation moisture content then "pumping" will occur, i.e. water in addition to air will be forced out of the soil.

These distinctions in load-deformation processes should be kept in mind during the discussions that follow in subsequent sections of this chapter.

Finally, in contrast to the above processes that involve void volume decrease, there are conditions under which soils may actually increase in volume. When the void volume increases under static and/or dynamic load, the soil is said to **dilate**. **Dilation** can occur in either saturated or partially saturated soils. It is a function of the initial void ratio, confinement stress, and the magnitude and direction of the loading/unloading imposed on the soil. **Expansion**, on the other hand, is generally considered to be due to the presence of expansive clay minerals, such as montmorillonite (commercially known as "bentonite"), in the soil and the response of these minerals to the introduction of water into the void spaces. The physico-chemical properties of expansive clay minerals cause inter-particle repulsions to take place in the presence of water so that even under considerable externally applied loads these soils will undergo an increase in void volume that leads to swelling. A variation of the expansion is **heave** which can occur due to various factors such as frost action or reduction in overburden pressure due to excavation.

2.6.1 Time Dependent Load-Deformation (Consolidation) Process

Deformation of a saturated soil is more complicated than that of a dry soil since water, which fills the voids, must be squeezed out of the soil before readjustment of the soil grains can occur. The more permeable a soil is, the faster the deformation under load will occur. However, when the load on a saturated soil is quickly increased, the increase is initially carried by the pore water resulting in the buildup of an **excess pore water pressure**, **Δu**. **Excess pore water pressure is water pressure greater than the hydrostatic pressure.** As drainage of the water takes place more and more load is gradually transferred from the pore water to the soil grains until the excess pore water pressure has dissipated completely and the soil grains readjust to a denser configuration under the applied load. This time dependent process is called **consolidation** and results in a decreased void ratio and greater unit weight relative to conditions before the load was applied. To illustrate this concept, one-dimensional (vertical) drainage of the water will be considered here. The process is analogous to loading a spring-supported piston in a cylinder filled with water. The spring-piston analogy is shown schematically in Figure 2-13 and is briefly discussed below.

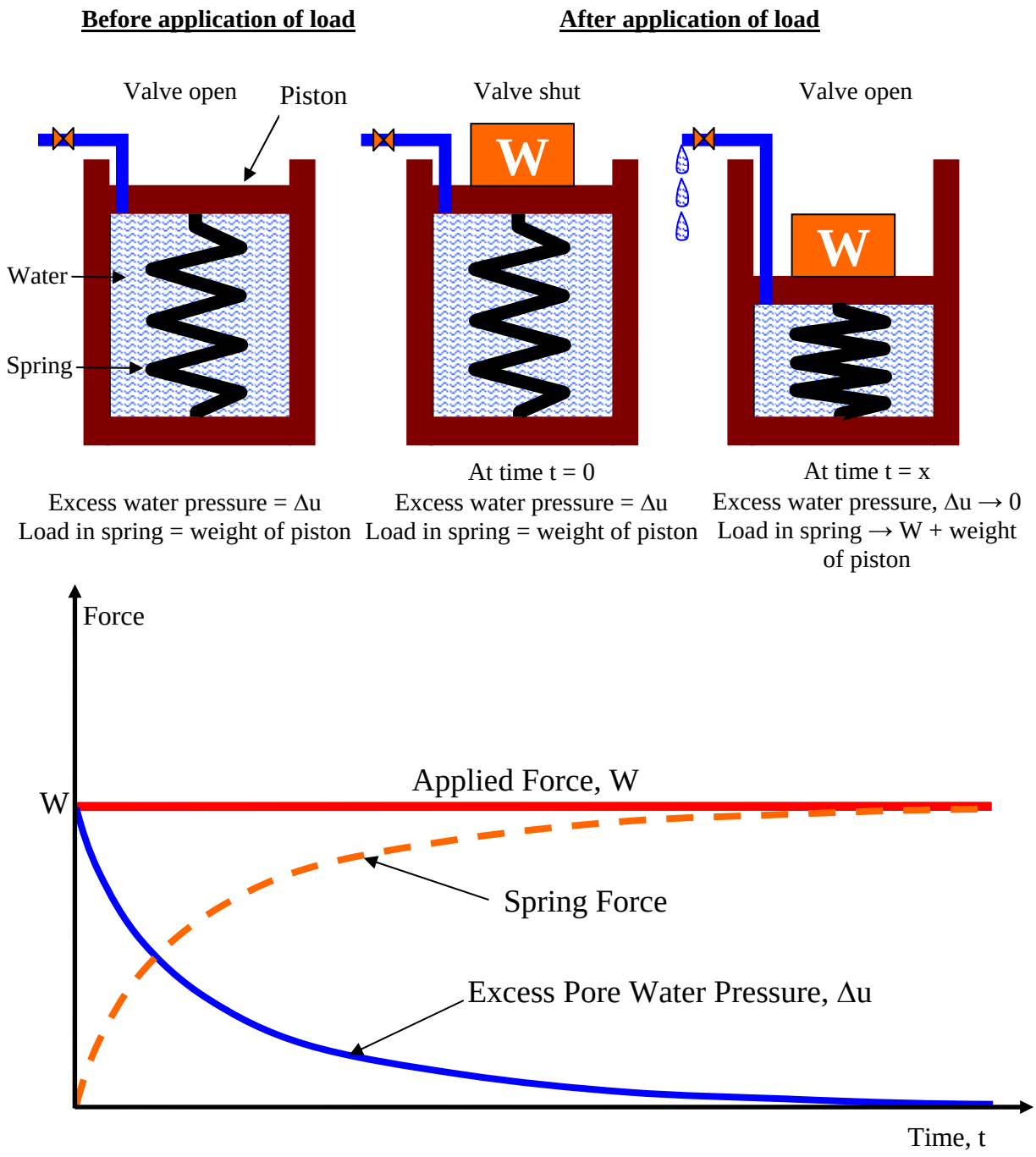


Figure 2-13. Spring-piston analogy for the consolidation process in fine-grained soils.

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In the spring-piston model, the spring represents the solid phase of the soil and the water below the piston is the pore water under saturated condition in the soil mass. Before a new load, W, is applied to the piston, the system is assumed to be in equilibrium, i.e., the drainage valve is open and there is no excess pore water pressure, $\Delta u = 0$. The spring alone is carrying any previously applied loads, such as the weight of the piston itself. The drainage valve is closed just before the new load is applied. If the valve is completely shut-off and the piston is leak-proof, then, there is no chance for water to escape. Such a condition represents a clay-water system in which the clay is very impermeable so that there is significant resistance to drainage of water in any direction. When the new load, W, is placed on the piston (this is called the initial or "time = 0" condition), the total applied pressure immediately below the piston, p_t, which equals the load, W, divided by the area of the piston, is immediately transferred to the water. Since the drainage valve is closed and water is virtually incompressible, the water pressure increases to a value equal to the total applied pressure, i.e., the excess water pressure $\Delta u = p_t$.

At "time = 0," the spring does not carry any of the applied load W. The excess water pressure is analogous to the pore water pressure that would be developed in a clay-water system under externally applied loads, e.g., loads due to construction of an embankment on soft saturated clay. If the valve is now opened, the water will drain to relieve the excess pressure in it. With the escape of the water, a part of the pressure carried by the water is transferred to the spring where it induces a stress increase analogous to an effective increase in the inter-particle stresses, $p_{o,}$ in a soil mass. The transfer of pressure from the water to the spring occurs over a period of time as shown on the bottom part of Figure 2-13, however, at any time during the process, the increased stress in the spring, p_o, plus the excess pressure in the water, Δu, must equal the applied pressure, p_t. This transfer of pressure from the water to the spring goes on until the flow stops. At that time all of the applied pressure, p_t, will be carried by the spring, p_o, and none by the water, i.e., $\Delta u = 0$, and the system will have come into equilibrium under the applied load. The time required to attain equilibrium depends on the avenue provided to the water to escape, i.e., the longest drainage path the water has to take to leave the system. In Figure 2-13 the longest drainage path is the length of the cylinder. Obviously, the system would drain quicker if there were another standpipe-type drain at the bottom of the cylinder.

Regardless of the number of avenues provided for drainage, the rate of excess water pressure drop generally decreases with time as shown in the lower half of Figure 2-13. After the spring water system attains an equilibrium condition under the imposed load, the compression of the piston is analogous to the settlement of the clay-water system under an externally applied load. This process is called **consolidation**.

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2.6.2 Comparison of Drainage Rates between Coarse-Grained and Fine-Grained Soils

Figure 2-14 shows a comparison of excess pore water pressure dissipation in coarse-grained and fine-grained soils. The relatively large pore spaces in coarse-grained soils permit the water to drain quicker in comparison to fine-grained soils. This leads to a quick transfer of applied loads to the soil solids with an associated decrease in void space. This quick load transfer results in a displacement that is commonly termed "rapid" in contrast to the "long-term" displacement that is associated with the consolidation process in fine-grained soils.

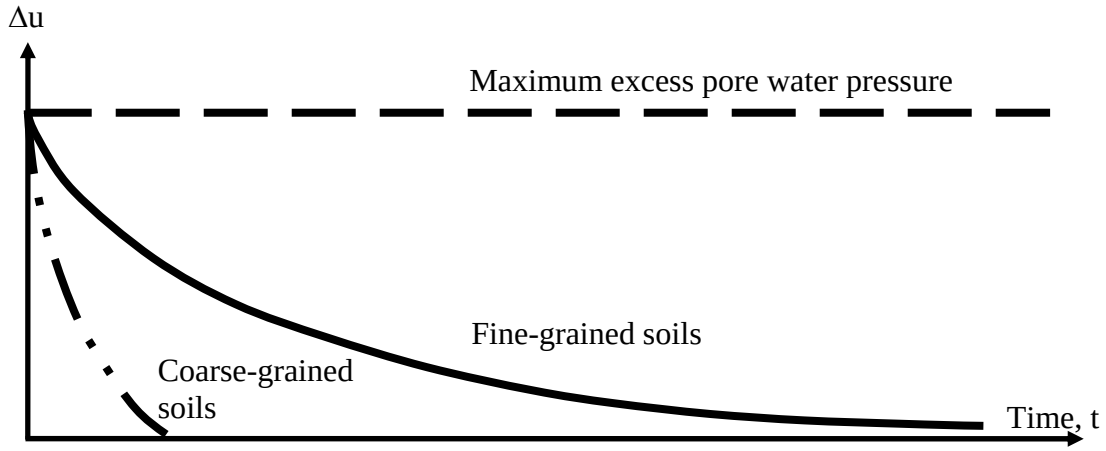


Figure 2-14. Comparison of excess pore water pressure dissipation in coarse-grained and fine-grained soils.

2.7 LATERAL STRESSES IN FOUNDATION SOILS

In most cases, the vertical stress at any depth in a soil mass due to its self weight is the summation of the simple products of the unit weight of each soil layer and its corresponding thickness down to the depth of interest. This vertical stress was denoted by p_t and the effective component of this pressure was denoted by p_o. Due a variety of factors, including depositional patterns, the lateral stress, p_h, in a soil mass is usually not the same as the vertical stress, p_o. Since the vertical stress is known with reasonable certainty for practical purposes, the lateral stress can be assumed to be a certain percentage of the vertical stress and can be expressed as follows:

$$p_h = K\, p_o \qquad 2\text{-}14$$

For an elastic solid, the value of the proportionality constant, K, can be expressed in terms of Poisson's ratio, ν, as follows:

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$$K = \frac{\nu}{1 - \nu} \qquad 2\text{-}15$$

Poisson's ratio, ν, is defined as a ratio of lateral to vertical strains. The value of Poisson's ratio is a function of the type of material, e.g., ν is practically zero for cork (hence its suitability as a bottle stopper), for concrete ν is between 0.1 and 0.2, and for steel ν is between 0.27 and 0.30. A theoretical upper limit of Poisson's ratio is 0.5 (rubber comes close to this limiting value). In the case of soils, ν will have a different value depending upon the type of soil and its moisture condition. For example, for free-draining soils a reasonable value of ν would be in the range of 0.25 to 0.35, while for very soft saturated clays under rapid loading conditions the value of ν would be close to 0.5. Thus, for free-draining soils, the value of K based on elasticity theory will range from 33% to 54% corresponding to ν=0.25 and ν=0.35, respectively, while for soft clays the value of $K \approx 1$ since $\nu \approx 0.5$.

Even though a soil mass is not an elastic body, the point to be noted here is that at any point within the soil mass both vertical and horizontal (or lateral) stresses exist. When external forces are imposed on a soil mass, they will result in an increase in vertical stresses as discussed in Sections 2.5 and 2.6. Equation 2-14 indicates that an increase in vertical stresses will in turn lead to an increase in lateral stresses. While the increase in vertical stresses is important in assessing vertical settlements, change in lateral stresses may affect the load acting, for example, against piles supporting a bridge abutment, see Figure 2-15. In this figure, it can be seen that the increase in vertical stress imposed by the embankment leads to an increase in the lateral stress in the ground that causes lateral deformation ("squeeze") of the soft soil. As the soft soil spreads laterally it will have an effect on foundations. Therefore, it is important to evaluate the increase in lateral stresses due to vertical loadings.

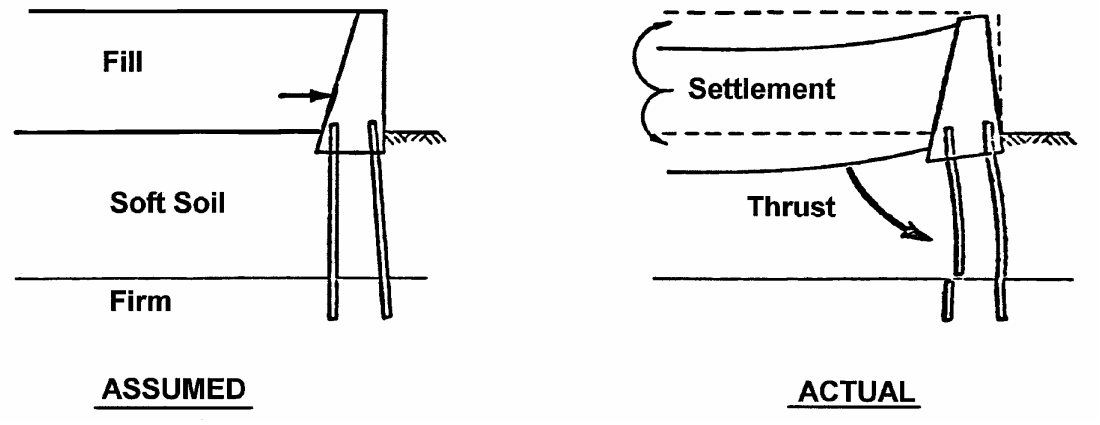


Figure 2-15. Schematic of effect of lateral stresses.

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A two-dimensional (2-D) representation of the lateral stresses transverse to an embankment centerline is shown in Figure 2-16. This schematic was developed with a soft layer of soil under the embankment. It can be seen that significant lateral stresses are generated in the soil below the embankment load. Note that the vertical stresses due to the embankment can cause zones of tensile stresses to develop near the toes of the embankment as shown by the hatched zones in Figure 2-16. This means that tensile cracks are likely to develop near the toes of the embankments for this particular case. This knowledge can help the geotechnical specialist to select proper ground improvement measures rationally and to develop and implement an instrumentation program. The key point to understand based on the schematics shown in Figures 2-15 and 2-16 is that lateral deformations can be three-dimensional and can affect a number of facilities such as buried utilities, embankment slopes and bridge foundations. Lateral deformations can also affect off-site structures very easily leading to potential legal actions. The three-dimensional (3-D) lateral deformations coupled with vertical deformations due to vertical stresses can create a complex state of deformation that needs to be carefully considered in the design of geotechnical features.

Similar to the estimation of vertical stresses, the theory of linear elasticity yields equations for lateral stress distribution. However, in these equations Poisson's ratio is assumed to be a constant. Hence, the use of chart solutions in these cases is not as simple as for the vertical stress case since complicated equations have to be evaluated (Poulos and Davis, 1974). One can prepare spreadsheet solutions based on the equations or use commercially available computer programs that have already programmed the equations. Program FoSSA (2003) by ADAMA Engineering (Version 1.0 was licensed to FHWA) is an example of a program capable of computing the vertical and lateral stresses due to surface loading, including embankment and multiple footings. Figures 2-10 and 2-16 were generated using the FoSSA program.

2.7.1 Effect of Shear Strength of Soils on Lateral Pressures

Up to now the stresses in soils have been explained by using unit weights and the theory of elasticity. Elastic theory, when suitably modified to reflect observed phenomena in soils, provides a tool to obtain a reasonable first approximation to a solution for many problems in geotechnical engineering. However, elastic theory does not recognize the role of shear strength of soil in the development of lateral pressures. For example, soils have an ability to stand vertically or at a certain slope. The reason for this observed ability is that soil has shear strength and to some degree can support itself. This shear strength may come from friction and/or cohesion between the soil particles. It is intuitive that these components of shear strength should also somehow affect the lateral pressures in soils computed by use of the theory of elasticity. The shear strength of soils and its representation for analytical purposes

is discussed in the Section 2.8 followed in Section 2.9 by a demonstration of how the shear strength parameters can be used to express lateral pressures. Readers are referred to Lambe and Whitman (1979) or Holtz and Kovacs (1981) for detailed discussions.

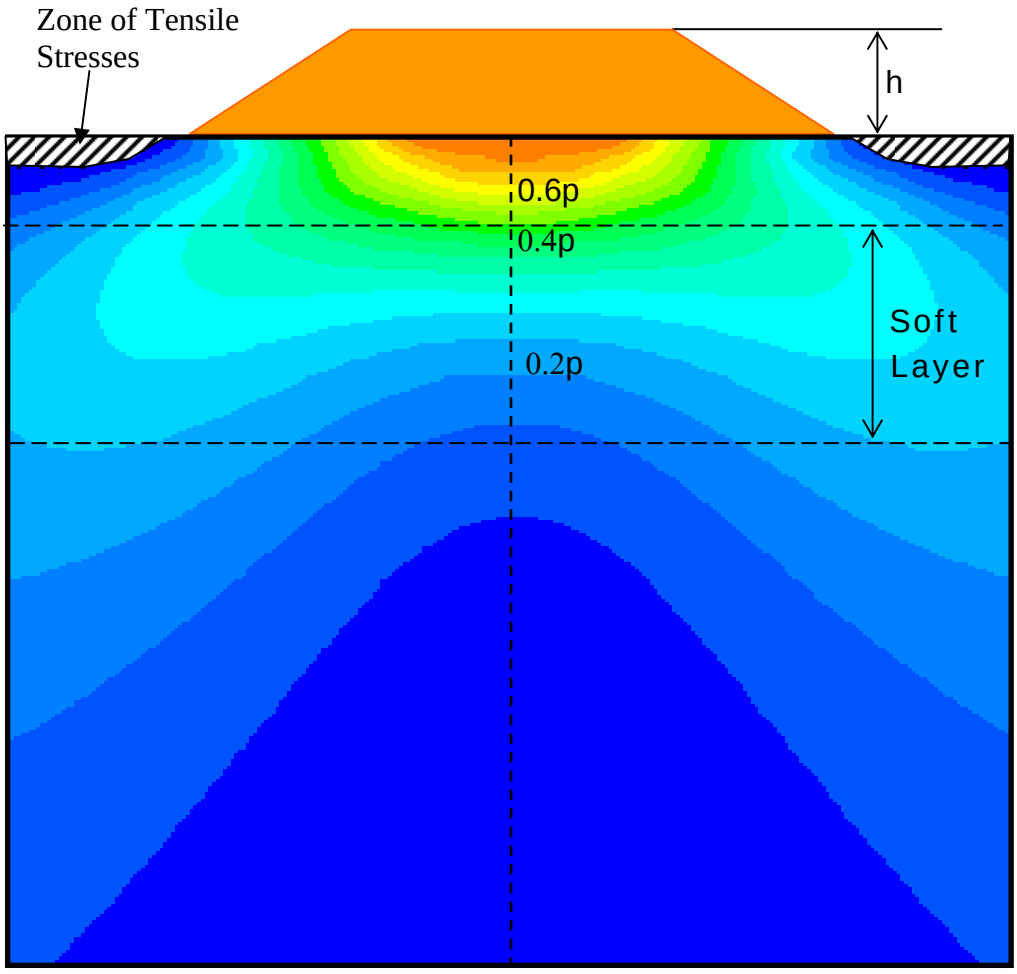


Figure 2-16. Schematic of vertical stress distribution under embankment loading. Graphic generated by FoSSA (2003) program.

(Note: Version 1.0 of FoSSA program is licensed to FHWA. See Appendix E for a brief overview of the FoSSA program).

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2.8 STRENGTH OF SOILS TO RESIST IMPOSED STRESSES

If the imposed stress in a soil mass is increased until the deformations (movements) become unacceptably large, a "failure" is considered to have taken place. In this case, the strength of the soil is considered to be insufficient to withstand the applied stress.

The strength of geologic materials is a variable property that is dependent on many factors, including material properties, magnitude and direction of the applied forces and their rate of application, drainage conditions of the mass, and the magnitude of confining pressure. Unlike steel whose strength is usually discussed in terms of either tension or compression and concrete whose strength is generally discussed in terms of compressive strength only, the strength of soil is generally discussed in terms of shear strength. Typical geotechnical failures occur when the shear stresses induced by applied loads exceed the soil's shear strength somewhere within the soil mass.

2.8.1 Basic Concept of Shearing Resistance and Shearing Strength

The basic concept of shearing resistance and shearing strength can be understood by first studying the principle of friction between solid bodies. Consider a prismatic block B resting on a plane surface XY as shown in Figure 2-17. The block B is subjected to two forces:

- A normal force, P_n, that acts perpendicular to the plane XY, and
- A tangential force, F_a, that acts parallel to the plane XY.

Assume that the normal force, P_n, is constant and that the tangential force, F_a, is gradually increased. At small values of F_a, the block B will not move since the applied force, F_a, will be balanced by an equal and opposite force, F_r, on the plane of contact XY. The resisting force, F_r, is developed as a result of surface roughness on the bottom of the block B and the plane surface XY. The angle, θ, formed by the resultant R of the two forces F_r and P_n with the normal to the plane XY is known as the **angle of obliquity**.

If the applied horizontal force, F_a, is gradually increased, the resisting force, F_r, will likewise increase, always being equal in magnitude and opposite in direction to the applied force. When the force F_a reaches a value that increases the angle of obliquity to a certain maximum value θ_m, the block B will start sliding along the plane. Recall that during this entire process the normal force, P_n, remains constant. The following terminology can now be developed:

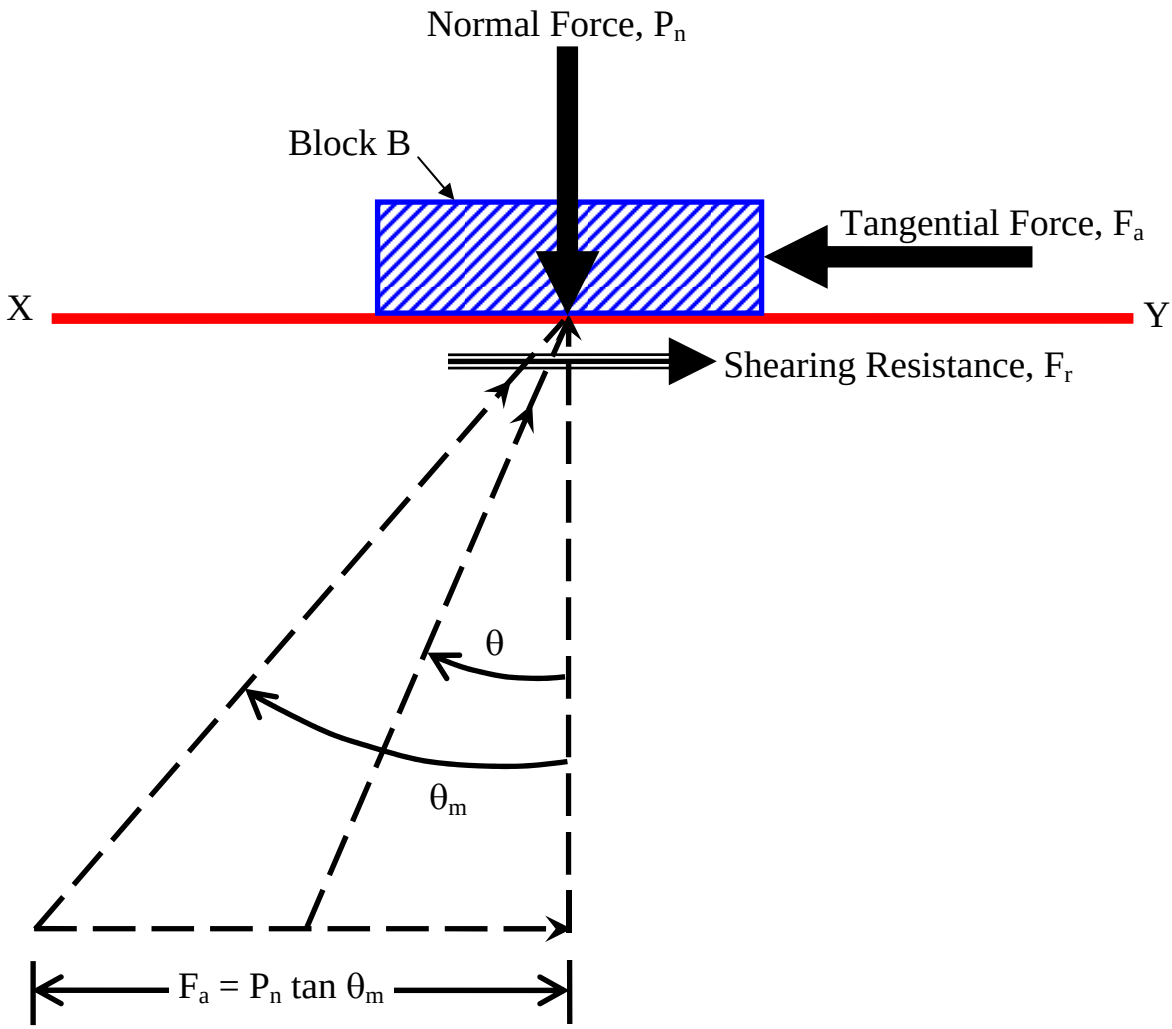


Figure 2-17. Basic concept of shearing resistance and strength (after Murthy, 1989).

- If the block B and the plane surface XY are made of the same material, the angle θ_m is equal to ϕ, which is termed the **angle of friction** of the material. The value tan ϕ is called the **coefficient of friction**.

- If the block B and the plane surface XY are made of dissimilar materials, the angle θ_m is equal to δ, which is termed the **angle of interface friction** between the bottom of the block and the plane surface XY. The value tan δ is called the **coefficient of interface friction**.

- The applied horizontal force, F_a, on the block B is a shearing force and the developed force is called **frictional resistance** or **shearing resistance**. The maximum frictional or

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shearing resistance that the materials are capable of developing on the interface is $(F_a)_{max}$.

If the same experiment is conducted with a greater normal force, P_n, the maximum frictional or shearing resistance $(F_a)_{max}$, will be correspondingly greater. A series of such experiments would show that for the case where the block and surface are made of the same material, the maximum frictional or shearing resistance is approximately proportional to the normal load P_n as follows:

$$(F_a)_{max} = P_n \tan \phi \qquad 2\text{-}16$$

If A is the overall contact area of the block B on the plane surface XY, the relationship in Equation 2-16 may be written as follows to obtain stresses on surface XY:

$$\frac{(F_a)_{max}}{A} = \left(\frac{P_n}{A}\right)\tan\phi \qquad 2\text{-}17$$

or

$$\tau = \sigma_n \tan\phi \qquad 2\text{-}18$$

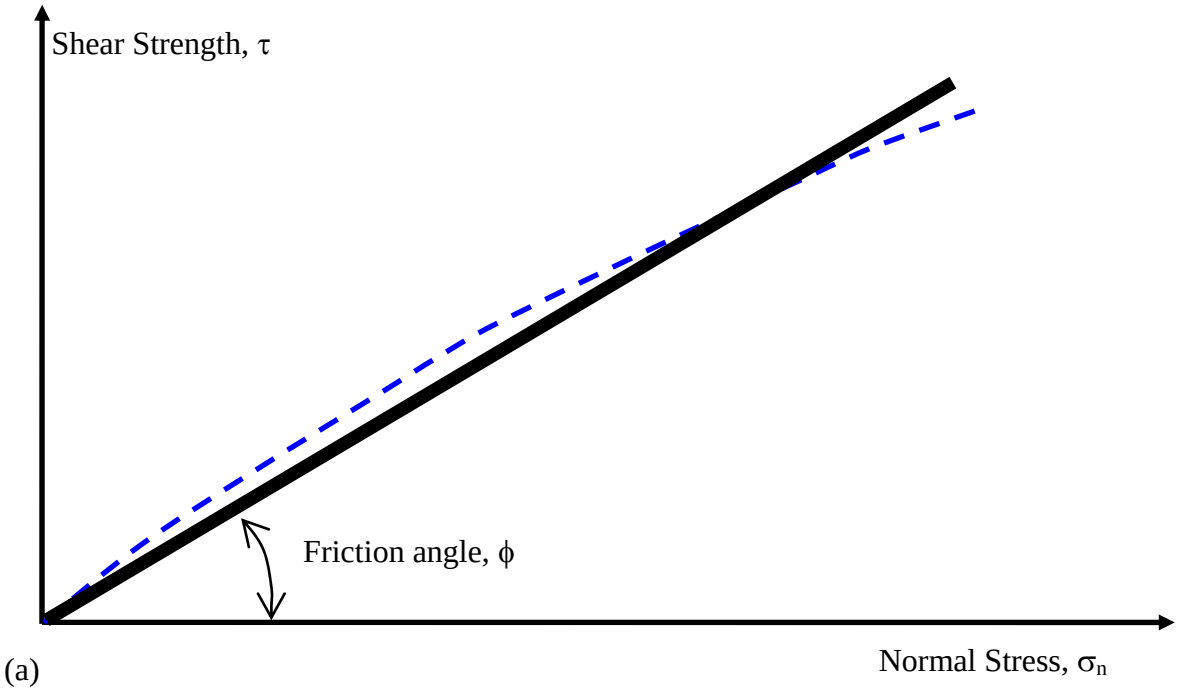
The term σ_n is called the **normal stress** and the term τ is called the **shear strength**. A graphical representation of Equation 2-18 is shown in Figure 2-18a. In reality, the relationship is curved, but since most geotechnical problems involve a relatively narrow range of pressures, the relationship is assumed to be linear as represented by Equation 2-18 over that range.

The concept of frictional resistance explained above applies to soils that possess only the frictional component of shear strength, i.e., generally coarse-grained granular soils. But soils that are not purely frictional exhibit an additional strength component due to some kind of internal electro-chemical bonding between the particles. This bonding between the particles is typically found in fine-grained soils and is termed **cohesion, c**. Simplistically, the shear strength, τ, of such soils is expressed by two additive components as follows and can be graphically represented as shown in Figure 2-18(b):

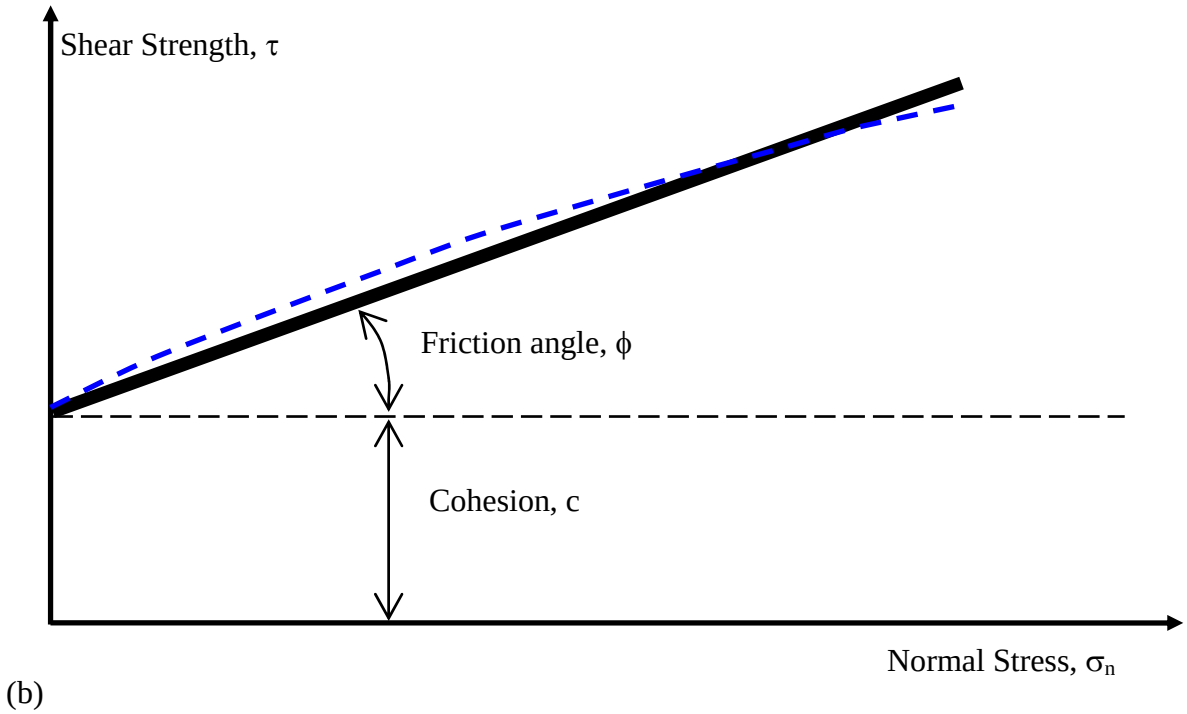
$$\tau = c + \sigma_n \tan\phi \qquad 2\text{-}19$$

Again, in reality, the relationship is curved. But, as noted above, since most geotechnical problems involve a relatively narrow range of pressures, the relationship is assumed to be linear as represented by Equation 2-19 over that range.

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(a)



(b)

Figure 2-18. Graphical representation of shearing strength.

Equation 2-19 was first proposed by French engineer Coulomb and is used to express shear strength of soils. When plotted on arithmetic axes the resulting straight line is conventionally known as the Mohr-Coulomb (M-C) failure envelope. "Mohr" is included in "Mohr-Coulomb" because Equation 2-19 can also be derived based on concept of Mohr's circle. The development of the Mohr-Coulomb failure envelope based on the application of Mohr's circle is presented in Appendix B.

As indicated previously, the deformation of soils occurs under effective stresses. In terms of effective stresses, Equation 2-19 can be re-written as follows:

$$\tau' = c' + (\sigma_n - u) \tan \phi' = c' + \sigma' \tan \phi' \qquad 2\text{-}20$$

where c' = effective cohesion, σ' is the effective normal stress and ϕ' is the effective friction angle. Further discussion on the cohesion and friction angle is presented in Chapter 4.

In geotechnical engineering, the normal stresses are commonly expressed using the overburden pressure concept introduced in Section 2.3. In terms of overburden pressure, the term σ_n in above equations is the same as p_t and the term σ' is the same as p_o. Thus, Equations 2-19 and 2-20 can be expressed in terms of overburden stresses as follows:

$$\tau = c + p_t \tan\phi \qquad 2\text{-}21$$

$$\tau' = c' + (p_t - u) \tan \phi' = c' + p_o \tan \phi' \qquad 2\text{-}22$$

Since this manual relates to geotechnical engineering, Equations 2-21 and 2-22 will be used to express the M-C failure envelope. The physical meaning of the M-C failure envelope shown in Figure 2-18(a) and Figure 2-18(b) may be explained as follows:

- Every point on the M-C failure envelope represents a combination of normal and shear stress that results in failure of the soil, i.e., the Mohr failure envelope essentially defines the strength of the soil. In other words, **any point along the M-C envelope defines the limiting state of stress for equilibrium**.

- If the state of stress is represented by a point below the M-C failure envelope then the soil will be stable for that state of stress.

- States of stress beyond the M-C failure envelope cannot exist since failure would have occurred before that point could be reached.

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2.9 STRENGTH OF SOILS RELATED TO LATERAL EARTH PRESSURES

The concept of shear strength described in the previous section can now be used to understand the phenomenon of lateral earth pressure in a soil mass, which is related to problems of slope stability and earth retention. From a theoretical viewpoint, problems in these three areas (earth pressures, slope stability, and retaining structures) fall into a class of problems involving plasticity theory and are best solved by some form of equilibrium solution. Many geotechnical engineering text books (e.g., Lambe and Whitman, 1979; Holtz and Kovacs, 1981) deal with these solutions extensively. From a practical viewpoint, values of earth pressure are needed either directly or indirectly to determine:

a) If an unrestrained slope is stable and
b) If not, what kind of retaining structure will be required to stabilize the slope.

The simplest consideration of earth pressure theory starts with the assessment of the vertical geostatic effective stress, p_o, at some depth in the ground (effective overburden pressure) as considered in Section 2.3. The lateral geostatic effective stress, p_h, at this depth is given in general terms by Equation 2-14 where, for an ideally elastic solid, the value of the lateral earth pressure coefficient, K, is given by Equation 2-15. However, the behavior of real soils under loads is not always ideally elastic. To simplify the discussion of this topic, consider only dry coarse-grained cohesionless soils. The geostatic effective stress condition on a soil element at any depth, z, is shown in Figure 2-19a. Since the ground is "at-rest" without any external disturbance, this condition is commonly referred to as the "**at-rest**" condition with zero deformation. The coefficient of lateral earth pressure for this condition is labeled $\mathbf{K_o}$.

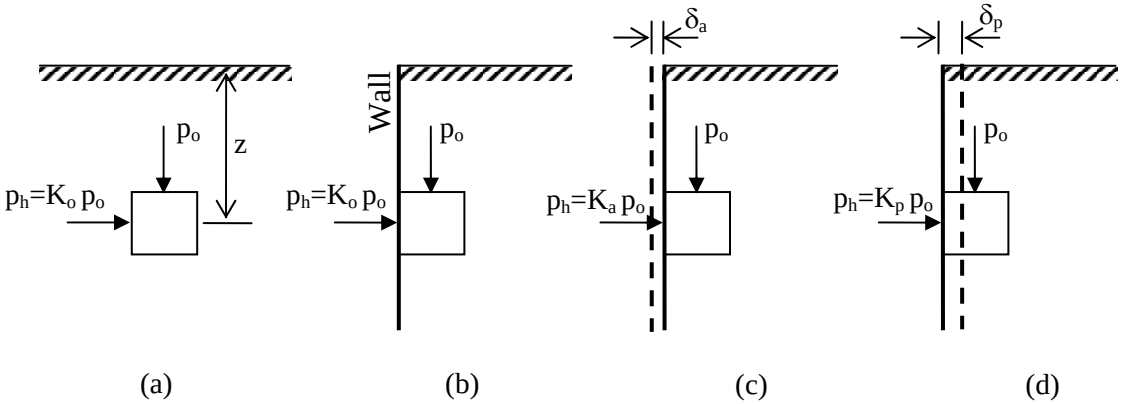


Figure 2-19. Stress states on a soil element subjected only to body stresses: (a) In-situ geostatic effective vertical and horizontal stresses, (b) Insertion of hypothetical infinitely rigid, infinitely thin frictionless wall and removal of soil to left of wall, (c) Active condition of wall movement away from retained soil, (d) Passive condition of wall movement into retained soil.

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To relate to the lateral earth pressures acting on retaining structures, assume that a hypothetical, infinitely thin, infinitely rigid "wall" is inserted into the soil without changing the "at rest" stress condition in the soil. For the sake of discussion, assume that the hypothetical wall maintains the "at rest" stress condition in the soil to the right of the wall when the soil to the left of the wall is removed. This condition is shown in Figure 2-19b. Now suppose that the "at rest" condition is removed by allowing the hypothetical vertical wall to move slightly to the left, i.e., away from the soil element as shown in Figure 2-19c. In this condition, the vertical stress would remain unchanged. However, since the soil is cohesionless and cannot stand vertically on its own, it actively follows the wall. In this event, the horizontal stress decreases, which implies that the lateral earth pressure coefficient is less than K_o since the vertical stress remains unchanged. When this occurs the soil is said to be in the "**active**" state. The lateral earth pressure coefficient at this condition is called the "**coefficient of active earth pressure," K_a**, and its value at failure is expressed in terms of effective friction angle, ϕ', as follows:

$$K_a = \frac{1 - \sin\phi'}{1 + \sin\phi'} \qquad 2\text{-}23$$

Returning to the condition shown in Figure 2-19b, now suppose that the "at rest" condition is removed by moving the hypothetical vertical wall to the right, i.e., into the soil element as shown in Figure 2-19d. Again, the vertical stress would remain unchanged. However, the soil behind the wall passively resists the tendency for it to move, i.e., the horizontal stress would increase, which implies that the lateral earth pressure coefficient would become greater than K_o since the vertical stress remains unchanged. When this occurs the soil is said to be in the "**passive**" state. The lateral earth pressure coefficient at this condition is called the "**coefficient of passive earth pressure," K_p**, and its value at failure is expressed in terms of effective friction angle, ϕ', as follows:

$$K_p = \frac{1 + \sin\phi'}{1 - \sin\phi'} \qquad 2\text{-}24$$

When failure occurs during either of the two processes described above, **"Rankine" failure zones** form within the soil mass. The details of how the failure zones develop are described in most geotechnical engineering textbooks and will not be treated here. The so-called "Rankine" failure zones and their angles from the horizontal are shown in Figure 2-20.

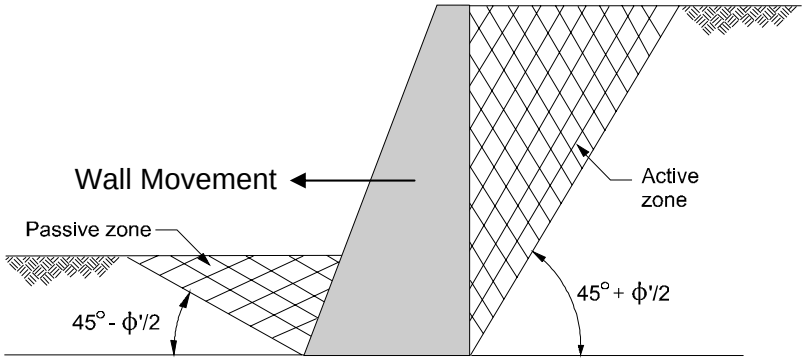


Figure 2-20. Development of Rankine active and passive failure zones for a smooth retaining wall.

2.9.1 Distribution of Lateral Earth and Water Pressures

The earth pressure coefficients, K_a and K_p, can be substituted into Equation 2-14 to obtain equations for active and passive lateral earth pressures, respectively as follows:

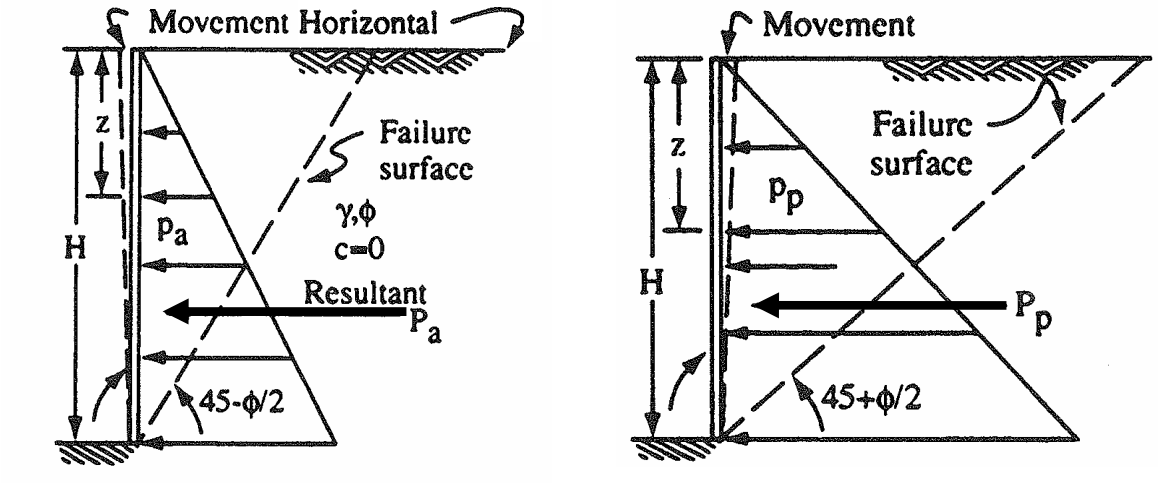
$$p_a = K_a\, p_o \qquad 2\text{-}25a$$

$$p_p = K_p\, p_o \qquad 2\text{-}25b$$

It can be seen from Equations 2-25a and 2-25b that the lateral pressures p_a and p_p are a certain fraction of the vertical effective overburden pressure p_o. Thus, active and passive lateral earth pressures are effective pressures and their distribution will be same as that for p_o. The overburden pressure increases in proportion to the unit weight and is typically triangular for a given geomaterial. The general distribution of the active and passive pressures along with the configuration of active and passive failure surfaces is shown in Figure 2-21a and 2-21b, respectively.

In cases where ground water exists, the lateral pressure due to the water at any depth below the ground water level is equal to the hydrostatic pressure at that point since the friction angle of water is zero and use of either Equation 2-23 or 2-24 leads to a coefficient of lateral pressure for water, K_w equal to 1.0. The computation of the vertical water pressure was demonstrated previously in Example 2-1. Since K_w=1, the same computation applies for the lateral pressure as well. The lateral earth pressure is computed by using the vertical effective overburden pressure p_o at any depth and applying Equations 2-25a and 2-25b. The lateral earth pressure is added to the hydrostatic water pressure to obtain the total lateral pressure acting on the wall at any point below the ground water level. For a typical soil friction angle of 30 degrees, K_a = 1/3. Since K_w = 1, it can be seen that the **lateral pressure due to water**

is approximately 3 times that due the active lateral earth pressure. A general case for the distribution of combined active lateral earth pressure and lateral water pressure is shown in Figure 2-22. As will be discussed in Chapter 10 (Earth Retaining Structures), this disparity in lateral pressures has serious consequences when the stability of walls is considered and is the reason why drainage behind walls is so important.



(a) (b)

Active pressure at depth z: $p_a = K_a \gamma z$ Passive pressure at depth z: $p_p = K_p \gamma z$

Active force within depth z: $P_a = K_a \gamma z^2/2$ Passive force within depth z: $P_p = K_p \gamma z^2/2$

Figure 2-21. Failure surfaces, pressure distribution and forces (a) active case, (b) passive case.

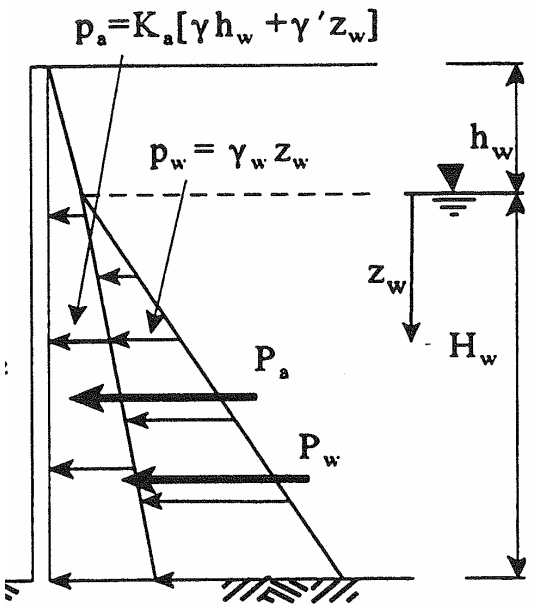


Figure 2-22. General distribution of combined active earth pressure and water pressure.

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2.9.2 Deformations Associated with Lateral Pressures

The active and passive pressures are predicated on the development of a certain amount of lateral deformation in the soil. The magnitudes of these lateral deformations and their effect on the development of earth pressures at failure are discussed in Chapter 10 (Earth Retaining Structures).

2.10 UNSATURATED SOIL MECHANICS

As discussed in this Chapter, soil is three phase system that consists of solid particles, liquid and gas. Classical soil mechanics concentrates primarily on the behavior of saturated or dry soils, i.e., a two phase system. For soils in a saturated state, the principle of effective stress is invoked to quantify stress and strain in the soil mass. For soils in a dry state, pore water pressure does not exist and the total stress and effective stress are the same. In reality, all the pore space in soil within the depth of significant influence of geotechnical features is rarely occupied by liquid or gas alone. This is particularly true for soils above the ground water table and soils that are mechanically compacted as in the case of earthworks. In such soils the degree of saturation is generally intermediate between 0% (dry soil) and 100% (saturated soil). Under these conditions, negative pore pressures, i.e., suction, may exist within the soil mass depending upon the type of soil and its grain size distribution. An example of the presence of negative pore pressures is the capillary rise often encountered above the water table. Such negative pore pressures affect all aspects of soil behavior ranging from volume change and shear strength to seepage. Consequently, unsaturated soil behavior impacts a broad array of engineering issues ranging from foundation design and performance to flow through earth embankments and the engineering of facilities on or in expansive, collapsible and compacted soils (ASCE 1993, 1997).

To date the tendency in engineering practice has often been to apply a total stress approach where the effects of negative pore pressures are not properly simulated. In the last couple of decades significant progress has been made to model such negative pore pressures and that field of study is often called “unsaturated soil mechanics.” Discussion of the engineering behavior of unsaturated soils is beyond the scope of this manual. At this stage, it is important simply to realize that advanced studies beyond those discussed in this manual may be required on projects where unsaturated state can significantly affect the engineering behavior of soils. The interested readers are directed to the work by Fredlund and Rahardjo (1993), who provide a comprehensive treatment of unsaturated soils.

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CHAPTER 3.0
SUBSURFACE EXPLORATIONS

To perform properly, a structure must interact favorably with the soil on which it rests. The modern geotechnical specialist, who often must build in areas that were considered too poor to build upon a few years ago, must be well versed in the fundamentals of soil mechanics. This knowledge will be used in the design of structural foundations and earthworks to answer the following questions. Will settlements be excessive? Can the structure tolerate settlements? Will the proposed foundation type perform better than another type? Can the foundation soils safely support the imposed embankment or footing loads? Will the proposed cut or fill slopes have adequate stability? Are the foundation and earthwork designs cost-effective?

The engineer should have adequate knowledge of the subsurface conditions at a site before attempting to answer these questions. A site- and project-specific subsurface model must be developed for the cost-effective engineering design of a facility. Figure 3-1 shows a flow chart that identifies a recommended process for developing a subsurface model for engineering design. The investment of a few tens of thousands of dollars in a systematic approach as outlined in Figure 3-1 could result in design and construction savings of hundreds of thousands of dollars by preventing costly failures or overly conservative designs.

The process shown in Figure 3-1 is logical and is generally followed on many projects. In many cases, however, old “rules-of-thumb” and “status quo” approaches can result in an unconscious “by-passing” of critical steps. In particular, selection of the correct tests to determine the relevant engineering properties, the interpretation of the results of those tests, and summarization of data are often poorly performed. Rigorous attention to the rational process in Figure 3-1 is required to assure efficient and thorough exploration and testing programs, especially since many projects are fragmented to the extent that drilling, testing, and design are performed by different parties. This document provides guidance on all the items presented in Figure 3-1. The three major steps in the flow chart in Figure 3-1 and the applicable chapters in this document are as follows:

Step 1: Subsurface Exploration and Field Testing (this Chapter)

Step 2: Laboratory Testing and Test Interpretation (Chapters 4 and 5)

Step 3: Engineering Design (Chapters 6 to 10 and Appendix A)

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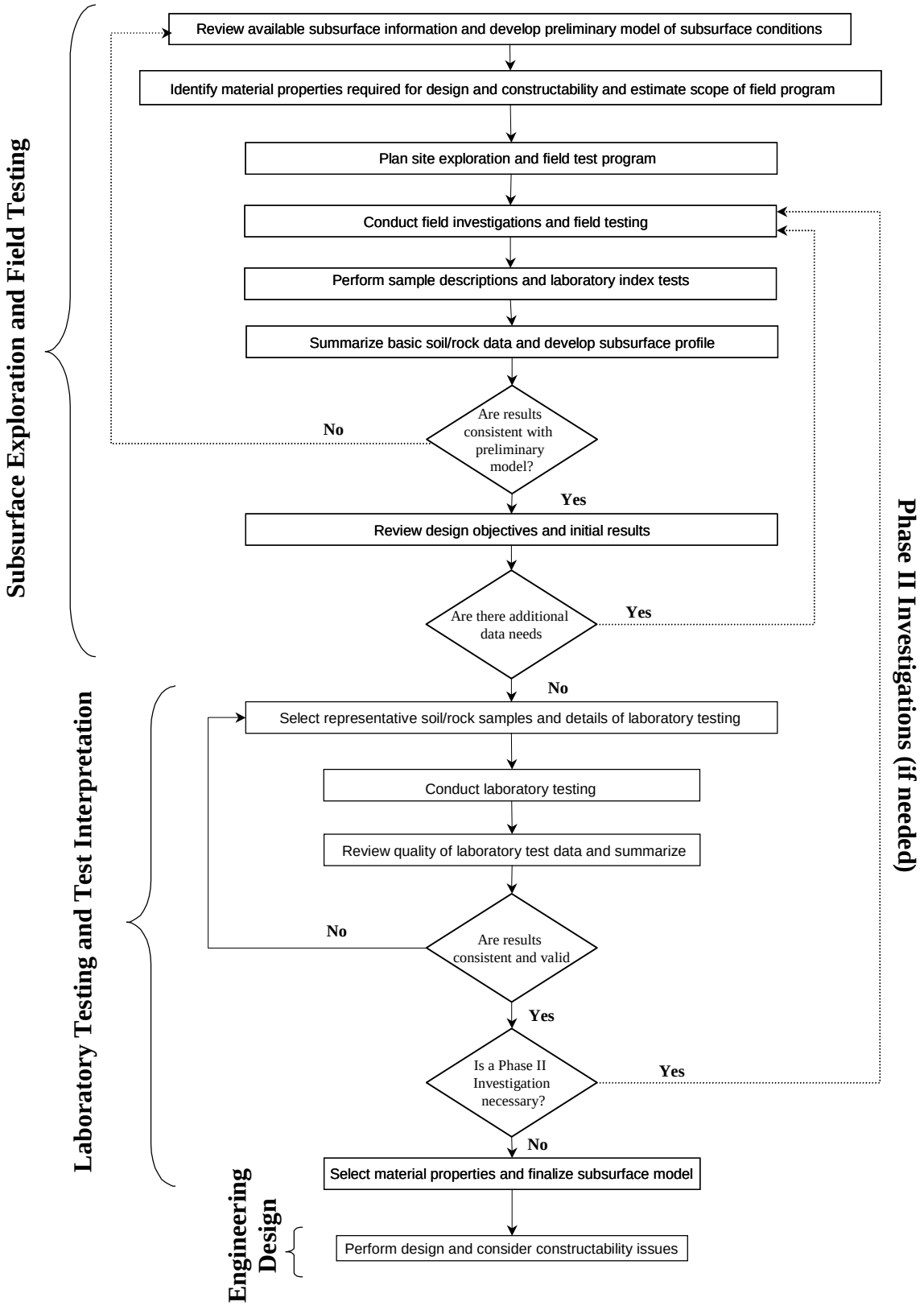


Figure 3-1. Recommended process for developing subsurface model for engineering design (FHWA, 2002a).

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3.01 Primary References

The primary references for this Chapter as well as Chapters 4 and 5 are as follows:

FHWA (2002a). *Geotechnical Engineering Circular 5 (GEC5) - Evaluation of Soil and Rock Properties*. Report No FHWA-IF-02-034. Authors: Sabatini, P.J, Bachus, R.C, Mayne, P.W., Schneider, J.A., Zettler, T.E., Federal Highway Administration, U.S. Department of Transportation.

FHWA (2002b). *Subsurface Investigations (Geotechnical Site Characterization)*. Report No. FHWA NHI-01-031, Authors: Mayne, P. W., Christopher, B. R., and DeJong, J., Federal Highway Administration, U.S. Department of Transportation.

AASHTO (2006). *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, Parts I and II, American Association of State Highway and Transportation Officials, Washington, D.C.

ASTM (2006). *Annual Book of ASTM Standards – Sections 4.02, 4.08, 4.09 and 4.13.* ASTM International, West Conshohocken, PA.

3.1 PREPARING FOR SUBSURFACE EXPLORATION

The initial step in any highway project must include consideration of the soil or rock on which the highway embankment and structures are to be supported. The extent of the site exploration will depend on many factors, not the least of which will be the project scheduling, general subsurface conditions, and the nature of the loads to be supported. In any event, certain basic steps should be followed before exploration equipment is mobilized to the project site. The first step in the exploration is to collect and analyze all existing data. A review of available information prior to the field reconnaissance will help establish what to look for at the site. In the Eighth Rankine Lecture, Glossop (1968) stated the following truism regarding site exploration: "**If you do not know what you should be looking for in a site investigation, you are not likely to find much of value.**" For a highway project, basic sources of geotechnical information should be reviewed to determine landform boundaries and to provide a basis for outlining the project subsurface exploration program. Those sources and functional uses are identified in Table 3-1.

Table 3-1
Sources of historical site data (after FHWA, 2002a)

Source	Functional Use	Location	Examples
Utility Maps	• Identifies buried utility locations • Identifies access restrictions • Prevents damage to utilities	Local agencies/utility companies	Power line identification prior to an intrusive exploration prevents extensive power outage, expensive repairs, and bodily harm
Aerial Photographs	• Identifies manmade structures • Identifies potential borrow source areas • Provides geologic and hydrological information which can be used as a basis for site reconnaissance • Track site changes over time	Local Soil Conservation Office, United States Geological Survey (USGS), local library, local & national aerial survey companies	Evaluating a series of aerial photographs may show an area on site which was filled during the time period reviewed
Topographic Maps	• Provides good index map of site area • Allows for estimation of site topography • Identifies physical features in the site area • Can be used to assess access restrictions	USGS, State Geological Survey	Engineer identifies access areas/restrictions, identifies areas of potential slope instability; and can estimate cut/fill capacity before visiting the site
Existing Subsurface Exploration Report	• May provide information on nearby soil/rock type; strength parameters; hydrogeological issues; foundation types previously used; environmental concerns	USGS, United States Environmental Protection Agency (USEPA), State/local agencies, developers, etc.	A five year old report for a nearby roadway widening project provides geologic, hydrogeologic, and geotechnical information for the area, reducing the scope of the exploration
Geologic Reports and Maps	• Provides information on nearby soil/rock type and characteristics; hydrogeological issues, environmental concerns	USGS and State Geological Survey	A twenty year old report on regional geology identifies earth fissure rock types (including fracture and orientation data) and groundwater flow patterns
Water/Brine Well Logs	• Provide stratigraphy of the site and/or regional area • Varied quality from state to state • Groundwater levels	State Geological Survey/Natural Resources, Department of water resources	A boring log of a water supply well two miles from the site area shows site stratigraphy facilitating evaluations of required depth of exploration

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Table 3-1 (Continued)
Sources of historical site data (after FHWA, 2002a)

Source	Functional Use	Location	Examples
Flood Insurance Maps	• Identifies 100 and 500 yr floodplains near water bodies • Caution against construction in a floodplain • Provide information for evaluation of scour potential	Federal Emergency Management Agency (FEMA), USGS, state/local agencies	Prior to exploration, the flood map shows that the site is in a 100 yr floodplain and the proposed structure is moved to a new location
Soil Survey	• Identifies site soil types • Permeability of site soils • Climatic and geologic information	Local Soil Conservation Service	The local soil survey provides information on near-surface soils to facilitate preliminary borrow source evaluation
Sanborn Fire Insurance Maps	• Useful in urban areas • Maps for many cities are continuous for over 100 years. • Identifies building locations and type • Identifies business type at a location (e.g., chemical plant) • May highlight potential environmental problems at an urban site	State library/Sanborn Company (www.sanborncompany.com)	A 1929 Sanborn map of St. Louis shows that a lead smelter was on site for 10 years. This information prevents an exploration in a contaminated area.

A necessary part involved in review of existing data is to identify the major geologic processes that occurred at the project site because this will permit the geotechnical specialist to develop an understanding of how the local soil and rock formations may have developed. The soil formation process and consideration of landforms in designs of geotechnical features is discussed briefly followed by discussions of subsurface exploration programs.

3.1.1 Soil Formations and Landforms

Soils are a result of the weathering of rocks. In general, rocks are classified as igneous, sedimentary, and metamorphic. Igneous rocks are products of melts (magma) generated an unknown distance below the earth's surface. Sedimentary rocks are cemented and/or compressed materials derived from pre-existing sediments deposited in layers by water or by air. A metamorphic rock is any rock that originates by a process of change from what it was previously. Any former igneous, sedimentary, or metamorphic rock can be metamorphosed (changed) into a new metamorphic rock by an increase in temperature and/or pressure and/or by reaction with surrounding hot fluids and gases. Regardless of the type of rock, most weathering takes place near the ground surface. Rock weathering can occur due to mechanical (physical) and/or chemical processes as follows:

- Mechanical or physical process refers to the process whereby the intact rock breaks into smaller fragments. Physical weathering may be caused by expansion resulting from unloading (e.g., exfoliation or spalling off of the exterior surface of the exposed rock), abrasion, temperature changes (e.g., freeze/thaw), erosion by wind or rain, crystal growth (e.g., ice and other crystals such as salt crystals that form as the result of the capillary action of water containing salts in solution), and organic activity (e.g., forces exerted by growing plants and roots in voids and crevasses of rock).

- Chemical process refers to the process whereby the minerals in the rock are altered into new compounds. Chemical weathering is usually preceded by hydration and hydrolysis and may be caused by, oxidation (e.g., chemical reaction with rainwater), solution (e.g., dissolution of limestone) and/or leaching (e.g., dissolution of the cementing agent in the rock). Chemical weathering commonly occurs by fluids seeping into the fractures caused by mechanical (physical) weathering processes. These fluids are chiefly acids created as rainwater dissolves carbon dioxide from the atmosphere and more carbon dioxide and organic acids from the soil. Most chemical weathering processes result in an increase in volume (that causes an increase in stress within the rock mass), lower density materials (e.g., soils), smaller particle sizes (e.g., clay sizes), and more stable minerals (that may decrease the rate of chemical weathering).

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The combined effects of the mechanical and chemical weathering processes vary considerably with climate and the mineralogy of the parent rock. The chemical reactions proceed most rapidly and completely in humid tropics and subtropics and least effectively in cold or arid climates (Goodman, 1993). Thus, in the Arctic regions and deserts, the mechanical processes of physical weathering act virtually alone to gradually breakup the rock into a fractured or rubbled mass whereas, in the tropics, the two weathering processes work together rapidly first to break up the rock and then to alter newly exposed rock surfaces during a project's life.

Once the intact rock is broken into fragments, the rate of weathering depends on the particle size and the climate. In general, small particles weather at a faster rate than large ones due to their larger surface area. The weathering processes can result in particle sizes that are not distinguishable by the naked eye (e.g., colloidal particle size) and can be identified only by equipment such as electron microscopes. Based on particle size, the principal terms used by civil engineers to describe soils are gravel, sand, silt and clay. These terms were discussed in Chapter 2 as a function of the particle sizes they represent and some of their physical characteristics. For example, silt and clay particles are finer than the No. 200 sieve (0.075 mm) and exhibit varying properties in presence of water.

Soils created by a particular geologic process assume characteristic topographic features, called **landforms**, which can be readily identified by the geotechnical specialist. A landform contains soils with generally similar engineering properties and typically extends irregularly over wide areas of a project alignment. Early identification of landforms can be used to optimize the subsurface exploration program. Landforms may be described according to the method of formation as **residual soil landforms** or **transported soil landforms.** Soils commonly associated with these two types of landforms are briefly described as follows:

3.1.1.1 Residual Soils

A residual soil landform is one that was formed in its present location through weathering of the parent (or bed) rock. Residual soils tend to be characterized by angular to subangular particles, mineralogy similar to parent rock, and the presence of large angular fragments within the overall soil mass. Because residual soil weathers from parent bedrock, its profile with depth represents a history of the weathering process. Figure 3-2 shows a typical weathering profile for metamorphic and igneous rocks. In Figure 3-2, the weathering profile is divided into three zones: *residual soil*, *weathered rock*, and *unweathered rock*. Deere and Patton (1971) present 12 other weathering-profile classification systems proposed by workers from around the world. Regardless of the weathering-profile classification, the following are some of the properties for such profiles:

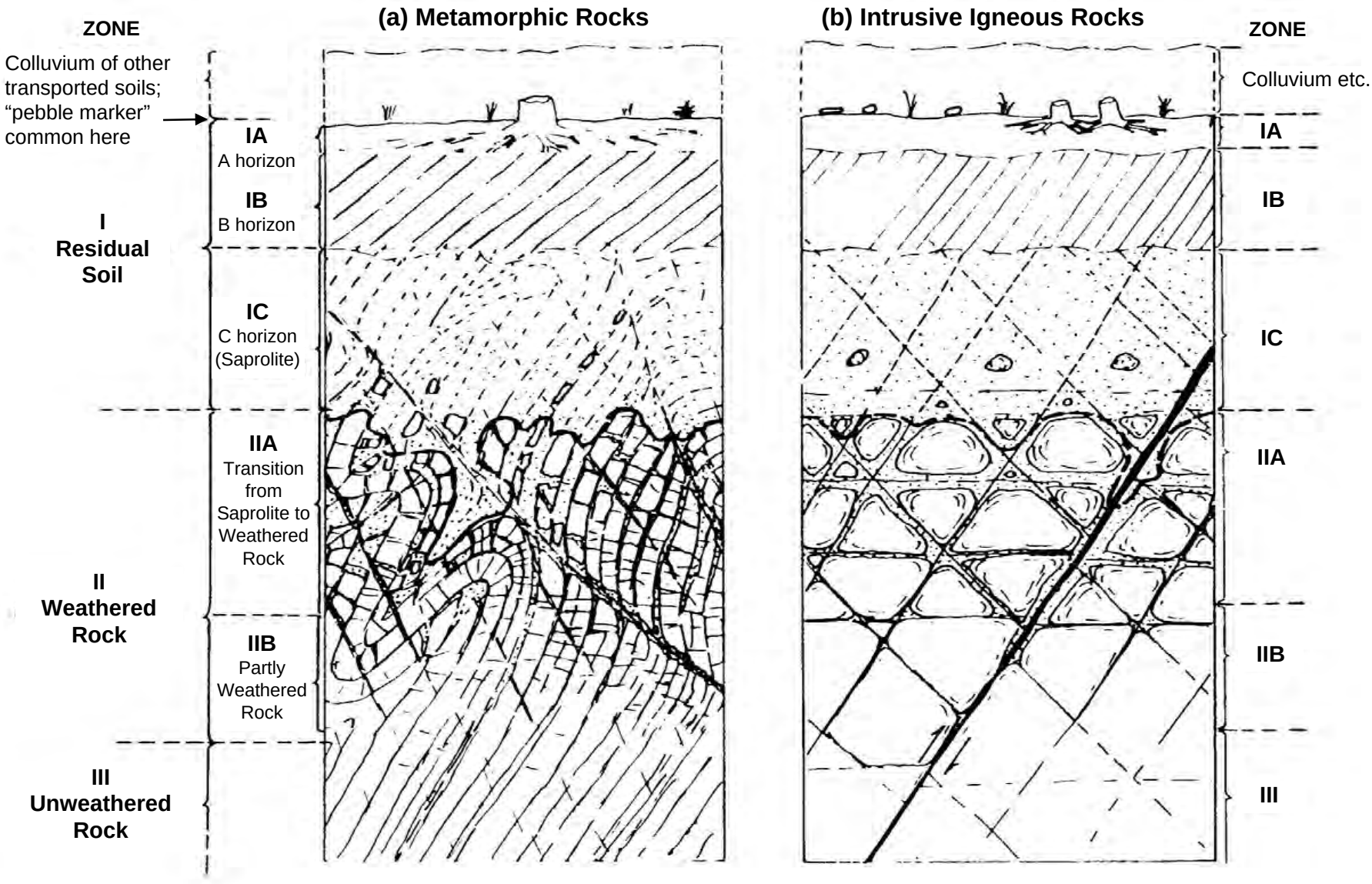


Figure 3-2. Typical weathering profile for metamorphic and igneous rocks (Deere and Patton, 1971).

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- The permeability and shear strength gradually change with depth. These two parameters control both the amount of rainfall infiltration and the location of the shear surface when external loads are applied on or in these soils.
- Soil profile thickness and properties depend upon parent bedrock, discontinuities, topography, and climate. Because these factors vary horizontally, the profile can vary significantly over relatively short horizontal distances.
- Deep profiles form in tropical regions where weathering agents are especially strong and advanced stages of chemical weathering form cemented soils called *laterites*. The technical literature often refers to residual soils as tropical soils.
- The material in the transitory zone between residual soil and unweathered rock is called *saprolite*. Saprolites are generally unsaturated, weakly bonded and heterogeneous soils with relict joint systems (Lambe, 1996). Saprolites have widely varying void ratios and widely varying mineralogy and shear strength (Vaughn, *et al.*, 1988).

3.1.1.2 Transported Soils

A transported soil is one that was formed from rock weathering at one location and transported by some exterior agent to another location. The transporting agent may be water (principal agent), a glacier, wind, and/or gravity. Often the deposits of transported soils are given names indicative of the mode of transportation causing the deposit, e.g., alluvial deposits, glacial till, etc. Transported soils are characterized by subrounded to rounded particles and a wide variety of particle sizes. Table 3-2 summarizes commonly encountered landforms composed of transported soils, their primary formational process, and their engineering significance.

3.1.1.3 Area Concept for Explorations Based on Landforms

Knowledge of the landforms and the engineering properties of the soils and rocks enables the designer to determine the most economical location for a highway alignment and grade, to evaluate design problems for each type of soil or rock, and to determine sources of granular borrow material. Once a landform is identified, the geotechnical specialist can develop an **"area" concept** for exploration. In this concept, the lateral extents of landforms in the immediate vicinity of the footprint of the proposed facility are first identified. Then, a limited exploration program (e.g., geologic mapping, geophysical work and some preliminary cone penetration tests and borings) is implemented at strategic locations such that the general characteristics of the landforms are identified. The exploration program can then be refined to obtain specific information on soil types of interest with respect to the footprint of the proposed facility and the anticipated loadings.

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Table 3-2
Common landforms of transported soils and their engineering significance

Agent	Landform	Formational Process and General Engineering Significance for Study
Water	Flood Plain	• Formed in valleys that are nearly flat and near the high water level of streams. At flood stage the valley is essentially a "flood plain" that is susceptible to widespread shallow flooding. • Generally poor construction site with fine-grained soils and water problems. Potential scour area. Spread footing design below ground will probably require undercut, low foundation pressure and scour protection. Pile foundations probable. Additional shallow explorations required along footing length to determine buried meandering channels. Historic high water levels should be used in design.
	Coastal Plain	• Formed similar to flood plain but in coastal areas. • Consider spread footings for moderate loads except for high water areas. Potential scour area. Soil "set-up" possible for friction piles (see Chapter 9).
	Terraces	• Formed when a stream or water body cuts into a previously deposited sediment or as the stream bed is lowered over geological periods due to normal erosion or to crustal deformations. Terraces are also known as *bajadas*. • Consider spread footings for lightly loaded foundations.
	Lakebed (Lacustrine, Varves)	• Formed by sedimentation in lake (fresh water) environments. *Varves* are a particular type of lake deposit formed during glacial periods from seasonal ice melting, which temporarily increased the runoff velocity so that precipitated sand layers alternate with layers of precipitates such as silt or silt-clay made at low velocities. • Suitable only for spread footings to support light loads and even then settlement may be expected. Pile foundation probable and often deep. Obtain undisturbed tube samples for laboratory testing. Consider drilling with "mud" rather than casing. Long-term water observations necessary to determine static water level due to impervious soil. Potential scour area.
	Deltas	• Formed by sediments precipitated at the mouths of rivers or streams into bays, oceans, or lakes. • The use of spread footings must be carefully studied as poor soils often underlie deltaic sands and gravels. The parent material is capable of sustaining high spread footing loads. Piles may be required to penetrate delta material and poor soil. Use casing of adequate size to obtain undisturbed samples of poor soil. Potential scour area.
	Alluvial Fans. Filled Valleys (Basin Deposits)	• Formed similar to delta deposits, but typically found in arid areas where mountain stream runoff flows into wide valleys or on to the plains at the mouths of streams. In arid climates, alluvial fans can become cemented by salts left in the ground by evaporating water or by dropping groundwater. Cemented soils can be loose to dense (e.g., *caliche*) or open-graded (*collapsible*). • Consider spread footings for low to moderate loads except at lower elevation of alluvial fans where high water table is possible. In case of collapsible soils, either treat the soils such that collapse potential is mitigated or use deep foundations to bypass such soils. If the caliche is firm to hard, spread foundations can be used.

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Table 3-2 (continued)
Common landforms of transported soils and their engineering significance

Agent	Landform	Formation and General Engineering Significance for Study
Ice (Glacier) and meltwater associated with ice	Moraines (Terminal, lateral)	• Formed by soil deposits pushed into ridges around the periphery of a glacier. *Terminal moraines* are ridges of material scraped or bulldozed to the front of a glacier; *lateral moraines* develop along the sides of a glacier. The moraine may not be a single nicely rolled ridge, but rather a highly serrated, above ground level, earth mass. • Advisable to use spread footings for all foundation loads. Piles should not be used due to very difficult driving and boulders. Core all rock to 10 ft (3.0 m) in case boulders are encountered.
	Glacial Till (ground moraine)	• Glacial Till (also termed ground moraine or simply till) is the deposit of ice-suspended material through the bottom of the glacier. As glaciers melted, materials suspended in the ice precipitated onto the underlying soil or rock to form glacial till. Till deposits are characterized by all sizes of particles with no obvious arrangement. Much of northern US has glacial till. • Where till is unsorted, dense and contains considerable sand and gravel, it is advisable to use spread footings for all foundation loads. Piles should not be used due to difficult driving conditions and boulders. Core all rock encountered to depth of 10 ft (3.0 m) as large boulders may be encountered. Long-term water observations necessary to determine static water level due to soil density.
	Outwash	• Sediments precipitated from glacial melts in the discontinuities between ridges in moraines. Small lakes may temporarily form in depressions behind ridges, producing lacustrine (fresh water) sediments. • Spread footing normally used to support moderate to heavy foundation loads. Piles, if required, will be short. Use large diameter sample spoon to permit representative sample to be obtained as average particle size may jam 1-⅜ in (35.3 mm) sample spoon. Standard penetration test may be erratically high due to large particle sizes. Commercial value as sand and gravel sources since the material often contains very little amount of fines, i.e., particle size less than No. 200 (0.075 mm) sieve.
	Eskers	• Eskers are deposits (usually as ridges) formed by precipitation of water-suspended material flowing in ice tunnels. • Advisable to use spread footings for all loads as soil contains much gravel and is dense. Piles not recommended. Large diameter sample spoon recommended as above for outwash. Commercial value as sand and gravel sources since the material often contains very little amount of fines, i.e., particle size less than No. 200 (0.075 mm) sieve.
	Drumlins	• Drumlins are isolated mounds of glacial debris varying from about 35 (10 m) ft to 230 ft (70 m) high and 650 ft (200 m) to 2600 ft (800 m) long. Most drumlins are of the order of 100 ft (30 m) or less in height and 1000 ft (300 m) or less in length. They often occur in groups called drumlin fields (several). • Suitable for spread footing design with moderate to heavy loads. Piles seldom used due to dense coarse nature of subsoil. Commercial value as sand and gravel sources since the material often contains very little amount of fines, i.e., particle size less than No. 200 (0.075 mm) sieve.

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Table 3-2 (continued)
Common landforms of transported soils and their engineering significance

Agent	Landform	Formation and General Engineering Significance for Study
Wind (Aeolian)	Loess	• Formed by wind blowing silt and clay with the deposit held together by a montmorillonite binder. Generally derived from glacial outwash in the US. Low density (often less than 90 pcf (14 kN/m^3)), low wet strength (i.e., collapsible upon water ingress), has the ability to stand on vertical cuts due to cementing agents between particles. • Consider spread footings for low to moderate loads. Heavy loads should be pile supported with the bearing resistance obtained below the loess deposit. Accurate ground water level determination important.
	Sand Dune	• Formed by wind action blowing the sand. Transport occurs mainly along the ground until an obstruction is met, whereupon a dune (or mound) forms. Later winds may demolish the dune and redeposit the material at a new location further downwind. Dune sands tend to be well rounded from abrasion. • Consider spread footings for small foundations not subject to vibratory loading. Heavy structural loads should be supported on friction piles.
Gravity	Colluvium	• Formed by physical and chemical weathering of bedrock. The fragmented particles, given sufficient topographic relief, tend to move down slopes under gravitational forces and accumulate as distinctive deposits along the lower portions of slopes, in topographic depressions, and especially at the base of cliffs. • The characteristics of colluvial materials vary according to the characteristics of the bedrock sources and the climate under which the weathering and transport occur. From an engineering viewpoint, colluvium is weakly stratified and consists of a heterogeneous mixture of soil and rock fragments ranging in size from clay particles to rock more than 3 ft (1 m) in diameter. Because they are found along the lowest portions of valley sides, such deposits frequently need to be partially excavated to allow passage of transportation facilities. The resulting cut slopes are commonly unstable and require constant monitoring and maintenance. Colluvial soils are prone to creep (slow movement with time) and landslides are common in such soils.
	Talus (Scree)	• Talus is colluvium composed of predominantly large fragments. Talus fragments can be huge boulders tens of feet across; however, a lower size limit has not been well defined. With time, the coarse fragments may degrade or finer materials may be added by wind or water transport so that these deposits slowly become infilled with a matrix of fine-grained materials. The degree of infilling of these talus deposits may vary horizontally and vertically. • Rock-supported talus is often inherently unstable and may be hazardous to even walk across. Furthermore, the open structure is porous. Talus deposits are not suitable for engineering structures. Talus deposits could be used to make riprap.

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The area concept is a powerful tool, particularly for linear highway facilities, as it streamlines the subsurface exploration program costs and provides the planning engineer with useful data during the design and construction phases of a project. It also permits early identification of the type and extent of problem soils to be encountered during construction and therefore allows construction costs to be estimated more accurately.

3.2 FIELD RECONNAISSANCE

Application of the area concept requires the use of proper subsurface exploration equipment and techniques. In particular the use of wide area exploration techniques such as remote sensing and geophysical techniques can provide insight of general subsurface conditions in the project area economically. An adequate site exploration can be accomplished only under the direction of a geotechnical specialist who knows the general limitations of the exploration equipment as well as the general demands of the project. A field reconnaissance, preferably with the bridge designer, roadway designer, and project manager, is recommended to assess subsurface conditions prior to establishing a subsurface exploration.

The field reconnaissance should include:

1. Inspection of nearby structures to determine their performance with the particular foundation type utilized. If settlement is suspected, the original structural plans should be reviewed and the structure surveyed by using the original benchmark.

2. For water crossings, inspection of structural footings and the stream banks up and down stream for evidence of scour. Take careful note of the stream bed material. Often large boulders exposed in the stream but not encountered in the borings, are an indication of potential subsurface obstructions to pile installation.

3. Recording the location, type, and depth of any existing structures or abandoned foundations that may infringe on the new highway facility.

4. Relating site conditions to the proposed boring operations. Record potential problems with utilities (overhead and underground), site access, private property, or obstructions.

Figure 3-3 is an example of a field reconnaissance form used to record data pertinent to the site. Upon completion of the site inspection, the geotechnical specialist should prepare a terrain reconnaissance report in which the general suitability of the site is assessed. The report should:

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Field Reconnaissance Report
_____ Department of Transportation

Project No: _____ County _____ Sta. No. _____

Reported By: _____ Date _____

1. Staking of Line
   Well Staked
   Poorly Staked (We can work)
   Request Division to Restake

2. Bench Marks
   In Place: Yes _____ No _____
   Distance from bridge - m (ft) _____

3. Property Owners
   Granted Permission: Yes _____ No _____
   Remarks on Back _____

4. Utilities
   Will Drillers Encounter Underground or Overhead Utilities? Yes _____ No _____
   Maybe _____ At Which Holes? _____
   What Type? _____
   Who to See for Definite Location _____
   _____
   _____

5. Geologic Formation

6. Surface Soils
   Sand _____ Clay _____ Sandy Clay _____
   Muck _____ Silt _____ Other _____

7. General Site Description
   Topography
   Level _____ Rolling _____ Hillside _____
   Valley _____ Swamp _____ Gullied _____
   Groundcover
   Cleared _____ Farmed _____ Buildings _____
   Heavy Woods _____ Light Woods _____
   Other _____
   Remarks on Back _____

8. Bridge Site
   Replacing _____
   Widening _____
   Relocation _____
   Check Appropriate Equipment
   Truck Mounted Drill Rig/Cone Rig
   Track Mounted Drill Rig/Cone Rig
   Failing 1500
   Truck Mounted Skid Rig
   Skid Rig
   Rock Coring Rig
   Wash Boring Equipment
   Water Wagon
   Pump
   Hose _____ m (ft)

8. Bridge Site - Continued
   Cut Section - m (ft) _____
   Fill Section - m (ft) _____
   If Stream Crossing:
   Will Pontoons Be Necessary? _____
   Can Pontoons Be Placed in Water Easily?
   _____
   Can Cable Be Stretched Across Stream?
   How Long? _____
   Is Outboard Motorboat Necessary? _____
   Current:
   Swift _____ Moderate _____ Slow _____
   Describe Streambanks scour.
   If Present Bridge Nearby:
   Type of Foundation _____
   Any Problems Evident in Old Bridge Including Scour _____
   (describe on back)
   Is Water Nearby for Wet Drilling - m (ft) _____
   Are Abandoned Foundations in Proposed Alignment? _____

9. Ground Water Table
   Close to Surface - m (ft) _____
   nearby Wells - Depth - m (ft) _____
   Intermediate Depth - m (ft) _____
   Artesian head - m (ft) _____

10. Rock
    Boulders Over Area? Yes _____ No _____
    Definite Outcrop? Yes _____ No _____
    (show sketch on back)
    What kind? _____

11. Special Equipment Necessary

12. Remarks on Access
    (Describe any Problems on Access)

13. Debris and Sanitary Dumps
    Stations _____
    Remarks _____
    _____
    _____
    _____

Reference: Modified from 1978 AASHTO Foundation Investigation Manual

Figure 3-3. Typical field reconnaissance form.

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1. Flag major potential problems, which may preclude construction.
2. Recommend beneficial shifts in location.
3. Present a general discussion of expected subsurface conditions.
4. Present cost estimate for extraordinary geotechnical treatments.
5. Prepare an estimate of subsurface exploration quantities, costs, and time.

This information should be transmitted to all the groups involved with the project such as the project manager, roadway designer, and bridge designer.

3.3 SUBSURFACE EXPLORATION PROGRAM

The procedures employed in any subsurface exploration program are dependent on a variety of factors that vary from site to site. The project design objectives and the expected subsurface conditions have the major influence on the subsurface explorations. Highway projects necessarily involve both earthwork and structural foundations. Typical boring programs for highways on new alignments are established such that basic information is first gathered along the entire highway alignment and subsequent detailed borings are taken as required at the locations of structures or in problem earthwork areas as disclosed by the initial basic program. Subsurface explorations for widening or improvements of existing highways generally are done in one stage as the location is predetermined.

Consideration should be given, particularly for large or complex projects, to performing geologic mapping and geophysical explorations after the field reconnaissance and prior to any invasive explorations such as borings. Geologic mapping and geophysical explorations can be quick and provide a much larger coverage of the project area as compared to invasive explorations. The information from field reconnaissance, geologic mapping and geophysical explorations can then be used to setup the conventional subsurface exploration and testing program. Geophysical explorations are discussed in Section 3.15.

After the field reconnaissance and geophysical explorations are completed, “invasive” explorations using drilled borings and in-situ tests must be performed to obtain in-situ properties and physical samples for identification and testing. The sampling techniques and tools are discussed in Section 3.4 and other sections of this chapter. The objectives for such explorations are as follows:

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1. Determine stratigraphy.
   a. physical description and extent of each stratum.
   b. thickness and elevation of top and bottom of each stratum.

2. For fine-grained soils (each stratum) determine:
   a. natural moisture contents.
   b. Atterberg limits.
   c. stiffness.
   d. presence of organic materials.
   e. evidence of desiccation or previous soil disturbance, shearing, or slickensides.
   f. swelling characteristics.
   g. unconfined compressive strength - typically estimated from Standard Penetration Tests or Cone Penetration Tests.
   h. shear strength.
   i. compressibility.

3. For coarse-grained soils (each stratum) determine:
   a. in-situ density (average and range) typically determined from Standard Penetration Tests or Cone Penetration Tests.
   b. grain-size distributions (gradation).
   c. presence of organic materials.

4. Determine depth to ground water (for each aquifer if more than one is present).
   a. piezometric surface over site area: existing, past, and probable range in future (observe at several times).
   b. perched water table.

5. Determine depth to bedrock.
   a. depth over entire site.
   b. type of rock.
   c. extent and character of weathering.
   d. joints, including distribution, spacing, whether open or closed, and joint infilling.
   e. faults.
   f. solution effects in limestone or other soluble rocks.
   g. core recovery and soundness (RQD).
   h. hardness and strength.

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3.4 SAMPLING TECHNIQUES AND TOOLS

The purpose of this section is to provide information on various in-situ testing methods that are currently used to establish site-specific soil and rock properties for design and construction. The execution of a conventional subsurface exploration and testing program usually includes rotary drilling, Standard Penetration Testing (SPT), disturbed and undisturbed sample recovery, and laboratory testing. Although procedures for these commonly performed activities are described in AASHTO and ASTM standards and are well known to most geo-professionals, important testing details are sometimes overlooked that can result in data having marginal quality. This section discusses the importance of carefully selecting and properly conducting the appropriate field and/or laboratory testing method.

In-situ testing methods are increasingly being used on transportation projects, however testing procedures and test limitations are not as well understood as those of the more conventional methods of subsurface exploration and testing such as the use of drilled borings. In this chapter, procedures for various in-situ and laboratory testing methods are presented as they relate to obtaining high quality data for the evaluation of engineering properties of soils and rocks for transportation projects. Information on equipment calibration, measured test parameters, quality control, and the range of ground conditions that apply to each test is also presented.

Several in-situ tests define the geostratigraphy and provide direct measurements of soil properties and geotechnical parameters. The common in-situ tests include: Standard Penetration Test (SPT), Cone Penetration Test (CPT), Piezocone Test (CPTu), Flat Plate Dilatometer Test (DMT), Pressuremeter Test (PMT), and Vane Shear Test (VST). Although the load is applied differently in each test, the purpose of each test is to measure the corresponding response of the soil in an attempt to evaluate the soil's engineering properties, such as strength and/or stiffness. Figure 3-4 depicts these various devices and a graphical representation of how load is applied.

Some state DOTs perform these tests by using agency-owned equipment. In many cases however, the agency may retain an outside contractor for these services either directly or as part of an overall project development package. Several technical reports and manuals are available that describe these test methods. A brief list of these references is provided in Table 3-3. Agencies that perform or contract for these testing services are encouraged to obtain the references identified in Table 3-3. In this manual, only the SPT and the CPT tests will be discussed since they are the most commonly used.

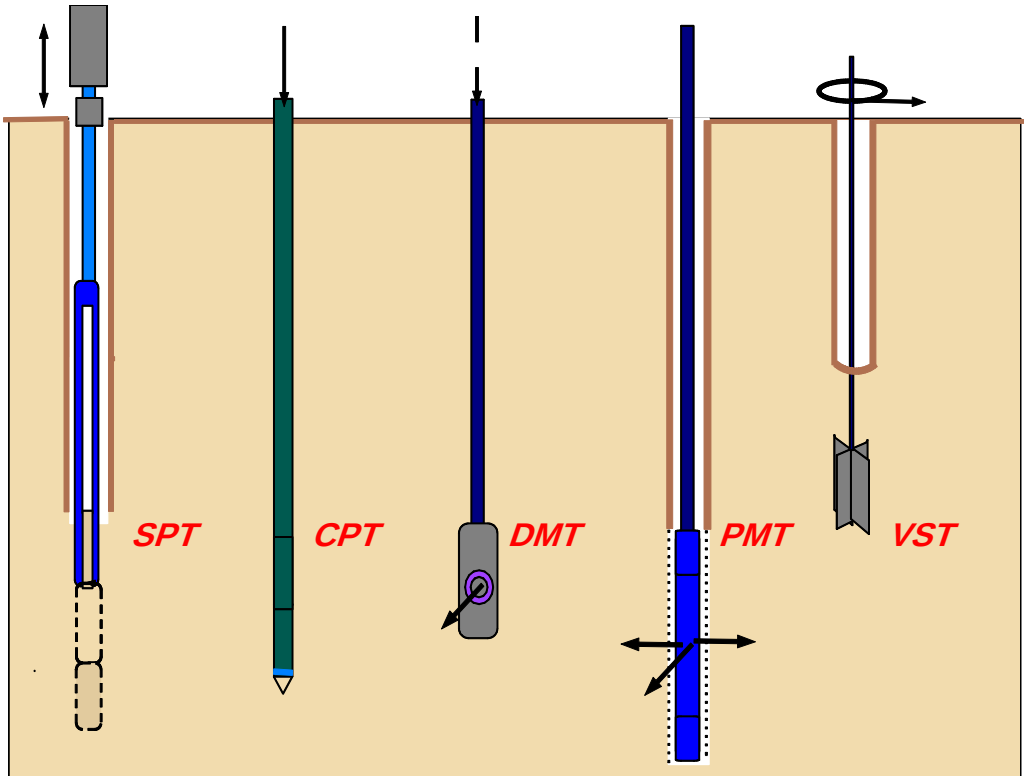


Figure 3-4. Common in-situ tests for geotechnical site characterization of soils (FHWA, 2002b).

Boreholes are required for conducting the SPT and normal versions of the PMT and VST. Therefore a drill rig and crew are required for the performance of these tests. Boreholes are not required for the CPT, CPTu, and DMT; therefore these tests are called "direct-push" technologies. Although boreholes are not required for these tests, special mobilized equipment and data acquisition systems are required. Specialized versions of the PMT (i.e., full-displacement type) and VST can be conducted without boreholes. In such cases either standard drill rigs or mobile hydraulic systems (cone trucks) are used to push the probes to the required test depths. Obviously direct push test methods are not suitable in soil profiles that contain boulders, hard cemented layers and bedrock. For such profiles, borehole methods prevail as the testing device may be advanced through the hard layers by coring or non coring techniques. An advantage of direct-push soundings is that cuttings or spoil are not generated, however, this advantage is offset by a significant disadvantage, i.e., no soil sample is retrieved for classification or subsequent laboratory testing. Another advantage of the CPT and CPTu tests is that they provide a continuous record of soil response through the entire depth of the direct push. The other tests are performed at discrete intervals so that the soil's response is measure at specific depths only. In addition, important layers can be missed with any of the discrete interval test methods.

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Table 3-3
Reference publications on in-situ testing (FHWA, 2002b)

Test Method	AASHTO/ ASTM Designation	Reference
SPT	AASHTO T206 ASTM D 1586	FHWA (2002b). *Subsurface Investigations (Geotechnical Site Characterization)*. Report No. FHWA NHI-01-031, Authors: Mayne, P. W., Christopher, B. R., and DeJong, J., Federal Highway Administration, U.S. Department of Transportation.
CPT, CPTu, SCPTu	ASTM D 3341, D5778	FHWA (1992a). *The Cone Penetrometer Test*. Report No. FHWA NHI-91-043, Authors: Riaund J-L and Miran J., Federal Highway Administration, U.S. Department of Transportation. Lunne, T., Robertson, P.K., and Powell, J.J.M. (1997) *Cone Penetration Testing in Geotechnical Practice*, E & F Spon.
DMT	Suggested ASTM Method	FHWA (1992b). *The Flat Dilatometer Test*. Report No. FHWA NHI-91-044, Authors: Riaund J-L and Miran J., Federal Highway Administration, U.S. Department of Transportation.
PMT	ASTM D 4719	FHWA (1989a). *The Pressuremeter Test for Highway Applications*. Report No. FHWA IP-89-008, Authors: Briaud J-L, Federal Highway Administration, U.S. Department of Transportation. Clarke, B.G. (1995) *Pressuremeters in Geotechnical Design*, Blackie Academic & Professional.
VST	ASTM D 2573	ASTM (1988). *Vane Shear Strength Testing in Soils: Field and Laboratory Studies*, American Society for Testing and Materials, Committee D-18 on Soil and Rock for Engineering Purposes, Philadelphia, PA.

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3.5 BORING METHODS

Geotechnical borings are a critical component of any subsurface exploration program. They are performed to satisfy several objectives including those listed below.

- identify the subsurface distribution of materials with distinctive properties, including the presence and thickness of distinct layers;
- retrieve samples of each layer for laboratory tests to determine engineering properties;
- determine depth to groundwater; and
- provide access for the introduction of in-situ testing devices.

There are many types of equipment used in current practice for advancing a soil or rock boring. Typical types of soil borings are listed in Table 3-4(a), rock coring methods in Table 3-4(b), and other exploratory techniques in Table 3-4(c). Detailed information on soil and rock boring procedures can be found in AASHTO (1988), FHWA (2002b), and ASTM D 4700. A brief description of typical soil boring methods is provided below (Day, 1999).

3.5.1 Auger Borings

An auger is an apparatus with a helical shaft that can be manually or mechanically advanced to bore a hole into soil. Large and small diameter augers are shown in Figure 3-5. The practice of advancing a borehole with a mechanical auger consists of rotating the auger while applying a downward pressure on the auger to penetrate soil and possibly weak or weathered rock. The auger may be continuous, where the helix extends along the entire length of the shaft, or discontinuous when the auger helix is at the bottom of the drill stem.

- *Discontinuous or single flight auger borings and bucket auger borings.* There are basically two types of discontinuous augers: discontinuous flight augers and bucket augers. Commonly available discontinuous flight augers have diameters ranging from 0.25 to 3 ft (0.075 to 1 m) and bucket augers have diameters ranging from 1 to 8 ft (0.3 to 2.5 m). For discontinuous flight auger borings, the auger is periodically removed from the hole and the soil lodged in the grooves of the flight auger is removed. When a bucket auger is used, it too is periodically removed from the hole and the soil in the bucket removed. A casing is generally not used for discontinuous flight and bucket auger borings. Therefore, these methods are not recommended for boreholes deeper than 35 ft (10 m), or where the hole may cave-in during the

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excavation of loose or soft soils, or when the boring is below the groundwater table. In firm stiff clays, discontinuous auger borings can be performed to depths in excess of 35 ft (10 m).

- *Continuous flight auger borings.* As the name implies, continuous flight augers have the auger flights continuous along the entire length of the auger. As shown in Figure 3-6a, there are two types of continuous flight augers: **solid stem** and **hollow stem**. For both of these type augers the drill cuttings are returned to the ground surface via the auger flights. The solid stem auger must be removed from the borehole to allow access to the hole for insertion of sampling or testing devices. Because the auger must be periodically removed from the borehole, a solid stem auger is not appropriate in sands and soft soils or in soil deposits where groundwater is close to the surface. A hollow-stem auger has a circular hollow core that allows for sampling through the center of the auger. As shown in Figure 3-6c, hollow-stem augers come in a variety of diameters. The hollow-stem auger acts like a casing and allows for sampling in loose or soft soils or when the excavation is below the ground water table. A plug (Figure 3-6d) is necessary when hollow stem augers are advanced to prevent cuttings from migrating through the hollow stem. The plug is removed to permit SPT sampling. In loose sands and soft clays extending below the water table, drilling fluids are often used to minimize and mitigate disturbance effects and keep the hole open. The components of the hollow stem auger system are shown in Figure 3-6b.



(a) (b)

Figure 3-5. (a) Large diameter auger, (b) Small diameter continuous flight auger.

Table 3-4(a)
Soil and soft rock boring methods (FHWA, 2002a)

Method	Procedure	Applications	Limitations / Remarks
Auger boring (ASTM D 1452)	Dry hole drilled with hand or power auger; samples recovered from auger flights	In soil and soft rock; to identify geologic units and water content above water table	Soil and rock stratification destroyed; sample mixed with water below the water table
Hollow-stem auger boring	Hole advanced by hollow-stem auger; soil sampled below auger as in auger boring above	Typically used in soils that would require casing to maintain an open hole for sampling	Sample limited by larger gravel; maintaining hydrostatic balance in hole below water table is difficult
Wash-type boring	Light chopping and strong jetting of soil; cuttings removed by circulating fluid and discharged into settling tub	Soft to stiff cohesive materials and fine to coarse granular soils	Coarse material tends to settle to bottom of hole; should not be used in boreholes above water table where undisturbed samples are desired.
Becker Hammer Penetration Test (BPT)	Hole advanced using double acting diesel hammer to drive a 6.6-in (168 mm) double-walled casing into the ground. Several sizes are available.	Typically used in soils with gravel and cobbles; casing is driven open-ended if sampling of materials is desired	Skin friction of casing difficult to account for; unsure as to the repeatability of test
Bucket Auger boring	A 2 to 4 ft (0.6 to 1.2 m) diameter drilling bucket with cutting teeth is rotated and advanced. At the completion of each advancement, the bucket is retrieved from the boring and soil is emptied on the ground.	Most soils above water table; can dig harder soils than above types and can penetrate soils with cobbles and boulders if equipped with a rock bucket	Not applicable in running sands; used for obtaining large volumes of disturbed samples and where it is necessary to enter a boring to make observations

Table 3-4(b)
Rock core drilling methods (FHWA, 2002a) [1]

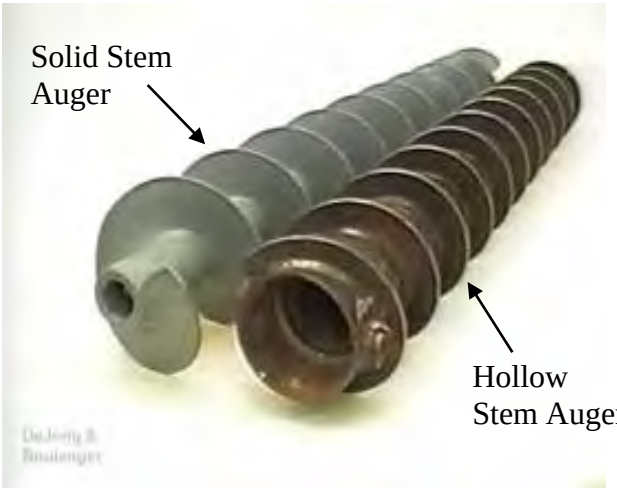
Method	Procedure	Type of sample	Applications	Limitations / Remarks
Rotary coring of rock (ASTM D 2113; AASHTO T 225)	Outer tube with diamond (or tungsten carbide) bit on lower end rotated to cut annular hole in rock; core protected by stationary inner tube; cuttings flushed upward by drill fluid	Rock cylinder 1 in to 4 in (25 to 100 mm) in diameter and as long as 10 ft (3 m), depending on rock soundness. Standard coring size is 2-1/8 in (54 mm) diameter.	To obtain continuous core in sound rock (percent of core recovered depends on fractures, rock variability, equipment, and driller skill)	Core lost in fracture or variable rock; blockage prevents drilling in badly fractured rock; dip of bedding and joint evident but not strike
Rotary coring of rock, wire line	Same as ASTM D 2113, but core and stationary inner tube retrieved from outer core barrel by lifting device or "overshot" suspended on thin cable (wire line) through special large-diameter drill rods and outer core barrel	Rock cylinder 1-1/8 in to 3-3/8 in (28 to 85 mm) wide and 5 ft to 10 ft (1.5 to 3 m) long	To recover core better in fractured rock which has less tendency for caving during core removal; to obtain much faster cycle of core recovery and resumption of drilling in deep holes	Core lost in fracture or variable rock; blockage prevents drilling in badly fractured rock; dip of bedding and joint evident but not strike
Rotary coring of swelling clay, soft rock	Similar to rotary coring of rock; swelling core retained by third inner plastic liner	Soil cylinder 1-1/8 in to 3-3/8 in (28 to 85 mm) wide and 2 ft to 5 ft (0.6 m to 1.5 m) long encased in plastic tube	In soils and soft rocks that swell or disintegrate rapidly in air (protected by plastic tube)	Sample smaller; equipment more complex than other soil sampling techniques

[1] See Section 3.6.4 for additional discussion on types of core barrels (i.e., single-, double-, or triple-tube).

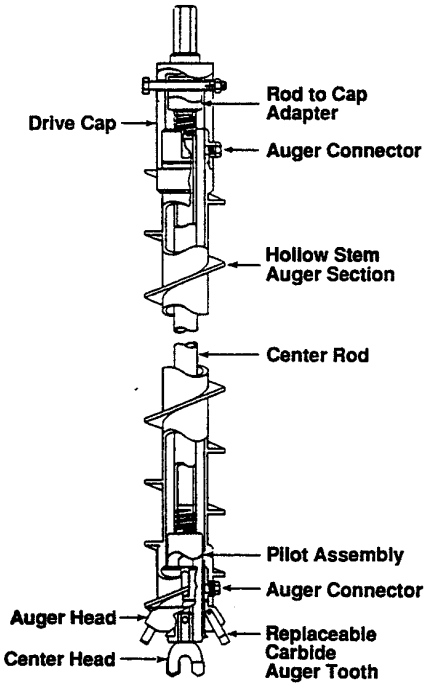
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Table 3-4(c)
Other exploratory techniques (FHWA, 2002a)

Method	Procedure	Type of sample	Applications	Limitations / Remarks
Borehole camera	Inside of core hole viewed by circular photograph or scan	No sample, but a visual representation of the material	To examine stratification, fractures, and cavities in hole walls	Best above water table or when hole can be stabilized by clear water
Pits and Trenches	Pit or trench excavated to expose soils and rocks	Chunks cut from walls of trench; size not limited	To determine structure of complex formations; to obtain samples of thin critical seams such as failure surface	Moving excavation equipment to site, stabilizing excavation walls, and controlling groundwater may be difficult; useful in obtaining depth to shallow rock and for obtaining undisturbed samples on pit/trench sidewalls; pits need to be backfilled
Rotary or cable tool well drill	Toothed cutter rotated or chisel bit pounded and churned	Pulverized	To penetrate boulders, coarse gravel; to identify hardness from drilling rates	Identification of soils or rocks difficult
Percussive Method (jack hammer or air track)	Impact drill used; cuttings removed by compressed air	Rock dust	To locate rock, soft seams, or cavities in sound rock	Drill becomes plugged by wet soil



(a)



(b)



(c)



(d)

Figure 3-6. (a) Solid stem auger and hollow stem auger, (FHWA, 2002b) (b) Hollow stem auger components (ASTM D 4700), (c) Sizes of hollow stem auger flights (FHWA, 2002b), (d) Outer and inner assembly of hollow stem auger (FHWA, 2002b).

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3.5.2 Wash-type Borings

Wash-type borings use circulating drilling fluid (e.g., water or mud) to remove cuttings from the borehole, Figure 3-7. Cuttings are created by the chopping, twisting, and jetting action of the drill bit that breaks the soil or rock into small fragments. Tri-cone bits are often used in dense soil or soft rock. If bentonite or a polymeric drilling mud cannot be used to maintain an open borehole, casings are often used to prevent cave-in of the borehole. The use of casing will require a significant amount of additional time and effort but will result in a protected borehole. When drilling mud is used during subsurface boring, it will be difficult to classify the soil from the auger cuttings because of contamination with the mud. Also, the outside of samples may become coated with drilling mud.

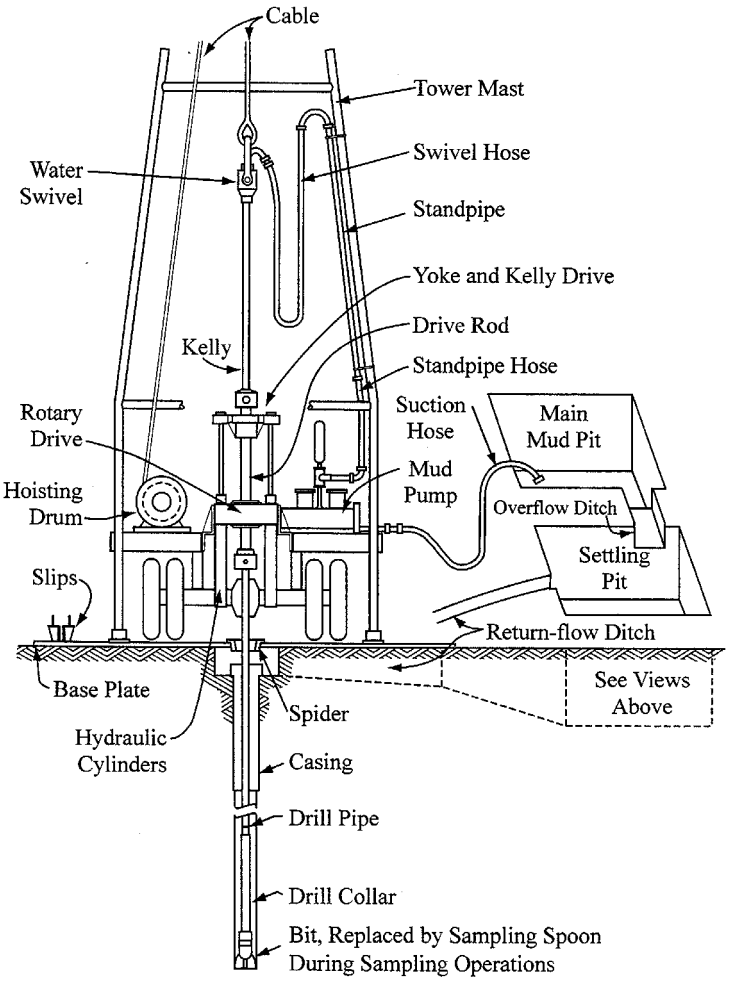
The properties of the drilling fluid and the quantity of water pumped through the drill bit will determine the size of particles that can be removed from the boring with the circulating fluid. In formations containing gravels, cobbles, or larger particles, coarse material may be left at the bottom of the boring. In these instances, cleaning the bottom of the boring with a larger diameter sampler (such as the 3 in (75 mm) OD split barrel sampler) may be needed to obtain a representative sample of the formation.

3.5.3 Coring in Rocks

The previously described methods are typically used for soil exploration. The following methods are primarily used for rock exploration.

- *Rotary coring*. This type of coring equipment is most commonly used for rock exploration when an intact core of the rock is desired. Power rotation of the drilling bit is accompanied with introduction of a circulating fluid to remove cuttings from the hole. The drilling bits are specifically designed to core rock, and inner/outer tubes or casings are used to capture the intact core. Table 3-4(b) lists various types of rotary coring techniques for rock, although many of these techniques are also applicable to dense or stiff soil.

- *Percussion drilling*. This type of drilling equipment is often used to penetrate hard rock for subsurface exploration or for the purpose of drilling wells. The drill bit works much like a jackhammer, rising and falling to break up and crush the rock material. Air is commonly used to clean the hole and transport the cuttings to the ground surface. Table 3-4(c) includes a description on the use of the percussion drilling techniques.



(a)



(b)



(c)

Figure 3-7. (a) Schematic of drilling rig for rotary wash methods (after Hvorslev, 1948), (b) Typical drilling configuration, (c) Settling basin (mud tank).

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3.6 SAMPLING METHODS

3.6.1 Disturbed Sampling of Soil

Disturbed sampling of soil provides a means to evaluate stratigraphy by visual examination and to obtain soil specimens for laboratory index testing. Disturbed samples are usually collected using split-barrel samplers (Figure 3-8; AASHTO T 206, ASTM D 1586), although several other techniques are available for disturbed sample collection in boreholes (see Table 3-5(a) and 3-5(b)). Shallow disturbed samples can also be obtained by using hand augers and test pits. Direct push methods, such as GeoProbe sampling, can be used to obtain continuous disturbed samples but these methods have limitations in sampling depth similar to those of solid stem and bucket augers (i.e., generally good for depths less than 33 feet (10 meter) unless in firm to stiff clays). Samples obtained via disturbed sampling methods are generally used for index property testing in the laboratory. They should not be used to prepare specimens for consolidation and strength tests.



Figure 3-8. Split barrel sampler.

3.6.2 Undisturbed Sampling of Soil

Undisturbed soil samples are required for performing laboratory strength and consolidation tests on cohesive soils having consistencies ranging from soft to stiff. High-quality samples for such tests are particularly important for approach embankments and for structural foundations and wall systems that may stress compressible strata. In reality, it is impossible to retrieve truly undisturbed samples since changes in the state of stress in the sample occur upon sampling and removal of the sample from depth. The goal of high-quality undisturbed sampling is to minimize the potential for: (1) alteration of the soil structure; (2) changes in moisture content or void ratio; and (3) changes in chemical composition of the soil. Due to cost and ease of use, the thin-walled Shelby tube (Figure 3-9) is the most commonly used sampler for obtaining relatively undisturbed samples of soft to stiff fine-grained soils.

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Table 3-5(a)
Common samplers to retrieve disturbed soil samples (modified after NAVFAC, 1986a)

Sampler	Typical Dimensions	Soils that Give Best Results	Method of Penetration	Cause of Low Recovery	Remarks
Split Barrel	Standard is 2 in (50 mm) outside diameter (OD) and 1-3/8 in (35 mm) inside diameter (ID)	All soils finer than gravel size particles that allow sampler to be driven; gravels invalidate drive data; A soil retainer may be required in granular soils.	140 lb (64 kg) hammer driven	Gravel may block sampler	A SPT is performed using a standard penetrometer and hammer (see text); samples are extremely disturbed
Continuous helical-flight auger	Diameters range 3 in to 16 in (75 to 400 mm; penetrations to depths exceeding 50 ft (15 m)	Most soils above water table; will not penetrate hard soils or those containing cobbles or boulders	Rotation	Hard soils, cobbles, boulders	Method of determining soil profile, bag samples can be obtained; log and sample depths must account for lag time between penetration of bit and arrival of sample at surface, to minimize errors in estimated sample depths

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Table 3-5(b)
Common samplers to retrieve disturbed soil samples (modified after NAVFAC, 1986a)

Sampler	Typical Dimensions	Soils that Give Best Results	Method of Penetration	Cause of Low Recovery	Remarks
Disc auger	Up to 3.5 ft (1 m) diameter; usually has maximum penetration depth of 25 ft (8 m)	Most soils above water table; will not penetrate hard soils or those containing cobbles or boulders	Rotation	Hard soils, cobbles, boulders	Method of determining soil profile, bag samples can be obtained; log and sample depths must account for lag time between penetration of bit and arrival of sample at surface, to minimize errors in estimated sample depths
Bucket auger	Up to 4 ft (1.2 m) diameter common; larger sizes available; with extensions, depth over 80 ft (25 m) are possible	Most soils above water table; can penetrate harder soils than above types and can penetrate soils with cobbles and boulders if equipped with a rock bucket	Rotation	Soil too hard to penetrate	Several bucket types available, including those with ripper teeth and chopping tools; progress is slow when extensions are used
Test boring of large samples, Large Penetration Test (LPT)	2 in to 3 in (50 to 75 mm) ID and 2.5 in to 3.5 in (63 mm to 89 mm) OD samplers (examples, Converse sampler, California Sampler)	In sandy to gravelly soils	Up to 350 lb (160 kg) 350 lb hammer driven	Large gravel, cobbles, and boulders may block sampler	Sample is intact but very disturbed; A resistance can be recorded during penetration, but is not equivalent to the SPT N-value and is more variable due to no standard equipment and methods

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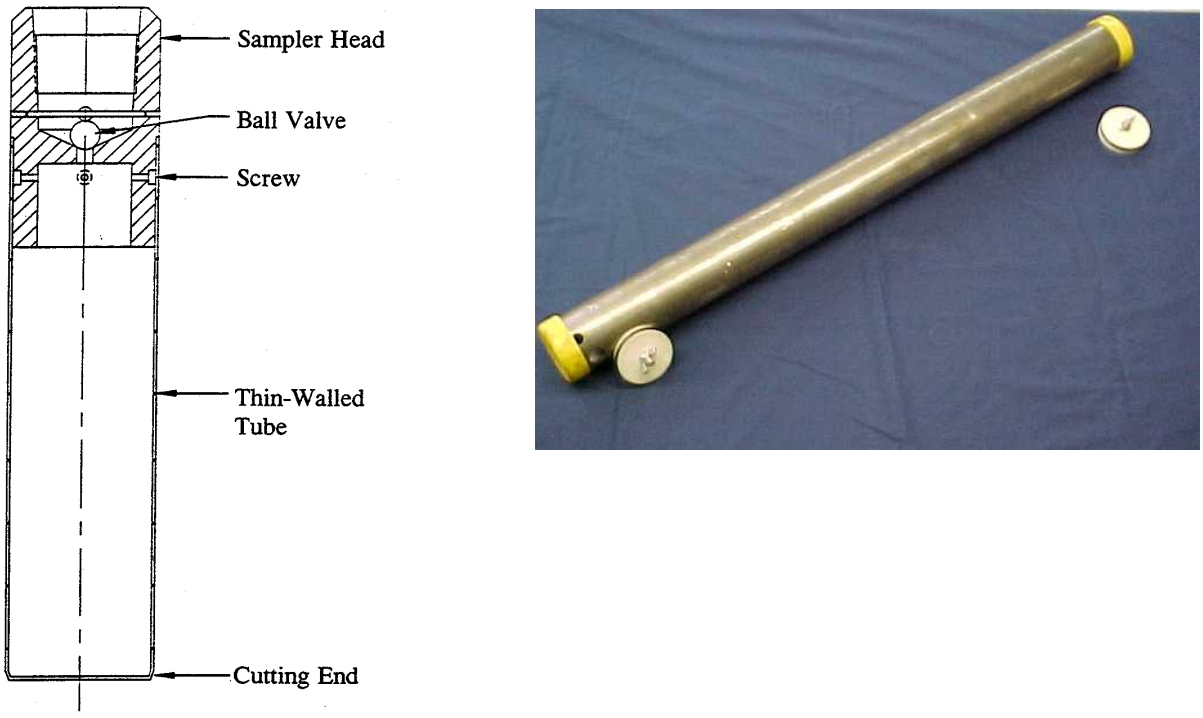


Figure 3-9. Schematic of thin-walled (Shelby) tube (after ASTM D 4700) and photo of tube with end caps (FHWA, 2002b).

Thin walled Shelby tube sampling is discussed in Section 3.5.3. Depending upon the in-situ condition of the fine-grained soil (e.g., stiffness and whether significant granular material is in the soil matrix), alternative sampling devices may be used to obtain nominally undisturbed soil samples. These alternative samplers include:

- Stationary piston sampler (Figure 3-10);
- Denison sampler (Figure 3-11);
- Pitcher samplers (Figure 3-12);
- Hydraulic piston sampler (Osterberg Sampler).

Summary information on these samplers is provided in Table 3-6 and detailed procedures for these sampling techniques are provided in FHWA (1997, 2002b). Although not common for typical transportation-related projects, a variety of special samplers are available to obtain samples of soil and soft rocks. These specialty samplers include the retractable plug sampler, the Sherbrooke sampler, and the Laval sampler.

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Table 3-6
Nominally undisturbed soil samplers (modified after NAVFAC, 1986a)

Sampler	Typical Dimensions	Soils that Give Best Results	Method of Penetration	Cause of Disturbance or Low Recovery	Remarks
Shelby tube (ASTM D 1587; AASHTO T 207)	3 in (76 mm) OD and 2-7/8 in (73 mm) ID most common; available from 2 in to 5 in (50 to 127 mm) OD; 30 in (760 mm) sampler length standard	Cohesive fine-grained or soft soils; gravelly and very stiff soils will crimp tube	Pressing with relatively rapid, smooth stroke; can be carefully hammer driven but this will induce additional disturbance	Erratic pressure applied during sampling, hammering, gravel particles, crimping of tube edge, improper soil types for sampler, pressing tube greater than 80% of tube length	Simplest device for undisturbed samples; boring should be clean before sampler is lowered; little waste area in sampler; not suitable for hard, dense or gravelly soils
Stationary piston	3 in (76 mm) OD most common; available from 2 in to 5 in (50 to 127 mm) OD; 30 in (760 mm) sampler length standard	Soft to medium clays and fine silts; not for sandy soils	Pressing with continuous, steady stroke	Erratic pressure during sampling, allowing piston rod to move during press, improper soil types for sampler	Piston at end of sampler prevents entry of fluid and contaminating material requires heavy drill rig with hydraulic drill head; samples generally less disturbed compared with Shelby tube; not suitable for hard, dense, or gravelly soil
Hydraulic piston (Osterberg)	3 in (76 mm) OD is most common; available from 2 in to 4 in (50 to 100 mm) OD; 36 in (910 mm) sampler length standard	Silts and clays, some sandy soils	Hydraulic or compressed air pressure	Inadequate clamping of drill rods, erratic pressure	Needs only standard drill rods; requires adequate hydraulic or air capacity to activate sampler; samples generally less disturbed compared with Shelby tube; not suitable for hard, dense, or gravelly soil
Denison	3.5 in to 7 in (89 to 177 mm) OD, producing samples 2-3/8 in 6.3 in (60 to 160 mm); 24 in (610mm) sampler length	Stiff to hard clay, silt, and sands with some cementation, soft rock	Rotation and hydraulic pressure	Improper operation of sampler; poor drilling procedures	Inner tube face projects beyond outer tube, which rotates; amount of projection can be adjusted; generally takes good samples; not suitable for loose sands and soft clays
Pitcher sampler	4 in (100 mm) OD; uses 3 in (76-mm) diameter Shelby tubes; sample length 24 in (610 mm)	Same as Denison	Same as Denison	Same as Denison	Differs from Denison in that inner tube projection is spring controlled; often ineffective in cohesionless soils
Foil Sampler	Continuous samples 2 in (50 mm) wide and as long as 65 ft (20 m)	Fine grained soils including soft sensitive clays, silts, and varved clays	Pushed into the ground with steady stroke; Pauses occur to add segments to sample barrel	Samplers should not be used in soils containing fragments or shells	Samples surrounded by thin strips of stainless steel, stored above cutter, to prevent contact of soil with tube as it is forced into soil

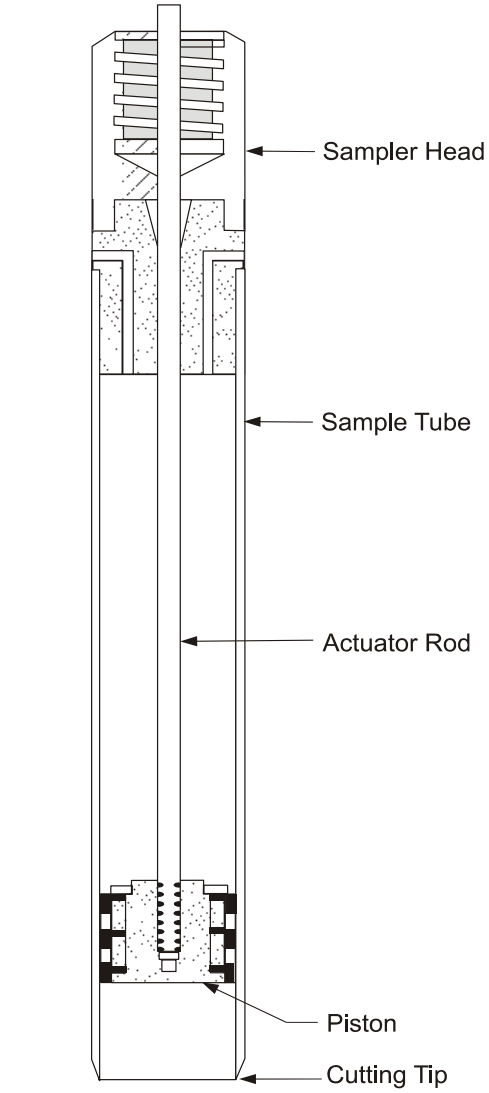




Figure 3-10. Stationary piston sampler schematic (after ASTM D 4700) and photo (FHWA, 2002b).

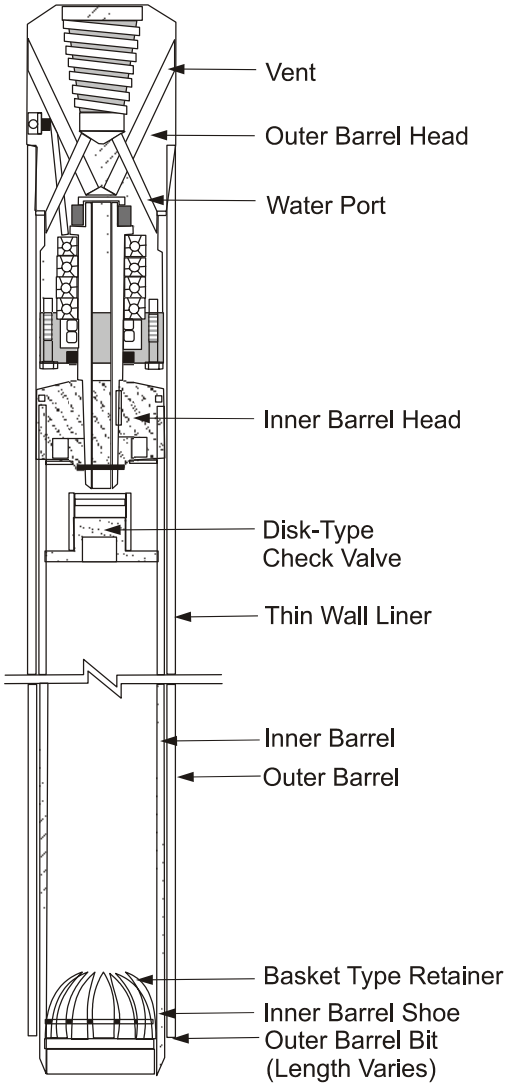


Figure 3-11. Denison sampler (FHWA, 1997).

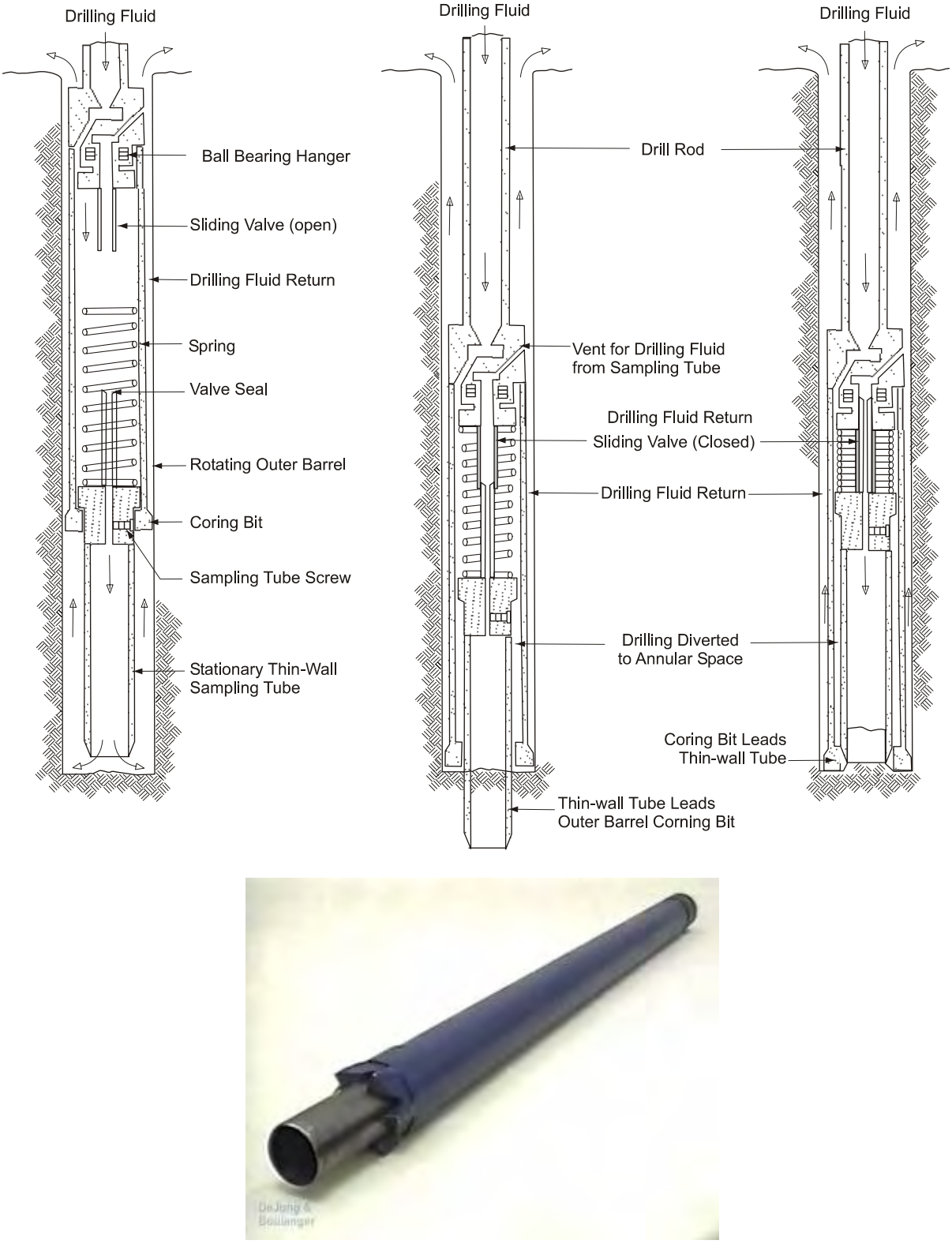


Figure 3-12. Pitcher sampler (FHWA, 1997, 2002b).

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When dealing with relatively shallow soils that are very stiff, brittle, partially cemented, or that contain coarse gravel or stones, the best method to obtain large relatively undisturbed samples is by block sampling. Block sampling involves isolating a soil column, encasing it in paraffin wax, and covering it with an open-ended box or tube (usually about 12 in (300 mm) square). The bottom is cut, sealed and covered, and the sample is transported to the laboratory. This sampling technique is generally difficult to implement at depths greater than approximately 10 ft (3 m).

3.6.3 Thin-Walled (Shelby) Tube Sampling

The importance of appropriate sampling practice using Shelby tubes cannot be over-emphasized. Poor sampling practices, exposure to extreme temperatures, and careless handling of samples can cause sample disturbance that may result in misleading test results that can lead to uneconomical or unsafe designs.

- Geometry of a Thin-Walled Tube: The area ratio (AR) and the inside clearance ratio (ICR) are parameters that are used to evaluate the disturbance potential for different types of soil samplers. These parameters are defined as follows:

$$AR = \frac{D_o^2 - D_i^2}{D_i^2} \text{ x } 100 \text{ percent} \qquad 3\text{-}1a$$

$$ICR = \frac{D_i - D_e}{D_e} \qquad 3\text{-}1b$$

where D_e = diameter at the sampler cutting tip, D_i = inside diameter of the sampling tube, and D_o = outside diameter of the sampling tube. For a sample to be considered undisturbed, the ICR should be approximately 1 percent and the AR should be 10 percent or less. Using a tube with this ICR value minimizes the friction buildup between the soil sample and the sampler during the advancement of the sampler. Using a tube with an AR value less than 10 percent enables the sampler to cut into the soil with minimal displacement of the soil. Thin-walled tubes (e.g., Shelby tubes) are typically manufactured to meet these specifications, but a thicker walled tube with an ICR of zero is commonly used in the Gulf states (e.g., Texas, Louisiana) to sample very stiff overconsolidated clays. The use of the thicker walled tube minimizes buckling of the sampler in the stiff deposits, and the ICR of zero minimizes sample expansion within the

tube. Additional information on suitable geometry for thin-walled tubes is provided in ASTM D 1587.

- Sample Tube Inspection and Storage: Tubes received from the manufacturer should be inspected to assure that no damage has occurred to the ends of the tubes. Plastic end caps, which will later be used to facilitate securing of the sample, should be placed on the ends of the tube at this time.

- Cleaning Borehole Prior to Sampling: Depending upon the methods used, drilling and sampling procedures will cause some disturbance in the vicinity of the advancing face of a borehole. This is especially the case if a sample is overpushed, if casing is advanced ahead of the borehole, or during continuous sampling operations. It is recommended that a borehole be advanced and cleaned to two to three diameters below the bottom of the previous sample to minimize disturbance. Additionally, after advancement of the borehole, caving may occur at the bottom of the hole. Thus, the bottom of the borehole should be cleaned out thoroughly before the sampling device is advanced. Improper cleaning will lead to severe disturbance of the upper material (accumulated settled material), and possibly disturbance of the entire sample. Cleaning is usually performed by washing materials out of the hole. It should be ensured that the jet holes are not directed downward, for this will erode soft or granular materials to an unknown depth. All settled material should be removed to the edge of the casing. In deep or wide borings, special cleaning augers may be used to decrease time for cleaning and produce a cleaner hole.

- Tube Advancement and Retrieval: Tubes should be advanced without rotation in a smooth and relatively rapid manner. The length of the sampler advancement should be limited to 24 in (600 mm) for a 30 in (760 mm) long tube to minimize friction along the wall of the sampler and allow for loose material in the hole. The amount of recovery should be compared to the advanced length of the sampler to assess whether material has been lost, the sample has swelled, or some caved material has been collected at the top of the tube. The possible presence of caved material should be noted at the top of the tube so that no laboratory moisture content or performance tests are performed on that material. After advancing to the target depth, the drill rod should be rotated one full turn to shear off the bottom of the sample. Prior to shearing, a waiting period of 5 to 15 minutes is recommended for tubes in soft soils to permit the sample to reach equilibrium inside the tube and prevent the sample from falling out the bottom of the tube during retrieval. This waiting period may be reduced for stiffer soils.

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- Preparation for Shipment: Upon removal of the sample from the borehole, the ends should be capped with the plastic end caps and the tube should be labeled. The label should be written directly on the tube with a permanent marking pen, and include: (1) tube and boring identification number; (2) sample depth; (3) top and bottom of sample; (4) length of recovery; (5) sampling date; (6) job name and/or number; and (7) sample description. Tube samples that are intended for laboratory performance testing (i.e., strength, consolidation, hydraulic conductivity) should never be extruded from the tube in the field and stored in alternative containers. Samples should be extruded only in the laboratory under controlled conditions. After a thin-walled tube sample has been taken, slough or cuttings from the upper end of the tube should be removed by use of a cleanout tool. The length of sample recovered should be measured and the soil classified for the log. About 1 in (25 mm) of material at the bottom end of the tube should be removed and the cuttings placed in a properly labeled storage jar. Both ends of the tube should then be sealed with at least a 1 in (25 mm) thick layer of microcrystalline (non-shrinking) wax after a plastic disk has been placed to protect the ends of the sample (Figure 3-13a). The use of relatively low temperature wax will minimize shrinkage and potential moisture migration within the sample. The remaining void above the top of the sample should be filled with moist sand. Plastic end caps should then be placed over both ends of the tube and electrician's tape wrapped over the joint between the collar of the cap and the tube and over the screw holes. The capped ends of the tubes are then dipped in molten wax. Alternatively, O-ring packers can be inserted into the sample ends and then sealed (Figure 3-13b). This method of sealing the sample may be preferable as it is cleaner and more rapid than waxing. In both cases, the sample must be sealed to ensure proper preservation of the sample. The tube should be kept vertical, with the top of the sample in the upright position. If the sample needs to be inverted for purposes such as sealing, care should be taken to ensure the sample does not slide within the tube. Samples must be stored upright in a protected environment to prevent freezing, desiccation, and alteration of the moisture content (ASTM D 4220).

  Shipment: Sample tubes must to be packed **upright** in accordance with guidelines provided in ASTM D 4220, or in an equivalent sample box. Tubes should be isolated from other sample tubes, and fit snugly in the case to protect against vibration or shock. The cushioning material between the samples should be at least 1 in (25 mm) thick, and the cushioning on the container floor should be at least 2 in (50 mm) thick. The samples should not be exposed to extreme heat or cold. If possible, the geotechnical specialist should deliver the samples to the laboratory or use a special delivery service provider who offers shipping of fragile items (e.g., FedEx) to ship samples. The use of a chain of custody form for sample traceability records is encouraged.

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(a)  (b) 

Figure 3-13. Shelby tube sealing methods, (a) Microcrystalline Wax, (b) O-Ring packer (FHWA, 2002b).

3.6.4 Undisturbed Sampling of Rock (Rock Coring)

When equipment for rock coring is being considered, the dimensions, type of core barrel, type of coring bit, and drilling fluid are important variables. The minimum depth of rock coring should be determined based on the local geology of the site and the type of structure to be constructed. Coring should also be performed to a depth that assures that refusal is not encountered on a boulder. A brief description of issues related to rock coring is provided in this document. Additional information on drilling rigs, methods of circulating drill cuttings (i.e., fluid or air), hole diameters, and casings is provided in ASTM D 2113.

3.6.4.1 Core Barrels

Four different types of core barrels are described in ASTM D 2113 including:

1) Single Tube - Figure 3-14(a);
2) Rigid Double Tube - Figure 3-14(b);
3) Swivel Double Tube - Figure 3-14(c); and
4) Triple Tube.

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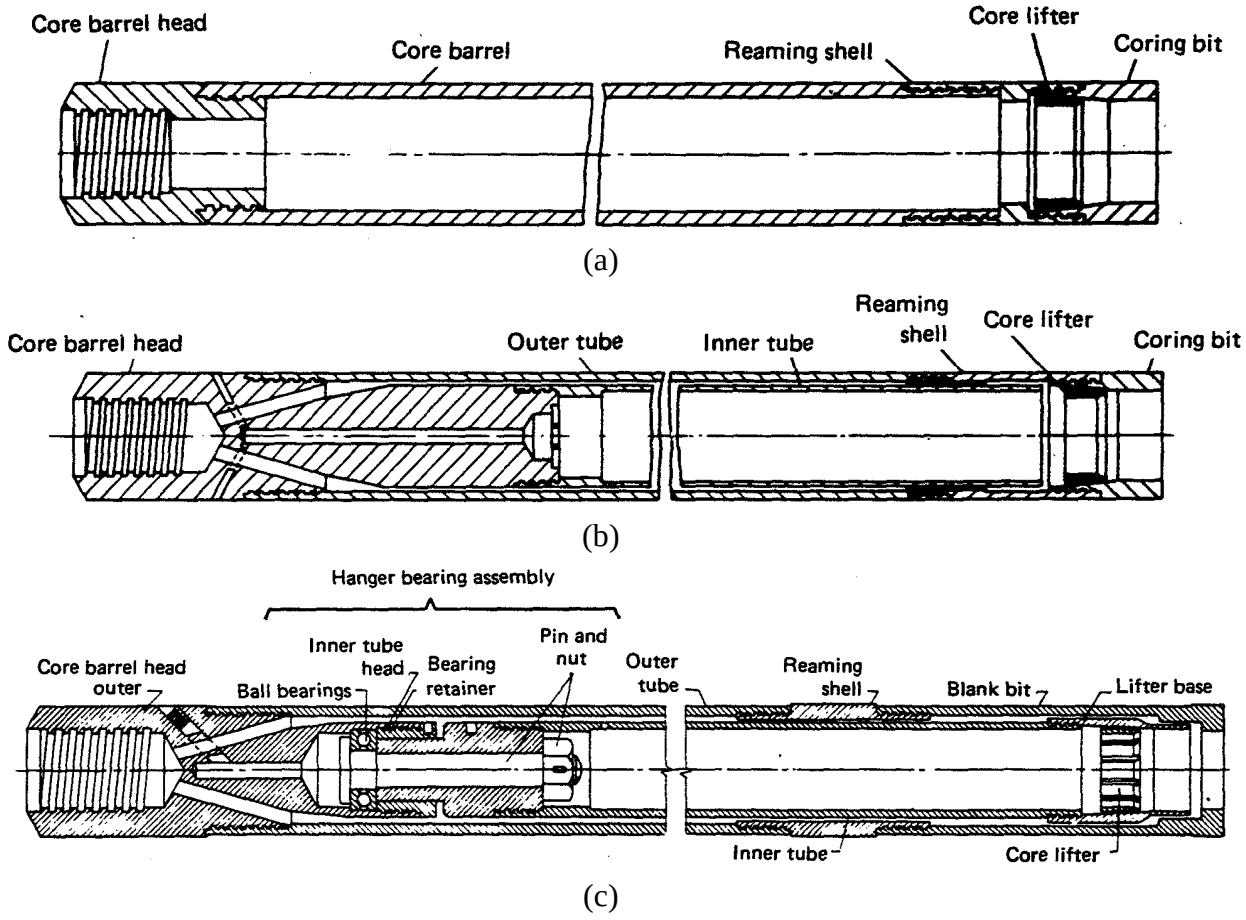


Figure 3-14. (a) Single, (b) and (c) Double tube rock core barrels (FHWA, 1997).

Since the double core barrel isolates the rock from the drilling fluid stream to yield better recovery, it is the minimum standard of core barrel that should be used in practice when an intact core is required for testing. Figure 3-15 shows the outer and inner assembly for a double-tube core barrel. The inner tube of a swivel-type core barrel does not rotate during drilling, which results in less disturbance and better recovery in weak and fractured rock. Rigid type double tube core barrels should not be used where core recovery is a concern. Triple tube swivel-type core barrels will produce better recovery and less core breakage than a double tube barrel.

Most rock coring today is done by use of the wireline method, which was introduced in the 1960s. In this method, an inner tube containing the core is detached from the core barrel assembly when the core barrel is full or a blockage occurs. The tube and core contained in it are pulled to the surface by wire dropped down the string of drill rods. A latch or "overshot assembly," which snaps on to the top of the inner tube, is used for this purpose. The inner

tube is then rapidly hoisted to surface within the string of drill rods. After the core is removed, the inner tube is dropped down into the outer core barrel and drilling resumes. Thus, the core is retrieved without having to pull all of the rods and production rates, particularly for deep cores, are therefore greater than those for conventional techniques.

Table 3-7 lists the available core sizes. The standard size rock core, NX, has a diameter of 2-1/8 in (54 mm). Generally larger core sizes will lead to less mechanical breakage and yield greater recovery, but the associated cost for drilling will be much higher. Since the size of the core will affect the percent recovery, the core barrel size should be clearly recorded on the log. Additionally, the core barrel length can increase recovery in fractured and weathered rock zones. In these zones a core barrel length of 5 ft (1.5 m) is recommended. Core barrel lengths should not be greater than 10 ft (3 m) under any conditions because of the potential for damage to the long cores.



(a) (b)

Figure 3-15. Double tube core barrel. (a) Outer barrel assembly (b) Inner barrel assembly (FHWA, 2002b).

3.6.4.2 Coring Bits

The coring bit is the bottommost component of the core barrel assembly. It is the grinding action of this component that cuts the core from the rock mass. The following three basic categories of bits are in use: diamond, carbide and sawtooth (Figure 3-16).

Coring bits are generally selected by the driller and are often approved by the geotechnical specialist. Bit selection should be based on a general knowledge of drill bit performance for the expected formations and the proposed drilling fluid.

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Table 3-7
Dimensions of core sizes (FHWA, 1997)

Size	Diameter of Core mm (in)	Diameter of Borehole mm (in)
EX,EXM	21.5 (0.846)	37.7 (1.484)
EWD3	21.2 (0.835)	37.7 (1.484)
AX	30.1 (1.185)	48.0 (1.890)
AWD4, AWD3	28.9 (1.138)	48.0 (1.890)
AWM	30.1 (1.185)	48.0 (1.890)
AQ Wireline, AV	27.1 (1.067)	48.0 (1.890)
BX	42.0 (1.654)	59.9 (2.358)
BWD4, BWD3	41.0 (1.614)	59.9 (2.358)
BXB Wireline, BWC3	36.4 (1.433)	59.9 (2.358)
BQ Wireline, BV	36.4 (1.433)	59.9 (2.358)
NX	54.7 (2.154)	75.7 (2.980)
NWD4,NWD3	52.3 (2.059)	75.7 (2.980)
NXB Wireline, NWC3	47.6 (1.874)	75.7 (2.980)
NQ Wireline, NV	47.6 (1.874)	75.7 (2.980)
HWD4,HXB Wireline,	61.1 (2.406)	92.7 (3.650)
HQ Wireline	63.5 (2.500)	96.3 (3.791)
CP, PQ Wireline	85.0 (3.346)	122.6 (4.827)



Figure 3-16. Coring bits: Diamond (top left), Carbide (top right), and Sawtooth (bottom center) (FHWA, 2002b).

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Diamond coring bits, such as surface set or impregnated-diamond types, are the most versatile since they can produce high-quality cores in soft to extremely hard rock materials (see Figure 3-10, top left). Compared to other types, diamond bits in general permit more rapid coring and, as noted by Hvorslev (1948), exert lower torsional stresses on the core. Lower torsional stresses permit the retrieval of longer cores and cores of smaller diameter. The wide variation in the hardness, abrasiveness, and degree of fracturing encountered in rock has led to the design of bits to meet specific conditions known to exist or expected to be encountered at given sites. Thus, wide variations in the quality, size, and spacing of diamonds, in the composition of the metal matrix, in the face contour, and in the type and number of waterways are found in bits of this type. Similarly, the diamond content and the composition of the metal matrix of impregnated bits are varied to meet differing rock conditions.

Carbide bits use tungsten carbide in lieu of diamonds. There are of several types of carbide bits. The standard type carbide bit is shown in Figure 3-16, top right. Bits of this type are used to core soft to medium hard rock. They are less expensive than diamond bits. However, the rate of drilling is slower than with diamond bits.

Sawtooth bits consist of teeth cut into the bottom of the bit (see Figure 3-10, bottom center). The teeth are faced and tipped with a hard metal alloy such as tungsten carbide to provide water resistance and thereby to increase the life of the bit. Although these bits are less expensive than diamond bits, they do not provide as high a rate of coring and do not have a salvage value. The saw tooth bit is used primarily to core overburden and very soft rock.

An important feature in all bits is the type of waterways provided in the bits for the passage of drilling fluid. Bits are available with so-called “conventional” waterways, which are passages cut on the interior face of the bit, or with bottom discharge waterways, which are internal passages that discharge at the bottom face of the bit behind a metal skirt separating the core from the discharge fluid. Bottom discharge bits should be used when soft rock or rock having soil-filled joints is cored to prevent erosion of the core by the drilling fluid before the core enters the core barrel.

Bit selection is based on the anticipated rock formation as well as the expected drilling fluid. Diamond bits are applicable in all rock types. They permit greater rates of coring than other types of bits. Carbide bits are less expensive than diamond bits and can be used in soft to medium-hard rock. Sawtooth bits are the least expensive of the three, however they have no salvage value. They lead to slower coring and are typically used only in soft rock.

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3.6.4.3 Drilling Fluid

In many instances, clear water is used as the drilling fluid in rock coring. If drilling mud is required to stabilize collapsing holes or to seal zones when there is loss of drill water, the geotechnical specialist should be notified to confirm that the type of drilling mud is acceptable. Drilling mud will clog open joints and fractures, which adversely affects permeability measurements and piezometer installations. Drilling fluid should be contained in a settling basin to remove drill cuttings and to allow recirculation of the fluid. Generally, drilling fluids can be discharged onto the ground surface. However, special precautions or handling may be required if the material is contaminated with oil or other substances. Such fluids may require disposal off site. Water flow over the ground surface should be avoided as much as possible. Local environmental agencies should be contacted for permits because some drilling fluids may have adverse effects on local surface and subsurface environments. Certain local agencies may also require implementation of a Storm Water Pollution Prevention Plan (SWPPP).

3.6.5 Observations During Rock Core Drilling

3.6.5.1 Drilling Rate/Time

The drilling rate should be monitored and recorded on the boring log in the units of minutes per 1 ft (0.3 m). Only time spent advancing the boring should be used to determine the drilling rate.

3.6.5.2 Core Photographs

Cores in the split core barrel should be photographed immediately upon removal from the borehole. A label should be included in the photograph to identify the borehole, the depth interval and the number of the core run. It may be desirable to get a "close-up" of interesting features in the core. Wetting the surface of the recovered core by using a spray bottle and/or sponge prior to photographing will often enhance the color contrasts of the core.

A tape measure or ruler should be placed across the top or bottom edge of the core box to provide a scale in the photograph. The tape or ruler should be at least 3 ft (1 m) long, and it should have relatively large, high contrast markings to be visible in the photograph.

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A color bar chart is often desirable in the photograph to provide indications of the effects of variation in film age, film processing, and the ambient light source. The photographer should strive to maintain uniform light conditions from day to day, and those lighting conditions should be compatible with the type of film selected for the project. The use of a digital camera is a convenient way to circumvent some of the problems associated with the use of film cameras for photographing rock cores.

3.6.5.3 Rock Classification

The rock type and its inherent discontinuities, joints, seams, and other facets should be documented. See Chapter 4 for a discussion of rock description and classification.

3.6.5.4 Recovery

The core recovery is the length of rock core recovered from a core run. The recovery ratio is the ratio of the length of core recovered to the total length of the core drilled on a given run, expressed as either a fraction or a percentage. Core length should be measured along the core centerline. When the recovery is less than the length of the core run, the non-recovered section should be assumed to be at the end of the run unless there is reason to suspect otherwise (e.g., weathered zone, drop of rods, plugging during drilling, loss of fluid, and rolled or re-cut pieces of core). Non-recovery should be marked as NCR (no core recovery) on the boring log, and entries should not be made for bedding, fracturing, or weathering in that interval.

Recoveries greater than 100 percent may occur if core that was not recovered during a run is subsequently recovered in the next run. Recoveries greater than 100 percent should be recorded and adjustments to data should not be made in the field.

3.6.5.5 Rock Quality Designation (RQD)

The RQD is a quantitative measure that represents a modified core recovery percentage. By definition the RQD is the sum of the lengths of all pieces of sound core over 4 in (100 mm) long divided by the length of the core run (Deere, 1963). The correct procedure for measuring RQD is illustrated in Figure 3-17. The RQD is an index of rock quality. Problematic rock that is highly weathered, soft, fractured, sheared, and jointed typically yields lower RQD values than more intact rock. Thus, RQD is simply a measurement of the percentage of "good" rock recovered from an interval of a borehole.

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It should be noted that the original definition of RQD reported by Deere (1963) was based on measurements made on NX-size core. Experience in recent years reported by Deere and Deere (1989) indicates that cores with diameters both slightly larger and smaller than NX may be used for computing RQD. The wire line cores using NQ, HQ, and PQ are also considered acceptable. Use of RQD for the smaller BQ and BX sizes is discouraged because of a greater potential for core breakage and loss that would result in a smaller value of RQD.

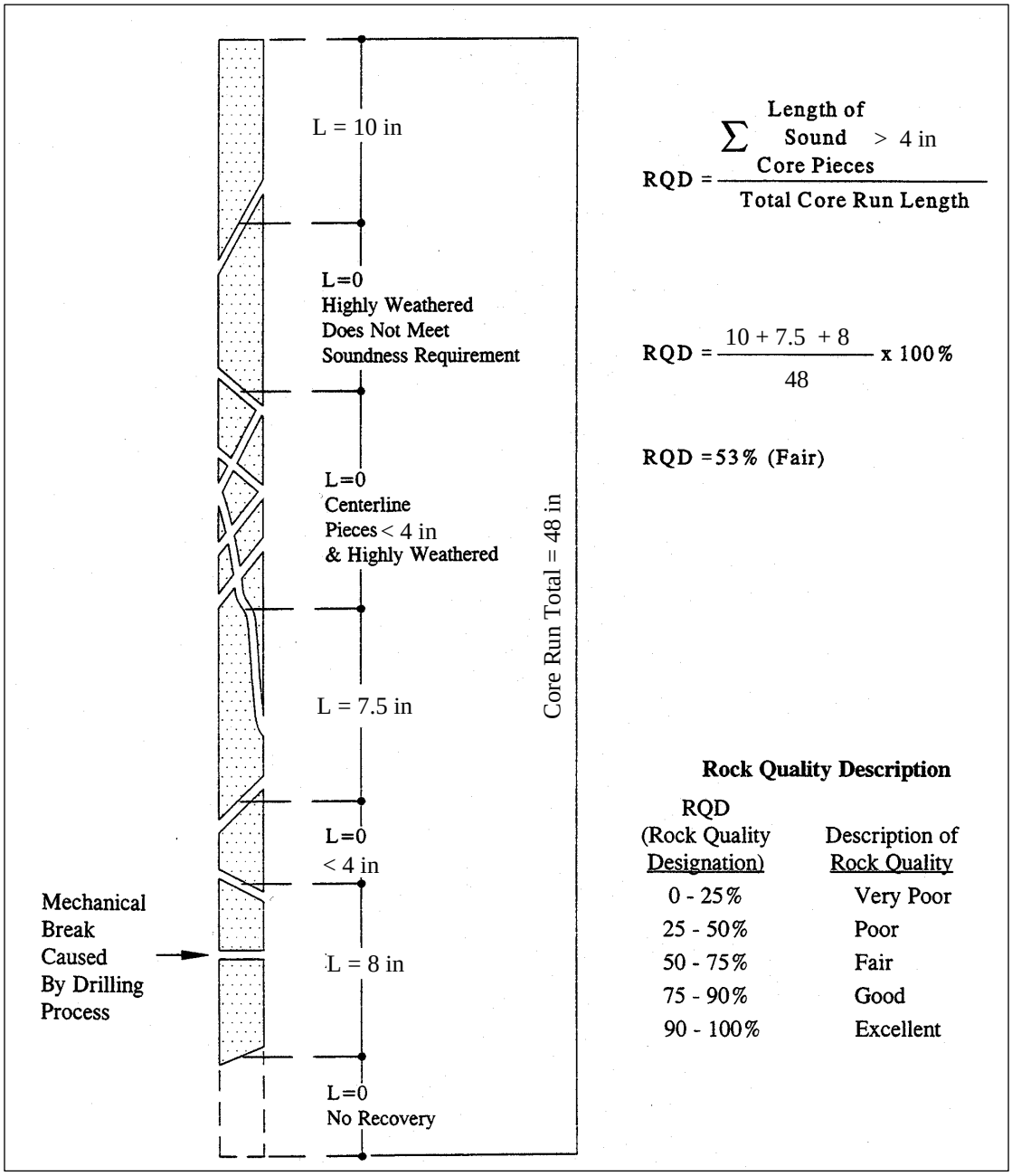


Figure 3-17. Modified core recovery as an index of rock mass quality (FHWA, 1997).

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Length Measurements of Core Pieces

The same piece of core could be measured three ways: along the centerline, from tip to tip, or along the fully circular barrel section (Figure 3-18). The recommended procedure is to measure the core length along the centerline. This method is advocated by the International Society for Rock Mechanics (ISRM), Commission on Standardization of Laboratory and Field Tests (ISRM, 1981). The centerline measurement is preferred because: (1) it results in a standardized RQD not dependent on the core diameter, and (2) it avoids unduly penalizing the rock quality for cases where fractures run parallel to the borehole and are cut by a second set of fractures.

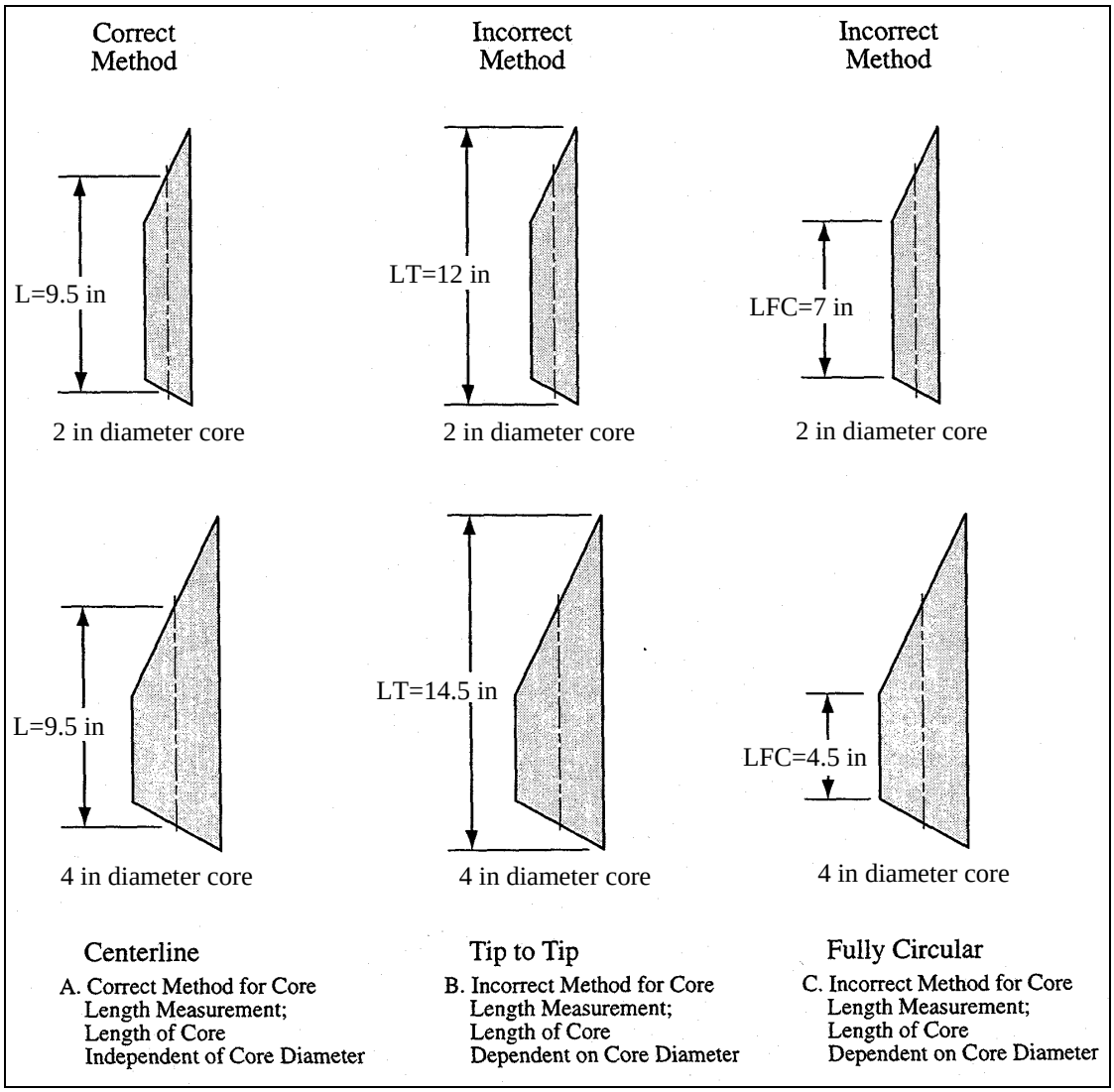


Figure 3-18. Length measurements for core RQD determination (FHWA, 1997).

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Assessment of Soundness

Pieces of core which are not "hard and sound" should not be counted for the RQD even though they possess the requisite 4 in (100 mm) length. The purpose of the soundness requirement is to downgrade the rock quality where the rock has been altered and weakened either by agents of surface weathering or by hydrothermal activity. Obviously, in many instances a judgment decision must be made as to whether or not the degree of chemical alteration is sufficient to reject the core piece.

One commonly used procedure is not to count a piece of core if there is any doubt about its meeting the soundness requirement as evidenced by discolored or bleached grains, heavy staining, pitting, or weak grain boundaries. This procedure may unduly penalize the rock quality, but it errs on the side of conservatism. A second procedure that is occasionally used includes the altered rock within the RQD summed percentage, but indicates by means of an asterisk (RQD*) that the soundness requirements have not been met. The advantage of this method is that the RQD* will provide some indication of the rock quality with respect to the degree of fracturing, while also noting its lack of soundness.

Core breaks caused by the drilling process should be fitted together and counted as one piece. Drilling breaks are usually evidenced by rough fresh surfaces. For schistose and laminated rocks, it is often difficult to discern the difference between natural breaks and drilling breaks. When in doubt about a break, it should be considered as natural in order to be conservative in the calculation of RQD for most uses. Obviously, this practice would not be conservative when the RQD is used as part of a ripping or dredging estimate.

3.6.5.6 Drilling Fluid Recovery

The loss of drilling fluid during the advancement of a boring can be indicative of the presence of open joints, fracture zones or voids in the rock mass being drilled. Therefore, the volumes of fluid losses and the intervals over which they occur should be recorded. For example, "no fluid loss" means that no fluid was lost except through spillage and filling the hole. "Partial fluid loss" means that a return was achieved, but the amount of return was significantly less than the amount being pumped in. "Complete water loss" means that no fluid returned to the surface during the pumping operation. A combination of opinions from the field personnel and the driller on this matter will result in the best estimate.

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3.6.5.7 Core Handling and Labeling

Rock cores from geotechnical explorations should be stored in structurally sound core boxes made of wood or corrugated waxed cardboard (Figure 3-19). Wooden boxes should be provided with hinged lids, with the hinges on the upper side of the box and a latch to secure the lid in a closed position.

Cores should be handled carefully during transfer from barrel to box to preserve mating across fractures and fracture-filling materials. Breaks in core that occur during or after the core is transferred to the core box should be refitted and marked with three short parallel lines across the fracture trace to indicate a mechanical break. Breaks made to fit the core into the core box and breaks made to examine an inner core surface should be marked as such. These deliberate breaks should be avoided unless absolutely necessary. Cores should be placed in the boxes from left to right, top to bottom. When the upper compartment of the box is filled, the next lower (or adjoining) compartment should be filled beginning at the left-hand side, and so on the same way until the box is filled. The depths of the top and bottom of the core and each noticeable gap in the formation should be marked by a clearly labeled wooden spacer block.

If there is less than 100 percent core recovery for a run, a cardboard tube spacer of the same length as the core loss should be placed in the core box either at the depth of core loss, if known, or at the bottom of the run. The depth of core loss, if known, or length of core loss should be marked on the spacer with a black permanent marker. The core box labels should be completed using an indelible black marking pen. An example of recommended core box markings is shown in Figure 3-19. The core box lid should have identical markings both inside and out, and both exterior ends of the box should be marked as shown in Figure 3-19. For angled borings, depths marked on core boxes and boring logs should be those measured along the axis of the boring. The angle and orientation of the boring should be noted on the core box and the boring log.



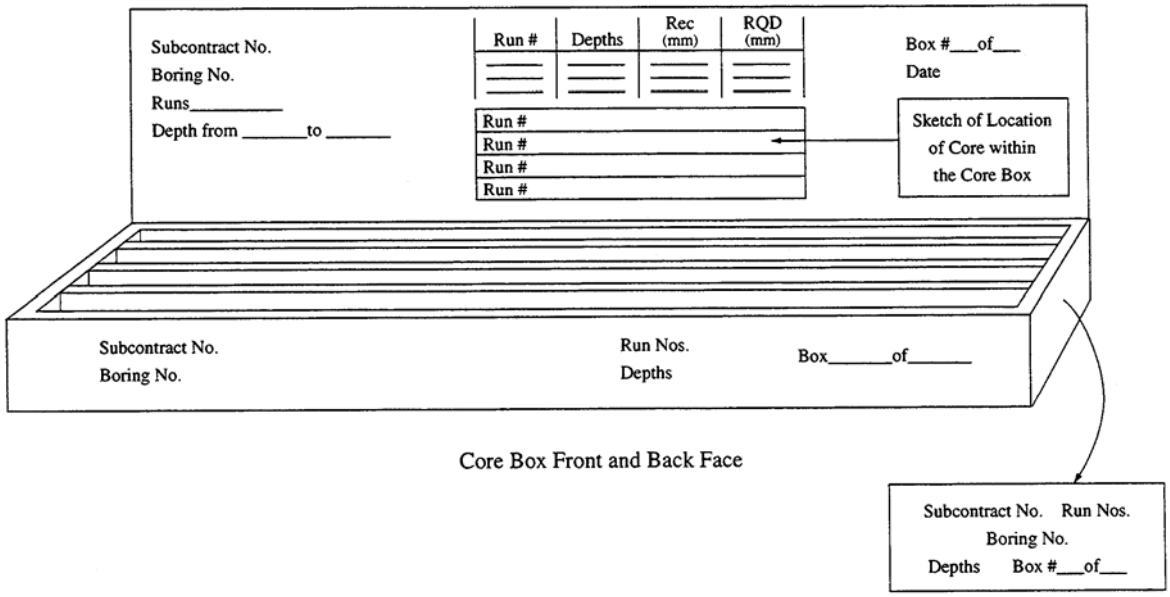


Figure 3-19. Core box for storage of recovered rock and labeling.

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3.6.5.8 Care and Preservation of Rock Samples

A detailed discussion of sample preservation and transportation is presented in ASTM D 5079. Four levels of sample protection are identified as follows:

a) routine care,
b) special care,
c) soil-like care, and
d) critical care.

Routine care in placing rock core in core boxes will be used for most geotechnical explorations. ASTM D 5079 suggests enclosing the core in a loose-fitting polyethylene sleeve prior to placing the core in the core box.

Special care is considered appropriate if the moisture state of the rock core (especially shale, claystone and siltstone) and the corresponding properties of the core may be affected by exposure. Special care can also be applied if it is important to maintain fluids other than water in the sample. Critical care is needed to protect samples against shock and vibration or variations in temperature, or both. For soil-like care, samples should be treated as indicated in ASTM D 4220.

3.6.6 Geologic Mapping

Geologic mapping is the systematic collection of local, detailed geologic data, and, for engineering purposes, is used to characterize and document the condition of a rock mass or outcrop. The data derived from geologic mapping are a portion of the data required for the design of a cut slope or for the stabilization of an existing slope. Geologic mapping can often provide more extensive and less costly information than drilling. Soil and soil-like materials, although occasionally mapped, are not considered in this section. For a detailed discussion of geologic mapping, the reader is referred to the FHWA manual on rock slopes (FHWA, 1998a).

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3.7 STANDARD PENETRATION TEST (SPT)

The standard penetration test (SPT) is performed during the advancement of a soil boring to obtain a disturbed drive sample (split barrel type) of the soil being penetrated and an approximate measure of its dynamic resistance. The test was introduced by the Raymond Pile Company in 1902 and remains today as the most common in-situ test performed worldwide. The procedures for the SPT are detailed in ASTM D 1586 and AASHTO T 206. A summary of the important features of the test follows.

The SPT involves the driving of a hollow thick-walled tube into the ground and measuring the number of blows to advance the split-barrel sampler having standard dimensions of 2 in (50 mm) outside diameter (OD) and 1-3/8 in (35 mm) inside diameter (ID) a vertical distance of 1 ft (300 mm), see Figure 3-20. A 140 pound (63.5 kilogram) hammer is repeatedly dropped from a height of 30 in (0.76 m) to achieve three successive 6 in (150 mm) increments of penetration. The first recorded increment is considered as a "seating" penetration, while the number of blows to advance the second and third increments are summed to give the N-value ("blow count") or SPT-resistance (reported in blows per foot (0.3 m)).

The SPT can be halted when a total of 100 blows have been counted or if the number of blows exceeds 50 in any given 6 in (150 mm) increment, or if the sampler fails to advance during 10 consecutive blows. SPT refusal is defined by penetration resistances exceeding 100 blows per 2 in (50 mm), although ASTM D 1586 has re-defined this limit at 50 blows per 1 in (25 mm). If bedrock, or an obstacle such as a boulder, is encountered, the boring may be advanced further by using diamond core drilling or non-core rotary methods (ASTM D 2113; AASHTO T 225) at the discretion of the geotechnical specialist. In certain cases, this SPT criterion may be utilized to define the top of bedrock within a particular geologic setting where boulders are not of concern or not of great impact on the project requirements. The advantages and disadvantages of the SPT are listed in Table 3-8.

Table 3-8
Advantages and disadvantages of the Standard Penetration Test (SPT)

Advantages	Disadvantages
• Obtain both a sample and an N-value	• Disturbed sample (index tests only)
• Simple and rugged	• N-value is a crude number for analysis
• Suitable in many soil types	• Not applicable in soft clays & loose silts
• Can be performed in weak rocks	• High variability and uncertainty
• Readily available throughout the U.S.	• Unreliable in gravelly soils

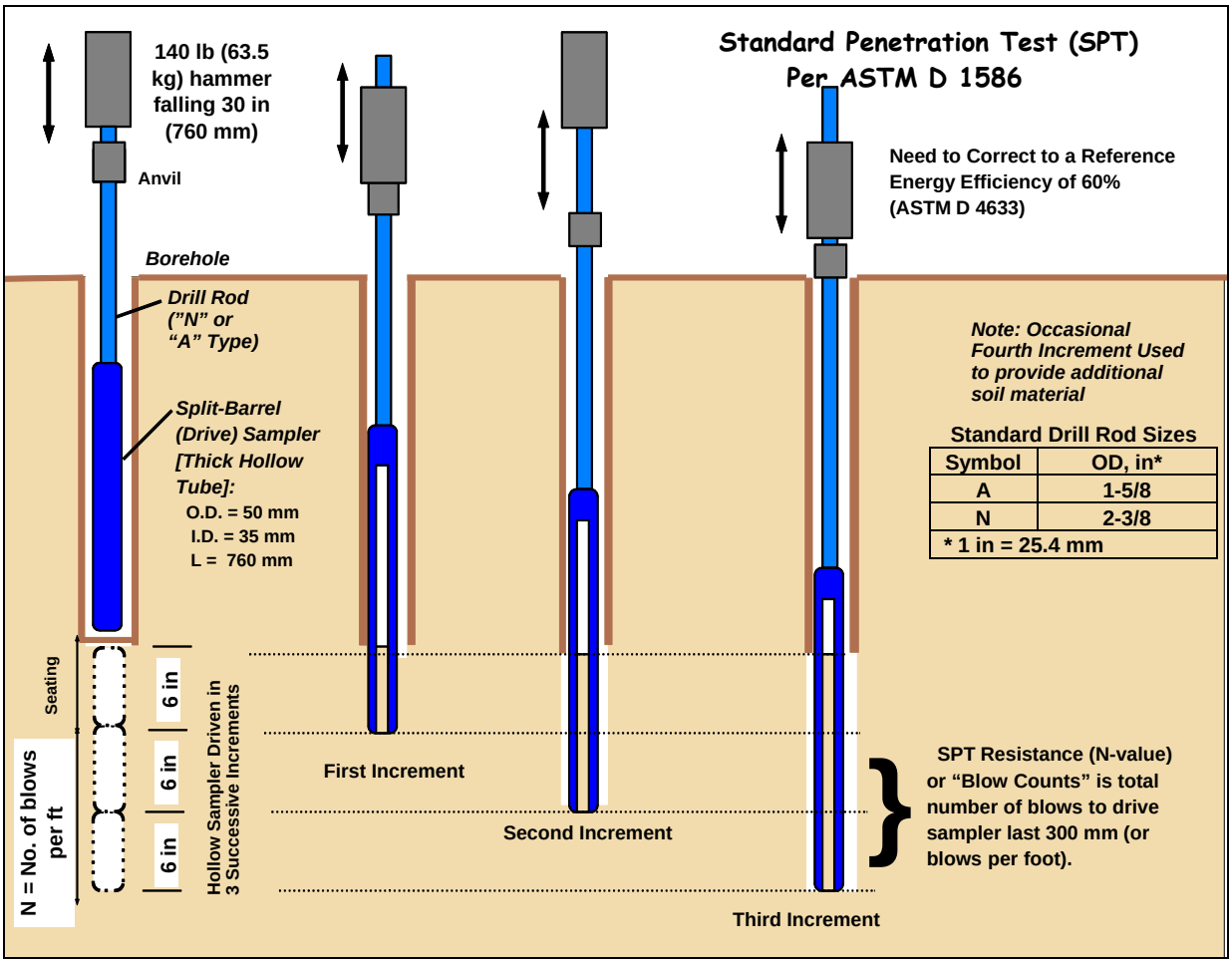


Figure 3-20. Sequence of driving split-barrel sampler during the Standard Penetration Test (modified after FHWA, 2002b).

The SPT is conducted at the bottom of a soil boring that has been advanced by use of either flight augers or rotary wash drilling methods. The borehole can be cased or uncased. At regular depth intervals, the drilling process is interrupted to perform the SPT. Generally, at depths shallower than 10 ft (3 m) the SPT is performed continuously or at intervals of 2.5 ft (0.75 m). Below a depth of 10 ft (3 m) the SPT is generally performed at intervals of 5 ft (1.5 m) to the planned end of the boring or refusal. If the borehole extends below the groundwater table, the head of water in the borehole must be maintained at or above the ambient groundwater level to avoid inflow of water and borehole instability.

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Liners may be placed inside the split-barrel sampler with the same inside diameter as the cutting shoe, see Figure 3-21a. This allows samples to remain intact during transport to the laboratory. The liners may be arranged in a set of 1-inch (25 mm) high rings in which case "ring" samples of pre-determined height may be obtained. In U.S. practice, it is normal to omit the liner. The resistance of the sampler to driving is altered depending upon whether or not a liner is used (Skempton 1986, Kulhawy and Mayne, 1990). Therefore, **when the liners are used, their use should be clearly mentioned in the boring logs.**

Steel or plastic sampler "catchers" are often required to keep samples of clean granular soils in the split-barrel sampler. Figure 3-21 shows a variety of catchers. They are inserted inside the sampler between the cutting shoe and the sample barrel to help retain loose or flowing materials. These catchers permit the soil to enter the sampler during driving but upon withdrawal they close and thereby retain the sample. **Use of sample catchers should be noted on the boring log.**



(a)



(b)

Figure 3-21: (a) Stainless steel and brass liners, (b) Sample catchers (FHWA, 2002b).

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3.7.1 Energy Efficiency of Hammers

In current U.S. practice, three types of drop hammers and four types of drill rods are used in performing the SPT. Drop hammer types are typically donut, safety, and automatic (see Figure 3-22). Typical drill rod sizes are N or A (see Figure 3-20 for sizes). The test results are highly dependent upon the type of equipment used and the experience of the operator performing the test. One of the more important factors for obtaining useful data from the test is the energy efficiency of the system. The theoretical energy of a free-fall system with the specified mass and drop height is 350 ft-lb (48 kg-m), but the actual energy is less due to a number of factors including frictional losses and eccentric loading that are specific to the hammer drop. The energy efficiency of the rotating cathead and rope system commonly used in the past depends on numerous factors including: type of hammer, number of rope turns, conditions of the sheaves and rotating cathead (e.g., lubricated, rusted, bent, new, old), age of the rope, actual drop height, vertical plumbness, weather and moisture conditions (e.g., wet, dry, freezing), and other variables (see for example Skempton, 1986). In the recent past the trend has been towards the use of automated systems for lifting and dropping the mass in order to minimize these factors. Automated systems provide more reliable and more reproducible results than the rotating cathead and rope system used in the past.

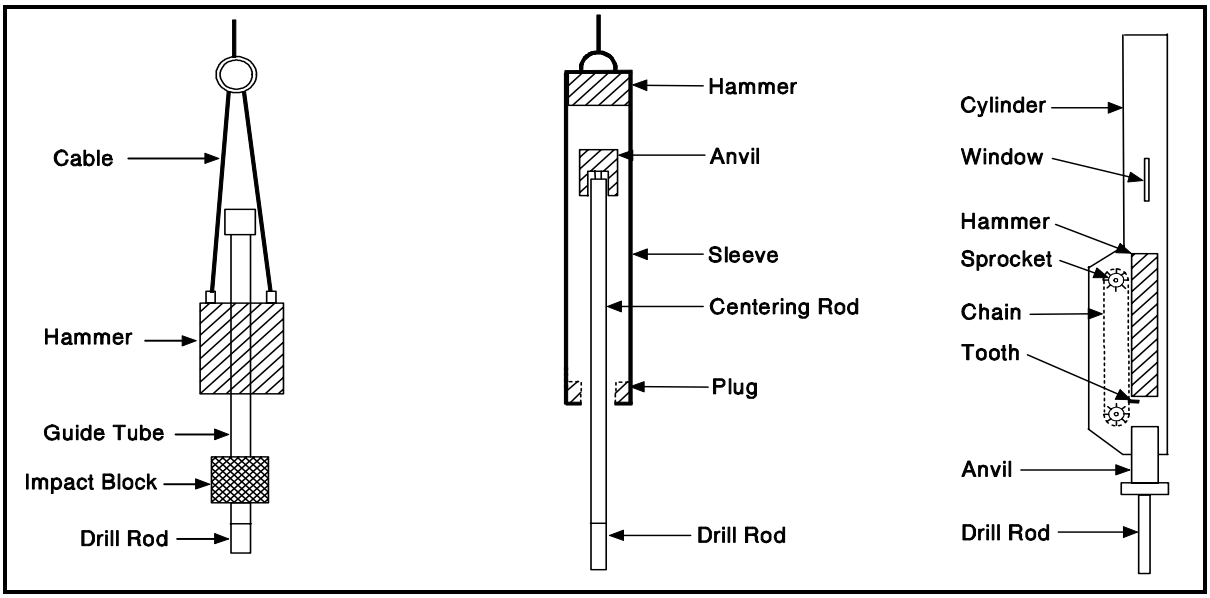


Figure 3-22. SPT hammer types, (a) Donut, (b) Safety, and (c) Automatic (FHWA, 2006a).

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A calibration of energy efficiency for a specific drill rig and operator is recommended by ASTM D 4633. Instrumented strain gages and accelerometer measurements are used for these calibrations in an attempt to standardize the energy levels. The standard of practice for energy efficiency varies from about 35% to 85% with cathead systems using donut or safety hammers. The average for cathead systems in the United States is approximately 60%. The newer automatic trip-hammers can deliver between 80 to 100% efficiency, depending upon the type of commercial system being used.

If energy efficiency (E_f) is measured, then the energy-corrected SPT N-value adjusted to 60% efficiency (N_{60}) is given by:

$$N_{60} = (E_f/60)\, N_{meas} \qquad 3\text{-}2$$

where N_{meas} is the N-value measured in the field during the test. N-values measured in the field should be corrected to N_{60} for all soils, if possible. The relative magnitudes of corrections for energy efficiency, sampler lining, rod lengths, and borehole diameter are given by Skempton (1986) and Kulhawy and Mayne (1990), but only as general guidelines. Theoretically it is mandatory to measure E_f to get the proper correction to N_{60}. In absence of data, AASHTO (2004 with 2006 Interims) recommends E_f = 60 for rope and cathead systems, i.e., donut and safety hammers and E_f = 80 for automatic hammer systems.

The efficiency may be obtained by comparing either the work done (W = F.d = force times displacement) or the kinetic energy ($KE = \frac{1}{2}mv^2$) with the potential energy of the system (PE = mgh), where m = mass, v = impact velocity, g = 32.2 ft/s^2 = 9.8 m/s^2= gravitational constant, and h = drop height. Thus, the energy ratio (ER) is defined as W/PE, or ER = KE/PE. **It is important to note that geotechnical foundation practice and engineering usage based on SPT correlations have been developed on the basis of the standard-of-practice, corresponding to an average ER ≈ 60 %. Thus, it is recommended to adjust measured N-values (N_{meas}) to N_{60} values.**

Figure 3-23 exemplifies the need for correcting measured N-values to a reference energy level where the successive SPTs were conducted by alternating the use of donut and safety hammers in the same borehole. The energy ratios were measured for each test and gave 34 < ER < 56 for the donut hammer (average = 45%) and 55 < ER < 69 for the safety hammer (average = 60%) at this site. The individual trends for the measured N-values from donut and safety hammers are quite apparent in Figure 3-23(a), whereas a consistent profile is obtained in Figure 3-23(b) once the data have been corrected to ER = 60%.

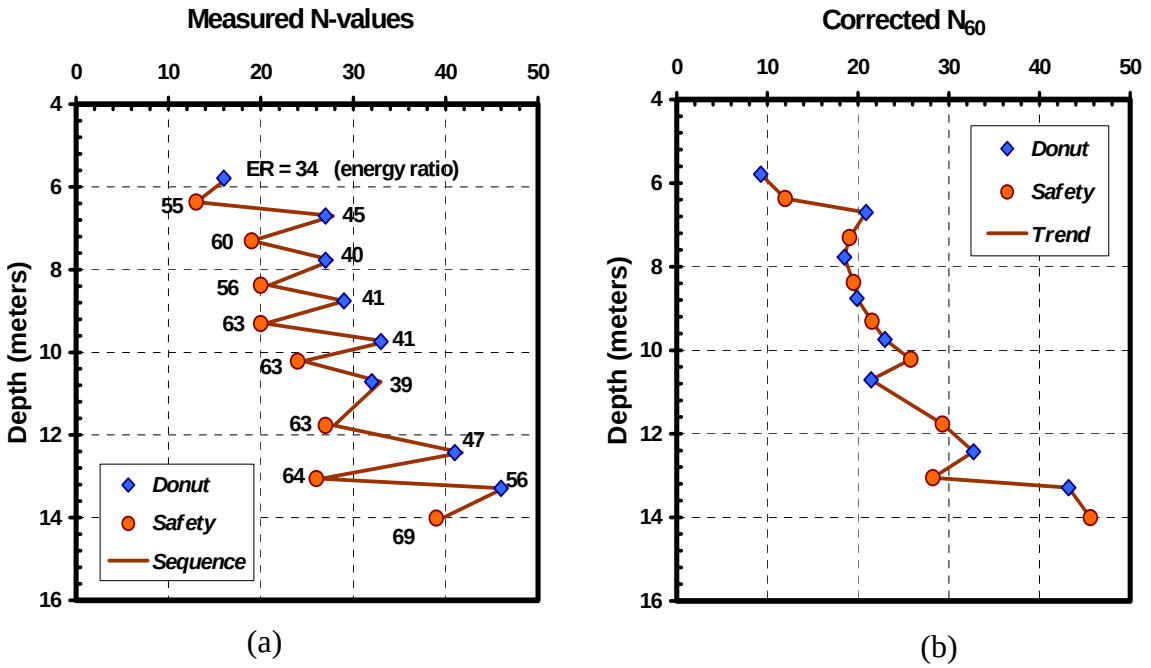


Figure 3-23. SPT N-values from (a) Uncorrected data, and (b) Corrected to 60% efficiency (Data modified after Robertson and Campanella, 1983).

3.7.2 Effect of Overburden Stress on N-values

Since N-values of similar materials increase with increasing effective overburden stress, the corrected blow count (N_{60}) is often normalized to 1-atmosphere (1 tsf or about 100 kPa) effective overburden stress by using overburden normalization schemes. The energy-corrected blow count normalized for overburden is referred to as $N1_{60}$, and is equal to:

$$N1_{60}=C_N\, N_{60} \qquad 3\text{-}3$$

where C_N is the overburden correction factor (or stress normalization parameter) calculated as (Peck, *et al.*, 1974):

C_N = $[0.77 \log_{10}(20/p_o)]$, and $C_N < 2.0$

p_o = vertical effective pressure at the depth where the SPT test is performed (tsf)

N_{60} = SPT blow count corrected for hammer efficiency (blows/ft) – refer to Equation 3-2.

Note that the constants in Equation 3-3 are unit dependent therefore the units of p_o must be tsf. Figure 3-24 presents the overburden correction factor as a function of vertical effective stress.

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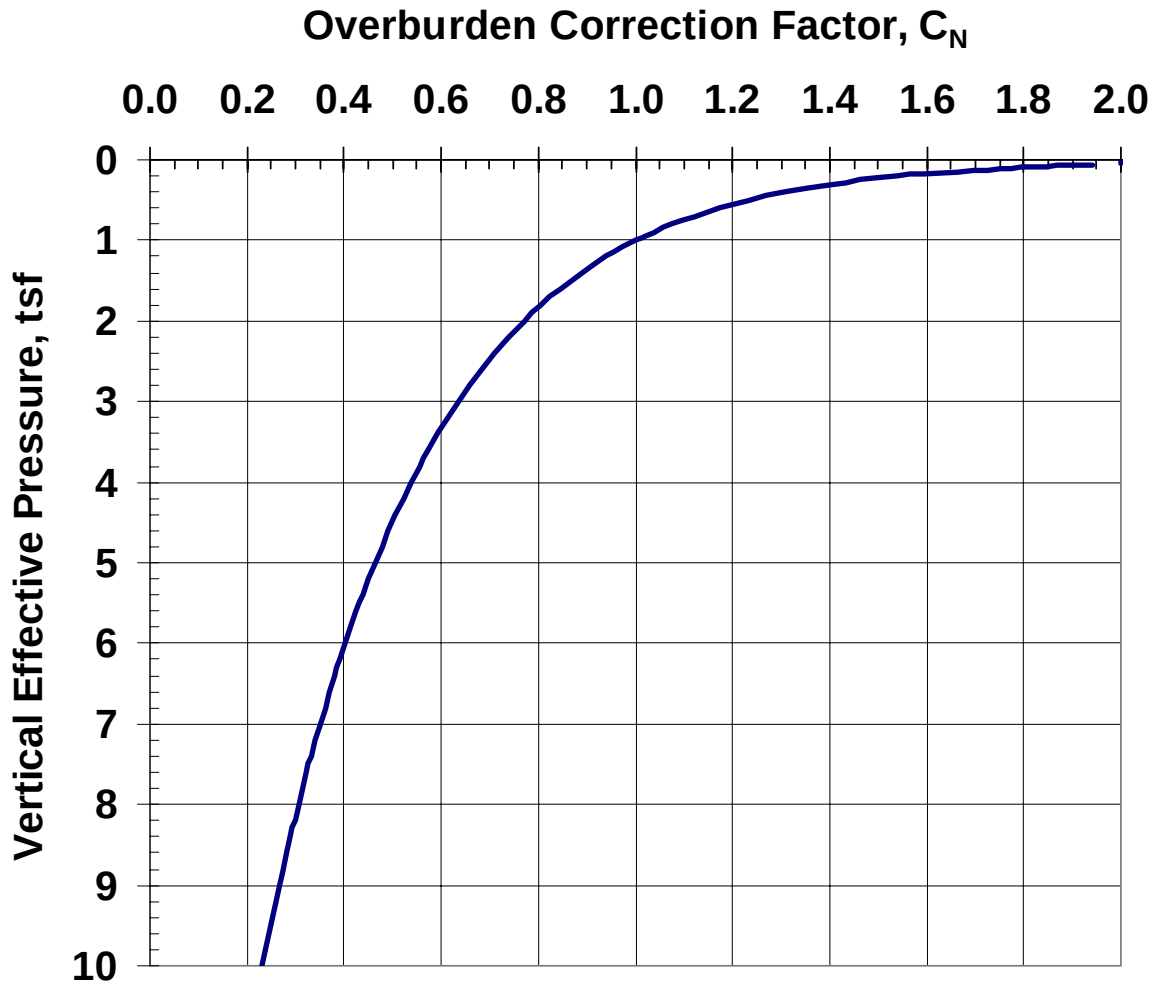


Figure 3-24. Variation of overburden correction factor, C_N, as a function of vertical effective stress.

Caution should be exercised in applying the overburden correction factor to indurated cemented soils, e.g., hard caliche soils encountered in the desert southwest. In such soils, the overburden pressure may not be a direct function of the depth of the soil. Therefore, the overburden correction is not recommended for such soils since it may lead to overly conservative designs.

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3.7.3 Correlation of SPT N-Values with Basic Soil Characteristics

SPT N-values are an indication of the relative density of cohesionless soils and the consistency of cohesive soil. Table 3-9 shows N-value ranges correlated to the relative density of sands and the consistency of fine-grained soils. It is emphasized that these correlations are unreliable for gravels, silts and clays and should serve only as crude estimates for these materials.

Table 3-9
Soil properties correlated with Standard Penetration Test values (after Peck, *et al.*, 1974)

Sands (Reliable)		Silts and Clays (Unreliable)	
N_{60}	Relative Density	N_{60}	Consistency
0-4	Very loose	Below 2	Very soft
5-10	Loose	2-4	Soft
11-30	Medium Dense	5-8	Medium
31-50	Dense	9-15	Stiff
Over 50	Very dense	16-30	Very stiff
		Over 30	Hard

3.7.3.1 Applicability of SPTs in Gravelly Soils

The SPT can be performed in a wide variety of soil types as well as weak rocks, however the SPT is not particularly useful in the characterization of gravelly soils. Since the split-spoon inside diameter is 1-⅜ in (35 mm), gravel sizes larger than 1-⅜ in (35 mm) will not enter the spoon. Therefore, soil descriptions may not reflect actual gravel content of the deposit. Also, gravel pieces may plug the end of the spoon and cause the SPT blow count to be erroneously large. Thus, the SPT in such cases produces refusal blow counts (i.e., > 50 blows per 1 in (25 mm)) that are misleading and lead to unconservative designs. In this case, "Large Penetration Tests" (LPTs), such as the Becker Penetration Test (BPT), are more suitable. The LPTs consist of driving a pipe (casing) larger than the standard split spoon sampler into the ground with a pile-driving hammer. While the pipe is being driven, the driving resistance or blow count/ft of penetration is recorded. Unlike the SPT, the LPT blow count is non-standardized and is a function of the drill rod size, pipe (sampler) size, hammer type, and hammer efficiency. Careful energy calibrations are required to correlate the LPT blow counts to SPT N-values However, this effort may be worthwhile considering that the results of SPT in gravelly soils are unreliable and misleading. Daniel, *et al.* (2003) present methods for evaluating LPT blow counts.

Since the gravel content cannot be measured by the SPT, it is recommended that consideration be given to obtaining bulk samples by drilling large diameter borings with

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augers similar to the one shown in Figure 3-5a. The bulk samples obtained from such borings will also help evaluate whether the soil deposit is indeed a gravel deposit or gravels are larger particles floating in a softer soil matrix. The bulk samples will also permit an accurate determination of the Unified Soil Classification System (USCS) designation (see Chapter 4), which will be useful from design as well as constructability considerations.

3.7.4 SPT Test Errors

Although the procedures for conducting the SPT test have been standardized, several errors can creep into the test. The most common errors are:

1. Effect of overburden pressure. Soils of the same density will give smaller blow counts near the ground surface. The overburden stress normalization parameter (C_N) can be used to correct for this factor.

2. Variations in the 30 in (770 mm) free fall of the drive weight. The drop height is often gauged by eye with the older rotating cathead and rope system Newer hammer systems automatically release the weight at a height of 30 inches. The energy correction factor accounts for this factor.

3. Interference with the free fall of the drive weight by the guides or the hoist rope required in the rotating cathead and rope system. Newer automatic hammer systems eliminate rope interference. The energy correction factor accounts for this factor.

4. Use of a drive shoe that is damaged or worn from too many "refusal" blow counts ($N_{meas} \geq 100$ blows/foot).

5. Failure to seat the sampler properly on undisturbed material in the bottom of the boring.

6. Inadequate cleaning of loosened material (slough) from the bottom of the boring.

7. Failure to maintain sufficient hydrostatic pressure in the borehole during drilling below the groundwater table. Unbalanced hydrostatic pressures between the borehole drill water and the groundwater table can cause the test zone to become "quick." This can happen when a continuous-flight auger is used with the end plugged and with a water level in the hollow stem below that in the hole.

8. Effect of gravel size as discussed in Section 3.7.3.1.

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9. Samples retrieved from dilatant soils (fine sands, sandy silts) that exhibit unusually high blow counts should be examined in the field to determine if the sampler drive shoe is plugged. Poor sample recovery is usually an indication of plugging.

10. Careless work on the part of the drill crew.

The use of qualified and experienced drillers cannot be overemphasized. Agencies that maintain their own drilling personnel and equipment generally achieve much more reliable and consistent results than those that routinely let boring contracts to the lowest bidder.

Soil type, density, and overburden pressure are the most significant factors affecting SPT N-values (assuming good workmanship and equipment). Table 3-10 lists factors affecting the SPT and SPT results.

Regardless of the impressive list of shortcomings, the SPT is not likely to be abandoned for several reasons:

1. The test is very economical in terms of cost per unit of information.

2. The test results provides soil samples, which can be tested for index properties and visually examined.

3. Long service life of the enormous amount of equipment in use.

4. The accumulation of a large SPT database that is continually expanding.

5. The results of the SPT have been correlated with a number of soil properties to provide estimates of the values of those properties. The estimated values are often used for preliminary designs in lieu of values obtained from tests run specifically to determine those properties.

6. The fact that other methods can be readily used to supplement the SPT when the borings indicate more refinement in sample/data collection.

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Table 3-10
Factors affecting the SPT and SPT results (after Kulhawy and Mayne, 1990)

Cause	Effects	Influence on SPT N-value
Inadequate cleaning of hole	SPT is performed in loose slough. Therefore soil may become trapped in sampler and may be compressed as sampler is driven, reducing recovery	Increases
Failure to maintain adequate head of water in borehole when test is performed below groundwater level	Bottom of borehole may become "quick"	Decreases
Careless measure of hammer drop	Hammer energy varies (generally variations cluster on low side)	Increases
Hammer weight inaccurate	Hammer energy varies (driller supplies weight; variations of 5 - 7 percent are common)	Increases or decreases
Hammer strikes drill rod collar eccentrically	Hammer energy reduced	Increases
Lack of hammer free fall because of ungreased sheaves, new stiff rope on weight, more than two turns on cathead, incomplete release of rope each drop	Hammer energy reduced	Increases
Sampler driven above bottom of casing	Sampler driven in disturbed, artificially densified soil	Increases greatly
Careless counting of hammer blows	Inaccurate results	Increases or decreases
Use of non-standard sampler	Correlations with SPT sampler invalid	Increases or decreases
Coarse gravel or cobbles in soil	Sampler becomes clogged or impeded	Increases
Use of bent drill rods	Inhibited transfer of energy of sampler	Increases

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3.8 LOG OF BOREHOLE INFORMATION ("BORING LOGS")

The importance of accurate field notes and good logging of boreholes cannot be overemphasized. The logger must realize that a good field description must be recorded. The field-boring log is the major portion of the factual data used in the analysis of foundation conditions.

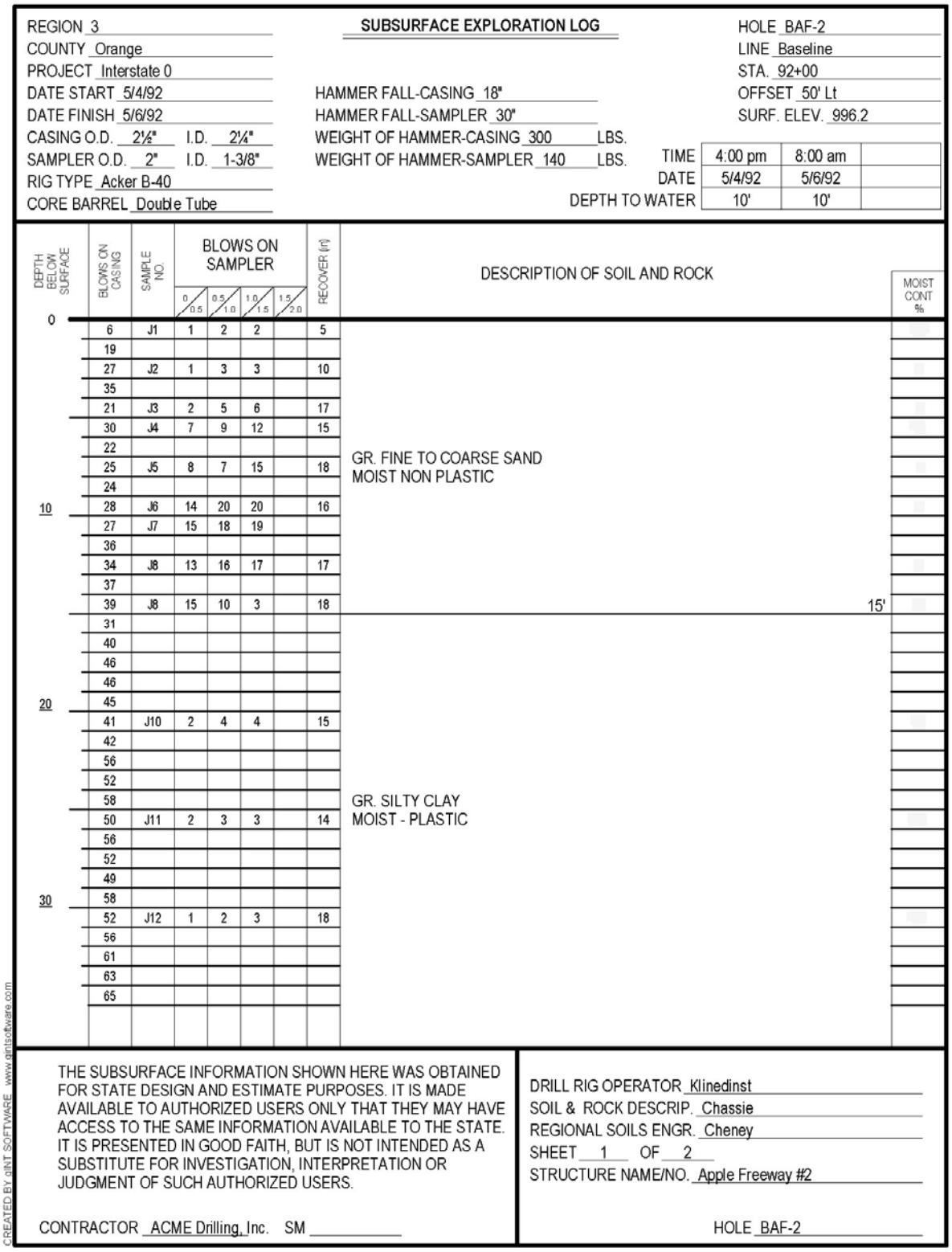
The boring log is a record that should contain all of the information obtained from a boring whether or not it may seem important at the time of drilling. It is important to record the maximum amount of information accurately. This record is the "field" boring log, as opposed to the "finished" boring log used in the preparation of the geotechnical data report. The finished log is drawn from the data presented in the field log supplemented by the results of visual identifications of samples and classification tests made in the laboratory. A typical boring log form is shown on Figures 3-25. The form presented in Figures 3-25 can be used for recording ***field*** data as well.

3.8.1 Boring Log Format

A wide variety of boring log forms are used by various agencies. The specific log to be used for a given type of boring will depend on local practice. The log in Figures 3-25 is just one example of a log used by geotechnical specialists. For detailed information on boring logs, the reader can refer to FHWA (1997, 2002b). The boring log shown in Figures 3-25 is used in this document simply to present the reader with an idea of the basic information that should be included in a boring log. Specific projects will likely require more detailed logs. Often separate logs are used for logging information from borings in soils and rocks unlike the log shown in Figures 3-25, which combines this information.

3.8.2 Duties of the Logger

The technical background and experience of the person who logs the field information will vary by organization. Some organizations will have a geotechnical engineer, an engineering geologist, a geologist, or a trained technician to accompany the drill crew, while others may train the drill crew foreman to log the borehole. In order to obtain the maximum amount of accurate data, the logger should work closely with the driller and be alert for changes in materials and operations while drilling is being performed. The logger is generally responsible for recording the following basic information on the field boring log:



REGION 3
COUNTY Orange
PROJECT Interstate 0
DATE START 5/4/92
DATE FINISH 5/6/92
CASING O.D. 2½" I.D. 2¼"
SAMPLER O.D. 2" I.D. 1-3/8"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-2
LINE Baseline
STA. 92+00
OFFSET 50' Lt
SURF. ELEV. 996.2

TIME	4:00 pm	8:00 am
DATE	5/4/92	5/6/92
DEPTH TO WATER	10'	10'

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/0.5	0.5/1.0	1.0/1.5	1.5/2.0	RECOVER (in)	DESCRIPTION OF SOIL AND ROCK	MOIST CONT %
0	6	J1	1	2	2		5		
	19								
	27	J2	1	3	3		10		
	35								
	21	J3	2	5	6		17		
	30	J4	7	9	12		15		
	22								
	25	J5	8	7	15		18	GR. FINE TO COARSE SAND MOIST NON PLASTIC	
	24								
10	28	J6	14	20	20		16		
	27	J7	15	18	19				
	36								
	34	J8	13	16	17		17		
	37								
	39	J8	15	10	3		18	15'	
	31								
	40								
	46								
	46								
20	45								
	41	J10	2	4	4		15		
	42								
	56								
	52								
	58							GR. SILTY CLAY MOIST - PLASTIC	
	50	J11	2	3	3		14		
	56								
	52								
	49								
30	58								
	52	J12	1	2	3		18		
	56								
	61								
	63								
	65								

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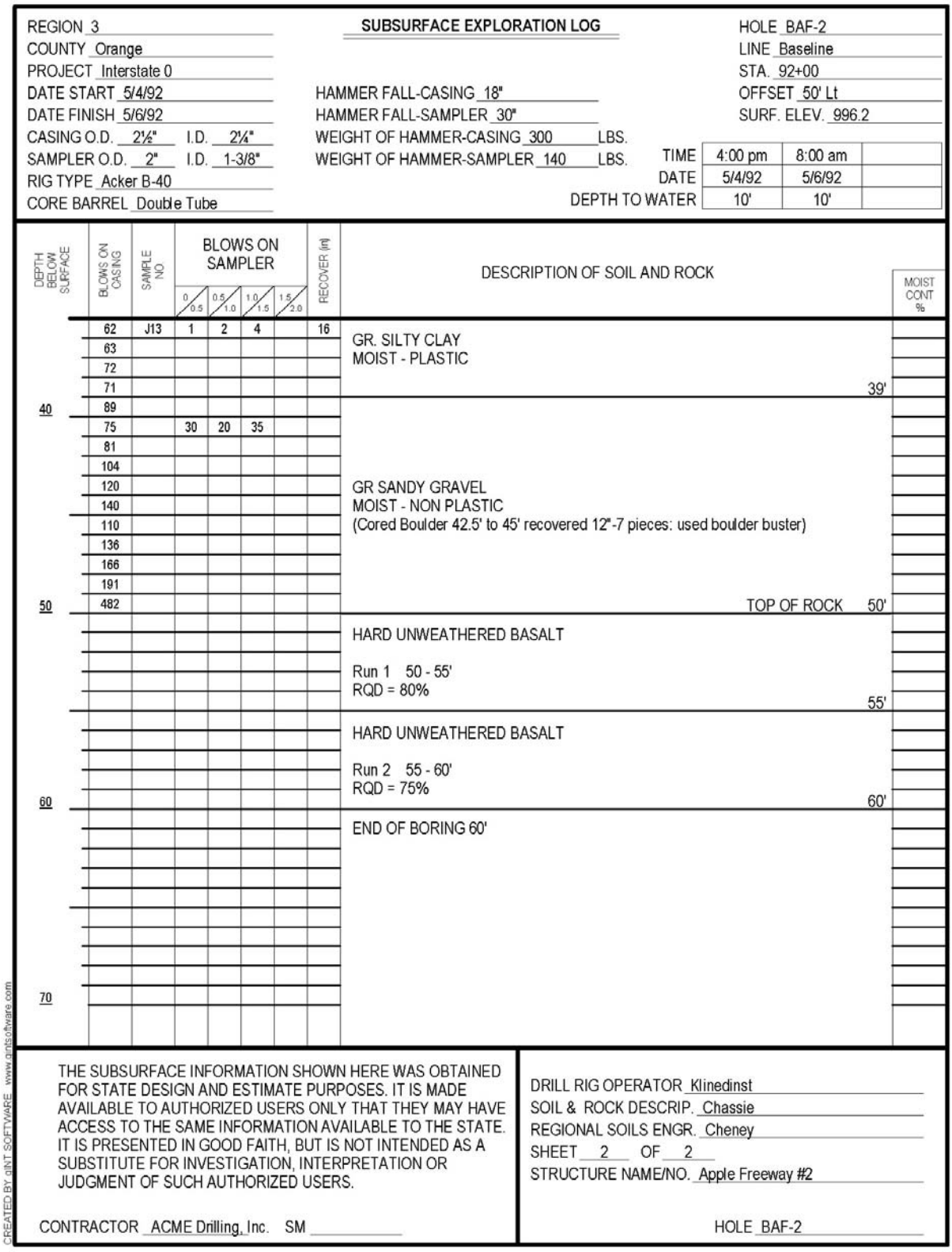
CONTRACTOR ACME Drilling, Inc. SM

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 1 OF 2
STRUCTURE NAME/NO. Apple Freeway #2

HOLE BAF-2

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Figure 3-25a. Example subsurface exploration log (0 – 35 ft depth).



REGION 3
COUNTY Orange
PROJECT Interstate 0
DATE START 5/4/92
DATE FINISH 5/6/92
CASING O.D. 2½" I.D. 2¼"
SAMPLER O.D. 2" I.D. 1-3/8"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-2
LINE Baseline
STA. 92+00
OFFSET 50' Lt
SURF. ELEV. 996.2

TIME	4:00 pm	8:00 am
DATE	5/4/92	5/6/92
DEPTH TO WATER	10'	10'

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/0.5	0.5/1.0	1.0/1.5	1.5/2.0	RECOVER (in)	DESCRIPTION OF SOIL AND ROCK	MOIST CONT %
	62	J13	1	2	4		16	GR. SILTY CLAY MOIST - PLASTIC	
	63								
	72								
	71							39'	
40	89								
	75		30	20	35				
	81								
	104								
	120							GR SANDY GRAVEL MOIST - NON PLASTIC (Cored Boulder 42.5' to 45' recovered 12"-7 pieces: used boulder buster)	
	140								
	110								
	136								
	166								
	191								
50	482							TOP OF ROCK 50'	
								HARD UNWEATHERED BASALT Run 1 50 - 55' RQD = 80%	
								55'	
								HARD UNWEATHERED BASALT Run 2 55 - 60' RQD = 75%	
60								60'	
								END OF BORING 60'	
70									

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SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 2 OF 2
STRUCTURE NAME/NO. Apple Freeway #2

HOLE BAF-2

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Figure 3-25b. Example subsurface exploration log (35 - 60 ft depth).

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1. General description of each soil and rock stratum, and the depth to the top and bottom of each stratum. As noted before, the log demonstrated in Figure 3-25 is intended to be a field log. On the final log, the description of the soil should be much more detailed and follow a specified soil classification system. Soils in the geotechnical engineering community are most often classified according to the Unified Soil Classification System (USCS). For example, the soils between depths 15 ft to 39 ft have been simply described in the field as "GR. SILTY CLAY, MOIST-PLASTIC." The full classification as per USCS on the final log may read as follows (the detailed description and classification of soils and the USCS are discussed in Chapter 4):

   Soft, wet, gray, high plasticity CLAY, with Silt; Fat CLAY (CH); (Alluvium)

2. The depth to groundwater at the time it is first encountered and afterwards at the end of each day, at completion of boring, and, if possible, at least 24 hours after completion of the boring.

3. The depth at which each sample is taken, the type of sample taken, its number, and any loss of samples taken during extraction from the hole.

4. The depths at which field tests are made and the results of the test.

5. Information generally required by the log format, such as:
   - Boring number and location.
   - Date of start and finish of the hole.
   - Name of driller (and of logger, if applicable).
   - Elevation at top of hole.
   - Depth of hole and reason for termination.
   - Diameter of any casing used.
   - Size of hammer and free fall used on casing (if driven).
   - Blows per foot to advance casing (if driven).
   - Description and size of sampler.
   - Size of drive hammer and free fall used on sampler in dynamic field tests.
   - Blow count for each 6 in (150 mm) to drive sampler. (Sampler should be driven three 6 in (150 mm) increments or to a total of 100 blows).
   - Type of drilling rig used.

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- Type and size of core barrel used.
- Length of time to drill each core run or foot of core run.
- Length of each core run and amount of core per run.
- Recovery of sample in inches and RQD of rock core.
- Project identification.

6. Notes regarding any other pertinent information and remarks on miscellaneous conditions encountered, such as:
   - Depth of observed groundwater, elapsed time from completion of drilling, conditions under which observations were made, and comparison with the elevation noted during reconnaissance (if any).
   - Artesian water pressure.
   - Obstructions encountered.
   - Difficulties in drilling (caving, coring boulders, surging or rise of sands in casing, caverns, etc.).
   - Loss of circulating water and addition of extra drilling water.
   - Drilling mud and casing as needed and why.
   - Odor of recovered sample.
   - Sampler plugged.
   - Poor recovery.

7. Any other information the collection of which may be required by agency policy (e.g., names and associations of visitors to the site, etc.).

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3.9 CONE PENETRATION TESTING (CPT)

The history of field cone penetrometers began with a design by the Netherlands Department of Public Works in 1930. This "Dutch" cone penetrometer was a mechanical operation using a manometer to read loads. Paired sets of inner and outer rods are pushed into the ground in 8 in (200 mm) intervals. In 1948, electric cones permitted continuous measurements to be taken downhole. In 1965, the addition of sleeve friction measurement devices allowed an indirect means for identifying soil types. Later, in 1974, the electric cone was combined with a piezoprobe to form the first piezocone penetrometer. Most recently, additional sensors have been added to form specialized devices such as the resistivity cone, acoustic cone, seismic cone, vibrocone, cone pressuremeter, and lateral stress cone.

The cone penetration test (CPT) was first introduced in the U.S. in 1965. Since that time, the CPT has developed into one of the most popular in-situ testing methods because it is fast, economical, and provides continuous profiling of the geostratigraphy and allows for continuous in-situ evaluation of soil properties. Depending upon equipment capability as well as soil conditions, 330 to 1150 ft (100 to 350 m) of penetration testing may be completed in one day.

As shown in Figure 3-26, the CPT involves the hydraulic push of an instrumented steel probe into the soil at a constant rate to obtain continuous vertical profiles of stresses and/or other measurements. No borehole, cuttings, or spoil are produced by this test. Testing is conducted in accordance with ASTM D 5778.

The CPT can be used in very soft clays to dense sands. It is not suitable for use in highly indurated or cemented soils or in soils containing significant amounts of gravel and boulders. The advantages and disadvantages of the CPT are listed in Table 3-11.

Table 3-11
Advantages and disadvantages of the Cone Penetration Test (CPT) (FHWA, 2002b)

Advantages	Disadvantages
• Fast and continuous profiling • Economical and productive • Results not operator-dependent • Strong theoretical basis in interpretation • Particularly suitable for soft soils	• High capital investment • Requires skilled operator to run • Electronic drift, noise, and calibration • No soil samples are obtained • Unsuitable for gravel/boulder deposits*
*Note: Except where special rigs are provided and/or additional drilling support is available.	

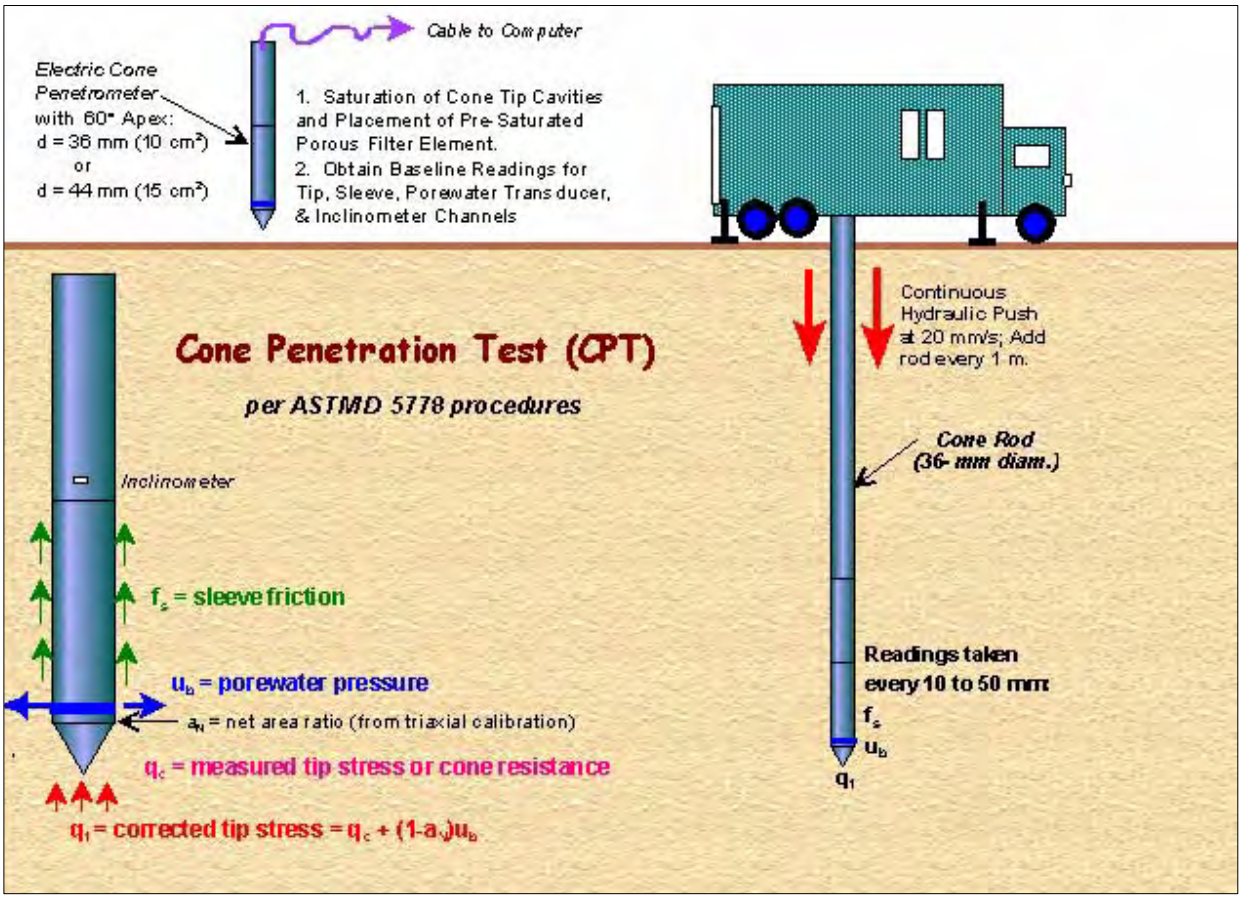


Figure 3-26. Procedures and components of the Cone Penetration Test (FHWA, 2002b).

Although the test provides continuous logging of the in-situ response of the soil, which can lead to more accurate and reliable analyses, no soil samples are available for laboratory testing. For that reason the CPT provides an excellent complement to the more conventional soil test boring with SPT measurements and subsequent laboratory testing on retrieved samples.

3.9.1 Equipment Description and Operation

Electronic cones are now the dominant cone type used in cone penetration testing. Therefore, mechanical cones are not discussed in this document. Electronic cones may be further divided into three primary types: (a) the standard friction cone (CPT), (b) the piezo-cone (PCPT or more commonly CPTu), and (c) the seismic cone piezo-cone (SCPTu). Each of these cones is briefly described here. To assist in following the brief descriptions, the standard terminology regarding the cone penetrometer is shown in Figure 3-27.

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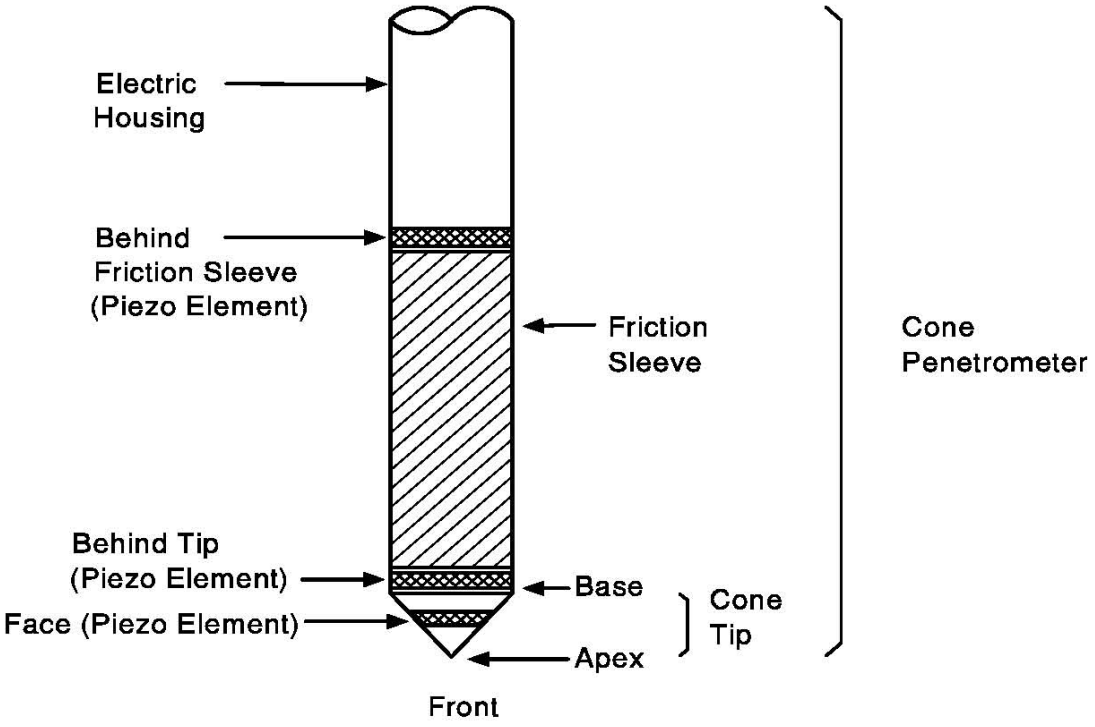


Figure 3-27. Cone penetrometer terminology (from Robertson and Campanella, 1989).

3.9.2 The Standard Cone Penetration Test (CPT)

The equipment necessary for performing a standard CPT includes a penetrometer, cone rod or drill rod, an electrical cable, a data acquisition system, and a hydraulic actuator attached to equipment that has sufficient reaction mass to advance the penetrometer. The equipment that provides the reaction mass can be a conventional drilling rig, however, a dedicated CPT truck commonly weighing 20 to 25 tons (200 to 250 kN) is more commonly used.

A standard cone penetrometer is a 1.4 in (35.7 mm) diameter cylindrical probe with a 60^{o} conical apex at the tip. The tip has a projected area of 1.6 in^2 (10 cm^2). The surface area of the sleeve above the cone is 23.3 in^2 (150 cm^2). More robust penetrometers are available with a 1.7 in (44 mm) diameter body, a 2.3 in^2 (15 cm^2) projected tip area, and a 31 to 35 in^2 (200 to 225 cm^2) sleeve surface area. A penetrometer having a projected cone area of 2.3 in^2 (15 cm^2) will generally provide the same response as one having a projected cone area of 1.6 in^2 (10 cm^2). The "size" of a cone is defined by its projected tip area, e.g. a 1.6 in^2 (10 cm^2) cone or a 2.3 in^2 (15 cm^2) cone. Figure 3-28 shows a number of different cone penetrometers and piezocones.

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Figure 3-28. Cone and piezocone penetrometers (note the quarter for scale) (FHWA, 2002b).

A section of standard cone rod is typically 3.3 ft (1 m) in length with a 1.4 in (35.7 mm) outer diameter and a 0.9 in (22 mm) inner diameter. Alternatively, the penetrometer can be pushed with standard AW drill rod (1¾ in (44.4 mm) OD; 1¼ in (31.8mm) ID) or EW drill rod (1⅜ in (34.9 mm) OD; 15/16 in (23.8 mm) ID).

The cone cable runs through the hollow cone/drill rods and attaches to an electronic data acquisition system at the ground surface. The data acquisition system generally consists of an analog signal conditioner, an analog to digital (A-D) converter, and a computer processor. Current data acquisition systems are attached to one or two computer monitors so the operator and engineer can observe data recorded during the sounding in real time. Real time monitoring allows for decisions to be made in the field with respect to the sounding. This is helpful if auxiliary tests, such as a pore pressure dissipation test, are to be performed in certain soil layers, or if the test is to be terminated once a certain layer is encountered. Printers can be attached to the computer processor to obtain a real-time printout of the data. Printed data are a good backup in case an unforeseen incident causes the computer to crash resulting in the loss of the electronically stored data. Data are typically recorded every ¾ to 2 in (20 to 50 mm) of vertical penetration.

The test procedure for the standard cone penetration test and the nature of the data acquired during the test are described in Sections 3.9.5 and 3.9.6, respectively.

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3.9.3 The Piezo-cone Penetration Test (CPTu)

The piezo-cone (CPTu) is essentially the same as the standard electronic friction cone except that it includes porous filter piezo-elements that may be located at the cone tip, on the cone face, behind the cone tip, or behind the friction sleeve. These porous filter elements are used to measure pore water pressure during penetration. Saturation of the porous element and cavity is essential to obtain reliable pore water pressure measurements.

3.9.4 The Seismic Piezocone Penetration Test (SCPTu)

For the seismic piezocone test (SCPTu), a geophone is located approximately 1.6 feet (500 millimeters) uphole from the cone tip. The geophone detects shear waves generated at the ground surface at intervals of approximately 3 or 5 ft (1 or 1.5 m), corresponding to successive rod additions. If necessary, adjustments should be made if AW or EW rods are used to advance the cone since they typically come in longer lengths.

3.9.5 Test Procedures

The test procedure for the CPT consists of hydraulically pushing the cone at a rate of 0.8 in/s (20 mm/s) in accordance with ASTM D 5778 by using either a standard drill rig or a specialized cone truck as the reaction mass (see Figure 3-29). The advance of the probe requires the successive addition of rods at approximately 3 or 5 ft (1 or 1.5 m) intervals. Readings of tip resistance (q_t), sleeve friction (f_s), inclination (i), and pore water pressure (u_m) are taken at least every 2 in (50 mm) (i.e., at approximately 2.5-sec intervals). For the seismic cone test, shear wave arrival times (t_s) are typically recorded at rod breaks corresponding to 3 or 5 ft (1 or 1.5 m) intervals.



Figure 3-29. Cone penetration testing from cone truck.

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3.9.6 CPT Profiles

The results of the individual channels of a piezocone penetration test are plotted with depth, as illustrated in a typical plot shown in Figure 3-30. Since soil samples are not obtained with the CPT, an indirect assessment of Soil Behavioral Type (SBT) is inferred by an examination of the readings. The numbers can be processed for use in empirical chart classification systems, or the raw readings can be easily interpreted for soil strata changes. A simplified soil classification chart for a standard electric friction cone is presented in Figure 3-31. The sleeve friction, often expressed in terms of a friction ratio $R_f = f_s/q_t$, also is a general indicator of soil type. For example, in sands, usually $0.5\% < R_f < 1.5\ \%$; and in clays, normally $3\% < R_f < 10\%$. In the lower half of the Figure 3-31, the center column shows an approximate relationship between the SPT N-value and the cone tip resistance, q_c. The SPT N-value obtained from this relationship should be considered to be equivalent to $N1_{60}$.

3.9.7 CPT Profile Interpretation

The CPT sounding shown in Figure 3-30 was taken in the immediate vicinity of the boring recorded in the boring log shown in Figures 3-25. These two logs permit an interesting comparison to be made of the SPT and CPT procedures. In the sounding shown in Figure 3-30, a clayey and sandy stratum (clay, clayey silt, silt, silty sand and sandy silt) occurs from the ground surface to a depth of 10 ft (3 m). These strata are underlain by a thick layer of sand and sandy silt to depth of approximately 20 ft (6 m), which in turn is underlain by a clay layer extending down to a depth of approximately 45 ft (14 m). Finally, a dense gravelly sand layer is encountered, which the cone penetrometer could not penetrate. The SPT tests could however be performed in this dense layer since it was possible to drill into this layer.

Figure 3-30 is a good example that demonstrates the advantage of continuous sounding compared to the samples obtained at discrete intervals using SPT procedures. For example, depending on the sampling interval in the SPT test, the silt layer within the clay layer may not have been undetected. Even if it had been detected, it would not have been possible to estimate its thickness accurately between the locations of the SPT samples because the SPT samples are commonly retrieved at 5 ft (1.5 m) intervals. The implications of this shortcoming can be significant in design. For example, silt consolidates faster than clay. If the designer is not aware of the silt layer, then he/she might design a wick drain surcharge system that, based on a clay layer 25 ft (7.5 m) thick, will take longer to consolidate than what might actually be the case. In fact, the CPT profile in Figure 3-30 shows that only the 15 ft (4.5 m) portion of the clay layer below the silt layer has excess pore pressures, which suggests that it will be the primary source of consolidation settlements.

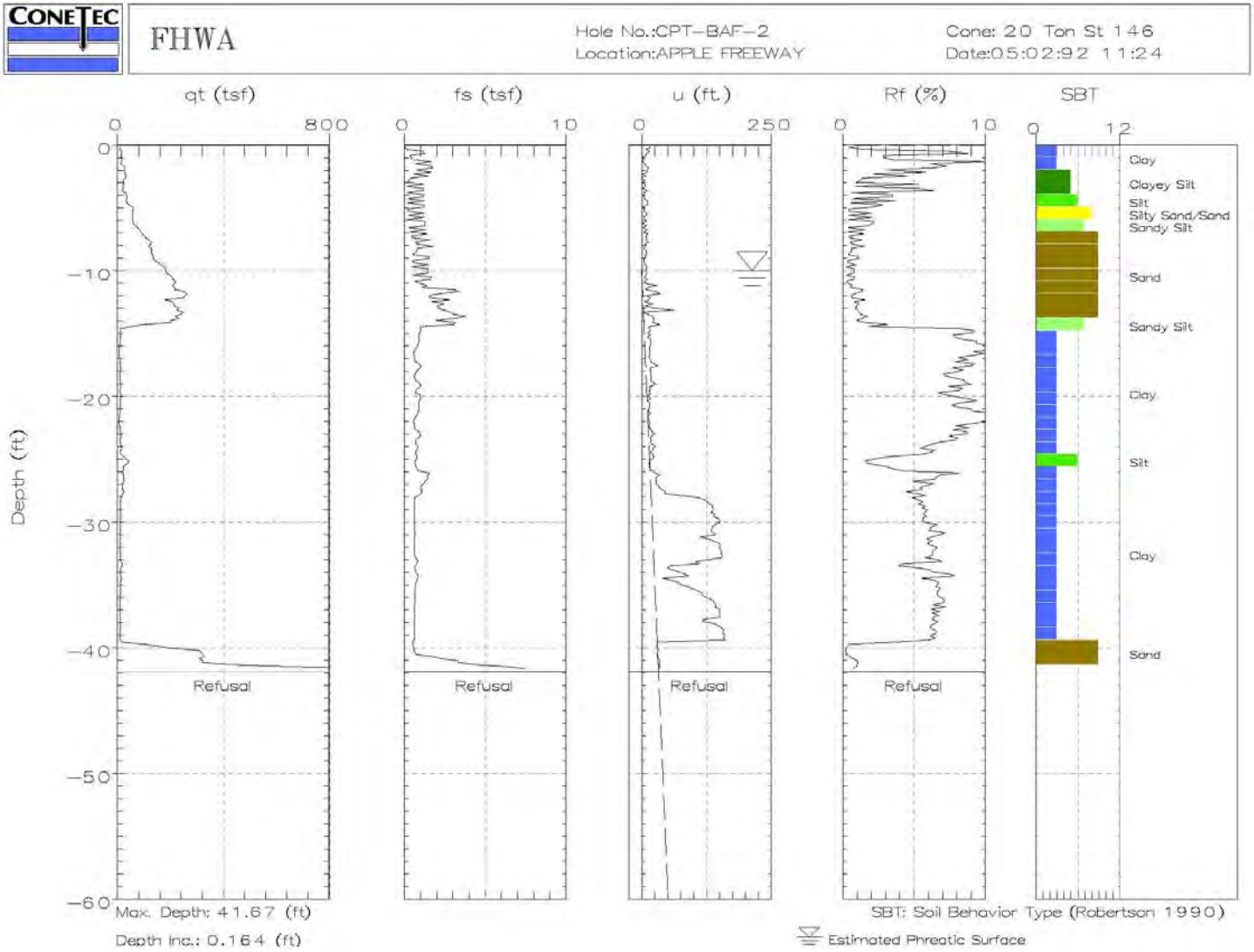
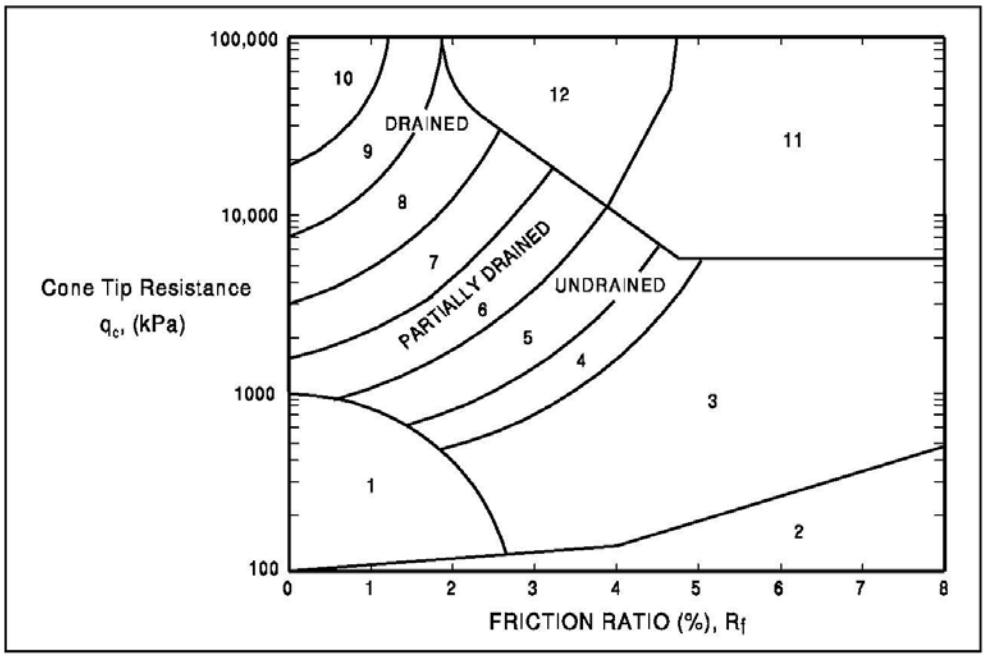


Figure 3-30. Piezo-cone results for Apple Freeway Bridge.

It is important for the reader to understand that CPT procedures do not allow retrieval of physical samples that can be tested in the laboratory to characterize various phenomena such as consolidation and shear strength. Thus, it is most beneficial to use the CPT with another method, such as the boring technique used in the SPT, that allows the retrieval of physical samples for laboratory testing. Performing the CPT before sampling in borings will permit identification of the specific depths where disturbed and undisturbed physical samples should be obtained for laboratory tests.



Zone	q_c/N	Soil Behavior Type
1)	2	sensitive fine grained
2)	1	organic material
3)	1	clay
4)	1.5	silty clay to clay
5)	2	clayey silt to silty clay
6)	2.5	sandy silt to clayey silt
7)	3	silty sand to sandy silt
8)	4	sand to silty sand
9)	5	sand
10)	6	gravelly sand to sand
11)	1	very stiff fine grained
12)	2	sand to clayey sand

Figure 3-31. A commonly used simplified soil classification chart for standard electronic friction cone (after Robertson, *et al.*, 1986).

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3.10 DILATOMETER TEST (DMT)

The dilatometer is an in-situ testing device that was developed in Italy in the early 1970s and first introduced in the U.S. in 1979. Like the cone penetrometer, the dilatometer is generally hydraulically pushed into the ground although it may also be driven. When the dilatometer can be pushed into the ground with tests conducted at 8 in (200 mm) increments, 100 to 130 ft (30 to 40 m) of soundings may be completed in a day. The primary utilization of the dilatometer test (DMT) in pile foundation design is the delineation of subsurface stratigraphy and interpreted soil properties. However, it would appear that the CPT/CPTu is generally better suited to this task than the DMT. The DMT may be a potentially useful test for the design of piles subjected to lateral loads. Design methods in this area show promise, but are still in the development stage. For design of axially loaded piles, the DMT has limited direct value. A picture of the DMT equipment is presented in Figure 3-32.

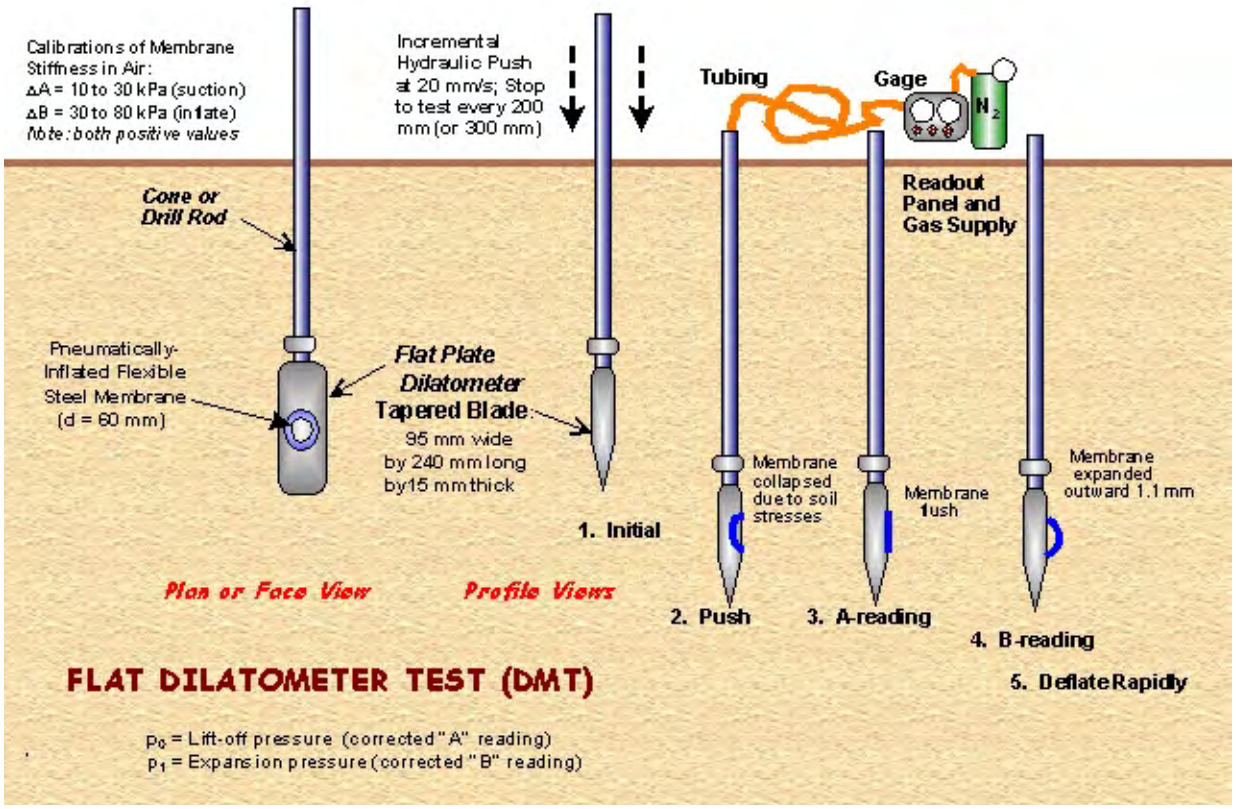


Figure 3-32. Dilatometer test equipment and procedure (FHWA 2002b).

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3.11 PRESSUREMETER TEST (PMT)

The pressuremeter is an in-situ device used to evaluate soil and rock properties. The pressuremeter has been used in Europe for many years and was introduced into the U.S. in the mid 1970s. The pressuremeter imparts lateral pressures to the soil, and the soil shear strength and compressibility are determined by interpretation of a pressure-volume relationship. The pressuremeter test (PMT) allows a determination of the load-deformation characteristics of soil in axisymmetric conditions. Deposits such as soft clays, fissured clays, sands, gravels and soft rock can be tested with pressuremeters. A pressuremeter test produces information on the elastic modulus of the soil as well as the at rest horizontal earth pressure, the creep pressure, and the soil limit pressure. A schematic of the pressuremeter test is presented in Figure 3-33.

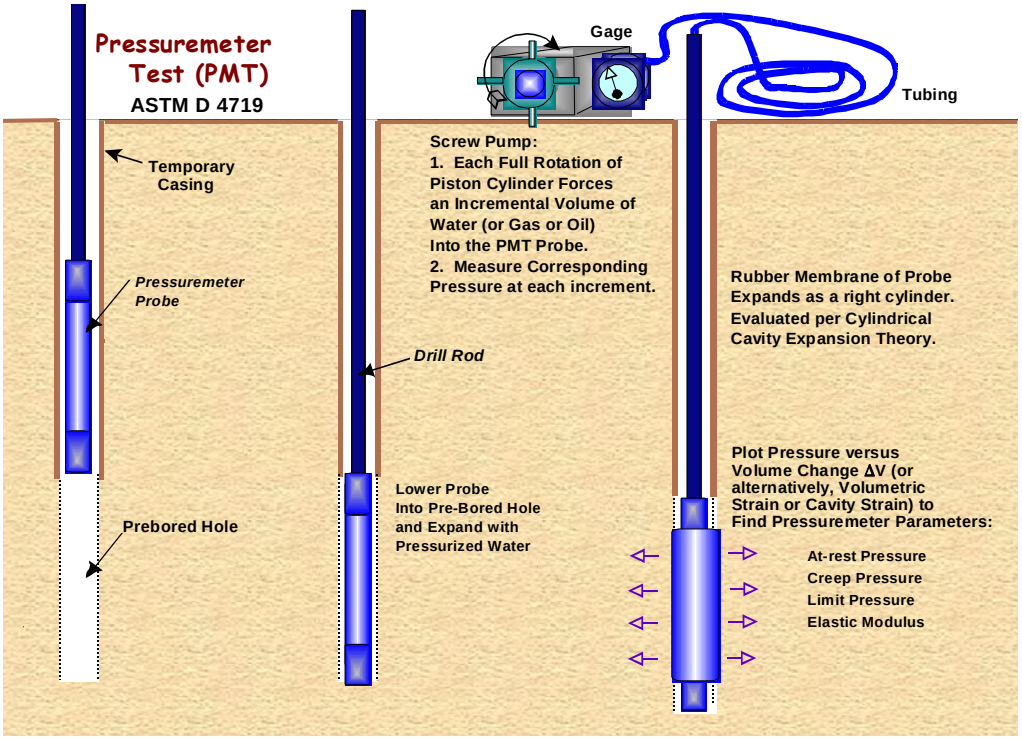


Figure 3-33. Pressuremeter test schematic (FHWA, 2002b).

The utilization of test results is based upon semi-empirical correlations from a large number of tests and observations on actual structures. For piles subjected to lateral loads, the pressuremeter test is a useful design tool and can be used for determination of p-y curves. For design of vertically loaded piles, the pressuremeter test has limited value. Pile design procedures using pressuremeter data have been developed and may be found in FHWA (1989a). Details on test procedures may be found in ASTM D 4719.

3.12 VANE SHEAR TEST (VST)

The vane shear test is an in-situ test for determining the undrained shear strength of soft to medium clays. Figure 3-34 is a schematic drawing of the essential components and test procedure. The test consists of forcing a four-bladed vane into undisturbed soil and rotating it until the soil shears. Two shear strengths are usually recorded, the peak shearing strength and the remolded shearing strength. These measurements are used to determine the **sensitivity of clay**, which is defined as the ratio of the peak undrained shearing strength to the remolded undrained shearing strength. Sensitivity, S_t, allows analysis of the soil resistance to be overcome during pile driving in clays which is useful for pile driveability analyses. It is necessary to measure skin friction along the steel connector rods which must be subtracted to determine the actual shear strength. The VST generally provides the most accurate undrained shear strength values for clays with undrained shear strengths less than 1 ksf (50 kPa). The test procedure has been standardized in AASHTO T 223-74 and ASTM D 2573.

It should be noted that the sensitivity of a clay determined from a vane shear test provides insight into the set-up potential of the clay deposit. However, the sensitivity value is a qualitative and not a quantitative indicator of soil set-up. Classification of clayey soils based on sensitivity values is presented in Table 3-12.

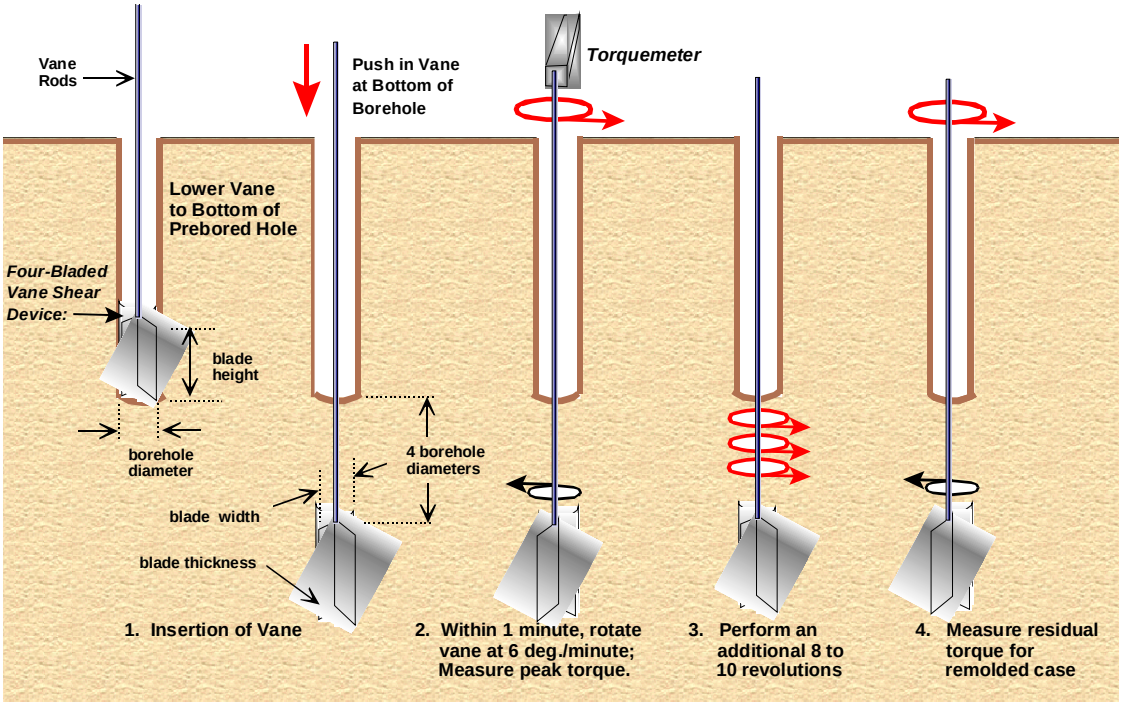


Figure 3-34. Vane shear test equipment and procedure (after FHWA, 2002b).

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Table 3-12
Classification of Sensitivity Values (Mitchell, 1976)

Classification	Sensitivity, S_t
Insensitive	~ 1.0
Slightly sensitive clays	1 – 2
Medium sensitive clays	2 – 4
Very sensitive clays	4 – 8
Slightly quick clays	8 – 16
Medium quick clays	16 – 32
Very quick clays	32 – 64
Extra quick clays	> 64

3.13 GROUNDWATER MEASUREMENTS

Observations of the groundwater level and pore water pressure are an important part of all geotechnical explorations. The identification of groundwater conditions should receive the same level of care given to soil descriptions and samples. Measurements of water entry during drilling and measurements of the groundwater level at least once following drilling should be considered a minimum effort to obtain water level data, unless alternate methods, such as installation of observation wells, are defined by the geotechnical specialist. Detailed information regarding groundwater observations can be obtained from ASTM D 4750 and ASTM D 5092.

3.13.1 Information on Existing Wells

Many states require the drillers of water wells to file logs of the wells they have drilled. These are good sources of information of the materials encountered and water levels recorded during well installation. The well owners, both public and private, may have records of the water levels after installation, which may provide extensive information on fluctuations of the water level. This information may be available at state agencies regulating the drilling and installation of water wells, such as the Department of Transportation, the Department of Natural Resources, State Geologist, Hydrology Department, Department of Environmental Quality, and Division of Water Resources.

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3.13.2 Open Borings

The water level in open borings should be measured after any prolonged interruption in drilling, at the completion of each boring, and at least 12 hours (preferably 24 hours) after completion of drilling. Additional water level measurements should be made at the completion of the field exploration and at other times designated by the engineer. The date and time of each observation should be recorded.

If the borehole has caved, the depth to the collapsed region should be recorded on the boring record as the collapse may have been caused by groundwater conditions. The elevations of the caved depths of certain borings may be consistent with groundwater table elevations at the site. This consistency may become apparent once the subsurface profile is constructed (see Chapters 4 and 11).

Drilling mud obscures observations of the groundwater level owing to filter cake action and the greater specific gravity of the drilling mud compared to that of the water. If drilling fluids are used to advance borings, the drill crew should be instructed to bail the hole prior to making groundwater observations.

3.13.3 Observation Wells

The observation well, also referred to as a piezometer, is the fundamental means for measuring water head in an aquifer and for evaluating the performance of dewatering systems. In theory, a “piezometer” measures the water pressure in a confined aquifer or at a specific horizon of the geologic profile, while an “observation well” measures the level of a water table in an aquifer (Powers, 1992). In practice, however, the two terms are often used interchangeably to describe any device for determining static water head.

The term “observation well” is applied to any well or drilled hole used for the purpose of long-term studies of groundwater levels and pressures. Existing wells and bore holes in which casing is left in place are often used to observe groundwater levels. These, however, are not considered to be as satisfactory as wells constructed specifically for the purpose of measuring groundwater conditions. The latter may consist of a standpipe installed in a previously drilled exploratory hole or a hole drilled solely for use as an observation well.

Details of typical observation well installations are shown in Figure 3-35. The simplest type of observation well is formed by a small-diameter polyvinyl chloride (PVC) pipe set in an open hole. The bottom of the pipe is slotted and capped, and the annular space around the

slotted pipe is backfilled with clean sand. The area above the sand is sealed with bentonite, and the remaining annulus is filled with grout, concrete, or soil cuttings. A surface seal, which is sloped away from the pipe, is commonly formed with concrete in order to prevent the entrance of surface water. The top of the pipe should also be capped to prevent the entrance of foreign material; there should be a small vent hole in the top of the removable cap. In some localities, regulatory agencies may stipulate the manner for installation and closure of observation wells.

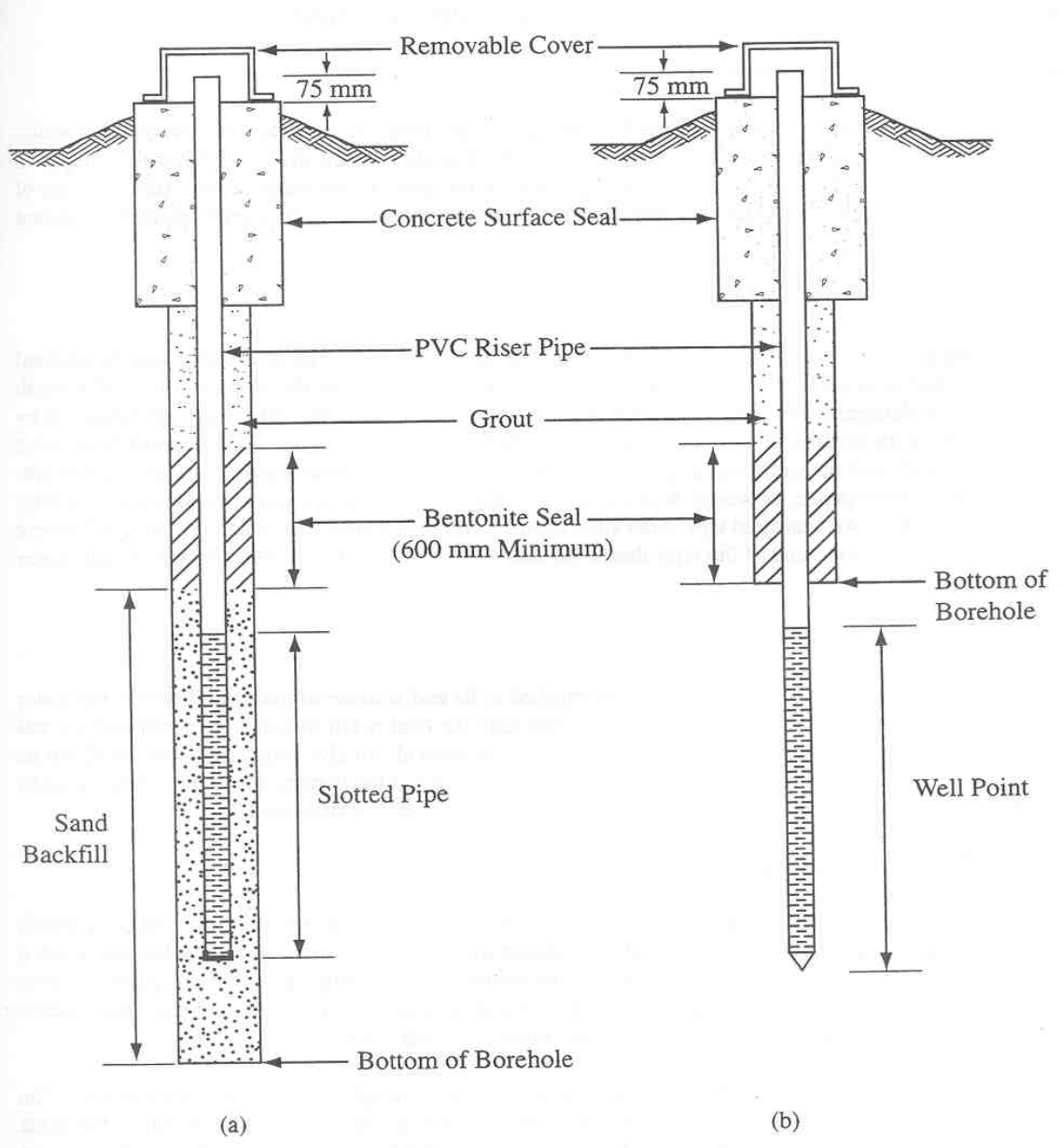


Figure 3-35. Representative details of observation well installations. (a) Drilled-in place stand-pipe piezometer, (b) Driven well point (FHWA, 1997).

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Driven or pushed-in well points are another common type of observation well for use in granular soil formations and very soft clay (Figure 3-35b). The well is formed by a stainless steel or brass well point threaded to a galvanized steel pipe. In granular soils, an open boring or rotary wash boring is advanced to a point several inches above the measurement depth and the well point is driven to the desired depth. A seal is commonly required in the boring above the well point with a surface seal at the ground surface. Note that observation wells may require development (see ASTM D 5092) to minimize the effects of installation, drilling fluids, etc. Minimum pipe diameters should allow introduction of a bailer or other pumping apparatus to remove fine-grained materials in the well to improve the response time.

Local jurisdictions may impose specific requirements on "permanent" observation wells, including closure and reporting of the location and construction that must be considered in the planning and installation. Licensed drillers and special fees may be required.

Piezometers are available in a number of designs. Commonly used piezometers are of the pneumatic and the vibrating wire type. Interested readers are directed to Dunnicliff (1988) and FHWA (1997) for a detailed discussion of the various types of piezometers.

3.13.4 Water Level Measurements

A number of devices have been developed for sensing or measuring the water level in observation wells. Following is a brief presentation of three methods that are commonly used to measure the depth to groundwater. In general, common practice is to measure the depth to the water surface by using the top of the casing as a reference, with the reference point at a common orientation (often north) marked or notched on the well casing.

3.13.4.1 Chalked Tape

In this method a short section at the lower end of a metal tape is chalked. The tape with a weight attached to its end is then lowered until the chalked section has passed slightly below the water surface. The depth to the water is determined by subtracting the depth of penetration of the line into water, as measured by the water line in the chalked section, from the total depth from the top of casing. This is probably the most accurate method, and the accuracy is useful in pump tests where very small drawdowns are significant. The method is cumbersome, however, when a series of rapid readings is taken since the tape must be fully removed each time. An enameled tape is not suitable unless it is roughened with sandpaper so it will accept chalk. The weight on the end of the tape should be small in volume so it does not displace enough water to create an error in the water level.

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3.13.4.2 Tape with a Float

In this method, a tape with a flat-bottomed float attached to its end is lowered until the float hits the water surface and the tape goes slack. The tape is then lifted until the float is felt to touch the water surface and the tape is just taut; the depth to the water surface is then measured. With practice this method can give rough measurements, but its accuracy is poor. A refinement is to mount a heavy whistle, open at the bottom, on a tape. When it sinks in the water, the whistle will give an audible beep as the air within it is displaced.

3.13.4.3 Electric Water-Level Indicator

This battery operated indicator consists of a weighted electric probe attached to the lower end of a length of electrical cable that is marked at intervals to indicate the depth. When the probe reaches the water a circuit is completed. This condition is registered by a meter mounted on the cable reel. Various manufacturers produce the instrument, utilizing a neon lamp, a horn, or an ammeter as the signaling device. The electric indicator has the advantage that it may be used in extremely small holes.

The instrument should be ruggedly built, since some degree of rough handling can be expected. The distance markings must be securely fastened to the cable. Some models are available in which the cable itself is manufactured as a measuring tape. The sensing probe should be shielded to prevent shorting out against metal risers. When the water is highly conductive, erratic readings can develop in the moist air above the actual water level. Sometimes careful attention to the intensity of the neon lamp or the pitch of the horn will enable the reader to distinguish the true level. A sensitivity adjustment on the instrument can be useful. If oil or iron sludge has accumulated in the observation well, the electric probe will give unreliable readings.

3.13.4.4 Data Loggers

When timed and frequent water level measurements are required, as for a pump test or slug test, data loggers are useful. Data loggers are in the form of an electric transducer near the bottom of the well that senses changes in water level as changes in pressure. A data acquisition system is used to acquire and store the readings. A data logger can eliminate the need for onsite technicians on night shifts during extended field permeability testing. A further significant saving is in the technician’s time back in the office. The preferred models of the data logger not only record the water level readings but permit the data to be downloaded into a personal computer and, with appropriate software, to be quickly reduced

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and plotted. These devices are also extremely useful for cases where measurement of artesian pressures is required or where data for tidal corrections during field permeability tests are necessary.

3.14 GUIDELINES FOR MINIMUM SUBSURFACE EXPLORATION

In regard to the scope of the subsurface exploration program for a structure or a geotechnical feature, one must consider the small cost of the borings in relation to the foundation costs. The knowledge gained from a thorough subsurface exploration program will allow the geotechnical specialist to evaluate various candidate foundation schemes and provide recommendations for those that can be built most efficiently and economically on the project site. Without an adequate subsurface exploration program, the result is generally an extremely conservative foundation recommendation.

Planning a subsurface exploration program should include determining the location and depth of borings, test pits, or other procedures to be used and establishing the methods of soil sampling and testing to be employed. Usually, the extent of the work is estimated based on available geological studies, earlier explorations, or records of existing structures. The number of borings and their locations in a site area will depend on the proposed structure, design parameters, access issues, geologic constraints, and expected stratigraphy.

Although no rigid rules apply universally to geotechnical explorations, certain general principles are usually followed in practice. Recommended guidelines for the minimum number of exploration points and their spacing are provided in Table 3-13. This table was developed based on a number of FHWA documents. This table should be used only as a first step in estimating the minimum number of borings for a particular design, as actual boring spacings will be dependent upon the project type and geologic environment. In all cases, it is recommended that the depth of the exploration should be such that the depth of significant influence (DOSI) is explored. For a given configuration of loading, the DOSI may exceed the minimum guidelines in Table 3-13 in which case the depth of exploration should be increased accordingly. Some other general guidance in addition to that in Table 3-13 is as follows:

- In areas underlain by heterogeneous soil deposits and/or rock formations, it will probably be necessary to exceed the minimum guidelines presented in Table 3-13 to capture variations in soil and/or rock type and to assess consistency across the site.

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Table 3-13
Guidelines for minimum number of exploration points and depth of exploration (modified after FHWA, 2002a)

Application	Minimum Number of Exploration Points and Location of Exploration Points	Minimum Depth of Exploration
Retaining walls	(1) A minimum of one exploration point for each retaining wall. (2) For retaining walls more than 100 ft (30 m) in length, exploration points spaced every 100 to 200 ft (30 to 60 m) with locations alternating from in front of the wall to behind the wall. (3) For anchored walls, additional exploration points in the anchorage zone spaced at 100 to 200 ft (30 to 60 m). (4) For soil-nail walls, additional exploration points at a distance of 1.0 to 1.5 times the height of the wall behind the wall spaced at 100 to 200 ft (30 to 60 m).	(1) Investigate to a depth below bottom of wall between 1 and 2 times the wall height or a minimum of 10 ft (3 m) into bedrock. (2) Exploration depth should be great enough to fully penetrate soft highly compressible soils (e.g. peat, organic silt, soft fine grained soils) into competent material of suitable bearing capacity (e.g., stiff to hard cohesive soil, compact dense cohesionless soil, or bedrock).
Embankment Foundations	(1) A minimum of one exploration point every 200 ft (60 m) (erratic conditions) to 400 ft (120 m) (uniform conditions) of embankment length along the centerline of the embankment. (2) At critical locations, (e.g., maximum embankment heights, maximum depths of soft strata) a minimum of three exploration points in the transverse direction to define the existing subsurface conditions for stability analyses. (3) For bridge approach embankments, at least one exploration point at abutment locations.	(1) Exploration depth should be, at a minimum, equal to twice the embankment height unless a hard stratum is encountered above this depth. (2) If soft strata are encountered extending to a depth greater than twice the embankment height, the exploration depth should be great enough to fully penetrate the soft strata into competent material (e.g., stiff to hard cohesive soil, compact to dense cohesionless soil, or bedrock).
Cut Slopes	(1) A minimum of one exploration point every 200 ft (60 m) (erratic conditions) to 400 ft (120 m) (uniform conditions) of slope length. (2) At critical locations (e.g., maximum cut depths, maximum depths of soft strata) a minimum of three exploration points in the transverse direction to define the existing subsurface conditions for stability analyses. (3) For cut slopes in rock, perform geologic mapping along the length of the cut slope.	(1) Exploration depth should be, at a minimum, 15 ft (4.5 m) below the minimum elevation of the cut unless a hard stratum is encountered below the minimum elevation of the cut. (2) Exploration depth should be great enough to fully penetrate through soft strata into competent material (e.g., stiff to hard cohesive soil, compact to dense cohesionless soil, or bedrock). (3) In locations where the base of cut is below ground-water level, increase depth of exploration as needed to determine the depth of underlying pervious strata.

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Table 3-13 (Continued)
Guidelines for minimum number of exploration points and depth of exploration (after FHWA, 2002a)

Application	Minimum Number of Exploration Points and Location of Exploration Points	Minimum Depth of Exploration
Shallow Foundations	(1) For substructure (e.g., piers or abutments) widths less than or equal to 100 ft (30 m), a minimum of one exploration point per substructure. (2) For substructure widths greater than 100 ft (30 m), a minimum of two exploration points per substructure. (3) Additional exploration points should be provided if erratic subsurface conditions or sloping rock surfaces are encountered.	Depth of exploration should be: (1) great enough to fully penetrate unsuitable foundation soils (e.g., peat, organic silt, soft fine grained soils) into competent material of suitable bearing capacity (e.g. stiff to hard cohesive soil, compact to dense cohesionless soil or bedrock); and (2) **at least to a depth where stress increase due to estimated footing load is less than 10% of the applied stress at the base of the footing**; and (3) in terms of the width of the footing: at least 2 times for axisymmetric case and 4 times for strip footing (interpolate for intermediate cases); and (4) if bedrock is encountered before the depth required by item (2) above is achieved, exploration depth should be great enough to penetrate a minimum of 10 ft (3 m) into the bedrock, but rock exploration should be sufficient to characterize compressibility of infill material of near-horizontal to horizontal discontinuities.
Deep Foundations	(1) For substructure (e.g., bridge piers or abutments) widths less than or equal to 100 ft (30 m), a minimum of one exploration point per substructure. (2) For substructure widths greater than 100 ft (30 m), a minimum of two exploration points per substructure. (3) Additional exploration points should be provided if erratic subsurface conditions are encountered. (4) Due to large expense associated with construction of rock-socketed shafts, conditions should be confirmed at each shaft location.	(1) In soil, depth of exploration should extend below the anticipated pile or shaft tip elevation a minimum of 20 ft (6 m), or a minimum of two times the maximum pile group dimension, whichever is deeper. All borings should extend through unsuitable strata such as unconsolidated fill, peat, highly organic materials, soft fine-grained soils, and loose coarse-grained soils to reach hard or dense materials. (2) For piles bearing on rock, a minimum of 10 ft (3 m) of rock core shall be obtained at each exploration point location to verify that the boring has not terminated on a boulder. (3) For shafts supported on or extending into rock, a minimum of 10 ft (3 m) of rock core, or a length of rock core equal to at least three times the shaft diameter for isolated shafts or two times the maximum shaft group dimension, whichever is greater, shall be extended below the anticipated shaft tip elevation to determine the physical characteristics of rock within the zone of foundation influence.

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- In the case of embankments, the guidance provided in Table 3-13 for the depth of exploration is the minimum recommended for any transportation facility, i.e., 2 times the height of the embankment. The minimum guidance may not be the same as the DOSI, which is a function of the geometry (crest width, height, configuration of side slopes, and the base width) of the embankment. For the same height of embankment, the DOSI increases as the base width of an embankment increases, and may vary from 4 to 6 times the height of the embankment. An example of this is shown in Figures 2-8 in Chapter 2, which shows that the DOSI can extend to depths much deeper than 2 times the height of the embankment. This may be particularly critical in cases where there are soft soils in the subsurface. Thus, for such situations, the geotechnical specialist should use tools such as the FoSSA program or published elastic solutions (Poulos and Davis, 1974) to determine the depth of exploration.

- For situations where large-diameter rock-socketed shafts will be used or where drilled shafts are being installed in karstic formations, it may be necessary to advance a boring at the location of each shaft.

- In a laterally homogeneous area, drilling or advancing a large number of borings may be redundant, since each sample tested would exhibit similar strength and compressibility properties.

- In all cases, it is necessary to understand how the design and construction of the geotechnical feature will affect the soil and/or rock mass in order to optimize the exploration.

During exploration, each exploration point (e.g., drill hole or CPT sounding) should be designated by a unique identification number to prevent duplication during subsequent explorations. For example, it is not unusual to find projects where borehole numbering was done by only single numbers so that the same designations were used during one or more subsequent explorations. A suggested method to avoid duplication is to designate that all bridge holes begin with the letter "B," followed by the initials of the highway or river being crossed and finally a sequential number. For example, the first boring for a structure on Apple Freeway would be designated DH-BAF-1, where the DH means a “drill hole” where SPTs were performed as opposed to CPT-BAF-1, where the CPT refers to the first CPT sounding performed for a bridge structure on Apple Freeway.

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The geotechnical specialist should plot the proposed boring locations on a site topographic map prior to initiation of drilling. Notes taken during the site visit should be reviewed before boring locations are selected so that site access restrictions can be considered. Boring locations should never be selected arbitrarily or randomly. Alternate boring locations should be considered and a contingency plan should be developed in case a boring needs to be relocated due to access restrictions or unexpected geologic conditions (e.g., locate a replacement boring within a maximum of 15 ft (4.5 m) from the location of a boring that could not be drilled at a particular location). Field personnel unfamiliar with the objectives and rationale behind the planning of the site exploration should maintain contact with the person in responsible charge of the field exploration during field activities and discuss issues such as the relocation of a boring with that person. Arbitrary or random boring selection will increase the chances of boring relocation, confusion, and wasted time in the field. Final boring locations should be surveyed and recorded as part of the permanent project record. Elevations and northing and easting should be provided for each boring.

3.14.1 Recommendations for Sampling Depth Intervals in Soils

It is difficult to establish a prescriptive drilling, sampling, and testing protocol that is applicable to all sites. To be most effective the geotechnical specialist should:

(1) apply conventional guidelines with project-specific requirements and constraints;

(2) recognize the advantages and limitations of the available sampling devices and in-situ testing methods.

Some general recommendations for minimum sampling depth intervals are as follows:

- For preliminary screening, disturbed samples might be taken continuously in the upper 10 ft (3 m), at 5 ft (1.5 m) intervals up to 100 ft (30 m), and possibly every 10 ft (3 m) at depths greater than 100 ft (30 m).

- Disturbed samples should be taken at every abrupt change in stratum as indicated by a noticeable change in the drilling pressure.

- Where footings are to be placed on natural soil, continuous spoon samples are recommended for a depth equal to 15 ft (4.5 m) or 1.5 times the width of the footing, whichever is greater, as measured below the anticipated footing base elevation.

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- For characterization and assessment of design properties in fine-grained soils, a minimum of one undisturbed sample should be taken in each stratum, with additional samples taken at 10- to 20-ft (3 to 6 m) intervals with depth.

- Undisturbed Shelby tube samples should be obtained at 5 ft (1.5 m) intervals in at least one boring in cohesive soils. For cohesive deposits greater than 30 ft (9 m) in depth, the tube sample interval can be increased to 10 ft (3 m). Undisturbed samples may not need to be taken in each boring if the deposit is relatively homogeneous within closely spaced borings.

These minimum guidelines and intervals may need to be increased depending upon the project requirements and site geologic conditions. The sampling interval may need to be increased when soil/rock conditions change frequently with depth; however, these changes need to be considered in the context of the design. Therefore, ongoing communication between field personnel and the office/design engineer is absolutely essential. Once the site stratigraphy has been established, it may not be necessary to sample every time there is a change in stratigraphy if the changes have no impact on design. For example, it may not be necessary to sample alternating layers of coarse-grained deposits where settlement is of concern, and for designs concerned with bearing capacity. Similarly, although samples below the anticipated extent of the area influenced by the load may be reduced, samples should be obtained in case the type of foundation changes between preliminary and final design.

The sampling interval will vary between individual projects and regional geologies. If soils are anticipated to be difficult to sample or trim in the laboratory due to defects (e.g., bent tubes, improper handling, etc.), the frequency of sample collection should be greater than average to offset the number of samples that may be unusable in the laboratory for performance property evaluation (e.g., shear strength). When borings are widely spaced, it may be appropriate to retrieve undisturbed samples in each boring. For closely spaced borings or in deposits of lateral uniformity, undisturbed samples may be needed only in select borings. If a thin clay seam is encountered during drilling and not sampled, the boring may need to be offset and re-drilled to obtain a sample.

It is often quite helpful to combine in-situ soundings with conventional disturbed/undisturbed sampling. For example, by performing CPT or CPTu soundings prior to conventional drilling and sampling, it may be possible to target representative and/or critical areas where samples can be obtained later. This concept was illustrated previously by the discussion in Section 3.9.7 and Figure 3-30. The use of precursor soundings may reduce some of the potential drilling redundancy in heterogeneous environments. Geophysical methods can also

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be used to provide useful information on conditions between and even beyond boring locations.

3.14.2 Recommendations for Sampling Depth Intervals in Rocks

For explorations for slopes and foundations within rock, it is important to consider structural geology in addition to the information obtained as part of a rock-coring program. For example, the orientation and characteristics of a clay-filled discontinuity are critical since they can be used to judge whether a rock slope will be stable or unstable or whether a structural foundation will undergo minor or significant settlement. A detailed structural geologic assessment may provide enough information to limit the scope of a rock-coring program significantly or even preclude such a program. For example, drilling and coring may not be required where applied loads are significantly less than the bearing capacity of the rock, where there is no possibility of sliding instability in a rock slope, or where there are extensive rock outcrops from which information can be obtained to establish the subsurface conditions confidently for design and constructability assessments (Wyllie, 1999).

3.14.3 Recommendations for Water Level Monitoring in Borings

The water level in each boring should be observed and the depth below the top of hole recorded on the drill log with the date and time of the reading for each of the following situations:

a) Water seepage or artesian pressure encountered during drilling. Artesian pressure may be measured by extending drill casing above the ground until flow stops. Report the pressure as the number of ft (m) of head above ground.

b) Water level at the end of each day and at completion of boring.

c) Water level 24 hours (minimum) after hole completion. Long term readings may require installation of a perforated plastic tube before abandoning the hole.

A false indication of water level may be obtained when water is used in drilling and adequate time is not permitted after the boring is completed for the water level to stabilize. In low permeability soils, such as clays, more than one week may be required to obtain accurate readings. Proper safety precautions should be taken if a hole is allowed to remain open for such an extended period of time.

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3.15 GEOPHYSICAL TESTS

As indicated in Section 3.3, geophysical testing can be used as part of the initial site exploration to provide supplementary information to data collected by other means (i.e., borings, test pits, geologic surveys, etc.). Geophysical testing can be used for establishing stratification of subsurface materials, the profile of the top of bedrock, the depth to groundwater, the boundaries of various types of soil deposits, the rippability of hard soil and rock, and the presence and depth of voids, buried pipes, and existing foundations. Data from geophysical testing should always be correlated with information from the direct methods of exploration discussed previously.

3.15.1 Types of Geophysical Tests

There are a number of different types of geophysical in-situ tests that can be used to obtain stratigraphic information from which engineering properties can be estimated. Table 3-14 provides a summary of the various geophysical methods that are currently available in U.S. practice. Further information on the procedures used for these methods is provided in FHWA (2003). Additional general discussion regarding the major test methods listed in Table 3-14 is presented below, with particular emphasis on potential applications to highway engineering.

1. **Seismic Methods**: These methods are becoming increasingly popular for geotechnical engineering practice because they have the potential to provide data regarding the compression and shear wave velocities of the subsurface materials. The shear wave velocity is directly related to small-strain material stiffness, which, in turn, is often correlated to compressive strength and soil/rock type. These techniques are often used for assessing the vertical stiffness profile in a soil deposit and for assessing the location at depth of the interface between soil and rock. Seismic refraction method involves measurement of time of arrival of the initial ground motion generated by the energy source while the seismic reflection method involves measurement of the energy arrival after the initial ground motion.

2. **Electrical Methods**: These methods are usually used to locate voids or locally distinct materials. With regards to highway applications, these procedures may be used to assess the potential for karst activity along a planned transportation corridor, or for locating large underground voids and/or specific underground anomalies such as storage drums and/or tanks. Electrical methods provide qualitative information only and are usually part of a two- or three-phased exploration program.

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Table 3-14
Geophysical testing techniques (modified after FHWA, 2002a)

Method	Basic Field Procedures	Applications	Limitations
SEISMIC METHODS			
Seismic Refraction	Impact load is applied to the ground surface. Seismic energy refracts off soil/rock layer interfaces and the *time of arrival* is recorded on the ground surface using several dozen geophones positioned along a line or performing repeated events using a single geophone.	• depth to bedrock • depth to water table • thickness and relative stiffness soil/rock layers	• does not work if stiffness decreases with depth or if soft layer underlies stiff layer • works best when sharp stiffness discontinuity is present
Spectral-Analysis-of-Surface-Waves (SASW)	Impact load is applied to the ground surface. Surface waves propagate along ground surface and are recorded on the ground surface with two geophones positioned along a line.	• depth to bedrock • measurement of shear wave velocity • thickness and stiffness of surface pavement layer • qualitative indicator of cracking in pavement	• resolution decreases significantly with increasing depth • accurate interpretation may require a significant amount of expertise • interpretation is difficult if a stiff layer overlies a soft layer and soft layer properties are desired
ELECTRICAL METHODS			
DC Resistivity	DC current is applied to the ground by electrodes. Voltages are measured at different points on the ground surface with other electrodes positioned along a line.	• depth to water table • inorganic groundwater contamination • groundwater salinity • soil layer thickness • delineation of certain vertical features (e.g., sinkholes, contamination plumes, waste trenches)	• slow; must install electrodes directly in the ground • resolution decreases significantly with increasing depth • resolution is difficult in highly heterogeneous deposits
Electromagnetics	Electrical coils are held over the ground. Current passing through the coils induces a magnetic field in the ground, which is measured with receiver coils.	• groundwater salinity • inorganic groundwater contamination • detection of buried metal objects • delineation of certain vertical features (e.g., sinkholes, contamination plumes, waste trenches)	• extra effort is required to characterize depth of target • resolution decreases significantly with increasing depth
Ground Penetrating Radar (GPR)	Electromagnetic energy is pulsed into the ground. This energy reflects off boundaries between different soil layers and is measured at the ground surface.	• depth to water table • identification of buried objects • thickness of pavement layers • void detection	• not effective below the water table or in clay • depth of penetration is limited to about 30 ft (10 m)

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Table 3-14
Geophysical testing techniques (modified after FHWA, 2002a)

Method	Basic Field Procedures	Applications	Limitations
GRAVITY AND MAGNETIC METHODS			
Gravity	The Earth's gravitational field is measured at the ground surface.	• identification of large subsurface voids • identification of large objects possessing unusually high or low densities	• results are non-unique (i.e. more than one subsurface condition can give the same result) • primarily, large-scale reconnaissance tool; applications in highway engineering are limited
Magnetics	The Earth's magnetic field is measured at the ground surface.	• identification of ferrous materials • identification of soil/rock containing large amounts of magnetic minerals	• results are non-unique (i.e. more than one subsurface condition can give the same results) • primarily a large-scale reconnaissance tool; applications in highway engineering are limited
NEAR-SURFACE NUCLEAR METHODS			
Neutron Moisture Content	Instrument is placed on the ground surface and neutrons are emitted into the ground. Energy of returning neutrons is related to the moisture content in the ground (hydrogen atoms decrease the energy of the neutrons detected at the sensor).	• estimate of water content in compacted soil • estimate of asphalt content in asphalt concrete • can be quantitative if properly calibrated to site conditions	• limited exploration depth (a few inches) • possible health and safety hazard if operators not properly trained • will detect hydrogen ion (i.e. gas, clay) in non-water bearing stratum
Gamma Density	Instrument is placed on the ground surface and gamma radiation is emitted into the ground. Returning gamma energy is a function of material density (denser materials absorb more gamma energy so less is detected at the sensor)	• estimate of density of soil or asphalt concrete	• limited exploration depth (less than one foot); • exploration depth further limited to a few inches if ground cannot be penetrated • possible health and safety hazard if operators not properly trained

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Table 3-14 (continued)
Geophysical testing techniques (modified after FHWA, 2002a)

Method	Basic Field Procedures	Applications	Limitations
BOREHOLE METHODS			
Crosshole/ Downhole	Energy sources and geophones are placed in boreholes and/or on ground surface; interval travel times are converted into seismic wave velocity as a function of depth in the borehole.	• measurement of wave velocities for seismic site response analysis • depth to water table • correlation of lithologic units with surface seismic • identification of thin layers at depth	• requires one or more boreholes and significant support field equipment
Suspension Logger	Field instrument is placed in a fluid-filled borehole and used to measure P-(compression) and S-(shear) wave velocities in surrounding soil or rock.	• measurement of wave velocities for seismic site response analysis • correlation of lithologic units with surface seismic • identification of thin layers at depth	• requires borehole and significant support field equipment, which is expensive • borehole must be fluid-filled
Electrical Logging	Field instrument is placed in a borehole. Electrical fields are directly applied or electromagnetically induced into surrounding soil or rock and electrical resistivity is measured.	• estimate of soil/rock permeability or porosity • identification of inorganic contaminant plumes or saltwater intrusion • identification of thin layers at depth	• requires borehole and significant support field equipment, which is expensive • generally cannot operate in a cased borehole • may require fluid-filled borehole • results may be dependent upon drilling mud salinity
Nuclear Logging	Field instrument is placed in a borehole. Surrounding soil or rock is irradiated with neutrons particles and/or gamma energy. Energy and neutrons returning to the instrument are measured and related to rock density, porosity and pore fluid type.	• estimate of soil/rock type, density, porosity, and pore fluid density • identification of thin layers at depth	• requires borehole and significant support field equipment, which is expensive • possible health and safety hazard if operators are not properly trained
Lithology Logging	Field instrument is placed in a borehole; naturally occurring electrical fields and radiation levels are related to soil or rock type.	• classification of soil or rock type • identification of thin layers at depth	• requires borehole and significant support field equipment, which is expensive • may require fluid-filled borehole • results are dependent upon site-specific conditions and/or borehole fluid salinity

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3. **Gravity and Magnetic Methods**: These methods are similar to electrical methods, except that they rely on correlations between the potential gravitational and/or magnetic influence of voids and subsurface anomalies and measured differences in the earth's micro-gravitational and/or magnetic fields, rather than on changes in electrical fields. These methods provide measurements at specific points unlike seismic and electrical methods that provide measurements over large areas.

4. **Near-surface nuclear methods**: These methods have been used for several years for compaction control of fills in the field. Through careful calibration, it is possible to assess the moisture content and density of compacted soils reliably. These methods have been widely adopted as reliable quantitative methods.

5. **Borehole Methods**: Downhole geophysical methods provide reliable indications of a wide range of soil properties. For example, downhole/crosshole methods provide reliable measures of shear wave velocity. As indicated previously, shear wave velocity is directly related to small-strain stiffness and is correlated to strength and soil/rock type. Although downhole logging methods have seen little use in highway construction, they have been the mainstay for deep geologic characterization in oil exploration. The principal advantage of downhole logging is the ability to obtain several different geophysical tests/indicators by "stringing" these tools together in a deep borehole.

3.15.2 Advantages and Disadvantages of Geophysical Tests

As with the other methods of exploration, geophysical testing offers some advantages and some disadvantages that should be considered before these techniques are recommended for a specific application. These are summarized as follows:

3.15.2.1 Advantages of Geophysical Tests

1. Many geophysical tests are non-invasive. Therefore such tests offer significant benefits in cases where conventional drilling, testing, and sampling are difficult (e.g., deposits of gravel, talus deposits, etc.) or where potentially contaminated soils may occur in the subsurface.

2. In general, geophysical testing can cover a relatively large geographical area thereby providing the opportunity to characterize large areas with relatively few tests. Geophysical testing is particularly well-suited to projects that have large longitudinal extent such as new highway construction.

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3. Geophysical measurements are used to assess the properties of soil and rock at very small strains, typically on the order of 0.001 percent, thereby providing information on truly elastic properties.

4. For the purpose of obtaining information on the subsurface, geophysical methods are relatively inexpensive considering the large area over which they provide information.

3.15.2.2 Disadvantages of Geophysical Tests

1. Most methods work best for situations in which there is a large difference in the property being measured between adjacent subsurface units. In seismic methods, it is difficult to develop good stratigraphic profiling if the general stratigraphy consists of hard material overlying soft material.

2. Each geophysical method has limitations that may be associated with equipment, signal noise, unfavorable site and subsurface conditions, and processing constraints.

3. Results can be non-unique and are generally interpreted qualitatively. Therefore useful results can be obtained only through analyses performed by a geotechnical specialist experienced with the particular testing method.
4. Specialized and more electronically sophisticated equipment is required as compared to the more conventional subsurface exploration tools.

3.15.3 Examples of Uses of Geophysical Tests

The following are a few examples where geophysical testing could be used on highway projects to compliment conventional exploration.

1. Highly Variable Subsurface Conditions: In several geologic settings, the subsurface conditions along a transportation corridor may be expected to be variable. This variability could be from underlying karst development above limestone; alluvial deposits, including buried terrace gravels, across a wide floodplain; buried boulders in a talus slope, etc. For these cases, conventional exploration techniques may be very difficult and if “refusal” is encountered at one depth, there is a strong likelihood that different materials could underlie the region. Development of a preliminary subsurface characterization profile by using geophysical testing could prove advantageous in designing future focused explorations.

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2. Regional Studies: Along a transportation corridor it may be necessary to assess the depth to (and through) rippable rock or highly cemented caliche. Alternative alignments may or may not be possible, but the cost implications may be significant. Therefore, it is important to obtain a profile related to rock/soil stiffness. Geophysical testing is a logical consideration for this application as a precursor to invasive explorations.

3. Settlement Sensitive Structures: The prior two examples related to cases where the geophysical testing served as the front-end of a multi-phase project. In the case where a settlement-sensitive structure is to be founded on deposits of sands, knowledge of the in-situ modulus of the sand deposit is critical. After the characteristics of the site are assessed, it may be helpful to quantify the deformation modulus by the use of geophysical testing at the specific foundation site.

These examples demonstrate that geophysical testing can play a potentially important role in the subsurface characterization of soils and rocks. As with the other investigative "tools" described in this document, the particular selection of the appropriate technology is very much a function of the site conditions and the goals of the characterization program.

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CHAPTER 4.0
ENGINEERING DESCRIPTION, CLASSIFICATION AND CHARACTERISTICS OF SOILS AND ROCKS

The geotechnical specialist is usually concerned with the design and construction of some type of geotechnical feature constructed on or out of a geomaterial. For engineering purposes, in the context of this manual, the geomaterial is considered to be primarily rock and soil. A geomaterial intermediate between soil and rock is labeled as an intermediate geomaterial (IGM). These three classes of geomaterials are described as follows:

- **Rock** is a relatively hard, naturally formed solid mass consisting of various minerals and whose formation is due to any number of physical and chemical processes. The rock mass is generally so large and so hard that relatively great effort (e.g., blasting or heavy crushing forces) is required to break it down into smaller particles.

- **Soil** is defined as a conglomeration consisting of a wide range of relatively smaller particles derived from a parent rock through mechanical weathering processes that include air and/or water abrasion, freeze-thaw cycles, temperature changes, plant and animal activity and by chemical weathering processes that include oxidation and carbonation. The soil mass may contain air, water, and/or organic materials derived from decay of vegetation, etc. The density or consistency of the soil mass can range from very dense or hard to loose or very soft.

- **Intermediate geomaterials** (IGMs) are transition materials between soils and rocks. The distinction of IGMs from soils or rocks for geotechnical engineering purposes is made purely on the basis of strength of the geomaterials. Discussions and special design considerations of IGMs are beyond the scope of this document.

The following three terms are often used by geotechnical specialists to describe a geomaterial: **identification**, **description** and **classification**. For soils, these terms have the following meaning:

- **Identification** is the process of determining which components exist in a particular soil sample, i.e., gravel, sand, silt, clay, etc.

- **Description** is the process of estimating the relative percentage of each component to prepare a word picture of the sample (ASTM D 2488). Identification and description are accomplished primarily by both a visual examination and the feel of the sample, particularly when water is added to the sample. Description is usually performed in the

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field and may be reevaluated by experienced personnel in the laboratory.

- **Classification** is the laboratory-based process of grouping soils with similar engineering characteristics into categories. For example, the Unified Soil Classification System, USCS, (ASTM D 2487), which is the most commonly used system in geotechnical work, is based on grain size, gradation, and plasticity. The AASHTO system (M 145), which is commonly used for highway projects, groups soils into categories having similar load carrying capacity and service characteristics for pavement subgrade design.

It may be noted from the above definitions that the description of a geomaterial necessarily includes its identification. Therefore, as used in this document, the term "description" is meant to include "identification."

The important distinction between classification and description is that standard AASHTO or ASTM laboratory tests must be performed to determine the classification. It is often unnecessary to perform the laboratory tests to classify every sample. Instead soil technicians are trained to identify and describe soil samples to an accuracy that is acceptable for design and construction purposes. ASTM D 2488 is used for guidance in such visual and tactile identification and description procedures. These visual/tactile methods provide the basis for a preliminary classification of the soil according to the USCS and AASHTO system.

During progression of a boring, the field personnel should describe only the soils encountered. Group symbols associated with classification should not be used in the field. It is important to send the soil samples to a laboratory for accurate visual description and classification by a laboratory technician experienced in soils work, as this assessment will provide the basis for later testing and soil profile development. Classification tests can be performed in the laboratory on representative samples to verify the description and assign appropriate group symbols based on a soil classification system (e.g., USCS). If possible, the moisture content of every sample should be determined since it is potentially a good indicator of performance. The test to determine the moisture content is simple and inexpensive to perform.

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4.01 Primary References

The primary references for this Chapter are as follows:

ASTM (2006). *Annual Book of ASTM Standards – Sections 4.02, 4.08, 4.09 and 4.13.* ASTM International, West Conshohocken, PA.

AASHTO (2006). *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, Parts I and II, American Association of State Highway and Transportation Officials, Washington, D.C.

FHWA (2002a). *Geotechnical Engineering Circular 5 (GEC5) - Evaluation of Soil and Rock Properties*. Report No FHWA-IF-02-034. Authors: Sabatini, P.J, Bachus, R.C, Mayne, P.W., Schneider, J.A., Zettler, T.E., Federal Highway Administration, U.S. Department of Transportation.

4.1 SOIL DESCRIPTION

Soil description/identification is the systematic naming of individual soils in both written and spoken forms (ASTM D 2488, AASHTO M 145). Soil classification is the grouping of soils with similar engineering properties into a category by using the results of laboratory-based index tests, e.g., group name and symbol (ASTM D 2487, AASHTO M 145). It is important to distinguish between a visual description of a soil and its classification in order to minimize potential conflicts between general visual evaluations of soil samples in the field and more precise laboratory evaluations supported by index tests.

The soil's description should include as a **minimum**:

- Apparent consistency (e.g., soft, firm, etc. for fine-grained soils) or density adjective (e.g., loose, dense, etc. for coarse-grained soils);
- Water content condition adjective (e.g., dry, moist, wet);
- Color description (e.g., brown, gray, etc.);
- Main soil type name, often presented in all capital letters (e.g. SAND, CLAY);
- Descriptive adjective for main soil type (e.g., fine, medium, coarse, well-rounded, angular, etc. for coarse-grained soils; organic, inorganic, compressible, laminated, etc., for fine-grained soils);
- Particle-size distribution adjective for gravel and sand (e.g., uniform, well-graded,

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gap-graded);

- Plasticity adjective (e.g., high, low) and soil texture (e.g., rough, smooth, slick, waxy, etc.) for inorganic and organic silts or clays;
- Descriptive term for minor type(s) of soil (with, some, trace, etc.);
- Minor soil type name with "y" added if the fine-grained minor component is less than 30 percent but greater than 12 percent or the coarse-grained minor component is 30 percent or more (e.g., silty for fine grained minor soil type, sandy for coarse-grained minor soil type);
- Descriptive adjective “with” if the fine-grained minor soil type is 5 to 12 percent (e.g., with clay) or if the coarse-grained minor soil type is less than 30 percent but 15 percent or more (e.g., with gravel). Note: some practices use the descriptive adjectives “some” and “trace” for minor components;
- Inclusions (e.g., concretions, cementation);
- Geological name (e.g., Holocene, Eocene, Pleistocene, Cretaceous), if known, in parenthesis or in notes column.

The various elements of the soil description are generally stated in the order given above. For example, a soil description might be presented as follows:

Fine-grained soils: Soft, wet, gray, high plasticity CLAY, with f. Sand; (Alluvium)

Coarse-grained soils: Dense, moist, brown, silty m-f SAND, with f. Gravel to c. Sand; (Alluvium)

When minor changes occur within the same soil layer (e.g., a change in apparent density), the boring log should indicate a description of the change, such as “same, except very dense.”

4.1.1 Consistency and Apparent Density

The consistency of fine-grained soils and apparent density of coarse-grained soils can be estimated from the energy-corrected SPT N-value, N_{60}. The consistency of clays and silts varies from very soft to firm to stiff to hard. The apparent density of coarse-grained soil ranges from very loose to dense to very dense. Suggested guidelines for estimating the in-place apparent density or consistency of soils are given in Tables 4-1 and 4-2, respectively.

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Table 4-1
Evaluation of the apparent density of coarse-grained soils (after Peck, *et al.*, 1974)

N_{60}	Apparent Density	Relative Density, %
0 – 4	Very loose	0 – 20
>4 - 10	Loose	20 – 40
>10 - 30	Medium dense	40 – 70
>30 - 50	Dense	70 – 85
>50	Very Dense	85 – 100
The above guidance may be misleading in gravelly soils.		

Table 4-2
Evaluation of the consistency of fine-grained soils (after Peck, *et al.*, 1974)

N_{60}	Consistency	Unconfined Compressive Strength, q_u, ksf (kPa)	Results of Manual Manipulation
<2	Very soft	< 0.5 (<25)	Specimen (height = twice the diameter) sags under its own weight; extrudes between fingers when squeezed.
2 - 4	Soft	0.5 – 1 (25 – 50)	Specimen can be pinched in two between the thumb and forefinger; remolded by light finger pressure.
4 - 8	Medium stiff	1 – 2 (50 – 100)	Can be imprinted easily with fingers; remolded by strong finger pressure.
8 - 15	Stiff	2 – 4 (100 – 200)	Can be imprinted with considerable pressure from fingers or indented by thumbnail.
15 - 30	Very stiff	4 – 8 (200 – 400)	Can barely be imprinted by pressure from fingers or indented by thumbnail.
>30	Hard	> 8 >400	Cannot be imprinted by fingers or difficult to indent by thumbnail.
Note that N_{60}-values should not be used to determine the design strength of fine grained soils.			

The apparent density or consistency of the soil formation can vary from these empirical correlations for a variety of reasons. Judgment remains an important part of the visual identification process. Field index tests (e.g., smear test, dried strength test, thread test) which will be described in the next section are suggested as aids in estimating the consistency of fine grained soils.

In some cases the sampler may pass from one layer into another of markedly different properties; for example, from a dense sand into a soft clay. In attempting to identify apparent

density, an assessment should be made as to what part of the blow count corresponds to each layer since the sampler begins to reflect the presence of the lower layer before it actually reaches it.

4.1.2 Water Content (Moisture)

The relative amount of water present in the soil sample should be described by an adjective such as dry, moist, or wet as indicated in Table 4-3.

Table 4-3
Adjectives to describe water content of soils (ASTM D 2488)

Description	Conditions
Dry	No sign of water and soil dry to touch
Moist	Signs of water and soil is relatively dry to touch
Wet	Signs of water and soil definitely wet to touch; granular soil exhibits some free water when densified

4.1.3 Color

The color must be described when the sample is first retrieved in the field at the as-sampled water content since the color may change with changes in the water content. Primary colors should be used (brown, gray, black, green, white, yellow, red). Soils with different shades or tints of basic colors are described by using two basic colors; e.g., gray-green. Some agencies may require use of the Munsell color system (USDA, 1993). When the soil is marked with spots of color, the term “mottled” can be applied. Soils with a homogeneous texture but having color patterns that change and are not considered mottled can be described as “streaked.”

4.1.4 Type of Soil

The constituent parts of a given soil type are defined on the basis of texture in accordance with particle-size designators separating the soil into coarse-grained, fine-grained, and highly organic designations. Soil with more than 50 percent by weight of the particles larger than the U.S. Standard No. 200 sieve (0.075 mm) is designated coarse-grained. Soil (inorganic and organic) with 50 percent or more by weight of the particles finer than the No. 200 sieve (0.075 mm) is designated fine-grained. Soil primarily consisting of less than 50 percent by volume of organic matter, dark in color, and with an organic odor is designated as organic soil. Soil with organic content more than 50 percent is designated as peat. The soil type designations used by FHWA follow ASTM D 2487; i.e., gravel, sand, silt, clay, organic silt, organic clay, and peat.

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4.1.4.1 Coarse-Grained Soils (Gravel and Sand)

Coarse-grained soils consist of a matrix of either gravel or sand in which more than 50 percent by weight of the soil is retained on the No. 200 sieve (0.075 mm). Coarse-grained soils may contain fine-grained soil, i.e., soils passing the No. 200 sieve (0.075 mm), but the percent by weight of the fine-grained portion is less than 50 percent. The gravel and sand components are defined on the basis of particle size as indicated in Table 4-4. The particle-size distribution is identified as well graded or poorly graded. Well graded coarse-grained soil contains a good representation of all particle sizes from largest to smallest, with ≤12 percent fines. Poorly graded coarse-grained soil is uniformly graded, i.e., most of the coarse-grained particles are about the same size, with ≤ 12 percent fines. Gap graded coarse grained soil can be either a well graded or poorly graded soil lacking one or more intermediate sizes within the range of the gradation.

Gravels and sands may be described by adding particle-size distribution adjectives in front of the soil type in accordance with the criteria given in Table 4-5. Based on correlation with laboratory tests, the following simple field identification tests can be used as an aid in identifying granular soils.

Table 4-4
Particle size definition for gravels and sands (after ASTM D 2488)

Component	Grain Size	Determination
Boulders*	12" + (300 mm +)	Measurable
Cobbles*	3" to 12" (300 mm to 75 mm)	Measurable
Gravel		
Coarse	¾" – 3" (19 mm to 75 mm)	Measurable
Fine	¾" to #4 sieve (¾" to 0.187") (19 mm to 4.75 mm)	Measurable
Sand		
Coarse	#4 to #10 sieve (0.19" to 0.079") (4.75 mm – 2.00 mm)	Measurable and visible to the eye
Medium	#10 to #40 sieve (0.079" to 0.017") (2.00 mm – 0.425 mm)	Measurable and visible to the eye
Fine	#40 to #200 sieve (0.017" to 0.003") (0.425 mm- 0.075 mm)	Measurable but barely discernible to the eye
*Boulders and cobbles are not considered soil or part of the soil's classification or description, except under miscellaneous description; i.e., with cobbles at about 5 percent (volume).		

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Table 4-5
Adjectives for describing size distribution for sands and gravels (after ASTM D 2488)

Particle-Size Adjective	Abbreviation	Size Requirement
Coarse	c.	< 30% m-f sand or < 12% f. gravel
Coarse to medium	c-m	< 12% f. sand
Medium to fine	m-f	< 12% c. sand and > 30% m. sand
Fine	f.	< 30% m. sand or < 12% c. gravel
Coarse to fine	c-f	> 12% of each size[1]

[1] 12% and 30% criteria can be modified depending on fines content. The key is the shape of the particle-size distribution curve. If the curve is relatively straight or dished down, and coarse sand is present, use c-f, also use m-f sand if a moderate amount of m. sand is present. If one has any doubts, determine the above percentages based on the amount of sand or gravel present.

Feel and Smear Tests: A pinch of soil is handled lightly between the thumb and fingers to obtain an impression of the grittiness (i.e., roughness) or softness (smoothness) of the constituent particles. Thereafter, a pinch of soil is smeared with considerable pressure between the thumb and forefinger to determine the degrees of grittiness (roughness), or the softness (smoothness) of the soil. The following guidelines may be used:

- Coarse- to medium-grained sand typically exhibits a very gritty feel and smear.
- Coarse- to fine-grained sand has less gritty feel, but exhibits a very gritty smear.
- Medium- to fine-grained sand exhibits a less gritty feel and smear that becomes softer (smoother) and less gritty with an increase in the fine sand fraction.
- Fine-grained sand exhibits a relatively soft feel and a much less gritty smear than the coarser sand components.
- Silt components less than about 10 percent of the total weight can be identified by a slight discoloration of the fingers after smear of a moist sample. Increasing silt increases discoloration and softens the smear.

Sedimentation Test: A small sample of soil is shaken in a test tube filled with water and allowed to settle. The time required for the particles to fall a distance of 4-inches (100 mm) is about 1/2 minute for particle sizes coarser than silt. About 50 minutes would be required for particles of 0.0002 in (0.005 mm) or smaller (often defined as "clay size") to settle out.

For sands and gravels containing more than 5 percent fines, the type of inorganic fines (silt or clay) can be identified by performing a shaking/dilatancy test. See fine-grained soils section.

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Visual Characteristics: Sand and gravel particles can be readily identified visually, but silt particles are generally indistinguishable to the eye. With an increasing silt component, individual sand grains become obscured, and when silt exceeds about 12 percent, the silt almost entirely masks the sand component from visual separation. Note that gray fine-grained sand visually appears to contain more silt than the actual silt content.

4.1.4.2 Fine-Grained Soils

Fine-grained soils are those having 50 percent or more by weight pass the No. 200 sieve. The so-called fines are either inorganic or organic silts and/or clays. To describe fine-grained soils, plasticity adjectives and soil-type adjectives should be used to further define the soil's plasticity and texture. The following simple field identification tests can be used to estimate the degree of plasticity of fine-grained soils.

Shaking (Dilatancy) Test (Holtz and Kovacs, 1981). Water is dropped or sprayed on a portion of a fine-grained soil sample mixed and held in the palm of the hand until it shows a wet surface appearance when shaken or bounced lightly in the hand or a sticky nature when touched. The test involves lightly squeezing the wetted soil sample between the thumb and forefinger and releasing it alternatively to observe its reaction and the speed of the response. Soils that are predominantly silty (nonplastic to low plasticity) will show a dull dry surface upon squeezing and a glassy wet surface immediately upon release of the pressure. This phenomenon becomes less and less pronounced in soils with increasing plasticity and decreasing dilatancy,

Dry Strength Test (Holtz and Kovacs, 1981). A relatively undisturbed portion of the sample is allowed to dry out and a fragment of the dried soil is pressed between the fingers. Fragments which cannot be crumbled or broken are characteristic of clays with high plasticity. Fragments which can be disintegrated with gentle finger pressure are characteristic of silty materials of low plasticity. Thus, in generally, fine-grained materials with relatively high dry strength are clays of high plasticity and those with relatively little dry strength are predominantly silts.

Thread Test (After Burmister, 1970). Moisture is added to or worked out of a small ball (about 1.5 in (40 mm) diameter) of fine grained soil and the ball kneaded until its consistency approaches medium stiff to stiff (compressive strength of about 2,100 psf (100 kPa)). This condition is observed when the material just starts to break or crumble. A thread is then rolled out between the palm of one hand and the fingers of the other to the smallest diameter possible before disintegration of the sample occurs. The smaller the thread achieved, the higher the plasticity of the soil. Fine-grained soils of high plasticity will have threads smaller

than 0.03 in (3/4 mm) in diameter. Soils with low plasticity will have threads larger than 0.12 in (3 mm) in diameter.

Smear Test (FHWA, 2002b). A fragment of soil smeared between the thumb and forefinger or drawn across the thumbnail will, by the smoothness and sheen of the smear surface, indicate the plasticity of the soil. A soil of low plasticity will exhibit a rough textured, dull smear while a soil of high plasticity will exhibit a slick, waxy smear surface.

Table 4-6 identifies field methods to approximate the plasticity range for the dry strength, thread, and smear tests.

Table 4-6
Field methods to describe plasticity (FHWA, 2002b)

Plasticity Range	Adjective	Dry Strength	Smear Test	Thread Smallest Diameter, in (mm)
0	Nonplastic	none - crumbles into powder with mere pressure	gritty or rough	ball cracks
1 - 10	low plasticity	low - crumbles into powder with some finger pressure	rough to smooth	1/4 – 1/8 (6 to 3)
>10 - 20	medium plasticity	medium - breaks into pieces or crumbles with considerable finger pressure	smooth and dull	1/16 (1.5)
>20 - 40	high plasticity	high - cannot be broken with finger pressure; spec. will break into pieces between thumb and a hard surface	Shiny	0.03 (0.75)
>40	very plastic	very high - can't be broken between thumb and a hard surface	very shiny and waxy	0.02 (0.5)

4.1.4.3 Highly Organic Soils

Colloidal and amorphous organic materials finer than the No. 200 sieve (0.075 mm) are identified and classified in accordance with their drop in plasticity upon oven drying (ASTM D 2487). Further identification markers are:

1. dark gray and black and sometimes dark brown colors, although not all dark colored soils are organic;
2. most organic soils will oxidize when exposed to air and change from a dark gray/black color to a lighter brown; i.e., the exposed surface is brownish, but when the sample is pulled apart the freshly exposed surface is dark gray/black;
3. fresh organic soils usually have a characteristic odor that can be recognized,

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particularly when the soil is heated;

4. compared to inorganic soils, less effort is typically required to pull the material apart and a friable break is usually formed with a fine granular or silty texture and appearance;
5. workability of organic soils at the plastic limit is weaker and spongier than an equivalent inorganic soil;
6. the smear, although generally smooth, is usually duller and appears more silty than an equivalent inorganic soil's; and
7. the organic content of organic soils can also be determined by the combustion test method (AASHTO T 267, ASTM D 2974).

Fine-grained soils, where the organic content appears to be less than 50 percent of the volume (about 22 percent by weight), should be described as soils with organic material or as organic soils such as clay with organic material or organic clays etc. If the soil appears to have an organic content greater than 50 percent by volume it should be described as peat. The engineering behavior of soils below and above the 50 percent dividing line is entirely different. It is therefore critical that the organic content of soils be determined both in the field and in the laboratory (AASHTO T 267, ASTM D 2974). Simple field or visual laboratory identification of soils as organic or peat is neither advisable nor acceptable.

It is very important not to confuse topsoil with organic soils or peat. Topsoil is the relatively thin layer of soil found on the surface composed of partially decomposed organic materials, such as leaves, grass, small roots etc. Topsoil contains many nutrients that sustain plant and insect life and should not be used to construct geotechnical features or to support engineered structures.

4.1.4.4 Minor Soil Type(s)

Two or more soil types may be present in many soil formations,. When the percentage of the fine-grained minor soil type is less than 30 percent but greater than 12 percent, or the total sample or the coarse-grained minor component is 30 percent or more of the total sample, the minor soil type is indicated by adding a "y" to its name (e.g., f. gravelly, c-f. sandy, silty, clayey). Note the gradation adjectives are given for granular soils, while the plasticity adjective is omitted for the fine-grained soils.

When the percentage of the fine-grained minor soil type is 5 to 12 percent or for the coarse-grained minor soil type is less than 30 percent but 15 percent or more of the total sample, the minor soil type is indicated by adding the descriptive adjective "with" to the group name (i.e., with clay, with silt, with sand, with gravel, and/or with cobbles).

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Some local practices also use the descriptive adjectives “some” and “trace” for minor components as follows:

- "trace" when the percentage is between 1 and 12 percent of the total sample; or
- "some" when the percentage is greater than 12 percent and less than 30 percent of the total sample.

4.1.4.5 Inclusions

Additional inclusions or characteristics of the sample can be described by using "with" and the descriptions described above. For example:

- with petroleum odor
- with organic matter
- with foreign matter (roots, brick, etc.)
- with shell fragments
- with mica
- with parting(s), seam(s), etc. of (give soil’s complete description)

4.1.4.6 Other Descriptors

Depending on local conditions, the soils may be described based on reaction to HCl acid, and type and degree of cementation. ASTM D 2488 provides guidance for such descriptors.

4.1.4.7 Layered Soils

Soils of different types can be found in repeating layers of various thickness. It is important that all such formations and their thicknesses are noted. Each layer is described as if it is a non-layered soil by using the sequence for soil descriptions discussed above. The thickness and shape of layers and the geological type of layering are noted according to the descriptive terms presented in Table 4-7. The thickness designation is given in parentheses before the type of layer or at the end of each description, whichever is more appropriate.

Examples of descriptions for layered soils are:

- Medium stiff, moist to wet 0.2 to 0.75 in (5 to 20 mm) interbedded seams and layers of gray, medium plastic, silty CLAY and lt. gray, low plasticity SILT; (Alluvium).

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- Soft moist to wet varved layers of gray-brown, high plasticity CLAY (0.2 to 0.75-in (5 to 20 mm)) and nonplastic SILT, trace f. sand (0.4 to 0.6 in (10 to 15 mm)); (Alluvium).

Table 4-7
Descriptive terms for layered soils (NAVFAC, 1986a)

Type of Layer	Thickness	Occurrence
Parting	< 1/16" (< 1.5 mm)	
Seam	1/16 to ½" (1.5 mm to 12 mm)	
Layer	½" to 12" (12 mm to 300 mm)	
Stratum	> 12" (>300 mm)	
Pocket		Small erratic deposit
Lens		Lenticular deposit
Varved (also layered)		Alternating seams or layers of silt and/or clay and sometimes fine sand
Occasional		One or less per 12" (300 mm) of thickness or laboratory sample inspected
Frequent		More than one per 12" (300 mm) of thickness or laboratory

4.1.4.8 Geological Name

The soil description should include the geotechnical specialist's assessment of the origin of the soil unit and the geologic name, if known. This information is generally placed in parentheses or brackets at the end of the soil description or in the field notes column of the boring log. Some examples include:

a. *Washington, D.C.*-Cretaceous Age Material with SPT N-values between 30 and 100: Very hard gray-blue silty CLAY (CH), moist **[Potomac Group Formation]**

b. *Newport News, VA*-Miocene Age Marine Deposit with SPT N-values around 10 to 15: Stiff green sandy CLAY (CL) with shell fragments, calcareous **[Yorktown Formation].**

c. *Tucson, AZ* – Holocene Age Alluvial Deposit with SPT N-values around 35: Cemented clayey SAND (SC), dry [**Pantano Formation].**

4.2 SOIL CLASSIFICATION

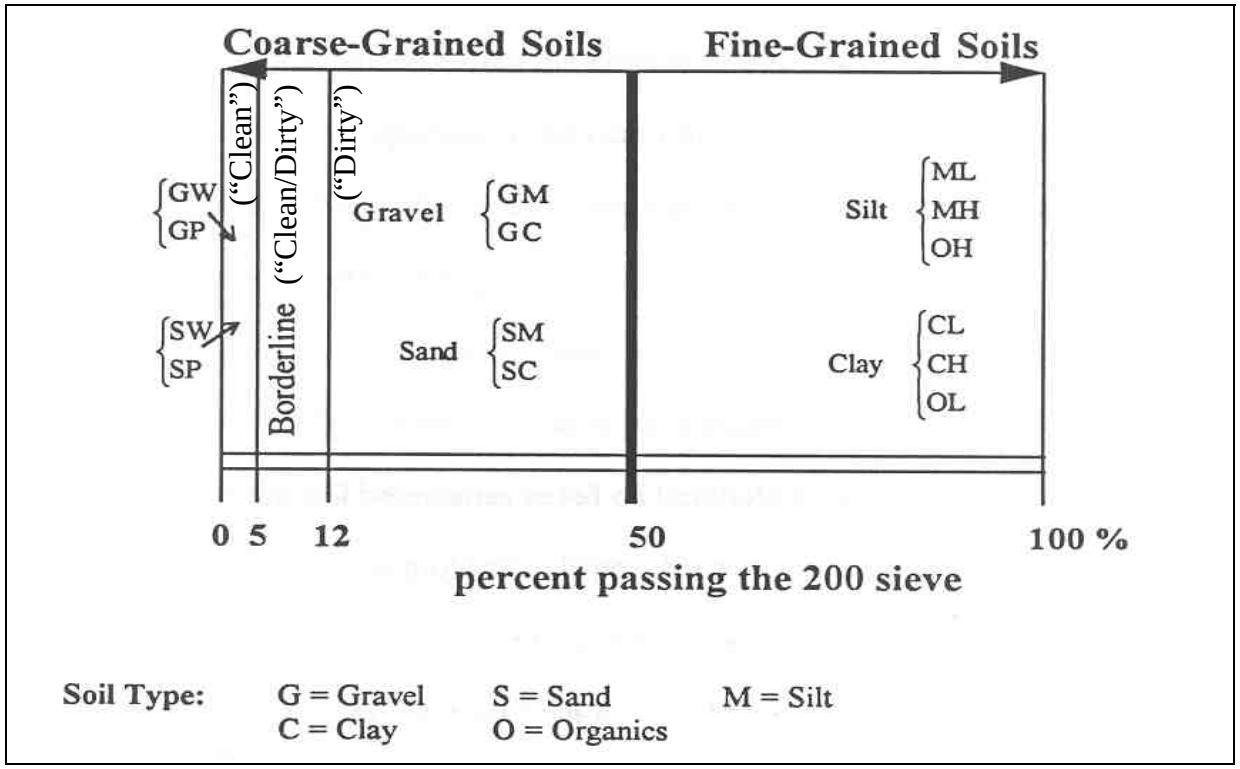
As previously indicated, final identification with classification is best performed in the laboratory. This process will lead to more consistent final boring logs and avoid conflicts with field descriptions. The Unified Soil Classification System (USCS) group name and symbol (in parenthesis) appropriate for the soil type in accordance with AASHTO M 145 (or ASTM D 3282) or ASTM D 2487 is the most commonly used system in geotechnical work and is covered in this section. For classification of highway subgrade material, the AASHTO classification system (see Section 4.2.2) is used. The AASHTO classification system is also based on grain size and plasticity.

4.2.1 Unified Soil Classification System (USCS)

The Unified Soil Classification System (ASTM D 2487) groups soils with similar engineering properties into categories base on grain size, gradation and plasticity. Table 4-8 provides a simplification of the group breakdown based on percent passing No. 200 sieve (0.075 mm) and Table 4-9 provides an outline of the complete laboratory classification method. The procedures, along with charts and tables, for classifying coarse-grained and fine-grained soils follow.

Table 4-8

Basic USCS soil designations based on percent passing No. 200 sieve (0.075 mm) (after ASTM D 2487; Holtz and Kovacs, 1981)



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Table 4-9

Soil classification chart (laboratory method) (after ASTM D 2487)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[a] **COARSE-GRAINED SOILS (Sands and Gravels)** - more than 50% retained on No. 200 (0.075 mm) sieve **FINE-GRAINED (Silts and Clays)** - 50% or more passes the No. 200 (0.075 mm) sieve			Soil Classification	
			Group Symbol	**Group Name[b]**
GRAVELS More than 50% of coarse Fraction retained on No. 4 Sieve	CLEAN GRAVELS < 5% fines	$C_u \geq 4$ and $1 \leq C_c \leq 3$[e]	GW	Well-graded gravel[f]
		$C_u < 4$ and/or $1 > C_c > 3$[e]	GP	Poorly-graded gravel[f]
	GRAVELS WITH FINES > 12% of fines[c]	Fines classify as ML or MH	GM	Silty gravel[f,g,h]
		Fines classify as CL or CH	GC	Clayey gravel[f,g,h]
SANDS 50% or more of coarse fraction passes No. 4 Sieve	CLEAN SANDS < 5% fines[d]	$C_u \geq 6$ and $1 \leq C_c \leq 3$[e]	SW	Well-graded Sand[i]
		$C_u < 6$ and/or $1 > C_c > 3$[e]	SP	Poorly-graded sand[i]
	SANDS WITH FINES > 12% fines[d]	Fines classify as ML or MH	SM	Silty sand[g,h,i]
		Fines classify as CL or CH	SC	Clayey sand[g,h,i]
SILTS AND CLAYS Liquid limit less than 50	Inorganic	PI > 7 and plots on or above "A" line[j]	CL	Lean clay[k,l,m]
		PI < 4 or plots below "A" line[j]	ML	Silt[k,l,m]
	Organic	$\frac{\text{Liquid limit - overdried}}{\text{Liquid limit - not dried}} < 0.75$	OL	Organic clay[k,l,m,n]
				Organic silt[k,l,m,o]
SILTS AND CLAYS Liquid limit 50 or more	Inorganic	PI plots on or above "A" line	CH	Fat clay[k,l,m]
		PI plots below "A" line	MH	Elastic silt[k,l,m]
	Organic	$\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$	OH	Organic clay[k,l,m,p]
				Organic silt[k,l,m,q]
Highly fibrous organic soils	Primary organic matter, dark in color, and organic odor		Pt	Peat

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Table 4-9 (Continued)
Soil classification chart (laboratory method) (after ASTM D 2487)

NOTES:

a Based on the material passing the 3 in (75 mm) sieve.

b If field sample contained cobbles and/or boulders, add "with cobbles and/or boulders" to group name.

c Gravels with 5 to 12% fines require dual symbols:
- GW-GM, well-graded gravel with silt
- GW-GC, well-graded gravel with clay
- GP-GM, poorly graded gravel with silt
- GP-GC, poorly graded gravel with clay

d Sands with 5 to 12% fines require dual symbols:
- SW-SM, well-graded sand with silt
- SW-SC, well-graded sand with clay
- SP-SM, poorly graded sand with silt
- SP-SC, poorly graded sand with clay

e $C_u = \frac{D_{60}}{D_{10}}$ $C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})}$

[C_u: Uniformity Coefficient; C_c: Coefficient of Curvature]

f If soil contains ≥ 15% sand, add "with sand" to group name.

g If fines classify as CL-ML, use dual symbol GC-GM, SC-SM.

h If fines are organic, add "with organic fines" to group name.

i If soil contains ≥ 15% gravel, add "with gravel" to group name.

j If the liquid limit and plasticity index plot in hatched area on plasticity chart, soil is a CL-ML, silty clay.

k If soil contains 15 to 29% plus No. 200 (0.075 mm), add "with sand" or "with gravel," whichever is predominant.

l If soil contains ≥ 30% plus No. 200 (0.075mm), predominantly sand, add "sandy" to group name.

m If soil contains ≥ 30% plus No. 200 (0.075 mm), predominantly gravel, add "gravelly" to group name.

n PI ≥ 4 and plots on or above "A" line.

o PI < 4 or plots below "A" line.

p PI plots on or above "A" line.

q PI plots below "A" line.

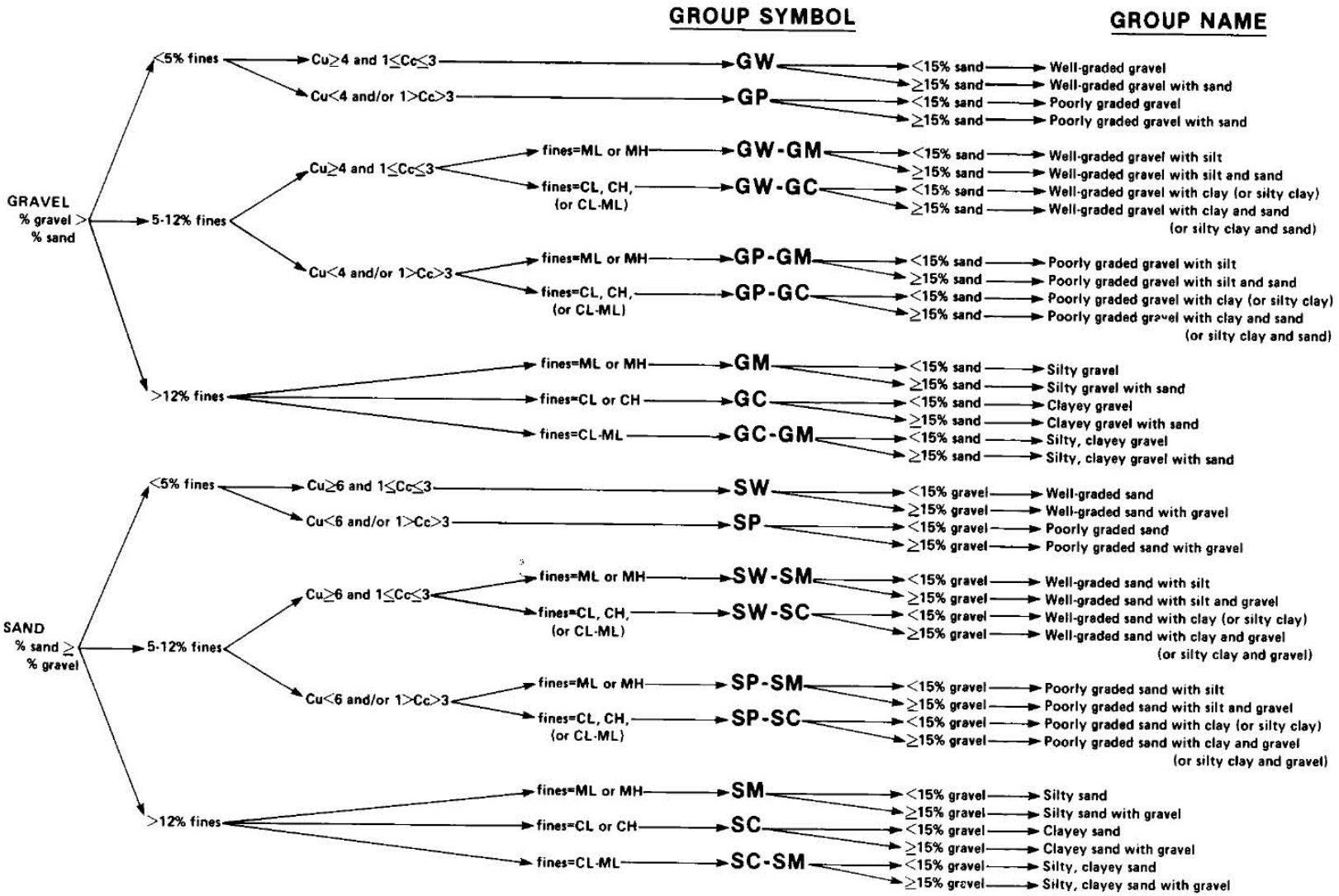


Figure 4-1: Flow chart to determine the group symbol and group name for coarse-grained soils (ASTM D 2487).

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4.2.1.1 Classification of Coarse-Grained Soils

Coarse-grained soils are defined as those in which 50 percent or more by weight are retained on the No. 200 sieve (0.075 mm). The flow chart to determine the group symbol and group name for coarse-grained soils is given in Figure 4-1. This figure is identical to Figure 3 in ASTM D 2487 except for the recommendation to capitalize the primary soil type; e.g., GRAVEL.

- **The shape of the grain-size distribution (GSD) curve or "gradation curve" as it is frequently called, is one of the more important aspects in a soil classification system for coarse-grained soils.** The shape of the gradation curve can be characterized by a pair of "shape" parameters called the coefficient of uniformity, C_u, and the coefficient of curvature, C_c, to which numerical values may be assigned. By assigning numerical values to such shape parameters it becomes possible to compare grain-size distribution curves for different soils without having to plot them on the same diagram. In order to define shape parameters certain characteristic particle sizes must be identified that are common to all soils. Since the openings of a sieve are square, particles of many different shapes are able to pass through a sieve of given size even though the abscissa on the gradation curve is expressed in terms of particle "diameter," which implies a spherical-shaped particle. Therefore, the "diameter" shown on the gradation curve is an effective diameter so that the characteristic particle sizes that must be identified to define the shape parameters are in reality effective grain sizes (EGS).

  A useful EGS for the characterizing the shape of the gradation curve is the grain size for which 10 percent of the soil by weight is finer. This EGS is labeled D_{10}. This size is convenient because Hazen (1911) found that the ease with which water flows through a soil is a function of the D_{10}. In other words, Hazen found that the sizes smaller than the D_{10} affected the permeability more than the remaining 90 percent of the sizes. Therefore, the D_{10} is a logical choice as a characteristic particle size. Other convenient sizes were found to be the D_{30} and the D_{60}, which pertain to the grain size for which thirty and sixty percent, respectively, of the soil by weight is finer. These EGSs are used as follows in the Unified Soil Classification System (USCS) for the classification of coarse grained soils.

- **Slope of the gradation curve**: The shape of the curve could be defined relative to an arbitrary slope of a portion of the gradation curve. Since one EGS has already been identified as the D_{10}, the slope of the gradation curve could be described by identifying another convenient point (EGS) that is "higher" on the curve. Hazen

selected this other convenient size as the D_{60} that indicates the particle size for which 60 percent of the soil by weight is finer. The slope between the D_{60} and the D_{10} can then be related to the degree of uniformity of the sample through a parameter called the "Coefficient of Uniformity" or the "Uniformity Coefficient," C_u, which is expressed as follows:

$$C_u = \frac{D_{60}}{D_{10}} \qquad 4\text{-}1$$

- **Curvature of the gradation curve**: The second "shape" parameter is used to evaluate the curvature of the gradation curve between the two arbitrary points, D_{60} and D_{10}. A third EGS, D_{30}, that indicates the particle size for which 30 percent of the soil by weight is finer, is chosen for this purpose. The curvature of the slope between the D_{60} and the D_{10} can then be related to the three EGS' through a parameter called the "Coefficient of Curvature" or the "Coefficient of Concavity" or the "Coefficient of Gradation," C_c, which is expressed as follows:

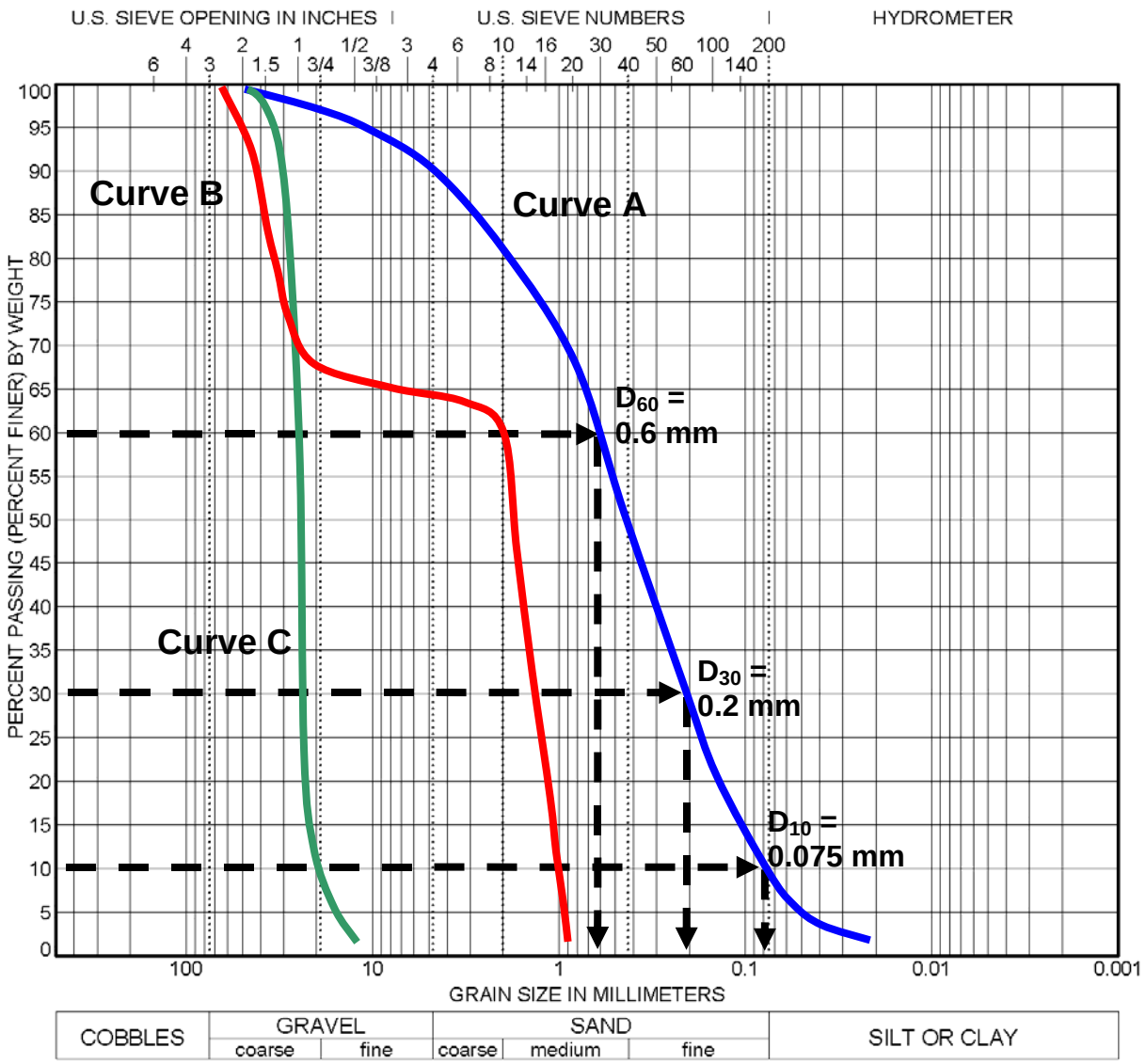
$$C_c = \frac{D_{30}^2}{D_{60} \text{ x } D_{10}} \qquad 4\text{-}2$$

By use of the two "shape" parameters, C_u and C_c, the uniformity of the coarse-grained soil (gravel and sand) can now be classified as well-graded (non-uniform), poorly graded (uniform), or gap graded (uniform or non-uniform). Table 4-10 presents criteria for such classifications.

Table 4-10
Gradation based on C_u and C_c parameters

Gradation	Gravels	Sands
Well-graded	$C_u \geq 4$ and $1 < C_c < 3$	$C_u \geq 6$ and $1 < C_c < 3$
Poorly graded	$C_u < 4$ and $1 < C_c < 3$	$C_u < 6$ and $1 < C_c < 3$
Gap graded*	C_c not between 1 and 3	C_c not between 1 and 3
*Gap-graded soils may be well-graded or poorly graded. In addition to the C_c value it is recommended that the shape of the GSD be the basis for definition of gap-graded.		

C_u and C_c are statistical parameters and provide good initial guidance. However, **the plot of the GSD curve must always be reviewed in conjunction with the values of C_u and C_c to avoid incorrect classification.** Examples of the importance of reviewing the GSD curves are presented in Figure 4-2 and discussed subsequently.



Curve	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c	Gradation
A	0.075	0.2	0.6	8.0	0.9	Well graded (1)
B	1	1.5	2	2.0	1.12	Poorly graded - Gap graded (2)
C	19	25	27	1.4	1.2	Poorly graded

(1) Soil does not meet C_u and C_c criteria for well-graded soil but GSD curve clearly indicates a well-graded soil

(2) The C_u and C_c parameters indicate a uniform (or poorly) graded material, but the GSD curve clearly indicates a gap-graded soil.

Note: For clarity only the D_{10}, D_{30}, and D_{60} sizes for Curve A are shown on the figure.

Figure 4-2. Evaluation of type of gradation for coarse-grained soils.

Discussion of Figure 4-2: Curve A in Figure 4-2 has C_u = 8 and C_c = 0.9. The soil represented by Curve A would not meet the criteria listed in Table 4-10 for well-graded soil, but yet an examination of the GSD curve shows that the soil is well-graded. Examination of the GSD curve is even more critical for the case of gap graded soils because the largest particle size evaluated by parameters C_u and C_c is D_{60} while the gap grading may occur at a size larger than D_{60} size as shown for a 2/3:1/3 proportion of gravel: sand mix represented by Curve B in Figure 4-2. Based on the criteria in Table 4-10, the soil represented by Curve B would be classified as a uniform or poorly graded soil which would be an incorrect classification. Such incorrect classifications can and do occur on construction sites where the contractor may (a) simply mix two stockpiles of uniformly graded soils leftover from a previous project. (b) use multiple sand and gravel pits to obtain borrow soils, and/or (c) mix soils from two different seams or layers of poorly graded material in the same gravel pit. Figure 4-2 is an illustration on the importance of evaluating the shape of the GSD curve in addition to the statistical parameters C_u and C_c. Practical aspects of the engineering characteristics of granular soils are discussed in Section 4.4.

4.2.1.2 Classification of Fine-Grained Soils

Fine-grained soils, or “fines,” are those in which 50 percent or more by weight pass the No. 200 (0.075 mm) sieve, The classification of fine-grained soils is accomplished by use of the plasticity chart (Figure 4-3). For fine-grained organic soils, Table 4-11 may be used. Inorganic silts and clays are those that do not meet the organic criteria as given in Table 4-11. The flow charts to determine the group symbol and group name for fine-grained soils are given in Figure 4-4a and 4-4b. These figures are identical to Figures 1a and 1b in ASTM D 2487 except that they are modified to show the soil type capitalized; e.g., CLAY. Dual symbols are used to classify organic silts and clays whose liquid limit and PI plot above the "A"-line, for example, CL-OL instead of OL and CH-OH instead of OH. To describe the fine-grained soil types more fully, plasticity adjectives and soil types used as adjectives should be used to further define the soil type's texture, plasticity, and location on the plasticity chart (see Table 4-12). Examples using Table 4-11 are given in Table 4-12. An example description of fine-grained soils is as follows:

Soft, wet, gray, high plasticity CLAY, with f. Sand; Fat CLAY (CH); (Alluvium)

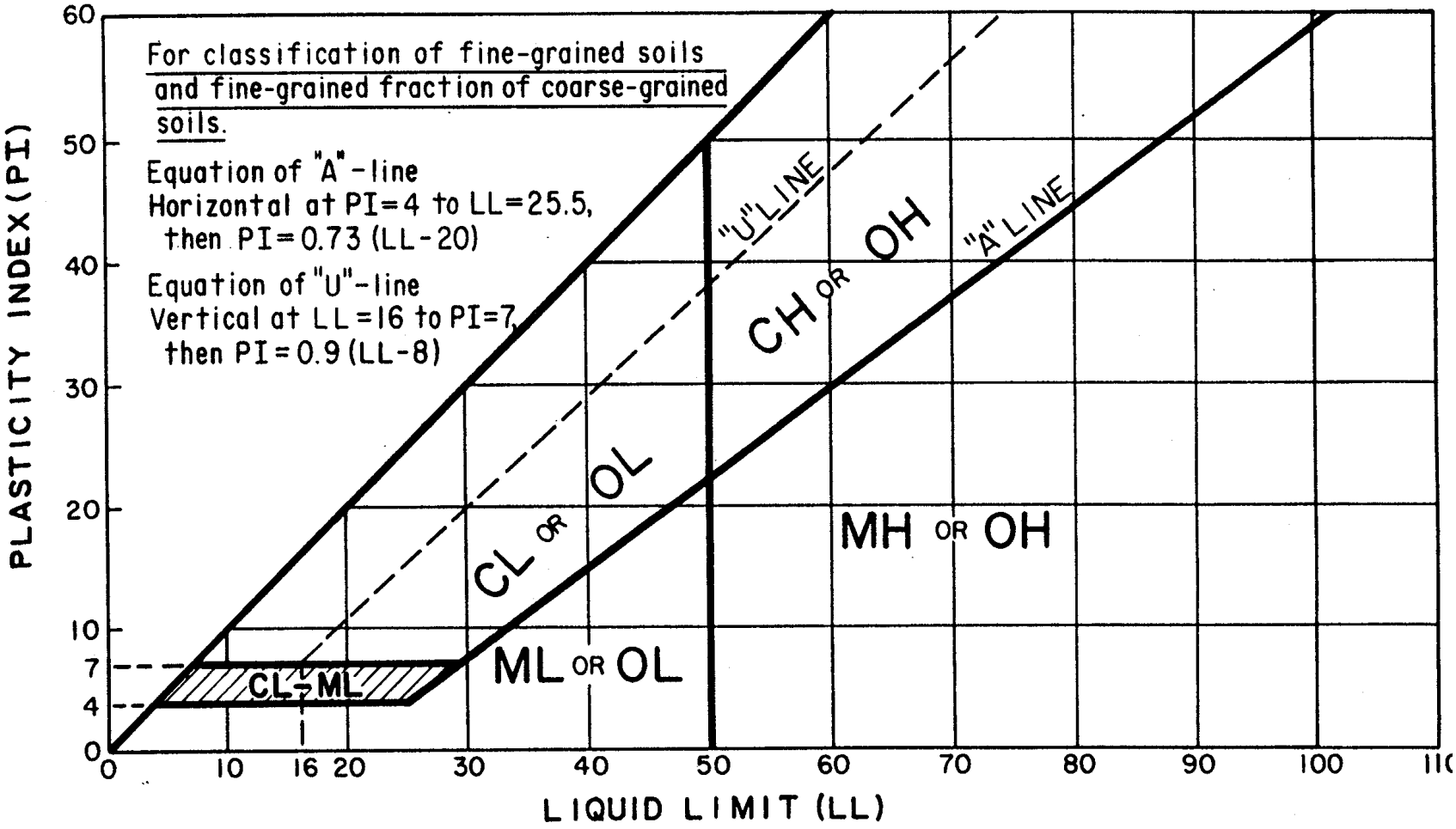


Figure 4-3. Plasticity chart for Unified Soil Classification System (ASTM D 2487).

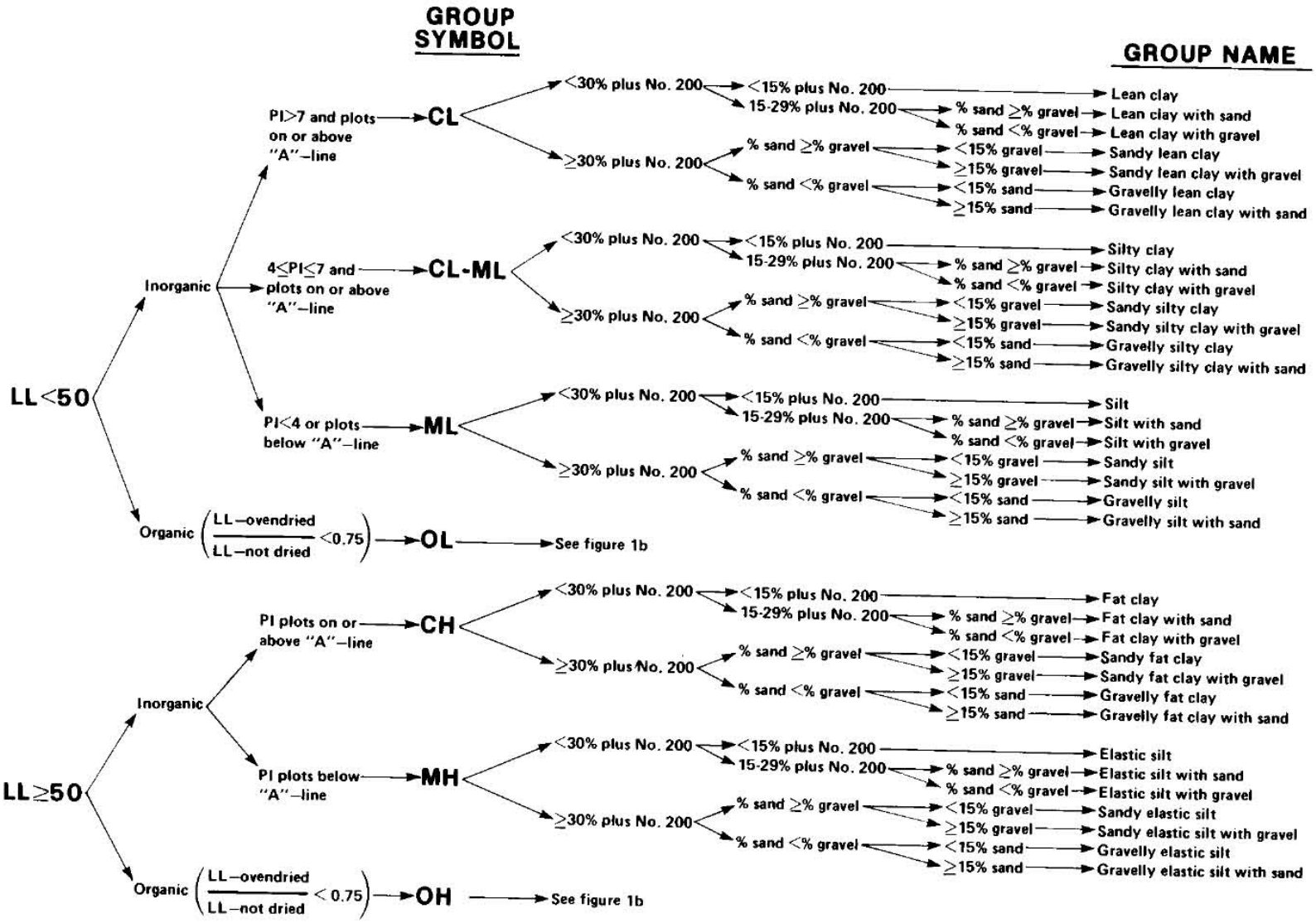


Figure 4-4a. Flow chart to determine the group symbol and group name for fine-grained soils (ASTM D 2487).

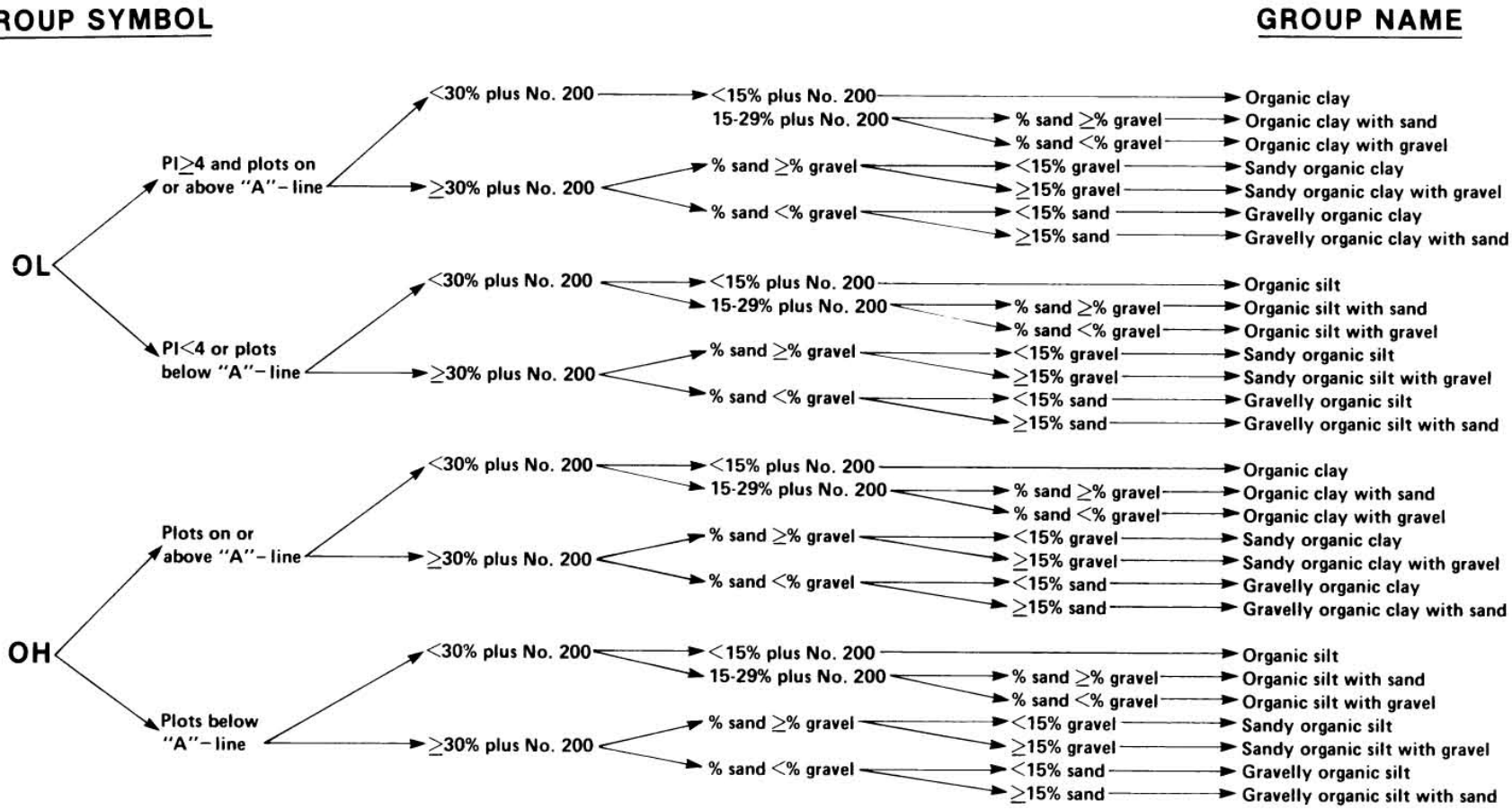


Figure 4-4b. Flow chart to determine the group symbol and group name for organic soils (ASTM D 2487).

Table 4-11
Soil plasticity descriptors (based on Figures 4-3, 4-4a and 4-4b)

Plasticity Index Range	Plasticity Adjective	Adjective for Soil Type, Texture, and Plasticity Chart Location		
		ML & MH (Silt)	CL & CH (Clay)	OL & OH (Organic Silt or Clay)[1]
0	nonplastic	-	-	ORGANIC SILT
1 - 10	low plasticity	-	silty	ORGANIC SILT
>10 - 20	medium plasticity	Clayey	silty to no adj.	ORGANIC clayey SILT
>20 - 40	high plasticity	Clayey	-	ORGANIC silty CLAY
>40	very plastic	Clayey	-	ORGANIC CLAY
Soil type is the same for above or below the "A"-line; the dual group symbol (CL-OL or CH-OH) identifies the soil types above the "A"-line.				

Table 4-12
Examples of description of fine-grained soils (based on Figures 4-3, 4-4a and 4-4b)

Group Symbol	PI	Group Name	Complete Description For Main Soil Type (Fine-Grained Soil)
CL	9	lean CLAY	low plasticity silty CLAY
ML	7	SILT	low plasticity SILT
ML	15	SILT	medium plastic clayey SILT
MH	21	elastic SILT	high plasticity clayey SILT
CH	25	fat CLAY	high plasticity silty CLAY or high plasticity CLAY, depending on smear test (for silty relatively dull and not shiny or just CLAY for shiny, waxy)
OL	8	ORGANIC SILT	low plasticity ORGANIC SILT
OL	19	ORGANIC SILT	medium plastic ORGANIC clayey SILT
CH	>40	fat CLAY	very plastic CLAY

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4.2.2 AASHTO Soil Classification System

The AASHTO soil classification system is shown in Table 4-13. The AASHTO classification system is useful in determining the relative quality of the soil material for use in earthwork structures, particularly embankments, subgrades, subbases and bases.

According to this system, soil is classified into seven major groups, A-1 through A-7. Soils classified under groups A-1, A-2 and A-3 are granular materials where 35% or less of the particles pass through the No. 200 sieve (0.075 mm). Soils where more than 35% pass the No. 200 sieve (0.075 mm) are classified under groups A-4, A-5, A-6 and A-7. Soils where more than 35% pass the No. 200 sieve (0.075 mm) are mostly silt and clay-size materials. The classification procedure is shown in Table 4-13. The classification system is based on the following criteria:

i *Grain Size*: The grain size terminology for this classification system is as follows:
- **Gravel**: fraction passing the 3 in (75 mm) sieve and retained on the No. 10 (2 mm) sieve.
- **Sand**: fraction passing the No. 10 (2 mm) sieve and retained on the No. 200 (0.075 mm) sieve
- **Silt and clay**: fraction passing the No. 200 (0.075 mm) sieve

ii *Plasticity*: The term *silty* and *clayey* are used as follows:
- **Silty**: use when the fine fractions of the soil have a plasticity index of 10 or less.
- **Clayey**: use when the fine fractions have a plasticity index of 11 or more.

iii. If cobbles and boulders (size larger than 3 in (75 mm)) are encountered they are excluded from the portion of the soil sample on which the classification is made. However, the percentage of material is recorded.

To evaluate the quality of a soil as a highway subgrade material, a number called the *group index* (GI) is also incorporated along with the groups and subgroups of the soil. The group index is written in parenthesis after the group or subgroup designation. The group index is given by Equation 4-3 where F is the percent passing the No. 200 (0.075 mm) sieve, LL is the liquid limit, and PI is the plasticity index.

$$GI = (F-35)[0.2+0.005(LL-40)] + 0.01(F-15)\,(PI-10) \qquad 4\text{-}3$$

Table 4-13

AASHTO soil classification system based on AASHTO M 145 (or ASTM D 3282)

GENERAL CLASSIFICATION	**GRANULAR MATERIALS (35 percent or less of total sample passing No. 200 sieve (0.075 mm)**							**SILT-CLAY MATERIALS (More than 35 percent of total sample passing No. 200 sieve (0.075 mm)**			
GROUP CLASSIFICATION	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis, percent passing:											
No. 10 (2 mm)	50 max.										
No. 40 (0.425 mm)	30 max.	50 max.	51 min.								
No. 200 (0.075 mm)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No 40 (0.425 mm)											
Liquid limit				40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Usual significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
Group Index**	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.

Classification procedure:

With required test data available, proceed from left to right on chart; correct group will be found by process of elimination. The first group from left into which the test data will fit is the correct classification.

*Plasticity Index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity Index of A-7-6 subgroup is greater than LL minus 30 (see Fig 4-5).

**See group index formula (Eq. 4-3). Group index should be shown in parentheses after group symbol as: A-2-6(3), A-4(5), A-7-5(17), etc.

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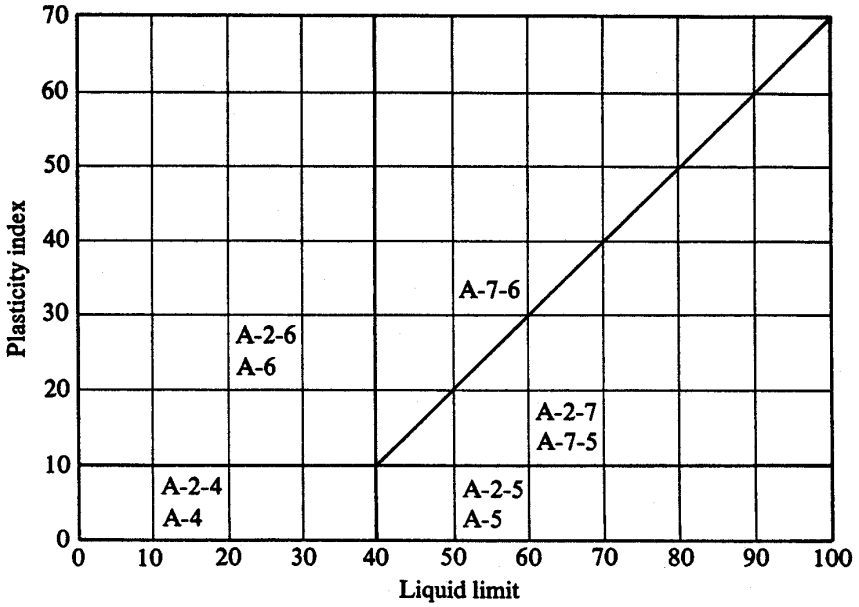


Figure 4-5. Range of liquid limit and plasticity index for soils in groups A-2, A-4, A-5, A-6 and A-7 per AASHTO M 145 (or ASTM D 3282).

The first term of Equation 4-3 is the partial group index determined from the liquid limit. The second term is the partial group index determined from the plasticity index. Following are some rules for determining group index:

- If Equation 4-3 yields a negative value for GI, it is taken as zero.
- The group index calculated from Equation 4-3 is rounded off to the nearest whole number, e.g., GI=3.4 is rounded off to 3; GI=3.5 is rounded off to 4.
- There is no upper limit for the group index.
- The group index of soils belonging to groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 will always be zero.
- When the group index for soils belonging to groups A-2-6 and A-2-7 is calculated, the partial group index for PI should be used, or

$$GI=0.01(F-15)\ (PI-10) \qquad 4\text{-}4$$

In general, the quality of performance of a soil as a subgrade material is inversely proportional to the group index.

A comparison of the USCS and AASHTO system is shown in Figures 4-6 and 4-7.

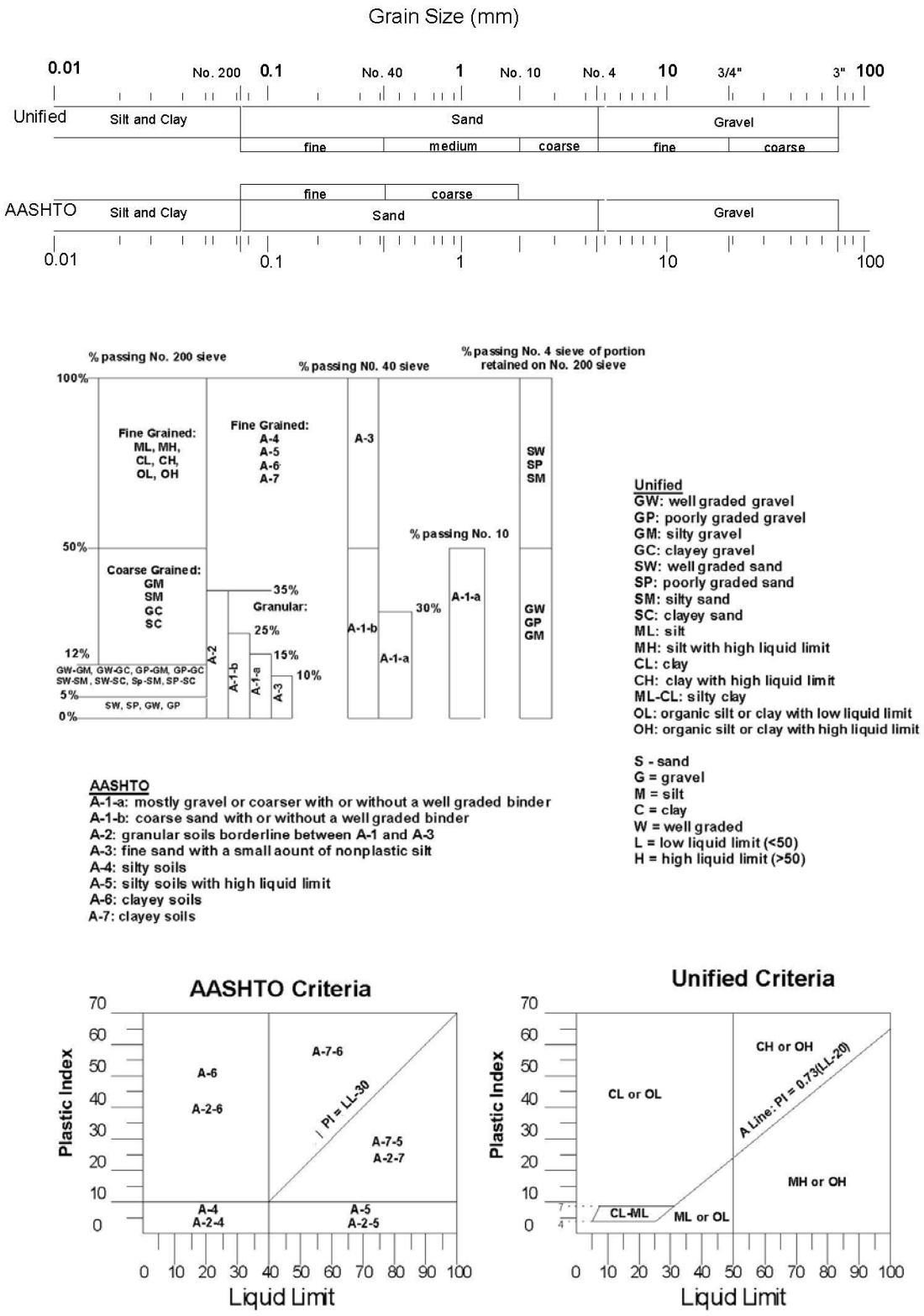


Figure 4-6. Comparison of the USCS with the AASHTO soil classification system (after Utah DOT – Pavement Design and Management Manual, 2005).

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Soil Group in Unified System	Comparable Soil Groups in AASHTO System		
	Most Probable	Possible	Possible but Improbable
GW	A-1-a	—	A-2-4, A-2-5, A-2-6, A-2-7
GP	A-1-a	A-1-b	A-3, A-2-4, A-2-5, A-2-6, A-2-7
GM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6	A-4, A-5, A-6, A-7-5, A-7-6, A-1-a
GC	A-2-6, A-2-7	A-2-4, A-6	A-4, A-7-6, A-7-5
SW	A-1-b	A-1-a	A-3, A-2-4, A-2-5, A-2-6, A-2-7
SP	A-3, A-1-b	A-1-a	A-2-4, A-2-5, A-2-6, A-2-7
SM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6, A-4, A-5	A-6, A-7-5, A-7-6, A-1-a
SC	A-2-6, A-2-7	A-2-4, A-6, A-4, A-7-6	A-7-5
ML	A-4, A-5	A-6, A-7-5	—
CL	A-6, A-7-6	A-4	—
OL	A-4, A-5	A-6, A-7-5, A-7-6	—
MH	A-7-5, A-5	—	A-7-6
CH	A-7-6	A-7-5	—
OH	A-7-5, A-5	—	A-7-6
Pt	—	—	—

Soil Group in AASHTO System	Comparable Soil Groups in Unified System		
	Most Probable	Possible	Possible but Improbable
A-1-a	GW, GP	SW, SP	GM, SM
A-1-b	SW, SP, GM, SM	GP	—
A-3	SP	—	SW, GP
A-2-4	GM, SM	GC, SC	GW, GP SW, SP
A-2-5	GM, SM	—	GW, GP, SW, SP
A-2-6	GC, SC	GM, SM	GW, GP SW, SP
A-2-7	GM, GC, SM, SC	—	GW, GP, SW, SP
A-4	ML, OL	CL, SM, SC	GM, GC
A-5	OH, MH, ML, OL	—	SM, GM
A-6	CL	ML, OL, SC	GC, GM, SM
A-7-5	OH, MH	ML, OL, CH	GM, SM, GC, SC
A-7-6	CH, CL	ML, OL, SC	OH, MH, GC, GM, SM

Figure 4-7. Comparison of soil groups in the USCS with the AASHTO Soil Classification Systems (Holtz and Kovacs, 1981).

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4.3 ENGINEERING CHARACTERISTICS OF SOILS

The major engineering characteristics of the main soil groups discussed in the previous section as related to foundation design are summarized as follows. A discussion on the practical aspects of the engineering characteristics is presented for granular and fine-grained soils following these summaries.

4.3.1 Engineering Characteristics of Coarse-Grained Soils (Sands and Gravels)

- Generally very good foundation material for supporting structures and roads.
- Generally very good embankment material.
- Generally the best backfill material for retaining walls.
- Might settle under vibratory loads or blasts.
- Dewatering may be difficult in open-graded gravels due to high permeability.
- Generally not frost susceptible.

4.3.2 Engineering Characteristics of Fine-Grained Soils (Inorganic Clays)

- Generally possess low shear strength.
- Plastic and compressible.
- Can lose part of shear strength upon wetting.
- Can lose part of shear strength upon disturbance.
- Can shrink upon drying and expand upon wetting.
- Generally very poor material for backfill.
- Generally poor material for embankments.
- Can be practically impervious.
- Clay slopes are prone to landslides.

4.3.3 Engineering Characteristics of Fine-Grained Soils (Inorganic Silts)

- Relatively low shear strength.
- High capillarity and frost susceptibility.
- Relatively low permeability.
- Frost heaving susceptibility
- Difficult to compact.

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4.3.4 Engineering Characteristics of Organic Soils

The term organic designates those soils, other than topsoil, that contain an appreciable amount of vegetative matter and occasionally animal organisms in various states of decomposition. Any soil containing a sufficient amount of organic matter to influence its engineering properties is called an organic soil. The organic matter is objectionable for three main reasons:

1. Reduces load carrying capacity of soil.
2. Increases compressibility considerably.
3. Frequently contains toxic gasses that are released during the excavation process.

Generally organic soils, whether peat, organic clays, organic silts, or even organic sands, are not used as construction materials.

4.4 PRACTICAL ASPECTS OF ENGINEERING CHARACTERISTICS OF COARSE-GRAINED SOILS

Grain size distribution is the single most important element in the design of structures on, in, or composed of granular soils. As discussed in Chapter 2, grain size distribution is determined by sieving a dried soil sample of known weight through a nest of U.S. Standard sieves with decreasing mesh opening sizes. Figures 2-3 and 4-2 presented sample grain size distribution curves, also known as gradation curves, and introduced the terminology “well graded,” “poorly graded,” and “gap graded.”

Much can be learned about a soil’s behavior from the shape and location of the curve. For instance, the “well graded” curve shown in Figure 4-2 represents a non-uniform soil with a wide range of particle sizes that are evenly distributed. Densification of a well-graded soil causes the smaller particles to move into the voids between the larger particles. As the voids in the soil are reduced, the density and strength of the soil increase. Specifications for select structural fill should contain required ranges of different particle sizes so that a dense, non-compressible backfill can be achieved with reasonable compactive effort. For example, the well-graded soil represented by Curve A shown in Figure 4-2 could be specified by providing the gradation limits listed in Table 4-14.

As shown by Curve C in Figure 4-2, a poorly graded or uniform soil is composed of a narrow range of particle sizes. When compaction is attempted, inadequate distribution of particle sizes prevents reduction of the volume of voids by infilling with smaller particles. Such uniform soils should be avoided as select fill material. However, uniform soils do have an

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important use as drainage materials. The relatively large and permanent void spaces act as conduits to carry water. Obviously, the larger the average particle size the larger the void space. The "French drain" is an example of the engineering use of a coarse uniform soil. Table 4-15 presents a typical specification for drainage materials having a narrow band of particle sizes. For material specifications related to drain material, it is important to specify that gap-graded materials shall not be acceptable. This is because gap-graded materials have variable permeabilities that may cause malfunction of the drain with associated damage to the geotechnical feature associated with the drain.

Table 4-14
Example gradation limits of well-graded granular material
(see Curve A in Figure 4-2)

Sieve Size	Percent Passing by Weight
2″ (50.8 mm)	100
#10 (2 mm)	75-90
#40 (0.425 mm)	40-60
#200 (0.075 mm)	0 – 15

Table 4-15
Example gradation limits of drainage materials
(see Curve C in Figure 4-2)

Sieve Size	Percent Passing by Weight
2″ (50.8 mm)	100
1 ½ ″ (37.5 mm)	90-100
¾ ″ (19 mm)	0-15

4.5 PRACTICAL ASPECTS OF ENGINEERING CHARACTERISITICS OF FINE-GRAINED SOILS

As indicated in Chapter 2, the plasticity index (PI) is the difference between the liquid limit (LL) and the plastic limit (PL). The PI represents the range of water content over which the soil remains plastic. In general, the greater the PI, the greater the amount of clay particles present and the more plastic the soil. The more plastic a soil, the more likely it will be to have the following characteristics:

1. Be more compressible.
2. Have greater potential to shrink upon drying and/or swell upon wetting.
3. Be less permeable.

In addition to the PI, the Liquidity Index (LI) is a useful indicator of the engineering characteristics of fine-grained soils. Table 2-4 in Chapter 2 identifies the strength and deformation characteristics of fine-grained soils in terms of the LI.

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4.6 DESCRIPTION OF ROCK

When providing rock descriptions, geotechnical specialists should use technically correct geological terms. Local terms in common use may be acceptable if they help describe distinctive characteristics. Rock cores should be logged when wet for consistency of color description and greater visibility of rock features such as hairline fractures. The guidelines presented in the ISRM (1981), should be reviewed for additional information regarding logging procedures for core drilling.

The rock's lithologic description should include as a minimum the following items:

- Rock type
- Color
- Grain size and shape
- Texture (stratification/foliation)
- Mineral composition
- Weathering and alteration
- Strength
- Other relevant notes

The various elements of the rock's description should be stated in the order listed above, for example:

"Limestone, light gray, very fine-grained, thin-bedded, unweathered, strong"

The rock description should include identification of discontinuities and fractures. The description should also include a drawing of the naturally occurring fractures and mechanical breaks.

4.6.1 Rock Type

Rocks are classified according to their origin into three major divisions: igneous, sedimentary, and metamorphic (see Table 4-16). These three groups are subdivided into types according to mineral and chemical composition, texture, and internal structure. For some projects a library of hand samples and photographs representing lithologic rock types present in the project area should be maintained.

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Table 4-16
Rock groups and types (FHWA, 1997)

Igneous		
Intrusive (Coarse Grained)	Extrusive (Fine Grained)	Pyroclastic
Granite Syenite Diorite Diabase Gabbro Peridotite Pegmatite	Rhyolite Trachyte Andesite Basalt	Obsidian Pumice Tuff
Sedimentary		
Clastic (Sediment)	Chemically Formed	Organic Remains
Shale Mudstone Claystone Siltstone Sandstone Conglomerate Limestone, oolitic	Limestone Dolomite Gypsum Halite	Chalk Coquina Lignite Coal
Metamorphic		
Foliated	Non-foliated	
Slate Phyllite Schist Gneiss	Quartzite Amphibolite Marble Hornfel	

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4.6.2 Color

Colors should be consistent with a Munsell Color Chart (USDA, 1993) and recorded for both wet and dry conditions as appropriate.

4.6.3 Grain Size and Shape

The grain size description should be classified according to the terms presented in Table 4-17. Table 4-18 is used to classify the shape of the grains. The grain size descriptions are consistent with those used in the USCS for soil particles.

Table 4-17
Terms to describe grain size (typically for sedimentary rocks)

Description	Grain Size (mm)	Characteristic of Individual Grains
Very coarse grained	#4 (> 4.75)	Can be easily distinguished by eye
Coarse grained	#10 to #4 (2.00 -4.75)	Can be easily distinguished by eye
Medium grained	#40 to #10 (0.425 -2.00)	Can be distinguished by eye
Fine grained	#200 to #40 (0.075-0.425)	Can be distinguished by eye with difficulty
Very fine grained	< #200 (< 0.075)	Cannot be distinguished by unaided eye

Table 4-18
Terms to describe grain shape (for sedimentary rocks)

Description	Characteristic
Angular	Showing very little evidence of wear. Grain edges and corners are sharp. Secondary corners are numerous and sharp.
Subangular	Showing some evidence of wear. Grain edges and corners are slightly rounded off. Secondary corners are slightly less numerous and slightly less sharp than in angular grains.
Subrounded	Showing considerable wear. Grain edges and corners are rounded to smooth curves. Secondary corners are reduced greatly in number and highly rounded.
Rounded	Showing extreme wear. Grain edges and corners are smoothed off to broad curves. Secondary corners are few in number and rounded.
Well-rounded	Completely worn. Grain edges or corners are not present. No secondary edges or corners are present.

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4.6.4 Stratification/Foliation

Significant non-fracture structural features should be described. The thickness should be described by using the terms in Table 4-19. The orientation of the bedding/foliation should be measured from the horizontal or with respect to the core axis.

Table 4-19. Terms to describe stratum thickness

Descriptive Term	Stratum Thickness in (mm)*
Very Thickly bedded	(> 1 m)
Thickly bedded	(0.5 to 1.0 m)
Thinly bedded	(50 mm to 500 mm)
Very Thinly bedded	(10 mm to 50 mm)
Laminated	(2.5 mm to 10 mm)
Thinly Laminated	(< 2.5 mm)
* Conventionally measured in m or mm. (1 m = 3.28 ft; 25.4 mm = 1 in)	

4.6.5 Mineral Composition

The mineral composition should be identified by a geologist based on experience and the use of appropriate references. The most abundant mineral should be listed first, followed by minerals in decreasing order of abundance. For some common rock types, the mineral composition need not be specified (e.g. dolomite, limestone).

4.6.6 Weathering and Alteration

Weathering and alteration is due to the weathering processes discussed in Chapter 3, e.g., physical, chemical and thermal mechanisms. Terms and abbreviations used to describe weathering and alteration are presented in Table 4-20.

4.6.7 Strength

The point load test described in Chapter 5 is recommended for the measurement of sample strength. The point-load index, I_s, obtained from the point load test should be converted to uniaxial compressive strength. Categories and terminology for describing rock strength based on the uniaxial compressive strength are presented in Table 4-21. Table 4-21 also presents guidelines for common qualitative assessments of strength that can be performed with the aid of a geologist's hammer and a pocket knife while the geotechnical specialist is mapping or doing primary logging of core at the drill rig site. The field estimates should be confirmed where appropriate by comparison with selected laboratory tests.

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Table 4-20
Terms to describe rock weathering and alteration (ISRM, 1981)

Grade (Term)	Description
I (Fresh)	Rock shows no discoloration, loss of strength, or other effects of weathering/alteration
II (Slightly Weathered/Altered)	Rock is slightly discolored, but not noticeably lower in strength than fresh rock
III (Moderately Weathered/Altered)	Rock is discolored and noticeably weakened, but less than half is decomposed; a minimum 2 in (50 mm) diameter sample cannot be broken readily by hand across the rock fabric
IV (Highly Weathered/Altered)	More than half of the rock is decomposed; rock is weathered so that a minimum 2 in (50 mm) diameter sample can be broken readily by hand across the rock fabric
V (Completely Weathered/Altered)	Original minerals of rock have been almost entirely decomposed to secondary minerals even though the original fabric may be intact; material can be granulated by hand
VI (Residual Soil)	Original minerals of rock have been entirely decomposed to secondary minerals, and original rock fabric is not apparent; material can be easily broke by hand

Table 4-21
Terms to describe rock strength (ISRM, 1981)

Grade (Description)	Field Identification	Approximate Range of Uniaxial Compressive Strength, psi (kPa)
R0 (Extremely Weak Rock)	Can be indented by thumbnail	35 (250) - 150 (1,000)
R1 (Very Weak Rock)	Can be peeled by pocket knife	150 (1,000) - 725 (5,000)
R2 (Weak Rock)	Can be peeled with difficulty by pocket knife	725 (5,000) - 3,500 (25,000)
R3 (Medium Strong Rock)	Can be indented 3/16 in (5 mm) with sharp end of pick	3,500 (25,000) - 7,000 (50,000)
R4 (Strong Rock)	Requires one blow of geologist's hammer to fracture	7,000 (50,000) - 15,000 (100,000)
R5 (Very Strong Rock)	Requires many blows of geologist's hammer to fracture	15,000 (100,000) - 36,000 (250,000)
R6 (Extremely Strong Rock)	Can only be chipped with blows of geologist's hammer	> 36,000 (>250,000)

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4.6.8 Hardness

Hardness is commonly assessed by the scratch test. Descriptions and abbreviations used to describe rock hardness are presented in Table 4-22.

Table 4-22
Terms to describe rock hardness (FHWA, 2002b)

Description (Abbr)	Characteristic
Soft (S)	Reserved for plastic material alone.
Friable (F)	Easily crumbled by hand, pulverized or reduced to powder.
Low Hardness (LH)	Can be gouged deeply or carved with a pocket knife.
Moderately Hard (MH)	Can be readily scratched by a knife blade; scratch leaves a heavy trace of dust and scratch is readily visible after the powder has been blown away.
Hard (H)	Can be scratched with difficulty; scratch produces little powder and is often faintly visible; traces of the knife steel may be visible.
Very Hard (VH)	Cannot be scratched with pocket knife. Leave knife steel marks on surface.

4.6.9 Rock Discontinuity

Discontinuity is the general term for any mechanical break in a rock mass that has zero or low tensile strength. Discontinuity is the collective term used for most types of joints, weak bedding planes, weak schistosity planes, weakness zones, and faults. The spacing between discontinuities is defined as the perpendicular distance between adjacent discontinuities. The spacing should be measured perpendicular to the planes in the set. Table 4-23 presents guidelines to describe discontinuity spacing.

Discontinuities should be described as closed, open, or filled. **Aperture** is the term used to describe the perpendicular distance separating the adjacent rock walls of an open discontinuity in which the intervening space is air- or water-filled. **Width** is the term used to describe the distance separating the adjacent rock walls of filled discontinuities. The terms presented in Table 4-24 should be used to describe apertures. Terms such as "wide," "narrow" and "tight" are used to describe the width of discontinuities such as thickness of veins, fault gouge filling, or joints openings. Guidelines for use of such terms are presented in Tables 4-23 and 4-24.

Table 4-23. Terms to describe discontinuities (after ISRM, 1981)

Discontinuity Type	**Amount of Infilling**	**Discontinuity Spacing (m)***
F - Fault J - Joint Sh - Shear Fo - Foliation V - Vein B - Bedding	Su - Surface Stain Sp - Spotty Pa - Partially Filled Fi - Filled No - None	EW - Extremely Wide (>6) VW - Very Wide (2-6) W - Wide (0.6-2) M - Moderate (0.2-0.6) C - Close (0.06-0.2) VC - Very Close (0.02-0.06) EC - Extremely close (<0.02)
Discontinuity Width (mm)*		**Surface Shape of Joint**
W - Wide (12.5-5.0) MW - Moderately Wide (2.5-12.5) N - Narrow (1.25-2.5) VN - Very Narrow (<1.25) T - Tight (~ 0)		Wa - Wavy Pl - Planar St - Stepped Ir - Irregular
Type of Infilling	**Roughness of Surface**	
Cl - Clay Ca - Calcite Ch - Chlorite Fe - Iron Oxide Gy - Gypsum/Talc H - Healed No - None Py - Pyrite Qz - Quartz Sd - Sand	Slk - Slickensided (surface has smooth, glassy finish with visual evidence of striations) S - Smooth (surface appears smooth and feels so to the touch) SR - Slightly Rough (asperities on the discontinuity surface are distinguishable and can felt) R - Rough (some ridges and side-angle steps are evident; asperities are clearly visible, and discontinuity surface feels very abrasive) V R - Very Rough (near-vertical steps and ridges occur on the discontinuity surface	
* Conventionally measured in m or mm. (1 m = 3.28 ft; 1 in = 25.4 mm)		

Table 4-24. Terms to classify discontinuities based on aperture size (ISRM, 1981)

Aperture (mm)*	**Description**	
<0.1 0.1 - 0.25 0.25 – 0.5	Very tight Tight Partly open	"Closed Features"
0.5 - 2.5 2.5 - 10 > 10	Open Moderately open Wide	"Gapped Features"
1-100 100-1000 >1 m	Very wide Extremely wide Cavernous	"Open Features"
* Conventionally measured in mm, cm or m. (1 m = 3.28 ft; 1 in = 25.4 mm)		

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For faults or shears that are not thick enough to be represented on the boring log, the measured thickness is recorded numerically in millimeters.

Discontinuities are further characterized by the surface shape of the joint and the roughness of its surface in addition to the fill material separating the adjacent rock walls of the discontinuities. Filling is characterized by its type, amount, width (i.e., perpendicular distance between adjacent rock walls) and strength. If non-cohesive fillings are identified, then the filling should be identified qualitatively, e.g., fine sand. Refer to Table 4-23 for guidelines to characterize these features.

4.6.10 Fracture Description

Naturally occurring fractures are numbered and described by using the same terminology that is used for discontinuities. The number of naturally occurring fractures observed in each 1 ft (0.5 m) of core should be recorded as the fracture frequency. Mechanical breaks, thought to have occurred during drilling, are not counted. The following criteria can be used to identify natural breaks:

1. A rough brittle surface with fresh cleavage planes in individual rock minerals suggests an artificial fracture.

2. A generally smooth or somewhat weathered surface with soft coating or infilling materials, such as talc, gypsum, chlorite, mica, or calcite indicates a natural discontinuity.

3. In rocks showing foliation, cleavage or bedding it may be difficult to distinguish between natural discontinuities and artificial fractures when the discontinuities are parallel with the incipient weakness planes. If drilling has been carried out carefully then the questionable breaks should be counted as natural features to be on the conservative side.

4. Depending upon the drilling equipment, part of the length of core being drilled may occasionally rotate with the inner barrels in such a way that grinding of the surfaces of discontinuities and fractures occurs. In weak rock types it may be very difficult to decide if the resulting rounded surfaces represent natural or artificial features. When in doubt, conservatively assume that they are natural.

The fracture description can be strongly time dependent and moisture content dependent in the case of certain varieties of shales and mudstones that have relatively weakly developed

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diagenetic bonds. A diagenetic bond is the bond that is formed in a deposited sediment by chemical and physical processes during its conversion to rock. A frequent problem is "discing," in which an initially intact core separates into discs on incipient planes. The process generally becomes noticeable perhaps within a few minutes of core recovery. This phenomenon is experienced in several different forms:

1. Stress relief cracking and swelling by the initially rapid release of strain energy in cores recovered from areas of high stress, especially in the case of shaley rocks.

2. Dehydration cracking experienced in the weaker mudstones and shales that may reduce RQD values from 100 percent to 0 percent in a matter of minutes. The initial integrity might possibly have been due to negative pore water pressure.

3. Slaking and cracking experienced by some of the weaker mudstones and shales when they are subjected to wetting and drying.

Any of these forms of "discing" may make logging of fracture frequency unreliable. Whenever such conditions are anticipated, core should be logged by a geotechnical specialist as it is being recovered and at subsequent intervals until the phenomenon is predictable.

4.6.11 Rock Mass Classification

In determining the rock strength for transportation facilities constructed in, on, or of rock, it is most important to account for the presence of discontinuities, such as joints, faults or bedding planes. Therefore, for most conditions, the **rock mass** strength properties, rather than the intact rock properties must be determined for use in design. The rock mass is the in-situ, fractured rock that will almost always have significantly lower strength than the intact rock because of discontinuities that divide the rock mass into blocks. Therefore, the strength of the rock mass will depend on such factors as the shear strength of the surfaces of the blocks, the spacing and continuous length of the discontinuities and their alignment relative to the direction of loading. These factors were identified in the previous sections. Using these factors, Bieniawski (1989) proposed a method for estimating rock mass properties from an index that characterizes the overall properties of the rock mass quality. This index is known as the **rock mass rating (RMR)**. Originally developed for tunnel support design, the RMR has been adopted by AASHTO (2004 with 2006 Interims) because the RMR is determined from readily measurable parameters. Table 4-25 identifies the following five measurable parameters and assigns relative ratings to each parameter:

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Table 4-25
Geomechanics classification of rock masses (AASHTO 2004 with 2006 Interims)

PARAMETER		RANGES OF VALUES						
1	Strength of intact rock material	Point load strength index	>1,200 psi	600 to 1,200 psi	300 to 600 psi	150 to 300 psi	For this low range – uniaxial compressive test is preferred	
		Uniaxial compressive strength	>30,000 psi	15,000 to 30,000 psi	7,500 to 15,000 psi	3,600 to 7,500 psi	1,500 to 3,600 psi	500 to 1,500 psi	150 to 500 psi
	Relative Rating		15	12	7	4	2	1	0
2	Drill core quality RQD	90% to 100%	75% to 90%		50% to 75%		25% to 50%	<25%	
	Relative Rating	20	17		13		8	3	
3	Spacing of joints	>10 ft	3 to 10 ft		1 to 3 ft		2 in. to 1 foot	<2 in.	
	Relative Rating	30	25		20		10	5	
4	Condition of joints	• Very rough surfaces • Not continuous • No separation • Hard joint wall rock	• Slightly rough surfaces • Separation <0.05” • Hard joint wall rock		• Slightly rough surfaces • Separation <0.05” • Soft joint wall rock		• Slickensided surfaces - or - • Gouge <0.2 in thick – or- • Joints open 0.05-0.2” • Continuous joints	• Soft gouge >0.2” thick - or - • Joints open >0.2” • Continuous joints	
	Relative Rating	25	20		12		6	0	
5	Ground water conditions (use one of the three evaluation criteria as appropriate to the method of exploration)	Inflow per 30 ft tunnel length	None		<400 gallons/hr		400 to 2,000 gallons/hr	>2,000 gallons/hr	
		Ratio= joint water pressure/ major principal stress	0		0.0 to 0.2		0.2 to 0.5	>0.5	
		General Conditions	Completely Dry		Moist only (interstitial water)		Water under moderate pressure	Severe water problems	
	Relative Rating		10		7		4	0	

Note: 1 psi = 6.895 kPa; 1 in = 25.4 mm

1. Strength of intact rock material.
2. Drill core quality as expressed by RQD.
3. Spacing of joints.
4. Condition of joints.
5. Ground water conditions.

The RMR is determined as the sum of the five relative ratings. The RMR should be adjusted in accordance with the criteria in Table 4-26. **The rock classification should be determined in accordance with Table 4-27 where RMR refers to the adjusted value**.

Table 4-26
Geomechanics rating adjustment for joint orientations
(after AASHTO 2004 with 2006 Interims)

Orientations of joints		Very favorable	Favorable	Fair	Unfavorable	Very Unfavorable
Ratings	Tunnels	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

Table 4-27
Geomechanics rock mass classes determined from total ratings
(AASHTO 2004 with 2006 Interims)

RMR (Note 1)	100 to 81	80 to 61	60 to 41	40 to 21	<20
Class No.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock
Note 1: RMR is adjusted for structural application and rock joint orientation as per Table 4-26 prior to evaluating the Class No.					

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4.7 SUBSURFACE PROFILE DEVELOPMENT

The mark of successfully accomplishing a subsurface exploration is the ability to draw a subsurface profile of the project site complete with soil types, rock interfaces, and the relevant design properties. The subsurface profile is a visual display of subsurface conditions as interpreted from all of the methods of explorations and testing described previously. Uncertainties in the development of a subsurface exploration usually indicate the need for additional explorations or testing. Because of the diverse nature of the geologic processes that contribute to soil formation, actual subsurface profiles can be extremely varied both vertically and horizontally, and can differ significantly from interpreted profiles developed from boring logs. Therefore, subsurface profiles developed from boring logs should contain some indication that the delineation between strata do not necessarily suggest that distinct boundaries exist between the strata or that the interpolations of strata thickness between borings are necessarily correct. The main purpose of subsurface profiles is to provide a starting point for design and not necessarily to present an accurate description of subsurface conditions.

In the optimum situation, the subsurface profile is developed in stages. First, a rough profile is established from the driller's logs by the geotechnical specialist. The object is to discover any obvious gaps or question marks while the drill crew is still at the site so that additional work can be performed immediately. Once a crew has left the site, a delay of months may occur before their schedule permits them to reoccupy the site, not to mention the additional cost to remobilize/demobilize. The drilling inspector or crew chief should be required to call the project geotechnical specialist when the last scheduled boring has begun to request instructions for any supplemental borings.

When all borings are completed and laboratory visuals and moisture content data received, the initial subsurface profile should be revised. Estimated soil layer boundaries and accurate soil descriptions should be established for soil deposits. Estimated bedrock interfaces should be identified. Most importantly, the depth to perched or regional groundwater should be indicated. The over-complication of the profile by noting minute variations between adjacent soil samples can be avoided by:

1. Reviewing the geologic history of the site, e.g., if the soil map denotes a lakebed deposit overlying a glacial till deposit, do not subdivide the lakebed deposit because adjacent samples have differing amounts of silt and clay. Realize before breaking down the soil profile that probably only two layers exist and variations are to be expected within each. Important variations such as the average thickness of silt and clay varves can be noted adjacent to the visual description of the layer.

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2. Remembering that the soil samples examined are only a minute portion of the soil underlying the site and must be considered in relation to adjacent samples as well as adjacent borings.

A few simple rules should be followed at this stage to interpret the available data properly:

1. Review the USDA Soil Survey map for the county and determine major surface and near-surface deposits that can be expected at the site.

2. Examine the subsurface log containing SPT results and the laboratory visual descriptions with accompanying moisture contents.

3. Review representative soil samples to check laboratory identifications and to calibrate your interpretations with those of the laboratory technicians who performed the visual description.

4. Establish rational mechanics for drawing the soil profile. For example:

    a. Use a vertical scale of 1 in equals 10 ft or 20 ft; generally, any smaller scale tends to compress data visually and prevent proper interpretation.

    b. Use a horizontal scale equal to the vertical scale, if possible, to simulate actual relationships. However, the total length should be kept within 36 inches (920 millimeter) to permit review in a single glance.

When the subsurface layer boundaries and descriptions have been established, determine the extent and details of laboratory testing. Do not casually read the driller's log and randomly select certain samples for testing. Plan the test program intelligently from the subsurface profile and for the proposed feature. Identify major soil deposits and assign appropriate tests for the design project under investigation.

The final subsurface profile is the geotechnical specialist's best interpretation of all available subsurface data. The final subsurface profile should include the following:

- interpreted boundaries of soil and rock
- the average physical properties of the soil layers, e.g., unit weight, shear strength, etc.
- a visual description of each layer including USCS symbols for soil classification
- location of the ground water level, and

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- notations for special items such as boulders, artesian pressure, etc.

If the inclusion of all of the information listed above clutters the subsurface profile, then complementary tables containing some of that information should be developed to accompany the profile. Figures 4-8 and 4-9 show a typical boring location plan and an interpreted subsurface profile. Note that **the interpreted boundaries of rock and groundwater profiles are for internal agency use. Such interpretations should not be presented in bid documents.** Another example of boring location plan and subsurface profile is presented in Chapter 11 (Geotechnical Reports).

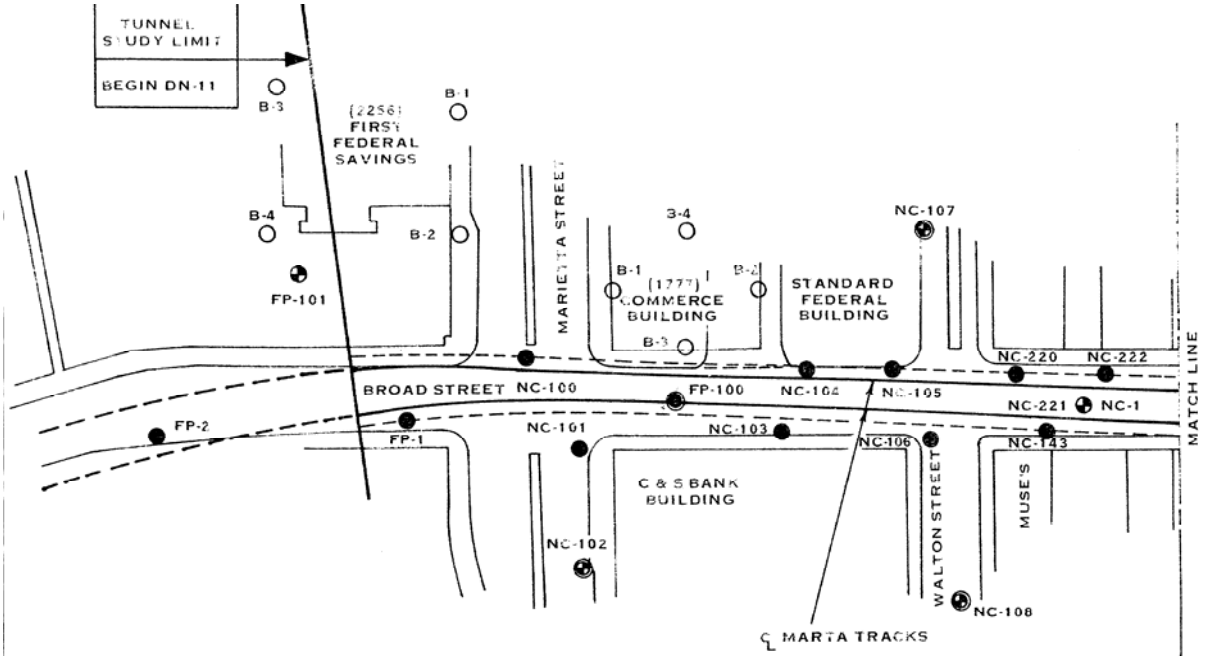


Figure 4-8. Example boring location plan (FHWA, 2002a).

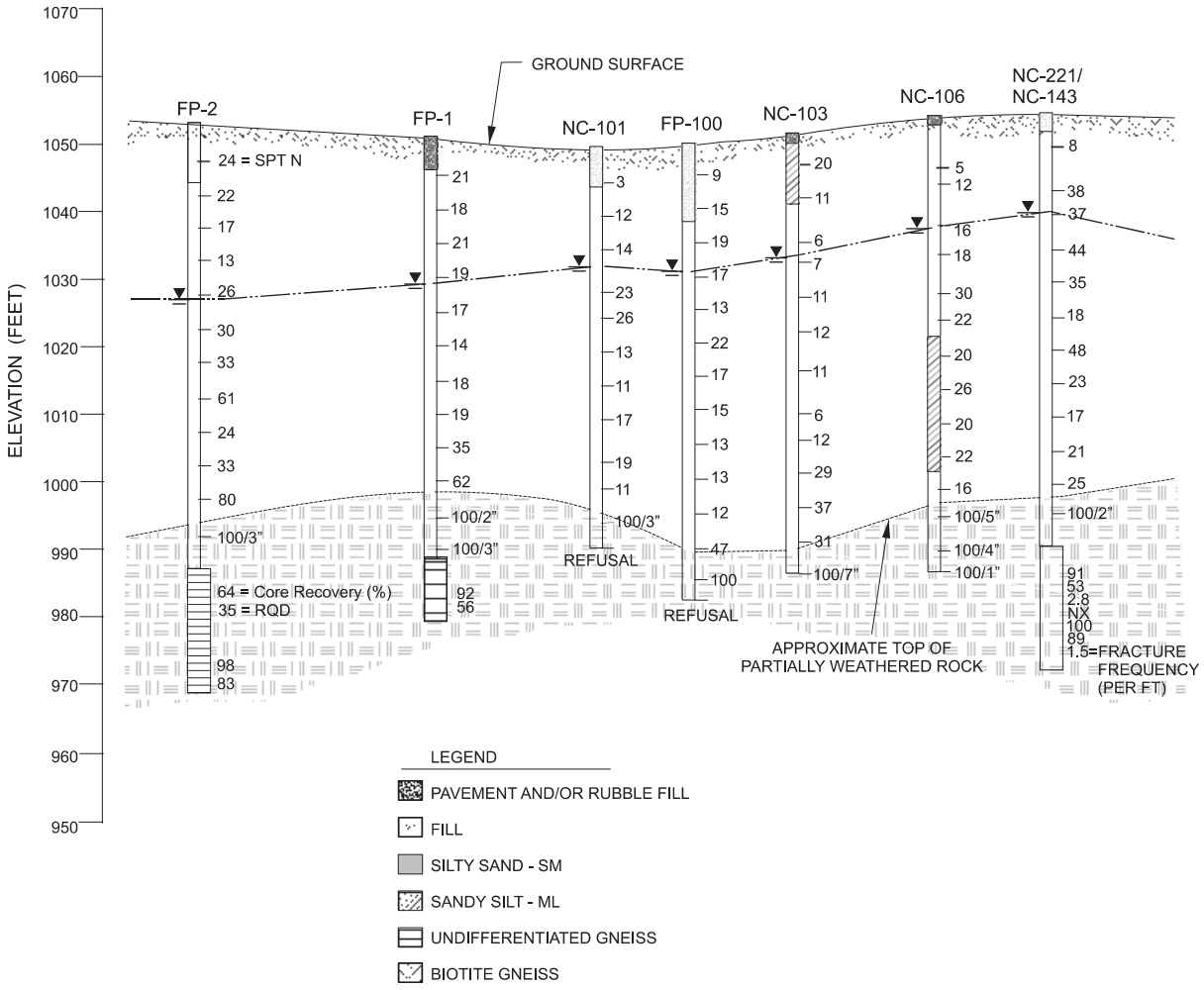


Figure 4-9. Example interpreted subsurface profile (FHWA, 2002a).

4.7.1 Use of Historical Data in Development of Subsurface Profile

Data from historical boring logs from the area can be used to supplement data provided by the current boring logs in developing a subsurface profile, however, such historical logs need to be reviewed carefully well in advance of drilling activities to ensure that the data are accurate. In some cases, boring log locations are referenced to the center alignment of a roadway without the location of the borehole having been actually surveyed. It is imperative to ensure that a consistent coordinate system is used to establish the correct relative location of all borings. Since borings would have likely been performed over an extended period of time or for different contracts along a roadway alignment (i.e., project centerlines are commonly changed during project development), it is possible that coordinate systems will not be consistent. Simply stated, if a historical boring cannot be located confidently on a site

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plan, then the boring has limited usefulness for establishing stratigraphy. Also, it is likely that different drill rigs with different operators and different energy efficiencies were used in the collection of SPT data on historical boring logs. This factor must also be recognized when an attempt is made to correlate engineering properties to SPT blow count values. However, the geotechnical specialist should realize that while there may be potential limitations in the use of historical borings, it is necessary to review these borings relative to the design under consideration. As an example, a historical boring may indicate a thick layer of very soft clay as evidenced by the description "weight of rod/weight of hammer" in the SPT recording box of the log at a large number of test depths. While shear strength and consolidation properties cannot be reliably estimated based on SPT blow count values, the historical boring may provide useful information concerning the depth to a firm stratum.

Most DOTs have collected large amounts of subsurface data from previous investigations within their states. Unfortunately, much of these data are archived with related project data once the project has been completed, and thus may not be readily available or accessible for use during future projects. Additionally, the subsurface data may not be fully utilized if the locations of the borings are not identified properly or if the plan drawing of the project site is not maintained with the boring logs. To overcome this problem, many DOTs currently use longitude and latitude to identify the boring locations, in lieu of or in conjunction with the conventional positioning format that uses station and offset. Unfortunately, the vast majority of the historical subsurface boring information is available only on paper. Therefore, a considerable amount of work is required to convert that data into electronic form before it can be fully appreciated and used to establish an electronic database of the subsurface information.

Several DOTs have recently commenced using electronic boring records for their projects. Not only does the use of electronic boring records provide a redundancy to compliment the paper copy, but it also preserves data in a way that has the potential for automated electronic data management. One method of electronic data management increasingly used by DOTs involves the use of a centralized electronic database in conjunction with Geographic Information System (GIS) techniques to locate and identify borings on a plan. In its most simplistic form, the electronically stored data are managed and assessed visually by using GIS software, where each boring location is identified on a plan map. An appropriately developed database and GIS can be used to great advantage by the DOT. Specifically, in addition to the previously mentioned advantages of having electronic data records compliment paper logs, it is possible to:

1. catalog borings that were conducted previously;
2. inventory data regarding specific problematic formations across the state; and

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3. develop cross sections that depict subsurface conditions across a site or within a region.

This type of application of electronic boring records and data base accessibility can facilitate the development of subsequent subsurface investigations that are appropriately focused and that optimize the utility of existing data.

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CHAPTER 5.0
LABORATORY TESTING
FOR GEOTECHNICAL DESIGN AND CONSTRUCTION

Laboratory testing of soils and rocks is a fundamental element of geotechnical engineering. The complexity of testing required for a particular project may range from a simple moisture content determination to sophisticated triaxial strength testing. A laboratory test program should be well-planned to optimize the test data for design and construction. The geotechnical specialist, therefore, should recognize the project's issues ahead of time so as to optimize the testing program, particularly strength and consolidation testing.

Laboratory testing of samples recovered during subsurface investigations is the most common technique to obtain values of the engineering properties necessary for design. A laboratory-testing program consists of "index tests" to obtain general information on categorizing materials, and "performance tests" to measure specific properties that characterize soil behavior for design and constructability assessments (e.g., shear strength, compressibility, hydraulic conductivity, etc.). This chapter provides information on common laboratory test methods for soils and rocks including testing equipment, general procedures related to each test, and parameters measured by the tests.

5.01 Primary References

The primary references for this Chapter are as follows:

ASTM (2006). *Annual Book of ASTM Standards – Sections 4.02, 4.08, 4.09 and 4.13.* ASTM International, West Conshohocken, PA.

AASHTO (2006). *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, Parts I and II, American Association of State Highway and Transportation Officials, Washington, D.C.

FHWA (2002a). *Geotechnical Engineering Circular 5 (GEC5) - Evaluation of Soil and Rock Properties*. Report No FHWA-IF-02-034. Authors: Sabatini, P.J, Bachus, R.C, Mayne, P.W., Schneider, J.A., Zettler, T.E., Federal Highway Administration, U.S. Department of Transportation.

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5.1 QUALITY ASSURANCE FOR LABORATORY TESTING

Laboratory testing will be required for most projects. Therefore, it is necessary to select the appropriate types and quantities of laboratory tests to be performed. A careful review of all data obtained during the field investigation and a thorough understanding of the preliminary design of geotechnical, structural and hydraulic features of the project are essential to develop an appropriately scoped laboratory testing program. In some cases owners may hire external testing laboratories to perform select tests. It is necessary that testing requests be clear and sufficiently detailed. Unless specialized testing is required, the owner should require that all testing be performed in accordance with the appropriate specifications for laboratory testing such as those codified in AASHTO and/or ASTM. Several tables are presented in this chapter that summarize various common tests for soils and rocks per AASHTO and ASTM standards. In order to assure that the results of laboratory testing are representative, several precautions must be taken before the tests themselves are performed. These precautions include: sample tracking, sample storage, sample handling to prevent sample disturbance, and sample selection. Discussion of each of these precautions follows.

5.1.1 Sample Tracking

Whether the laboratory testing is performed in-house or is subcontracted, samples will likely be assigned a laboratory identification number that differs from the identification number assigned in the field. A list should be prepared to match the laboratory identification number with the field identification number. This list can also be used to provide tracking information to ensure that each sample arrived at the lab. When laboratory testing is requested, both the field identification number and the laboratory identification number should be used on the request form. An example request form is shown in Figure 5-1. A spreadsheet or database program is useful to manage sample identification data.

5.1.2 Sample Storage

Undisturbed soil samples should be transported and stored so that that the moisture content is maintained as close as possible to the natural conditions (AASHTO T 207, ASTM D 4220 and D 5079). Samples should not be placed, even temporarily, in direct sunlight. Shelby tubes should be stored in an upright position with the top side of the sample up in a humid room with relative humidity above 90%.

Long-term storage of soil samples in Shelby tubes is not recommended. As storage time increases, moisture will migrate within the tube. Potential for disturbance and moisture migration within the sample will increase with time, and samples tested 30 days after their retrieval should be noted on the laboratory data sheet. Excessive storage time can lead to

additional sample disturbance that will affect strength and compressibility properties. Additionally, stress relaxation, temperature changes, and storage in a room with humidity below 90 percent may have detrimental effects on the samples. Long-term storage of soil samples should be in temperature- and humidity-controlled environments. The temperature control requirements may vary from sub freezing to ambient and above, depending on the environment of the parent formation. The relative humidity for soil storage normally should be maintained at 90 percent or higher to prevent moisture evaporation from the samples.

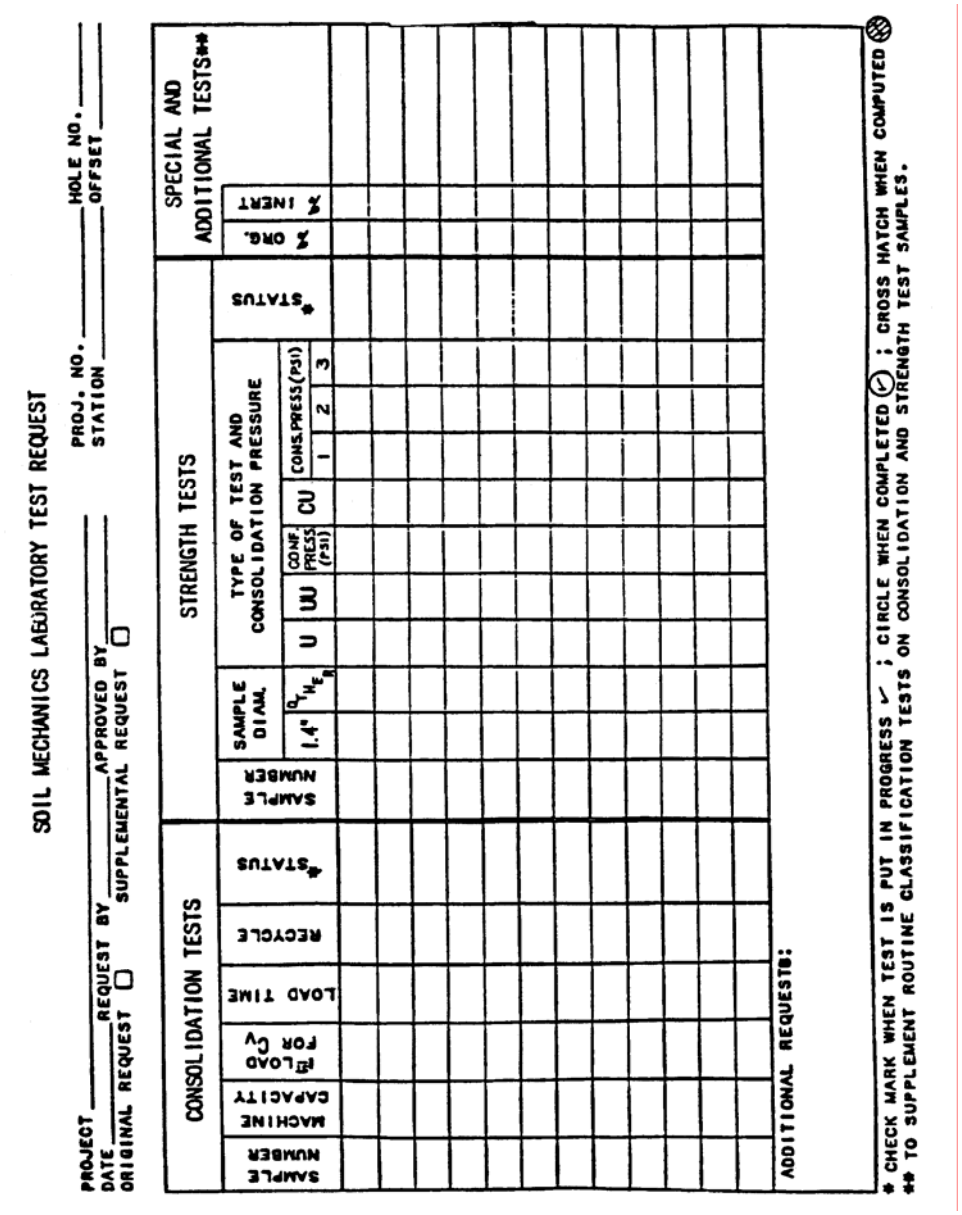


Figure 5-1. Sample laboratory test request form (Note: only some tests are included in this sample form).

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Long-term storage of soil samples in Shelby tubes is not recommended for another reason. During long term storage the sample tubes may corrode. Corrosion accompanied by adhesion of the soil to the tube may result in the development of such a large sidewall resistance that some soils may experience internal failures during extrusion. Often these failures cannot be seen by the naked eye; x-ray radiography (ASTM D 4452) will likely be necessary to confirm the presence of such conditions. If these samples are tested as "undisturbed" specimens, the results may be misleading.

5.1.3 Sample Handling

Careless handling of nominally undisturbed soil samples after they have been retrieved may cause major disturbances that could influence test results and lead to serious design and construction consequences. Samples should always be handled by experienced personnel in a manner that ensures that the sample maintains structural integrity and its natural moisture condition. Saws and knives used to prepare soil specimens should be clean and sharp. Preparation time should be kept to a minimum, especially where the maintenance of the moisture content is critical. Specimens should not be exposed to direct sun, freezing, or precipitation.

5.1.4 Effects of Sample Disturbance

As a soil sample is removed from the ground during a conventional soil investigation, its in-situ effective stress condition is being changed. In addition, nominally undisturbed specimens taken from samples obtained from drilled boreholes will become disturbed as a result of the drilling itself, sampling, sample extrusion, and sample trimming to form a specimen for testing. These processes will also change the effective stress condition in the soil sample, i.e., the effective stress in the soil at the time after a sample is trimmed and prepared for testing is different from that of the same soil in the ground. Therefore the utmost care should be taken to minimize the effect of these processes in order for the results of laboratory tests to represent the in-situ soil behavior accurately.

5.1.5 Specimen Selection

The selection of representative specimens for testing is one of the most important aspects of sampling and testing procedures. Selected specimens must be representative of the formation or deposit being investigated. The geotechnical specialist should study the boring logs, understand the geology of the site, and visually examine the samples before selecting the test specimens. Samples should be selected on the basis of their color, physical appearance, structural features and an understanding of the disturbance of the samples. Specimens should be selected to represent all types of materials present at the site, not just the worst or the best.

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Samples with discontinuities and intrusions may fail prematurely in the laboratory. The first inclination would be to test these samples. However, if these features are small and randomly located, they may not necessarily cause such failures in the field. Therefore samples having such local features should be noted, but not necessarily selected for testing since such samples may not be representative of the stratum in terms of its response to applied loads.

Certain considerations regarding laboratory testing, such as when, how much, and what type, can be decided only by an experienced geotechnical specialist. The following minimal criteria should be considered when the scope of the laboratory testing program is being determined:

- Project type (bridge, embankment, building, reconstruction or new construction, etc.)
- Size of the project (geographic extent).
- Loads to be imposed on the foundation soils (geometry, type, direction and magnitude).
- Performance requirements for the project (e.g., settlement and lateral deformation limitations).
- Vertical and horizontal variations in the subsurface profile as determined from boring logs and visual identification of subsurface material types in the laboratory.
- Known or suspected peculiarities of subsurface strata at the project location (e.g., swelling soils, collapsible soils, organics, etc.)
- Presence of visually observed intrusions, slickensides, fissures, concretions, etc.

The selection of tests should be considered preliminary until the geotechnical specialist is satisfied that the test results are sufficient to develop reliable subsurface profiles and provide the parameters needed for design.

5.2 LABORATORY TESTING FOR SOILS

Table 5-1 provides a listing of commonly-performed soil laboratory tests. Tables 5-2 and 5-3 provide a summary of typical soil index and performance tests, respectively. Additional information on these tests is provided in subsequent sections.

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Table 5-1
Commonly performed laboratory tests on soils (after FHWA, 2002a)

Test Category	Name of Test	Test Designation	
		AASHTO	ASTM
Visual Identification	Practice for Description and Identification of Soils (Visual-Manual Procedure)	-	D 2488
	Practice for Description of Frozen Soils (Visual-Manual Procedure)	-	D 4083
Index Properties	Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating Method	T 265	D 2216
	Test Method for Specific Gravity of Soils	T 100	D 854; D 5550
	Method for Particle-Size Analysis of Soils	T 88	D 422
	Test Method for Classification of Soils for Engineering Purposes	M 145	D 2487; D 3282
	Test Method for Amount of Material in Soils Finer than the No. 200 (0.075 mm) Sieve		D 1140
	Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils	T 89; T 90	D 4318
Compaction	Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,375 ft. lbs/ft^3)	T 99	D 698
	Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,250 ft.lbs/ft^3)	T 180	D 1557
Strength Properties	Test Method for Unconfined Compressive Strength of Cohesive Soil	T 208	D 2166
	Test Method for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression	T 296	D 2850
	Test Method for Consolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression	T 297	D 4767
	Method for Direct Shear Test of Soils under Consolidated Drained Conditions	T 236	D 3080
	Test Methods for Modulus and Damping of Soils by the Resonant-Column Method	-	D 4015
	Test Method for Laboratory Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil	-	D 4648
	Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils	-	D 1883
	Test Method for Resilient Modulus of Soils	T 294	-
	Test Method for Resistance R-Value and Expansion Pressure of Compacted Soils	T 190	D 2844
Consolidation, Swelling, Collapse Properties	Test Method for One-Dimensional Consolidation Properties of Soils	T 216	D 2435
	Test Method for One-Dimensional Consolidation Properties of Soils Using Controlled-Strain Loading	-	D 4186
	Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils	T 258	D 4546
	Test Method for Measurement of Collapse Potential of Soils	-	D 5333
Permeability	Test Method for Permeability of Granular Soils (Constant Head)	T 215	D 2434
	Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter	-	D 5084
Corrosivity (Electro-chemical)	Test Method for pH for Peat Materials	-	D 2976
	Test Method for pH of Soils	-	D 4972
	Test Method for pH of Soil for Use in Corrosion Testing	T 289	G 51
	Test Method for Sulfate Content	T 290	D 4230
	Test Method for Resistivity	T 288	D 1125; G57
	Test Method for Chloride Content	T 291	D 512
Organic Content	Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils	T 194	D 2974

Table 5-2
Methods for index testing of soils (after FHWA, 2002a)

Test	Procedure	ASTM and/or AASHTO	Applicable Soil Types	Applicable Soil Properties	Limitations / Remarks
Moisture content, w_n	Dry soil in oven at 100 ± 5 °C	D 2216 T 265	Gravel, sand, silt, clay, peat	e_o, γ	Simple index test for all materials.
Unit weight and density	Extract a tube sample; measure dimensions and weight;	D 2216 T 265	Soils where undisturbed samples can be taken, i.e., silt, clay, peat	γ_t, γ_{dry}, ρ_{tot}, ρ_{dry}, p_t	Not appropriate for clean granular materials where undisturbed sampling is not possible. Very useful index test.
Atterberg limits, LL, PL, PI, SL, LI	LL – Moisture content associated with closure of the groove at 25 blows of specimen in Casagrande cup PL – Moisture content associated with crumbling of rolled soil at 1/8-in (3mm)	D 4318 T 89 T 90	Clays, silts, peat; silty and clayey sands to determine whether SM or SC	Soil classification and used in consolidation parameters	Not appropriate in non-plastic granular soil. Recommended for all plastic materials.
Mechanical sieve	Place air dry material on a series of successively smaller screens of known opening size and vibrate to separate particles of a specific equivalent diameter	D 422 T 88	Gravel, sand, silt	Soil classification	Not appropriate for clay soils. Useful, particularly in clean and dirty granular materials.
Wash sieve	Flush fine particles through a U.S. No. 200 (0.075 mm) sieve with water.	C 117 D 1140 T 88	Sand, silt, clay	Soil classification	Needed to assess fines content in dirty granular materials.
Hydrometer	Allow particles to settle, and measure specific gravity of the solution with time.	D 422 D 1140 T 88	Fine sand, silt, clay	Soil classification	Helpful to assess relative quantity of silt and clay.
Sand Equivalent	Sample passing No. 4 (4.75 mm) sieve is separated into sand and clay size particles	D 2419 T 176	Gravel, Sand, silt, clay	Aggregate classification Compaction	Useful for aggregates
Specific gravity of solids	The volume of a known mass of soil is compared to the known volume of water in a calibrated pyncnometer	D 854 D 5550 T 100	Sand, silt, clay, peat	Used in calculation of e_o	Particularly helpful in cases where unusual solid minerals are encountered.
Organic content	After performing a moisture content test at 110 °C (230° F), the sample is ignited in a muffle furnace at 440 °C (824° F) to measure the ash content.	D 2974 T 194	All soil types where organic matter is suspected to be a concern	Not related to any specific performance parameters, but samples high in organic content will likely have high compressibility.	Recommended on all soils suspected to contain organic materials.

Symbols used in Table 5-2

e_o: in-situ void ratio γ_{dry}:dry unit weight γ: unit weight $_t$: total vertical stress
ρ_{dry}:dry density ρ_{tot}:total density γ_t:total unit weight p

Table 5-3
Methods for performance testing of soils (after FHWA, 2002a)

Test	Procedure	Applicable Soil Types	Soil Properties	Limitations / Remarks
1-D oedometer	Incremental loads are applied to a soil specimen confined by a rigid ring; deformation values are recorded with time; loads are typically doubled for each increment and applied for 24 hours each.	Primarily clays and silts; granular soils can be tested, but typically are not.	p_c, OCR, C_c, $C_{c\varepsilon}$, C_r, $C_{r\varepsilon}$, C_α, $C_{\alpha\varepsilon}$, c_v, k	Recommended for fine grained soils. Results can be useful index to other critical parameters.
Constant rate of strain oedometer	Loads are applied such that Δu is between 3 and 30 percent of the applied vertical stress during testing	Clays and silts; not applicable to free draining granular soils.	p_c, C_c, $C_{c\varepsilon}$, C_r, $C_{r\varepsilon}$, c_v, k	Requires special testing equipment, but can reduce testing time significantly.
Unconfined compression (UC)	A specimen is placed in a loading apparatus and sheared under axial compression with no confinement.	Clays and silts; cannot be performed on granular soils or fissured and varved materials	$s_{u,UC}$	Provides rapid means to approximate undrained shear strength, but disturbance effects, test rate, and moisture migration will affect results.
Unconsolidated undrained (UU) triaxial shear	The specimen is not allowed to consolidate under the confining stress, and the specimen is loaded at a quick enough rate to prevent drainage.	Clays and silts	$s_{u,UU}$	Sample must be nearly saturated. Sample disturbance and rate effects will affect measured strength.
Isotropic consolidated drained compression (CIDC)	The specimen is allowed to consolidate under the confining stress, and then is sheared at a rate slow enough to prevent build-up of pore water pressures.	Sands, silts, clays	ϕ', c', E	Can be run on clay specimen, but time consuming. Best triaxial test to obtain deformation properties.
Isotropic consolidated undrained compression (CIUC)	The specimen is allowed to consolidate under the confining stress with drainage allowed, and then is sheared with no drainage allowed, but pore water pressures measured.	Sands, silts, clays, peats	ϕ', c', $s_{u,CIUC}$, E	Recommended to measure pore pressures during test. Useful test to assess effective stress strength parameters. Not recommended for measuring deformation properties.
Direct shear	The specimen is sheared on a forced failure plane at a constant rate, which is a function of the hydraulic conductivity of the specimen.	Compacted fill materials; sands, silts, and clays	ϕ', ϕ'_r	Requires assumption of drainage conditions. Relatively easy to perform.

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Test	Procedure	Applicable Soil Types	Soil Properties	Limitations / Remarks
Flexible Wall Permeameter	The specimen is encased in a membrane, consolidated, backpressure saturated, and measurements of flow with time are recorded for a specific gradient.	Relatively low permeability materials ($k \leq 1x10^{-5}$ cm/s); clays & silts	k	Recommended for fine grained materials. Backpressure saturation required. Confining stress needs to be provided. System permeability must be at least an order of magnitude greater than that of the specimen. Time needed to allow inflow and outflow to stabilize.
Rigid Wall Permeameter	The specimen is placed in a rigid wall cell, vertical confinement is applied, and flow measurements are recorded with time under constant head or falling head conditions.	Relatively high permeability materials; sands, gravels, and silts	k	Need to control gradient. Not for use in fine grained soils. Monitor for sidewall leakage.

Symbols used in Table 5-3

ϕ':	peak effective stress friction angle	OCR:	overconsolidation ratio	$C_{c\varepsilon}$:	modified compression index
ϕ'_r	residual effective stress friction angle	c_v:	vertical coefficient of consolidation	C_r:	recompression index
c':	effective stress cohesion intercept	E:	Young's modulus	$C_{r\varepsilon}$:	modified recompression index
s_u:	undrained shear strength	k:	hydraulic conductivity	C_α:	secondary compression index
p_c:	preconsolidation stress	C_c:	compression index	$C_{\alpha\varepsilon}$:	modified secondary compression index

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5.3 LABORATORY INDEX TESTS FOR SOILS

5.3.1 General

Data generated from laboratory index tests provide an inexpensive way to assess soil consistency and variability among samples collected from a site. Information obtained from index tests is used to select samples for engineering property testing as well as to provide an indicator of general engineering behavior. For example, a soil with a high plasticity index (PI) can be expected to have high compressibility, low hydraulic conductivity, and high swell potential. Common index tests discussed in this section include moisture content, unit weight (wet density), Atterberg limits, particle size distribution, visual classification, specific gravity, and organic content. Index testing should be conducted on each type of soil material on every project. Information from index tests should be assessed prior to a final decision regarding the specimens selected for subsequent performance testing.

5.3.2 Moisture Content

The moisture (or water) content test is one of the simplest and least expensive laboratory tests to perform. Moisture content is defined as the ratio of the weight of the water in a soil specimen to the dry weight of the specimen. Natural moisture contents (w_n) of sands are typically $0 \leq w_n \leq 20$ %, whereas for inorganic and insensitive silts and clays, the typical range is $10 \leq w_n \leq 40$ %. However, for clays it is possible to have more water than solids (i.e., $w_n > 100\%$), depending upon the mineralogy, formation environment, and structure of the clay. Therefore, soft and highly compressible clays, as well as sensitive, quick, or organically rich clays, can exhibit water contents in the range of $40 \leq w_n \leq 300$ % or more.

Moisture content can be tested a number of different ways including: (1) a drying oven (ASTM D 2216); (2) a microwave oven (ASTM D 4643); or (3) a field stove or blowtorch (ASTM D 4959). While the microwave or field stove (or blowtorch) methods provide a rapid evaluation of moisture content, potential errors inherent with these methods require confirmation of results obtained by using ASTM D 2216. The radiation heating induced by the microwave oven and the excessive temperature induced by the field stove may release water entrapped in the soil structure (adsorbed water) that would normally not be released at 230^o F (110^o C), the maximum temperature specified by ASTM D 2216. Therefore, the microwave oven and field stove methods may yield greater values of moisture content than would occur from ASTM D 2216.

Field measurements of moisture content often rely on a field stove or microwave due to the speed of testing. For control of compacted material, it is common to use a nuclear gauge

(ASTM D 3017) in the field to assess moisture contents rapidly. Nuclear gage readings may indicate widely varying moisture contents for micaceous soils, i.e., soils containing a significant amount of mica particles. Results from nuclear techniques should be "calibrated" or confirmed by using the drying oven method (ASTM D 2216).

Moisture contents of soils as determined from in-situ moisture content tests may be altered during sampling, sample handling, and sample storage. Because the top end of the sample tube may contain water or collapse material from the borehole, moisture content tests should not be performed on material near the top of the tube. Also, as storage time increases, moisture will migrate within a specimen and lead to altered values of moisture content. If the sample is not properly sealed, moisture loss through drying of the sample will likely occur.

5.3.3 Unit Weight

The terms density (ρ) and unit weight (γ) are often incorrectly used interchangeably. The correct usage is that density implies mass while unit weight implies weight measurements. Density and unit weight are related through the gravitational constant (g) as follows: $\gamma = \rho g$. In this document they will be referenced as "density (unit weight)" if the usage is independent of the specific definition.

In the laboratory, soil unit weight and mass density are easily measured on tube (undisturbed) samples of natural soils. The moist (total) mass density is $\rho_t = M_t/V_t$, where M_t is the total mass of the soil sample including the mass of the moisture in the pores and V_t is the total volume of the soil sample. Similarly the dry mass density is given by $\rho_d = M_s/V_t$, where M_s is the mass of the solid component of the soil sample and V_t is the total volume of the soil sample. Likewise, the moist unit weight is $\gamma_t = W_t/V_t$, where W_t is the total weight including the weight of the water in the pores and V_t is the total volume of the soil sample. Similarly, the dry unit weight is defined as $\gamma_d = W_s/V_t$ where W_s is the weight of the solid component of the soil sample and V_t is the total volume of the soil sample. The relationship between the total and dry mass density and unit weight in terms of natural moisture content, w, is given by:

$$\rho_d = \frac{\rho_t}{1 + w} \qquad 5\text{-}1$$

Since $\gamma = \rho g$ the relationship between total and dry unit weight is given by:

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$$\gamma_d = \frac{\gamma_t}{1 + w} \qquad 5\text{-}2$$

Field measurements of soil mass density (unit weight) are generally restricted to shallow surface samples such as those obtained during placement of compacted fills. In those cases, field measurements of soil mass density (unit weight) can be accomplished by using drive tubes (ASTM D 2937), the sand cone method (ASTM D 1556), or a nuclear gauge (ASTM D 2922). To obtain unit weights or mass densities with depth, either high-quality thin-walled tube samples must be obtained (ASTM D 1587), or relatively expensive geophysical logging by gamma ray techniques (ASTM D 5195) can be employed.
Table 5-4 presents typical unit weights along with a range of void ratios for a variety of soils.

5.3.4 Particle Size Distribution

Particle size distributions by mechanical sieve and hydrometer analyses are useful for soil classification purposes. Procedures for grain size analyses are contained in ASTM D 422 and AASHTO T88. Testing is accomplished by shaking air-dried material through a stack of sieves having decreasing opening sizes. Table 2-3 in Chapter 2 listed U.S. standard sieve sizes and their associated opening sizes. Each successive screen in the stack has a smaller opening to capture progressively smaller particles. The amount retained on each sieve is collected, dried and weighed to determine the percentage of material passing that sieve size. An example of how to determine the grain size distribution from sieve data is shown in Figure 5-2. The grain size distribution curve corresponding to the data in Figure 5-2 is presented in Figure 5-3.

Testing of the finer grained particles is accomplished by suspending the chemically dispersed particles in a water column and measuring the change in the specific gravity of the liquid as the particles fall from suspension. This part of the test is commonly referred to as a hydrometer analysis.

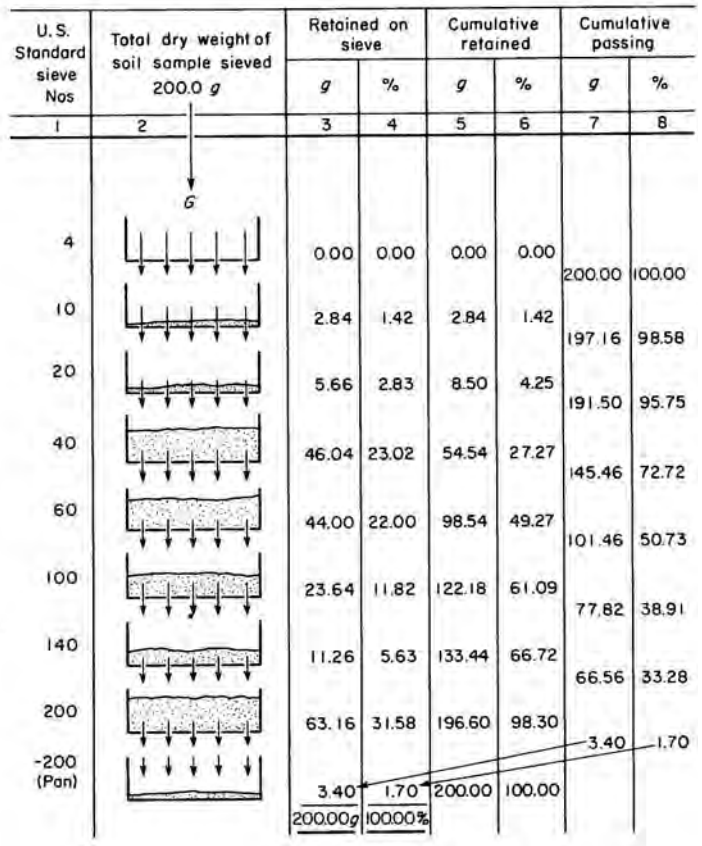
Obviously, obtaining a representative specimen is an important aspect of this test. When soil samples are dried or washed for testing, it may be necessary to break up the soil clods. Care should be taken to avoid crushing of soft carbonate or sand particles. If the soil contains a substantial amount of fibrous organic materials, these may tend to plug the sieve openings during washing. The material settling over the sieve during washing should be constantly stirred to avoid plugging.

Table 5-4

Typical particle sizes, uniformity coefficients, void ratios and unit weights (from Kulhawy and Mayne, 1990)

Soil Type	Approximate Particle Size, mm			Uniformity Coefficient	Void Ratio		Normalized Unit Weight			
							Dry γ_{dry}/γ_w		Saturated γ_{sat}/γ_w	
	D_{max}	min	60	$_{60}/D_{10}$	max	min	Min	Max	Min	Max
Uniform granular soil										
Equal spheres (theoretical)	-	-	-	1.0	0.92	0.35	-	-	-	-
Standard Ottawa sand	0.84	0.59	0.67	1.1	0.80	0.50	1.47	1.76	1.49	2.10
Clean, uniform sand	-	-	-	1.2 to 2.0	1.00	0.40	1.33	1.89	1.35	2.18
Uniform, inorganic silt	0.05	0.005	0.012	1.2 to 2.0	1.10	0.40	1.28	1.89	1.30	2.18
Well-graded granular soil										
Silty sand	2.0	0.005	0.02	5 to 10	0.90	0.30	1.39	2.04	1.41	2.28
Clean, fine to coarse sand	2.0	0.05	0.09	4 to 6	0.95	0.20	1.36	2.21	1.38	2.37
Micaceous sand	-	-	-	-	1.20	0.40	1.22	1.92	1.23	2.21
Silty sand and gravel	100	0.005	0.02	15 to 300	0.85	0.14	1.43	2.34	1.44	2.48
Silty or sandy clay	2.0	0.001	0.003	10 to 30	1.80	0.25	0.96	2.16	1.60	2.36
Gap-graded silty clay with gravel or larger	250	0.001	-	-	1.00	0.20	1.35	2.24	1.84	2.42
Well-graded gravel, sand, silt, and clay	250	0.001	0.002	25 to 1,000	0.70	0.13	1.60	2.37	2.00	2.50
Clay (30 to 50% < 2μ size)	0.05	0.5μ	0.001	-	2.40	0.50	0.80	1.79	1.51	2.13
Colloidal clay (over 50% < 2μ size)	0.01	10Å	-	-	12.00	0.60	0.21	1.70	1.14	2.05
Organic silt	-	-	-	-	3.00	0.55	0.64	1.76	1.39	2.10
Organic clay (30 to 50% < 2μ size)	-	-	-	-	5.40	0.70	0.48	1.60	1.30	2.00

Note: γ_w= 62.4 pcf (9.80 kN/m^3); μ = 10^{-3} mm; Å : Angstrom = 10^{-7} mm



U.S. Standard sieve Nos	Total dry weight of soil sample sieved 200.0 g	Retained on sieve		Cumulative retained		Cumulative passing	
		g	%	g	%	g	%
1	2	3	4	5	6	7	8
4	G	0.00	0.00	0.00	0.00	200.00	100.00
10		2.84	1.42	2.84	1.42	197.16	98.58
20		5.66	2.83	8.50	4.25	191.50	95.75
40		46.04	23.02	54.54	27.27	145.46	72.72
60		44.00	22.00	98.54	49.27	101.46	50.73
100		23.64	11.82	122.18	61.09	77.82	38.91
140		11.26	5.63	133.44	66.72	66.56	33.28
200		63.16	31.58	196.60	98.30	3.40	1.70
-200 (Pan)		3.40	1.70	200.00	100.00		
		200.00g	100.00%				

Figure 5-2. Example grain size distribution based on sieve analysis (Jumikis, 1962).

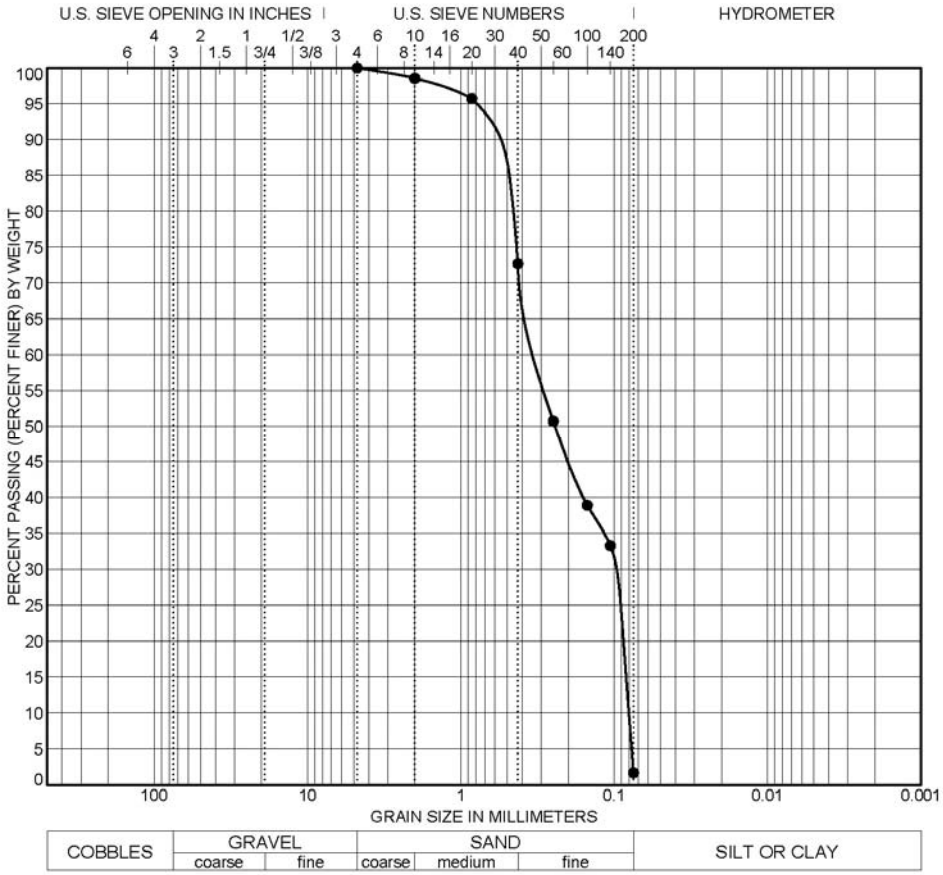


Figure 5-3. Grain size distribution curve based on data in Figure 5-2.

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Particle size testing is relatively straightforward, but the results can be misleading if procedures are not performed correctly and/or if equipment is not maintained in good working condition. If the sieve screen is distorted, large particles may be able to pass through sieve openings that typically would retain the particles. Material lodged within the sieve from previous tests could become dislodged during shaking, thereby increasing the weight of material retained on the following sieve. Therefore, sieves should be cleaned thoroughly after each test. A wire brush may distort finer sieve meshes during cleaning, so a plastic brush should be used to clean the U.S. No. 40 (0.425 mm) sieve and finer. Openings of fine mesh No. 200 sieve (0.075 mm)) are easily distorted as a result of normal handling and use. Therefore, fine-mesh sieves should be replaced often. A simple way to determine whether sieves should be replaced is to examine the stretch of the sieve fabric on its frame periodically. The fabric should remain taut; if it sags, it has been distorted and should be replaced. A common cause of serious errors is the use of “dirty” sieves. Some soil particles, because of their shape, size or adhesion characteristics, have a tendency to lodge in the sieve openings. This is especially true of the fine mesh sieves.

Representative samples of fine-grained soils (i.e., samples containing more than 50% of particles with diameter less than the U.S. No. 200 sieve size (075 mm) should not be oven dried prior to testing because some particles may cement together leading to a calculated lower fines content from mechanical sieve analyses than is actually present. When fine-grained particles are a concern, the wash sieve method (ASTM D 1140) should be performed to assess the fines content.

If the clay-size content is an important parameter, hydrometer analyses should be performed even though the hydrometer test provides only approximate results due to oversimplified assumptions. However, the results can still be used as a general index of silt and clay-size content. Depending upon the chemical makeup of the fine grained particles, the traditional sodium hexametaphosphate solution used to disperse the clay-size particles may not provide adequate dispersion. If the clay-size particles are not dispersed, the hydrometer data leads to the interpretation of a lower than actual clay-size content. In some cases the concentration of the dispersing agent may need to be increased or a different dispersing agent may need to be used. If the sieve and hydrometer analyses are performed correctly, the gradation curve should be continuous over a range that includes all particle sizes.

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5.3.4.1 Sand Equivalent

The sand equivalent test is a rapid test to show the relative proportions of fine dust or claylike materials in aggregate (or soils). A sample of aggregate passing the No. 4 sieve (4.75-mm) sieve and a small amount of flocculating solution are poured into a graduated cylinder and are agitated to loosen the claylike coatings from the sand particles. The sample is then irrigated with additional flocculation solution forcing the claylike material into suspension above the sand. After a prescribed sedimentation period, the height of flocculated clay and height of sand are determined. The sand equivalent is determined from the ratio of the height of the sand to height of the clay and expressed as a percentage. Cleaner aggregates will have higher sand equivalent values. For asphalt pavements, agencies often specify a minimum sand equivalent around 25 to 35 (Roberts, *et al.*, 1996). Higher values are used in case of compacted structural fill which may support structures (see Section 8.6).

5.3.5 Atterberg Limits

The Atterberg limits of a fine grained soil represent the moisture content at which the physical state of the soil changes. The tests for the Atterberg limits are referred to as index tests because they serve as an indication of several physical properties of the soil, including strength, permeability, compressibility, and shrink/swell potential. These limits also provide a relative indication of the plasticity of the soil, where plasticity refers to the ability of a silt or clay to retain water without changing state from a semi-solid to a viscous liquid. In geotechnical engineering practice, the Atterberg limits generally refer to the liquid limit (LL), plastic limit (PL), and shrinkage limit (SL). The limits were defined and discussed in Chapter 2. In this chapter the definition is extended further in terms of quantifiable parameters that permit their measurements in the laboratory. These quantifiable definitions are as follows:

- Liquid Limit (LL) - This limit represents the moisture content at which any increase in moisture content will cause a plastic soil to behave as a viscous liquid. The LL is defined as the moisture content at which a standard groove cut in a remolded sample will close over a distance of ½-inch (13 mm) at 25 blows of the liquid limit device (Figure 5-4). The test is performed on material passing a US Standard No. 40 sieve (0.425 mm). During the test the material is brought to various moisture contents, usually by adding water. The plot of moisture contents vs. blows required to close the groove is called a “flow curve” and the value of the liquid limit moisture content is obtained from the flow curve at 25 blows.

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Figure 5-4. Some of the equipment used for Atterberg limits testing of soil.

- Plastic Limit (PL) - This limit represents the moisture content at which the transition between the plastic and semisolid state of a soil occurs. The PL is defined as the moisture content at which a thread of soil just crumbles when it is carefully rolled out by hand to a diameter of 1/8-inch (3 mm).

- Shrinkage Limit (SL) – This limit represents the moisture content corresponding to the change between the semisolid to solid state of the soil. The SL is also defined as the moisture content at which any further reduction in moisture content will not result in a decrease in the volume of the soil.

Based on the above index values, there are two useful related indices, namely, the Plasticity Index (PI) and the Liquidity Index (LI), which were defined in Chapter 2 as follows:

$$PI = LL - PL \qquad 2\text{-}11$$

$$LI = \frac{w - PL}{PI} \qquad 2\text{-}12$$

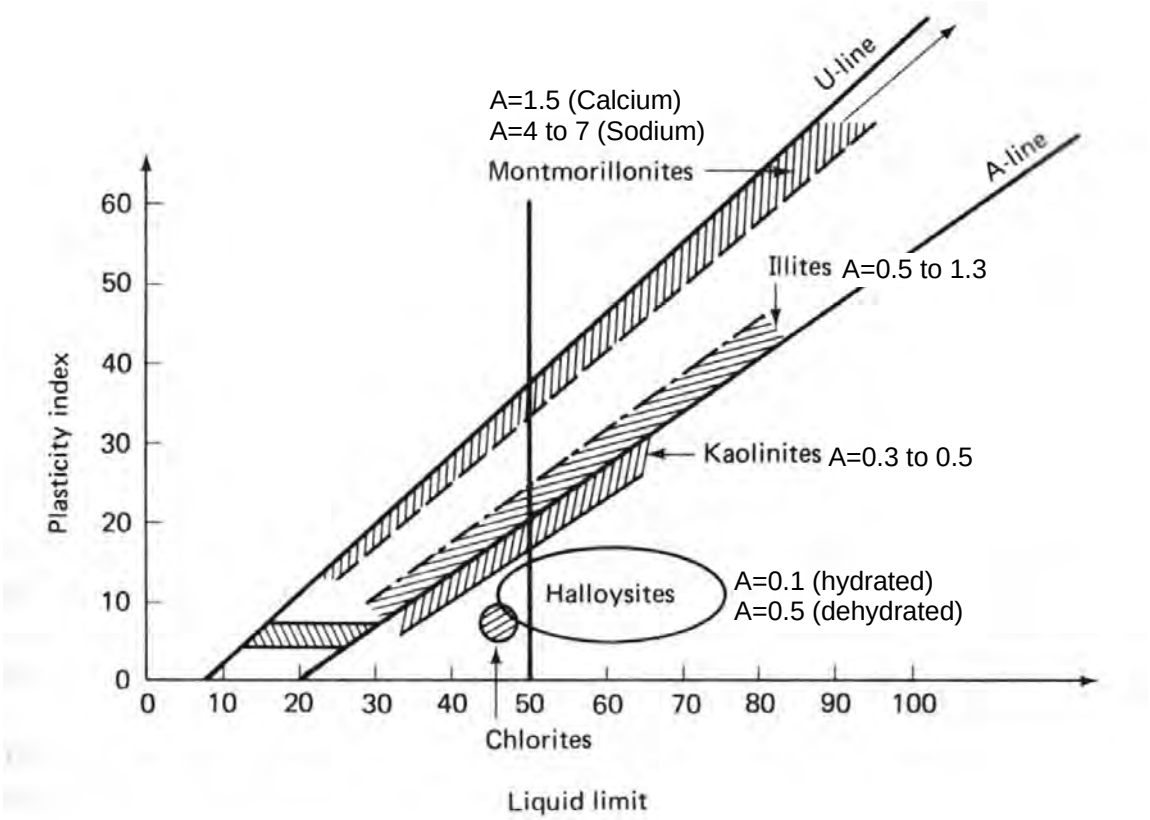
where w is the natural (in-situ) water content of the soil. Numerous engineering correlations have been developed that relate PI and LI to clay soil properties, including undrained and drained strength to PI and compression index to LI.

Another useful index proposed by Skempton (1953) based on the proportion of clay and PI is known as the "Activity Index." The activity index of a clay soil is denoted by A and is generally defined as follows:

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$$A = \frac{PI}{CF} \qquad 5\text{-}3$$

where CF is the clay fraction is usually taken as the percentage by weight of the soil with a particle size less than 0.002 mm. Clays with $0.75 < A < 1.25$ are classified as "normal" clays while those with $A < 0.75$ are "inactive" and $A > 1.25$ are "active." Values of activity index, A, can be correlated to the type of clay mineral that, in turn, provides important information relative to the expected behavior of a clay soil. A clay soil that consists predominantly of the clay mineral montmorillonite behaves very differently from a clay soil composed predominantly of kaolinite. Figure 5-5 also shows the activities of various clay minerals and their location on the Casagrande's plasticity chart. The symbol for the activity index (A) in Figure 5-5 should not be confused with the "A-line" also shown in the figure.



Activity Index, A, of other minerals			
Attapulgite	0.5-1.2	Mica (muscovite)	0.2
Allophane	0.5-1.2	Quartz	0
Calcite	0.2		

Figure 5-5. Location of clay minerals on the Casagrande Plasticity Chart and Activity Index values (after Skempton, 1953, Mitchell, 1976, Holtz and Kovacs, 1981).

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Modified Activity Index, A_m: Based on their studies regarding the swell potential of compacted natural and artificial clay soils, Seed *et al.* (1962) proposed that for natural clay soils compacted as per the requirements of ASTM D 698 and Atterberg limits determined by ASTM D 4318 (AASHTO T 89, T 90), a Modified Activity Index, A_m, defined as follows is more appropriate:

$$A_m = \frac{PI}{CF - 5} \qquad 5\text{-}4$$

The above definition is used to define the swell potential of soils (see Section 5.7).

5.3.5.1 Significance of the "A-line" and "U-line" on Plasticity Chart

As shown in Figure 4-3 in Chapter 4, the equation for the A-line and U-line are:

$$A - line: PI = 0.73(LL - 20) \qquad 5\text{-}5$$

$$U - line: PI = 0.9(LL - 8) \qquad 5\text{-}6$$

The A-line generally separates soils whose behavior is more claylike (points plotting above the A-Line) from those that exhibit a behavior more characteristic of silt (points plotting below the A-line). The A-line also separates organic (below) from inorganic (above) soils. The LL = 50 line generally represents the dividing line between silt, clay and organic fractions of the soil that exhibit low plasticity (LL<50) and high plasticity (LL>50). The U-line shown in Figure 5-5 represents the upper range of PI and LL coordinates that have been found for soils. When the limits of any soil plot above the U-line, the results should be considered spurious and the tests should be rerun. Note that in Figure 5-5 the clay mineral montmorillonite plots well above the A-line and just below the U-line. If a soil plots in this range, it probably contains a significant amount of the clay mineral montmorillonite that expands in presence of water.

5.3.6 Specific Gravity

The specific gravity of solids (G_s) is a measure of solid particle density and is referenced to an equivalent volume of water. Specific gravity of solids is defined as $G_s = (M_s/V_s)/ \rho_d$ where M_s is the mass of the soil solids and V_s is the volume of the soil solids and ρ_d is the mass density of water = 1,000 kg/m^3 or 1 Mg/m^3. This formulation represents the theoretically correct definition of specific gravity and can be rewritten as $G_s = \rho_s / \rho_d$.

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However, since $\gamma = \rho g$ the gravitational constant appears in both the numerator and denominator of the expression and the equation for G_s can also be given as $G_s = \gamma_s/\gamma_w$ where γ_s = unit weight of solid particles in the soil mass and γ_w = unit weight of water = 62.4 pcf (1,000 kg/m^3 or 1 Mg/m^3).

The typical values of specific gravity of most soils lie within the narrow range of $G_s = 2.7 \pm 0.1$. Exceptions include soils with appreciable organics (e.g., peat), ores (e.g., mine tailings), or calcareous (high calcium carbonate content) constituents (e.g., caliche). It is common to assume a reasonable G_s value within the range listed above for preliminary calculations. Laboratory testing by AASHTO T100 or ASTM D 854 or D 5550 can be used to confirm the magnitude of G_s, particularly on projects where little previous experience exists and unusually low or high unit weights are measured.

5.3.7 Organic Content

A visual assessment of organic materials may be very misleading in terms of engineering analysis. Laboratory test method AASHTO T194 or ASTM D 2974 should be used to evaluate the percentage of organic material in a specimen where the presence of organic material is suspected based on field information or from previous experience at a site. The test involves weighing and heating a previously dried sample to a temperature of 824°F (440°C) and holding this temperature until no further change in weight occurs. At this temperature, the organics in the sample turn to ash and the sample is re-weighed. Therefore, with the assumption that the weight of the ash is negligible, the percentage of organic matter is the ratio of the difference in weight before and after heating the sample to 824°F (440°C) to the weight of the original dried sample. The sample used for the test can be a previously dried sample from a moisture content evaluation. Usually organic soils can be distinguished from inorganic soils by their characteristic odor and their dark gray to black color. In doubtful cases, the liquid limit should be determined for an oven-dried sample (i.e., dry preparation method) and for a sample that is not pre-dried before testing (i.e., wet preparation method). If drying decreases the value of the liquid limit by about 30 percent or more, the soil may usually be classified as organic (Terzaghi, *et al.*, 1996).

Soils with relatively high organic contents have the ability to retain water. Water retention may result in higher moisture content, higher primary and secondary compressibility, and potentially higher corrosion potential. Organic soils may or may not be relatively weak depending on the nature of the organic material. Highly organic fibrous peats can exhibit high strengths despite having a very high compressibility. In some instances such soils may even exhibit tensile strength.

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5.3.8 Electro Chemical Classification Tests

Electro chemical classification tests provide the geotechnical specialist with quantitative information related to the aggressiveness of the soil conditions with respect to corrosion and the potential for deterioration of typical foundation materials. Electro chemical tests include determination of pH, resistivity, sulfate ion content, sulfides, and chloride ion content. Depending on the application, limits of these electro chemical properties are established based on various factors such as corrosion rates for metals and disintegration rates for concrete. Tests to characterize the aggressiveness of a soil environment are important for design applications that include metallic elements, especially for ground anchors comprised of high strength steel and for metallic reinforcements in mechanically stabilized earth walls. ASTM and AASHTO test procedures are listed under "Corrosivity (Electrochemical)" in Table 5-1.

5.3.9 Laboratory Classification

In addition to field identification (ASTM D 2488), soils should be classified in the laboratory by using the Unified Soil Classification System (USCS) in accordance with ASTM D 2487 or by the AASHTO soil classification system in accordance with AASHTO T 145. These two systems were discussed in Chapter 4. The USCS will be used throughout the remainder of this document. Classification in the laboratory occurs in a controlled environment and more time can be spent on this classification than the identification exercise performed in the field. Laboratory and/or field identification is also important so that defects and features of the soil can be recorded that would not typically be noticed from index testing or standard classification. Some of the features include degree of calcium carbonate cementation, mica content, joints, and fractures.

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5.4 CONSOLIDATION TESTING

5.4.1 Process of Consolidation

As discussed in Chapter 2, consolidation is a time-dependent decrease in the volume of a soil mass under applied loading. In highway design, static loading is represented by the permanent load placed on the soil by embankments and structures. Depending on the configuration of the load and the subsurface conditions, the stress increase due to the externally applied loads may extend below the water table where all the voids are filled with water. An applied load will cause the soil grains to readjust to a more compact position to carry the load. This readjustment cannot take place until the water, which is incompressible, escapes from the voids.

As discussed in Chapter 2, the rate of the readjustment of the soil particles is a function of the void size, which controls the rate at which the water can escape from the voids. The settlement associated with the readjustment of the soil particles due to migration of water out of the voids is known as **primary consolidation**.

The amount of primary consolidation will depend on the initial void ratio of the soil. The greater the initial void ratio, the more water that can be squeezed out, and the greater the primary consolidation. The rate at which primary consolidation occurs is dependent on the rate at which the water is squeezed out of the soil voids. **Secondary compression** occurs after primary consolidation is complete. Secondary compression occurs under constant load. It is caused by the soil particles reorienting or deforming under constant load at a very slow rate. This process is known as "**creep**" and it occurs in most soils when they are subjected to long-term applied loads. Therefore, secondary compression is also a time-dependent process. However, secondary compression is not dependent on water being squeezed out of the soil as is consolidation. That is why it is called "secondary compression" and not "secondary consolidation." Primary consolidation accounts for the major portion of settlement in saturated fine-grained soils. Primary consolidation and secondary compression both contribute significantly to settlements in organic soil.

Some natural deposits of fine-grained soils experienced compression in geologic history due to the weight of glaciers, due to the weight of overlying soil that has been eroded, or due to desiccation. Since their void ratios were substantially reduced in the past by these processes, these soils are less compressible today. Such soils are called "**preconsolidated**" or "**overconsolidated**" since they have been subjected to greater stresses in the past than exist at present. This concept is important because overconsolidated soils can be reloaded such as by the load from an embankment or bridge substructure without settling appreciably until the

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currently applied load exceeds the preconsolidation load. Saturated fine-grained soil deposits, which have never consolidated under loads other than the current loads, are called "**normally consolidated**." On the other end of the spectrum, soils whose present loading induces stresses in the soil that are greater than the maximum effective stress they have experienced in the past are called "**under consolidated.**" This means that the consolidation process under the existing loading is on-going and the soil will continue to consolidate until that process is complete, even if no additional loads are applied.

5.4.2 Consolidation Testing

To predict the amount of consolidation in saturated fine-grained and organic soils, adequate testing must be performed. An undisturbed soil sample should be obtained in the field with a Shelby tube sampler. The oedometer or one-dimensional consolidometer is the primary laboratory equipment used to evaluate consolidation and settlement potential of fine-grained soils. A consolidation test is typically performed on a specimen obtained from an undisturbed sample retrieved from the deposit of fine-grained soils to evaluate the consolidation characteristics of the soil and define the settlement-time relationship of the in-situ soils under proposed foundation loads. The equipment for a consolidation test includes:

1. A loading device that applies a vertical load to the soil specimen,

2. A metal ring (fixed or free) that laterally confines the soil specimen and restricts deformation to the vertical direction only (i.e., only one-dimensional compression is modeled),

3. Porous discs placed on the top and bottom of the sample to allow the sample to drain,

4. A dial indicator or linear variable differential transducer (LVDT) to measure vertical displacement. Properly calibrated, each device should provide the same accuracy, but the electronic output of an LVDT can be incorporated into an automated recording system for quicker, more efficient, and higher resolution readings.

5. A timer to assess the duration of loading increments. Monitoring of time for manual systems can be accommodated by use of a wall clock with a second hand. The internal clock of a computer is used for automated systems

6. A surrounding container to permit the specimen to remain submerged during the test.

Figure 5-6 shows a schematic of a consolidation test. The consolidation-loading device may be a weighted lever arm as shown in Figure 5-7b, a pneumatic device, or an automated

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loading frame as shown in Figure 5-7c. Automated loading frames are recommended for use in production testing because they provide the most flexibility in testing options. The pneumatic device provides flexibility in loads and load increment ratios (LIR) that can be applied during testing. A weighted lever arm provides a robust, relatively simple system for consolidation testing, however, because data are generally recorded manually, it is difficult to expedite testing or vary the loading schedule since data reduction cannot typically be performed in real time.

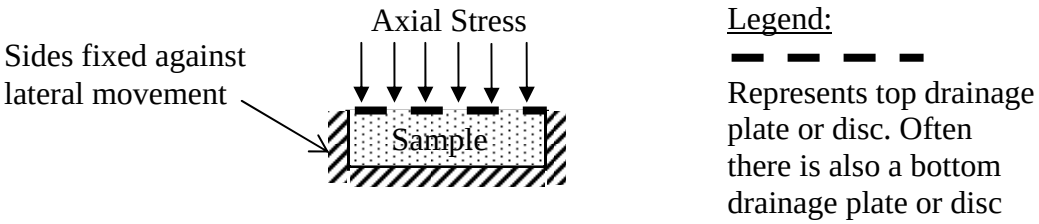


Figure 5-6. Schematic of a consolidation test.

Consolidation cells may be either fixed ring or floating ring. Friction and drag are created in the ring as the specimen compresses in relation to the ring. In a fixed ring test the sample compresses from the top only, potentially resulting in high incremental side shear forces. In a floating ring test the sample compresses from the top and bottom thus providing the advantage of minimizing drag forces. However, the floating ring method has the following disadvantages: it is more difficult to set up; it has the potential for sidewall leakage that would result in an inaccurate assessment of the rate of consolidation, and soil may squeeze out near the junction of the sidewall and the bottom porous disc. Because of these disadvantages, the fixed ring method is most commonly used.

5.4.3 Procedures

The consolidation properties of fine-grained soils are evaluated in the laboratory by using the one-dimensional consolidation test. The most common laboratory method is the incremental load (IL) method (ASTM D 2435). The weighted lever arm oedometer shown in Figure 5-7b is commonly used for performing the procedure. The automated load-frame apparatus shown in Figure 5-7c provides higher quality test results compared to the weighted lever apparatus. High-quality undisturbed samples obtained by using Shelby tubes (ASTM D 1587), piston samplers, or other special samplers are preferred for laboratory consolidation tests.

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(a)



(b)



(c)

Figure 5-7. (a) Components of consolidation test equipment, (b) Weighted lever arm - incremental load consolidation apparatus, (c) Automated load-frame and computerized consolidation apparatus (Photographs courtesy of GeoComp Corporation).

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5.4.4 Presentation and Understanding the Consolidation Test Results

The consolidation test should be run in such a way that sufficient time is allowed for the applied pressure (total stress) increment to be transmitted from the pore water, where it acts initially as a excess pore water pressure, to the soil structure where it ultimately becomes an applied effective stress increment. The time it takes for this transfer to occur is the basis for the process being called "consolidation" and not "compression." Therefore, the effective stress corresponding to the applied pressure is generally plotted versus void ratio. The resulting "**consolidation curve**" permits an evaluation of the preconsolidation pressure and values for other parameters pertaining to the consolidation characteristics of the soil sample.

Plots of void ratio versus effective pressure on arithmetic and logarithmic scales are shown in Figure 5-8. The semi log plot is more widely used in practice and will be used in subsequent sections of this manual. The consolidation curve on the void ratio versus semi log pressure plot is commonly referred to as the "**e-log p**" relationship. As discussed in detail in Chapter 7 and as shown on Figure 5-8, the slope of the loading portion of the e-lop p curve is called the compression index, which is denoted by the symbol C_c. The slope of the re-load portion of the e-log p curve is called the re-compression index; it is denoted by the symbol C_r.

Some geotechnical specialists prefer to use a plot of percent strain versus log of pressure instead of the e-log p plot. In this case the slope of the virgin compression portion of the consolidation curve is called the modified compression index denoted by the symbol $C_{c\varepsilon}$ and the slope of the rebound portion of the curve is called the modified recompression index denoted by the symbol $C_{r\varepsilon}$. The modified indices reflect the relationship between strain and void ratio, i.e., strain (ε) = $\Delta e/(1+e_o)$. Therefore, to convert the strain-based indices ($C_{c\varepsilon}$ and $C_{r\varepsilon}$) to the void-ratio-based indices (C_c and C_r) multiply the strain based values by ($1 + e_o$). Void-ratio-based values (e-log p) will be used in the remainder of this manual.

Analysis of consolidation test data allows the engineer to determine:

1. **<u>Initial Void Ratio</u> (e_o)**

   The value of the initial void ratio is very important because it defines the amount of void space at the start of the loading. It is this initial void space that will be reduced as the water is squeezed out of the voids with time. The initial void ratio e_o is a key parameter used in settlement computations to determine the magnitude of settlement.

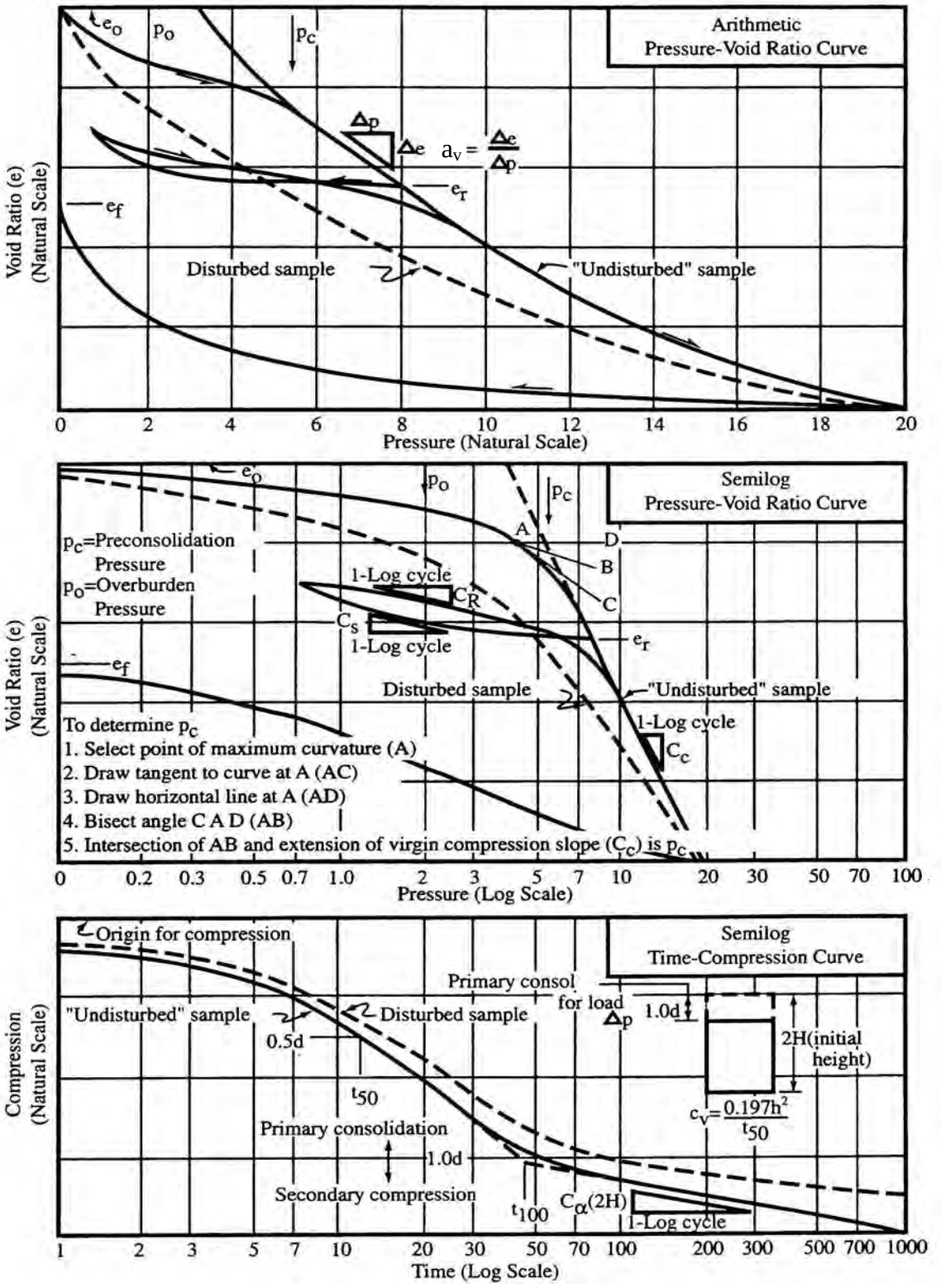


Figure 5–8. Consolidation test relationships (after NAVFAC, 1986a).

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2. Preconsolidation Pressure (p_c)

The e-log p relationship generally displays a distinct break at approximately the maximum past effective stress (p_c). The graphical technique developed by Casagrande (1936) is generally used to determine the value of p_c, which is known as preconsolidation pressure. The Casagrande procedure is included in the middle portion of Figure 5-8 and is discussed in detail in Chapter 7.

The maximum effective stress to which a soil has been loaded in the past will have a major influence on the amount of settlement to be expected under a proposed loading. In fact, 10 times more settlement may occur in a normally consolidated soil than a preconsolidated soil for equal load increments up to the preconsolidation pressure. Values of preconsolidation pressure should be carefully established for the entire depth of the fine-grained soil deposit under consideration. Normally, a minimum, maximum and most probable value of p_c will be determined from laboratory test results and plotted as a range with depth.

3. Compression Index (C_c)

The slope of the consolidation curve beyond p_c is called the compression index (C_c). It is a measure of the load-deformation characteristic of the soil during "virgin" compression.

4. Recompression Index (C_r)

An unload/reload segment of the consolidation curve is also shown in Figure 5-8. The slope of the reload curve is called the recompression index (C_r). It is a measure of the load-deformation characteristic of the soil upon reloading after some amount of load release. As is obvious in Figure 5-8, the slope of the reload portion of the consolidation curve is not as steep as the slope of the virgin portion of the curve since the void ratio change accompanying the virgin loading is unrecoverable. Figure 5-8 also shows that if, upon reloading, the applied pressure exceeds the pressure from which the soil was unloaded, the slope of the reload curve reverts back to the virgin compression slope, C_c. In general, $C_c \approx 10\ C_r$.

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5. Coefficient of Consolidation (c_v)

The coefficient of consolidation is an indicator of the rate of drainage during consolidation. The value may be determined by the t_{50} (log time) method or the t_{90} (square root of time) method. Both of these methods are described in Chapter 7 (Approach Roadway Deformations). As shown in the bottom portion of Figure 5-8, the compression-log time curve for a given load increment is used to determine the coefficient of consolidation (c_v), which is a measure of the time rate of primary consolidation. The value of c_v is determined for each load increment. These values are sometimes plotted on a separate axis below the consolidation curve .

6. Secondary Compression Index (C_α)

Of great importance in organic materials, secondary compression may account for the majority of settlement that takes place over a long period of time in such soils. The compression-log time curve for a given load increment is used to determine the secondary compression index (C_α), which is basically the slope of the curve over one log cycle beyond the time required for primary consolidation (t_{100}) as shown in the bottom portion of Figure 5-8.

7. Effects of Sample Disturbance on Consolidation Test Results

The influence of sample disturbance on consolidation test results is shown on Figure 5-8 by the dashed lines. The dash lines indicate that disturbance:

a. Eliminates the distinct break in the e-log p curve at the preconsolidation pressure (p_c).

b. Lowers the estimated value of the preconsolidation pressure (p_c) and the measured value of the compression index (C_c).

c. Decreases the measured values of c_v.

d. Increases the recompression index (C_r).

e. Decreases the secondary compression index (C_α).

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The general effects of disturbance are (a) under- or over-prediction of the magnitude of expected settlement and (b) over-prediction of the time for its occurrence.

The importance of the consolidation test results as applied to design is summarized below. The test results may be applied to project design after a series of tests have been completed to represent the total depth of the fine-grained soil deposit. The two most important predictions are:

1. **The amount of settlement**. The value is determined by analyzing the consolidation curve between the existing overburden pressure and the final pressure induced by the highway load at various depths. The amount of settlement may vary dramatically depending upon the maximum past pressure to which the soil has been loaded. The total amount of long-term settlement should include an estimate of settlement due to secondary compression, especially for times past the time for 100% primary consolidation if that is less than the design life of the constructed facility.

2. **The time for settlement**. The time for primary consolidation to occur may be estimated from the results of the compression versus time plots at loads between the overburden pressure and final pressure induced by the applied load. The important factors in the settlement-time relationship are:

   (a) Time required is proportional to the square of the longest distance required for water to drain from the deposit. This distance is the thickness of the layer if water drains in one direction only (generally vertically upward to the surface), and one-half the layer thickness if more permeable soils exist above and below the consolidating layer.

   (b) Time required for consolidation varies inversely with the coefficient of consolidation.

   (c) Rate of settlement decreases as time increases.

Settlement computations based on consolidation test results are demonstrated in Chapter 7 (Approach Roadway Deformations).

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5.4.5 Comments on the Consolidation Tests

The consolidation test results are necessary to assess the consolidation properties of the soil. As will be shown in subsequent sections of this document, the consolidation test is one of the most important tests for fine-grained soil as it provides data regarding stress history and compressibility. It is important to consider all laboratory testing variables and their potential effects on the values of soil properties computed from the test results. Information that will need to be provided to a laboratory for a consolidation test includes the loading schedule (i.e., magnitude and duration of loads). It is important to evaluate the loading schedule to be used, especially the duration of loading since time is required for the applied total stress increment to be transferred from the pore water to the soil structure so that it becomes an effective stress acting on the soil mass. Important issues related to consolidation tests are discussed below.

- **Loading Sequence**: The loading sequence selected for a consolidation test will depend on the type of soil being tested and the particular application being considered for the project (e.g., embankment, shallow foundation). The selection of a loading sequence should never be left to the discretion of the laboratory. As an example, if the clay soil is heavily overconsolidated, it is possible that a laboratory-determined maximum load for the consolidation test will not be sufficient to exceed p_c.

- **Range of Applied Loads**: The range of applied loads for the test should well exceed the effective stresses that are required for settlement analyses. This range should cover the smallest and largest effective stresses anticipated in the field and will depend on depth, foundation loads, and excavations. The anticipated preconsolidation stress should be exceeded by at least a factor of four during the laboratory test. If the preconsolidation stress is not significantly exceeded during the loading schedule, p_c, and C_c (or $C_{c\varepsilon}$) may be underestimated due to specimen disturbance effects.

- **Load Increment Ratio (LIR):** By definition the LIR= $\Delta\sigma/\sigma_{initial}$ where $\Delta\sigma$ is the incremental stress and $\sigma_{initial}$ is the previous stress. A LIR=1 corresponds to a doubling of the vertical stress applied to the specimen at each successive load increment during a consolidation test. A LIR of 1 is commonly used for most tests. Experience with soft sensitive soils suggests that as the stress approaches the value of p_c, a smaller LIR will facilitate a better estimate of p_c. Typically, laboratories provide a unit cost for a consolidation test that may be based on 6 to 8 load increments with a separate cost for each additional increment.

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- **Unload-Reload Cycle**: It is recommended that an unload-reload cycle be performed, especially for cases where accurate settlement predictions are required, specifically to obtain a value for C_r. Since most samples will inevitably be somewhat disturbed, a C_r value based on the initial loading of a consolidation test sample will be greater than that for an undisturbed sample, resulting in an overestimation of settlements in the overconsolidated region. A value of C_r based on an unload-reload cycle is more likely to be representative of the actual behavior of the soil in the overconsolidated region.

- **Duration of Load Increment**: The duration of each load increment should be selected to ensure that the sample is approximately 100 percent consolidated prior to application of the next load increment. For relatively low to moderate plasticity silts and clays, durations of 3 to 12 hours will be appropriate for loads in the normally consolidated range. For fibrous organic materials, primary consolidation may be completed in 15 minutes for each load increment. For high plasticity materials, the duration for each load increment may need to be 24 hours or more to ensure complete primary consolidation and to evaluate secondary compression behavior. Conversely, primary consolidation may occur in less than 3 hours for loads less than p_c.

  If the time period is too short for a given load increment (i.e., the sample is not allowed to achieve approximately 100 percent consolidation before the next load increment is applied), then values of C_c may be underestimated and values of c_v may be overestimated. The duration of time required, however, can be optimized by using pneumatic, hydraulic, or electro-mechanical loading systems that include automated loading and data acquisition systems. Continuous deformation versus time measurements and the square root of time method described in Chapter 7 (Approach Embankment Deformations) can be used to estimate the beginning and end of primary consolidation during the test. Once the end of primary consolidation is detected, the system can automatically apply the next load increment. Alternatively, some laboratories can provide real-time deformation versus log time plots to enable the engineer to evaluate whether 100 percent primary consolidation has been achieved.

- **Secondary Compression**: In cases where secondary compression is important (e.g., organic soils), secondary compression should be assessed on the basis of the deformation versus log-time response. The consolidation test for each load increment should be run long enough to establish a linear trend between vertical displacement and log time.

5.4.6 Useful Correlations between Consolidation Parameters and Index Values

This section presents some useful correlations between consolidation parameters and other index values. These correlations can be used by the designer to check the validity of the laboratory tests results or to develop a prediction of the range of values of consolidation parameters that can be expected from yet-to-be performed consolidation tests. **It must be emphasized that predictions based on correlations should never be substituted for proper testing and that any assumptions regarding consolidation parameters should always be verified through testing.**

5.4.6.1 Compression Index, C_c

Over 70 different equations have been published for correlating C_c with the index properties of clays. Table 5-5 lists some of the more useful correlations. Figure 5-9 shows correlations between natural water content and C_c for fine-grained soils, peats and shales **Note that the coordinates in Figure 5-9 are both logarithmic so that values of C_c can vary by as much as a factor of 5 with respect to the average trend line in these empirical correlations. Values of C_c obtained from Table 5-5 or Figure 5-9 should not be used for final design.**

Table 5-5
Correlations for C_c (modified after Holtz and Kovacs, 1981)

Correlation	Soil
$C_c=0.156\ e_o + 0.0107$ [(1)] $C_c \approx 0.5 G_s (PI/100)$ [(2)]	All Clays
$C_c=0.30\ (e_o - 0.27)$	Inorganic, silt, silty clay
$C_c=0.009\ (LL-10)$ [(3)]	Clay of medium to slight sensitivity ($S_t < 4$, $LL<100$)[(4)]
$C_c=0.0115\ w_n$ [(5)]	Organic Soils, Peat
$C_c=0.75\ (e_o - 0.50)$	Low plasticity clays

[(1)] e_o = initial void ratio, [(2)] PI = Plasticity Index, [(3)] LL=Liquid Limit, [(4)] S_t = sensitivity =Undisturbed undrained shear strength/Remolded undrained shear strength (see Table 3-12 in Chapter 3, [(5)] w_n = natural water content

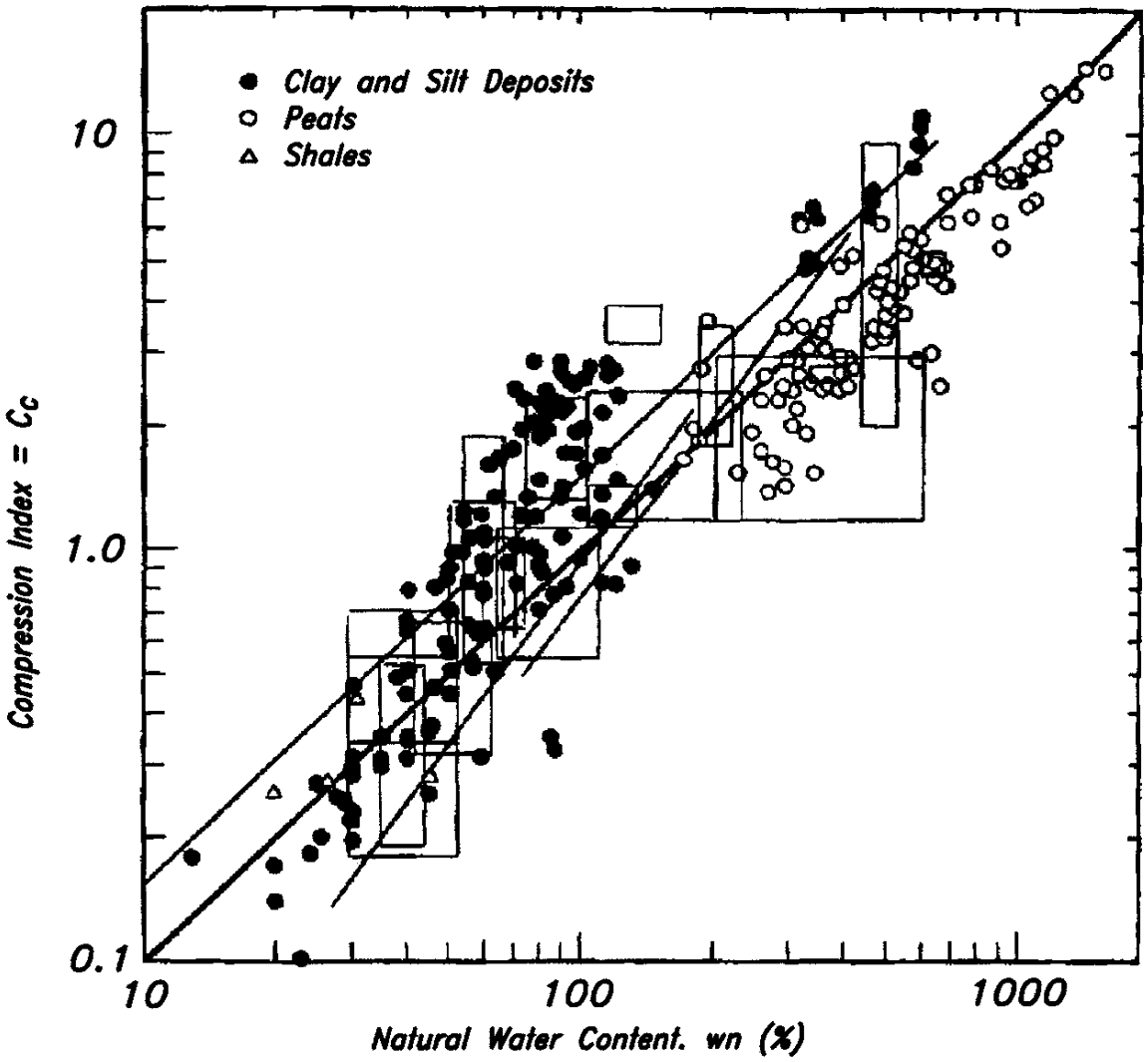


Figure 5-9. Empirical correlation between compression index and natural (in-situ) water content (from Terzaghi, *et al.*, 1996).

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5.4.6.2 Recompression Index, C_r

The ratio of C_r / C_c typically ranges from 0.02 to 0.20 (Terzaghi, and Peck, 1967). The low value is typical of highly structured and bonded soft clay or silt, while the largest ratio corresponds to micaceous silts and fissured stiff clays and shales. In reality, the value of C_r depends on whether loading or unloading is occurring, since some hysteresis effects develop when the soil is subjected to cycles of loading and unloading.

Generally, it is sufficiently accurate to assume C_r is constant for most clay deposits. It may not be adequate to rely on a single value of C_r for loading and unloading in the case of highly structured soft clays or stiff clay shales. In the case of highly structured soft clays the initial value of C_r is steep as a result of flocculation (edge to face structure of clays) and bonding that allows the soil to be stable at high void ratios until the stress exceeds the preconsolidation pressure (Terzaghi and Peck, 1967). The subsequent rebound slope can be significantly different from the initial $C_{r.}$

5.4.6.3 Coefficient of Vertical Consolidation, c_v

Because of the wide range of permeabilities that exist in soils (see Table 5-10), the coefficient of consolidation can itself vary widely, from less than 10 ft^2/yr (≈1 m^2/yr) for clays of low permeability to 10,000 ft^2/yr (≈1,000 m^2/yr) or more for very sandy clays, fissured clays and weathered rocks. Some typical values for clays are given in Table 5-6 and an approximate correlation with liquid limit is shown in Figure 5-10.

Just as permeabilities in the horizontal and vertical directions can be significantly different due to variations in soil particle orientation, non-homogeneity, etc., so too can the in situ coefficient of horizontal consolidation, c_h, be much different from the coefficient of vertical consolidation c_v measured in the laboratory for the same reasons. For example, the in situ coefficient of horizontal consolidation, c_h, for clays containing fissures or fine bands of sand, may often be much greater than c_v measured in the laboratory for the clay alone. In such cases, the in-situ c_h may govern the actual rate of consolidation under field loading conditions.

Table 5-6
Typical values of coefficient of vertical consolidation, c_v
(after Carter and Bentley, 1991)

Soil	c_v		
	($cm^2/s \times 10^{-4}$)	(m^2/yr)	(ft^2/yr)
Boston Blue Clay (CL)	40±20	12±6	135±70
Organic silt (OH)	2-10	0.6-3	7-34
Glacial lake clays (CL)	6.5-8.7	2.0-2.7	22-30
Chicago silty clay (CL)	8.5	2.7	29
Swedish medium sensitive clays (CL-CH)			
1. laboratory	0.5-0.7	0.1-0.2	1.7-2.4
2. field	0.7-3.0	0.2-1.0	2.4-10.2
San Francisco Bay Mud (CL)	2-4	0.6-1.2	6.8-13.6
Mexico City clay (MH)	0.9-1.5	0.3-0.5	3.1-5.1

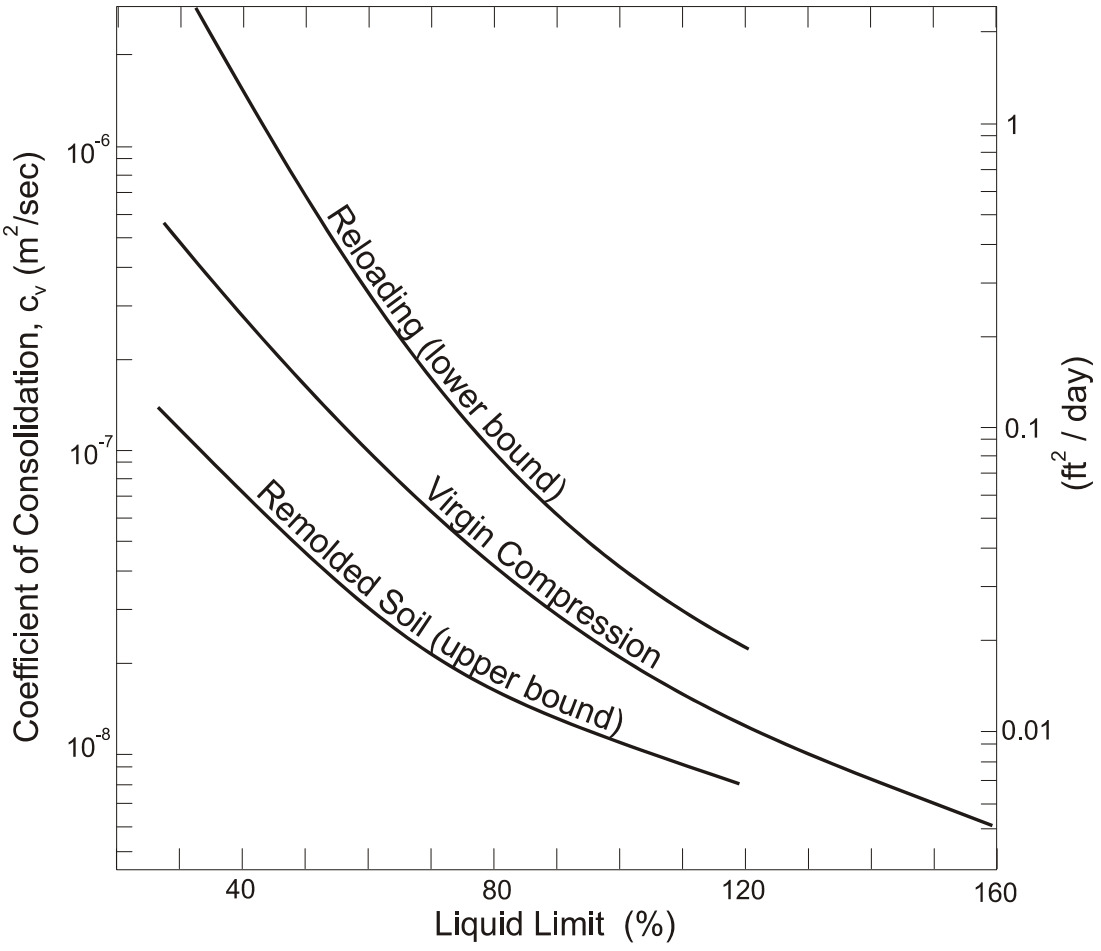


Figure 5-10. Approximate correlations between c_v and LL (NAVFAC, 1986a).

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5.4.6.4 Coefficient of Secondary Compression, C_α

Table 5-7 presents typical values of C_α in terms of C_c for various geomaterials. As shown below by Equations 5-7, the coefficient, C_α, may be expressed either in units of strain ($C_{\alpha\varepsilon}$) or void ratio ($C_{\alpha e}$) per log cycle of time. As indicated previously, to convert void-ratio-based consolidation curve indices to strain-based indices divide the void-ratio-based values by ($1 + e_o$).

$$C_{\alpha\varepsilon} = \frac{d\varepsilon}{d(\log t)}; \qquad C_{\alpha e} = \frac{de}{d(\log t)}; \qquad C_{\alpha\varepsilon} = \frac{C_{\alpha e}}{(1+e_o)} \qquad 5\text{-}7$$

$C_{\alpha e}$ is usually assumed to be related to C_c with values of $C_{\alpha e}/C_c$ typically in the range 0.025-0.006 for inorganic soils and 0.035-0.085 for organic soils. Figure 5-11 presents a correlation between $C_{\alpha e}$ and natural water content.

Table 5-7
Typical Values of $C_{\alpha e}/C_{ce}$ (Terzaghi, *et al.*, 1996)

Soil	C_α/C_c
Granular soils including rockfill	0.02 ± 0.01
Shale and mudstone	0.03 ± 0.01
Inorganic clays and silts	0.04 ± 0.01
Organic clays and silts	0.05 ± 0.01
Peat and muskeg	0.06 ± 0.01

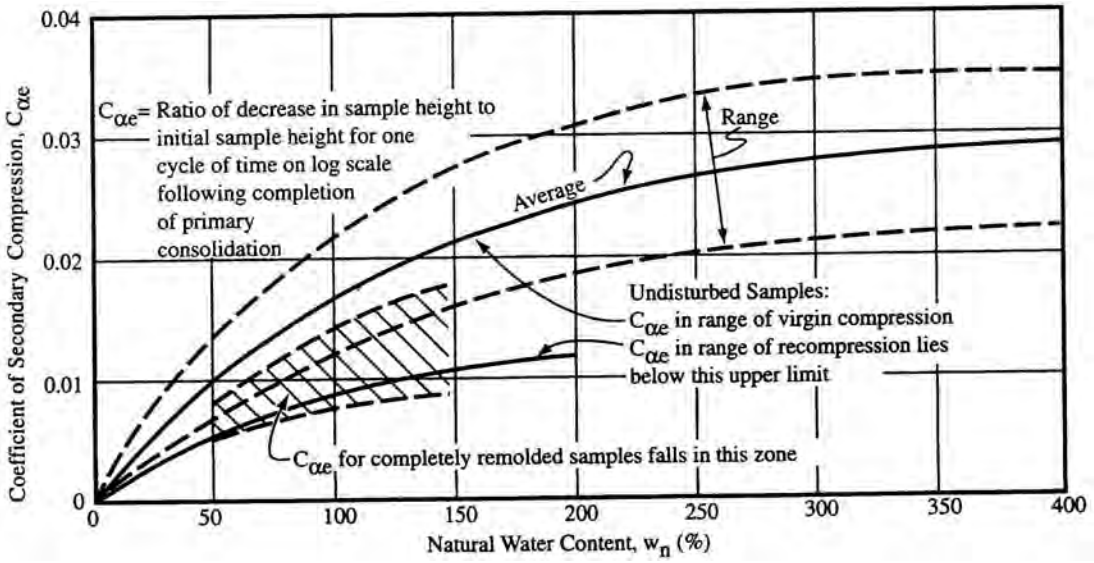


Figure 5-11. Correlation between $C_{\alpha e}$ and natural water content (NAVFAC, 1986a).

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5.5 SHEAR STRENGTH OF SOILS

The shear strength of soils is extremely important to foundation design. In addition, slopes of all kinds, including hills, river banks, and man-made cuts and fills, stay in place only because of the shear strength of the material of which they are composed. Knowledge of the shear strength of soil is important for the design of structural foundations, embankments, retaining walls, pavements, and cuts. Table 5-8 provides a summary of specific issues related to the design and construction of typical highway design elements that should be considered in developing and implementing a laboratory and in-situ testing program for evaluating soil shear strength.

5.5.1 Concept of Frictional and Cohesive Strengths

The concept of shear strength was introduced in Chapter 2 where it was shown to be comprised of two components, **friction (ϕ)** and **cohesion (c)**. In terms of the classification of soils introduced in Chapter 3, these two components of the shear strength can be generalized as follows:

1. Coarse-grained soils, such as gravel and sand, and fine-grained silt, derive strength primarily from friction between particles. Therefore they are considered to be "**cohesionless**" or "**frictional"** soils and are often denoted as "ϕ-soils."

2. Fine-grained soils, composed mainly of clay, derive strength primarily from the electro-chemical attraction, or bond, between particles. Therefore they are considered to be "**cohesive**" soils and are often denoted as "c-soils."

3. Mixtures of cohesionless and cohesive soils derive strength from both interparticle friction and bonding. Such soils are commonly denoted as "**c-ϕ soils**."

5.5.1.1 Strength Due to Friction

The strength due to friction between soil particles is dependent on the stress state of the soil (e.g., overburden pressure) and the angle of internal friction (ϕ) between the particles. As discussed in Chapter 2, the frictional resistance of soil is equal to the normal stress, σ_n, times the tangent of friction angle, ϕ. The tangent of ϕ is equal to the coefficient of friction (μ) between the soil particles.

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Table 5-8
Summary of issues relevant to shear strength evaluation in support of the design of typical geotechnical features (after FHWA, 2002a)

Design Element	Issues Relevant to Shear Strength Evaluation
Shallow Foundation	• Soil shear strength information required for depths up to 2 times the width of the footing, unless weak zones are found below this depth. The depth of bottom of footing will be based, in part, on requirements with respect to frost penetration depths and scour depths.
Drilled Shaft	• The excavation of a hole to construct a drilled shaft results in stress relief and disturbance in the soil that ultimately results in a reduction in shear strength from that corresponding to in-situ (i.e., before construction) conditions. The magnitude of the stress relief and disturbance will depend upon the method of construction, soil type, saturation condition, and type of strength (e.g., side shear or end bearing).
Driven Pile	• The shear strength of the soil may vary significantly between the time when the pile (or pile group) is first driven and tested to the time when the superstructure loads are applied to the pile (or pile group). The time-dependent phenomena of strength increase is referred to as "**pile set-up**" and is often observed for driven piles in saturated normally consolidated (NC) to moderately over consolidated (OC) clay and fine-grained material. A decrease in strength with time is referred to as "**relaxation**" and is often observed for heavily OC clays, dense silts, dense fine sands, and weak laminated rock. Shear strengths should therefore be evaluated for both long and short term conditions. • Changes in site conditions that affect the in-situ the effective stress state may increase or decrease shear strength and pile capacity. These may include site dewatering or additional surface loading from an embankment. • An increase in granular soil strength may occur due to densification during driving. This increased strength will need to be considered such that an appropriate pile driving system can be selected for construction.
Retaining Walls	• The analysis of non-gravity cantilevered and anchored walls requires an evaluation of earth pressures on the active side and passive side of the excavation. For undrained loadings in some clayey soils, particularly low to medium plasticity materials, there can be a large difference in undrained strength between the strength used for the active side and the passive side of the excavation. • For soils that may exhibit peak, fully softened, and residual conditions, an estimate of the tolerable deflection of the wall system needs to be made and this deflection used to select the appropriate strength condition for analysis.
Slopes	• The shear strength of discontinuities (e.g., fissures) in soil (and rock) needs to be evaluated since it may represent the critical (i.e., lowest) shear strength for design. • Weathering and other physiochemical reactions may occur at a quick enough rate to weaken soil bonds and reduce shear strength. • Strength loss may occur in cut slopes due to soil softening (in presence of water) and continuing deformations. Large deformation residual strengths should be used for long-term analyses.

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The equation for frictional resistance, τ, is written in terms of normal stress, σ_n, as follows:

$$\tau = \sigma_n \tan \phi \qquad 5\text{-}8$$

The coefficient of friction, tan ϕ, between individual particles depends on both their mineral hardness and surface roughness. However, the measured friction angle of a soil sample or deposit also depends on the density of the mass caused by interlocking of particles. For a detailed discussion of factors affecting frictional resistance, the reader is referred to textbooks such as by Holtz and Kovacs (1981).

5.5.1.2 Strength Due to Cohesion

The concept of cohesive strength is more difficult to explain and often misunderstood. The designer must develop a good understanding of this concept otherwise there will be a disconnect between reality and the design of some structures, e.g., the first bench cut in shoring.

There are two types of cohesion in soils: **true cohesion** and **apparent cohesion**. These are briefly discussed as follows (after Mitchell, 1976):

1. **True cohesion** may result from chemical cementation (just like in rocks) and/or forces of attraction (e.g., electrostatic and electromagnetic attractions) between colloidal (10^{-3} mm to 10^{-6} mm) clay particles. True cohesion is stress-independent unlike frictional resistance that is a function of normal stress.

2. **Apparent cohesion** may develop because of capillary stresses and mechanical interlocking as follows:

    - **Capillary stresses** develop between particles in a partially saturated soil due to surface tension in the water. The surface tension (negative pressure) in the water produces an equal and opposite effective stress between the soil particles, which results in an apparent cohesion since it too is stress-independent. The magnitude of this type of apparent cohesion can be extremely large, especially in fine-grained soils. Such capillary stresses can be overcome by an increase in the degree of saturation.

- **Apparent mechanical forces** are often exhibited by the interlocking of rough (angular) soil particles. The interlock between the soil particles can offer some resistance to shear stresses even in the absence of a normal stress. This type of apparent cohesion is often the cause of cohesion measured in compacted soils. However, such apparent mechanical forces are susceptible to significant reduction by vibrations and other types of mechanical disturbance.

Figure 5-12 presents a graphical representation of the potential contribution of various mechanisms of cohesion. It can be seen that true cohesion in soils exists only when the particle size is colloidal. Unless the complete soil sample is composed of colloidal particles, true cohesion due to interparticle attraction cannot be relied on. Cementation by deposition is often observed in arid environments (e.g., desert southwest), but it is difficult to quantify. As indicated above, capillary stresses can provide a large apparent cohesion, but such cohesion can be overcome by saturation. Since cohesion cannot be defined with confidence, its contribution to long-term shear strength in c-ϕ soils is often disregarded or greatly minimized by using only a small value such as 100 to 500 psf (5 to 25 kPa). For purely cohesive soils, the designer should be careful in evaluating the cohesion for long-term design purposes. Further discussion on apparent cohesion in the context of compacted soils is included in Section 5.8.4.1.

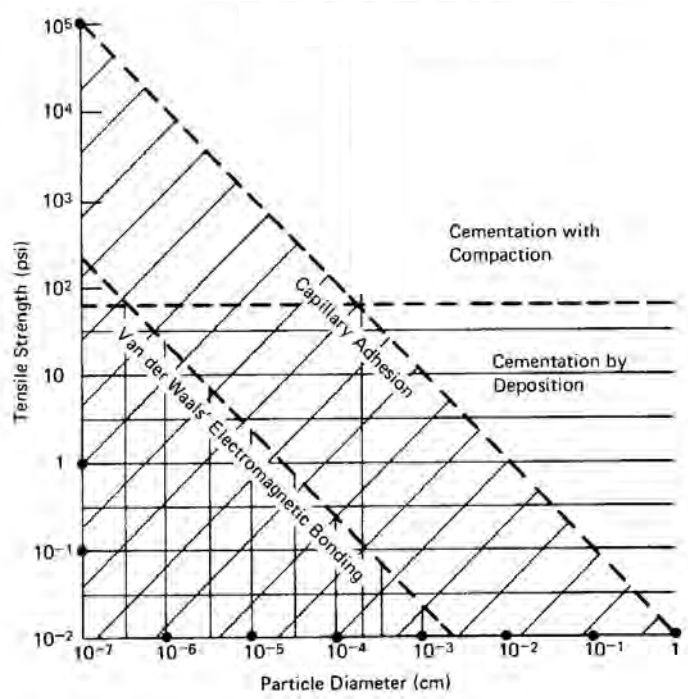


Figure 5-12. Potential contributions of various bonding mechanisms to cohesive strength (after Ingles, 1962).

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5.5.1.3 Simplified Expression for Shear Strength of Soils

As indicated in Chapter 2, the shear strength, τ, of soils is expressed simplistically by two additive components as follows:

$$\tau = c + \sigma_n \tan \phi \qquad 5\text{-}9$$

In terms of effective stresses, the effective shear strength, τ', can be re-written as follows:

$$\tau' = c' + (\sigma_n - u) \tan \phi' = c' + \sigma' \tan \phi' \qquad 5\text{-}10$$

where u is the pore water pressure, c' is the effective cohesion, σ' is the effective normal stress, and ϕ' is the effective friction angle.

The shear strength soil is influenced by many factors including the effective stress state, mineralogy, packing arrangement of the soil particles, soil hydraulic conductivity, rate of loading, stress history, sensitivity, and other variables. As a result, **the shear strength of soil is not a unique property**. The following sections present and discuss various laboratory tests to determine the shear strength for various types of construction and loading conditions. Typical laboratory strength tests are introduced including the unconfined compression test (AASHTO T208; ASTM D 2166), the triaxial test (AASHTO T234; ASTM D 4767), and the direct shear test (AASHTO T236; ASTM D 3080). A detailed discussion on testing equipment and procedures is beyond the scope of this document. The interested reader should review the AASHTO and ASTM standards for detailed information on testing equipment and procedures. The following sections also describe information that must be conveyed to a laboratory testing firm to ensure that the strength testing is performed consistent with the requirements imposed by the design (e.g., selection of confining pressures consistent with the imposed loads).

5.5.2 Strength Testing of Soils in the Laboratory

The shear strength of a soil is the maximum shear stress that the soil structure can resist before failure. Failure is generally defined as continuing displacement without an increase in applied stress. Since the water filling the pores has no shear strength, shear stresses are carried by the structure of soil grains. However, the shear strength of the soil structure is indirectly dependent on the pressure in the pore water, which influences the friction term as shown by the excess pore water pressure term, u, in Equation 5-10. Foundation designers must consider the effects of expected construction operations on the subsoils when planning

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a test program. For example, when a highway embankment or structural footing is suddenly placed on a soft clay deposit, the pore water initially carries all the load and the available shear strength does not increase until drainage begins and the excess pore water pressure decreases. In planning a test program for such a situation the designer should request unconsolidated undrained (UU) triaxial tests to determine the undrained shear strength of the soil which, in this case, would be the critical strength value, i.e., the initial shear strength before consolidation begins. Additional consolidated undrained (CU) or consolidated drained (CD) tests would also be used to determine the increase in shear strength as consolidation occurs and excess pore water pressures dissipate. These results can be used to determine alternate methods of applying the loads safely, especially if the undrained strength is insufficient to sustain the proposed loading. Stage construction involves placement of an increment of load and a waiting period to allow strength gain through excess pore water pressure dissipation so the soil deposit can safely support the next load increment.

The majority of strength tests are conducted on cohesive soils since obtaining undisturbed samples of non-cohesive soils is difficult. Strength tests on cohesive soils are usually conducted on high quality undisturbed samples obtained from thin wall sampling tubes. The preferred test for most projects where cohesive soils are involved is the triaxial compression test. The number and types of tests must be selected by the designer to suit the project conditions. For each test the designer should clearly indicate the consolidation or confining pressure to be used. These pressures are determined from the p_o diagram for each specific project (refer to Chapter 2 for discussion of the p_o diagram). The range usually extends from the effective overburden pressure to the pressure induced by the highway loading. The program objective should be to establish a profile of soil strength with depth. Soil strength parameters are frequently expressed as a ratio of shear strength over the effective overburden pressure (τ/p_o).

The most common laboratory soil strength tests are:

- Unconfined compression test
- Triaxial compression test, and
- Direct shear test

Each of these tests is briefly discussed below. For the triaxial compression and the direct shear tests, it is important that each test be performed on a new sample. **The practice of performing multi-stage shear strength tests on a single sample is not recommended.**

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5.5.2.1 Unconfined Compression (UC) Tests

The unconfined compression test is a quick, relatively inexpensive means to obtain an estimation of the undrained shear strength of cohesive specimens. In this test a cylindrical specimen of the soil is loaded axially as shown in Figure 5-13 without any lateral confinement to the specimen, at a sufficiently high rate to prevent drainage. Since there is no confinement, residual negative pore pressures that may exist in the sample following sample preparation generally control the state of effective stress in the sample. The shear stresses induced in the specimen by the axial load result in a shear failure. The magnitude of the shear stress at the moment of failure represents the shear strength of the soil under these conditions of loading and drainage. Therefore, the shear strength obtained from this test is called the "undrained shear strength (s_u)." In most cases, the value of undrained shear strength obtained from an unconfined compression test is conservative. The maximum axial compressive stress measured at failure represents the compressive strength of the soil under these conditions of loading, drainage, and confinement. Therefore, the compressive strength obtained from this test is called the "unconfined compressive strength (q_u)." These two strengths terms should not be confused; one is a shear strength the other a compressive strength. It can be shown graphically by a Mohr's circle construction (Appendix B) that the undrained shear strength (s_u) is equal to one-half the unconfined compressive strength (q_u).

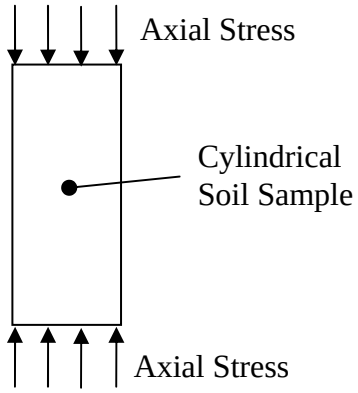


Figure 5-13. Schematic of an unconfined compression test.

The unconfined compression test cannot be performed on granular soils, dry or crumbly soils, silts, peat, or fissured or varved materials. Because there is no control over the effective stress state of the specimen, this test is not recommended for evaluating strength properties for compressible clay soils subjected to embankment or structural foundation loads. The reliability of this test decreases with increasing sampling depth because the sample tends to swell after removal from the ground due to confining stress release. The

swelling results in greater particle separation and reduced shear strength. Testing the full diameter extruded specimen as soon as possible after removal from the tube can:

- minimize swelling
- reduce disturbance
- preserve the natural moisture content.

Unfortunately, despite these shortcomings, this test is commonly used in practice because of its simplicity and low cost.

5.5.2.2 Triaxial Tests

The triaxial test is very versatile in the sense that the shear strength can be evaluated under compression as well as extension loading conditions. A schematic of triaxial compression test is shown in Figure 5-14 where the axial stress is greater than the confining stress. Lateral pressures at various depths below the ground surface can be simulated by confining pressures. Note that the confining pressures acts on the entire sample and is equal to the axial stress before the application of an axial stress increment. Typically, failure of the sample is caused by increasing the axial stress (compression) until a shear failure takes place. In an extension test, the confining pressures are increased while keeping the axial stress constant. Pore water pressures during the test can be measured.

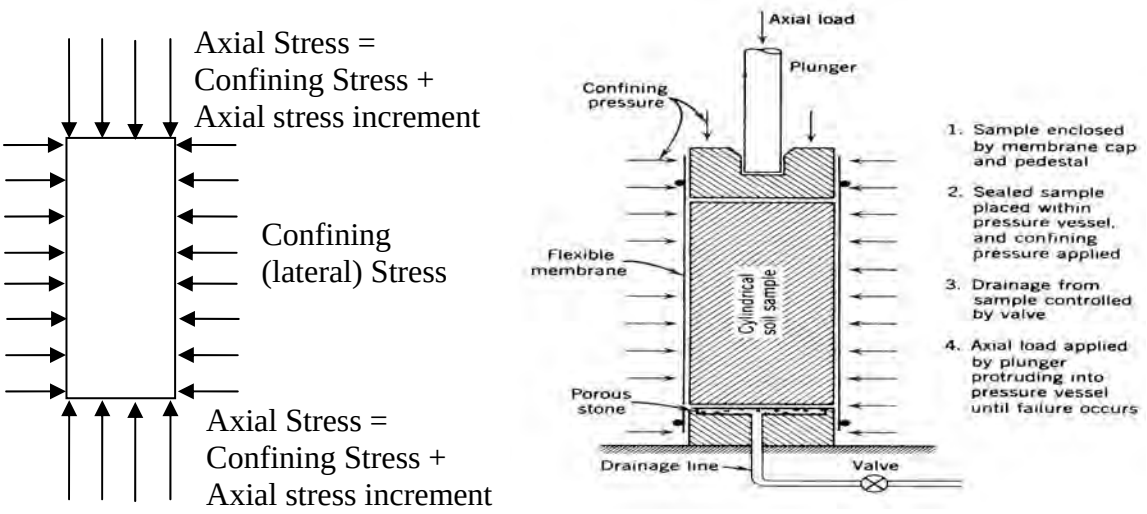
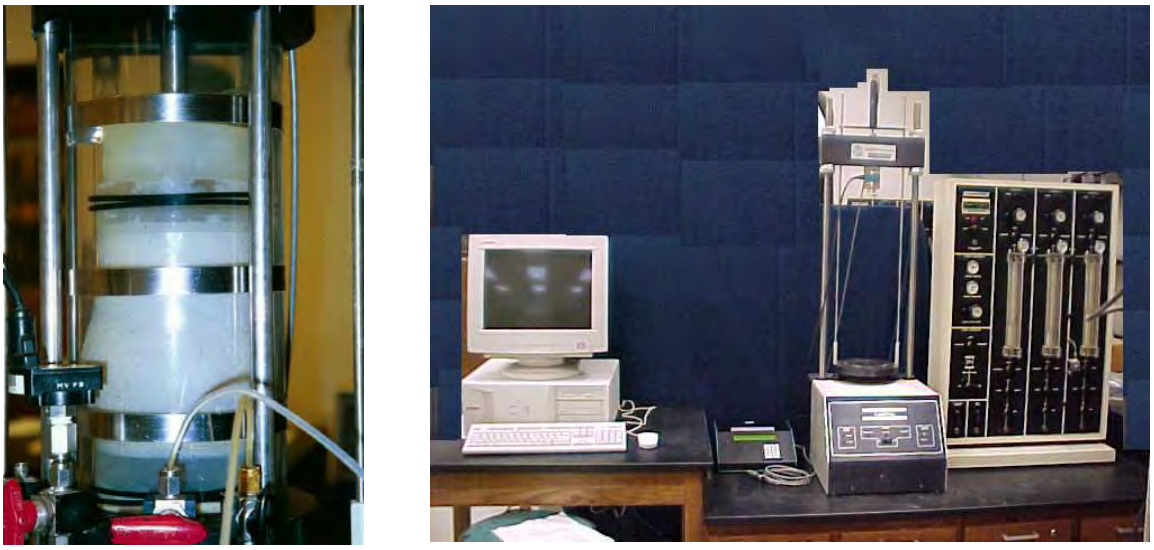


Figure 5-14. Schematic of a triaxial compression test (Lambe and Whitman, 1979).

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(a) **(b)**

Figure 5-15. (a) Failure of a loose sand specimen in a triaxial cell; and (b) Load frame, pressure panel, and computerized data acquisition system (Photographs courtesy of GeoComp Corporation).

Equipment – Triaxial systems today use electronic instrumentation to provide continuous monitoring and periodic acquisition of test data (see Figure 5-15b). Force is measured by using a force transducer or load cell that is typically mounted outside the triaxial cell. More advanced systems have the transducer incorporated within the testing cell to reduce the effects of rod-friction. Linear variable differential transducers (LVDTs) are used to monitor deformations. Additionally, volume measurements can be taken with a device that makes use of an LVDT to measure the rise or fall of a bellofram cylinder. This change in movement is calibrated to the volume of water taken in or pushed out of the sample. Pressure transducers are mounted on the base of the test cell to monitor the confining pressure within the cell and the pore water pressure within the sample.

Unconsolidated-Undrained (UU) Test

In the UU test, no drainage or consolidation is allowed during either the application of the confining pressure or the application of the axial load that induces shear stress. The shear stresses induced in the specimen by the axial load result in failure. As indicated in Section 5.5.2, the UU test models the response of a soil that has been subjected to a rapid application of an axial load such as that due to construction of an embankment. It is difficult to obtain repeatable results for UU testing due to the effects of sample disturbance. The accuracy of the UU test is dependent on the soil sample retaining its original structure until testing occurs. The undrained shear strength of the soil, s_u, is measured in this test.

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Consolidated-Drained (CD) Test

In the CD test, the specimen is allowed to consolidate completely under the confining pressure prior to the application of axial load, i.e., the confining pressure acts as an effective stress throughout the soil specimen. The axial load is applied at a rate slow enough to allow drainage of pore water so that there is no buildup of excess pore water pressures, i.e., the stresses imposed by the axial load are effective stresses. The shear stresses induced in the specimen by the axial load result in failure. The time required to conduct this test in low permeability soil may be as long as several months. Therefore it is not common to conduct a CD test on low permeability soils. The CD test models the long-term (drained) condition in soil. Effective stress strength parameters (i.e., ϕ' and c') are evaluated from the results of the CD test.

Consolidated-Undrained (CU) Test

The initial part of the CU test is similar to the CD test in that the specimen is allowed to consolidate under the confining pressure. However, unlike the CD test, the axial load is applied with the drainage lines closed in the CU test. Thus, during shearing there is continual development (+ or -) of excess pore water pressure. The rate of axial load application for this test is more rapid than that for a CD test. Pore pressures are typically measured during the CU test so that both total stress and effective stress strength parameters can be obtained. Recall that total stress equals effective stress + pore water pressure as expressed by Equation 2-13. The pore water pressure may be + or – depending upon whether the specimen dilates or compresses during application of the axial load. The shear stresses induced in the specimen by the axial load result in failure. The effective stress parameters evaluated for most soils based on CU testing with excess pore water pressure measurements will be similar to those obtained from CD testing, thus making CD tests unnecessary for typical applications.

During triaxial testing, the confining pressure, which acts uniformly over the entire specimen, is considered to be the minor principal stress. By definition, a principal stress is one that acts on a plane where shear stress is zero. The interface between the soil and the membrane isolating it from the fluid in the chamber is assumed to be frictionless during the entire test, i.e. no shear stresses develop along the circumference of the specimen. Likewise, the applied axial load causes a normal stress to act on the top and bottom of the specimen. As shown in Figure 5-14, this vertical normal stress acts in addition to the confining pressure. Therefore, the combined vertical stress acting on the top and bottom of the specimen during the triaxial test is considered to be the major principal stress not only because the plane (horizontal) on which it acts is orthogonal to the minor principal stress plane (vertical), but

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mainly because the interface shear stress between the specimen and the top and bottom caps is assumed to be equal to or close to zero. To assure this condition, the end caps are usually coated with a lubricant to make them virtually frictionless. Because of these boundary stress conditions, the specimen is free to shear on a plane consistent with the directions of the major and minor principal stress planes and its inherent shear strength as expressed by c and ϕ.

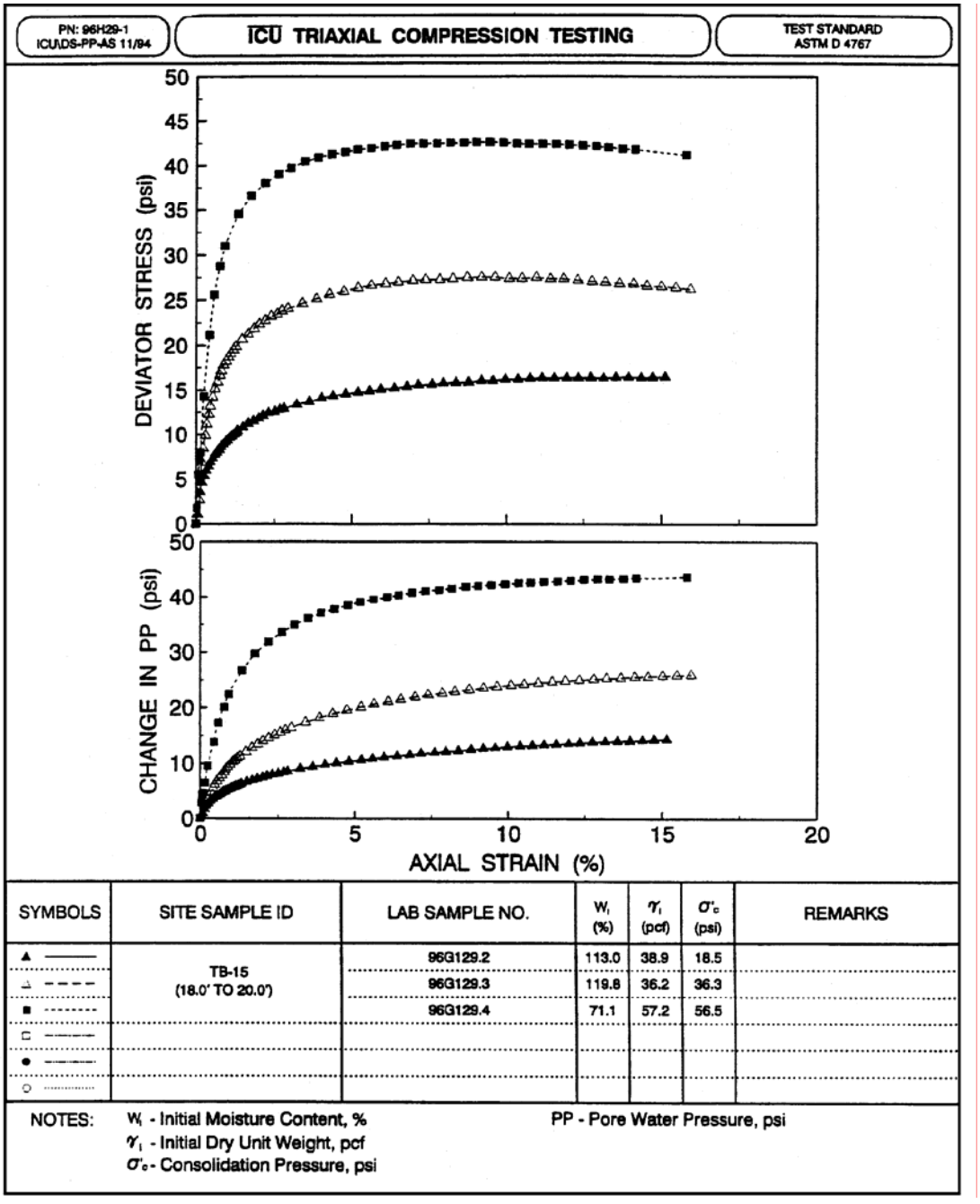


Figure 5-16. Typical stress-strain curves from CU test.

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5.5.2.3 Direct Shear Tests

The oldest form of shear test upon soil is the direct shear test, first used by Coulomb (1776). A schematic of the essential elements of the direct shear apparatus are shown in Figure 5-17. The soil is held in a box that is split across its middle; the bottom portion of the box is usually fixed against lateral movement. A confining normal force, N, is applied, and then a tangential shear force, T, is applied so as to cause relative displacement between the two parts of the box. The magnitude of the shear force is recorded as a function of the shear displacement, and usually, the change in thickness of the soil sample is also recorded. Although it is widely used in practice, the direct shear device lacks a number of features that limit is applicability. For example, there is no way to control the confining pressure. Also, since there is no way to measure excess pore water pressures generated during shearing of saturated clay specimens, use of the direct shear test is generally limited to cohesionless soils.

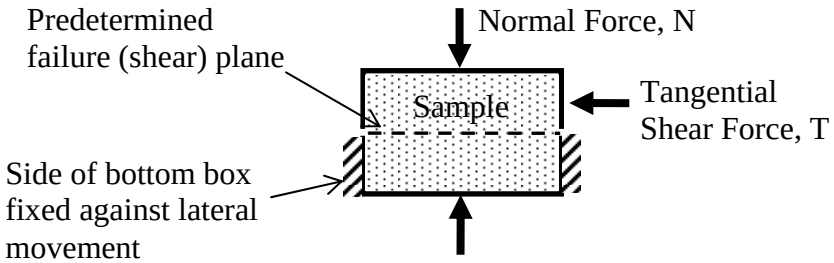


Figure 5-17. Schematic of the Direct Shear Test.

Equipment – The apparatus and procedures for direct shear testing are discussed in ASTM D 3080. A specimen is prepared in a split square or circular box. Figure 5-18 shows a circular specimen. The specimen is sheared as one part of the box is displaced horizontally with respect to the other. Generally, the lower part of the box is fixed against lateral movement and the shear force is applied to the upper part of the box through a loading frame as shown in Figure 5-18. The central two of the six screws visible in the top portion of the box extend into the bottom portion and are used to hold the assembly together while the specimen is being prepared. This shear box assembly is then placed in a reservoir which could be filled with water to allow saturation of the specimen prior to shearing. Before the test is begun, the two central screws are removed and the four corner screws, which rest on the top surface of the bottom portion of the box, are turned to slightly raise the top part of the box so that there is no contact between it and the bottom part of the box. This is done to prevent the error that would result from the frictional resistance between the two boxes at their contact. Load cells are used to monitor the shear force and LVDTs are used to monitor both horizontal and

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vertical deformation. By use of this instrumentation, as well as a loading frame that provides a constant rate of horizontal deformation, it is possible to automate the direct shear test.



Figure 5-18. Direct shear testing box (Photograph courtesy of GeoComp Corporation).

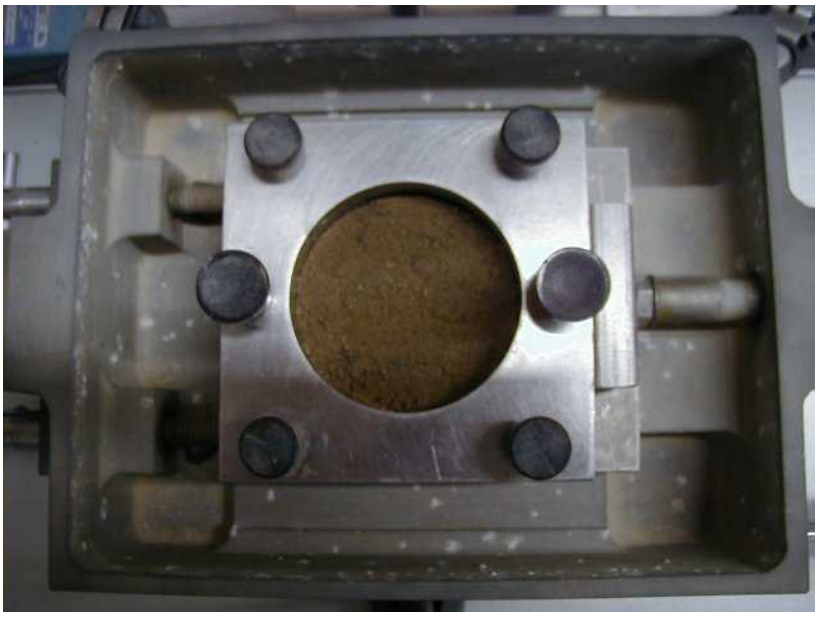


Figure 5-19. Soil sample mounted in direct shear testing apparatus (Photograph courtesy of GeoComp Corporation).

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Test Procedures – In the direct shear test, the soil is first consolidated under an applied normal stress. After consolidation is completed, which will be virtually instantaneous in cohesionless soils, the specimen is sheared directly at a constant rate. The rate of shear is typically selected as a function of the hydraulic conductivity of the specimen. Direct shear testing is commonly performed on compacted materials used for embankment fills and retaining structures. Direct shear testing can also be performed on natural materials. However, the lack of control on soil specimen drainage makes the evaluation of undrained strength unreliable. The direct shear test can also be used to evaluate the drained strength of natural materials by shearing the sample at a rate slow enough to ensure that no significant pore water pressures develop, however there is no way to verify this condition by measurement.

In addition to providing data that allows the determination of the peak effective stress friction angle (ϕ'), the direct shear test data can also be used for the evaluation of effective stress residual strengths ($c'_r \approx 0$; ϕ'_r). The effective stress residual strength parameters are necessary for stability and landslide analyses. Residual strengths are associated with very large shear strains along a predefined or preferential slip surfaces that result in very large deformations. Data from a reversing direct shear test can also be used to evaluate residual shear strengths. In a reversing direct shear test, the direction of shearing in the test is reversed several times thereby causing the accumulation of displacements at the slip surface.

A characteristic of the direct shear test that distinguishes it from the triaxial test is that the shear failure in the direct shear device is forced to occur on a horizontal plane so that the orientations of the major and minor principal stress planes are not apparent. Ordinarily this characteristic is considered to be a disadvantage of the direct shear test. However this characteristic is advantageous for designs involving geosynthetics where the shearing resistance of the interface between the soil and the geosynthetic or between two pieces of geosynthetic is often required. Direct shear machines have been modified to test the interface shear strength between various types of engineering materials, as described in ASTM D 5321.

5.5.3 Factors Affecting Strength Testing Results

It is important for the designer to realize that all laboratory tests on soils must be carefully performed. This is particularly important for strength testing since the use of strength parameters are a key to successful foundation design. The following seven factors in particular affect the results of strength testing:

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1. Sample disturbance
2. Mode of shearing
3. Confining pressures
4. Specimen size
5. Saturation
6. Displacement at failure
7. Rate of shearing and strain required to reach peak strength

A detailed discussion of each of these factors is presented in FHWA (2002a). In addition to recognizing the effect of the factors that can affect the strength testing results, it is extremely important for the designer to perform the proper tests depending on project requirements. The selection of an appropriate test to be used to provide relevant information for a particular geotechnical structure should consider, at a minimum, the following questions:

(1) How fast will construction occur relative to the hydraulic conductivity of the soil (i.e., should drained or undrained strength tests be performed)?
(2) How does the direction of applied load affect measured shear strengths and the appropriate strength to be used for an analysis?
(3) How do the expected levels of deformation for the geotechnical structure affect the selection of shear strength? and
(4) How does the manner in which the feature is constructed affect the shear strength to be used in analysis?

5.5.4 Comparison of Laboratory and Field Strengths

Soil samples are obtained from the ground for laboratory testing by sampling from boreholes and sealing and transporting these samples to the laboratory. The degree of disturbance affecting the samples will vary according to the type of soil, sampling method and the skill of the driller. At best some disturbance will occur from the removal of in-situ stresses during sampling and from the preparation of specimens in the laboratory for testing. In general, disturbance tends to reduce the shear strength obtained from unconfined or unconsolidated tests and increase the shear strength obtained from consolidated tests. There is, therefore, considerable merit in measuring the in-situ shear strength. The field vane shear test discussed in Chapter 3 is the most commonly used field test for direct measurement of the undrained shear strength of soft to medium clays. In reviewing the different types of field and laboratory tests available to determine the undrained shear strength in clays, the designer should expect the field vane shear test to provide the most accurate value of s_u, with UC and UU tests yielding lower results and CU tests yielding slightly higher results.

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It is important that the results of in-situ tests be interpreted carefully and calibrated with laboratory tests. Without careful calibrations, the in-situ tests can yield inaccurate results.

5.5.5 Selection of Design Shear Strength

Frequently, on a large project the designer will receive a large quantity of undrained shear strength test results from both the field and laboratory. This data must be synthesized to permit rational interpretation of the results. The tests should be analyzed on a hole-by-hole basis. All tests from one hole should be reviewed and the results for each type of test should be plotted separately versus depth to determine the pattern of strength variation for each test type and to assess the reliability of the data, e.g., a CU test result that is lower than a UC test result at the same depth should be considered suspect. The general pattern of shear strength results should show an increase in strength with depth in a normally consolidated clay deposit. Overconsolidated clays may exhibit this pattern only at greater depths since the amount of preconsolidation increases shear strength in the upper portions of the soil deposit. Section 5.14 presents values of the coefficient of variation of measured soil properties that should be taken into account while selecting the final design shear strength.

5.5.6 Correlations of Shear Strength Parameters with Index Parameters

This section presents some useful correlations between shear strength parameters and other index values or field conditions. These correlations may be used by the designer to check the general validity of the laboratory test results or to develop a preliminary assessment about the shear strength characteristics of the soils on the project site. In the latter case, it must be emphasized that predictions based on correlations alone should never be used for design and that any assumptions regarding shear strength parameters must always be verified through testing.

5.5.6.1 Undrained Shear Strength of Cohesive Soils

For most saturated clays tested under quick undrained conditions, the angle of shearing resistance, ϕ_u, is zero. This means that the shear strength of the clay is a fixed value and is equal to the apparent cohesion, c_u, at a specific moisture content and preconsolidation pressure. A value for the undrained shear strength may be crudely estimated for a sample for which uncorrected SPT N-values are known by molding a specimen of the clay between the fingers and by applying the observations indicated in Table 4-2 in Chapter 4. However, as noted in the footnote of Table 4-2**, the values of SPT blow count listed there should not be used to determine the design strength of fine grained soils.**

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Undrained Shear Strength

For most normally consolidated clays the undrained shear strength (s_u) is proportional to the effective overburden pressure (p_o). For such soils, Skempton (1957) proposed the relationship shown in Figure 5-20 between the s_u/p_o and plasticity index (PI). Figure 5-20 also includes results obtained by a number of other researchers. As can be seen in the figure, the composite of all findings varies so much that **such relations should be used with caution.** However, such correlations, particularly the correlation by Skempton (1957), are useful for obtaining preliminary estimates and for checking laboratory results of project-specific tests performed on normally consolidated clays.

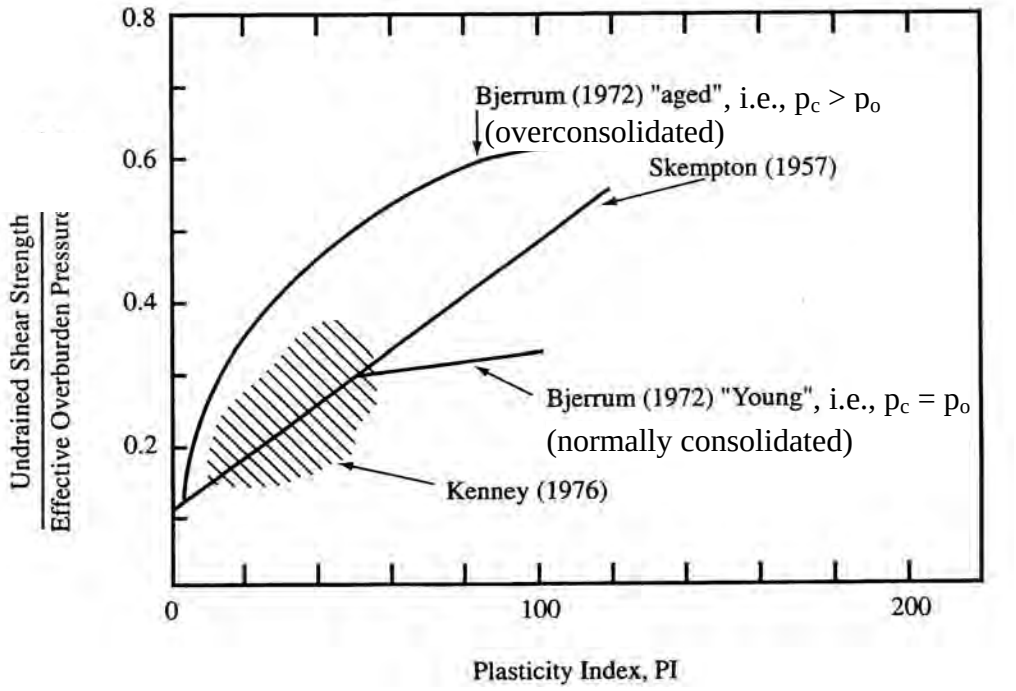


Figure 5-20. Relationship between the ratio of undrained shear strength to effective overburden pressure and plasticity index for normally consolidated and overconsolidated clays (after Holtz and Kovacs, 1981).

The shear strength of undisturbed clays depends on the consolidation history of the clay as well as its fabric characteristics. In general, the undrained strength ratio, s_u/p_o, increases with increasing overconsolidation as measured by the overconsolidation ratio, OCR. **It is recommended that laboratory tests be performed to determine the undrained strength ratio for overconsolidated clays rather than relying on any published correlations.** In practical terms, it is more straightforward to measure the undrained shear strength of overconsolidated clays than to predict it from other indices.

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5.5.6.2 Drained and Effective Shear Strength of Cohesive Soils

It is often important to carry out stability calculations in terms of effective stresses. The soil strength parameters, c' and ϕ', used in these calculations should be obtained from either drained direct shear box or drained triaxial tests or from CU triaxial tests with pore water pressure measurements (giving ϕ'_{cu} and c'_{cu}). Generally, there is a minor difference in the results obtained from these two tests for saturated clays because the soil is being tested under different boundary conditions and stress paths. In-situ tests such as CPTs can also be used to estimate the drained and effective shear strength parameters of cohesive soils.

For clays, empirical correlations have been developed to relate ϕ' to the plasticity characteristics of the soil. Figure 5-21 shows a slight trend of ϕ' decreasing with increasing PI. The existence of these relationships arises because both PI and shear strength reflect the clay mineral composition of the soil; as the clay mineral content increases, the PI increases and the strength decreases. From Figure 5-21, it can be seen that the drained friction angle values can be ± 8° in variance with respect to the dashed trend line.

Considering the overall importance of ϕ' in stability calculations, foundations design, and landslide analyses, it is essential to assess ϕ' directly by means of consolidated drained direct shear tests, consolidated drained triaxial tests, or consolidated undrained triaxial tests with pore water pressure measurements. The consequences of merely estimating ϕ' can be economically unwise. As an example, in stability analyses for relatively long, shallow slip surfaces that may be associated with a landslide, the required forces that would need to be resisted by some form of stabilization system (e.g., retaining wall, micropiles) would vary significantly depending on the drained friction angle of the soil. It is highly recommended that geotechnical designers develop historical data summaries of ϕ' versus PI to check the validity of future test results.

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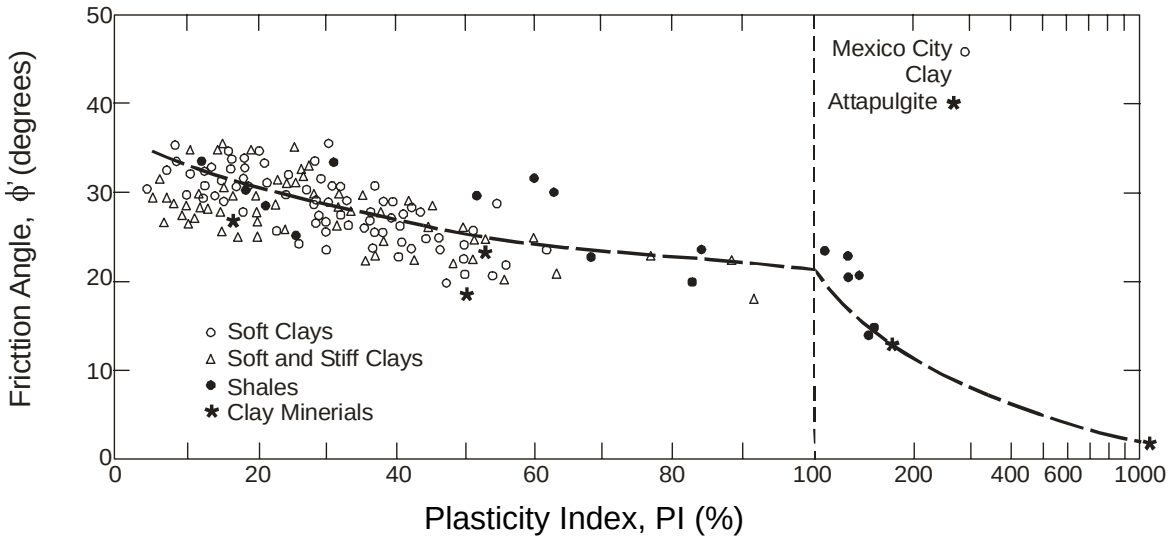
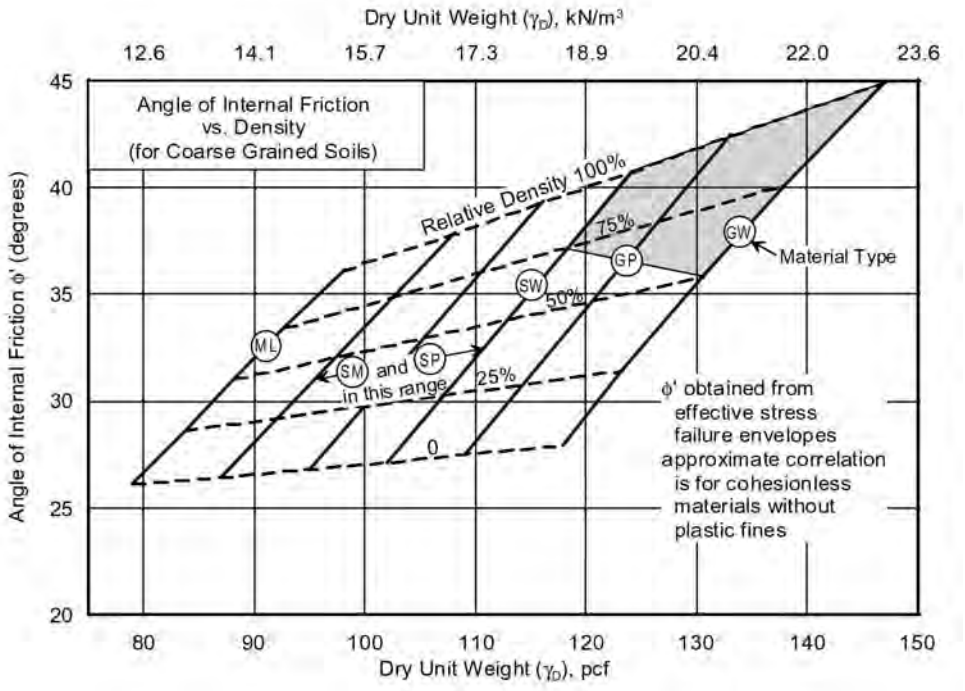


Figure 5-21. Relationships between ϕ and PI. (after Terzaghi, *et al.*, 1996).

5.5.6.3 Shear Strength of Cohesionless Soils

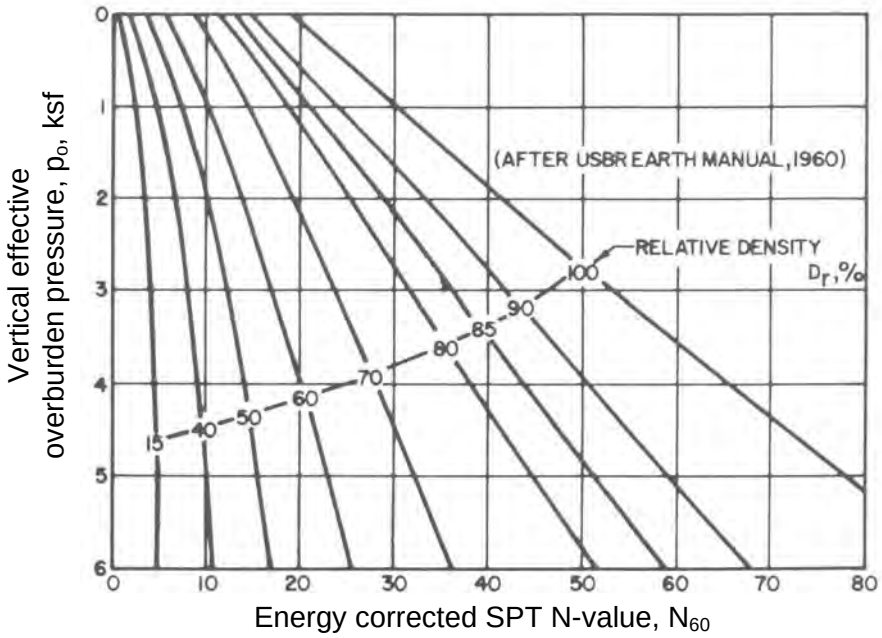
Because of their high permeability, pore water pressures do not build up significantly when cohesionless soils are subjected to shearing forces. The complication of total and effective stresses is therefore avoided and the phenomenon of apparent cohesion, or undrained shear strength does not occur. Consequently, the shear strength of cohesionless soils is defined exclusively in terms of frictional resistance between the grains, as measured by the angle of shearing resistance, ϕ. Typical values of ϕ for sands and gravels are given in Figure 5-22 as a function of dry unit weight and relative density. The material types indicated in the figure relate to the Unified Classification System (USCS).

Figure 5-22 requires determination of relative density. A reasonable estimate of relative density can be obtained from Figure 5-23. Figure 5-23 was originally developed based on data obtained using rope and cathead operated hammers. Thus, it is recommended that an energy corrected SPT N-value, i.e., N_{60}, be used as shown in Figure 5-23. However, note that Figure 5-23 is a function of both N-value and the vertical effective overburden pressure, p_o. Therefore, N_{60}-value should not be corrected for overburden pressure, i.e., C_N=1.0 (see Section 3.7.2) while using Figure 5-23.



Note: Use caution in the shaded portion of the chart due to the potential for unreliable SPT N-values in gravels

Figure 5-22. Correlation between relative density, material classification and angle of internal friction for coarse-grained soils (NAVFAC, 1986a).



1 ksf = 47.9 kPa

Figure 5-23. Correlation between relative density and SPT resistance (NAVFAC, 1986a).

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5.6 PERMEABILITY

5.6.1 General

Permeability, also known as hydraulic conductivity, is one of the major parameters used in selecting soils for various types of construction. In some cases, it may be desirable to place a high-permeability fill immediately under a pavement surface or behind a wall to facilitate the removal of water. In other cases, such as retention pond dikes, it may be detrimental to use high-permeability materials. Permeability also significantly influences the choice of backfill materials for various elements such as trenches and retaining walls.

Unlike the fill soils discussed in the previous paragraph, the permeability of a natural soil is strongly influenced by its macroscopic structure, e.g., clays containing fissures or fine bands of sand will have permeabilities that are many times greater than that of the clay material itself. Also, stratified soils often have horizontal permeabilities that are many times the vertical permeability. Because of the small size of laboratory specimens and the way they are obtained and prepared, large scale in-situ features are absent and test results do not give a true indication of field values in soils with a pronounced macro-structure. Moreover, laboratory tests usually constrain water to flow vertically through the specimen whereas the horizontal permeability may be much greater, and hence of overriding importance, so far as site conditions are concerned. Field permeability tests overcome these shortcomings, but, since the pattern of water flow from a well used to determine in situ permeabilities can only be estimated, interpretation of the field test results is difficult and uncertain. Thus, one set of problems is exchanged for another.

5.6.2 Equipment

Laboratory permeability testing is performed to determine the permeability or hydraulic conductivity (k) of a soil specimen. For natural soils, tests are conducted on specimens from tube samples. For fill and borrow soils, tests are performed on compacted materials. Two types of tests are commonly performed, the rigid wall test (AASHTO T215; ASTM D 2434) and the flexible wall test (ASTM D 5084).

The equipment for the rigid wall test includes a rigid wall permeameter, a water tank, a vacuum pump, and manometer tubes (see Figure 5-24). The permeameter must be large enough to minimize sidewall leakage. Therefore, the diameter of the rigid wall device should be at least 8 to 12 times that of the largest soil particle in the sample being tested. Frequently, the side wall of the cylinder is coated with petroleum jelly to prevent sidewall leakage. Porous stones and filter paper placed on the top and bottom of the test specimen to

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prevent soil particle erosion by retaining fine particles must not restrict flow through the soil otherwise the permeability of the porous stones or filter paper will be measured. A vacuum pump is used to remove air from the sample and to help saturate the specimen prior to testing. In a rigid wall test saturation is performed from the bottom of the specimen upward (see ASTM D 2434). Manometer outlets should be available on the sides of the cell to measure head loss over the specimen.

Rigid wall permeameters are not recommended for low permeability (i.e., $k \leq 2 \times 10^{-5}$ ft/min (1×10^{-6} cm/s)) soils due to the potential for sidewall leakage. Rigid wall permeameters are typically used for sandy and gravelly soils (ASTM D 2434) with a permeability greater than $2x10^{-2}$ ft/min ($1x10^{-3}$ cm/s). Rigid wall systems are used for granular materials because the permeability of the flexible wall system (valves, pore stones, tubing, etc.) may be less than that of the specimen. Therefore the flexible wall system itself may affect the permeability value of granular soils and a measured value of permeability lower than that of the specimen may result.



Figure 5-24. Rigid wall permeameter (Photograph courtesy of GeoComp Corporation).

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Figure 5-25. Flexible wall permeameter (Photograph courtesy of GeoComp Corporation).

The equipment for a flexible wall test includes a flexible wall permeameter cell, a cell reservoir, a headwater reservoir, a tailwater reservoir, top and base caps, a flexible membrane, porous stones, and filter paper (see Figure 5-25). The specimen can be tested over a range of confining stresses under backpressure saturation. The separate headwater and tailwater reservoirs can be monitored, and falling head or constant head tests can be performed. Since the flexible membrane encases the specimen, side leakage is prevented. Flexible wall permeameter cells consist of influent and effluent lines as well as porous stones and filter paper. The hydraulic conductivity of the system should be tested before a soil specimen is tested to ensure that the system's conductivity is at least one order of magnitude greater than that anticipated for the soil. The triaxial cell can be used as a flexible wall permeameter. In fact, permeability measurements are often made as part of a drained triaxial (CD) test.

The determination of permeability by testing is predicated on the validity of Darcy's Law for laminar flow through porous media. If any of the assumptions of Darcy's Law are violated, the results of permeability testing will be invalid.

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5.6.3 Procedures

Flexible wall permeameters (ASTM D 5084) are used for materials with a hydraulic conductivity (k) less than or equal to $2x10^{-2}$ ft/min ($1x10^{-3}$ cm/sec). The flexible membrane used to encase the specimen prevents sidewall leakage for fine-grained soils that are likely to occur in a rigid wall system. The confining stress of the hydraulic conductivity test should be specified to the laboratory. As confining stress increases, the hydraulic conductivity of fine grained soils will typically decrease due to consolidation of the specimen and reduction of void ratio. The confining stress should be equal to the anticipated effective stress-state in the soil.

The hydraulic gradient, defined as the difference in hydraulic head across the specimen divided by the length of the specimen, should also be specified to the laboratory. Typical hydraulic gradients in field situations are less than 5, however the use of such a small gradient in the laboratory will result in extremely long testing times for materials having hydraulic conductivities less than $2x10^{-5}$ ft/min ($1x10^{-6}$ cm/sec). If the hydraulic gradient across the specimen is too high, turbulent flow will occur and Darcy's Law will be violated with the result that the measured hydraulic conductivity will be less than that which will occur in the field. Suggested values of hydraulic gradient, as presented in Table 5-9, are a function of the anticipated hydraulic conductivity.

Saturation of the specimen is necessary to achieve accurate results. A hydraulic conductivity test should be ended when steady flow is occurring. The flow through the permeameter is considered to be steady when four or more consecutive hydraulic conductivity measurements fall within ±25 percent of the average k value if k is greater than 1×10^{-8} cm/sec, or if four or more measurements fall within ±50 percent of the average if k is less than 1×10^{-8} cm/sec.

Table 5-9
Recommended maximum hydraulic gradient for permeability testing

Hydraulic Conductivity, cm/sec*	Recommended Maximum Hydraulic Gradient
1×10^{-3} to 1×10^{-4}	2
1×10^{-4} to 1×10^{-5}	5
1×10^{-5} to 1×10^{-6}	10
1×10^{-6} to 1×10^{-7}	20
less than 1×10^{-7}	30
* Conventionally expressed in cm/sec. [1 cm/sec ≈ 2 ft/min = 0.6 m/min]	

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5.6.4 Useful Correlations of Permeability with Index Values

The typical range of permeability values for various soil types and USCS groups is presented in Table 5-10, which is based on information originally presented by Casagrande and Fadum (1940). Superimposed on Table 5-10 are "typical soil groups" identified by their USCS symbols (Carter and Bentley, 1991). The range of permeability values corresponding to those groups is typical for compacted soils of that type where compaction is according to ASTM D 1557. Typical permeability values for highway construction materials are given in Table 5-11.

Numerous correlations of permeability with grain size can be found in the literature. Figure 5-26 presents logarithmic plots of k versus D_{10}, based on experimental results. Figure 5-26 includes the well known Hazen's formula. All the correlations shown in Figure 5-26 were developed for sands and gravels. The great range of particle size present in most clays and the effects of clay mineralogy make such correlations of limited use for clays.

Hazen's equation is the most common correlation equation used to estimate permeability for sands ($k \geq 10^{-3}$ cm/sec). This equation is written as:

$$k = C(D_{10})^2 \qquad 5\text{-}14$$

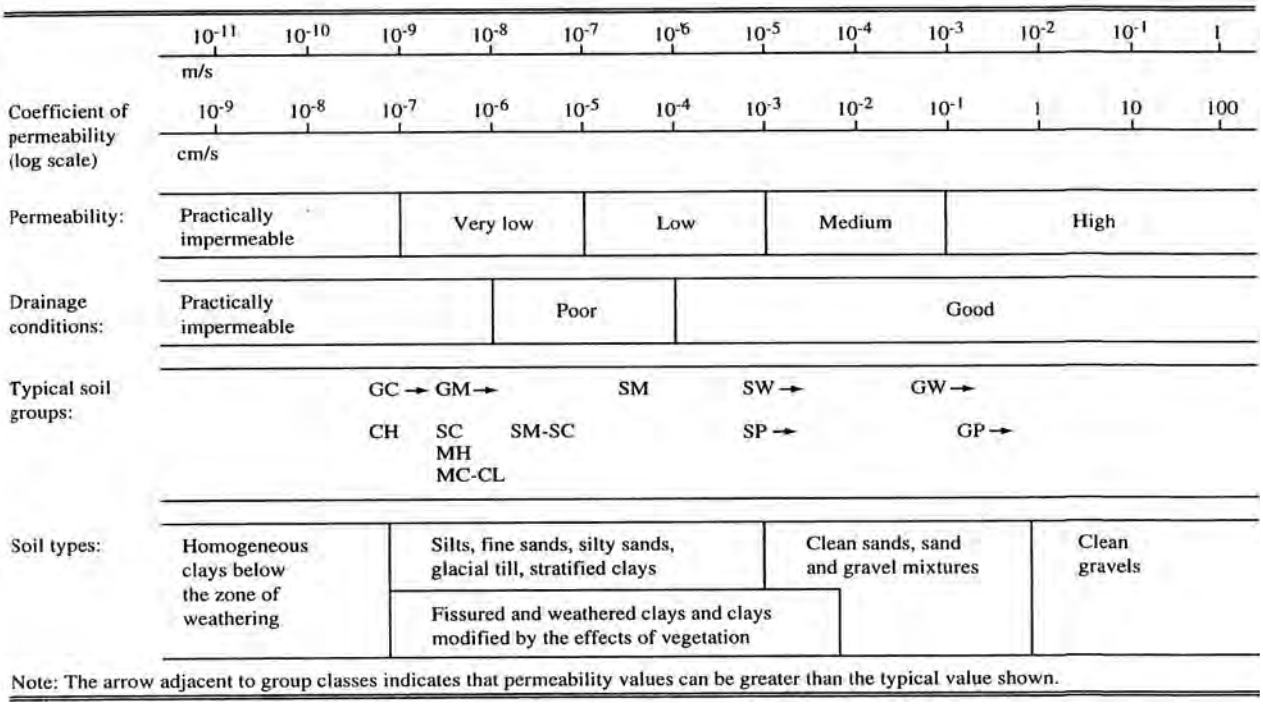
where: k is the permeability in cm/s;

C = a coefficient ranging from 0.4 to 1.2 depending on sand size/sorting; and

D_{10} = effective grain size in mm at 10% passing by weight as determined from sieve analysis.

Hazen's equation should be used with caution since it provides very approximate estimates of k applicable only to clean sands having less than 5% passing the No. 200 sieve (0.075 mm) and with D_{10} sizes between 0.1 and 3.0 mm (Holtz and Kovacs, 1981). Hazen's equation is valid only for $k \geq 10^{-3}$ cm/sec.

Table 5-10
Typical permeability values in soils (after Carter and Bentley, 1991)



Note: The arrow adjacent to group classes indicates that permeability values can be greater than the typical value shown.

Table 5-11
Typical permeability values for highway materials (after Krebs and Walker, 1971)

Materials	**Permeability (cm/sec)**
Uniformly graded coarse aggregate	$40 - 4x10^{-1}$
Well-graded aggregate without fines	$4x10^{-1} - 4x10^{-3}$
Concrete sand, low dust content	$7x10^{-2} - 7x10^{-4}$
Concrete sand, high dust content	$7x10^{-4} - 7x10^{-6}$
Silty and clayey sands	$10^{-5} - 10^{-7}$
Compacted silt	$7x10^{-6} - 7x10^{-8}$
Compacted clay	Less than 10^{-7}
Bituminous concrete (new pavements)*	$4x10^{-3} - 4x10^{-6}$
Portland cement concrete	less than 10^{-8}
* Values as low as 10^{-8} have been reported for sealed, traffic compacted highway pavement.	

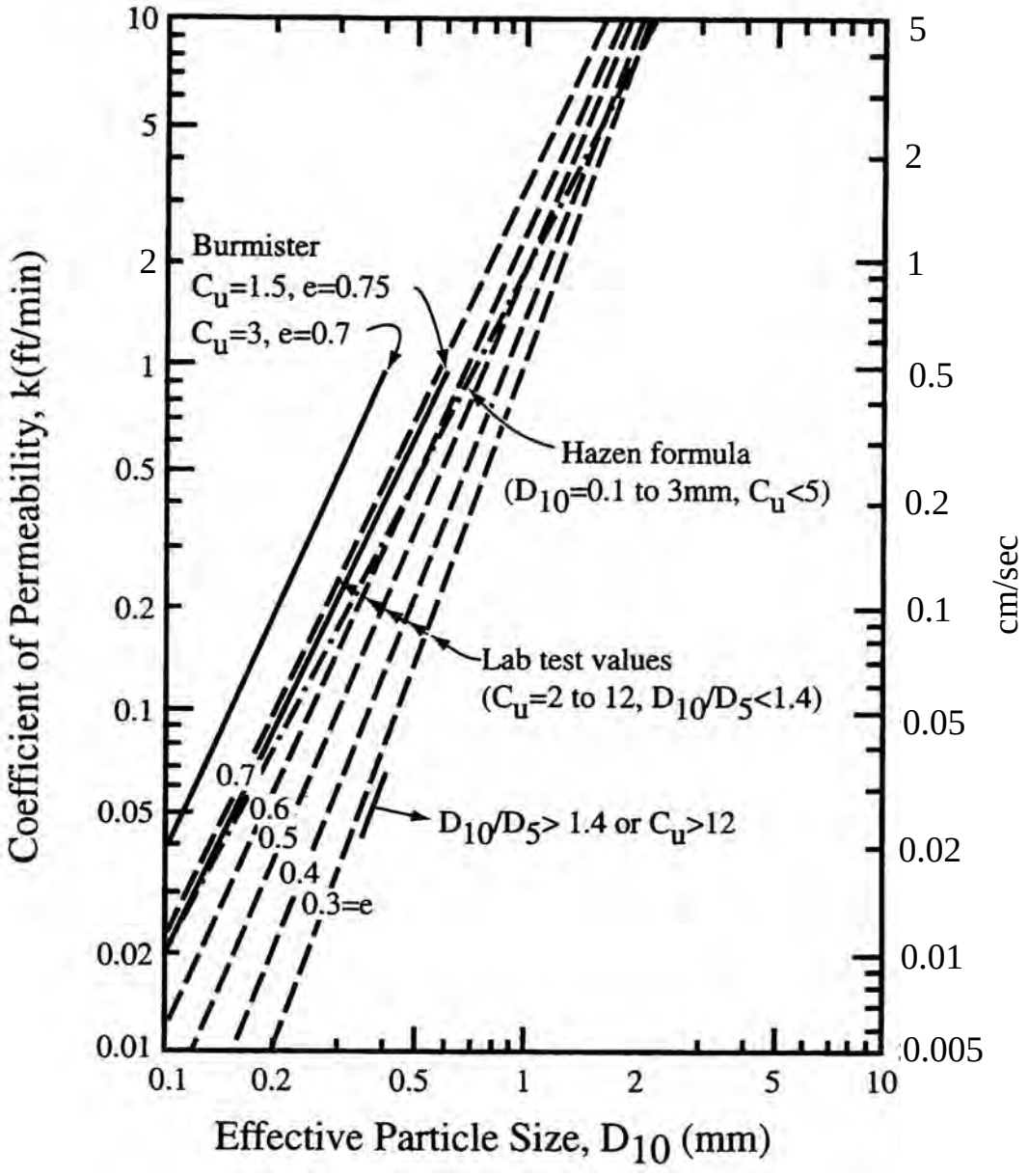


Figure 5-26. The permeability of sands and gravels (after NAVFAC, 1986a).

Note: In Figure 5-26, correlations shown are for remolded compacted sands and sand-gravel mixtures with C_u values as indicated.

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5.7 VOLUME CHANGE PHENOMENA DUE TO LOADING AND MOISTURE

Depending on mineralogy and depositional patterns, natural soils can exhibit either swell (expansion) or collapse under various degrees of loading and moisture ingress. Moisture may be in liquid or frozen form. For foundation design, it is very important to recognize and evaluate the potential for soils to swell or collapse. It is important to realize that these phenomena happen in both natural and compacted soils. Every year millions of dollars are spent dealing with the consequences of swelling (expanding) and collapsing soils. This section briefly discusses these two mechanisms and the tests that can be performed to evaluate the swell (expansion) and collapse potentials.

5.7.1 Swell Potential of Clays

Swelling is a characteristic reaction of some clays to water ingress. The potential for swell depends on the mineralogical composition of the soil fines. While montmorillonite (smectite) exhibits a high degree of swell potential, illite has no to moderate swell potential, and kaolinite exhibits almost none. The percentage of volumetric swell of a soil depends on the amount and type of clay, its relative density, the compaction moisture content and dry density, permeability, location of the groundwater table, the presence of vegetation and trees, overburden pressure, etc. Expansive soils are found throughout the U.S., however, damage caused by expansive clays is most prevalent in certain parts of California, Wyoming, Colorado, and Texas, where the climate is considered to be semi-arid and periods of intense rainfall are followed by long periods of drought. This pattern of wet and dry cycles results in periods of extensive near-surface drying and desiccation crack formation. During intense precipitation, water enters the deep cracks causing the soil to swell; upon drying, the soil will shrink. This weather pattern results in cycles of swelling and shrinking that can be detrimental to the performance of pavements, slabs on-grade, and retaining walls built on or in such soils.

Deep-seated volume changes in expansive soils are rare. More common are volume changes within the upper 3-10 feet (1- 3 m) of a soil deposit. These upper few feet are more likely to be affected by seasonal moisture content changes due to climatic changes. The zone over which volume changes are most likely to occur is defined as the active zone. The active zone can be evaluated by plotting the moisture content with depth for samples taken during the wet season and for samples taken during the dry season at the same location. The depth at which the moisture content becomes nearly constant is the limit of the active zone depth, which is also referred to as the depth of seasonal moisture change. The active zone is an important consideration in foundation design. In the design of piles or drilled shafts, it is important to recognize that full side friction resistance may not be realized in this zone. As

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the soil undergoes cycles of shrinking and swelling, it may lose contact with the pile or shaft. Alternatively, as the soil swells, it may impose significant uplift pressures on the foundation element.

In the field, the presence of surface desiccation cracks and/or fissures in a clay deposit is an indication of expansion potential. Experience has indicated that the most problematic expansive near-surface soils are typically highly plastic, stiff, fissured, overconsolidated clays. Several classification methods are used to identify expansive soils in the laboratory. Currently, there is not a standard classification procedure; different methods are used in various locations across the U.S. Typically, methods include the use of Atterberg limits and/or clay size percentage to describe a soil qualitatively as having low, medium, high, or very high expansion potential. Generally, soils with a plasticity index less than 15 percent will not exhibit expansive behavior. For soils with a plasticity index greater than 15 percent, the clay content of the soil should be evaluated in addition to the Atterberg limits. Figure 5-27 shows the swelling potential of natural soils and soils compacted to standard Proctor procedures (ASTM D 698) as a function of modified activity index, A_m, (Equation 5-4) and clay fraction.

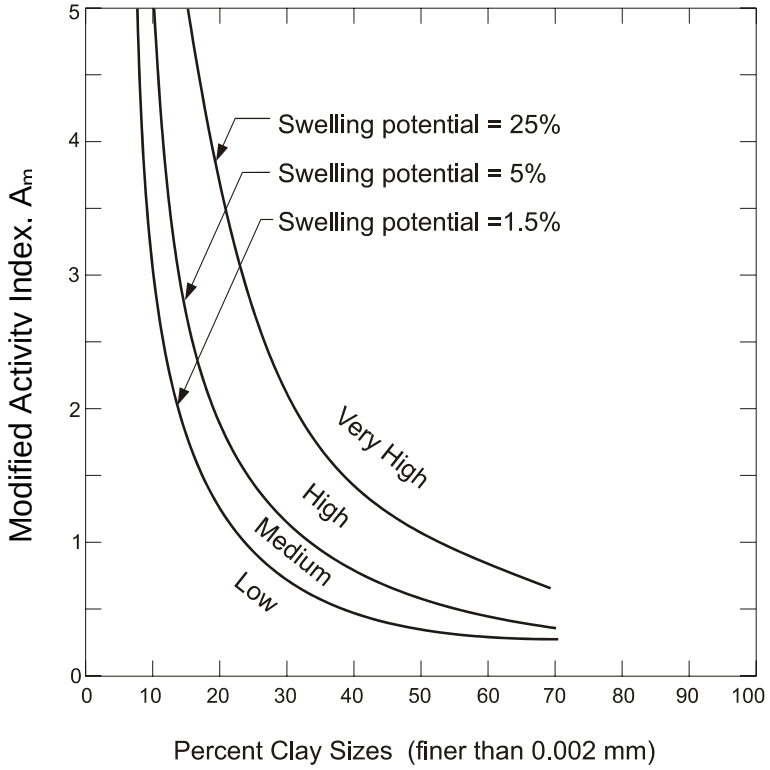


Figure 5-27. Classification of swell potential for soils (after Seed *et al.*, 1962).

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5.7.1.1 Evaluation of Expansion (Swell) Potential

For situations where it is necessary to construct a facility in and around expansive soils, it will be necessary to estimate the magnitude of swell, i.e., surface heave, and the corresponding swelling pressures that may occur if the soil becomes wetted. The swelling pressure represents the magnitude of pressure that would be necessary to resist the tendency of the soil to swell. A one-dimensional swell potential test can be performed in an oedometer on undisturbed or recompacted samples according to AASHTO T256 or ASTM D 4546. In this test, the swell potential is evaluated by observing and measuring the swell of a laterally confined specimen when it is lightly surcharged and flooded with water. Alternatively, if the swelling pressure is to be measured, the height of the specimen is kept constant by adding load after the specimen is inundated. The swelling pressure is then defined as the vertical pressure necessary to maintain zero volume change. Swelling pressures in some expansive soils may be so large that the loads imposed by lightweight structures or pavements do little to counteract the swelling.

The use of the one-dimensional swell potential test to evaluate in-situ swell potential of natural and compacted clay soils has limitations including:

- Lateral swell and lateral confining pressure are not simulated in the laboratory. The calculated magnitude of swell in the vertical direction may not be a reliable estimate of soil expansion for structures that are not confined laterally (e.g., bridge abutments);

- The rate of swell calculated in the laboratory will not likely be indicative of the rate of swell experienced in the field. Laboratory tests cannot simulate the actual availability of water in the field.

It should be noted that there is a lack of a standard definition of swell potential in the technical literature based in part on variations in the test procedures, e.g., the condition of the test specimen (remolded or undisturbed), the magnitude of the surcharge, etc. Therefore the geotechnical specialist must be sure that the conditions used in the laboratory swell test simulate those expected in the field. In general, soils classified as CL or CH according to the USCS and A-6 or A-7 according to the AASHTO classification system should be considered potentially expansive.

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5.7.2 Collapse Potential of Soils

There are several types of soils that can experience collapse under moisture ingress. Examples of such soils are wind-blown deposits such as loess, or alluvial soils deposited in arid or semi-arid environments where evaporation of soil moisture takes place at such a rapid rate that the deposits do not have time to consolidate under their self weight or where the deposits are cemented by precipitated salts. Such soils are predominantly composed of silts and some clay. Typically, the structure of such soils is flocculated and the soil particles are held together by "clay bridges" or some other cementing agent such as calcium carbonate. In both cases disturbed samples obtained from these deposits are generally classified as silt. When dry or at low moisture content the in-situ material gives the appearance of a stable deposit. At elevated moisture contents these soils generally undergo sudden changes in volume and collapse. **Full saturation is not required to realize collapse of such soils; often collapse of the soil structure occurs at moisture contents corresponding to pre-collapse degrees of saturation between 50 to 70%.** Such soils, unlike other non-cohesive soils, will stand on almost a vertical slope until inundated. Collapse-susceptible soils typically have a low relative density, a low unit weight and a high void ratio. Figure 5-28 is a useful tool for assessing whether a soil is collapsible or not based on LL and dry unit weight.

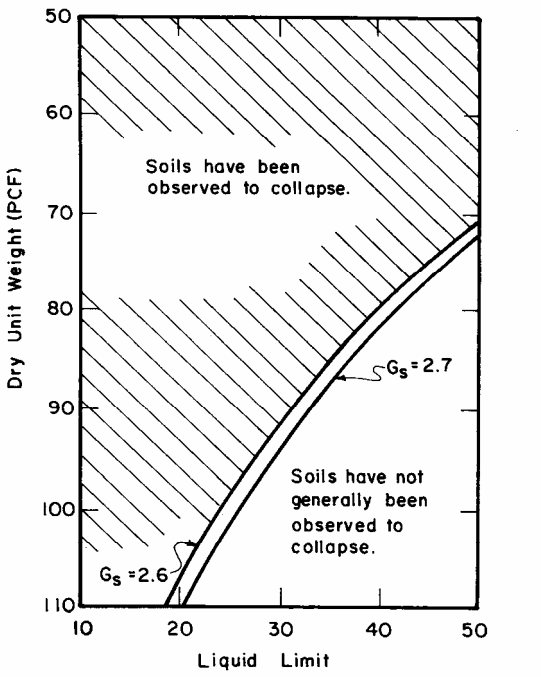


Figure 5-28. Chart for evaluation of collapsible soils (after Holtz and Hilf, 1961).

Structures founded on such soils may be seriously damaged if the soils are inundated and collapse. Therefore, if a soil is suspected to be collapse susceptible, then it is of primary importance to estimate the magnitude of potential collapse that may occur if the soil becomes wetted. To do this, a one-dimensional collapse potential test can be performed in an oedometer on undisturbed or recompacted samples according to ASTM D 5333. For this test, a sample is placed in an oedometer at it natural or compacted moisture content and the vertical pressure on the sample is increased in increments to the anticipated final loading in the field. Readings of vertical deformation are taken during the loading sequence. At the anticipated final load level, water is introduced to the sample and the resulting deformation due to collapse is recorded. The percent collapse (%C) is defined as:

$$\%C = \frac{100\,\Delta H_c}{H_o} \qquad 5\text{-}15$$

where ΔH_c is the change in height upon wetting and H_o is the initial height of the specimen. Conceptually, C is a strain. Therefore, for a soil layer with a given thickness, H, the settlement due to collapse, $s_{collapse}$, if the entire thickness is inundated may be calculated as:

$$s_{collapse} = H\left(\frac{(\%C)}{100}\right) \qquad 5\text{-}16$$

The collapse potential (CP) is calculated as the percent collapse (%C) of a soil specimen subjected to a total load of 4 ksf (200 kPa) as measured by using procedures specified in ASTM D 5333. The CP is an index value used to compare the susceptibility of various soils to collapse. Table 5-12 provides a relative indication of the degree of severity for various values of CP.

Table 5-12
Qualitative assessment of collapse potential (after ASTM D 5333)

Collapse Potential (CP)	Severity of Problem
0	None
0.1 to 2%	Slight
2.1 to 6%	Moderate
6.1 to 10%	Moderately Severe
>10%	Severe

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5.7.3 Expansion of Soils due to Frost Action

The expansion of soils due to frost action is commonly known as **frost heave**. Three conditions are required for frost heave to occur. These are (a) freezing surface, (b) source of water, and (c) fine grained soils in which capillary rise can occur. Frost action in soils can have important engineering consequences as follows (after Holtz and Kovacs, 1981):

- The volume of the soil can immediately increase about 10% just due to the volumetric expansion of water upon freezing.

- The formation of ice crystals and lenses in the soil can cause heaving and damage to light surface structures such as small buildings, and highway pavements. Frost action can also displace retaining walls due to increased lateral pressures.

When water in saturated fine-grained soils freezes, it forms lenses of ice oriented roughly parallel to the surface exposed to low temperature (Terzaghi, *et al.,* 1996). Due to the inherent variability in the distribution of pore space, soils affected by frost action do not freeze and expand uniformly. Therefore, just as with swelling and collapsing soils, differential movement occur, and causes structural damage. Upon thawing, the moisture content of the soil increases which leads to reduction in shear strength and a consequent reduction in bearing capacity. Thus, the freeze-thaw cycle results in significant distress to structures and in particular highway pavements.

Only fine-grained soils are susceptible to frost action. However, the critical grain size marking the boundary between soils that are subject to ice-lens formation and those that are not depends on the uniformity of the soil, i.e., the distribution of pore space. The following conditions noted by Terzaghi, *et al.* (1996) may be used as a general guide for evaluating the frost susceptibility of soils:

- In perfectly uniform soils, i.e., a single particle size soils, ice lenses do not develop unless the grains are smaller than 0.01 mm.

- Uniform soils must contain at least 10% of grains smaller than 0.02 mm.

- In mixed-grain soils, ice lenses form when grains with a size less than 0.02 mm constitute at least 3% of the total aggregate.

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- In soils with less than 1% of grains smaller than 0.02 mm, ice lenses are not formed under any conditions which may be encountered in the field.

Common frost susceptible soils include silts (ML, MH), silty sands (SM), and low plasticity clays (CL, CL-ML). One of the most common methods to mitigate the detrimental effects of frost is to place the foundations below the anticipated frost depth. The depth of frost action depends primarily on air temperature below freezing and duration, soil permeability and soil water content. Figure 5-29 can be used for a preliminary estimate of the frost depth. More positive measures to mitigate damage due to frost action include lowering of the ground water table and, depending on the depth of the frost penetration, removal of the frost susceptible soils in the subgrade or foundation. Use of impervious membranes, chemical additives, and even foamed insulation (Styrofoam) under highways, buildings, and railroads have been successfully employed (Holtz and Kovacs, 1981).

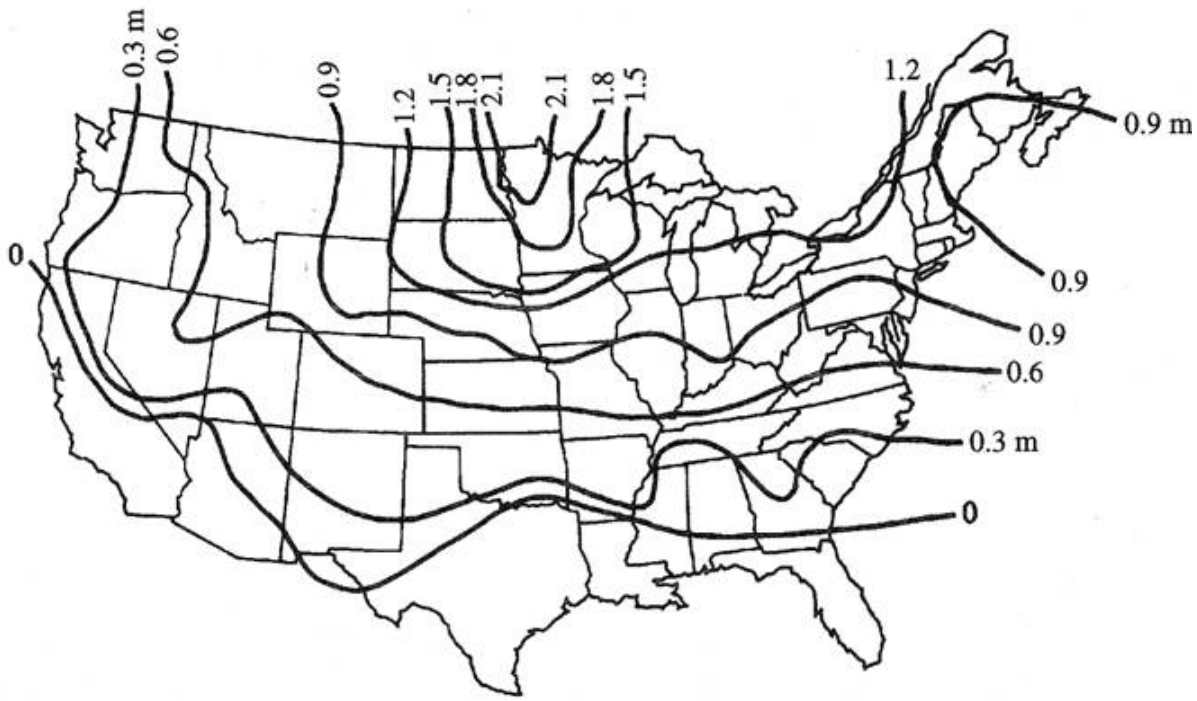


Figure 5-29. Approximate frost depth map for United States (Bowles, 1996). (1 m = 3.28 ft)

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5.8 COMPACTION CHARACTERISTICS OF SOIL

5.8.1 Concept of Compaction

In the construction of highway embankments, earth dams, retaining walls, structural foundations and many other facilities, loose soils must be compacted to increase their densities. Compaction is the process of densifying soil under controlled moisture conditions by application of a given amount and type of energy. Compaction increases the density of the soil, which generally leads to:

- an increase in the strength and stiffness characteristics of the soil,
- a decrease in the amount of undesirable settlement of structures under both static and dynamic loads,
- a reduction in soil permeability, and
- an increase in the stability of slopes and embankments.

Unless compaction is properly controlled, there is a potential that the volume change phenomena described in Section 5.7 (swell, collapse and frost heave) can occur.

The density of compacted soils is measured in terms of the dry unit weight, γ_d, of the soil. The dry unit weight is a measure of the amount of solid materials present in a unit volume of soil. The greater the amount of solid materials, the stronger and more stable the soil will be. Pertinent parameters for evaluating the results of laboratory and field compaction tests are:

- dry “density” or dry “unit weight.”
- compaction water content.
- type of energy input, e.g., impact, static, vibratory, kneading.
- amount of energy input expressed in ft-lbs/ft^3.

Table 5-13 presents a summary of the characteristics of the most commonly used laboratory compaction tests. Figure 5-30 shows a typical hammer and a mold which is used for performing compaction tests in the laboratory. A comparison of the various values in Table 5-13 reveals that the energy level in the Modified Proctor compaction (MPC) test is 4.5 times that for the Standard Proctor compaction (SPC) test.

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Table 5-13
Characteristics of laboratory compaction tests

Common Name	ASTM (AASHTO) Designation	Mold Dimensions			Hammer		No. of Layers	Blows/ Layer	Energy (ft-lbs/ft^3)
		Diam. (in)	Height (in)	Vol. (ft^3)	Wt. (lbs)	Drop Ht. (in)			
Standard Proctor	D 698 (T 99)	4	4½	1/30	5.5	12	3	25	12,375
Modified Proctor	D 1557 (T 180)	4	4½	1/30	10	18	5	25	56,250
Note: Both tests are performed on minus No. 4 (4.75 mm) fraction of the soil.									

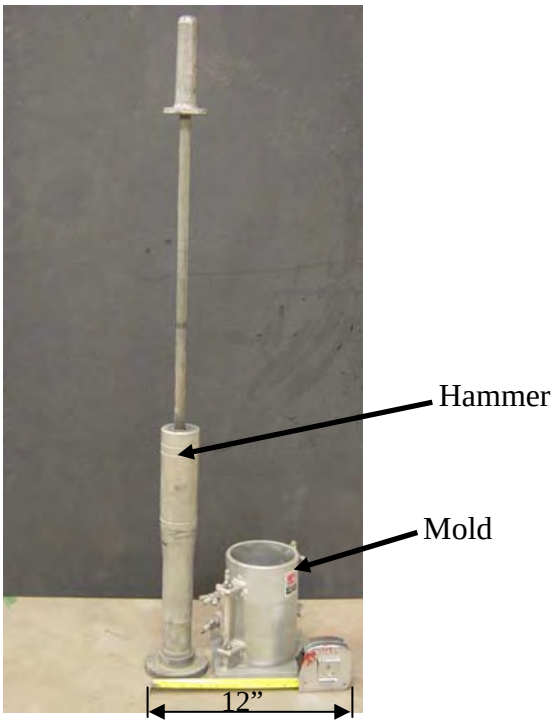


Figure 5-30. Hammer and mold for laboratory compaction test (tape measure is for scale purpose only).

5.8.2 Test Procedures

At least 3 (preferably 5) samples of the same type of soil are prepared at various water contents and compacted according to the requirements listed in Table 5-13. Following compaction, the moist unit weight of the compacted soil (γ_t) in the mold is easily calculated as the weight of the soil (measured) divided by the volume of the mold (constant = 1/30 ft^3). The water content (w) is determined as per ASTM D 2216-05 and the dry unit weight is then calculated as (see Table 2-2 in Chapter 2):

$$\gamma_d = \frac{\gamma_t}{(1+w)} \qquad 5\text{-}17$$

The dry unit weight (pcf (kN/m^3)) for each compacted sample is plotted versus its compaction moisture content (%). The resulting curve is called a **compaction curve**. Figure 5-31 shows compaction curves for the same soil using Standard Proctor compaction (SPC) test parameters and Modified Proctor compaction (MPC) test parameters as listed in Table 5-13. The typical compaction curves as presented in Figure 5-31 have the following characteristics:

- **Maximum dry density** ($\gamma_{d\text{-}max}$) is the dry density corresponding to the peak of the compaction curve for a given type and amount of input energy. Note from Figure 5-31, that the SPC $\gamma_{d\text{-}max}$ is less than the MPC $\gamma_{d\text{-}max}$. Note from Table 5-13 that although the type of energy (impact) is the same for both SPC and MPC, the amount of energy in the MPC test is 4.5 times that of the SPC test.

- **Optimum moisture content** (w_{opt}) is the compaction water content at which the soil attains its maximum dry density for a given input energy. Note from Figure 5-31, that the SPC w_{opt} is greater than the MPC w_{opt}.

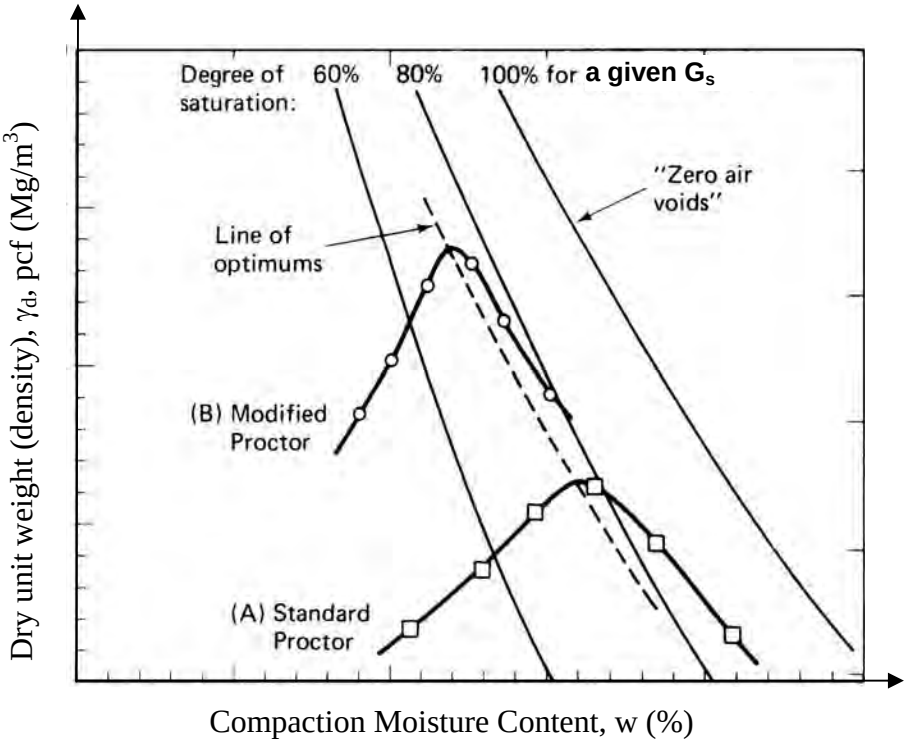


Figure 5-31. Compaction curves (after Holtz and Kovacs, 1981).

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- **Zero air voids curve** is the curve that corresponds to S=100% regardless of the amount or type of energy input. The importance of the zero-air-voids curve is that it denotes the limits of compaction, i.e., if the moisture content of a fill is too high for a given amount of input energy, the compacted fill may begin to "pump" as its voids become fully saturated with moisture. This can happen even at low moisture contents if the input energy is very large as may be the case with too many passes of a too heavy a piece of compaction equipment. Points on the zero air voids curve are calculated from the basic equation for dry unit weight given by Equation 5-18 by setting S=1 and choosing arbitrary values of compaction moisture content within the range of the compaction curve.

$$\gamma_d = \frac{G_s \gamma_w}{(1+e)} = \frac{G_s \gamma_w}{\left(1+\frac{wG_s}{S}\right)} \qquad 5\text{-}18$$

where: G_s = specific gravity of solid particles
γ_w = unit weight of water
e = void ratio
w = water content expressed as a decimal
S = degree of saturation expressed as a decimal.

Note that the S=100% (zero air voids) curve is calculated for a specific value of G_s, in this case 2.7. Curves corresponding to other degrees of saturation can be calculated in the same way by setting S=80 for the 80% saturation curve, S=60 for the 60% saturation curve and so forth. The saturation curve for a degree of saturation less than 100% is often useful for developing compaction specifications for silty soils since such soils frequently have sharply peaked compaction curves. Therefore, they can begin to "pump" even though the degree of saturation is less then 100%.

- **Line of optimums** - As its name suggests the "line of optimums" is obtained by passing a curve through the peaks of the compaction curves that were developed for a certain type of soil compacted at various energy input levels. Testing laboratories frequently develop such curves for various types of soil based on information in their job files. The line of optimums can be used as a guide for developing compaction specifications where no laboratory test data are available.

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The above observations are true for all types of soils and apply to all methods of compaction. The most important concept about compaction curves as discussed above is that an increase in the amount of compaction (more energy) results in an increase in the maximum dry density and a corresponding decrease in the optimum moisture content. Therefore, this concept should be recognized when the geotechnical specialist is required to develop specifications for field compaction of soils.

5.8.3 Implication of Laboratory Tests on Field Compaction Specifications

With reference to Figure 5-31 it is obvious that for a given compaction curve the same dry unit weight can be obtained at two different compaction moisture contents, one below optimum and the other above optimum. For fine-grained soils this difference in moisture contents relates to a difference in soil structure that may affect engineering properties such as shear strength and permeability.

It is very important that compaction specifications be given in terms of three parameters: the compaction energy (Standard or Modified Proctor), the desired dry density expressed as a percentage of the maximum dry density, and the compaction moisture content expressed as a range (+ or -) with respect to the optimum moisture content. For example, since the input energy of Modified Proctor is greater than the input energy of Standard Proctor (see Table 5-13) the Modified Proctor curve plots above the Standard Proctor curve so that 95% of MPC $\gamma_{d\text{-}max}$ may be greater than 100% of SPC $\gamma_{d\text{-}max}$. Likewise, a compaction moisture content of 1 or 2% above optimum for modified Proctor compaction may be below the standard Proctor optimum moisture content.

Unfortunately, laboratory compaction curves mainly serve as guidelines for field compaction. This approach is inconsistent because the impact type of energy input in the laboratory is not the same as the type of energy delivered by the equipment commonly used in construction. Figure 5-32 illustrates this point by presenting the types of compactive effort (static, vibratory, kneading) corresponding to the equipment typically used in practice. Note that none of the compaction processes in Figure 5-32 involves impact type of energy that is used to determine the compaction characteristics of the soils in a laboratory SPC or MPC test.

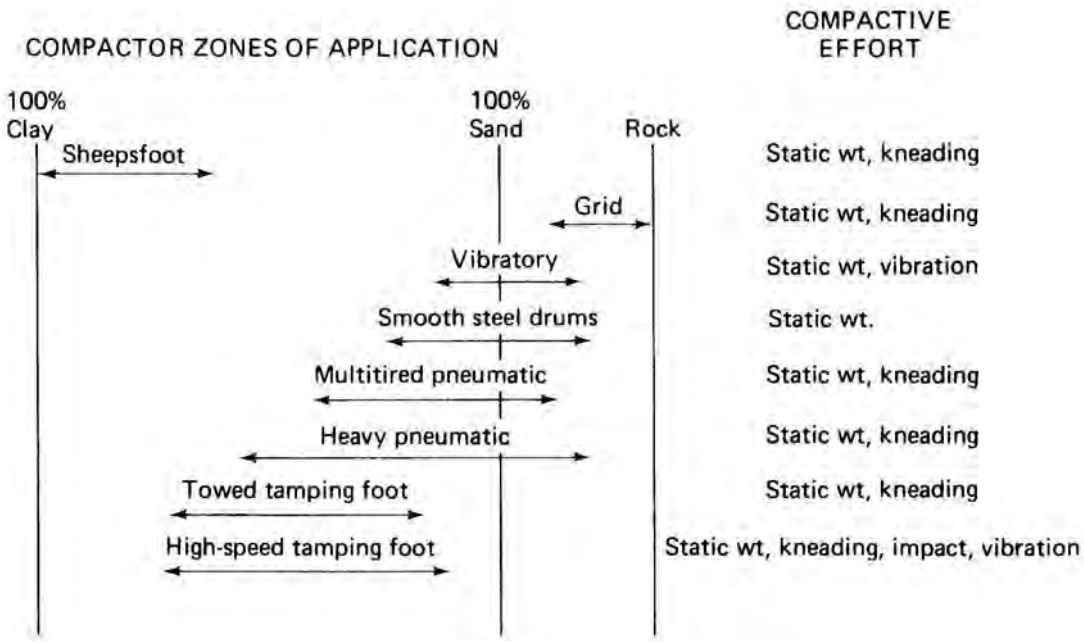


Figure 5-32. Compactors recommended for various types of soil and rock (Schroeder, 1980).

Due to the obvious disconnect between the types of energy in the laboratory and the field, some method is needed to express the laboratory-measured compaction parameters, i.e., maximum dry unit weight ($\gamma_{d\text{-}max}$) and optimum moisture content (w_{opt}), in terms of field compaction. Most commonly, this relationship is achieved by so-called **performance based or end-product specifications** wherein a certain **relative compaction, RC,** also known as **percent compaction**, is specified. The RC is simply the ratio of the desired field dry unit weight, $\gamma_{d\ field}$, to the maximum dry density measured in the laboratory, $\gamma_{d\ max}$, expressed in percent as follows:

$$RC = \frac{\gamma_{d\,field}}{\gamma_{d\,max}} x\,100\% \qquad 5\text{-}19$$

The relative compaction, RC, is not the same as relative density, D_r, that was defined in Chapter 2. Relative density applies only to granular soils with fines less than 12% (ASTM D 2049), while relative compaction is used across a wide variety of soils. Lee and Singh (1971) published the following relationship between RC and D_r based on a statistical evaluation of 47 different granular soils compacted by using Modified Proctor energy (Wright, *et al.*, 2003).

D_r = 0% for RC = 80%

D_r = 100% for RC = 100%

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Assuming a linear interpolation, the above relationship can be expressed as follows:

$$D_r(\%) = 5[RC(\%) - 80] \qquad 5\text{-}20$$

or

$$RC(\%) = 80 + \frac{D_r(\%)}{5} \qquad 5\text{-}21$$

In terms of Standard Proctor, Equations 5-20 and 5-21 are approximately as follows:

$$D_r(\%) = 5[RC(\%) - 85] \qquad 5\text{-}22$$

or

$$RC(\%) = 85 + \frac{D_r(\%)}{5} \qquad 5\text{-}23$$

Figure 5-33 presents the above equations in a graphical format. Table 5-14 presents the values of D_r for values of RC values ranging from 85% to 100% for MPC and from 90% to 105% for SPC.

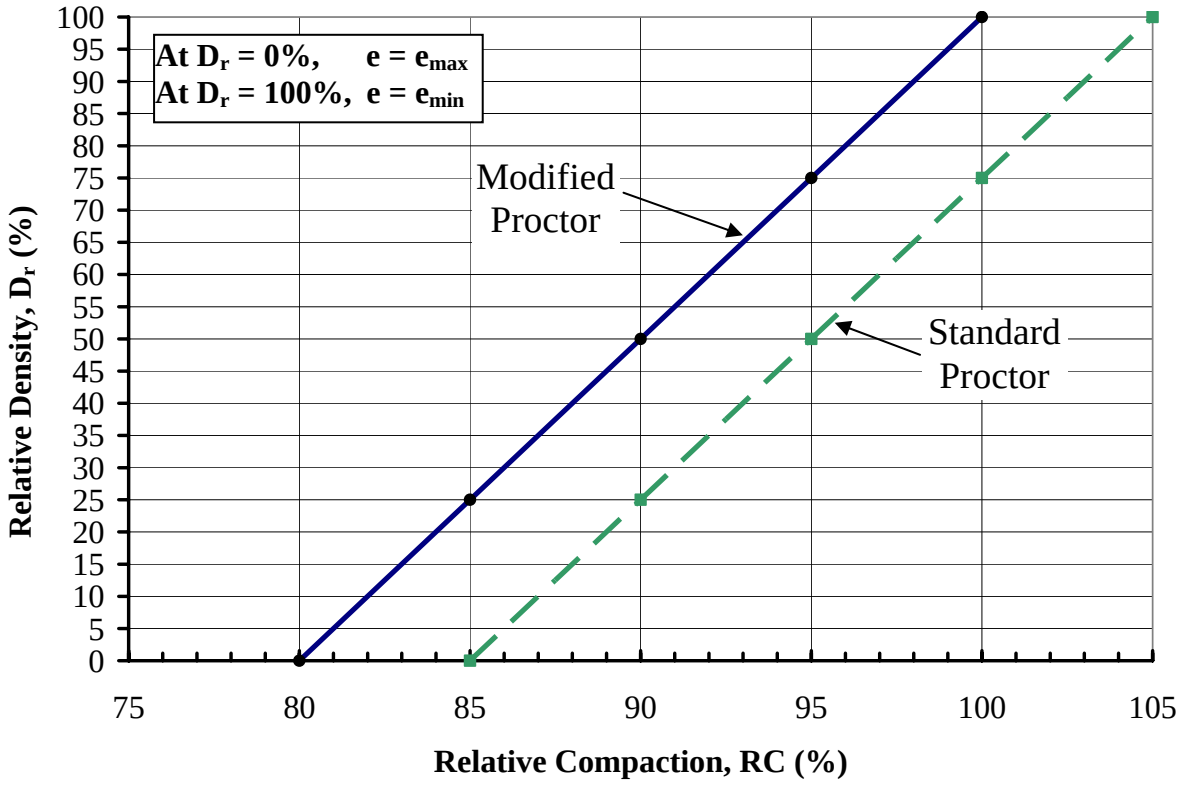


Figure 5-33. Relative density, relative compaction and void ratio concepts.

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Table 5-14
Some values of D_r as a function of RC
based on Modified and Standard Proctor Compaction Test

RC (%) MPC (SPC)*	D_r (%)	RC (%) MPC (SPC)*	D_r (%)	RC (%) MPC (SPC)*	D_r (%)
85 (90)	25	90 (95)	50	95 (100)	75
86 (91)	30	91 (96)	55	96 (101)	80
87 (92)	35	92 (97)	60	97 (102)	85
88 (93)	40	93 (98)	65	98 (103)	90
89 (94)	45	94 (99)	70	99 (104)	95
				100 (105)	100
* MP: Modified Proctor; SP: Standard Proctor					

Figure 5-33 and Table 5-14 indicates that for every 1% increase in RC, the increase in D_r is 5% regardless of compaction energy. This is rather significant when it is realized that the shear strength parameter, ϕ, of granular soils is a direct function of relative density as shown in Figure 5-22 and as illustrated by the following simple computations:

- Based on Figure 5-22, the angle of internal friction for well-graded sands (SW soils) for values of D_r between 50% and 100% varies from 33º to 41º. From Table 5-14, values of D_r between 50% and 100% correspond to RC values of 90 and 100%, respectively for Modified Proctor and 95 and 105%, respectively for Standard Proctor. In other words, for SW soils, for every 1% increase in RC, the angle of internal friction increases by 0.8º.

- Alternatively, the increase in the coefficient of friction, tan ϕ, would be tan (41º)/ tan (33º) = 1.33 or a 33% increase over a 10% change in RC. In other words, there is a 3.3% increase in shear strength for every 1% increase in RC.

Select materials are often specified in the construction of transportation facilities such as embankments, foundations, and pavement sub-bases and bases. The select materials are granular soils as discussed in Chapters 6 (Slope Stability), 7 (Approach Roadway Deformations), 8 (Shallow Foundations) and 10 (Earth Retaining Structures). The above simple example illustrates the importance of carefully specifying RC for such materials. RC values of 90 to 100% of standard Proctor values are commonly used. Based on Table 5-14, this range of RC corresponds to a D_r between 25% and 75%.

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For most transportation applications, the RC value is prescribed in **performance based specifications**. In this case, it does not matter which equipment or type of compaction energy the contractor chooses to use as long as the end-product meets the specified RC. The prudent contractor would choose the equipment according to the type of soil. Often the contractor chooses to use the equipment he/she owns or is cheapest to lease or rent. Unfortunately, this equipment may not always be the most efficient equipment for the work. Figure 5-32 can be used as a preliminary guide in selecting the type of equipment and mode of compaction energy as a function of soil type. In Figure 5-32 the "100%" above the word clay on the left and the word sand on the right indicates boundaries for the range of soils types in between, e.g. 100% clay means that the soil to be compacted is all fine grained, therefore use of a sheepsfoot roller is recommended. The figure also suggests that a sheepsfoot roller can be used for various soil mixtures consisting of up to approximately 35% fine grained soils and 70 % coarse grained soils.

An example of the influence of the choice of compaction equipment and energy is shown in Figure 5-34. Assume that Curve 1 is obtained from laboratory tests to develop the compaction curve for a borrow material that the contractor has identified for a given project. Further assume that the specification for the project requires that RC = 90%. If M represents the point of maximum dry density, γ_{dmax}, then RC=90% would mean that Points P and Y represent the limits of Curve 1 within which the contractor has to operate. In other words, the contractor cannot use compaction moisture contents less than a or c on the compaction moisture content axis.

To properly evaluate the choice of the compaction equipment, the contractor should perform compaction tests at various RC values in the laboratory to develop a line of optimums and a family of curves similar to Curve 2 and 3 shown in Figure 5-34. Once this data is developed, then it can be observed from Figure 5-34, that the most economical water content would be that corresponding to point R along the line of optimums, i.e., the moisture content given by Point b on the X-axis. Point R represents the minimum compactive effort to attain RC=90%. To avoid inadequate compaction and risk failed field quality control tests, a prudent contractor usually aims to achieve somewhat higher dry density. Thus, the contractor often chooses to select a target curve similar to Curve 2 and aim to maintain moisture content in Zone B.

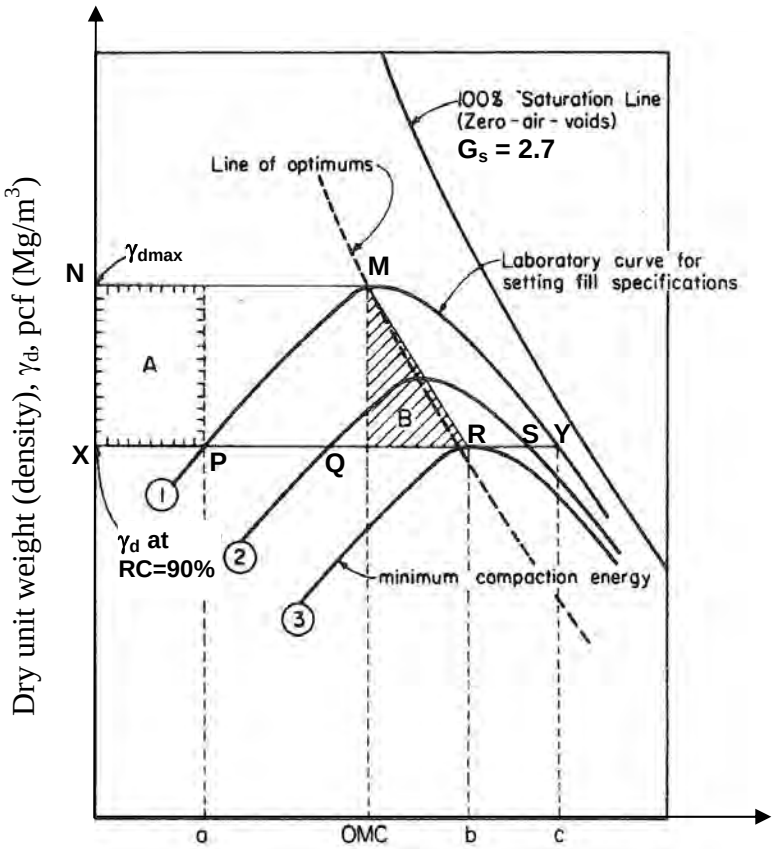


Figure 5-34. Example evaluation of economical field compaction conditions (after Bowles, 1979)

5.8.4 Engineering Characteristics of Compacted Soils

Typical values for the engineering characteristics of compacted soils are given in Table 5-15. The values of the engineering properties refer to soils compacted to maximum dry density by using the standard Proctor test. The data in Table 5-15 are based on more than 1500 soil tests performed by the Bureau of Reclamation in Denver, CO. The large majority of soils were from 17 western states in the U.S. with some foreign soils (USBR, 1960). The background information for the values in Table 5-15 is given in the notes section of the table.

Table 5-15
Average engineering properties of compacted inorganic soils (after USBR, 1960)

USCS	Standard Proctor Compaction (ASTM D 698/AASHTO T 99)		As Compacted Cohesion, c′ psi (kPa)	Saturated Cohesion, c'_{sat} psi (kPa)	Friction Angle, ϕ′ (deg)	Void Ratio, e [Permeability, k (ft/yr)]
	Maximum Dry Density, pcf (kN/m^3)	Optimum Moisture Content (%)				
GW	>119 (>18.7)	<13.3	*	*	>38	* [27,000±13,000]
GP	>110 (>17.3)	<12.4	*	*	>37	* [64,000±34,000]
GM	>114 (>17.9)	<14.5	*	*	>34	* [>0.3]
GC	>115 (>18.1)	<14.7	*	*	>31	* [>0.3]
SW	119±5 (18.7±0.8)	13.3±2.5	5.7±0.6 (39±4)	*	38±1	0.37±* [*]
SP	110±2 (17.3±0.3)	12.4±1.0	3.3±0.9 (23±6)	*	37±1	0.50±0.03 [>15.0]
SM	114±1 (17.9±0.2)	14.5±0.4	7.4±0.9 (51±6)	2.9±1.0 (20±7)	34±1	0.48±0.02 [7.5±4.8]
SM-SC	119±1 (18.7±0.2)	12.8±0.5	7.3±3.1 (50±21)	2.1±0.8 (14±6)	33±4	0.41±0.02 [0.8±0.6]
SC	115±1 (18.1±0.2)	14.7±0.4	10.9±2.2 (75±15)	1.6±0.9 (11±6)	31±4	0.48±0.01 [0.3±0.2]
ML	103±1 (16.2±0.2)	19.2±0.7	9.7±1.5 (67±10)	1.3±* (9±*)	32±2	0.63±0.02 [0.59±0.23]
ML-CL	109±2 (17.1±0.3)	16.8±0.7	9.2±2.4 (63±17)	3.2±* (22±*)	32±3	0.54±0.03 [0.13±0.07]
CL	108±1 (17.0±0.2)	17.3±0.3	12.6±1.5 (87±10)	1.9±0.3 (13±2)	28±2	0.56±0.01 [0.08±0.03]
MH	82±4 (12.9±0.6)	36.3±3.2	10.5±4.3 (72±30)	2.9±1.3 (20±9)	25±3	1.15±0.12 [0.16±0.10]
CH	94±2 (14.8±0.3)	25.5±1.2	14.9±4.9 (103±34)	1.6±0.86 (11±6)	19±5	0.80±0.04 [0.05±0.05]

Notes:
1. The entry ± indicates 90 percent confidence limits of the average value; * denotes insufficient data.
2. For permeability, 1 ft/yr ≈ 10^{-6} cm/sec.
3. All shear strengths, void ratios and permeabilities were determined on samples prepared at Standard Proctor maximum dry density and optimum moisture content.
4. The values of cohesion, c′, and friction angle, ϕ′, are based on a straight-line Mohr strength envelope on an effective stress basis. The value c'_{sat}, was obtained by saturating the sample and shearing it to failure. Consolidated-undrained (CU) triaxial tests were used to determine all the shear strengths.
5. Since all laboratory tests, except large-sized permeability tests, were performed on the minus No. 4 (4.75 mm) fraction of soil, data on average values for gravels are not available for most properties. However, an indication as to whether these average values will be greater than or less than the average values for the corresponding sand group are given in the table (note entries with > or < symbol).
6. Void ratio was derived from the maximum dry density and specific gravity of the soil.
7. In USCS, there are no upper boundaries of liquid limit of MH and CH soils. The maximum limits for MH and CH soils tested by USBR (1960) were 81% and 88%, respectively. Soils with higher liquid limits than these will have inferior engineering properties.

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5.8.4.1 Effect of Increase in Moisture Content on Shear Strength of Compacted Soils

The cohesion values, c' (as-compacted) and c'_{sat} (after saturation of compacted soil) listed in Table 5-15 are instructive in the context of the apparent cohesion concept discussed in Section 5.5.1.2. In the soil's compacted state at optimum moisture content (OMC), the capillary stresses and the apparent mechanical forces assume their peak values at that particular compaction energy. Capillary stress, as discussed in Section 5.5.1.2, is due to surface tension in the water between individual soil grains. The magnitude of capillary stress is larger in fine-grained soils than coarse-grained soils as demonstrated by the increasing values of c' in Table 5-15 as the soil type changes from granular to fine-grained.

The same trend is observed with the c'_{sat} values. However, the values of c'_{sat} are approximately 10% (for CH soils) to 40% (for SM soils) of the corresponding c' values. This drastic reduction in cohesive strength is attributable to the effect of capillary stresses being significantly reduced by the increase in moisture content required to reach saturation resulting in much lower apparent cohesive strengths. The reduction may also represent loss of apparent mechanical forces due to reduction in the interlocking of the particles because of the lubricating effect of water.

Based on the above discussions, it is important to ensure that compacted soils are protected against increases in moisture content because the strength of such soils will decrease with associated detrimental effects on the facilities they support.

5.9 ELASTIC PROPERTIES OF SOILS

The stress-strain behavior of soils and rocks is highly nonlinear or inelastic. However, as indicated in Chapter 2, elastic theory provides a convenient first order approximation to stresses and strains induced in soils by external loads. A pair of elastic constants is required when elastic theory is used to solve such problems, e.g., elastic modulus (E) and Poisson's ratio (ν), or shear modulus (G) and bulk modulus (B), or some other pair of elastic constants. The pair of E and ν is most widely used since both parameters are readily measurable. Consequently, many of the elastic equations in geotechnical engineering are formulated with this pair. Therefore, typical values of E and ν for soils are presented in this section.

The elastic properties of soils may be measured from laboratory stress-strain curves such as those shown in Figure 5-16. The elastic properties, E_s and ν, of a soil may be estimated from empirical relationships presented in Table 5-16 for **preliminary** design or for final design

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where the prediction of deformation is not critical to the performance of the structure, i.e., when the structural design can tolerate the potential inaccuracies inherent in the correlations. The definition of E_s is not always consistent for the various correlations and methods of in-situ measurement. FHWA (2002a) provides additional details regarding the definition and determination of E_s. Where evaluation of elastic settlement is critical to the design of the foundation or selection of the foundation type, in-situ methods such as pressuremeter or dilatometer tests should be used for evaluating the modulus of the impacted strata.

The modulus of elasticity for normally consolidated cohesionless soils tends to increase with depth. An alternative method of defining the soil modulus for granular soils is to assume that the modulus, E_s, increases linearly with depth, starting at zero at the ground surface, in accordance with the following equation:

$$E_s \text{ (tsf)} = n_h \times z \qquad 5\text{-}24$$

where: n_h = rate of increase of soil modulus with depth as defined in Table 5-17 (tsf/ft)
z = depth in feet below the ground surface (ft)

The formulation provided in Equation 5-24 is used primarily for analysis of lateral response or buckling of deep foundations.

5.10 COMMON SENSE GUIDELINES FOR LABORATORY TESTING OF SOILS

Sampling and testing of soils is one of the first and most important steps in the design and construction of all types of structures. Omissions or errors introduced here, if undetected, will be carried through the process of design and construction and will often result in costly and possibly unsafe facilities. Table 5-18 lists topics that should be considered for proper handling of samples, preparation of test specimens, and laboratory test procedures. Table 5-18 should in no way be construed as being a complete list of guidelines to avoid possible errors and omissions in handling or testing of soil specimens; there are more. These are just some of the more common ones.

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Table 5-16
Elastic constants of various soils (after AASHTO 2004 with 2006 Interims)

Soil Type	Typical Range of Young's Modulus Values, E_s (tsf)	Poisson's Ratio, ν
Clay:		
Soft sensitive	25-150	0.4-0.5 (undrained)
Medium stiff to stiff	150-500	
Very stiff	500-1,000	
Loess	150-600	0.1-0.3
Silt	20-200	0.3-0.35
Fine Sand:		
Loose	80-120	0.25
Medium dense	120-200	
Dense	200-300	
Sand:		
Loose	100-300	0.20-0.36
Medium dense	300-500	
Dense	500-800	0.30-0.40
Gravel:		
Loose	300-800	0.20-0.35
Medium dense	800-1,000	
Dense	1,000-2,000	0.30-0.40
Estimating E_s from SPT N-value		
Soil Type		E_s (tsf)
Silts, sandy silts, slightly cohesive mixtures		4 $N1_{60}$
Clean fine to medium sands and slightly silty sands		7 $N1_{60}$
Coarse sands and sands with little gravel		10 $N1_{60}$
Sandy gravel and gravels		12 $N1_{60}$
Estimating E_s (tsf) from q_c static cone resistance		
Sandy soils	$2q_c$ where (q_c is in tsf)	
Note: 1 tsf = 95.76 kPa		

Table 5-17
Rate of increase of soil modulus with depth n_h (tsf/ft) for sand (AASHTO 2004 with 2006 Interims)

Consistency	Dry or Moist	Submerged
Loose	30	15
Medium	80	40
Dense	200	100
Note: 1 tsf/ft = 314.7 kPa/m		

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Table 5-18

Common sense guidelines for laboratory testing of soils

1. Protect samples to prevent moisture loss and structural disturbance.
2. Carefully handle samples during extrusion; samples being extruded should be properly supported upon their exit from the tube.
3. Avoid long term storage of soil samples in Shelby tubes.
5. Properly number and identify samples.
5. Store samples in properly controlled environments.
6. Visually examine and identify soil samples after removal of smear from the sample surface.
7. Use pocket penetrometer or miniature vane only for an indication of consistency not strength.
8. Carefully select “representative” specimens for testing.
9. Have a sufficient number of samples to select from.
10. Always consult the field logs for proper selection of samples.
11. Recognize disturbances caused by sampling, the presence of cuttings, drilling mud or other foreign matter.
12. Do not depend solely on the visual identification of soils for classification.
13. Always perform organic content tests when classifying soils as peat or organic. Visual classifications of organic soils may be very misleading.
15. Do not dry soils in overheated or underheated ovens.
15. Discard old worn-out equipment; old sieves for example, particularly fine (<No. 40) mesh ones need to be inspected and replaced often; worn compaction molds or compaction hammers should be checked and replaced if needed. An error in the volume of a compaction mold is amplified 30x when translated to unit volume.
16. Performance of Atterberg limits tests requires carefully adjusted drop height of the liquid limit machine and proper rolling of plastic limit specimens.
17. Do not use tap water for tests where distilled water is specified.
18. Properly cure stabilization test specimens.
19. Never assume that all samples are saturated as received.
20. Perform saturation by applying properly staged back pressures of adequate magnitude.
21. Use properly fitting o-rings, membranes, etc. in triaxial or permeability tests.
22. Evenly trim ends and sides of undisturbed samples.
23. Be careful to identify and report slickensides and natural fissures.
25. Do not mistakenly identify failures due slickensides as shear failures.
25. Do not use stress-strain curves from unconfined compression test results to determine elastic moduli.
26. Incremental loading of consolidation tests should be performed only after the completion of the primary stage.
27. Use proper loading rate for strength tests.
28. Do not guesstimate e-log p curves from accelerated, incomplete consolidation tests.
29. Avoid "reconstructing" soil specimens, disturbed by sampling or handling, for undisturbed testing.
30. Correctly label all laboratory test specimens.
31. Do not take shortcuts by using non-standard equipment or non-standard test procedures.
32. Periodically calibrate testing equipment and maintain calibration records.
33. Always test a sufficient number of samples to obtain representative results in variable material.
34 Take proper precautions to assure the safety of personnel when performing any test procedure.

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5.11 LABORATORY TESTS FOR ROCK

5.11.1 Introduction

This section provides information on common laboratory test methods for rock including testing equipment, general procedures related to each test, and parameters measured by the tests. Table 5-19 provides a list of commonly performed laboratory tests for rock associated with typical projects for highway applications. Although other laboratory test methods for rock are available including triaxial strength testing, rock tensile strength testing, and durability testing related to rock soundness, most design procedures for structural foundations and slopes on or in rock are developed based on empirical rules related to RQD, degree of fracturing, and the unconfined compressive strength of the rock. The use of more sophisticated laboratory testing for rock properties is usually limited to the most critical projects. Details on other laboratory testing procedures for rock are provided in FHWA, 1997). Table 5-20 provides summary information on the typical rock index and performance tests.

Table 5-19
Common rock tests performed in the laboratory

Test Category	Name of Test	ASTM Test Designation
Point Load Strength	Suggested method for evaluating point-load strength	D 5731
Compressive Strength	Compressive strength of intact rock core specimen (in unconfined compression)	D 2938
Direct Shear Strength	Laboratory direct shear strength tests for rock specimens under constant normal stress	D 5607
Durability	Slake durability of shales and similar weak rocks	D 4644
Strength-Deformation	Elastic moduli of intact rock core specimens in uniaxial compression	D 3148

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Table 5-20
Summary information on laboratory test methods for rock (FHWA, 2002a)

Test	Procedure	Applicable Rock Types	Applicable Rock Properties	Limitations / Remarks
Point-Load Strength Test	Rock specimens in the form of core, cut blocks, or irregular lumps are broken by application of concentrated load through a pair of spherically truncated, conical platens.	Generally not appropriate for rock with uniaxial compressive strength less than 520 ksf (25 MPa)	Provides an index of uniaxial compressive strength	Can be performed in the field with portable equipment or in the laboratory; in soft or weak rock, test results need to be adjusted to account for platen indentation
Unconfined Compressive Strength of Intact Rock Core	A cylindrical rock specimen is placed in a loading apparatus and sheared under axial compression with no confinement until peak load and failure are obtained.	Intact rock core	Uniaxial compressive strength	Simplest and fastest test to evaluate rock strength; fissures or other anomalies will often cause premature failure
Laboratory Direct Shear Test	A rock specimen is placed in the lower half of the shear box and encapsulated in either synthetic resin or mortar. The specimen must be positioned so that the line of shear force lies in the plane of the discontinuity to be investigated. The specimen is then mounted in the upper shear box and the normal load and shear force are applied.	Used to assess peak and residual shear strength of discontinuity	Peak and residual shear strength	May need to perform in-situ direct shear test if design is controlled by potential slip along a discontinuity filled with very weak material
Elastic Moduli of Intact Rock Core	Procedure is similar to that for unconfined compressive strength of intact rock. Lateral strains are also measured	Intact rock core	Modulus and Poisson's ratio	Modulus values (and Poisson's ratio) vary due to nonlinearity of stress-strain curve.
Slake Durability	Dried fragments of rock are placed in a drum made of wire mesh that is partially submerged in distilled water. The drum is rotated, the sample dried, and the sample is weighed. After two cycles of rotating and drying, the weight loss and the shape of size of the remaining rock fragments are recorded.	Shale or other soft or weak rocks	Index of degradation potential of rock	

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5.11.2 Point-Load Strength Test

The point load strength test is used to estimate the unconfined compressive strength of rock. Both core samples and fractured rock samples can be tested. The test is conducted by compressing a piece of the rock between two points on cone-shaped platens (see Figure 5-35) until the rock specimen breaks in tension between these two points. Each of the cone points has a 1/5 in (5 mm) radius of curvature and the cone bodies themselves include a 60° apex angle. The equipment is portable, and tests can be carried out quickly and inexpensively in the field. Because the point load test provides an index value for the compressive strength, usual practice is to calibrate the results with a limited number of uniaxial compression tests on prepared core samples. The point load test is also used with other index values to assess the degradation potential of shales.

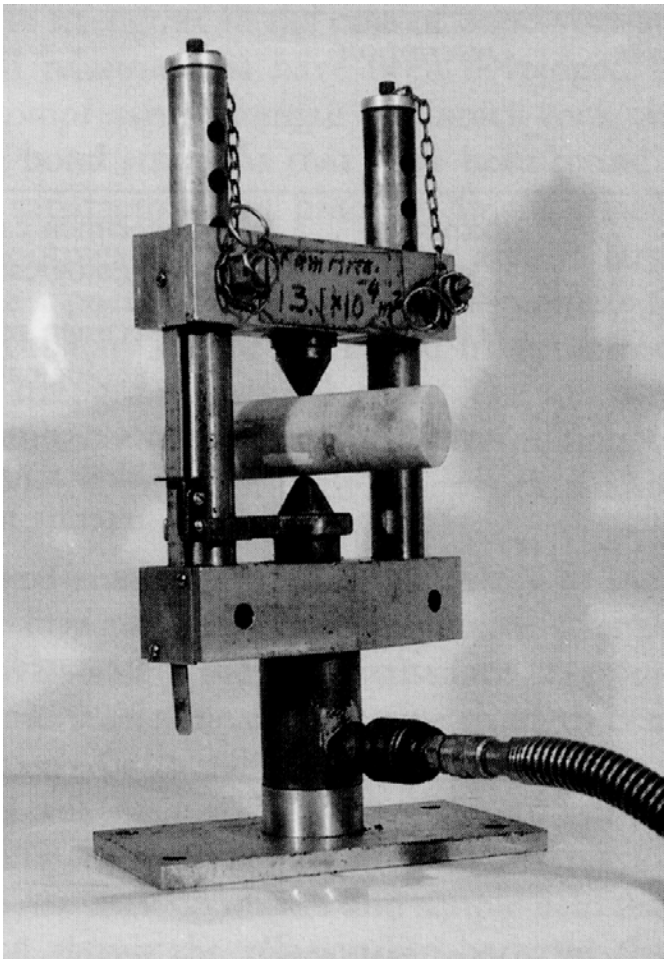


Figure 5-35. Point load strength test equipment (Wyllie, 1999).

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If the distance between the contact points of the platens is D and the breaking load is P, then the point load strength, I_s, is calculated as:

$$I_s = \frac{P}{D_e^{\,2}} \qquad 5\text{-}25$$

where D_e is the equivalent core diameter given by:

(1) $D_e = D^2$ for diametral tests; or
(2) $D_e = 4 \times A$ for axial, block, or lump tests where $A = W \times D$. The area A is the minimum cross-sectional area of a lump sample for a plane through the platen contact points where W is the specimen width.

The size-corrected point load strength index, $I_{s(50)}$ of a rock specimen is defined as the value of I_s that would have been measured by a diametral test with D = 2 in (50 mm). For tests performed on specimens other than 2 in (50 mm) in diameter, the results can be standardized to the size-corrected point load strength index according to:

$$I_{s(50)} = k_{PLT}\, I_s \qquad 5\text{-}26$$

The value of the size correction factor, k_{PLT}, is given by:

$$k_{PLT} = \left(\frac{D}{50}\right)^{0.45} \quad (D \text{ in mm}) \qquad 5\text{-}27$$

It has been found that, on average, the uniaxial compressive strength, σ_c, is about 20 to 25 times the point load strength index, with a value of 24 commonly used, i.e.,

$$\sigma_c = 24\, I_{s(50)} \qquad 5\text{-}28$$

However, tests on many different types of rock show that the σ_c / $I_{s(50)}$ ratio can vary between 15 and 50, especially for anisotropic rocks. Consequently, the most reliable results are obtained if a series of uniaxial calibration tests are carried out. Point load test results are not acceptable if the failure plane lies partially along a pre-existing fracture in the rock, or is not coincident with the line between the platens. For tests in weak rock where the platens indent

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the rock, the test results should be adjusted by measuring the amount of indentation and correcting the distance D (Wyllie, 1999).

5.11.3 Unconfined Compressive Strength of Intact Rock Core

The unconfined compressive strength of intact rock core can be evaluated by using ASTM D 2938. In this test, rock specimens of regular geometry, generally rock cores, are used. The rock core specimen is cut to length so that the length to diameter ratio is 2.5 to 3.0 and the ends of the specimen are machined flat. ASTM D 2938 provides tolerance requirements related to the flatness of the ends of the specimen, the perpendicularity of the ends of the specimens, and the smoothness of the length of the specimen. The specimen is placed in a loading frame, see Figure 5-36a. Axial load is then continuously applied to the specimen at a uniform rate until peak load and failure are obtained. The unconfined or uniaxial compressive strength of the specimen is calculated by dividing the maximum load carried by the specimen during the test by the initial cross-sectional area of the specimen.

This test is more expensive than the point load strength test, but it is also more accurate with respect to in situ strength. Careful consideration of the design requirements should be made before deciding which test to perform, the unconfined compression test, a performance test, or the simpler point load strength test, an index test.

5.11.4 Elastic Modulus of Intact Rock Core

The test to determine the elastic modulus of intact rock is performed similarly to the unconfined compressive test discussed previously, except that deformation is monitored during application of load. This test is performed when it is necessary to estimate both the elastic modulus and the Poisson's ratio of the intact rock core. Because of this dual purpose, it is common to measure both axial (or vertical) and lateral (or diametral) strain during compression. It is preferable to use strain gauges glued directly to the rock surface (see Figure 5-36b) as compared to LVDTs mounted on the platens since slight imperfections at the contact between the platens and the rock may lead to movements that are not related to strain in the rock (Wyllie, 1999).

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(a) (b)

Figure 5-36. (a) Unconfined compression strength test on intact rock core, (b) Use of strain gage on intact rock core sample for measurement of stress-strain characteristics. (Photographs courtesy of Geomechanics Laboratory, University of Arizona).

5.11.5 Laboratory Direct Shear Test

The apparatus and procedures for direct shear testing are discussed in ASTM D 5607. The direct shear test is typically used to evaluate the shear strength of a rock discontinuity. Overall, the equipment for the direct shear test on rock is similar to that for soil including a direct shear testing machine, a device for applying normal pressure, and vertical and horizontal displacement monitoring devices. A schematic of the test set up is shown in Figure 5-37. For testing rock specimens, an encapsulating material such as a high strength gypsum cement is poured around the specimen in the upper and lower holding ring. The specimen is sheared as one holding ring is displaced horizontally with respect to the other such that the discontinuity surface is exactly parallel to the direction of the shear load. Load cells are used to monitor the shear force and LVDTs or dial gauges are used to monitor both horizontal and vertical deformation. Multiple LVDTs should be used to monitor vertical deformation and potential rotation of the specimen in the vertical plane.

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Typically, the results of a direct shear test on rock are presented on two separate plots: one a plot of shear stress versus shear displacement and the other a plot of normal displacement versus shear displacement. Normal stresses should be adjusted to account for potential decreases in the shear contact area. After the sample is sheared, the sample is reset to its original position, the normal load is increased, and another test is performed. Each test will produce a pair of shear stress and normal stress values for both peak and residual conditions. The friction angle of the discontinuity surface can be evaluated from this data.

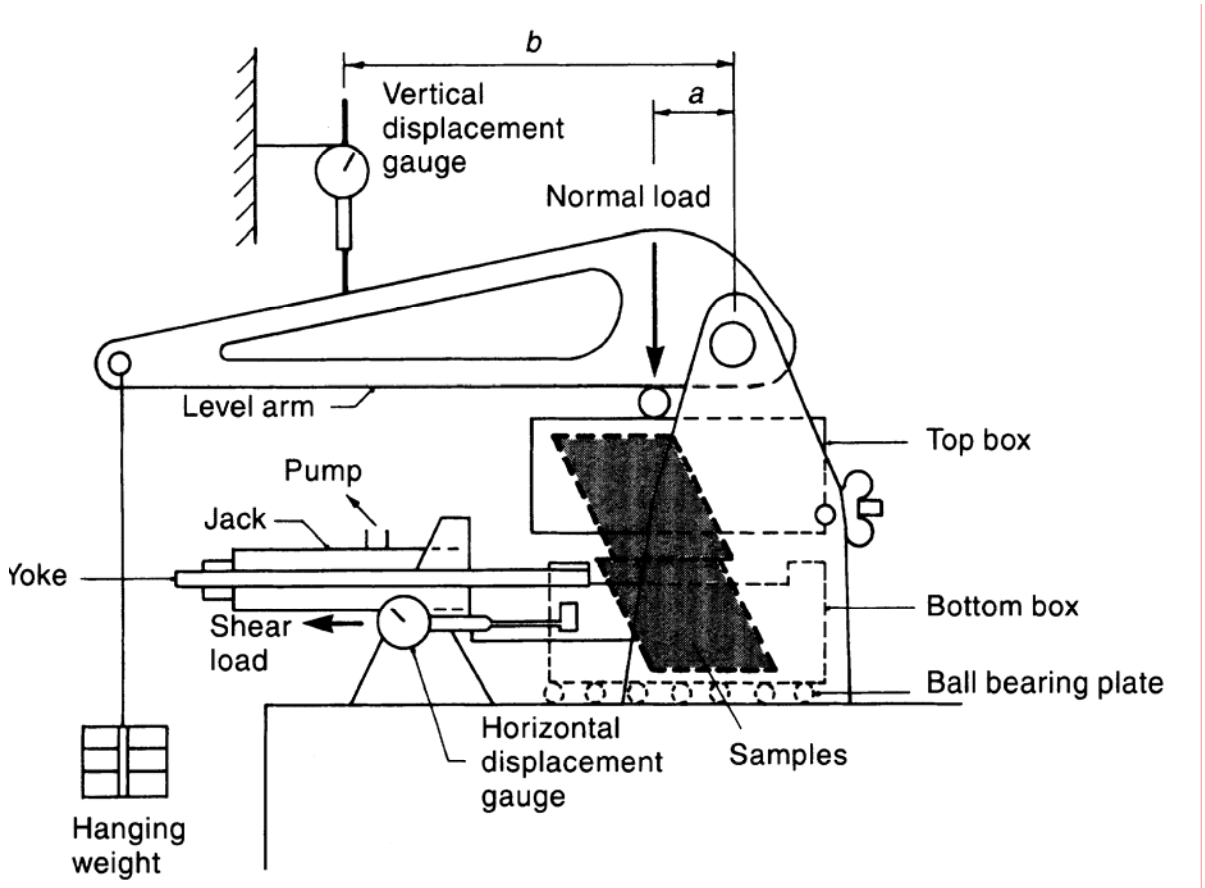


Figure 5-37. Laboratory direct shear testing equipment for rock (Wyllie, 1999).

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5.12 ELASTIC PROPERTIES OF ROCKS

Preliminary estimates of the elastic modulus of intact rock can be made from Table 5-21. Note that some of the rock types identified in the table are not present in the U.S. As discussed in Chapter 4, **it is extremely important to use the elastic modulus of the rock mass for computation of in-situ displacements of rock under applied loads. Use of the intact modulus will result in unrealistic and unconservative estimates of displacement. Section 5.12.1 presents some guidance for estimating the elastic modulus of a rock mass.**

Poisson's ratio for rock should be determined from tests on intact rock core. Where tests on rock core are not practical, Poisson's ratio may be estimated from Table 5-22.

Table 5-21
Summary of elastic moduli for intact rock (AASHTO 2004 with 2006 Interims).

Rock Type	No. of Values	No. of Rock Types	Elastic Modulus, E_i (psi $\times 10^6$)			Standard Deviation (psi $\times 10^6$)
			Maximum	Minimum	Mean	
Granite	26	26	15.5	0.93	7.64	3.55
Diorite	3	3	16.2	2.48	7.45	6.19
Gabbro	3	3	12.2	9.8	11.0	0.97
Diabase	7	7	15.1	10.0	12.8	1.78
Basalt	12	12	12.2	5.20	8.14	2.60
Quartzite	7	7	12.8	5.29	9.59	2.32
Marble	14	13	10.7	0.58	6.18	2.49
Gneiss	13	13	11.9	5.13	8.86	2.31
Slate	11	2	3.79	0.35	1.39	0.96
Schist	13	12	10.0	0.86	5.97	3.18
Phyllite	3	3	2.51	1.25	1.71	0.57
Sandstone	27	19	5.68	0.09	2.13	1.19
Siltstone	5	5	5.76	0.38	2.39	1.65
Shale	30	14	5.60	0.001	1.42	1.45
Limestone	30	30	13.0	0.65	5.7	3.73
Dolostone	17	16	11.4	0.83	5.22	3.44
Note: 1 psi = 6.895 kPa						

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Table 5-22
Summary of Poisson's ratio for intact rock (AASHTO 2004 with 2006 Interims)

Rock Type	No. of Values	No. of Rock Types	Poisson's Ratio, ν			Standard Deviation
			Maximum	Minimum	Mean	
Granite	22	22	0.39	0.09	0.20	0.08
Gabbro	3	3	0.20	0.16	0.18	0.02
Diabase	6	6	0.38	0.20	0.29	0.06
Basalt	11	11	0.32	0.16	0.23	0.05
Quartzite	6	6	0.22	0.08	0.14	0.05
Marble	5	5	0.40	0.17	0.28	0.08
Gneiss	11	11	0.40	0.09	0.22	0.09
Schist	12	11	0.31	0.02	0.12	0.08
Sandstone	12	9	0.46	0.08	0.20	0.11
Siltstone	3	3	0.23	0.09	0.18	0.06
Shale	3	3	0.18	0.03	0.09	0.06
Limestone	19	19	0.33	0.12	0.23	0.06
Dolostone	5	5	0.35	0.14	0.29	0.08

5.12.1 Elastic Modulus of Rock Mass

The elastic modulus of a rock mass (E_m) shall be taken as the lesser of the intact modulus of a sample of rock core (E_i) or the modulus computed from one of the following equations:

$$E_m = 145000 \times [10^{(RMR-10)/40}] \qquad 5\text{-}29$$

where: E_m = Elastic modulus of the rock mass (psi)
RMR = Rock Mass Rating (see Chapter 4)

Note that in almost all cases, the elastic modulus of the rock mass, E_m, is less than the elastic modulus of the intact rock, E_i.

The elastic modulus of the rock mass can also be determined from the following equation:

$$E_m = E_m/E_i \times E_i \qquad 5\text{-}30$$

where E_i is the elastic modulus of the intact rock. E_m/E_i is basically a reduction factor to account for discontinuities in the rock mass and can be determined by using the guidance in

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Table 5-23. In using Table 5-23, it is important that the elastic modulus for the intact rock, E_i, be determined from tests rather than by using the data in Table 5-21. For critical or large structures, determination of rock mass modulus (E_m) by in-situ tests may be warranted. A discussion of suitable in-situ tests can be found in FHWA (2002a).

Table 5-23
Estimation of E_m based on RQD (AASHTO 2004 with 2006 Interims).

RQD (Percent)	E_m/E_i	
	Closed Joints	Open Joints
100	1.00	0.60
70	0.70	0.10
50	0.15	0.10
20	0.05	0.05
Note: Refer to Chapter 3 for guidance on determination of RQD and a description of rock joints.		

5.13 COMMON SENSE GUIDELINES FOR LABORATORY TESTING OF ROCKS

As with soils, omissions or errors introduced during laboratory testing of rock, if undetected, will be carried though the process of design and construction and will often result in costly and possibly unsafe facilities. Table 5-24 lists topics that should be considered and given proper attention so that a reasonable assessment of the rock properties will be assured and an optimization of the geotechnical investigation can be realized in terms of economy, performance, and safety. Guidance in proper handling and storage of rock cores may be found in ASTM D 5079.

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Table 5-24
Common sense guidelines for laboratory testing of rocks

1. Provide protection of samples to avoid moisture loss and structural disturbance.
2. Clearly indicate proper numbering and identification of samples.
3. Store samples in controlled environments to prevent drying, overheating & freezing.
5. Take care in the handling and selection of "representative" specimens for testing.
5. Consult the field logs while selecting test specimens.
6. Recognize disturbances and fractures caused by coring procedures.
7. Maintain trimming and testing equipment in good operating condition.
8. Use properly fitting, platens, o-rings and membranes in triaxial, uniaxial, and shear tests.
9. Maintain tolerances in trimming of ends and sides of intact cores.
10. Document frequency, spacing, conditions and infilling of joints and discontinuities.
11. Periodically calibrate instruments used to measure load, deflection, temperatures and time.
12. Use a properly-determined loading rate for strength tests.
13. Photo document samples cores, fracture patterns and test specimens for possible use in a report.
15. Carefully align and level all specimens in directional loading apparatuses and test frames.
15. Record initial baselines, offsets, and eccentricities prior to testing.
16. Save remnant rock pieces after destructive testing by uniaxial, triaxial and direct shear tests.
17. Conduct nondestructive tests (i.e., porosity, unit weight, ultrasonics) prior to destructive strength tests (compression, tensile, shear).
18. Take proper precautions to assure the safety of personnel when any test procedure is performed.

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5.14 PRACTICAL ASPECTS FOR LABORATORY TESTING

A poor understanding sometimes exists among geologists, structural engineers, and some foundation engineers about the type and amount of laboratory testing required for design of geotechnical features whether they happen to be structural foundations or earthwork. This weakness may render subsequent analyses useless. Organizations that have neither the proper testing facilities nor trained soils laboratory personnel should contract testing to competent AASHTO/ASTM certified private testing firms. This solution can be effective only if the project foundation designer can confidently request the necessary testing and review the results to select design values. A fair estimate of the costs associated with a private testing laboratory may be obtained by assuming the following number of person-days (pd) per test and multiplying by current labor costs:

- visual description of an SPT sample including moisture content (0.05 pd),
- visual description of a tube sample including moisture content and unit weight (0.1 pd),
- classification tests (0.7 pd),
- undrained triaxial test (0.9 pd),
- drained triaxial test (2.0 pd),
- consolidation test (2.0 pd).

These values include all work required to present a completed test result to the foundation designer. Alternatively, most private testing laboratories provide a schedule of services and associated costs that can be used to obtain a more accurate estimate of the cost of a proposed laboratory test program.

Blanket consultant contracts "to perform testing necessary for design" usually result in unnecessarily large quantities of testing being performed, much of which does not apply to the project geotechnical issues. For example, if a multi span structure is crossing an area having a soft clay surface deposit underlain by sands, inordinate amounts of time and money should not be spent to determine the strength and consolidation parameters of the soft clay layer at pier and abutment locations in great detail. Generally a pile foundation will be designed by using SPT N-values and the only laboratory testing that may be needed in the soft clay layer may be to estimate drag forces on the piles. Also, non-standard strength testing such as torvanes, penetrometers, etc., which are not covered by ASTM or AASHTO standards, should not be permitted. Such devices should be used only for field index tests to determine consistency.

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5.15 VARIABILITY OF MEASURED PROPERTIES

Chapters 3, 4 and 5 presented methodologies to perform subsurface explorations, to describe identify, and classify subsurface materials, and to implement and interpret a laboratory test program. The topics covered in these chapters are presented in the temporal sequence in which they are performed on an actual project. Therefore, the geotechnical specialist should continuously evaluate the results of laboratory tests with respect to the initial subsurface model prepared as part of Step 1 of the flow chart presented in Figure 3-1 of Chapter 3. Table 5-25 presents the values of the coefficient of variation of measured properties that should be taken into consideration as the subsurface model is finalized for engineering design. The data in Table 5-25 can be used by the geotechnical specialist as follows:

- Perform sensitivity (parametric) studies to evaluate the effect of variability in properties with respect to the subsurface profile and the type, magnitude and direction of the anticipated loading and establish the best-case and worst-case scenarios,

- Evaluate the need to perform additional explorations,

- Exercise judgment with respect to the results of engineering analyses and designs and convey the uncertainty to the project team, in particular to the structural engineer, and

- Establish the need for instrumentation to monitor the performance of the facility during and after construction .

The finalization of the subsurface model should be performed by a geotechnical specialist who is experienced in the design and construction aspects of the proposed facility. Active input should be sought from the field inspectors and the laboratory personnel who were actually involved in the collection of the data. At this stage, it is recommended that the geotechnical specialist seek a peer review from one or more **qualified and experienced** geotechnical specialist(s) with the specific purpose of having them evaluate whether or not the collected data and subsurface model is adequate to permit a cost-effective design of the facility. The experienced geotechnical specialist(s) can also provide information on potential value analysis alternatives (value engineering) for the design of the facility based on the collected data. The importance of such peer reviews cannot be overemphasized. Finally, the owner of the facility should be informed of the findings so that the owner can make decisions such as authorizing more field explorations and/or laboratory tests or modifying the facilities as appropriate based on the results of the geotechnical investigation thus far.

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Table 5-25
Values of coefficient of variation, V, for geotechnical properties and in situ tests (after Duncan, 2000)

Measured or interpreted parameter value	**Coefficient of Variation, V (Note 1)**
Unit weight, γ	3 to 7 %
Buoyant unit weight, γ_b	0 to 10 %
Effective stress friction angle, ϕ'	2 to 13 %
Undrained shear strength, s_u	13 to 40 %
Undrained strength ratio (s_u/p_o)	5 to 15 %
Compression index, C_c	10 to 37 %
Preconsolidation pressure, p_c	10 to 35 %
Hydraulic conductivity of saturated clay, k	68 to 90 %
Hydraulic conductivity of partially-saturated clay, k	130 to 240 %
Coefficient of consolidation, c_v	33 to 68 %
Standard penetration blow count, N	15 to 45 %
Electric cone penetration test, q_c	5 to 15 %
Mechanical cone penetration test, q_c	15 to 37 %
Vane shear test undrained strength, s_{uVST}	10 to 20 %
Note 1: Coefficient of Variation, V, is defined as standard deviation divided by the average (mean) value expressed as a percentage.	

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CHAPTER 6.0
SLOPE STABILITY

Ground stability must be assured prior to consideration of other foundation related items. Embankment foundation problems involve the support of the embankment by natural soil. Problems with embankments and structures occasionally occur that could be prevented by initial recognition of the problem and appropriate design. Stability problems most often occur when the embankment is to be built over soft soils such as low strength clays, silts, or peats. Once the soil profile, soil strengths, and depth of ground water table have been determined by field explorations and/or field and laboratory testing, the stability of the embankment can be analyzed and a factor of safety estimated. If the embankment is found to be unstable, measures can then be taken to stabilize the foundation soils.

As illustrated in Figure 6-1, there are four major types of instability that should be considered in the design of embankments over weak foundation soils. Recommendations on how to recognize, analyze, and solve each of the first three problems are presented in this chapter. Lateral squeeze is more closely related to the evaluation of foundation deformation and is discussed in Chapter 7 (Approach Roadway Deformations).

The stability problems illustrated in Figure 6-1 can be classified as “internal” or "external." "Internal" embankment stability problems generally result from the selection of poor quality embankment materials and/or improper placement of the embankment fills and/or improper placement requirements. The infinite slope failure mode is an example of an “internal” stability problem; often such a failure is manifested as sloughing of the surface of the slope. Internal stability can be assured through project specifications by requiring granular materials with minimum gradation and compaction requirements. An example of a typical specification for approach roadway construction is presented in Chapter 7. The failure modes shown in Figure 6-1b, c and d, can be classified as “external” stability problems.

6.01 Primary Reference

The primary reference for this chapter is as follows:

FHWA (2001a). *Soil Slope and Embankment Design Reference Manual.* Report No. FHWA NHI-01-026, Authors: Collin, J. G., Hung, J. C., Lee, W. S., Munfakh, G., Federal Highway Administration, U.S. Department of Transportation.

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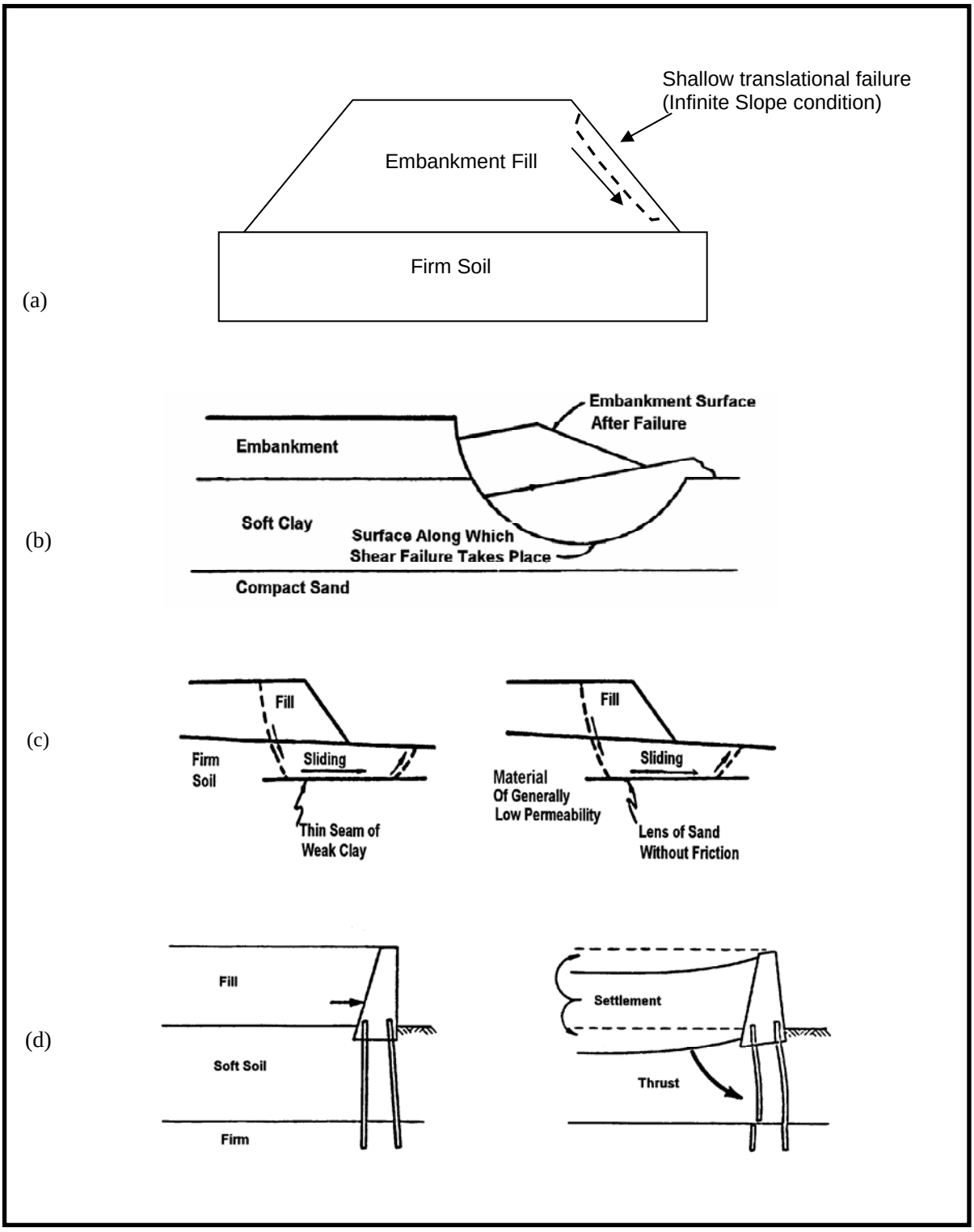


Figure 6-1. Embankment failures: (a) Infinite slope failure in embankment fill, (b) Circular arc failure in embankment fill and foundation soil, (c) Sliding block failure in embankment fill and foundation soil, and (d) Lateral squeeze of foundation soil.

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6.1 EFFECTS OF WATER ON SLOPE STABILITY

Very soft, saturated foundation soils or ground water generally play a prominent role in geotechnical failures in general. They are certainly major factors in cut slope stability and in the stability of fill slopes involving both "internal" and "external" slope failures. The effect of water on cut and fill slope stability is briefly discussed below.

- **Importance of Water**

  Next to gravity, water is the most important factor in slope stability. The effect of gravity is known, therefore, water is the key factor in assessing slope stability.

- **Effect of Water on Cohesionless Soils**

  In cohesionless soils, water does not affect the angle of internal friction (ϕ). The effect of water on cohesionless soils below the water table is to decrease the intergranular (effective) stress between soil grains (σ'_n), which decreases the frictional shearing resistance (τ').

- **Effect of Water on Cohesive Soils**

  Routine seasonal fluctuations in the ground water table do not usually influence either the amount of water in the pore spaces between soil grains or the cohesion. The attractive forces between soil particles prevent water absorption unless external forces such as pile driving, disrupt the grain structure. However, certain clay minerals do react to the presence of water and cause volume changes of the clay mass.

  An increase in absorbed moisture is a major factor in the decrease in strength of cohesive soils as shown schematically in Figure 6-2. Water absorbed by clay minerals causes increased water contents that decrease the cohesion of clayey soils. These effects are amplified if the clay mineral happens to be expansive, e.g., montmorillonite.

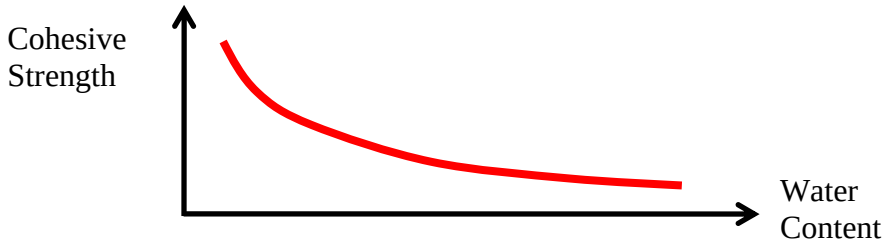


Figure 6-2. Effect of water content on cohesive strength of clay.

- **Fills on Clays**

  Excess pore water pressures are created when fills are placed on clay or silt. Provided the applied loads do not cause the undrained shear strength of the clay or silt to be exceeded, as the excess pore water pressure dissipates consolidation occurs, and the shear strength of the clay or silt increases with time. For this reason, the factor of safety increases with time under the load of the fill.

- **Cuts in Clay**

  As a cut is made in clay the effective stress is reduced. This reduction will allow the clay to expand and absorb water, which will lead to a decrease in the clay strength with time. For this reason, the factor of safety of a cut slope in clay may decrease with time. Cut slopes in clay should be designed by using effective strength parameters and the effective stresses that will exist in the soil after the cut is made.

- **Slaking - Shales, Claystones, Siltstones, etc.**

  Sudden moisture increase in weak rocks can produce a pore pressure increase in trapped pore air accompanied by local expansion and strength decrease. The "slaking" or sudden disintegration of hard shales, claystones, and siltstones results from this mechanism. If placed as rock fill, these materials will tend to disintegrate into a clay soil if water is allowed to percolate through the fill. This transformation from rock to clay often leads to settlement and/or shear failure of the fill. Index tests such as the jar-slake test and the slake-durability test used to assess slaking potential are discussed in FHWA (1978).

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6.2 DESIGN FACTOR OF SAFETY

A minimum factor of safety as low as 1.25 is used for highway embankment side slopes. This value of the safety factor should be increased to a minimum of 1.30 to 1.50 for slopes whose failure would cause significant damage such as end slopes beneath bridge abutments, major retaining structures and major roadways such as regional routes, interstates, etc The selection of the design safety factor for a particular project depends on:

- The method of stability analysis used (see Section 6.4.5).
- The method used to determine the shear strength.
- The degree of confidence in the reliability of subsurface data.
- The consequences of a failure.
- How critical the application is.

6.3 INFINITE SLOPE ANALYSIS

A slope that extends for a relatively long distance and has a consistent subsurface profile may be analyzed as an infinite slope. The failure plane for this case is parallel to the surface of the slope and the limit equilibrium method can be applied readily.

6.3.1 Infinite Slopes in Dry Cohesionless Soils

A typical section or "slice" through the potential failure zone of a slope in a dry cohesionless soil, e.g., dry sand, is shown in Figure 6-3, along with its free body diagram. The weight of the slice of width b and height h having a unit dimension into the page is given by:

$$W = \gamma\, b\, h \qquad 6\text{-}1$$

where γ is the effective unit weight of the dry soil. For a slope with angle β as shown in Figure 6-3, the normal (N) and tangential (T) force components of W are determined as follows:

$$N = W \cos\beta \quad \text{and} \qquad 6\text{-}2$$

$$T = W \sin\beta \qquad 6\text{-}3$$

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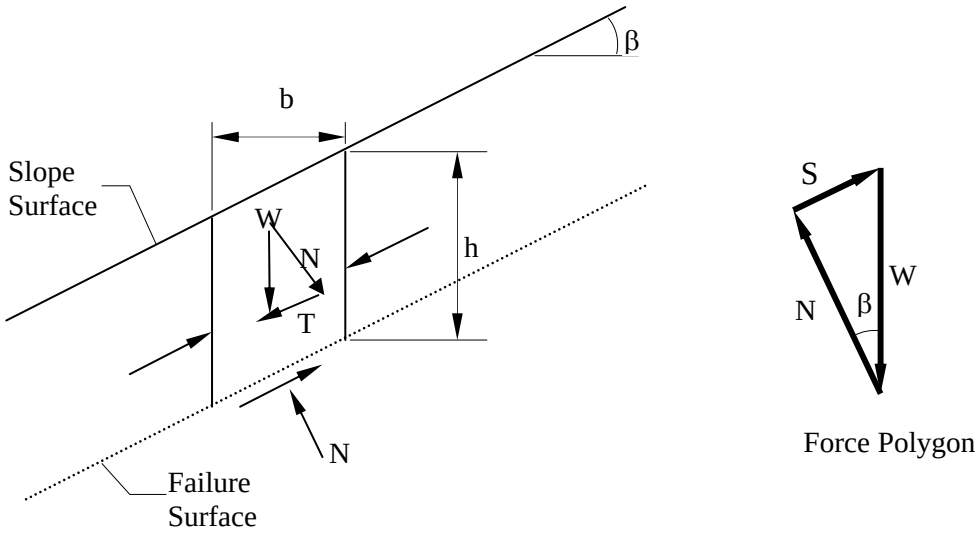


Figure 6-3. Infinite slope failure in dry sand.

The available shear strength along the failure plane is given by:

$$S = N \tan \phi \qquad 6\text{-}4$$

The factor of safety (FS) is defined as the ratio of available shear strength to strength required to maintain stability. Thus, the FS will be given by:

$$FS = \frac{S}{T} = \frac{N \tan \phi}{W \sin \beta} = \frac{(W \cos \beta) \tan \phi}{W \sin \beta} = \frac{\tan \phi}{\tan \beta} \qquad 6\text{-}5$$

For an infinite slope analysis, the FS is independent of the slope depth, h, and depends only on the angle of internal friction, ϕ, and the angle of the slope, β. The slope is said to have reached **limit equilibrium** when FS=1.0. Also, at a FS = 1.0, the maximum slope angle will be limited to the angle of internal friction, ϕ.

6.3.2 Infinite Slopes in c-ϕ Soils with Parallel Seepage

If a saturated slope in a c-ϕ soil has seepage parallel to the surface of the slope as shown in Figure 6-4, the same limit equilibrium concepts may be applied to determine the FS, which will now depend on the effective normal force (N'). In the following analysis, effective shear strength parameters, c' and ϕ' are used.

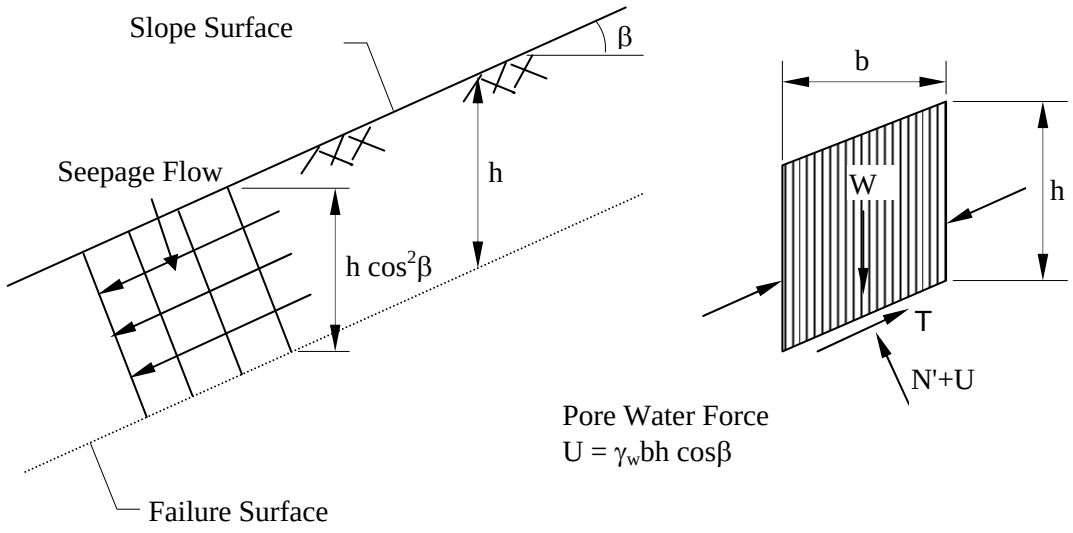


Figure 6-4. Infinite slope failure in a c-ϕ soil with parallel seepage.

From Figure 6-4, the pore water force acting on the base of a typical slice having a unit dimension into the page is:

$$U = \left(\gamma_w h \cos^2 \beta \right) \frac{b}{\cos \beta} = \gamma_w b h \cos \beta \qquad 6\text{-}6$$

where h is any depth less than or equal to the depth of saturation and b is a unit width.

The available frictional strength, S, along the failure plane will depend on ϕ' and the effective normal force, N' =N-U, where N is the total normal force. The equation for S is:

$$S = c' \frac{b}{\cos \beta} + (N - U) \tan \phi' \qquad 6\text{-}7$$

The factor of safety for this case will be:

$$FS = \frac{S}{T} = \frac{(c' \; b/\cos \beta) + (N - U) \tan \phi'}{W \sin \beta} \qquad 6\text{-}8$$

By substituting $W = \gamma_{sat}$ b h into the above expression and rearranging terms, the FS is given by:

$$FS = \frac{c' + h(\gamma_{sat} - \gamma_w)(\cos^2\beta)\tan\phi'}{\gamma_{sat} h \sin\beta \cos\beta} \qquad 6\text{-}9$$

where $\gamma' = (\gamma_{sat} - \gamma_w)$.

For c' = 0, the above expression may be simplified to:

$$FS = \frac{\gamma'}{\gamma_{sat}} \frac{\tan\phi'}{\tan\beta} \qquad 6\text{-}10$$

From Equation 6-10 it is apparent that for a *cohesionless* material with parallel seepage, the FS is also independent of the slope depth, h, just as it is for a dry cohesionless material as given by Equation 6-5. The difference is that the FS for the dry material is reduced by the factor γ'/γ_{sat} for saturated cohesionless materials to account for the effect of seepage. For typical soils, this reduction will be about 50 percent in comparison to dry slopes.

The above analysis can be generalized if the seepage line is assumed to be located at a normalized height, m, above the failure surface where m =z/h. In this case, the FS is:

$$FS = \frac{c' + h\cos^2\beta[(1-m)\gamma_m + m\gamma']\tan\phi'}{h\sin\beta\cos\beta[(1-m)\gamma_m + m\gamma_{sat}]} \qquad 6\text{-}11$$

and γ_{sat} and γ_m are the saturated and moist unit weights of the soil below and above the seepage line. The above equation may be readily reformulated to determine the critical depth of the failure surface in a c'-ϕ' soil for any seepage condition.

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6.4 CIRCULAR ARC FAILURE

Experience and observations of failures of embankments constructed over relatively deep deposits of soft soils have shown that when failure occurs, the embankment sinks down, the adjacent ground rises and the failure surface follows a circular arc as illustrated in Figure 6-5.

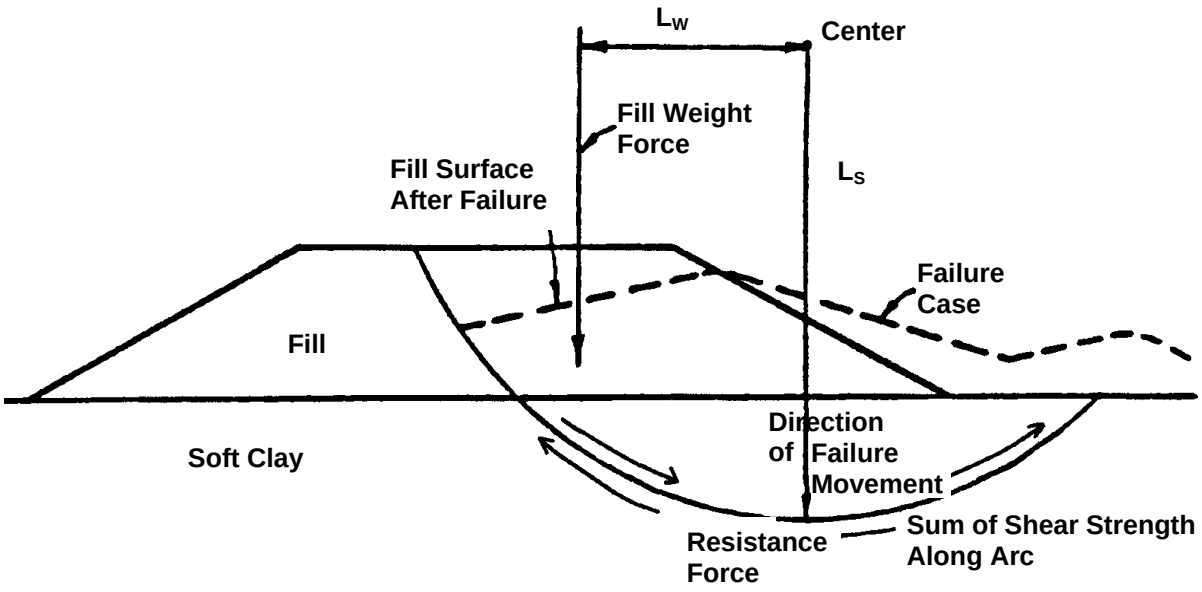


Figure 6-5. Typical circular arc failure mechanism.

At failure the driving and resistance forces act as follows:

- The force driving movement consists of the embankment weight. The driving moment is the product of the weight of the embankment acting through its center of gravity times the horizontal distance from the center of gravity to the center of rotation (L_W).

- The resisting force against movement is the total shear strength acting along the failure arc. The resisting moment is the product of the resisting force times the radius of the circle (L_S).

The factor of safety against slope instability is equal to the ratio of the resisting moment to driving moment.

$$\text{Factor of Safety} = \frac{\text{Total Shear Strength} \times L_S}{\text{Weight Force} \times L_W} = \frac{\text{Resisting Moment}}{\text{Driving Moment}} \qquad 6\text{-}12$$

Failure takes place when the factor of safety is less than 1, i.e., the driving moment > resisting moment.

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6.4.1 Simple Rule of Thumb for Factor of Safety

A rule of thumb based on simplified bearing capacity theory can be used to make a preliminary "guestimate" of the factor of safety (FS) against circular arc failure for an embankment built on a clay foundation without presence of free water. The rule of thumb is as follows:

$$FS \cong \frac{6\,c}{\gamma_{Fill} \times H_{Fill}} \qquad 6\text{-}13$$

Where: c = unit cohesion of clay foundation soil (psf)
γ_{Fill} = unit weight fill (pcf)
H_{Fill} = height of fill (feet)

Since the rule of thumb assumes that there is no influence from groundwater, c and γ_{Fill} are effective stress parameters.

For example, the factor of safety for the proposed embankment illustrated in Figure 6-6 can be computed as follows:

$$FS = \frac{(6)(1{,}100 \ \text{psf})}{(130 \ \text{pcf})(30 \ \text{ft})} = 1.69$$ Use Rule of Thumb 6-13

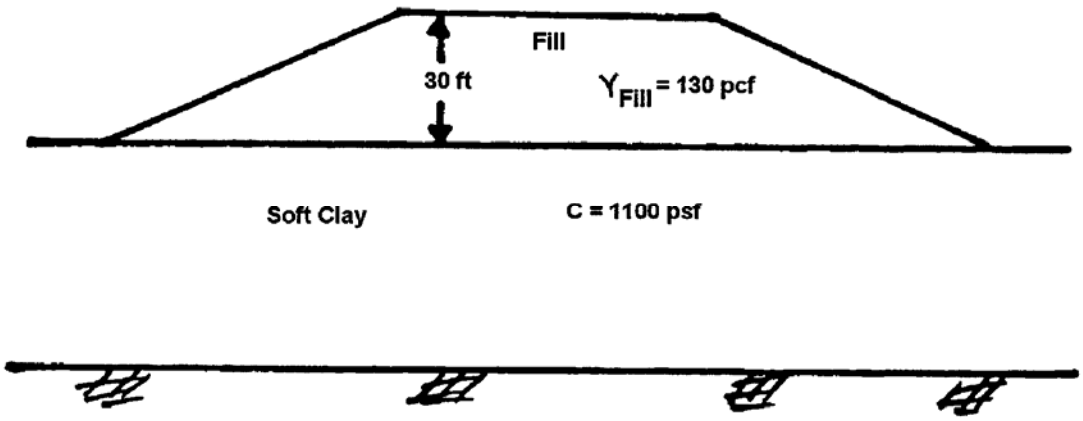


Figure 6-6. Example proposed embankment.

The factor of safety computed by using this rule of thumb should never be used for final design. This simple equation obviously does not take into account such factors as fill strength or fill slope angle and does not identify the location of a critical failure surface. **If**

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the factor of safety computed by using the rule of thumb is less than 2.5, a more sophisticated stability analysis is required.

However, this rule of thumb can be helpful very early in the design stage to make a quick preliminary check on whether stability may be a problem and if more detailed analyses should be conducted. It can also be of use in the field while borings and sampling are being performed. For example, if in-situ vane shear tests are being carried out as part of the field investigation for a proposed embankment, the geotechnical specialist can use the vane strength with Equation 6-13 to estimate the FS in the field. This estimate can aid in directing the drilling, sampling, and testing program while the drill crew is at the site and help insure that critical strata are adequately explored and sampled. Finally, the FS calculated by the rule of thumb can be used to check for *gross* errors in computer output or input.

6.4.2 Stability Analysis Methods (General)

There are several available methods that can be used to perform a circular arc stability analysis for an approach embankment over soft ground. The simplest basic method is known as the **Normal** or **Ordinary Method of Slices**, also known as Fellenius' method (Fellenius, 1936) or the Swedish circle method of analysis. The Ordinary Method of Slices can easily be performed by hand calculations and is also a method by which the computation of driving and resisting forces is straightforward and easily demonstrated. For this method, the failure surface is assumed to be the arc of a circle as shown in Figure 6-7 and the factor of safety against sliding along the failure surface is defined as the ratio of the moment of the total available resisting forces on the trial failure surface to the net moment of the driving forces due to the embankment weight, that is:

$$FS = \frac{\text{Sum of Resisting Forces} \times \text{Moment Arm (R)}}{\text{Sum of Driving Forces} \times \text{Moment Arm (R)}} \qquad 6\text{-}14$$

Note that since the method consists of computing the driving and resisting forces along the failure arc, the moment arm R is the same for both the driving and resisting forces. Thus, Equation 6-14 reduces to:

$$FS = \frac{\text{Sum of Resisting Forces}}{\text{Sum of Driving Forces}} \qquad 6\text{-}14a$$

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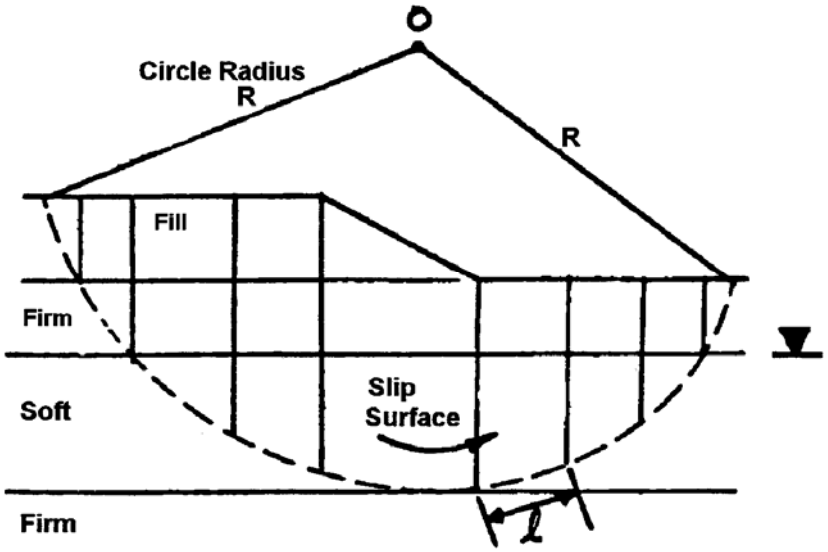


Figure 6-7. Geometry of Ordinary Method of Slices.

For slope stability analysis, the mass within the failure surface is divided into vertical slices as shown in Figures 6-7 and 6-8. A typical vertical slice and its free body diagram is shown in Figure 6-9 for the case where water is not a factor. The case with the presence of water is shown in Figure 6-10. The following assumptions are then made in the analysis using Ordinary Method of Slices:

1. The available shear strength of the soil can be adequately described by the Mohr-Coulomb equation:

$$\tau = c + (\sigma - u) \tan \phi \qquad 6\text{-}15$$

where:

τ = effective shear strength
c = cohesion component of shear strength
$(\sigma - u) \tan \phi$ = frictional component of shear strength
σ = total normal stress on the failure surface at the base of a slice due to the weight of soil and water above the failure surface
u = water uplift pressure against the failure surface
ϕ = angle of internal friction of soil
$\tan \phi$ = coefficient of friction along failure surface

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2. The factor of safety is the same for all slices.

3. The factors of safety with respect to cohesion (c) and friction (tan ϕ) are equal.

4. Shear and normal forces on the sides of each slice are ignored.

5. The water pressure (u) is taken into account by reducing the total weight of the slice by the water uplift force acting at the base of the slice.

Equation 6-15 is expressed in terms of total strength parameters. The equation could easily have been expressed in terms of effective strength parameters. Therefore, the convention to be used in the stability analysis, be it total stress or effective stress, should be chosen and specified. In soil problems involving water, the engineer may compute the normal and tangential forces by using either total soil weights and boundary water forces (both buoyancy and unbalanced hydrostatic forces) or submerged (buoyant) soil weights and unbalanced hydrostatic forces. The results are the same. When total weight and boundary water forces are used, the equilibrium of the entire block is considered. When submerged weights and hydrostatic forces are used, the equilibrium of the mineral skeleton is considered. The total weight notation is used herein as this method is the simplest to compute.

6.4.3 Ordinary Method of Slices - Step-By-Step Computation Procedure

To compute the factor of safety for an embankment by using the Ordinary Method of Slices, the step-by-step computational procedure is as follows:

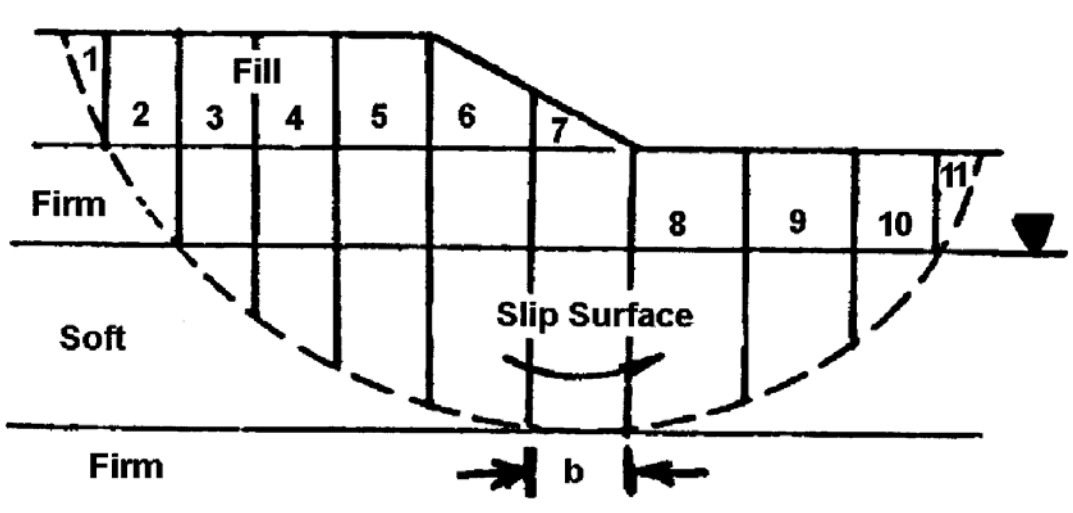


Figure 6-8. Example of dividing the failure mass in slices.

Step 1. Draw a cross-section of the embankment and foundation soil profile on a scale of either 1-inch = 10 feet or 1-inch = 20 feet scale both horizontal and vertical.

Step 2. Select a circular failure surface such as shown in Figure 6-7.

Step 3. Divide the circular mass above the failure surface into 10 - 15 vertical slices as illustrated in Figure 6-8.

To simplify computation, locate the vertical sides of the slices so that the bottom of any one slice is located entirely in a single soil layer or at the intersection of the ground water level and the circle.

Locate the top boundaries of vertical slices at breaks in the slope. The slice widths do not have to be equal. For convenience assume a one-foot (0.3 m) thick section of embankment. This unit width simplifies computation of driving and resisting forces.

Also, as shown in Figure 6-9 and 6-10 the driving and resisting forces of each slice act at the intersection of a vertical line drawn from the center of gravity of the slice to the failure circle to establish a centroid point on the circle. Lines (called rays) are then drawn from the center of the circle to the centroid point on the circular arc. The α angles are then measured from the vertical to each ray.

When the water table is sloping, use Equation 6-16 to calculate the water pressure on the base of the slice:

$$u = h_w \gamma_w \cos^2 \alpha_w \qquad 6\text{-}16$$

where: α_w = slope of water table from horizontal in degrees.
h_w = depth from ground water surface to the centroid point on the circle.

Step 4: Compute the total weight (W_T) of each slice.

For illustration, the resisting and driving forces acting on individual slices with and without water pressure are shown on Figures 6-9 and 6-10.

To compute W_T, use total soil unit weight, γ_t, both above and below the water table.

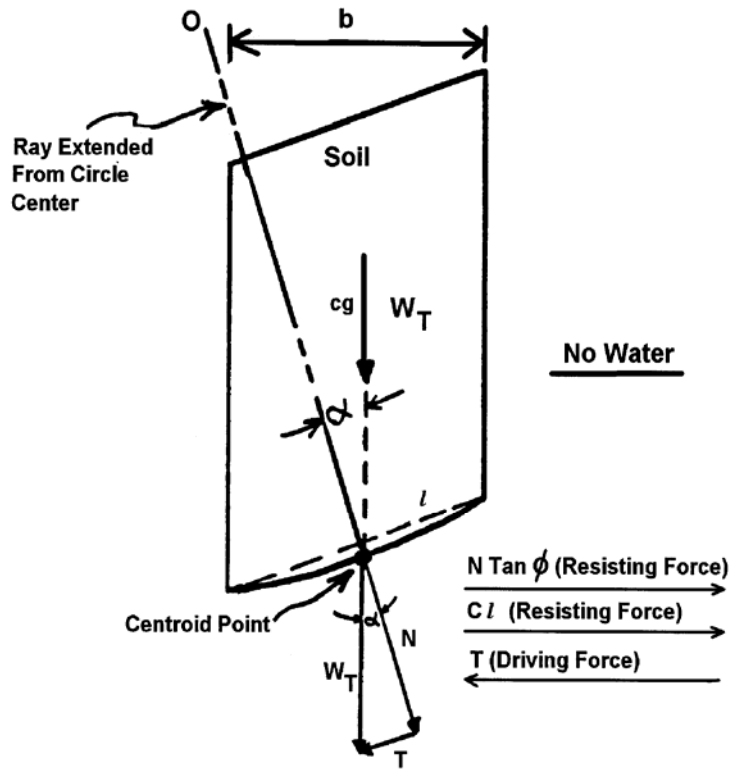


Figure 6-9. Forces on a slice without water effect.

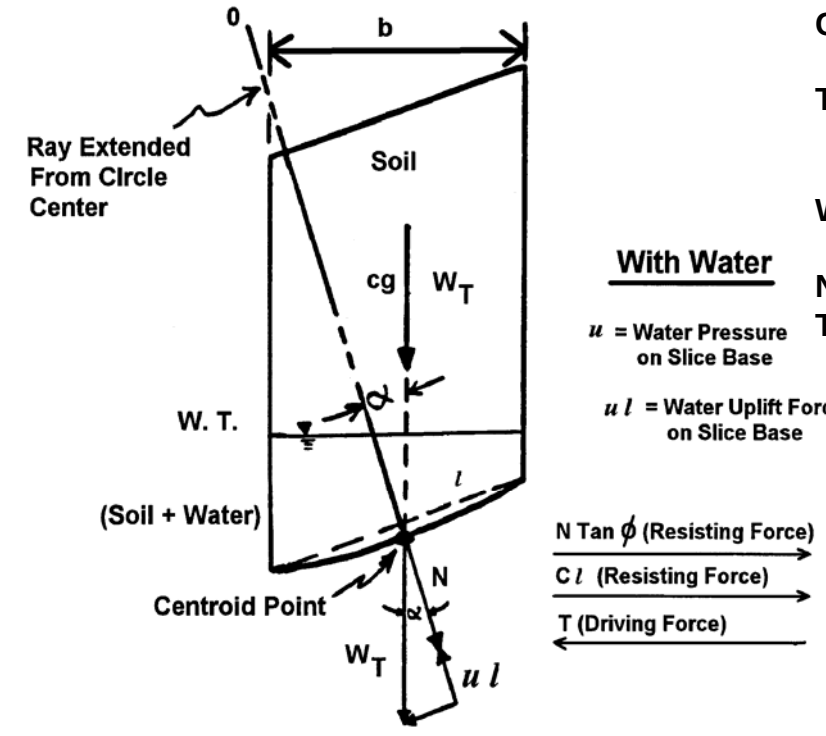


Figure 6-10. Forces on a slice with water effect.

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$$W_T = \gamma_t \times \text{Average Slice Height} \times \text{Slice Width} \quad \text{6-17}$$

For example: Assume
γ_t = 120 pcf (18.9 kN/m^3)
Average height of slice = 10 ft (3 m)
Slice width = 10 ft (3 m)

Then for a unit thickness into the plane of the paper, W_T = (120 pcf) (10 ft) (10 ft) (1 ft) = 12,000 lbs (53.3 kN)

Step 5: Compute frictional resisting force for each slice depending on location of ground water table.

$$N = W_T \cos \alpha \quad \text{6-18a}$$

$$N' = W_T \cos \alpha - ul \quad \text{6-18b}$$

N = total normal force acting against the slice base
N' = effective normal force acting against the slice base
W_T = total weight of slice (from Step 4 above)
α = angle between vertical and line drawn from circle center to midpoint (centroid) of slice base (Note: α is also equal to the angle between the horizontal and a line tangent to the base of the slice)
u = water pressure on the base of the slice = average height of water, $h_w \times \gamma_w$. Use γ_w = 62.4 pcf (9.8 kN/m^3)
l = arc length of slice base. To simplify computations, take l as the secant to the arc.
$u\,l$ = water uplift force against base of the slice per unit thickness into the plane of the paper.
ϕ = internal friction angle of the soil.
$\tan \phi$ = coefficient of friction along base of the slice.

Note that **the effect of water is to reduce the normal force against the base of the slice and thus reduce the frictional resisting force**. To illustrate this reduction, take the same slice used in Step 4 and compute the friction resistance force for the slice with no water and then for the ground water table located 5 feet above the base of the slice.

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Assume: $\phi = 25^o$ $\alpha = 20^o$ l = 11 ft (3.3 m)

If there is no water in the slice, u l = 0 and Equation 6-18b reverts to Equation 6-18a and the total frictional resistance can be computed as follows:

$N = W_T \cos \alpha$ = (12,000 lbs) (cos 20^o) = 11,276 lbs (50.18 kN)
N tan ϕ = (11,276 lbs) (tan 25^o) = 5,258 lbs (23.4 kN)

If there is 5-ft of water above the midpoint of the slice, Equation 6-18b is used directly and the effective frictional resistance is computed as follows:

$u\,l = (h_w)(\gamma_w)(l)$ = (5 ft)(62.4 pcf))(11 ft)(1 ft) = 3,432 lbs (15.3 kN)
$N' = W_T \cos \alpha - u\,l$ = 11,276 lbs - 3,432 lbs = 7,844 lbs (34.9 kN)
$N' \tan \phi$ = (7,844 lbs) (tan 25°) = 3,658 lbs (16.3 kN)

Step 6: Compute cohesive resisting force for each slice.

c = cohesive soil strength
l = length of slice base

Example: c = 200 psf (9.6 kPa)
l = 11 ft (3.6 m)
cl = (200 psf)(11 ft)(1 ft) = 2,200 lbs (9.8 kN)

Step 7: Compute tangential driving force, T, for each slice.

$$T = W_T \sin \alpha \qquad 6\text{-}19$$

T is the component of total weight of the slice, W_T, acting tangent to the slice base. T is the driving force due to the weight of both soil and water in the slice.

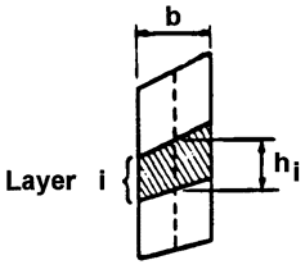
Example: Given W_T = 12,000 lbs (53.3 kN)
$\alpha = 20^o$
$T = W_T \sin \alpha$ = (12,000 lbs)(sin 20^o) = 4,104 lbs (18.2 kN)

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Step 8: Sum resisting forces and driving forces for all slices and compute factor of safety.

$$FS = \frac{\sum \text{Resisting Forces}}{\sum \text{Driving Forces}} = \frac{\sum N' \tan\phi + \sum c\,1}{\sum T} \qquad 6\text{-}20$$

Tabular computation forms for use in performing a method of slices stability analysis by hand are included on Figures 6-11 and 6-12.



γ_i = unit weight of layer i
h_i = height of layer at center of slice
W_i = partial weight = $b\ h_i\ \gamma_i$
$\sum W_i$ = total weight of slice W_T

Slice No.	b	h_i	γ_i	W_i	$\sum W_i = W_T$

Figure 6-11a. Tabular form for computing weights of slices.

Slice No.	W_T (from Table 6-11a)	l	α	c	ϕ	u	ul	$W_T\cos\alpha$	$N' = W_T\cos\alpha - ul$	$N'\tan\phi$	cl	$T = W_T\sin\alpha$
									Σ			

$$FS = \frac{\Sigma\,(W_T\cos\alpha - ul)\tan\phi + \Sigma\,cl}{\Sigma\,W_T\sin\alpha} = \frac{\Sigma\,N'\tan\phi + \Sigma\,cl}{\Sigma\,W_T\sin\alpha} = \underline{\qquad\qquad}$$

Legend: Refer to Figure 6-10 for definition of various slice quantities

$_T$ = Total weight of Slice (soil + water)
Base length of the slice
= Cohesion at base of slice
ϕ = = angle of internal friction
pore water pressure at base of slice
=

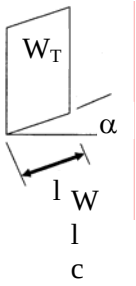
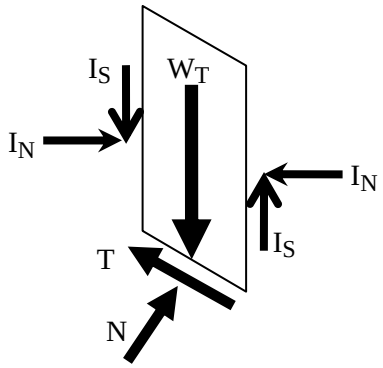


Figure 6-11b. Tabular form for calculating factor of safety by Ordinary Method of Slices.

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6.4.4 Recommended Stability Methods

The basic static forces on a typical slice are shown in Figure 6-12. The limit equilibrium method of slices is based on the principles of statics, i.e., summation of moments, vertical forces, and horizontal forces. The Ordinary Method of Slices ignores both interslice shear (I_S) and interslice normal (I_N) forces and satisfies only moment equilibrium. There are many other methods available for performing a slope stability analysis besides the Ordinary Method of Slices. These include the Bishop Method (Bishop, 1955), the Simplified Janbu Method (Janbu, 1954) and the Spencer Method (Spencer, 1967). These methods are primarily variations and refinements of the Ordinary Method of Slices. The differences among these more refined methods lie in the assumptions made regarding the interslice shear and normal forces acting on the sides of slices. The Bishop Method, also known as the Simplified Bishop Method, includes interslice normal forces (I_N) but ignores interslice shear (I_S) forces. Again, Bishop's method satisfies only moment equilibrium. The Simplified Janbu Method is similar to the Bishop Method in that it includes the interslice normal (I_N) forces and ignores the interslice shear (I_S) forces. The difference between the Bishop Method and the Simplified Janbu Method is that the Simplified Janbu Method satisfies only horizontal force equilibrium, as opposed to moment equilibrium. The Spencer Method considers both normal and shear interslice side forces as well as moments. Therefore the Spencer Method is theoretically more rigorous than the other methods.



Legend:

W_T	Total weight of slice
N	Normal force at base of slice
T	Tangential force at base of slice
I_S	Interslice shear (vertical) force
I_N	Interslice normal (horizontal) force

Figure 6-12. Typical static forces on a slice of sliding mass without seepage.

The Ordinary Method of Slices is more conservative and gives unrealistically lower factors of safety than the Bishop Method or the other more refined methods. The only reason for inclusion of the Ordinary Method of Slides here is to demonstrate the principles of slope stability. For purely cohesive soils the Ordinary Method of Slices and Bishop's method give identical results. For soils that have frictional strength, the Bishop Method should be used as a minimum. While none of the methods is 100 percent correct theoretically, currently available procedures such as Bishop's method, Janbu's Simplified method or Spencer's method are sufficiently accurate for practical analysis and design. For more information on these and other slope stability methods, the reader is referred to FHWA (2001a).

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The method of analysis that should be used to determine a factor of safety depends on the soil type, the source of the soil strength parameters, the level of confidence in the values, and the type of slope that is being designed. Slope stability analyses should be performed only by qualified and experienced geotechnical specialists. Guidelines recommended for the analysis of slope stability are given in Table 6-1.

Table 6 -1. Slope stability guidelines for design

Foundation Soil Type	Type of Analysis	Source of Strength Parameters (see Chapter 5)	Remarks (see Note 1)
Cohesive	**Short-term** (embankments on soft clays – immediate end of construction – $\phi = 0$ analysis).	• UU or field vane shear test or CU triaxial test. • Use undrained strength parameters at p_o	Use **Bishop Method**. An angle of internal friction should not be used to represent an increase of shear strength with depth. The clay profile should be divided into convenient layers and the appropriate cohesive shear strength assigned to each layer.
	Stage construction (embankments on soft clays – build embankment in stages with waiting periods to take advantage of clay strength gain due to consolidation).	• CU triaxial test. Some samples should be consolidated to higher than existing in-situ stress to determine clay strength gain due to consolidation under staged fill heights. • Use undrained strength parameters at appropriate p_o for staged height.	Use **Bishop Method** at each stage of embankment height. Consider that clay shear strength will increase with consolidation under each stage. Consolidation test data needed to estimate length of waiting periods between embankment stages. Piezometers and settlement devices should be used to monitor pore water pressure dissipation and consolidation during construction.
	Long-term (embankment on soft clays and clay cut slopes).	• CU triaxial test with pore water pressure measurements or CD triaxial test. • Use effective strength parameters.	Use **Bishop Method** with combination of cohesion and angle of internal friction (effective strength parameters from laboratory test).
	Existing failure planes	• Direct shear or direct simple shear test. Slow strain rate and large deflection needed. • Use residual strength parameters.	Use **Bishop, Janbu or Spencer Method** to duplicate previous shear surface.
Granular	**All types**	• Obtain effective friction angle from charts of standard penetration resistance (SPT) versus friction angle or from direct shear tests.	Use **Bishop Method** with an effective stress analysis.
Note 1: Methods recommended represent minimum requirement. More rigorous methods such as Spencer's method should be used when a computer program has such capabilities.			

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6.4.5 Remarks on Safety Factor

For side slopes of routine highway embankments, a minimum design safety factor of 1.25 **as determined by the Ordinary Method of Slices** is used. For slopes that would cause greater damage upon failure, such as end slopes beneath bridge abutments, major retaining structures, and major roadways such as regional routes, interstates, etc., the design safety factor should be increased to at least 1.30 to 1.50. For cut slopes in fine-grained soils, which can lose shear strength with time, a design safety factor of 1.50 is desirable.

6.5 CRITICAL FAILURE SURFACE

The step-by-step procedure presented in the preceding section illustrates how to compute the factor of safety for one selected circular arc failure surface. The complete analysis requires that a large number of assumed failure surfaces be checked in order to find the critical one, i.e., the surface with the lowest factor of safety. This task would obviously be a tedious and time consuming operation if done by hand. Therefore a computer program becomes a valuable tool for performing such computations. Any method for stability analysis is easily adapted to computer solution. For critical circle methods a grid of possible circle centers is defined, and a range of radius values established for each. The computer can be directed to perform stability analyses for each circle center over the range of radii and then to print out all the safety factors or just the minimum one and its radius. A plot of minimum safety factor for each circle center in the form of contours can be used to define the location of the most critical circle and the minimum safety factor as shown in Figure 6-13. The radius of the most critical surface can be used to locate the intersection points of the circle with the ground surface above and below the slope. This is useful in identifying structures above and below the slope that may be potentially impacted by slope instability.

Figure 6-13 shows just one of several ways that computer programs can be used to search for the most critical failure surface. It is beyond the scope of this manual to discuss these in detail. However, the following points should be noted as one uses a computer program for locating the most critical failure surface:

1. Check multiple circle center locations and compare the lowest safety factors. There may be more than one “local” minimum and a single circle center location may not necessarily locate the lowest safety factor for the slope.

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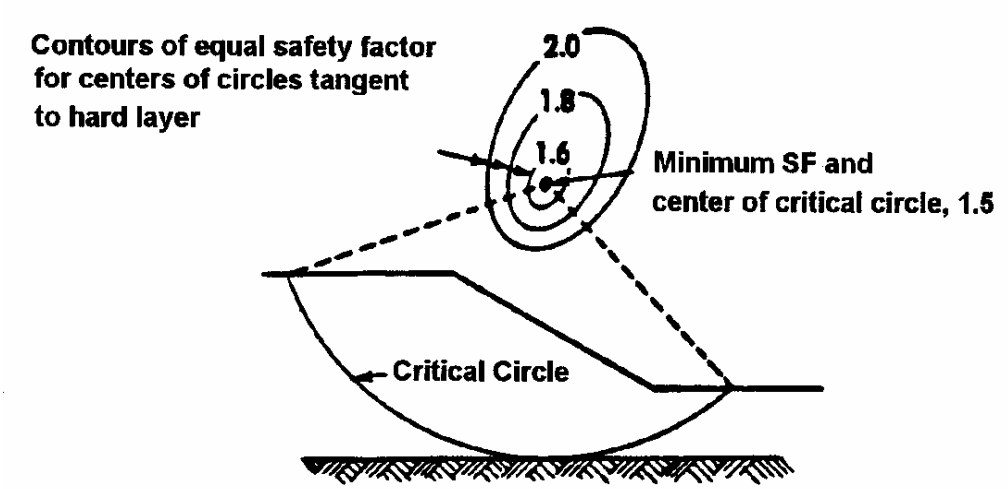


Figure 6-13. Location of critical circle by plotting contours of minimum safety factors for various trial circles.

2. Search all areas of the slope to find the lowest safety factor. The designer may find multiple areas of the slope where the safety factors are low and comparable. In this case, the designer should try to identify insignificant failure modes that lead to low safety factors for which the consequences of failure are small. This is often the case in cohesionless soils, where the lowest safety factor is found for a shallow failure plane located close the slope face.

3. Review the soil stratigraphy for "secondary" geological features such as thin relatively weak zones where a slip surface can develop. Often, circular failure surfaces are locally modified by the presence of such weak zones. Therefore computer software capable of simulating such failures should be used. Some of the weak zones may be man-made, e.g., when new fills are not adequately keyed into existing fills for widening projects.

4. Conduct stability analyses to take into account all possible loading and unloading schemes to which the slope might be subjected during its design life. For example, if the slope has a detention basin next to it, then it might be prudent to evaluate the effect of water on the slope, e.g., perform an analysis for a rapid drawdown condition.

5. Use the drained or undrained soil strength parameters as appropriate for the conditions being analyzed

6. Use stability charts to develop a "feel" for the safety factor that may be anticipated. Stability charts are discussed in the next section. Such charts may also be used to verify the results of computer solutions.

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6.6 DESIGN (STABILITY) CHARTS

Slope stability charts are useful for preliminary analysis to compare alternates that may be examined in more detail later. Chart solutions also provide a quick means of checking the results of detailed analyses. Engineers are encouraged to use these charts before performing a computer analysis in order to determine the approximate value of the factor of safety. The chart solution allows some quality control and a check for the subsequent computer-generated solutions.

Slope stability charts are also used to back-calculate strength values for failed slopes, such as landslides, to aid in planning remedial measures. In back-calculating strength values a factor of safety of unity is assumed for the conditions at failure. Since soil strength often involves both cohesion and friction, there are no unique values that will give a factor of safety equal to one. Therefore, selection of the most appropriate values of cohesion and friction depends on local experience and judgment. Since the friction angle is usually within a narrow range for many types of soils and can be obtained by laboratory tests with a certain degree of confidence, it is generally fixed for the back-calculations in practice and the value of cohesion is varied until a factor of safety of one is obtained.

The major shortcoming in using design charts is that most charts are for ideal, homogeneous soil conditions that are not typically encountered in practice. Design charts have been devised with the following general assumptions:

1. Two-dimensional limit equilibrium analysis.
2. Simple homogeneous slopes.
3. Slip surfaces of circular shapes only.

It is imperative that the user understands the underlying assumptions for the charts before using them for the design of slopes.

Regardless of the above shortcomings, many practicing engineers use these charts for non-homogeneous and non-uniform slopes with different geometrical configurations. To do this correctly, one must use an average slope inclination and weighted averages of c, ϕ, or c', ϕ' or c_u calculated on the basis of the proportional length of slip surface passing through different relatively homogeneous layers. Such a procedure is extremely useful for preliminary analyses and saves time and expense. In most cases, the results are checked by performing detailed analyses using more suitable and accurate methods, for example, one of the methods of slices discussed previously.

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6.6.1 Historical Background

Some of the first slope stability charts were published by Taylor (1948). Since then various charts were developed by many investigators. Two of the most common stability charts are presented in this manual. These were developed by Taylor (1948) and Janbu (1968).

6.6.2 Taylor's Stability Charts

Taylor's Stability Charts (Taylor, 1948) were derived from solutions based on circular failure surfaces for the stability of simple, homogeneous, finite slopes without seepage (i.e., condition of effective stress). The general equations that Taylor developed as the basis for his stability charts are relationships between the height (H) and inclination (β) of the slope, the unit weight of the soil (γ), and the values of the soil's *developed* (*mobilized*) shear strength parameters, c_d and ϕ_d. These developed (mobilized) quantities are as follows:

$$c_d = \frac{c'}{F_c}; \quad \tan \phi_d = \frac{\tan \phi'}{F_\phi} \qquad 6\text{-}21$$

Where F_c is the average factor of safety with respect to cohesion and F_ϕ, is the average factor of safety with respect to friction angle, i.e., $\phi_d = \arctan (\tan \phi' / F_\phi)$. As an approximation, the following equation may be used for the developed friction angle:

$$\phi_d \approx \frac{\phi'}{F_\phi} \qquad 6\text{-}22$$

However, for soils possessing both frictional and cohesive components of strength, the factor of safety in slope stability analyses generally refers to the overall factor of safety with respect to shearing strength, FS, which equals τ/τ_d where τ = shear strength and τ_d = the developed (mobilized) shear strength. Therefore, the general Mohr-Coulomb expression for developed shear strength in terms of combined factors of safety is:

$$\tau_d = \frac{\tau}{FS} = \frac{c'}{F_c} + \sigma' \frac{\tan \phi}{F_\phi} \qquad 6\text{-}23$$

Equation 6-23 can be re-written in terms of developed shear strength parameters as follows:

$$\tau_d = c_d + \sigma' \tan \phi_d \qquad 6\text{-}24$$

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There are an unlimited number of combinations of F_c and F_ϕ that can result in a given value of FS. However, Equations 6-21 and 6-23 suggest that for the case where the value of $F_c = F_\phi$, the factor of safety with respect to shearing strength, FS, also equals that value. The importance of this condition will be illustrated in Section 6.6.2.1 by an example problem.

To simplify the determination of the factor of safety, Taylor calculated the stability of a large number of slopes over a wide range of slope angles and developed friction angles, ϕ_d. He represented the results by a dimensionless number that he called the "Stability Number," N_s, which he defined as follows:

$$N_s = \frac{c_d}{\gamma H} = \frac{c'}{F_c \gamma H} \qquad 6\text{-}25$$

Equation 6-25 can be rearranged to provide an expression for F_c as a function of the Stability Number and three variables, c′, H and γ, as follows:

$$F_c = \frac{c'}{N_s \gamma H} \qquad 6\text{-}26$$

Taylor published his results in the form of curves that give the relationship between N_s and slope angle, β, for various values of developed friction angles, ϕ_d, as shown in Figure 6-14. Note that factors of safety do not appear in the chart. The chart is divided into two zones, A and B. As shown in the inset for Zone A, the critical circle for steep slopes passes through the toe of the slope with the lowest point on the failure arc at the toe of the slope. As shown in the inset for Zone B, for shallower slopes the lowest point of the critical circle is not at the toe, and three cases must be considered as follows:

- **Case 2:** For shallow slope angles or small developed friction angles the critical circle may pass below the toe of the slope. This condition corresponds to Case 2 in the inset for Zone B. The values of N_s for this case are given in the chart by the long dashed curves.

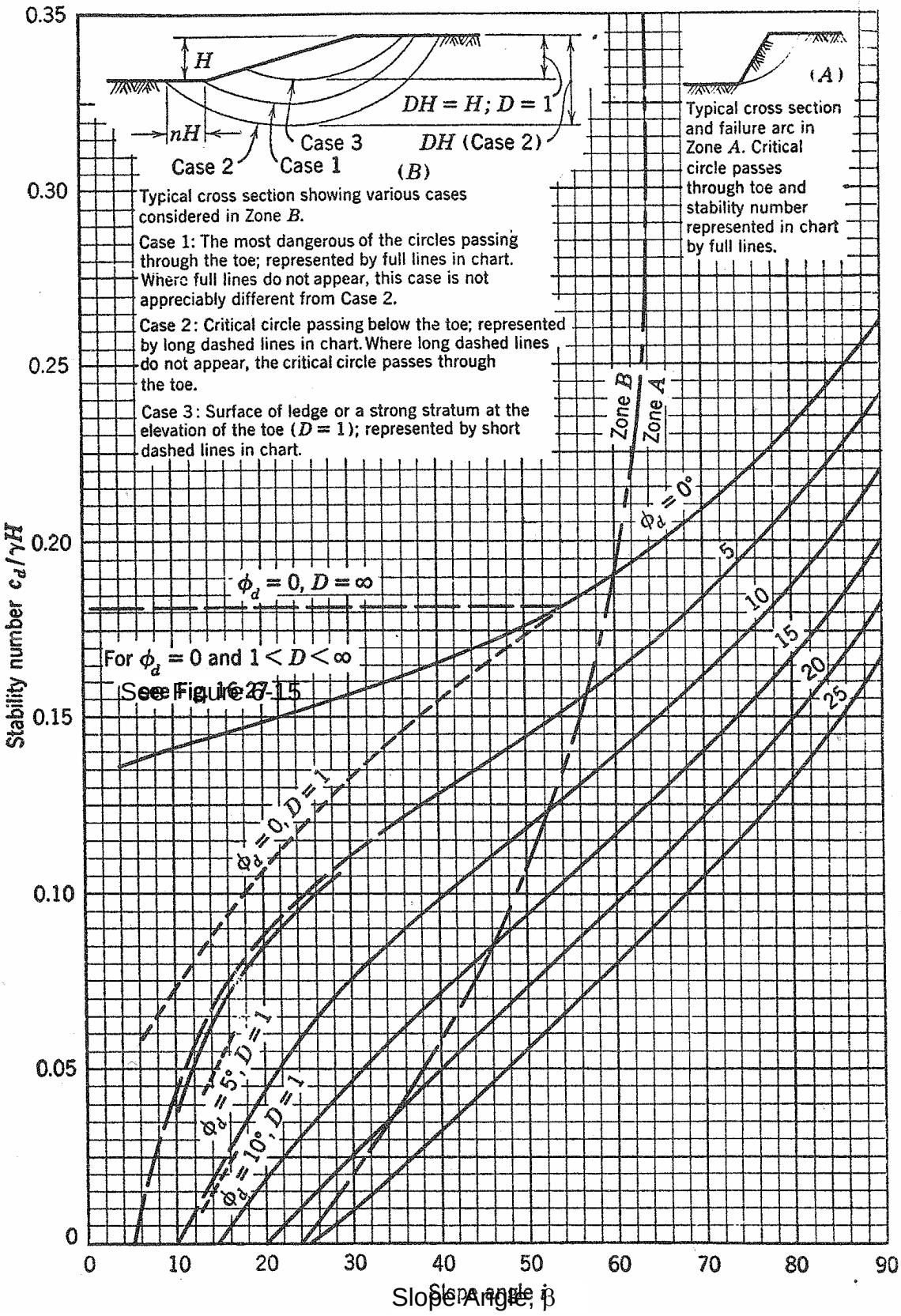


Figure 6-14. Taylor's chart for soils with friction angle (after Taylor, 1948).

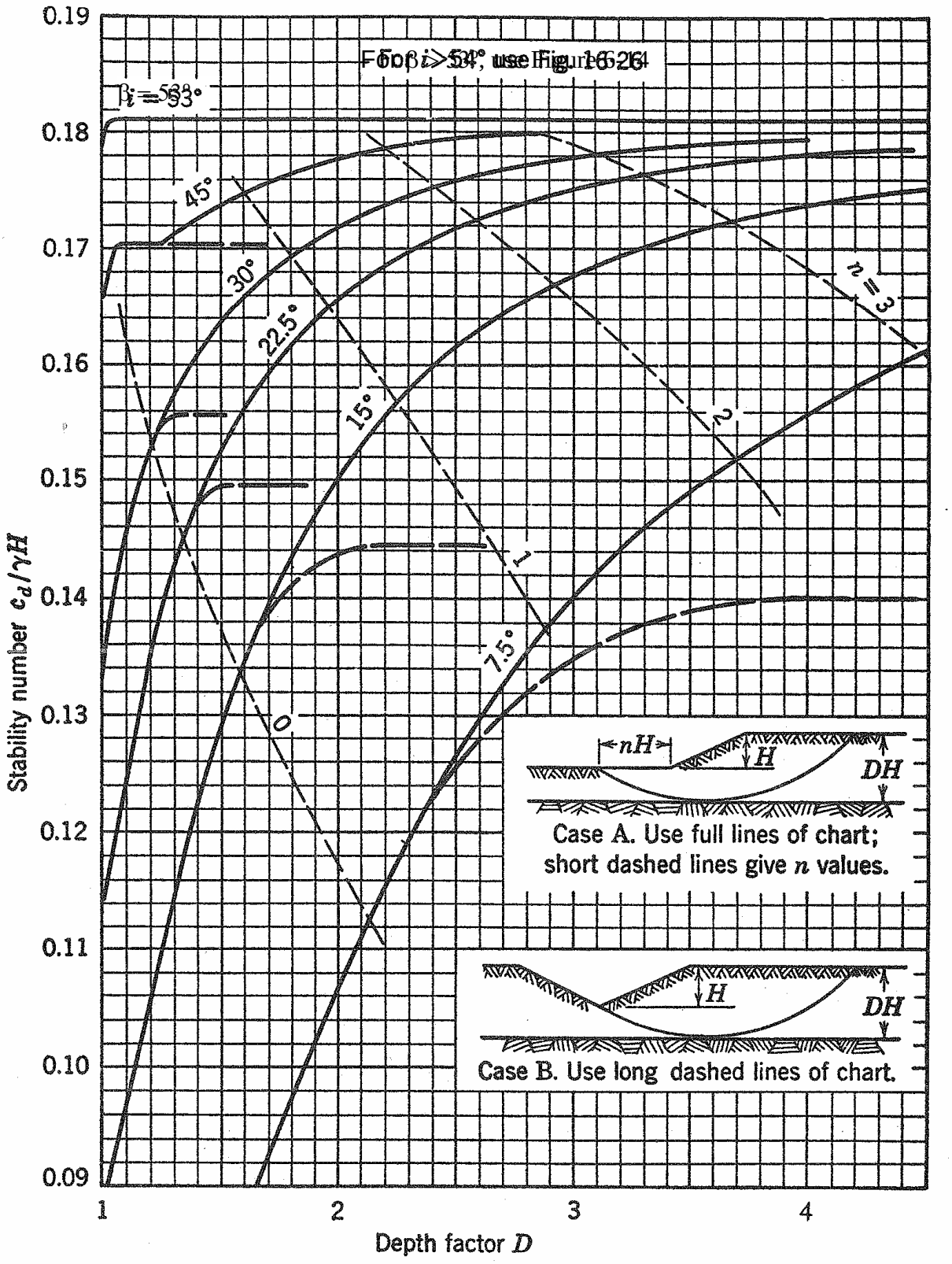


Figure 6-15. Taylor's chart for ϕ' =0 conditions for slope angles (β) less than 54° (after Taylor, 1948).

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- **Case 1:** Where long dashed curves do not appear in the chart, the critical circle passes through the toe. This condition corresponds to Case 1. Stability numbers for Case 1 are given by the solid lines in the chart both when there is and when there is not a more dangerous circle that passes below the toe, i.e., the curves for Case 1 are an extension of the curves that correspond to a toe circle failure in Zone A. In both Case 1 and Case 2 the failure circle passes through the soil below the toe of the slope. The depth ratio, *D*, which is a multiple of the slope height H, is used to define the depth (*D*H) from the top of the slope to an underlying strong material through which the failure circle does not pass.

- **Case 3**: This case corresponds to the condition where there is an underlying strong layer at the elevation of the toe (*D*=1). This case is represented by short dashed lines in the chart.

Comment on $\phi_d = 0$ condition: The condition of $\phi_d = 0$ in Taylor's Stability Chart is somewhat misleading since, as noted previously, Taylor's charts were derived for simple slopes without seepage, i.e., for an effective stress analysis. The condition of "$\phi_d = 0$" was used by Taylor to simplify the analysis and permit generation of the stability charts by assuming that shear strength is constant with depth. Basically, in the Mohr-Coulomb equation, Taylor assumed an average intergranular pressure, σ'_{avg} instead of an actual value of σ' which varies with depth. Since stability analyses are much simpler to perform when the shear strength is constant, he introduced this concept into his stability charts by considering the effective cohesion to be the average shear strength and by considering the friction angle to be zero. Thus the condition where $\phi_d = 0$ is merely an example of substitution of an average value for a variable quantity. However, in the context of Taylor's definition of $\phi_d = 0$, the stability charts are often used in practice for estimating the factor of safety and location of the critical circle in a homogeneous saturated clay in undrained shear.

As shown in Figure 6-14, the critical circle for the "$\phi_d = 0$" case passes below the toe for slopes with inclinations less than 53º. In practice the depth to which the failure circle extends is limited by an underlying strong material. Thus, the value of N_s for this case is greatly dependent on this limiting value of depth. The chart shown in Figure 6-15 is used exclusively for the "$\phi_d = 0$" case and supplements the curves shown in Figure 6-14 for that condition. The coordinates in Figure 6-15 allow the chart to be used easily and enable the user to evaluate a number of parameters that may be of interest in practice. For example, the chart can be used to determine nH, which is the distance from the toe of the slope to where the critical failure surface passing below the toe may be expected to emerge.

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6.6.2.1 Determination of the Factor of Safety for a Slope

As indicated in Section 6.6.2, in order to use Taylor's charts to determine the minimum overall factor of safety with respect to shear strength for a slope of given height H and inclination β having soil properties γ, c' and ϕ', the condition $FS = F_c = F_\phi$ must be satisfied. The general computational approach is as follows:

1. Assume a reasonable value for the common factors of safety $FS = F_c = F_\phi$.
2. Use Equations 6-21 to calculate the corresponding values of c_d and ϕ_d.
3. For the given value of β and the calculated value of ϕ_d, read the corresponding value of the stability number N_s from Figure 6-14.
4. Use an inverted form of Equation 6-26 to calculate the slope height H corresponding to the assumed factor of safety.
5. If the calculated value of H is within an acceptable distance of the actual height, e.g., ± 0.5 feet, the assumed value of the common factor of safety represents the minimum overall factor of safety of the slope with respect to shear strength, F_s.
6. If the calculated value of H is not within the desired acceptable range, the process is repeated with a new assumed value of the common factor of safety until the recomputed value of H falls within that range.
7. The new assumed value of the common factor of safety for subsequent iterations is generally less than the previously chosen value if the calculated value of H is less than the actual value of H. Conversely, a. larger value of the new common factor of safety is assumed if the calculated value of H is greater than the actual value of H.

The use of Taylor's chart is illustrated by the following example.

Example 6-1: Determine the factor of safety for a 30 ft high fill slope. The slope angle is 30°. The fill is constructed with soil having the following properties:
Total unit weight, γ = 120 pcf; Effective cohesion, c' = 500 psf
Effective friction angle, ϕ' = 20°

Solution:

First assume a common factor of safety of 1.6 for both cohesion and friction angle so that $F_c = F_\phi = 1.6$. Since $F_\phi = 1.6$, the developed friction angle, ϕ_d, can be computed as follows:

$$\phi_d = \arctan\left(\frac{\tan\phi'}{F_\phi}\right) = \arctan\left(\frac{\tan 20^o}{1.6}\right) = 12.8^o$$

For ϕ_d = 12.8º, and β = 30º, the value of the stability number N_s from Figure 6-14 is approximately 0.065. Thus, from Equation 6-26

$$0.065 = \frac{500 \quad psf}{(1.6) \quad (120 \quad pcf) \quad (H)}$$

or

$$H = \frac{500 \quad psf}{(1.6) \quad (120 \quad pcf) \quad (0.065)} = 40.1 \text{ ft}$$

Since computed height H = 40.1 ft is greater than the actual height of 30-ft, the value of the common safety factor must be greater than 1.6. Assume $F_c = F_\phi$ = 1.9 and recompute as follows:

If F_ϕ = 1.9, then ϕ_d = 10.8º and N_s from Figure 6-14 is approximately 0.073 based on which the recomputed value of H is as follows:

$$H = \frac{500 \quad psf}{(1.9) \quad (120 \quad pcf) \quad (0.073)} = 30.04 \text{ ft}$$

The height of 30.04 ft is virtually identical to the correct height of 30 ft. Therefore, the minimum factor of safety with respect to shearing strength is approximately 1.9.

Alternate Graphical Approach

An alternate graphical approach for determining the minimum factor of safety with respect to shearing strength is also available. The procedure is as follows:

1. Assume a reasonable value for F_ϕ and calculate ϕ_d.
2. For the given value of β and the calculated value of ϕ_d read the corresponding value of the stability number N_s from Figure 6-14.
3. Use Equation 6-26 to calculate F_c
4. Repeat the process for at least two other assumed values of F_ϕ over a range of expected factors of safety so that at least three pairs of F_ϕ and F_c are obtained.
5. Plot the calculated points on F_c versus F_ϕ coordinates and draw a curve through the points.
6. Draw a line through the origin that represents $F_c = F_\phi$.
7. The minimum overall factor of safety of the slope with respect to shear strength is the value of factor of safety at the intersection of the calculated with the $F_c = F_\phi$ line.

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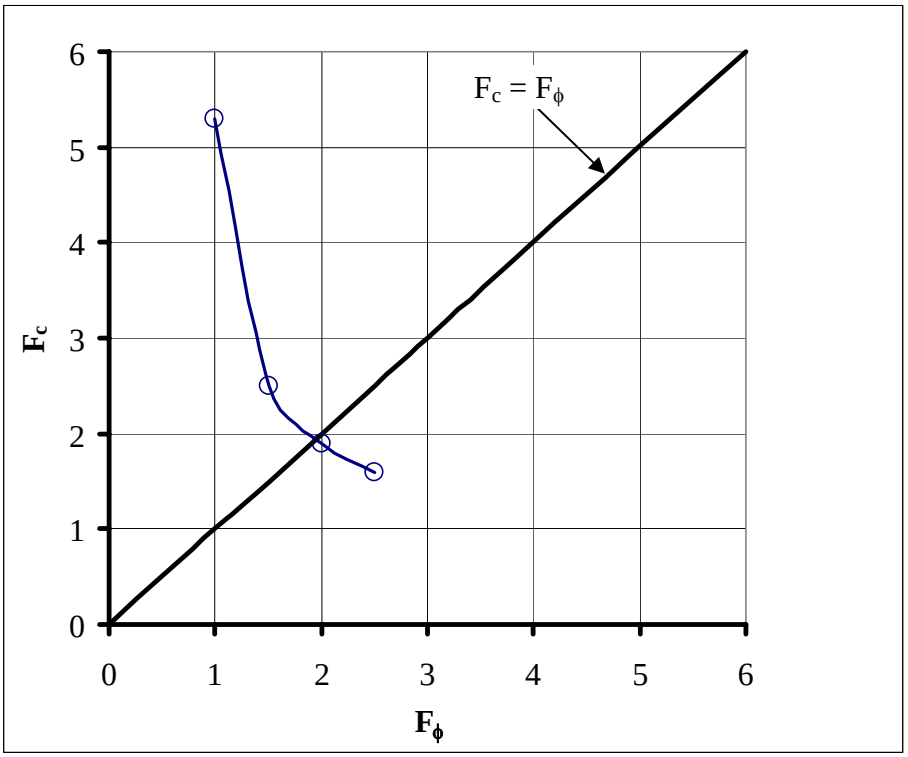
Example 6-1a: Solve Example 6-1 by using the alternate graphical approach.

Solution:

Set up a table for ease of computation (steps 1 through 4) as follows:

Assumed F_ϕ	Calculated ϕ_d	N_s from Figure 6-14	Calculated F_c
1.0	20	0.026	5.3
1.5	14	0.055	2.5
2.0	10	0.075	1.9
2.5	8	0.087	1.6

As shown in the figure below, plot the data as per steps 5 and 6 of the procedure. Read the value of $F_c = F_\phi = 1.95$ at the intersection of plotted curves. This value is the minimum factor of safety with respect to shearing strength, FS. This value is close to the value of 1.9 calculated in Example 6-1. This example problem is also solved by the use of a computer program, ReSSA, in Appendix D and the computer analysis yielded a FS =1.96 which is close to the values computed by the use of stability chart.



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6.6.3 Janbu's Stability Charts

Janbu (1968) published stability charts for slopes in soils with uniform strength for $\phi = 0$ and $\phi > 0$ conditions. These charts are presented in Figures 6-16 through 6-19. This series of charts accounts for several different conditions and provides factors for surcharge loading at the top of the slope, submergence, and tension cracks that can be expected to influence the design of typical highway slopes.

The stability chart for slopes in soils with uniform shear strength throughout the depth of the layer and with $\phi = 0$ is shown in Figure 6-16. Charts for correction factors for the conditions when surcharge loads, submergence and tension cracks are present are shown in Figures 6-17 through 6-19. Step-by-step guidance for the use Janbu's charts follows.

Steps for using Janbu's Charts on Figures 6-16 through 6-19, for $\phi = 0$ material.

Step 1. Use the chart at the bottom of Figure 6-16 to determine the position of the center of the critical circle, which is located at a coordinate point defined by X_o, Y_o with respect to a cartesian coordinate system whose origin is at the toe of the slope. Following are some guidelines that can be used to identify the critical center:

- For slopes steeper than 53°, the critical circle passes through the toe. For slopes flatter than 53°, the critical circle passes below the toe.
- In addition to the toe circle, at least four circles with different depths below the toe, D, should be analyzed to ensure that the actual minimum factor of safety and the actual critical circle have been found. The following suggestions may be used to select the circles (Duncan and Wright, 2005):
  - If there is water outside the slope, a circle passing above the water may be critical.
  - If a soil layer is weaker than the one above it, the critical circle may extend into the lower (weaker) layer. This applies to layers both above and below the toe.
  - If a soil layer is stronger than the one above it, the critical circle may be tangent to the top of the stronger layer.

For each of the assumed circles, perform Steps 2 to 6.

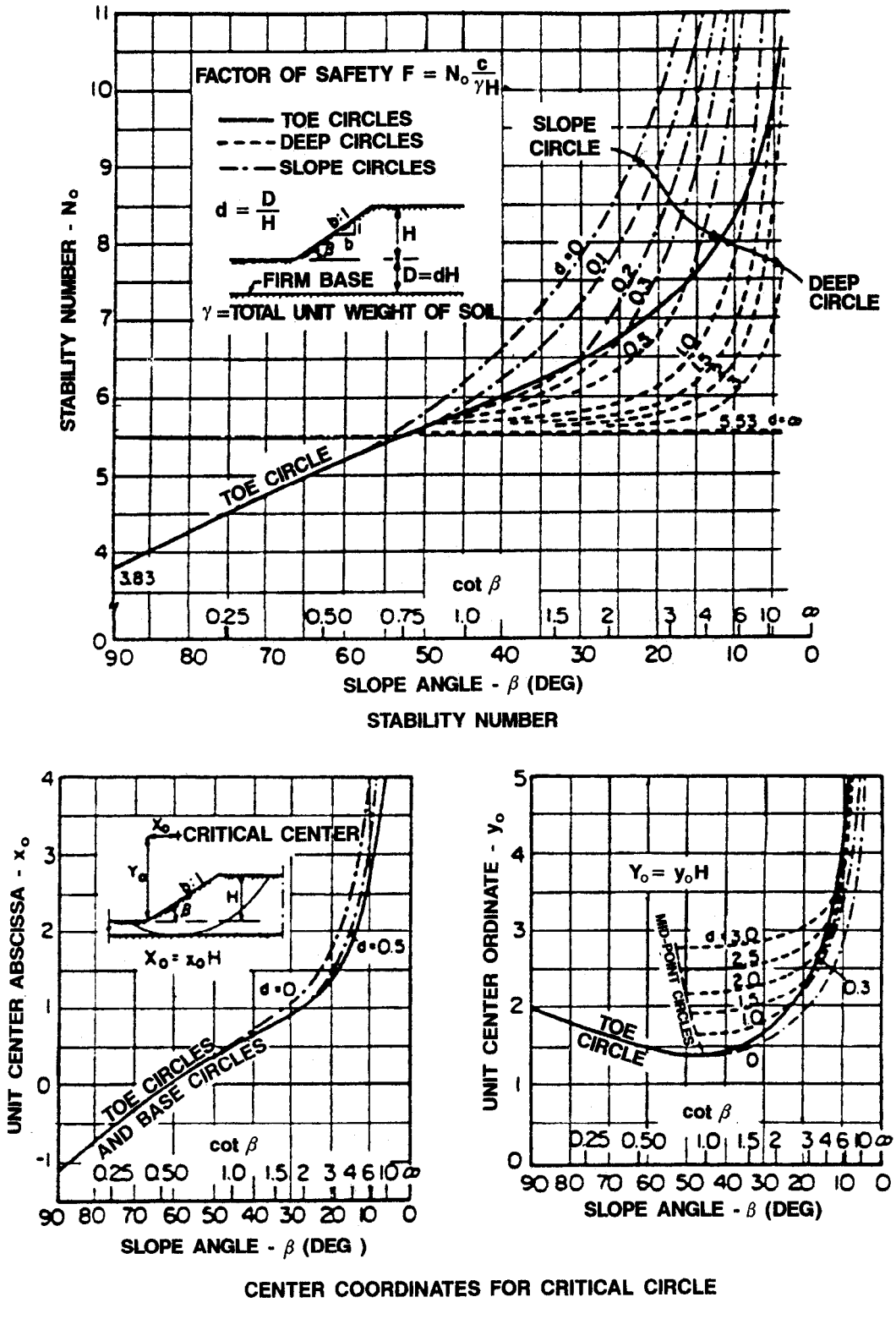


Figure 6-16. Stability charts for ϕ = 0 soils (Janbu, 1968).

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Step 2. Using the assumed critical circle as a guide, estimate the average value of strength, c, by calculating the weighted average of the strengths along the failure surface. The number of degrees intersected along the arc by each soil layer as a percentage of the entire angle subtended by the arc is used as the weighting factor.

Step 3. Calculate the depth factor, d where d = D/H. (Note that the depth factor, d, for Janbu's charts is different from the depth ratio *D* for Taylor's chart.)

Step 4. Calculate P_d by using the following equation:

$$P_d = (\gamma H + q - \gamma_w H_w)/(\mu_t \mu_q \mu_w) \qquad 6\text{-}27$$

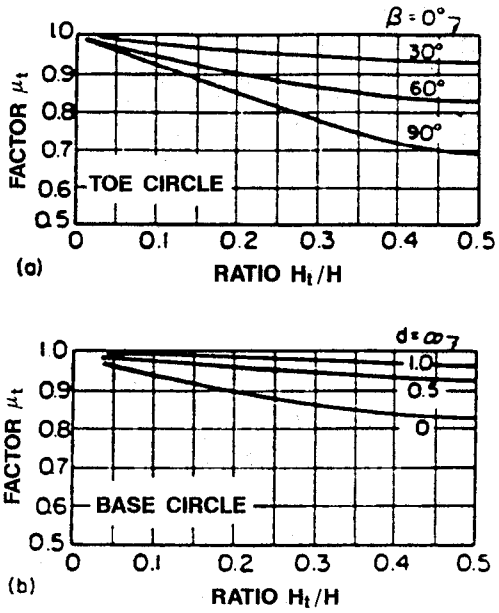
where: q = surcharge load
γ_w = unit weight of water
H_w = depth of water outside the slope
μ_t = tension crack correction factor (Figure 6-17)
μ_q = surcharge correction factor (Figure 6-18, top)
μ_w = submergence correction factor (Figure 6-18, bottom)

Step 5. Use the chart at the top of Figure 6-16 to determine the value of the stability number, N_o, which depends on the slope angle β, and the value of d.

Step 6. Calculate the factor of safety (FS) by using the following equation:

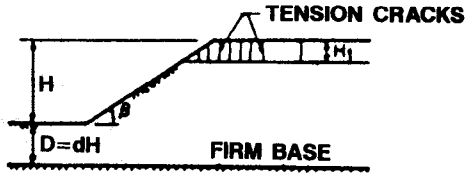
$$FS = N_o c/P_d \qquad 6\text{-}28$$

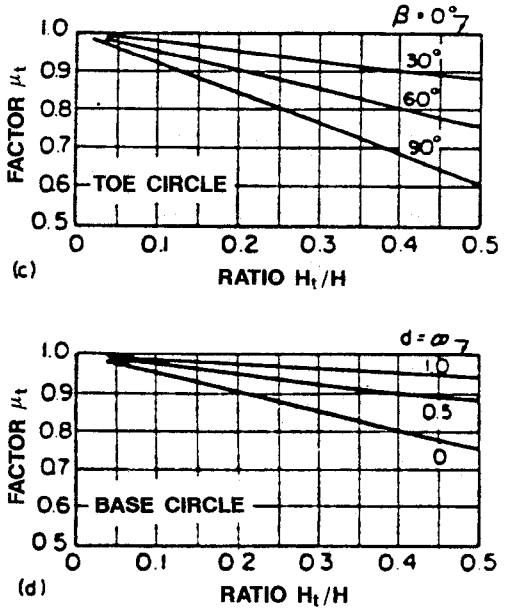
Step 7. Repeat Steps 2 to 6 for all the circles assumed in Step 1. Compare the FS to obtain the most critical circle as the circle with the lowest FS. If it appears that the minimum FS is for a circle close to the toe, i.e., d=0, then it is prudent to check if the critical failure surface is within the height of the slope, H. In this case, the toe of the slope is adjusted to the point of intersection of assumed circle with the slope and all dimensions, (i.e., D, H, and H_w) are adjusted accordingly in the calculations and steps 1 to 6 are repeated (Duncan and Wright, 2005).



No water in crack i.e., no hydrostatic pressure in crack

KEY SKETCH





Crack filled with water, i.e., full hydrostatic pressure in crack

KEY SKETCH

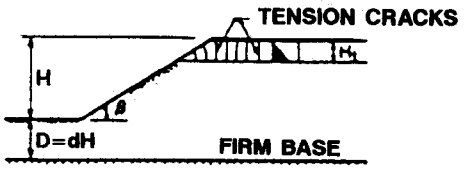


Figure 6-17. Reduction factors to account for tension cracks to be used with stability charts for ϕ=0 and ϕ > 0 soils (Janbu, 1968).

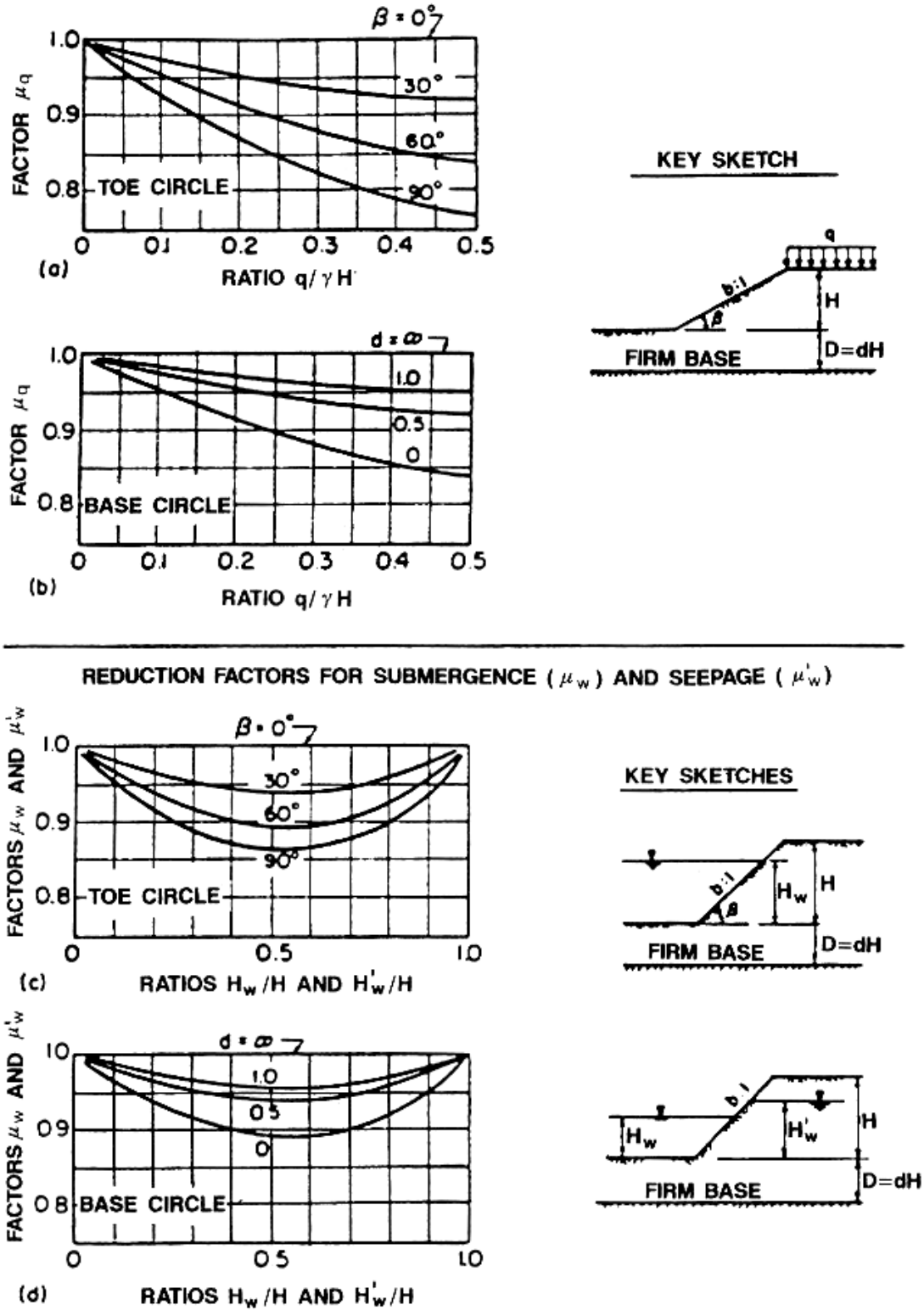


Figure 6-18. Reduction factors to account for surcharge (upper) and submergence and/or seepage (lower) to be used with stability charts for ϕ=0 and ϕ > 0 soils (Janbu, 1968).

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Steps for using Janbu's Charts on Figures 6-17 through 6-19, for $\phi > 0$ materials.

Step 1. Use judgment to estimate the location of the critical circle. For most conditions of simple slopes in uniform soils with $\phi > 0$, the critical circle passes through the toe of the slope. The critical stability numbers given in Figure 6-19 were developed from analyses of toe circles.

Where conditions are not uniform and there is a weak layer beneath the toe of the slope, a circle passing beneath the toe may be more critical than a toe failure. Figure 6-19 may be used to calculate the factor of safety for such cases provided the values of c and ϕ used in the analysis represent the correct average values for the circle considered.

If there is a weak layer above the toe of the slope, a circle passing above the toe of the slope may be more critical. Similarly, if there is water outside the toe of the slope, a circle passing above the water may be more critical. When these types of circles are analyzed, the value of H should be equal to the height from the base of the weak layer, or the water level, to the top of the slope.

Step 2. Use the estimated circle in Step 1 as a guide to estimate the average values of c and ϕ. This can be done by calculating the weighted average values of c and ϕ. The number of degrees intersected along the arc by each soil layer as a percentage of the entire angle subtended by the arc is used as the weighting factor for each parameter.

Step 3. Calculate P_d by using Equation 6-27.

Step 4. Calculate P_e by using the following equation:

$$P_e = (\gamma H + q - \gamma_w H'_w)/(\mu_q \mu'_w) \qquad 6\text{-}29$$

where: H'_w = height of water within the slope (Figure 6-18, bottom)
μ_q = surcharge correction factor (Figure 6-18, top)
μ'_w = seepage correction factor (Figure 6-18, bottom)

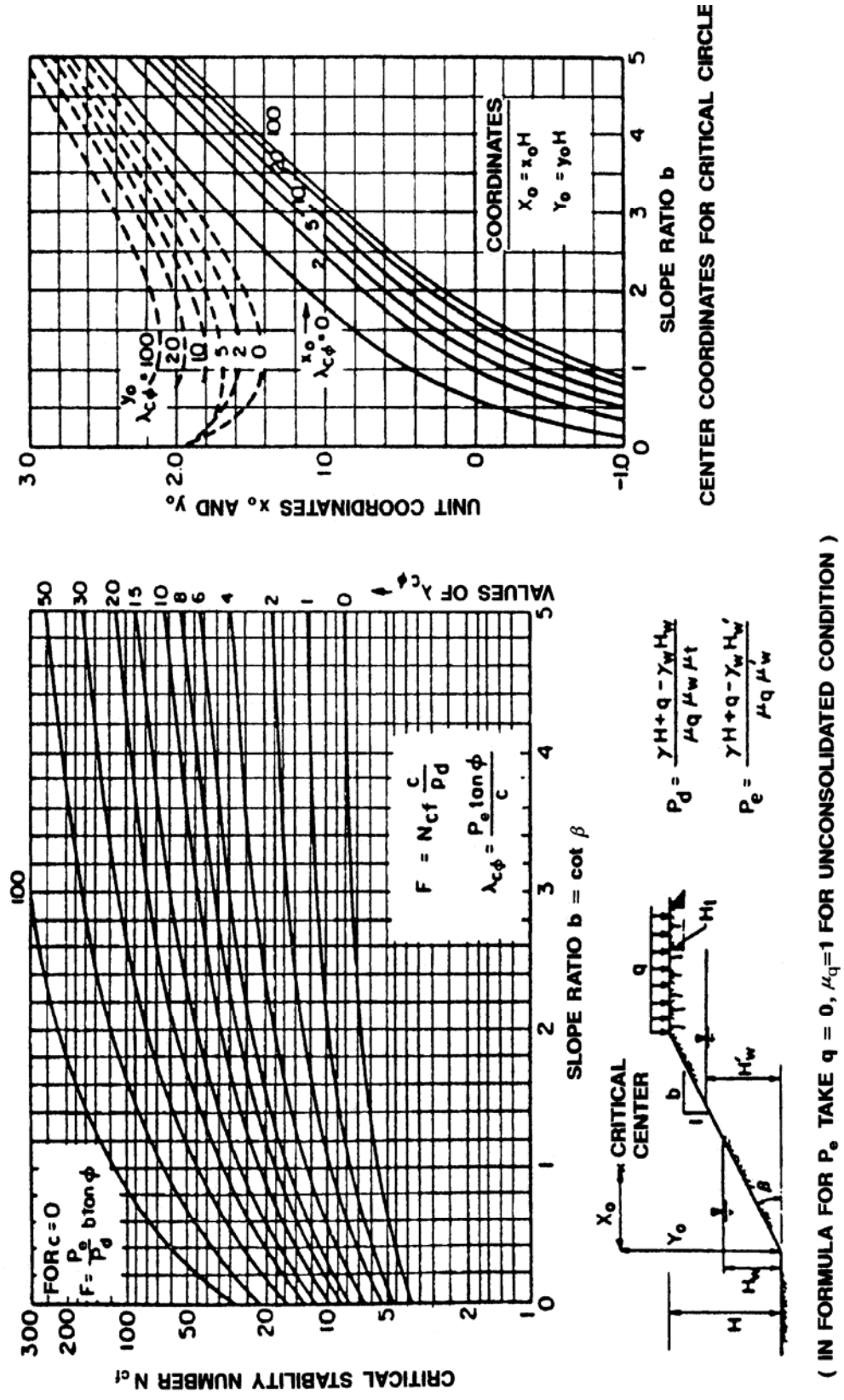


Figure 6-19. Stability charts for ϕ > 0 (Janbu, 1968).

Step 5. Calculate the dimensionless parameter $\lambda_{C\phi}$ by using the following equation:

$$\lambda_{C\phi} = P_e \tan\phi/c \qquad 6\text{-}30$$

For c=0, $\lambda_{C\phi}$ is infinite therefore skip to Step 6.

Step 6. Use the chart in Figure 6-19 to determine the value of the critical stability number, N_{cf}, which is dependent on the slope angle, β, and the value of $\lambda_{C\phi}$.

Step 7. Calculate the factor of safety for the slope as follows:

For c > 0 $\quad FS = N_{cf}\, c/ P_d \qquad 6\text{-}31$

For c = 0 $\quad FS = P_e\, b \tan \phi/ P_d \qquad 6\text{-}32$

Step 8. Determine the actual location of the critical circle by using the chart on the right side of Figure 6-19. The center of the circle is located at a coordinate point defined by X_o, Y_o with respect to a cartesian coordinate system whose origin is at the toe of the slope. The circle passes through the toe of the slope (the origin), except for slopes flatter than 53°, where the critical circle passes tangent to the top of firm soil or rock. If the critical circle is much different from the one assumed in Step 1 for the purpose of determining the average strength, Steps 2 through 8 should be repeated.

If a slope contains more than one soil layer, it may be necessary to calculate the factor of safety for circles at more than one depth. If the underlying soil layer is weaker than the layer above it, the critical circle will extend into the lower layer, and either a toe circle or a deep circle within this layer will be critical. If the underlying soil layer is stronger than the layer above it, the critical circle may or may not extend into the lower layer, depending on the relative strengths of the two layers. Both possibilities should be examined (Duncan and Wright, 2005).

The use of Janbu's charts is illustrated by the following example.

Example 6-2: Figure 6-20 shows a 35 ft high slope with a grade of 1.5H:1V. The soil properties within the slope and under it are shown on the figure. Groundwater is immediately under the slope. Calculate the factor of safety for a toe circle by using total stress analysis based on the soil properties shown. (Note: The circle in Figure 6-20 is plotted in Step 5 of the solution.)

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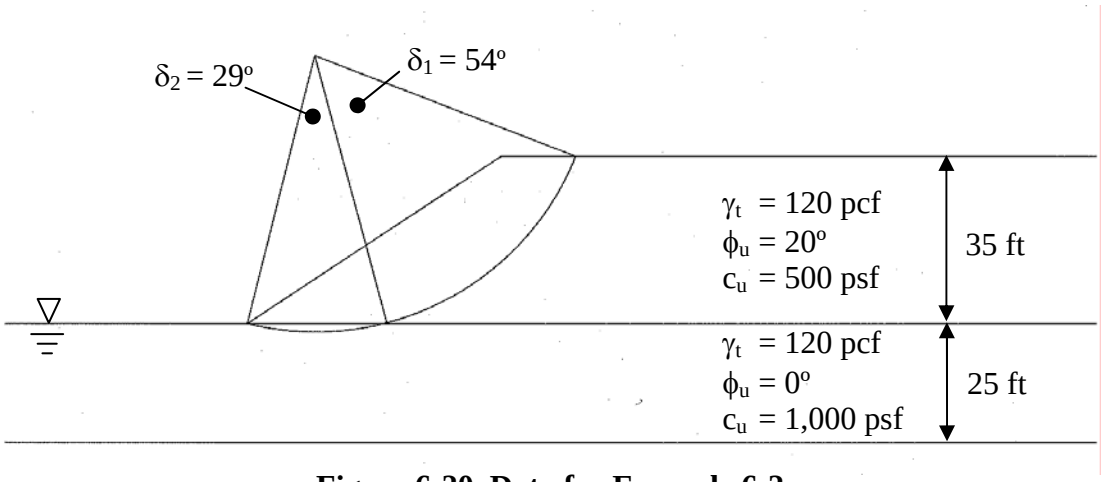


Figure 6-20. Data for Example 6-2.

Solution:

The correction factors μ_t, μ_q, μ_w and μ'_w are all equal to 1.0 since there is no tension crack (H_t = 0), no surcharge on the slope (q = 0), no water above the toe of the slope ($\gamma_w H_w$= 0), and no seepage out of the slope ($\gamma_w H'_w$= 0).

1. Calculate P_d by using Equation 6-27 as follows:

   $P_d = (\gamma H + q - \gamma_w H_w)/(\mu_t \mu_q \mu_w)$
   P_d = (120 pcf)(35 ft)/[(1)(1)(1)] = 4,200 psf

2. Calculate P_e by using Equation 6-29 as follows:

   $P_e = (\gamma H + q - \gamma_w H'_w)/(\mu_q \mu'_w)$
   P_e = (120 pcf)(35 ft)/[(1)(1)] = 4,200 psf

3. For a toe circle, it is likely that a segment of the circle will pass through the soil below the toe and the average shear strength parameters along the circle will be different than those for the two layers. However, since at this stage the length of the segment passing through the soil below the toe is unknown, assume that the shear strength values of the soil within the slope height are representative and calculate the parameter $\lambda_{C\phi}$ by using Equation 6-30 as follows:

   $\lambda_{C\phi} = P_e \tan\phi/c$ = (4,200 psf) (tan 20°)/(500 psf) = 3.06

4. From Figure 6-19 obtain the approximate center coordinates of the critical circle by using b=1.5 and $\lambda_{C\phi}$ = 3.06 as follows

$x_o \approx 0.4$ $y_o \approx 1.6$ Thus, $X_o = (H)(x_o) = (35\text{ ft})(0.4) = 14\text{ ft}$
$Y_o = (H)(y_o) = (35\text{ ft})(1.6) = 56\text{ ft}$

5. Plot the critical circle on the given slope, as shown in Figure 6-20. Note that the subtended angles for the failure circle within the slope and the foundation are $\delta_1 = 54^o$ and $\delta_2 = 29$ degrees, respectively.

6. Calculate c_{av}, tan ϕ_{av} and $\lambda_{C\phi}$ based on the angular distribution of the failure surface within the slope and foundation soil using δ_1 and δ_2 as follows:

   $c_{av} = [(54^o)(500\text{ psf}) + (29^o)(1{,}000\text{ psf})] / (54^o+29^o) = 674.7\text{ psf}$

   $\tan \phi_{av} = [(54^o)(\tan 20^o) + (29^o)(\tan 0^o)] / (54^o+29^o) = 0.236$ (or $\phi_{av} = 13.3^o$)

   Thus, according to Equation 6-30;
   $\lambda_{C\phi} = P_e \tan\phi / c = (4{,}200\text{ psf})(0.236)/(674.7\text{ psf}) = 1.47 \approx 1.5$

7. From Figure 6-19 obtain the center coordinates of the critical circle by using b=1.5 and $\lambda_{C\phi} = 1.5$ as follows

   $x_o \approx 0.5$ $y_o \approx 1.55$ Thus, $X_o = (H)(x_o) = (35\text{ ft})(0.5) = 17.5\text{ ft}$
   $Y_o = (H)(y_o) = (35\text{ ft})(1.55) = 54.3\text{ ft}$

   This circle is close to the circle obtained in the previous iteration, so retain $\lambda_{C\phi} = 1.5$ and $c_{av} = 674.7$ psf .

8. From Figure 6-19, obtain $N_{cf} = 10.0$ for b = 1.5 and $\lambda_{C\phi} = 1.5$.

9. Calculate the factor of safety, FS, by using Equation 6-28 as follows :

   $FS = N_o c/P_d = (10)(674.7\text{ psf}) / (4{,}200\text{ psf})$
   $FS = 1.61$

   This calculation sequence is only for a given circle. This sequence is repeated for several circles and the resulting FS compared to find the minimum FS. With the advent of computer programs, this method is now more often used to verify the results of the computer generated most critical circle rather than computing the minimum FS by repeating the above sequence of calculations for several circles.

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6.7 SLIDING BLOCK FAILURE

A "sliding block" type failure can occur where:

1. the foundation soil contains thin seams of weak clay or organic soils,

2. a shallow layer of weak soil exists at the ground surface and is underlain by firm soil, and

3. the foundation soil contains thin sand or silt lenses sandwiched between less permeable soil. The weak layers or lenses provide a plane of weakness along which sliding can occur. In the case of sand or silt lenses trapped between less permeable soils, the mechanism that can cause sliding is as follows. As the fill load is placed, the water pressure is increased in the sand or silt lense. Since the water cannot escape due to the impermeable soil above and below, the sand or silt loses frictional strength as a result of the intergranular effective stress between soil grains being decreased due to the excess pore water pressure.

Typical "sliding block" type failures are illustrated in Figure 6-21. When sliding occurs, an active wedge type failure occurs through the fill and a passive wedge type failure occurs below the fill toe as soil in the toe area is pushed out of the way. The sliding mass moves essentially as a block, thus the term "sliding block." These concepts are illustrated in Figure 6-22.

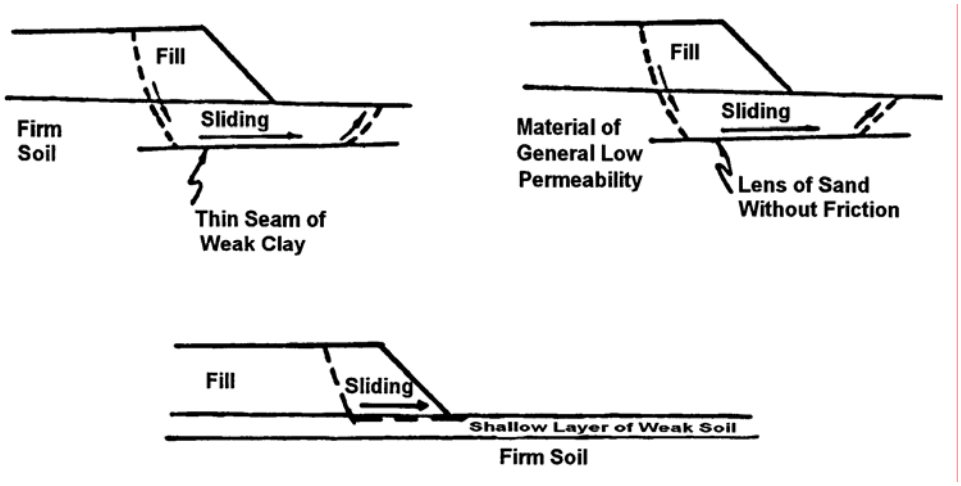


Figure 6-21. Sliding block failure mechanism.

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6.7.1 Sliding Block – Hand Method of Analysis

A simple sliding block analysis to estimate the factor of safety against sliding is straightforward and can be performed easily and quickly by hand. For the analysis, the potential sliding block is divided into three parts; (1) an active wedge at the head of the slide, (2) a central block, and (3) a passive wedge at the toe as shown in Figure 6-22.

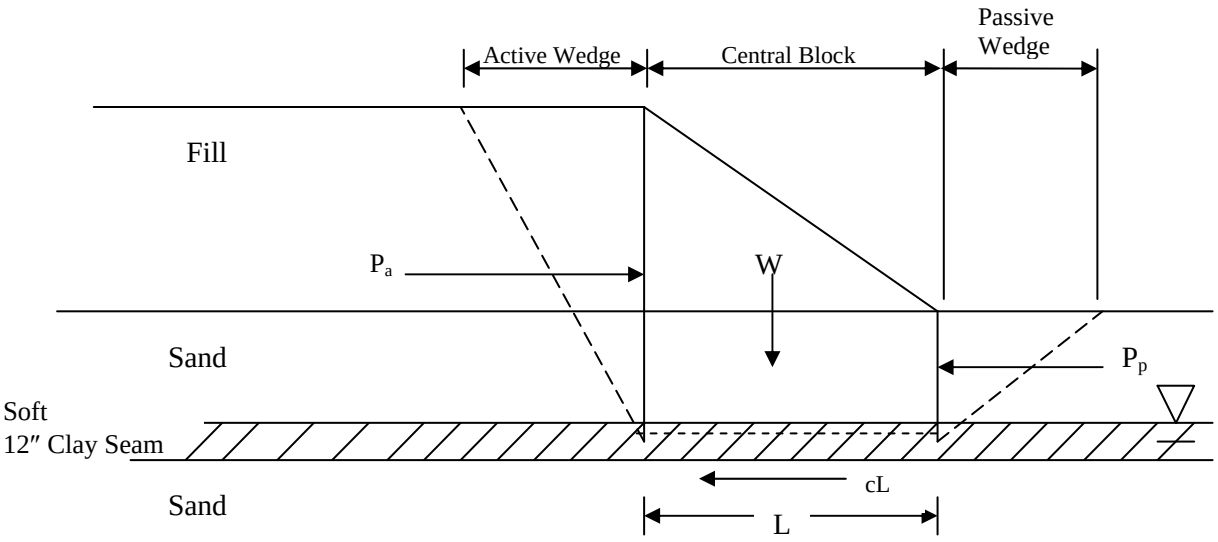


Figure 6-22. Geometry and force components for sliding block analysis.

For the problem illustrated in Figure 6-22, the factor of safety would be computed by summing forces horizontally, to give:

$$FS = \frac{\text{Horizontal Resisting Forces}}{\text{Horizontal Driving Forces}} = \frac{P_p + cL}{P_a} \qquad 6\text{-}33$$

where: P_a = Active force (driving)
P_p = Passive force (resisting)
cL = Resisting force due to cohesion of clay

The assumption is made that the loading is rapid so that there is no frictional component of resistance. For convenience of computation of a 1 ft thick slice of embankment is assumed.

Several trial locations of the active and passive wedges must be checked to determine the minimum factor of safety. Note that since wedge type failures occur at the head and toe of the slope, similar to what occurs behind retaining walls, the active and passive forces are

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assumed to act against vertical planes that are treated as "imaginary" retaining walls, and the active and passive forces are computed the same as for retaining wall problems.

6.7.1.1 Computation of Forces - Simple Sliding Block Analysis

For the simple sliding block problem illustrated Figure 6-22 the forces used to compute the factor of safety can be calculated by using the Rankine approach as follows:

Driving Force – Rankine Active Force

$$P_a = 1/2\ \gamma\ H^2\ K_a \qquad 6\text{-}34$$

Where: P_a = active force (kips) (kN)
γ = unit weight of soil in the active wedge (kcf) (kN/m^3)
H = height of soil layer in active wedge (ft) (m)
K_a = active earth pressure coefficient for level ground surface
$K_a = (1-\sin\phi)/(1+\sin\phi) = \tan^2(45^o - \phi/2)$ (see Chapter 2)
ϕ = angle of internal friction of soil in the active wedge.

Resisting Force – Rankine Passive Force

$$P_p = 1/2\ \gamma\ H^2\ K_p \qquad 6\text{-}35$$

Where: P_p = passive force (kips) (kN)
γ = unit weight of soil in the passive wedge (kcf) (kN/m^3)
H = height of soil layer in passive wedge (ft) (m)
K_p = passive earth pressure coefficient for level ground surface
$K_p = (1+\sin\phi)/(1-\sin\phi) = \tan^2(45^o + \phi/2)$ (see Chapter 2)
ϕ = angle of internal friction of soil in the passive wedge.

Resisting Force (kips or kN) = Clay cohesion (c in ksf or kPa) x Length of central wedge (L in ft or m)

Computation Tips:

The following design tips should be kept in mind when a sliding block analysis is performed.

1. Be aware that the active or passive wedge can pass through more than one soil type with different strengths or unit weights. If that is the case then the active or passive

pressure distribution changes at the boundary between the different soils. This abrupt change in pressure is due to a change in either the angle of internal friction that affects the value of the earth pressure coefficient K_a or K_p and/or a change in the unit weight of the soil. The easiest way to handle this condition is to compute the active or passive earth pressure distribution diagram for each soil. There may be a discontinuity in the pressure diagram at the boundary between the two different soil layers. Then compute the active or passive force for each segment of the pressure distribution diagram from the area of each segment.

2. When the active or passive pressure is being computed for soils below the ground water table, the buoyant (effective) unit weight of the soil must be used.

The step-by step procedure for the Sliding Block Method of Analysis is illustrated by the following numerical example.

Example 6-3: Find the safety factor for the 20 ft high embankment illustrated in Figure 6-23 by using the simple sliding block method and Rankine earth pressure coefficients. Consider a 1 ft wide strip of the embankment into the plane of the paper.

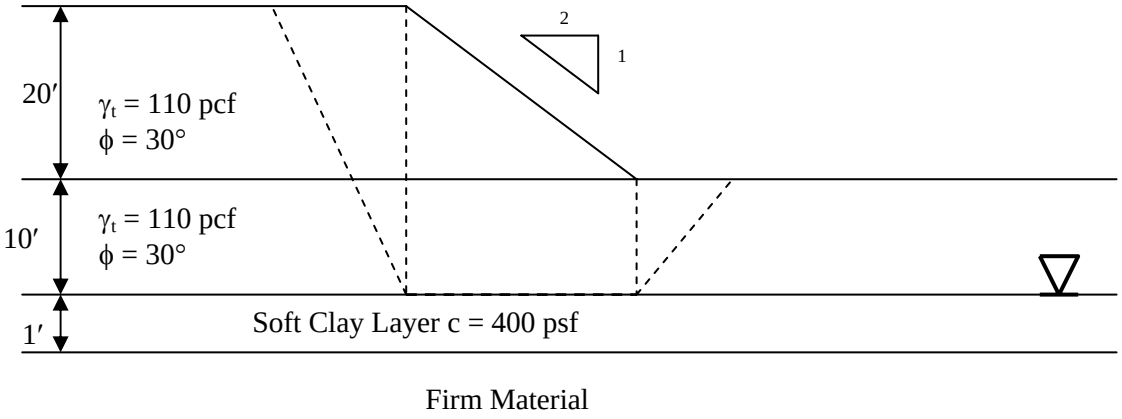


Figure 6-23. Example simple sliding block method using Rankine pressure coefficients.

Solution

Step 1: Compute driving force, P_a, by using Equation 6-34

- Active Driving Force (P_a) by using Equation 6-34

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$P_a = \frac{1}{2}\gamma_t H^2 K_a$ (use γ_t as the water table is below the failure plane)

$$K_a = \tan^2\left(45 - \frac{\phi}{2}\right) = \tan^2\left(45 - \frac{30^o}{2}\right) = 0.33$$

$$P_a = \frac{1}{2}(0.110\,\text{kcf})(30\,\text{ft})^2(0.33)(1\text{ft}) = 16.5\ \text{kips}$$

Step 2: Compute resisting forces

- Central Block Resistance

$$cl = (0.400\,\text{ksf})(40\,\text{ft})(1\text{ ft}) = 16.0\ \text{kips}\ (71.1\text{ kN})$$

- Passive Resisting Force by using Equation 6-35

$$P_p = \frac{1}{2}\gamma_t H^2 K_p$$

$$K_p = \tan^2\left(45 + \frac{\phi}{2}\right) = \tan^2\left(45 + \frac{30^o}{2}\right) = 3.0$$

$$P_p = \left(\frac{1}{2}\right)(0.110\,\text{kcf})(10\,\text{ft})^2(3)(1\,\text{ft}) = 16.5\,\text{kips}$$

Step 3: Compute factor of safety by using Equation 6-33

$$\text{Safety Factor} = \frac{cl + P_p}{P_a} = \frac{16.0\,\text{kips} + 16.5\,\text{kips}}{16.5\,\text{kips}} = 1.97$$

6.7.2 Computation of Forces - Complicated Sliding Block Analysis

The Rankine approach is a useful tool to portray the mechanism of a planar failure condition. However a general force diagram applicable to a more difficult sliding block type problem can account for the effects of water pressure, cohesion, friction, and a sloping failure plane in

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the analysis. This analysis procedure, which is described in FHWA (2001a), can be used both to estimate the factor of safety for assumed failure surfaces in design or to "back-analyze" sliding block landslide problems.

Computer solutions are also available for failure modes defined by planar and non-circular surfaces. However most of those solutions do not use the simplified Rankine block approach but rather a more complex failure plane such as that used in Janbu's method. In general a computer solution is preferred for these planar failure problems because of the flexibility they offer in handling a variety of conditions that result in a more complex failure plane.

6.8 SLOPE STABILITY ANALYSIS USING COMPUTER PROGRAMS

Slope stability procedures are well suited to computer analysis due to the interactive nature of the solution. Also, the simplified hand solution procedures do not properly account for interslice forces, irregular failure surfaces, seismic forces, and external loads such as line load surcharges or tieback forces. Several user-friendly computer programs exist to analyze two-dimensional slope stability problems. One of the advantages of a computer program is that it allows parametric studies to be performed by varying parameters of interest, e.g., shear strength parameters. More complex computer programs are available for three dimensional slope stability analysis. As a minimum, a basic two-dimensional slope stability program is recommended for routine use.

Desirable geotechnical features of such a program should include:

- Multiple analysis capability
  a. Circular arc (Bishop)
  b. Non-circular (Janbu)
  c. Sliding block

- Variable input parameters to account for specific conditions
  a. Heterogeneous soil systems
  b. Pseudo-static seismic loads
  c. Ground anchor forces
  d Piezometric levels

- Random generation of multiple failure surfaces with an option to analyze a specific failure surface.

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Desirable software features include:

- User-friendly input screens including a summary screen that shows the cross section and soil boundaries in profile.
- Help screens and error tracking messages.
- Expanded output options for both resisting forces in friction, cohesion or tieback computations and driving forces in static or dynamic computations.
- Ordered output and plotting capability for the failure surface of 10 minimum safety factors.
- Documentation of program.

A major problem for software users is technical support, maintenance and update of programs. Slope stability programs are in a continual process of improvement that can be expected to continue indefinitely. Highway agencies should implement only software that is documented and verified and for which the seller agrees to provide full technical support, maintenance and update. The following web page for the FHWA National Geotechnical Team contains links to distributors of FHWA software:

http://www.fhwa.dot.gov/engineering/geotech/index.cfm

Similar services are provided for commercially available slope stability programs such as the ReSSA (2001), SLOPE/W, SLIDE, STABL series (e.g., PCSTABL, XSTABL, GSTABL), and UTEXAS. Appendix D provides an overview of use of the ReSSA program.

Finally, it is extremely important for the designer to understand that the design is only as good as the input parameters. Therefore, the designer should put major emphasis where it belongs, which is on:

- Investigation
- Sampling
- Testing
- Development of soil profile
- Design soil strengths
- Ground water table location

Computer programs are only tools that aid in the design. The answers are only as good as the input data. Don't get carried away with plugging in the numbers and examining the results. You may learn the "garbage in - garbage out" principle the hard way.

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6.9 IMPROVING THE STABILITY OF EMBANKMENTS

There are usually several technically feasible solutions to a stability problem. The chosen solution should be the most economical considering the following factors:

1. Available materials.
2. Quantity and cost of materials.
3. Construction time schedules.
4. Line and grade requirements.
5. Right-of-way issues.

6.9.1 Embankment Stability Design Solutions

Table 6-2 presents a summary of practical solutions to mitigate embankment stability problems. Figures 6-24 to 6-26 illustrate some of the mitigation methods listed in Table 6-2. One of the solutions listed in Table 6-2 is the use of ground improvement. This solution can be used for cases where the internal stability of the embankment is not an issue due to the use of competent embankment materials, but the foundation materials are weak enough to affect the stability of the embankment slope. By improving the ground under the embankment, the resistance along the failure surface within the foundation is improved, thereby increasing the safety factor against slope failure. Relatively poor soils can be reinforced with geosynthetics to offset their low shear strength so that acceptable embankments can be constructed.

Another solution is related to reinforcement of the embankment soils themselves. This solution can be used where the foundation is adequate but the locally available soils may not be suitable for construction of embankments at the desired slope angles. In this case, the embankment soils may be strengthened by the inclusion of reinforcements. Such slopes are called reinforced soil slopes (RSS). The RSS technology can be used to construct slopes at angles up to 69-degrees from horizontal. The RSS design method is discussed here as an example of a remediation method. Only the basics of the RSS design method are presented herein. Detailed design procedures for RSS technology can be found in FHWA (2001b).

6.9.2 Design Approach for Reinforced Soil Slopes

The design of internal reinforcement for safe, steep slopes requires a rigorous analysis. The design of the reinforcement for this application is critical, as failure of the reinforcement would result in failure of the slope. The overall design requirements for reinforced slopes are similar to those for unreinforced slopes. The factor of safety must be adequate for both the short-term and long-term conditions and for all possible modes of failure.

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Table 6-2

Practical design solutions to mitigate embankment stability problems

*1. Relocate highway alignment.	A line shift of the highway to an area having better soils may be the most economical solution.
*2. Reduce grade line. (flatten slope)	A reduction in grade line will decrease the weight of the embankment and will improve stability (Figure 6-24).
3. Counterweight berms.	A counterweight berm outside of the center of rotation, as illustrated in (Figure 6-25), provides an additional resisting moment that increases the factor of safety. Berms should be built concurrently with the embankment. The embankment should never be completed prior to berm construction since the critical time for shear failure is at the end of embankment construction. The top surface of a berm should be sloped to drain water away from the embankment. Also, care should be exercised in selection of materials and compaction specifications to assure the design unit weight will be achieved for berm construction.
4. Excavation of soft soil and replacement with shear key.	The strength of soft soils is often insufficient to support embankments. In such cases, the soft soils are excavated and replaced with granular material that acts like a shear key (Figure 6-26).
5. Displacement of soft soil.	For deep soft deposits, excavation is difficult. The soft soil can be displaced by generating continuous shear failures along the advancing fill front until the embankment is on firm bottom. The mudwave forced up in front of the fill must be excavated to insure continuous displacement and prevent large pockets of soft soil from being trapped under the fill
6. Slow rate or stage	Many weak subsoils will tend to gain strength during the loading process as consolidation occurs and pore water pressures dissipate. For soils that consolidate relatively fast, such as some silts and silty clays, this method is practical. Proper instrumentation is desirable to monitor the state of stress in the soil during the loading period to insure that loading does not proceed so rapidly that a shear failure occurs. Typical instrumentation consists of slope inclinometers to monitor stability, piezometers to measure excess pore water pressure, and settlement devices to measure the amount and rate of settlement. Planning of the instrumentation program and data interpretation should be done by a qualified and experienced geotechnical engineer. This option could also be used if weak subsoils are pretreated with wick drains
7. Lightweight embankment.	In some areas of the country lightweight materials such as blast furnace slag, shredded rubber tires, or expanded shale are available. The slag material weighs about 80 pcf (12.6 kN/m^3). Sawdust fill weighs about 50 pcf (7.9 kN/m^3) and has a friction angle of 35^o or more. Expanded Polystyrene Foam (EPS) is available throughout the country and weighs 1 to 3 pcf (0.15 to 0.5 kN/m^3). Use of such materials decreases the driving force. Typical advantages and disadvantages of the use of such materials, and specifications for lightweight fills are included in FHWA (2006b).
8. Ground improvement	Recently developed techniques such as stone columns, soil mixing, geosynthetics, soil nailing, ground anchors, and grouting can be used to increase resisting forces. Specialty contractors should be considered for these design solutions.
9. Reinforcement of embankment soils.	The embankment soils can be strengthened by incorporating reinforcements with the compacted soil. The reinforcement generally permits steeper slopes compared to unreinforced embankments.

*Always consider these solutions first since they are relatively simple and inexpensive.

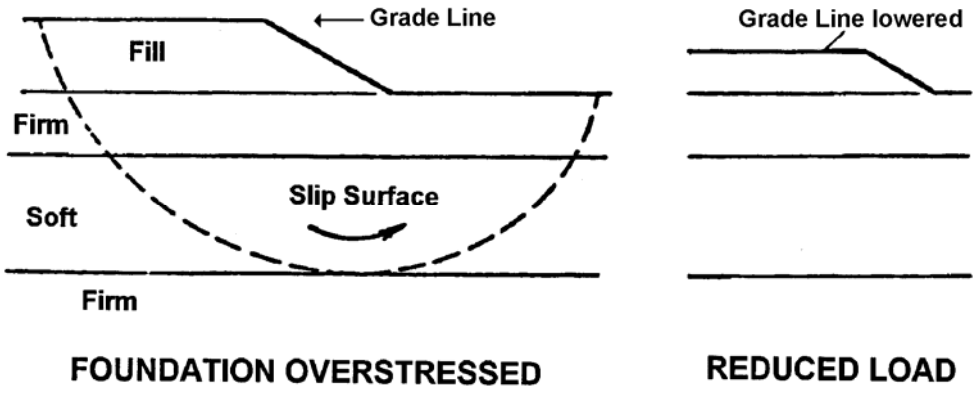


Figure 6-24. Reduction of grade line to improve slope stability.

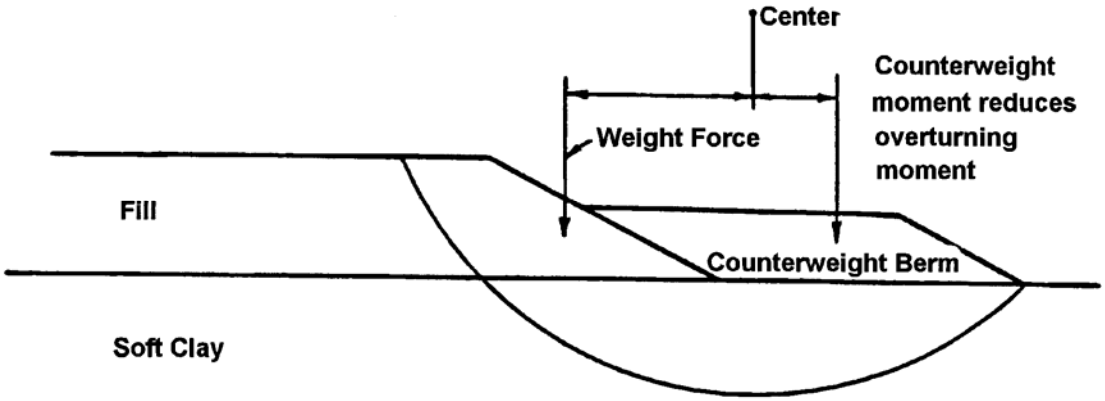


Figure 6-25. Use of counterweight berm to improve slope stability.

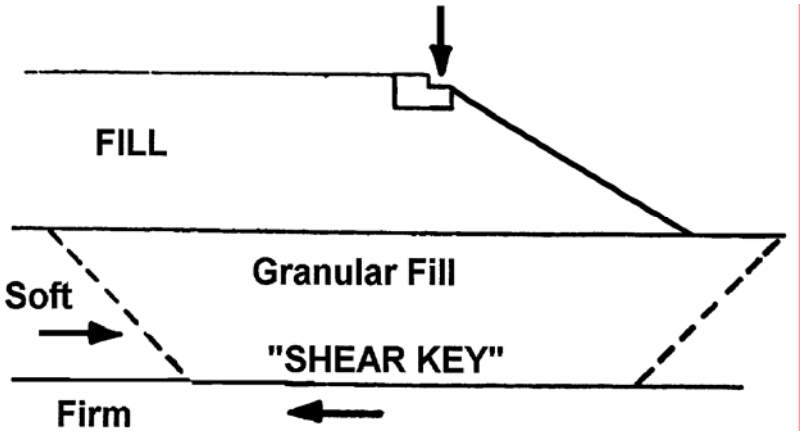


Figure 6-26. Use of shear key to improve slope stability.

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As illustrated in Figure 6-27, there are three possible failure modes for reinforced slopes:

1. Internal - the failure plane passes through the reinforcing elements.

2. External - the failure surface passes behind and underneath the reinforced mass. The reinforced mass is the mass of soil that contains the reinforcements.

3. Compound - the failure surface passes behind and through the reinforced soil mass.

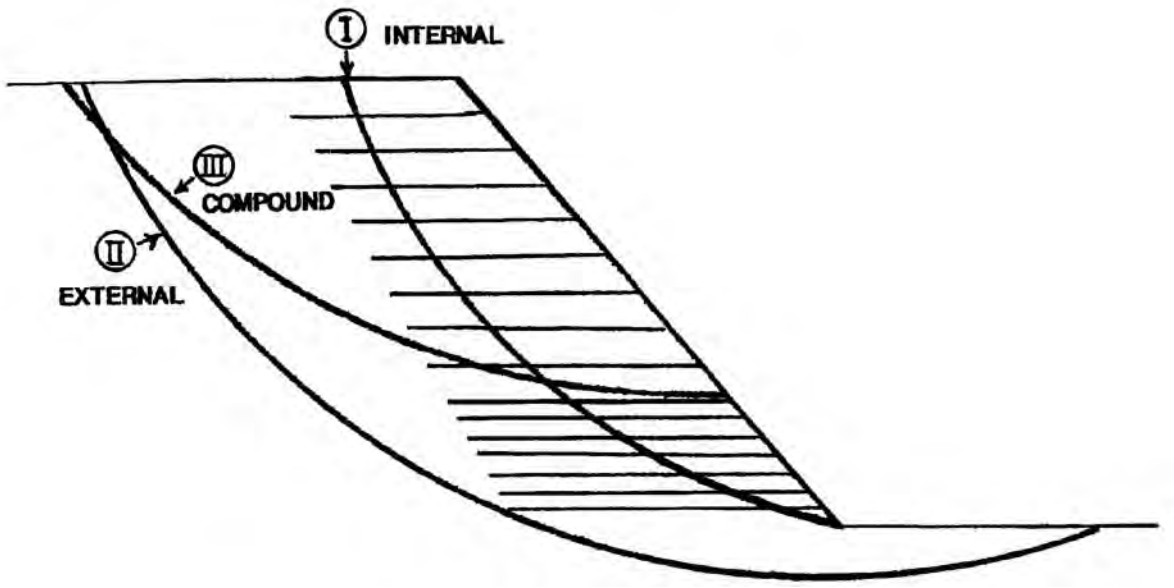


Figure 6-27. Failure modes for Reinforced Soil Slopes.

In some cases, the calculated minimum safety factor can be approximately equal in two or even all three modes if the reinforcement strengths, lengths, and vertical spacing are optimized (FHWA, 2001b). FHWA (2001b) contains a detailed discussion of the analysis and design of RSS'. A convenient chart solution is presented in this manual for preliminary feasibility-level design of the RSS.

6.9.2.1 Preliminary Feasibility Design of RSS

A preliminary design for a feasibility evaluation can be easily made by the use of design charts. These charts can also be used for the final design of low slopes, i.e., slope height less than 20 ft (6 m), where the consequences of failure are not critical. Figure 6-28 is a widely used chart that presents a simplified method based on a two-part, wedge-type failure surface. Use of the chart is limited by the assumptions noted on the figure. Figure 6-28 is not

intended to be a single design tool. Other design charts available from the literature could also be used, e.g., FHWA (2001b), Leshchinsky and Perry (1987).

The procedure for using the charts shown in Figure 6-28 is as follows:

1. For an assumed (desired) safety factor, F, determine the factored friction angle, ϕ'_f, in degrees as follows (Note: this is similar to the factored friction angle in Taylor's stability chart):

$$\phi'_f = \arctan\left(\frac{\tan\ \phi'}{F}\right)$$

2. Using ϕ'_f read the force coefficient K from Part A and determine $T_{S\text{-}MAX}$ as follows:

$$T_{S\text{-}MAX} = 0.5\ K\ \gamma_f\ (H')^2$$

where $H' = H + q/\gamma$ is the effective height, q = surcharge, and γ_f = fill unit weight.

3. Determine the length of the reinforcement at the top, L_T, and bottom, L_B, of the slope from Part B.

4. Determine the distribution of reinforcement:

   - For low slope heights ($H \leq 20$ ft) assume a uniform reinforcement distribution, and use $T_{S\text{-}MAX}$ to determine the spacing or the required tension, T_{MAX}, for each reinforcement layer.

   - For high slope heights ($H > 20$ ft), divide the slope into two or three reinforcement zones of equal height, and use a factored $T_{S\text{-}MAX}$ in each zone for spacing or design tension requirements.

For 2 zones:		For 3 zones:	
T_{Bottom}	= 3/4 $T_{S\text{-}MAX}$	T_{Bottom}	= 1/2 $T_{S\text{-}MAX}$
T_{Top}	= 1/4 $T_{S\text{-}MAX}$	T_{Middle}	= 1/3 $T_{S\text{-}MAX}$
		T_{Top}	= 1/6 $T_{S\text{-}MAX}$

The force is assumed to be uniformly distributed over the entire zone.

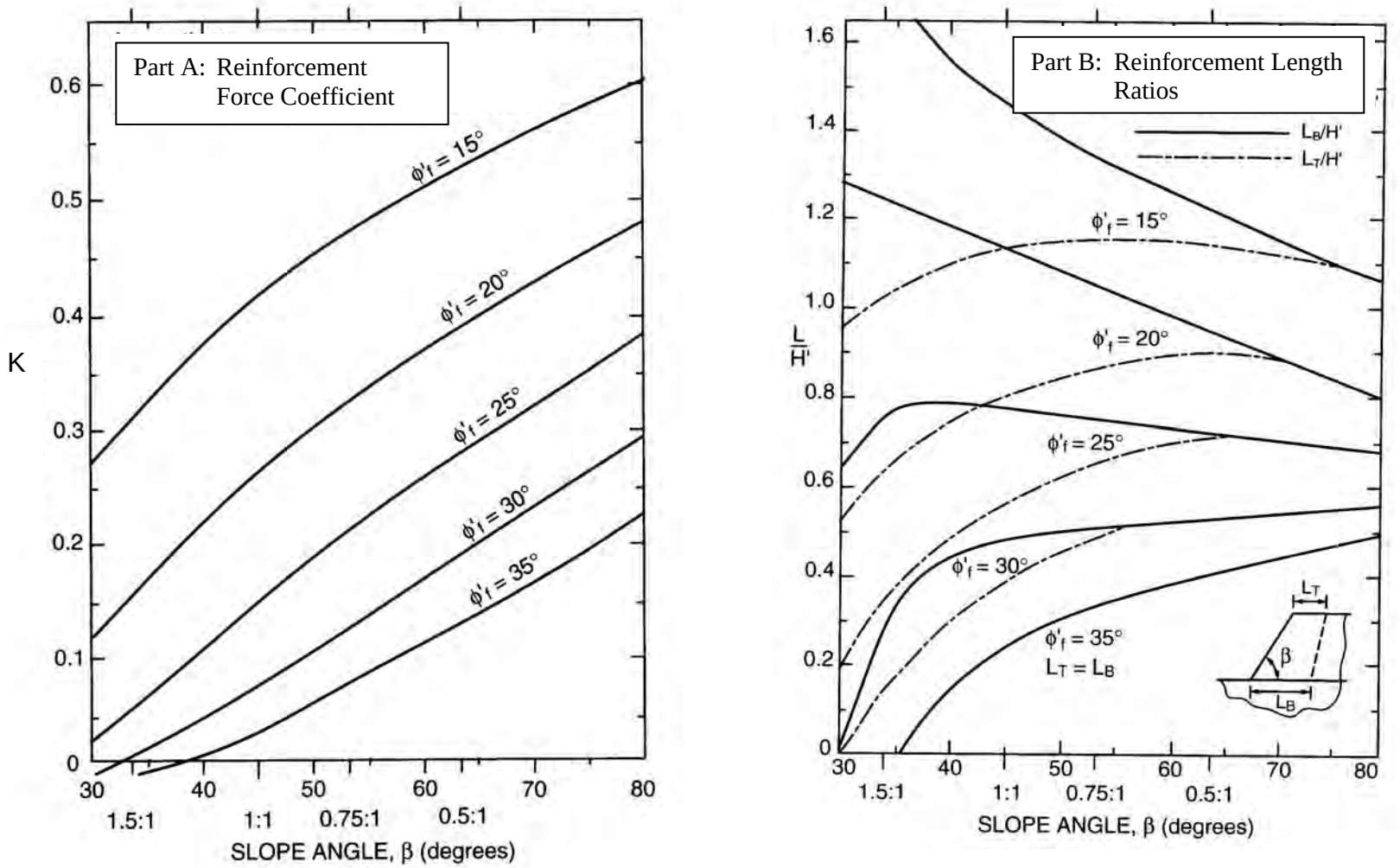


Chart assumptions:

(1) extensible reinforcement, (2) slopes constructed with uniform cohesionless soils (c=0), (3) no pore water pressures within slope, (4) competent, level foundation soils, (5) no seismic forces, (6) uniform surcharge, q, not greater than $0.2\gamma_f H$, (7) relatively high soil/reinforcement interface friction angle = $0.9\phi'$ (may not be appropriate for some geotextiles).

Figure 6-28. Chart solution for determining the reinforcement strength requirements (after Schmertmann, *et al.*, 1987).

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- Determine the requirements for vertical spacing of the reinforcement, S_v, or the maximum design tension, T_{MAX}, for each reinforcement layer.

- For each zone, calculate T_{MAX} for each reinforcing layer in that zone based on an assumed S_v or, if the allowable reinforcement strength is known, calculate the minimum vertical spacing and number of reinforcing layers, N, required for each zone based on Equation 6-36 and the use of consistent units.

$$T_a R_c = T_d = \frac{T_{zone} S_v}{H_{zone}} = \frac{T_{zone}}{N} \qquad 6\text{-}36$$

where:

T_a = sum of available tensile force per width of reinforcement for all reinforcement layers.

R_c = coverage ratio of the reinforcement that equals the width of the reinforcement, b, divided by the horizontal spacing S_h.

S_v = vertical spacing of reinforcement; multiples of compacted layer thickness for ease of construction.

T_{zone} = maximum reinforcement tension required for each zone.
= $T_{S\text{-}MAX}$ for low slopes (H< 20 ft)

H_{zone} = height of zone.
= T_{top}, T_{middle}, and T_{Bottom} for high slopes (H > 20 ft)

N = number of reinforcement layers.

- In general, use short (4 - 6.5 ft (1.2 – 2 m)) lengths of reinforcement layers to maintain a maximum vertical spacing of 16 in (400 mm) or less for face stability and compaction quality. This short reinforcement should be placed in continuous layers and need not be as strong as the primary load bearing reinforcement, but it must be strong enough to survive construction (e.g., minimum survivability requirements for geotextiles in road stabilization applications in AASHTO M-288) and provide localized tensile reinforcement to the surficial soils.

For detailed analyses required for final design, refer to FHWA (2001b). The computer program ReSSA (2001) noted earlier, can perform analysis and design of reinforced soil slopes using the methods described in FHWA (2001b).

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6.10 IMPROVING THE STABILITY OF CUT SLOPES

The two most common types of cut slope failures are deep-seated and shallow surface failures. Both of these types of failure and their mitigation are discussed in this section.

6.10.1 Deep Seated Failure

A deep seated failure usually occurs in slopes cut into clay. The clay has insufficient shear strength to support the slope, and shear failure generally occurs along a circular arc. If the clay contains water-bearing silt or sand layers, seepage forces will also contribute to the instability. Figure 6-29 shows an example of a deep seated failure and a possible design solution. Table 6-3 lists typical design solutions to potential cut slope stability problems in clay.

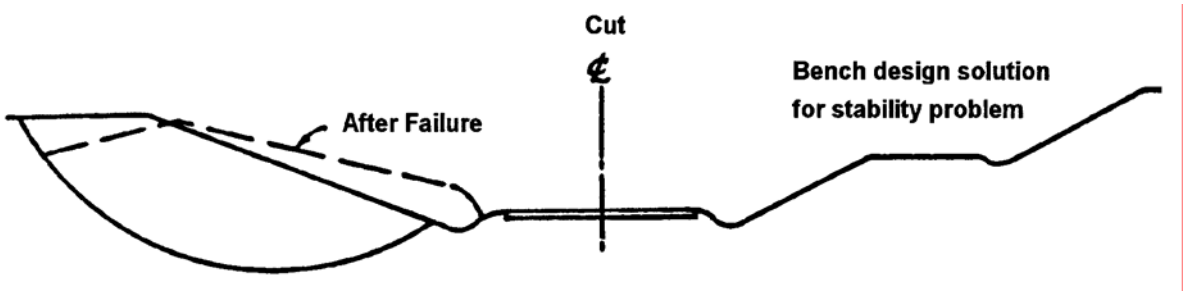


Figure 6-29. Deep seated slope failure (left) and bench slope design (right) to prevent slope failure.

Table 6-3
Typical design solutions to mitigate cut slope stability problems

Design Solution	Effect on Stability
a. Flatten slope.	Reduces driving force.
b. Bench slope.	Reduces driving force.
c. Buttress toe.	Increases resisting force.
d. Lower water table.	Reduces seepage force.
e. Reinforcement (e.g., nails)	Increases resisting force

The design of cut slopes in clay should NOT be based on the undrained strength of the clay determined by tests on samples obtained before the cut is made. Designs based on undrained strength will be unconservative since the effective stress is reduced when the cut is made because load is removed. This decrease in effective stress allows the clay to swell and

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lose strength if water is made available to the clay as shown in Figure 6-30. Therefore, the design of cut slopes in clays should be based on effective strength parameters so that the reduction in effective stress resulting from the excavation can be taken into account. It is important to remember that an undrained clay in a cut gradually weakens and may fail long after construction.

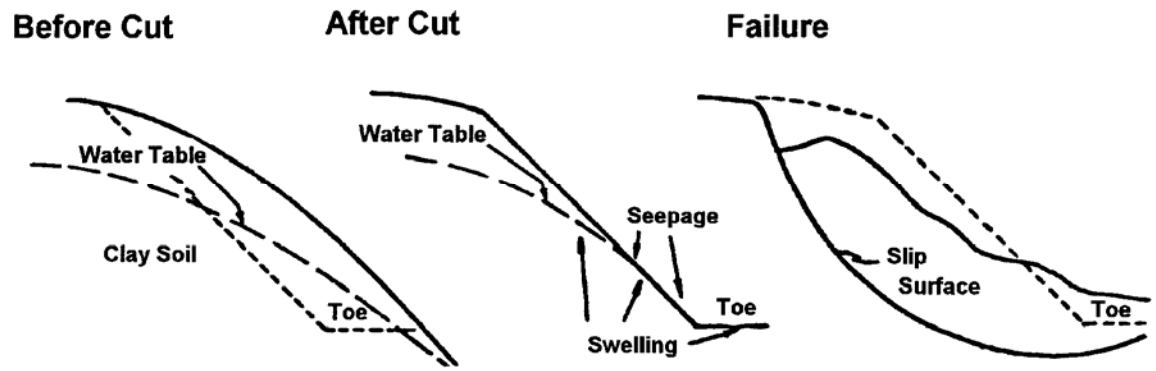


Figure 6-30: Typical cut slope failure mechanism in clay soils.

6.10.2 Shallow Surface Failures

Shallow surface failures (sloughs) are most common in cut slopes in layered clay or silt. This type of failure may involve either an entire slope or local areas in the slope. The prime cause of shallow surface failures is water seepage. Water seepage reduces the strength of the surface soils, causing them to slide or flow.

Sloughing of slopes due to ground water seepage can often be remedied by placing a 2-3 ft (0.6-1 m) thick rock or gravel blanket over the critical area. The blanket reduces the seepage forces, drains the water, and acts as a counter-weight on the unstable soil. The blanket should be "keyed" into the ditch at the toe of the slope. The key should extend about 4 feet (1.2 m) below the ditch line and be about 4 ft (1.2 m) wide. A geotextile should be placed both under the key and against the slope before placement of the gravel blanket. Construction of the gravel blanket should proceed from the toe upwards. The most effective placement is by a dozer that will track over and compact the lower areas of the gravel blanket while the upper areas are being constructed.

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6.10.3 Factor of Safety - Cut Slopes

As indicated previously, a minimum design safety factor of 1.25 is used for routine highway embankment side slopes. A minimum factor of safety against sliding of 1.50 is recommended for the stability of cut slopes in fine-grained soils. The greater factor of safety for cut slopes is based upon the knowledge that cut slopes may deteriorate with time as a result of natural drainage conditions that embankments generally do not experience. In addition, there is a greater degree of uncertainty about the homogeneity of the soils in cut slopes than in embankment slopes that are engineered and constructed under controlled conditions.

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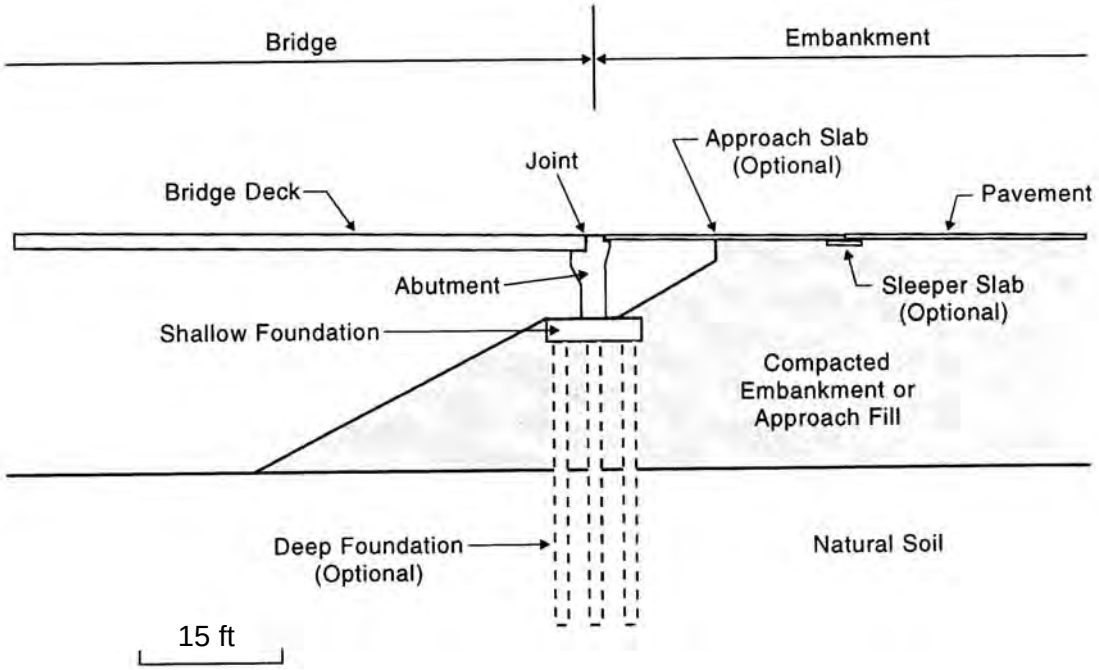
CHAPTER 7.0
APPROACH ROADWAY DEFORMATIONS

Often roadways are constructed on embankment fills to meet the requirements of the vertical grade of a roadway alignment. Fills placed to accommodate the vertical profile as the roadway approaches a bridge are often referred to as "approach embankment fills" or "approach roadway fills." Typical elements of a bridge approach system are shown in Figure 7-1. The abutment configuration may vary as shown in Figure 7-2. An abutment fill slope is also referred to as an "end-slope." The common element to all types of abutments is an approach fill. Deformation, both vertical and lateral, of approach fills is the most prevalent foundation problem in highway construction. The embankment deformation near a bridge structure, leads to the ubiquitous "bump at the end of the bridge." Figure 7-3 shows some of the problems leading to the existence of the bump.

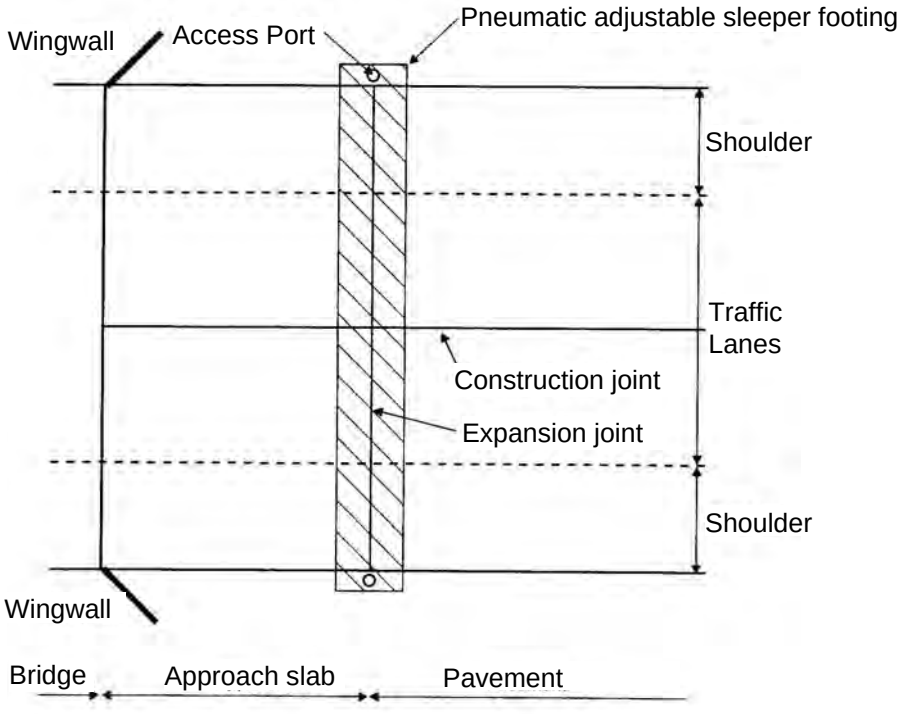
Approach slabs are often used by most state agencies to provide a smooth transition between the bridge deck and the roadway pavement. The slab usually is designed to withstand some embankment settlement and a reduction in subgrade support near the abutment. Joints must be provided to accommodate cyclic thermal movements of the bridge deck, abutment and roadway pavement. Figure 7-1b shows one common joint set. However, if the approach embankments are not properly engineered, the approach slab merely moves the bump at the end of the bridge to the approach slab-roadway interface. Unlike stability problems, the results of approach embankment deformations are seldom catastrophic but the cost of perpetual maintenance of continuing deformation can be immense. The difficulty in preventing these problems is not so much a lack of technical knowledge as a lack of communication between personnel involved in the roadway design and those involved in the structural design and construction.

7.1 TYPICAL APPROACH ROADWAY DEFORMATION PROBLEMS

Roadway designers allow use of inexpensive available soils for approach fills to reduce project costs. The bridge structures are necessarily designed for little or no deformation to maintain specified highway clearances and to insure integrity of structural members. In most agencies the responsibility for approach embankment design is not defined as a structural issue, which results in roadway embankment requirements being used up to the structure. In reality, **the approach embankment requires special materials and placement criteria to prevent internal deformations and to mitigate external deformations.** A discussion of the types of deformation associated with approach fills follows.



(a)



(b)

Note: This plan detail is only one way of handling the bridge/fill interface. An approach slab with expansion between the superstructure and the approach slab without a sleeper slab is another.

Figure 7-1. (a) Elements of a bridge approach system, (b) Plan view of an approach system (modified after NCHRP, 1997).

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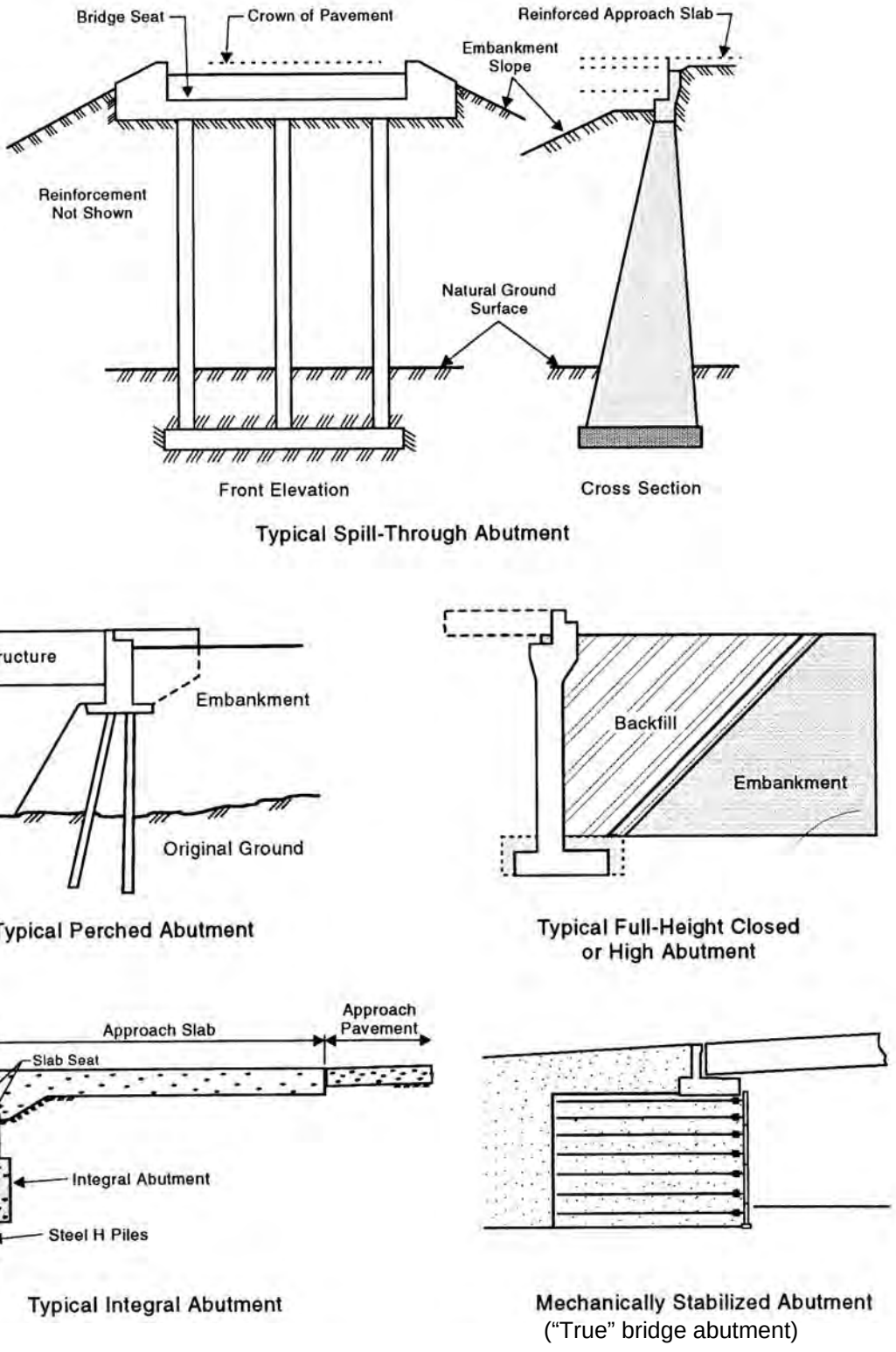


Figure 7-2. Types of abutments (modified after NCHRP, 1990).

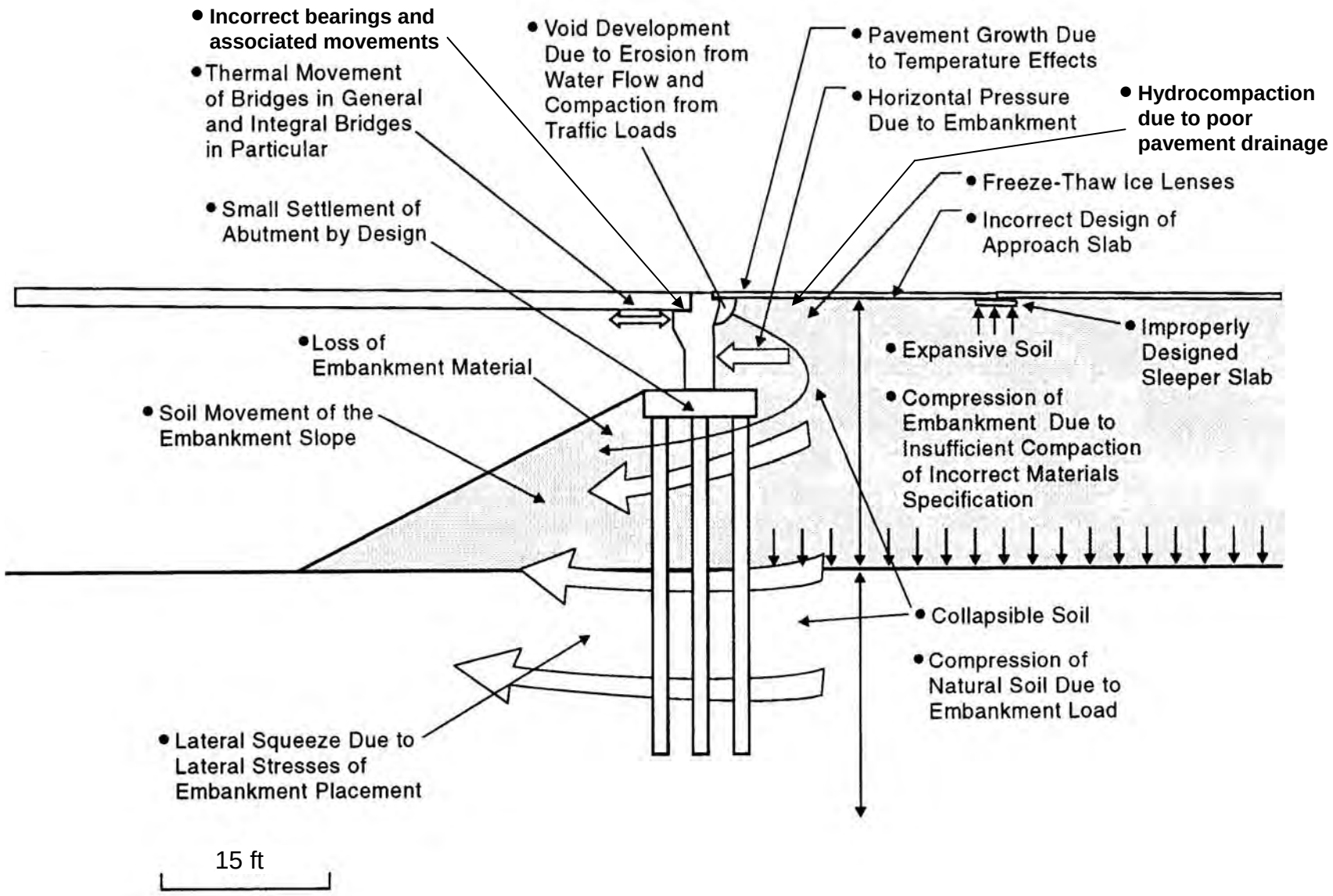


Figure 7-3. Problems leading to the existence of a bump (modified after NCHRP, 1997).

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Most state agencies, as noted earlier, use bridge approach slabs to provide a transitional roadway between the pavement on the approach embankment and the actual structure of the bridge. Due to the deformation of the approach embankment fills for various reasons shown in Figure 7-3, these slabs can settle and/or rotate creating problems for the abutment as well as the joints. Depending on the configuration of the approach slab, e.g., how the slab is connected to the abutment and/or the wing walls, voids may develop under the slab as the approach fill settles. Such voids can then fill with water, which can further compound the problem, e.g., water pressures acting against structural elements, softening of the soils with associated reduction in strength, freeze-thaw issues, etc. Due to the above considerations, design problems with approach roadway embankments are classified as follows:

- Internal deformation **within** the embankment
- External deformation in native soils **below** the embankment

As mentioned previously, it is important to realize that the deformation considerations for the embankment include both vertical as well as lateral deformations. Vertical deformations are commonly referred to as "settlements." Lateral deformations can result in rotation of the structure that is commonly referred to as "tilting."

Internal deformation is a direct result of compression of the materials used in the construction of the embankment fill. The importance of adequate drainage with respect to the internal behavior of the embankment cannot be overemphasized. Poor drainage can (a) cause softening of the embankment soils leading to vertical and lateral deformations, (b) reduce the stability of soils near the slope leading to lateral deformations and associated vertical deformations near the crest of the slope, and (c) potentially lead to migration of fill material and creation of voids or substantial vertical and lateral deformations.

External deformation is due to the vertical and lateral deformation of the foundation soils on which the embankment is placed. Furthermore, deformation of foundation soils may include both immediate and consolidation deformations depending on the type of foundation soils. Lateral squeeze of the foundation soils can occur if the soils are soft and if their thickness is less than the width of the end slope of the embankment. Consolidation settlement and lateral squeeze are not an issue within embankment fills since coarse-grained soils placed under controlled compaction conditions are generally used.

This chapter discusses internal as well as external deformations of approach fills. Design solutions to mitigate the detrimental effect of these deformations are presented. Guidelines for construction monitoring are also provided.

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7.2 INTERNAL DEFORMATION WITHIN EMBANKMENTS

Internal deformation within embankments can be easily controlled by using fill materials that have the ability to resist the anticipated loads imposed on them. A well constructed soil embankment will not excessively deform internally if quality control is exercised with regard to material and compaction. Standard specifications and construction drawings should be prepared for the approach embankment area, normally designated to extend 50 ft (15 m) behind the wingwall. The structural designer should have the responsibility for selecting the appropriate cross section for the approach embankment depending on selection of the foundation type. A typical approach embankment cross section is shown in Figure 7-4.

Special attention should be given to the interface area between the structure and the approach embankment, as this is where the "bump at the end of the bridge" occurs. The reasons for the bump are (a) poor compaction of embankment material near the structure, (b) migration of fine soil into drainage material, and (c) loss of embankment material due to poor drainage details as discussed earlier. Poor compaction is usually caused by restricted access of standard compaction equipment. Proper compaction can be achieved by optimizing the soil gradation in the interface area to permit compaction to maximum density with minimum effort. Figure 7-5 shows a detail for placement of drainage material. Considerations for the specification of select structural backfill and underdrain filter material to minimize the “bump” problem are included in the next two sections. Similar drainage results can be obtained by the use of prefabricated geocomposite drains that are attached to the backwall and connected to an underdrain.

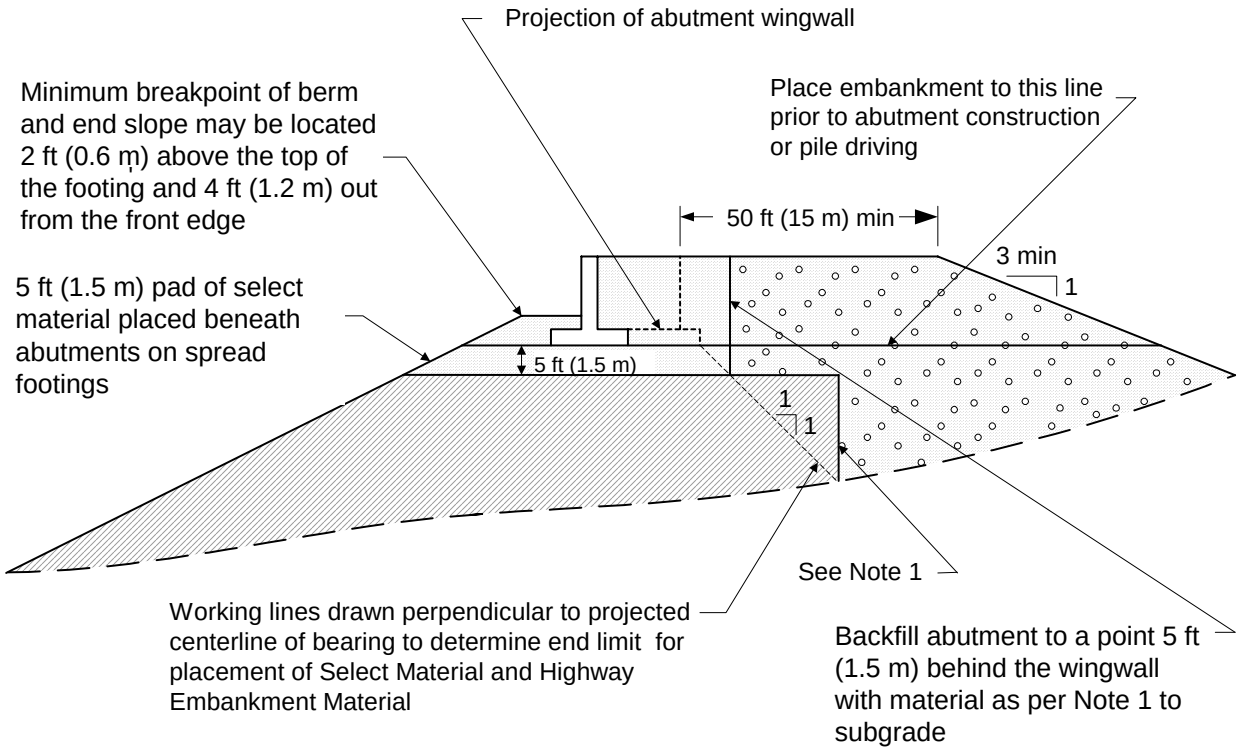
7.2.1 General Considerations for Select Structural Backfill

Select structural backfill is usually placed in relatively small quantities and in relatively confined areas. Structural backfill specifications must be designed to ensure construction of a durable, dense backfill. Table 7-1 lists considerations for the specification of select structural backfill.

7.2.2 General Considerations for Drainage Aggregate

The drainage aggregate, such as that used for underdrain filters, should consist of crushed stone, sand, gravel or screened gravel. Suggested gradation for drainage aggregate is provided in Table 7-2. The AASHTO standard gradation No. 57 or 67 should be equally suitable.

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Select Structural Fill
(Minimum 100% compaction, T99)

Highway Embankment Material, 6 in (150 mm) Max. Topsize
(Minimum 95% compaction, T180)

Highway Embankment Material
(Minimum 90% compaction, T180)

Note 1: Highway embankment material and select material shall be placed simultaneously of the vertical payment line

Figure 7-4. Suggested approach embankment details.

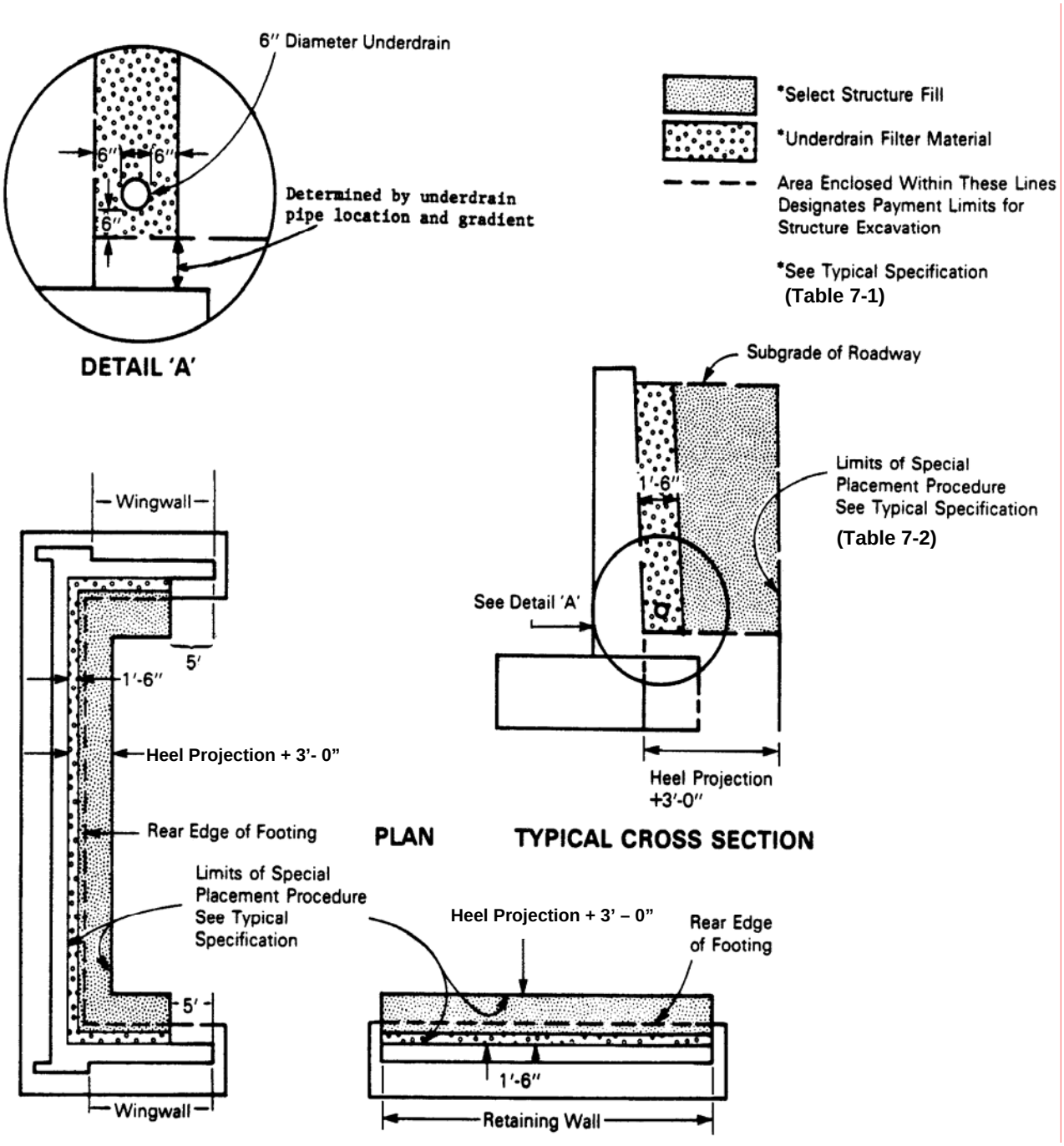


Figure 7-5. Structural backfill placement limits for porous drainage aggregate. (1 ft = 0.3 m; 1 in = 25.4 mm)

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Table 7-1
General considerations for specification of select structural backfill

Consideration	Comment
Lift Thickness	Limit to 6" to 8" (150 mm to 200 mm), so compaction is possible with small equipment.
Topsize (largest particle size)	Limit to less than ¾ of lift thickness.
Gradation/Percent Fines	Use well graded soil for ease of compaction. Typical gradation is as follows: **Sieve Size** / **Percent Passing (by weight)** 4-in (100 mm) / 100 No. 40 (0.425 mm) / 0 to 70 No. 200 (0.075 mm) / 0 to 15 The limitation on percent fines (particles smaller than No. 200 sieve) is to prevent piping and allow gravity drainage. For rapid drainage, consideration may be given to limiting the percent fines to 5%.
Plasticity Index	The plasticity index (PI) should not exceed 10 to control long-term deformation.
Durability	This consideration attempts to address breakdown of particles and resultant settlement. The material should be substantially free of shale or other soft, poor-durability particles. Where the agency elects to test for this requirement, a material with a magnesium sulfate soundness loss exceeding 30 should be rejected.
T99 Density Control	Small equipment cannot achieve AASHTO T180 densities. Minimum of 100 percent of standard Proctor maximum density is required.
Compatibility	Particles should not move into voids of adjacent fill or drain material

Table 7-2
Suggested gradation for drainage aggregate

Sieve Size	Percent Passing (by weight)
1-in (25.4 mm)	100
½-in (12.7 mm)	30 to 100
No. 3 (6.3 mm)	0 to 30
No. 10 (2.00 mm)	0 to 10
No. 20 (0.85 mm)	0 to 5

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As with the select backfill, the soundness of the drainage aggregate should be tested. The drainage aggregate should have a loss not exceeding 20 percent by weight after four (4) cycles of the magnesium sulfate soundness test.

The maximum loose lift thickness for the drainage aggregate should not exceed 6 in (150 mm). Placement and compaction operations should be conducted in a manner so as to insure that the top surface of each lift of the drainage aggregate should not be contaminated by the adjacent backfill materials. Compaction of the drainage aggregate is commonly achieved by two passes of a vibratory compactor approved by the engineer. No compaction control tests are normally required for the drainage aggregate.

7.2.3 Use of Geosynthetics to Control Internal Deformations

In geographic areas where select materials are not available, the use of geosynthetic materials to reinforce the abutment backfill and approach area can reduce the bump at the end of the bridge. Such reinforced fills can be designed by using the principles of Reinforced Soil Slopes (RSS) discussed in Chapter 6 (Slope Stability)

It is suspected that high dynamic loads are routinely induced in the abutment backfill due to vehicle impact loads. Poorly designed or constructed drainage layers or non-durable drainage aggregate can cause either piping of fines or accelerated pavement subsidence due to breakdown of aggregates. As indicated previously, the use of geotextiles or geocomposite drains can be an effective method of minimizing internal embankment deformation and the resulting “bump at the end of the bridge.”

7.3 EXTERNAL DEFORMATION IN FOUNDATION SOILS BELOW EMBANKMENTS

Once the issue of internal deformation within fills has been addressed, the designer must concentrate on the evaluation of the deformation of foundation soils and any engineered soils on which the fills will be placed. As explained in Chapter 2, deformations in foundation soils under embankments occur due to the pressure imposed by the embankments. Depending on the type of foundation soils, one or both of the following deformations may occur:

- Immediate (elastic) deformation
- Consolidation (or long-term) deformation

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Immediate or elastic deformations occur in all soils regardless of whether they are cohesive or cohesionless. Consolidation deformations typically occur in fine-grained soils that are saturated at the time additional loads are applied. Many and varied procedures exist for computation of these types of deformations. Two methods are presented in this chapter; one each for cohesionless and cohesive soils. However, there is a critical first step that is common to both modes of deformation. This first step involves the estimation of the stress distribution within the foundation soils due to the pressures imposed by the embankment fills. This step is discussed next.

7.3.1 Procedure for Estimating Stress Distribution in Foundation Soils under Fills

The basic steps involved in estimating stresses in native soils under fills are as follows:

1. Develop a soil profile including soil unit weights, SPT results ($N1_{60}$), moisture contents and interpreted consolidation test values.

2. Draw effective overburden pressure (p_o) diagram with depth.

3. Plot total embankment pressure (p_f) on the p_o diagram at ground surface level.

4. Distribute the total embankment pressure with depth by using the appropriate pressure coefficient charts presented in Figure 7-6.

   (Note: The charts in Figure 7-6 are limited to only two locations, Section B-B and Section C-C, and assume that the end and side slopes have the same grades. Programs such as FoSSA (2003) may be used for case of unequal end and side slopes, or if pressure coefficients at locations other than along Section B-B or C-C are desired.)

The principles to remember are: (1) stresses induced in the soil from an embankment load are distributed with depth in proportion to the embankment width, and (2) the additional stresses in the soil decrease with depth.

Following is a step-by-step procedure to use the chart in Figure 7-6. A worked example is presented afterwards to illustrate the use of the chart numerically:

Step 1. Determine the distance b_f from the centerline of the approach embankment to the midpoint of side slope. Multiply the numerical value of "b_f" by the appropriate values shown to the right of the chart to develop the depths at which the distributed pressures will be computed, e.g., $0.2b_f$, $0.4b_f$, etc.

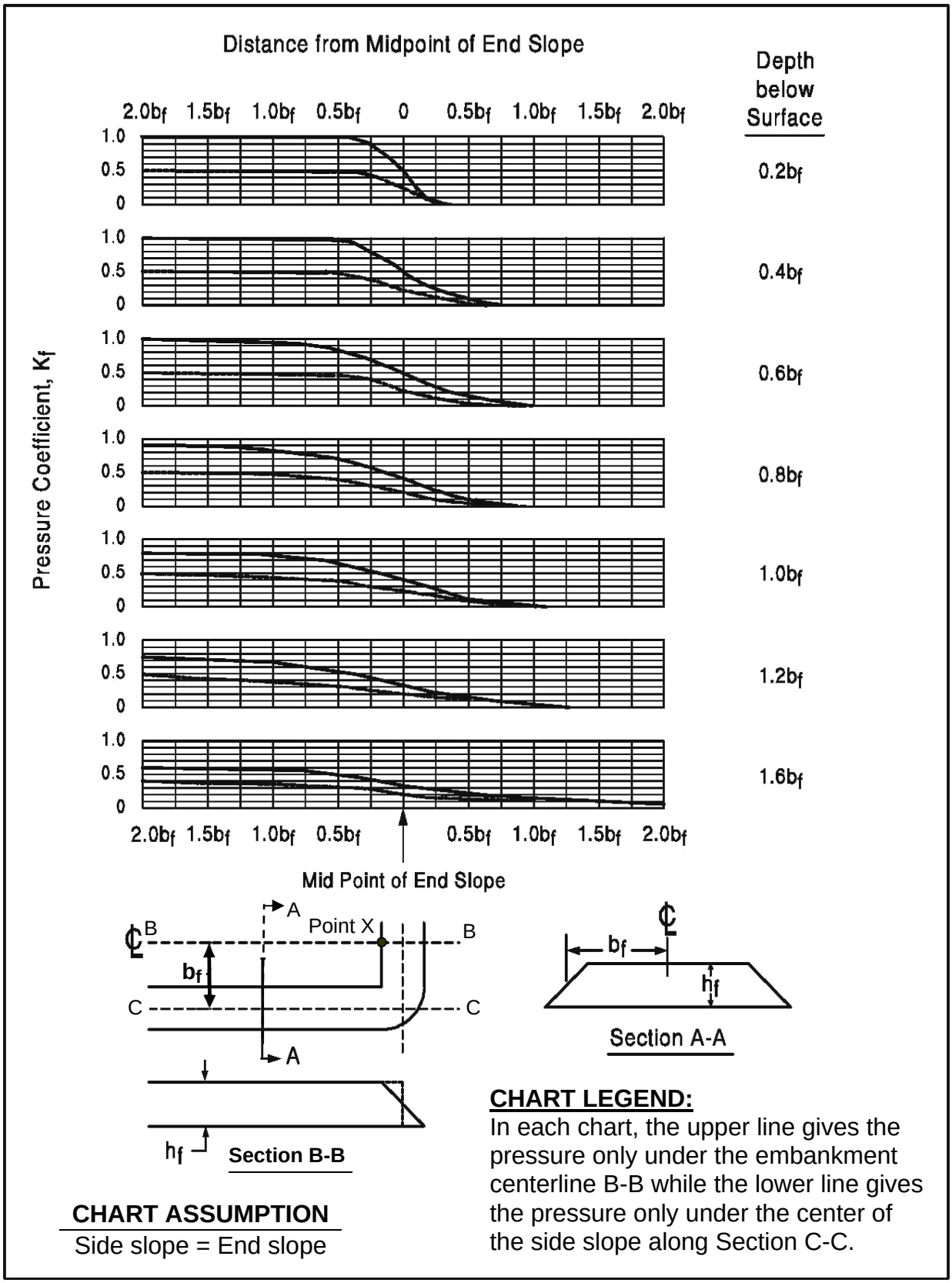


Figure 7-6. Pressure coefficients beneath the end of a fill (after NYSDOT).

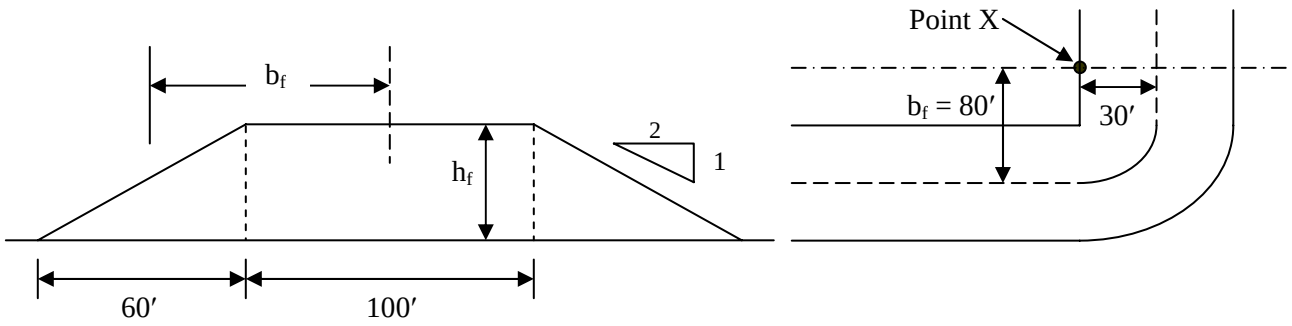
Step 2. Select the point X on the approach embankment where the vertical stress prediction is desired, normally at the intersection of the centerline of the embankment and the abutment. In this case the side slope is called the end slope. Measure the distance from X to the midpoint of the end slope. Return to the chart and scale that distance as a multiple of b_f on the horizontal axis from the appropriate side of the midpoint centerline line of the end slope.

Step 3. Read vertically up or down from the plotted distance on the horizontal axes to the various curves corresponding to depth below surface. The "K_f" value on the left vertical axis should be read and recorded on a computation sheet with the corresponding depth. Note that the upper line gives the pressure under the embankment centerline (Section B-B) while the lower line gives the pressure under the mid of the side slope (Section C-C).

Step 4. Multiply each "K_f" value by the value of total embankment pressure ($\gamma_f h_f$) to determine the amount of the pressure increment (Δp) transmitted to each depth, where γ_f is the unit weight of the embankment fill soil and h_f is height of the embankment fill.

The application of this step-by-step procedure and the charts shown on Figure 7-6 to a typical embankment problem is illustrated by the following worked example problem.

Example 7-1: The geometry of a fill slope is as follows:
Fill height h_f = 30 ft; Fill unit weight γ_f = 100 pcf
End and side slopes (2H:1V); Embankment top width = 100 ft



Find: The stress increase (Δp) under the proposed abutment centroid (Point X) at a depth of 0.8 b_f below the base of the fill.

Solution:

Figure 7-6 will be used to determine the stress increase. To use the chart first compute the following quantities:

- Distance from midpoint of end slope to Point X = 30 ft.
- Distance from centerline to mid point of side slope b_f = (100 ft/2) + (60 ft/2) = 80 ft.

Enter stress distribution chart for a depth of $0.8b_f$ = (0.8)(80 ft) = 64 ft and a distance measured from the ***midpoint of the end slope to Point X expressed as a multiple of b_f*** = (30 ft/80 ft) b_f = 0.38 b_f. Enter the plot with this value to the left of the value of zero on the abscissa, i.e., upslope from the midpoint on the end slope.

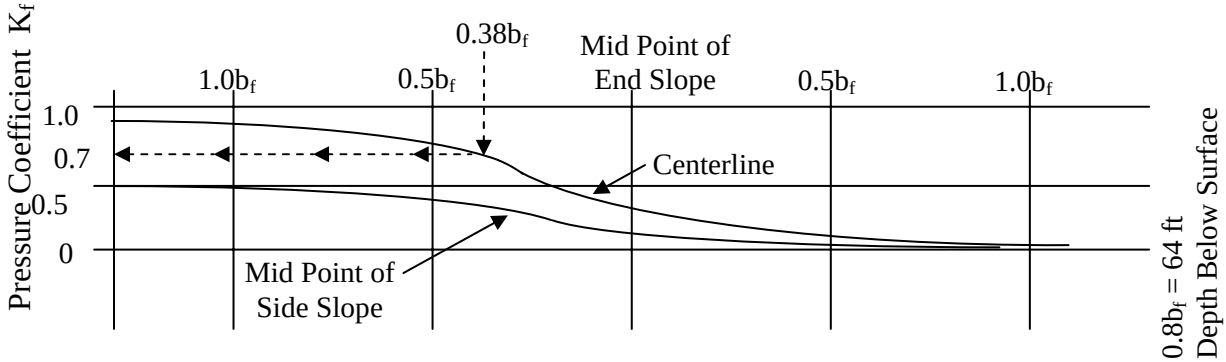
In Figure 7-6 read K_f = 0.7 from the chart for $0.8b_f$. Therefore, at a depth of 64 ft below the embankment at Point X

$\Delta p = K_f \gamma_f h_f$

Δp = (0.7) (100 pcf) (30 ft) = 2,100 psf

Repeat the above steps for distances to other points along the centerline of the embankment expressed as a multiple of b_f and measured (+ and -) from the midpoint of end slope to develop the horizontal distribution of vertical stress increases due to the embankment at a depth of 64 ft below and beyond the base of the end slope along the embankment centerline.

Horizontal Distribution of Vertical Stress Increases Below and Beyond the End Slope at a Depth of 64-ft Below the Embankment



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7.4 COMPUTATION OF IMMEDIATE SETTELEMENT

All geomaterials, whether cohesionless or cohesive, will experience settlements immediately after application of loads. Whether or not the settlements will continue with time after the application of the loads will be a function of how quickly the water can drain from the voids as explained in Chapter 2. Long-term consolidation-type settlements are generally not experienced in cohesionless soils where pore water can drain quickly or in dry or slightly moist cohesive soils where significant amounts of pore water are not present. Therefore, embankment settlements caused by consolidation of cohesionless or dry cohesive soil deposits are frequently ignored as they are much smaller compared to immediate settlements in such soils. Consolidation type settlement for saturated cohesive soils is discussed in Section 7.5.

Many methods have been published in the geotechnical literature for the computation of immediate settlements in soils or rocks. These methods vary from the use of rules of thumb based on experience to the use of complex nonlinear elasto-plastic constitutive models. All methods are based on some form of estimate of soil compressibility. In the geotechnical literature, soil compressibility is expressed using several different terms such as “bearing capacity index,” “compression index,” “elastic modulus,” “constrained modulus,” etc.

For computing external embankment settlements, the method by Hough (1959) as modified by AASHTO (2004 with 2006 Interims) can be used since it is simple and provides a first-order conservative estimate of immediate settlements. The original Hough method (Hough, 1959) was based on uncorrected SPT N-values and included recommendations for cohesionless as well as cohesive soils such as sandy clay and remolded clay. AASHTO modified the Hough (1959) method for use with $N1_{60}$ values and eliminated the recommendations for sandy clay and remolded clay. Since the method presented here is AASHTO’s version of the Hough method, it will be referred to as the “Modified Hough” method.

Even after the modifications, the settlements estimated by Modified Hough method are usually overestimated by a factor of 2 or more based on the data in FHWA (1987). While such conservative estimates may be acceptable from the viewpoint of the earthwork quantities (see discussion regarding compaction factor in Section 7.4.1.1), they may be excessive with respect to the behavior of the structures founded within, under or near the embankment. In cases where structures are affected by embankment settlement, more refined estimates of the immediate settlements are warranted. **For more refined estimates of immediate settlements it is recommended that the designer use either the modified method of Schmertmann, *et al.* (1978), which takes into account the strain distribution**

with depth, or the D'Appolonia (1968, 1970) method, which takes into account the effect of preconsolidation. Both methods provide equally suitable results. Schmertmann's modified method is presented in Chapter 8 (Shallow Foundations).

7.4.1 Modified Hough Method for Estimating Immediate Settlements of Embankments

The following steps are used in Modified Hough method to estimate immediate settlement:

Step 1. Determine the bearing capacity index (C′) by entering Figure 7-7 with $N1_{60}$ value and the visual description of the soil.

Step 2. Compute settlement by using the following equation. Subdivide the total thickness of the layer impacted by the applied loads into 10 ft ± (3 m ±) increments and sum the incremental solutions:

$$\Delta H = H\left(\frac{1}{C'}\right)\log_{10}\frac{p_o + \Delta p}{p_o} \qquad 7\text{-}1$$

where: ΔH = settlement of subdivided layer (ft)

H = thickness of subdivided soil layer considered (ft)

C' = bearing capacity index (Figure 7-7)

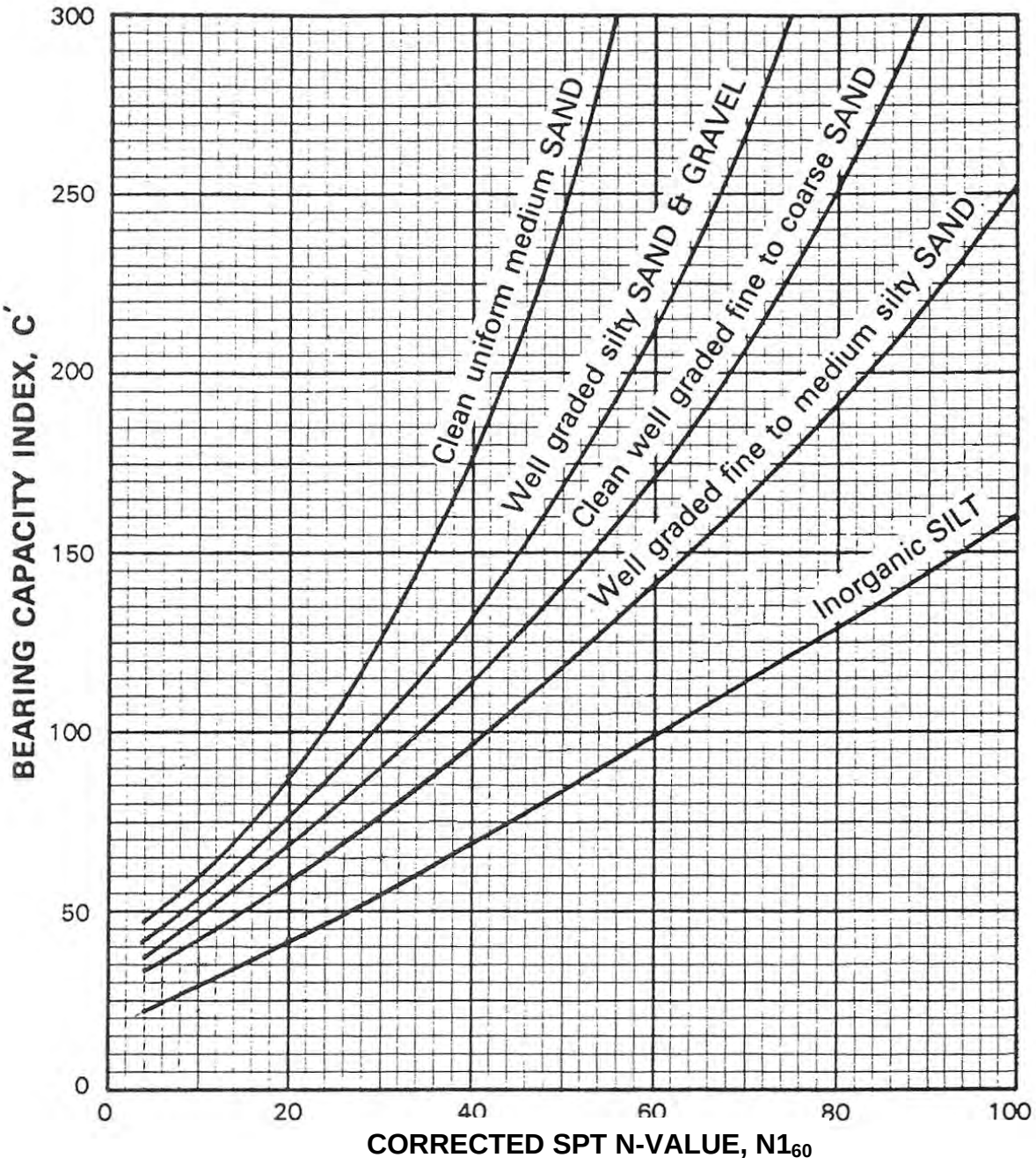
p_o = existing effective overburden pressure (psf) at center of the subdivided layer being considered. For shallow surface deposits, a minimum value of 200 psf should be used to prevent unrealistic settlement predictions.

Δp = distributed embankment pressure (psf) at center of the subdivided layer being considered

Note that the term $p_o + \Delta p$ represents the final pressure applied to the foundation subsoil, p_f.

A key point is that the logarithm term in Equation 7-1 incorporates the fundamental feature of dissipation of applied stress with depth. The use of Modified Hough method is illustrated numerically in Example 7-2.

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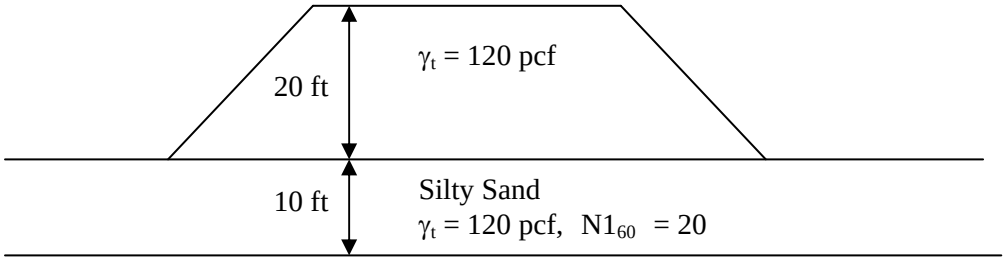


(Note: The "Inorganic SILT" curve should generally not be applied to soils that exhibit plasticity because N-values in such soils are unreliable)

Figure 7-7. Bearing capacity index (C') values used in Modified Hough method for computing immediate settlements of embankments (AASHTO, 2004 with 2006 Interims; modified after Hough, 1959).

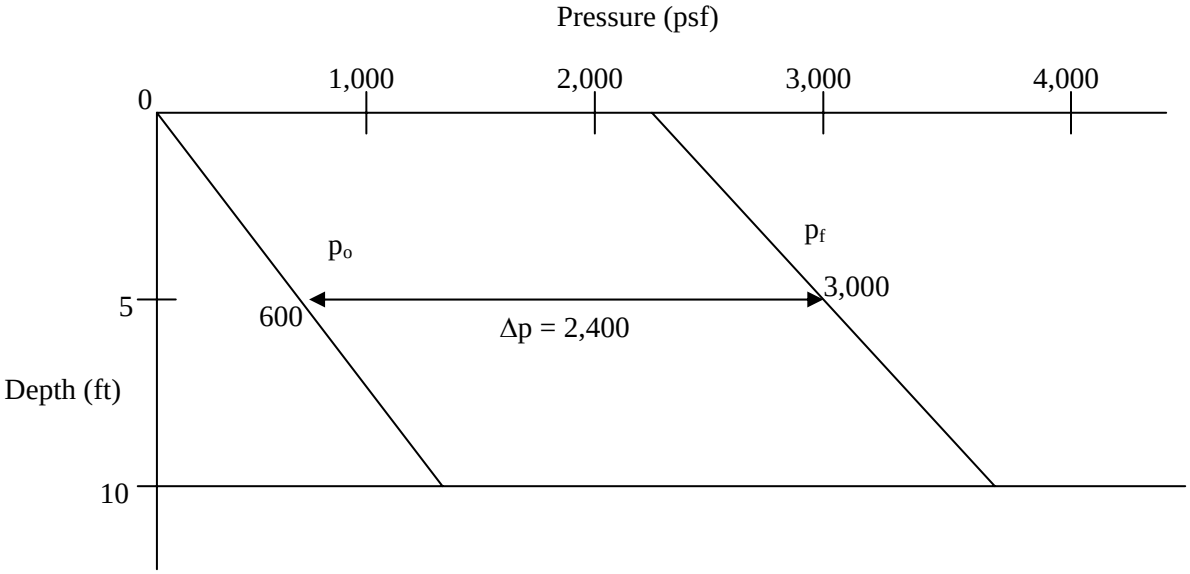
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Example 7-2: For the geometry shown in the following figure, determine the settlement at the center of a wide embankment placed on a silty sand layer by using Modified Hough method and the p_o diagram.



Solution:

The original overburden pressure at the center of the 10 ft thick silty sand deposit can be computed as p_o = (10 ft/2) (120 pcf) = 600 psf. Since, the embankment is "wide" the stress does not practically dissipate with depth. Therefore, increase in the stress at this depth due to the 20 ft high wide embankment can be computed as Δp = (20 ft) (120 pcf) = 2,400 psf. The p_o diagram based on these values of p_o and Δp is shown below.



From Figure 7-7, find C′ for "silty sand." Using $N1_{60}$ = 20 and the "silty sand" curve, C′ ≈ 58. Find immediate settlement using Equation 7-1 as follows:

$$\Delta H = H\left(\frac{1}{C'}\right)\log_{10}\frac{p_o + \Delta p}{p_o}$$

$$\Delta H = 10\text{ ft}\left(\frac{1}{58}\right)\log_{10}\frac{600\text{ psf} + 2{,}400\text{ psf}}{600\text{ psf}} = 0.12\text{ ft} = 1.44\text{ in}$$

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7.4.1.1 Comments on the Computed Settlement of Embankments

The implication of the amount of embankment settlement is that when the embankment is completed, additional fill will be required to bring the top of the embankment to the design grade. For example, a 1 in (25 mm) settlement on a 60-ft (18 m) wide, 1-mile (5,280 ft or 1,610 m) long embankment will result in a need for approximately 1,000 yd^3 (~750 m^3) of additional fill. Some state agencies refer to such settlement estimates as the "compaction factor" and note it in the contract plans so that the contractor can make appropriate allowances in the bid price to accommodate the additional embankment fill material needed to achieve the required design grades. It is in this regard the conservative estimate of the settlement resulting from the Modified Hough method may be acceptable and may even be preferable to prevent construction change orders.

7.5 COMPUTATION OF CONSOLIDATION (LONG-TERM) SETTLEMENTS

Unless the geomaterial is friable, consolidation settlements in fine-grained saturated soils occur over a period of time as a function of the permeability of the soils. This concept was introduced in discussed in Chapter 2 by using the spring-piston analogy. The features of the laboratory consolidation test were discussed in Chapter 5. In this chapter the data obtained from the consolidation test are used to demonstrate the computation of long-term settlements due to the consolidation phenomena, i.e., primary consolidation and secondary compression.

Theoretically, a necessary condition for consolidation settlement is that the soil must be saturated, i.e., degree of saturation, S = 100%. While the laboratory test for moisture content of a soil is inexpensive and relatively straightforward to perform and generally yields reliable, reproducible results, there are a number of parameters in consolidation analysis that cannot be determined with confidence as indicated by the data in Table 5-25. Therefore, depending on the magnitude and configuration of the load with respect to the size and moisture content of the compressible soil layer, it is possible that consolidation settlements may occur in soils that are judged to be "nearly saturated" but not "fully saturated." This is because such nearly saturated soils may approach full saturation after application of a load of sufficient magnitude to cause the pore spaces filled with air to compress (immediate settlement) to the extent that the degree of saturation is virtually 100%. Therefore, the geotechnical specialist should carefully evaluate the in-situ degree of saturation with respect to the degree of saturation of the soil sample at the beginning and end of the consolidation test. The geotechnical specialist should also carefully evaluate the reliability of other parameters determined during the performance of the consolidation test to make an informed judgment regarding the potential for consolidation settlements to occur. Unnecessarily

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conservative assumptions regarding the magnitude and time rate of consolidation settlements may lead to recommendations for deep foundations or for unnecessary implementation of costly ground improvement measures.

Settlement resulting from primary consolidation may take months or even years to be completed. Furthermore, because soil properties may vary beneath the location of loading, the duration of the primary consolidation and the amount of settlement may also vary with the location of the applied load, resulting in differential settlement. If such settlements are not within tolerable limits the geotechnical feature as well as a structure founded on or in it may be damaged. In the case of embankments, differential settlements that occur along the longitudinal axis of the embankment because of changes in thickness and/or consolidation properties of underlying clays can cause transverse cracking on the surface of the embankment where pavement structures are usually constructed.

When the areal extent of the applied load is wide compared to the thickness of the compressible layer beneath it, a large portion of the soil will consolidate vertically (one-dimensionally) with very little lateral displacement because of the constraining forces exerted by the neighboring soil elements. However, when the areal extent of the applied load is smaller than the thickness of the compressible layer or when there is a finite soft layer at a certain depth below the loaded area, significant lateral stresses and associated deformations can occur as shown earlier in Figure 2-16 in Chapter 2. Back-to-back retaining walls and a narrow embankment for an approach ramp on soft soils are examples of this condition. Due to the potential for significant lateral stresses and associated lateral deformations, the geotechnical specialist should carefully evaluate the loading geometry with respect to subsurface conditions and ascertain whether the problem is 1-D or 3-D. This type of evaluation is important because 3-D deformations can affect a number of facilities such as buried utilities, bridge foundations, and the stability of embankment slopes.

The determination of the vertical component of 3-D consolidation deformation is commonly based on the one-dimensional consolidation test (ASTM D 2435). Typically, the results of the one-dimensional consolidation test are expressed in an e-log p plot which is the so-called "consolidation curve." As indicated in Chapter 5, settlement due to consolidation can be estimated from the slope of the consolidation curve. This procedure is generally used in practice despite the fact that not all of the points beneath the embankment undergo one-dimensional consolidation. However, before the laboratory test results are used, it is very important to correct the consolidation curves for the effects of sampling. Thus, before proceeding with the discussion of computing consolidation settlements, the correction of the laboratory consolidation curves is discussed.

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7.5.1 Correction of Laboratory One-Dimensional Consolidation Curves

As indicated in Chapter 3, the process of sampling soils will cause some disturbance no matter how carefully the samples are taken. This sampling disturbance will affect virtually all measured physical properties of the soil. The sampling disturbance will usually cause the "break" in the laboratory consolidation curve to occur at a lower maximum past vertical pressure (p_c) than would be measured for a truly undisturbed specimen. The effect of disturbance from the sampling procedure is illustrated in Figure 7-8 where, for the sake of comparison, the vertical strain rather than void ratio (e) is plotted versus the logarithm of the vertical effective stress.

Figure 7-8 shows three consolidation curves for a red-colored plastic clay from Fond du Lac, Wisconsin. Samples were taken alternately with 3 in (75 mm) and 2 in (50 mm) thin walled samplers. The 3 in (50 mm) sampler apparently caused less disturbance than the 2 in (50 mm) sampler. The curve for the remolded sample is the flattest curve without a well defined break between reloading and virgin compression.

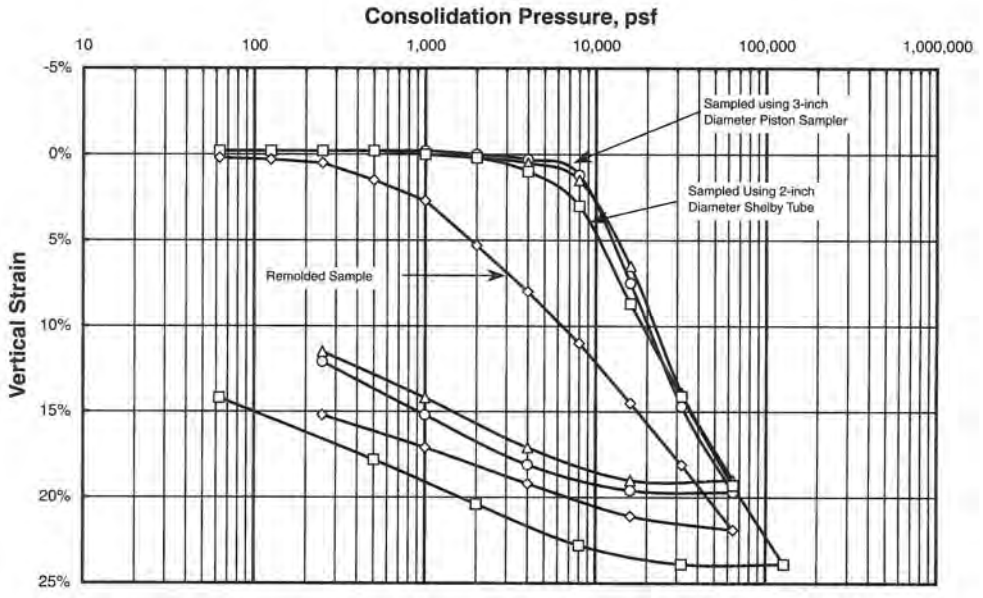


Figure 7-8. Effect of sample disturbance on the shape of the one-dimensional consolidation curve (Reese, *et al.*, 2006).

Even for good quality samples, it is still necessary to "correct" the e-log p curve since no sampling technique is perfect. There are several methods available to correct the consolidation curve. The laboratory curve can be corrected according to Figures 7-9a and 7-9b for normally consolidated and overconsolidated soils, respectively. Table 7-3 presents the reconstruction procedures.

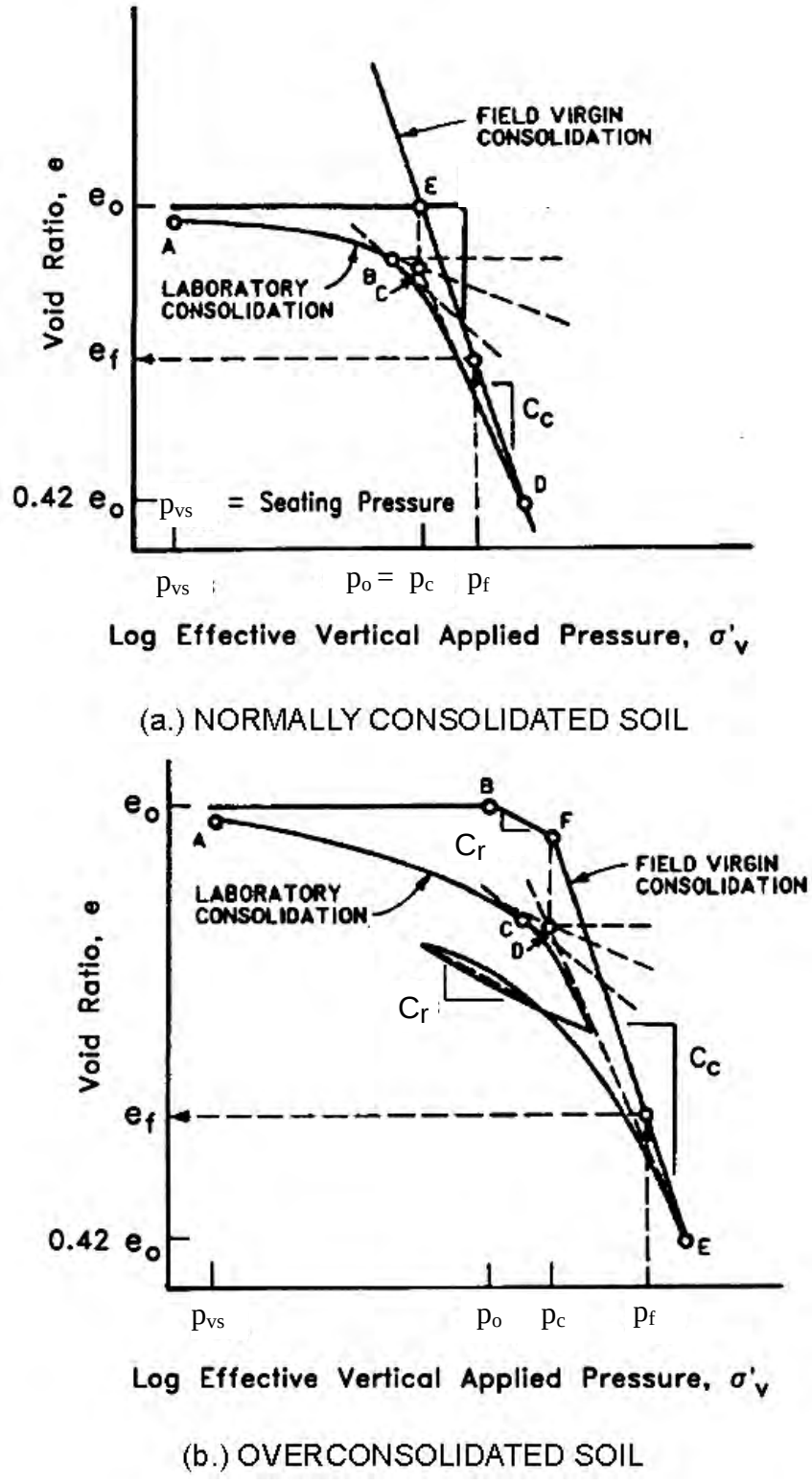


Figure 7-9. Construction of field virgin consolidation relationships (adapted from USACE, 1994).

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Table 7-3
Reconstruction of virgin field consolidation curve (modified from USACE, 1994).

Step	Description
a. Normally Consolidated Soil (Figure 7-9a)	
1	By eye choose the point B at the point of minimum radius of curvature (maximum curvature) of the laboratory consolidation curve.
2	Plot point C by the Casagrande construction procedure: (1) Draw a horizontal line through point B; (2) Draw a line tangent to the consolidation curve at point B; (3) Draw the bisector between the horizontal and tangent lines; and (4) Draw a line tangent to the "virgin" portion of the laboratory consolidation curve. Point C is the intersection of the tangent to the virgin portion of the laboratory curve with the bisector. Point C indicates the maximum preconsolidation (past) pressure p_c.
3	Plot point E at the intersection of a horizontal line through e_o and the vertical extension of point C, that corresponds to p_c as found from Step 2. The value of e_o is given as the initial void ratio prior to testing in the consolidometer.
4	Plot point D on the laboratory virgin consolidation curve at a void ratio $e = 0.42e_o$. Extend the laboratory virgin consolidation curve to that void ratio if necessary. On the basis of many laboratory tests, Schmertmann (1955) found that the laboratory curve for various degrees of disturbance intersects the field virgin curve at a value of $e= 0.42e_o$.
5	The field virgin consolidation curve is the straight line determined by points E and D.
6	The field compression index, C_c, is the slope of the line ED.
b. Overconsolidated Soil (Figure 7-9b)	
1	Plot point B at the intersection of a horizontal line through the given e_o and the vertical line representing the initial estimated in situ effective overburden pressure p_o.
2	Draw a line through point B parallel to the mean slope, C_r, of the rebound laboratory curve.
3	Plot point D by using Step 2 in Table 7-3a for normally consolidated soil.
4	Plot point F by extending a vertical line through point D up through the intersection of the line of slope C_r extending through B.
5	Plot point E on the laboratory virgin consolidation curve at a void ratio $e = 0.42e_o$.
6	The field virgin consolidation curve is the straight line through points F and E. The field reload curve is the straight line between points B and F.
7	The field compression index, C_c, is the slope of the line FE.

7.5.2 Computation of Primary Consolidation Settlements

Depending upon the magnitude of the existing effective stress relative to the maximum past effective stress at a given depth, in-situ soils can be considered normally consolidated, overconsolidated (preconsolidated), or underconsolidated. The behavior of in-situ soils to additional loads is highly dependent upon the stress history. The overconsolidation ratio, OCR, which is a measure of the degree of overconsolidation in a soil is defined as p_c/p_o. The value of OCR provides a basis for determining the effective stress history of the clay at the time of the proposed loading as follows:

- OCR = 1 - the clay is considered to be "normally consolidated" under the existing load, i.e., the clay has fully consolidated under the existing load ($p_c = p_o$).

- OCR > 1 - the clay is considered to be "overconsolidated" under the existing load, i.e., the clay has consolidated under a load greater than the load that currently exists ($p_c > p_o$).

- OCR < 1 – the clay is considered to be "underconsolidated" under the existing load, i.e., consolidation under the existing load is still occurring and will continue to occur under that load until primary consolidation is complete, even if no additional load is applied ($p_c < p_o$).

The manner in which primary settlements are computed for each of these three conditions varies as will be discussed in the following sections.

7.5.2.1 Normally Consolidated Soils

The settlement of a geotechnical feature or a structure resting on n layers of normally consolidated soils ($p_c = p_o$) can be computed from Figure 7-10a where n is the number of layers into which the consolidating layer is divided:

$$S_c = \sum_{i}^{n} \frac{C_c}{1+e_o} H_o \log_{10}\left(\frac{p_f}{p_o}\right) \qquad 7\text{-}2$$

where:
- C_c = compression index
- e_o = initial void ratio
- H_o = layer thickness
- p_o = initial effective vertical stress at the center of layer n
- p_f = $p_o + \Delta p$ = final effective vertical stress at the center of layer n.

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The final effective vertical stress is computed by adding the stress change due to the applied load to the initial vertical effective stress. The total settlement will be the sum of the compressions of the n layers of soil.

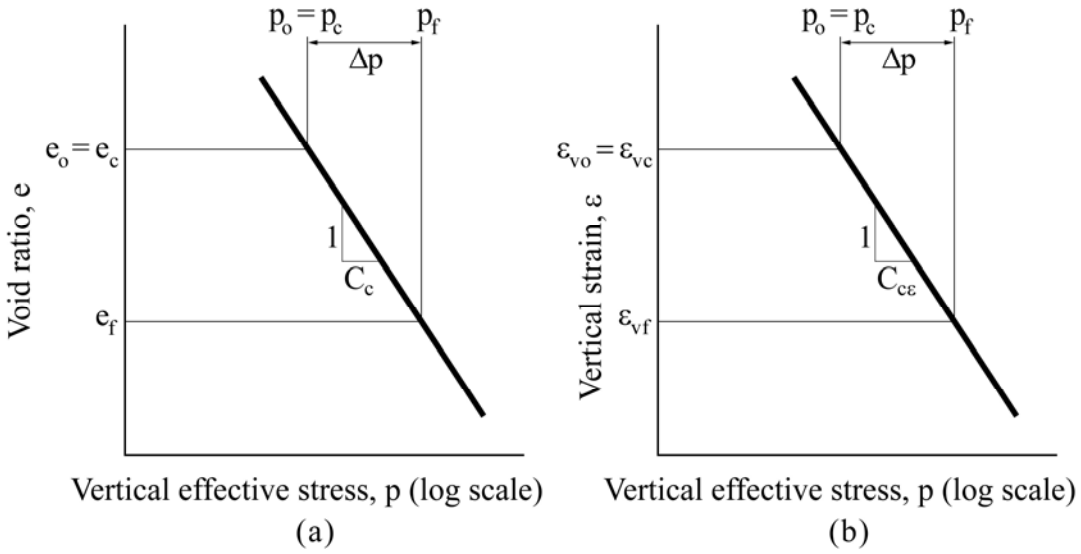


Figure 7-10. Typical consolidation curve for normally consolidated soil, (a) Void ratio versus vertical effective stress and (b) Vertical strain versus vertical effective stress.

Normally the slope of the virgin portion of the e-log p curve is determined from the corrected one-dimensional consolidation curve measured on specimens taken from each relevant soil in the stratigraphic profile. The procedure for determining the corrected curve is presented in Table 7-6a. Common correlations for estimating C_c were presented in Section 5.4.6.1 of Chapter 5 and can be used to check laboratory results.

Sometimes the consolidation data is presented in terms of vertical strain (ε_v) instead of void ratio. In this case the slope of the virgin portion of the modified consolidation curve is called the modified compression index and is denoted as $C_{c\varepsilon}$ as shown in Figure 7-10b. Settlement is computed by using Equation 7-3 for normally consolidated soils where all of the other terms are defined as for Equation 7-2.

$$S_c = \sum_{1}^{n} H_o C_{c\varepsilon} \log_{10}\left(\frac{p_f}{p_o}\right) \qquad 7\text{-}3$$

By comparing Equations 7-2 and 7-3, it can be seen that $C_{c\varepsilon} = C_c / (1+e_o)$

7.5.2.2 Overconsolidated (Preconsolidated) Soils

If the water content of a clay layer below the water table is closer to the plastic limit than the liquid limit, the soil is likely overconsolidated, i.e., OCR >1. This means that in the past the clay was subjected to a greater stress than now exists. Preconsolidation could have occurred because of any number of factors including but not limited to the weight of glaciers which is especially prevalent in the northern tier of states and in the northeast, the weight of a natural soil deposit that has since eroded away, the weight of a previously placed fill that has since been removed, loads due to structures that have since been demolished, desiccation, etc.

As a result of preconsolidation, the field state of stress will reside on the initially flat portion of the e-log p curve. Figures 7-11a and 7-11b illustrate the case where a load increment, Δp, is added so that the final stress, p_f, is greater than the maximum past effective stress, p_c. For this condition, the settlements for the case of n layers of overconsolidated soils will be computed from Equation 7-4 or Equation 7-5 that correspond to Figure 7-11a and 7-11b, respectively.

$$S = \sum_{1}^{n} \frac{H_o}{1+e_o}\left(C_r \log_{10}\frac{p_c}{p_o} + C_c \log_{10}\frac{p_f}{p_c}\right) \qquad 7\text{-}4$$

$$S = \sum_{1}^{n} H_o\left(C_{r\varepsilon} \log_{10}\frac{p_c}{p_o} + C_{c\varepsilon} \log_{10}\frac{p_f}{p_c}\right) \qquad 7\text{-}5$$

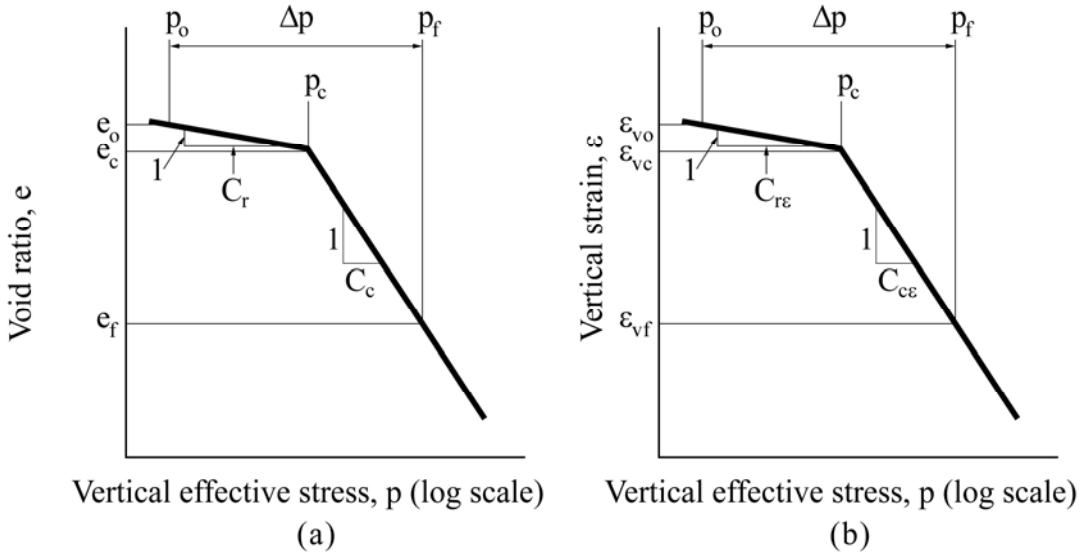


Figure 7-11. Typical consolidation curve for overconsolidated soil, (a) Void ratio versus vertical effective stress and (b) Vertical strain versus vertical effective stress.

The total settlement is computed by summing the settlements computed from each subdivided compressible layer within the zone of influence (Z_I). The assumption is made that the initial and final stress calculated at the center of each sublayer is representative of the average stress for the sublayer, and the material properties are reasonably constant within the sublayer. The sublayers are typically 5 ft (1.5 m) to 10 ft (3 m) thick in highway applications. In cases where the various stratigraphic layers represent combinations of both normally and overconsolidated soils, the settlement is computed by using the appropriate combinations of Equations 7-2 through 7-5.

7.5.2.3 Underconsolidated Soils

Underconsolidation is the term used to describe the effective stress state of a soil that has not fully consolidated under an existing load, i.e., OCR < 1. Consolidation settlement due to the existing load will continue to occur under that load until primary consolidation is complete, even if no additional load is applied. This condition is shown in Figure 7-12 by Δp_o. Therefore, any additional load increment, Δp, would have to be added to p_o. Consequently, if the soil is not recognized as being underconsolidated, the actual total primary settlement due to $\Delta p_o + \Delta p$ will be greater than the primary settlement computed for an additional load Δp only, i.e., the settlement may be under-predicted. As a result of under-consolidation, the field state of stress will reside entirely on the virgin portion of the consolidation curve as shown in Figure 7-12. The settlements for the case of n layers of under-consolidated soils are computed by Equation 7-6 or Equation 7-7 that correspond to Figure 7-12a and 7-12b, respectively.

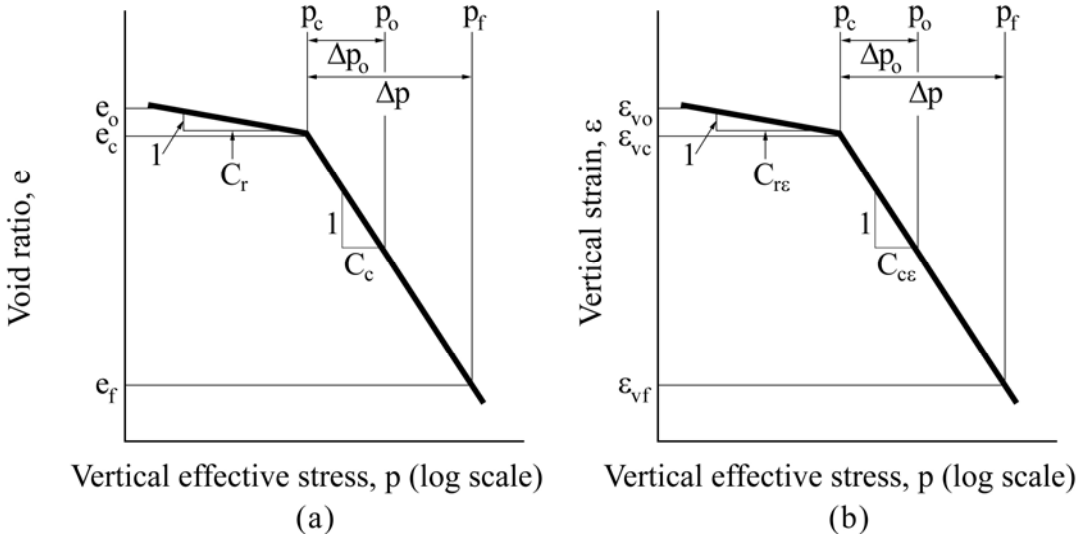


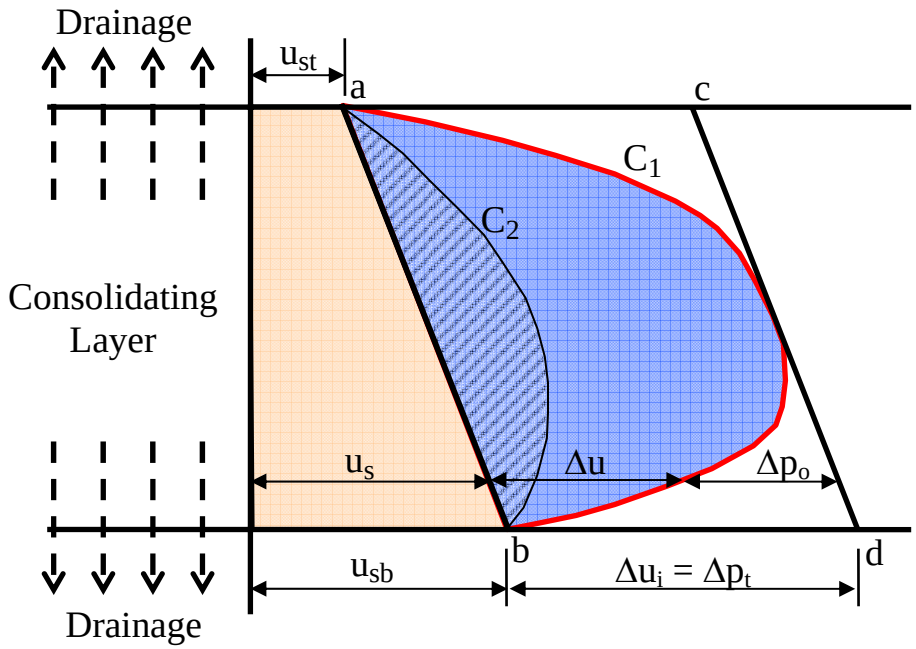
Figure 7-12. Typical consolidation curve for under-consolidated soil – (a) Void ratio versus vertical effective stress and (b) Vertical strain versus vertical effective stress.

$$S = \sum_{1}^{n} \frac{H_o}{1+e_o}\left(C_c \log_{10} \frac{p_o}{p_c} + C_c \log_{10} \frac{p_f}{p_o} \right) \quad 7\text{-}6$$

$$S = \sum_{1}^{n} H_o \left(C_{c\varepsilon} \log_{10} \frac{p_o}{p_c} + C_{c\varepsilon} \log_{10} \frac{p_f}{p_o} \right) \quad 7\text{-}7$$

7.5.3 Consolidation Rates (Time Rate of Consolidation Settlement)

The rate of consolidation should be considered for the design of geotechnical features and structures on compressible clay. For example, a geotechnical feature such as an embankment will settle relative to a bridge foundation supported on piles, creating an undesirable "bump at the end of the bridge." Hence, time rate of consolidation, as well as differential settlements between the bridge and embankment, is important. The concept of time rate of consolidation is explained with respect to Figure 7-13.



Definitions:
- u_{st} = hydrostatic pore water pressure at top of layer
- u_{sb} = hydrostatic pore water pressure at bottom of layer
- u_s = hydrostatic pore water pressure at any depth
- Δu_i = initial excess pore water pressure
- Δu = excess pore water pressure at any depth after time t
- u_t = u_s + Δu = total pore water pressure at any depth after time t

Figure 7-13. Diagram illustrating consolidation of a layer of clay between two pervious layers (modified after Terzaghi, *et al.* 1996).

- The initial hydrostatic pore water pressure distribution, u_s, is assumed to be linear in a layer of saturated clay. Line a-b in Figure 7-13 shows the initial hydrostatic pore water pressure distribution through a clay layer at a certain depth below the ground water elevation where u_{st} is the pore water pressure at the top of the clay layer and u_{sb} is the pore water pressure at the bottom of the clay layer. Experimental measurement of pore pressures in saturated clays subjected to one-dimensional loading indicate that when a load is applied the pore water pressure will instantaneously increase an amount equal to the total vertical stress increment, Δp_t, uniformly throughout the entire thickness of the consolidating layer as shown by a-c-d-b in Figure 7-13. The initial increase in the pore water pressure, Δu_i, above the static value is called the initial excess pore water pressure and it is equal to Δp_t. The total initial pore water pressure which is the sum of the hydrostatic pressure and the initial excess pore water pressures is shown as line c-d in Figure 7-13.

- With time, water will drain out of the consolidating layer to relieve the excess pore water pressure and the applied total vertical stress increment, Δp_t, will be slowly transferred to the soil particles, i.e., at any given time after application of the load, the initial excess pore water pressure will decrease at all depths to an excess pore water pressure having a value less than of Δu_i. The pattern of the excess pore water pressure at any given time is not parallel to line c-d, but is curvilinear similar to curve C_1 in Figure 7-13. Curves such as C_1 and C_2 are known as *iscochrones* because they are lines of equal time. The difference between the line a-b and curve C_1, for example, represents the excess pore water pressure, Δu, at any point within the consolidating layer at any time after application of the vertical load stress increment, Δp_t.

- If the clay layer is confined between two sand layers that are more permeable, the initial excess pore water pressure will drop immediately to zero at the drainage boundaries as shown in Figure 7-13 and the total vertical stress increment Δp_t and will be equal to the effective vertical stress increment, Δp_o. The rate of this transfer with depth depends upon the boundary drainage conditions. With time, the vertical distribution of excess pore water pressure within the consolidating layer will evolve from the initial distribution (a-c-d-b), to the C_1 distribution, to the C_2 distribution, and finally to the initial distribution of the hydrostatic pressure represented by line a-b.

- At any depth, the difference between a pore water pressure isochrone, such as C_1, and the initial excess pore water pressure c-d is equal to the effective vertical stress increment, Δp_o, i.e., the amount of Δp_t that has been transferred to the soil structure. Since the isochrone C_1 develops after a certain period of time, the difference between C_1 and c-d

also represents the distribution of the effective stress increments with depth at a given time after application of load.

- Note that the distribution shown in Figure 7-13 pertains only to the specific boundary drainage condition where a more permeable material exists above and below the consolidating clay layer. In this case the clay layer is considered to be "doubly drained" with the longest distance to a drainage boundary being half the layer thickness. If the clay layer is underlain by a less permeably material (e.g., rock), drainage will occur in only one direction and the isochrones at a given time will be different from those shown for double drainage in Figure 7-13. In this case the clay layer is considered to be "singly drained" with the longest distance to a drainage boundary being the entire layer thickness. During the consolidation process the principle of effective stress will be in operation at every depth, i.e., $\Delta p_t = \Delta u + \Delta p_o$ and settlement will be occurring due to the effective stress increment Δp_o. The drainage boundary condition will affect the time it takes for settlement to occur, but it has no effect on the magnitude of settlement, which is determined by use of the equations presented previously in which settlement is a function of Δp_o only.

7.5.3.1 Percent Consolidation

As indicated previously, immediately after application of load, Δu, will drop to zero at the drainage boundaries because the water will drain immediately into the more pervious layers. Since the excess pore water pressure is zero at the drainage boundaries, the soil there has undergone 100% consolidation. However, at interior points, the pore water pressure dissipates more slowly with time depending on the permeability of the compressible soil. At any time after application of a load, the actual degree or percentage of consolidation at a given depth is defined as $(\Delta u_i - \Delta u)/\Delta u_i$, where Δu is the excess pore water pressure at that depth at that time and Δu_i = the initial excess pore water pressure which, as indicated previously, equals the total stress increment Δp_t. Thus, where $\Delta u_i = \Delta u$ (i.e., at the instant of loading), the percent consolidation is zero. When $\Delta u = 0$ (i.e., at the end of consolidation), the percent consolidation is 100. This relationship is valid at any depth within the consolidating layer at any time from the instant of loading to the completion of primary consolidation.

While plots of the type shown in Figure 7-13 give an indication of the pore pressure variation within the consolidating layer at any time and are useful to explain the theory of consolidation, from a practical viewpoint it is usually more beneficial to obtain the *average* degree or percent of consolidation, U, within the entire layer to indicate when the entire clay

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layer has undergone a certain average amount of consolidation of say 10, 50, or 80 percent. With reference to Figure 7-13, the average degree of consolidation at any time is defined as the difference between the area under the initial excess pore water pressure curve (a-c-d-b) and the area under the isochrone at that time, e.g., the cross hatched area under isochrone C_2 divided by the area under the initial excess pore water pressure curve (a-c-d-b). The result is expressed as a percentage. Therefore, at the instant Δp_t is applied the area under the isochrone is exactly equal to the area (a-c-d-b) as indicated above and the average percent consolidation (U) equals zero. At the end of primary consolidation all excess pore water pressures have dissipated and the area under the isochrone is zero. Thus, the average percent consolidation (U) equals 100. Since, according to the principle of effective stress, $\Delta p_t = \Delta u + \Delta p_o$, the amount of settlement at any time after the application of load is directly related to the amount of consolidation that has taken place up to that time. As a practicality the average degree of consolidation at any time, t, can be defined as the ratio of the settlement at that time, S_t, to the settlement at the end of primary consolidation, $S_{ultimate}$, when excess pore water pressures are zero throughout the consolidating layer, i.e., $U = S_t/S_{ultimate}$. This relationship is used to develop a so-called "settlement-time curve" as will be discussed later.

Table 7-4 shows the average degree of consolidation (U) corresponding to a normalized time expressed in terms of a time factor, T_v, where:

$$T_v = \frac{c_v t}{H_d^2} \quad , \quad \text{which can be written as} \quad t = \frac{T_v H_d^2}{c_v} \qquad 7\text{-}8$$

where: c_v = coefficient of consolidation (ft^2/day) (m^2/day)
H_d = the longest distance to a drainage boundary (ft) (m)
t = time (day).

Any consistent set of units can be used in Equation 7-8 since T_v is dimensionless. As indicated previously, the longest drainage distance of a soil layer confined by more permeable layers on both ends is equal to one-half of the layer thickness. When confined by a more permeable layer on one side and an impermeable boundary on the other side, the longest drainage distance is equal to the layer thickness. The value of the dimensionless time factor T_v may be determined from Table 7-4 for any average degree of consolidation. U. The actual time, t, it takes for this percent of consolidation to occur is a function of the boundary drainage conditions, i.e., the longest distance to a drainage boundary, as indicated by Equation 7-8. By using the normalized time factor, T_v, settlement time can be computed for various percentages of settlement due to primary consolidation, to develop a predicted settlement-time curve. A typical settlement-time curve for a clay deposit under an embankment loading is shown in Figure 7-14.

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Table 7-4
Average degree of consolidation, U, versus Time Factor, T_v,
for uniform initial increase in pore water pressure

U %	T_v
0	0.000
10	0.008
20	0.031
30	0.071
40	0.126
50	0.197
60	0.287
70	0.403
80	0.567
90	0.848
93.1	1.000
95.0	1.163
98.0	1.500
99.4	2.000
100.0	Infinity



Figure 7-14. Typical settlement-time curve for clay under an embankment loading.

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7.5.3.2 Step-by-Step Procedure to Determine Amount and Time for Consolidation

The step-by-step process for determining the amount of and time for consolidation to occur for a single-stage construction of an embankment on soft ground is outlined below:

1. From laboratory consolidation test data determine the e-log p curve and estimate the change in void ratio that results from the added weight of the embankment. Create the virgin field consolidation curve by using the guidelines presented in Table 7-3.

2. Determine if the foundation soil is normally consolidated, overconsolidated or under-consolidated.

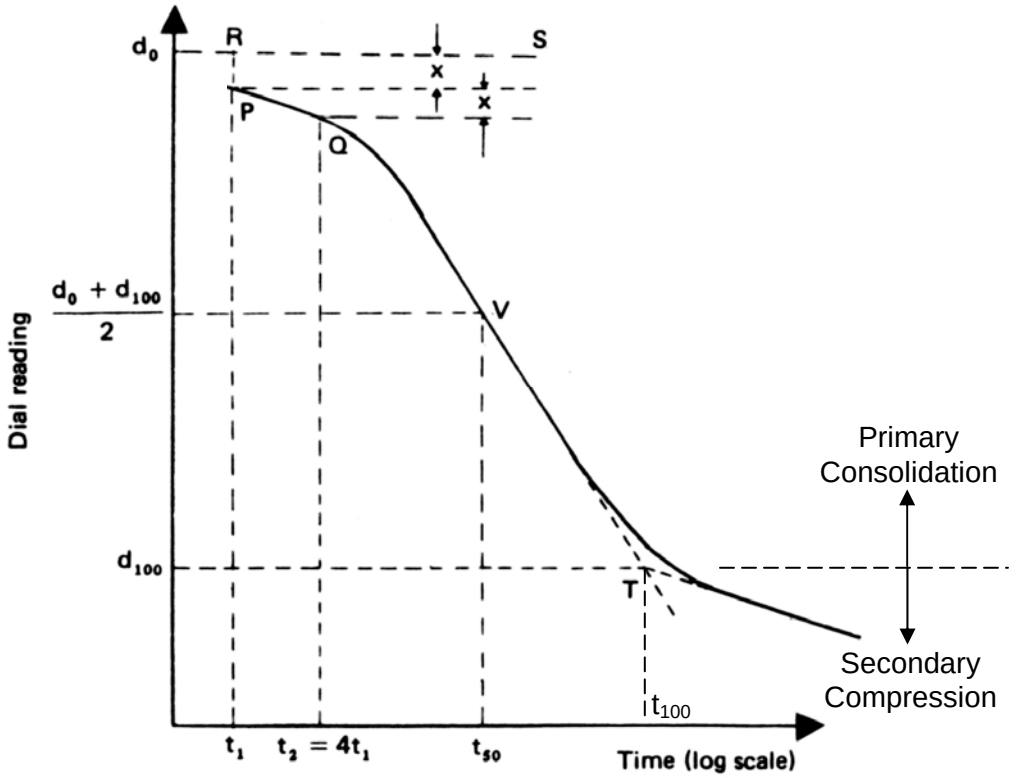
3. Use Equations 7-2 to 7-7 to compute the primary consolidation settlement for normally consolidated, overconsolidated and under-consolidated foundation soils.

4. Determine c_v from laboratory consolidation test data. Two graphical procedures are commonly used for this determination are the **logarithm-of-time method** (log t) proposed by Casagrande and Fadum (1940) and the **square-root-of-time method** ($\sqrt{t}$) proposed by Taylor (1948). These methods are shown in Figures 7-15 and 7-16, respectively. Because both methods are different approximations of theory, they do not give the same answers. Often the $\sqrt{t}$ method gives slightly greater values of c_v than the log t method.

5. Use Equation 7-8 to calculate the time to achieve 90% - 95% primary consolidation.

For a more detailed discussion on the consolidation theory, the reader is referred to Holtz and Kovacs (1981). An alternative approach to hand calculations is the use of a computerized method. For example, program FoSSA (2003) by ADAMA Engineering, Version 1.0 licensed to FHWA, which was introduced in Chapter 2, calculates the time rate of settlement for various boundary conditions including the effects of staged construction and strip drains in addition to calculating the stresses and settlements. FoSSA (2003) also allows for simulation of multiple layers undergoing simultaneous consolidation. In any event, the step-by-step hand calculations can serve to verify the correctness of benchmark cases and thereby be used to ascertain the correctness of any computerized procedure.

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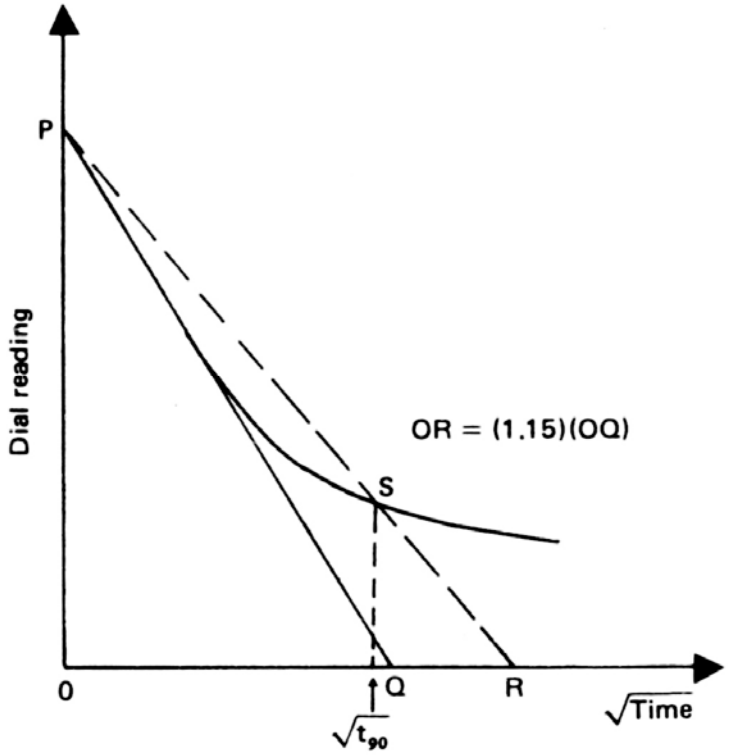
Step-by-step procedure:

1. Plot the dial readings for sample deformation for a given load increment against time on a semi-log paper.
2. Plot two points, P and Q on the upper portion of the consolidation curve which correspond to time t_1 and t_2, respectively. Note that $t_2 = 4\ t_1$.
3. The difference of the dial readings between P and Q is equal to x. Locate point R, which is at a distance x above point P.
4. Draw the horizontal line RS. The dial reading corresponding to this line is d_0, which corresponds to 0% consolidation.
5. Project the straight-line portions of the primary consolidation and the flatter portion towards the end of the consolidation curve to intersect at T. The dial reading corresponding to T is d_{100}, i.e., 100% primary consolidation. The sample deformation beyond t_{100} is due to secondary compression (see Section 7.5.4).
6. Determine the point V on the consolidation curve which corresponds to a dial reading of $(d_0+d_{100})/2 = d_{50}$. The time corresponding to the point V is t_{50}, i.e., 50% consolidation.
7. Determine c_v from Equation 7-8 for desired U. Example: For U=50% the value of T_v for is 0.197 from Table 7-4. Thus, c_v can be determined as follows:

$$c_v = \frac{0.197\,H_d^2}{t_{50}}$$

Figure 7-15. Logarithm-of-time method for determination of c_v.

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Step-by-step procedure:

1. Plot the dial reading and the corresponding square-root-of-time, $\sqrt{t}$.
2. Draw the tangent PQ to the early portion of the plot.
3. Draw a line PR such that OR = (1.15) (OQ).
4. The abscissa of the point S (i.e., the intersection of PR and the consolidation curve) will give $\sqrt{t_{90}}$, i.e., the square-root-of-time for 90% consolidation.
5. Determine c_v from Equation 7-8 for U=90%. From Table 7-4, the value of T_v for U=90% is 0.848. Thus, c_v can be determined as follows:

$$c_v = \frac{0.848\ H_d^2}{t_{90}}$$

Figure 7-16. Square-root-of-time method for determination of c_v.

Comments on c_v value: The value of c_v is determined for a given load increment. It varies from increment to increment and is different for loading and unloading. Moreover, c_v, usually varies considerably among samples of the same soil. Therefore, **if the actual rate of consolidation is critical to the design, as in certain stability problems where excess pore water pressures must be known accurately, pore pressures must actually be measured in the field as construction proceeds.**

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Regardless of whether hand-calculations or computerized methods are used, the important factors to remember are:

- the time required for consolidation is proportional to the square of the longest distance required for water to drain from the deposit and,

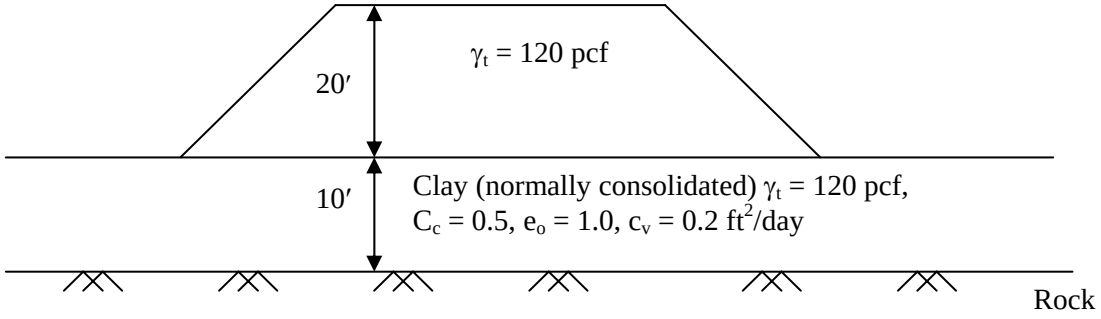
- the rate of settlement decreases as time increases.

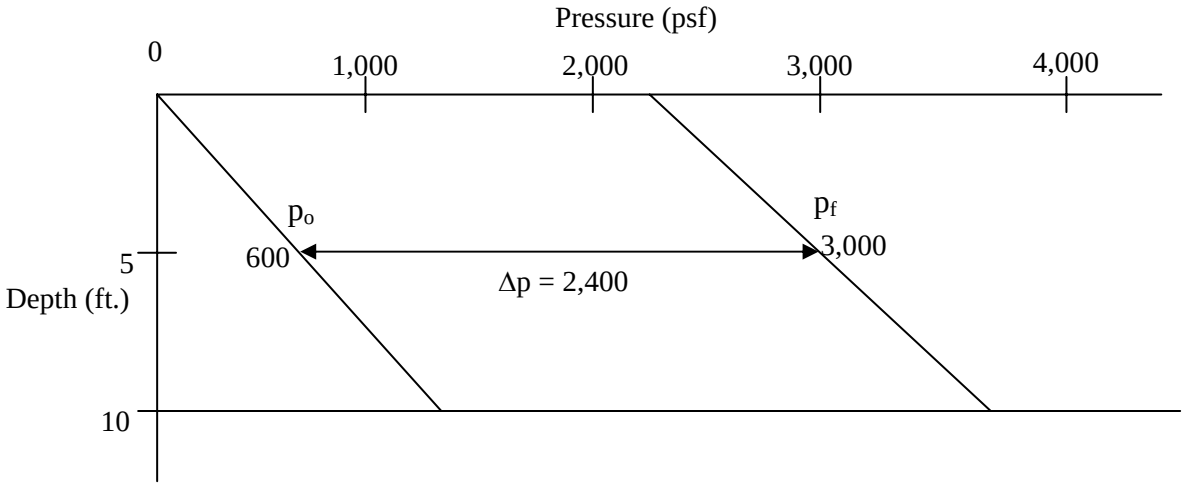
The maximum length of vertical drainage path, H_d, bears further explanation. This term should not be confused with the H term in the equation for the computation of the settlement magnitude. H is an arbitrarily selected value usually representing a portion of the total compressible layer thickness. For calculating the magnitude of settlement the sum of the sublayer H values must equal the total thickness of the clay layer. For calculating the time rate of settlement, the H_d term in Equation 7-8 is the maximum vertical distance that a water molecule must travel to escape from the compressible layer to a more permeable layer. In the case of a 20 ft (6 m) thick clay layer bounded by a sand layer on top and a virtually impermeable rock stratum on the bottom, the H_v term would equal to 20 ft (6 m). The water molecule must travel from the bottom of the layer to the top of the layer to escape, i.e., single drainage. However, if the clay layer was bounded top and bottom by more permeable sand deposits, the H_v distance would be 10 ft (3 m). The water molecule in this case, needs only to travel from the center of the layer to either boundary to escape, i.e., double drainage. However, regardless of the boundary drainage conditions, the sum of the sublayer H values must equal 20 ft (6 m) in the settlement computations.

The mechanism for determining the maximum horizontal path for escape of a water molecule is similar. The influence of horizontal drainage may be significant if the width of the loaded area is small. For instance, during consolidation under a long, narrow embankment, a water molecule can escape by traveling a distance equal to one half the embankment width. However, for very wide embankments the beneficial effect of lateral drainage may be small as the time for lateral escape of a water molecule increases as the square of one-half the embankment width.

The concepts of consolidation settlement and time rates of consolidation with reference to an embankment loading are illustrated by the following example.

Example 7-3: Determine the magnitude of and the time for 90% consolidation for the primary settlement of a "wide" embankment by using the p_o diagram.





Solution:

Since the embankment is "wide," the vertical stress at the base of the embankment is assumed to be the same within the 10-ft thick clay layer. Since soil is normally consolidated, use Equation 7-2 to determine the primary consolidation settlement as follows:

$$\Delta H = H \frac{C_c}{1+e_o} \log_{10} \frac{p_o + \Delta p}{p_o}$$

$$\Delta H = 10 \text{ ft} \left(\frac{0.5}{1+1.0} \right) \log_{10} \frac{600 \text{ psf} + 2{,}400 \text{ psf}}{600 \text{ psf}} = 1.75 \text{ ft} = 21 \text{ inches (0.53 m)}$$

Find time for 90% consolidation use T_v = 0.848 from Table 7-4. Assume single vertical drainage due to impervious rock underlying clay layer and use Equation 7-8 to calculate the time required for 90% consolidation to occur.

$$t_{90} = \frac{TH_d^2}{c_v}$$

$$t_{90} = \frac{(0.848)(10\text{ ft})^2}{0.2\text{ ft}^2/\text{day}} = 424\text{ days}$$

7.5.4 Secondary Compression of Cohesive Soils

Secondary compression is the process whereby the soil continues to displace vertically after the excess pore water pressures are dissipated to a negligible level i.e., primary compression is essentially completed. Secondary compression is normally evident in the settlement-log time plot when the specimen continues to consolidate beyond 100 percent of primary consolidation, i.e., beyond t_{100}, as shown in Figure 7-15. An example is shown in Figure 7-17, where secondary compression occurs beyond t_{100} = 392 mins. There are numerous hypotheses as to the reason for the secondary compression. The most obvious reason is associated with the simplifications involved in the theory of one-dimensional consolidation derived by Terzaghi. More rigorous numerical solutions accounting for the simplifications can often predict apparent secondary compression effects.

The magnitude of secondary compression is estimated from the coefficient of secondary compression, C_α, as determined from laboratory tests by using Equation 7-9 that is derived from Figure 7-17.

$$C_\alpha = \frac{\Delta e}{\log_{10}\left(\frac{t_{2\,lab}}{t_{1\,lab}}\right)} \qquad 7\text{-}9$$

where: $t_{1\,lab}$ = time when secondary compression begins and is typically taken as the time when 90 percent of primary compression has occurred

$t_{2\,lab}$ = an arbitrary time on the curve at least one log-cycle beyond t_{90} or the time corresponding to the service life of the structure

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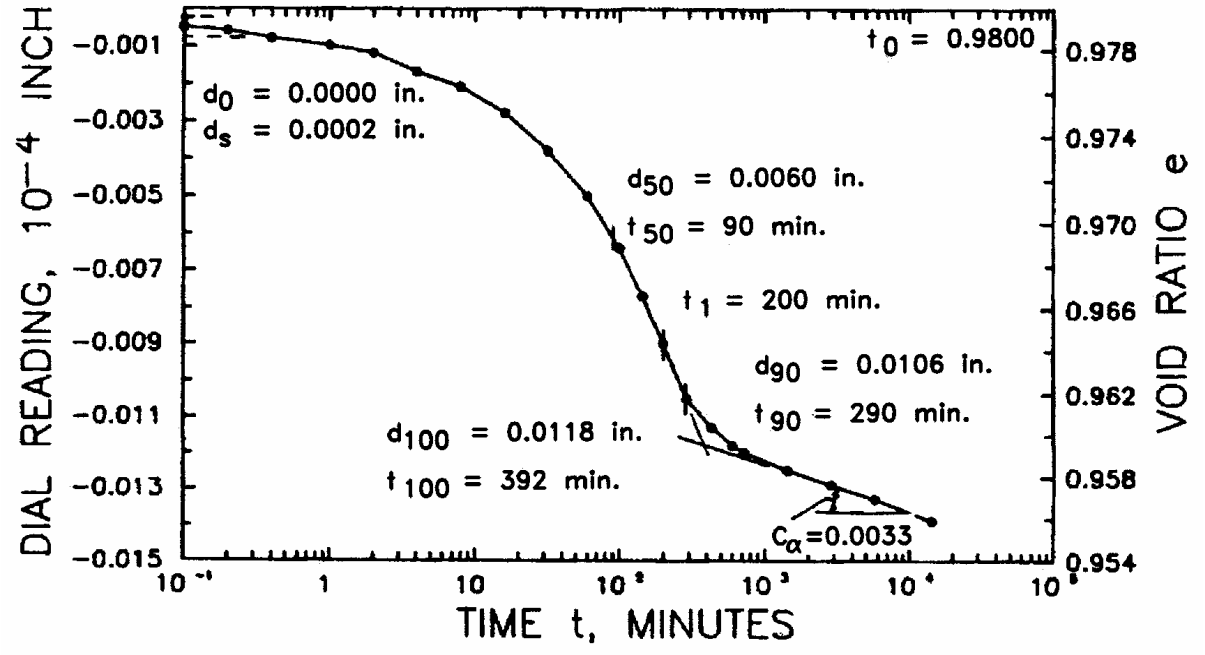


Figure 7-17: Example time plot from one-dimensional consolidometer test for determination of secondary compression (USACE, 1994). (1 in = 25.4 mm)

The settlement due to secondary compression (S_s) is then determined from Equation 7-10.

$$S_s = \frac{C_\alpha}{1+e_o} H_c \log_{10}\left(\frac{t_2}{t_1}\right) \qquad 7\text{-}10$$

where: t_1 = time when approximately 90 percent of primary compression has occurred for the actual clay layer being considered as determined from Equation 7-8.

t_2 = the service life of the structure or any other time of interest.

The values of C_α can be determined from the dial reading vs. log time plots associated with the one-dimensional consolidation test as shown in Figure 7-17. Typical ranges of the ratio of C_α/C_c presented in Section 5.4.6.4 of Chapter 5 can be used to check laboratory test results.

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7.6 LATERAL SQUEEZE OF FOUNDATION SOILS

When the geometry of the applied load is larger than the thickness of the compressible layer or when there is a finite soft layer within the depth of significant influence (DOSI) below the loaded area, significant lateral stresses and associated lateral deformations can occur as shown earlier in Figure 2-16 in Chapter 2. For example, as shown in Figure 7-18, if the thickness of a soft soil layer beneath an embankment fill is such that it less than the width, b_e, of an end or side slope, then the soft soil may squeeze out.

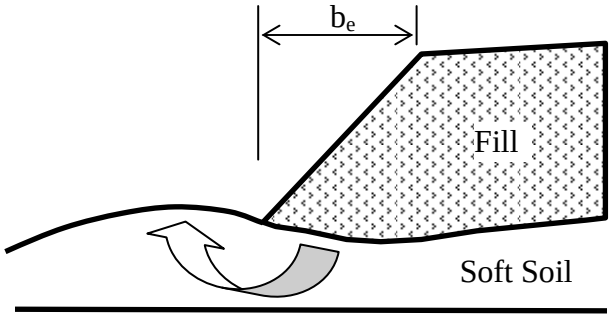


Figure 7-18. Schematic of lateral squeeze phenomenon.

The lateral squeeze phenomenon is due to an unbalanced load at the surface of the soft soil. The lateral squeeze behavior may be of two types, (a) short-term undrained deformation that results from a local bearing capacity type of deformation, or (b) long-term drained, **creep**-type deformation. **Creep refers to the slow deformation of soils under sustained loads over extended periods of time and can occur at stresses well below the shear strength of the soil.** As discussed in Section 5.4.1, secondary compression is a form of creep deformation while primary consolidation is not.

The lateral squeeze phenomenon can be observed in the field. For example, field observations and measurements have shown that some bridge abutments supported on piles driven through compressible soils tilted toward the embankment fill. Many of the abutments experienced large horizontal movements resulting in damage to the structure. The cause of this problem is attributed to the unbalanced fill load, which "squeezes" the soil laterally as discussed previously. This "lateral squeeze" of the soft foundation soil can apply enough lateral thrust against the piles to bend or even shear the piles. This problem is illustrated in Figure 7-19. The bridge abutment may tilt forward or backward depending on a number of factors including the relative configuration of the fill and the abutment, the relative stiffness of the piles or shafts and the soft deposit, the strength and thickness of the soft layer, rate of construction of the fill, and depth to bearing layer.

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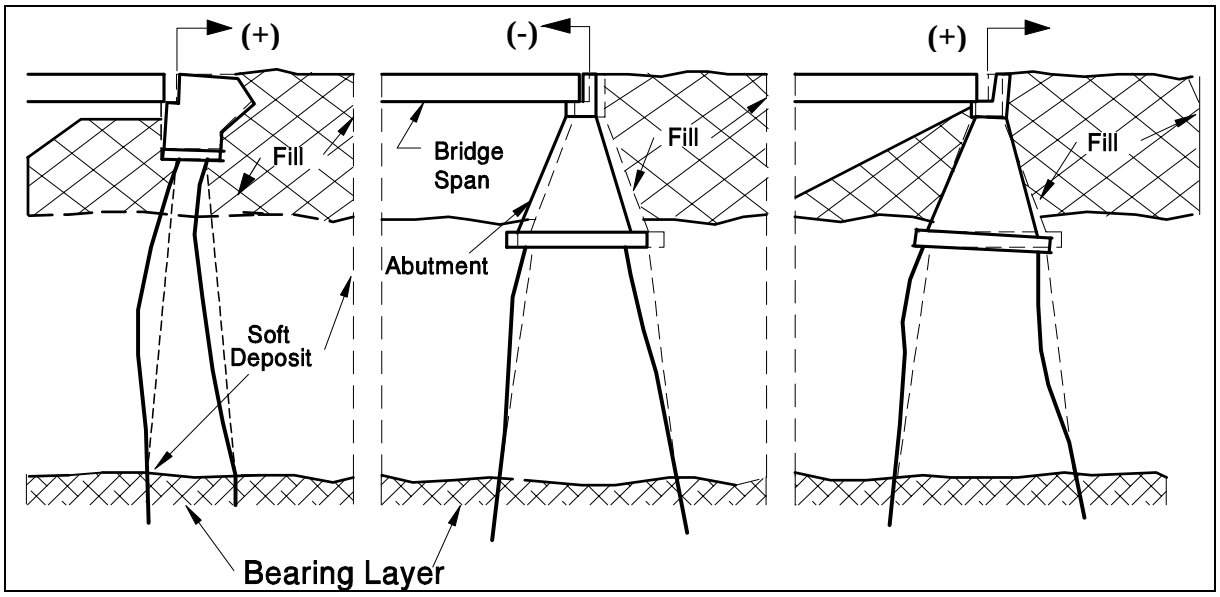


Figure 7-19. Examples of abutment tilting due to lateral squeeze (FHWA, 2006a).

7.6.1 Threshold Condition for Lateral Squeeze

Experience has shown that lateral squeeze of the foundation soil can occur and abutment tilting may result if the surface load applied by the weight of the fill exceeds 3 times the undrained shear strength, s_u, of the soft foundation soil, i.e.,

$$(\gamma)(H) > 3s_u \qquad 7\text{-}11$$

where, γ is the unit weigh of the fill and H is the height of the fill. The possibility of abutment tilting can be evaluated in design by using the above relationship. Whether the lateral squeeze will be short-term or long-term can be determined by evaluating the consolidation rate of settlement with respect to the rate of application of the load. For practical purposes, the unit weight of an embankment fill can be assumed to be approximately 125 pcf (19.7 kN/m^3). The undrained shear strength, s_u, of the foundation soil can be determined either from in-situ field vane shear tests or from laboratory triaxial tests on high quality undisturbed Shelby tube samples.

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7.6.2 Calculation of the Safety Factor against Lateral Squeeze

The safety factor against failure by squeezing, FS_{SQ}, may be calculated by Equation 7-12 (Silvestri, 1983). The geometry of the problem and the forces involved are shown in Figure 7-20.

$$FS_{SQ} = \left[\frac{2s_u}{\gamma D_S \tan\theta}\right] + \left[\frac{4.14 s_u}{\gamma H}\right] \qquad 7\text{-}12$$

where: θ = angle of slope
γ = unit weight of the fill
D_S = depth of soft soil beneath the toe of the end slope or side slope of the fill
H = height of the fill
s_u = undrained shear strength of soft soil beneath the fill

Caution is advised when Equation 7-12 is used. It was found that when $FS_{SQ} < 2$, a rigorous slope stability analysis and possibly advanced numerical analysis, e.g., finite element analysis should be performed. When the depth of the soft layer, D_S, is greater than the base width of the end slope, $b=H/\tan\theta$, general slope stability behavior governs the design. In that case, the methods described in Chapter 6 (Slope Stability) may be used to evaluate the stability of the foundation soils.

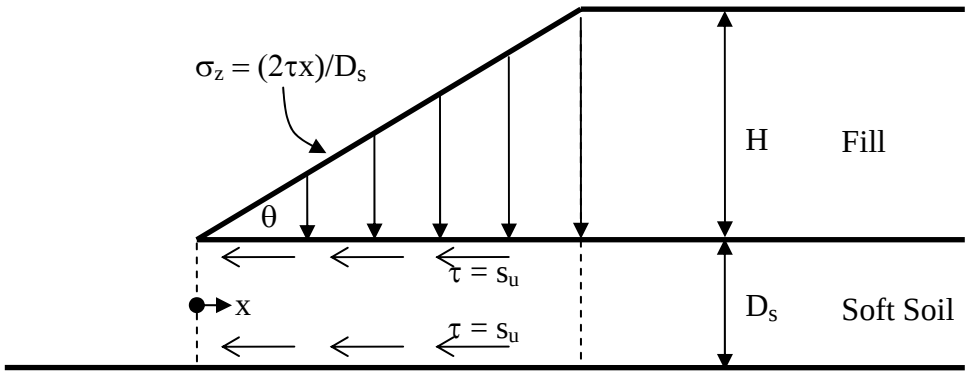


Figure 7-20. Definitions for calculating safety factor against lateral squeeze (after Silvestri, 1983).

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7.6.3 Estimation of Horizontal Movement of Abutments

The amount of horizontal movement the abutment may experience can also be estimated in design. Information from case histories for nine structures where measurements of abutment movements occurred is documented in Table 7-5.

The data presented in Table 7-5 provides a basis for estimating horizontal movement for abutments under similar conditions, provided a reasonable estimate of the post-construction fill settlement is made by using data from consolidation tests on high quality undisturbed Shelby tube samples. Note that the data for the abutments listed in Table 7-5 shows the horizontal movement (tilt) to range from 6 to 33% of the vertical fill settlement, with the average being 21%. Therefore, as a first approximation, it can be said that if the fill load exceeds the $3s_u$ limit prescribed by Equation 7-11, then the horizontal movement (tilt) of an abutment can be reasonably estimated as approximately 25% of the vertical fill settlement for the conditions listed in Table 7-5.

Table 7-5
Summary of abutment movements (Nicu, *et al.*, 1971)

Foundation	Fill Settlement (inches)	Abutment Settlement (inches)	Abutment Tilting (inches)	Ratio of Abutment Tilting to Fill Settlement
Steel H-piles	16	Unknown	3	0.19
Steel H-piles	30	0	3	0.10
Soil bridge	24	24	4	0.17
Cast-in-place pile	12	3.5	2.5	0.19
Soil bridge	12	12	3	0.25
Steel H-piles	48	0	2	0.06
Steel H-piles	30	0	10	0.33
Steel H-piles	5	0.4	0.5 to 1.5	0.1 to 0.3
Timber Piles	36	36	12	0.33

7.7 DESIGN SOLUTIONS - DEFORMATION PROBLEMS

Both the magnitude and time rate of settlement can affect fill structures, which in turn may affect the performance of other structures such as bridge abutments that are built within or in the vicinity of the fills. There are various methods to reduce the magnitude and time rate of settlement. All of these methods can be considered as ground improvement and are discussed in detail in FHWA (2006b). Two of these methods are briefly discussed in this manual. The reader is referred to FHWA (2006b) for further details. Solutions to prevent abutment tilting due to lateral squeeze are discussed in Section 7.7.3.

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7.7.1 Reducing the Amount of Settlement

Settlement can be reduced by either increasing the resistance or reducing the load. Several ground improvement methods that are particularly suitable for reducing the amount of settlement are noted below.

7.7.1.1 Category 1 - Increasing the Resistance

Common ground improvement techniques that increase resistance include the following:

- Excavation and recompaction.
- Excavation and replacement.
- Vertical inclusions such as stone columns, shafts and piles. Embankments supported in this way are known as column supported embankments.
- Horizontal inclusions such as geosynthetics.
- Grouting, e.g., soil mixing, jet grouting.
- Dynamic compaction.

7.7.1.2 Category 2 - Reducing the Load

Common load reduction techniques include the following:

- Reduce grade line (reduction in height and/or flattening the slope)
- Use lightweight fill material, e.g., expanded shale, foamed concrete, geofoam.
- Bypass the soft layer with a deep foundation. Deep foundations may be used in conjunction with a load transfer platform (see FHWA 2006b).

7.7.2 Reducing Settlement Time

Often the major design consideration related to a settlement problem is the time for the settlement to occur. Low permeability clays and silty clays can take a long time to consolidate under an applied load. The settlement time is critical on most projects because it has a direct impact on construction schedules and delays increase project costs. Settlement time is also important to the maintenance personnel of a highway agency. The life cycle cost of annual regrading and resurfacing of settling roadways is usually far greater than the cost of design treatments to eliminate settlement before or during initial construction.

The two most common methods used to accelerate settlement and reduce settlement time are:

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1. Application of surcharge.
2. Installation of vertical drains in the foundation soils.

Note that both of the above techniques lead to an increase in the resistance. These techniques are briefly discussed below and their use is illustrated in the Apple Freeway example in Appendix A.

7.7.2.1 Surcharge Treatment

An embankment surcharge is constructed to a predetermined height, usually 1 to 10 ft (0.3 to 3 m) above final grade elevation based on settlement calculations. The surcharge is maintained for a predetermined waiting period (typically 3 to 12 months) based on settlement-time calculations. Depending upon the strength of the consolidating layer(s) the surcharge may have to be constructed in stages. The actual dimensions of the surcharge and the waiting period for each stage depend on the strength and drainage properties of the foundation soil as well as the initial height of the proposed embankment. The length of the waiting period can be estimated by using laboratory consolidation test data. The actual settlement occurring during embankment construction is then monitored with geotechnical instrumentation. When the settlement with surcharge equals the settlement originally estimated for the embankment, the surcharge is removed, as illustrated in Figure 7-21.

If the surcharge is not removed after the desired amount of settlement has occurred, then additional settlement will continue to occur. Note that the stability of a surcharged embankment must be checked as part of the embankment design to ensure that an adequate short term safety factor exists. The stability is often field verified by monitoring with instrumentation such as inclinometers, piezometers and settlement points as discussed later.

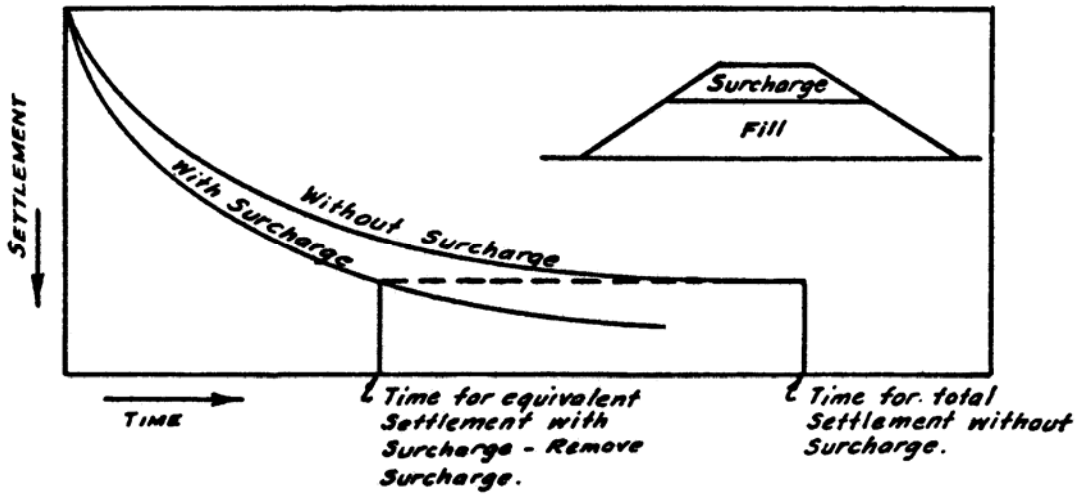


Figure 7-21. Determination of surcharge time required to achieve desired settlement.

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7.7.2.2 Vertical Drains

Primary consolidation of some highly plastic clays can take many years to be completed. Surcharging alone may not be effective in reducing settlement time sufficiently since the longest distance to a drainage boundary may be significant. In such cases, vertical drains can be used to accelerate the settlement, either with or without surcharge treatment. The vertical drains accelerate the settlement rate by reducing the drainage path the water must travel to escape from the compressible soil layer to half the horizontal distance between drains, as illustrated in Figure 7-22. In most applications, a permeable sand blanket, 2 to 3 ft (0.6 to 1 m) thick, should be placed on the ground surface to permit free movement of water away from the embankment area and to create a working platform for installation of the drains. The drains are installed prior to placement of the embankment. The applied pressure from the embankment generates excess pore water pressure.

Recall that the consolidation time is proportional to the square of the length of the longest drainage path. Thus if the length of the drainage path is shortened by 50%, the consolidation time is reduced by a factor of four. Vertical drains and sand blankets should have high permeability to allow the water squeezed out of the subsoil to travel relatively quickly through the drains and the blanket.

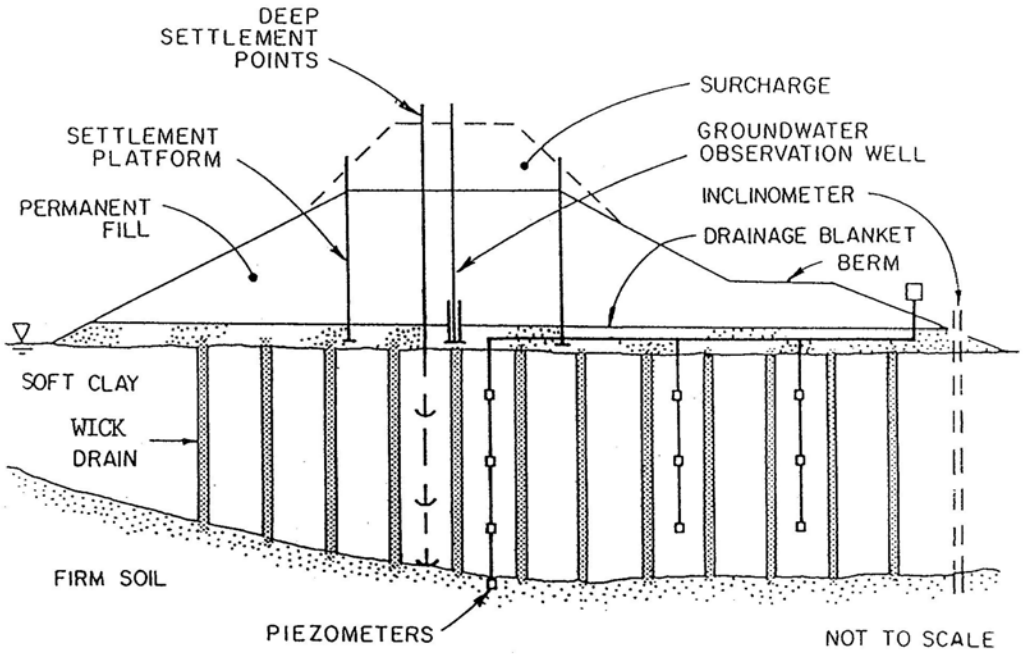


Figure 7-22. Use of vertical drains to accelerate settlement (NCHRP, 1989).

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Wick drains are small prefabricated drains consisting of a plastic core that is wrapped with geotextile. Wick drains are typically 4 inches (100 mm) wide and about 1/4 inch (7 mm) thick. The drains are produced in rolls that can be fed into a mandrel. Wick drains are installed by pushing or vibrating a mandrel into the ground with the wick drain inside. When the bottom of the compressible soil is reached, the mandrel is withdrawn and the trimmed portion of the wick drain left in the ground. To minimize smear of the compressible soil, the cross-sectional area of the mandrel is recommended to be limited to a maximum of about 10 in^2 (6,450 mm^2). Predrilling of dense soil deposits may be required in some cases to reach the design depth. Use of wick drains in the United States began in the early 1970s. Design and construction guidance on the use of wick drains is provided in FHWA (1986, 2006b).

The feasibility of a surcharge solution should always be considered first since vertical drains are generally more expensive.

7.7.3 Design Solutions to Prevent Abutment Tilting

A recommended solution to minimize abutment-tilting is to induce settlement of the fill before the abutment piles or shafts are installed. If the construction time schedule or other factors do not permit pre-consolidation of the foundation soils before the piles or shafts are installed, then abutment tilting issues can be mitigated by the following design provisions:

1. Use sliding plate expansion shoes large enough to accommodate the anticipated horizontal movement.

2. Make provisions to fill in the bridge deck expansion joint over the abutment by inserting either metal plate fillers or larger neoprene joint fillers.

3. Design the deep foundations for downdrag forces due to settlement. This solution does not improve the horizontal displacement effects.

4. Use backward battered piles at the abutment and particularly at the wingwalls.

5. Use lightweight fill materials to reduce driving forces

Displacements should also be monitored during and after construction so that the predicted movements can be compared to actual displacements. Displacements should be monitored by survey monuments or protected prisms installed on the face of the abutment and wingwalls and should be tied into permanent benchmarks.

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7.8 PRACTICAL ASPECTS OF EMBANKMENT SETTLEMENT

Few engineers realize the influence of embankment construction on the response of subsoils. The total weight of an embankment has an impact on the type of foundation treatment that may be appropriate. For instance, a relatively low height embankment of 10 ft (3 m) may be effectively surcharged because the additional surcharge weight could be 30 to 40 percent of the proposed embankment weight. However, when the embankment height exceeds 50 ft (15 m) the influence of a 5 or 10 ft (1.5 or 3 m) trapezoid of soil on top of this heavy 50 ft (15 m) mass is small and probably not cost-effective. Conversely, as the embankment height increases, the use of a shallow foundation for support of the abutment becomes more attractive. A 30 ft (9 m) high, 50 ft (15 m) long approach embankment weighs about 15,000 tons (130 MN) compared to the insignificant weight of a total (stub type) abutment loading that may equal 1,000 tons (9 MN). The width of an embankment also has an effect on total settlement. Wider embankments cause a pressure increase deeper into the subsoil. As might be expected, wider embankments may also cause more immediate and consolidation settlement and increase the time for consolidation to occur.

Recent developments in computer software readily permit computer analysis of approach embankment settlement. Programs such as FoSSA (2003), discussed in Chapter 2, allow the user to compute settlements along abutments and to evaluate the effects of settlements on pipes buried in end slopes or pipes placed diagonally under approach fills.

7.9 CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Approach embankment construction should be clearly defined in standard drawings as to materials and limits of placement. Such standards assure uniformity in construction due to the familiarity of the construction personnel with the operations being performed and results expected. Designers should attempt to use standard details wherever possible. Attempts at small changes in materials or limits are generally counterproductive to good construction where repetition of good practice is an important factor.

The philosophy of approach embankment details is to insure adequate bearing capacity for abutments or piers placed in the embankment and to minimize settlement of the pavement or footing. Typical highway embankments require compaction to 90 percent of maximum dry density (AASHTO T180) to control pavement settlement. **Designers should specify materials and compaction control as shown in Figure 7-4, to limit differential settlement between the structure and approach fill**. If piles are used to support footings in

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fill, the largest particle size of embankment material should be limited to 6 in (150 mm) to ease pile installation either by driving or pre-drilling. If spread footings are used, a minimum of 5 ft (1.5 m) of select material compacted to 100 percent of maximum dry density (AASHTO T99) should be placed beneath the footing and extended beyond the wingwalls. This layer provides uniform support for the footing and a rigid transition between the structure and the fill to minimize differential settlement. Construction control is usually referenced to percent compaction on the standard design drawings.

7.9.1 Embankment Construction Monitoring by Instrumentation

The observational approach to design involves monitoring subsoil behavior during early construction stages to verify design and to predict responses to subsequent construction. Basic soil mechanics concepts can be used to predict future subsoil behavior accurately if data from instrumentation are analyzed after initial construction loads have been placed. Occasionally a design problem arises that is unique or extremely critical and that can be safely solved only by utilizing the observational approach.

Embankment placement must be carefully observed and monitored on projects where stability and/or settlement are critical. The monitoring should include visual observation by the construction inspection staff and the use of instrumentation. Without the aid of various forms of instrumentation, it is impossible to determine accurately what is happening to the foundation. Instrumentation can be used to warn of imminent failure or to indicate whether settlement is occurring as predicted. The type of instruments to be used and where they will be placed should be planned by a qualified and experienced geotechnical specialist. Actual interpretation and analysis of the data should also be performed by someone with a background in soil mechanics; however, the project engineer and inspector should understand the purpose of each type of instrumentation and how the data are to be used.

7.9.1.1 Inspector's Visual Observation

In areas of marginal embankment stability, the inspector should walk the surface of the embankment daily looking for any sign of cracking or movement. Hairline cracks often develop at the embankment surface just prior to failure. If the inspector discovers any such features, all fill operations should cease immediately. All instrumentation should be read immediately. The geotechnical specialist should be notified. Subsequent readings will indicate when it is safe to resume operations. Unloading by removal of fill material or other mitigation methods are sometimes necessary to prevent an embankment failure.

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7.9.1.2 Types of Instrumentation

The typical instrumentation specified to monitor foundation performance on projects where stability and settlement are critical consists of:

1. **Slope Inclinometers** are used to monitor subsurface lateral deformation. A slope inclinometer typically consists of a 3 in (75 mm) internal diameter (ID) plastic tube with four grooves cut at 90-degree intervals around the inside. The slope inclinometer tube is installed in a borehole. The bottom of the slope inclinometer tube must be founded in firm soil or rock. A readout probe that fits into the grooves is lowered down the tube and angular deflection of the tube is measured. The amount and location of horizontal movement in the foundation soil can then be measured. For embankments built over very soft subsoils, telescoping inclinometer casing should be used to account for vertical consolidation. In soft ground conditions, several inches of lateral movement due to squeeze may occur without shear failure as the embankment is built. Therefore, from a practical construction control standpoint, the rate of movement rather than the amount is the better indicator of imminent failure. Slope inclinometer readings should be made often during the critical embankment placement period, daily if fill placement is proceeding rapidly, and readings should be plotted immediately on a movement versus time plot. Fill operations should cease if a sudden increase in the rate of movement occurs.

2. **Piezometers** indicate the amount of excess pressure build-up within the water-saturated pores of the soil. There are critical levels to which the water pressure in the subsoil will increase just prior to failure. The geotechnical specialist can estimate the critical water pressure level during design. Normally, the primary function of piezometers during fill placement is to warn of failures. Once the embankment placement is complete, the piezometers are used to measure the rate of consolidation. There are several different types of piezometers. The simplest is the open standpipe type, which is essentially a well point with a metal or plastic pipe attached to it. The pipe is extended up through the fill in sections as the fill height increases. This type of open well piezometer has the disadvantage that the pipes are susceptible to damage if hit by construction equipment. Also, the response time of open well piezometers is often too slow in soft clays to warn of potential embankment failure. There are several types of remote piezometers that eliminate the requirement for extending a pipe up through the fill. The remote units consist of a piezometer transducer that is sealed in a borehole with leads carried out laterally under the base of the embankment to a readout device that records the pore water pressure measured by the transducer. Pneumatic or vibrating wire piezometers

have a more rapid response to changes in pore water pressure than open-stand pipe piezometers.

3. **Settlement devices** are used to measure the amount and rate of settlement of the foundation soil due to the load from the embankment. Typically they are installed on or just below the existing ground surface before any fill is placed. The simplest settlement device is a settlement plate usually a 3 or 4 ft (0.9 to 1.2 m square plywood mat or steel plate with a vertical reference rod (usually ¾ in (19 mm) pipe) attached to the plate. The reference rods are normally added 4 ft (1.2 m) at a time as the height of the embankment increases. The elevation of the top of the reference rod is surveyed periodically to measure the foundation settlement. Remote pneumatic settlement devices are also available. As with the remote piezometer devices, the remote settlement devices have the advantage of not having a reference rod extending up through the fill.

7.9.1.3 Typical Locations for Instruments

Instrument installations should be spaced approximately 250 to 500 ft (75 to 150 m) along the roadway alignment in critical areas. Typical locations of instruments for an embankment over soft ground are shown in Figure 7-23:

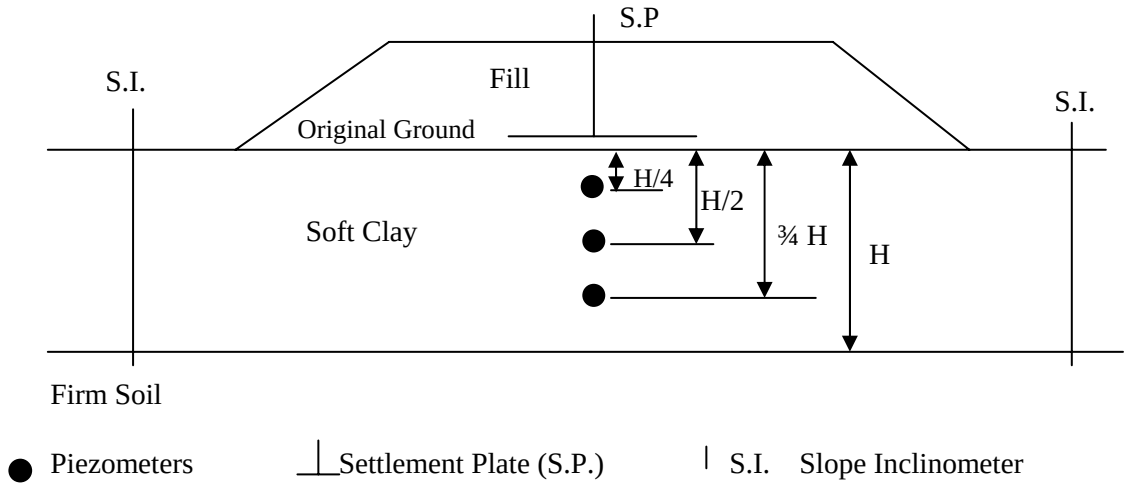


Figure 7-23. Typical locations for various types of monitoring instruments for an embankment constructed over soft ground.

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Exhibit G

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January 18, 2022

Ms. Christine Zeivel
Assistant Counsel
Division of Legal Counsel
Illinois Environmental Protection Agency
1021 North Grand Avenue East
P.O. Box 19276
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Re: Construction Chronology of Pond 2 at Joliet 29 Generating Station

Dear Ms. Zeivel:

Sargent & Lundy (S&L) has prepared this letter documenting the chronology of construction activities at the Pond 2 site at Midwest Generational, LLC's ("MWG") Joliet 29 Generating Station ("Joliet 29") from Pond 2's original construction circa 1978 to the installation of Pond 2's existing high-density polyethylene (HDPE) geomembrane liner in 2008. Like my December 2, 2021 letter to the Agency related to the 2008 reconstruction of the access ramp into Pond 2, this chronology has been prepared to identify the materials and corresponding installation methods that were specified and/or likely utilized to construct Pond 2's existing embankments and liners for the Agency's review and consideration as the Agency prepares its recommendation to the Illinois Pollution Control Board on whether MWG should be permitted to re-use Pond 2's existing geomembrane liner as proposed in MWG's petition for an adjusted standard from 35 Ill. Adm. Code 845.740(a) (Illinois Pollution Control Board Case No. AS 2021-001).

The chronological record presented herein is based on the enclosed design drawings, technical specifications, construction quality assurance (CQA) reports, construction correspondence, aerial photographs, and soil boring logs. These records are organized as follows:

- **Attachment 1 ("2016 History of Construction"):** Geosyntec Consultants. *History of Construction, Ash Pond 2, Joliet 29 Station*. Dated October 2016.
- **Attachment 2 ("2015 Subsurface Investigation by Geosyntec"):** Soil boring logs corresponding to borings J-B-1 and J-B-2 drilled through Pond 2's embankments in 2015 by Geosyntec Consultants (Geosyntec).

- **Attachment 3 ("2005 Geotechnical Analysis by KPRG"):** KPRG and Associates, Inc. "Geotechnical Analysis of Soil Surrounding Settling Basins/Ponds." KPRG Project No. 15805. Dated October 13, 2005.
- **Attachment 4 ("2011 Hydrogeologic Assessment by Patrick Engineering"):** Patrick Engineering Inc. *Hydrogeologic Assessment Report, Joliet Generating Station No. 29,* Patrick Project No. 21053.070. Dated February 2011.
- **Attachment 5 ("Expert Opinion of Mr. Michael B. Maxwell, LPG"):** Weaver Consultants Group North Central, LLC. *Expert Opinion in Support of Midwest Generation LLC's Petition for Adjusted Standard Joliet 29 Station, PCB21-01*. WCG Project No. 5244-302-07-01. Dated December 6, 2021.
- **Attachment 6 ("Preliminary Drafts of Sheet Nos. C020 & C031"):** Preliminary draft versions of Sheet Nos. C020 and C031 for re-lining Pond 2, issued for review on May 9, 2007.
- **Attachment 7 ("2008 Re-Lining Technical Specifications"):** Natural Resource Technology, Inc. *Technical Specifications for Ash Impoundment #2 Liner Replacement*. Joliet 29 Generation Station, 1800 Channahon Road, Joliet, Illinois. Natural Resource Technology Project No. 1862. Dated August 3, 2007.
- **Attachment 8 ("2008 Re-Lining Field Change Requests"):** Field Change Request Nos. 1 and 2 submitted by Brieser Construction Company working on the 2008 Pond 1 and Pond 2 re-lining projects.
- **Attachment 9 ("2008 Re-Lining Project Invoices"):** Job Invoice Nos. 35546, 35547, and 35549 submitted by Brieser Construction Company to MWG.
- **Attachment 10 ("2008 Re-Lining Construction Records"):** *Construction Documentation Transmittal, Ash Impoundment #1 and #2 Liner Replacement*. Letter from Ms. Heather M. Simon (Natural Resource Technology, Inc.) to Mr. Brian DelCorio (Midwest Generation, LLC). Dated December 23, 2008. The 2008 Re-Lining Construction Records were attached as Exhibit 15 to the original petition, and are enclosed herewith for convenience.
- **Attachment 11 ("2008 Re-Lining Construction Photograph"):** Photograph dated April 30, 2008 showing the first panels of Pond 2's new HDPE geomembrane liner being installed along the interior of pond's eastern embankment.

Although the technical specifications provided in Attachment 8 are not the final technical specifications issued for construction, it may be inferred from the construction records enclosed herewith that the specifications for the Pond 2 re-lining work were finalized as proposed in the attached August 3, 2007 version or were finalized with minimal changes that did not have significant impacts on how Brieser Construction Company was instructed to execute the re-lining work.

As demonstrated in the forthcoming chronological record for Pond 2 developed from the preceding design, construction, photographic, and subsurface investigation records, it is my professional opinion that:

- Pond 2's embankments and subgrade consist of natural earthen materials obtained from on-site and/or off-site borrow sources.
- It is highly unlikely that coal combustion residuals (CCR) were used as fill material for the pond's embankments or subgrade.

- Pond 2's original pozzolan-stabilized base liner – a material identified as "Poz-o-Pac" – was left in-place when the pond was re-lined in 2008 and is an encapsulated use of fly ash and boiler slag aggregate akin to a low-strength concrete.
- Prior to installing Pond 2's current HDPE geomembrane liner in 2008, CCR stored above the pond's original Poz-o-Pac liner at that time was removed from the pond.
- CCR was not used as fill material under Pond 2's new HDPE geomembrane liner as a cushion layer or other purpose.

The chronological record presented in this letter is divided into two sections related to the use of the Pond 2 site as a means of storing CCR generated by Joliet 29:

- Pond 2 with Poz-o-Pac Liner (1978–2008)
- Pond 2 with Geomembrane Liner (2008–Present)

Pond 2 with Poz-o-Pac Liner (1978–2008)

Embankment Construction

In 1978, Joliet 29 constructed Ponds 1 and 2. Per Section S on Sheet 2 of Drawing 5079-C-5019 in Attachment 1, Pond 2's embankments were constructed by excavating material below the existing ground surface shown within the specified pond area (approximately El. 530 feet) to form 3-horizontal-to-1-vertical (3H:1V) side slopes. Per Note 2 on Drawing 5079-C-5100 in Attachment 1, the existing ground surface shown on the typical cross section for Pond 2 was based on a topographic survey performed by Aero-Metric Engineering on November 18, 1974. Per Section U for Pond 1 on Sheet 3, the embankments for Ponds 1 and 2 were to be constructed by "remov[ing] existing 'muck' not suitable for [each] embankment [and] replac[ing] with compacted suitable fill."

A total of eight borings have been drilled through Pond 2's embankments by three engineering consultants: JS29-GT-2 and JS29-GT-3 by KPRG in 2005; B-MW-3, B-MW-4, B-MW-5, and B-MW-10 by Patrick Engineering in 2011; and J-B-1 and J-B-2 by Geosyntec in 2015. The locations of these borings are shown on Figure 1 in Attachment 2. The Geosyntec, KPRG, and Patrick Engineering soil boring logs are provided in Attachments 2, 3, and 4, respectively.

Based on borings JS29-GT-3 and B-MW-10, Pond 2's northern embankment primarily consists of a brown clay. At JS29-GT-3, the brown clay extends from grade down to 19 feet below the ground surface (BGS) and contains some gravel, sand, and silt. At B-MW-10, a black/gray sandy silt was identified beneath the brown clay from 7 to 19 feet BGS, followed by a gray silty clay with trace amounts of sand from 19 to 41 feet BGS. At 41 feet BGS, Patrick Engineering noted that auger refusal was encountered, thereby representing the surface of the site's uppermost limestone bedrock layer.

Per the three borings drilled through Pond 2's southern embankment since 2011, the embankment primarily consists of a brown clay underlain by sand and gravel. At borings B-MW-4 and J-B-1, the brown clay layer extends down to 6 feet and 10 feet BGS, respectively, followed by a predominately brown/tan sand and gravel layer containing some limestone fragments; some black and gray silty gravels were also observed in this layer in boring J-B-1. Meanwhile, the brown clay was not observed in boring B-MW-3, which was drilled in the

southeastern corner of Pond 2. Instead, a sand and gravel layer was identified down to 18.5 feet BGS followed by the aforementioned brown/tan sand and gravel layer until the aforementioned limestone bedrock layer was encountered at 41 feet BGS.

Unlike the borings drilled through the pond's northern and southern embankments, the three borings drilled through Pond 2's western embankment did not identify consistent fill materials. At boring B-MW-5, a gravel topsoil layer was identified down to 8.5 feet BGS followed by a black silty clay with sand and gravel down to 23 feet BGS. This black silty clay layer was also identified in boring JS29-GT-2 at a similar depth (10 feet BGS) as boring B-MW-5, but a dark brown/black clay and gravel layer with some sand and silt was identified above the black silty clay layer. Meanwhile, a silty sand and gravel surficial layer was identified in boring JB-2 down to 15 feet BGS. Finally, the black and tan gravel and sand layer that was also observed at the Pond 2's southern embankment was identified at boring B-MW-5 from 23 to 42 feet BGS and at boring JB-2 from 15 to 35 feet BGS.

Ash was not identified as a primary fill material in any of the eight borings drilled through Pond 2's embankments since 2005. Bottom ash or slag were only identified within the upper foot of KPRG borings JS29-GT-2 and JS29-GT-3. Given the absence of bottom ash beyond a depth of 1 foot at these borings and the general absence of bottom ash in the other six borings, these two instances are more likely to be from bottom ash particles being present at the surface of the pond's access roads than ash being used as fill material.

Because KPRG boring JS29-GT-3; Patrick Engineering borings B-MW-3, B-MW-4, and B-MW-10; and Geosyntec boring J-B-1 were all drilled through Pond 2's perimeter access road, if ash was used as fill material to construct the pond's embankments when they were built circa 1978, ash material would likely have been encountered in the corresponding boring logs. However, as previously stated, none of these borings identified ash as fill material. Moreover, as explained by Weaver Consultants Group's (WCG) Mr. Michael B. Maxwell in his December 6, 2021 expert opinion submitted to the Agency (enclosed herewith as Attachment 5), groundwater data collected at the site does not indicate the presence of CCR in the proximity of Pond 2 (*i.e.*, ash fill was not used to construct Pond 2's embankments). Mr. Maxwell's conclusion is based on a statistical trend analysis performed by WCG on the detection groundwater monitoring constituents listed in Appendix III to 40 CFR Part 257 Subpart D ("Appendix III"), the U.S. Environmental Protection Agency's (EPA) "Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments", which the U.S. EPA acknowledges are "known to be leading indicators of releases of contaminants associated with CCR" (see 80 *Fed. Reg.* 74, p. 21342). If CCR was present under Pond 2's liner, it would be expected that the concentrations of Appendix III groundwater monitoring constituents would be consistently measured above their respective statistically-derived prediction limits.

Given the lack of ash material observed in the soil borings drilled through Pond 2's embankments, Mr. Maxwell's expert opinion, and the explicit and implicit construction specifications on the 1978 design drawings for Pond 2 to remove existing material from the area, it is more likely than not that ash was not used as a primary fill material to construct Pond 2's embankments or a portion thereof when they were built circa 1978. Based on the attached soil boring logs from Geosyntec, KPRG, and Patrick Engineering, Pond 2's embankments consist of a combination of brown clay, black/gray silt and clay, and brown/tan sand and gravel materials. These materials are a combination of natural earthen materials obtained from on-site

and/or off-site borrow sources, and the deeper embankment materials and supporting foundation soils are likely soils native to the Pond 2 site.

Poz-o-Pac Liner Construction

Per Section S on Sheet 2 of Drawing 5079-C-5019 in Attachment 1, the final floor elevation for Pond 2 was specified as El. 516 feet. However, the contractor was instructed to over-excavate the area by at least 2 feet below this elevation to install the pond's Poz-o-Pac liner and the liner's subbase. Note 4 on the same drawing states, "Prior to the installation of the Poz-o-Pac, the subbase shall be prepared by undercutting to a minimum of 1 foot below the bottom of the Poz-o-Pac filling with 2-6" lifts to a compaction of 90% Proctor with consolidation." Per the aforementioned Section S, the Poz-o-Pac liner was then to be installed above the compacted subbase (yielding a final floor elevation of El. 516 feet) and extended along the interior side slopes of Pond 2's embankments.

Per the Federal Highway Administration's (FHWA) "User Guidelines for Waste and Byproduct Materials in Pavement Construction" (FHWA Publication No. FHWA-RD-97-148), Poz-o-Pac was a patented base course product consisting of a blend of lime, fly ash, and aggregate (the patent expired in the 1970s). Per the FHWA guideline, Poz-o-Pac and similar formulations may be described as pozzolan-stabilized base (PSB) mixtures. Per Notes 1 through 3 on Sheet 2 of Drawing 5079-C-5019 in Attachment 1, Pond 2's Poz-o-Pac liner was to be constructed as follows:

- The Poz-o-Pac mixture was to consist of 3% hydrated lime, 20% fly ash, and 77% boiler slag aggregate;
- The 1-foot-thick liner was to be installed by placing the Poz-o-Pac material in two, 6-inch-thick lifts and compacting each lift to a minimum density of 136.9 pounds per cubic foot (pcf); and
- The Poz-o-Pac liner was to be given at least 7 days to cure prior to a bituminous seal coat being applied to the liner surface.

The preceding design specifications for Pond 2's Poz-o-Pac liner are generally consistent with the materials, mix designs, and curing times for PSB mixtures discussed in FHWA-RD-97-148. The 23% of activator (hydrated lime) plus fly ash content of the Poz-o-Pac mix design is within the 12 to 30% range mentioned in the FHWA guideline, as is the minimum 7-day curing time specified for the Poz-o-Pac material. The guideline also notes that boiler slag aggregates have been utilized in "many well-constructed PSB mixes." Finally, as referenced by the guideline, the 3% hydrated lime content in the Poz-o-Pac mixture is similar to the lime and Portland cement content (3 to 4%) in the PSB mixtures used to construct new runways, taxiways, and aprons at Newark International Airport in the 1970s, which "[a]fter 20 or more years…continue to perform satisfactorily."

As discussed in FHWA-RD-97-148, PSB mixtures like Poz-o-Pac are similar to a low-strength concrete when hardened but, prior to curing, are "produced at a compactable consistency, not a plastic consistency, for placement at or near optimum moisture content and densification by roller compaction." The preceding construction specifications for installing Pond 2's 1-foot-thick Poz-o-Pac liner in two, 6-in.-thick lifts compacted to a minimum density of 136.9 pcf are consistent with this statement from the FHWA guideline. In other words, Pond 2's Poz-o-Pac liner represents an encapsulated use of fly ash and boiler slag aggregate akin to a low-strength

concrete liner rather than unencapsulated subgrade materials and that was to be installed in accordance with recognized and generally accepted construction practices for PSB mixtures.

Pond 2 with Geomembrane Liner (2008–Present)

In 2007, MWG initiated a systematic re-lining program for the ash ponds at their Joliet 29, Powerton, and Will County Generating Stations with high-density polyethylene (HDPE) geomembrane liners. Like Joliet 29 Ponds 1 and 2, the ash ponds at MWG's other coal-fired power plants were constructed in the late 1970s with Poz-o-Pac liners. The first ash pond to be re-lined as part of this program was Pond 2. Due to its age, Natural Resource Technology (NRT), the engineer-of-record for the Pond 2 re-lining project, assumed the pond's Poz-o-Pac liner was in poor condition and, accordingly, initially planned to have the contractor installing the new HDPE geomembrane liner to first remove the original Poz-o-Pac liner. This initial plan is evident in NRT's instruction in Note 5 on a preliminary version of Sheet No. C020 issued for review on May 9, 2007 (see Attachment 6), which states, "Contractor shall remove existing liner from impoundments and dispose at an approved landfill." Moreover, the pond subgrade in Section A on a preliminary version of Sheet No. C031 (also included in Attachment 6) issued with the aforementioned draft version of Sheet No. C020 is identified as "Native Soil," implying that the original Poz-o-Pac liner was to be removed and Pond 2's new liner was to be installed on the natural foundation soils below it.

Prior to issuing the design drawings and technical specifications for the Pond 2 re-lining project for bids, MWG dewatered and began removing ash stored in Pond 2 to prepare the pond to be re-lined. At that time, MWG and NRT found the pond's original Poz-o-Pac liner to be in good condition, counter to their initial assumption, and opted to leave the original liner in-place and install the new HDPE geomembrane liner over it. Accordingly, prior to issuing the project's design drawings for bids in the fall of 2007, NRT (1) removed the note from Sheet No. C020 instructing the contractor to remove Pond 2's existing liner, and (2) revised their identification of the pond subgrade shown in Section A on Sheet No. C030 from "Native Soil" to "Subgrade Soil;" it is unknown why the existing Poz-o-Pac liner was not explicitly identified on Section A or the other sections shown on Sheet No. C030. The bid versions of Sheet Nos. C020 and C030 and the other design drawings issued for bids are included in Attachment 7.

In early April 2008, Brieser Construction Company ("Brieser") began the subgrade preparation work in Pond 2. One of the first activities specified for this work per Sheet No. C020 in Attachment 7 was to install marker posts along the pond subgrade. On April 14, 2008, Brieser submitted Field Change Request #1 (Attachment 8) to MWG for installing these marker posts. In this field change request, Brieser states, "The 9 Marker Posts require drilling into bedrock in lieu of soil. Drilling into rock requires specialized equipment and more time. We will hire a subcontractor for this work." As previously noted for the various soil borings drilled through Pond 2's embankments and as stated in the 2011 Hydrogeologic Assessment by Patrick Engineering (Attachment 3), the upper limestone bedrock layer at the Pond 2 site has been identified no shallower than 35 feet BGS, which corresponds to approximately El. 500 feet. Given the top of Pond 2's original Poz-o-Pac liner is at approximately El. 516 feet, the "bedrock" to which Brieser is referring is presumed to be the pond's original Poz-o-Pac liner. Based on this field change request and the absence of subsequent change order requests for removing any portion of the existing liner, it is presumed that Brieser left Pond 2's original Poz-o-Pac liner in place.

In addition to installing marker posts along Pond 2's base, the technical specifications and design drawings for the project (Attachment 7) required Brieser to perform the following subgrade preparation work prior to installing the pond's new HDPE geomembrane liner:

- Per Notes 5 and 7 of Sheet No. C020, Brieser was to prepare Pond 2's subgrade to receive the pond's new HDPE geomembrane liner by:
    - Removing vegetation, rocks, and other debris greater than 3 inches present along the subgrade and dispose of the material removed from the impoundment area at an approved facility,
    - Grading the pond's side slopes flat to remove erosion rills, and
    - Installing marker posts along the pond's base.
- In addition to the preceding notes on Sheet No. C020, per Section 02300 (Earthwork), Article 3.05 (Liner Subgrade):
    - The liner subgrade along the Pond 2's side slopes was to be graded to 3H:1V or as otherwise approved by MWG and/or NRT.
        - Per Section S on Sheet 2 of Drawing 5079-C-5019 in Attachment 1 and as previously stated, Pond 2's embankments were to have interior 3H:1V side slopes when they were constructed circa 1978.
        - Therefore, to meet this requirement, it is presumed that Brieser would only have needed to do minor cut and fill work, if any, to establish the specified slopes, in addition to removing any unsuitable material above the existing Poz-o-Pac liner.
    - The liner subgrade along Pond 2's floor was to be relatively flat, not exceeding a 1% slope.
        - Per Section S on Sheet 2 of Drawing 5079-C-5019 in Attachment 1, the top of Pond 2's original Poz-o-Pac liner was to be relatively flat at El. 516 feet when it was installed circa 1978.
        - Therefore, to meet this requirement, it is presumed that Brieser would only have needed to do minor cut and fill work, if any, to establish the specified slopes for the floor, in addition to removing any unsuitable material above the existing Poz-o-Pac liner.
        - Indeed, Brieser identified "unsuitable material that [was] deposited in [the bottom of] the pond" and submitted Field Change Request #2 on April 17, 2008 to remove the material. See Attachment 8.
        - Per this field change request, Brieser estimated approximately 1,200 cubic yards of material would need to be removed from the bottom of Pond 2. Based on a bottom area of approximately 1.6 acres per Figure 2 of Attachment 1, this corresponds to approximately six inches of material at the base of the pond that needed to be removed.
        - Per Job Invoice No. 35549 in Attachment 9, which is also dated April 17, 2008, the material to be removed was identified as "coal residue" by Brieser and therefore presumed to be CCR. Per this invoice and the other two job invoices in Attachment 9, Brieser removed the CCR remaining on the pond floor.
    - The liner subgrade was to be proof-rolled with a smooth-drum compactor to identify soft spots to be removed and replaced with structural fill as directed by MWG and/or NRT and Brieser's subcontractor responsible for installing the new geomembrane liner.

On April 28, 2008, a representative from NRT inspected Pond 2's subgrade for conformance to NRT's corresponding specifications for preparing the pond's subgrade. The representative's field notes are included in the construction records for re-lining Joliet 29 Ponds 1 and 2, enclosed herewith as Attachment 10. The representative noted, "The subgrade looked good, except one spot on the slope had a foot wide hole…Brieser said that they would fill it in." No records indicating the location of this hole or how it was remediated are known to exist. However, it is presumed that the hole was filled using either limestone screenings specified for the warning and cushion layers above Pond 2's new liner or anchor trench excavation spoils given that both materials would have been readily available to fill in this relatively small hole.

By April 30, 2008, Brieser had finished the subgrade preparation work and had started installing Pond 2's new geomembrane liner and the 16-oz non-woven geotextile cushion layer between the new liner and the original Poz-o-Pac liner. The photograph in Attachment 11 dated April 30, 2008, shows the first panels of the new HDPE geomembrane liner and underlying geotextile being installed along the interior side slope of the pond's eastern embankment. The top surface of the original Poz-o-Pac liner can also be observed along the pond floor and interior side slope. Per this photograph, the non-woven geotextile cushion layer is being placed in direct contact with the original Poz-o-Pac liner, and the new geomembrane liner is being installed directly over the geotextile cushion layer. This construction sequencing and layering for Pond 2's new liner are consistent with Sections A, B, and C on the as-built / record drawing of Sheet C031 (dated December 19, 2008) included in Attachment 10.

Based on the preceding discussion and referenced design and construction records, it is my opinion that:

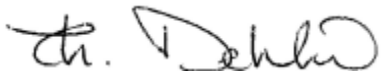
- Pond 2's original Poz-o-Pac liner was left in-place along the pond's floor and interior side slopes,
- CCR stored above Pond 2's original Poz-o-Pac liner at the time Briesler mobilized to the site to re-line the pond was removed from the pond by Briesler, and
- CCR was not used as fill material under Pond 2's new HDPE geomembrane liner as a cushion layer or other purpose.

Conclusion

Based on the chronological record established in the preceding sections and by the attached design, construction, photographic, and subsurface investigation records, it is my opinion that:

- Pond 2's embankments predominately consist of natural earthen materials obtained from on-site and/or off-site borrow sources that were placed and/or graded when the embankments were originally constructed circa 1978.
- Deeper embankment and supporting foundation materials are likely soils native to the Pond 2 site.
- It is more likely than not that ash was not used as a primary fill material to construct Pond 2's embankments.
- Pond 2's original Poz-o-Pac liner, which was installed circa 1978 when the pond's embankments were constructed and represents an encapsulated use of fly ash and boiler slag aggregate akin to a low-strength concrete, was left in-place along the pond's floor and interior side slopes.
- CCR stored above Pond 2's original Poz-o-Pac liner was removed from the pond by Briesler.
- CCR was not used as fill material under Pond 2's new HDPE geomembrane liner as a cushion layer or other purpose.

Best Regards,



Thomas J. Dehlin
Project Engineer

Enclosures:
Attachment 1 – 2016 History of Construction
Attachment 2 – 2015 Subsurface Investigation by Geosyntec
Attachment 3 – 2005 Geotechnical Analysis by KPRG
Attachment 4 – 2011 Hydrogeologic Assessment by Patrick Engineering
Attachment 5 – Expert Opinion of Mr. Michael B. Maxwell, LPG
Attachment 6 – Preliminary Drafts of Sheet Nos. C020 & C031
Attachment 7 – 2008 Re-Lining Technical Specifications
Attachment 8 – 2008 Re-Lining Field Change Requests
Attachment 9 – 2008 Re-Lining Project Invoices
Attachment 10 – 2008 Re-Lining Construction Records
Attachment 11 – 2008 Re-Lining Construction Photograph

Attachment 1

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HISTORY OF CONSTRUCTION
ASH POND 2
JOLIET 29 STATION
OCTOBER 2016

Geosyntec Consultants (Geosyntec) prepared this history of construction report for Ash Pond 2 located at the Joliet 29 Station (Site) in Joliet, Illinois, which is owned and operated by Midwest Generation, LLC (Midwest Generation). This history of construction report addresses the requirements of the Coal Combustion Residuals (CCR) Rule codified in the Code of Federal Regulations Title 40, Part 257, Subpart D. These regulations were published in the Federal Register on 17 April 2015 and became effective on 19 October 2015. This report identifies and addresses the specific requirements of §257.73(c) of the CCR Rule regarding preparing a history of construction report for CCR surface impoundments. Specifically, this report provides the history of construction through 17 October 2016 for Ash Pond 2.

This report was prepared under the direction of Ms. Jane Soule, P.E., and was reviewed in accordance with Geosyntec's internal review policy by Mr. Robert White of Geosyntec.

1. CCR Rule Requirements for History of Construction

History of construction requirements for existing CCR surface impoundments are included in the structural integrity criteria presented in §257.73 of the CCR Rule. The preamble of the CCR Rule (Page 21380) states that the history of construction for an existing CCR impoundment (in this case, Ash Pond 2) is required to include information only to the extent available and that only factual documentation, not anecdotal or speculative information, is to be included. Additionally, the preamble states that no new information should be generated to satisfy the requirements of §257.73(c).

2. History of Construction

2.1 Owner and Unit Identification - §257.73 (c)(1)(i)

Owner and unit identification for Ash Pond 2 is presented in Table 1 below.

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Table 1: Owner and Unit Identification

UNIT NAME	OWNER/OPERATOR	IDENTIFICATION NUMBER
Ash Pond 2	Midwest Generation 804 Carnegie Center Princeton, NJ 08540	IL0064254

2.2 Unit Location on USGS Map – §257.73 (c)(1)(ii)

The Site is located approximately 35 miles southwest of Lake Michigan on the Des Plaines River in Joliet, Illinois. Figure 1 presents the location of Ash Pond 2 on a 7.5-minute United States Geological Survey (USGS) topographic quadrangle map.

2.3 Purpose of the CCR Units – §257.73 (c)(1)(iii)

Ash Pond 2 served as a settling pond for sluiced CCR and other process waters related to electrical power generation at the Site. While CCR is present in the pond, CCR is no longer sluiced to Ash Pond 2.

2.4 Name and Size of the Watershed – §257.73 (c)(1)(iv)

Ash Pond 2 is located in the Des Plaines River watershed (HUC 071200040905), which is approximately 23,808 acres in size (USGS, 2015). However, Ash Pond 2 was constructed with elevated embankments on the south, east and west perimeters, and surface water run-on to the pond is limited to the area within the embankment crests and the access road located north of the pond.

2.5 Description of Foundation– §257.73 (c)(1)(v)

Site observations and construction documents show Ash Pond 2 is surrounded by embankments on the south, east, and west. There are no embankments on the north side of the pond where existing ground elevations generally increase to the north; however, Site investigations indicate that fill material may be present along the northern boundary. For engineering purposes, material located along the northern embankment is considered consistent with embankment fill. Native materials do not provide any lateral support for the embankments and therefore the pond does not contain abutments. The remainder of this section addresses the foundation materials for the pond's embankments.

2.5.1 Physical Properties of Foundation Materials

Information on the physical properties of the foundation materials for Ash Pond 2 is based on published geologic information and field investigations performed at the Site by KPRG in 2005, Patrick Engineering in 2011, and Geosyntec in 2015. Detailed descriptions of these investigations and the regional geology at the Site are included in Geosyntec (2016).

Foundation materials in the vicinity of Ash Pond 2 vary from clay to sand and gravel with Silurian Dolomite as a bedrock layer at approximately 40 feet below the embankment crests.

2.5.2 Engineering Properties of Foundation

Table 2 presents engineering properties for the foundation materials at the Site developed for the periodic structural stability and safety factor assessments (Geosyntec, 2016). These engineering properties are based on investigations performed at the Site, published correlations, and laboratory testing of samples collected from foundation soils during the Site investigations. Engineering properties were not developed for the Silurian Dolomite bedrock layer due to its very dense consistency, relative depth below the ground surface, and negligible contribution to the slope stability analyses.

Table 2: Foundation Material Engineering Properties

MATERIAL	UNIT WEIGHT (PCF)	DRAINED FRICTION ANGLE (DEGREES)	EFFECTIVE COHESION (PSF)
Sand/Gravel	125	38	25

2.6 Description of the Materials, Methods, and Dates of Construction - §257.73 (c)(1)(vi)

The following sections describe the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of Ash Pond 2, the method of site preparation and construction of each zone of the unit, and the approximate dates of construction of each successive stage of construction of the unit, to the extent the information is available.

Information presented in the following sections is based on available construction drawings (NUS, 1978, NUS, 1979), liner replacement construction drawings (NRT, 2007; NRT, 2008) and subsequent investigations at the Site. No as-built construction drawings or construction completion reports detailing the actual materials and methods used for the original construction of the pond was available for this report; however, some as-built data was available for the liner replacement project.

Based on available construction drawings (NUS, 1978), excavation was required to construct Ash Pond 2 because the original ground surface is indicated at approximately the design embankment crest elevation.

Construction drawings for Ash Pond 2 do not indicate that it was constructed with engineered zones of different soil types typical of large earthen dams; therefore, the size and range of each zone or stage of construction is not applicable.

Interior embankments were designed at an inclination of 3H:1V (horizontal:vertical), with the exception of the concrete-lined inlet apron area on the western inboard slope, which is inclined at 2H:1V (NUS, 1978). Exterior embankment slopes were shown on the available construction drawings to be inclined at 3H:1V or flatter. The interior slopes and pond bottom, except the concrete-lined inlet apron, were originally designed with a 1 foot thick Poz-o-Pac ™ liner system (NUS, 1978). The construction drawings also include site preparation requirements (NUS, 1978).

The available construction drawings also provide the design of a reinforced concrete retaining wall located south of the western half of Ash Pond 2 and north of the silo building. The retaining wall has a maximum retained height of approximately 17 feet and is approximately 250 feet in length with approximately 75-foot long wing walls extending southward at each end of the wall.

In 2009, the original Poz-o-Pac™ liner system was replaced with the existing high-density polyethylene (HDPE) geomembrane liner system. As-built drawings developed as part of the liner replacement project show that the southern, northern, and eastern interior slopes of the pond range from 2H:1V to 3H:1V (Ruettiger, Tonelli & Associates, Inc., 2009). Site surveys show that downstream slope inclinations are approximately 3H:1V or flatter on the slope south of the eastern half of Ash Pond 2 and the slope on the southern half of the eastern perimeter toward the clarifier (Aero-Metric, 2008). The interior slope of the east embankment for Pond 1 (the downstream slope of the west embankment for Ash Pond 2) was originally designed at 3H:1V; however, design drawings for the liner replacement of Pond 1 show this slope re-designed at 2H:1V (NRT, 2008). No as-built records were available for the Pond 1 liner replacement project.

In September 2016, approximately 100 cubic yards of engineered fill was placed on the Ash Pond 2 embankment crest in the southeast corner of the pond to provide additional freeboard for the pond. A drawing indicating the fill location and compaction requirements is included in Appendix A-1.

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2.6.1 Engineering Properties

Engineering properties used for the design and construction of the Ash Pond 2 embankment materials were not available at the time of this report. However, engineering properties were estimated for use in the factor of safety assessment performed for the pond in accordance with the CCR Rule. The estimated engineering properties were based on investigations performed at the Site, published correlations, and laboratory testing of embankment materials and are presented in Geosyntec (2016) and reproduced in Table 3. For engineering analyses, two different materials were identified in the embankments for Ash Pond 2: stiff brown clay and black silty gravel. Observed depths of these two materials varied around Ash Pond 2.

Table 3: Embankment Fill Engineering Properties

MATERIAL	UNIT WEIGHT (PCF)	DRAINED FRICTION ANGLE (DEGREES)	EFFECTIVE COHESION (PSF)
Brown Clay	115	30	25
Silty Gravel	125	32	25

2.6.2 Construction Dates

Available construction dates for Ash Pond 2 are unknown; however, available construction drawings were approved for construction in 1977 and 1978 (NUS, 1977; NUS, 1978). Replacement of the original Poz-o-Pac™ liner system with the HDPE liner system was completed in 2009.

2.7 Drawings - §257.73 (c)(1)(vii)

Available construction drawings relevant to the design, construction, operation, and maintenance of Ash Pond 2[1] are included in Appendix A. Appendix A-2 includes available construction drawings (NUS, 1978; NUS, 1979), Appendix A-3 includes drawings from the liner replacement performed in 2009 for Ash Pond 2 (NRT, 2007), Appendix A-4 includes an as-built drawing from the Ash Pond 2 liner replacement project (Ruettiger, Tonelli & Associates, Inc., 2009), and

[1] Ash Pond 2 is also referred to as Ash Impoundment 2 in drawings prepared by NRT (2007).

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Appendix A-5 includes relevant construction drawings from the liner replacement performed for Pond 1 (NRT, 2008)[2] as they relate to western boundary of Ash Pond 2.

2.8 Instrumentation - §257.73 (c)(1)(viii)

There is no instrumentation related to Ash Pond 2; thus, there are no records of instrumentation associated with hydraulic structures, embankments or slope performance related to Ash Pond 2.

2.9 Area-Capacity Curve - §257.73 (c)(1)(ix)

An area-capacity curve for Ash Pond 2 is included as Figure 2.

2.10 Spillway Description and Calculations - §257.73 (c)(1)(x)

Ash Pond 2 does not include a spillway.

2.11 Construction Specifications and Provisions for Surveillance, Maintenance and Repair - §257.73 (c)(1)(xi)

The only construction specification available for this report is an HDPE geomembrane specification for the liner replacement project performed in 2009. The specification was included in a draft application for construction permit approval and is marked "not for construction." Generally, the HDPE geomembrane specification identifies that an HDPE, white, 60-mil, textured geomembrane be used for the project. It also identifies deployment and seaming requirements, quality control procedures, and requirements for materials placed above the geomembrane. The geomembrane specification is included in Appendix B.

As part of the 2009 liner replacement project, warning posts were installed at the toe of interior basin slopes above the geomembrane liner system. These posts are utilized as a visual guide to identify the toe of slope during CCR removal operations to limit potential damage to the liner system.

2.12 Record of Any Structural Instability - §257.73 (c)(1)(xii)

Based on discussions with Site staff and review of available information, there are no records or knowledge of structural instability for Ash Pond 2.

[2] Liner replacement drawings are based on the North American Vertical Datum of 1929 (NAVD29). The NUS construction drawings do not provide a referenced datum, however, elevations are generally consistent with those in the liner replacement drawings.

engineers | scientists | innovators

3. References

Aero-Metric, 2008. Topographic Mapping of Joliet 29 Station, prepared for Midwest Generation, LLC., (AutoCAD file)

Geosyntec, 2016. Soil Properties Calculations, Joliet 29 Station, October.

KPRG and Associates, Inc., 2005. Geotechnical Analysis of Soil Surrounding Settling Basins/Ponds, KPRG Project No. 15805, October.

Natural Resource Technology (NRT), 2007. Ash Impoundment #2 Liner Replacement, Midwest Generation, LLC, Joliet Station No. 29:

Title Sheet, Sheet No. TS
Existing Conditions, Sheet C010
Liner Subgrade Preparation, Sheet C020
Warning Layer Plan, Sheet No. C030
Details and Sections, Sheet No. C031

Natural Resource Technology (NRT), 2008. Ash Impoundment #1 Liner Replacement, Midwest Generation, LLC, Joliet Station No. 29:

Warning Layer Plan, Sheet No. C030
Details and Sections, Sheet No. C031

NUS Corporation, 1978. Waste Water Treatment Facilities Joliet 7-8:

Location Plot and Plan, Sheet No. 5079 C 5100.
Ponds & Basins Profiles, Sections & Details, Sheet No. 5079 C 5019, Sheet 2 of 3.
Ponds & Basins Profiles, Sections & Details, Sheet No. 5079 C 5019, Sheet 3 of 3.
Detail Plan – Ash Silo Area, Sheet No. 5079 C 51.
Ash Pond 1 & 2 – Outlet Weirs, Sheet No. 5079 C 5503.
Retaining Wall at Silos – Plan, Sections & Elevations, Sheet 5079 C 5507

NUS Corporation, 1979. Waste Water Treatment Facilities Joliet 7-8:

Site Plan – East Yard Area, Sheet No. 5079 C 5103.
Pipe Support Plan and Details – PS 834, 836 thru 846, Sheet 5079 C 5743

Patrick Engineering, 2011. Hydrogeological Assessment Report, Joliet 29 Generating Station, Joliet, Illinois, Patrick Project No. 21053.070, February.

Ruettiger, Tonelli & Associates, Inc., 2009. Midwest Generation Joliet 29 Power Plant, Ash Impoundments, Ash Pond 2 Subgrade As-Built.

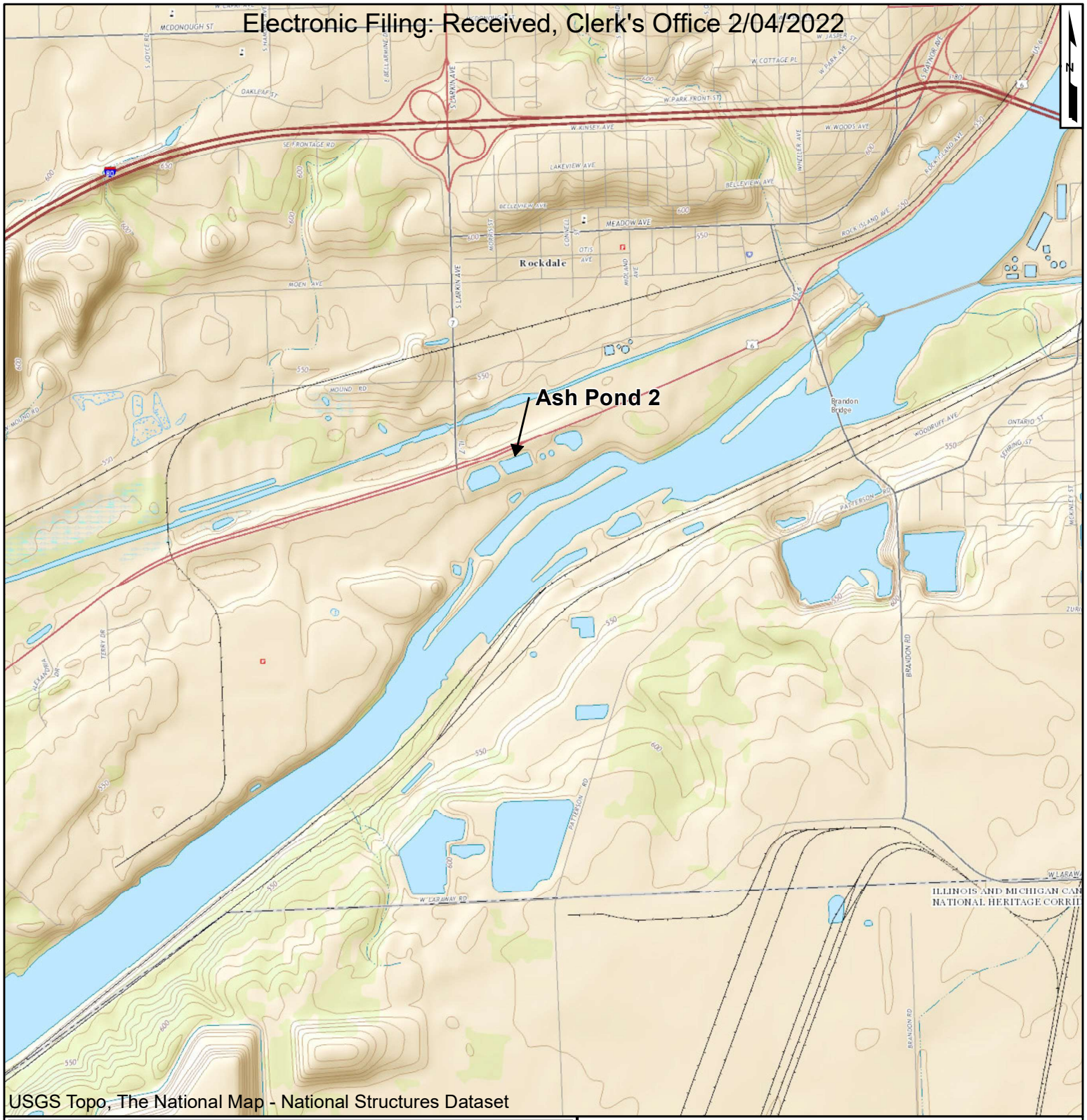
USGS, 2015. "Watershed Boundary Dataset," accessed via The National Map, accessed 1 February 2016.

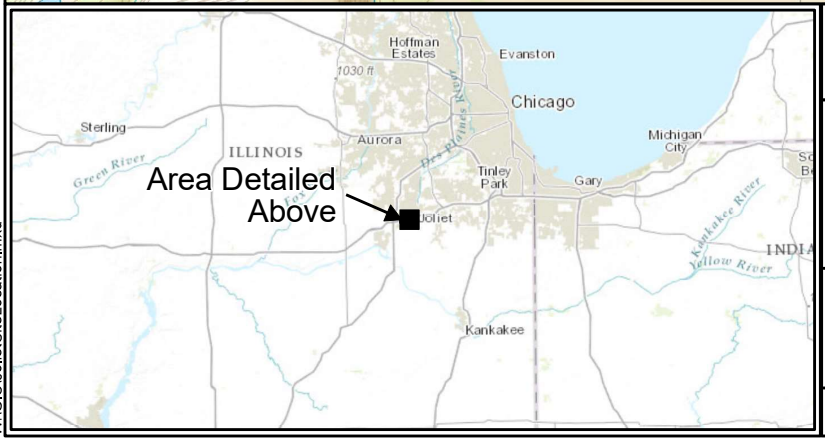
Attachments

Figure 1:	Vicinity Map
Figure 2:	Area-Capacity Curves
Appendix A:	Construction Drawings
Appendix A-1	2016 Additional Fill Drawing
Appendix A-2	NUS Construction Drawings
Appendix A-3	Liner Replacement Construction Drawings
Appendix A-4	Ash Pond 2 Liner Replacement As-Built
Appendix A-5	Pond 1 Liner Replacement Construction Drawings
Appendix B	Technical Specifications

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2,000 1,000 0 2,000 Feet

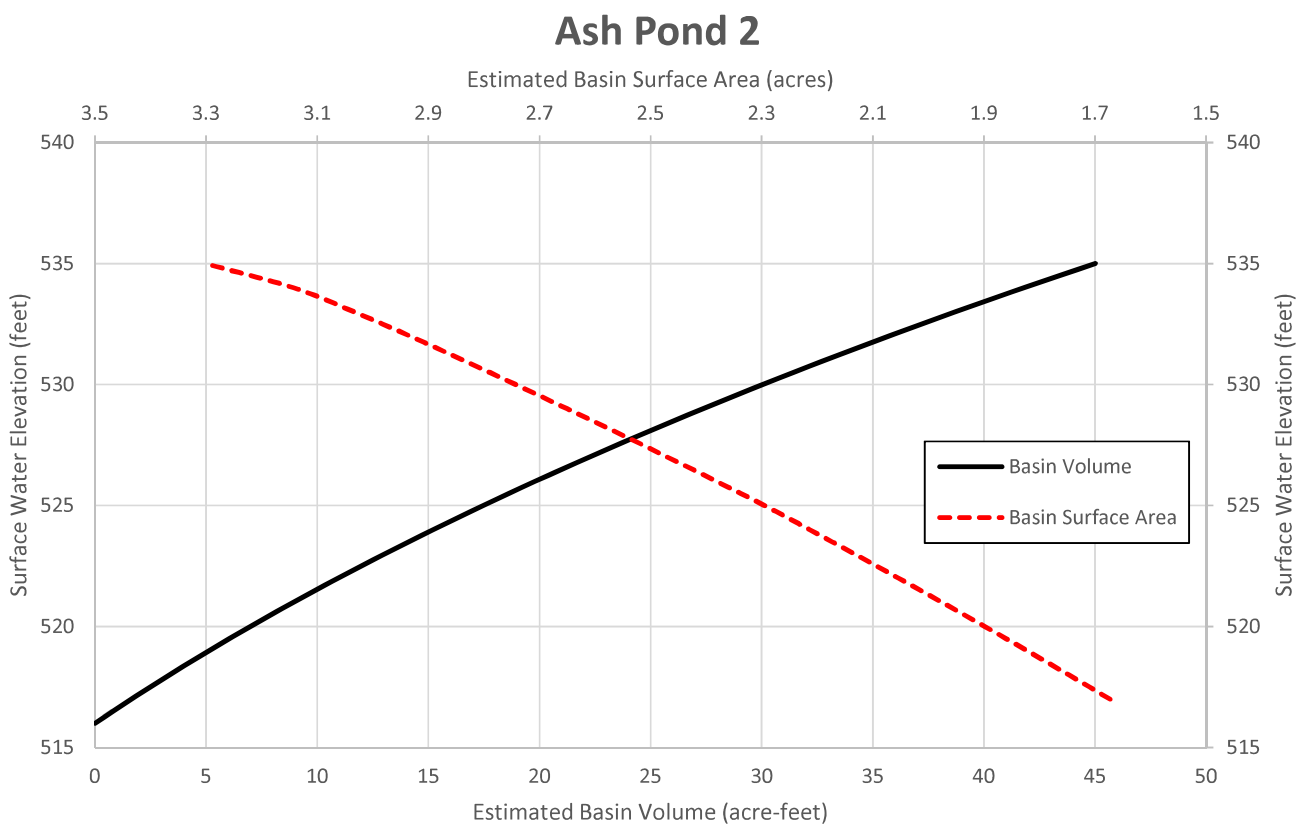
Site Location

Ash Pond 2
Joliet 29 Station
Joliet, Illinois

Geosyntec consultants

San Diego	October 2016	Figure 1

W:\GIS\JolietSiteLocation.mxd



Notes:
(1) Surface water elevations are NAVD88.
(2) Basin volumes are estimated based on as-built information and 2008 site topography.

Geosyntec consultants	AREA-CAPACITY CURVE ASH POND 2 JOLIET 29 STATION JOLIET, ILLINOIS	**FIGURE 2**
OCTOBER 2016		
SW0251-05		

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APPENDIX A

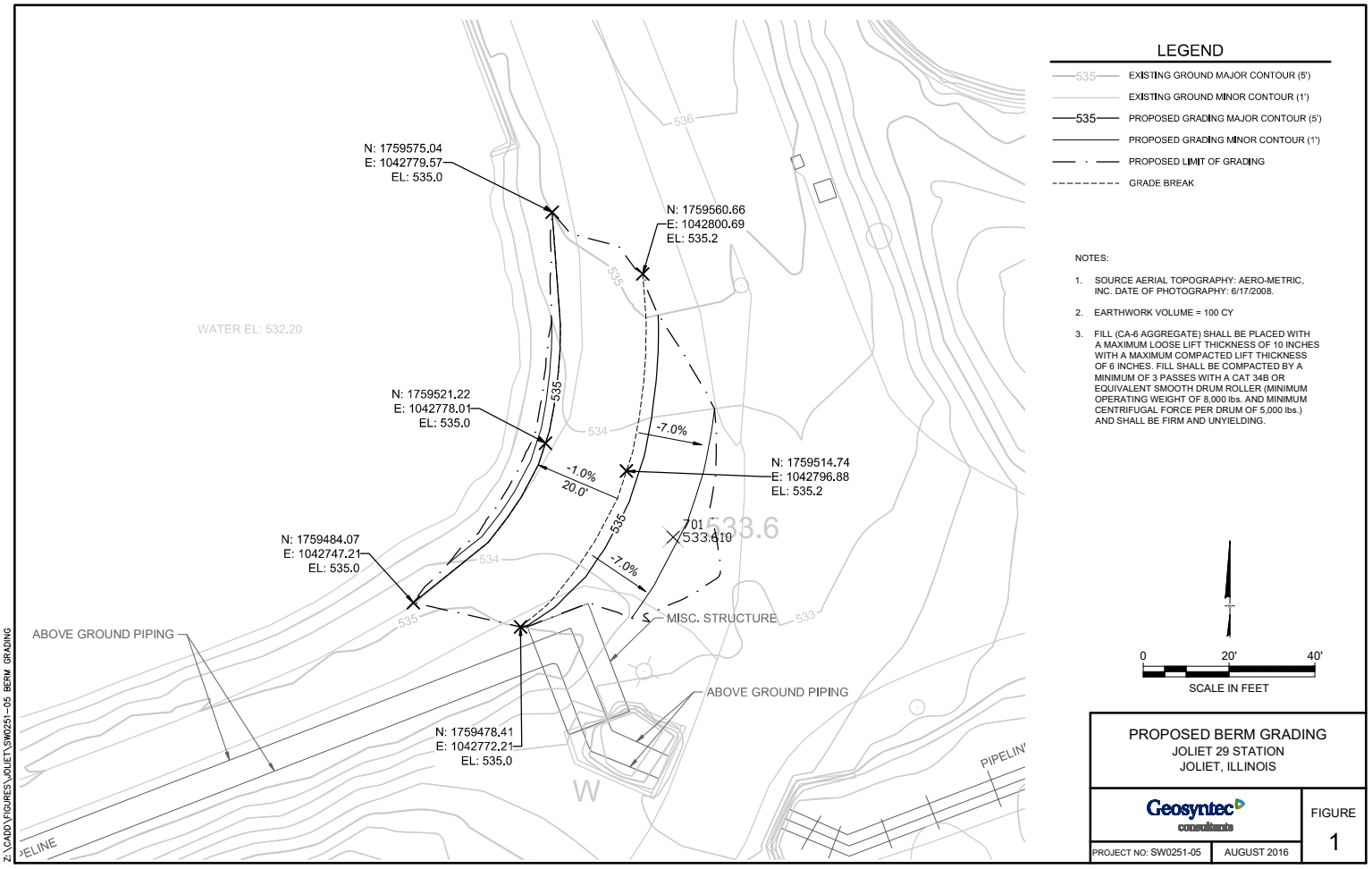
Construction Drawings

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APPENDIX A-1

2016 Additional Fill Drawing

Electronic Filing: Received, Clerk's Office 2/04/2022

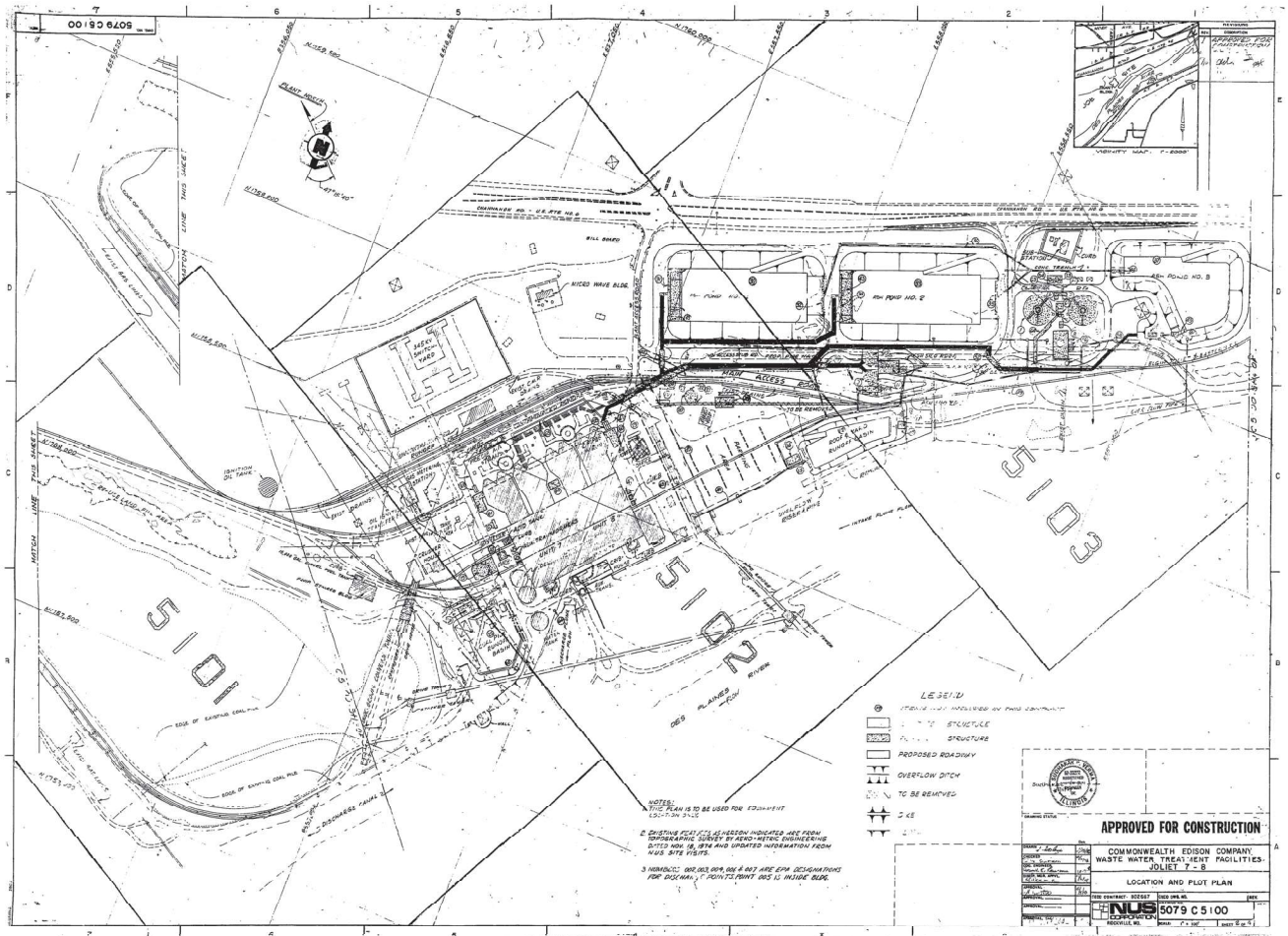


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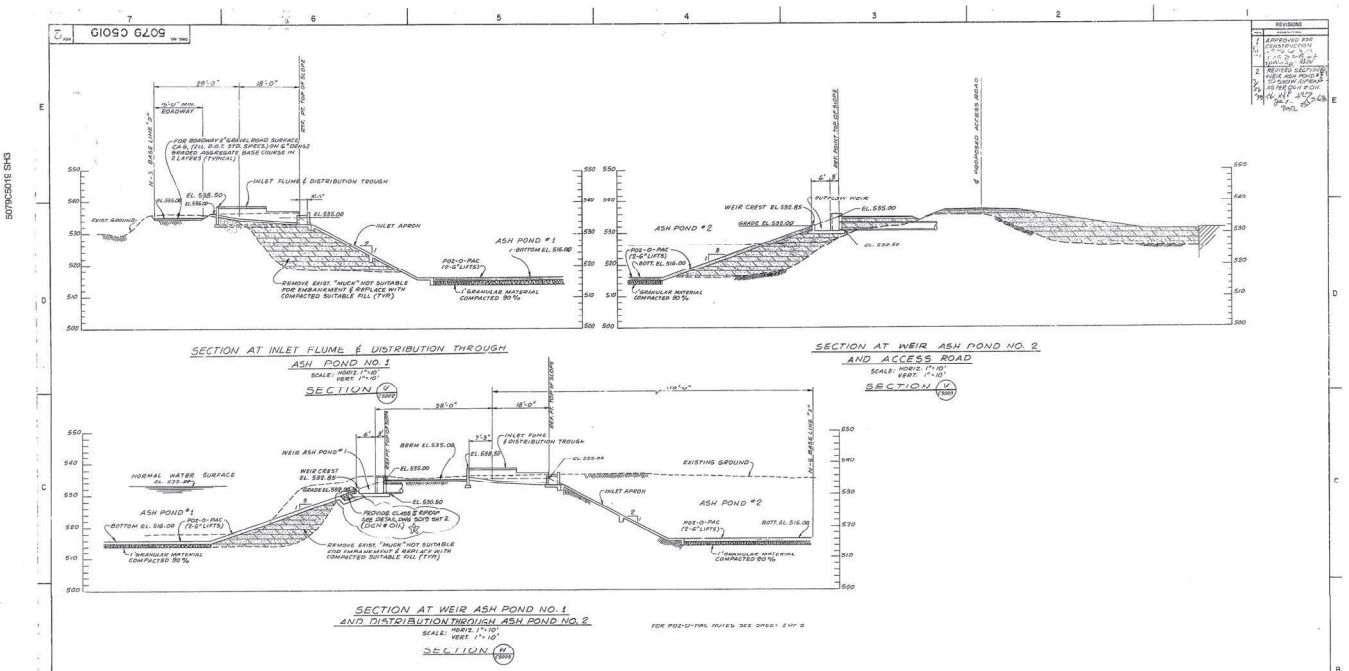
APPENDIX A-2

NUS Construction Drawings

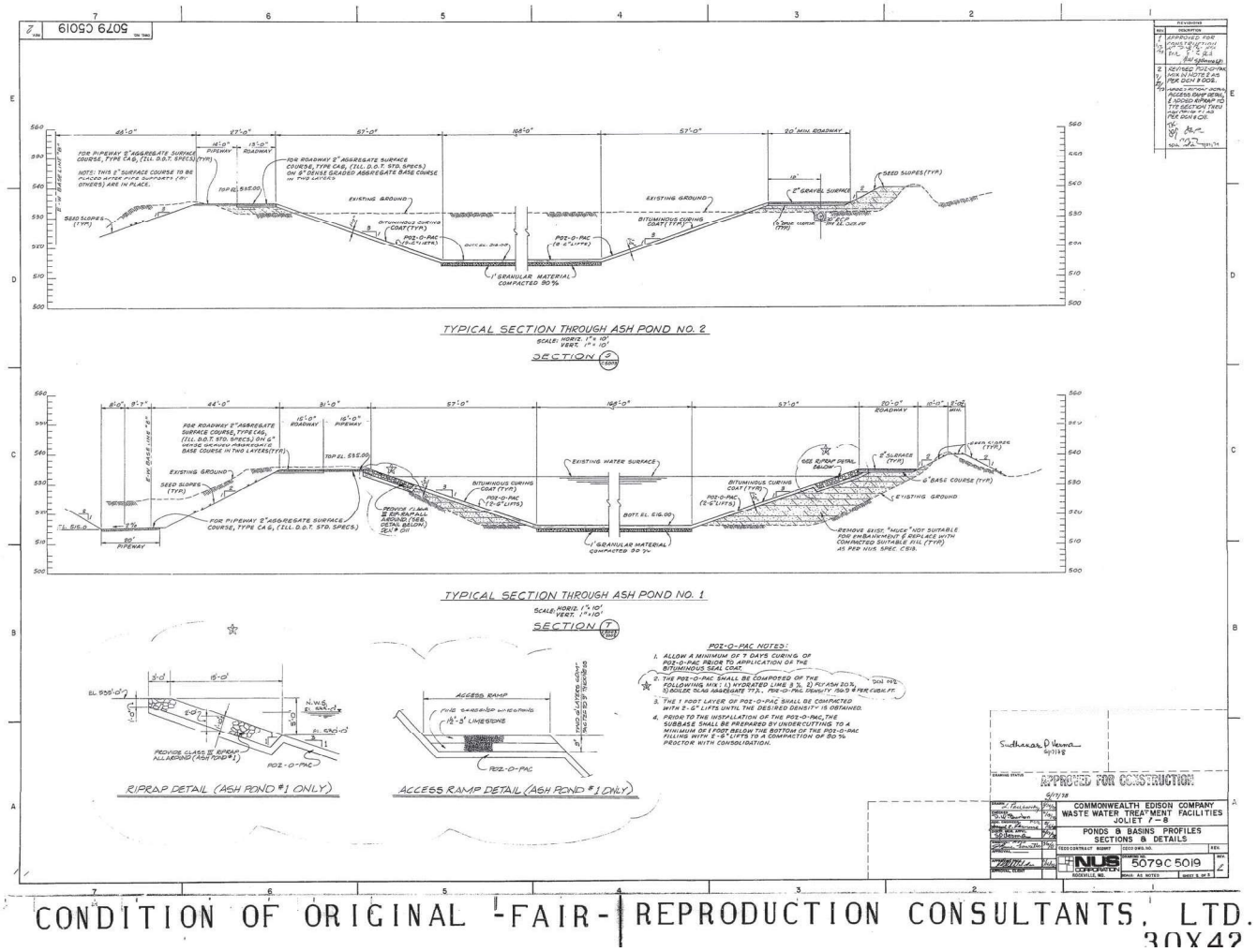
Electronic Filing: Received, Clerk's Office 2/04/2022



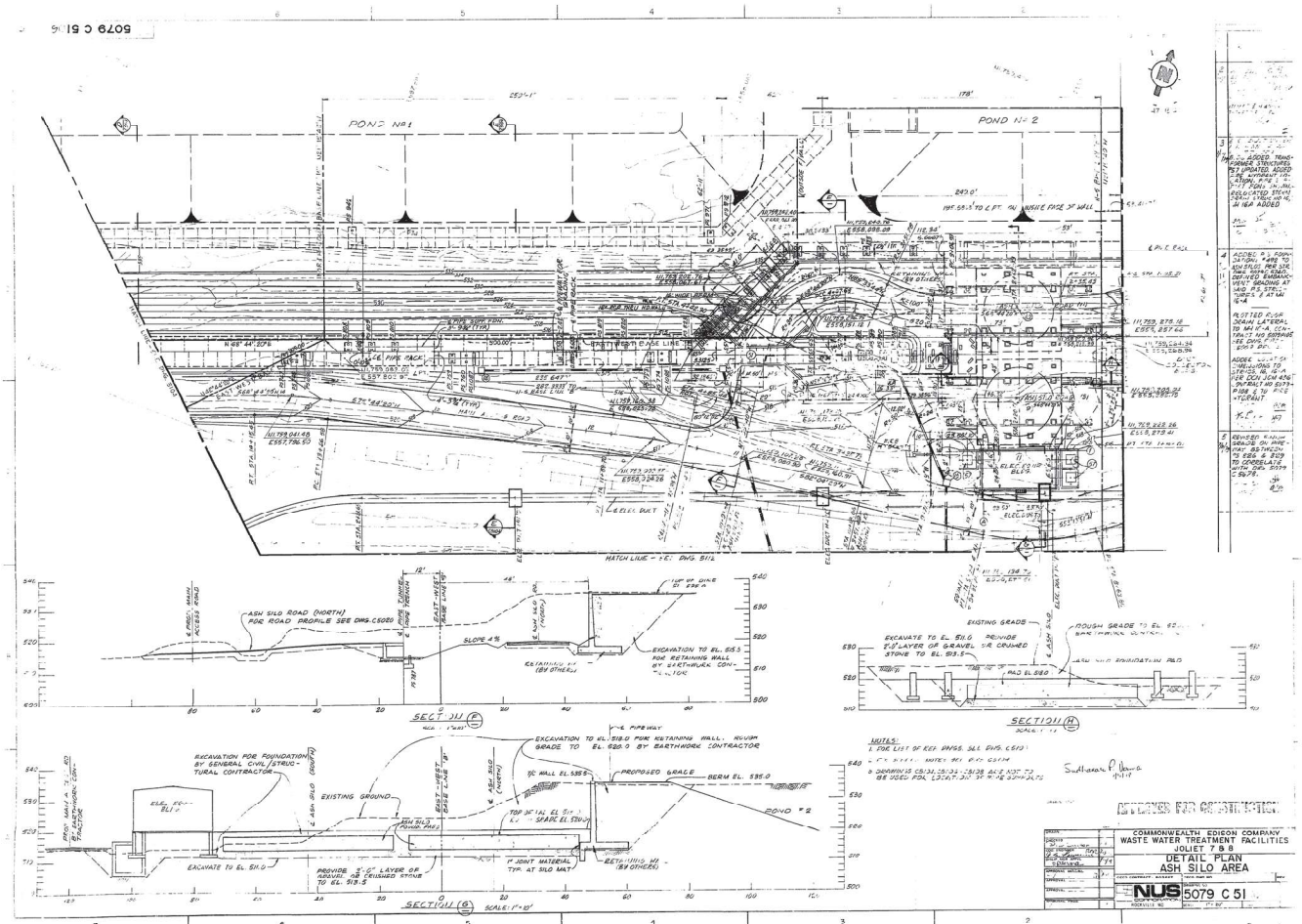
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- BLUELINE PRINT -
30X42



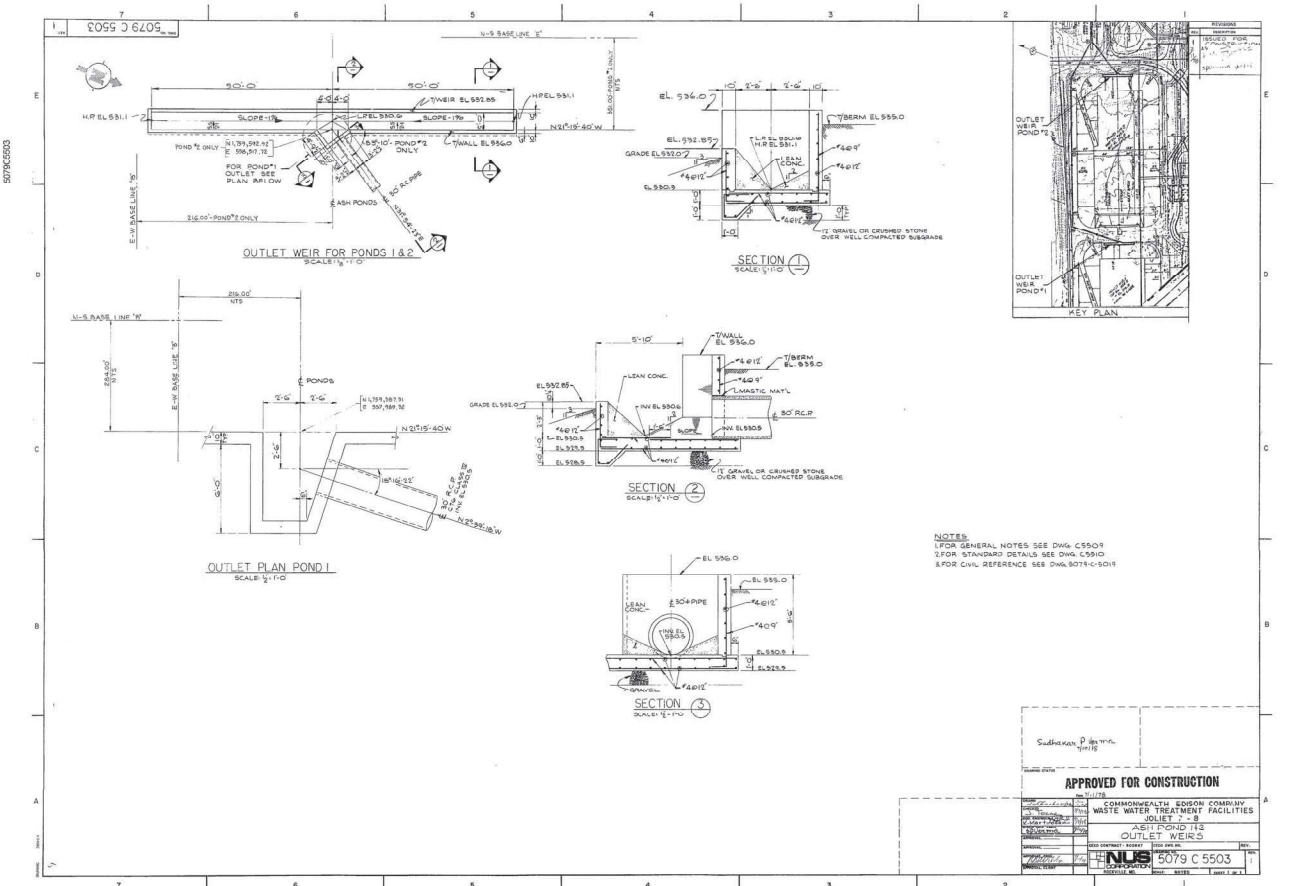
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30X42



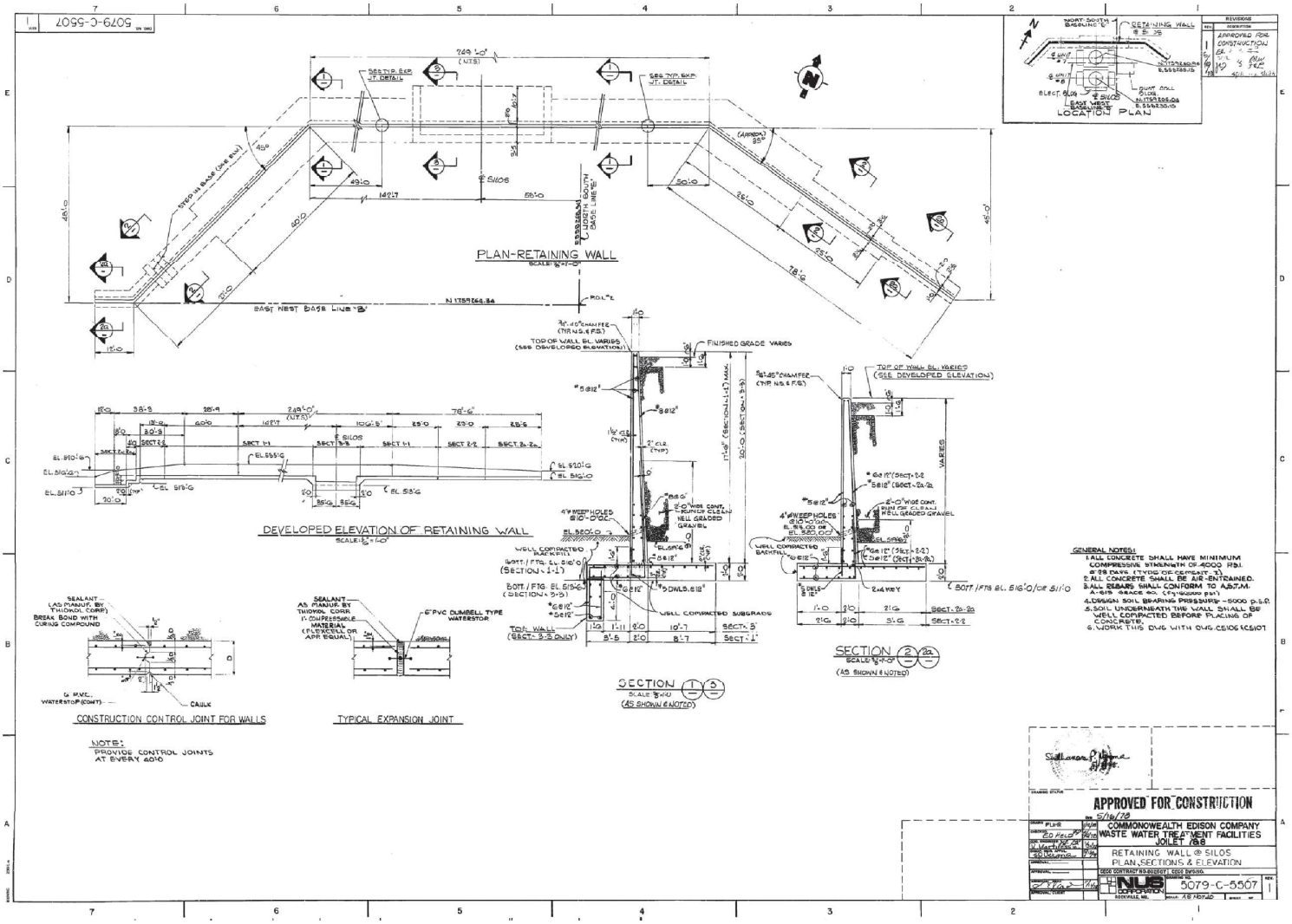
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CONDITION OF ORIGINAL -FAIR- | REPRODUCTION CONSULTANTS, LTD.
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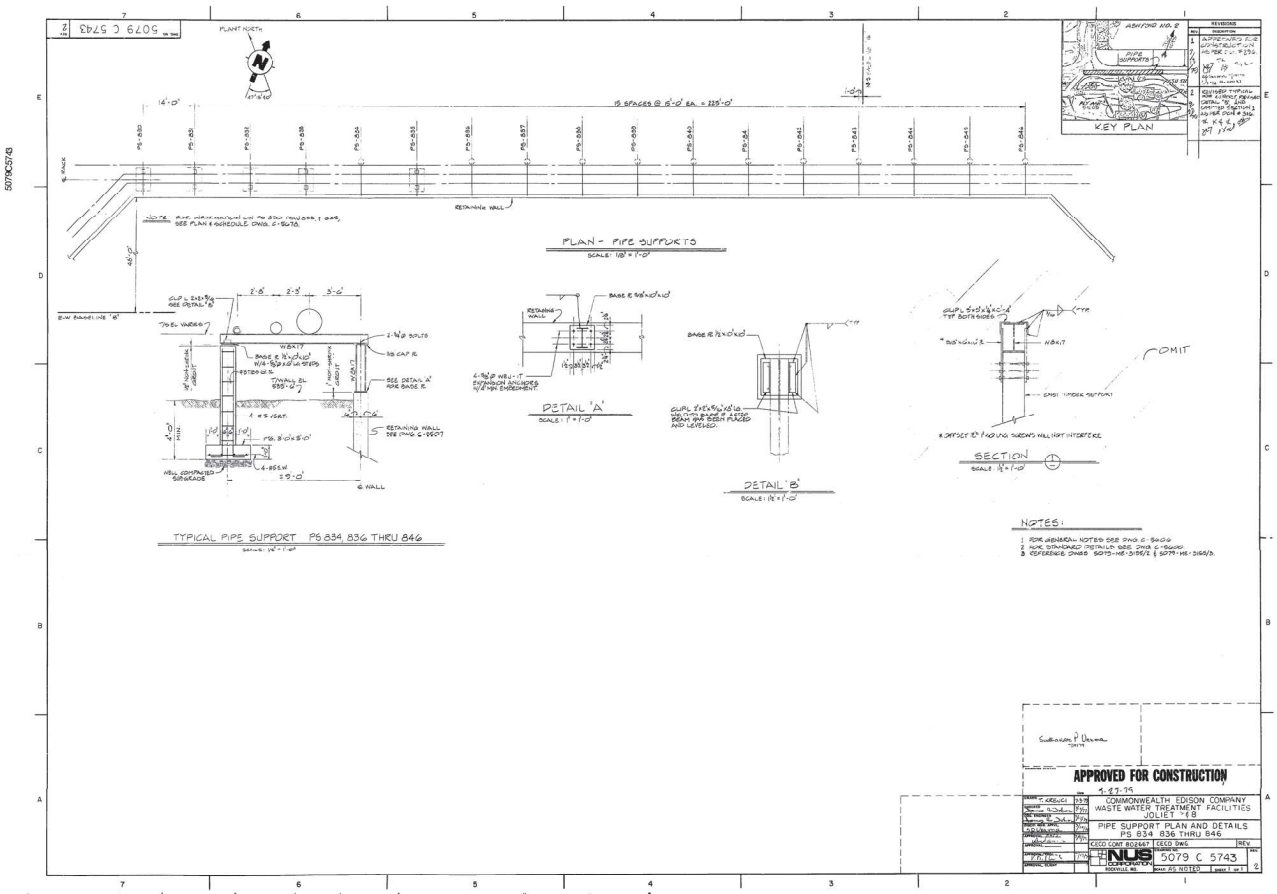
CONDITION OF ORIGINAL "-FAIR-" REPRODUCTION CONSULTANTS, LTD.
30X42


PLAN-RETAINING WALL
SCALE: 1/8"=1'-0"
DEVELOPED ELEVATION OF RETAINING WALL
SCALE: 1/8"=1'-0"
SECTION
SCALE: 1/4"=1'-0"
(AS SHOWN & NOTED)
SECTION
SCALE: 1/4"=1'-0"
(AS SHOWN & NOTED)
LOCATION PLAN
CONSTRUCTION CONTROL JOINT FOR WALLS
TYPICAL EXPANSION JOINT
NOTE:
PROVIDE CONTROL JOINTS AT EVERY 40'-0
GENERAL NOTES:
1. ALL CONCRETE SHALL HAVE MINIMUM COMPRESSIVE STRENGTH OF 4000 PSI. @ 28 DAYS. (TYPE OR CEMENT 2)
2. ALL CONCRETE SHALL BE AIR-ENTRAINED.
3. ALL REBARS SHALL CONFORM TO A.S.T.M. A-615 GRADE 60. (fy=60000 psi)
4. DESIGN SOIL BEARING PRESSURE - 5000 P.S.F.
5. SOIL UNDERNEATH THE WALL SHALL BE WELL COMPACTED BEFORE PLACING OF CONCRETE.
6. WORK THIS DWG WITH DWG. CS106 RCS101
APPROVED FOR CONSTRUCTION
5/16/78
COMMONWEALTH EDISON COMPANY
WASTE WATER TREATMENT FACILITIES
JOLIET #6
RETAINING WALL @ SILOS
PLAN, SECTIONS & ELEVATION
NUS CORPORATION
ROCKVILLE, MD.
5079-C-5507

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CONDITION OF ORIGINAL -FAIR- | REPRODUCTION CONSULTANTS, LTD.
30X42



CONDITION OF ORIGINAL - FAIR - | REPRODUCTION CONSULTANTS. LTD.
30X42

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APPENDIX A-3

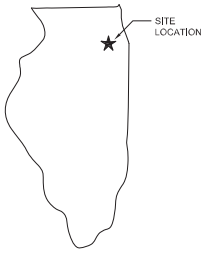
Liner Replacement Construction Drawings

Electronic Filing: Received, Clerk's Office 2/04/2022

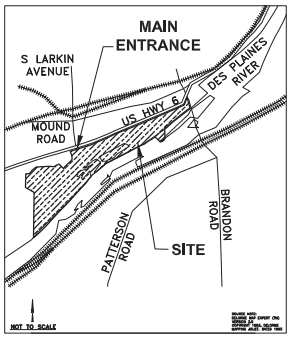
ASH IMPOUNDMENT DESIGN
JOLIET STATION NO. 29
MIDWEST GENERATION
JOLIET, WILL COUNTY, ILLINOIS

LIST OF DRAWINGS

SHEET NO.	TITLE	DRAWING NO.
TS	TITLE SHEET	D1862TS-00
C010	EXISTING CONDITIONS	D1862C010-01
C020	LINER SUBGRADE PREPARATION	D1862C020-01
C030	WARNING LAYER PLAN	D1862C030-01
C031	DETAILS AND SECTIONS	D1862C031-01



ILLINOIS



SITE VICINITY

PREPARED FOR:

MIDWEST GENERATION, LLC
1800 CHANNAHON ROAD
JOLIET, ILLINOIS 60436

NOT FOR CONSTRUCTION

SEPTEMBER 2007

TITLE SHEET

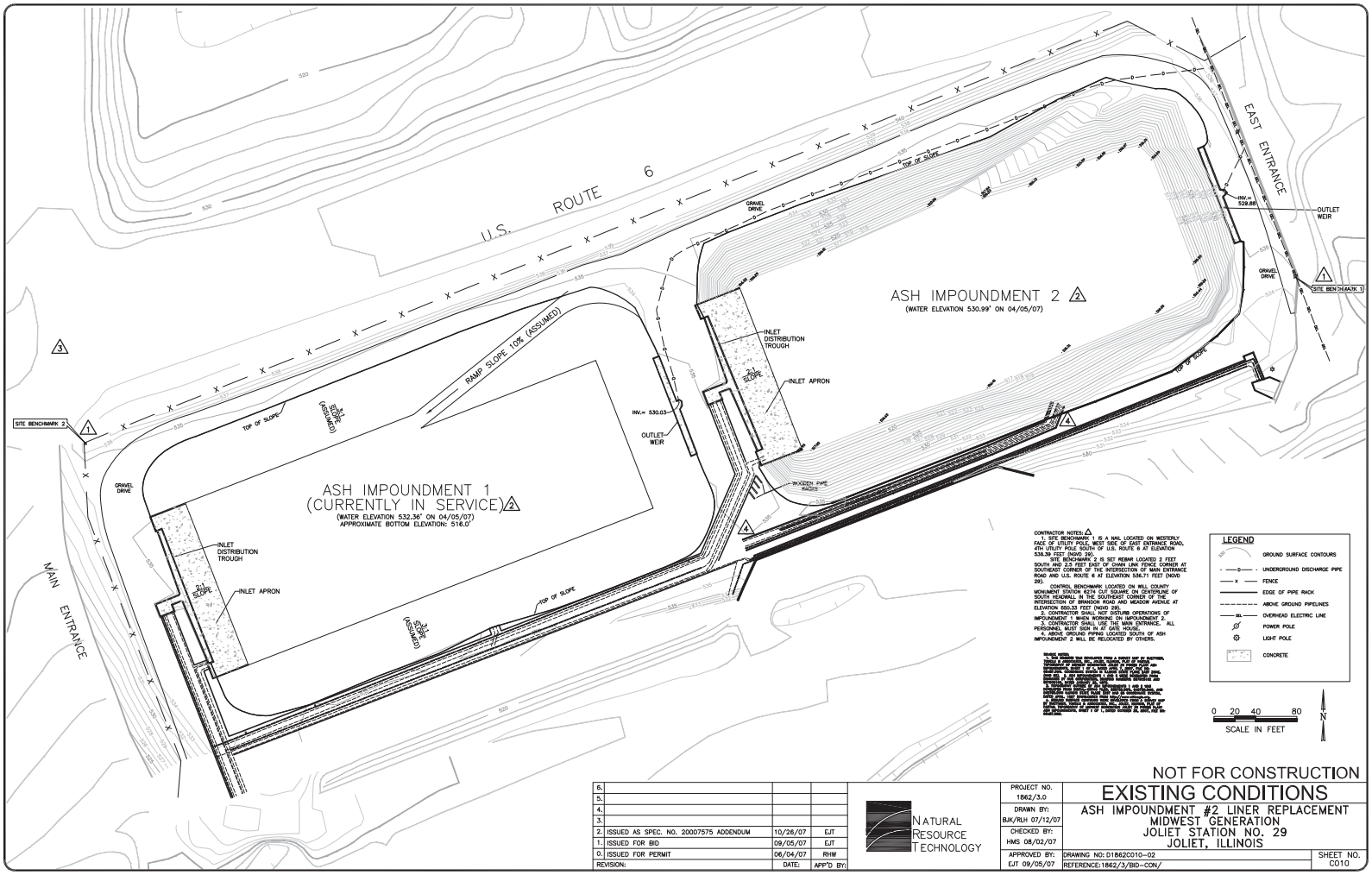
ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

SHEET NO. TS

PROJECT NO. 1862.3.01
DRAWN BY: BJK 07/12/07
CHECKED BY: HMS 09/02/07
APPROVED BY: EJT 09/05/07
DRAWING NO: D1862TS-00
REFERENCE: 1862.3/BID-CON/

NATURAL RESOURCE TECHNOLOGY

REVISION:	DATE:	APP'D BY:
0. ISSUED FOR BID	09/05/07	EJT
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NOT FOR CONSTRUCTION

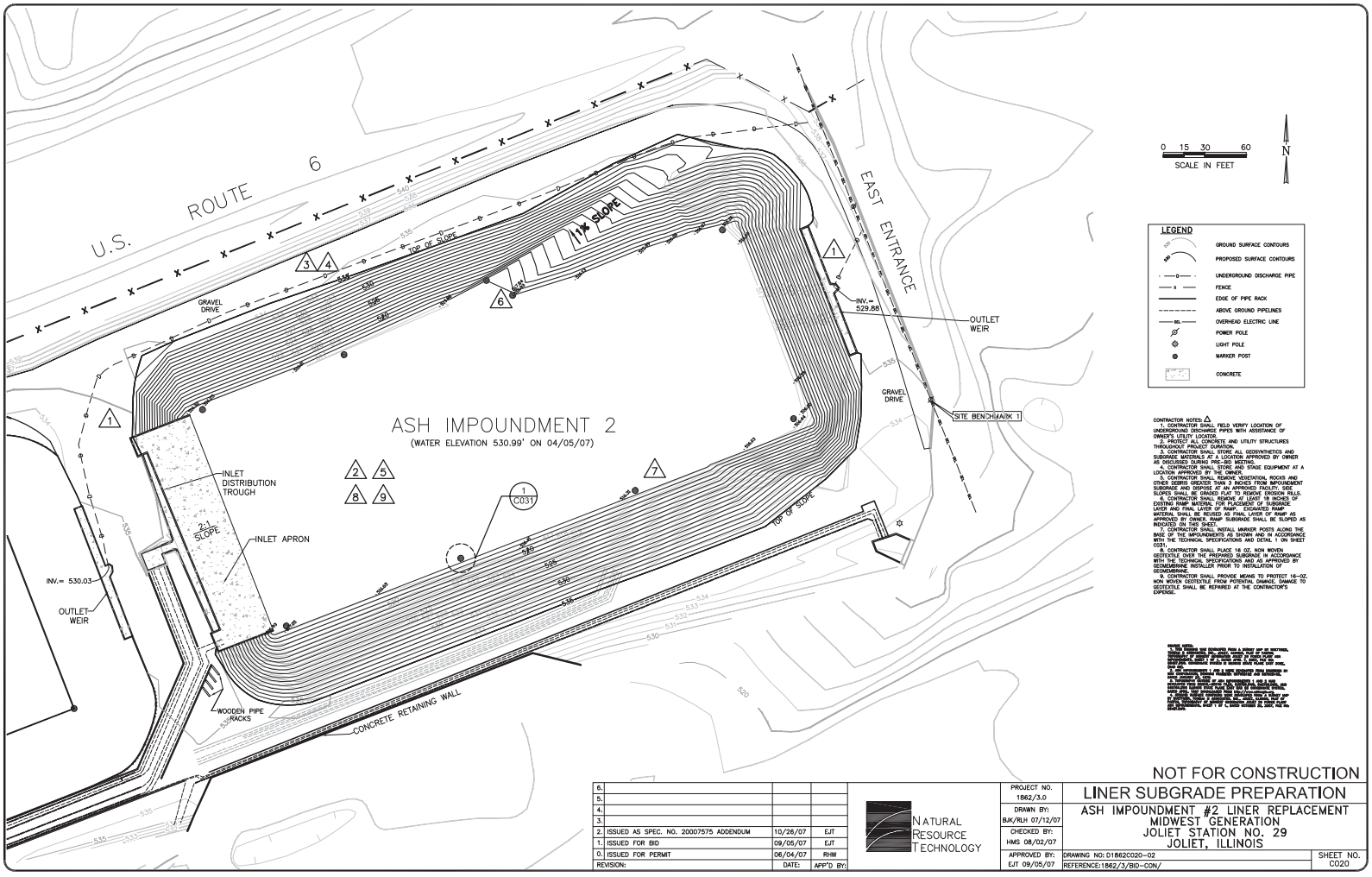
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1. ISSUED FOR BID	09/05/07	EJT
0. ISSUED FOR PERMIT	06/04/07	RHW

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.	1862/3.0
DRAWN BY:	BJK/RLH 07/12/07
CHECKED BY:	HMS 08/02/07
APPROVED BY:	EJT 09/05/07
DRAWING NO:	D1862C010-02
REFERENCE:	1862/3/BID-CON/
SHEET NO.	C010

EXISTING CONDITIONS

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS



CONTRACTOR NOTES:

1. CONTRACTOR SHALL FIELD VERIFY LOCATION OF UNDERGROUND DISCHARGE PIPES WITH ASSISTANCE OF OWNER'S UTILITY LOCATOR.
2. PROTECT ALL CONCRETE AND UTILITY STRUCTURES THROUGHOUT PROJECT DURATION.
3. CONTRACTOR SHALL STORE ALL GEOSYNTHETICS AND SUBGRADE SOILS AT A PRE-LOCATION APPROVED BY OWNER AT A DISTANCE NOT TO EXCEED 1 MILE FROM EXISTING.
4. CONTRACTOR SHALL STORE AND STAGE EQUIPMENT AT A LOCATION APPROVED BY THE OWNER.
5. CONTRACTOR SHALL REMOVE VEGETATION, ROCKS AND OTHER DEBRIS GREATER THAN 3 INCHES FROM IMPOUNDMENT SUBGRADE AND DISPOSE AT AN APPROVED FACILITY. SITE SLOPE CONTRACTOR SHALL REMOVE ALL LOOSE, ERODED FILLS.
6. CONTRACTOR SHALL REMOVE A MINIMUM 6" OF EXISTING RAMP MATERIAL FOR PLACEMENT OF SUBGRADE LAYER AND FINAL LAYER OF RAMP. EXCAVATED RAMP MATERIAL SHALL BE REUSED AS FINAL LAYER OF RAMP AS APPROVED BY OWNER. RAMP SUBGRADE SHALL BE SLOPED AS INDICATED ON THIS SHEET.
7. CONTRACTOR SHALL INSTALL MARKER POSTS ALONG THE BASE OF THE IMPOUNDMENTS AS SHOWN AND IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS AND DETAIL 1 ON SHEET C031.
8. CONTRACTOR SHALL PLACE 16 OZ. NON WOVEN GEOTEXTILE OVER THE PREPARED SUBGRADE IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS AND AS APPROVED BY GEOMEMBRANE INSTALLER PRIOR TO INSTALLATION OF GEOMEMBRANE.
9. CONTRACTOR SHALL PROVIDE MEANS TO PROTECT 16-OZ. NON WOVEN GEOTEXTILE FROM POTENTIAL DAMAGE. DAMAGE TO GEOTEXTILE SHALL BE REPAIRED AT THE CONTRACTOR'S EXPENSE.

REVISION:	DATE:	APP'D BY:
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2. ISSUED AS SPEC. NO. 20007575 ADDENDUM	10/26/07	EJT
1. ISSUED FOR BID	09/05/07	EJT
0. ISSUED FOR PERMIT	06/04/07	RHW

NATURAL RESOURCE TECHNOLOGY

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DRAWN BY:	BJK/RLH 07/12/07
CHECKED BY:	HMS 08/02/07
APPROVED BY:	EJT 09/05/07

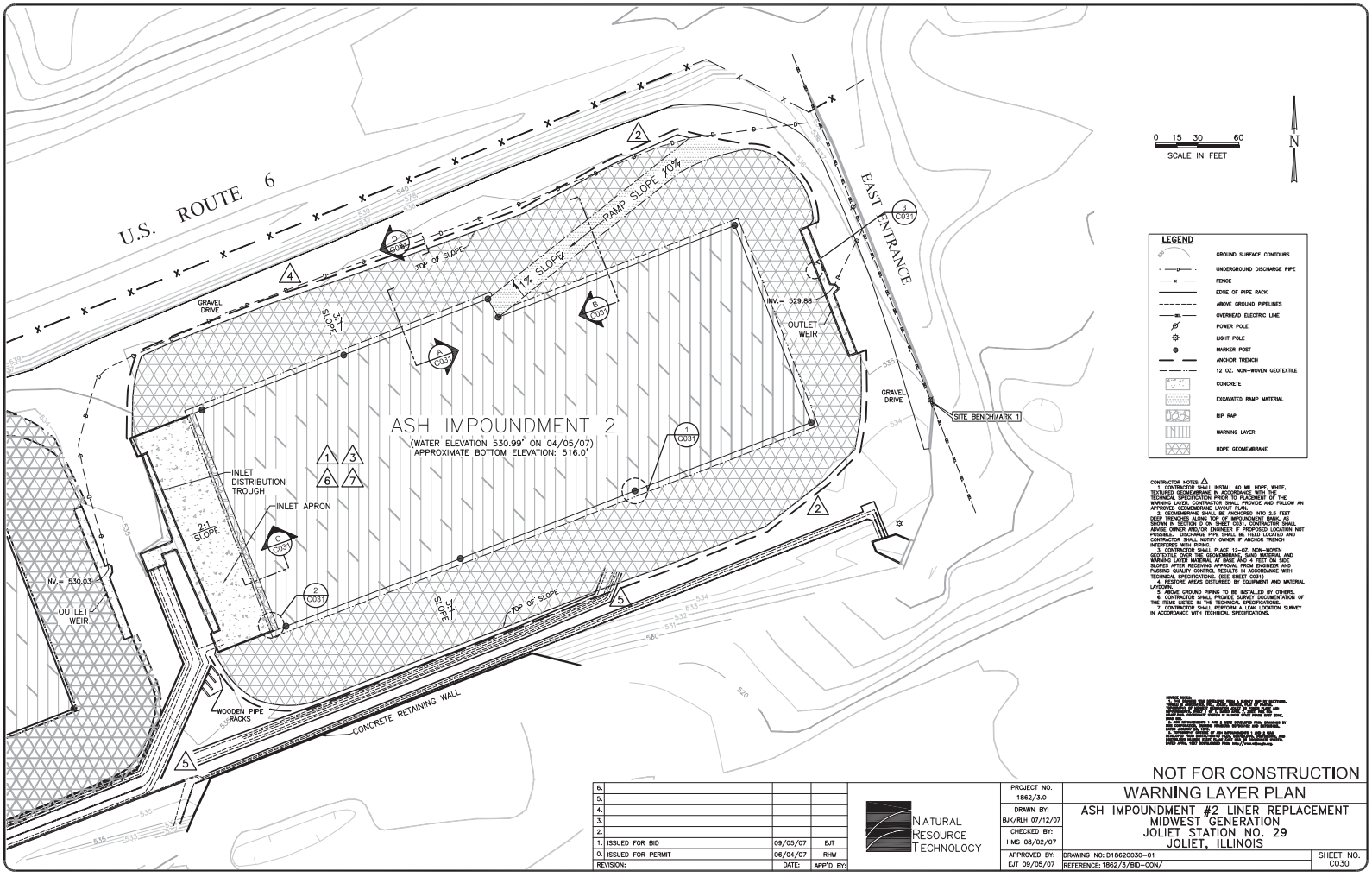
NOT FOR CONSTRUCTION

LINER SUBGRADE PREPARATION

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

DRAWING NO: D1862C020-02
REFERENCE:1862/3/BID-CON/

SHEET NO. C020



CONTRACTOR NOTES:
1. CONTRACTOR SHALL INSTALL 60 MIL HDPE, WHITE, TEXTURED GEOMEMBRANE IN ACCORDANCE WITH THE TECHNICAL SPECIFICATION PRIOR TO PLACEMENT OF THE WARNING LAYER. CONTRACTOR SHALL PROVIDE AND FOLLOW AN APPROVED GEOMEMBRANE LAYOUT PLAN.
2. GEOMEMBRANE SHALL BE ANCHORED INTO 2.5 FEET DEEP TRENCHES ALONG TOP OF IMPOUNDMENT BANK AS SHOWN IN SECTIONS A ON SHEET C031. CONTRACTOR SHALL MINIMIZE WRINKLES IN GEOMEMBRANE TO THE EXTENT NOT POSSIBLE. DISCHARGE PIPE SHALL BE FIELD LOCATED AND CONTRACTOR SHALL NOTIFY OWNER IF ANCHOR TRENCH INTERFERES WITH PIPING.
3. CONTRACTOR SHALL PLACE 12-OZ. NON-WOVEN GEOTEXTILE OVER THE GEOMEMBRANE, SAND MATERIAL AND WARNING LAYER MATERIAL AT BASE AND 4 FEET ON SIDE SLOPES. CONTRACTOR SHALL PERFORM AS REQUIRED AND PASSING QUALITY CONTROL RESULTS IN ACCORDANCE WITH TECHNICAL SPECIFICATIONS, CSEI SHEET C031.
4. RESTORE AREAS DISTURBED BY EQUIPMENT AND MATERIAL LAYDOWN.
5. ABOVE GROUND PIPING TO BE INSTALLED BY OTHERS.
6. CONTRACTOR SHALL PROVIDE SURVEY DOCUMENTATION OF THE ITEMS LISTED IN THE TECHNICAL SPECIFICATIONS.
7. CONTRACTOR SHALL PERFORM A LEAK LOCATION SURVEY IN ACCORDANCE WITH TECHNICAL SPECIFICATIONS.

NOTICE TO CONTRACTOR
1. THE LOCATIONS AND DESCRIPTIONS OF UTILITIES SHOWN ON THESE PLANS ARE APPROXIMATE ONLY AND ARE BASED ON THE RECORDS OF THE VARIOUS UTILITY COMPANIES AND OTHER SOURCES. THE CONTRACTOR SHALL NOTIFY ALL UTILITY COMPANIES AND OTHERS POSSESSING UNDERGROUND FACILITIES IN THE AREA OF THE WORK AT LEAST 48 HOURS BEFORE BEGINNING EXCAVATION. THE CONTRACTOR SHALL ALSO CONTACT THE ILLINOIS ONE CALL SYSTEM, INC. AT 1-800-892-0123 AT LEAST 48 HOURS BEFORE BEGINNING EXCAVATION.

NOT FOR CONSTRUCTION

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1. ISSUED FOR BID	09/05/07	EJT
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REVISION:	DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

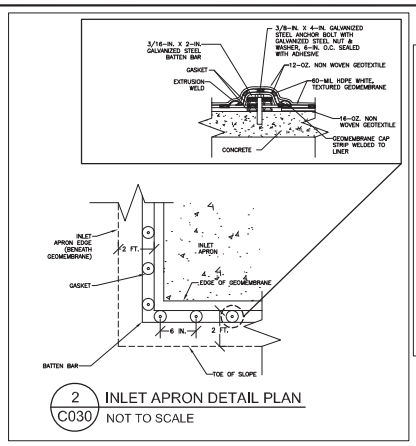
PROJECT NO.	1862/3.0
DRAWN BY:	BJK/RLH 07/12/07
CHECKED BY:	HMS 08/02/07
APPROVED BY:	EJT 09/05/07

WARNING LAYER PLAN

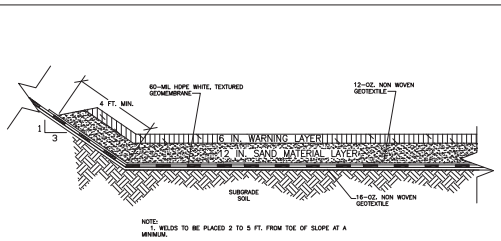
ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

DRAWING NO: D1862C030-01
REFERENCE: 1862/3/BID-CON/

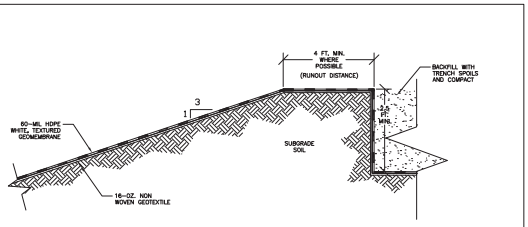
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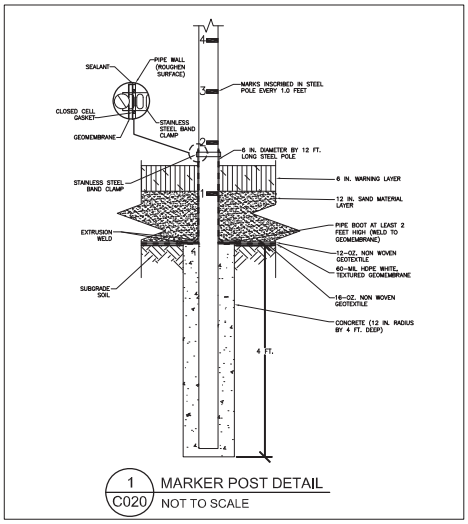
2 C030 INLET APRON DETAIL PLAN
NOT TO SCALE



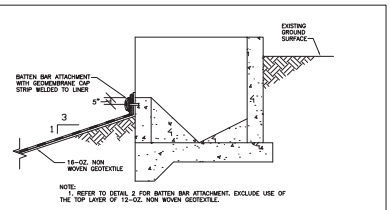
A C030 SLOPE TRANSITION SECTION
NOT TO SCALE



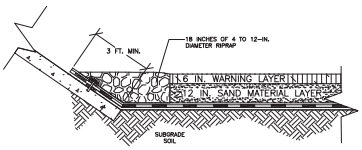
D C030 ANCHOR TRENCH SECTION
NOT TO SCALE



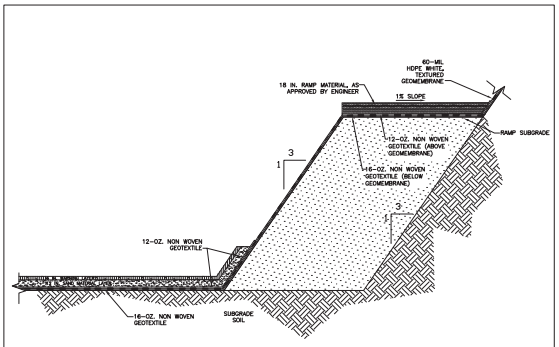
1 C020 MARKER POST DETAIL
NOT TO SCALE



3 C030 OUTLET WEIR DETAIL
NOT TO SCALE



C — INLET APRON SECTION
NOT TO SCALE



B C030 RAMP SECTION
NOT TO SCALE

NOT FOR CONSTRUCTION

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1. ISSUED FOR BID	09/05/07	EJT	
0. ISSUED FOR PERMIT	06/04/07	RHW	
REVISION:	DATE:	APP'D BY:	

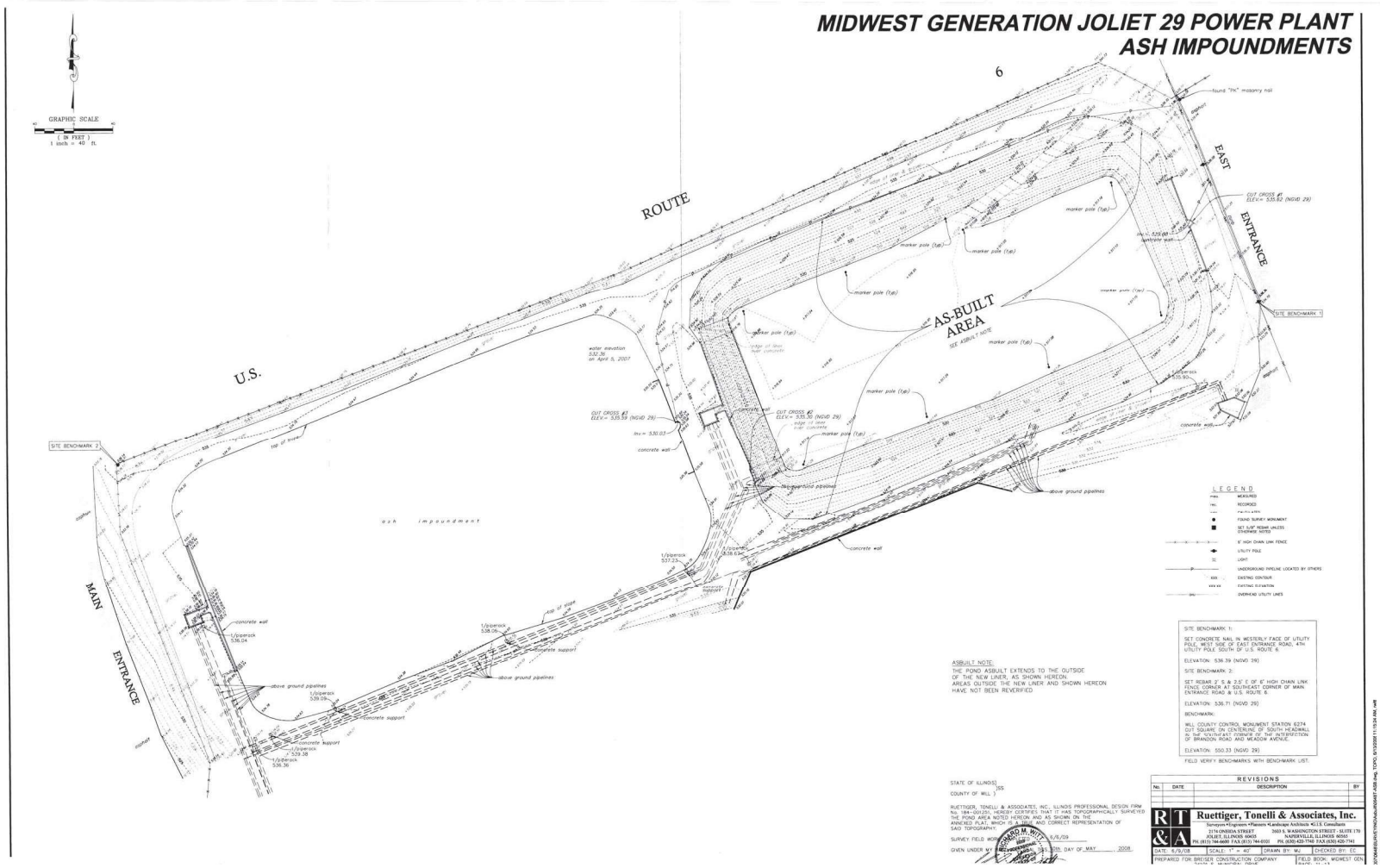
NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/3.0	DETAILS AND SECTIONS
DRAWN BY: BJK/RLH 07/12/07	ASH IMPOUNDMENT #2 LINER REPLACEMENT
CHECKED BY: HMS 08/02/07	MIDWEST GENERATION
	JOLIET STATION NO. 29
	JOLIET, ILLINOIS
APPROVED BY: EJT 09/05/07	DRAWING NO: D1862C031-01
	REFERENCE:1862/3/BID-CON/
	SHEET NO. C031

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APPENDIX A-4

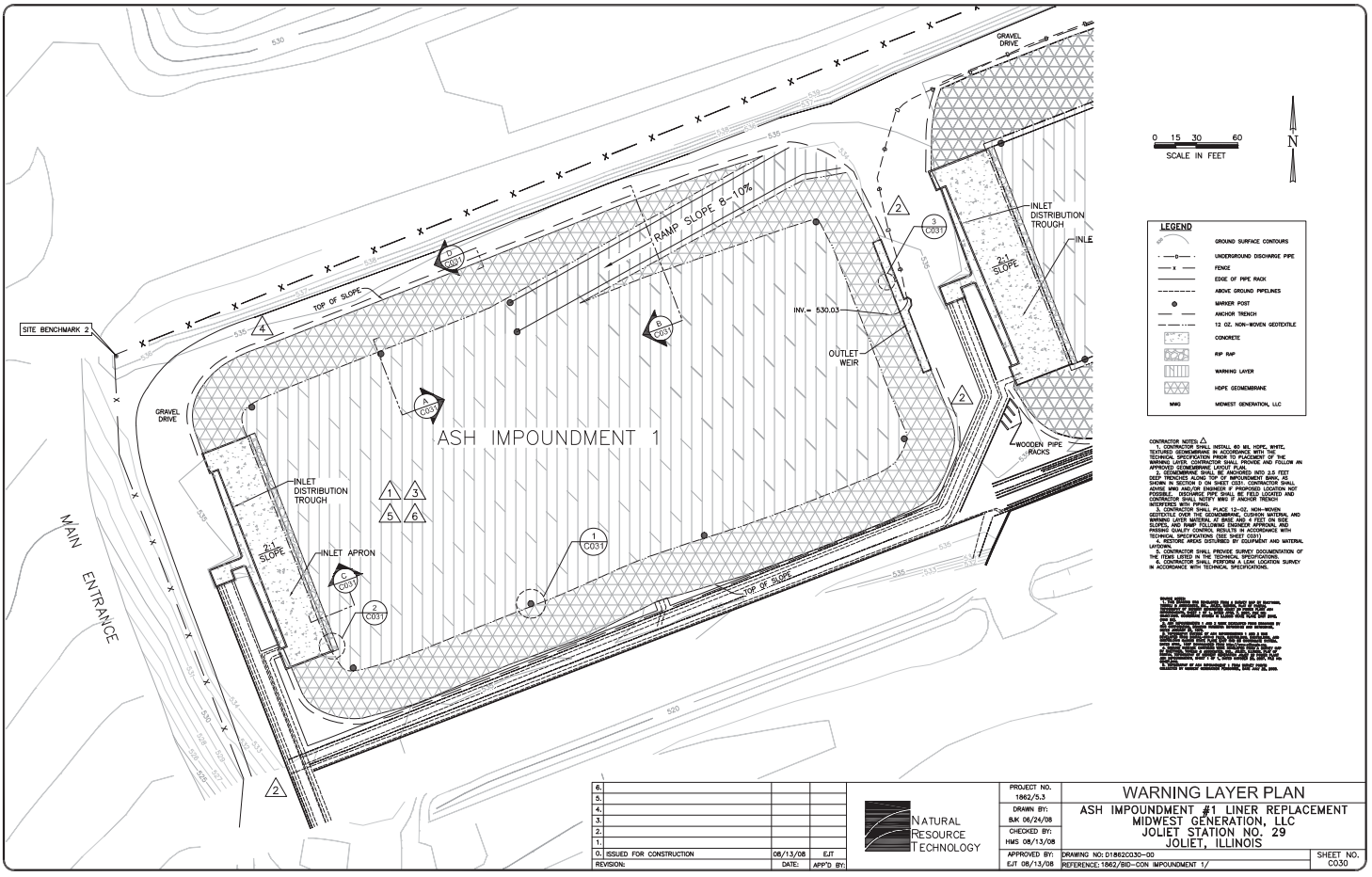
Ash Pond 2 Liner Replacement As-Built


MIDWEST GENERATION JOLIET 29 POWER PLANT
ASH IMPOUNDMENTS
GRAPHIC SCALE
(IN FEET)
1 inch = 40 ft.
ROUTE
U.S.
6
EAST
ENTRANCE
MAIN
ENTRANCE
AS-BUILT
AREA
SEE ASBUILT NOTE
ash impoundment
SITE BENCHMARK 1
SITE BENCHMARK 2
found "PK" masonry nail
CUT CROSS
ELEV.= 535.82 (NGVD 29)
CUT CROSS
ELEV.= 535.59 (NGVD 29)
CUT CROSS
ELEV.= 535.50 (NGVD 29)
water elevation
532.76
on April 5, 2007
concrete wall
above ground pipelines
concrete support
marker pole (typ)
LEGEND
MEASURED
RECORDED
FOUND SURVEY MONUMENT
SET 5/8" REBAR UNLESS
OTHERWISE NOTED
6' HIGH CHAIN LINK FENCE
UTILITY POLE
LIGHT
UNDERGROUND PIPELINE LOCATED BY OTHERS
EXISTING CONTOUR
EXISTING ELEVATION
OVERHEAD UTILITY LINES
ASBUILT NOTE:
THE POND ASBUILT EXTENDS TO THE OUTSIDE OF THE NEW LINER, AS SHOWN HEREON. AREAS OUTSIDE THE NEW LINER AND SHOWN HEREON HAVE NOT BEEN REVERIFIED.
SITE BENCHMARK 1:
SET CONCRETE NAIL IN WESTERLY FACE OF UTILITY POLE, WEST SIDE OF EAST ENTRANCE ROAD, 4TH UTILITY POLE SOUTH OF U.S. ROUTE 6.
ELEVATION: 536.39 (NGVD 29)
SITE BENCHMARK 2:
SET REBAR 2' S. & 2.5' E. OF 6' HIGH CHAIN LINK FENCE CORNER AT SOUTHEAST CORNER OF MAIN ENTRANCE ROAD & U.S. ROUTE 6.
ELEVATION: 536.71 (NGVD 29)
BENCHMARK:
WILL COUNTY CONTROL MONUMENT STATION 6274
CUT SQUARE ON CENTERLINE OF SOUTH HEADWALL IN THE SOUTHEAST CORNER OF THE INTERSECTION OF BRANDON ROAD AND MEADOW AVENUE.
ELEVATION: 550.33 (NGVD 29)
FIELD VERIFY BENCHMARKS WITH BENCHMARK LIST.
STATE OF ILLINOIS }
COUNTY OF WILL } SS
RUETTIGER, TONELLI & ASSOCIATES, INC., ILLINOIS PROFESSIONAL DESIGN FIRM No. 184-001251, HEREBY CERTIFIES THAT IT HAS TOPOGRAPHICALLY SURVEYED THE POND AREA NOTED HEREON AND AS SHOWN ON THE ANNEXED PLAT, WHICH IS A TRUE AND CORRECT REPRESENTATION OF SAID TOPOGRAPHY.
SURVEY FIELD WORK COMPLETED 6/5/09
GIVEN UNDER MY HAND AND SEAL THIS 5th DAY OF MAY, 2008.
REVISIONS
No. DATE DESCRIPTION BY
Ruettiger, Tonelli & Associates, Inc.
Surveyors • Engineers • Planners • Landscape Architects • G.I.S. Consultants
219 ONEIDA STREET JOLIET, ILLINOIS 60435 PH. (815) 744-6600 FAX (815) 744-6100
3600 S. WASHINGTON STREET - SUITE 170 NAPERVILLE, ILLINOIS 60565 PH. (630) 420-7740 FAX (630) 420-7741
DATE: 6/8/08 SCALE: 1" = 40' DRAWN BY: MJ CHECKED BY: EC
PREPARED FOR: BREISER CONSTRUCTION COMPANY FIELD BOOK: MIDWEST GEN

Electronic Filing: Received, Clerk's Office 2/04/2022

APPENDIX A-5

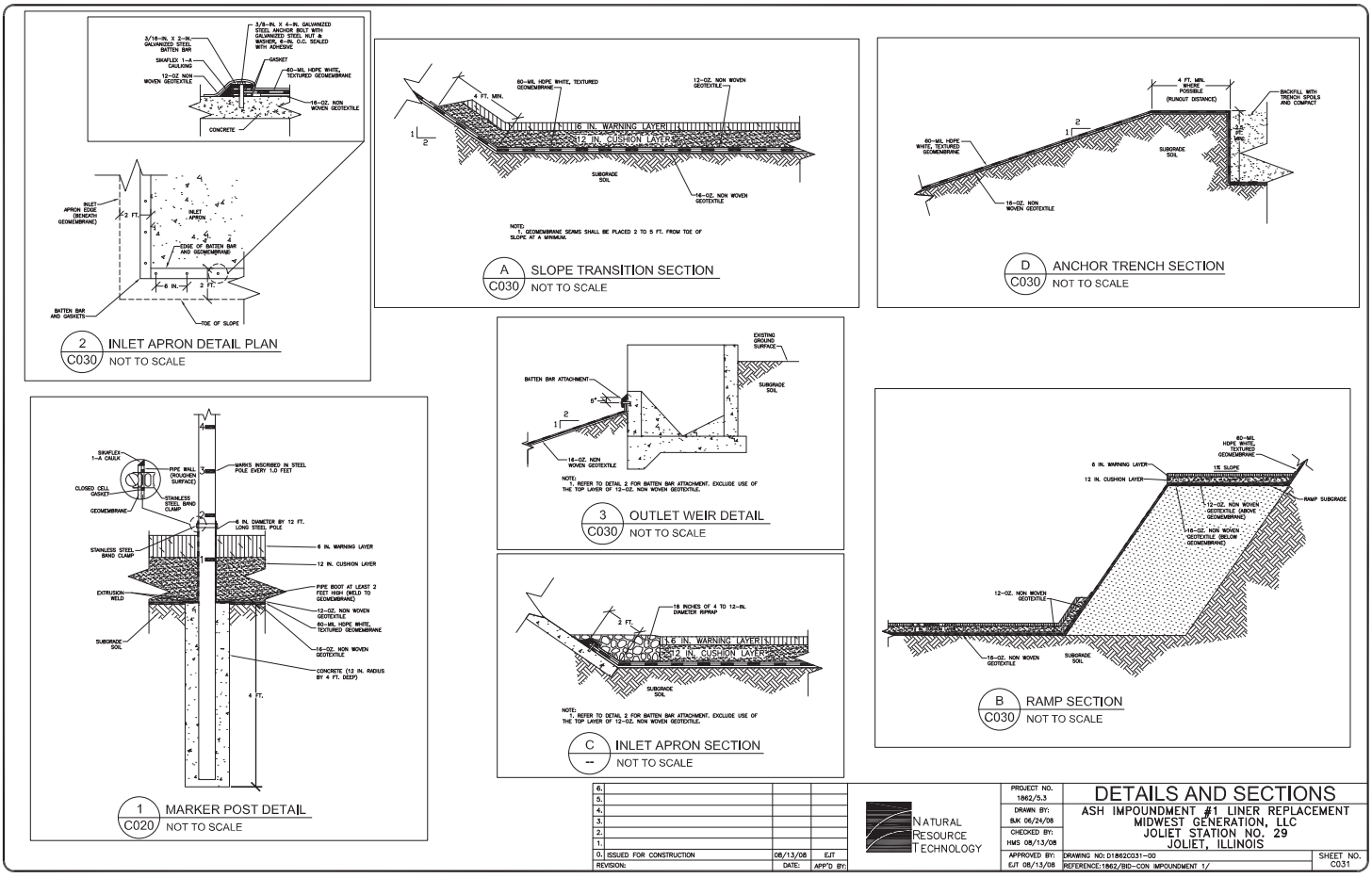
Pond 1 Liner Replacement Construction Drawings



6.			
5.			
4.			
3.			
2.			
1.			
0.	ISSUED FOR CONSTRUCTION	08/13/08	EJT
REVISION:		DATE:	APP'D. BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/5.3	WARNING LAYER PLAN
DRAWN BY: BJK 06/24/08	ASH IMPOUNDMENT #1 LINER REPLACEMENT MIDWEST GENERATION, LLC JOLIET STATION NO. 29 JOLIET, ILLINOIS
CHECKED BY: HMS 08/13/08	
APPROVED BY: EJT 08/13/08	DRAWING NO: D1862C030-00
	REFERENCE: 1862/BID-CON IMPOUNDMENT 1/
	SHEET NO. C030



6.			
5.			
4.			
3.			
2.			
1.			
0.	ISSUED FOR CONSTRUCTION	08/13/08	EJT
REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.	1862/5.3
DRAWN BY:	BJK 06/24/08
CHECKED BY:	HMS 08/13/08
APPROVED BY:	EJT 08/13/08

DETAILS AND SECTIONS

ASH IMPOUNDMENT #1 LINER REPLACEMENT
MIDWEST GENERATION, LLC
JOLIET STATION NO. 29
JOLIET, ILLINOIS

DRAWING NO: D1862C031-00
REFERENCE: 1862/BID-CON IMPOUNDMENT 1/

SHEET NO. C031

Electronic Filing: Received, Clerk's Office 2/04/2022

APPENDIX B

Technical Specifications

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SECTION 02600
HIGH DENSITY POLYETHYLENE (HDPE) GEOMEMBRANE

PART 1 - GENERAL

1.01 WORK INCLUDES

A. Furnish all labor, materials, tools, supervision, transportation, and installation equipment necessary for installation of 60-mil High Density Polyethylene (HDPE) geomembrane, as specified herein, and as shown on Contract Drawings.

1.02 REFERENCE STANDARDS

A. ASTM D1004 – Test Method for Initial Tear Resistance of Plastic Film and Sheeting.

B. ASTM D1238 – Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.

C. ASTM D1505 – Test Method for Density of Plastics by the Density-Gradient Technique.

D. ASTM D1603 – Test Method for Carbon Black in Olefin Plastics.

E. ASTM D4833 – Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.

F. ASTM D5199 – Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

G. ASTM D5397 – Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test.

H. ASTM D5596 – Test Method for Microscopic Evaluation of Dispersion of Carbon Black in Polyolefin Geosynthetics.

I. ASTM D5994 Standard Test Method for Measuring Core Thickness of Textured Geomembranes.

J. ASTM D6392 –Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods.

K. ASTM D6693 Standard Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes.

L. GRI Test Method, GM 13 - Test Methods, Test Properties and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes

M. GRI Test Method, GM 14 – Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes.

N. GRI Test Method, GM 19 – Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes.

1.03 DEFINITIONS

A. Geomembrane Installer: hired by Contractor or Owner responsible for field handling, transporting, storing, deploying, seaming and testing of the geomembrane seams.

B. Geomembrane Manufacturer: hired by Geomembrane Installer to provide HDPE geomembrane.

C. Geosynthetic Quality Assurance Consultant: Consultant, independent from the Owner, Manufacturer, and Installer, responsible for field oversight of geosynthetics installation, and related testing, usually under the direction of the Owner.

D. Geosynthetic Quality Assurance Laboratory (Testing Laboratory): Party, independent from the Owner, Manufacturer and Installer, responsible for conducting laboratory tests on samples of geosynthetics obtained at the site or during manufacturing, usually under the direction of the Owner.

D. Lot: A quantity of resin (usually the capacity of one rail car) used in the manufacture of geomembranes. Finished roll will be identified by a roll number traceable to the resin lot used.

E. Resin Supplier: selected by Geomembrane Manufacturer to provide resin used in manufacturing geomembrane.

F. Panel: Unit area of a geomembrane that will be seamed in the field that is larger than $100ft^2$.

G. Patch: Unit area of a geomembrane that will be seamed in the field that is less than $100ft^2$.

H. Subgrade Surface (Bedding Layer): Soil Layer surface which immediately underlies the geosynthetic material(s).

1.04 QUALITY ASSURANCE

A. Qualifications:

1. Geomembrane Installer:

a. 5 years of continuous experience in installation of HDPE geomembrane.

b. Experience totaling a minimum of 5,000,000 square feet of installed HDPE geomembrane on some combination of at least 10 completed facilities.

c. Personnel performing seaming operations qualified by experience or by successfully passing seaming tests. Master seamer shall have experience

seaming a minimum of 3,000,000 square feet of geomembrane using same type of seaming apparatus to be used on this project.

B. Quality Assurance Program:

1. Geomembrane Manufacturer/Installer shall conform with requirements of these Technical Specifications.

2. The Engineer will document geomembrane installation including panel placement, seaming, pre-qualification seam testing, non-destructive seam and repair testing, repair size and locations, weather conditions.

3. The Owner will engage and pay for the services of a Geosynthetic Quality Assurance Consultant and Laboratory to monitor geomembrane installation.

1.05 SUBMITTALS

A. Prior to project start, submit the following to Geosynthetic Quality Assurance Consultant in accordance with Section 01300, Submittals:

1. Raw Materials:

a. Name of Resin Supplier, location of supplier's production plant(s), resin brand name and product number.

b. Source and nature of plasticizers, fillers, carbon black and any other additives along with their percent addition to geomembrane material.

c. Test results documenting conformance with the "index properties" of GRI Test Method, GM 13.

2. Geomembrane Manufacturer's Certification:

a. Written certification that Geomembrane Manufacturer's Quality Control Plan was fully implemented during production of geomembrane material supplied for this project. (Submittal shall be made within 5 working days of delivery to site).

3. Geomembrane Installer's Seaming Personnel

a. Corporate background information indicating compliance with qualification requirements.

b. Training completed by personnel.

c. Seaming experience for each personnel.

4. Geomembrane Manufacturer Production Information:

a. Corporate background information indicating compliance with qualification requirements.

b. Quality control plan for manufacturing.

c. Copy of quality control certificates demonstrating compliance with the quality control plan for manufacturing and the test property requirements of GRI Test method, GM 13 (i.e. mill certificates).

5. Geomembrane Installer's Information:

a. Corporate background information indicating compliance with qualification requirements.

b. List of completed facilities, totaling 5,000,000 square feet minimum for which Geomembrane Installer has completed installation of a HDPE geomembrane. Include name and purpose of facility, location, date of installation, and quantity installed.

c. Resumes of personnel performing field seaming operation, along with pertinent experience information. Include documentation regarding which seamers are qualified to use thermal fusion welding apparatus.

d. Installation quality control plan.

6. Installation panel layout diagram identifying placement of geomembrane panels, seams, and any variance or additional details which deviate from Contract Drawings or Technical Specifications. Layout shall be drawn to scale and shall be adequate for use as a construction plan. Layout shall include dimensions and pertinent seam and anchorage details.

7. Installation Sequence and Schedule shall be included as part of Construction Progress Schedule.

8. Description of seaming apparatus to be used indicating compliance with specified requirements.

B. During installation, submit the following to the Geosynthetic Quality Assurance Consultant:

1. Daily records/logs prepared by Geomembrane Installer documenting work performed, personnel involved, general working conditions, and any problems encountered or anticipated on project. Submit on a weekly basis.

2. Copy of subgrade acceptance signed by Geomembrane Installer for areas to be covered with geomembrane each day.

C. Within 10 days of geomembrane installation completion, submit the following to Geosynthetic Quality Assurance Consultant:

1. Geomembrane installation certification that Work was performed under Geomembrane Installer's approved quality control plan and in substantial compliance with Technical Specifications and Contract Drawings.

2. As-built panel diagram identifying placement of geomembrane panels, seams, repairs, and destructive seam sample locations.

3. Copy of warranty for material (including factory seams) and installation covering both for a period of 2 years from the date of substantial completion.

D. The Geosynthetic Quality Assurance Consultant will review and inspect HDPE geomembrane installation upon completion of all Work specified in this Section. Deficiencies noted shall be corrected at no additional cost to the Owner.

E. The Geosynthetic Quality Assurance Consultant will provide written final acceptance of the geomembrane installation after completion of material placement above geomembrane. Written conditional geomembrane installation acceptance can be provided to the Contractor prior to completion of material placement above geomembrane when the following conditions are satisfied, if necessary, and requested by the Contractor:

1. The entire geomembrane installation is completed or any pre-determined subsection if the project is phased.

2. All installation quality assurance/control documentation has been completed and submitted to the Geosynthetic Quality Assurance Consultant or Owner.

3. Verification of the adequacy of all field seams, repairs and associated testing is complete.

1.06 DELIVERY, STORAGE, AND HANDLING

A. Transportation:

1. Geomembrane rolls shall be transported, unloaded and handled at the job site in accordance with manufacturer recommendations. Damaged material may be rejected by the Geosynthetic Quality Assurance Consultant. Manufacturer packaging shall be labeled in accordance with Section 02700, 2.02G.

B. On-site Storage:

1. Geomembrane rolls which have been delivered to job site shall be unloaded and stored in original, unopened packaging in a secure location, determined by Owner and/or Geosynthetic Quality Assurance Consultant.

2. Store geomembrane rolls to ensure adequate protection against exposure to the following:

a. Equipment;

b. Strong oxidizing chemicals, acids, or bases;

c. Flames, including welding sparks;

d. Temperatures in excess of 160 deg. F;

e. Dust;

f. Ultraviolet radiation (i.e. sunlight); and

g. Inclement weather.

3. Whenever possible, provide a 6-inch minimum air space between rolls.

4. Containers/rolls shall not be stacked.

C. On-Site Handling:

1. Handle rolls per Geomembrane Manufacturer's recommendations and as necessary to prevent damage.

PART 2 - PRODUCTS

2.01 MATERIALS

A. High Density Polyethylene (HDPE) White Textured Geomembrane.

1. HDPE geomembrane shall be white, textured, 60-mil product approved by the Engineer and/or Geosynthetic Quality Assurance Consultant.

2. The Contractor shall submit, with the bid, written certification from the proposed Geomembrane Manufacturer that geomembrane products proposed in the bid satisfy the following requirements:

a. The proposed Geomembrane Manufacturer shall have a minimum of 5 years of continuous experience manufacturing HDPE geomembrane totaling 1,000,000 square feet.

b. The proposed HDPE compound shall be comprised entirely of virgin materials. Compliance with this specification shall be documented in accordance with Geomembrane Manufacturer's quality control program and submitted to the Geosynthetic Quality Assurance Consultant with the written conformance certification.

c. The proposed Geomembrane Manufacturer shall certify that any plasticizers, fillers and additives incorporated into the manufacturing process for the proposed HDPE geomembrane have demonstrated acceptable performance on past projects.

d. The proposed geomembrane shall meet the requirements of Geosynthetic Research Institute's test method GM 13.

e. The nominal thickness of proposed geomembrane shall be 60 mil., or as approved by the Engineer and/or Geosynthetic Quality Assurance Consultant.

3. Geomembrane sheets shall be visually consistent in appearance and shall contain no holes, blisters, undisbursed raw materials or other signs of contamination by foreign material. Geomembrane must have no striations, roughness or bubbles on the surface.

B. Seaming Apparatus

1. Thermal fusion welding machines used for joining geomembrane surfaces may be either extrusion or hot wedge. These machines shall include sufficient temperature and rate-of-travel monitoring devices to allow continuous monitoring of operating conditions.

2. One spare, operable thermal fusion seaming device shall be maintained on site at all times.

C. Field Test Equipment

1. Field Tensiometer: the field tensiometer shall be calibrated within three months prior to project start date over the range of field test values.

2. Air Channel Test Equipment: air channel test equipment shall consist of hoses, fittings, valves and pressure gauge(s) needed to deliver and monitor the pressure of compressed air through an approved pressure feed device.

3. Air Compressor: the air compressor utilized for field testing shall be capable of producing and maintaining an operating pressure of at least 50 psi.

4. Vacuum Box: the vacuum box shall consist of a vacuum gage, valve, and a gasket around the edge of the open bottom needed to apply vacuum to a surface.

2.02. CONFORMANCE TESTING REQUIREMENTS

A. Geomembrane shipped to site shall undergo conformance testing. Manufacturer's roll certificates may be used for conformance evaluation at the option of the Geosynthetic Assurance Consultant. Nonconforming material shall either be retested at the direction of the Geosynthetic Quality Assurance Consultant or removed from site and replaced at Contractor's expense.

B. Conformance Test Methods

1. Samples will be located and collected by the Geosynthetic Quality Assurance Consultant at a rate of one sample per 100,000 square feet of geomembrane delivered to site.

2. One sample will be obtained from each geomembrane production batch delivered to the site.

3 Samples shall be cut by Geomembrane Installer and be at least 45 square feet in size.

4. Samples shall be tested in accordance with Table 1 (Smooth) or Table 2 (Textured) specified in GRI Test Method GM13.

5. Geomembrane thickness shall be measured a minimum of three times per panel during deployment to verify conformance with GRI Test Method GM13.

C. Role of Testing Laboratories

1. The Geosynthetic Quality Assurance Consultant will be responsible for acquiring samples of the geomembrane for conformance testing. The Owner or Geosynthetic Quality Assurance Consultant will retain an independent, third party laboratory to perform conformance testing on samples of geomembrane.

2. Retesting of geomembrane panels by the Geomembrane Installer because of failure to meet any of the conformance specifications can only be authorized by the Geosynthetic Quality Assurance Consultant. Non-conforming panels may be retested in accordance with Subsection 2.03(B) and 2.03(D) under authorization of the Geosynthetic Quality Assurance Consultant only.

3. The Geomembrane Manufacturer and/or Geomembrane Installer may perform independent tests in accordance with methods and procedures specified in Subsection 2.03(B). Results shall not be substituted for quality assurance testing described herein.

D. Procedures for Determining Conformance Test Failures

1. If conformance test results fail to meet specifications, the roll and/or batch may be retested using specimens from either the original roll sample or from another sample collected by the Geosynthetic Quality Assurance Consultant. Two additional tests (retests) shall be performed for each failed test procedure. Each retest shall consist of multiple specimen tests if multiple specimens are specified in the test procedure. If the results of both retests meet specifications, the roll and batch will be considered to have passed conformance testing.

2. Failure of any retest shall be cause for rejection of the entire roll or batch depending on the type of failing test. The Geosynthetic Quality Assurance Consultant reserves the right to collect samples from other roll of a particular batch for further conformance testing. The Geosynthetic Quality Assurance Consultant may choose to accept only a portion of the batch on the basis of the results of conformance testing of samples collected from other rolls.

3. If retesting does not result in conformance with the specifications as defined in preceding paragraph, or if there are any other nonconformities with the material

specifications, the Contractor shall remove the rolls from use in project. The Contractor shall also be responsible for removal of rejected geomembrane from the site and replacement with acceptable geomembrane at no additional cost to the Owner.

PART 3 - EXECUTION

3.01 PRE-CONSTRUCTION MEETING

A. A Pre-Construction Meeting shall be held at the site in accordance with Section 01040, Project Administration, to discuss and plan the details of geomembrane installation. This meeting shall be attended by the Geomembrane Installer, Owner, Geosynthetic Quality Assurance Consultant and the General Contractor.

B. The following topics relating to geomembrane installation shall be addressed:

1. Responsibilities of each party.

2. Lines of authority and communication.

3. Methods for documenting, reporting and distributing documents and reports.

4. Procedures for packaging and storing archive samples.

5. Review of the schedule for all installation and quality assurance testing, including third-party testing turnaround times.

6. Review of panel layout, access and numbering systems for panels and seams including details for marking on the HDPE geomembrane.

7. Procedures and responsibilities for preparation and submittal of as-built drawings.

8. Temperature and weather limitations, installation procedures for adverse weather conditions and defining acceptable subgrade or ambient moisture and temperature conditions for working during liner installation.

9. Subgrade conditions, dewatering responsibilities and subgrade maintenance plan.

10. Deployment techniques including allowable subgrade for geomembrane.

11. Procedures for covering of the geomembrane to prevent damage.

12. Plan for minimizing wrinkles in the geomembrane.

13. Measurement and payment schedules.

14. Site health and safety procedures/protocols.

3.02 SUBGRADE PREPARATION

A. Contractor shall prepare a subgrade surface in accordance with Section 02243, Subgrade Layer Preparation, and excavate and backfill in accordance with Section 02222, Anchor Trenching, Backfilling and Compaction.

B. The Contractor shall not excavate more than the amount of anchor trench required for one day of geosynthetics deployment, unless otherwise specified by the Geosynthetic Quality Assurance Consultant. Rounded corners shall be provided in the trenches where the geosynthetics enter the trench to allow them to be uniformly supported by the subgrade and to avoid sharp bends. The geosynthetics shall not be supported by loose soils in anchor trenches.

C. The Geomembrane Installer shall visually inspect the subgrade immediately prior to geomembrane deployment. Inspection shall verify that there are no potentially harmful foreign objects present, such as sharp rocks and other deleterious debris. Any foreign objects encountered shall be removed by Geomembrane Installer or Contractor. All subgrade damaged by construction equipment and deemed unsuitable for geomembrane deployment shall be repaired prior to geomembrane deployment. All repairs shall be approved by the Geosynthetic Quality Assurance Consultant and Geomembrane Installer. The responsibility for preparation, repairs, and maintenance of the subgrade shall be defined in the preconstruction meeting. The Geomembrane Installer shall provide the Geosynthetic Quality Assurance Consultant with written acceptance of subgrade surface over which geomembrane is deployed (Part 1 .05B*)* for each day of deployment.

3.03 GEOMEMBRANE DEPLOYMENT

A. Geomembrane shall not be deployed until all applicable certifications/quality control certificates listed in subsection 1.05 of this section and conformance testing listed in subsection 2.03 of this section are submitted and approved by the Geosynthetic Quality Assurance Consultant. Any geomembrane deployed prior to approval by the Geosynthetic Quality Assurance Consultant shall be at the sole risk of the Geomembrane Installer and/or Contractor. If material installed prior to approval by the Geosynthetic Quality Assurance Consultant does not meet the requirements of this specification, it shall be removed from the site at no additional cost to the Owner.

B. Geomembrane will be deployed according to submitted panel layout drawing as approved by the Geosynthetic Quality Assurance Consultant. The Geosynthetic Quality Assurance Consultant is to be notified of and approve any revisions or modifications to the approved panel layout drawing prior to deploying geomembrane in the area of review.

C. Adequate temporary anchoring (sand bags, tires, etc.) that will not damage the geomembrane shall be placed on a deployed panel to prevent uplift by wind.

D. Geomembrane shall not be deployed if:

1. Ambient temperatures are below 41 degrees F (5 degrees C) or above 104 degrees F (40 degrees C) measured six inches above geomembrane surface unless approved by the Geosynthetic Quality Assurance Consultant.

2. Precipitation is expected or in the presence of excessive moisture or ponded water on the subgrade surface.

3. Winds are excessive as determined by Geomembrane Installer in agreement with the Geosynthetic Quality Assurance Consultant.

4. The Geosynthetic Quality Assurance Consultant will have the authority to suspend work during such conditions.

E. The Geomembrane Installer shall be responsible for conformance with the following requirements:

1. Equipment utilized for installation/quality assurance testing does not damage geomembrane. Such equipment shall have rubber tires and a ground pressure not exceeding 5 psi or total weight exceeding 750 lbs. Only equipment necessary for installation and quality assurance testing is allowed on the deployed geomembrane.

2. Personnel working on geomembrane do not damage geomembrane (activities such as smoking or wearing damaging clothing shall not be allowed).

3. Method of deployment does not damage geomembrane.

4. Method of deployment minimizes wrinkles.

5. Temporary loading or anchoring does not damage geomembrane.

6. Direct contact with geomembrane is minimized.

F. No vehicles shall be allowed on deployed geomembrane under any circumstances.

3.04 FIELD SEAMS

A. Seam Layout

1. In general, seams shall be oriented parallel to the line of the maximum slope. In corners and at other odd-shaped geometric intersections, number of seams should be minimized. If at all possible, seams shall not be located at low points in the subgrade unless geometry requires seaming to be done at these locations.

2. A seam numbering system compatible with the panel numbering system shall be agreed upon at the Pre-Construction Meeting.

B. Seaming Processes/Equipment

1. Approved processes for field seaming (panel to panel) are extrusion or hot wedge fusion-type seam methods. No other processes can be used without prior written authorization from the Geosynthetic Quality Assurance Consultant. Only equipment which has been specifically approved by make and model shall be used, if applicable.

2. The Geomembrane Installer will meet following requirements regarding use, availability, and cleaning of welding equipment at job site:

a. Intersecting hot wedge seams shall be patched using extrusion welding process.

b. Electric generator for equipment shall be placed on a smooth base such that no damage occurs to geomembrane. A smooth insulating plate or fabric shall be placed beneath hot equipment after usage.

3. The Geomembrane Installer shall keep records for performance and testing of all seams.

C. Seaming Requirements/Procedures

1. Weather Conditions - Range of weather conditions under which geomembrane seaming can be performed are as follows:

a. Unless otherwise authorized in writing by Geosynthetic Quality Assurance Consultant, no seaming shall be attempted or performed at an ambient temperature below 41 degrees F (5 degrees C) or above 104 degrees F (40 degrees C).

b. Between ambient temperatures of 32 degrees F (0 degrees C) and 41 degrees F (5 degrees C), seaming shall be performed only if geomembrane is preheated by either sun or a hot air device, provided there is no excessive ambient cooling resulting from high winds. Pre-qualification seams shall be produced under identical conditions.

c. Above 41 degrees F (5 degrees C), no preheating of geomembrane will be required.

d. Geomembrane shall be dry and protected from wind.

e. Seaming shall not be performed during any precipitation event.

f. Seaming shall not be performed in areas where ponded water has collected below surface of geomembrane.

2. If the Geomembrane Installer chooses to use methods which may allow seaming at ambient temperatures below 41 degrees F or above 104 degrees F, the Geomembrane Installer shall demonstrate and submit certification to Geosynthetic Quality Assurance Consultant that methods and techniques used to perform seaming produce seams that are equivalent to seams produced at temperatures above 41 degrees F and below 104 degrees F. The Geosynthetic Quality Assurance Consultant may deny approval for use of the proposed technique regardless of demonstration results.

3. Overlapping - Geomembrane panels shall have finished overlap as follows:

a. Minimum of 6 inches for thermal fusion welding.

b. Insufficient overlap will be considered a failed seam.

4. Pre-qualification tests for geomembrane fusion welding shall be conducted by a minimum of 2 pre-qualification seams conducted per day per welding machine by each seaming technician performing welding with that machine. At least one test shall be performed at the start of each work day, with tests at intervals of no greater than 5 hours and additional pre-qualification tests following work interruptions, weather changes, changes to machine settings, or as directed by the Geosynthetic Quality Assurance Consultant. Pre-qualification seams shall be made under the same conditions as the actual seams.

    a. Pre-qualification seam samples shall be 5 feet long by 1-foot wide (minimum) after seaming, with seam centered along its length. Each pre-qualification seam shall be labeled with the date, geomembrane temperature, seaming unit identifier, seam number or test location, technician performing the test seam and description of testing results.

    b. Seam overlap shall be in accordance with subsection 3.04(C)(3).

    c. Pre-qualification seams shall be inspected for proper squeeze-out, footprint pressure, and general appearance.

    d. Four specimens, each 1-inch in length, shall be cut from opposite ends of the pre-qualification seam sample by the Geomembrane Installer. The remainder of pre-qualification seam shall be retained by the Geosynthetic Quality Assurance Consultant and may be submitted for laboratory testing.

    e. The Geomembrane Installer shall complete two shear tests and two peel tests.

    f. Pre-qualification seams failed by inspection or testing may be retested at request of the Geomembrane Installer. If the second pre-qualification seam fails, then the seaming apparatus or seaming technique shall be disqualified from use until two consecutive, satisfactory pre-qualification seams are obtained.

5. Seam Preparation

    a. Prior to seaming, seam area shall be clean and free of moisture, dust, dirt, debris of any kind, and foreign material.

    b. Seams shall be aligned so as to minimize number of wrinkles and fishmouths.

6. General Seaming Procedures

    a. Fishmouths or wrinkles at seam overlaps shall be cut along ridge of the wrinkle to achieve a flat overlap. Cut fishmouths or wrinkles shall be repaired, and/or patched in accordance with Part 3.07.

    b. Seaming shall extend to the outside edge of geomembrane panels including material placed in anchor trenches.

c. For cross seams, the intersecting thermal fusion seams shall be patched using the extrusion welding process.

3.05 NON-DESTRUCTIVE TESTING

A. Each field seam shall be non-destructively tested over its entire length by the Installer. Testing shall be conducted as field seaming progresses, not at completion of all seams, unless specifically agreed to by the Geosynthetic Quality Assurance Consultant in writing.

B. Vacuum Testing – shall be performed in accordance with ASTM D5641, Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber.

C. Air Pressure Testing – shall be performed in accordance with ASTM D5820, Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes, and GRI GM 6, Pressurized Air Channel Test for Dual Seamed Geomembranes.

D. Each seam tested non-destructively shall be marked with the date of the test, name of the testing technician, length of the seam, test method and results. The same shall also be recorded by the Geosynthetic Quality Assurance Consultant on the appropriate CQA documentation.

E. Non-Destructive Seam Test Failures

1. Seams failing non-destructive testing shall be repaired by the Geomembrane Installer according to Part 3.07. Seams shall be non-destructively retested. If the seam defect cannot be located, the entire section of seams affected shall be repaired and retested.

3.06 DESTRUCTIVE TESTING

A. The Owner shall have the option to conduct destructive testing of geomembrane panel seams completed in the field. Destructive seam sampling and testing shall be performed by the Geomembrane Installer under the observation of the Geosynthetic Quality Assurance Consultant.

B. Sampling Procedure

1. For each sample location, the Geosynthetic Quality Assurance Consultant will:

a. Assign a sample number and mark the sample accordingly.

b. Record the sample location on the as-built layout drawing.

c. By sample number, record reason for collecting sample (e.g., as part of statistical testing program, suspicious seam, retest, etc.).

d. Record pertinent information, including date, time, seam number, number of seaming unit, and name of seamer, on both the seam sample and CQA documentation.

2. Each destructive sample shall be at least 12 inches wide (at least 6 inches on each side of seam) by 54 inches long. Samples will be cut by the Geomembrane Installer into three parts and distributed as follows:

a. A 12-inch by 12-inch portion shall be cut and tested in accordance with subsection 3.06(C) by the Geomembrane Installer.

b. A 12-inch by 12-inch portion shall be cut and retained by the Geomembrane Installer. The Geomembrane Installer may elect to omit this requirement.

c. A 12-inch by 12-inch portion shall be cut and retained by the Geosynthetic Quality Assurance Consultant as an archive sample.

d. A 12-inch by 18-inch portion shall be submitted by the Geosynthetic Quality Assurance Consultant for laboratory testing as described in Part 3.06(D).

3. Ten specimens, each 1 inch wide by 12 inches long with seam centered perpendicular to width, shall be collected and field tested by the Geomembrane Installer prior to shipping the sample to the laboratory. If all samples pass field tensiometer test described in Part 3.06(C), then the laboratory sample shall be collected according to procedure described in Part 3.06(B)(2)(d).

4. Holes cut into geomembrane resulting from destructive seam sampling shall be immediately repaired by Geomembrane Installer in accordance with repair procedures described in Part 3.07.

C. Field Test Methods

1. Ten 1-inch-wide samples described above under Part 3.06(B)(3) shall be field tested for peel (5 samples) and shear (5 samples).

2. One end of seam sample shall be field tested for peel and shear at end of each continuous field seam 100 feet long or greater.

3. Testing shall be performed in accordance to with ASTM D6392 using a field tensiometer or equivalent device to qualitatively and quantitatively determine mode of failure.

4. Seam shall be considered passing if failure in both peel and shear meet criteria listed in GRI GM 19, Table 2.

5. The procedures specified in Subsection 3.06(D) shall be implemented when sample passes field tensiometer test.

D. Laboratory Test Methods

1. Laboratory testing of seam samples shall be conducted by the Geosynthetic Quality Asssurance Laboratory under contract with the Geosynthetic Quality Assurance Consultant or Owner. Five specimens shall be tested in shear and five in peel.

2. Laboratory testing shall be conducted in accordance with ASTM D6392.

3. For both seam shear and peel tension tests, an indication will be given for each specimen tested which defines locus of failure.

4. For shear tests, the following values, along with the mean and standard deviation where appropriate, will be reported for each specimen tested:

   a. Maximum tension in pounds per square inch.

   b. Elongation at break (up to a tested maximum of 100 percent).

   c. Locus of failure using ASTM designations.

5. For peel tests, the following values, along with the mean and standard deviation where appropriate, will be reported for each specimen tested:

   a. Maximum tension in pounds per square inch.

   b. Seam separation (expressed as percent of original seam area).

   c. Locus of failure.

4. Retesting of seams due to nonconformance with specifications may be performed at the discretion of the Geosynthetic Quality Assurance Consultant.

E. Destructive Seam Test Failure

1. Shear and peel test results derived from testing described in Parts 3.06(C) and 3.06(D) shall comply with GRI GM 19, Table 2 for seam to be considered acceptable.

2. The Geomembrane Installer has two options in determining the repair boundary whenever a seam has failed destructive testing:

a. The seam can be reconstructed between the two previously tested and passed destructive sample locations; or,

b. The Geomembrane Installer can trace the welding path to an intermediate location at least ten feet from point of failed test in each direction and obtain destructive test samples collected from these locations. If destructive tests on these samples are acceptable, then the seam shall be reconstructed between the intermediate locations. If either sample fails, the process may be repeated until an acceptable seam test has been performed on both sides of the original failed sample. If a passing sample is not realized on one (or both) side of the original failed sample, then seam repair must extend to the end(s) of the seam. Retesting of seams according to this procedure shall utilize the sampling methodology described in Part 3.06(B). The Owner reserves the right to terminate this process, at the discretion of the Geosynthetic Quality Assurance Consultant, after the second retesting. An additional sample taken from the reconstructed zone must pass destructive seam testing, if destructive sample failure(s) causes reconstruction.

3. The Geosynthetic Quality Assurance Consultant shall be responsible for documenting all actions taken in repairing seams. The Geomembrane Installer will be responsible for keeping the Geosynthetic Quality Assurance Consultant informed of seaming progress.

3. Additional fees for destructive seam test failures shall be assessed to the Contractor and deducted from payment. This fee shall be assessed only if the failing sample is a laboratory sample.

3.07 DEFECTS AND REPAIRS

A. The geomembrane shall be examined by the Geomembrane Installer and the Engineer for defects, holes, blisters, undispersed raw materials, and any signs of contamination by foreign matter. The geomembrane surface shall be swept and/or washed by the Geomembrane Installer if the amount of dust or mud inhibits examination. The Contractor shall provide a water truck, an operator, clean water and hoses as reasonably necessary to assist the Geomembrane Installer in this activity.

B. Portions of geomembrane exhibiting flaws, or failing a non-destructive or destructive (if conducted) test, shall be repaired or replaced by the Geomembrane Installer. Repair procedures available include:

1. Patching - used to repair large holes, tears, undispersed raw materials, contamination by foreign matter, holes resulting from destructive sampling (if conducted), and locations where seam overlap is insufficient;

2. Capping - used to repair large lengths of failed seams; and

3. Additional Procedures - used upon recommendation of the Geomembrane Installer if agreed to by the Engineer.

C. Patches or caps.

1. Extend patch or cap 6 inches (minimum) beyond the edge of the defect.

2. Round corners of patch and/or cap (suggest 3-inch radius).

3. Repair procedures, equipment, materials, and techniques will be approved by the Geosynthetic Quality Assurance Consultant prior to repair.

4. Geomembrane below large caps shall be appropriately cut to avoid water or gas collection between two sheets.

D. The Geomembrane Installer shall mark on the geomembrane (using a non-puncturing writing utensil), repair date, time, and personnel involved.

E. Each repair shall be non-destructively tested in accordance with Part 3.05. Large caps may require destructive test sampling at the discretion of the Geosynthetic Quality Assurance Consultant (in accordance with Part 3.06).

F. Repairs which fail testing shall be redone and retested until a passing result is obtained. The Geomembrane Installer will perform non-destructive testing or repairs and will document retesting of repairs.

G. The Geosynthetic Quality Assurance Consultant will document repairs, repair testing, and retesting results.

H. The Geomembrane Installer shall cut and seam wrinkles which may adversely affect long-term integrity of the geomembrane, hinder subsequent construction of overlying layers, or impede drainage off of the geomembrane after it is covered by soil. Seaming shall be done in accordance with procedures described in Parts 3.04(B) and 3.04(C), and it shall be subject to test provisions of Parts 3.05 (non-destructive testing) and 3.06 (destructive testing – if conducted).

3.08 PROTRUSIONS AND CONNECTIONS TO GEOMEMBRANE

A. If required, the Geomembrane Installer shall install geomembrane around utility poles, guy wires, and other structures according to the Contract Drawings and the following requirements:

1. Use minimum 1-ft long membrane pipe boots and steel straps to seal the geomembrane around pole or structure.

2. Use standard welding procedures to seam the membrane boot to the geomembrane.

3. Seaming performed on and around penetrations, and other appurtenances shall be non-destructively tested using the vacuum testing method.

3.09 SURVEY DOCUMENTATION

A. The Geomembrane Installer shall survey the completed geomembrane prior to covering and provide the Geosynthetic Quality Assurance Consultant with 24-hour notification of survey. The Contractor shall document the location of all seams (panel corners acceptable), destructive test samples (if conducted) and repairs. The Contractor shall provide survey data to the Geosynthetic Quality Assurance Consultant within one working day of survey completion and in accordance with Section 01050.

3.10 DAILY FIELD INSTALLATION REPORTS

A. At the beginning of each day, the Geomembrane Installer shall provide the Geosynthetic Quality Assurance Consultant with a report for all work completed the previous day.

B. The Daily Field Installation Report shall include the following:

1. The total amount and location of geomembrane placed.

2. The total length and location of seams completed, technician name and welding unit numbers.

3. A drawing or sketch depicting the geomembrane installed the previous day including the panel number, seam number and locations of non-destructive and destructive testing (if conducted).

4. Results of pre-qualification test seams, if available.

5. Results of non-destructive testing.

C. Destructive test results (if conducted) shall be reported within 48 hours or prior to covering the geomembrane, whichever is practical.

3.10 MATERIAL ABOVE GEOMEMBRANE

A. The Geosynthetic Quality Assurance Consultant and Geomembrane Installer shall verify the area of geomembrane completion prior to placement of material over the geomembrane.

B. Soils - Requirements for placement of general fill are described in Sections 02221 and 02222. Apply following general criteria for covering of the geomembrane:

1. Do not place soils on the geomembrane at an ambient temperature below 32 degrees F, (0 degrees C) nor above 104 degrees F (40 degrees C), unless otherwise specified.

2. Do not drive equipment used for placing soil directly on the geomembrane.

3. A minimum thickness of 1 foot of soil is specified between a low ground pressure dozer (maximum contact pressure of 5 lb/sq. inch) and the geomembrane.

4. A minimum thickness of 2 feet of soil is required between rubber-tired vehicles and the geomembrane.

5. Do not compact soils placed directly on geomembrane.

6. Damage to the geomembrane resulting from placement of cover soils shall be repaired in accordance with Part 3.07 by the Geomembrane Installer at the Contractor's expense.

7. Do not push soil downslope. Soil shall be placed over the geomembrane starting from base of the slope, up to top of the slope.

END OF SECTION

Attachment 2

EAST EAMES STREET / US HIGHWAY 6

ACCESS RAMP

JS-29-GT-3

MW-10

J-C-4

J-C-4a

OUTLET
STRUCTURE / WEIR

WALL

W.E.
525.5

N

ASH POND 2
W.E. 532.2

J-C-3

INLET DISTRIBUTION
TROUGH

INLET FLUME

MW-3

J-C-1

J-B-1

J-C-2a

J-C-2

J-B-2

J-C-2b

POND 1 JS-29-GT-2

MW-5

MW-4

J-C-6a

J-C-6

J-C-5

J-C-5a

CONCRETE
RETAINING
WALL

TANK

TANK

PIPELINE

WALLS

LEGEND

- 520 — EXISTING GROUND MAJOR CONTOUR
- EXISTING GROUND MINOR CONTOUR
- MW-03 MONITORING WELL (PATRICK, 2011)
- J-B-1 BORING (GEOSYNTEC, 2016)
- J-C-1 CPT SOUNDING (GEOSYNTEC, 2016)
- JS-29-GT-2 BORING (KPRG, 2005)

NOTE:

1. ALL EXPLORATION LOCATIONS ARE APPROXIMATE.

0 60' 120'

SCALE IN FEET

SOURCE AERIAL TOPOGRAPHY:
AERO-METRIC, INC.
DATE OF PHOTOGRAPHY: 6/19/2008
HORIZONTAL DATUM: NAD83 IL SPC WEST
VERTICAL DATUM: NAVD88

SUBSURFACE EXPLORATIONS
ASH POND 2
JOLIET 29 STATION
JOLIET, ILLINOIS

Geosyntec consultants

PROJECT NO: SW0251-05

OCTOBER 2016

FIGURE
1

Z:\CADD\FIGURES\JOLIET\SW0251-05 F01_SUB EXPLORATIONS

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Tel: (858) 674-6559
Fax: (858) 674-6586

PROJECT Joliet Station
PROJECT LOCATION Joliet, IL
PROJECT NUMBER SW0251-05

KEY SHEET - CLASSIFICATIONS AND SYMBOLS

GS FORM: KEY 09/99

EMPIRICAL CORRELATIONS WITH STANDARD PENETRATION RESISTANCE N VALUES *

	N VALUE * (BLOWS/FT)	CONSISTENCY	UNCONFINED COMPRESSIVE STRENGTH (TONS/SQ FT)
FINE GRAINED SOILS	0 - 2	VERY SOFT	<0.25
	3 - 4	SOFT	0.25 - 0.50
	5 - 8	FIRM	0.50 - 1.00
	9 - 15	STIFF	1.00 - 2.00
	16 - 30	VERY STIFF	2.00 - 4.00
	31 - 50	HARD	>4.00
	>50	VERY HARD	

	N VALUE * (BLOWS/FT)	RELATIVE DENSITY
COARSE GRAINED SOILS	0 - 4	VERY LOOSE
	5 - 10	LOOSE
	11 - 30	MEDIUM DENSE
	31 - 50	DENSE
	>50	VERY DENSE

* ASTM D 1586; NUMBER OF BLOWS OF 140 POUND HAMMER FALLING 30 INCHES TO DRIVE A 2 IN. O.D., 1.4 IN. I.D. SAMPLER ONE FOOT.

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART

MAJOR DIVISIONS			SYMBOLS	DESCRIPTIONS
COARSE GRAINED SOILS — MORE THAN 50% OF MATERIAL COARSER THAN NO. 200 SIEVE SIZE	GRAVEL AND GRAVELLY SOILS — MORE THAN 50% OF COARSE FRACTION RETAINED ON NO.4 SIEVE	CLEAN GRAVELS — LITTLE OR NO FINES	GW	WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
			GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
		GRAVELS WITH FINES — APPRECIABLE AMOUNT OF FINES	GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
			GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
	SAND AND SANDY SOILS — MORE THAN 50% OF COARSE FRACTION PASSING NO.4 SIEVE	CLEAN SANDS — LITTLE OR NO FINES	SW	WELL GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
			SP	POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
		SANDS WITH FINES — APPRECIABLE AMOUNT OF FINES	SM	SILTY SANDS, SAND-SILT MIXTURES
			SC	CLAYEY SANDS, SAND-CLAY MIXTURES
FINE GRAINED SOILS — MORE THAN 50% OF MATERIAL FINER THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50	ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
			CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
			OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50	MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILT
			CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
			OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS			PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENT

NOTE: DUAL SYMBOLS USED FOR BORDERLINE CLASSIFICATIONS

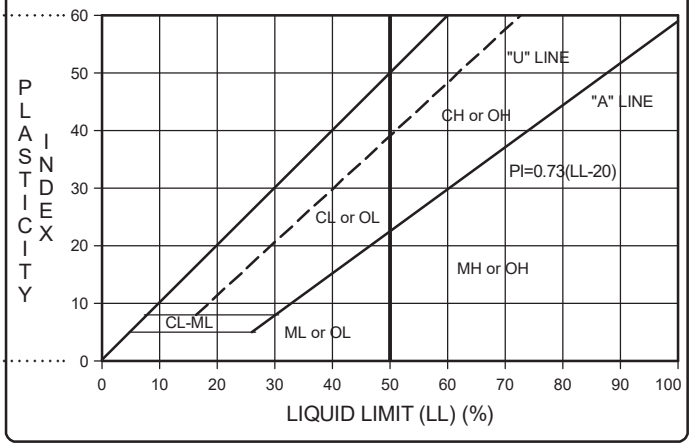
PARTICLE SIZE IDENTIFICATION

BOULDERS	>300 mm
COBBLES	75 - 300 mm
GRAVEL: COARSE	19.0 - 75 mm
GRAVEL: FINE	4.75 - 19 mm
SAND: COARSE	2.00 - 4.75 mm
SAND: MEDIUM	0.425 - 2.00 mm
SAND: FINE	0.075 - 0.425 mm
SILT	0.075 - 0.002 mm
CLAY	<0.002 mm

WELL GRADED - HAVING WIDE RANGE OF GRAIN SIZES AND APPRECIABLE AMOUNTS OF ALL INTERMEDIATE PARTICLE SIZES

POORLY GRADED - PREDOMINANTLY ONE GRAIN SIZE, OR HAVING A RANGE OF SIZES WITH SOME INTERMEDIATE SIZES MISSING

PLASTICITY CHART



OTHER MATERIAL SYMBOLS

- Siltstone
- Sandstone
- Siltstone/Claystone
- Claystone
- Shale
- Siltstone/Sandstone
- Conglomerate
- Granitic
- Sand
- Silt
- Silty Sand
- Alluvium
- Artificial Fill
- Debris Fill
- Asphalt
- Cement

WELL SYMBOLS

- GRANULAR BENTONITE
- BENTONITE CEMENT GROUT
- FILTER PACK
- CONCRETE
- NATIVE/ SLOUGH
- CENTRAL-IZER

SAMPLER AND OTHER SYMBOLS

- GRAB SAMPLE
- SPLIT SPOON
- STANDARD PENETRATION TEST (SPT)
- SHELBY TUBE
- CALIFORNIA SAMPLER
- BULK SAMPLE

- Water Level at Time Drilling, or as Shown
- Static Water Level

MSL: Mean Sea Level
MC: Moisture Content
WA: #200 Wash
DD: Dry Density
SA: Sieve Analysis
PI: Plasticity Index
SG: Specific Gravity
LL: Liquid Limit
c: Cohesion
K: Hydraulic Conductivity
Phi: Friction Angle

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GS FORM: BORE 1/99

BOREHOLE RECORD

BORING J-B-1 **SHEET** 1 OF 2
START DATE 12/17/2015 **ELEVATION** 535.0 FT MSL
FINISH DATE 12/17/2015
PROJECT Joliet Station
LOCATION Joliet, IL
PROJECT NUMBER SW0251-05

DEPTH (ft)	MATERIAL DESCRIPTION	ELEVATION (ft)	SAMPLES: NUMBER	TYPE	BLOW COUNTS	N VALUE	% RECOVERY	TIME	COMMENTS
	FILL: 2 inches of gravel over lean CLAY with sand (CL); light brown; moist; stiff; trace gravel and medium to fine sand		J-B-1-1						MC: 15.2 SA: 80.7 LL: 46, PI: 25
5	Sand and gravel decreases	530	J-B-1-2		5/8/11		100		MC: 18.3 SA: 89.9 PP: 4.5 tsf LL: 43 PI: 23
10	Silty GRAVEL with sand (GM); black and tan; moist; medium dense; coarse angular gravel	525	J-B-1-3		21/22/8		80		Drive casing to 10' MC: 12.2 SA: 29.4
15	**NATIVE:** Well-graded GRAVEL with silt and sand (GW-GM); tan; moist; very dense; large coarse rounded and angular gravel; limestone fragments	520	J-B-1-4		20/40/50		70		MC: 5.6 SA: 7.5 Sample placed in bag
20	Poorly graded GRAVEL with silt and sand (GP-GM); light brown; moist; very dense; fine angular gravel; limestone fragments	515	J-B-1-5		11/55/5"		80		Rig chatter @ 20' MC: 6.0 SA: 10.7
25	Silty GRAVEL with sand (GM); limestone fragments; tan and grey; moist; very dense; coarse to medium sand	510	J-B-1-6		42/50/5"		80		MC: 9.9 SA: 21.8
30		505							

CONTRACTOR Strata
EQUIPMENT Mobile B57
DRILL MTHD Mud Rotary
DIAMETER 6"
LOGGER J. Griffin **REVIEWER** J. Soule

NORTHING 15074043.60
EASTING 1333763.03
ANGLE Vertical
BEARING ------
PRINTED 10/12/16

REMARKS: California sampler used 3" O.D. split barrel sampler lined with thin-walled brass tubes. No groundwater observed during mud rotary drilling.

COORDINATE SYSTEM:

SEE KEY SHEET FOR SYMBOLS AND ABBREVIATIONS

BORING LOG GEOTECH (SW0251) SW0251-05.GPJ SAN DIEGO GINT LIBRARY.GLB 10/12/16

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BOREHOLE RECORD

BORING J-B-1 **SHEET** 2 OF 2
START DATE 12/17/2015 **ELEVATION** 535.0 FT MSL
FINISH DATE 12/17/2015
PROJECT Joliet Station
LOCATION Joliet, IL
PROJECT NUMBER SW0251-05

DEPTH (ft)	MATERIAL DESCRIPTION	SYMBOLIC LOG	ELEVATION (ft)	SAMPLES NUMBER	SAMPLES TYPE	SAMPLES BLOW COUNTS	SAMPLES N VALUE	SAMPLES % RECOVERY	TIME	COMMENTS
	Tan gravel			J-B-1-7		11/11/17		40		100% drilling mud loss @ 30'
	END OF BORING @ 31.5' BACKFILL WITH GROUT									
35			500							
40			495							
45			490							
50			485							
55			480							
60			475							

CONTRACTOR Strata
EQUIPMENT Mobile B57
DRILL MTHD Mud Rotary
DIAMETER 6"
LOGGER J. Griffin **REVIEWER** J. Soule

NORTHING 15074043.60
EASTING 1333763.03
ANGLE Vertical
BEARING ------
PRINTED 10/12/16

REMARKS: California sampler used 3" O.D. split barrel sampler lined with thin-walled brass tubes. No groundwater observed during mud rotary drilling.

COORDINATE SYSTEM:
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GS FORM: BORE 1/99

BOREHOLE RECORD

BORING J-B-2 **SHEET** 1 OF 2
START DATE 12/17/2015 **ELEVATION** 535.0 FT MSL
FINISH DATE 12/17/2015
PROJECT Joliet Station
LOCATION Joliet, IL
PROJECT NUMBER SW0251-05

DEPTH (ft)	MATERIAL DESCRIPTION	ELEVATION (ft)	SAMPLES NUMBER	TYPE	BLOW COUNTS	N VALUE	% RECOVERY	TIME	COMMENTS
	FILL: Silty SAND with gravel (SM); moist; brown		J-B-2-1						
5	Silty GRAVEL with sand (GM); black; moist; medium dense; angular coarse gravel and coarse to fine sand	530	J-B-2-2		11/7/7		80		MC: 11.8 SA: 20.1
10	Coarse limestone fragments	525	J-B-2-3		4/7/4		50		Drive casing to 10'
15	Poorly graded GRAVEL with silt (GP-GM); tan and black; moist; medium dense to dense; fine gravel and trace sand	520	J-B-2-4		9/15/12		0		No recovery
			J-B-2-5		10/21/18		10		MC: 9.2 SA: 7.1
20	**NATIVE:** Poorly graded GRAVEL with silt and sand (GP-GM); red; moist; medium dense to dense; limestone fragments.	515	J-B-2-6		8/8/11		5		Casing to 20'; 100% drilling mud loss at 20'; No sample recovered for J-B-2-6
25		510	J-B-2-7		18/22/23		70		3" SS no liners to attempt better recovery MC: 6.6 SA: 7.5
30		505							Casing to 30', no liner

CONTRACTOR Strata
EQUIPMENT Mobile B57
DRILL MTHD Mud Rotary
DIAMETER 6"
LOGGER J. Griffin **REVIEWER** J. Soule

NORTHING 15073969.82
EASTING 1333284.12
ANGLE Vertical
BEARING ------
PRINTED 10/12/16

REMARKS: California sampler used 3" O.D. split barrel sampler lined with thin-walled brass tubes. No groundwater observed during mud rotary drilling.

COORDINATE SYSTEM:

SEE KEY SHEET FOR SYMBOLS AND ABBREVIATIONS

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GS FORM: BORE 1/99

BOREHOLE RECORD

BORING J-B-2 **SHEET** 2 OF 2
START DATE 12/17/2015 **ELEVATION** 535.0 FT MSL
FINISH DATE 12/17/2015
PROJECT Joliet Station
LOCATION Joliet, IL
PROJECT NUMBER SW0251-05

DEPTH (ft)	MATERIAL DESCRIPTION	SYMBOLIC LOG	ELEVATION (ft)	SAMPLES NUMBER	SAMPLES TYPE	SAMPLES BLOW COUNTS	SAMPLES N VALUE	SAMPLES % RECOVERY	TIME	COMMENTS
	Poorly graded GRAVEL (GP); fine gravel; some sand and trace silt; tan; moist; very dense			J-B-2-8		22/21/24		70		MC: 6.2 SA: 2.7
35			500	J-B-2-9		36/36/27		80		Casing to 35', no liner
	END OF BORING @ 36.5' REMOVE CASING AND BACKFILL WITH GROUT									
40			495							
45			490							
50			485							
55			480							
60			475							

CONTRACTOR Strata
EQUIPMENT Mobile B57
DRILL MTHD Mud Rotary
DIAMETER 6"
LOGGER J. Griffin **REVIEWER** J. Soule

NORTHING 15073969.82
EASTING 1333284.12
ANGLE Vertical
BEARING ------
PRINTED 10/12/16

REMARKS: California sampler used 3" O.D. split barrel sampler lined with thin-walled brass tubes. No groundwater observed during mud rotary drilling.

COORDINATE SYSTEM:
SEE KEY SHEET FOR SYMBOLS AND ABBREVIATIONS

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Attachment 3

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SUMMARY LETTER

October 13, 2005

Ms. Maria L. Race
Midwest Generation EME, LLC
One Financial Place
440 South LaSalle Street, Suite 3500
Chicago, Illinois 60605

VIA FEDERAL EXPRESS

KPRG Project No. 15805

Re: Geotechnical Analysis of Soil Surrounding Settling Basins/Ponds

Dear Ms. Race:

KPRG and Associates, Inc. (KPRG) has recently received the geotechnical testing results from the soil boring program implemented in the vicinity of various ponds located at six of the Midwest Generation stations. Specifically, these stations and the number of borings advanced at each were:

- Waukegan Station (5 borings)
- (
- Will County Station (5 borings)
- Joliet #29 Station (6 borings)
- Joliet #9 Station (3 borings)
- Powerton Station (9 borings)

This letter report provides a project objective, documents the field procedures, identifies the geotechnical laboratory specifications and summarizes the geotechnical testing results. Each item is discussed separately below.

PROJECT OBJECTIVE

Based on discussions with Midwest Generation, the objective of the project was to obtain stratigraphic and geotechnical data from the vicinity of specific ponds at the various station locations. The results of the investigation would provide a physical characteristic data base for subsequent engineering evaluations, planning and decision analysis. The soil sample collection for geotechnical analysis was targeted for the approximate equivalent base elevation of each pond as specified by Midwest Generation.

FIELD PROCEDURES

Prior to mobilizing for drilling activities, Midwest Generation contracted Lucky Locators, Inc. to provide utility clearance at each pre-established drilling location. Once the utility clearance was provided, KPRG mobilized a geoprobe rig which utilizes a direct hydraulic push technology for collecting soil cores. Continuous 5-foot core samples were collected during drilling at each location. The core samples were screened in the filed for total organic vapors with a photoionization detector (PID) and where appropriate, compressive strength readings were taken using a hand penetrometer. At the approximate base elevation of the adjoining pond, an attempt was made to push a Shelby Tube for collection of an undisturbed sample for subsequent geotechnical analysis. If the subsurface conditions did not allow for sample collection by pushing a Shelby Tube, an acetate core sample was collected for submittal for geotechnical analysis. If the targeted interval consisted of sufficiently coarse material that would not allow for either proper Shelby Tube or acetate core sampling, a representative volume of retrieved sample was placed into a plastic baggie for submittal for geotechnical analysis. Table 1 summarizes the overall results of the geotechnical sampling effort relative to station, sample identification number, sample collection type and depth.

Upon completion of sampling at each location, the boring was abandoned by placing unsampled core material back into the hole and filling the remainder of the boring with granular bentonite. A surface patch was then placed to match the surrounding surficial material.

GEOTECHNICAL LABORATORY SPECIFICATIONS

KPRG subcontracted Terracon Consulting Engineers (Terracon) to perform the geotechnical laboratory analyses. The following geotechnical testing methods were run by Terracon:

- Grain Size with Hydrometer (ASTM Method D 422)
- Atterberg Limits (ASTM Method D 4318)
- Bulk Density (ASTM Method D 2937)
- Specific Gravity (ASTM Method D 854)
- Moisture Content (ASTM Method D 2216)
- Permeability (ASTM Method D 5084)
- USCS Soil Classification

In accordance with KPRG's proposal, Terracon was instructed to first run the Grain Size Distribution and Atterberg Limits testing. Based on these results, permeability testing was only performed if the Plasticity Index (PI) was less than 11 or if there was less than a 30% fraction passing the 200 mesh sieve. If both of these criteria were met (i.e., a PI of greater than 11 and greater than 30% fraction passing the 200 mesh sieve), the material should have a permeability in the order of 10^{-7} cm/sec which should provide sufficient

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information for most desk-top engineering evaluations. As noted further below, only a few of the samples actually met these criteria.

It is noted that geoprobe acetate tube and/or baggie samples are not considered "undisturbed" samples and that some remolding/recompaction was required for completing permeability tests.

RESULTS

Table 1 summarizes the various samples collected for geotechnical analysis by station location and depth interval. The table notes whether the sample sent to the laboratory was a Shelby Tube, acetate tube or baggie sample.

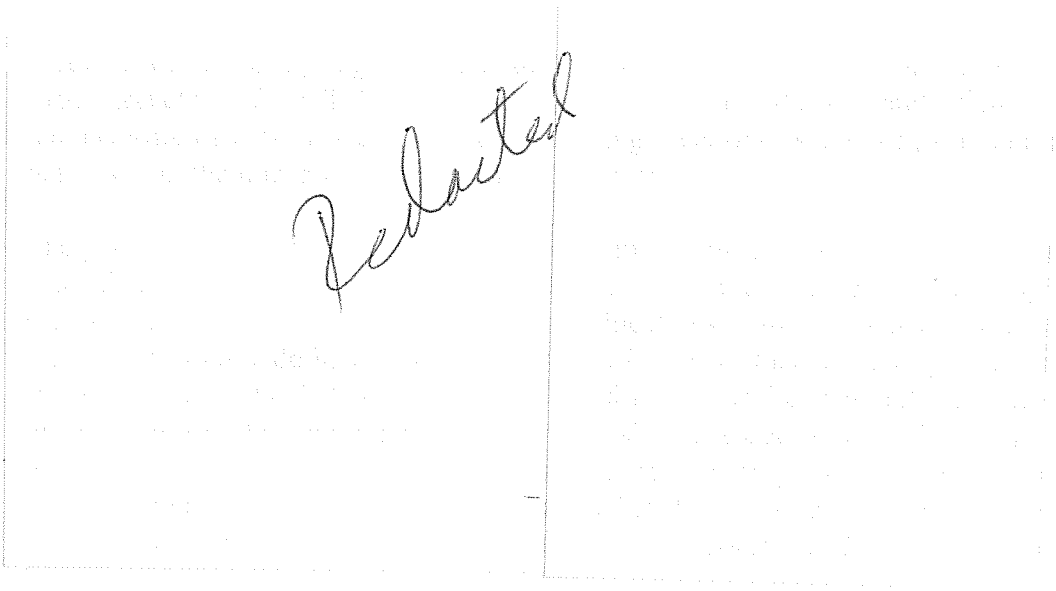
The results of the geotechnical investigation program are organized separately for specific stations and provided in Attachments 1 through 6 along with sample location maps. A brief summary for each station is provided below. The complete geotechnical laboratory report is provided in Attachment 7.

Waukegan Station

A total of five borings were drilled and sampled at the Waukegan Station (WS-GT-1 through WS-GT-5). The approximate sample locations are provided on Figure 1-1 in Attachment 1 along with the results of the geotechnical testing in Table 1-1 and the associated soil boring logs.

A review of the boring logs indicates that the subsurface materials were generally sandy with some gravel and/or silts and clays. Some areas were noted to containing fill material generally consisting of ash/slag.

The geotechnical data in Table 1-1 from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) also document these materials to be classified as sands with some gravel, silt and/or clay. Permeabilities were found to range from 1.0×10^{-3} cm/sec to 2.3×10^{-2} cm/sec. These permeabilities are consistent with sandy/gravelly materials.



Will County Station

A total of five borings were drilled and sampled at the Will County Station (WC-GT-1 through WC-GT-5). The approximate sample locations are provided on Figure 3-1 in Attachment 3 along with the results of the geotechnical testing in Table 3-1 and the associated soil boring logs.

A review of the boring logs indicates that the subsurface stratigraphy varied across the site. The northern most boring (WC-GT-1) has a sandy/gravelly unit overlying a clay unit with weathered bedrock being encountered between 4.5 and 5 feet below ground surface (bgs). Borings WC-GT-2 through WC-GT-4 located on the west central portion of the property generally had a 1.5 to 2.5 foot thick fill layer with ash/slag and underlying sandy and gravelly units. Bedrock was generally encountered at around 10 feet bgs. The southern most boring (WC-GT-5) had a silty/sandy/gravelly layer overlaying weathered bedrock which was encountered at about 2.5 feet bgs.

The geotechnical data in Table 3-1 from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) also document these materials to be classified as sands with some gravel or silts/clays. Permeabilities for the clayey and silty materials at borings WC-GT-4 and WC-GT-3 were estimated to range from 3.65×10^{-7} cm/sec to 1.86×10^{-6} cm/sec, respectively. It is noted, however, that the remolding for these samples could not meet the analytical method standard requirements due to the coarse fractions and that the values provided a verbal estimates. The true values could not be quantified due to the noted remolding issue and, therefore, are not included in the formal quantified results table provided by the geotechnical laboratory in Attachment 7. The coarser sandy and/or gravelly materials at locations WC-GT-2 and WC-GT-1 showed permeabilities at 4.02×10^{-3} and 1.35×10^{-1} cm/sec, respectively. The permeability for sample WC-GT-5 could not be run due to the relative amount of gravel which precluded being able to properly

remold a sample for the permeability analysis. This of itself suggests a relatively high permeability layer.

Joliet Station #29

A total of six borings were drilled and sampled at Joliet Station #29 (JS29-GT-1, through JS29-GT-6). The approximate sample locations are provided on Figure 4-1 in Attachment 4 along with the results of the geotechnical testing in Table 4-1 and the associated soil boring logs.

A review of the boring logs indicates that the subsurface stratigraphy varied across the site from primarily sand/gravel at location JS29-GT-1 to primarily clay at locations JS29-GT-3, JS29-GT-5 and JS29-GT-6. The boring logs for the remaining locations indicate an interlayering of the coarse and fine materials. Some minor amounts of ash/slag were noted at some locations within the upper foot of material. Bedrock was definitively encountered only at location JS29-GT-6 at a depth of approximately 15 feet bgs.

The geotechnical data in Table 4-1 from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) indicates that the sample from location JS29-GT-6 met the previously defined criteria of a high PI (greater than 11) and greater than a 30% fraction passing the 200 mesh sieve. Therefore, it can be generally assumed that the materials are of low permeability as previously discussed and no further permeability testing was performed on this sample. The results of the permeability tests for locations JS29-GT-1, JS29-GT-3 and JS29-GT-5 ranged from 4.7×10^{-4} to 2.96×10^{-2} cm/sec. The permeabilities for samples JS29-GT-2 and JS29-GT-4 could not be run due to the relative amount of gravel which precluded being able to properly remold a sample for the permeability analysis. This of itself suggests relatively high permeability layers at those locations.

Joliet Station #9

A total of three borings were drilled and sampled at Joliet Station #9 (JS9-GT-1, through JS9-GT-3). The approximate sample locations are provided on Figure 5-1 in Attachment 5 along with the results of the geotechnical testing in Table 5-1 and the associated soil boring logs.

A review of the boring logs indicates that the subsurface stratigraphy varied across the site. Location JS9-GT-1 showed interlayerd gravel/sand and clay with the bottom three feet of the boring being silty sand. Location JS9-GT-2 showed primarily silty and silty sand material with some gravel. A peat layer was also encountered in the bottom three feet of the boring. Location JS9-GT-3 had primarily sandy and gravelly materials to its total depth of 15 feet bgs. A slag layer was logged between approximately 4 and 6 feet bgs.

The geotechnical data in Table 5-1 from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) also document these materials to be rather coarse with high permeabilities.

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The permeability for location JS9-GT-2 was determined to be 2.73 X 10^{-2} cm/sec. The permeabilities for samples JS9-GT-1 and JS9-GT-3 could not be run due to the relative amount of gravel which precluded being able to properly remold a sample for the permeability analysis. This of itself suggests relatively high permeability layers at those locations.

Powerton Station

A total of nine borings were drilled and sampled at Powerton Station (PS-GT-1, through PS-GT-9). The approximate sample locations are provided on Figure 6-1 in Attachment 6 along with the results of the geotechnical testing in Table 6-1 and the associated soil boring logs.

A review of the boring logs indicates a varied stratigraphy from primarily clayey at locations PS-GT-1 and PS-GT-5 to an interlayering of sandy and clayey units at the other locations. It is noted that at locations PS-GT-7 through PS-GT-9, a slag/ash unit was logged starting at between 2 and 3 feet bgs and extending to approximately 15 feet bgs. A two foot ash layer was also logged between 2 and 4 feet bgs at location PS-GT-5.

The geotechnical data from samples collected at elevations approximately equivalent to the base of the various adjacent ponds (as determined by Midwest Generation) indicates that the sample from location PS-GT-5 met the previously defined criteria of a high PI (greater than 11) and greater than a 30% fraction passing the 200 mesh sieve. Therefore, it can be generally assumed that the materials are of low permeability as previously discussed and no further permeability testing was performed on this sample. The remaining permeabilities ranged from 1.6 X 10^{-7} cm/sec to 2.31 X 10^{-2} cm/sec; the lower permeabilities associated with clayey and silty soils and the higher values associated with sandier soils.

KPRG appreciates the opportunity for providing our technical services to Midwest Generation on this project. If there are any questions, please contact me at 262-781-0475.

Sincerely,
KPRG and Associates, Inc.

Richard R. Gnat

Richard R. Gnat, P.G.
Principal

TABLE

Table 1. Summary of Samples Collected for Geotechnical Analysis

STATION	BORING ID	SHELBY TUBE (Depth Ft)	GEOPROBE TUBE (Depth Ft)	BAGGIE SAMPLE
Waukegan	WS-GT-1		5-10	
	WS-GT-2	7.5-10	5-10	
	WS-GT-3		5-10	
	WS-GT-4		22-27	
	WS-GT-5		22-27	
Will County	WC-GT-1		5-10	
	WC-GT-2		5-10	
	WC-GT-3		3-8	3-8
	WC-GT-4		5-10	
	WC-GT-5		5-9	5-9
Joliet #29	JS29-GT-1		19-24	15-19
	JS29-GT-2		19-24	
	JS29-GT-3		19-24	17-19
	JS29-GT-4		17-22	
	JS29-GT-5		9-14	
	JS29-GT-6		11-14	11-14
Joliet #9	JS9-GT-1		7-12	7-10
	JS9-GT-2		7-11.5	7-10
	JS9-GT-3		8-13	8-11
Powerton	PS-GT-4	10-11.5		
	PS-GT-5	17-19		
	PS-GT-6		15-20	
	PS-GT-7		10-15	
	PS-GT-8		10-13	
	PS-GT-9		13-18	

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ATTACHMENT 1
Waukegan Station Geotechnical Study Results

Suggested
Possible Alternate
Soil Sample Sites cleared by Lucky Locators Inc.
WS-GT-1
WS-GT-2
WS-GT-3
WS-GT-4
WS-GT-5

Figure 1-1

Table 1-1. Soil Sample Geotechnical Data - Midwest Generation, Waukegan Station, Waukegan, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
WS-GT-1	5 to 10'	Sand with trace gravel	5.6	114	NP	NP	94	1	2.63	1.05x10-2
WS-GT-2	7.5'-10'	Silty Sand, trace gravel, dark brown	15.2	107	NP	NP	79	7	2.44	1.52x10-2
			18.1							
WS-GT-3	5 to 10'	Sand with trace gravel	11.2	99	NP	NP	86	0	2.65	2.3x10-2
WS-GT-4	22-27'	Sand with trace gravel	5.4	114	NP	NP	53	2	2.64	2.16x10-2
WS-GT-5	22-27'	Sand, trace gravel, black	4.4	96	NP	NP	15	0	2.73	1.0x10-3
		(Bottom Ash?)								

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
NA - Not Analyzed
NP - Not Plastic

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LOG OF BORING WS-GT-1

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND and GRAVEL, gray and orange brown. Dry.	1	0.0		
1–3	SP		SLAG, black, medium to coarse sand and gravel, some bottom ash. Dry.	2	0.0	80	
3–5	SP		SAND, fine to medium, light brown, trace silt. Slightly Moist.				
5–10			Push Geoprobe Tube 5 to 10.				
10			End of boring at 10 feet.				

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LOG OF BORING WS-GT-2

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND and GRAVEL, brown and black. Dry.	1	0.0		
1–4	SP		SAND, fine to medium, brown, trace silt and gravel. Slightly Moist. - wet	2	0.0	80	
4–5	SP		SAND, fine to medium, little silt. Very Moist.				
5–10			Push Geoprobe Tube 5 to 10. Pushed Shelby tube in new boring 5 to 10 feet. 18" recovery.				
10			End of boring at 10 feet.				

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LOG OF BORING WS-GT-3

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND and GRAVEL, dark brown. Dry.	1	0.0		
1–2	SP		Bottom Ash, black and gray, fine, some sand and gravel. Dry.				
2–3	CO		COAL, black, some gray clayey bottom ash. Moist.	2	0.0	80	
3–4	SP		SAND, fine to medium, black and brown, little silt. Moist.				
4–5			Push Geoprobe Tube 5 to 10. Full recovery.				
5–6							
6–7							
7–8							
8–9							
9–10							
10–11			End of boring at 10 feet.				
11–12							
12–13							
13–14							
14–15							
15–16							
16–17							
17–18							
18–19							
19–20							

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LOG OF BORING WS-GT-4

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND and GRAVEL, brown. Dry.	1	0.0		
1–3	GW		Bottom Ash and SAND and GRAVEL Mixture. Very Moist.	2	0.0	100	
3–10	GW		Bottom Ash, black, medium to coarse sand and gravel, some fines. Slightly Moist.	3	0.0		
				4	0.0	80	
			- wet, some organics				
10–13	SP		SAND, fine to medium, some silt and clay, brown, organics. Slightly Moist.	5	0.0		
13–19	SP		Bottom Ash, black, granular, medium to coarse sand and gravel. Slightly Moist.	6	0.0	70	
				7	0.0		
19–22	SP		SAND, gray, fine to medium, trace silt.	8	0.0		
22–27			Push Geoprobe Tube 22 to 27 feet. Full Recovery				
27			End of boring at 27 feet.				

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LOG OF BORING WS-GT-5

Midwest Generation
Waukegan Station
Waukegan, IL

Project No. 15805

Date Completed : 08/08/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND and GRAVEL, brown, grass. Dry.	1	0.0		
1–4	SM		Bottom Ash, light gray, fine sand and silt powder. Dry.	2	0.0	80	
			- 3" light brown SAND, fine to medium. Dry.	3	0.0		
4–9	SM		Bottom Ash, fine to medium sand and silt, brown some gray, some slag. Slightly Moist.	4	0.0	100	
9–22	SP		Bottom Ash, black, granular, medium to coarse sand and gravel. Slightly Moist.	5	0.0		
				6	0.0	60	
				7	0.0	80	
				8	0.0	100	
22–27			Push Geoprobe Tube 22 to 27 feet. 24" Recovery.				
27			End of boring at 27 feet.				

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ATTACHMENT 3
Will County Station Geotechnical Study Results

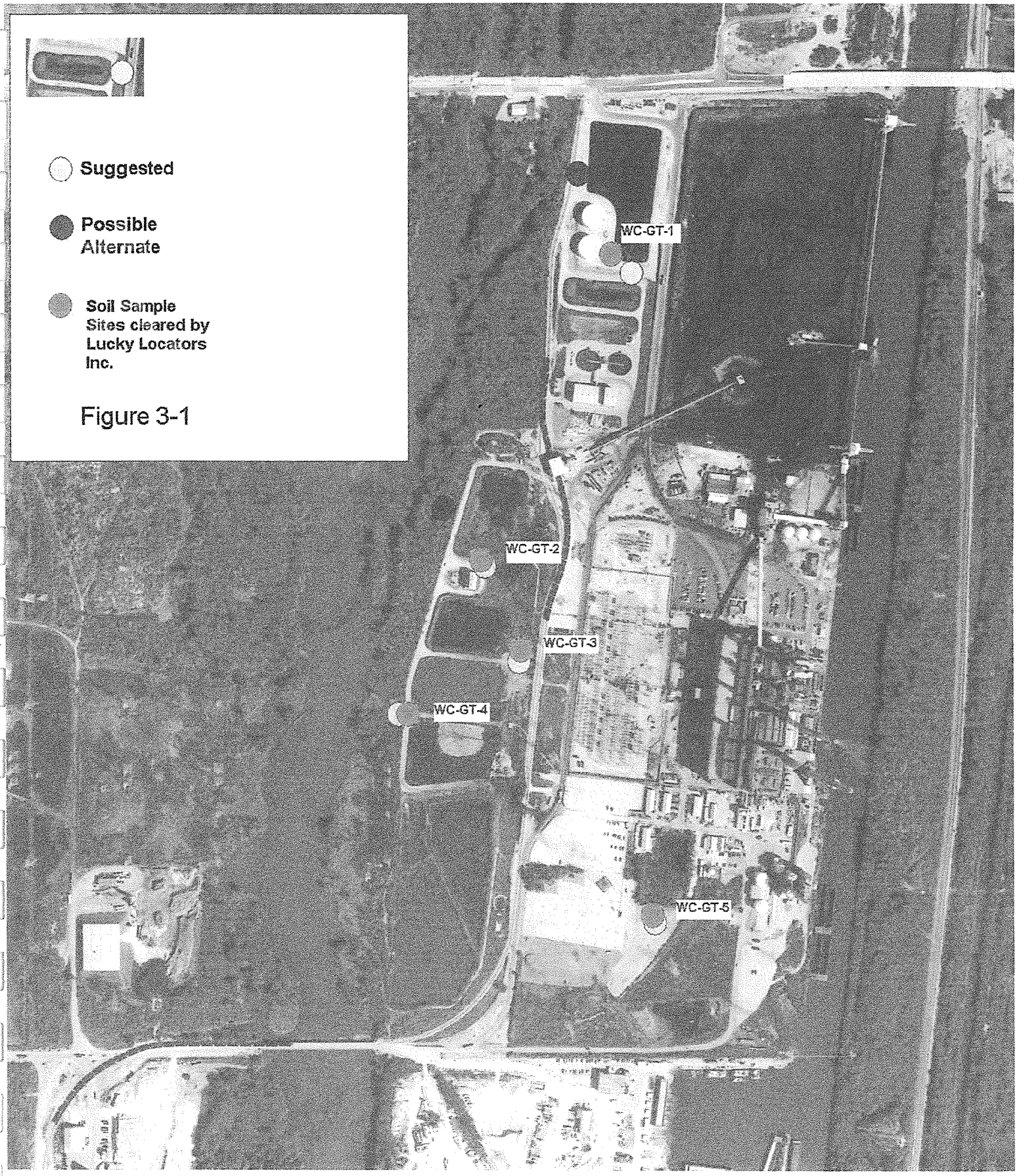

Suggested
Possible Alternate
Soil Sample Sites cleared by Lucky Locators Inc.
WC-GT-1
WC-GT-2
WC-GT-3
WC-GT-4
WC-GT-5

Figure 3-1

Table 3-1. Soil Sample Geotechnical Data - Midwest Generation, Will County Station, Romeoville, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
WC-GT-1	5 to 10'	Clayey Sand, dark brown to tan	3.4	118	31	15	25.1	11.4	2.66	1.35x10-1
WC-GT-2	5 to 10'	Sand with gravel, dark brown	18.1	92	NP	NP	35.1	11.9	2.65	4.02x10-3
WC-GT-3	3 to 8'	Lean Clay, dark brown	10.0	103	35	12	25.6	19.7	2.71	1.86x10-6***
WC-GT-4	5 to10'	Silty Clay, dark brown	9.5	128	25	7	35.4	23.3	2.7	3.65x10-7***
WC-GT-5	5-9'	Sandy Clay with Gravel	4.2	119	NP	NP	39	35	2.65	*

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
***Verbal estimate provided by geotechnical lab. The data package in Attachment 7 indicates that due to the coarse fraction the samples could not be ideally remolded. The above verbal estimate is not a quantitaive number due to the remolding issue and is therefore not reported as such in Attachment 7.
NA - Not Analyzed
NP - Not Plastic

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LOG OF BORING WC-GT-1

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed : 08/09/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		GRAVEL and SAND, light brown / gray, trace silt and clay. Dry.	1	0.0		
1–3	CL		CLAY, dark brown, some sand and gravel. Dry.	2	3.0	80	>4.5
3–5	GW		SLAG and Bottom Ash, black and dark gray, medium to coarse sand, little silt. Dry to Slightly Moist. - clayey weathered bedrock, gray, moist	3	25		

End of Boring at 5 feet.
Push geoprobe tube 0 to 5 feet in new boring.

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LOG OF BORING WC-GT-2

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed : 08/09/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	ML		Bottom Ash, brown and black, fine, little gravel. Dry. - increase gravel	1	0.0		
3–5	SP		SAND, fine to medium, dark brown to brown, little silt. Slightly Moist to Moist.	2	0.0	80	
6–7	SP			3	0.0		
8–9	SP		- very moist	4	0.0	80	
10			End of Boring at 10 feet. Push geoprobe tube 5 to 10 feet in new boring.				

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LOG OF BORING WC-GT-3

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed : 08/09/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SP		Bottom Ash and Coal, black, fine to medium, little gravel. Slightly Moist.	1	0.0		
2	GW		SAND-SILT-GRAVEL mixture, with crushed limestone, Slightly Moist.				
3–4	CL/GW		CLAY and GRAVEL, dark brown. Slightly Moist.	2	0.0	70	
5	CL/GW		- layer orange brown sand and gravel				
6–7	CL/GW			3	0.0		
8–9	GW		SLAG, black, fine to medium sand with fine gravel. Moist.	4	0.0	40	
	GW		- clayey weathered bedrock, gray				
10			End of Boring at 9.5 feet.				
11			Attempt push Shelby Tube, colapsed.				
12			Push geoprobe tube 3 to 8 feet in new boring. 28 " recovery.				
13–20							

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KPRG and Associates, Inc.

LOG OF BORING WC-GT-4

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed : 08/09/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SP		Bottom Ash, sand and gravel. Dry. - black silt and fine sand, trace gravel. Dry. - gray	1	0.0		
2	CL/GW		CLAY and GRAVEL, some sand, dark brown. Dry.				
3–4	GW		SAND and GRAVEL, light brown. Dry.	2	0.0	100	
5–6			Pushed Geoprobe Tube 5 to 10. 41" recovery.	3	0.0		
7–9				4	0.0	70	
10			End of Boring at 10 feet.				
11–20							

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KPRG and Associates, Inc.

LOG OF BORING WC-GT-5

Midwest Generation
Will County Station
Romeoville, IL

Project No. 15805

Date Completed : 08/09/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

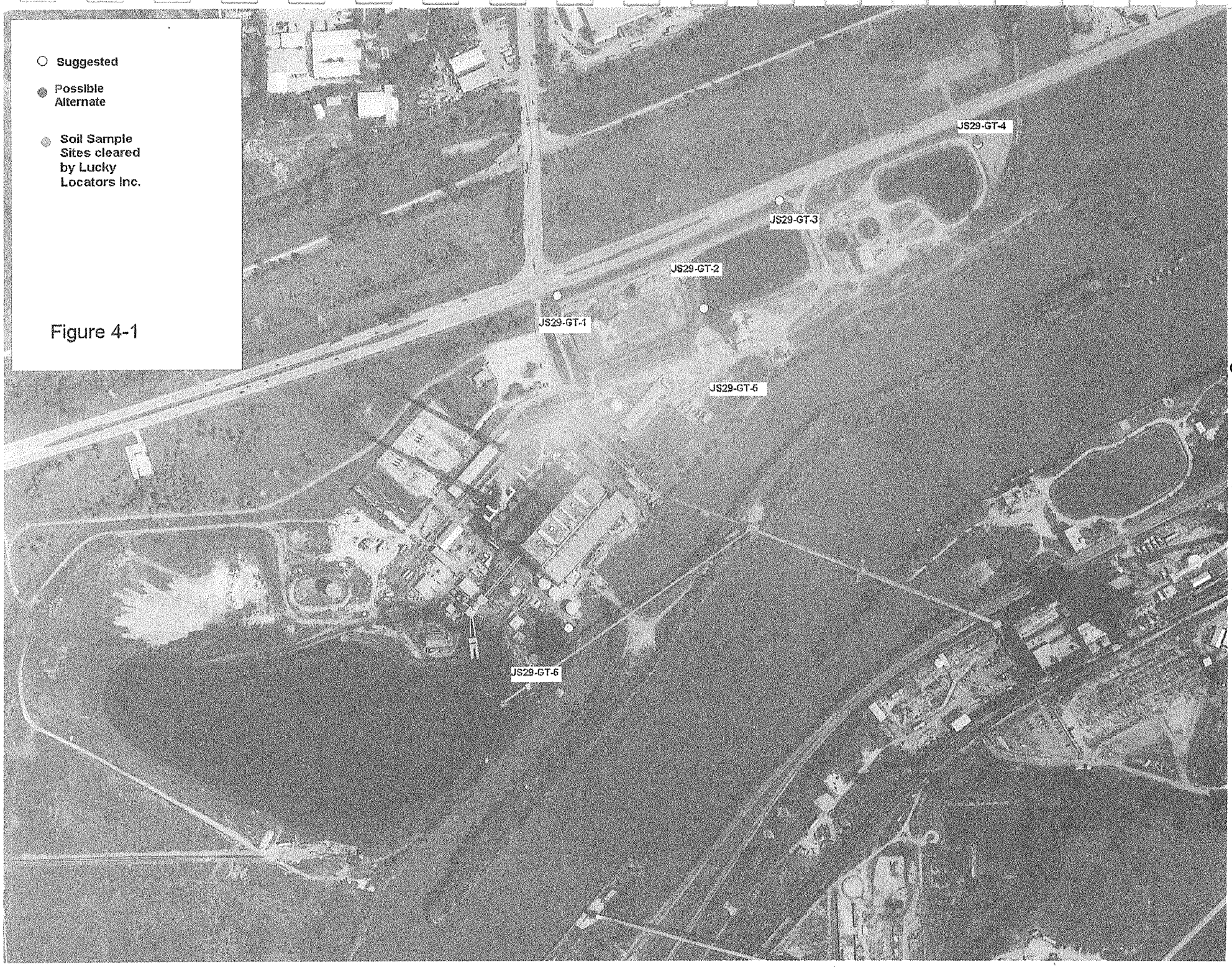
Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		SAND-SILT-GRAVEL Mixture, brown, black, white, orange/brown. Dry to Slightly Moist.	1	0.0		
1–2	WBR		Weathered Bedrock, limestone. Moist.	2	0.0	100	

End of Boring at 2.5 feet.

Repeated boring for sample volume. Bagged.

ATTACHMENT 4

Joliet Station #29 Geotechnical Study Results



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Table 4-1. Soil Sample Geotechnical Data - Midwest Generation, Joilet Station #29, Joliet, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
JS-29-GT-1	19-24'	Sand, fine grained, trace clay and gravel, dark yellow	5.3	120	NP	NP	13.9	8.7	2.62	2.96x10-2
JS-29-GT-2	19-24	Gravelly sand, brown	10.0	87.0	NP	NP	21	14	2.66	*
		Gravelly sand, trace clay, dark brown	6.0							
JS-29-GT-3	19-24	Sand, with gravel, trace clay, brown	8.6	121**	NP	NP	13	9	2.64	2.51x10-2
		Lean clay, gray	7.3							
JS-29-GT-4	17-22	Limestone with fine to coarse sand	4.1	124.0	NP	NP	11	7	2.7	*
JS29-GT-5	5-14'	Clayey gravel with sand, dark gray	26.0	94.0	34	11	32	18.7	2.56	4.7x10-4
JS-29-GT-6	11-14'	Organic clay, dark gray, black	74.6	53.0	78	17	88.9	65.4	2.41	NA

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
NA - Not Analyzed
NP - Not Plastic

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LOG OF BORING JS29-GT-1

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		Bottom Ash and GRAVEL, dark gray. Dry.	1	0.0		
1–2	GW		Crushed Limestone, gravel and sand, clayey at 1.5 to 2 feet. Slightly Moist.	2	0.0	80	
2–3	GW		SAND and GRAVEL, orange brown, little silt, very stiff. Dry to Slightly Moist.	3	0.0		
3–4	GW						
4–5	GW			4	0.0	70	
5–6	GW						
6–7	GW			5	0.0		
7–8	GW						
8–9	GW			6	0.0	60	
9–10	GW						
10–11	GW						
11–12	GW						
12–13	GW						
13–14	GW		- 10 "clayey	7	0.0		
14–15	GW						
15–16	GW						
16–17	GW			8	0.0	50	
17–18	GW						
18–19	GW			9	0.0		
19–20	GW		Push Geoprobe Tube 19 to 24. 33" recovery.				
20–21	GW						
21–22	GW						
22–23	GW						
23–24	GW						
24–25			End of Boring at 24 feet.				
25–26							
26–27							
27–28							
28–29							
29–30							

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LOG OF BORING JS29-GT-2

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SM		SAND and SILT, fine to medium, dark brown, some slag. Dry.	1	0.0		
1–2	GW		Crushed Limestone, sand and gravel. Dry.				
2–6	GW/CL		CLAY and GRAVEL, dark brown, black, some sand and silt. Slightly Moist.	2	0.0	60	
5–6			- 6" clayey, black, soft				
6–10			- 6" coarse gravel and cobbles	3 4	0.0 0.0	40	
10–15	CL		SILT and CLAY, black, some sand and gravel, soft, organic odor. Moist.	5	0.0	40	1.0
11–14			- some limestone gravel	6	0.0		1.0
15–22			Push Geoprobe Tube 15 to 19. 19" recovery. Push Geoprobe Tube 19 to 22. 22" recovery.				
22			End of Boring at 22 feet.				

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LOG OF BORING JS29-GT-3

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	CL		Bottom Ash, dark brown, clay, little gravel. Dry.	1	0.0		
	GW		Crushed Limestone, sand and gravel. Dry.				
3–4	CL		CLAY, dark brown, brown, some sand and silt, trace gravel. Slightly Moist.	2	0.0	100	4.0 - >4.5
5–6			- mostly brown, slightly moist	3	0.0	100	4.0 - >4.5
7–8			- 1" black layer	4	0.0		4.0 - >4.5
9–11			- trace gray silt	5	0.0	100	4.0 - >4.5
12–14			- softer	6	0.0		1.0 - 1.5
15	CL		CLAY, brown, little to trace sand and silt, trace gravel. Slightly Moist.				
16	CL		CLAY, brown, with gray silt, some dark. Moist.				
17–18	CL		CLAY, dark brown, some silt, sand and gravel. Moist.	7	0.0	100	1.0 - 4.0
			- vug of dark gray fine sand, wet.				
19–24			Push Geoprobe Tube 19 to 24. 30" recovery.				
25			End of Boring at 24 feet.				

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LOG OF BORING JS29-GT-4

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–5	CL/GP		GRAVEL CLAY and GRAVEL, coarse, dark brown, some sand and silt, stiff. Dry. - some brown and orange brown	1 2	0.0 0.0	60	
5–6	CL		SILT and CLAY, dark brown and black, close to peat. Moist.	3	0.0		1.5
6–17	GW		SAND and GRAVEL, orange brown, some coarse gravel, trace silt. Dry.	4 5 6 7 8	0.0 0.0 0.0 0.0 0.0	60 50 50	
17–22			Push Geoprobe Tube 17 to 22. 33" recovery.				
22			End of Boring at 22 feet.				

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LOG OF BORING JS29-GT-5

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0-2	TS		Top Soil, black, clayey, some gravel. Slightly Moist. GRAVEL, brown, some sand and silt. Dry.	1	0.0		
2-4	CL		CLAY, dark brown and black, some silt, little sand and gravel, moderately soft. Slightly Moist. - cobble	2	0.0	80	1.5 - 2.0
4-6				3	0.0	75	
6-8							
8-10			- cobble	4	0.0		
10-12				5	0.0	50	
12-14			- wet gravel	6	0.0		

End of Boring at 14 feet.

Attempted Shelby Tube, colapsed then refusal.

Retained Geoprobe Tube 5 to 9. 34" recovery.
Retained Geoprobe Tube 9 to 14. 22" recovery.

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LOG OF BORING JS29-GT-6

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

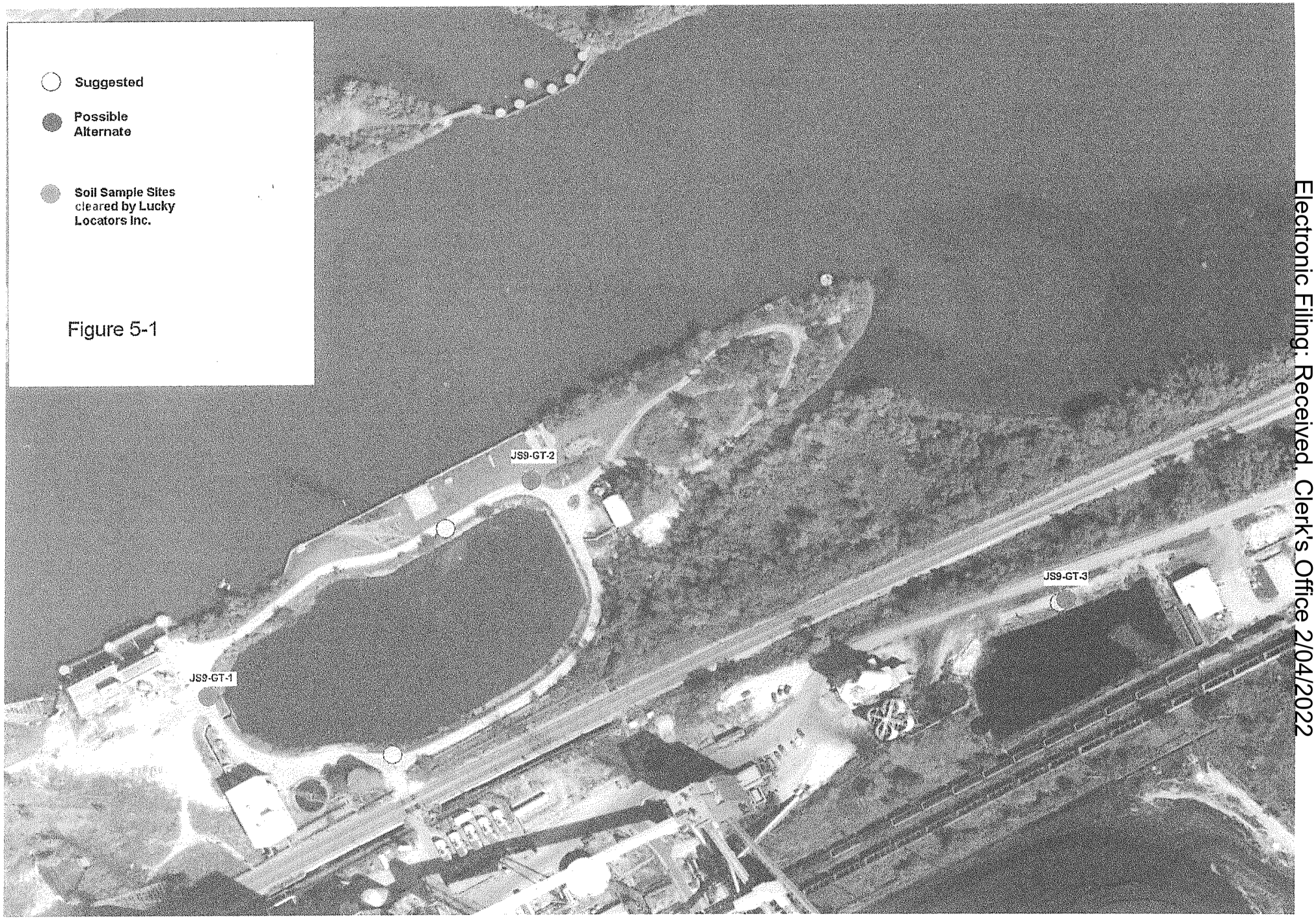
Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0-1	ML		Bottom Ash, silt, black, some gravel. Dry.				
1-2	GW		Crushed Limestone, sand and gravel. Dry.	1	0.0		
2-3	CL		CLAY, black, some sand and gravel and bottom ash. Dry.				
3-6	GW		SAND and GRAVEL, orange brown, some silt and clay. Dry.	2	0.0	70	
				3	0.0		
6-9	CL		CLAY, black, with sand and gravel. Slightly Moist. - orange brown, dry	4	0.0	70	
9-10	CG		GRAVEL, black, some silt and clay. Wet.	5	0.0		
10-15	PT		PEAT, blalck, soft. Slightly Moist to Moist. - wet - weathered bedrock	6	0.0	100	1.0 - 1.5

End of Boring at 15 feet.

Bagged 11 to 14 feet. Also from new hole 11 to 14 feet.

ATTACHMENT 5
Joliet Station #9 Geotechnical Study Results



Electronic Filing: Received, Clerk's Office 2/04/2022

Table 5-1. Soil Sample Geotechnical Data - Midwest Generation, Joliet Station #9, Joliet, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
JS-9-GT-1	7-12'	Sand, with gravel, gray	4	110	16	NP	32	23	2.63	*
		Organic clay, with gravel	20.0							
JS-9-GT-2	7-11.5'	Clayey sand, with organics, trace gravel, dark brown	23.7	91.0	NP	NP	51	21		2.73x10-2
		Organic clay, occasional shells and peat, trace gravel, black, dark brown	56.3							
JS-9-GT-3	8-13'	Sand, with gravel, gray	5.5	86	NP	NP	11	7	2.66	*

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
NA - Not Analyzed
NP - Not Plastic

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LOG OF BORING JS9-GT-1

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0	GW		Crushed Limestone and SILT, gray and black. Dry.	1	0.0		
1	CL		CLAY, dark brown, with gravel, little silt and fine to medium sand. Slightly Moist.	2	0.0	100	
2							
3			- 3" crushed limestone gravel	3	0.0		
4							
5			- 3" crushed limestone gravel				
6	GW		SAND-SILT-GRAVEL Mixture, black, moderately stiff. Moist. - gravel	4	0.0	60	
7							
8	SM		SILT and fine SAND, black, some clay. little gravel. Moist.	5	0.0		
9			- 3" gravel				
10							
11			End of Boring at 10 feet.				
12			Push Geoprobe Tube in new boring 7 to 12 feet. 26" Recovery.				
13							
14							
15							
16							
17							
18							
19							
20							

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LOG OF BORING JS9-GT-2

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	ML		SILT, gray, with fine sand and gravel. Moist.	1	0.0		
1–2	CL/GW		CLAY and GRAVEL, dark brown, some silt and fine to medium sand. Moist.	2	0.0	90	
2–7	SM		SAND-SILT-CLAY Mixture, black, little gravel. Moist.	3	0.0		
				4	0.0	30	
7–10	PT		PEAT, black/dark brown, trace shells. Moist.	5	0.0		<1.0

End of Boring at 10 feet.

Push Geoprobe Tube in new boring 7 to 11.5 feet.
Refusal. 35" Recovery.

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LOG OF BORING JS9-GT-3

Midwest Generation
Joliet Station #29
Joliet, IL

Project No. 15805

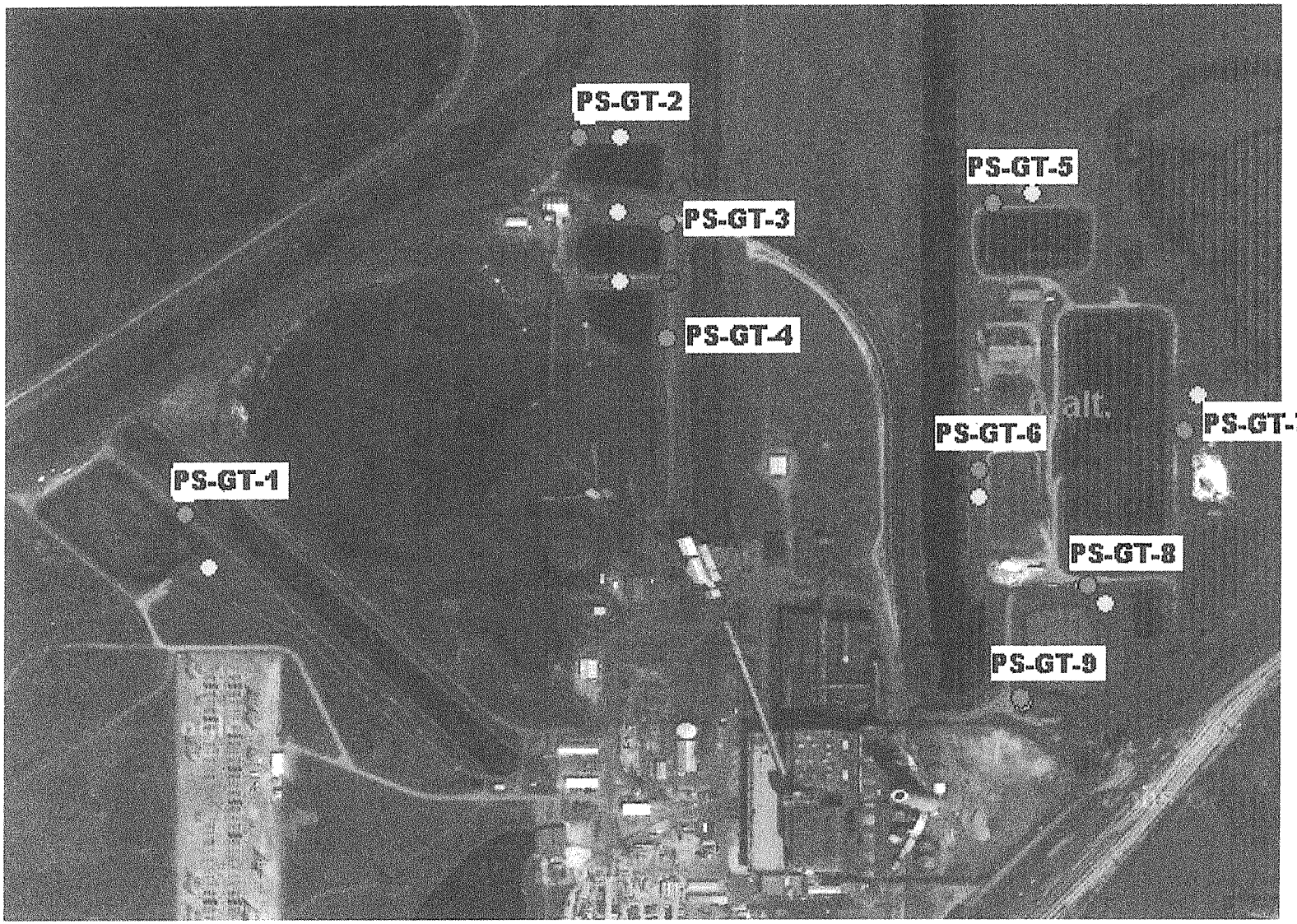
Date Completed : 08/10/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SM		SILT and fine SAND, organics, black. Moist.	1	0.0		
1–2	SM		SAND-SILT-CLAY Mixture, black, trace coarse gravel. Slightly Moist.	2	0.0	50	
2–4	GW		Crushed Limestone GRAVEL. Slightly Moist.	3	0.0		
4–6	SM		SLAG, black, granular, sand and gravel. Slightly Moist.	4	0.0		
6–8	GW		SAND and GRAVEL, red, little clay and silt. Very Moist.	5	0.0	30	
8–15	GW		Crushed Limestone GRAVEL, tan, with gray and black fine sand and silt. Very Moist.	6	0.0		
				7	0.0	30	

End of Boring at 15 feet.

Push Geoprobe Tube in new boring 8 to 13 feet. 18" Recovery.

ATTACHMENT 6
Powerton Station Geotechnical Study Results





○ Suggested

● Possible Alternate

● Soil sample sites, cleared by Lucky Locators Inc.

Figure 6-1

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Table 6-1. Soil Sample Geotechnical Data - Midwest Generation, Powerton Station, Pekin, IL

Sample	Depth	Soil Description	Moisture (%)	Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Permeability Test (cm/s)
					LL (%)	PI (%)				
PS-GT-1	10'-12'	Clayey Sand/Sandy Clay, with gravel, dark brown	7.8	115	NP	NP	83	17	2.7	6.2x10-5
			9.7		22	NP	79	48	2.56	
PS-GT-2	7-8.5	Sand, trace clay and gravel, medium to coarse grained, brown	9.5	126.7	22	NP	79	48	2.7	1.1x10-4
PS-GT-3	7'-9'	Topsoil, with gravel, dark brown (possible cave-in)	12.9	112					2.7	
		Sandy Lean Clay, trace gravel and organics, dark brown	28.0	110	31	15	58	17	2.68	2x10-4
PS-GT-4	10'-11.5'	Sand, with clay and gravel, trace organics fine to coarse grained, dark brown	7.9	116	NP	NP	33	16	2.77	1.6x10-7
PS-GT-5	17-19	Clayey Sand, with gravel, dark brown	16.0							
		Lean Clay, trace sand	38.5	93	53	27	63	44	2.44	NA
PS-GT-6	1'	Fill: Sand, fine to medium coarse, trace gravel, dark brown	4.9	113.5	NP	NP	33	5	2.52	8.37x10-3
PS-GT-7	10-13'	Sand, with silt and gravel, dark brown, black	7.6	118.0	21	3	44	17	2.63	2.2x10-3
PS-GT-8	10-15'	Fill: cinders, metal shavings, glass, black	9.0	86**	NP	NP	14	4		
		Silty sand, trace clay, dark gray	12.0	115.0	NP	NP	34	14	2.61	2.31x10-2
PS-GT-9	15-20'	Fill: Sand, trace clay and gravel, dark brown	7.9	113.0	NP	NP	30	21	2.64	1.7x10-3
		Clayey sand, with gravel, brown and gray	9.8							

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
NA - Not Analyzed
NP - Not Plastic

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LOG OF BORING PS-GT-1

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	SC		CLAY top soil, brown, with sand-silt-gravel mixture, organics. Slightly Moist to Dry. - less clay	1	0.0		
3–4	CL		CLAY, brown, some silt, little sand, trace gravel. Slightly Moist.	2	0.0	90	4.0 to >4.5
5–6				3	0.0		2.0 to 2.5
6–9			- darker (dark brown) - increase gravel	4	0.0	60	
10–12			Push Shelby Tube 10-12. 19 " recovery.				
12			End of Boring at 18 feet.				

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LOG OF BORING PS-GT-2

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0	SC		CLAY top soil, brown and light brown, organics. Dry.				
1	CL		CLAY, brown, some silt and fine sand, trace gravel. Dry.	1	0.0		
2							
3				2	0.0	70	>4.5
4							
5	SP		SAND, fine, brown and orange brown, some silt. Slightly Moist to Dry.	3	0.0	100	
6			- dark brown				
7							
8				4	0.0	100	
9			- some clayey layers				
10							
11	CL		CLAY, gray, little medium sand and fine gravel, soft. Moist. (Native)	5	0.0		1.0
12							
13			End of Boring at 12 feet.				
14			Push Shelby Tube in new boring 7 to 8.5 feet. 27" recovery.				
15							
16							
17							
18							
19							
20							

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LOG OF BORING PS-GT-3

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		Bottom Ash, black, fine, and GRAVEL, fine to medium, limestone. Dry.	1	0.0		
1–2	CL		CLAY, dark brown, some silt and fine sand, trace gravel. Dry.	2	0.0	100	>4.5
2–5	GW		SAND and GRAVEL, brown and orange brown, some clay in layers. Slightly Moist.	3	0.0		
5–7	CL		CLAY, brown and dark brown, some fine sand and silt, trace gravel, Moist. - fine sand and silt seam, brwon	4	0.0		1.0
				5	0.0	100	4.0
7–9			Push Shelby Tube 7 to 9 feet. 21.5" recovery.				

End of Boring at 9 feet.

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(DRAFT) LOG OF BORING PS-GT-4

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		GRAVEL and SILT, gray and black. Dry.	1	0.0		
1–3	GW		CLAY-SAND-GRAVEL Mixture, brown some dark brown and black. Slightly Moist.	2	0.0	100	
4–7	SM		SAND and SILT, brown, fine, little gravel. Slightly Moist. - gray and light brown	3	0.0		
8–9	CL		CLAY, dark gray to black, little medium sand, trace gravel. Slightly Moist to Moist.	4	0.0	90	1.0
9–10				5	0.0		4.0
10–11			Push Shelby Tube 10-11.5. Refusal. 21.5" recovery.				
12			End of Boring at 11.5 feet.				

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LOG OF BORING PS-GT-5

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	GW		Top Soil, clayey, brown, some sand and gravel. Dry.	1	0.0		
2–4	SM		Bottom Ash, brown, sand and silt. Dry.	2	0.0	80	
4			- grade to dark brown and black				
4–15	CL		CLAY and SILT, brown and gray, some slag, medium to coarse sand and fine gravel. Moist.	3	0.0		
				4	0.0	80	
				5	0.0		
			12-14 - granular, little fines	6	0.0	80	
15–17	CL		PEAT, brown, moderately soft. Moist.	7	0.0	50	
17–19			Push Shelby Tube 17-19. 22" recovery.				
19–20			End of Boring at 19 feet.				

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ENVIRONMENTAL CONSULTATION & REMEDIATION
KPRG and Associates, Inc.

LOG OF BORING PS-GT-6

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	SC		CLAY, brown, and Bottom Ash, brown, and Slag, sand, stiff. Dry.	1	0.0		
1–6	GW		SLAG and Bottom Ash, black, fine to medium sand and silt. Dry. - mixed with orange/brown clay and gravel.	2	0.0	100	
				3	0.0		
6–8	CL		CLAY, dark brown and black, some silt, trace gravel. Moist.	4	0.0	90	4.0
8–13	CL		CLAY-SAND-GRAVEL Mixture, brown. Slightly Moist. - 3" light brown silt and fine sand seam - darker	5	0.0		1.0
				6	0.0		
13–18			Attempt to Push Shelby Tube 13-15. Refusal. Push geoprobe tube 13-18. 40 " recovery.				
18–20			End of Boring at 18 feet.				

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LOG OF BORING PS-GT-7

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	CL		CLAY and SILT, organics, light brown, some sand and gravel . Dry. - transistion (mixed layer)	1	0.0		
2–13	SM		SLAG and Bottom Ash, black and dark brown, some medium to coarse sand and silt. Dry. - clayey, brown, very stiff	2 3 4 5	0.0 0.0 0.0 0.0	100 100 100	

End of Boring at 13 feet. Refusal.

Push geoprobe tube in seperate boring 8 to 13.

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LOG OF BORING PS-GT-8

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–2	SP		SAND, fine to medium, brown and dark brown, little silt, trace gravel, very stiff. Dry.	1	0.0		
3–15	SM		SLAG and Bottom Ash, black and dark gray, fine to medium sand, some silt and clay, very stiff. Dry.	2	0.0	100	
			- clayey, brown				
			- granular, medium to coarse sand	3	0.0		
				4	0.0	100	
			- a few clayey layers, slightly moist				
				5	0.0	100	
15–20			Push geoprobe tube 15 to 20 feet. 44" recovery.				

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KPRG and Associates, Inc.

LOG OF BORING PS-GT-9

Midwest Generation
Powerton Station
Pekin, IL

Project No. 15805

Date Completed : 08/11/05
Drilling Method : Direct-Push
Drilling Company : CABENO Env. Field Services
Operator : D. Joyce
Logged By : P. Allenstein

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	PID Screening	PID (ppm)	% Recovery	Compressive Strength
0–1	GW		Crushed Limestone, silt, sand and gravel. Dry.				
1–3	GW		CLAY and GRAVEL, brown, stiff. Dry.	1	0.0		
3–14	SM		SLAG and Bottom Ash, black and dark gray, medium to coarse sand, little silt. Dry to Slightly Moist.	2	0.0	100	
			- 6" gray clay with medium to coarse sand	3	0.0		>4.5
				4	0.0	100	>4.5
				5	0.0	100	
14–15	CL		CLAY, gray, trace silt, black ribbon. Moist.	6	0.0		1.5
15–20			Could not anchor to attempt Shelby Tube. Push geoprobe tube 15 to 20 feet. 44" recovery.				

ATTACHMENT 7
Geotechnical Laboratory Report

KPRG Project No. 15805 Laboratory Results
Terracon Project No. 58055075
October 11, 2005

Sample	Depth	Soil Description	Moisture (%)	Dry Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Coefficient of Permeability (cm/s)
					LL (%)	PI (%)				
CS-GT-1	5-10'	Sand, fine to coarse, trace gravel and silt, brown, dark brown, black	10.4	117**	NP	NP	24	12	2.71	2.2x10-3
CS-GT-2	10'-12'	Sand, fine to coarse grained, gray (crushed limestone) (top)	1.7		NP	NP	24	14	2.68	*
CS-GT-2	10'-12'	Lean Clay, trace sand, gray (bottom)	15.9	117	36	18	94	88		N/A
		(2nd test)	16.2		36	19				
CS-GT-4	5'-7'	Sand, with gravel, fine to medium, gray (crushed concrete)	2.2		NP	NP			2.65	*
CS-GT-4	5'-7'	Lean Clay, trace sand and gravel, gray	22.2	110	38	19	72	65	2.69	N/A
CS-GT-5	5'-7.5'	Sand, with gravel and clay, dark brown (possible cave-in)	7.3		NP	NP			2.5	
		Lean Clay, with sand, brown and gray	22.0	112	27	19	37	33	2.7	2.3x10-8
CS-GT-6	10-12.5'	Sandy Lean Clay, with gravel, brown and dark brown	6.3	118**	31	13	77	62	2.58	N/A
WS-GT-1	5 to 10'	Sand with trace gravel	5.6	114	NP	NP	94	1	2.63	1.05x10-2
WS-GT-2	7.5'-10'	Silty Sand, trace gravel, dark brown	15.2	107	NP	NP	79	18	2.44	1.52x10-2
			18.1							
WS-GT-3	5 to 10'	Sand with trace gravel	11.2	99	NP	NP	86	0	2.65	2.3x10-2
WS-GT-4	22-27'	Sand with trace gravel	5.4	114	NP	NP	53	2	2.64	2.16x10-2
WS-GT-5	22-27'	Sand, trace gravel, black	4.4	96	NP	NP	15	0	2.73	1.21x10-2
		(Bottom Ash?)								
WC-GT-1	5 to 10'	Clayey Sand, dark brown to tan	3.4	118	NP	NP	26	17	2.66	1.35x10-1
WC-GT-2	5 to 10'	Sand with gravel, dark brown	18.1	92	NP	NP	35	12	2.65	4.02x10-3
WC-GT-3	3 to 8'	Lean Clay, dark brown	10.0	103	35	12	26	20	2.71	***
WC-GT-4	5 to10' (btm)	Silty Clay, dark brown	9.5	128	25	7			2.7	***
WC-GT-4	5 to 10'	Sandy Gravel, with clay					35	23		
WC-GT-5	5-9'	Sandy Clay with Gravel	4.2	119	NP	NP	39	35	2.65	*

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KPRG Project No. 15805 Laboratory Results
Terracon Project No. 58055075
October 11, 2005

Sample	Depth	Soil Description	Moisture (%)	Dry Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Coefficient of Permeability (cm/s)
					LL (%)	PI (%)				
PS-GT-1	10'-12'	Clayey Sand, with gravel, dark brown	7.8	115	NP	NP	83	34	2.7	6.2x10-5
PS-GT-1	10'-12'	Sandy Clay, with gravel, dark brown	9.7		22	NP	79	48	2.56	
PS-GT-2	7-8.5	Clayey Sand, trace gravel, medium to coarse grained, brown	9.5	126.7	22	NP	79	48	2.7	1.1x10-4
PS-GT-3	7'-9'	Topsoil, with gravel, dark brown (possible cave-in)	12.9	112					2.7	
PS-GT-3	7'-9'	Sand, trace clay, gravel and organics, dark brown	28.0	110	31	15	58	17	2.68	2x10-4
PS-GT-4	10'-11.5'	Sand, with clay and gravel, trace organics fine to coarse grained, dark brown	7.9	116	NP	NP	33	16	2.77	1.6x10-7
PS-GT-5	17-19	Clayey Sand, with gravel, dark brown	16.0							
PS-GT-5	17-19	Sandy Lean Clay, trace gravel, brown	38.5	93	53	27	63	44	2.44	N/A
PS-GT-6	15-20'	Fill: Sand, fine to medium coarse, trace gravel, dark brown	4.9	113.5	NP	NP	33	5	2.52	8.37x10-3
PS-GT-7	10-13'	Sand, with silt and gravel, dark brown, black	7.6	118.0	21	3	44	17	2.63	2.2x10-3
PS-GT-8	10-15'	Fill: cinders, metal shavings, glass, black	9.0	86**	NP	NP	14	4		
PS-GT-8	10-15'	Silty sand, trace clay, dark gray	12.0	115.0	NP	NP	34	14	2.61	2.31x10-2
PS-GT-9	15-20' (top)	Silty Sand, dark gray	9.8		22	3	30	14		
PS-GT-9	15-20' (mid)	Gravel, with silt and sand, dark brown					12	7		
PS-GT-9	15-20' (btm)	Sand, trace clay and gravel, dark brown	7.9	113.0	24	3	30	21	2.64	1.7x10-3

Electronic Filing: Received, Clerk's Office 2/04/2022

KPRG Project No. 15805 Laboratory Results
Terracon Project No. 58055075
October 11, 2005

Sample	Depth	Soil Description	Moisture (%)	Dry Density (pcf)	Atterberg		Grain Size #40	Hydrometer (% passing #200)	Specific Gravity	Coefficient of Permeability (cm/s)
					LL (%)	PI (%)				
JS-9-GT-1	7-12'	Sand, with gravel, gray	4	110	16	NP	32	23	2.63	*
JS-9-GT-1	7-12'	Organic Clay, with gravel	20.0							
JS-9-GT-2	7-11.5'	Clayey Sand, with organics, trace gravel, dark brown	23.7	91.0	NP	NP	51	21		2.73x10-2
JS-9-GT-2	7-11.5'	Organic Clay, occasional shells and peat, trace gravel, black, dark brown	56.3							
JS-9-GT-3	8-13'	Sand, with gravel, gray	5.5	86	NP	NP	11	7	2.66	*
JS-29-GT-1	19-24'	Sandy Gravel, trace clay, dark yellow	5.3	120	16	NP	14	9	2.62	2.96x10-2
JS-29-GT-2	19-24	Gravelly Sand, brown	10.0	87.0	NP	NP	21	14	2.66	*
JS-29-GT-2	19-24	Gravelly Sand, trace clay, dark brown	6.0		NP	NP				
JS-29-GT-3	19-24	Poorly graded gravel with clay and sand, brown	8.6	121**	NP	NP	13	9	2.64	2.51x10-2
JS-29-GT-3	19-24	Lean clay, gray	7.3							
JS-29-GT-4	17-22	Limestone with fine to coarse sand	4.1	124.0	NP	NP	11	7	2.7	*
JS29-GT-5	5-9'	Clayey Gravel with sand, dark gray	26.0	94.0	34	11	32	19	2.56	4.7x10-4
	9-14' (top)	Gravel, with silt and sand, dark gray			NP	NP	16	10		
	9-14' (btm)	Silty Gravel			21	NP	23	16		
JS-29-GT-6	11-14'	Organic Silt, dark gray, black	74.6	53.0	78	17	89	65	2.41	N/A

*Unable to perform permeability test, too much stone, not enough soil sample
**Remolded sample to obtain the dry density
***Unable to properly remold sample, too much large aggregate
NP=Non Plastic Soil

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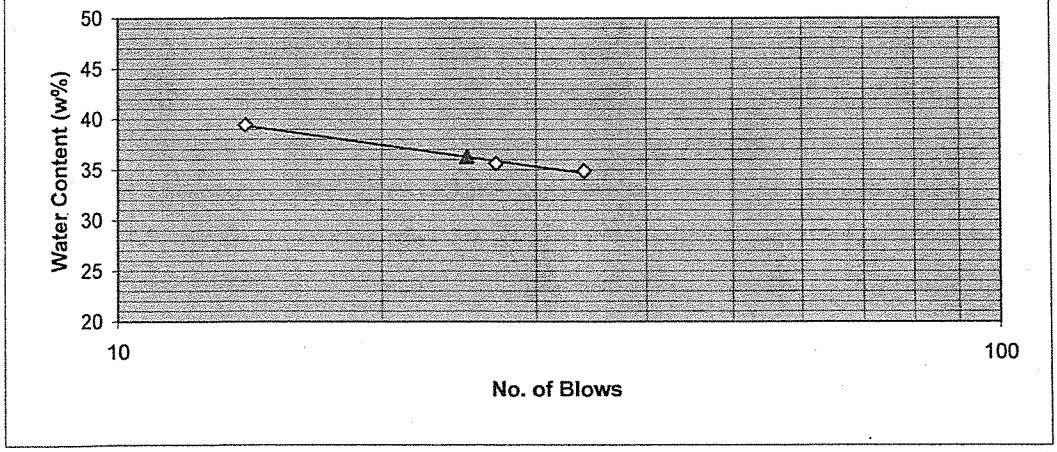
Terracon

Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
			CS-GT-2		
Location of project:		Boring No:	(top)	Sample Depth:	10'-12'
Description of Soil:	Sand, fine to coarse grained, gray	Tested By:	KF		

Liquid Limit Determination:

Can no.	49	115	119	
Mass of wet soil + can, gm	46.68	45.43	55.20	
Mass of dry soil + can, gm	42.72	41.78	48.39	
Mass of Can, gm	31.36	31.53	31.12	
Mass of dry soil, gm	11.36	10.25	17.27	
Mass of moisture, gm	3.96	3.65	6.81	
Water Content, w%	34.86	35.61	39.43	
No. of Blows	34	27	14	
Notes				



Plastic Limit Determination:

Can no.	400	109		
Mass of wet soil + can, gm	46.90	49.62		
Mass of dry soil + can, gm	44.49	46.83		
Mass of Can, gm	31.25	31.21		
Mass of dry soil, gm	13.24	15.62		
Mass of moisture, gm	2.41	2.79		
Water Content, w%	18.20	17.86		

Liquid Limit	36
Plastic Limit	18
Plasticity Index	18

By: TK

Terracon Consultants

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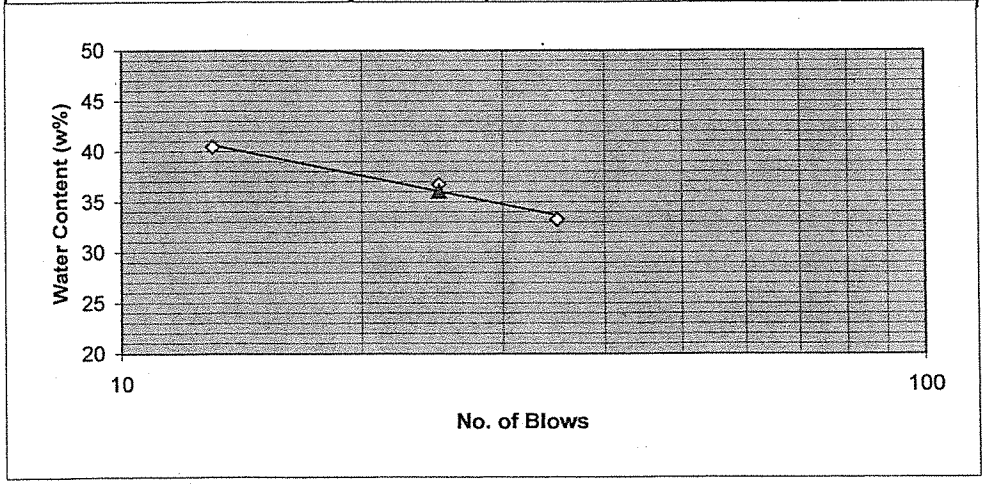
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	CS-GT-2 (Bottom)	Sample Depth:	10'-12'
Description of Soil:	Lean Clay, trace sand, gray	Tested By:	KF		

Liquid Limit Determination:

Can no.	456	400D	52A	
Mass of wet soil + can, gm	50.10	54.66	57.12	
Mass of dry soil + can, gm	45.51	48.37	49.64	
Mass of Can, gm	31.71	31.24	31.14	
Mass of dry soil, gm	13.80	17.13	18.50	
Mass of moisture, gm	4.59	6.29	7.48	
Water Content, w%	33.26	36.72	40.43	
No. of Blows	35	25	13	
Notes				



Plastic Limit Determination:

Can no.	109	115		
Mass of wet soil + can, gm	40.97	39.71		
Mass of dry soil + can, gm	39.51	38.49		
Mass of Can, gm	31.21	31.53		
Mass of dry soil, gm	8.30	6.96		
Mass of moisture, gm	1.46	1.22		
Water Content, w%	17.59	17.53		

Liquid Limit	**36**
Plastic Limit	**18**
Plasticity Index	**19**

By: TK

Terracon Consultants

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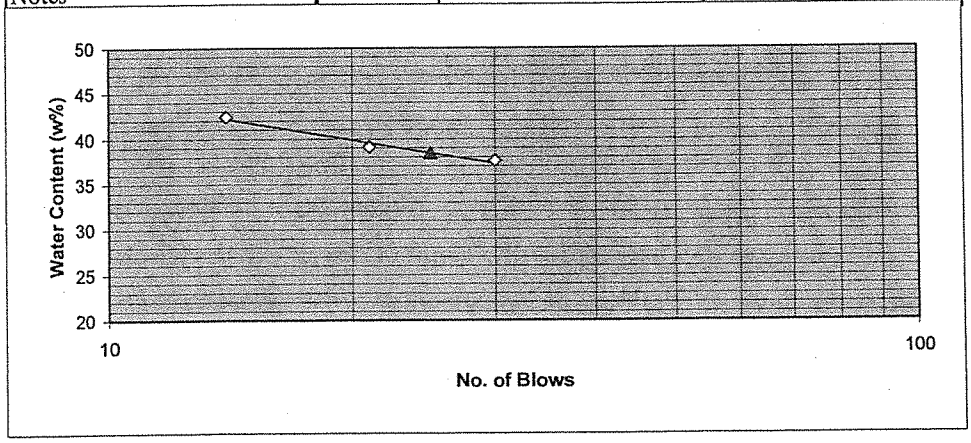
Terracon

Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	CS-GT-4	Sample Depth:	5'-7'
Description of Soil:	Lean Clay, trace sand and gravel, gray	Tested By:	KF		

Liquid Limit Determination:

Can no.	BJ	DE	CC	
Mass of wet soil + can, gm	41.32	44.93	43.45	
Mass of dry soil + can, gm	35.78	38.32	36.70	
Mass of Can, gm	21.03	21.40	20.79	
Mass of dry soil, gm	14.75	16.92	15.91	
Mass of moisture, gm	5.54	6.61	6.75	
Water Content, w%	37.56	39.07	42.43	
No. of Blows	30	21	14	
Notes				



Plastic Limit Determination:

Can no.	DW	456		
Mass of wet soil + can, gm	29.94	42.32		
Mass of dry soil + can, gm	28.48	40.56		
Mass of Can, gm	21.15	31.74		
Mass of dry soil, gm	7.33	8.82		
Mass of moisture, gm	1.46	1.76		
Water Content, w%	19.92	19.95		

Liquid Limit	38
Plastic Limit	20
Plasticity Index	19

By: TK
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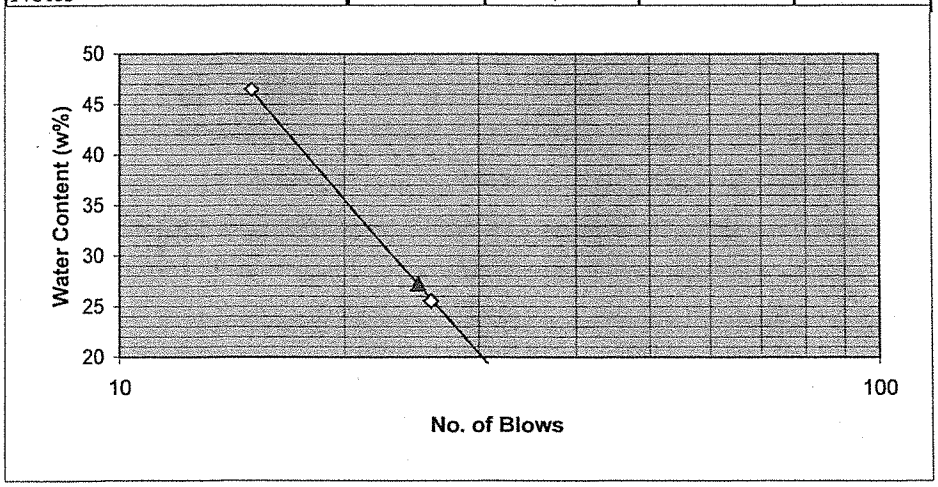
Terracon

Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	CS-GT-5	Sample Depth:	5'-7.5'
Description of Soil:	Lean Clay, with sand, brown and gray	Tested By:	KF		

Liquid Limit Determination:

Can no.	33	DR	BC	
Mass of wet soil + can, gm	47.30	45.06	43.52	
Mass of dry soil + can, gm	45.27	40.13	36.29	
Mass of Can, gm	32.45	20.82	20.73	
Mass of dry soil, gm	12.82	19.31	15.56	
Mass of moisture, gm	2.03	4.93	7.23	
Water Content, w%	15.83	25.53	46.47	
No. of Blows	34	26	15	
Notes				



Plastic Limit Determination:

Can no.	400-A	52-A		
Mass of wet soil + can, gm	41.20	39.92		
Mass of dry soil + can, gm	39.83	39.90		
Mass of Can, gm	31.87	28.06		
Mass of dry soil, gm	7.96	11.84		
Mass of moisture, gm	1.37	0.02		
Water Content, w%	17.21	0.17		

Liquid Limit	27
Plastic Limit	9
Plasticity Index	19

By: TK
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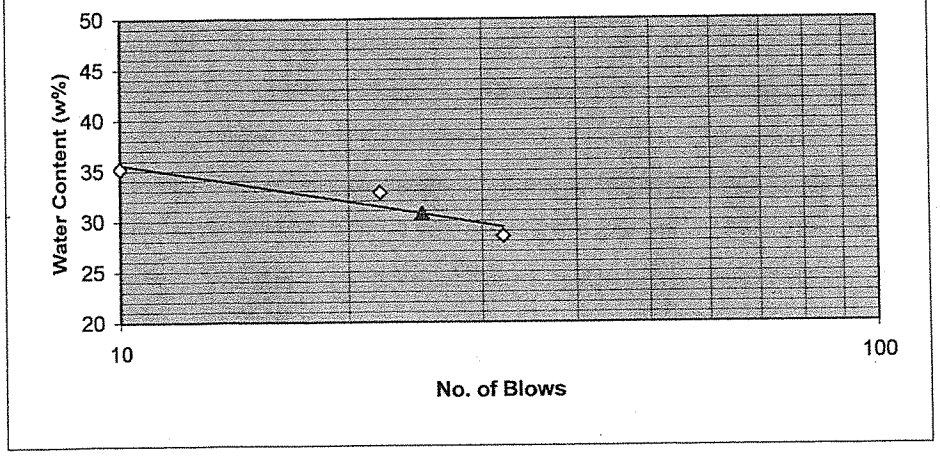
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	CS-GT-6	Sample Depth:	10'-12.5'
Description of Soil:	Sandy Lean Clay, with gravel, brown and dark	Tested By:	KF		

Liquid Limit Determination:

Can no.	AC	49	119	
Mass of wet soil + can, gm	48.64	57.98	54.65	
Mass of dry soil + can, gm	42.52	51.40	48.55	
Mass of Can, gm	21.03	31.34	31.22	
Mass of dry soil, gm	21.49	20.06	17.33	
Mass of moisture, gm	6.12	6.58	6.10	
Water Content, w%	28.48	32.80	35.20	
No. of Blows	32	22	10	
Notes				



Plastic Limit Determination:

Can no.	59	131		
Mass of wet soil + can, gm	39.33	37.76		
Mass of dry soil + can, gm	38.07	36.78		
Mass of Can, gm	31.24	31.13		
Mass of dry soil, gm	6.83	5.65		
Mass of moisture, gm	1.26	0.98		
Water Content, w%	18.45	17.35		

Liquid Limit	**31**
Plastic Limit	**18**
Plasticity Index	**13**

By: TK

Terracon Consultants

3 pt. ATTERBERG

LIQUID LIMIT DETERMINATION

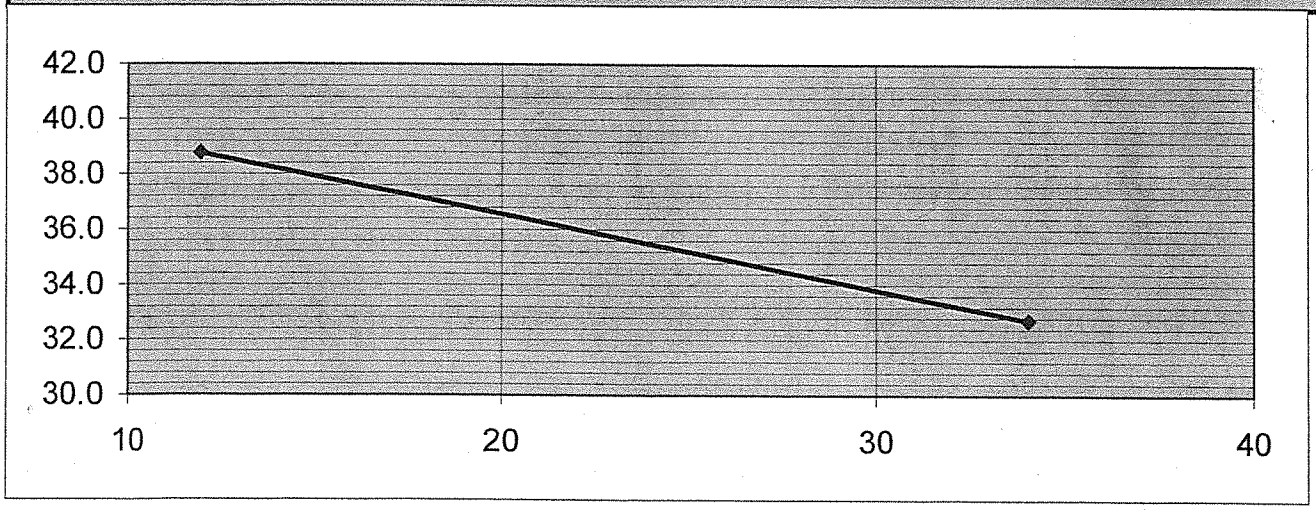
	POINT 1	POINT 2	POINT 3	POINT 4
POINT No.				
WET SOIL + TARE	9.92	13.87	13.87	
DRY SOIL + TARE	7.79	10.35	10.35	
TARE	1.28	1.27	1.27	
No. OF BLOWS	34	12	12	
MOISTURE %	**32.7**	**38.8**	**38.8**	**#DIV/0!**
CORECTION FACT.	1.000	1.000	1.000	1.000
MOISTURE @ 25	**32.7**	**38.8**	**38.8**	**#DIV/0!**

PLASTIC LIMIT DETERMINATION

	POINT 1	POINT 2
POINT No.		
WET SOIL + TARE	11.32	10.51
DRY SOIL + TARE	9.42	8.81
TARE	1.26	1.29
MOISTURE %	**23.3**	**22.6**

For 3 pts.		
L.L.	P.L.	P.I.
34.5	**22.9**	**11.6**

For 4 pts.		
L.L.	P.L.	P.I.
#VALUE!	**23**	**#VALUE!**



Project : KPRG Laboratory Testing
Project No. : 58055075
Location : WCGT-3, 3 to 8' Top of Sample
Description : Lean Clay, dark brown

TK

3 pt. ATTERBERG

LIQUID LIMIT DETERMINATION

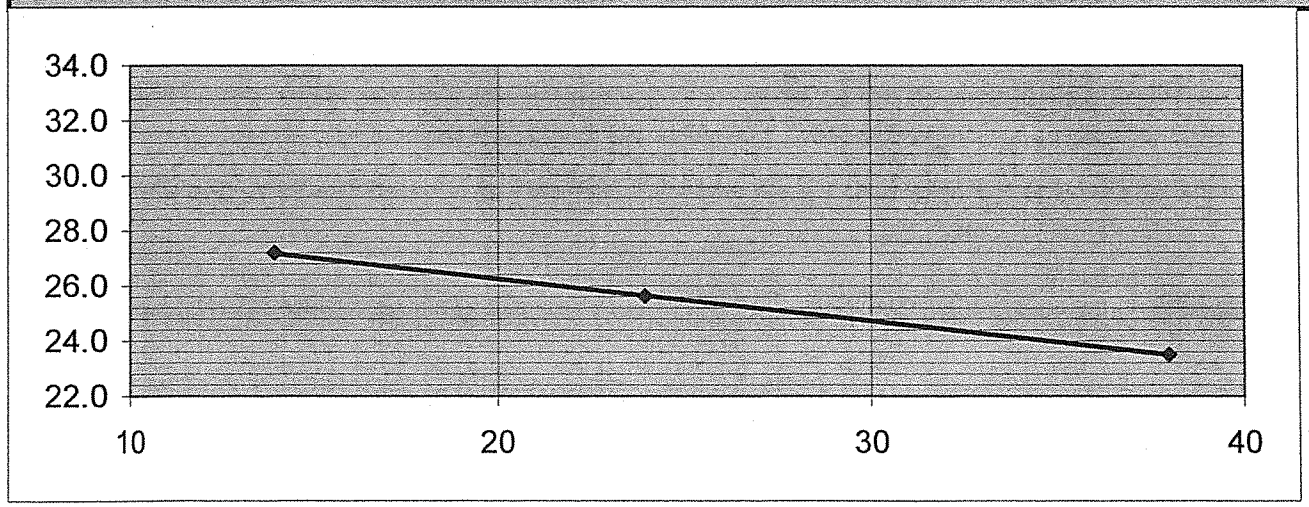
POINT No.	POINT 1	POINT 2	POINT 3	POINT 4
WET SOIL + TARE	19.50	21.32	24.54	
DRY SOIL + TARE	17.37	18.86	21.29	
TARE	8.31	9.26	9.34	
No. OF BLOWS	38	24	14	
MOISTURE %	**23.5**	**25.6**	**27.2**	**#DIV/0!**
CORECTION FACT.	1.000	1.000	1.000	1.000
MOISTURE @ 25	**23.5**	**25.6**	**27.2**	**#DIV/0!**

PLASTIC LIMIT DETERMINATION

POINT No.	POINT 1	POINT 2
WET SOIL + TARE	25.62	28.26
DRY SOIL + TARE	23.04	25.27
TARE	9.07	9.35
MOISTURE %	**18.5**	**18.8**

For 3 pts.		
L.L.	P.L.	P.I.
25.2	**18.6**	**6.6**

For 4 pts.		
L.L.	P.L.	P.I.
#VALUE!	**19**	**#VALUE!**



Project : KPRG Laboratory Testing
Project No. : 58055075
Location : WCGT-4, Btm of Sample From 5 to 10'
Description : Silty Clay, dark brown

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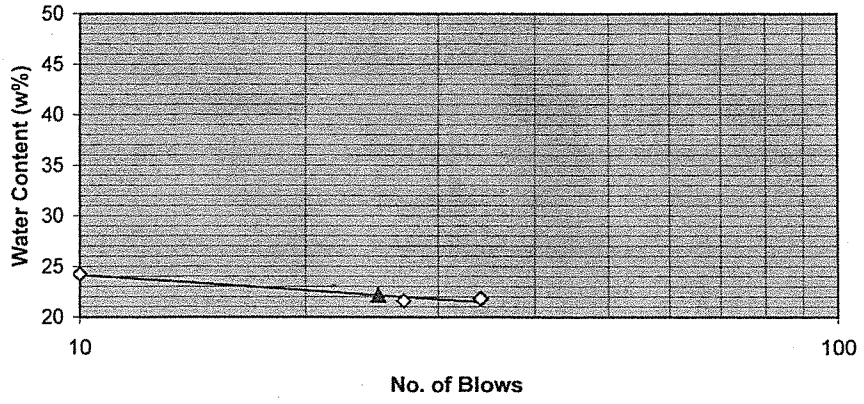
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	PS-GT-2	Sample Depth:	7'-8.5'
Description of Soil:	Clayey Sand, trace gravel, medium to coarse grained, brown	Tested By:	KF		

Liquid Limit Determination:

Can no.	59	BQ	1Q	
Mass of wet soil + can, gm	55.18	52.21	59.59	
Mass of dry soil + can, gm	50.89	46.74	54.11	
Mass of Can, gm	31.22	21.40	31.50	
Mass of dry soil, gm	19.67	25.34	22.61	
Mass of moisture, gm	4.29	5.47	5.48	
Water Content, w%	21.81	21.59	24.24	
No. of Blows	34	27	10	
Notes				



Plastic Limit Determination: **Unable to perform, too sandy**

Can no.				
Mass of wet soil + can, gm				
Mass of dry soil + can, gm				
Mass of Can, gm				
Mass of dry soil, gm				
Mass of moisture, gm				
Water Content, w%				

Liquid Limit	22
Plastic Limit	N/A
Plasticity Index	N/A

By: TLS
Terracon Consultants

Electronic Filing: Received, Clerk's Office 2/04/2022

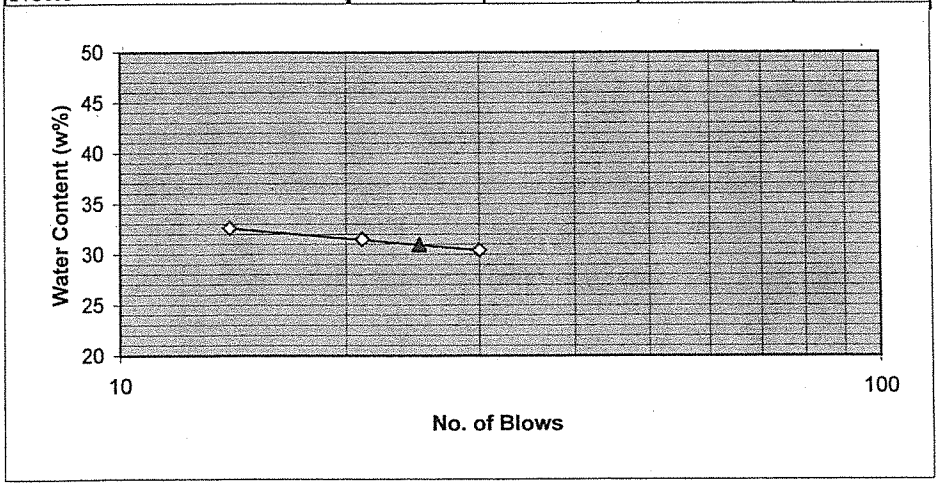
Terracon

Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	PS-GT-3	Sample Depth:	7'-9'
Description of Soil:	Sand, trace clay, organics, and gravel, dark brown	Tested By:	KF		

Liquid Limit Determination:

Can no.	FP	EK	BA	
Mass of wet soil + can, gm	42.58	43.90	46.56	
Mass of dry soil + can, gm	37.67	38.51	40.43	
Mass of Can, gm	21.52	21.39	21.61	
Mass of dry soil, gm	16.15	17.12	18.82	
Mass of moisture, gm	4.91	5.39	6.13	
Water Content, w%	30.40	31.48	32.57	
No. of Blows	30	21	14	
Notes				



Plastic Limit Determination:

Can no.	BN	46		
Mass of wet soil + can, gm	30.73	39.43		
Mass of dry soil + can, gm	29.37	38.28		
Mass of Can, gm	21.36	31.01		
Mass of dry soil, gm	8.01	7.27		
Mass of moisture, gm	1.36	1.15		
Water Content, w%	16.98	15.82		

Liquid Limit	**31**
Plastic Limit	**16**
Plasticity Index	**15**

By: TK

Terracon Consultants

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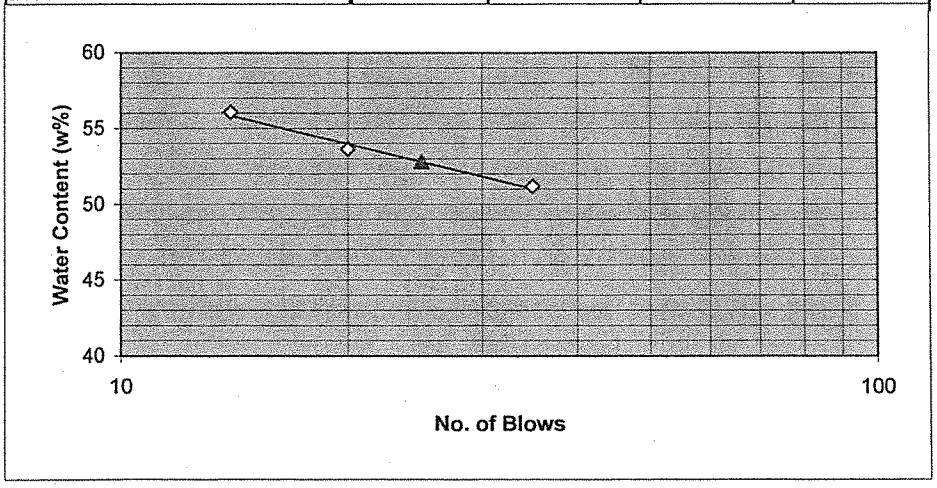
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing		Job No:	58055075	
Location of project:		Boring No:	PS-GT-5	Sample Depth:	17'-19'
Description of Soil:	Sandy Lean Clay, trace gravel, dark brown	Tested By:	KF		

Liquid Limit Determination:

Can no.	AU	AC	EB	
Mass of wet soil + can, gm	38.74	47.26	41.01	
Mass of dry soil + can, gm	32.78	38.09	34.09	
Mass of Can, gm	21.13	20.99	21.75	
Mass of dry soil, gm	11.65	17.10	12.34	
Mass of moisture, gm	5.96	9.17	6.92	
Water Content, w%	51.16	53.63	56.08	
No. of Blows	35	20	14	
Notes				



Plastic Limit Determination:

Can no.	BM	AN		
Mass of wet soil + can, gm	31.90	29.18		
Mass of dry soil + can, gm	29.70	27.60		
Mass of Can, gm	21.12	21.52		
Mass of dry soil, gm	8.58	6.08		
Mass of moisture, gm	2.20	1.58		
Water Content, w%	25.64	25.99		

Liquid Limit	53
Plastic Limit	26
Plasticity Index	27

By: TK

Terracon Consultants

1pt. ATTERBERG

LIQUID LIMIT DETERMINATION

POINT No.	POINT 1	POINT 2
WET SOIL + TARE	18.67	15.48
DRY SOIL + TARE	16.27	13.52
TARE	1.28	1.30
No. OF BLOWS	19	16
MOISTURE %	**16.0**	**16.0**
CORECTION FACT.	0.967	0.947
MOISTURE @ 25	**15.5**	**15.2**

PLASTIC LIMIT DETERMINATION

POINT No.	POINT 1	POINT 2
WET SOIL + TARE	15.45	12.46
DRY SOIL + TARE	13.58	10.99
TARE	1.35	1.30
MOISTURE %	**15.3**	**15.2**

L.L.	**16**	**16**
L.L. @ 25 BLOWS	**15**	**15**
PLASTIC LIMITS	**15**	**15**
PLASTIC INDEX	**0**	**0**

Project : KPRG Laboratory Testing
Project No. : 58055075
Location : JS29GT-1
Description : Sandy Gravel, trace clay, dark yellow

TK

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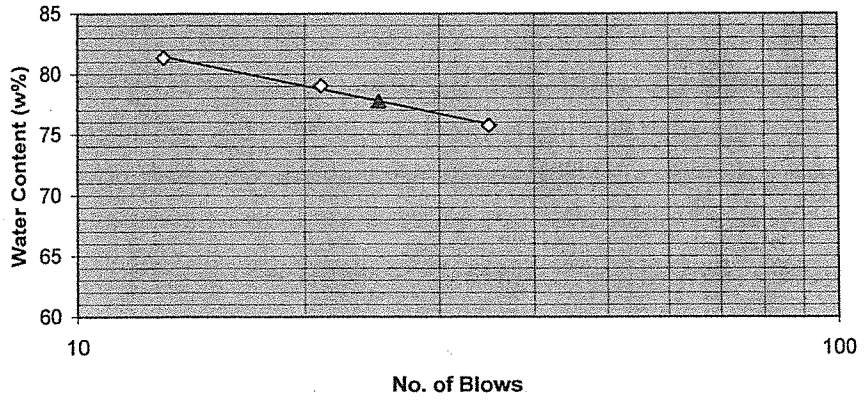
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Laboratory Test Results of Atterberg Limits ASTM D4318

Project:	KPRG Laboratory Testing	Job No:	58055075
Location of project:		Boring No:	JS-29-GT-6 Sample Depth: 11-14'
Description of Soil:	Organic Silt, dark gray and black	Tested By:	MZ

Liquid Limit Determination:

Can no.	131	CE	400C	
Mass of wet soil + can, gm	35.84	25.29	35.20	
Mass of dry soil + can, gm	33.81	23.48	33.37	
Mass of Can, gm	31.13	21.19	31.12	
Mass of dry soil, gm	2.68	2.29	2.25	
Mass of moisture, gm	2.03	1.81	1.83	
Water Content, w%	75.75	79.04	81.33	
No. of Blows	35	21	13	
Notes				



Plastic Limit Determination:

Can no.	119	DU		
Mass of wet soil + can, gm	37.16	29.96		
Mass of dry soil + can, gm	35.31	26.24		
Mass of Can, gm	31.26	21.33		
Mass of dry soil, gm	4.05	4.91		
Mass of moisture, gm	1.85	3.72		
Water Content, w%	45.68	75.76		

Liquid Limit	78
Plastic Limit	61
Plasticity Index	17

By: TK
Terracon Consultants

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 10/7/2005

SAMPLE ID: CS-GT-1 5-7' -#4 MATERIAL
DESCR.: Sand, fine to coarse grained, trace gravel and silt, brown, dark brown and black

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	88.50	WET WT, g	195.8		
D & T, g	82.00	DIA, in	1.94	4.93	cm
T, g	19.37	HT, in	1.96	4.98	cm
		AREA		19.05	cm^2
MOIST-		DENSITY:	128.9	PCF WET	
URE, %	**10.4**	DENSITY:	**116.8**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	30.7	PROCTOR:	NA
SATURATION, %:	63.3	OPTIMUM:	NA
VOID RATIO:	0.44	COMPACTION, %:	#VALUE!
		OVER OPTIMUM, %:	#VALUE!

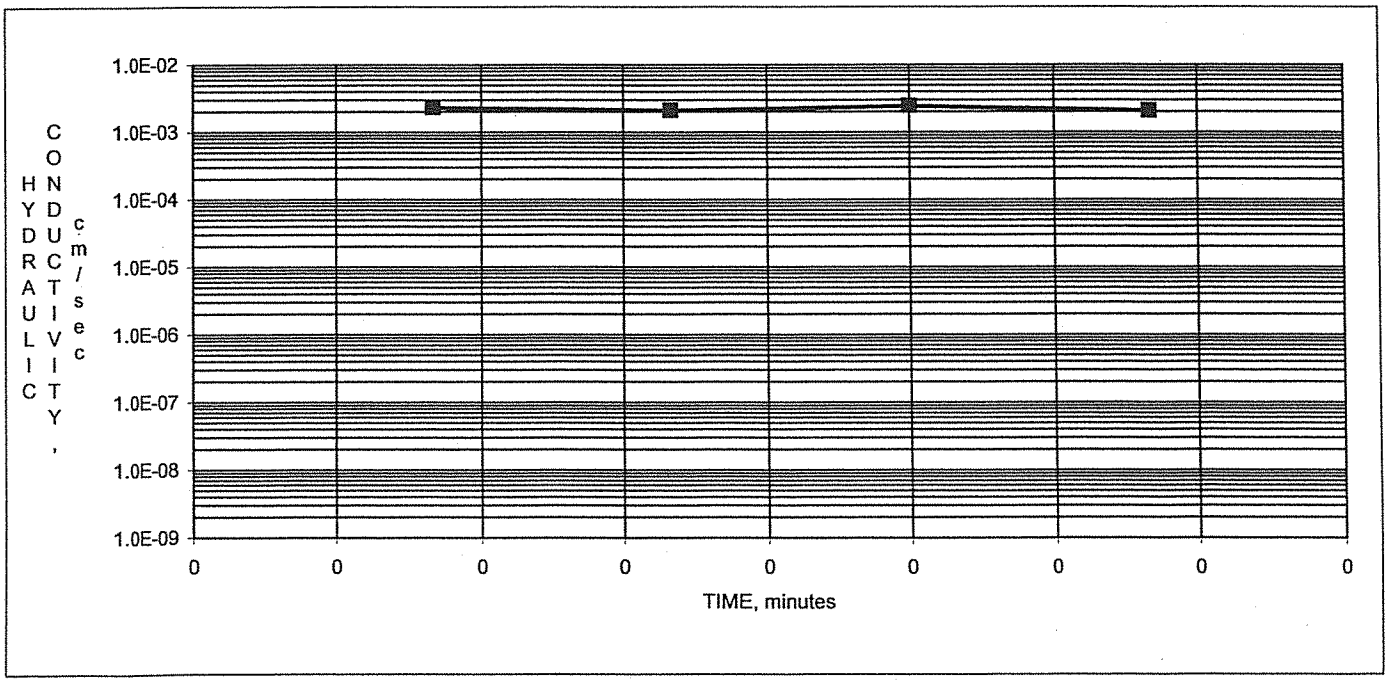
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
20.8	30.1	0	9.3									
21.8	28.8	0	7.0	0.284104	2.31E-03	1.0	1.3	0.77	1.4	3	21	0.980
22.6	28.0	0	5.4	0.259511	2.11E-03	0.8	0.8	1.00	1.1	6	21	0.980
23.2	27.2	0	4.0	0.300105	2.44E-03	0.6	0.8	0.75	0.8	9	21	0.980
23.8	26.9	0	3.1	0.254892	2.07E-03	0.6	0.3	2.00	0.6	7	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 2.2E-03 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0327



Terracon

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE
ID: CS-GT-5 5.0' - 7.5'
DESCR.: SILTY CLAY, WITH SAND, BROWN & GRAY

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	79.26	WET WT, g	229.7		
D & T, g	68.61	DIA, in	2.00	5.09	cm
T, g	20.38	HT, in	2.19	5.56	cm
		AREA		20.36	cm^2
MOIST-		DENSITY:	126.6	PCF WET	
URE, %	**22.1**	DENSITY:	**103.7**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	38.5	PROCTOR:	112.4
SATURATION, %:	95.3	OPTIMUM:	22.0
VOID RATIO:	0.63	COMPACTION, %:	92.3
		OVER OPTIMUM, %:	0.1

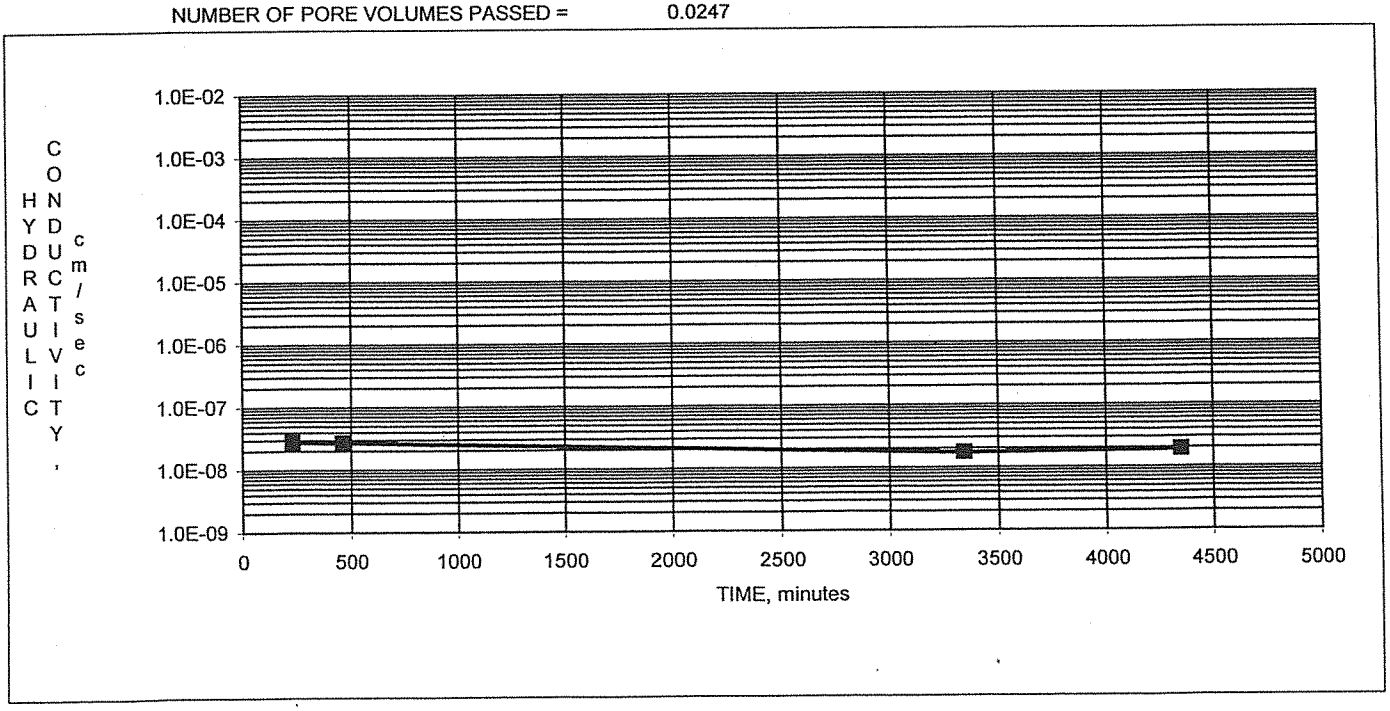
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
4.1	70.2	0	66.1									
4.4	69.9	229	65.5	0.009119	2.75E-08	0.3	0.3	1.00	11.8	21	22	0.956
4.7	69.6	461	64.9	0.009203	2.74E-08	0.3	0.3	1.00	11.7	20	22	0.956
6.7	67.2	3345	60.5	0.070204	1.72E-08	2.0	2.4	0.83	10.9	24	21	0.980
7.5	66.4	4351	58.9	0.026802	1.88E-08	0.8	0.8	1.00	10.6	17	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 2.3E-08 cm/sec

MAXIMUM HYDRAULIC GRADIENT	1.0E-03 TO 1.0E-04	2	0.75< RATIO <1.25	% < 25 AT > 1.0E-8 OR % < 50 AT < 1.0E-8
	1.0E-04 TO 1.0E-05	5		
	1.0E-05 TO 1.0E-06	10		
	1.0E-06 TO 1.0E-07	20		
	1.0E-07 TO 1.0E-10	30		

NUMBER OF PORE VOLUMES PASSED = 0.0247



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PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/14/2005

Location of Sample WSGT-1 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 5 to 10'

Description of Soil Sand, fine, trace gravel, light brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.62 Wt. Soil (lb.) 1.170

Area, A, cm^2 45.60 Moisture Content _____

Length, L, cm 6.350000 Volume (ft^3) 0.01023

Dry Density 114.4

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	7	20	38.5	127	12290.2	0.01139	1.10236	20	1.000	1.03E-02
2	17.2	20	15.5	127	12157.9	0.02829	2.70866	20	1.000	1.04E-02
3	24.3	20	11	127	12189.9	0.03987	3.82677	20	1.000	1.04E-02
4	29.8	20	9	127	12230.9	0.04873	4.69291	20	1.000	1.04E-02
5	33.2	20	8.2	127	12415.1	0.05348	5.22835	20	1.000	1.02E-02
6	37.5	20	6.8	127	11628.9	0.06449	5.90551	20	1.000	1.09E-02
7	40.9	20	6.5	127	12123.7	0.06747	6.44094	20	1.000	1.05E-02
8									Avg	1.05E-02
9										
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WS-GT-2 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 7.5-10

Description of Soil Silty Sand, trace gravel, light brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 6.23 Wt. Soil (lb.) 0.798

Area, A, cm^2 30.48 Moisture Content 8.9

Length, L, cm 6.350000 Volume (ft^3) 0.00685

Dry Density 107.0

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	13.2	20	19.08	127	7677.47	0.03439	2.07874	20	1.000	1.65E-02
2	19.5	20	12.8	127	7608.7	0.05126	3.07087	20	1.000	1.67E-02
3	27.8	20	10.2	127	8643.92	0.06432	4.37795	20	1.000	1.47E-02
4	32.2	20	8.87	127	8706.53	0.07397	5.07087	20	1.000	1.46E-02
5	35	20	8.17	127	8716.77	0.0803	5.51181	20	1.000	1.46E-02
6	36.7	20	7.52	127	8412.97	0.08725	5.77953	20	1.000	1.51E-02
7	39.6	20	7.24	127	8739.76	0.09062	6.23622	20	1.000	1.45E-02
8	41	20	6.95	127	8686.29	0.0944	6.45669	20	1.000	1.46E-02
9									AVG	1.52E-02
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WS-GT-3 Sampled _____ Report _____

Boring- _____ Sample- Bottom Depth- 5 to 10'

Description of Soil Sand, fine, trace gravel, light brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.62 Wt. Soil (lb.) 1.120

Area, A, cm^2 45.60 Moisture Content 11.2

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 98.6

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	3.3	20	31.5	127	4740.5	0.01392	0.51969	20	1.000	2.68E-02
2	8.7	20	14	127	5554.52	0.03133	1.37008	20	1.000	2.29E-02
3	13.5	20	9.5	127	5848.67	0.04616	2.12598	20	1.000	2.17E-02
4	17.2	20	7	127	5490.68	0.06265	2.70866	20	1.000	2.31E-02
5	21.5	20	5.5	127	5392.63	0.07974	3.38583	20	1.000	2.36E-02
6	24.3	20	5	127	5540.84	0.08771	3.82677	20	1.000	2.29E-02
7	32.3	20	4	127	5891.99	0.10964	5.08661	20	1.000	2.16E-02
8	32.3	20	4	127	5891.99	0.10964	5.08661	20	1.000	2.16E-02
9									AVG	2.30E-02
10										
11										
12										

Note:

Tested by: _____ Checked by: TK

Rowdy Miller Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WSGT-4 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 22 to 27'

Description of Soil Fine Sand Grading to a Fine To Coarse Sand With Gravel

Materials Used: Fine Sand @ Top of Sample.

Unit Weight Determination:

Diameter, D, cm 6.23 Wt. Soil (lb.) 0.822

Area, A, cm^2 30.48 Moisture Content 5.4

Length, L, cm 6.350000 Volume (ft^3) 0.00685

Dry Density 113.9

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	5.4	20	41.15	127	6773.75	0.01594	0.85039	22	0.953	1.79E-02
2	14.7	20	11.08	127	4965.04	0.05921	2.31496	22	0.953	2.44E-02
3	20.3	20	9.02	127	5581.72	0.07274	3.19685	22	0.953	2.17E-02
4	23.5	20	7.49	127	5365.56	0.0876	3.70079	22	0.953	2.26E-02
5	25.5	20	7.08	127	5503.5	0.09267	4.01575	22	0.953	2.20E-02
6	27.5	20	6.89	127	5775.87	0.09522	4.33071	22	0.953	2.10E-02
7	28	20	6.46	127	5513.87	0.10156	4.40945	22	0.953	2.20E-02
8									AVG	2.16E-02
9										
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WS-GT-5 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 22-27

Description of Soil Sand, Fine to Coarse Grained, Trace Gravel, Black

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 5.08 Wt. Soil (lb.) 0.619

Area, A, cm^2 20.27 Moisture Content 4.4

Length, L, cm 8.260000 Volume (ft^3) 0.00591

Dry Density 100.3

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	210.9	2.01	1	99.6156	4274.58	0.09917	25.5327	20	1.000	2.33E-02
2	210.9	2.01	150	579.431	641187	0.00066	25.5327	20	1.000	9.04E-04
3										
4										
5										
6										
7										
8										
9									AVG	1.21E-02
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/29/2005

Location of Sample WC-GT-1 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 5 to 10'

Description of Soil Clayey Sand, dark brown to tan

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 6.35 Dry Density 115.000

Area, A, cm^2 31.67 Moisture Content 3.4

Length, L, cm 6.350000

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	1.2	20	24	127	912.073	0.02631	0.18898	22	0.953	1.33E-01
2	2.6	20	14	127	1152.76	0.04511	0.40945	22	0.953	1.05E-01
3	4.1	20	10	127	1298.44	0.06315	0.64567	22	0.953	9.32E-02
4	5	20	8	127	1266.77	0.07894	0.7874	22	0.953	9.55E-02
5	5.3	20	8	127	1342.77	0.07894	0.83465	22	0.953	9.01E-02
6	5.5	20	8	127	1393.44	0.07894	0.86614	22	0.953	8.69E-02
7	6	20	8	127	1520.12	0.07894	0.94488	22	0.953	7.96E-02
8	6.8	20	7	127	302.26	0.44994	1.07087	22	0.953	4.00E-01
9									AVG	1.35E-01
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: Trevor Kauffeld

Terracon

PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/13/2005

Location of Sample WC-GT-2 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 5 to 10'

Description of Soil Sand, with gravel, dark brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.60 Dry Density 90.900

Area, A, cm^2 45.36 Moisture Content 18.1

Length, L, cm 6.350000

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	9.8	20	32.3	127	14359.7	0.01365	1.54331	20	1.000	8.84E-03
2	63	20	18.4	127	52586.6	0.02396	9.92126	20	1.000	2.42E-03
3	65	20	17.3	127	51012.4	0.02548	10.2362	20	1.000	2.49E-03
4	71	20	17.05	127	54916.1	0.02586	11.1811	20	1.000	2.31E-03
									AVG	4.02E-03

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE
ID: PS-GT-1 10.0'-12.0'
DESCR.: CLAYEY SAND/SANDY CLAY,WITH GRAVEL, DARK BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	68.74	WET WT, g	208.6		
D & T, g	65.16	DIA, in	2.00	5.08	cm
T, g	19.41	HT, in	2.04	5.19	cm
		AREA		20.29	cm^2
MOIST-		DENSITY:	123.6	PCF WET	
URE, %	7.8	DENSITY:	**114.6**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	32.0	PROCTOR:	115.0
SATURATION, %:	44.9	OPTIMUM:	7.8
VOID RATIO:	0.47	COMPACTION, %:	99.7
		OVER OPTIMUM, %:	0.0

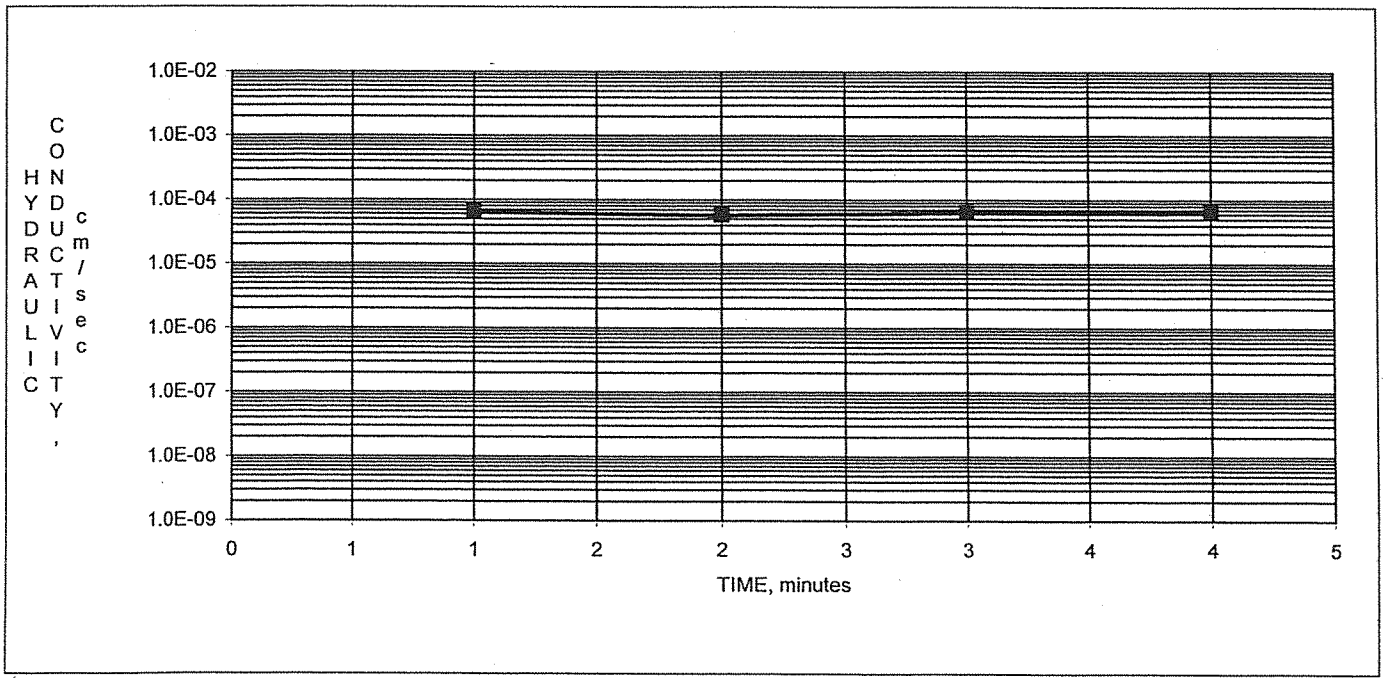
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER:	100.0	psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0	psi	

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
24.7	43.2	0	18.5									
25.5	42.3	1	16.8	0.096392	6.39E-05	0.8	0.9	0.89	3.2	2	21	0.980
26.2	41.6	2	15.4	0.087011	5.76E-05	0.7	0.7	1.00	3.0	7	21	0.980
26.9	40.9	3	14.0	0.095310	6.31E-05	0.7	0.7	1.00	2.7	1	21	0.980
27.5	40.2	4	12.7	0.097455	6.46E-05	0.6	0.7	0.86	2.4	4	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 6.2E-05 cm/sec

MAXIMUM HYDRAULIC GRADIENT			
1.0E-03 TO 1.0E-04	2	0.75< RATIO <1.25	% < 25 AT > 1.0E-8 OR % < 50 AT < 1.0E-8
1.0E-04 TO 1.0E-05	5		
1.0E-05 TO 1.0E-06	10		
1.0E-06 TO 1.0E-07	20		
1.0E-07 TO 1.0E-10	30		

NUMBER OF PORE VOLUMES PASSED = 0.0263



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MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE
ID: PS-GT-2 7.0' TO8.5'
DESCR.: CLAYEY SAND, TRACE GRAVEL, MEDIUM COURSE, BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	74.82	WET WT, g	230.3		
D & T, g	70.08	DIA, in	1.99	5.06	cm
T, g	20.32	HT, in	2.03	5.16	cm
		AREA		20.09	cm^2
MOIST-		DENSITY:	138.7	PCF WET	
URE, %	9.5	DENSITY:	126.7	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	24.8	PROCTOR:	125.0
SATURATION, %:	77.8	OPTIMUM:	9.7
VOID RATIO:	0.33	COMPACTION, %:	101.3
		OVER OPTIMUM, %:	-0.2

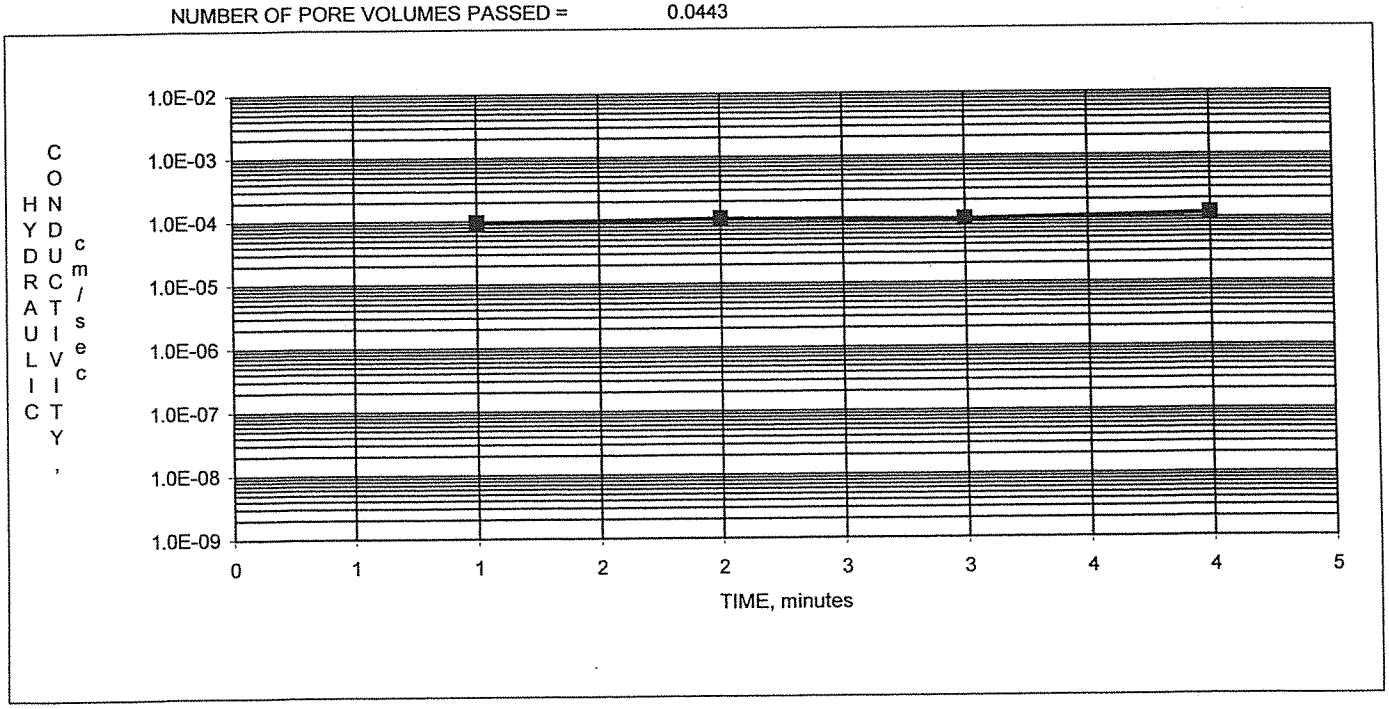
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
20.8	37.2	0	16.4									
21.8	36.0	1	14.2	0.144039	9.58E-05	1.0	1.2	0.83	2.8	9	21	0.980
22.8	34.9	2	12.1	0.160037	1.06E-04	1.0	1.1	0.91	2.3	1	21	0.980
23.6	34.0	3	10.4	0.151400	1.01E-04	0.8	0.9	0.89	2.0	4	21	0.980
24.4	33.1	4	8.7	0.178483	1.19E-04	0.8	0.9	0.89	1.7	13	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 1.1E-04 cm/sec

MAXIMUM HYDRAULIC GRADIENT	1.0E-03 TO 1.0E-04	2	0.75< RATIO <1.25	% < 25 AT > 1.0E-8 OR % < 50 AT < 1.0E-8
	1.0E-04 TO 1.0E-05	5		
	1.0E-05 TO 1.0E-06	10		
	1.0E-06 TO 1.0E-07	20		
	1.0E-07 TO 1.0E-10	30		

NUMBER OF PORE VOLUMES PASSED = 0.0443



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MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE ID: PS-GT-3 7.0'-9.0'
DESCR.: SAND, WITH CLAY, TRACE GRAVEL & ORGANICS, DARK BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	79.03	WET WT, g	208.3		
D & T, g	72.30	DIA, in	1.99	5.06	cm
T, g	20.26	HT, in	2.02	5.12	cm
		AREA		20.13	cm^2
MOIST-		DENSITY:	126.2	PCF WET	
URE, %	12.9	DENSITY:	111.8	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	33.7	PROCTOR:	115.0
SATURATION, %:	68.7	OPTIMUM:	12.9
VOID RATIO:	0.51	COMPACTION, %:	97.2
		OVER OPTIMUM, %:	0.0

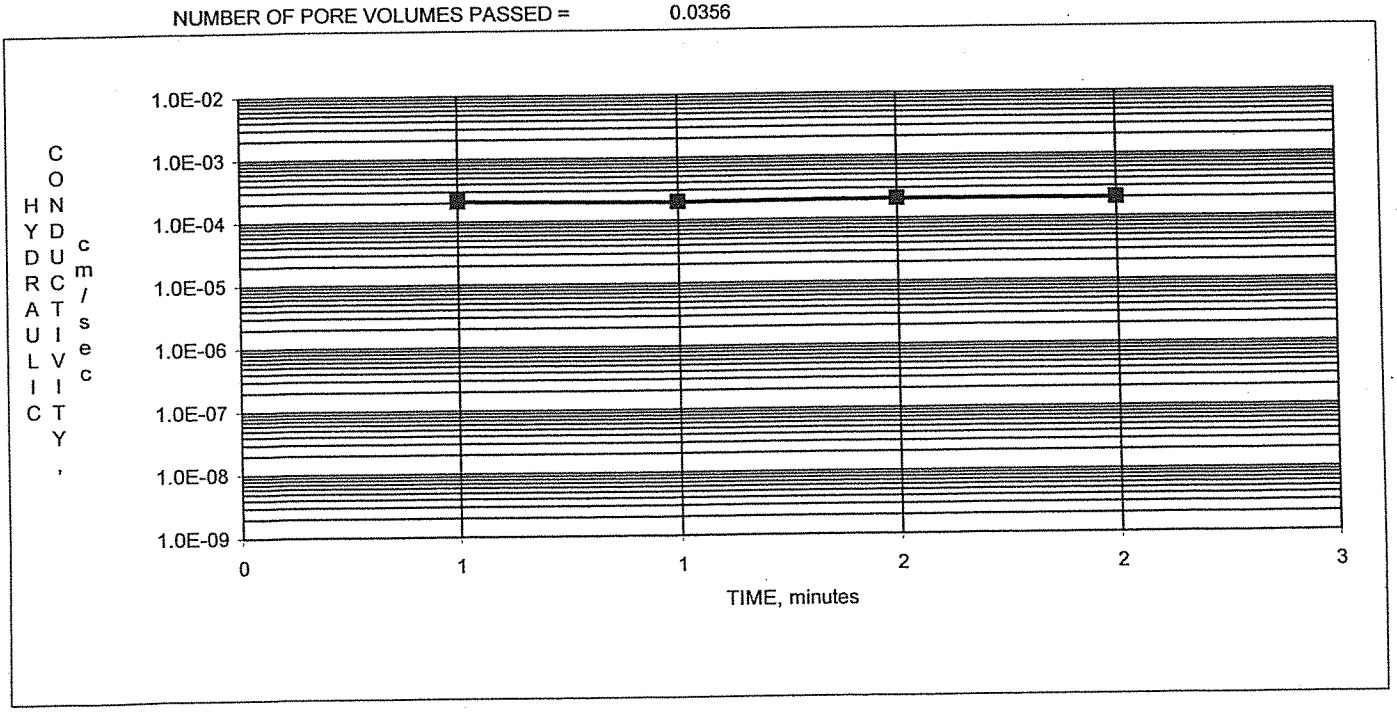
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
22.1	39.1	0	17.0									
23.3	37.8	0	14.5	0.159065	2.09E-04	1.2	1.3	0.92	2.8	4	21	0.980
24.3	36.8	1	12.5	0.148420	1.95E-04	1.0	1.0	1.00	2.4	3	21	0.980
25.2	35.9	1	10.7	0.155485	2.05E-04	0.9	0.9	1.00	2.1	1	21	0.980
26.0	35.2	2	9.2	0.151040	1.99E-04	0.8	0.7	1.14	1.8	2	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 2.0E-04 cm/sec

MAXIMUM HYDRAULIC GRADIENT	1.0E-03 TO 1.0E-04	2	0.75< RATIO <1.25	% < 25 AT > 1.0E-8 OR % < 50 AT < 1.0E-8
	1.0E-04 TO 1.0E-05	5		
	1.0E-05 TO 1.0E-06	10		
	1.0E-06 TO 1.0E-07	20		
	1.0E-07 TO 1.0E-10	30		

NUMBER OF PORE VOLUMES PASSED = 0.0356



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MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS USING A FLEXIBLE WALL PERMEAMETER

ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL

FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 9/20/2005

SAMPLE ID: PS-GT-4
DESCR.: SAND, WITH CLAY & GRAVEL, TRACE ORGANICS, FINE TO COURSE GRAINED, DARK BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	66.57	WET WT, g	223.0		
D & T, g	60.35	DIA, in	1.97	5.00	cm
T, g	20.37	HT, in	2.08	5.29	cm
		AREA		19.66	cm^2
MOIST-		DENSITY:	133.9	PCF WET	
URE, %	**15.6**	DENSITY:	**115.9**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	31.2	PROCTOR:	115.0
SATURATION, %:	92.5	OPTIMUM:	15.7
VOID RATIO:	0.45	COMPACTION, %:	100.8
		OVER OPTIMUM, %:	-0.1

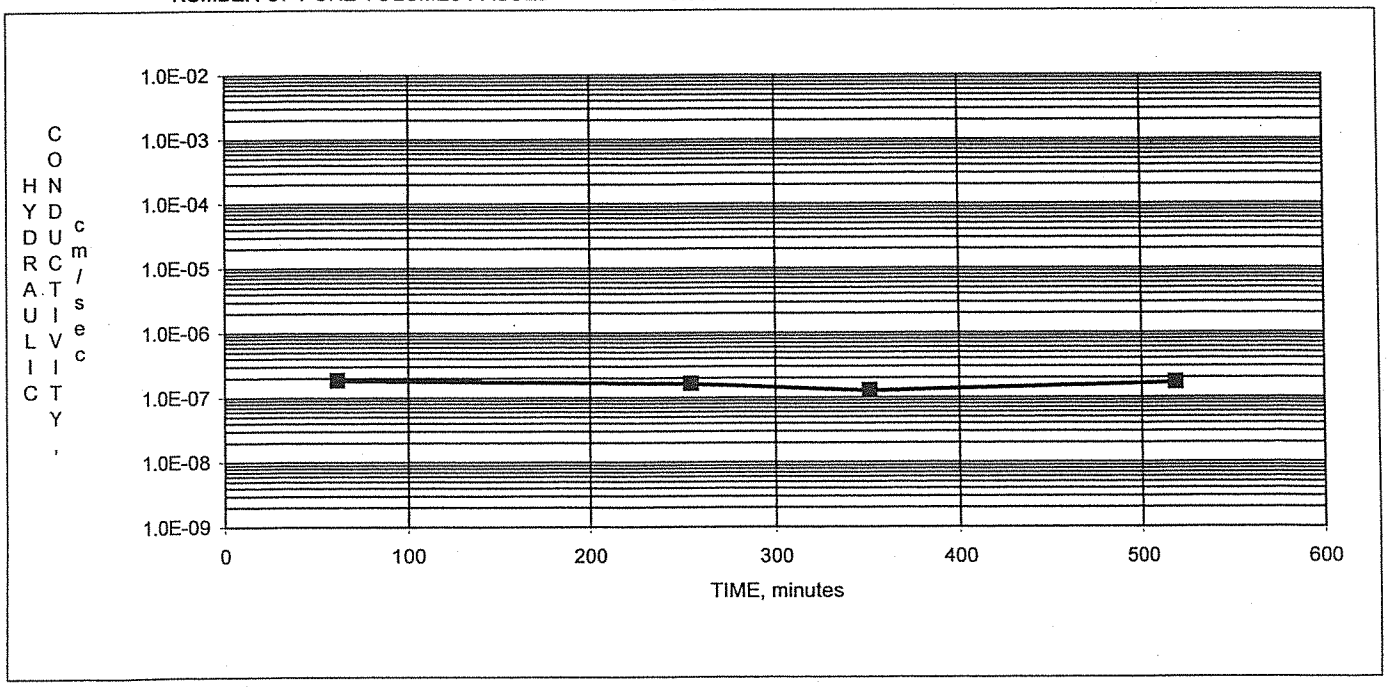
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
4.1	71.3	0	67.2									
4.6	70.7	62	66.1	0.016505	1.85E-07	0.5	0.6	0.83	12.5	16	21	0.980
5.9	69.1	254	63.2	0.044864	1.63E-07	1.3	1.6	0.81	12.0	1	21	0.980
6.4	68.5	351	62.1	0.017558	1.26E-07	0.5	0.6	0.83	11.7	21	21	0.980
7.5	67.2	519	59.7	0.039414	1.67E-07	1.1	1.3	0.85	11.3	4	20	1.005

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 1.6E-07 cm/sec

MAXIMUM HYDRAULIC GRADIENT			0.75< RATIO <1.25	% < 25 AT > 1.0E-8 OR % < 50 AT < 1.0E-8
	1.0E-03 TO 1.0E-04	2		
	1.0E-04 TO 1.0E-05	5		
	1.0E-05 TO 1.0E-06	10		
	1.0E-06 TO 1.0E-07	20		
	1.0E-07 TO 1.0E-10	30		

NUMBER OF PORE VOLUMES PASSED = 0.0332



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PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 10/1/2005

Location of Sample PS-GT-6 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 13 to 18'

Description of Soil Sand, fine to coarse, trace gravel, trace rubble, dark brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 6.23 Dry Density 107.000

Area, A, cm^2 30.48 Moisture Content 4.3

Length, L, cm 6.350000

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	17.6	20	25.1	127	13466.4	0.02614	2.77165	22	0.953	8.99E-03
2	31.8	20	14.7	127	14249.8	0.04463	5.00787	22	0.953	8.49E-03
3	36.8	20	13	127	14583.3	0.05047	5.79528	22	0.953	8.30E-03
4	38.8	20	12.6	127	14902.8	0.05207	6.11024	22	0.953	8.12E-03
5	40.8	20	12.2	127	15173.5	0.05378	6.4252	22	0.953	7.98E-03
6	42.7	20	11.4	127	14838.8	0.05755	6.72441	22	0.953	8.16E-03
7	47.8	20	9.7	127	14134	0.06764	7.52756	22	0.953	8.56E-03
									AVG	8.37E-03

Note:

Tested by: _____ Checked by: TK
Rowdy Miller Trevor Kauffeld

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING — TERRACON JOB #: 58055075 — DATE: 10/7/2005

SAMPLE ID: PS-GT-7 10.0'-13.0' — #4 MATERIAL

DESCR.: SAND WITH SILT and GRAVEL (SW-SM), DARK GRAY

Durham Perm Cell — BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	88.50	WET WT, g	191.6		
D & T, g	83.87	DIA, in	1.94	4.93	cm
T, g	19.37	HT, in	1.96	4.98	cm
		AREA		19.05	cm^2
MOIST-		DENSITY:	126.2	PCF WET	
URE, %	7.2	DENSITY:	117.7	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	30.1	PROCTOR:	NA
SATURATION, %:	44.9	OPTIMUM:	NA
VOID RATIO:	0.43	COMPACTION, %:	#VALUE!
		OVER OPTIMUM, %:	#VALUE!

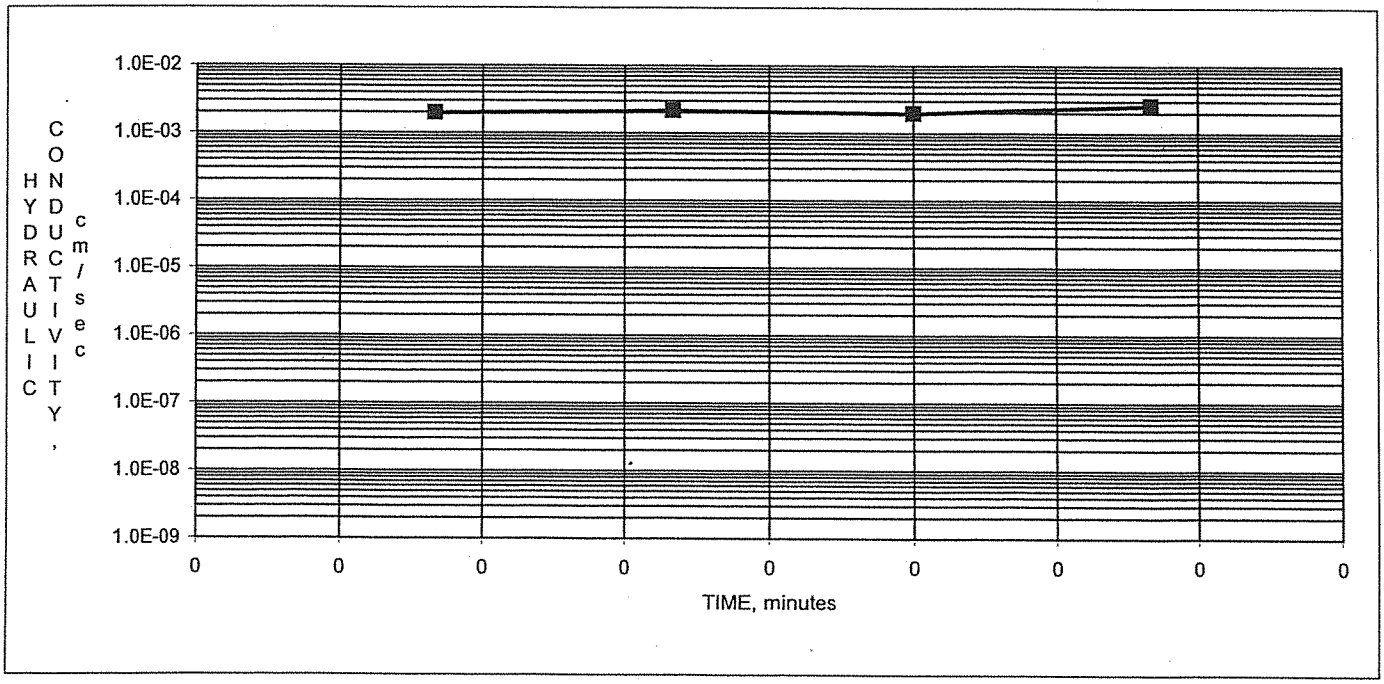
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
20.8	30.1	0	9.3									
21.8	29.1	0	7.3	0.242140	1.96E-03	1.0	1.0	1.00	1.5	9	21	0.980
22.6	28.2	0	5.6	0.265108	2.15E-03	0.8	0.9	0.89	1.1	1	21	0.980
23.2	27.6	0	4.4	0.241162	1.96E-03	0.6	0.6	1.00	0.9	10	21	0.980
23.8	27.0	0	3.2	0.318454	2.58E-03	0.6	0.6	1.00	0.6	19	21	0.980

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 2.2E-03 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	OR
	1.0E-06 TO 1.0E-07	20		% < 50 AT
	1.0E-07 TO 1.0E-10	30		< 1.0E-8

NUMBER OF PORE VOLUMES PASSED = 0.0333



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PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/18/2005

Location of Sample PS-GT-8 Sampled _____ Report _____

Boring- _____ Sample- Bottom Depth- 10 to 15'

Description of Soil Silty Sand, trace clay, dark gray

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.62 Wt. Soil (lb.) 1.320

Area, A, cm^2 45.60 Moisture Content 12.0

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 115.3

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	3.3	20	31.5	127	4740.5	0.01392	0.51969	20	1.000	2.68E-02
2	8.7	20	14	127	5554.52	0.03133	1.37008	20	1.000	2.29E-02
3	13.5	20	9.2	127	5663.97	0.04767	2.12598	20	1.000	2.24E-02
4	17.2	20	7	127	5490.68	0.06265	2.70866	20	1.000	2.31E-02
5	21.5	20	5.5	127	5392.63	0.07974	3.38583	20	1.000	2.36E-02
6	24.3	20	5	127	5540.84	0.08771	3.82677	20	1.000	2.29E-02
7	32.3	20	4	127	5891.99	0.10964	5.08661	20	1.000	2.16E-02
8	32.3	20	4	127	5891.99	0.10964	5.08661	20	1.000	2.16E-02
9									AVG	2.31E-02
10										
11										
12										

Note:

Tested by: _____ Checked by: TK

Rowdy Miller Trevor Kauffeld

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING — TERRACON JOB #: 58055075 — DATE: 10/7/2005

SAMPLE ID: PS-GT-9 15.0'-20.0' — #4 MATERIAL

DESCR.: SAND WITH GRAVEL & SILT, DARK YELLOWISH BROWN

Durham Perm Cell — BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	51.97	WET WT, g	183.1		
D & T, g	50.15	DIA, in	1.94	4.94	cm
T, g	20.20	HT, in	1.95	4.96	cm
		AREA		19.15	cm^2
MOIST-		DENSITY:	120.3	PCF WET	
URE, %	6.1	DENSITY:	**113.4**	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	32.7	PROCTOR:	NA
SATURATION, %:	33.7	OPTIMUM:	NA
VOID RATIO:	0.49	COMPACTION, %:	#VALUE!
		OVER OPTIMUM, %:	#VALUE!

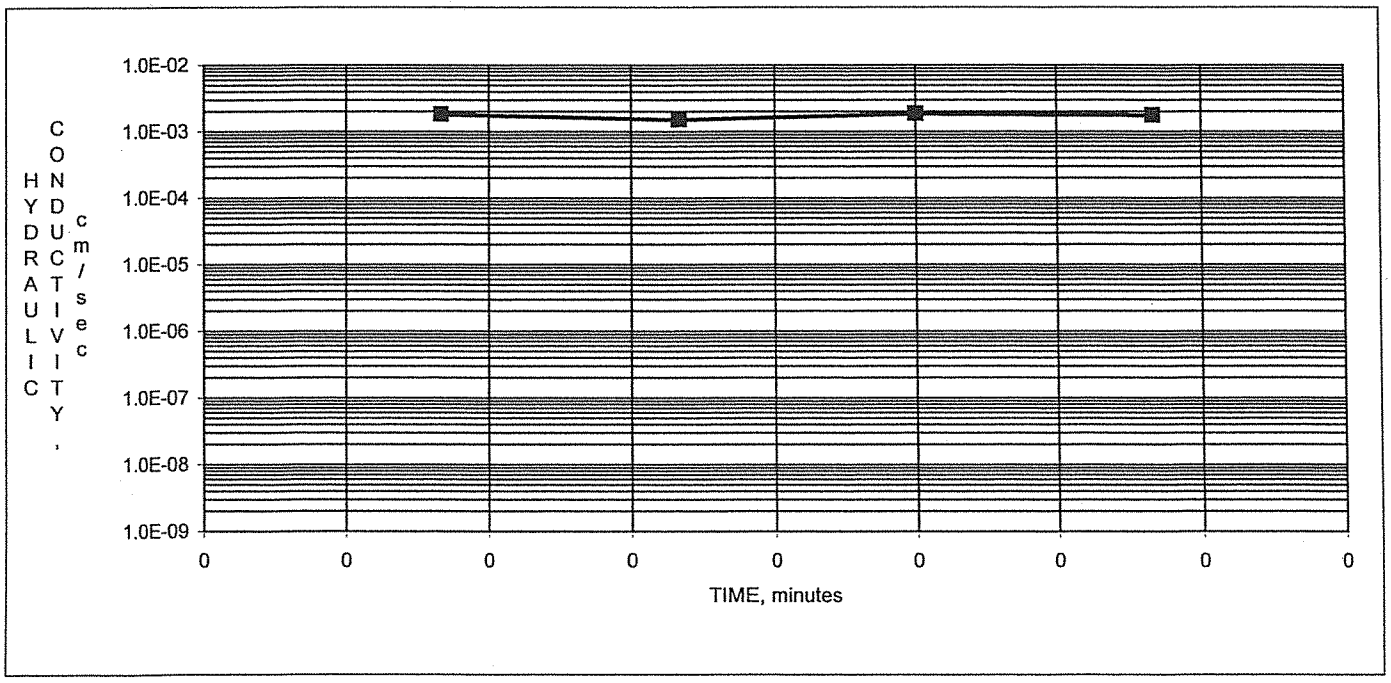
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER:	100.0	psi
				BIAS PRESSURE (=LOWER-UPPER)		0.0	psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
10.5	16.3	0	5.8									
11.1	15.7	0	4.6	0.231802	1.82E-03	0.6	0.6	1.00	0.9	5	22	0.956
11.5	15.3	0	3.8	0.191055	1.50E-03	0.4	0.4	1.00	0.8	13	22	0.956
11.9	14.9	0	3.0	0.236389	1.85E-03	0.4	0.4	1.00	0.6	7	22	0.956
12.2	14.6	0	2.4	0.223144	1.75E-03	0.3	0.3	1.00	0.5	1	22	0.956

HYDRAULIC CONDUCTIVITY (k) = AVERAGE 1.7E-03 cm/sec

MAXIMUM HYDRAULIC GRADIENT				
	1.0E-03 TO 1.0E-04	2	0.75< RATIO <1.25	% < 25 AT > 1.0E-8 OR % < 50 AT < 1.0E-8
	1.0E-04 TO 1.0E-05	5		
	1.0E-05 TO 1.0E-06	10		
	1.0E-06 TO 1.0E-07	20		
	1.0E-07 TO 1.0E-10	30		

NUMBER OF PORE VOLUMES PASSED = 0.0173



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PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/16/2005

Location of Sample JS-29-GT-1 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 19 to 24'

Description of Soil Sand, fine grained, trace clay and gravel, dark yellow

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.58 Wt. Soil (lb.) 1.290

Area, A, cm^2 45.13 Moisture Content 5.3

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 119.9

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	2.5	20	31.5	127	3553.68	0.01407	0.3937	20	1.000	3.57E-02
2	7.1	20	14	127	4485.54	0.03166	1.11811	20	1.000	2.83E-02
3	11.2	20	9.5	127	4801.42	0.04665	1.76378	20	1.000	2.65E-02
4	14	20	7	127	4422.36	0.06331	2.20472	20	1.000	2.87E-02
5	17.6	20	5.5	127	4368.21	0.08058	2.77165	20	1.000	2.91E-02
6	18.8	20	5	127	4241.85	0.08864	2.96063	20	1.000	2.99E-02
7	24	20	4	127	4332.11	0.1108	3.77953	20	1.000	2.93E-02
8	24	20	4	127	4332.11	0.1108	3.77953	20	1.000	2.93E-02
9									AVG	2.96E-02
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

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PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/12/2005

Location of Sample JS-9-GT-2 Sampled _____ Report _____

Boring- _____ Sample- _____ Depth- 7 to 11.5'

Description of Soil Clayey Sand, with organics, trace gravel, dark brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.62 Wt. Soil (lb.) 1.150

Area, A, cm^2 45.60 Moisture Content 23.7

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 91.0

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	3	20	31.5	127	4309.54	0.01392	0.47244	20	1.000	2.95E-02
2	7.1	20	14	127	4533	0.03133	1.11811	20	1.000	2.80E-02
3	11.9	20	9.5	127	5155.49	0.04616	1.87402	20	1.000	2.46E-02
4	13.3	20	7	127	4245.7	0.06265	2.09449	20	1.000	2.99E-02
5	18.2	20	5.5	127	4564.92	0.07974	2.86614	20	1.000	2.78E-02
6	20.8	20	5	127	4742.78	0.08771	3.27559	20	1.000	2.68E-02
7	27	20	4	127	4925.19	0.10964	4.25197	20	1.000	2.58E-02
8	27	20	4	127	4925.19	0.10964	4.25197	20	1.000	2.58E-02
9									AVG	2.73E-02
10										
11										
12										

Note:

Tested by: _____ Checked by: TK

Rowdy Miller Trevor Kauffeld

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PERMEABILITY TEST ON GRANULAR SOIL
ASTM D 2434

Project Number 58055075 Project Name KPRG Laboratory Testing

Test Number _____ Date 9/15/2005

Location of Sample JS-29-GT-3 Sampled _____ Report _____

Boring- _____ Sample- Bottom Depth- 19 to 24'

Description of Soil Sand, with gravel, trace clay, brown

Materials Used: _____

Unit Weight Determination:

Diameter, D, cm 7.59 Wt. Soil (lb.) 1.340

Area, A, cm^2 45.25 Moisture Content 8.6

Length, L, cm 6.350000 Volume (ft^3) 0.01022

Dry Density 120.7

Degree of Compactness Unknown- No proctor available

Test No.	Head,h(cm)	Q (cm^3)	t (s)	QL	Ath	Velocity (Q/At)	Hyd. Grad. (h/L)	Temp, C.	Temp. Corr.	k (cm/s)
1	2.9	20	31.5	127	4133.15	0.01403	0.45669	20	1.000	3.07E-02
2	7.3	20	14	127	4624.07	0.03157	1.14961	20	1.000	2.75E-02
3	11.3	20	9.5	127	4857.08	0.04653	1.77953	20	1.000	2.61E-02
4	16.4	20	7	127	5194.16	0.06315	2.58268	20	1.000	2.45E-02
5	21.7	20	5.5	127	5400.02	0.08037	3.41732	20	1.000	2.35E-02
6	23.9	20	5	127	5406.81	0.08841	3.76378	20	1.000	2.35E-02
7	31	20	4	127	5610.41	0.11051	4.88189	20	1.000	2.26E-02
8	31	20	4	127	5610.41	0.11051	4.88189	20	1.000	2.26E-02
9									AVG	2.51E-02
10										
11										
12										

Note:

Tested by: Rowdy Miller Checked by: TK Trevor Kauffeld

Electronic Filing: Received, Clerk's Office 2/04/2022

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT: KPRG LABORATORY TESTING TERRACON JOB #: 58055075
DATE: 10/7/2005

SAMPLE ID: JS 29-GT-5 5.0' - 9.0' Top 8" -#4 MATERIAL
DESCR.: CLAYEY GRAVEL WITH SAND (GC), DARK GRAY WITH YELLOWISH BROWN

Durham Perm Cell
BURETTE Area 0.317 cm^2

INITIAL

MOISTURE%		DENSITY			
W & T, g	48.02	WET WT, g	172.0		
D & T, g	44.14	DIA, in	1.94	4.93	cm
T, g	20.33	HT, in	1.96	4.98	cm
		AREA		19.05	cm^2
MOIST-		DENSITY:	113.3	PCF WET	
URE, %	16.3	DENSITY:	97.4	PCF DRY	

SPEC GRAV:	2.700	REMOLD (Y/N):	YES
POROSITY, %:	42.2	PROCTOR:	NA
SATURATION, %:	60.2	OPTIMUM:	NA
VOID RATIO:	0.73	COMPACTION, %:	#VALUE!
		OVER OPTIMUM, %:	#VALUE!

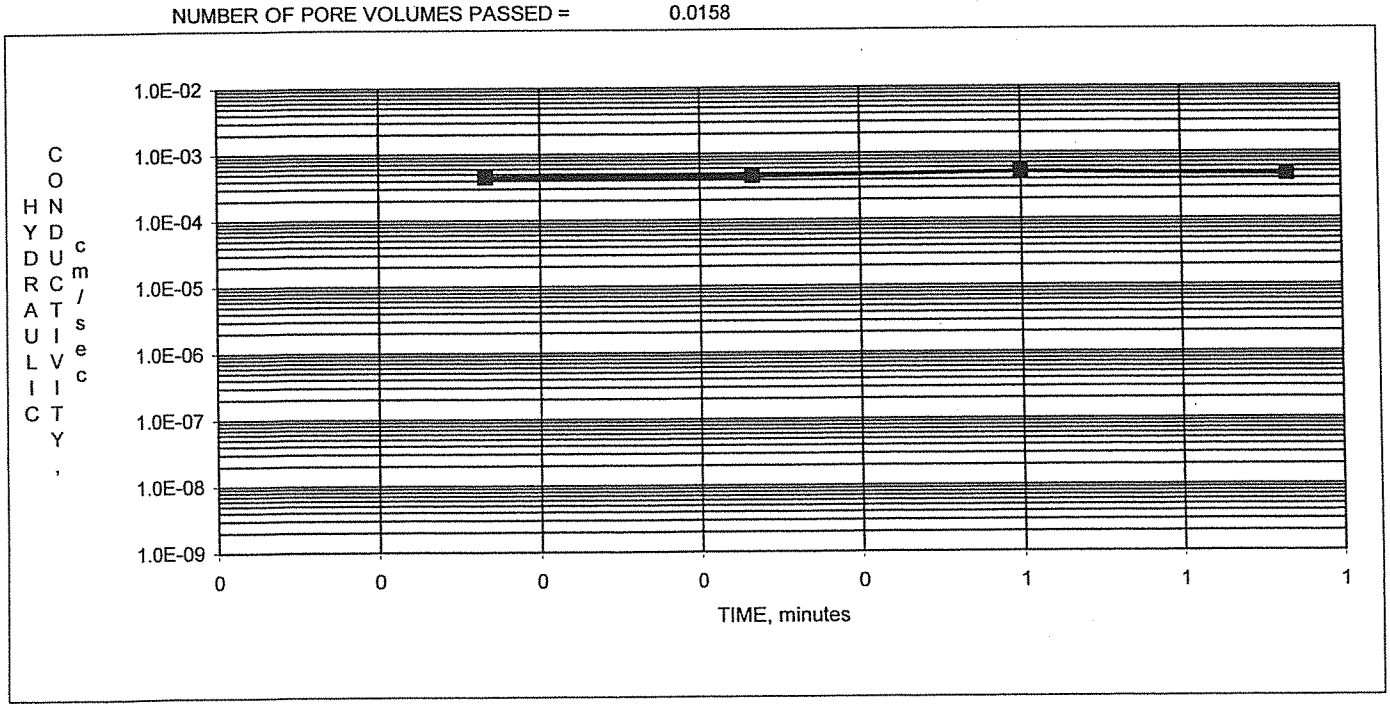
SATURATION:	LATERAL PRESS.:	105.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0 psi
TEST:	LATERAL PRESS.:	105.0	psi	UPPER: 100.0 psi	LOWER: 100.0 psi
				BIAS PRESSURE (=LOWER-UPPER)	0.0 psi

Upper cm^3	Lower cm^3	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
10.6	20.9	0	10.3									
11.2	20.4	0	9.2	0.112940	4.47E-04	0.6	0.5	1.20	1.8	5	22	0.956
11.7	19.9	0	8.2	0.115069	4.55E-04	0.5	0.5	1.00	1.6	3	22	0.956
12.2	19.4	1	7.2	0.130053	5.14E-04	0.5	0.5	1.00	1.4	9	22	0.956
12.6	19.0	1	6.4	0.117783	4.66E-04	0.4	0.4	1.00	1.3	1	22	0.956

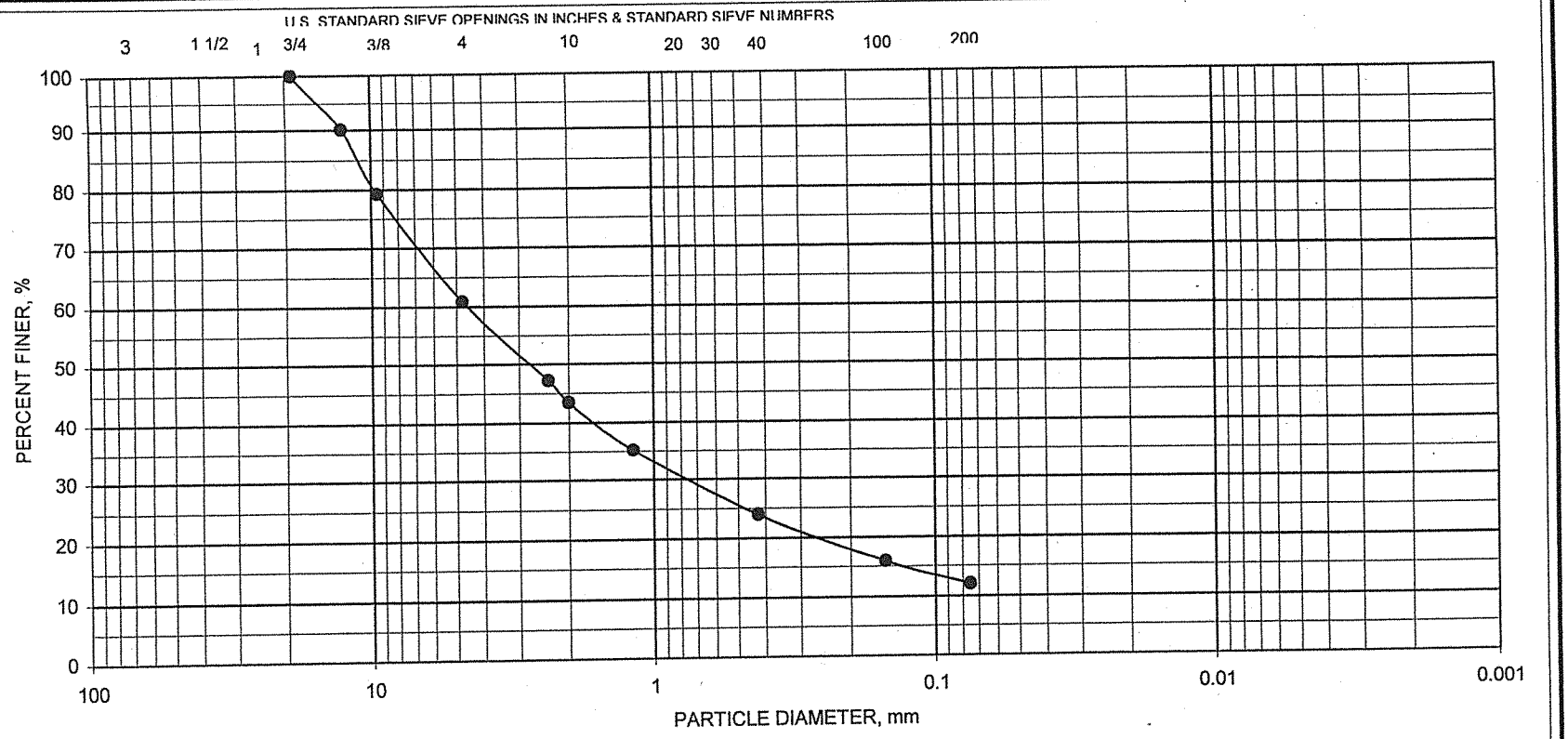
HYDRAULIC CONDUCTIVITY (k) = AVERAGE 4.7E-04 cm/sec

MAXIMUM HYDRAULIC GRADIENT	1.0E-03 TO 1.0E-04	2	0.75< RATIO <1.25	% < 25 AT > 1.0E-8 OR % < 50 AT < 1.0E-8
	1.0E-04 TO 1.0E-05	5		
	1.0E-05 TO 1.0E-06	10		
	1.0E-06 TO 1.0E-07	20		
	1.0E-07 TO 1.0E-10	30		

NUMBER OF PORE VOLUMES PASSED = 0.0158



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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
CS-GT-1		5 to 10'	Sand, fine to coarse grained, trace gravel and silt, brown, dark brown, blac	SP				

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

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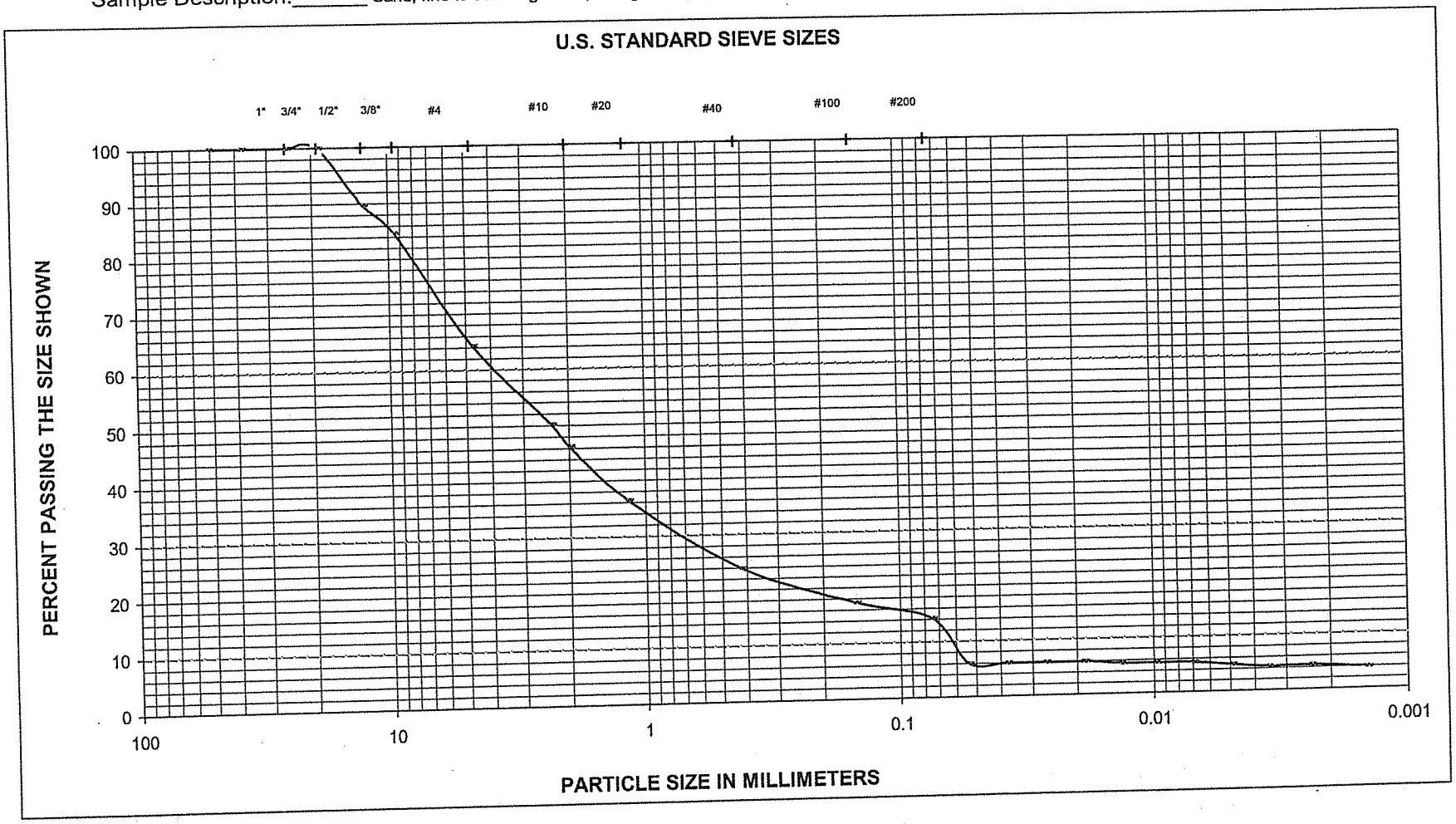
Sieve CS-GT-1.xls

Electronic Filing: Received, Clerk's Office 2/04/2022

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GRAIN SIZE DISTRIBUTION CURVE

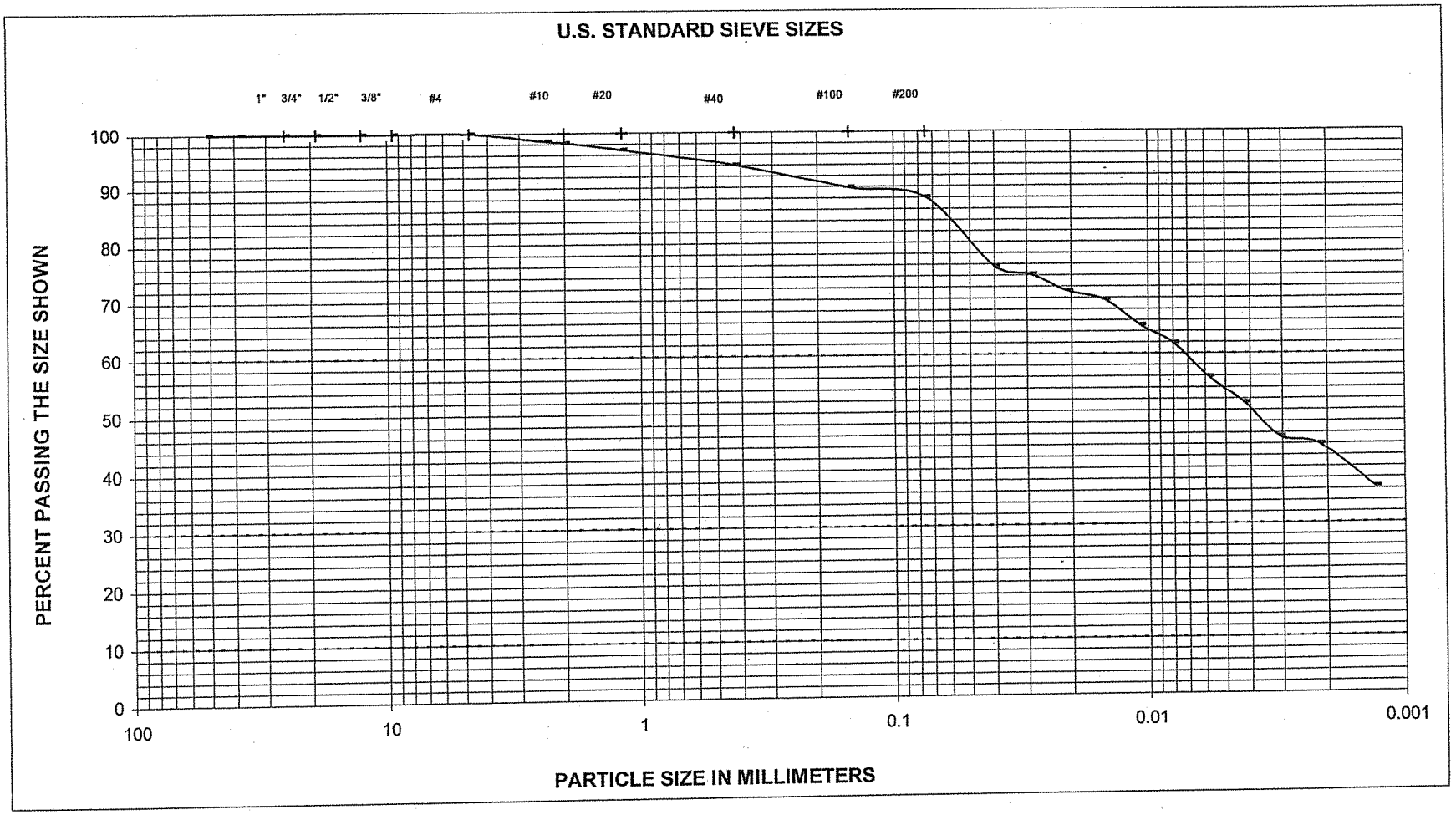
Project Name: KPRG Laboratory Testing
Terracon Project #: 58055075
Boring Number: CS-GT-2
Sample No.: 10-12' (top)
Date: 8/29/2005
Sample type.:
Sample Description: Sand, fine to coarse grained, with gravel, gray (crushed limestone)



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GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing
Terracon Project #: 58055075
Boring Number: CS-GT-2
Sample No.: bottom
Date: 8/29/2005
Sample type.:
Sample Description: Lean clay, trace sand, gray

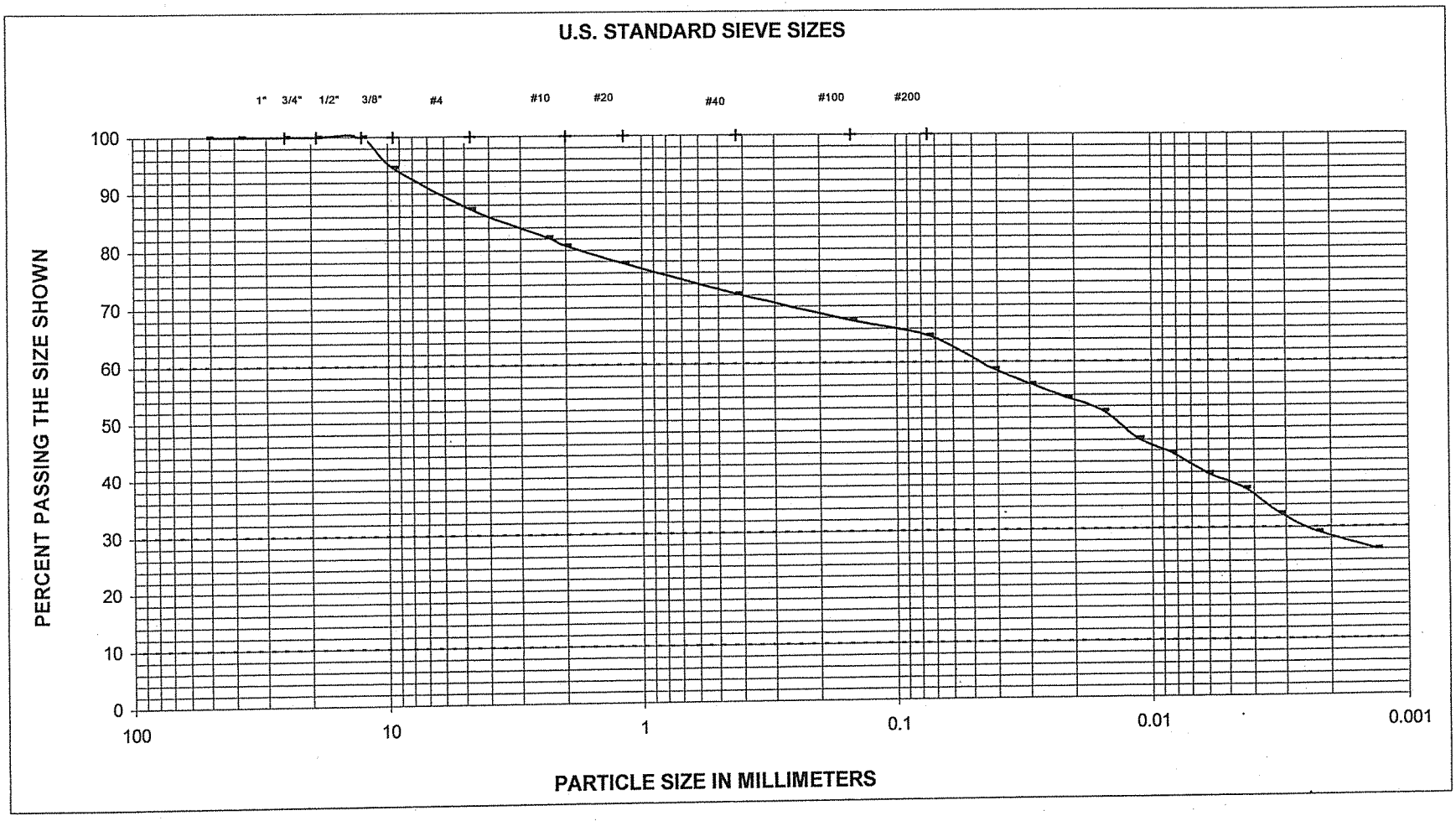


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GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing
Boring Number CS-GT-4
Date: 8/25/2005
Terracon Project #: 58055075
Sample No.:
Sample type.:
Sample Description: Lean Clay, Trace Sand and Gravel, Gray



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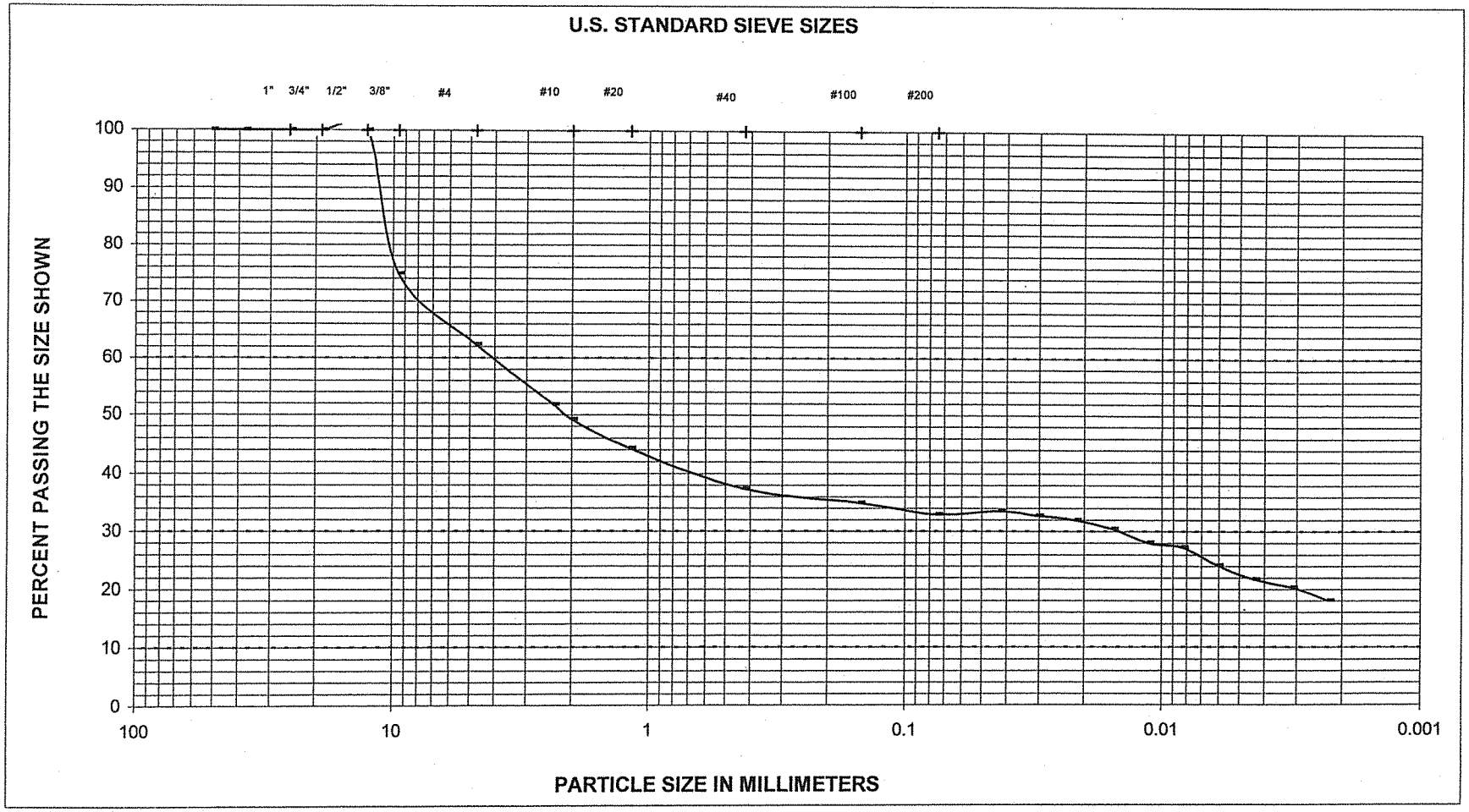
Terracon

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing Boring Number CS-GT-5 Date: 8/25/2005

Terracon Project #: 58055075 Sample No.: Sample type.:

Sample Description: Silty clay, with sand, brown and gray



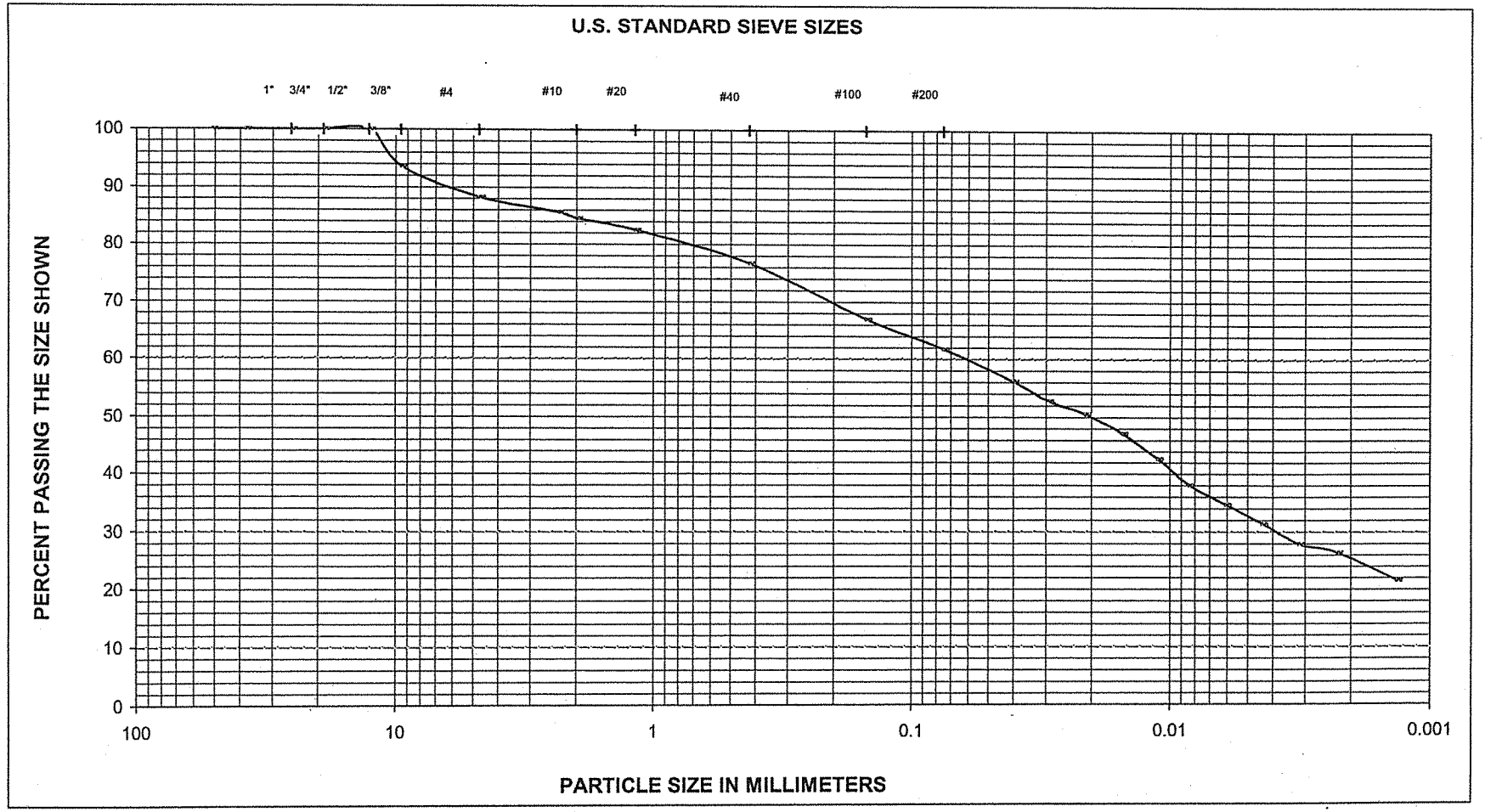
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

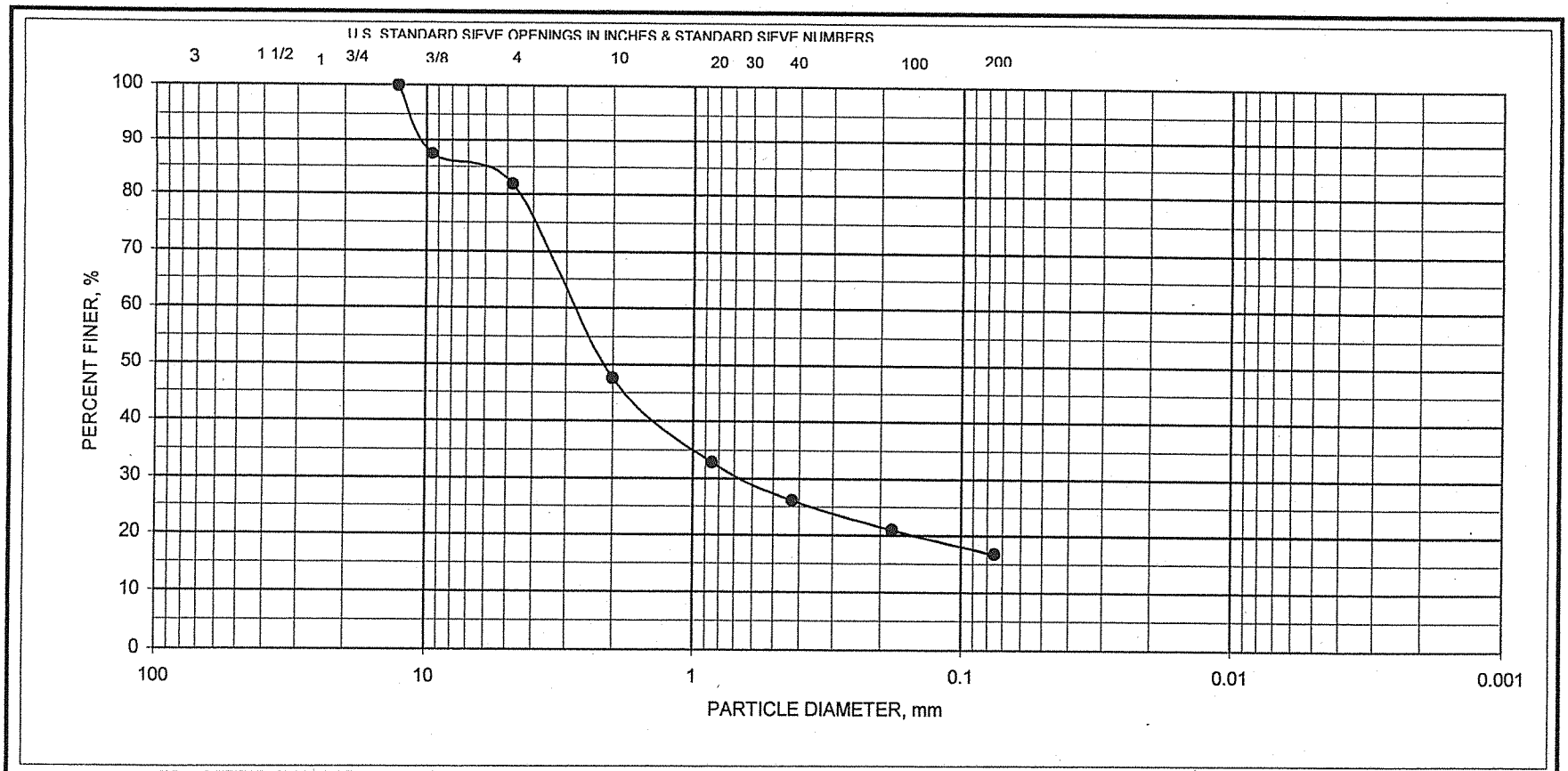
Project Name: KPRG Labarotory Testing | Boring Number CS-GT-6 | Date: 8/29/2005

Terracon Project #: 58055075 | Sample No.: | Sample type.:

Sample Description: Sandy Lean Clay, with gravel, brown and dark brown



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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-1		5 to 10'-Top	Clayey Gravelly Sand	SC				

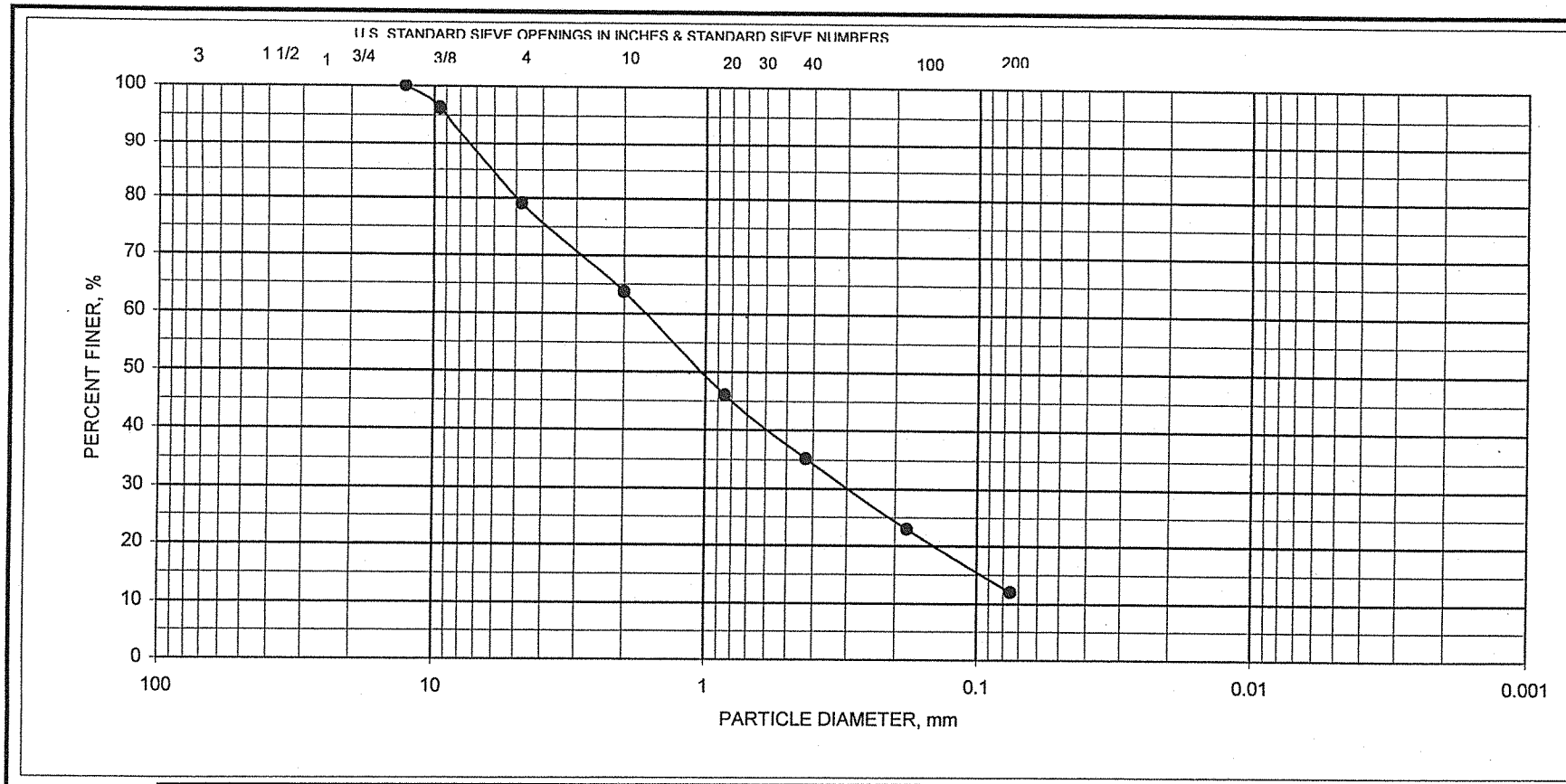
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 10/1/2005

Terracon

Sieve WCGT-1.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-2		5 to 10' BTM	VeryDark Brown Fine To Coarse Sand With Gravel, Trace Clay and Glass Slag	SC				

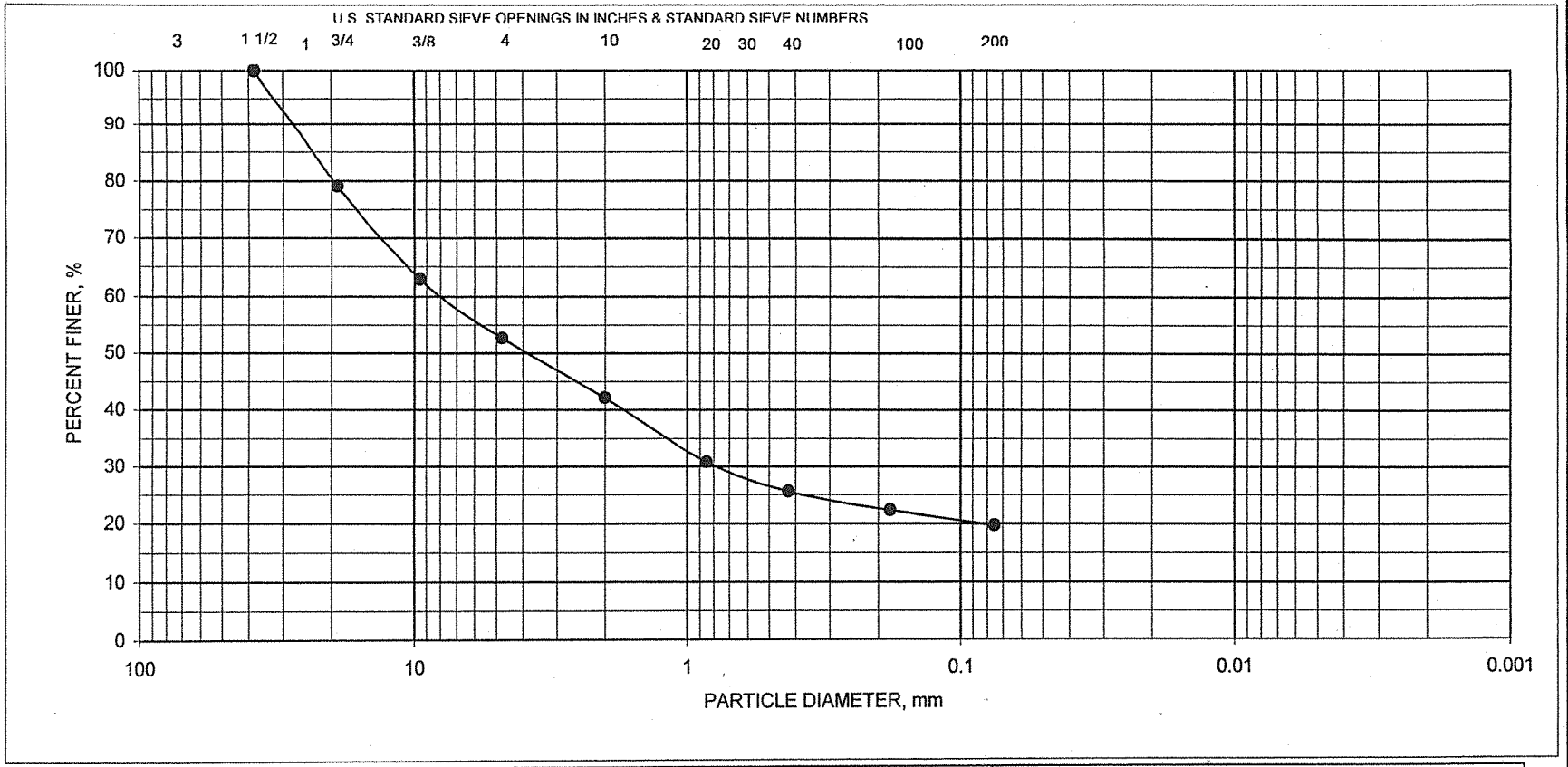
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/30/2005

Terracon

Sieve WCGT-2.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-3		3 to 8' (Top)	Clayey Gravelly Fine To Coarse Sand	SC				

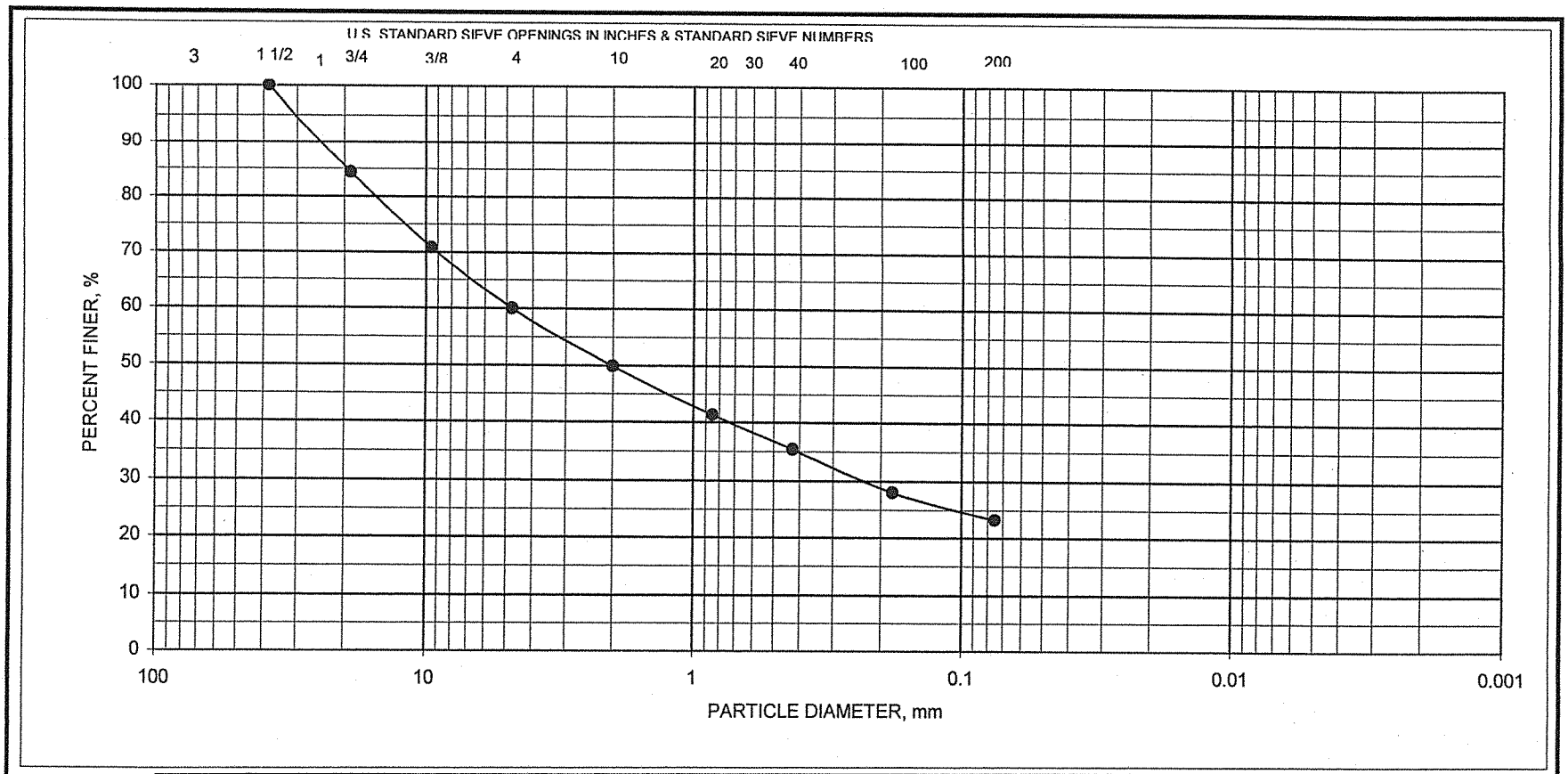
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 10/4/2005

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Sieve WCGT-3.xls

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-4		5 to 10'-Bottom of Sample	Sandy Fine To Coarse Gravel With Clay	GC				

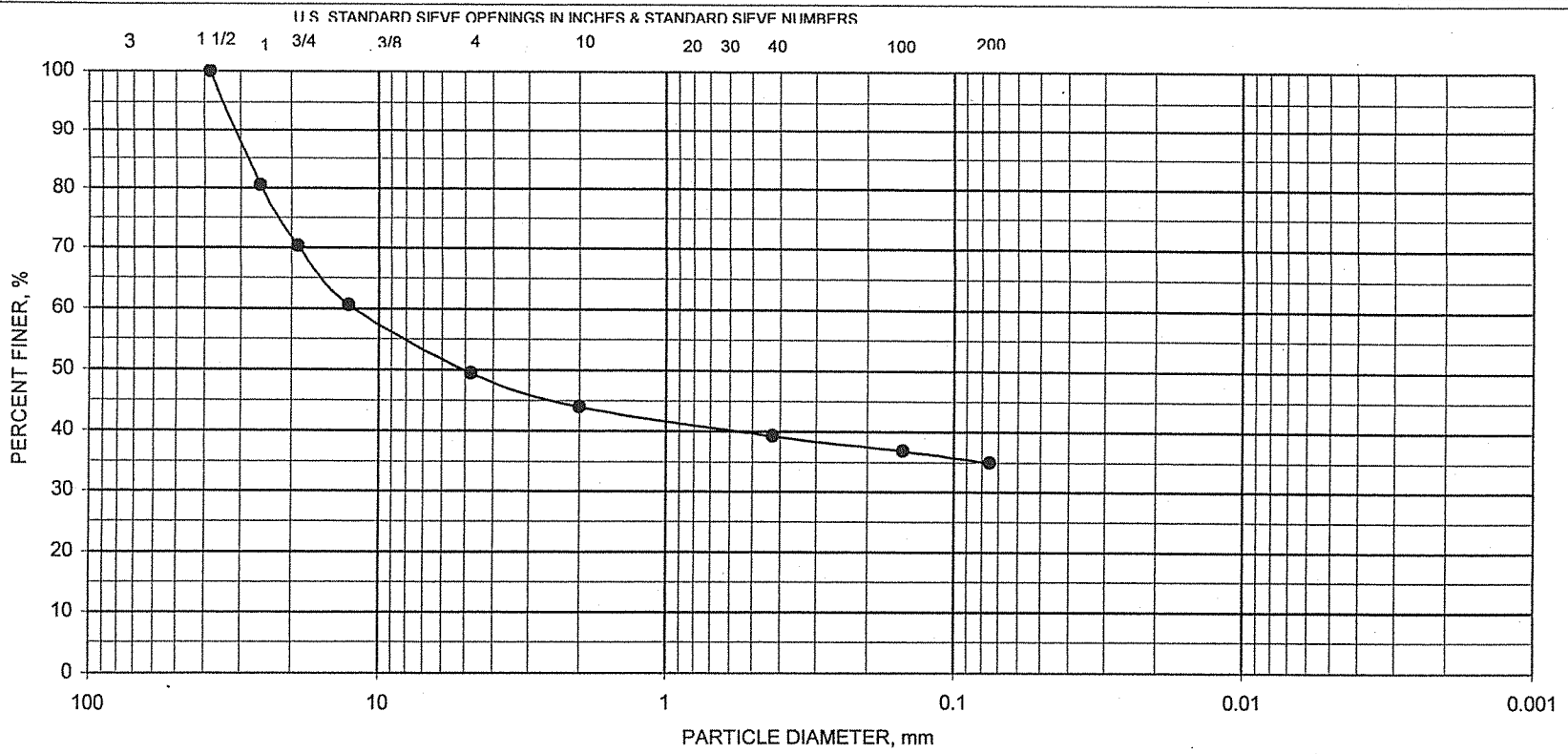
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/24/2005

Terracon

Sieve WCGT-4.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WCGT-5		5 to 9'-Bottom of Sample	Sandy clay with gravel	CL				

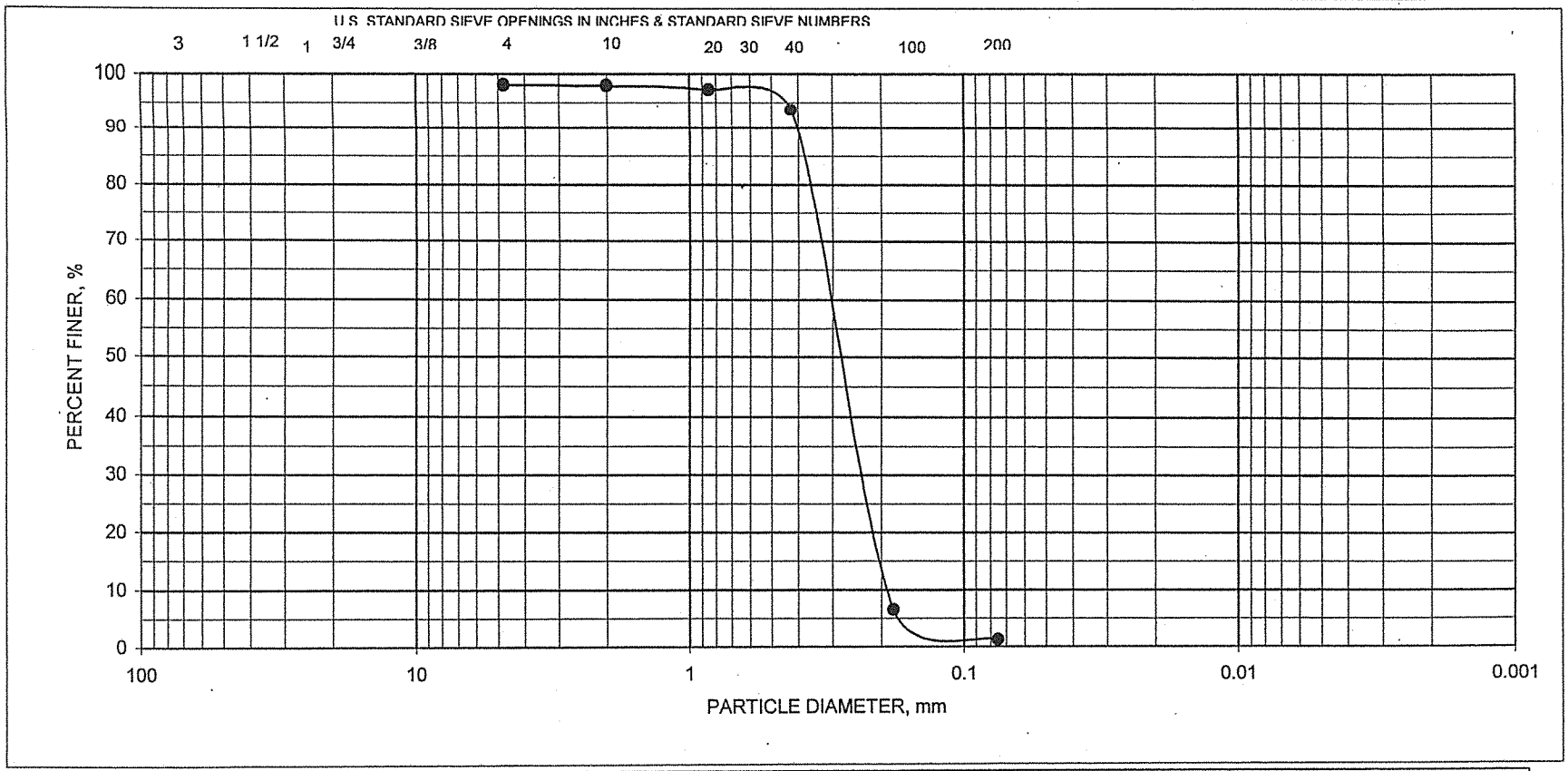
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/29/2005

Terracon

Sieve WCGT-5.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WSGT-1		5 to 10'	Fine Sand, Trace Gravel & Silt	SP	14	NP	NP	NP

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/21/2005

Terracon

Sieve WSGT-1.xls

Electronic Filing: Received, Clerk's Office 2/04/2022

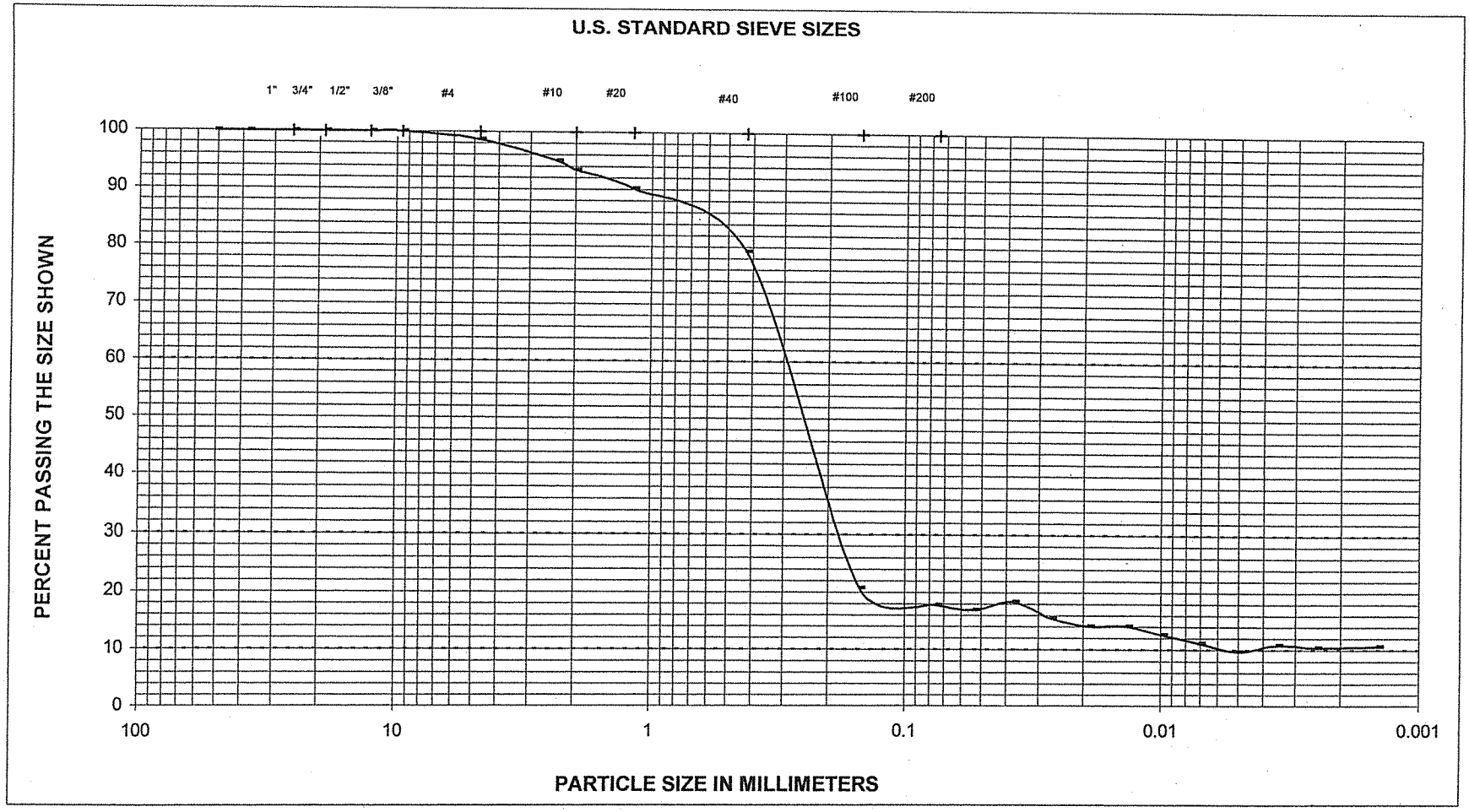
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GRAIN SIZE DISTRIBUTION CURVE

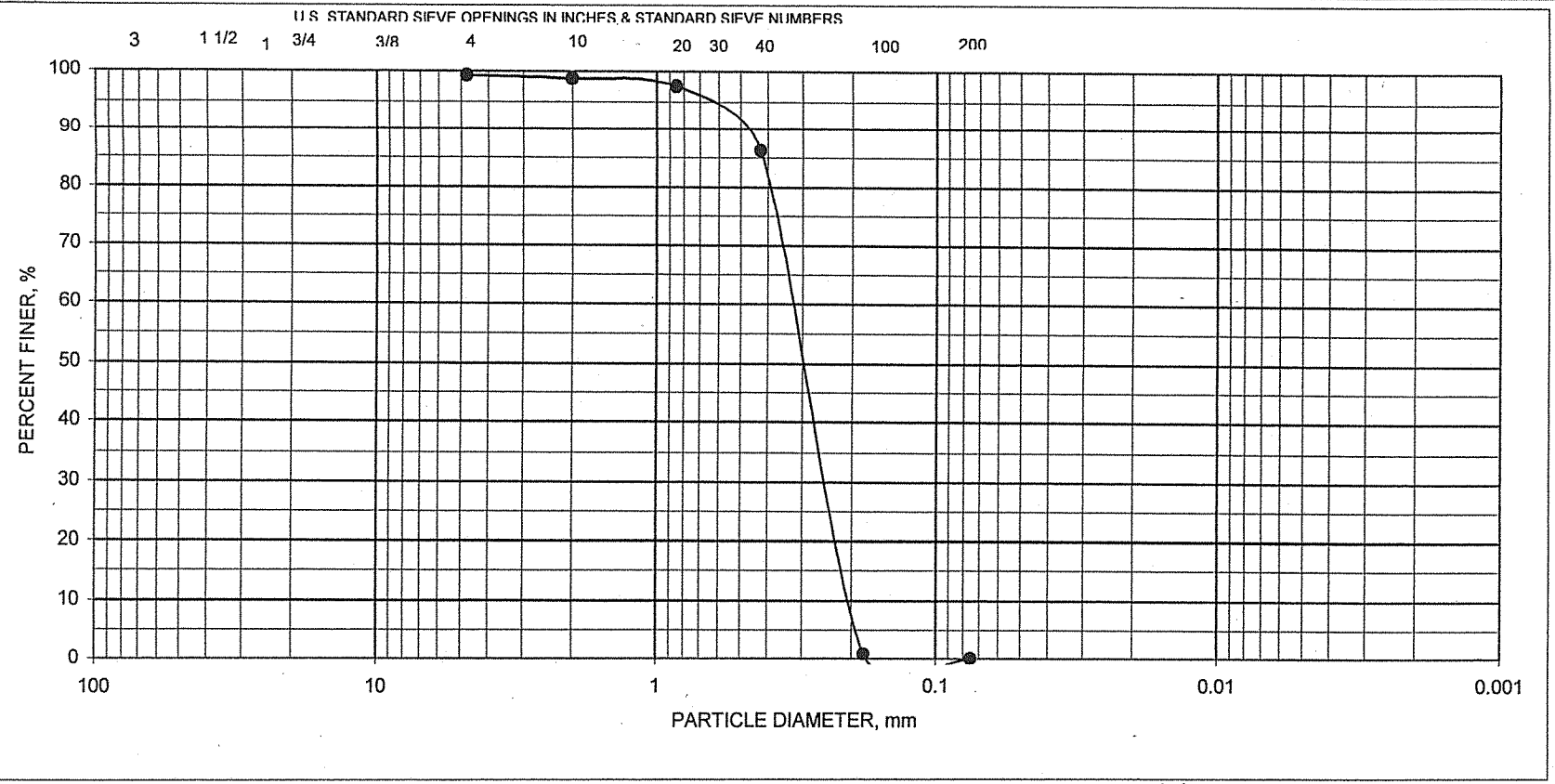
Project Name: KPRG Laboratory Testing
Terracon Project #: 58055075
Sample Description: Silty sand, trace gravel, dark brown

Boring Number: WS-GT-2
Sample No.:

Date: 8/26/2005
Sample type.:



Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WSGT-3			Fine Sand, Trace Silt	SP	11.2	NP	NP	NP

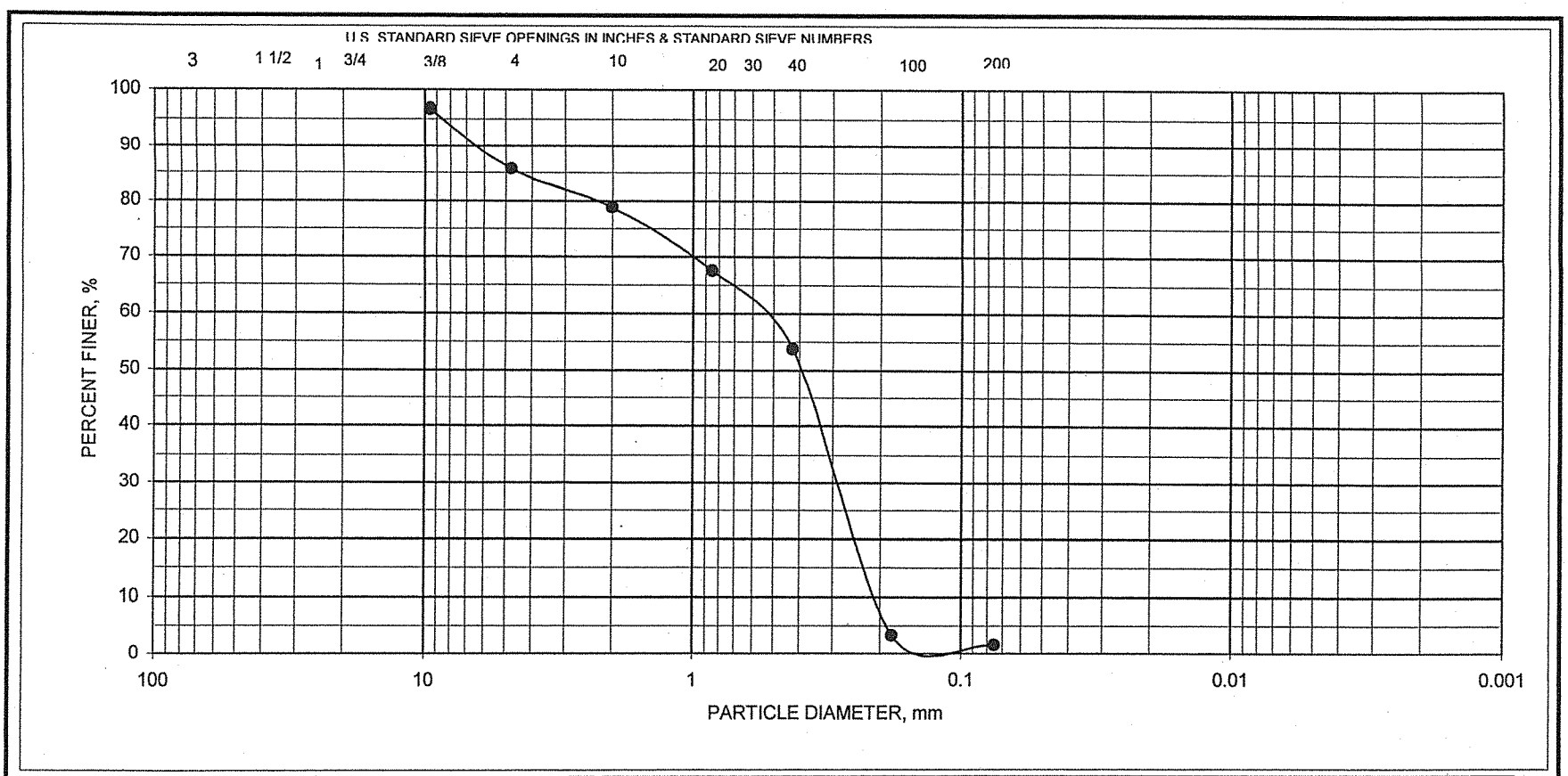
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/22/2005

Terracon

Sieve WSGT-3.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WSGT-4		5 to 10'-Bottom of Sample	Fine to Medium Sand With Gravel	SP	9.5	NP	NP	NP

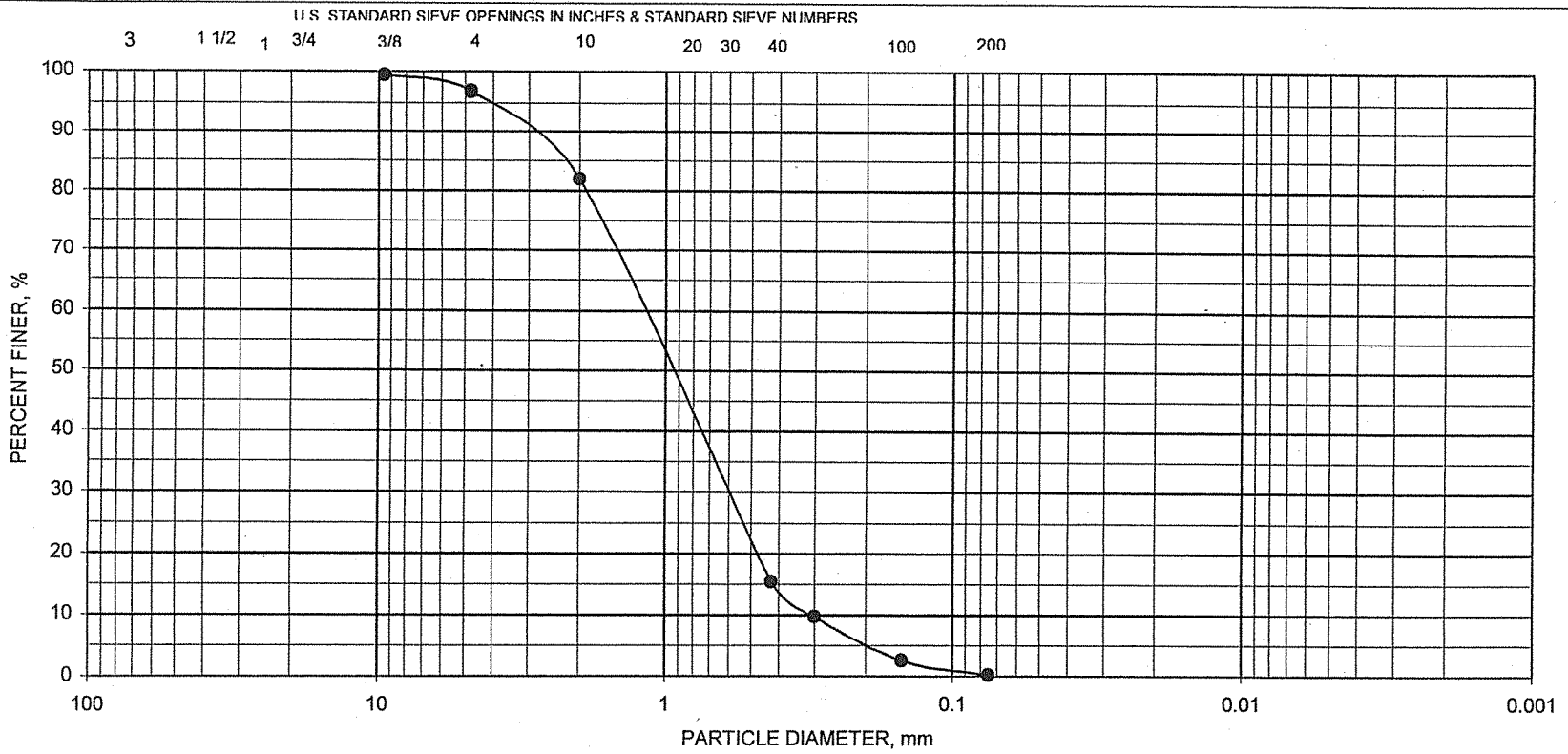
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/22/2005

Terracon

Sieve WSGT-4.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
WSGT-5		22 to 27'	Sand, trace gravel, black	SP	9.5	NP	NP	NP

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/28/2005

Terracon

Sieve WSGT-5.xls

Electronic Filing: Received, Clerk's Office 2/04/2022

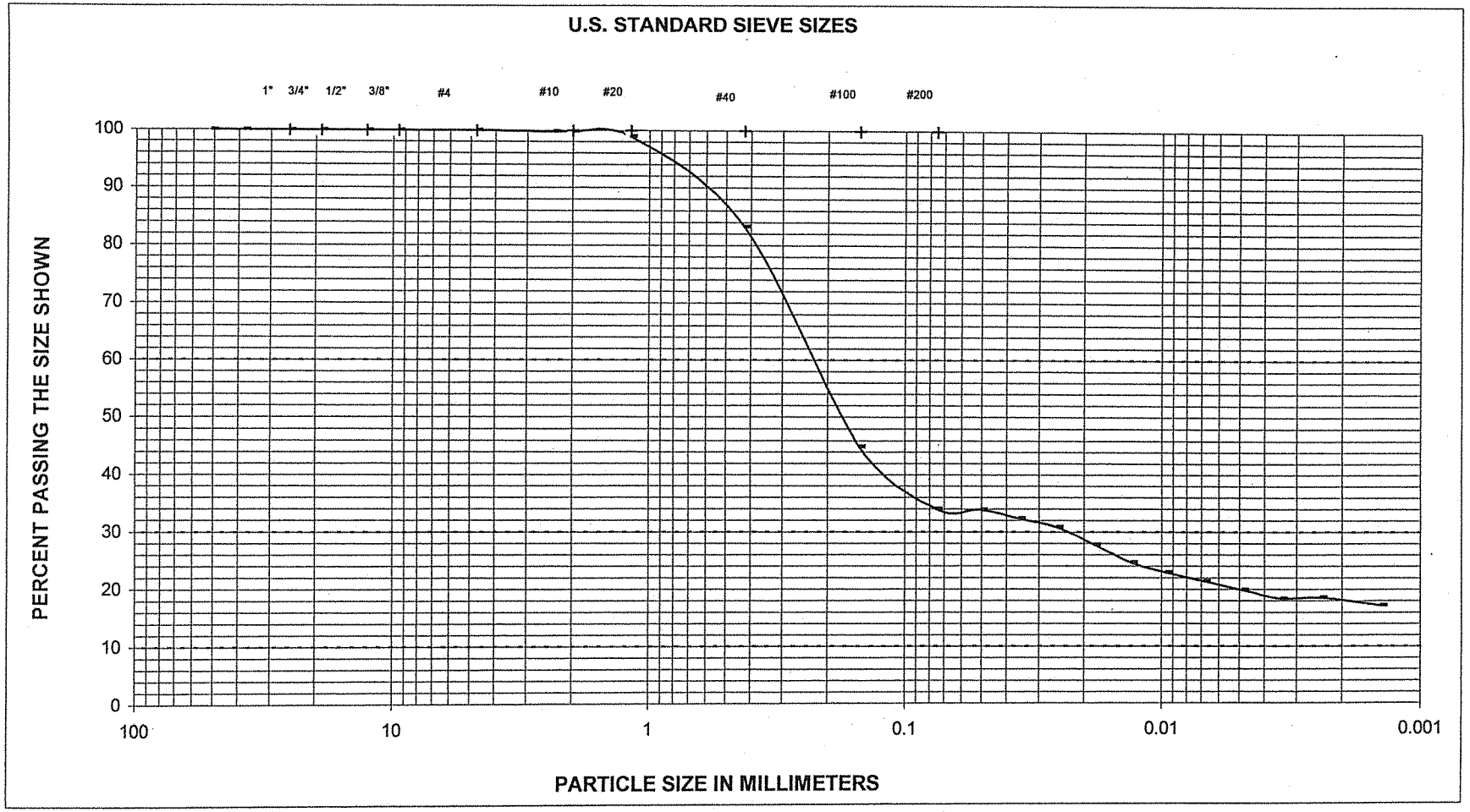
Terracon

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing Boring Number PS-GT-1 Date: 8/29/2005

Terracon Project #: 58055075 Sample No.: Sample type.:

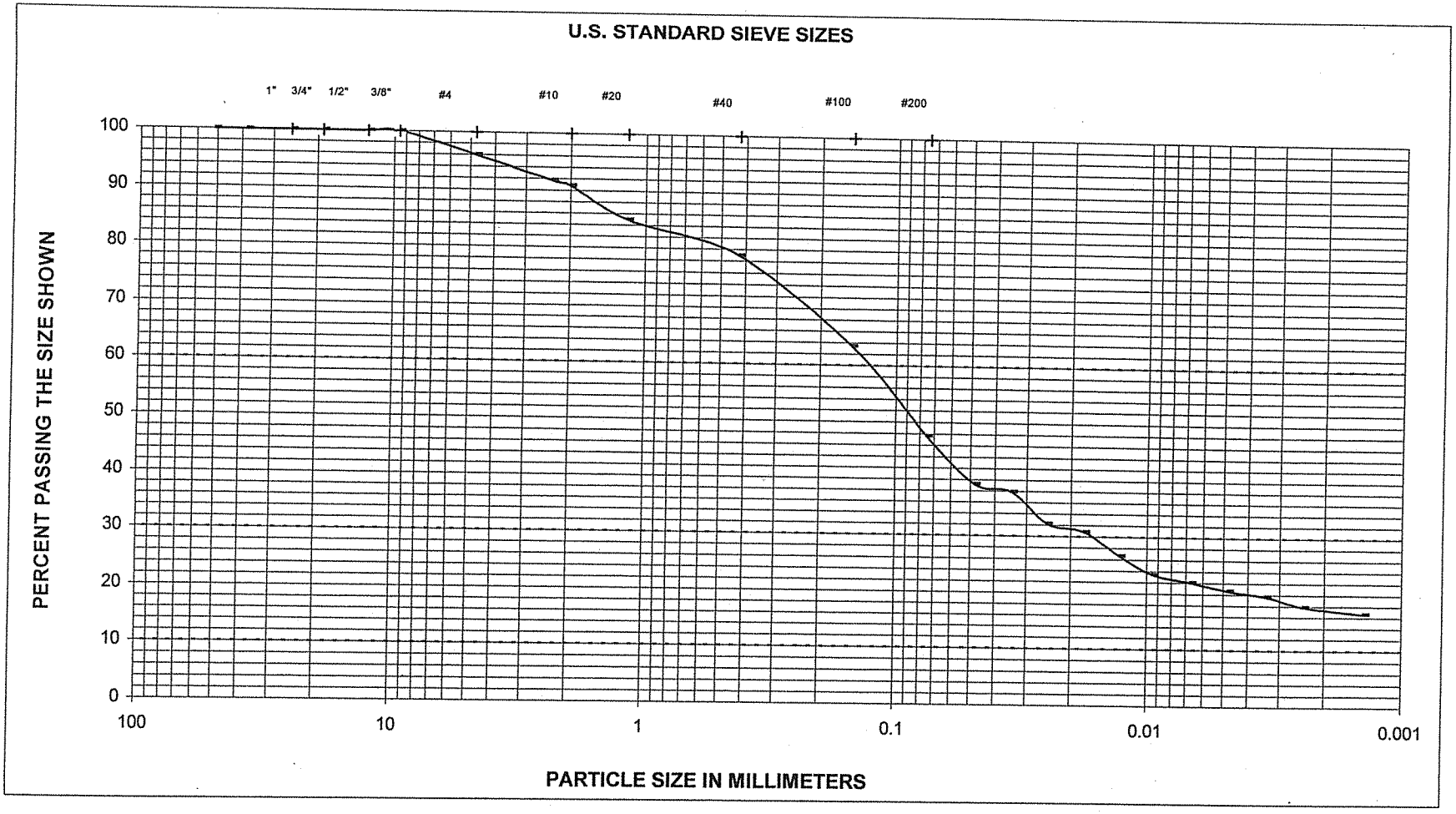
Sample Description: Clayey sand, dark brown



Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing
Terracon Project #: 58055074
Boring Number PS-GT-2
Sample No.:
Date: 8/25/2005
Sample type.:
Sample Description: Clayey sand, trace gravel, medium to coarse grained, brown



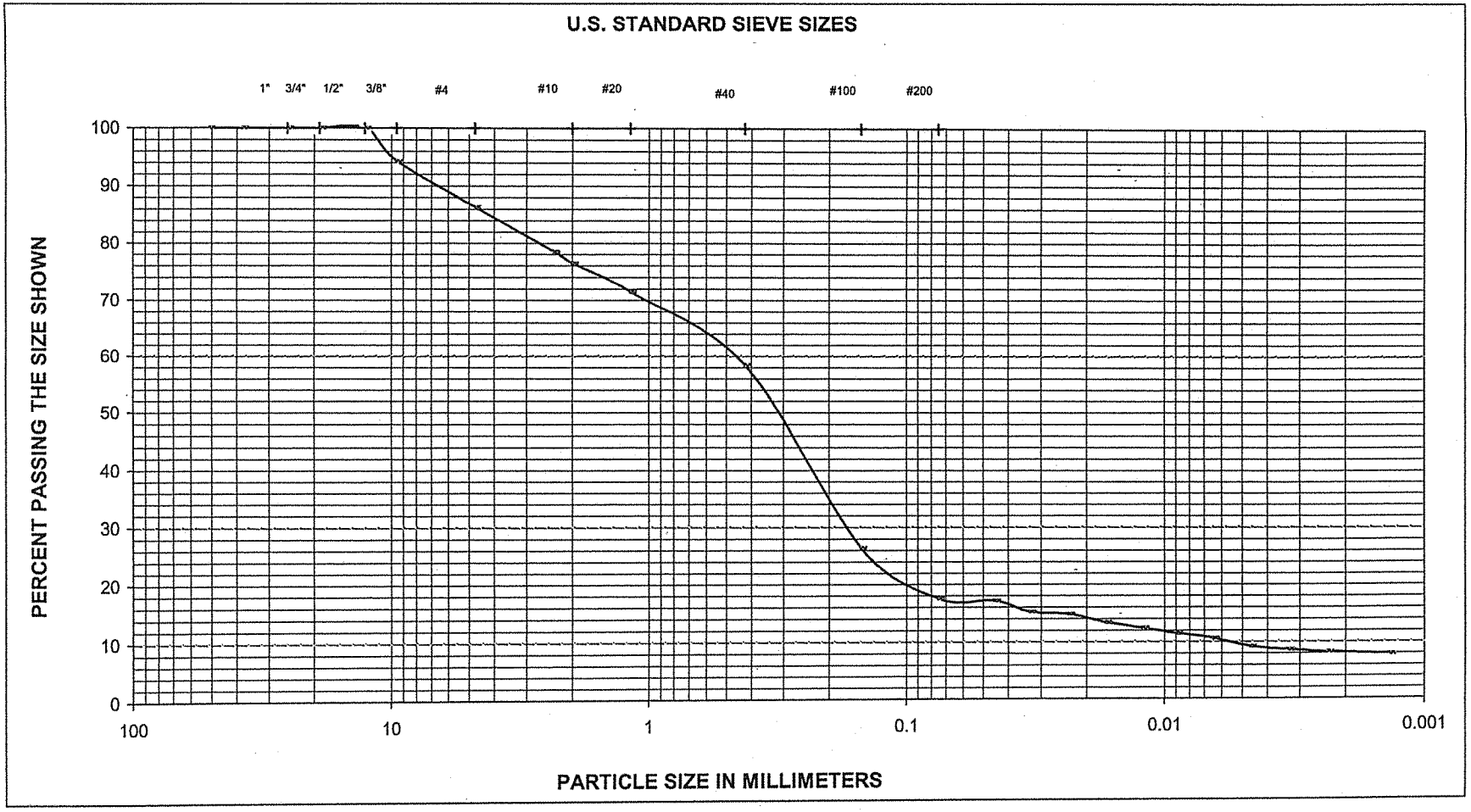
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing | Boring Number: PS-GT-3 | Date: 8/26/2005

Terracon Project #: 58055075 | Sample No.: 7-9' | Sample type.:

Sample Description: Sand, trace clay, gravel and organics, dark brown



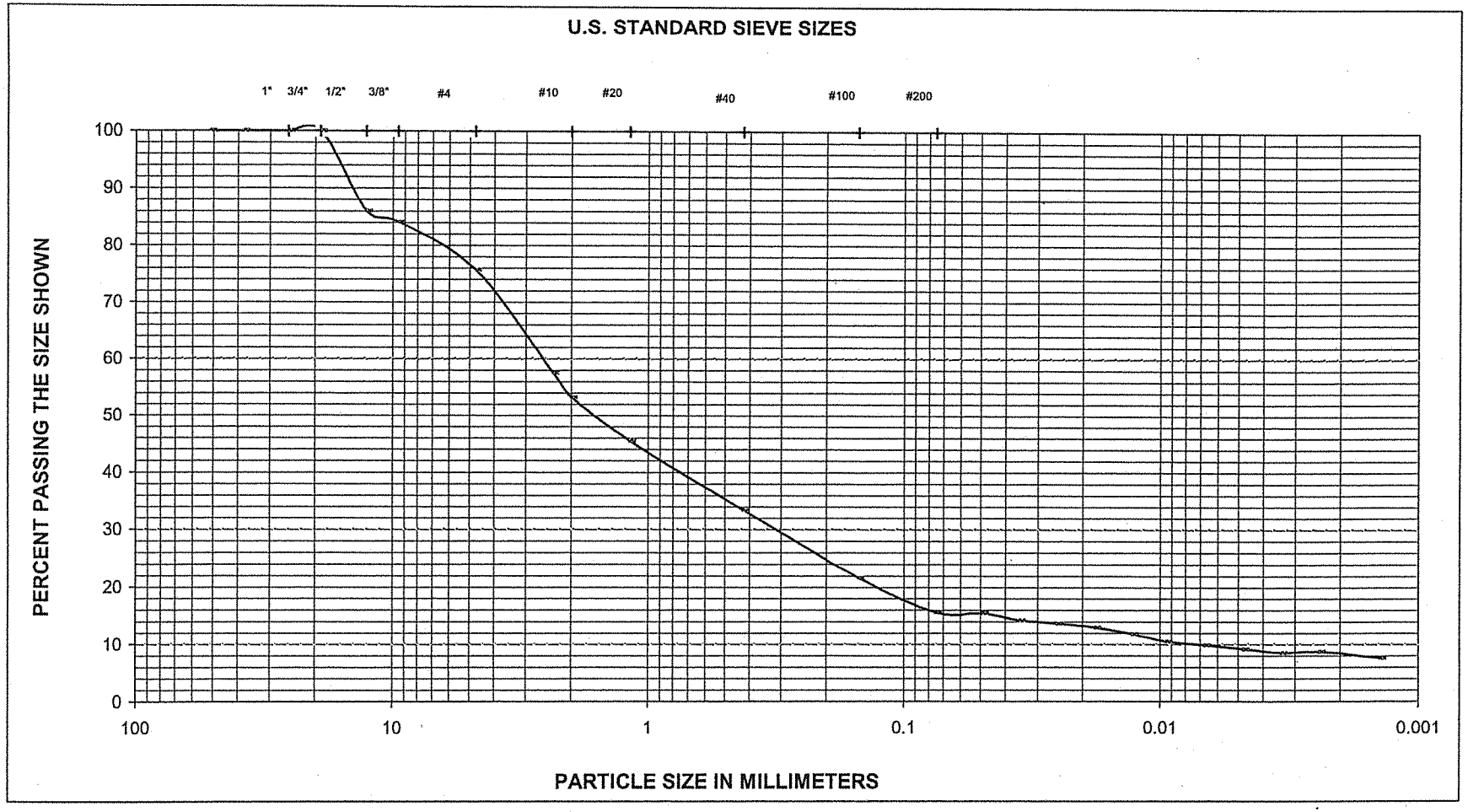
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing Boring Number PS-GT-4 Date: 8/29/2005

Terracon Project #: 58055075 Sample No.: Sample type.:

Sample Description: Sand, with clay and gravel, trace organics, fine to coarse grained, dark brown



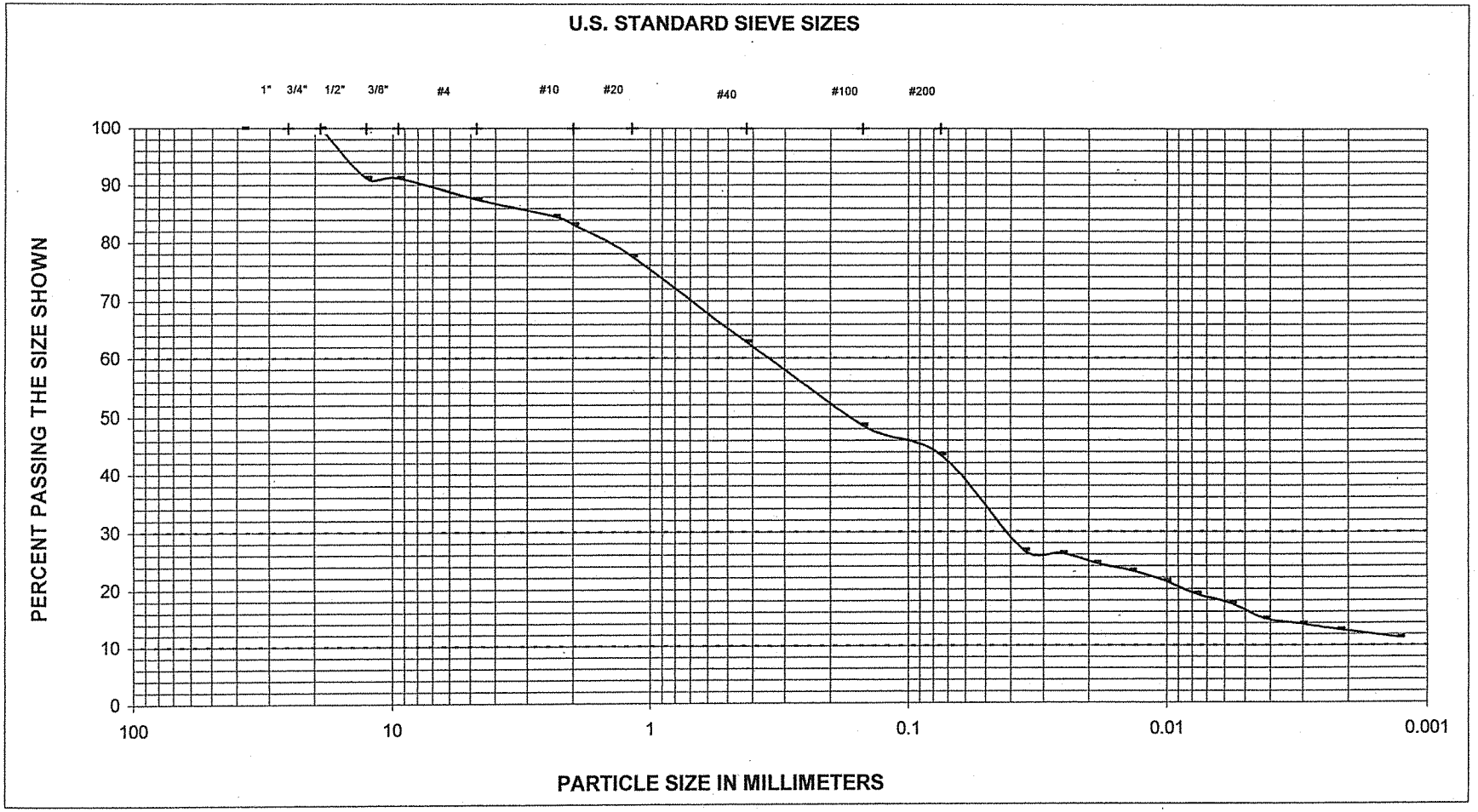
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

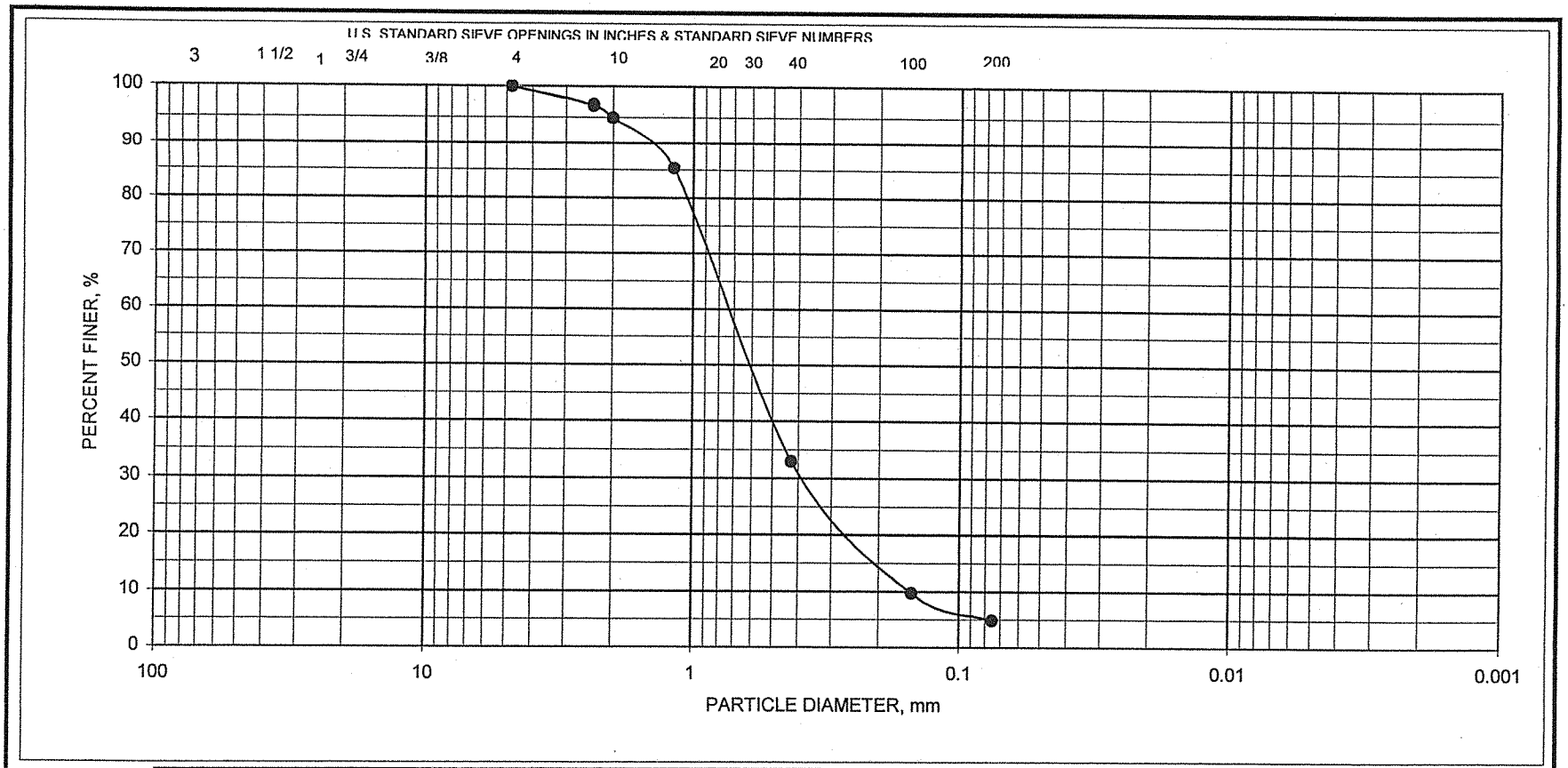
Project Name: KPRG Laboratory Testing Boring Number PS-GT-5 Date: 8/26/2005

Terracon Project #: 58055075 Sample No.: Sample type.:

Sample Description: Clayey Sand, trace gravel, brown



Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-6		15-20'	Fill: Sand, fine to medium coarse, trace gravel, dark brown	SP				

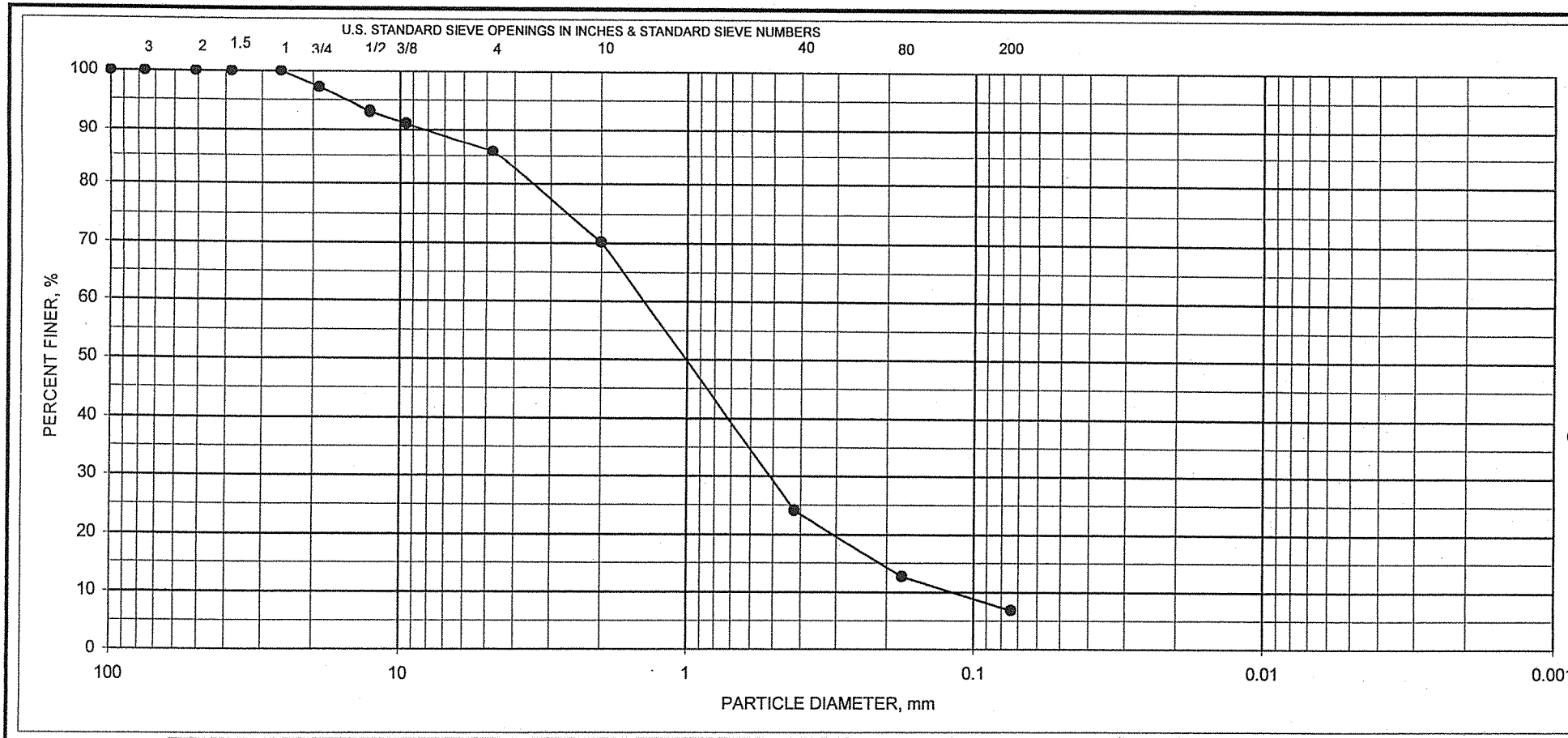
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Grad PS-GT-6.xls

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-7		10.0 TO 13.0	WELL GRADED SAND WITH SILT, DARK GRAY	SW-SM	7.0	21	18	3

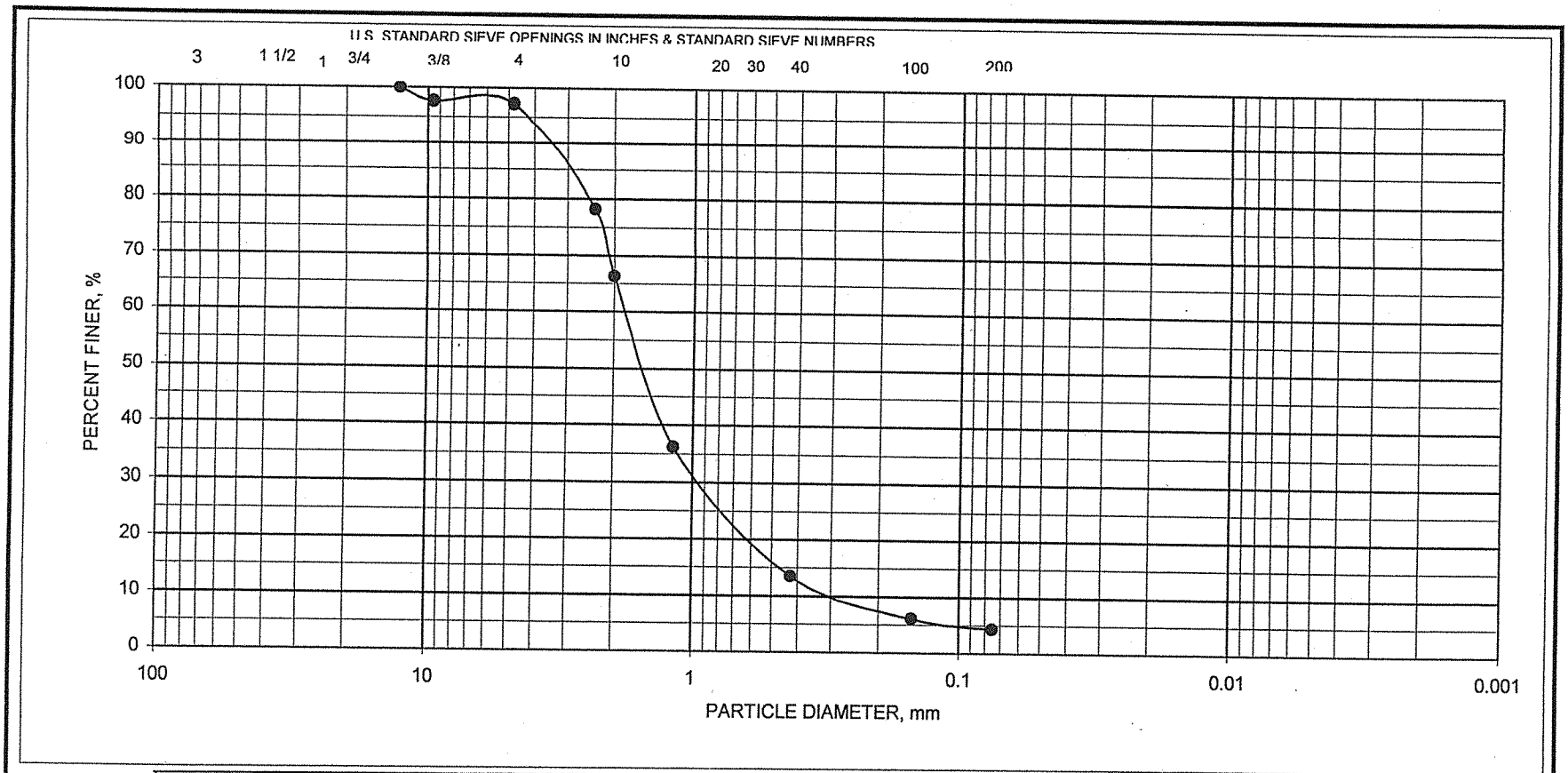
PROJECT KPRG LABORATORY TESTING

JOB NO. 58055075 DATE 10/7/2005

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Terracon

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-8 (top)		10 to 15'	Cinders, metal shavings, glass, black					

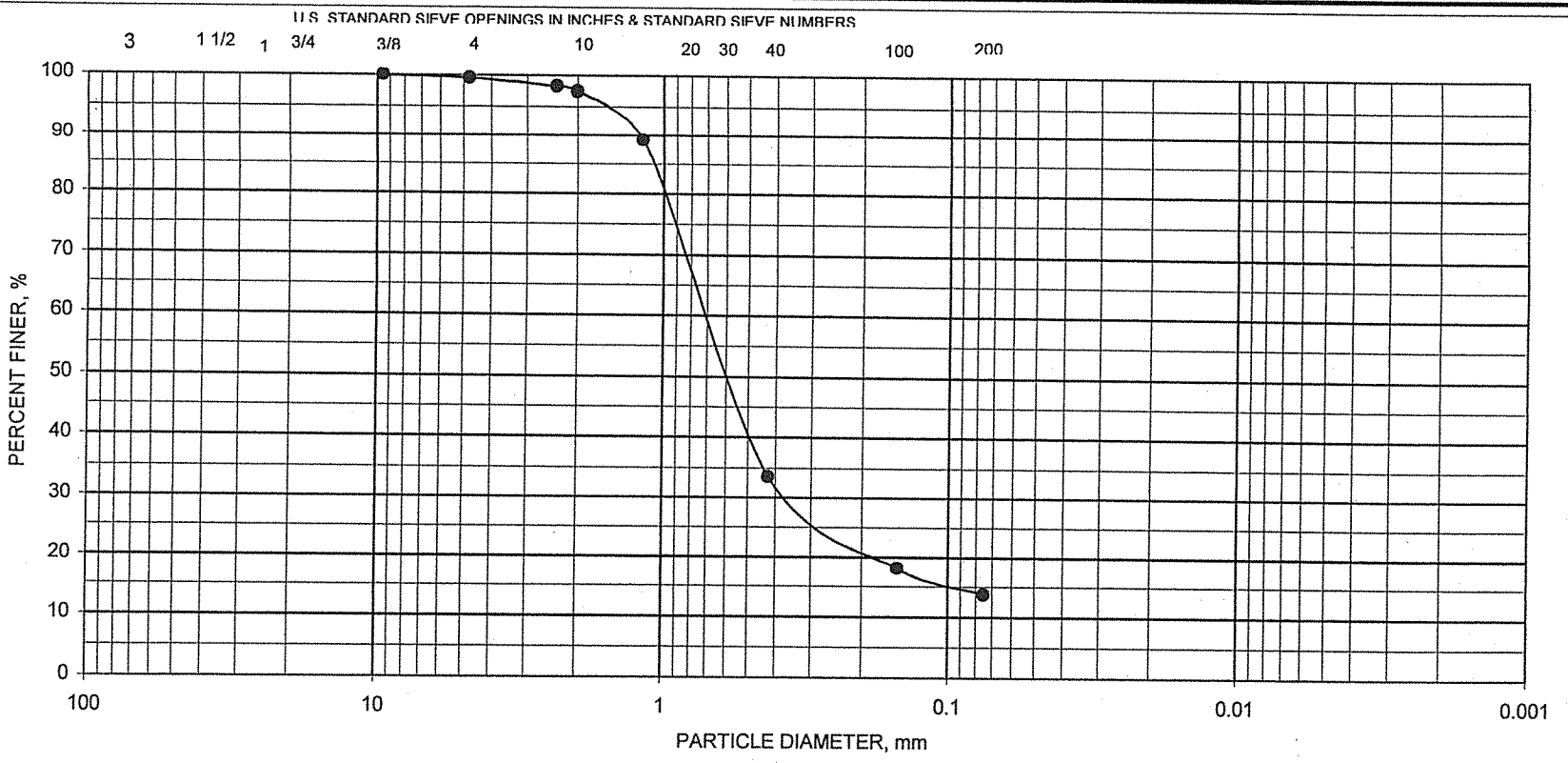
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Sieve PS-GT-8

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-8 (bottom)		10 to 15'	Silty Sand, trace clay, dark gray	SM				

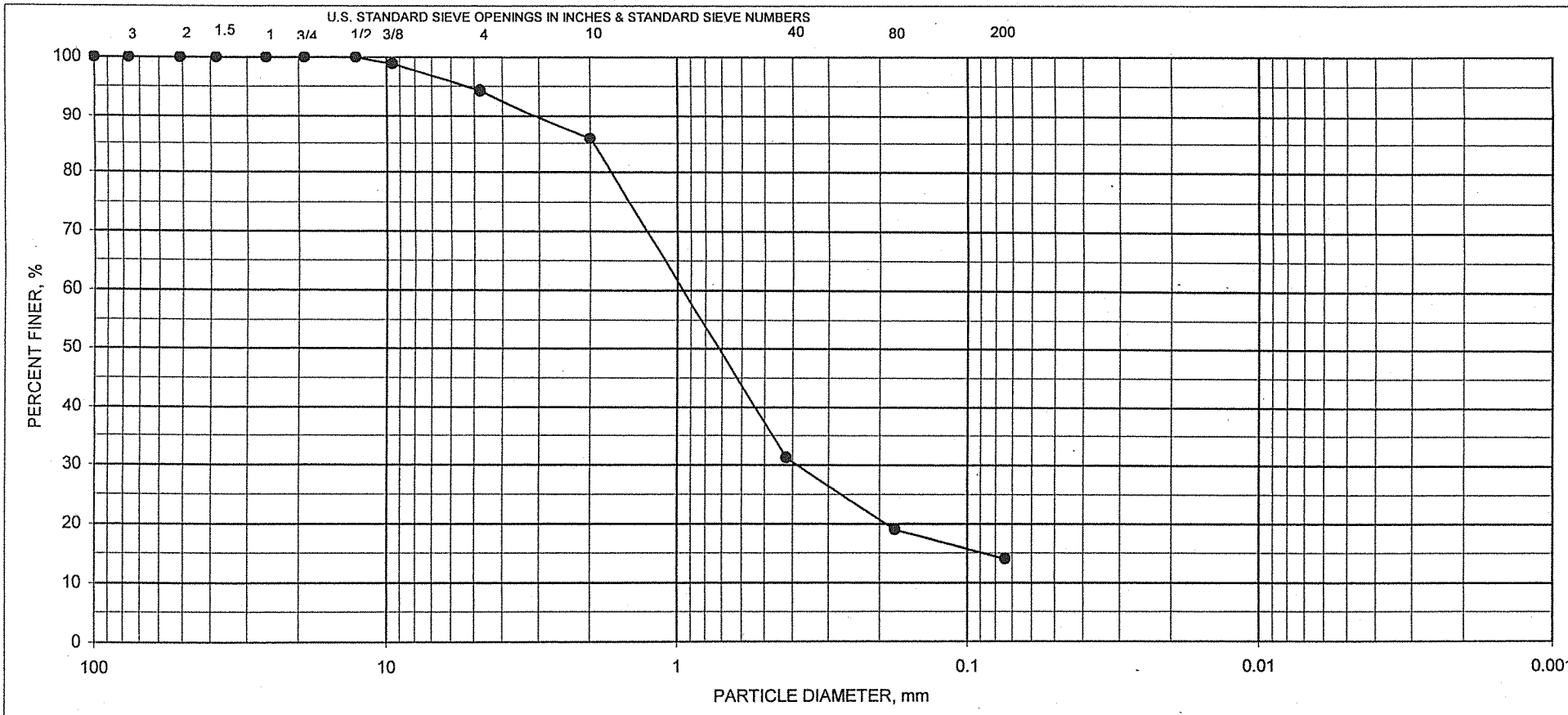
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Sieve PS-GT-8 (bottom).xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-9	TOP 16"	15.0 TO 20.0	SILTY SAND, DARK GRAY	SM	8.9	22	19	3

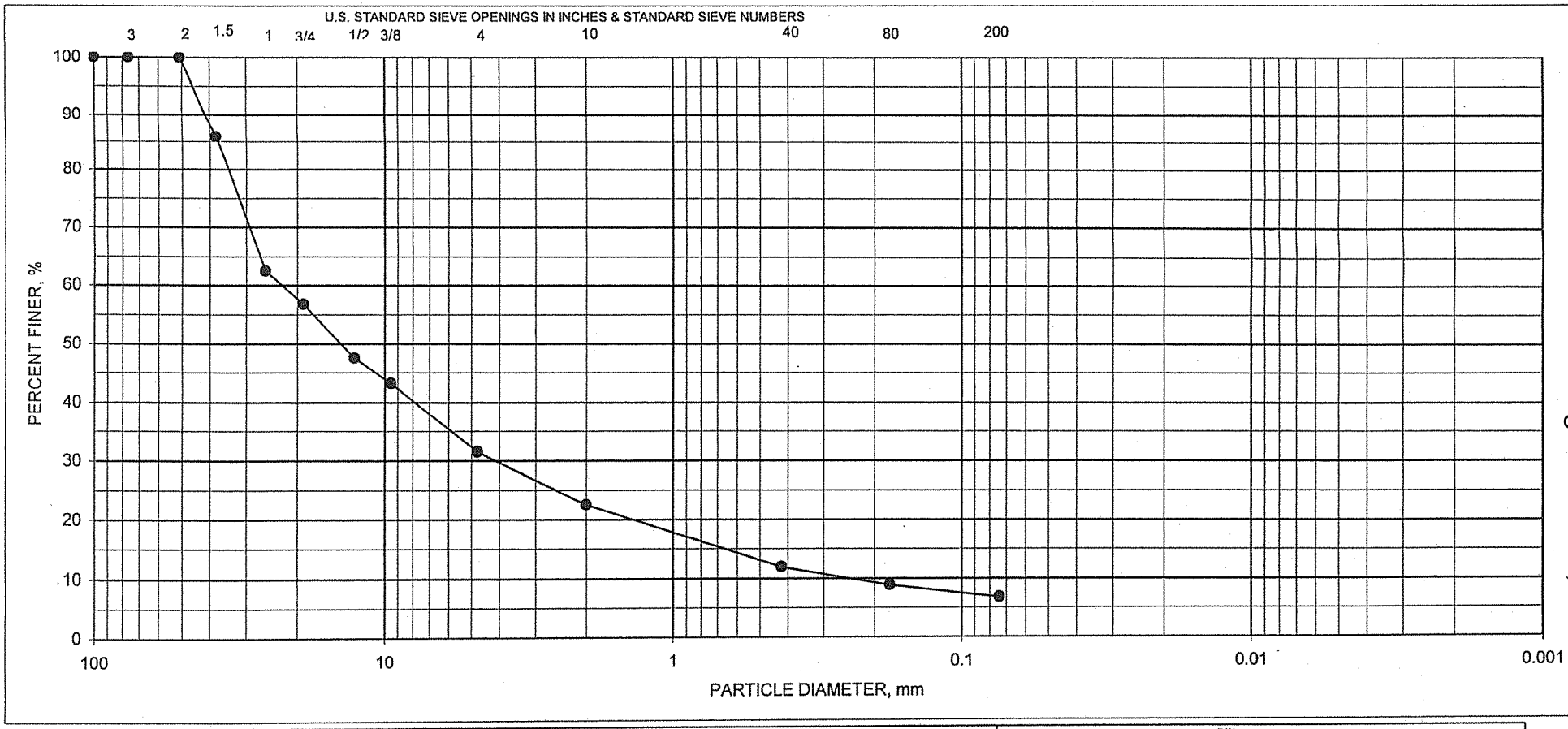
PROJECT KPRG LABORATORY TESTING

JOB NO. 58055075 DATE 10/7/2005

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Terracon

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-9	MIDDLE 8"	15.0 TO 20.0	POORLY GRADED GRAVEL WITH SILT & SAND, DARK YELLOWISH BROWN	GP-GM	3.3			

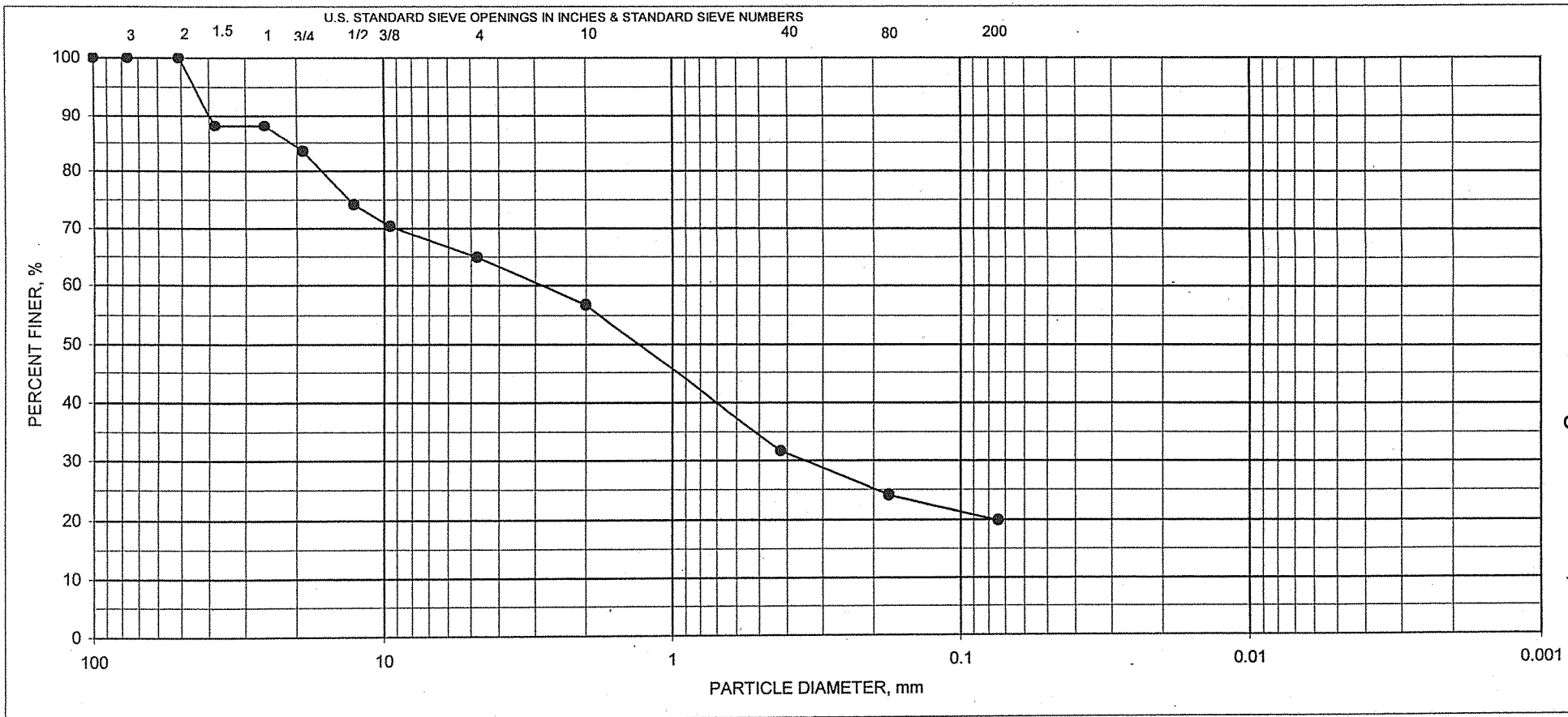
PROJECT KPRG LABORATORY TESTING

JOB NO. 58055075 DATE 10/7/2005

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Terracon

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
PS-GT-9	BOTTOM 8"	15.0 TO 20.0	SILTY SAND WITH GRAVEL, DARK GRAY TRACE LIGHT GRAY	SM	16.4	24	21	3

PROJECT KPRG LABORATORY TESTING

JOB NO. 58055075 DATE 10/7/2005

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Terracon

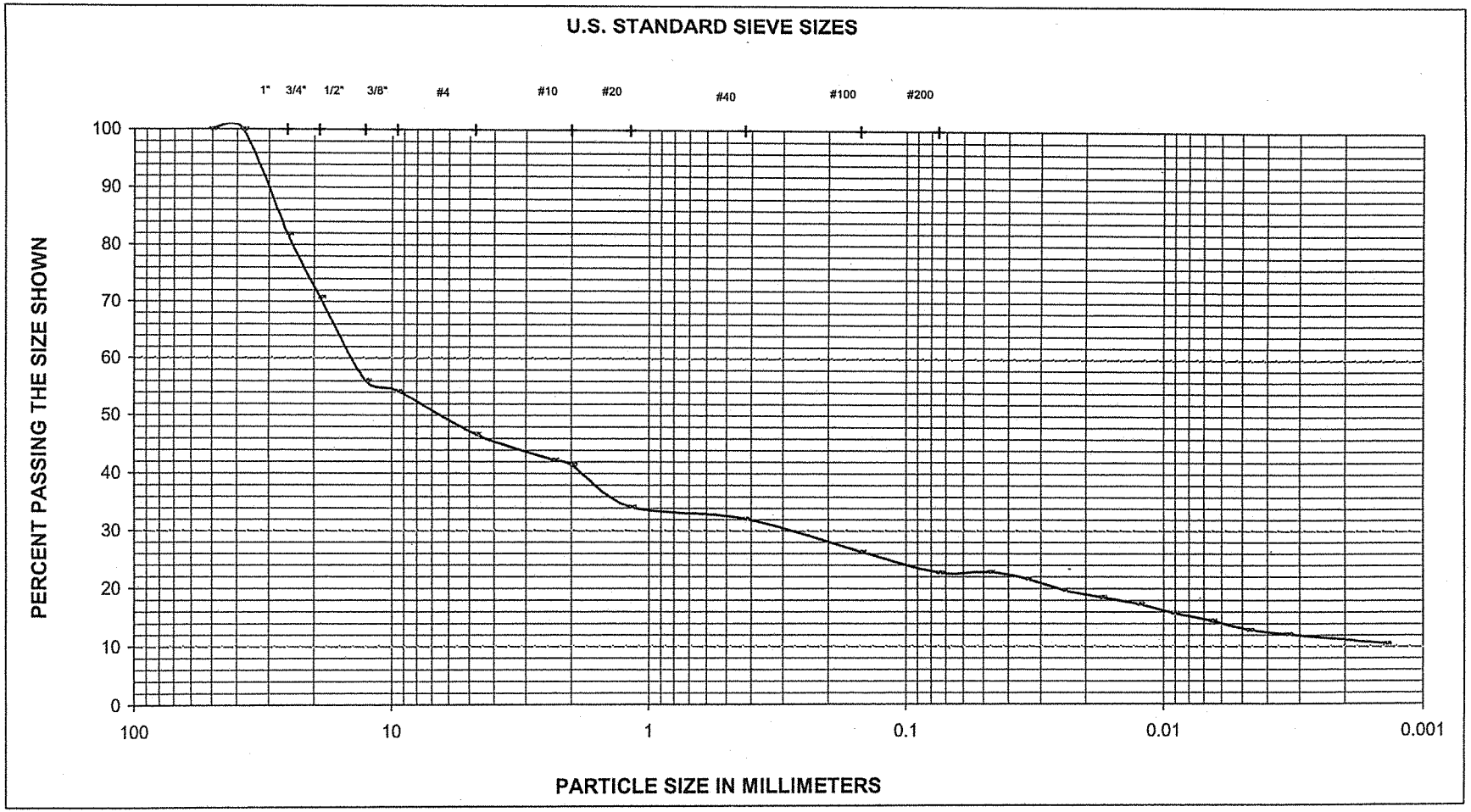
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

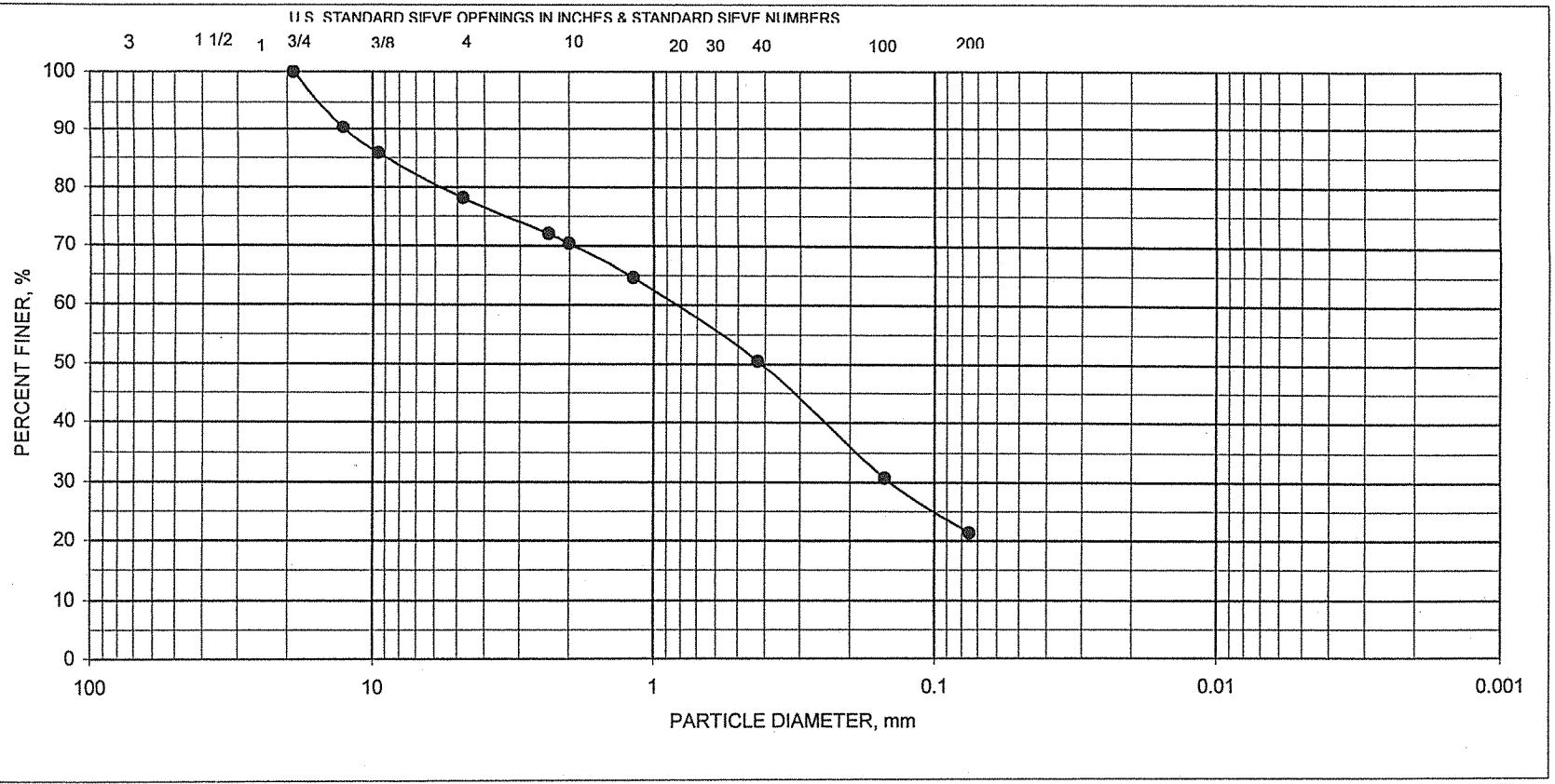
Project Name: KPRG Laboratory Testing
Terracon Project #: 58055075
Sample Description: Sand, with gravel, gray

Boring Number JS-9-GT-1
Sample No.: 7-12'

Date: 9/26/2005
Sample type.:



Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS-9-GT-2		7 to 11.5'	Clayey Sand, with organics, with gravel, dark brown	SC				

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 7/11/2005

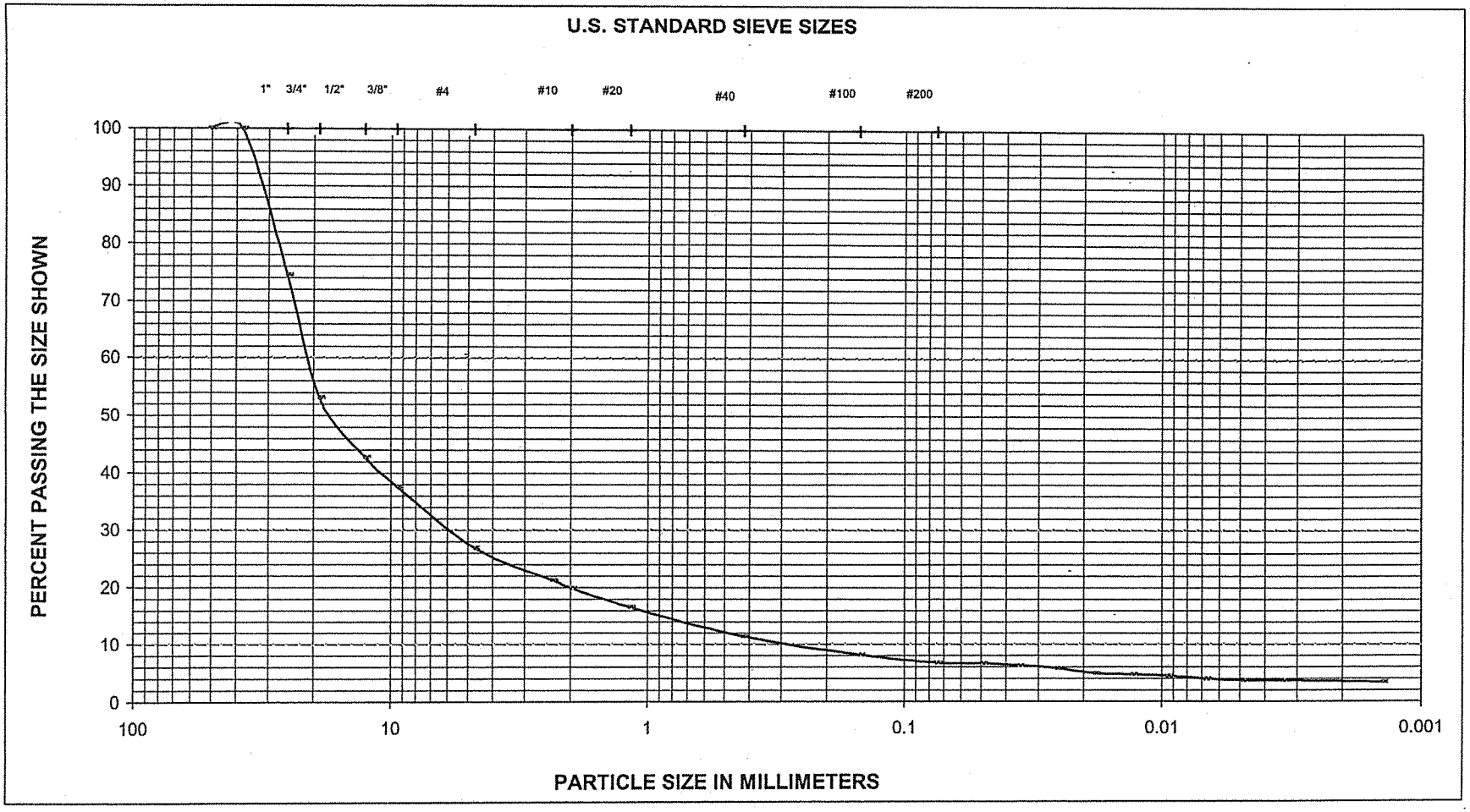
Terracon

Sieve JS-9-GT-2.xls

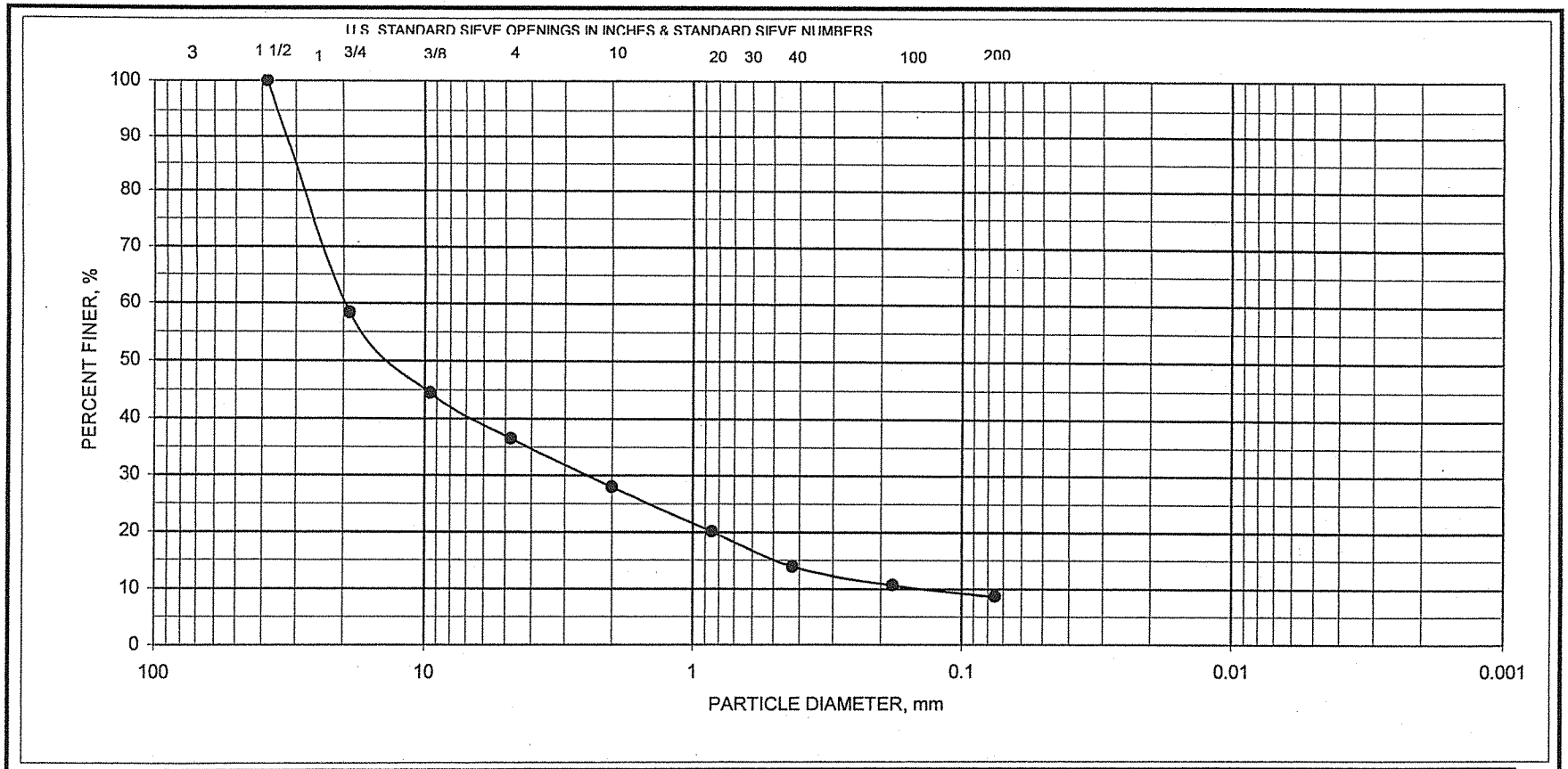
Electronic Filing: Received, Clerk's Office 2/04/2022

GRAIN SIZE DISTRIBUTION CURVE

Project Name: KPRG Laboratory Testing
Boring Number JS-9-GT-3
Date: 9/26/2005
Terracon Project #: 58055075
Sample No.: 8-13'
Sample type.:
Sample Description: Sand, with gravel, gray



Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS29GT-1		19 to 24'	Sandy Gravel, Trace Clay	GW		NP	NP	NP

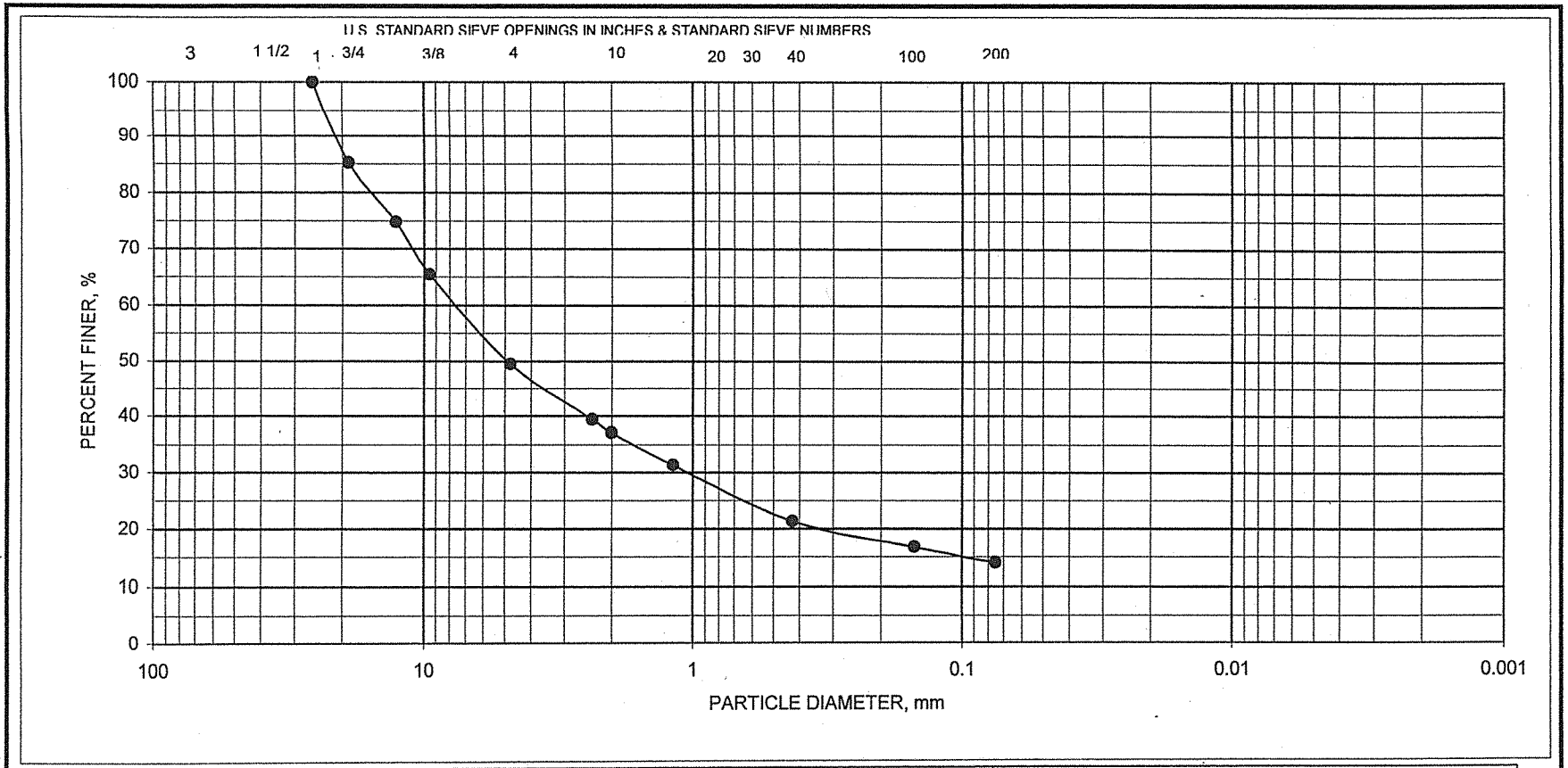
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 9/21/2005

Terracon

Sieve JS29GT-1.xls

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS-29-GT-2		19 to 24'	Clayey Gravel, brown	GC				

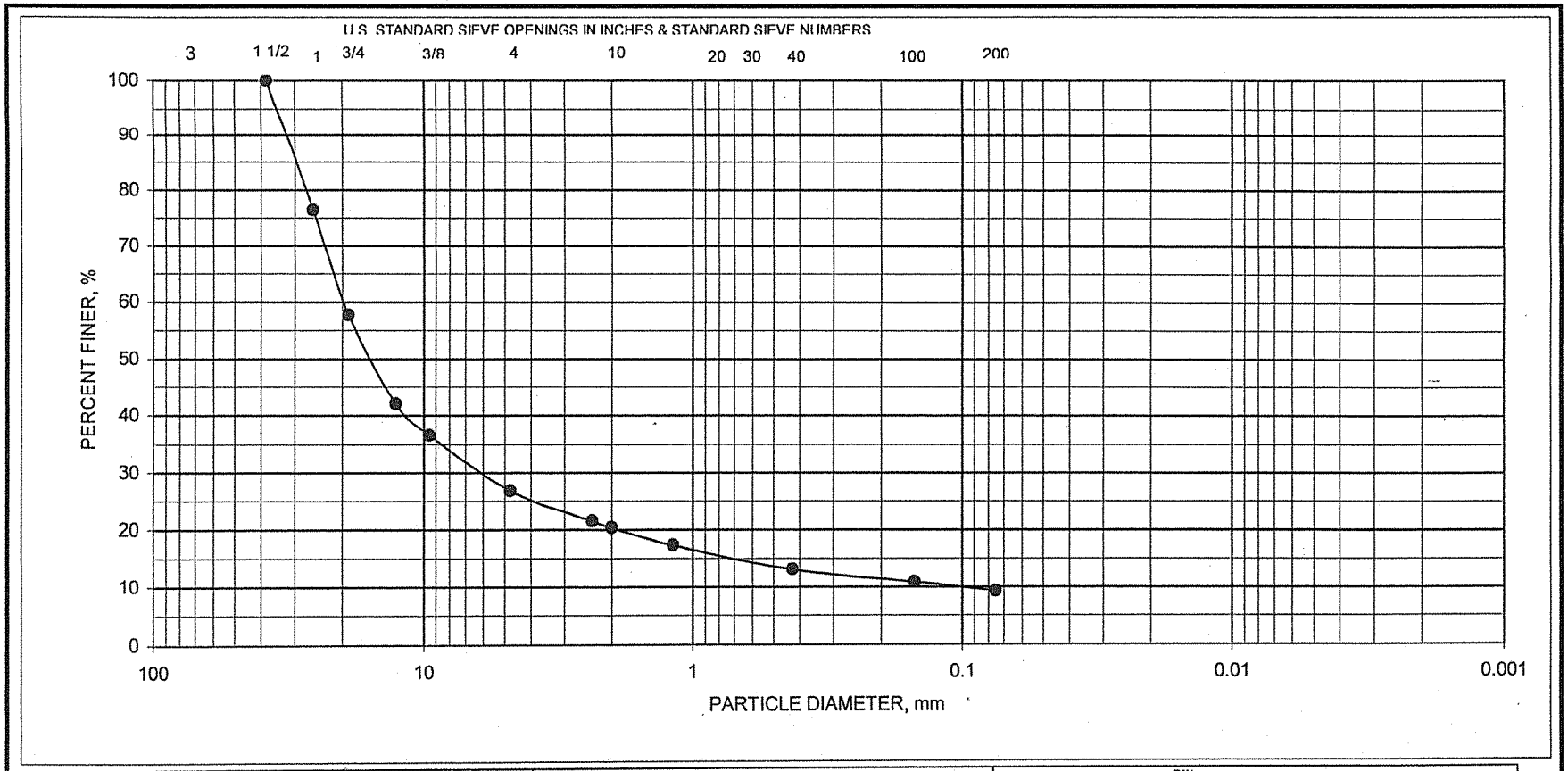
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Sieve JS-29-GT-2.xls

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS-29-GT-3		19-24'	Poorly graded gravel with clay and sand, gray	GP-GC				

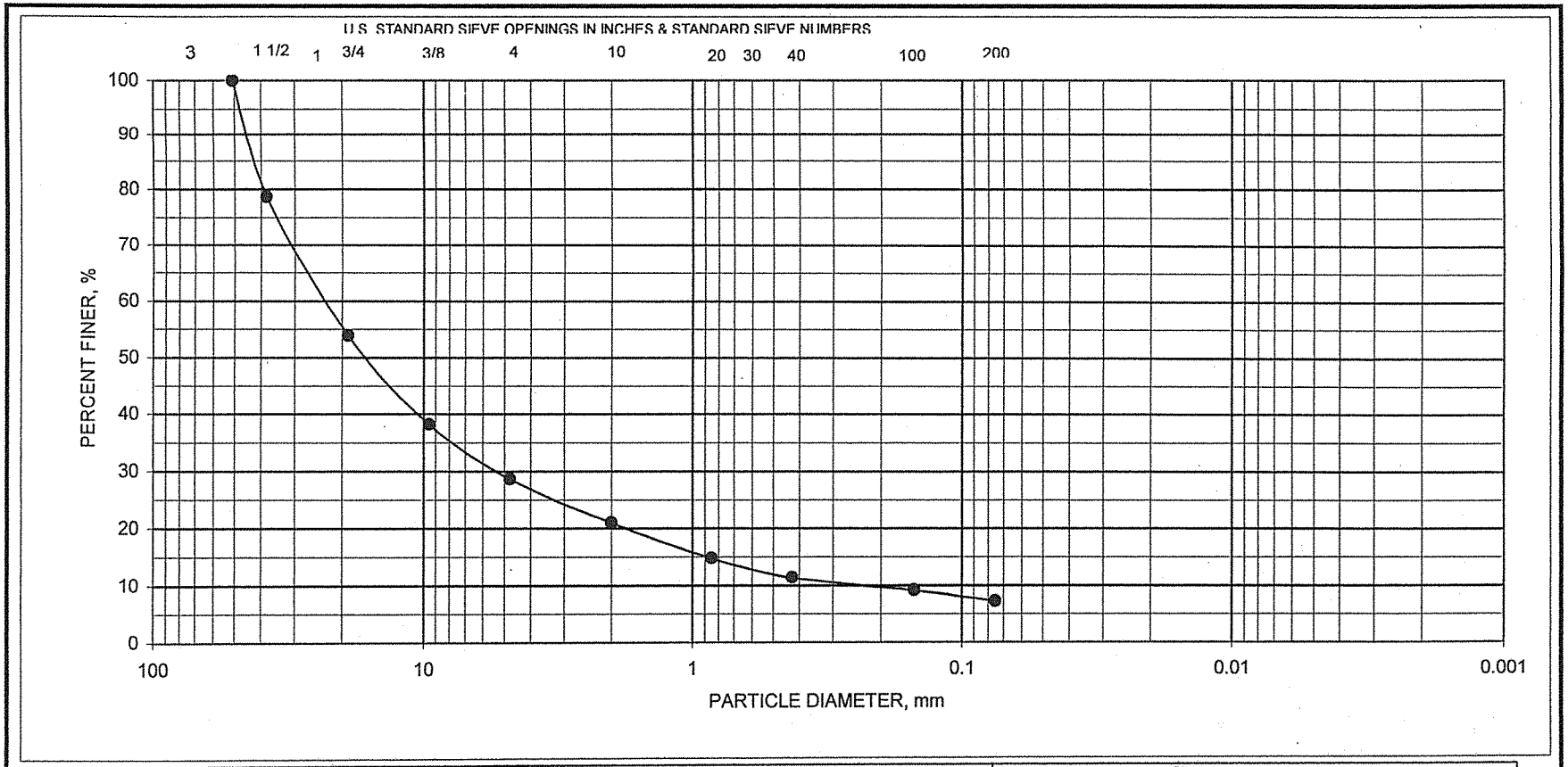
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Grad JS-29-GT-3.xls

Electronic Filing: Received, Clerk's Office 2/04/2022



GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS29GT-4		17 to 22'	Dolomitic Limestone With Fine To Coarse Sand	GP				

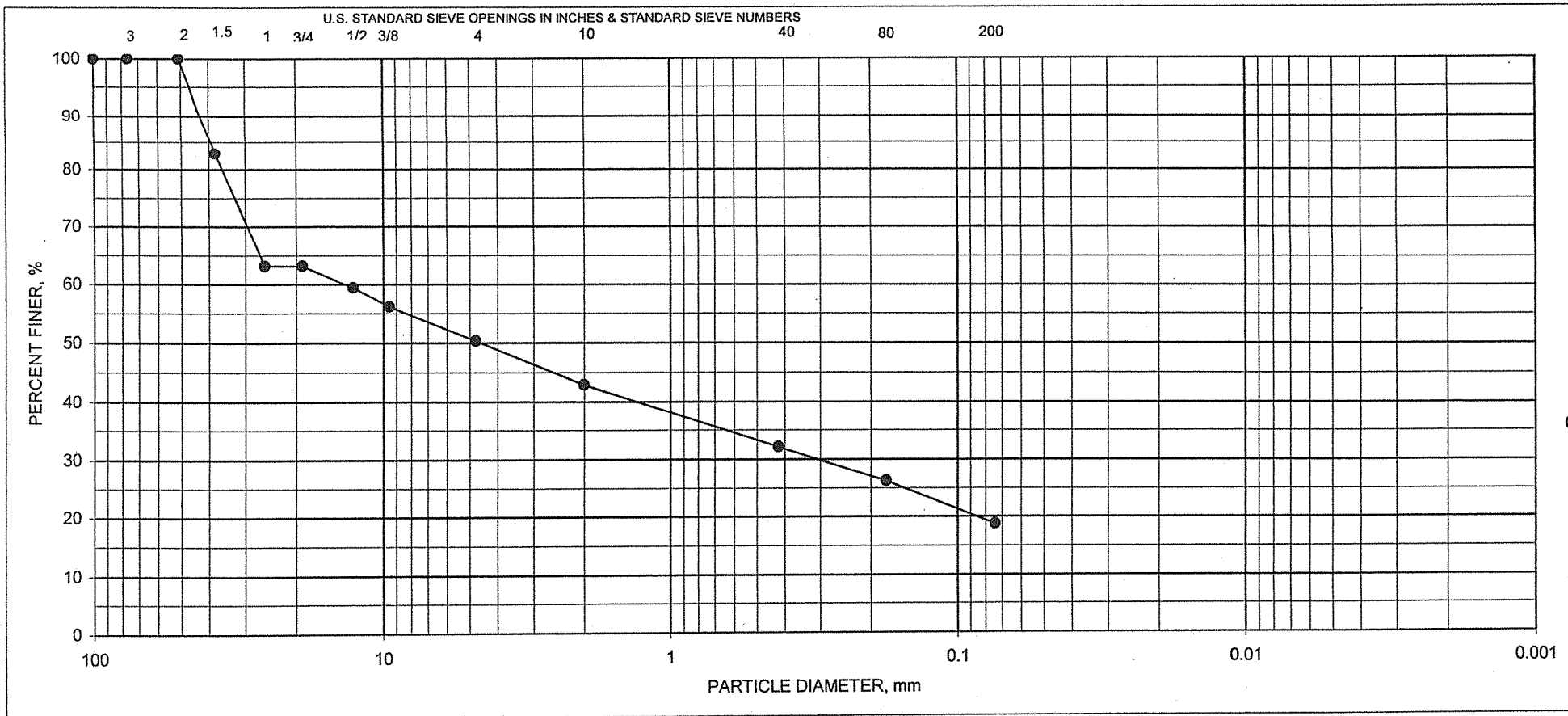
PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 10/6/2005

Terracon

Sieve JS29GT-4.xls

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS 29-GT-5	TOP 8"	5.0 TO 9.0	CLAYEY GRAVEL WITH SAND, DARK GRAY WITH YELLOWISH BROWN	GC	26.0	34	23	11

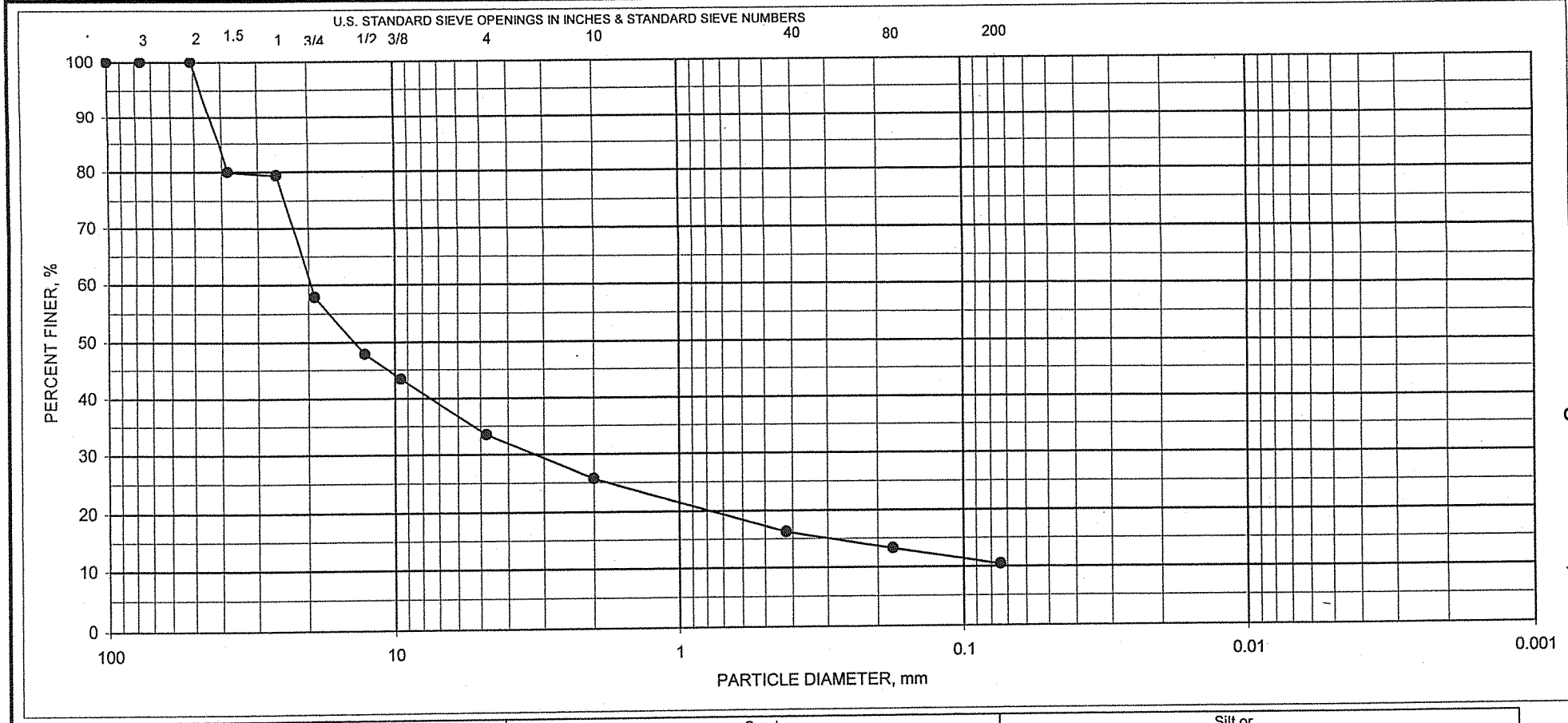
PROJECT KPRG LABORATORY TESTING

JOB NO. 58055075 DATE 10/7/2005

Terracon

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS 29-GT-5	TOP 7"	9.0 TO 14.0	POORLY GRADED GRAVEL WITH SILT & SAND, DARK GRAY	GP-GM	8.5			

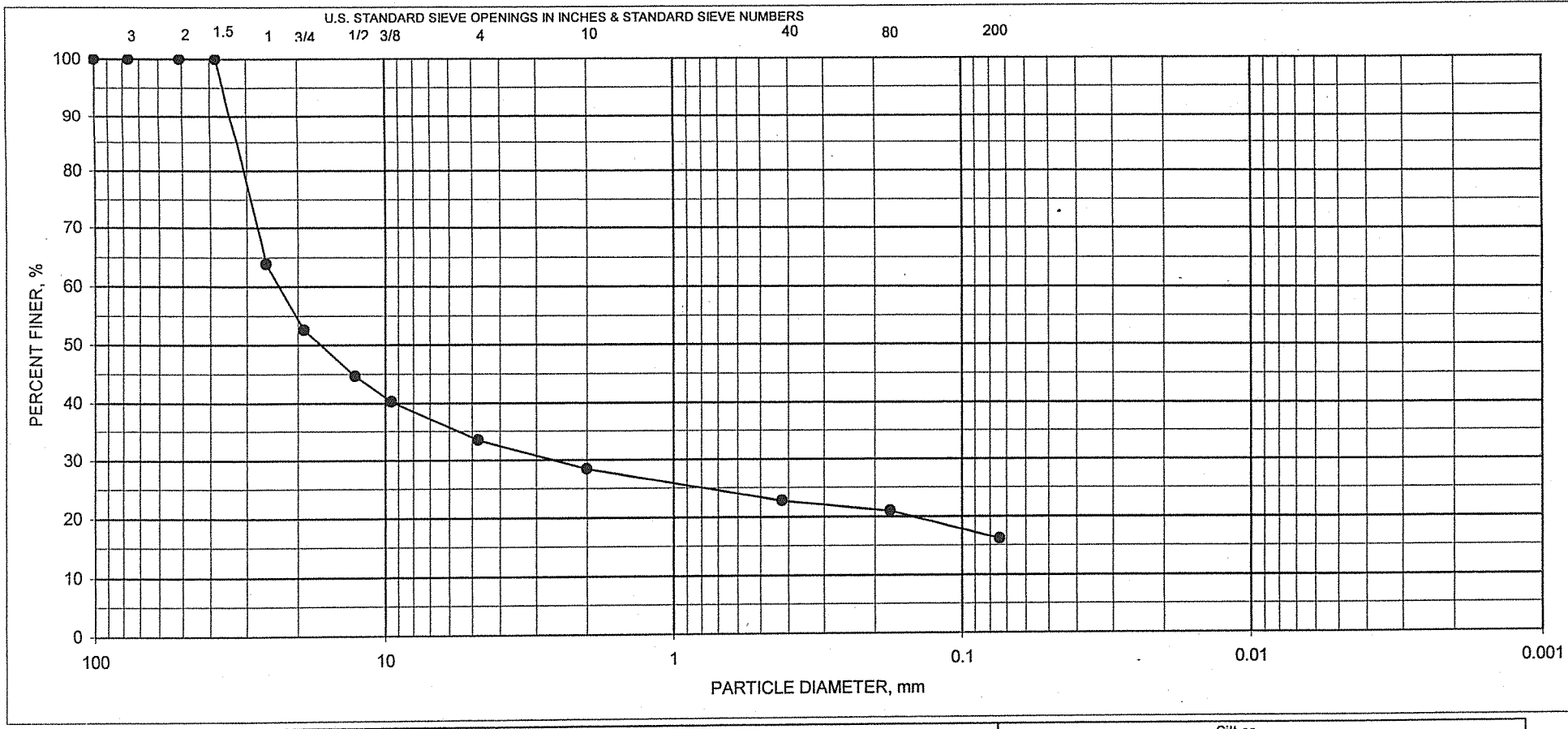
PROJECT KPRG LABORATORY TESTING

JOB NO. 58055075 DATE 10/7/2005

Terracon

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS 29-GT-5	BOTTOM 10"	9.0 TO 14.0	SILTY GRAVEL WITH SAND, DARK GRAY	GM	8.9	21	21	NP

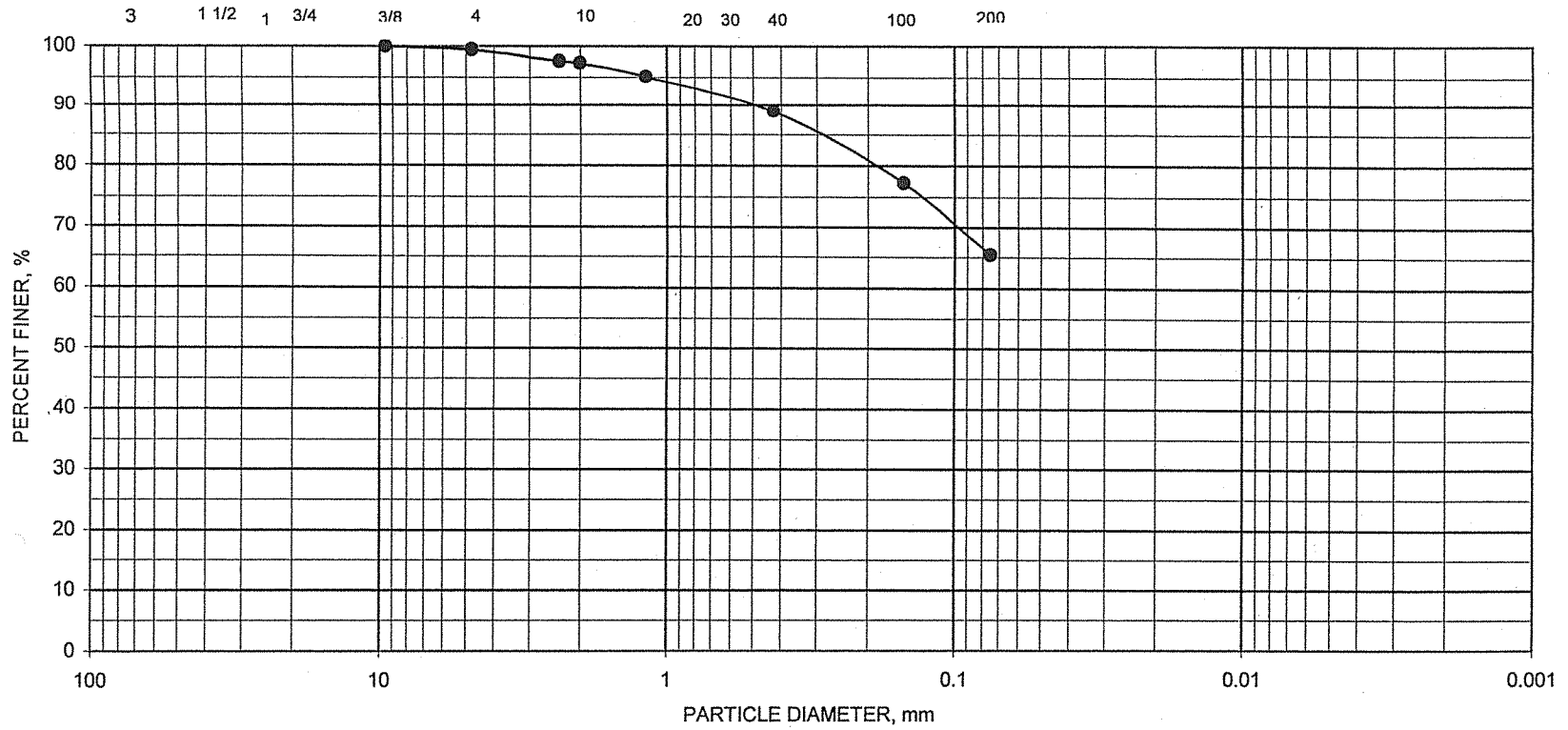
PROJECT KPRG LABORATORY TESTING

JOB NO. 58055075 DATE 10/7/2005

Terracon

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GRAVEL		Sand			Silt or Clay
Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE DISTRIBUTION CURVE

BORING NO.	SAMPLE NO.	DEPTH, feet	ASTM DESCRIPTION	UNIFIED SYMBOL	NAT. WC, %	ATTERBERG LIMITS LL	PL	PI
JS-29-GT-6		11 to 14'	Organic Silt, dark gray, black	OH				

PROJECT KPRG Laboratory Testing

JOB NO. 58055075 DATE 8/25/2005

Terracon

Sieve JS-29-GT-6.xls

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Attachment 4

Electronic Filing: Received, Clerk's Office 2/04/2022

HYDROGEOLOGIC ASSESSMENT REPORT
JOLIET GENERATING STATION NO. 29
JOLIET, ILLINOIS

SUBMITTED BY:
MIDWEST GENERATION, LLC
235 REMINGTON BLVD, SUITE A
BOLINGBROOK, ILLINOIS 60440

SUBMITTED TO:
ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
1021 N GRAND AVENUE EAST
SPRINGFIELD, ILLINOIS 62702

PREPARED BY:
PATRICK ENGINEERING INC.
4970 VARSITY DRIVE
LISLE, ILLINOIS 60532

PATRICK PROJECT NO. 21053.070

FEBRUARY 2011

PATRICK ENGINEERING

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1.0 INTRODUCTION

1.1 Background

Pursuant to the request of the Illinois Environmental Protection Agency (Illinois EPA), this document presents the Hydrogeologic Assessment Report for the on-site ash pond areas at the Midwest Generation, LLC (MWG) Joliet Generating Station No. 29 in Joliet, Illinois. This hydrogeologic assessment was performed in accordance with the Hydrogeologic Assessment Plan, approved by the Illinois EPA, dated September 3, 2010.

As defined by the Hydrogeologic Assessment Plan, the purpose of this investigation was to: (i) evaluate the potential, if any, for migration of ash-related constituents from the on-site ash ponds and to conduct monitoring for groundwater constituents regulated by the Illinois Part 620 groundwater standards, as requested by the Illinois EPA; (ii) characterize the subsurface hydrogeology; and (iii) identify potable well use within 2,500 feet of the ash ponds. The results of this investigation are described in this Hydrogeologic Assessment Report.

1.2 Site Location and Description

The Joliet No. 29 facility (the Site) is located in Section 19, Township 35 North, Range 10 East, in the City of Joliet, Will County, Illinois. Figure 1 provides a Site Location Map.

The Site includes three active ash ponds (Ash Pond 1, Ash Pond 2, and Ash Pond 3). Two of the ponds are lined with a high-density polyethylene (HDPE), while the third is lined with 12" of geo-composite material on the bottom; the total area of the three ash ponds is approximately 10 acres. Figure 2 shows the locations of the three ash ponds.

1.3 Regional Settng

The Site is located along the Des Plaines River just to the south of the city of Joliet. The surrounding land use is almost entirely industrial with some parcels of undeveloped land. It is important to note that industrial properties are located hydraulically upgradient of the Site.

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Patrick Engineering Inc. (Patrick) conducted a review of publically available geological information from the Illinois State Geological Survey website. Based upon water well logs from the area, the geology beneath the Site consists of approximately 5-30 feet of sandy loam, underlain by Silurian Dolomite to approximately 176 feet below ground surface, and Maquoketa shale from approximately 176 to 241 feet below ground surface. The Maquoketa shale is generally considered to be an aquitard that separates the shallow groundwater in the unconsolidated units and the Silurian dolomite from the underlying aquifers.

Groundwater flow in the shallow, unconsolidated aquifer should be largely controlled by the Des Plaines River with groundwater flowing towards the river during most periods of the year. Groundwater flow in the deeper aquifers is controlled by the regional hydraulic gradient in these aquifers, which is to the northeast. The Site lies within the Joliet Depression, which is a cone of depression of the groundwater surface caused by the large withdrawals of the groundwater from the deeper aquifers due to industrial and municipal use in the area.

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2.0 HYDROGEOLOGIC ASSESSMENT METHODOLOGY

The following sections present the methodologies used to evaluate the potential for migration of ash-related constituents from the ash ponds and to monitor for all Part 620-regulated constituents, to characterize the subsurface hydrogeology, and to identify potable well use within 2,500 feet of the Site.

2.1 Evaluation of Ash-Related Constituent Migration Potential

The Illinois EPA requested that an evaluation of the potential for migration of ash-related constituents from the ash ponds and that monitoring for all Part 620-regulated constituents be performed in accordance with the groundwater standards included in 35 Illinois Administrative Code (IAC) Part 620, Subparts C and D. Accordingly, groundwater monitoring wells were installed at the Site in locations both upgradient and downgradient of the three ash ponds.

2.1.1 Installation of Groundwater Monitoring Wells

Patrick installed eleven (11) groundwater monitoring wells spaced approximately 150 to 300 feet apart around the perimeter of the ash ponds. The well locations were selected so that both upgradient and downgradient wells were represented, based upon available data regarding the expected groundwater flow direction. The spacing of the well locations at the Site along the downgradient edge of the ash ponds was calculated so as to detect a groundwater plume emanating from a point source beneath the ash ponds. Figure 3 shows the location of the eleven monitoring wells.

Three of the installed monitoring wells are located upgradient of the ash ponds; the additional eight wells are located downgradient of the ash ponds. The well borings were advanced using hollow-stem augers to depths ranging from 27.5 to 42 feet below ground surface (bgs). Borings were terminated after the field geologist determined that the boring was installed approximately 10 feet past the first intersection of the groundwater table in order to ensure that a representative

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groundwater sample could be obtained. Upon termination of each boring, a 2-inch diameter, PVC well was installed in order to collect samples of the groundwater in the uppermost aquifer. The monitoring wells were completed to approximately 3 feet above grade, with PVC casing, and were covered with a stick-up, steel well protector with a locking cap. Soil lithology was inspected and logged by an experienced geologist during the boring process. Boring logs with well construction information are included as Appendix A.

2.1.2 Initial Groundwater Sampling and Analytical Testing

The groundwater sampling event for the Site took place on December 6, 2010. The groundwater elevation in each of the eleven wells was measured prior to sampling. For all but one of the eleven wells, MW-09, the depth to groundwater was outside the effective range of the peristaltic pump. Groundwater samples were collected from MW-09 with a peristaltic pump, using established low-flow sampling techniques. For the remaining ten (10) wells, groundwater samples were collected using a disposable polyethylene bailer; a different bailer was used for each well to prevent cross-contamination. Each well was purged until at least three well volumes had been extracted or until the groundwater was observed to be clear. Groundwater was then baled into a decontaminated, stainless steel container and thereafter transferred to the sampling containers via peristaltic pump. Temperature, pH, and conductivity measurements were taken using a portable meter in all wells; refer to Table 1 for these field parameter results. All groundwater samples were filtered in the field using a disposable, 0.45µm, in-line filter to allow for the analytical testing of dissolved compounds. The samples were immediately placed on ice in a cooler and kept at a temperature no higher than 4º F. The samples were transported to TestAmerica, an Illinois-EPA accredited analytical laboratory, in accordance with chain-of-custody procedures to maintain the integrity of the samples.

The analytical laboratory tested groundwater samples from each of the wells for the compounds listed in Table 2. Analytes tested include the inorganic compounds listed in 35 IAC 620.410(a), excluding both radium and the poly-aromatic hydrocarbons (PAHs) listed in 35 IAC 620.410(b).

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2.2 Characterization of Subsurface Hydrogeology

The subsurface hydrogeology beneath the ash ponds was characterized by determining Site lithology and the groundwater flow patterns in the vicinity of the ash ponds as described below.

2.2.1 Site Lithology

The Site lithology was determined by logging soil samples collected from the soil borings created during the installation of the groundwater monitoring wells. The soil borings were installed under the direction of an experienced geologist. Each boring was sampled at 2-foot intervals using a 2-inch O.D. split-spoon sampler (ASTM D 1586). Each soil sample was inspected and logged by the geologist during the boring process. Boring logs with well construction information are provided as Appendix A.

2.2.2 Topographic and Water Elevation Surveys

A survey crew measured both the top-of-casing and ground surface elevations of all installed monitoring wells and the groundwater elevations within each of the monitoring wells on December 6, 2010. The survey crew concurrently measured the water elevation in two of the three of the ash ponds and the Des Plaines River. The water surface of Ash Pond 2 was inaccessible the day of the survey due to a low water elevation in the pond. However, the remaining groundwater elevation data collected from the Site was sufficient in determining groundwater flow characteristics for the purposes of this assessment.

2.2.3 Hydraulic Testing of Selected Wells

Patrick conducted four *in situ* hydraulic conductivity tests on wells MW-4, MW-6, MW-9, and MW-11 on December 21, 2010. The testing consisted of one rising-head and one falling-head slug test performed at each well. Using a data-logging pressure transducer, Patrick measured the rate of groundwater level recovery in the wells after either inserting a slug into, or removing a slug from, each monitoring well.

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2.3 Identification of Potable Well Use

Natural Resource Technology, Inc. (NRT) has previously completed an investigation of potable water well use within 2,500 feet of the Joliet No. 29 ash ponds. MWG submitted the results of this investigation to the Illinois EPA by letter dated July 15, 2009. These results are summarized in Appendix B.

The following databases and sources of information were used in order to identify local community water sources and water well locations in the vicinity of the Site:

- Illinois State Geological Survey (ISGS) -Water Well Database Query;
- Illinois State Water Survey (ISWS) Private Well Database and water well construction report request; and
- Illinois Division of Public Water Supply web-based Geographic System (GIS) files.

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3.0 HYDROGEOLOGIC ASSESSMENT RESULTS

3.1 Evaluation of Ash-Related Constituent Migration Potential

The analytical laboratory results for the hydrogeologic assessment are presented in Table 2. Full laboratory data packages from TestAmerica are provided as Appendix C. Antimony, chloride, manganese, sulfate, and total dissolved solids (TDS) were detected in one or more monitoring wells at concentrations exceeding the Part 620 Class I Groundwater Quality Standards. In some cases, the highest concentrations of a given compound were found in the upgradient wells. Beryllium, cadmium, chromium, cyanide, iron, lead, mercury, silver, thallium, zinc, and nitrogen/nitrite were not detected in any of the groundwater samples.

A determination of the potential for the individual ash ponds to be contributing to the distribution of analytes in the underlying groundwater and the extent, if any, of such contribution cannot be made from the results of this single sampling event alone. To develop a true, statistically-significant upgradient background concentration for the various compounds will require a number of sequential sampling events over time. Based on a statistically-developed background value, downgradient concentrations can be compared to the background value over time to determine the likelihood and extent of any constituent migration from the on-site ash ponds. A plan to develop such an analytical database through additional sampling is presented in the last section of this report.

3.2 Characterization of Subsurface Hydrogeology

The lithology of the Site is predominantly sand and gravel with intermittent seams of clay and gravel. Auger refusal was encountered throughout the Site at depths ranging from 35 to 42 feet below ground surface. Split spoon samples from these depth returned fragments of limestone, indicating the top of the bedrock layer. Refer to Figure 4 for a geologic cross-section of the Site.

The results of the topographic and water elevation surveys are presented in Table 3.

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The uppermost groundwater unit at the Site is found at depths ranging from 29 to 34 feet bgs. The direction of groundwater flow is to the south towards the Des Plaines River, which runs along the southern boundary of the Site. The hydraulic gradient is approximately 0.0009 based upon the groundwater elevation data collected on December 6, 2010. A potentiometric surface map is provided as Figure 5.

Patrick used the hydraulic testing data to calculate the hydraulic conductivity of the uppermost aquifer using the Bouwer and Rice method. Hydraulic conductivity calculations are provided in Appendix D. The hydraulic conductivity of Site soils ranged from 1.948 x 10^{-3} to 6.949 x 10^{-3} ft/second. The average hydraulic conductivity was 3.896 x 10^{-3} ft/second. Using the highest calculated hydraulic conductivity and the measured hydraulic gradient, Patrick calculated the maximum groundwater velocity to be approximately 0.30 ft/day (3.896 x 10^{-3} ft/sec x 0.0009 x 60 sec/min x 60 min/hour x 24 hours/day).

3.3 Identification of Potable Well Use

As stated above, NRT has previously completed an investigation of potable water well use within 2,500 feet of the Joliet No. 29 ash ponds. MWG submitted the results of this investigation to the Illinois EPA by letter dated July 15, 2009. According to this letter, seventeen potable/industrial use wells are located within a 2,500-foot radius of the Site's ash ponds (refer to Appendix B.) However, most of these wells are screened in much deeper aquifers. Only two of the wells (Numbers 19 and 4) are located downgradient from the ash impoundments. Both of these industrial use wells are owned by MWG, and are drilled at 1,525 feet below ground surface and are screened below the Maquoketa shale, a significant aquitard separating shallower aquifers from the screened interval of the MWG wells.

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4.0 LONG-TERM MONITORING PLAN

In order to properly assess the groundwater monitoring data collected in this single sampling event, MWG will conduct a quarterly groundwater sampling program in which the same monitoring wells described in this report will be sampled for the identical analyte list employed during this investigation. MWG proposes to begin this quarterly monitoring program in March 2011, and will submit the results of the sampling program to the Illinois EPA on an ongoing, quarterly basis. MWG proposes to continue this program until sufficient statistically-significant data is available to properly assess the groundwater data. If the quarterly sampling results continue to show non-detect results for certain of the analytes, as was the case in this single sampling event, MWG may propose to Illinois EPA that these analytes be eliminated from future sampling events.

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GROUNDWATER FIELD PARAMETER DATA
Joliet #29 Station, Joliet, Illinois
Midwest Generation
21053.070
Feb. 28, 2011

Groundwater Field Paramter Data - Joliet # 29 Station

Monitoring Well	Date	Time	Conductance (S/cm)*	Temperature °C	pH
MW-01	12/6/2010	14:20	1.04	7.52	7.82
MW-02	12/6/2010	13:41	1.10	9.30	7.85
MW-03	12/6/2010	10:14	7.83	10.91	7.84
MW-04	12/6/2010	10:55	1.84	10.69	7.71
MW-05	12/6/2010	11:40	1.36	8.86	7.82
MW-06	12/6/2010	9:26	1.20	8.53	8.04
MW-07	12/6/2010	8.53	2.12	9.72	8.08
MW-08	12/6/2010	14:52	1.17	12.70	7.75
MW-09	12/6/2010	11:00	2.97	11.94	7.03
MW-09	12/6/2010	11:03	2.93	12.57	6.99
MW-09	12/6/2010	11:06	2.94	12.51	6.97
MW-09	12/6/2010	11:09	2.97	12.24	7.01
MW-09	12/6/2010	11:12	2.99	11.57	7.03
MW-10	12/6/2010	15:17	1.51	9.26	7.65
MW-11	12/6/2010	15.54	1.32	11.97	7.72

Notes:

* (S/cm) = Specific Conductivity measured in Seconds/Centimeters

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GROUNDWATER ANALYTICAL RESULTS

Joliet Station #29, Illinois

Midwest Generation

21053.070

February 28, 2011

Chemical Name	Sample Analysis Method	Groundwater Remediation Objective (mg/L)	MW-1 mg/L	MW-2 mg/L	MW-3 mg/L	MW-4 mg/L	MW-5 mg/L	MW-6 mg/L	MW-7 mg/L
		Class I*	12/6/10	12/6/10	12/7/10	12/7/10	12/7/10	12/7/10	12/7/10
Antimony	Metals 6020	0.006	0.0043	**0.012**	0.004	ND	ND	ND	ND
Arsenic	Metals 6020	0.05	0.0011	ND	ND	ND	ND	ND	0.001
Barium	Metals 6020	2.0	0.13	0.082	0.089	0.065	0.061	0.075	0.13
Beryllium	Metals 6020	0.004	ND	ND	ND	ND	ND	ND	ND
Cadmium	Metals 6020	0.005	ND	ND	ND	ND	ND	ND	ND
Chromium	Metals 6020	0.1	ND	ND	ND	ND	ND	ND	ND
Cobalt	Metals 6020	1.0	ND	ND	0.0013	ND	ND	ND	ND
Copper	Metals 6020	0.65	0.0032	0.0032	ND	ND	ND	ND	ND
Cyanide	Dissolved 9014	0.2	ND	ND	ND	ND	ND	ND	ND
Iron	Metals 6020	5.0	ND	ND	ND	ND	ND	ND	ND
Lead	Metals 6020	0.0075	ND	ND	ND	ND	ND	ND	ND
Manganese	Metals 6020	0.15	ND	ND	0.1	**0.33**	0.0065	0.14	**0.29**
Mercury	Mercury 7470A	0.002	ND	ND	ND	ND	ND	ND	ND
Nickel	Metals 6020	0.1	0.0034	0.0033	0.011	0.0067	ND	0.0056	0.0045
Selenium	Metals 6020	0.05	ND	ND	ND	0.0025	ND	0.0029	ND
Silver	Metals 6020	0.05	ND	ND	ND	ND	ND	ND	ND
Thallium	Metals 6020	0.002	ND	ND	ND	ND	ND	ND	ND
Zinc	Metals 6020	5.0	ND	ND	ND	ND	ND	ND	ND
Boron	Metals 6020	2	0.31	0.31	0.24	0.46	0.42	0.32	0.51
Sulfate	Dissolved 9038	400	180	190	120	300	110	140	250
Chloride	Dissolved 9251	200	140	140	**260**	**270**	150	130	**430**
Nitrogen/Nitrate	Nitrogen By calc	10	ND	3.1	ND	0.81	ND	ND	ND
Total Dissolved Solids	Dissolved 2540C	1,200	590	600	930	1100	750	650	1200
Fluoride	Dissolved 4500 FC	4	0.45	0.62	0.43	0.49	0.4	0.4	0.36
Nitrogen/Nitrite	Dissolved 4500 NO2	NA	ND	ND	ND	ND	ND	ND	ND
Nitrogen/Nitrate/Nitrite	Dissolved 4500 NO3	NA	1.9	3.1	ND	0.81	ND	ND	ND

Notes:

Class I Groundwater Standards from 35 IAC Part 620

Bold Values areas exceed groundwater objectives

mg/L = Milligrams per Liter

ND-non detect

-Determination of the potential for the individual ash ponds to be contributing to the distribution of analytes in the underlying groundwater cannot be made from the results of this single sampling event alone. To develop a true, statistically-significant upgradient background concentration for the various compounds will require a number of sequential sampling events over time. After a statistically developed background value is available, the downgradient concentrations can be compared to this background value over time to determine the likelihood of contaminant migration from the on-site ash ponds. A plan to develop such an analytical database through additional sampling is discussed in the last section of this report.

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GROUNDWATER ANALYTICAL RESULTS

Joliet Station #29, Illinois

Midwest Generation

21053.070

February 28, 2011

Chemical Name	Sample Analysis Method	Groundwater Remediation Objective (mg/L)	MW-8 mg/L	MW-9 mg/L	MW-10 mg/L	MW-11 mg/L
		Class I*	**12/6/10**	**12/6/10**	**12/6/10**	**12/6/10**
Antimony	Metals 6020	0.006	ND	ND	ND	ND
Arsenic	Metals 6020	0.05	ND	ND	ND	0.0013
Barium	Metals 6020	2.0	0.0054	0.031	0.05	0.064
Beryllium	Metals 6020	0.004	ND	ND	ND	ND
Cadmium	Metals 6020	0.005	ND	ND	ND	ND
Chromium	Metals 6020	0.1	ND	ND	ND	ND
Cobalt	Metals 6020	1.0	ND	0.0047	ND	ND
Copper	Metals 6020	0.65	ND	ND	ND	ND
Cyanide	Dissolved 9014	0.2	ND	ND	ND	ND
Iron	Metals 6020	5.0	ND	ND	ND	ND
Lead	Metals 6020	0.0075	ND	ND	ND	ND
Manganese	Metals 6020	0.15	0.0051	**1.1**	0.12	0.052
Mercury	Mercury 7470A	0.002	ND	ND	ND	ND
Nickel	Metals 6020	0.1	0.0025	0.0094	0.0052	0.0022
Selenium	Metals 6020	0.05	ND	ND	ND	ND
Silver	Metals 6020	0.05	ND	ND	ND	ND
Thallium	Metals 6020	0.002	ND	ND	ND	ND
Zinc	Metals 6020	5.0	ND	ND	ND	ND
Boron	Metals 6020	2	0.29	0.36	0.5	0.47
Sulfate	Dissolved 9038	400	210	**1600**	130	140
Chloride	Dissolved 9251	200	130	140	**200**	160
Nitrogen/Nitrate	Nitrogen By calc	10	0.33	ND	0.39	0.39
Total Dissolved Solids	Dissolved 2540C	1,200	670	**2600**	860	770
Fluoride	Dissolved 4500 FC	4	0.51	0.61	0.43	0.34
Nitrogen/Nitrite	Dissolved 4500 NO2	NA	ND	ND	ND	ND
Nitrogen/Nitrate/Nitrite	Dissolved 4500 NO3	NA	0.33	ND	0.39	0.39

Notes:

Class I Groundwater Standards from 35 IAC Part 620

Bold Values areas exceed groundwater objectives

mg/L = Milligrams per Liter

ND-non detect

-Determination of the potential for the individual ash ponds to be contributing to the distribution of analytes in the underlying groundwater cannot be made from the results of this single sampling event alone. To develop a true, statistically-significant upgradient background concentration for the various compounds will require a number of sequential sampling events over time. After a statistically developed background value is available, the downgradient concentrations can be compared to this background value over time to determine the likelihood of contaminant migration from the on-site ash ponds. A plan to develop such an analytical database through additional sampling is discussed in the last section of this report.

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Table 3

GROUNDWATER ELEVATION SURVEY DATA

Joliet #29 Station, Joliet, Illinois

Midwest Generation

21053.070

Feb. 28, 2011

PATRICK ENGINEERING	Water Elevation (feet)	Depth to Water (feet bgs)	Lid Elevation (feet)	Ground Elevation (feet)	Top of Riser Elevation (feet)
MONITORING WELLS					
MW-1	505.460	29.30	535.222	531.464	534.760
MW-2	505.083	29.20	534.799	531.186	534.283
MW-3	505.082	33.70	539.255	535.540	538.782
MW-4	504.926	34.10	539.503	535.800	539.026
MW-5	504.987	34.70	540.149	536.428	539.687
MW-6	505.061	34.00	539.550	535.858	539.061
MW-7	505.050	34.30	539.792	535.862	539.350
MW-8	505.173	31.70	537.347	533.720	536.873
MW-9	505.238	29.20	534.941	531.126	534.438
MW-10	505.227	34.80	540.532	536.949	540.027
MW-11	505.173	34.30	539.960	536.521	539.473
ASH PONDS					
East Pond	530.127	NS	NS	NS	NS
Mid Pond	NS	NS	NS	NS	NS
West Pond	533.112	NS	NS	NS	NS
RIVER					
Des Plaines River	504.827	NS	NS	NS	NS

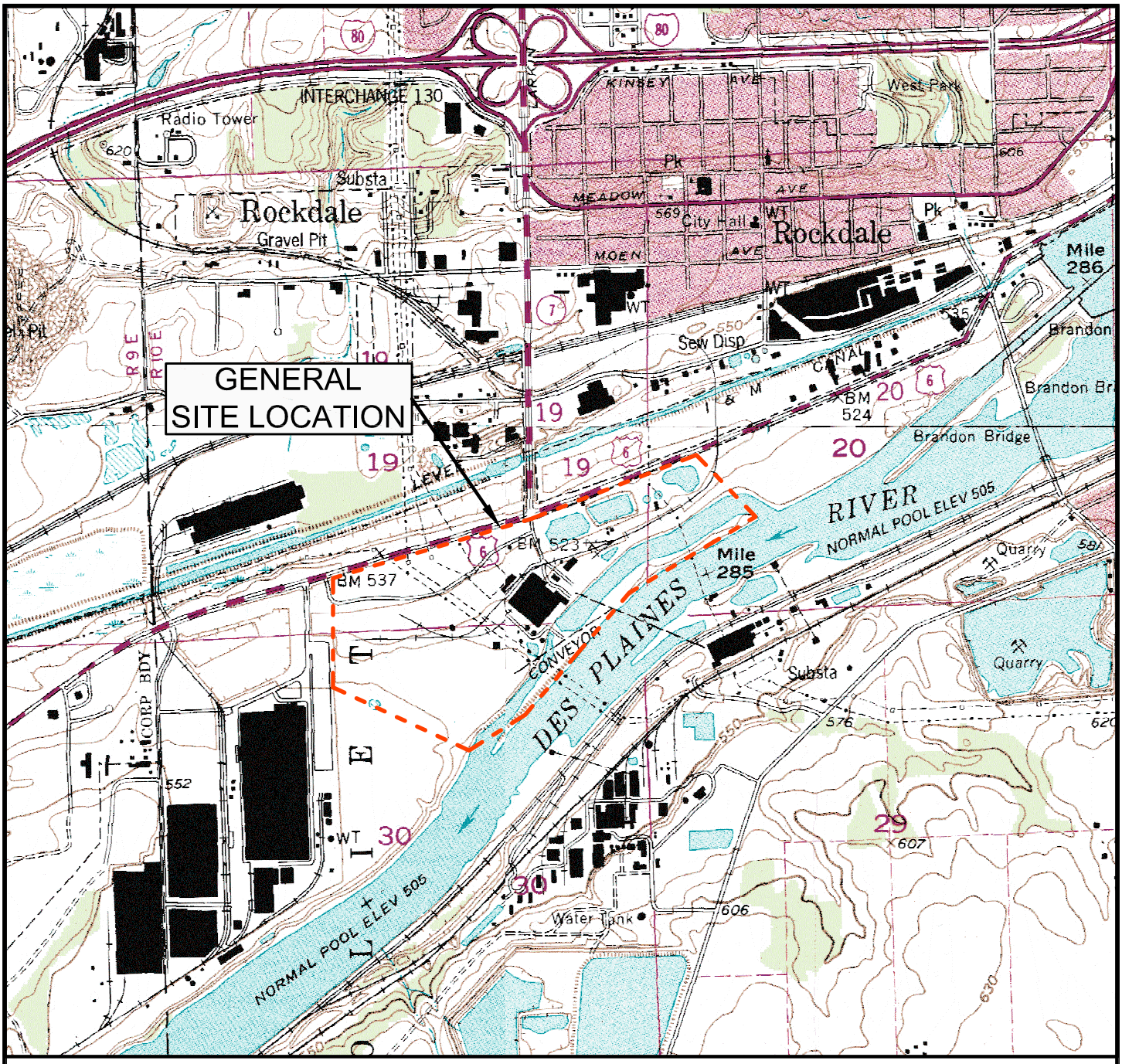
Notes:

*Survey data taken on 12/6/10

NS = not surveyed

bgs = below ground surface

Elevations are leveled from site control points per Commonwealth Edison Drawing "Coordinates & Elevations for Coal Monuments & Test Borings-Joliet Station 29" revised



LEGEND

SITE BOUNDARY

N

0 2,000'

GRAPHIC SCALE

NOTE:
THIS DRAWING WAS PREPARED USING ILLINOIS' PLAINFIELD (1993), JOLIET (1993), CHANNAHON (1993), AND ELWOOD (1993) 7.5 MINUTE-SERIES TOPOGRAPHIC QUADRANGLE MAP.

Date: FEB. 2011	FIGURE 1 SITE LOCATION MAP	PATRICK ENGINEERING INC.
Proj No.: 21053.070	JOLIET STATION NO. 29 JOLIET, ILLINOIS	
App. By: RMF		

4970 Varsity Drive
Lisle, Illinois 60532-4101
TEL. (630) 795-7200
FAX (630) 724-1681
PROFESSIONAL DESIGN FIRM LICENSE NO. 184-000409

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LEGEND

ASH POND

N

0 300'

GRAPHIC SCALE

AERIAL IMAGE SOURCE:
LANDISCOR AERIAL INFORMATION INC., JULY 2008

Date: FEB. 2011	FIGURE 2 ASH POND LOCATIONS MAP	PATRICK ENGINEERING INC.
Proj No.: 21053.070	JOLIET STATION NO. 29 JOLIET, ILLINOIS	4970 Varsity Drive Lisle, Illinois 60532-4101 TEL. (630) 795-7200 FAX (630) 724-1681
App. By: RMF		PROFESSIONAL DESIGN FIRM LICENSE NO. 184-000409

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LEGEND

MW-01 Monitoring Well Location (November 2010)

N

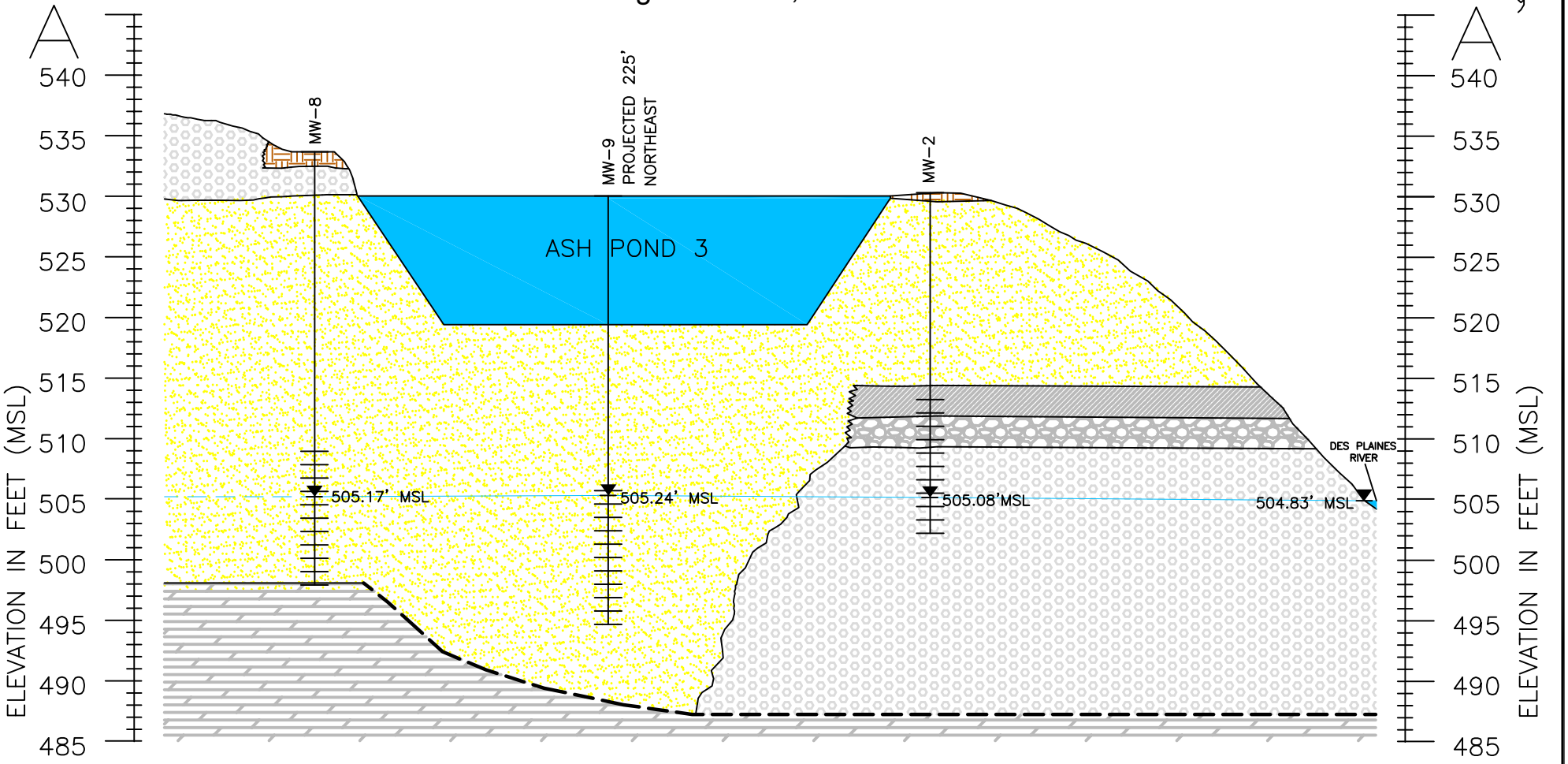
0 300'

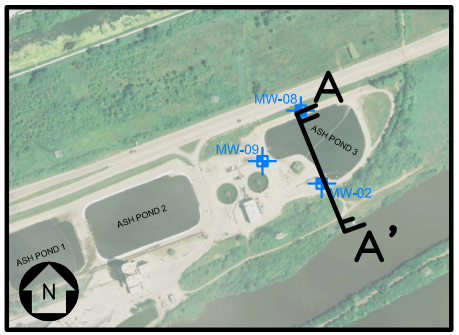
GRAPHIC SCALE

AERIAL IMAGE SOURCE:
LANDISCOR AERIAL INFORMATION INC., JULY 2008

Date: FEB. 2011	FIGURE 3 MONITORING WELL LOCATION MAP	PATRICK ENGINEERING INC.
Proj No.: 21053.070	JOLIET STATION NO. 29 JOLIET, ILLINOIS	4970 Varsity Drive Lisle, Illinois 60532-4101 TEL. (630) 795-7200 FAX (630) 724-1681
App. By: RMF		PROFESSIONAL DESIGN FIRM LICENSE NO. 184-000409

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CROSS SECTION A-A'
NOT TO SCALE

LEGEND

- FILL
- CLAYEY GRAVEL
- SANDY GRAVEL
- GROUNDWATER ELEVATION (FT. / MSL)
- GRAVEL
- SILTY CLAY
- DOLOMITIC LIMESTONE

VERTICAL SCALE 10' 0
0 75'
HORIZONTAL SCALE

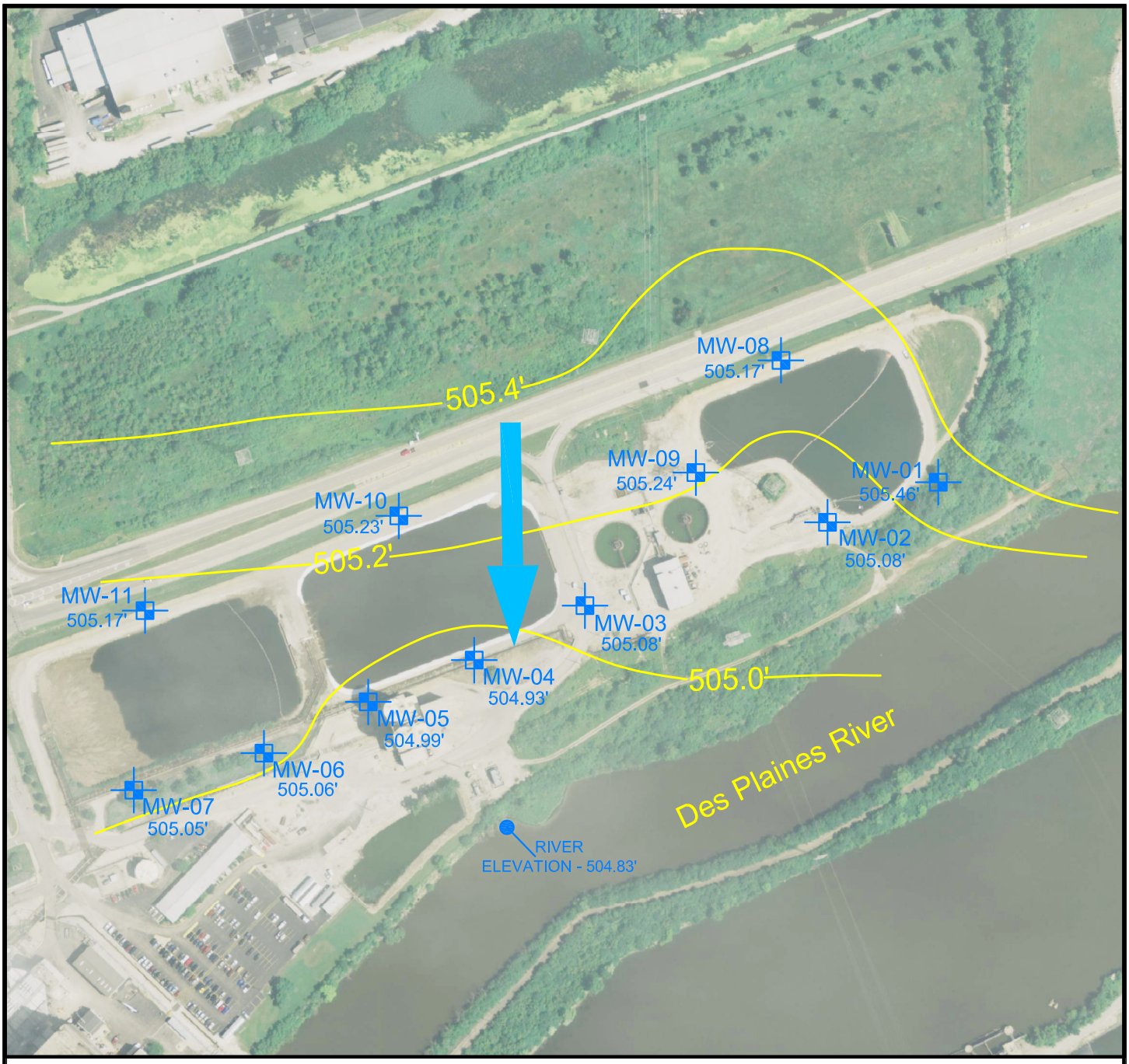
PATRICK ENGINEERING INC.
4970 Varsity Drive TEL. (630) 795-7200
Lisle, Illinois 60532-4101 FAX (630) 724-1681
http://www.patrickengineering.com
PROFESSIONAL DESIGN FIRM LICENSE NO. 184-000409

FIGURE 4
CROSS SECTION A-A' - SITE LITHOLOGY

JOLIET STATION NO. 29
JOLIET, ILLINOIS

DATE: FEBRUARY 2011
PROJ. NO.: 21053.070
APP. BY: RMF

Electronic Filing: Received, Clerk's Office 2/04/2022



LEGEND

MW-01
505.46'
Monitoring Well Location (November 2010) with Groundwater Elevation (ft. / MSL)

Groundwater Flow Direction

550.0
Potentiometric Surface Contour (ft. / MSL)

N

0 300'

GRAPHIC SCALE

AERIAL IMAGE SOURCE:
LANDISCOR AERIAL INFORMATION INC., JULY 2008

Date: FEB. 2011	FIGURE 5 POTENTIOMETRIC SURFACE MAP	PATRICK ENGINEERING INC.
Proj No.: 21053.070	JOLIET STATION NO. 29 JOLIET, ILLINOIS	4970 Varsity Drive Lisle, Illinois 60532-4101 TEL. (630) 795-7200 FAX (630) 724-1681
App. By: RMF		PROFESSIONAL DESIGN FIRM LICENSE NO. 184-000409

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-1** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **531.5**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL □ LL 10 20 30 40 50; Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
531.5	0.0		Topsoil with fine to coarse gravel, moist				
			1' to 2' rounded coarse gravel at surface	SS-1 1.0-2.5 8"R	8 10 5		Bentonite seal 2.0'-14.0'. Stickup protective cover installed.
				SS-2 3.5-5.0 10"R	12 32 14		
			Fine to coarse sand and gravel, limestone fragments				
				SS-3 6.0-7.5 10"R	12 12 7		
			Limestone fragments, wet	SS-4 8.5-10.0 0.5"	8 4 4		
520.5	11.0		Fine to coarse sand and gravel, some black clay, limestone fragments, wet	SS-5 11.0-12.5 8"R	5 5 5		
				SS-6 13.5-15.0 6"R	45 6 10		Sand pack 14.0'-26.25'
514.5	17.0	▽	Saturated	SS-7 16.0-17.5 10"R	8 6 8		Set screen (slot 0.010) 16.25'-26.25'
			Limestone fragments, saturated	SS-8 18.5-20.0 6"R	14 10 11		
511.5	20.0						

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **10/27/10** ENDED **10/27/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **17.0**
▽ **15.0'**
▽

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-1** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **531.5**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
511.5	20.0		Fine to coarse sand and gravel, with limestone fragments, weathered, saturated				
				SS-9 21.0-22.5 8"R	22 25 13		
				SS-10 23.5-25.0 8"R	15 11 10		
			Wet to saturated				
				SS-11 26.0-27.5 10"R	12 16 18		
504.0	27.5		Saturated				
			End of Boring at 27.5'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **10/27/10** ENDED **10/27/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **17.0**
▼ **15.0'**
▼

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-2** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **531.2**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
531.2	0.0		Fine to coarse gravel (CA-6)				1" - 6" cobbles at surface
530.2	1.0		Brown fine to coarse sand and gravel, moist	SS-1 1.0-2.5 6"R	5 7 5		
							Bentonite seal 2.0'-14.0'. Stickup protective cover installed.
			1" limestone fragments	SS-2 3.5-5.0 0.5"R	8 12 6		
525.2	6.0		Brown fine to coarse sand and gravel, moist	SS-3 6.0-7.5 3"R	5 9 6		
			1" limestone fragments	SS-4 8.5-10.0 9"R	11 8 10		
			Little silty clay, moist to wet	SS-5 11.0-12.5 3"R	6 37 11		
517.7	13.5		Coarse gravel with black silty clay, trace roots, trace coarse sand, moist	SS-6 13.5-15.0 4"R	15 4 3		Sand pack 14.0'-26.5'
515.2	16.0		Black silty clay, with fine to coarse sand and gravel, moist	SS-7 16.0-17.5 8"R	12 6 12		Set screen 16.5'-26.5'
512.7	18.5	▽	Brown silty fine to coarse sand, trace fine gravel, saturated	SS-8 18.5-20.0 6"R	3 4 3		

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **10/29/10** ENDED **10/29/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **18.5**
▼ **21.5'**
▼

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-2** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **531.2**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) * 1 2 3 4 5	NOTES & TEST RESULTS
511.2	20.0						
510.2	21.0		Limestone fragments, trace light brown silty clay, moist	SS-9 21.0-22.5 8"R	13 16 13		
				SS-10 23.5-25.0 4"R	14 13 13		
			Limestone fragments, saturated				
502.7	28.5		End of Boring at 28.5'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **10/29/10** ENDED **10/29/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **18.5**
▼ **21.5'**
▼

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-3** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **535.5**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) * 1 2 3 4 5	NOTES & TEST RESULTS
535.5	0.0		Coarse gravel (CA-6)				
				SS-1 1.0-2.5			Bentonite seal 2.0'-30.5'. Stickup protective cover installed.
			Fine to coarse sand and gravel, dry	SS-2 3.5-5.0	8 10 12		
				SS-3 6.0-7.5			
				SS-4 8.5-10.0	12 11 10		
				SS-5 11.0-12.5			
				SS-6 13.5-15.0	9 12 13		
				SS-7 16.0-17.5			
517.0	18.5		Tan fine to coarse sand, with coarse gravel, dry	SS-8 18.5-20.0	12 17 23		

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/1/10** ENDED **11/1/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-3** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **535.5**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) * 1 2 3 4 5	NOTES & TEST RESULTS
514.5	21.0		Tan fine to coarse sand, with coarse gravel, dry	SS-9 21.0-22.5			
				SS-10 23.5-25.0	14 32 36		
				SS-11 26.0-27.5			
				SS-12 28.5-30.0	21 16 15		Sand pack 28.0'-40.5'
504.5	31.0		▽ Saturated	SS-13 31.0-32.5	15 11 12		Set screen (slat 0.010) 30.5'-40.5'
				SS-14 33.5-35.0			
				S-15 36.0-37.5			
				SS-16 38.5-40.0	50/0.5'		
494.5	41.0		End of Boring at 41.0'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/1/10** ENDED **11/1/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-4** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **535.8**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) * 1 2 3 4 5	NOTES & TEST RESULTS
535.8	0.0		Coarse gravel (CA-6), dry				
534.8	1.0		Brown silty clay, trace coarse sand, stiff, dry	SS-1 1.0-2.5 6"R	6 6 7		Bentonite seal 2.0'-27.5'. Stickup protective cover installed.
				SS-2 3.5-5.0 10"R	4 7 9		
529.8	6.0		Brown fine to coarse sand and gravel, trace limestone fragments	SS-3 6.0-7.5 6"R	20 22 12		
				SS-4 8.5-10.0 6"R	10 12 16		
				SS-5 11.0-12.5 8"R	11 20 23		
				SS-6 13.5-15.0 4"R	9 8 9		
			Limestone fragments, dry	SS-7 16.0-17.5 2"R	31 31		
				SS-8 18.5-20.0 4"R	24 40		

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/1/10** ENDED **11/1/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.5**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-4** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **535.8**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
515.8	20.0		Brown fine to coarse sand and gravel, trace limestone fragments				
				SS-9 21.0-22.5 4"R	60/6"		
			Fine to coarse sand and gravel, dry				
				SS-10 23.5-25.0 6"R	35 36		
				SS-11 26.0-27.5 10"R	28 21 10		
							Sand pack 27.5'-39.5'
				SS-12 28.5-30.0 6"R	12 8 8		Set screen (slot 0.010) 29.5'-39.5'
504.3	31.5	▽	Saturated	SS-13 31.0-32.5 8"R	13 17 13		
502.8	33.0		Fine to coarse sand, saturated				
				SS-14 33.5-35.0 18"R	13 24 24		
			Fine to coarse sand and gravel, with limestone fragments				
				SS-15 36.0-37.5			
				SS-16 38.5-40.0 10"R	21 50/3"		
495.8	40.0		End of Boring at 40.0'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/1/10** ENDED **11/1/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.5**
▽
▽

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-5** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **536.4**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
536.4	0.0		Fine to coarse gravel, topsoil, dry				
				SS-1 1.0-2.5			Bentonite seal 2.0'-32.0'. Stickup protective cover installed.
				SS-2 3.5-5.0			
				SS-3 6.0-7.5			
527.9	8.5		Black silty clay, coarse sand, moist to wet	SS-4 8.5-10.0 1"R	2 4 2		
				SS-5 13.5-15.0 8"R	2 4 3		
				SS-6 16.0-17.5			
			Coarse gravel fragments	SS-7 18.5-20.0 0.5"R	4 3 3		
				SS-8 21.0-22.5			

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/2/10** ENDED **11/2/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-5** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **536.4**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL □---○---△ LL (10 20 30 40 50) / Unconfined Compressive Strength (TSF) ✳ (1 2 3 4 5)	NOTES & TEST RESULTS
513.9 513.4	22.5 23.0						
			Tan to light brown fine to coarse sand, little coarse gravel, dry	SS-9 23.5-25.0 12"R	27 35 38		
				SS-10 26.0-27.5	42 49		
				SS-11 28.5-30.0 8"R	7 8 9		
							Sand pack 30.0'-42.0'
505.4	31.0		▽ Fine to coarse sand and gravel, saturated	SS-12 31.0-32.5 4"R	7 10 27		
							Set screen (slot 0.010") 32.0'-42.0'
				SS-13 33.5-35.0			
				SS-14 36.0-37.5			
				SS-15 38.5-40.0	29 18		
			Tan to light brown fine to coarse sand, little coarse gravel, dry				
494.4	42.0		End of Boring at 42.0'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/2/10** ENDED **11/2/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-6** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **535.9**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 50 LL / Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
535.9	0.0		Gravel (CA-6), topsoil, dry				
				SS-1 1.0-2.5			Bentonite seal 2.0'-30.5'. Stickup protective cover installed.
				SS-2 3.5-5.0			
				SS-3 6.0-7.5			
527.4	8.5		Brown to tan fine to coarse sand and gravel, trace limestone, gravel seams, dry	SS-4 8.5-10.0 12"R	12 12 12		
				SS-5 11.0-12.5			
				SS-6 13.5-15.0 14"R	23 30 27		
				SS-7 16.0-17.5			
				SS-8 18.5-20.0 12"R	18 28 24		

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/3/10** ENDED **11/3/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-6** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **535.9**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) * 1 2 3 4 5	NOTES & TEST RESULTS
514.9	21.0		Brown to tan fine to coarse sand and gravel, trace limestone, gravel seams, dry	SS-9 21.0-22.5			
				SS-10 23.5-25.0 14"R	23 34 18/3"		
				SS-11 26.0-27.5			
				SS-12 28.5-30.0 12"R	33 21 27		Sand pack 28.0'-40.5'
504.9	31.0	▽	Fine to coarse sand and gravel, saturated	SS-13 31.0-32.5 12"R			Set screen (slot 0.010) 30.5'-40.5'
				SS-14 33.5-35.0			
				SS-15 36.0-37.5			
497.4	38.5		Limestone bedrock	SS-16 38.5-40.0 0.5"R	50/0.5"		
495.4	40.5		End of Boring at 40.5'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/3/10** ENDED **11/3/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-7** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **535.9**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 50 LL / Unconfined Compressive Strength (TSF) 1 2 3 4 5	NOTES & TEST RESULTS
535.9	0.0		Gravel (CA-6), topsoil, dry				
				SS-1 1.0-2.5			Bentonite seal 2.0'-28.75'. Stickup protective cover installed.
				SS-2 3.5-5.0			
				SS-3 6.0-7.5			
527.4	8.5		Tan to brown fine to coarse sand and gravel, dry	SS-4 8.5-10.0 8"R	32 16 17		
				SS-5 11.0-12.5			
				SS-6 13.5-15.0	13 21		
				SS-7 16.0-17.5			
				SS-8 18.5-20.0	28 17		

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/3/10** ENDED **11/3/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**
▼
▼

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-7** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **535.9**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
515.9	20.0		Tan to brown fine to coarse sand and gravel, dry				
				SS-9 21.0-22.5			
				SS-10 23.5-25.0 8"R	21 28 1		
				SS-11 26.0-27.5			Sand pack 26.5'-38.75'
				SS-12 28.5-30.0 12"R	22 31 37		Set screen (slot 0.010) 28.75'-38.75'
504.9	31.0		▽ Saturated	SS-13 31.0-32.5 10"R	12 8 5		
496.4	39.5		End of Boring at 39.5'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/3/10** ENDED **11/3/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-8** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **533.7**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
533.7	0.0		Fine to coarse gravel fill, dry				
532.7	1.0		Dark brown silty clay, some fine to coarse sand, stiff, moist	SS-1 1.0-2.5 6"R	2 5 9		Bentonite seal 2.0'-25.5'. Stickup protective cover installed.
530.2	3.5		Black/brown fine to coarse sand and gravel, moist	SS-2 3.5-5.0 6"R	5 5 10		
			Limestone fragments, dry	SS-3 6.0-7.5 8"R	13 16 14		
				SS-4 8.5-10.0 8"R	7 15 22		
				SS-5 11.0-12.5 8"R	15 13 13		
				SS-6 13.5-15.0 8"R	17 14 12		
				SS-7 16.0-17.5 8"R	5 12 8		
				SS-8 18.5-20.0 3"R	12 9 9		

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **10/27/10** ENDED **10/27/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **27.0**
▽
▽

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-8** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **533.7**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL □---○---△ LL (10 20 30 40 50) / Unconfined Compressive Strength (TSF) ✳ (1 2 3 4 5)	NOTES & TEST RESULTS
513.7	20.0		Black/brown fine to coarse sand and gravel, moist				
				SS-9 21.0-22.5 4"R	5 4 5		
			Moist to wet	SS-10 23.5-25.0 6"R	6 9 18		Sand pack 23.0'-35.5'
							Screen set (slot 0.010) 25.5'-35.5'
				SS-11 26.0-27.5 8"R	6 9 8		
506.7	27.0	▽	Saturated				
				SS-12 28.5-30.0 6"R	4 8 8		
				SS-13 33.5-35.0 2"R	50/1"		
498.2	35.5		End of Boring at 35.5'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **10/27/10** ENDED **10/27/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **27.0**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-9** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **531.1**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) * 1 2 3 4 5	NOTES & TEST RESULTS
531.1	0.0		Coarse sand and gravel (CA-6), dry				
530.1	1.0		Coarse gravel, with black silty clay, trace root seams, moist	SS-1 1.0-2.5 6"R	15 14 13		Bentonite seal 2.0'-34.75'. Stickup protective cover installed.
527.6	3.5		Coarse gravel fragments, with fine to coarse sand, dry	SS-2 3.5-5.0 2"R	4 5 6		
				SS-3 6.0-7.5			
				SS-4 8.5-10.0			
520.1	11.0		Limestone fragments, with light brown silty fine to coarse sand, dry	SS-5 11.0-12.5 8"R	34 37		
				SS-6 13.5-15.0 10"R	20 16 16		
				SS-7 16.0-17.5 6"R	10 15 23		
512.6	18.5		Limestone fragments, with light brown to dark orange fine to coarse sand, moist	SS-8 18.5-20.0 10"R	15 24 28		

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **10/29/10** ENDED **10/29/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **26.0**

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-9** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **531.1**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL–LL (10 20 30 40 50) / Unconfined Compressive Strength (TSF) ✳ (1 2 3 4 5)	NOTES & TEST RESULTS
511.1	20.0		Limestone fragments, with light brown to dark orange fine to coarse sand, moist				
				SS-9 21.0-22.5			
							Sand pack 22.5'-34.75'
507.6	23.5		Light brown/orange fine to coarse sand, with coarse gravel, moist	SS-10 23.5-25.0 12"R	15 29 36		
							Screen set (slot 0.010) 24.75'-34.75'
505.1	26.0	▽		SS-11 26.0-27.5 1"R	16 10 8		
502.6	28.5		Light brown coarse sand, some fine to coarse gravel, little fine sand, saturated	SS-12 28.5-30.0 10"R	6 10 13		
				SS-13 31.0-32.5			
				SS-14 33.5-35.0 6"R	18 50/4"		
496.1	35.0		End of Boring at 35.0'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **10/29/10** ENDED **10/29/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **26.0**
▽
▽

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-10** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **536.9**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
536.9	0.0		Coarse gravel, dry				
				SS-1 1.0-2.5 10"R	5 4 5		Bentonite seal 2.0'-28.0'. Stickup protective cover installed.
			Brown clay				
				SS-2 3.5-5.0 10"R	3 2 2		
				SS-3 6.0-7.5 16"R	2 1 1		
529.9	7.0		Black/gray sandy silt, moist				
				SS-4 8.5-10.0 12"R	1 3 1		
				SS-5 11.0-12.5 18"R	1 1 1		
				SS-6 13.5-15.0 18"R	1 2 2		
				SS-7 16.0-17.5 18"R	1 3 2		
517.9	19.0		Gray silty clay, trace coarse sand, soft, wet	SS-8 18.5-20.0 18"R	2 3 4		

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/2/10** ENDED **11/2/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**
▼
▼

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-10** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **536.9**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL □ LL 10 20 30 40 50 / Unconfined Compressive Strength (TSF) ✳ 1 2 3 4 5	NOTES & TEST RESULTS
515.9	21.0		Gray silty clay, trace coarse sand, soft, wet	SS-9 21.0-22.5 8"R	12 28 31		
				SS-10 23.5-25.0 10"R	11 24 21		
				SS-11 26.0-27.5 12"R	6 13 17		
				SS-12 28.5-30.0 18"R	13 19 24		Sand pack 28.0'-40.5'
505.9	31.0		▽	SS-13 31.0-32.5 10"R	28 24 14		Screen set (slot 0.010) 30.5'-40.5'
				SS-14 33.5-35.0 18"R	16 63 12		
				SS-15 36.0-37.5			
				SS-16 38.5-40.0 18"R	9 14		
495.9	41.0		End of Boring at 41.0'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/2/10** ENDED **11/2/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**
▽
▼

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-11** SHEET **1** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

LOGGED BY **AFG**
GROUND ELEVATION **536.5**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL □---○---△ LL (10 20 30 40 50) / Unconfined Compressive Strength (TSF) ✳ (1 2 3 4 5)	NOTES & TEST RESULTS
536.5	0.0		Fine to coarse sand and gravel, fill, dry				
				SS-1 1.0-2.5			Bentonite seal 2.0'-27.0'. Stickup protective cover installed.
				SS-2 3.5-5.0	3 2 2		
				SS-3 6.0-7.5			
			Grades to dark gray clayey silt	SS-4 8.5-10.0	3 2 2		
				SS-5 11.0-12.5			
522.5	14.0		Dark gray clayey silt, soft, moist	SS-6 13.5-15.0	1 2 2		
				SS-7 16.0-17.5			
				SS-8 18.5-20.0	1 3 5		

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/4/10** ENDED **11/4/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**
▽
▼

PATRICK ENGINEERING INC.

BORING NUMBER **B-MW-11** SHEET **2** OF **2**
CLIENT **Midwest Generation**
PROJECT & NO. **21053.070**
LOCATION **Joliet No. 29**

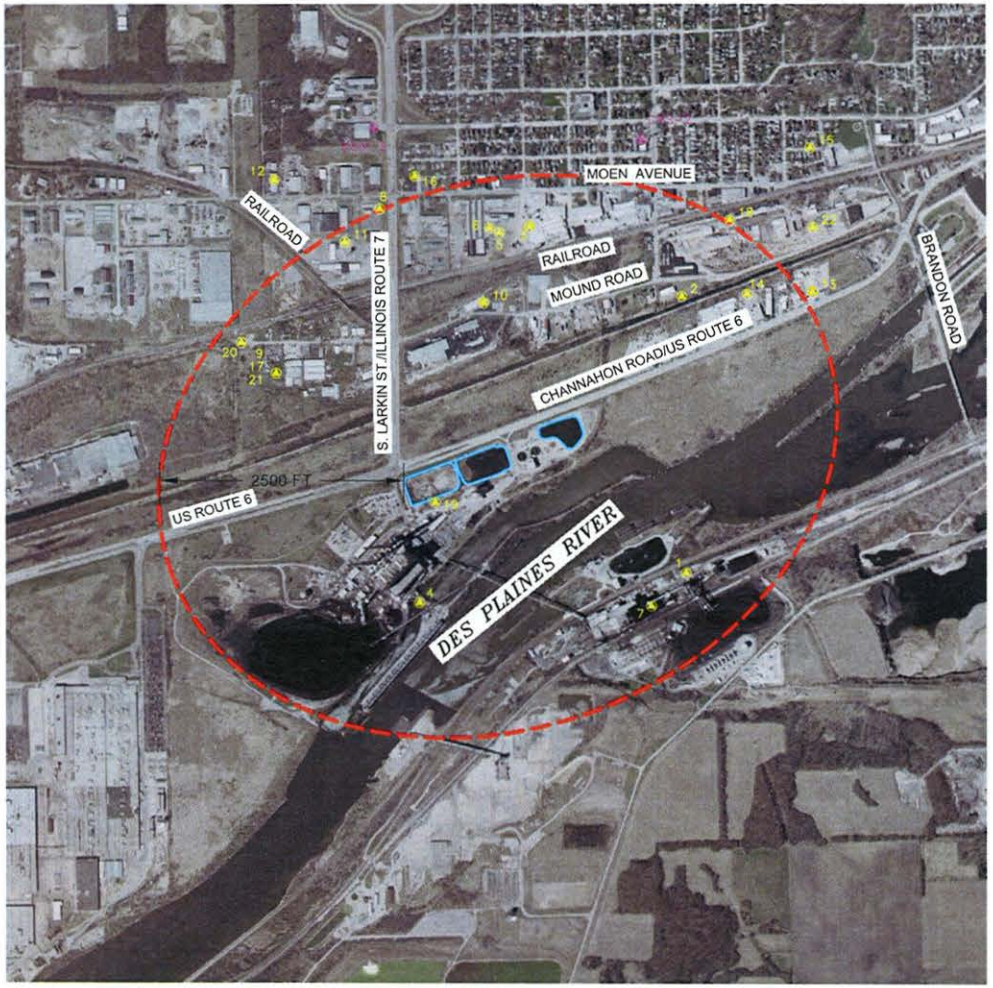
LOGGED BY **AFG**
GROUND ELEVATION **536.5**

ELEVATION	DEPTH (FT)	STRATA	SOIL/ROCK DESCRIPTION	SAMPLE TYPE & NO. DEPTH (FT) RECOVERY(IN)	BLOW COUNTS	Water Content PL 10 20 30 40 LL 50 / Unconfined Compressive Strength (TSF) * 1 2 3 4 5	NOTES & TEST RESULTS
516.5	20.0		Dark gray clayey silt, soft, moist				
				SS-9 21.0-22.5			
			Light brown fine to coarse silt and gravel, moist	SS-10 23.5-25.0	9 11 12		
				SS-11 26.0-27.5			Sand pack 27.0'-39.5'
				SS-12 28.5-30.0	1 3 13		Screen set (slot 0.010) 29.5'-39.5'
505.5	31.0		▽	SS-13 31.0-32.5	8 7 8		
				SS-14 33.5-35.0			
				SS-15 36.0-37.5			
				SS-16 38.5-40.0	36 50/2"		
497.0	39.5		End of Boring at 39.5'				

DRILLING CONTRACTOR **Groff Testing**
DRILLING METHOD **4.25" I.D. HSA**
DRILLING EQUIPMENT **CME**
DRILLING STARTED **11/4/10** ENDED **11/4/10**

REMARKS
Installed 2" diameter PVC monitoring well.

WATER LEVEL (ft.)
▽ **31.0**



LEGEND

- CWS-1 — COMMUNITY WELL LOCATION
- POTABLE WELL LOCATION (APPROXIMATE)
- ASH POND
- 2,500 FOOT RADIUS OF ASH POND SYSTEMS

NOTE:
REFER TO SUMMARY TABLE FOR SPECIFIC WELL INFORMATION.

SOURCE:
2005 DIGITAL ORTHOPHOTO FROM ILLINOIS NATURAL RESOURCES GEOSPATIAL DATA CLEARINGHOUSE
WELL LOCATIONS FROM ILLINOIS STATE GEOLOGICAL SURVEY, ILLINOIS ENVIRONMENTAL PROTECTION AGENCY, AND ILLINOIS STATE WATER SURVEY.

N

0 600 1200
SCALE IN FEET

DRAWN BY: RLH/KNW DATE: 05/20/09
CHECKED BY: HMS DATE: 05/22/09
APPROVED BY: HMS DATE: 07/07/09
DRAWING NO: 1792-3-B03
REFERENCE: 16TDL050930.sid, 050945.sid, 065930.sid, 065945.sid.

POTABLE WATER WELLS

JOLIET STATION NO. 29
MIDWEST GENERATION
ROCKDALE, WILL COUNTY, ILLINOIS

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.
1792/3.0

FIGURE NO.
1

Electronic Filing: Received, Clerk's Office 2/04/2022

TestAmerica
THE LEADER IN ENVIRONMENTAL TESTING

ANALYTICAL REPORT

Job Number: 500-29703-1

Job Description: Joliet Ash Pond Assessments

For:
Midwest Generation EME LLC
1800 Channahon Road
Joliet, IL 60436

Attention: James DiCola

Approved for release.
Cindy R Pritchard
Project Mgmt. Assistant
12/17/2010 1:46 PM

Designee for
Bonnie M Stadelmann
Project Manager II
bonnie.stadelmann@testamericainc.com
12/17/2010

cc: Andrew Gagnon
Ms. Maria Race

These test results meet all the requirements of NELAC for accredited parameters.

The Lab Certification ID#:
TestAmerica Chicago 100201

All questions regarding this test report should be directed to the TestAmerica Project Manager whose signature appears on this report. All pages of this report are integral parts of the analytical data. Therefore, this report should be reproduced only in its entirety.

TestAmerica Laboratories, Inc.
TestAmerica Chicago 2417 Bond Street, University Park, IL 60484
Tel (708) 534-5200 Fax (708) 534-5211 www.testamericainc.com

ACCREDITED IN ACCORDANCE WITH nelac

Job Narrative
500-29703-1

Comments
No additional comments.

Receipt
All samples were received in good condition within temperature requirements.

Metals
The matrix spike / matrix spike duplicate (MS/MSD) recoveries for sample 500-29703-1 were outside control limits for Ag. The MSD was also out for Se. The associated laboratory control sample (LCS) recovery met acceptance criteria.

No other analytical or quality issues were noted.

Field Service / Mobile Lab
No analytical or quality issues were noted.

General Chemistry
Method(s) 353.2, SM 4500 NO3 F: The nitrate continuing calibration verification (CCV) for 101888 recovered above the upper control limit. The samples associated with this CCV were non-detects for the affected analytes; therefore, the data have been reported. MW-06 (500-29703-6), MW-07 (500-29703-7), MW-09 (500-29703-9)

No other analytical or quality issues were noted.

EXECUTIVE SUMMARY - Detections

Client: Midwest Generation EME LLC Job Number: 500-29703-1

Lab Sample ID / Analyte	Client Sample ID	Result / Qualifier	Reporting Limit	Units	Method
500-29703-1	**MW-01**				
Dissolved					
Antimony		0.0043	0.0030	mg/L	6020
Arsenic		0.0011	0.0010	mg/L	6020
Barium		0.13	0.0025	mg/L	6020
Boron		0.31	0.050	mg/L	6020
Copper		0.0032	0.0020	mg/L	6020
Nickel		0.0034	0.0020	mg/L	6020
Sulfate-Dissolved		180	50	mg/L	9038
Chloride-Dissolved		140	10	mg/L	9251
Nitrogen, Nitrate-Dissolved		1.9	0.10	mg/L	Nitrate by calc
Total Dissolved Solids-Dissolved		590	10	mg/L	SM 2540C
Fluoride-Dissolved		0.45	0.10	mg/L	SM 4500 F C
Nitrogen, Nitrate Nitrite-Dissolved		1.9	0.20	mg/L	SM 4500 NO3 F
500-29703-2	**MW-02**				
Dissolved					
Antimony		0.012	0.0030	mg/L	6020
Barium		0.082	0.0025	mg/L	6020
Boron		0.31	0.050	mg/L	6020
Copper		0.0032	0.0020	mg/L	6020
Nickel		0.0033	0.0020	mg/L	6020
Sulfate-Dissolved		190	50	mg/L	9038
Chloride-Dissolved		140	10	mg/L	9251
Nitrogen, Nitrate-Dissolved		3.1	0.10	mg/L	Nitrate by calc
Total Dissolved Solids-Dissolved		600	10	mg/L	SM 2540C
Fluoride-Dissolved		0.62	0.10	mg/L	SM 4500 F C
Nitrogen, Nitrate Nitrite-Dissolved		3.1	0.20	mg/L	SM 4500 NO3 F
500-29703-3	**MW-03**				
Dissolved					
Antimony		0.0040	0.0030	mg/L	6020
Barium		0.089	0.0025	mg/L	6020
Boron		0.24	0.050	mg/L	6020
Cobalt		0.0013	0.0010	mg/L	6020
Manganese		0.10	0.0025	mg/L	6020
Nickel		0.011	0.0020	mg/L	6020
Sulfate-Dissolved		120	50	mg/L	9038
Chloride-Dissolved		260	10	mg/L	9251
Total Dissolved Solids-Dissolved		930	10	mg/L	SM 2540C
Fluoride-Dissolved		0.43	0.10	mg/L	SM 4500 F C

EXECUTIVE SUMMARY - Detections

Client: Midwest Generation EME LLC Job Number: 500-29703-1

Lab Sample ID / Analyte	Client Sample ID	Result / Qualifier	Reporting Limit	Units	Method
500-29703-4	**MW-04**				
Dissolved					
Barium		0.065	0.0025	mg/L	6020
Boron		0.46	0.050	mg/L	6020
Manganese		0.33	0.0025	mg/L	6020
Nickel		0.0067	0.0020	mg/L	6020
Selenium		0.0025	0.0025	mg/L	6020
Sulfate-Dissolved		300	50	mg/L	9038
Chloride-Dissolved		270	10	mg/L	9251
Nitrogen, Nitrate-Dissolved		0.81	0.10	mg/L	Nitrate by calc
Total Dissolved Solids-Dissolved		1100	10	mg/L	SM 2540C
Fluoride-Dissolved		0.49	0.10	mg/L	SM 4500 F C
Nitrogen, Nitrate Nitrite-Dissolved		0.81	0.10	mg/L	SM 4500 NO3 F
500-29703-5	**MW-05**				
Dissolved					
Barium		0.061	0.0025	mg/L	6020
Boron		0.42	0.050	mg/L	6020
Manganese		0.0065	0.0025	mg/L	6020
Sulfate-Dissolved		110	25	mg/L	9038
Chloride-Dissolved		150	10	mg/L	9251
Total Dissolved Solids-Dissolved		750	10	mg/L	SM 2540C
Fluoride-Dissolved		0.40	0.10	mg/L	SM 4500 F C
500-29703-6	**MW-06**				
Dissolved					
Barium		0.075	0.0025	mg/L	6020
Boron		0.32	0.050	mg/L	6020
Manganese		0.14	0.0025	mg/L	6020
Nickel		0.0056	0.0020	mg/L	6020
Selenium		0.0029	0.0025	mg/L	6020
Sulfate-Dissolved		140	50	mg/L	9038
Chloride-Dissolved		130	10	mg/L	9251
Total Dissolved Solids-Dissolved		650	10	mg/L	SM 2540C
Fluoride-Dissolved		0.40	0.10	mg/L	SM 4500 F C

EXECUTIVE SUMMARY - Detections

Client: Midwest Generation EME LLC Job Number: 500-29703-1

Lab Sample ID / Analyte	Client Sample ID	Result / Qualifier	Reporting Limit	Units	Method
500-29703-7	**MW-07**				
Dissolved					
Arsenic		0.0010	0.0010	mg/L	6020
Barium		0.13	0.0025	mg/L	6020
Boron		0.51	0.050	mg/L	6020
Manganese		0.29	0.0025	mg/L	6020
Nickel		0.0045	0.0020	mg/L	6020
Sulfate-Dissolved		250	50	mg/L	9038
Chloride-Dissolved		430	50	mg/L	9251
Total Dissolved Solids-Dissolved		1200	10	mg/L	SM 2540C
Fluoride-Dissolved		0.36	0.10	mg/L	SM 4500 F C
500-29703-8	**MW-08**				
Dissolved					
Barium		0.054	0.0025	mg/L	6020
Boron		0.29	0.050	mg/L	6020
Manganese		0.0051	0.0025	mg/L	6020
Nickel		0.0025	0.0020	mg/L	6020
Sulfate-Dissolved		210	50	mg/L	9038
Chloride-Dissolved		130	10	mg/L	9251
Nitrogen, Nitrate-Dissolved		0.33	0.10	mg/L	Nitrate by calc
Total Dissolved Solids-Dissolved		670	10	mg/L	SM 2540C
Fluoride-Dissolved		0.51	0.10	mg/L	SM 4500 F C
Nitrogen, Nitrate Nitrite-Dissolved		0.33	0.10	mg/L	SM 4500 NO3 F
500-29703-9	**MW-09**				
Dissolved					
Barium		0.031	0.0025	mg/L	6020
Boron		0.36	0.050	mg/L	6020
Cobalt		0.0047	0.0010	mg/L	6020
Manganese		1.1	0.0025	mg/L	6020
Nickel		0.0094	0.0020	mg/L	6020
Sulfate-Dissolved		1600	250	mg/L	9038
Chloride-Dissolved		140	10	mg/L	9251
Total Dissolved Solids-Dissolved		2600	10	mg/L	SM 2540C
Fluoride-Dissolved		0.61	0.10	mg/L	SM 4500 F C

EXECUTIVE SUMMARY - Detections

Client: Midwest Generation EME LLC Job Number: 500-29703-1

Lab Sample ID / Analyte	Client Sample ID	Result / Qualifier	Reporting Limit	Units	Method
500-29703-10	**MW-10**				
Dissolved					
Barium		0.050	0.0025	mg/L	6020
Boron		0.50	0.050	mg/L	6020
Manganese		0.12	0.0025	mg/L	6020
Nickel		0.0052	0.0020	mg/L	6020
Sulfate-Dissolved		130	50	mg/L	9038
Chloride-Dissolved		200	10	mg/L	9251
Nitrogen, Nitrate-Dissolved		0.39	0.10	mg/L	Nitrate by calc
Total Dissolved Solids-Dissolved		860	10	mg/L	SM 2540C
Fluoride-Dissolved		0.43	0.10	mg/L	SM 4500 F C
Nitrogen, Nitrate Nitrite-Dissolved		0.39	0.10	mg/L	SM 4500 NO3 F
500-29703-11	**MW-11**				
Dissolved					
Arsenic		0.0013	0.0010	mg/L	6020
Barium		0.064	0.0025	mg/L	6020
Boron		0.47	0.050	mg/L	6020
Manganese		0.052	0.0025	mg/L	6020
Nickel		0.0022	0.0020	mg/L	6020
Sulfate-Dissolved		140	50	mg/L	9038
Chloride-Dissolved		160	10	mg/L	9251
Nitrogen, Nitrate-Dissolved		0.39	0.10	mg/L	Nitrate by calc
Total Dissolved Solids-Dissolved		770	10	mg/L	SM 2540C
Fluoride-Dissolved		0.34	0.10	mg/L	SM 4500 F C
Nitrogen, Nitrate Nitrite-Dissolved		0.39	0.10	mg/L	SM 4500 NO3 F

METHOD SUMMARY

Client: Midwest Generation EME LLC Job Number: 500-29703-1

Description	Lab Location	Method	Preparation Method
Matrix: Water			
Metals (ICP/MS)	TAL CHI	SW846 6020	
Preparation, Soluble	TAL CHI		Soluble Metals
Sample Filtration, Field			FIELD_FLTRD
Mercury (CVAA)	TAL CHI	SW846 7470A	
Preparation, Mercury	TAL CHI		SW846 7470A
Sample Filtration, Field			FIELD_FLTRD
Cyanide	TAL CHI	SW846 9014	
Cyanide, Distillation	TAL CHI		SW846 9010B
Sample Filtration, Field			FIELD_FLTRD
Sulfate, Turbidimetric	TAL CHI	SW846 9038	
Sample Filtration, Field			FIELD_FLTRD
Chloride	TAL CHI	SW846 9251	
Sample Filtration, Field			FIELD_FLTRD
Nitrogen, Nitrate-Nitrite	TAL CHI	SM Nitrate by calc	
Sample Filtration, Field			FIELD_FLTRD
Solids, Total Dissolved (TDS)	TAL CHI	SM SM 2540C	
Sample Filtration, Field			FIELD_FLTRD
Fluoride	TAL CHI	SM SM 4500 F C	
Sample Filtration, Field			FIELD_FLTRD
Nitrogen, Nitrite	TAL CHI	SM SM 4500 NO2 B	
Sample Filtration, Field			FIELD_FLTRD
Nitrogen, Nitrate	TAL CHI	SM SM 4500 NO3 F	
Sample Filtration, Field			FIELD_FLTRD

Lab References:

TAL CHI = TestAmerica Chicago

Method 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.

METHOD / ANALYST SUMMARY

Client: Midwest Generation EME LLC Job Number: 500-29703-1

Method	Analyst	Analyst ID
SW846 6020	Kolarczyk, Paul F	PFK
SW846 7470A	Roach, Jessica	JR
SW846 9014	Moore, Colleen L	CLM
SW846 9038	Boyd, Cheryl L	CLB
SW846 9251	Deb, Khona	KD
SM Nitrate by calc	Ficarello, Peter M	PMF
SM SM 2540C	Boyd, Cheryl L	CLB
SM SM 4500 F C	Moore, Colleen L	CLM
SM SM 4500 NO2 B	Moore, Colleen L	CLM
SM SM 4500 NO3 F	Ficarello, Peter M	PMF

SAMPLE SUMMARY

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Lab Sample ID	Client Sample ID	Client Matrix	Date/Time Sampled	Date/Time Received
500-29703-1	MW-01	Water	12/06/2010 1425	12/07/2010 1250
500-29703-2	MW-02	Water	12/06/2010 1345	12/07/2010 1250
500-29703-3	MW-03	Water	12/07/2010 1010	12/07/2010 1250
500-29703-4	MW-04	Water	12/07/2010 1100	12/07/2010 1250
500-29703-5	MW-05	Water	12/07/2010 1145	12/07/2010 1250
500-29703-6	MW-06	Water	12/07/2010 0930	12/07/2010 1250
500-29703-7	MW-07	Water	12/07/2010 0855	12/07/2010 1250
500-29703-8	MW-08	Water	12/06/2010 1455	12/07/2010 1250
500-29703-9	MW-09	Water	12/06/2010 1115	12/07/2010 1250
500-29703-10	MW-10	Water	12/06/2010 1520	12/07/2010 1250
500-29703-11	MW-11	Water	12/06/2010 1600	12/07/2010 1250

SAMPLE RESULTS

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Job Number: 500-29703-1

Client Sample ID: MW-01
Lab Sample ID: 500-29703-1

Date Sampled: 12/06/2010 1425
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2048	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.31	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 1936	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	0.0011	mg/L	0.0010	1.0
Barium	0.13	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	<0.0010	mg/L	0.0010	1.0
Copper	0.0032	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	<0.0025	mg/L	0.0025	1.0
Nickel	0.0034	mg/L	0.0020	1.0
Selenium	<0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1023	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	0.0043	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1305	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1608	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0609	
Sulfate	180	mg/L	50	10
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1704	
Chloride	140	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	1.9	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2329	

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Job Number: 500-29703-1

Client Sample ID: MW-01
Lab Sample ID: 500-29703-1

Date Sampled: 12/06/2010 1425
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Total Dissolved Solids	590	mg/L	10	1.0
Method: Dissolved-SM 4500 F C		Date Analyzed:	12/13/2010 1218	
Fluoride	0.45	mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B		Date Analyzed:	12/08/2010 1043	
Nitrogen, Nitrite	<0.020	mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F		Date Analyzed:	12/14/2010 1610	
Nitrogen, Nitrate Nitrite	1.9	mg/L	0.20	2.0

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Job Number: 500-29703-1

Client Sample ID: MW-02
Lab Sample ID: 500-29703-2

Date Sampled: 12/06/2010 1345
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2056	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.31	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 1955	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	<0.0010	mg/L	0.0010	1.0
Barium	0.082	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	<0.0010	mg/L	0.0010	1.0
Copper	0.0032	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	<0.0025	mg/L	0.0025	1.0
Nickel	0.0033	mg/L	0.0020	1.0
Selenium	<0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1028	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	0.012	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1312	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1609	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0610	
Sulfate	190	mg/L	50	10
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1705	
Chloride	140	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	3.1	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2335	

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Job Number: 500-29703-1

Client Sample ID: MW-02
Lab Sample ID: 500-29703-2

Date Sampled: 12/06/2010 1345
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Total Dissolved Solids	600	mg/L	10	1.0
Method: Dissolved-SM 4500 F C		Date Analyzed:	12/13/2010 1226	
Fluoride	0.62	mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B		Date Analyzed:	12/08/2010 1044	
Nitrogen, Nitrite	<0.020	mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F		Date Analyzed:	12/14/2010 1611	
Nitrogen, Nitrate Nitrite	3.1	mg/L	0.20	2.0

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Job Number: 500-29703-1

Client Sample ID: MW-03
Lab Sample ID: 500-29703-3

Date Sampled: 12/07/2010 1010
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2057	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.24	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 1957	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	<0.0010	mg/L	0.0010	1.0
Barium	0.089	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	0.0013	mg/L	0.0010	1.0
Copper	<0.0020	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	0.10	mg/L	0.0025	1.0
Nickel	0.011	mg/L	0.0020	1.0
Selenium	<0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1029	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	0.0040	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1313	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1609	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0611	
Sulfate	120	mg/L	50	10
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1705	
Chloride	260	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	<0.10	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2337	

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Job Number: 500-29703-1

Client Sample ID: MW-03
Lab Sample ID: 500-29703-3

Date Sampled: 12/07/2010 1010
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Total Dissolved Solids	930	mg/L	10	1.0
Method: Dissolved-SM 4500 F C		Date Analyzed:	12/13/2010 1230	
Fluoride	0.43	mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B		Date Analyzed:	12/08/2010 1045	
Nitrogen, Nitrite	<0.020	mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F		Date Analyzed:	12/15/2010 1450	
Nitrogen, Nitrate Nitrite	<0.10	mg/L	0.10	1.0

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Job Number: 500-29703-1

Client Sample ID: MW-04
Lab Sample ID: 500-29703-4

Date Sampled: 12/07/2010 1100
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2058	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.46	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 2000	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	<0.0010	mg/L	0.0010	1.0
Barium	0.065	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	<0.0010	mg/L	0.0010	1.0
Copper	<0.0020	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	0.33	mg/L	0.0025	1.0
Nickel	0.0067	mg/L	0.0020	1.0
Selenium	0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1046	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	<0.0030	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1318	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1609	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0707	
Sulfate	300	mg/L	50	10
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1706	
Chloride	270	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	0.81	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2339	

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Job Number: 500-29703-1

Client Sample ID: MW-04
Lab Sample ID: 500-29703-4

Date Sampled: 12/07/2010 1100
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Total Dissolved Solids	1100	mg/L	10	1.0
Method: Dissolved-SM 4500 F C		Date Analyzed:	12/13/2010 1233	
Fluoride	0.49	mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B		Date Analyzed:	12/08/2010 1046	
Nitrogen, Nitrite	<0.020	mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F		Date Analyzed:	12/15/2010 1452	
Nitrogen, Nitrate Nitrite	0.81	mg/L	0.10	1.0

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Job Number: 500-29703-1

Client Sample ID: MW-05
Lab Sample ID: 500-29703-5

Date Sampled: 12/07/2010 1145
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2059	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.42	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 2003	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	<0.0010	mg/L	0.0010	1.0
Barium	0.061	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	<0.0010	mg/L	0.0010	1.0
Copper	<0.0020	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	0.0065	mg/L	0.0025	1.0
Nickel	<0.0020	mg/L	0.0020	1.0
Selenium	<0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1039	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	<0.0030	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1320	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1609	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0708	
Sulfate	110	mg/L	25	5.0
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1706	
Chloride	150	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	<0.10	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2341	

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Job Number: 500-29703-1

Client Sample ID: MW-05
Lab Sample ID: 500-29703-5

Date Sampled: 12/07/2010 1145
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Total Dissolved Solids	750	mg/L	10	1.0
Method: Dissolved-SM 4500 F C		Date Analyzed:	12/13/2010 1237	
Fluoride	0.40	mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B		Date Analyzed:	12/08/2010 1046	
Nitrogen, Nitrite	<0.020	mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F		Date Analyzed:	12/15/2010 1458	
Nitrogen, Nitrate Nitrite	<0.10	mg/L	0.10	1.0

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Job Number: 500-29703-1

Client Sample ID: MW-06
Lab Sample ID: 500-29703-6

Date Sampled: 12/07/2010 0930
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2100	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.32	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 2005	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	<0.0010	mg/L	0.0010	1.0
Barium	0.075	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	<0.0010	mg/L	0.0010	1.0
Copper	<0.0020	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	0.14	mg/L	0.0025	1.0
Nickel	0.0056	mg/L	0.0020	1.0
Selenium	0.0029	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1040	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	<0.0030	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1322	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1610	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0709	
Sulfate	140	mg/L	50	10
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1707	
Chloride	130	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	<0.10	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2343	

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Job Number: 500-29703-1

Client Sample ID: MW-06
Lab Sample ID: 500-29703-6

Date Sampled: 12/07/2010 0930
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier		Unit	RL	Dilution
Total Dissolved Solids	650		mg/L	10	1.0
Method: Dissolved-SM 4500 F C			Date Analyzed:	12/13/2010 1240	
Fluoride	0.40		mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B			Date Analyzed:	12/08/2010 1046	
Nitrogen, Nitrite	<0.020		mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F			Date Analyzed:	12/14/2010 1534	
Nitrogen, Nitrate Nitrite	<0.10	^	mg/L	0.10	1.0

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Job Number: 500-29703-1

Client Sample ID: MW-07
Lab Sample ID: 500-29703-7

Date Sampled: 12/07/2010 0855
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2101	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.51	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 2008	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	0.0010	mg/L	0.0010	1.0
Barium	0.13	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	<0.0010	mg/L	0.0010	1.0
Copper	<0.0020	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	0.29	mg/L	0.0025	1.0
Nickel	0.0045	mg/L	0.0020	1.0
Selenium	<0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1040	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	<0.0030	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1324	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1610	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0710	
Sulfate	250	mg/L	50	10
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1707	
Chloride	430	mg/L	50	25
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	<0.10	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2345	

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Job Number: 500-29703-1

Client Sample ID: MW-07
Lab Sample ID: 500-29703-7

Date Sampled: 12/07/2010 0855
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier		Unit	RL	Dilution
Total Dissolved Solids	1200		mg/L	10	1.0
Method: Dissolved-SM 4500 F C			Date Analyzed:	12/13/2010 1244	
Fluoride	0.36		mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B			Date Analyzed:	12/08/2010 1047	
Nitrogen, Nitrite	<0.020		mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F			Date Analyzed:	12/14/2010 1536	
Nitrogen, Nitrate Nitrite	<0.10	^	mg/L	0.10	1.0

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Job Number: 500-29703-1

Client Sample ID: MW-08
Lab Sample ID: 500-29703-8

Date Sampled: 12/06/2010 1455
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2102	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.29	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 2011	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	<0.0010	mg/L	0.0010	1.0
Barium	0.054	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	<0.0010	mg/L	0.0010	1.0
Copper	<0.0020	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	0.0051	mg/L	0.0025	1.0
Nickel	0.0025	mg/L	0.0020	1.0
Selenium	<0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1041	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	<0.0030	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1325	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1610	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0711	
Sulfate	210	mg/L	50	10
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1708	
Chloride	130	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	0.33	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2347	

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Job Number: 500-29703-1

Client Sample ID: MW-08
Lab Sample ID: 500-29703-8

Date Sampled: 12/06/2010 1455
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Total Dissolved Solids	670	mg/L	10	1.0
Method: Dissolved-SM 4500 F C		Date Analyzed:	12/13/2010 1247	
Fluoride	0.51	mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B		Date Analyzed:	12/08/2010 1047	
Nitrogen, Nitrite	<0.020	mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F		Date Analyzed:	12/14/2010 1612	
Nitrogen, Nitrate Nitrite	0.33	mg/L	0.10	1.0

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Job Number: 500-29703-1

Client Sample ID: MW-09
Lab Sample ID: 500-29703-9

Date Sampled: 12/06/2010 1115
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2105	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.36	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 2013	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	<0.0010	mg/L	0.0010	1.0
Barium	0.031	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	0.0047	mg/L	0.0010	1.0
Copper	<0.0020	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	1.1	mg/L	0.0025	1.0
Nickel	0.0094	mg/L	0.0020	1.0
Selenium	<0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1042	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	<0.0030	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1327	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1611	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0712	
Sulfate	1600	mg/L	250	50
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1708	
Chloride	140	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	<0.10	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2349	

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Job Number: 500-29703-1

Client Sample ID: MW-09
Lab Sample ID: 500-29703-9

Date Sampled: 12/06/2010 1115
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier		Unit	RL	Dilution
Total Dissolved Solids	2600		mg/L	10	1.0
Method: Dissolved-SM 4500 F C			Date Analyzed:	12/13/2010 1300	
Fluoride	0.61		mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B			Date Analyzed:	12/08/2010 1048	
Nitrogen, Nitrite	<0.020		mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F			Date Analyzed:	12/14/2010 1538	
Nitrogen, Nitrate Nitrite	<0.10	^	mg/L	0.10	1.0

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Job Number: 500-29703-1

Client Sample ID: MW-10
Lab Sample ID: 500-29703-10

Date Sampled: 12/06/2010 1520
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2106	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.50	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 2016	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	<0.0010	mg/L	0.0010	1.0
Barium	0.050	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	<0.0010	mg/L	0.0010	1.0
Copper	<0.0020	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	0.12	mg/L	0.0025	1.0
Nickel	0.0052	mg/L	0.0020	1.0
Selenium	<0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1043	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	<0.0030	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1329	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1611	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0713	
Sulfate	130	mg/L	50	10
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1709	
Chloride	200	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	0.39	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2351	

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Job Number: 500-29703-1

Client Sample ID: MW-10
Lab Sample ID: 500-29703-10

Date Sampled: 12/06/2010 1520
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Total Dissolved Solids	860	mg/L	10	1.0
Method: Dissolved-SM 4500 F C		Date Analyzed:	12/13/2010 1303	
Fluoride	0.43	mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B		Date Analyzed:	12/08/2010 1048	
Nitrogen, Nitrite	<0.020	mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F		Date Analyzed:	12/15/2010 1505	
Nitrogen, Nitrate Nitrite	0.39	mg/L	0.10	1.0

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Job Number: 500-29703-1

Client Sample ID: MW-11
Lab Sample ID: 500-29703-11

Date Sampled: 12/06/2010 1600
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Method: Dissolved-6020		Date Analyzed:	12/13/2010 2108	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Beryllium	<0.0010	mg/L	0.0010	1.0
Boron	0.47	mg/L	0.050	1.0
Method: Dissolved-6020		Date Analyzed:	12/14/2010 2019	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Arsenic	0.0013	mg/L	0.0010	1.0
Barium	0.064	mg/L	0.0025	1.0
Cadmium	<0.00050	mg/L	0.00050	1.0
Chromium	<0.0050	mg/L	0.0050	1.0
Cobalt	<0.0010	mg/L	0.0010	1.0
Copper	<0.0020	mg/L	0.0020	1.0
Iron	<0.10	mg/L	0.10	1.0
Lead	<0.00050	mg/L	0.00050	1.0
Manganese	0.052	mg/L	0.0025	1.0
Nickel	0.0022	mg/L	0.0020	1.0
Selenium	<0.0025	mg/L	0.0025	1.0
Silver	<0.00050	mg/L	0.00050	1.0
Thallium	<0.0020	mg/L	0.0020	1.0
Zinc	<0.020	mg/L	0.020	1.0
Method: Dissolved-6020		Date Analyzed:	12/17/2010 1044	
Prep Method: Soluble Metals		Date Prepared:	12/08/2010 1252	
Antimony	<0.0030	mg/L	0.0030	1.0
Method: Dissolved-7470A		Date Analyzed:	12/08/2010 1330	
Prep Method: 7470A		Date Prepared:	12/08/2010 0920	
Mercury	<0.00020	mg/L	0.00020	1.0
Method: Dissolved-9014		Date Analyzed:	12/09/2010 1611	
Prep Method: 9010B		Date Prepared:	12/09/2010 1250	
Cyanide, Total	<0.010	mg/L	0.010	1.0
Method: Dissolved-9038		Date Analyzed:	12/09/2010 0714	
Sulfate	140	mg/L	50	10
Method: Dissolved-9251		Date Analyzed:	12/13/2010 1710	
Chloride	160	mg/L	10	5.0
Method: Dissolved-Nitrate by calc		Date Analyzed:	12/15/2010 1641	
Nitrogen, Nitrate	0.39	mg/L	0.10	1.0
Method: Dissolved-SM 2540C		Date Analyzed:	12/08/2010 2353	

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Job Number: 500-29703-1

Client Sample ID: MW-11
Lab Sample ID: 500-29703-11

Date Sampled: 12/06/2010 1600
Date Received: 12/07/2010 1250
Client Matrix: Water

Analyte	Result/Qualifier	Unit	RL	Dilution
Total Dissolved Solids	770	mg/L	10	1.0
Method: Dissolved-SM 4500 F C		Date Analyzed:	12/13/2010 1307	
Fluoride	0.34	mg/L	0.10	1.0
Method: Dissolved-SM 4500 NO2 B		Date Analyzed:	12/08/2010 1048	
Nitrogen, Nitrite	<0.020	mg/L	0.020	1.0
Method: Dissolved-SM 4500 NO3 F		Date Analyzed:	12/15/2010 1507	
Nitrogen, Nitrate Nitrite	0.39	mg/L	0.10	1.0

DATA REPORTING QUALIFIERS

Client: Midwest Generation EME LLC Job Number: 500-29703-1

Lab Section	Qualifier	Description
Metals		
	F	MS or MSD exceeds the control limits
General Chemistry		
	^	ICV,CCV,ICB,CCB, ISA, ISB, CRI, CRA, DLCK or MRL standard: Instrument related QC exceeds the control limits.

QUALITY CONTROL RESULTS

Quality Control Results

Client: Midwest Generation EME LLC Job Number: 500-29703-1

QC Association Summary

Lab Sample ID	Client Sample ID	Report Basis	Client Matrix	Method	Prep Batch
Metals					
Prep Batch: 500-101452					
LCS 500-101452/8-A	Lab Control Sample	T	Water	7470A	
MB 500-101452/7-A	Method Blank	T	Water	7470A	
500-29703-1	MW-01	D	Water	7470A	
500-29703-1DU	Duplicate	D	Water	7470A	
500-29703-1MS	Matrix Spike	D	Water	7470A	
500-29703-1MSD	Matrix Spike Duplicate	D	Water	7470A	
500-29703-2	MW-02	D	Water	7470A	
500-29703-3	MW-03	D	Water	7470A	
500-29703-4	MW-04	D	Water	7470A	
500-29703-5	MW-05	D	Water	7470A	
500-29703-6	MW-06	D	Water	7470A	
500-29703-7	MW-07	D	Water	7470A	
500-29703-8	MW-08	D	Water	7470A	
500-29703-9	MW-09	D	Water	7470A	
500-29703-10	MW-10	D	Water	7470A	
500-29703-11	MW-11	D	Water	7470A	
Prep Batch: 500-101483					
LCS 500-101483/2-A	Lab Control Sample	S	Water	Soluble Metals	
MB 500-101483/1-A	Method Blank	S	Water	Soluble Metals	
500-29703-1	MW-01	D	Water	Soluble Metals	
500-29703-1DU	Duplicate	D	Water	Soluble Metals	
500-29703-1MS	Matrix Spike	D	Water	Soluble Metals	
500-29703-1MSD	Matrix Spike Duplicate	D	Water	Soluble Metals	
500-29703-2	MW-02	D	Water	Soluble Metals	
500-29703-3	MW-03	D	Water	Soluble Metals	
500-29703-4	MW-04	D	Water	Soluble Metals	
500-29703-5	MW-05	D	Water	Soluble Metals	
500-29703-6	MW-06	D	Water	Soluble Metals	
500-29703-7	MW-07	D	Water	Soluble Metals	
500-29703-8	MW-08	D	Water	Soluble Metals	
500-29703-9	MW-09	D	Water	Soluble Metals	
500-29703-10	MW-10	D	Water	Soluble Metals	
500-29703-11	MW-11	D	Water	Soluble Metals	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

QC Association Summary

Lab Sample ID	Client Sample ID	Report Basis	Client Matrix	Method	Prep Batch
Metals					
Analysis Batch:500-101510					
LCS 500-101452/8-A	Lab Control Sample	T	Water	7470A	500-101452
MB 500-101452/7-A	Method Blank	T	Water	7470A	500-101452
500-29703-1	MW-01	D	Water	7470A	500-101452
500-29703-1DU	Duplicate	D	Water	7470A	500-101452
500-29703-1MS	Matrix Spike	D	Water	7470A	500-101452
500-29703-1MSD	Matrix Spike Duplicate	D	Water	7470A	500-101452
500-29703-2	MW-02	D	Water	7470A	500-101452
500-29703-3	MW-03	D	Water	7470A	500-101452
500-29703-4	MW-04	D	Water	7470A	500-101452
500-29703-5	MW-05	D	Water	7470A	500-101452
500-29703-6	MW-06	D	Water	7470A	500-101452
500-29703-7	MW-07	D	Water	7470A	500-101452
500-29703-8	MW-08	D	Water	7470A	500-101452
500-29703-9	MW-09	D	Water	7470A	500-101452
500-29703-10	MW-10	D	Water	7470A	500-101452
500-29703-11	MW-11	D	Water	7470A	500-101452
Analysis Batch:500-101835					
LCS 500-101483/2-A	Lab Control Sample	S	Water	6020	500-101483
MB 500-101483/1-A	Method Blank	S	Water	6020	500-101483
500-29703-1	MW-01	D	Water	6020	500-101483
500-29703-1DU	Duplicate	D	Water	6020	500-101483
500-29703-1MS	Matrix Spike	D	Water	6020	500-101483
500-29703-1MSD	Matrix Spike Duplicate	D	Water	6020	500-101483
500-29703-2	MW-02	D	Water	6020	500-101483
500-29703-3	MW-03	D	Water	6020	500-101483
500-29703-4	MW-04	D	Water	6020	500-101483
500-29703-5	MW-05	D	Water	6020	500-101483
500-29703-6	MW-06	D	Water	6020	500-101483
500-29703-7	MW-07	D	Water	6020	500-101483
500-29703-8	MW-08	D	Water	6020	500-101483
500-29703-9	MW-09	D	Water	6020	500-101483
500-29703-10	MW-10	D	Water	6020	500-101483
500-29703-11	MW-11	D	Water	6020	500-101483

Quality Control Results

Client: Midwest Generation EME LLC Job Number: 500-29703-1

QC Association Summary

Lab Sample ID	Client Sample ID	Report Basis	Client Matrix	Method	Prep Batch
Metals					
Analysis Batch:500-101913					
LCS 500-101483/2-A	Lab Control Sample	S	Water	6020	500-101483
MB 500-101483/1-A	Method Blank	S	Water	6020	500-101483
500-29703-1	MW-01	D	Water	6020	500-101483
500-29703-1DU	Duplicate	D	Water	6020	500-101483
500-29703-1MS	Matrix Spike	D	Water	6020	500-101483
500-29703-1MSD	Matrix Spike Duplicate	D	Water	6020	500-101483
500-29703-2	MW-02	D	Water	6020	500-101483
500-29703-3	MW-03	D	Water	6020	500-101483
500-29703-4	MW-04	D	Water	6020	500-101483
500-29703-5	MW-05	D	Water	6020	500-101483
500-29703-6	MW-06	D	Water	6020	500-101483
500-29703-7	MW-07	D	Water	6020	500-101483
500-29703-8	MW-08	D	Water	6020	500-101483
500-29703-9	MW-09	D	Water	6020	500-101483
500-29703-10	MW-10	D	Water	6020	500-101483
500-29703-11	MW-11	D	Water	6020	500-101483
Analysis Batch:500-102128					
LCS 500-101483/2-A	Lab Control Sample	S	Water	6020	500-101483
MB 500-101483/1-A	Method Blank	S	Water	6020	500-101483
500-29703-1	MW-01	D	Water	6020	500-101483
500-29703-1DU	Duplicate	D	Water	6020	500-101483
500-29703-1MS	Matrix Spike	D	Water	6020	500-101483
500-29703-1MSD	Matrix Spike Duplicate	D	Water	6020	500-101483
500-29703-2	MW-02	D	Water	6020	500-101483
500-29703-3	MW-03	D	Water	6020	500-101483
500-29703-4	MW-04	D	Water	6020	500-101483
500-29703-5	MW-05	D	Water	6020	500-101483
500-29703-6	MW-06	D	Water	6020	500-101483
500-29703-7	MW-07	D	Water	6020	500-101483
500-29703-8	MW-08	D	Water	6020	500-101483
500-29703-9	MW-09	D	Water	6020	500-101483
500-29703-10	MW-10	D	Water	6020	500-101483
500-29703-11	MW-11	D	Water	6020	500-101483

Report Basis
D = Dissolved
S = Soluble
T = Total

Quality Control Results

Client: Midwest Generation EME LLC Job Number: 500-29703-1

QC Association Summary

Lab Sample ID	Client Sample ID	Report Basis	Client Matrix	Method	Prep Batch
General Chemistry					
Analysis Batch:500-101499					
LCS 500-101499/4	Lab Control Sample	T	Water	SM 4500 NO2 B	
MB 500-101499/3	Method Blank	T	Water	SM 4500 NO2 B	
500-29703-1	MW-01	D	Water	SM 4500 NO2 B	
500-29703-1MS	Matrix Spike	D	Water	SM 4500 NO2 B	
500-29703-1MSD	Matrix Spike Duplicate	D	Water	SM 4500 NO2 B	
500-29703-2	MW-02	D	Water	SM 4500 NO2 B	
500-29703-3	MW-03	D	Water	SM 4500 NO2 B	
500-29703-4	MW-04	D	Water	SM 4500 NO2 B	
500-29703-5	MW-05	D	Water	SM 4500 NO2 B	
500-29703-6	MW-06	D	Water	SM 4500 NO2 B	
500-29703-7	MW-07	D	Water	SM 4500 NO2 B	
500-29703-8	MW-08	D	Water	SM 4500 NO2 B	
500-29703-9	MW-09	D	Water	SM 4500 NO2 B	
500-29703-10	MW-10	D	Water	SM 4500 NO2 B	
500-29703-11	MW-11	D	Water	SM 4500 NO2 B	
Analysis Batch:500-101531					
LCS 500-101531/2	Lab Control Sample	T	Water	SM 2540C	
MB 500-101531/1	Method Blank	T	Water	SM 2540C	
500-29703-1	MW-01	D	Water	SM 2540C	
500-29703-1DU	Duplicate	D	Water	SM 2540C	
500-29703-1MS	Matrix Spike	D	Water	SM 2540C	
500-29703-2	MW-02	D	Water	SM 2540C	
500-29703-3	MW-03	D	Water	SM 2540C	
500-29703-4	MW-04	D	Water	SM 2540C	
500-29703-5	MW-05	D	Water	SM 2540C	
500-29703-6	MW-06	D	Water	SM 2540C	
500-29703-7	MW-07	D	Water	SM 2540C	
500-29703-8	MW-08	D	Water	SM 2540C	
500-29703-9	MW-09	D	Water	SM 2540C	
500-29703-10	MW-10	D	Water	SM 2540C	
500-29703-11	MW-11	D	Water	SM 2540C	
Analysis Batch:500-101547					
LCS 500-101547/4	Lab Control Sample	T	Water	9038	
MB 500-101547/3	Method Blank	T	Water	9038	
500-29703-1	MW-01	D	Water	9038	
500-29703-2	MW-02	D	Water	9038	
500-29703-3	MW-03	D	Water	9038	

Quality Control Results

Client: Midwest Generation EME LLC Job Number: 500-29703-1

QC Association Summary

Lab Sample ID	Client Sample ID	Report Basis	Client Matrix	Method	Prep Batch
General Chemistry					
Prep Batch: 500-101579					
HLCS 500-101579/3-A	High Level Control Sample	T	Water	9010B	
LCS 500-101579/2-A	Lab Control Sample	T	Water	9010B	
LLCS 500-101579/4-A	Low Level Control Sample	T	Water	9010B	
MB 500-101579/1-A	Method Blank	T	Water	9010B	
500-29703-1	MW-01	D	Water	9010B	
500-29703-2	MW-02	D	Water	9010B	
500-29703-3	MW-03	D	Water	9010B	
500-29703-4	MW-04	D	Water	9010B	
500-29703-5	MW-05	D	Water	9010B	
500-29703-6	MW-06	D	Water	9010B	
500-29703-7	MW-07	D	Water	9010B	
500-29703-8	MW-08	D	Water	9010B	
500-29703-9	MW-09	D	Water	9010B	
500-29703-10	MW-10	D	Water	9010B	
500-29703-11	MW-11	D	Water	9010B	
Analysis Batch:500-101622					
HLCS 500-101579/3-A	High Level Control Sample	T	Water	9014	500-101579
LCS 500-101579/2-A	Lab Control Sample	T	Water	9014	500-101579
LLCS 500-101579/4-A	Low Level Control Sample	T	Water	9014	500-101579
MB 500-101579/1-A	Method Blank	T	Water	9014	500-101579
500-29703-1	MW-01	D	Water	9014	500-101579
500-29703-2	MW-02	D	Water	9014	500-101579
500-29703-3	MW-03	D	Water	9014	500-101579
500-29703-4	MW-04	D	Water	9014	500-101579
500-29703-5	MW-05	D	Water	9014	500-101579
500-29703-6	MW-06	D	Water	9014	500-101579
500-29703-7	MW-07	D	Water	9014	500-101579
500-29703-8	MW-08	D	Water	9014	500-101579
500-29703-9	MW-09	D	Water	9014	500-101579
500-29703-10	MW-10	D	Water	9014	500-101579
500-29703-11	MW-11	D	Water	9014	500-101579
Analysis Batch:500-101632					
LCS 500-101632/4	Lab Control Sample	T	Water	9038	
MB 500-101632/3	Method Blank	T	Water	9038	
500-29703-4	MW-04	D	Water	9038	
500-29703-5	MW-05	D	Water	9038	
500-29703-6	MW-06	D	Water	9038	
500-29703-7	MW-07	D	Water	9038	
500-29703-8	MW-08	D	Water	9038	
500-29703-9	MW-09	D	Water	9038	
500-29703-10	MW-10	D	Water	9038	
500-29703-11	MW-11	D	Water	9038	

Quality Control Results

Client: Midwest Generation EME LLC Job Number: 500-29703-1

QC Association Summary

Lab Sample ID	Client Sample ID	Report Basis	Client Matrix	Method	Prep Batch
General Chemistry					
Analysis Batch:500-101787					
LCS 500-101787/4	Lab Control Sample	T	Water	SM 4500 F C	
MB 500-101787/3	Method Blank	T	Water	SM 4500 F C	
500-29703-1	MW-01	D	Water	SM 4500 F C	
500-29703-1MS	Matrix Spike	D	Water	SM 4500 F C	
500-29703-1MSD	Matrix Spike Duplicate	D	Water	SM 4500 F C	
500-29703-2	MW-02	D	Water	SM 4500 F C	
500-29703-3	MW-03	D	Water	SM 4500 F C	
500-29703-4	MW-04	D	Water	SM 4500 F C	
500-29703-5	MW-05	D	Water	SM 4500 F C	
500-29703-6	MW-06	D	Water	SM 4500 F C	
500-29703-7	MW-07	D	Water	SM 4500 F C	
500-29703-8	MW-08	D	Water	SM 4500 F C	
500-29703-9	MW-09	D	Water	SM 4500 F C	
500-29703-10	MW-10	D	Water	SM 4500 F C	
500-29703-11	MW-11	D	Water	SM 4500 F C	
Analysis Batch:500-101815					
LCS 500-101815/40	Lab Control Sample	T	Water	9251	
MB 500-101815/39	Method Blank	T	Water	9251	
500-29703-1	MW-01	D	Water	9251	
500-29703-2	MW-02	D	Water	9251	
500-29703-3	MW-03	D	Water	9251	
500-29703-4	MW-04	D	Water	9251	
500-29703-5	MW-05	D	Water	9251	
500-29703-6	MW-06	D	Water	9251	
500-29703-7	MW-07	D	Water	9251	
500-29703-8	MW-08	D	Water	9251	
500-29703-9	MW-09	D	Water	9251	
500-29703-10	MW-10	D	Water	9251	
500-29703-11	MW-11	D	Water	9251	
Analysis Batch:500-101888					
LCS 500-101888/38	Lab Control Sample	T	Water	SM 4500 NO3 F	
MB 500-101888/19	Method Blank	T	Water	SM 4500 NO3 F	
500-29703-1	MW-01	D	Water	SM 4500 NO3 F	
500-29703-2	MW-02	D	Water	SM 4500 NO3 F	
500-29703-6	MW-06	D	Water	SM 4500 NO3 F	
500-29703-7	MW-07	D	Water	SM 4500 NO3 F	
500-29703-8	MW-08	D	Water	SM 4500 NO3 F	
500-29703-9	MW-09	D	Water	SM 4500 NO3 F	
500-29703-9MS	Matrix Spike	D	Water	SM 4500 NO3 F	
500-29703-9MSD	Matrix Spike Duplicate	D	Water	SM 4500 NO3 F	

Quality Control Results

Client: Midwest Generation EME LLC Job Number: 500-29703-1

QC Association Summary

Lab Sample ID	Client Sample ID	Report Basis	Client Matrix	Method	Prep Batch
General Chemistry					
Analysis Batch:500-101968					
LCS 500-101968/13	Lab Control Sample	T	Water	SM 4500 NO3 F	
LCS 500-101968/26	Lab Control Sample	T	Water	SM 4500 NO3 F	
MB 500-101968/12	Method Blank	T	Water	SM 4500 NO3 F	
MB 500-101968/25	Method Blank	T	Water	SM 4500 NO3 F	
500-29703-3	MW-03	D	Water	SM 4500 NO3 F	
500-29703-4	MW-04	D	Water	SM 4500 NO3 F	
500-29703-5	MW-05	D	Water	SM 4500 NO3 F	
500-29703-10	MW-10	D	Water	SM 4500 NO3 F	
500-29703-11	MW-11	D	Water	SM 4500 NO3 F	
Analysis Batch:500-101971					
500-29703-1	MW-01	D	Water	Nitrate by calc	
500-29703-2	MW-02	D	Water	Nitrate by calc	
500-29703-3	MW-03	D	Water	Nitrate by calc	
500-29703-4	MW-04	D	Water	Nitrate by calc	
500-29703-5	MW-05	D	Water	Nitrate by calc	
500-29703-6	MW-06	D	Water	Nitrate by calc	
500-29703-7	MW-07	D	Water	Nitrate by calc	
500-29703-8	MW-08	D	Water	Nitrate by calc	
500-29703-9	MW-09	D	Water	Nitrate by calc	
500-29703-10	MW-10	D	Water	Nitrate by calc	
500-29703-11	MW-11	D	Water	Nitrate by calc	

Report Basis
D = Dissolved
T = Total

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Soluble

Lab Sample ID: MB 500-101483/1-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/13/2010 2046
Date Prepared: 12/08/2010 1252

Analysis Batch: 500-101835
Prep Batch: 500-101483
Units: mg/L

Instrument ID: ICPMS2
Lab File ID: MS2121310E.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Beryllium	<0.0010		0.0010
Boron	<0.050		0.050

Method Blank - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Soluble

Lab Sample ID: MB 500-101483/1-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/14/2010 1930
Date Prepared: 12/08/2010 1252

Analysis Batch: 500-101913
Prep Batch: 500-101483
Units: mg/L

Instrument ID: ICPMS2
Lab File ID: MS2121410B.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Arsenic	<0.0010		0.0010
Barium	<0.0025		0.0025
Cadmium	<0.00050		0.00050
Chromium	<0.0050		0.0050
Cobalt	<0.0010		0.0010
Copper	<0.0020		0.0020
Iron	<0.10		0.10
Lead	<0.00050		0.00050
Manganese	<0.0025		0.0025
Nickel	<0.0020		0.0020
Selenium	<0.0025		0.0025
Silver	<0.00050		0.00050
Thallium	<0.0020		0.0020
Zinc	<0.020		0.020

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Soluble

Lab Sample ID: MB 500-101483/1-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/17/2010 1021
Date Prepared: 12/08/2010 1252

Analysis Batch: 500-102128
Prep Batch: 500-101483
Units: mg/L

Instrument ID: ICPMS2
Lab File ID: MS2121710A.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Antimony	<0.0030		0.0030

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Lab Control Sample - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Soluble

Lab Sample ID: LCS 500-101483/2-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/13/2010 2047
Date Prepared: 12/08/2010 1252

Analysis Batch: 500-101835
Prep Batch: 500-101483
Units: mg/L

Instrument ID: ICPMS2
Lab File ID: MS2121310E.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Beryllium	0.0500	0.0488	98	80 - 120	
Boron	1.00	1.01	101	80 - 120	

Lab Control Sample - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Soluble

Lab Sample ID: LCS 500-101483/2-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/14/2010 1933
Date Prepared: 12/08/2010 1252

Analysis Batch: 500-101913
Prep Batch: 500-101483
Units: mg/L

Instrument ID: ICPMS2
Lab File ID: MS2121410B.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Arsenic	0.100	0.0999	100	80 - 120	
Barium	0.500	0.488	98	80 - 120	
Cadmium	0.0500	0.0529	106	80 - 120	
Chromium	0.200	0.204	102	80 - 120	
Cobalt	0.500	0.517	103	80 - 120	
Copper	0.250	0.270	108	80 - 120	
Iron	1.00	0.965	96	80 - 120	
Lead	0.100	0.0997	100	80 - 120	
Manganese	0.500	0.519	104	80 - 120	
Nickel	0.500	0.539	108	80 - 120	
Selenium	0.100	0.104	104	80 - 120	
Silver	0.0500	0.0522	104	80 - 120	
Thallium	0.100	0.103	103	80 - 120	
Zinc	0.500	0.548	110	80 - 120	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Lab Control Sample - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Soluble

Lab Sample ID: LCS 500-101483/2-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/17/2010 1022
Date Prepared: 12/08/2010 1252

Analysis Batch: 500-102128
Prep Batch: 500-101483
Units: mg/L

Instrument ID: ICPMS2
Lab File ID: MS2121710A.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Antimony	0.500	0.432	86	80 - 120	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Matrix Spike/
Matrix Spike Duplicate Recovery Report - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Dissolved

MS Lab Sample ID:	500-29703-1	Analysis Batch:	500-101835	Instrument ID:	ICPMS2
Client Matrix:	Water	Prep Batch:	500-101483	Lab File ID:	MS2121310E.csv
Dilution:	1.0			Initial Weight/Volume:	1.0 mL
Date Analyzed:	12/13/2010 2054			Final Weight/Volume:	1.0 mL
Date Prepared:	12/08/2010 1252				

MSD Lab Sample ID:	500-29703-1	Analysis Batch:	500-101835	Instrument ID:	ICPMS2
Client Matrix:	Water	Prep Batch:	500-101483	Lab File ID:	MS2121310E.csv
Dilution:	1.0			Initial Weight/Volume:	1.0 mL
Date Analyzed:	12/13/2010 2055			Final Weight/Volume:	1.0 mL
Date Prepared:	12/08/2010 1252				

	% Rec.						
Analyte	MS	MSD	Limit	RPD	RPD Limit	MS Qual	MSD Qual
Beryllium	95	95	75 - 125	0	20		
Boron	98	99	75 - 125	1	20		

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Matrix Spike/
Matrix Spike Duplicate Recovery Report - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Dissolved

MS Lab Sample ID:	500-29703-1	Analysis Batch:	500-101913	Instrument ID:	ICPMS2
Client Matrix:	Water	Prep Batch:	500-101483	Lab File ID:	MS2121410B.csv
Dilution:	1.0			Initial Weight/Volume:	1.0 mL
Date Analyzed:	12/14/2010 1944			Final Weight/Volume:	1.0 mL
Date Prepared:	12/08/2010 1252				

MSD Lab Sample ID:	500-29703-1	Analysis Batch:	500-101913	Instrument ID:	ICPMS2
Client Matrix:	Water	Prep Batch:	500-101483	Lab File ID:	MS2121410B.csv
Dilution:	1.0			Initial Weight/Volume:	1.0 mL
Date Analyzed:	12/14/2010 1946			Final Weight/Volume:	1.0 mL
Date Prepared:	12/08/2010 1252				

	% Rec.						
Analyte	MS	MSD	Limit	RPD	RPD Limit	MS Qual	MSD Qual
Arsenic	107	111	75 - 125	3	20		
Barium	94	96	75 - 125	2	20		
Cadmium	102	103	75 - 125	1	20		
Chromium	95	101	75 - 125	6	20		
Cobalt	95	100	75 - 125	6	20		
Copper	96	103	75 - 125	6	20		
Iron	90	98	75 - 125	9	20		
Lead	98	99	75 - 125	1	20		
Manganese	98	104	75 - 125	6	20		
Nickel	97	103	75 - 125	7	20		
Selenium	121	126	75 - 125	5	20		F
Silver	64	62	75 - 125	2	20	F	F
Thallium	102	103	75 - 125	1	20		
Zinc	105	113	75 - 125	7	20		

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Matrix Spike/
Matrix Spike Duplicate Recovery Report - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Dissolved

MS Lab Sample ID:	500-29703-1	Analysis Batch: 500-102128	Instrument ID: ICPMS2
Client Matrix:	Water	Prep Batch: 500-101483	Lab File ID: MS2121710A.csv
Dilution:	1.0		Initial Weight/Volume: 1.0 mL
Date Analyzed:	12/17/2010 1026		Final Weight/Volume: 1.0 mL
Date Prepared:	12/08/2010 1252		

MSD Lab Sample ID:	500-29703-1	Analysis Batch: 500-102128	Instrument ID: ICPMS2
Client Matrix:	Water	Prep Batch: 500-101483	Lab File ID: MS2121710A.csv
Dilution:	1.0		Initial Weight/Volume: 1.0 mL
Date Analyzed:	12/17/2010 1027		Final Weight/Volume: 1.0 mL
Date Prepared:	12/08/2010 1252		

	% Rec.						
Analyte	MS	MSD	Limit	RPD	RPD Limit	MS Qual	MSD Qual
Antimony	87	91	75 - 125	4	20		

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Duplicate - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Dissolved

Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/13/2010 2053
Date Prepared: 12/08/2010 1252

Analysis Batch: 500-101835
Prep Batch: 500-101483
Units: mg/L

Instrument ID: ICPMS2
Lab File ID: MS2121310E.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Sample Result/Qual	Result	RPD	Limit	Qual
Beryllium	<0.0010	<0.0010	NC	20	
Boron	0.31	0.307	0.7	20	

Duplicate - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Dissolved

Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/14/2010 1941
Date Prepared: 12/08/2010 1252

Analysis Batch: 500-101913
Prep Batch: 500-101483
Units: mg/L

Instrument ID: ICPMS2
Lab File ID: MS2121410B.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Sample Result/Qual	Result	RPD	Limit	Qual
Arsenic	0.0011	<0.0010	NC	20	
Barium	0.13	0.130	2	20	
Cadmium	<0.00050	<0.00050	NC	20	
Chromium	<0.0050	<0.0050	NC	20	
Cobalt	<0.0010	<0.0010	NC	20	
Copper	0.0032	0.00325	2	20	
Iron	<0.10	<0.10	NC	20	
Lead	<0.00050	<0.00050	NC	20	
Manganese	<0.0025	<0.0025	NC	20	
Nickel	0.0034	0.00317	7	20	
Selenium	<0.0025	<0.0025	NC	20	
Silver	<0.00050	<0.00050	NC	20	
Thallium	<0.0020	<0.0020	NC	20	
Zinc	<0.020	<0.020	NC	20	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Duplicate - Batch: 500-101483

Method: 6020
Preparation: Soluble Metals Dissolved

Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/17/2010 1025
Date Prepared: 12/08/2010 1252

Analysis Batch: 500-102128
Prep Batch: 500-101483
Units: mg/L

Instrument ID: ICPMS2
Lab File ID: MS2121710A.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Sample Result/Qual	Result	RPD	Limit	Qual
Antimony	0.0043	<0.0030	NC	20	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101452

Method: 7470A
Preparation: 7470A

Lab Sample ID: MB 500-101452/7-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 1248
Date Prepared: 12/08/2010 0920

Analysis Batch: 500-101510
Prep Batch: 500-101452
Units: mg/L

Instrument ID: HG6
Lab File ID: 120810R.CSV
Initial Weight/Volume: 25 mL
Final Weight/Volume: 25 mL

Analyte	Result	Qual	RL
Mercury	<0.00020		0.00020

Lab Control Sample - Batch: 500-101452

Method: 7470A
Preparation: 7470A

Lab Sample ID: LCS 500-101452/8-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 1250
Date Prepared: 12/08/2010 0920

Analysis Batch: 500-101510
Prep Batch: 500-101452
Units: mg/L

Instrument ID: HG6
Lab File ID: 120810R.CSV
Initial Weight/Volume: 25 mL
Final Weight/Volume: 25 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Mercury	0.00200	0.00203	101	80 - 120	

Matrix Spike/
Matrix Spike Duplicate Recovery Report - Batch: 500-101452

Method: 7470A
Preparation: 7470A
Dissolved

MS Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 1308
Date Prepared: 12/08/2010 0920

Analysis Batch: 500-101510
Prep Batch: 500-101452

Instrument ID: HG6
Lab File ID: 120810R.CSV
Initial Weight/Volume: 25 mL
Final Weight/Volume: 25 mL

MSD Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 1310
Date Prepared: 12/08/2010 0920

Analysis Batch: 500-101510
Prep Batch: 500-101452

Instrument ID: HG6
Lab File ID: 120810R.CSV
Initial Weight/Volume: 25 mL
Final Weight/Volume: 25 mL

Analyte	% Rec. MS	% Rec. MSD	Limit	RPD	RPD Limit	MS Qual	MSD Qual
Mercury	125	116	75 - 125	7	20		

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Duplicate - Batch: 500-101452

Method: 7470A
Preparation: 7470A
Dissolved

Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 1306
Date Prepared: 12/08/2010 0920

Analysis Batch: 500-101510
Prep Batch: 500-101452
Units: mg/L

Instrument ID: HG6
Lab File ID: 120810R.CSV
Initial Weight/Volume: 25 mL
Final Weight/Volume: 25 mL

Analyte	Sample Result/Qual	Result	RPD	Limit	Qual
Mercury	<0.00020	<0.00020	NC	20	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101579

Method: 9014
Preparation: 9010B

Lab Sample ID: MB 500-101579/1-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/09/2010 1605
Date Prepared: 12/09/2010 1250

Analysis Batch: 500-101622
Prep Batch: 500-101579
Units: mg/L

Instrument ID: SPEC5
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Result	Qual	RL
Cyanide, Total-Dissolved	<0.010		0.010

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Lab Control Sample - Batch: 500-101579

Method: 9014
Preparation: 9010B

Lab Sample ID: LCS 500-101579/2-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/09/2010 1605
Date Prepared: 12/09/2010 1250

Analysis Batch: 500-101622
Prep Batch: 500-101579
Units: mg/L

Instrument ID: SPEC5
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Cyanide, Total-Dissolved	0.100	0.105	105	80 - 120	

High Level Control Sample - Batch: 500-101579

Method: 9014
Preparation: 9010B

Lab Sample ID: HLCS 500-101579/3-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/09/2010 1606
Date Prepared: 12/09/2010 1250

Analysis Batch: 500-101622
Prep Batch: 500-101579
Units: mg/L

Instrument ID: SPEC5
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Cyanide, Total-Dissolved	0.400	0.405	101	90 - 110	

Low Level Control Sample - Batch: 500-101579

Method: 9014
Preparation: 9010B

Lab Sample ID: LLCS 500-101579/4-A
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/09/2010 1606
Date Prepared: 12/09/2010 1250

Analysis Batch: 500-101622
Prep Batch: 500-101579
Units: mg/L

Instrument ID: SPEC5
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Cyanide, Total-Dissolved	0.0400	0.0437	109	75 - 125	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101547

Method: 9038
Preparation: N/A

Lab Sample ID: MB 500-101547/3
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/09/2010 0550
Date Prepared: N/A

Analysis Batch: 500-101547
Prep Batch: N/A
Units: mg/L

Instrument ID: SPEC3
Lab File ID: N/A
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Sulfate-Dissolved	<5.0		5.0

Lab Control Sample - Batch: 500-101547

Method: 9038
Preparation: N/A

Lab Sample ID: LCS 500-101547/4
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/09/2010 0551
Date Prepared: N/A

Analysis Batch: 500-101547
Prep Batch: N/A
Units: mg/L

Instrument ID: SPEC3
Lab File ID: N/A
Initial Weight/Volume: 100 mL
Final Weight/Volume: 100 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Sulfate-Dissolved	20.0	18.4	92	80 - 120	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101632

Method: 9038
Preparation: N/A

Lab Sample ID: MB 500-101632/3
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/09/2010 0654
Date Prepared: N/A

Analysis Batch: 500-101632
Prep Batch: N/A
Units: mg/L

Instrument ID: SPEC3
Lab File ID: N/A
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Sulfate-Dissolved	<5.0		5.0

Lab Control Sample - Batch: 500-101632

Method: 9038
Preparation: N/A

Lab Sample ID: LCS 500-101632/4
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/09/2010 0655
Date Prepared: N/A

Analysis Batch: 500-101632
Prep Batch: N/A
Units: mg/L

Instrument ID: SPEC3
Lab File ID: N/A
Initial Weight/Volume: 100 mL
Final Weight/Volume: 100 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Sulfate-Dissolved	20.0	19.6	98	80 - 120	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101815

Method: 9251
Preparation: N/A

Lab Sample ID: MB 500-101815/39
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/13/2010 1654
Date Prepared: N/A

Analysis Batch: 500-101815
Prep Batch: N/A
Units: mg/L

Instrument ID: AQ2
Lab File ID: 2010-12-13-17-30-12.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Chloride-Dissolved	<2.0		2.0

Lab Control Sample - Batch: 500-101815

Method: 9251
Preparation: N/A

Lab Sample ID: LCS 500-101815/40
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/13/2010 1655
Date Prepared: N/A

Analysis Batch: 500-101815
Prep Batch: N/A
Units: mg/L

Instrument ID: AQ2
Lab File ID: 2010-12-13-17-30-12.csv
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Chloride-Dissolved	50.0	52.1	104	80 - 120	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101531

Method: SM 2540C
Preparation: N/A

Lab Sample ID: MB 500-101531/1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 2321
Date Prepared: N/A

Analysis Batch: 500-101531
Prep Batch: N/A
Units: mg/L

Instrument ID: No Equipment Assigned
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Result	Qual	RL
Total Dissolved Solids-Dissolved	<10		10

Lab Control Sample - Batch: 500-101531

Method: SM 2540C
Preparation: N/A

Lab Sample ID: LCS 500-101531/2
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 2323
Date Prepared: N/A

Analysis Batch: 500-101531
Prep Batch: N/A
Units: mg/L

Instrument ID: No Equipment Assigned
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Total Dissolved Solids-Dissolved	250	260	104	80 - 120	

Matrix Spike - Batch: 500-101531

Method: SM 2540C
Preparation: N/A

Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 2333
Date Prepared: N/A

Analysis Batch: 500-101531
Prep Batch: N/A
Units: mg/L

Instrument ID: No Equipment Assigned
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Sample Result/Qual	Spike Amount	Result	% Rec.	Limit	Qual
Total Dissolved Solids-Dissolved	590	250	854	105	75 - 125	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Duplicate - Batch: 500-101531

Method: SM 2540C
Preparation: N/A

Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 2331
Date Prepared: N/A

Analysis Batch: 500-101531
Prep Batch: N/A
Units: mg/L

Instrument ID: No Equipment Assigned
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Sample Result/Qual	Result	RPD	Limit	Qual
Total Dissolved Solids-Dissolved	590	598	1	20	

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101787

Method: SM 4500 F C
Preparation: N/A

Lab Sample ID: MB 500-101787/3
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/13/2010 1131
Date Prepared: N/A

Analysis Batch: 500-101787
Prep Batch: N/A
Units: mg/L

Instrument ID: PC-Titrate
Lab File ID: 10121300.txt
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Fluoride-Dissolved	<0.10		0.10

Lab Control Sample - Batch: 500-101787

Method: SM 4500 F C
Preparation: N/A

Lab Sample ID: LCS 500-101787/4
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/13/2010 1134
Date Prepared: N/A

Analysis Batch: 500-101787
Prep Batch: N/A
Units: mg/L

Instrument ID: PC-Titrate
Lab File ID: 10121300.txt
Initial Weight/Volume: 100 mL
Final Weight/Volume: 100 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Fluoride-Dissolved	10.0	10.3	103	80 - 120	

Matrix Spike/
Matrix Spike Duplicate Recovery Report - Batch: 500-101787

Method: SM 4500 F C
Preparation: N/A

MS Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/13/2010 1221
Date Prepared: N/A

Analysis Batch: 500-101787
Prep Batch: N/A

Instrument ID: PC-Titrate
Lab File ID: 10121300.txt
Initial Weight/Volume: 100 mL
Final Weight/Volume: 100 mL

MSD Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/13/2010 1224
Date Prepared: N/A

Analysis Batch: 500-101787
Prep Batch: N/A

Instrument ID: PC-Titrate
Lab File ID: 10121300.txt
Initial Weight/Volume: 100 mL
Final Weight/Volume: 100 mL

Analyte	% Rec. MS	% Rec. MSD	Limit	RPD	RPD Limit	MS Qual	MSD Qual
Fluoride-Dissolved	107	105	75 - 125	1	20		

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101499

Method: SM 4500 NO2 B
Preparation: N/A

Lab Sample ID: MB 500-101499/3
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 1040
Date Prepared: N/A

Analysis Batch: 500-101499
Prep Batch: N/A
Units: mg/L

Instrument ID: SPEC5
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Result	Qual	RL
Nitrogen, Nitrite-Dissolved	<0.020		0.020

Lab Control Sample - Batch: 500-101499

Method: SM 4500 NO2 B
Preparation: N/A

Lab Sample ID: LCS 500-101499/4
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 1041
Date Prepared: N/A

Analysis Batch: 500-101499
Prep Batch: N/A
Units: mg/L

Instrument ID: SPEC5
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Nitrogen, Nitrite-Dissolved	0.100	0.0995	100	80 - 120	

Matrix Spike/
Matrix Spike Duplicate Recovery Report - Batch: 500-101499

Method: SM 4500 NO2 B
Preparation: N/A

MS Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 1043
Date Prepared: N/A

Analysis Batch: 500-101499
Prep Batch: N/A

Instrument ID: SPEC5
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

MSD Lab Sample ID: 500-29703-1
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/08/2010 1044
Date Prepared: N/A

Analysis Batch: 500-101499
Prep Batch: N/A

Instrument ID: SPEC5
Lab File ID: N/A
Initial Weight/Volume: 50 mL
Final Weight/Volume: 50 mL

Analyte	% Rec. MS	% Rec. MSD	Limit	RPD	RPD Limit	MS Qual	MSD Qual
Nitrogen, Nitrite-Dissolved	93	94	75 - 125	1	20		

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101888

Method: SM 4500 NO3 F
Preparation: N/A

Lab Sample ID: MB 500-101888/19
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/14/2010 1515
Date Prepared: N/A

Analysis Batch: 500-101888
Prep Batch: N/A
Units: mg/L

Instrument ID: AQ2
Lab File ID: 2010-12-14-16-16-11.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Nitrogen, Nitrate Nitrite-Dissolved	<0.10	^	0.10

Lab Control Sample - Batch: 500-101888

Method: SM 4500 NO3 F
Preparation: N/A

Lab Sample ID: LCS 500-101888/38
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/14/2010 1606
Date Prepared: N/A

Analysis Batch: 500-101888
Prep Batch: N/A
Units: mg/L

Instrument ID: AQ2
Lab File ID: 2010-12-14-16-16-11.csv
Initial Weight/Volume: 100 mL
Final Weight/Volume: 100 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Nitrogen, Nitrate Nitrite-Dissolved	1.00	1.08	108	80 - 120	

Matrix Spike/
Matrix Spike Duplicate Recovery Report - Batch: 500-101888

Method: SM 4500 NO3 F
Preparation: N/A

MS Lab Sample ID: 500-29703-9
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/14/2010 1613
Date Prepared: N/A

Analysis Batch: 500-101888
Prep Batch: N/A

Instrument ID: AQ2
Lab File ID: 2010-12-14-16-16-11.csv
Initial Weight/Volume: 10 mL
Final Weight/Volume: 10 mL

MSD Lab Sample ID: 500-29703-9
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/14/2010 1614
Date Prepared: N/A

Analysis Batch: 500-101888
Prep Batch: N/A

Instrument ID: AQ2
Lab File ID: 2010-12-14-16-16-11.csv
Initial Weight/Volume: 10 mL
Final Weight/Volume: 10 mL

Analyte	% Rec. MS	% Rec. MSD	Limit	RPD	RPD Limit	MS Qual	MSD Qual
Nitrogen, Nitrate Nitrite-Dissolved	91	97	75 - 125	5	20		

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Method Blank - Batch: 500-101968

Method: SM 4500 NO3 F
Preparation: N/A

Lab Sample ID: MB 500-101968/12
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/15/2010 1433
Date Prepared: N/A

Analysis Batch: 500-101968
Prep Batch: N/A
Units: mg/L

Instrument ID: AQ2
Lab File ID: 20101215.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Nitrogen, Nitrate Nitrite-Dissolved	<0.10		0.10

Method Blank - Batch: 500-101968

Method: SM 4500 NO3 F
Preparation: N/A

Lab Sample ID: MB 500-101968/25
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/15/2010 1501
Date Prepared: N/A

Analysis Batch: 500-101968
Prep Batch: N/A
Units: mg/L

Instrument ID: AQ2
Lab File ID: 20101215.csv
Initial Weight/Volume: 1.0 mL
Final Weight/Volume: 1.0 mL

Analyte	Result	Qual	RL
Nitrogen, Nitrate Nitrite-Dissolved	<0.10		0.10

Quality Control Results

Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Lab Control Sample - Batch: 500-101968

Method: SM 4500 NO3 F
Preparation: N/A

Lab Sample ID: LCS 500-101968/13
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/15/2010 1435
Date Prepared: N/A

Analysis Batch: 500-101968
Prep Batch: N/A
Units: mg/L

Instrument ID: AQ2
Lab File ID: 20101215.csv
Initial Weight/Volume: 100 mL
Final Weight/Volume: 100 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Nitrogen, Nitrate Nitrite-Dissolved	1.00	1.15	115	80 - 120	

Lab Control Sample - Batch: 500-101968

Method: SM 4500 NO3 F
Preparation: N/A

Lab Sample ID: LCS 500-101968/26
Client Matrix: Water
Dilution: 1.0
Date Analyzed: 12/15/2010 1503
Date Prepared: N/A

Analysis Batch: 500-101968
Prep Batch: N/A
Units: mg/L

Instrument ID: AQ2
Lab File ID: 20101215.csv
Initial Weight/Volume: 100 mL
Final Weight/Volume: 100 mL

Analyte	Spike Amount	Result	% Rec.	Limit	Qual
Nitrogen, Nitrate Nitrite-Dissolved	1.00	1.14	114	80 - 120	

Electronic Filing: Received, Clerk's Office 2/04/2022

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

Lab Job #: 500-29703

Chain of Custody Number:

Page ____ of ____

Temperature °C of Cooler: (3.4)(2.9)

Report To (Billing)
Contact: Andrew Gaynor
Company: Patrick Eng.
Address: 4985 Varsity Dr.
Address: Lisle IL 60532
Phone: 630-795-7359
Fax: 630-724-9290
E-Mail: AGaynor@PatrickEngineering.com

Bill To (if different)
Contact:
Company:
Address:
Address:
Phone:
Fax:
PO#/Reference#

Client: Patrick Engineering
Client Project #: 21053.070
Project Name: Midwest Gen. Ash pond
Project Location/State: Joliet, IL
Lab Project #:
Sampler: DM
Lab PM:

Preservative
Parameter

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

Lab ID	MS/MSD	Sample ID	Sampling Date	Sampling Time	# of Containers	Matrix	Dissolved NO3-NO2	Dissolved TDS, F, SO4, Cl	Dissolved organic	Nitric Acid	Dissolved NO2	Comments
1		MW-01	12/6/10	14:25	5	W	X	X	X	X	X	
2		MW-02	12/6/10	13:45								
3		MW-03	12/6/10	10:10								
4		MW-04	12/7/10	11:00								
5		MW-05	12/7/10	11:45								
6		MW-06	12/7	9:30								
7		MW-07	12/7/10	8:55								
8		MW-08	12/6/10	14:55								
9		MW-09	12/6/10	11:15								
10		MW-10	12/6/10	15:20								
11		MW-11	12/6/10	16:05								

Turnaround Time Required (Business Days)
___ 1 Day ___ 2 Days ___ 5 Days ___ 7 Days ___ 10 Days X 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
DM	Patrick Eng	12/7/10	1250		TestAmerica	12/7/10	1250
Relinquished By	Company	Date	Time	Received By	Company	Date	Time
Relinquished By	Company	Date	Time	Received By	Company	Date	Time

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

Lab Comments:

12/17/2010

TAL-4124-500 (1209)

Login Sample Receipt Check List

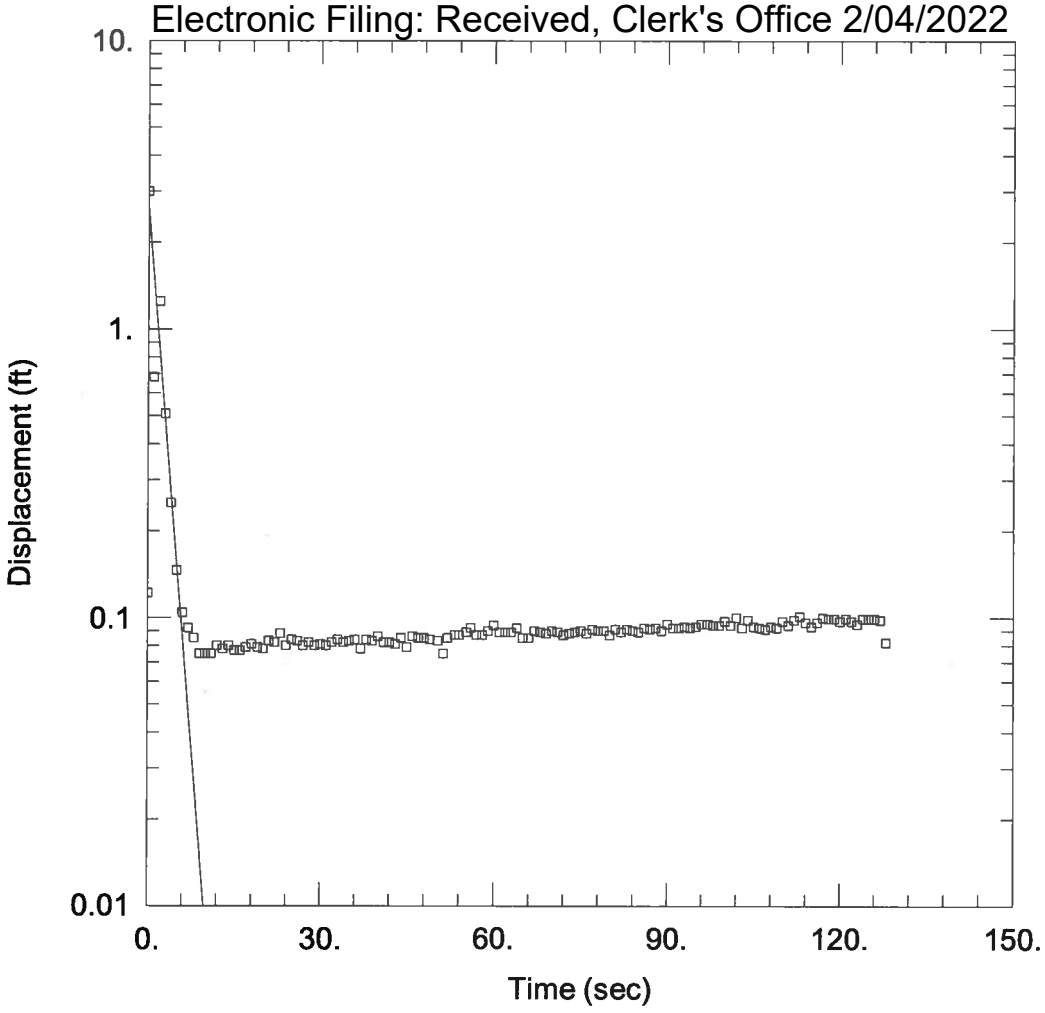
Client: Midwest Generation EME LLC

Job Number: 500-29703-1

Login Number: 29703
List Source: TestAmerica Chicago
Creator: Kelsey, Shawn M
List Number: 1

Question	T / F/ NA	Comment
Radioactivity either was not measured or, if measured, is at or below background	True	
The cooler's custody seal, if present, is 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 sample IDs on the containers and the COC.	True	
Samples are received within Holding Time.	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	
VOA sample vials do not have headspace or bubble is <6mm (1/4") in diameter.	N/A	
If necessary, staff have been informed of any short hold time or quick TAT needs	True	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	

Electronic Filing: Received, Clerk's Office 2/04/2022



WELL TEST ANALYSIS

Data Set: P:\...\Joliet 29 mw-11 u2.aqt
Date: 02/17/11 Time: 09:38:17

PROJECT INFORMATION

Company: Patrick Engineering
Client: Midwest Generation
Project: 21053.070
Location: Joliet #29
Test Well: MW-11 (u2)
Test Date: 12/22/10

AQUIFER DATA

Saturated Thickness: 8.22 ft Anisotropy Ratio (Kz/Kr): 1.

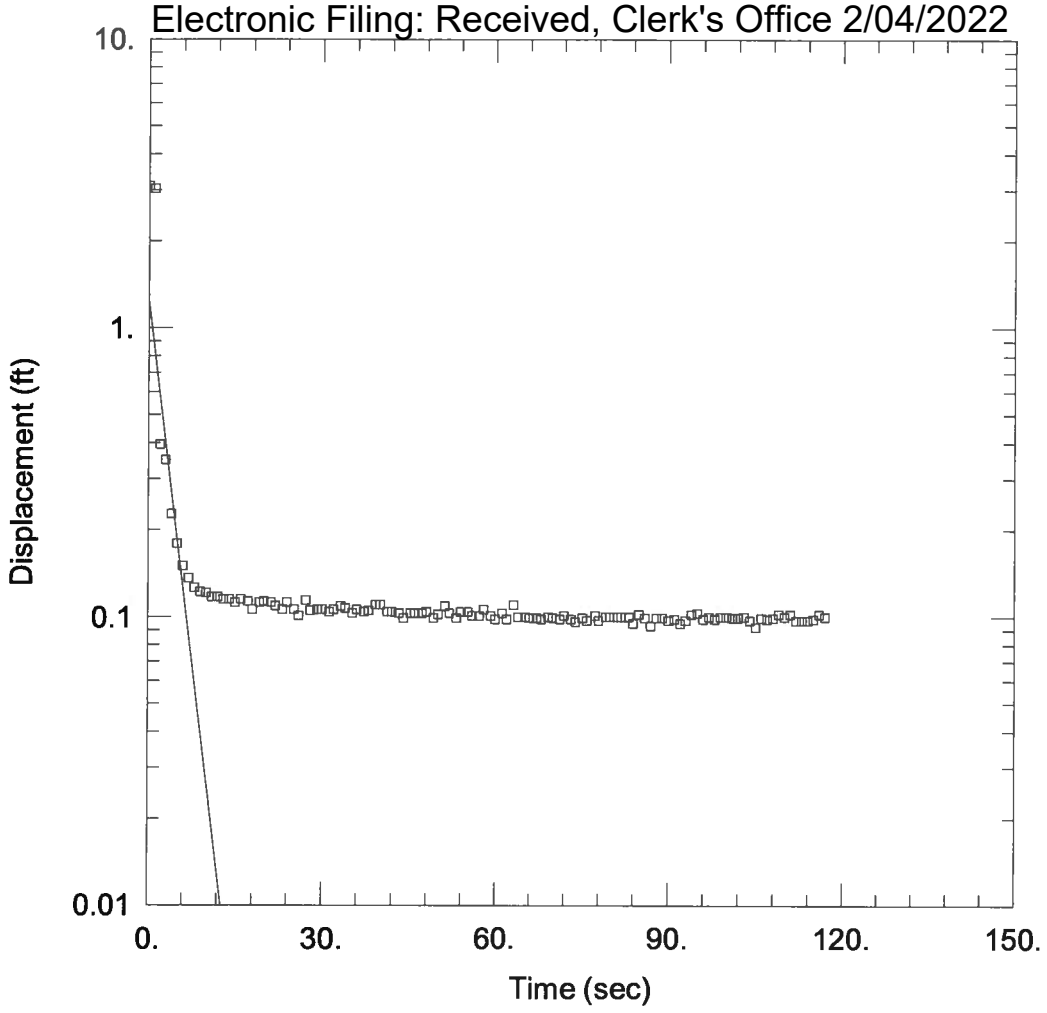
WELL DATA (MW-11 (u2))

Initial Displacement: 3. ft
Total Well Penetration Depth: 42.35 ft
Casing Radius: 0.2 ft
Static Water Column Height: 8.22 ft
Screen Length: 10. ft
Well Radius: 0.085 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 0.004685 ft/sec y0 = 2.66 ft

Electronic Filing: Received, Clerk's Office 2/04/2022



WELL TEST ANALYSIS

Data Set: P:\...\Joliet 29 mw-11 d1.aqt
Date: 02/17/11 Time: 09:42:17

PROJECT INFORMATION

Company: Patrick Engineering
Client: Midwest Generation
Project: 21053.070
Location: Joliet #29
Test Well: MW-11 (d1)
Test Date: 12/22/10

AQUIFER DATA

Saturated Thickness: 8.22 ft
Anisotropy Ratio (Kz/Kr): 1.

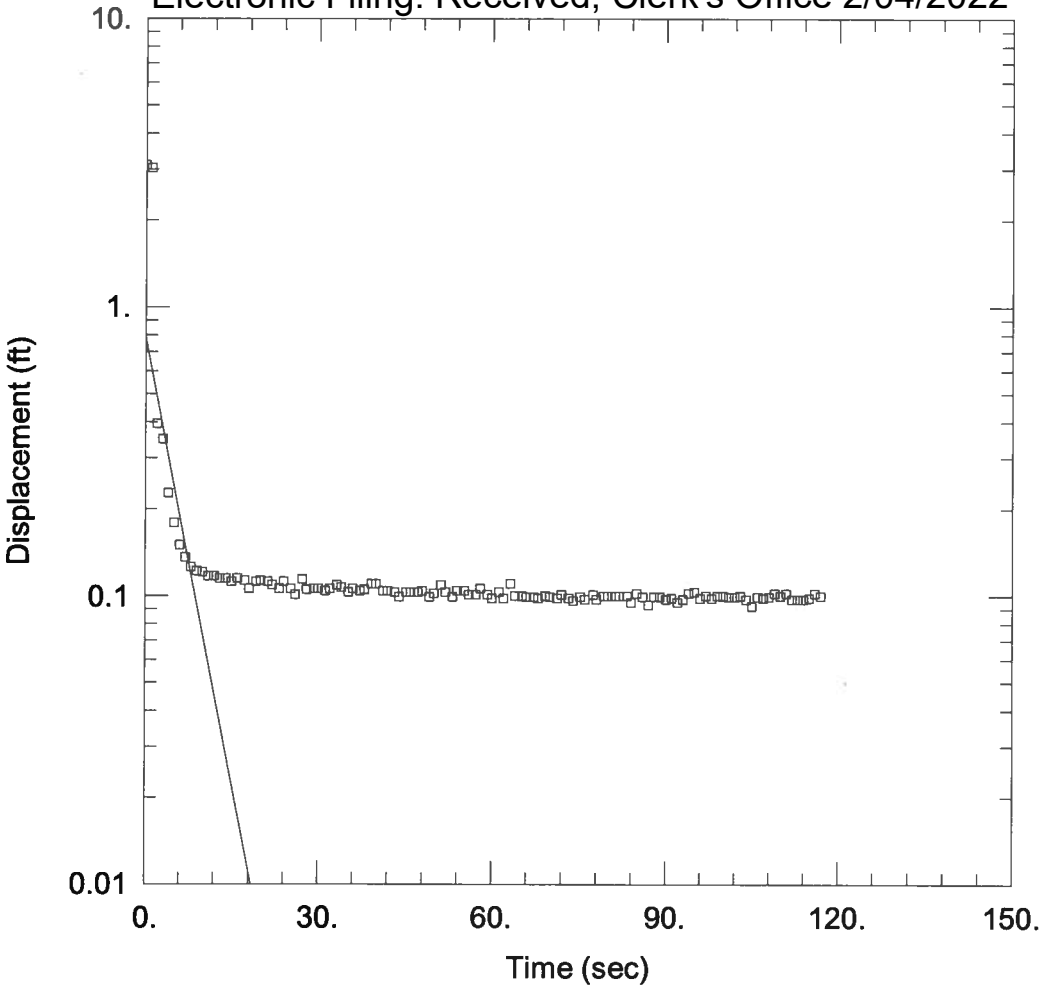
WELL DATA (MW-11 (d1))

Initial Displacement: 3.1 ft
Total Well Penetration Depth: 42.35 ft
Casing Radius: 0.2 ft
Static Water Column Height: 8.22 ft
Screen Length: 10. ft
Well Radius: 0.085 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.003131 ft/sec
y0 = 1.243 ft

Electronic Filing: Received, Clerk's Office 2/04/2022



WELL TEST ANALYSIS

Data Set: P:\...\Joliet 29 mw-9 u2.aqt
Date: 02/17/11 Time: 09:10:24

PROJECT INFORMATION

Company: Patrick Engineering
Client: Midwest Generation
Project: 21053.070
Location: Joliet #29
Test Well: MW-9 (u2)
Test Date: 12/22/10

AQUIFER DATA

Saturated Thickness: 8.22 ft Anisotropy Ratio (Kz/Kr): 1.

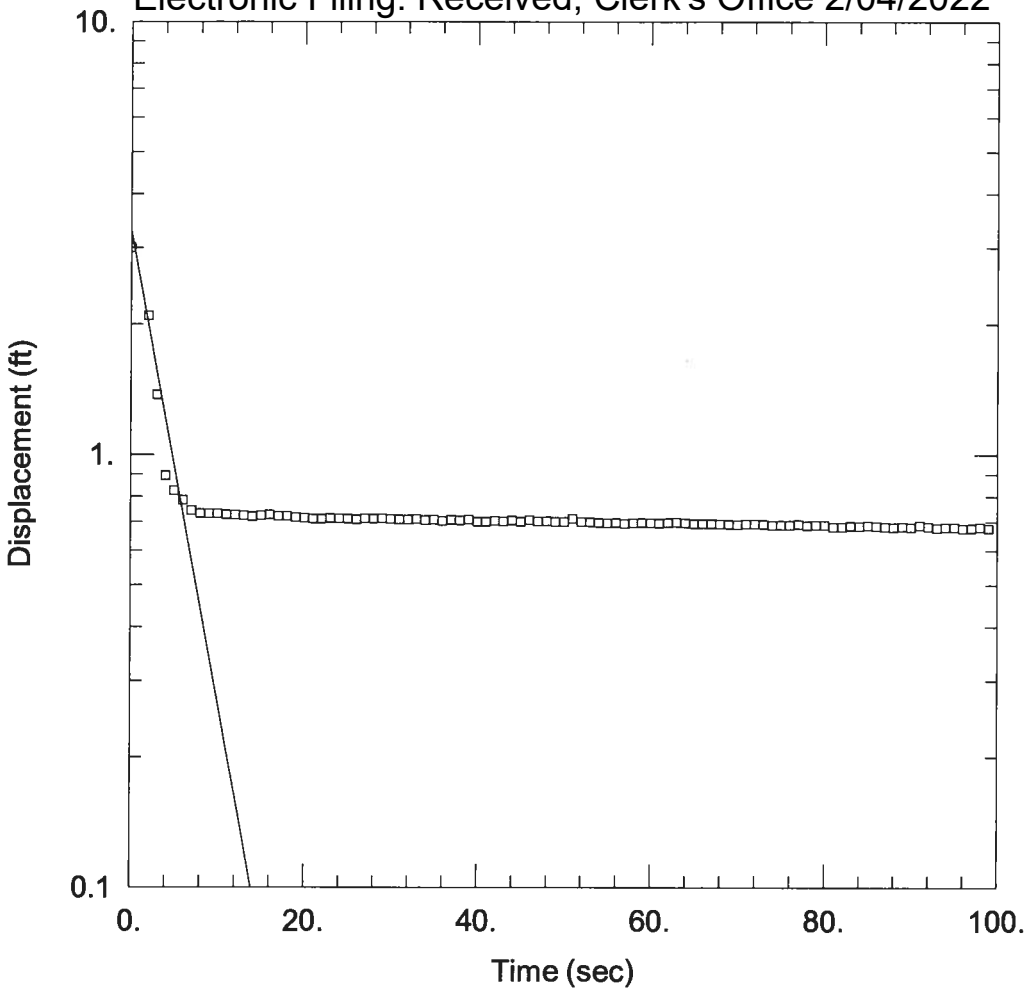
WELL DATA (MW-9 (u2))

Initial Displacement: 3.1 ft
Total Well Penetration Depth: 42.35 ft
Casing Radius: 0.2 ft
Static Water Column Height: 8.22 ft
Screen Length: 10. ft
Well Radius: 0.085 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 0.001948 ft/sec y0 = 0.787 ft

Electronic Filing: Received, Clerk's Office 2/04/2022



WELL TEST ANALYSIS

Data Set: P:\...\Joliet 29 mw-9 d1.aqt
Date: 02/17/11 Time: 09:10:52

PROJECT INFORMATION

Company: Patrick Engineering
Client: Midwest Generation
Project: 21053.070
Location: Joliet#29
Test Well: MW-9 (d1)
Test Date: 12/22/10

AQUIFER DATA

Saturated Thickness: 8.7 ft Anisotropy Ratio (Kz/Kr): 1.

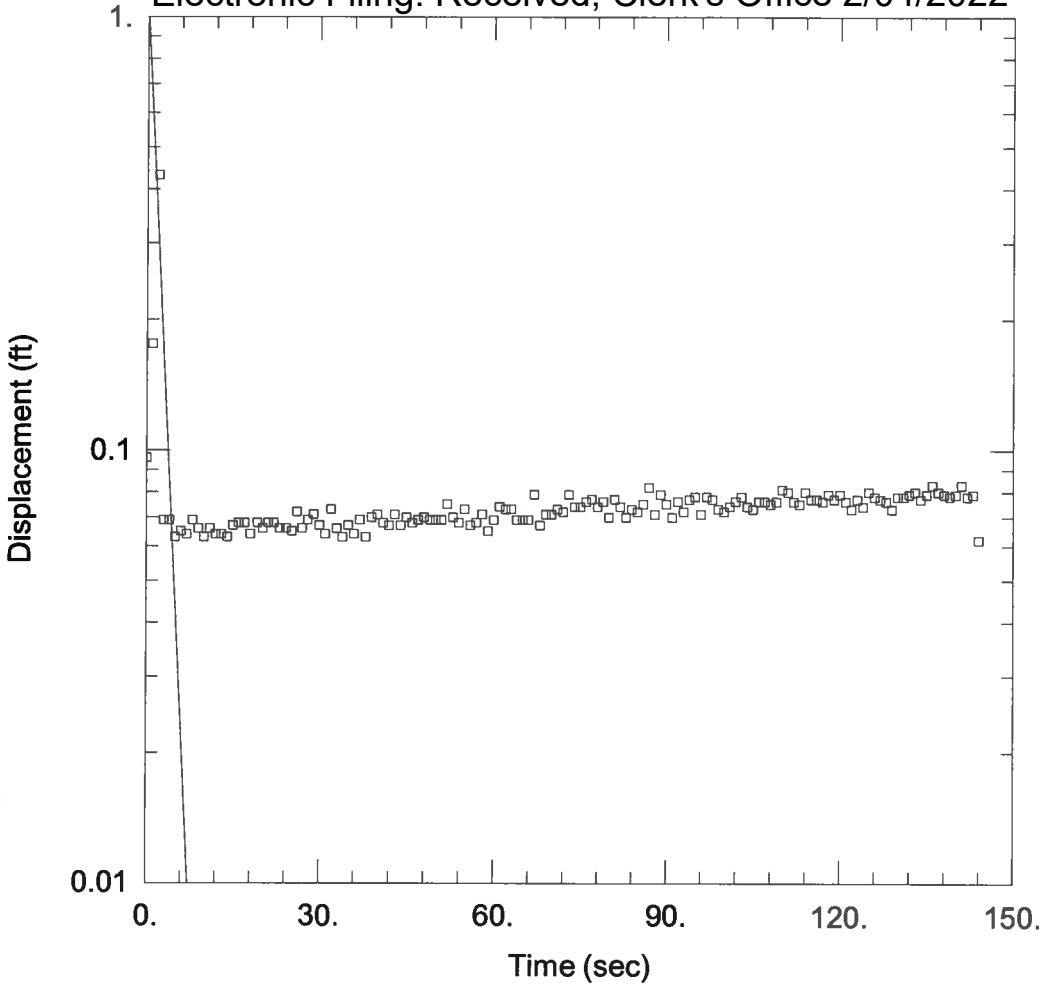
WELL DATA (MW-9 (d1))

Initial Displacement: 3. ft
Total Well Penetration Depth: 38. ft
Casing Radius: 0.2 ft
Static Water Column Height: 8.7 ft
Screen Length: 10. ft
Well Radius: 0.085 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 0.001934 ft/sec y0 = 3.316 ft

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WELL TEST ANALYSIS

Data Set: P:\...\Joliet 29 mw-6 u1.aqt
Date: 02/17/11 Time: 09:11:59

PROJECT INFORMATION

Company: Patrick Engineering
Client: Midwest Generation
Project: 21053.070
Location: Joliet #29
Test Well: MW-6 (u1)
Test Date: 12/22/10

AQUIFER DATA

Saturated Thickness: 8.22 ft
Anisotropy Ratio (Kz/Kr): 1.

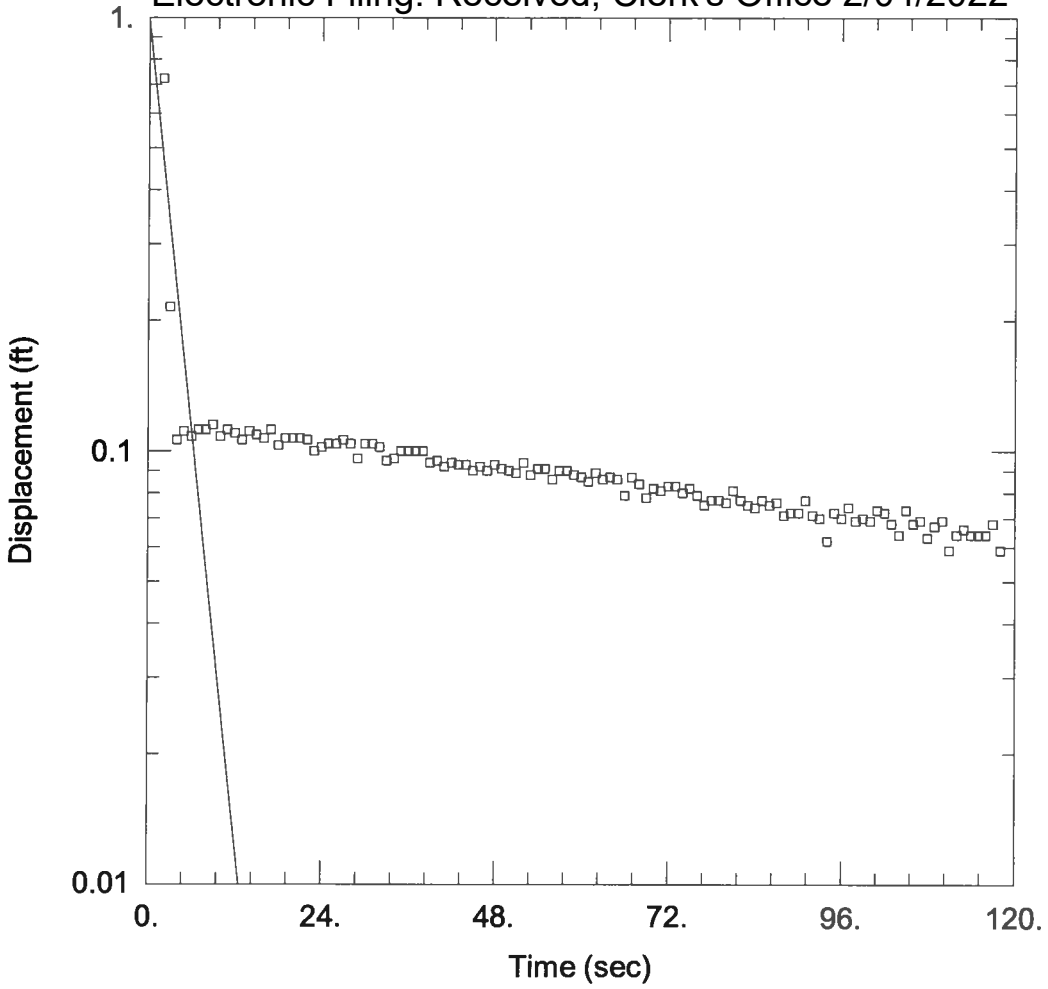
WELL DATA (MW-6 (u1))

Initial Displacement: 3. ft
Total Well Penetration Depth: 42.2 ft
Casing Radius: 0.2 ft
Static Water Column Height: 8.22 ft
Screen Length: 10. ft
Well Radius: 0.085 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.005274 ft/sec
y0 = 1.109 ft

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WELL TEST ANALYSIS

Data Set: P:\...\Joliet 29 mw-6 d2.aqt
Date: 02/17/11 Time: 09:13:14

PROJECT INFORMATION

Company: Patrick Engineering
Client: Midwest Generation
Project: 21053.070
Location: Joliet #29
Test Well: MW-6 (d2)
Test Date: 12/22/10

AQUIFER DATA

Saturated Thickness: 8.22 ft Anisotropy Ratio (Kz/Kr): 1.

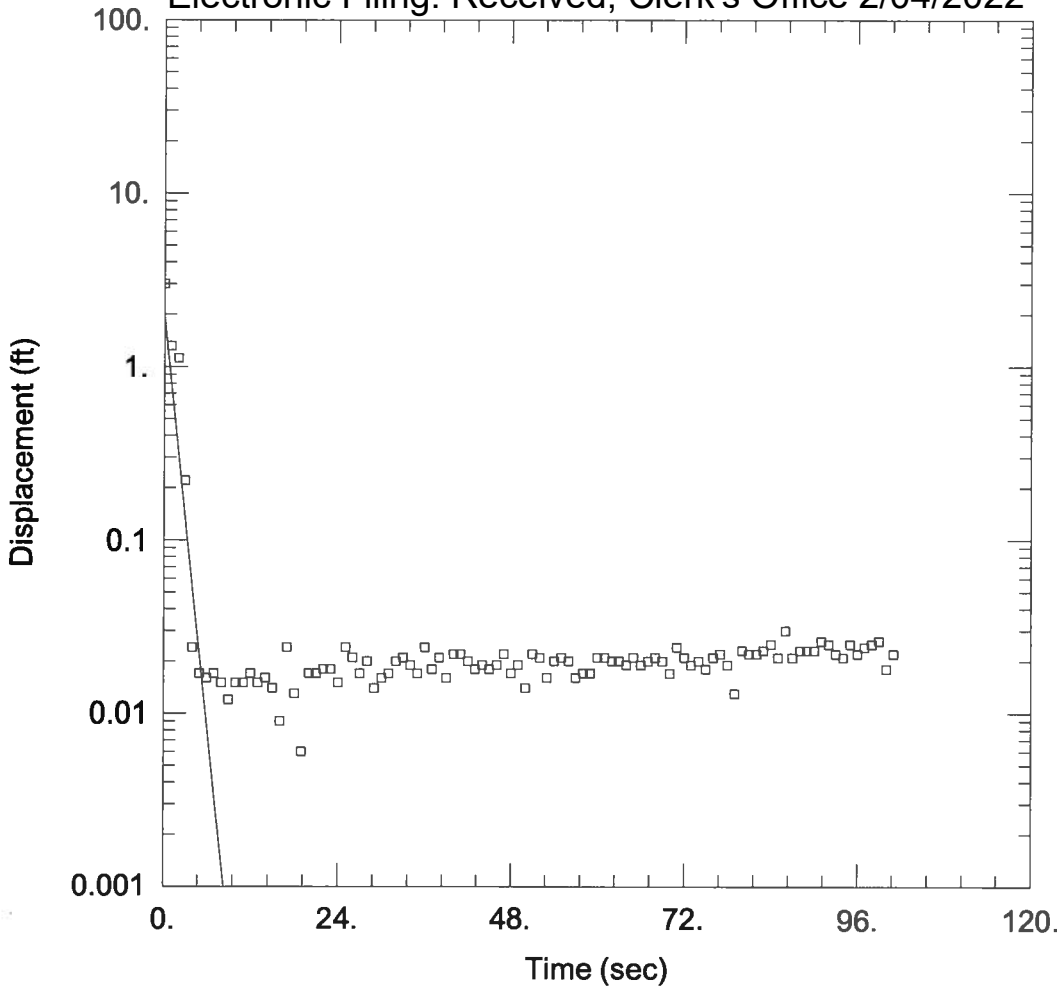
WELL DATA (MW-6 (d2))

Initial Displacement: 3. ft
Total Well Penetration Depth: 42.2 ft
Casing Radius: 0.2 ft
Static Water Column Height: 8.22 ft
Screen Length: 10. ft
Well Radius: 0.085 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 0.002987 ft/sec y0 = 0.9913 ft

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WELL TEST ANALYSIS

Data Set: P:\...\Joliet 29 mw-4 u2.aqt
Date: 02/17/11 Time: 09:47:55

PROJECT INFORMATION

Company: Patrick Engineering
Client: Midwest Generation
Project: 21053.070
Location: Joliet #29
Test Well: MW-4 (u2)
Test Date: 12/22/10

AQUIFER DATA

Saturated Thickness: 8.86 ft Anisotropy Ratio (Kz/Kr): 1.

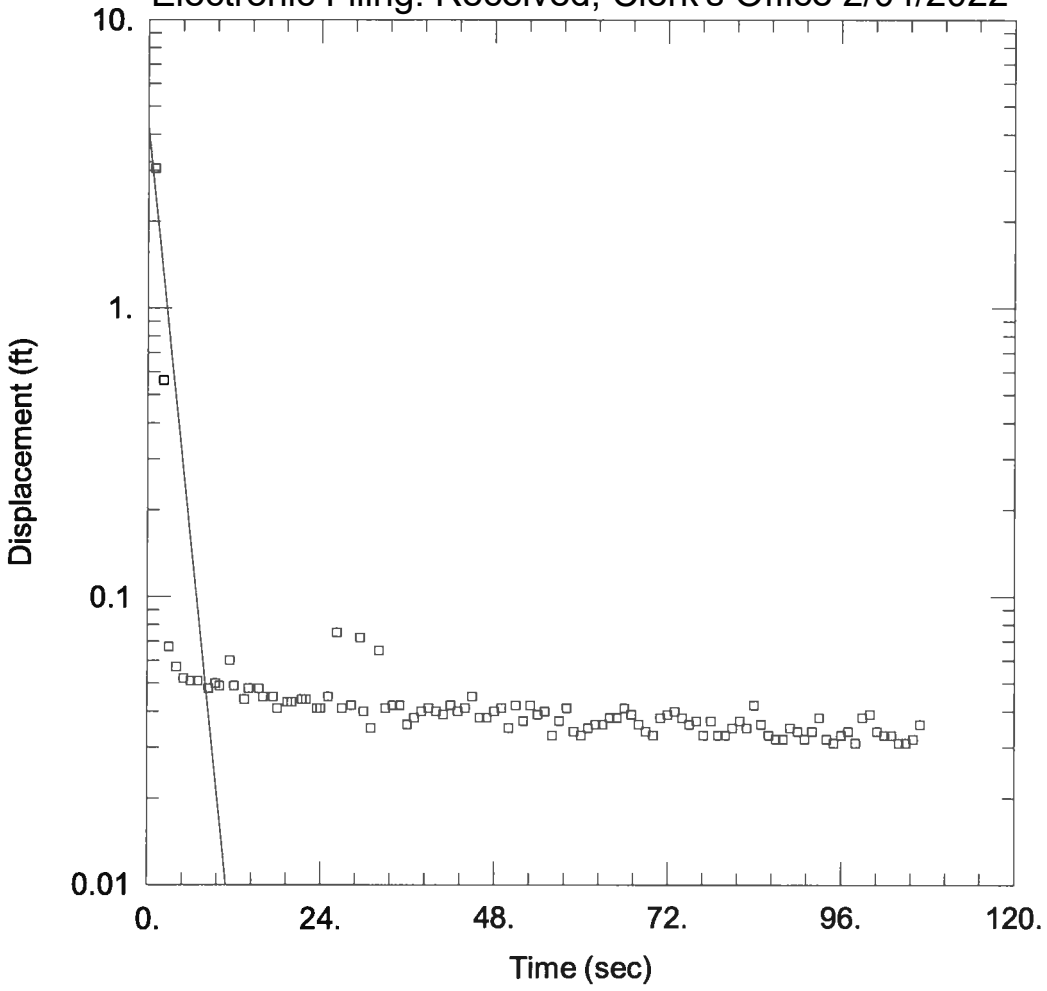
WELL DATA (MW-4 (u2))

Initial Displacement: 3. ft
Total Well Penetration Depth: 42.9 ft
Casing Radius: 0.2 ft
Static Water Column Height: 8.86 ft
Screen Length: 10. ft
Well Radius: 0.085 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 0.006949 ft/sec y0 = 1.978 ft

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WELL TEST ANALYSIS

Data Set: P:\...\Joliet 29 mw-4 d1.aqt
Date: 02/17/11 Time: 09:13:56

PROJECT INFORMATION

Company: Patrick Engineering
Client: Midwest Generation
Project: 21053.070
Location: Joliet #29
Test Well: MW-4 (d1)
Test Date: 12/22/10

AQUIFER DATA

Saturated Thickness: 8.86 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-4 (d1))

Initial Displacement: 3.1 ft
Total Well Penetration Depth: 42.9 ft
Casing Radius: 0.2 ft
Static Water Column Height: 8.86 ft
Screen Length: 10. ft
Well Radius: 0.085 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice
K = 0.004267 ft/sec y0 = 4.312 ft

Attachment 5

Weaver Consultants Group

Expert Opinion in Support of Midwest Generation LLC's Petition for Adjusted Standard Joliet 29 Station, PCB21-01
December 6, 2021
WCG Project No. 5244-302-07-01

Weaver Consultants Group North Central, LLC (WCG) conducted a review of the groundwater data at the Midwest Generation, LLC ("MWG") Joliet 29 Station and provides the following opinion regarding groundwater conditions at the coal combustion residuals ("CCR") surface impoundment (Pond 2) at the Joliet 29 Station. WCG's analysis of the groundwater data, including a statistical trends analysis, shows that the groundwater is not impacted by CCR that was historically in Pond 2, nor indicative of potential sources of CCR outside of the pond.

Information Considered

For purposes of the following Expert Opinion, WCG has reviewed publicly available information concerning the MWG Joliet 29 Station on the CCR Rule Compliance Data and Information website (available at: https://www.nrg.com/legal/coal-combustion-residuals.html) and other information provided by MWG. These references are listed in **Appendix A**.

Regulatory Framework

The materials stored in Pond 2 at the Joliet 29 Station that are the subject of the above referenced Adjusted Standard are CCR. CCR is defined in Section 3.142 of the Illinois Environmental Protection Act ("Act") as :

> *"Coal combustion residuals (CCR) means fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated from burning coal for the purpose of generating electricity by electric utilities and independent power producers."*[1]

The term "CCR surface impoundment" is defined in Section 3.143 of the Act as:

> CCR surface impoundment:

[1] 415 ILCS 5/3.142

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"a natural topographic depression, man-made excavation, or diked area, which is designed to hold an accumulation of CCR and liquids, and the unit treats, stores, or disposes of CCR"[2].

Illinois recently promulged rules and adopted regulation of CCR and CCR Surface Impoundments, the "IL CCR Rules", (PCB #R20-19). These rules are identified as 35 Ill. Adm. Code Part 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments and are based largely on the Federal CCR Rules (40 CFR Part 257), with some modifications. Pond 2 at the Joliet 29 Station is a CCR Surface Impoundment subject to the IL CCR Rules.

On May 11, 2021, MWG filed a Petition for an Adjusted Standard with the Illinois Pollution Control Board ("Board"), which requests, in part, an adjusted standard from 35 Ill. Adm. Code Part 845.740(a). Specifically, MWG is seeking to attain regulatory approval of closure by removal for Pond 2 without removing the impoundment liner.

Background

The Joliet 29 Station is located in a primarily industrial area and has produced electricity since the mid-1960s. The power plant has been operated by MWG since its acquisition in 1999. On March 18, 2016, the Plant ceased burning coal and on May 26, 2016, Joliet 29 began generating electricity with natural gas.

Pond 2 is located east of the operating Station. A site layout map is included as **Figure 1**. The monitoring network around Pond 2 consists of four monitoring wells (MW-3, MW-4, MW-5, and MW-10 [upgradient]) is also shown in **Figure 1**. Pond 2 was constructed in 1978 with 12-inch thick Poz-o-Pac™ dense aggregate liners[3]. Pond 2 was relined in 2008 with the new liner constructed with the following, from the bottom up: a bottom geotextile cushion layer placed on top of the Poz-o-Pac™, 60-mil high-density polyethylene (HDPE) geomembrane liner, a top geotextile cushion, a 12-inch-thick sand cushion layer, and 6-inch-thick limestone warning layer. [4]

The bottom elevation of Pond 2 is approximately 516 feet (ft.) above mean sea level (MSL). The highest recorded groundwater elevations since June 2011 in the vicinity of Pond 2 (i.e., in MW-03, MW-04, MW-05 and MW-10) ranged from approximately 511.5 ft. MSL at MW-05 and 511.8 ft. MSL at MW-10 (both data points observed in May 2020). The average groundwater elevation in the vicinity of Pond 2 between June 2011 and October 2020 was approximately 506.0 ft. MSL.

[2] 415 ILCS 5/3.143
[3] History of Construction Report, Ash Pond 2 Joliet 29 Station, Oct. 2016
[4] 2008 Relining Construction Record.

Coal ash from Pond 2 was removed by November 22, 2019, and Pond 2 is in the process of being closed as soon as a permit is received[5].

Groundwater Data Considered

WCG relied upon the extensive database of groundwater quality data collected from wells at the Joliet 29 Station from 2010 through the end of 2020. In 2010, at the request of Illinois EPA, MWG installed groundwater monitoring wells at the Joliet 29 Station, including around Pond 2. Since 2010, MWG has sampled the groundwater monitoring wells on a quarterly basis, resulting in a minimum of 41 groundwater sampling events. In addition to the groundwater monitoring data collected since 2010, groundwater monitoring has also been performed at the Joliet 29 Station in accordance with the Federal CCR Rules. The wells sampled were selected to meet the monitoring requirements of the Federal CCR Rules for Pond 2.

A detection monitoring program is being implemented for Pond 2 pursuant to the Federal CCR Rule. A detection monitoring program is appropriate for Pond 2 because no statistically significant increases above the background concentrations (i.e., prediction limits) attributable to Pond 2 have been identified in the groundwater monitoring data[6].

WCG Analysis of Groundwater Data

As discussed above, an extensive database of groundwater quality data has been collected at the Joliet 29 Station by MWG for over a decade. The most recent Annual Groundwater Monitoring Report produced for the monitoring wells associated with Federal/State CCR Pond 2 (including data through the end of 2020) indicates only sporadic concentrations of 40 CFR 257 Appendix III constituents exceeding the statistically derived prediction limits in both the upgradient and downgradient monitoring wells around Pond 2[7]. The sporadic concentrations in both upgradient and downgradient wells indicate that the constituents detected above the prediction limits are not from Pond 2.

Statistical Trend Analysis of the Joliet 29 Groundwater Data

WCG conducted statistical trend testing of the groundwater data to evaluate changes in groundwater constituent concentrations over time at the Joliet 29 Station. Our analysis included the detection groundwater monitoring constituents under 40 CFR 257 Appendix III (Appendix III). These are the

[5] Annual CCR Fugitive Dust Control Report, Joliet #29 Generating Station, December 10, 2020, pg. 2.
[6] KPRG, 31 January 2021.
[7] KPRG, 31 January 2021.

constituents recognized by USEPA as representing the most reliable indications of CCR impacts within groundwater. For completeness, WCG also evaluated trends for the 40 CFR 257 Appendix IV (Appendix IV) assessment groundwater monitoring constituents.

The monitoring wells evaluated at the Joliet 29 Station included the wells that were at the farthest downgradient locations. These wells are most relevant because they best represent groundwater quality after the natural groundwater mechanisms of advective dispersion and attenuation have influenced groundwater concentrations. In most cases, these wells are not necessarily located at the downgradient property boundary, and therefore use of these wells presents a conservative assessment of groundwater quality conditions because further advective dispersion and attenuation will occur before the groundwater migrates further downgradient, toward the property boundary. The following monitoring wells were included in the trend testing: MW-1, MW-2, MW-3, MW-4, MW-6, and MW-7.

WCG used the Mann-Kendall test to evaluate both upward and downward trends for the above referenced constituents. The statistical software program Sanitas Version 9.6 was utilized to conduct Mann-Kendall trend analyses on the groundwater monitoring data. The results from the Mann-Kendall Trend testing are summarized in the tables at the front of **Appendix B**. The supporting output from the statistical software is also presented in **Appendix B**, following the summary tables. In summary, the results indicate:

- Of the 132 trend tests performed, 64% exhibited no trend, 26% exhibited a downward trend (11 of 34 tests exhibited a statistically significant downward trend), and 10% exhibited an upward trend (only one of 13 tests exhibited a statistically significant upward trend).
- Of the data where a trend was observed, 72% of the trends are downward and 28% upward.

Many of the trend tests returned “no trend” results because many of the constituents evaluated were reported as not detected by the laboratory. Generally, the laboratory reporting limits are consistent from event to event and thus, results in no trend.

In cases where there were enough results reported above the laboratory detection limit so that meaningful trend testing could be performed, only one trend test indicated a statistically significant increasing trend over the approximately 10 years of data available. The one test that showed a statistically significant increasing trend was in MW-4 for barium. The concentrations of barium in MW-4 were below 0.1 mg/l, far below the Class I groundwater standard of 2.0 mg/l.

Evaluation of the Soil Surrounding MW-9 at Joliet 29 Station

MWG also conducted a site investigation at the Joliet 29 Station in November 2020 in the area in proximity to monitoring well MW-09, because it historically exhibited fluctuating concentrations of TDS and sulfate. MW-09 is side-gradient to Pond 2, and the groundwater results from the well are not associated with Pond 2. However, the results of the investigation provide further support of the absence of CCR or impacts from CCR at the Joliet 29 Station.

A total of 18 soil borings were advanced in the vicinity of MW-09 and various soil samples obtained from these borings were analyzed for sulfate, iron, and manganese. Boring logs describing the soils encountered during installation of these borings are included as **Appendix C.**

The soils in the investigation area consisted of a mixture of brown to gray sand, gravel, silty sand, and some clay. No coal ash materials were identified in the above boring logs. The laboratory analytical results from this investigation are also included in **Appendix C.** The results indicate concentrations of iron and manganese in the soil in this area generally at consistent concentrations, some which exceed the Soil Background Concentration in Metropolitan Statistical Areas included in the 35 Ill. Adm. Code Tiered Approach to Corrective Action (TACO) Regulations. However, the sulfate concentrations reported in the soil samples varied widely. Most of the sulfate concentrations were reported below 100 mg/kg. However, certain samples exhibited sulfate concentrations of an order of magnitude (or more) higher than 100 mg/kg. For example, sulfate was reported at SB-11 (11-13') reported sulfate at 2,000 mg/kg, SB-14 (3-4') reported sulfate at 4,000 mg/kg, SB-15 (6-8') reported sulfate at 16,000 mg/kg. There are no apparent distribution trends either horizontally or vertically in the soil.

The pH in the groundwater at MW-09 is more acidic, compared to the other locations, which is believed to be related to oxidation of a localized pocket of residual sulfide minerals near the MW-9. Sulfide minerals are common within the underlying Silurian dolomite bedrock[8], which comprises the parent material for the soil. Oxidation reactions of sulfide minerals results in the formation of sulfuric acid and mobilization of metals such as iron, manganese, and other metals, depending on the specific mineral and associated impurities. These oxidation reactions are believed to be associated with the groundwater quality conditions observed in the groundwater at MW-09. Thus, the sporadic sulfate and TDS groundwater concentrations are naturally occurring in the soil and not due to Station operations, including the presence of CCR in the soil or leaking from a pond.

[8] https://www.mdpi.com/2076-3263/6/2/29/htm.

Summary of Conclusions

The groundwater monitoring data collected pursuant to the Federal CCR Rule from monitoring wells in proximity of the surface impoundments at the Joliet 29 Station has not exhibited statistically significant increases for the Appendix III detection groundwater monitoring constituents. In addition, the long-term trend analysis of Appendix III detection monitoring and Appendix IV assessment monitoring constituents from the monitoring wells located downgradient of the surface impoundments indicate that groundwater quality has been improving over approximately the last 10 years.

Based on this analysis, the groundwater in proximity of Pond 2 at the Joliet 29 Station has not been adversely impacted by CCR in Pond 2. The location of the existing monitoring wells, constituents monitored, and duration the wells have been monitored are sufficient to detect statistically significant CCR impacts in the uppermost groundwater unit, if CCR were in the proximity of Pond 2.

Because the data does not indicate that CCR groundwater impacts are present, there is no indication that CCR impacted the soils beneath the liner, nor indication that there is CCR underneath the liner.



Michael B. Maxwell, LPG
Weaver Consultants Group
Chicago EPG Operations Manager

List of Attachments/Appendices:

Figure 1:	Site Map
Appendix A:	References
Appendix B:	Statistical Evaluation of Groundwater Data
Appendix C:	Data from November 2020 Soil Borings Near MW-09

FIGURES

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NOTE:
BACKGROUND MAP RETRIEVED FROM GOOGLE MAPS 2013



0 250'
APPROXIMATE SCALE

N

ENVIRONMENTAL CONSULTATION & REMEDIATION

K P R G

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SITE MAP

JOLIET #29 GENERATING STATION
JOLIET, ILLINOIS

Scale: 1" = 250' | Date: January 23, 2019

KPRG Project No. 12313.0 | FIGURE 1

APPENDIX A

References

Annual CCR Fugitive Dust Control Report, Joliet #29 Generating Station, NRG, December 10, 2020.

CCR Compliance Annual Groundwater Monitoring and Corrective Action Report – 2020, Joliet #29 Generating Station, KPRG and Associates, Inc., January 31, 2021.

Field Note Summary Impoundment #2 Liner Replacement, NRT, May 2008.

History of Construction, Ash Pond 2, Joliet Station, Geosyntec Consultants, October 2016.

https://www.mdpi.com/2076-3263/6/2/29/htm: Geochemical Characterization of Trace MVT Mineralization in Paleozoic Sedimentary Rocks…Geosciences, 2016.

Illinois Environmental Protection Act.

35 Illinois Administrative Code, Part 845.

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APPENDIX B

Statistical Evaluation of Groundwater Data

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Downgradient Groundwater Statistical Analysis
Mann-Kendall Trend Tests
Joliet 29 Station

Constituent	Well	Trend	Statistically Significant Trend? (99% Confidence Level)	Has well with stat. sig upward trend ever exceeded a GW standard?
Antimony, Dissolved	MW-01	none		
Antimony, Dissolved	MW-02	none		
Antimony, Dissolved	MW-03	none		
Antimony, Dissolved	MW-04	none		
Antimony, Dissolved	MW-06	none		
Antimony, Dissolved	MW-07	none		
Antimony, Total	MW-03	none		
Antimony, Total	MW-04	none		
Arsenic, Dissolved	MW-01	none		
Arsenic, Dissolved	MW-02	none		
Arsenic, Dissolved	MW-03	Down ↓	No	
Arsenic, Dissolved	MW-04	none		
Arsenic, Dissolved	MW-06	Down ↓	No	
Arsenic, Dissolved	MW-07	none		
Arsenic, Total	MW-03	Up ↑	No	
Arsenic, Total	MW-04	none		
Barium, Dissolved	MW-01	Down ↓	No	
Barium, Dissolved	MW-02	Down ↓	Yes	
Barium, Dissolved	MW-03	Up ↑	No	
Barium, Dissolved	MW-04	Up ↑	Yes	No
Barium, Dissolved	MW-06	Up ↑	No	
Barium, Dissolved	MW-07	none		
Barium, Total	MW-03	Down ↓	No	
Barium, Total	MW-04	Down ↓	No	
Beryllium, Dissolved	MW-01	none		
Beryllium, Dissolved	MW-02	none		
Beryllium, Dissolved	MW-03	none		
Beryllium, Dissolved	MW-04	none		
Beryllium, Dissolved	MW-06	none		
Beryllium, Dissolved	MW-07	none		
Beryllium, Total	MW-03	none		
Beryllium, Total	MW-04	none		
Boron, Dissolved	MW-01	Down ↓	No	
Boron, Dissolved	MW-02	Down ↓	Yes	
Boron, Dissolved	MW-03	Up ↑	No	
Boron, Dissolved	MW-04	Down ↓	No	
Boron, Dissolved	MW-06	Down ↓	Yes	
Boron, Dissolved	MW-07	Down ↓	No	
Boron, Total	MW-03	Down ↓	No	
Boron, Total	MW-04	none		
Cadmium, Dissolved	MW-01	none		
Cadmium, Dissolved	MW-02	none		
Cadmium, Dissolved	MW-03	none		
Cadmium, Dissolved	MW-04	none		
Cadmium, Dissolved	MW-06	none		
Cadmium, Dissolved	MW-07	none		
Cadmium, Total	MW-03	none		
Cadmium, Total	MW-04	none		
Calcium, Total	MW-03	none		

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Mann-Kendall Trend Tests

Joliet 29 Station

Constituent	Well	Trend	Statistically Significant Trend? (99% Confidence Level)	Has well with stat. sig upward trend ever exceeded a GW standard?
Calcium, Total	MW-04	Up ↑	No	
Chloride	MW-01	Down ↓	No	
Chloride	MW-02	none		
Chloride	MW-03	Down ↓	Yes	
Chloride	MW-04	Down ↓	No	
Chloride	MW-06	none		
Chloride	MW-07	Down ↓	No	
Chromium, Dissolved	MW-01	none		
Chromium, Dissolved	MW-02	none		
Chromium, Dissolved	MW-03	none		
Chromium, Dissolved	MW-04	none		
Chromium, Dissolved	MW-06	none		
Chromium, Dissolved	MW-07	none		
Chromium, Total	MW-03	none		
Chromium, Total	MW-04	none		
Cobalt, Dissolved	MW-01	none		
Cobalt, Dissolved	MW-02	none		
Cobalt, Dissolved	MW-03	none		
Cobalt, Dissolved	MW-04	Up ↑	No	
Cobalt, Dissolved	MW-06	none		
Cobalt, Dissolved	MW-07	none		
Cobalt, Total	MW-03	none		
Cobalt, Total	MW-04	none		
Fluoride	MW-01	Down ↓	No	
Fluoride	MW-02	Down ↓	Yes	
Fluoride	MW-03	none		
Fluoride	MW-04	none		
Fluoride	MW-06	Down ↓	Yes	
Fluoride	MW-07	Down ↓	Yes	
Lead, Dissolved	MW-01	none		
Lead, Dissolved	MW-02	none		
Lead, Dissolved	MW-03	none		
Lead, Dissolved	MW-04	none		
Lead, Dissolved	MW-06	none		
Lead, Dissolved	MW-07	none		
Lead, Total	MW-03	none		
Lead, Total	MW-04	none		
Lithium, Total	MW-03	none		
Lithium, Total	MW-04	Up ↑	No	
Mercury, Dissolved	MW-01	none		
Mercury, Dissolved	MW-02	none		
Mercury, Dissolved	MW-03	none		
Mercury, Dissolved	MW-04	none		
Mercury, Dissolved	MW-06	none		
Mercury, Dissolved	MW-07	none		
Mercury, Total	MW-03	none		
Mercury, Total	MW-04	none		
Molybdenum, Total	MW-03	Up ↑	No	
Molybdenum, Total	MW-04	Up ↑	No	

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Mann-Kendall Trend Tests

Joliet 29 Station

Constituent	Well	Trend	Statistically Significant Trend? (99% Confidence Level)	Has well with stat. sig upward trend ever exceeded a GW standard?
pH, Field	MW-03	Down ↓	No	
pH, Field	MW-04	Down ↓	No	
pH, Field	MW-06	Down ↓	No	
pH, Field	MW-07	Down ↓	Yes	
Radium 226 + 228, Comb	MW-03	none		
Radium 226 + 228, Comb	MW-04	none		
Selenium, Dissolved	MW-01	Up ↑	No	
Selenium, Dissolved	MW-02	none		
Selenium, Dissolved	MW-03	none		
Selenium, Dissolved	MW-04	none		
Selenium, Dissolved	MW-06	Down ↓	No	
Selenium, Dissolved	MW-07	none		
Selenium, Total	MW-03	none		
Selenium, Total	MW-04	none		
Sulfate	MW-01	Down ↓	No	
Sulfate	MW-02	Down ↓	No	
Sulfate	MW-03	Down ↓	Yes	
Sulfate	MW-04	Down ↓	No	
Sulfate	MW-06	Down ↓	No	
Sulfate	MW-07	Down ↓	No	
Thallium, Dissolved	MW-01	none		
Thallium, Dissolved	MW-02	none		
Thallium, Dissolved	MW-03	none		
Thallium, Dissolved	MW-04	none		
Thallium, Dissolved	MW-06	none		
Thallium, Dissolved	MW-07	none		
Thallium, Total	MW-03	none		
Thallium, Total	MW-04	none		
Total Dissolved Solids	MW-01	Up ↑	No	
Total Dissolved Solids	MW-02	Up ↑	No	
Total Dissolved Solids	MW-03	Down ↓	Yes	
Total Dissolved Solids	MW-04	Down ↓	Yes	
Total Dissolved Solids	MW-06	none		
Total Dissolved Solids	MW-07	Down ↓	No	

Joliet Stats Summary:

34	26%	Downward trends (11 significant)
13	10%	Upward trends (1 significant)
85	64%	No trend
132		**Total Tests Performed**

47 Total Tests where a trend is present

72% of tests where a trend is present are downward

28% of tests where a trend is present are upward

Electronic Filing: Received, Clerk's Office 2/04/2022

Trend Test

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database Printed 4/2/2021, 11:05 AM

Constituent	Well	Slope	Calc.	Critical	Sig.	N	%NDs	Normality	Xform	Alpha	Method
Antimony, Dissolved (mg/L)	MW-01	0	-6	-58	No	16	81.25	n/a	n/a	0.01	NP
Antimony, Dissolved (mg/L)	MW-02	0	-96	-176	No	34	91.18	n/a	n/a	0.01	NP
Antimony, Dissolved (mg/L)	MW-03	0	-128	-223	No	40	90	n/a	n/a	0.01	NP
Antimony, Dissolved (mg/L)	MW-04	0	-80	-223	No	40	92.5	n/a	n/a	0.01	NP
Antimony, Dissolved (mg/L)	MW-06	0	-21	-223	No	40	97.5	n/a	n/a	0.01	NP
Antimony, Dissolved (mg/L)	MW-07	0	0	223	No	40	100	n/a	n/a	0.01	NP
Antimony, Total (mg/L)	MW-03	0	0	30	No	10	100	n/a	n/a	0.01	NP
Antimony, Total (mg/L)	MW-04	0	0	30	No	10	100	n/a	n/a	0.01	NP
Arsenic, Dissolved (mg/L)	MW-01	0	-33	-58	No	16	68.75	n/a	n/a	0.01	NP
Arsenic, Dissolved (mg/L)	MW-02	0	-23	-176	No	34	97.06	n/a	n/a	0.01	NP
Arsenic, Dissolved (mg/L)	MW-03	-6.3e-12	-100	-223	No	40	27.5	n/a	n/a	0.01	NP
Arsenic, Dissolved (mg/L)	MW-04	0	36	223	No	40	45	n/a	n/a	0.01	NP
Arsenic, Dissolved (mg/L)	MW-06	-0.00...	-196	-223	No	40	22.5	n/a	n/a	0.01	NP
Arsenic, Dissolved (mg/L)	MW-07	0	-104	-223	No	40	60	n/a	n/a	0.01	NP
Arsenic, Total (mg/L)	MW-03	0.000...	10	30	No	10	0	n/a	n/a	0.01	NP
Arsenic, Total (mg/L)	MW-04	0	3	30	No	10	0	n/a	n/a	0.01	NP
Barium, Dissolved (mg/L)	MW-01	-0.01058	-56	-58	No	16	0	n/a	n/a	0.01	NP
Barium, Dissolved (mg/L)	**MW-02**	**-0.00...**	**-178**	**-176**	**Yes**	**34**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Barium, Dissolved (mg/L)	MW-03	0.000...	177	223	No	40	0	n/a	n/a	0.01	NP
Barium, Dissolved (mg/L)	**MW-04**	**0.002242**	**336**	**223**	**Yes**	**40**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Barium, Dissolved (mg/L)	MW-06	0.002711	206	223	No	40	0	n/a	n/a	0.01	NP
Barium, Dissolved (mg/L)	MW-07	0	50	223	No	40	0	n/a	n/a	0.01	NP
Barium, Total (mg/L)	MW-03	-0.00...	-13	-30	No	10	0	n/a	n/a	0.01	NP
Barium, Total (mg/L)	MW-04	-0.00...	-11	-30	No	10	0	n/a	n/a	0.01	NP
Beryllium, Dissolved (mg/L)	MW-01	0	0	58	No	16	100	n/a	n/a	0.01	NP
Beryllium, Dissolved (mg/L)	MW-02	0	0	176	No	34	100	n/a	n/a	0.01	NP
Beryllium, Dissolved (mg/L)	MW-03	0	0	223	No	40	100	n/a	n/a	0.01	NP
Beryllium, Dissolved (mg/L)	MW-04	0	0	223	No	40	100	n/a	n/a	0.01	NP
Beryllium, Dissolved (mg/L)	MW-06	0	0	223	No	40	100	n/a	n/a	0.01	NP
Beryllium, Dissolved (mg/L)	MW-07	0	0	223	No	40	100	n/a	n/a	0.01	NP
Beryllium, Total (mg/L)	MW-03	0	0	30	No	10	100	n/a	n/a	0.01	NP
Beryllium, Total (mg/L)	MW-04	0	0	30	No	10	100	n/a	n/a	0.01	NP
Boron, Dissolved (mg/L)	MW-01	-0.00...	-25	-58	No	16	0	n/a	n/a	0.01	NP
Boron, Dissolved (mg/L)	**MW-02**	**-0.02673**	**-356**	**-176**	**Yes**	**34**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Boron, Dissolved (mg/L)	MW-03	0.000...	19	223	No	40	0	n/a	n/a	0.01	NP
Boron, Dissolved (mg/L)	MW-04	-0.00...	-128	-223	No	40	0	n/a	n/a	0.01	NP
Boron, Dissolved (mg/L)	**MW-06**	**-0.00...**	**-229**	**-223**	**Yes**	**40**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Boron, Dissolved (mg/L)	MW-07	-0.00...	-191	-223	No	40	0	n/a	n/a	0.01	NP
Boron, Total (mg/L)	MW-03	-0.02859	-6	-38	No	12	0	n/a	n/a	0.01	NP
Boron, Total (mg/L)	MW-04	0	0	38	No	12	0	n/a	n/a	0.01	NP
Cadmium, Dissolved (mg/L)	MW-01	0	0	58	No	16	100	n/a	n/a	0.01	NP
Cadmium, Dissolved (mg/L)	MW-02	0	-13	-176	No	34	94.12	n/a	n/a	0.01	NP
Cadmium, Dissolved (mg/L)	MW-03	0	-29	-223	No	40	97.5	n/a	n/a	0.01	NP
Cadmium, Dissolved (mg/L)	MW-04	0	0	223	No	40	100	n/a	n/a	0.01	NP
Cadmium, Dissolved (mg/L)	MW-06	0	0	223	No	40	100	n/a	n/a	0.01	NP
Cadmium, Dissolved (mg/L)	MW-07	0	-7	-223	No	40	97.5	n/a	n/a	0.01	NP
Cadmium, Total (mg/L)	MW-03	0	0	30	No	10	100	n/a	n/a	0.01	NP
Cadmium, Total (mg/L)	MW-04	0	0	30	No	10	100	n/a	n/a	0.01	NP

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Trend Test

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database Printed 4/2/2021, 11:05 AM

Constituent	Well	Slope	Calc.	Critical	Sig.	N	%NDs	Normality	Xform	Alpha	Method
Chloride (mg/L)	MW-01	-3.938	-11	-58	No	16	0	n/a	n/a	0.01	NP
Chloride (mg/L)	MW-02	0	-4	-176	No	34	0	n/a	n/a	0.01	NP
Chloride (mg/L)	**MW-03**	**-8.834**	**-3.043**	**-2.58**	**Yes**	**41**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Chloride (mg/L)	MW-04	-4.891	-2.294	-2.58	No	41	0	n/a	n/a	0.01	NP
Chloride (mg/L)	MW-06	0	-13	-223	No	40	0	n/a	n/a	0.01	NP
Chloride (mg/L)	MW-07	-1.487	-40	-223	No	40	0	n/a	n/a	0.01	NP
Chromium, Dissolved (mg/L)	MW-01	0	0	58	No	16	100	n/a	n/a	0.01	NP
Chromium, Dissolved (mg/L)	MW-02	0	0	176	No	34	100	n/a	n/a	0.01	NP
Chromium, Dissolved (mg/L)	MW-03	0	0	223	No	40	100	n/a	n/a	0.01	NP
Chromium, Dissolved (mg/L)	MW-04	0	13	223	No	40	97.5	n/a	n/a	0.01	NP
Chromium, Dissolved (mg/L)	MW-06	0	0	223	No	40	100	n/a	n/a	0.01	NP
Chromium, Dissolved (mg/L)	MW-07	0	0	223	No	40	100	n/a	n/a	0.01	NP
Chromium, Total (mg/L)	MW-03	0	-1	-30	No	10	90	n/a	n/a	0.01	NP
Chromium, Total (mg/L)	MW-04	0	7	30	No	10	90	n/a	n/a	0.01	NP
Cobalt, Dissolved (mg/L)	MW-01	0	15	58	No	16	87.5	n/a	n/a	0.01	NP
Cobalt, Dissolved (mg/L)	MW-02	0	-10	-176	No	34	85.29	n/a	n/a	0.01	NP
Cobalt, Dissolved (mg/L)	MW-03	0	-76	-223	No	40	95	n/a	n/a	0.01	NP
Cobalt, Dissolved (mg/L)	MW-04	0.000...	74	223	No	40	15	n/a	n/a	0.01	NP
Cobalt, Dissolved (mg/L)	MW-06	0	-62	-223	No	40	87.5	n/a	n/a	0.01	NP
Cobalt, Dissolved (mg/L)	MW-07	0	-41	-223	No	40	95	n/a	n/a	0.01	NP
Cobalt, Total (mg/L)	MW-03	0	0	30	No	10	100	n/a	n/a	0.01	NP
Cobalt, Total (mg/L)	MW-04	0.000...	1	30	No	10	0	n/a	n/a	0.01	NP
Fluoride (mg/L)	MW-01	-0.01075	-52	-58	No	16	0	n/a	n/a	0.01	NP
Fluoride (mg/L)	**MW-02**	**-0.02597**	**-321**	**-176**	**Yes**	**34**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Fluoride (mg/L)	MW-03	0	0.2372	2.58	No	41	0	n/a	n/a	0.01	NP
Fluoride (mg/L)	MW-04	0	-0.486	-2.58	No	41	0	n/a	n/a	0.01	NP
Fluoride (mg/L)	**MW-06**	**-0.0074**	**-315**	**-223**	**Yes**	**40**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Fluoride (mg/L)	**MW-07**	**-0.00...**	**-320**	**-223**	**Yes**	**40**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Lead, Dissolved (mg/L)	MW-01	0	0	58	No	16	100	n/a	n/a	0.01	NP
Lead, Dissolved (mg/L)	MW-02	0	0	176	No	34	100	n/a	n/a	0.01	NP
Lead, Dissolved (mg/L)	MW-03	0	0	223	No	40	100	n/a	n/a	0.01	NP
Lead, Dissolved (mg/L)	MW-04	0	-23	-223	No	40	97.5	n/a	n/a	0.01	NP
Lead, Dissolved (mg/L)	MW-06	0	0	223	No	40	100	n/a	n/a	0.01	NP
Lead, Dissolved (mg/L)	MW-07	0	-7	-223	No	40	92.5	n/a	n/a	0.01	NP
Lead, Total (mg/L)	MW-03	0	0	30	No	10	100	n/a	n/a	0.01	NP
Lead, Total (mg/L)	MW-04	0	4	30	No	10	60	n/a	n/a	0.01	NP
Lithium, Total (mg/L)	MW-03	0	-7	-30	No	10	10	n/a	n/a	0.01	NP
Lithium, Total (mg/L)	MW-04	0.000...	15	30	No	10	0	n/a	n/a	0.01	NP
Mercury, Dissolved (mg/L)	MW-01	0	0	58	No	16	100	n/a	n/a	0.01	NP
Mercury, Dissolved (mg/L)	MW-02	0	0	176	No	34	100	n/a	n/a	0.01	NP
Mercury, Dissolved (mg/L)	MW-03	0	0	223	No	40	100	n/a	n/a	0.01	NP
Mercury, Dissolved (mg/L)	MW-04	0	0	223	No	40	100	n/a	n/a	0.01	NP
Mercury, Dissolved (mg/L)	MW-06	0	0	223	No	40	100	n/a	n/a	0.01	NP
Mercury, Dissolved (mg/L)	MW-07	0	0	223	No	40	100	n/a	n/a	0.01	NP
Mercury, Total (mg/L)	MW-03	0	0	30	No	10	100	n/a	n/a	0.01	NP
Mercury, Total (mg/L)	MW-04	0	0	30	No	10	100	n/a	n/a	0.01	NP
Molybdenum, Total (mg/L)	MW-03	0.000...	9	30	No	10	10	n/a	n/a	0.01	NP
Molybdenum, Total (mg/L)	MW-04	0.000...	14	30	No	10	0	n/a	n/a	0.01	NP

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Trend Test

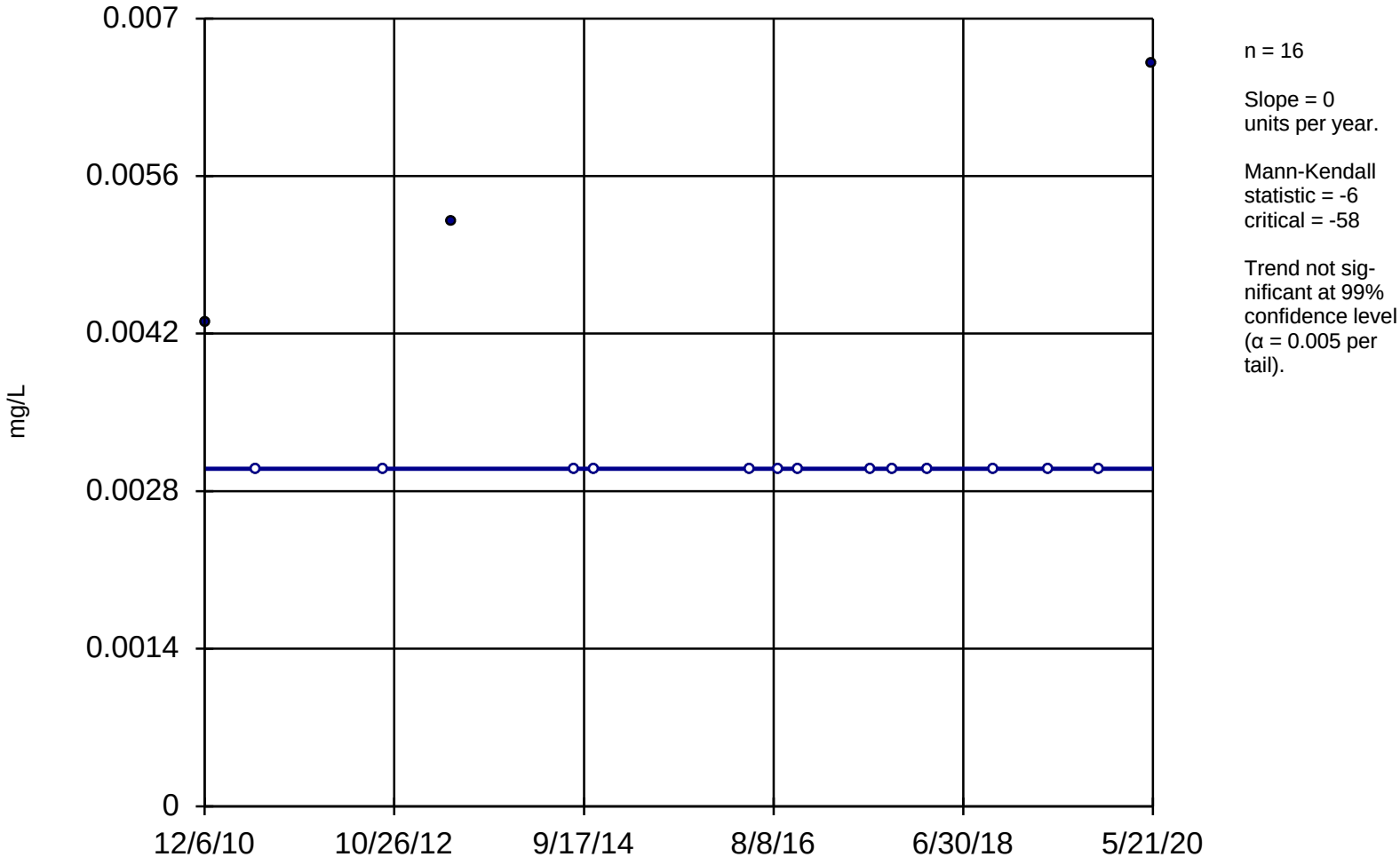
Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database Printed 4/2/2021, 11:05 AM

Constituent	Well	Slope	Calc.	Critical	Sig.	N	%NDs	Normality	Xform	Alpha	Method
pH, Field (Standard Units)	MW-03	-0.0136	-113	-214	No	39	0	n/a	n/a	0.01	NP
pH, Field (Standard Units)	MW-04	-0.01699	-116	-214	No	39	0	n/a	n/a	0.01	NP
pH, Field (Standard Units)	MW-06	-0.03421	-202	-214	No	39	0	n/a	n/a	0.01	NP
pH, Field (Standard Units)	**MW-07**	**-0.03777**	**-246**	**-214**	**Yes**	**39**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Radium 226 + Radium 228, Combin...	MW-03	0	-2	-30	No	10	70	n/a	n/a	0.01	NP
Radium 226 + Radium 228, Combin...	MW-04	0	-6	-30	No	10	70	n/a	n/a	0.01	NP
Selenium, Dissolved (mg/L)	MW-01	0.000...	44	58	No	16	37.5	n/a	n/a	0.01	NP
Selenium, Dissolved (mg/L)	MW-02	0	-102	-176	No	34	79.41	n/a	n/a	0.01	NP
Selenium, Dissolved (mg/L)	MW-03	0	26	223	No	40	32.5	n/a	n/a	0.01	NP
Selenium, Dissolved (mg/L)	MW-04	0	39	223	No	40	82.5	n/a	n/a	0.01	NP
Selenium, Dissolved (mg/L)	MW-06	-0.00...	-155	-223	No	40	27.5	n/a	n/a	0.01	NP
Selenium, Dissolved (mg/L)	MW-07	0	26	223	No	40	82.5	n/a	n/a	0.01	NP
Selenium, Total (mg/L)	MW-03	0.000...	5	30	No	10	10	n/a	n/a	0.01	NP
Selenium, Total (mg/L)	MW-04	0	17	30	No	10	80	n/a	n/a	0.01	NP
Sulfate (mg/L)	MW-01	-4.6	-30	-58	No	16	0	n/a	n/a	0.01	NP
Sulfate (mg/L)	MW-02	-7.826	-175	-176	No	34	0	n/a	n/a	0.01	NP
Sulfate (mg/L)	**MW-03**	**-6.868**	**-3.501**	**-2.58**	**Yes**	**41**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Sulfate (mg/L)	MW-04	-5.06	-2.356	-2.58	No	41	0	n/a	n/a	0.01	NP
Sulfate (mg/L)	MW-06	-0.4307	-49	-223	No	40	0	n/a	n/a	0.01	NP
Sulfate (mg/L)	MW-07	-5.456	-215	-223	No	40	0	n/a	n/a	0.01	NP
Thallium, Dissolved (mg/L)	MW-01	0	0	58	No	16	100	n/a	n/a	0.01	NP
Thallium, Dissolved (mg/L)	MW-02	0	0	176	No	34	100	n/a	n/a	0.01	NP
Thallium, Dissolved (mg/L)	MW-03	0	0	223	No	40	100	n/a	n/a	0.01	NP
Thallium, Dissolved (mg/L)	MW-04	0	0	223	No	40	100	n/a	n/a	0.01	NP
Thallium, Dissolved (mg/L)	MW-06	0	0	223	No	40	100	n/a	n/a	0.01	NP
Thallium, Dissolved (mg/L)	MW-07	0	0	223	No	40	100	n/a	n/a	0.01	NP
Thallium, Total (mg/L)	MW-03	0	0	30	No	10	100	n/a	n/a	0.01	NP
Thallium, Total (mg/L)	MW-04	0	0	30	No	10	100	n/a	n/a	0.01	NP
Total Dissolved Solids (mg/L)	MW-01	12.34	24	58	No	16	0	n/a	n/a	0.01	NP
Total Dissolved Solids (mg/L)	MW-02	3.834	21	176	No	34	0	n/a	n/a	0.01	NP
Total Dissolved Solids (mg/L)	**MW-03**	**-27.74**	**-4.189**	**-2.58**	**Yes**	**41**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Total Dissolved Solids (mg/L)	**MW-04**	**-17.39**	**-2.826**	**-2.58**	**Yes**	**41**	**0**	**n/a**	**n/a**	**0.01**	**NP**
Total Dissolved Solids (mg/L)	MW-06	0	-4	-223	No	40	0	n/a	n/a	0.01	NP
Total Dissolved Solids (mg/L)	MW-07	-9.923	-96	-223	No	40	0	n/a	n/a	0.01	NP

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-01



n = 16

Slope = 0
units per year.

Mann-Kendall
statistic = -6
critical = -58

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

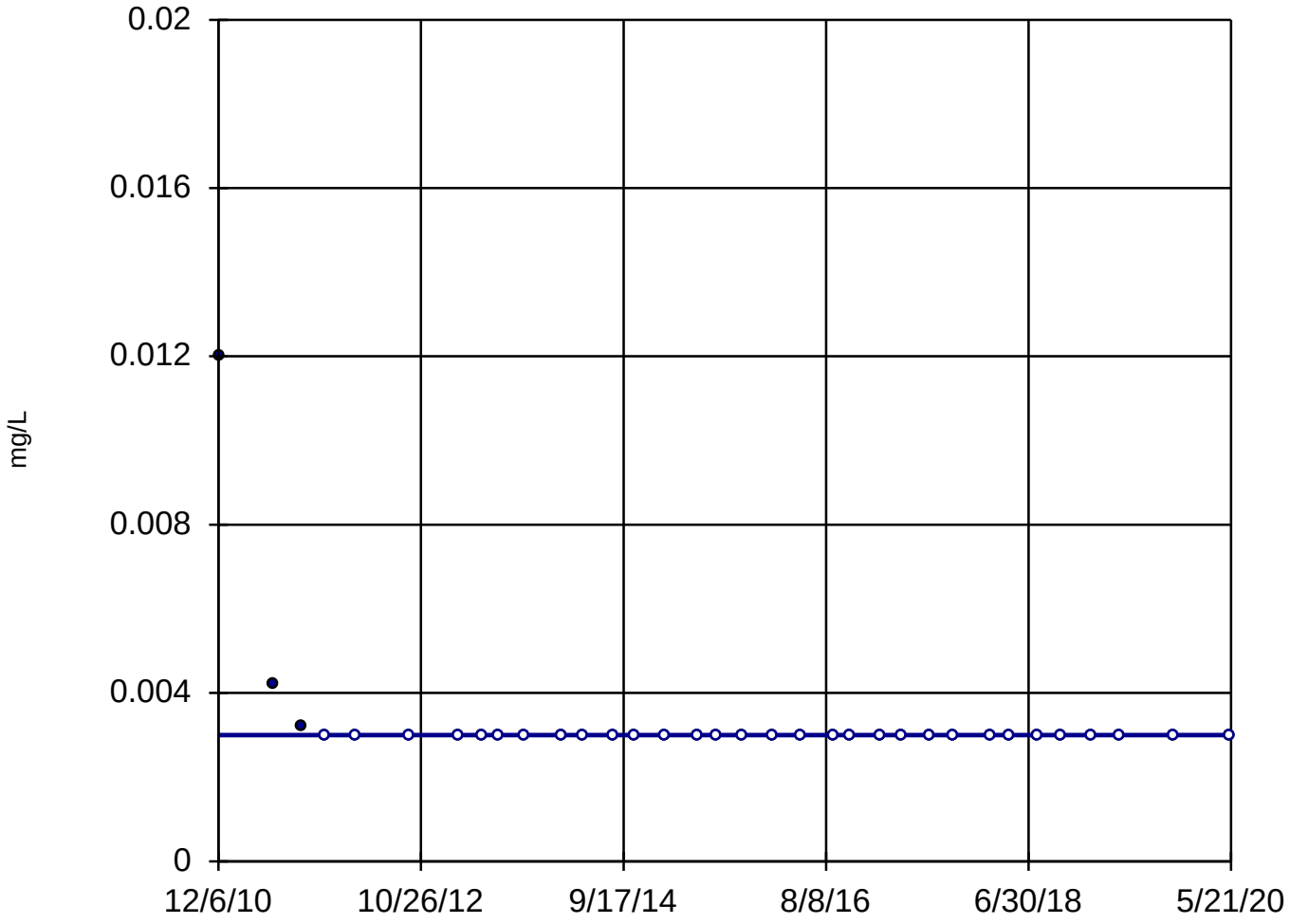
Constituent: Antimony, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = -96
critical = -176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

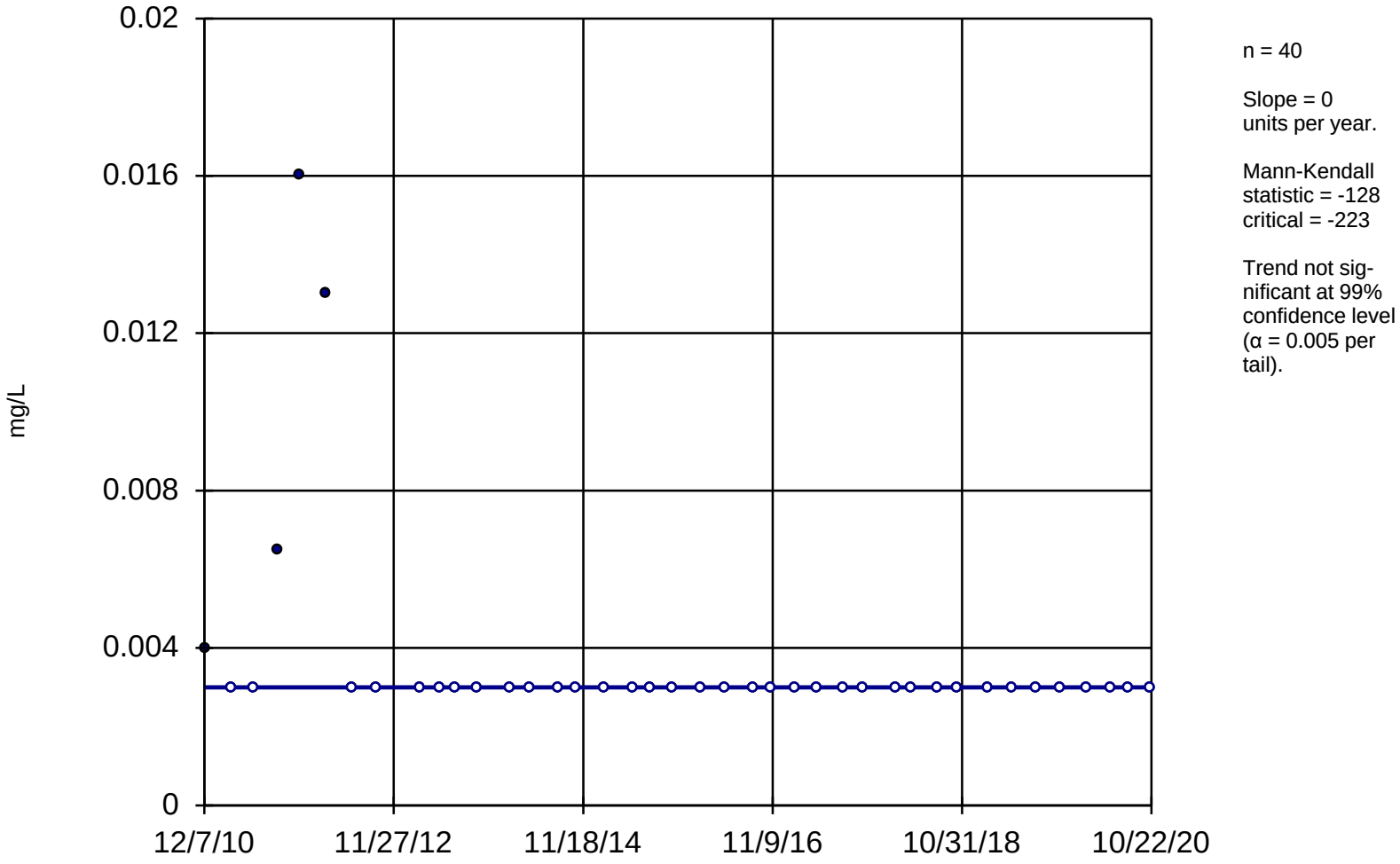
Constituent: Antimony, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-03



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -128
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

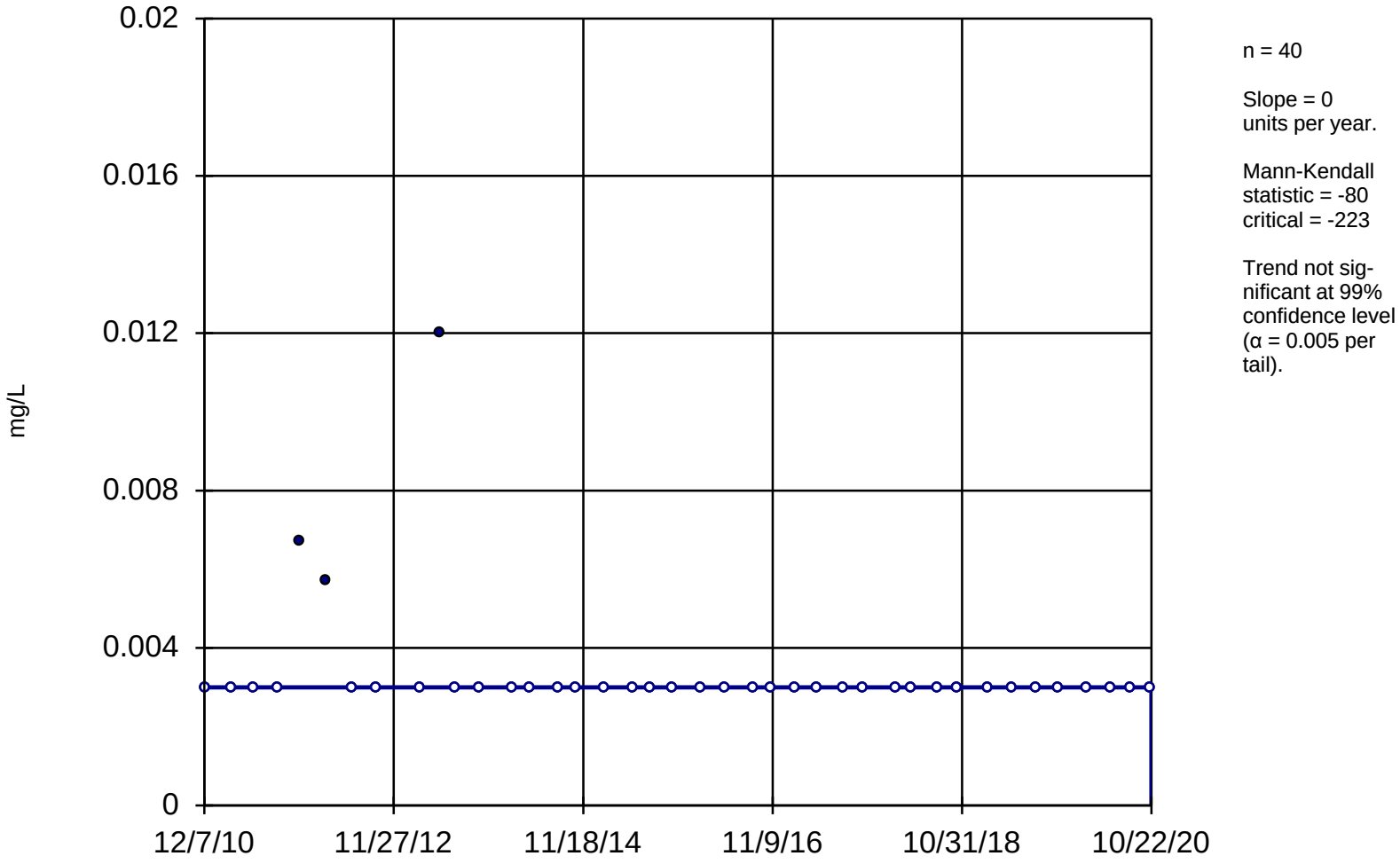
Constituent: Antimony, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -80
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

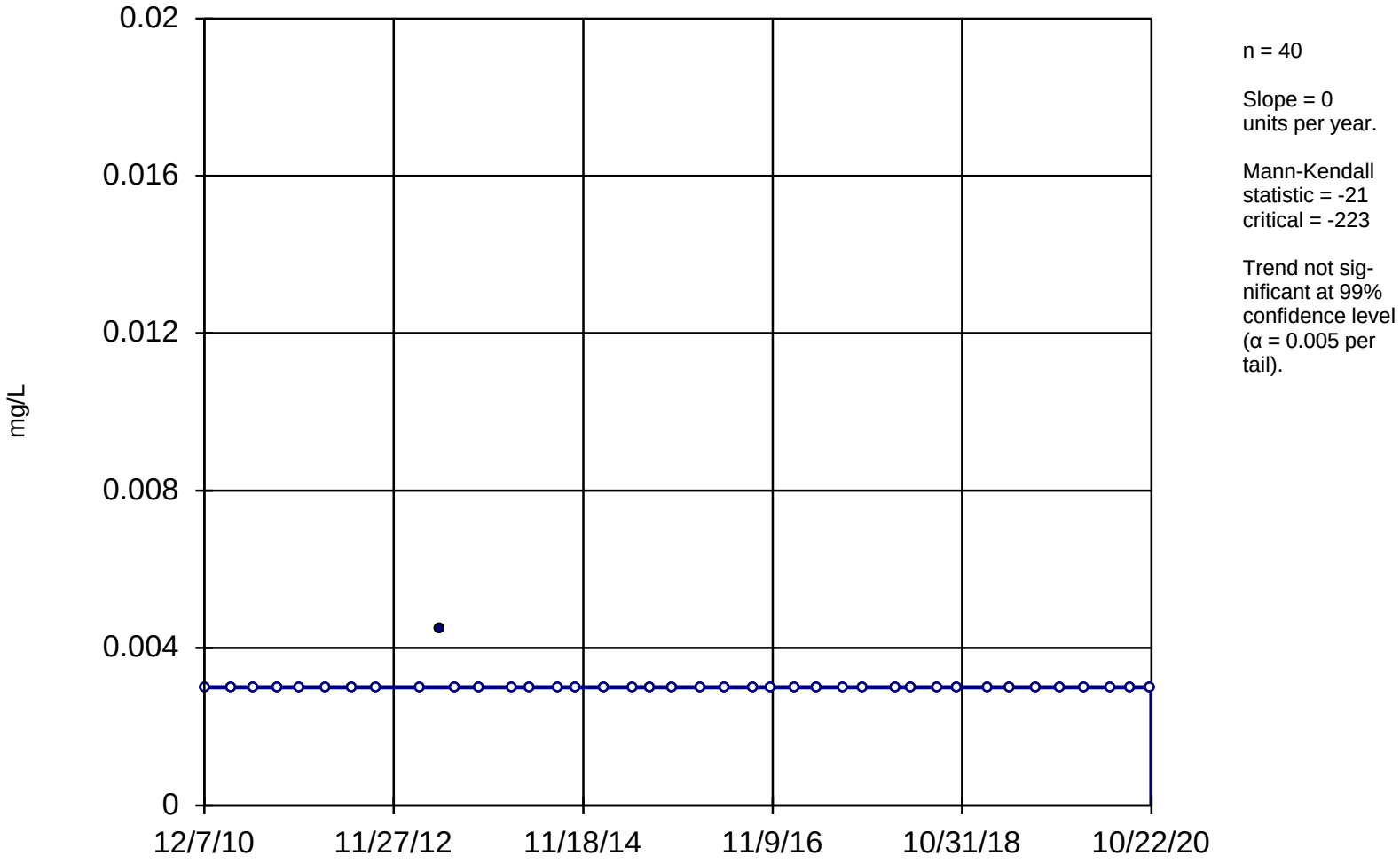
Constituent: Antimony, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -21
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

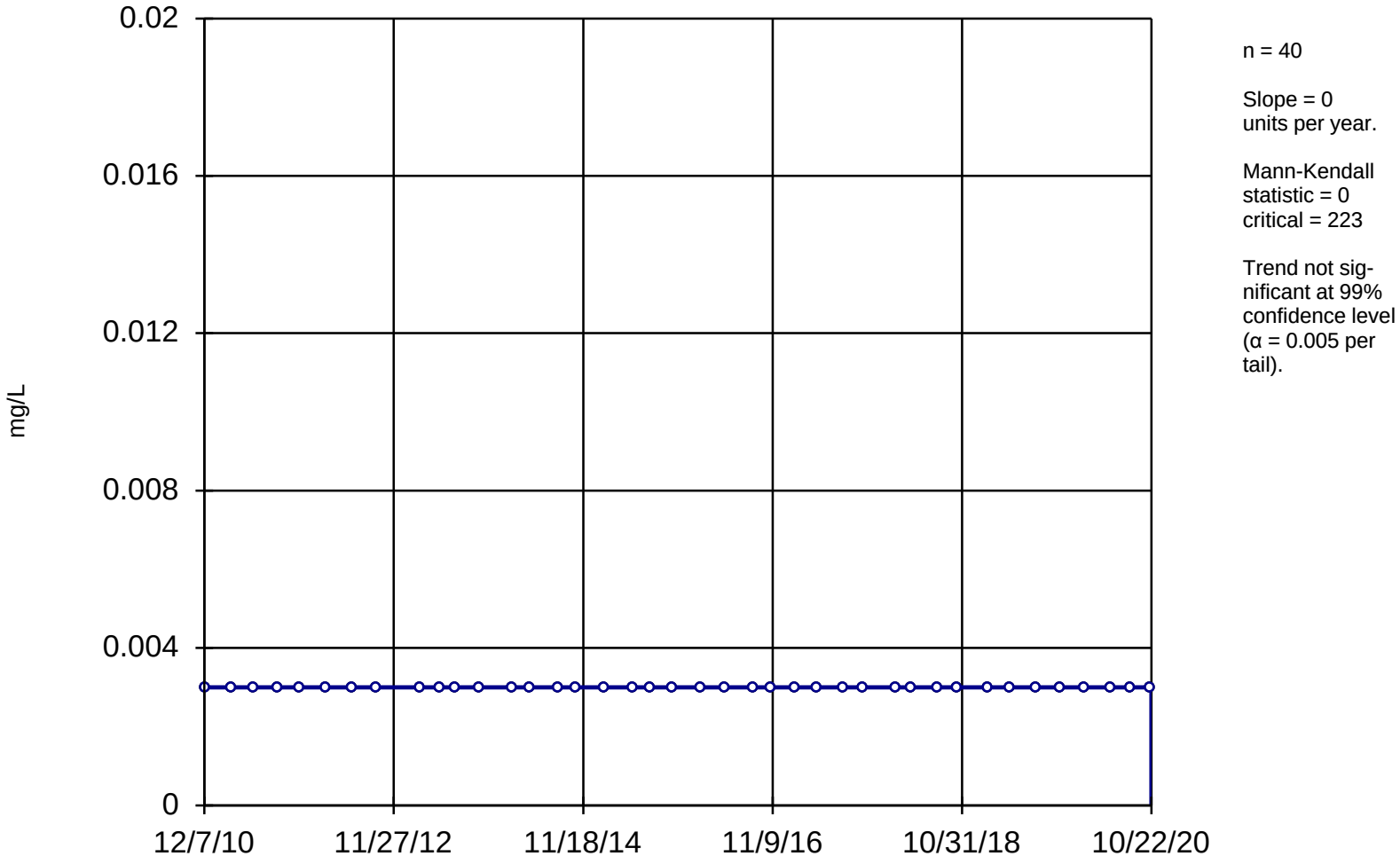
Constituent: Antimony, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

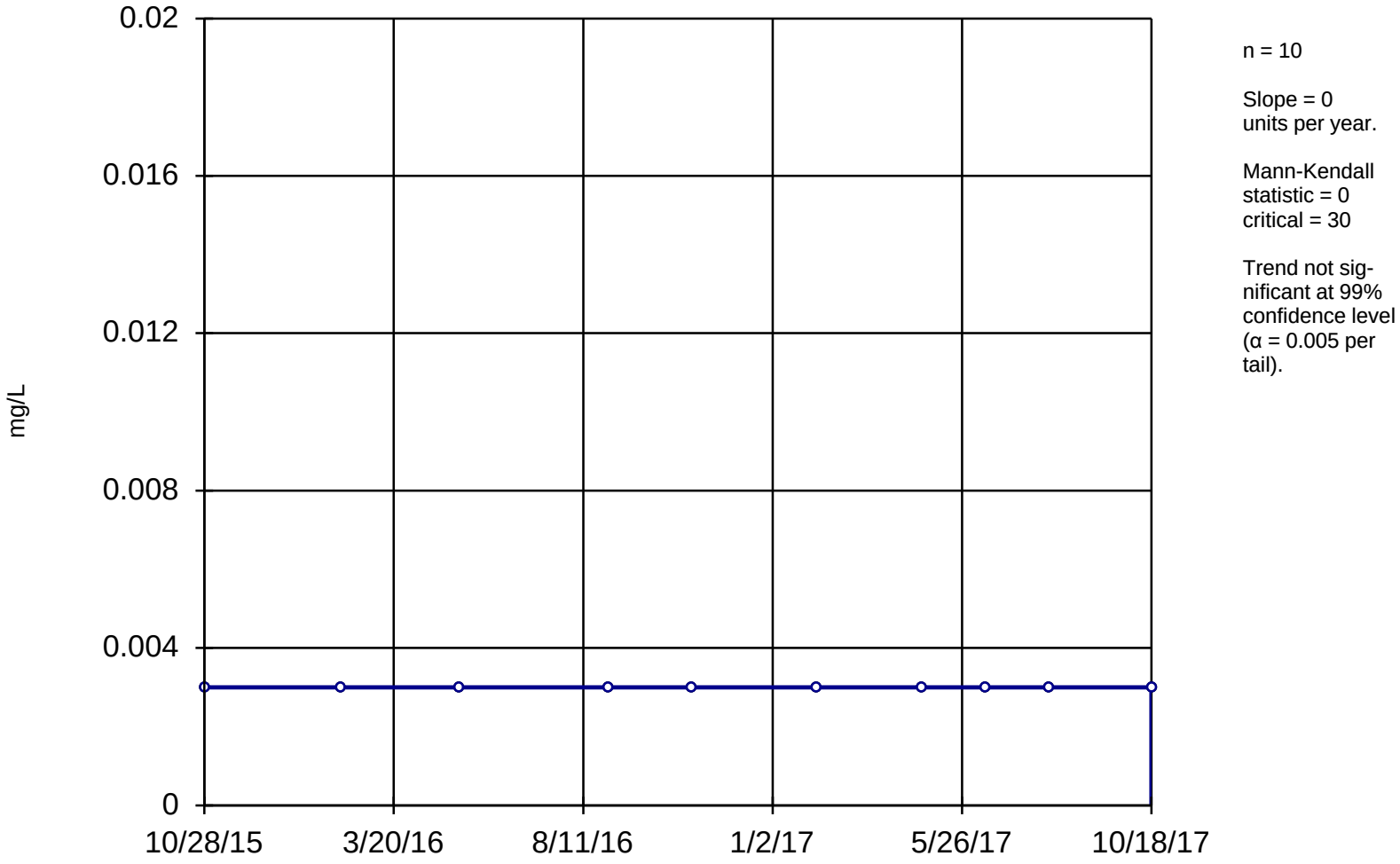
Constituent: Antimony, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



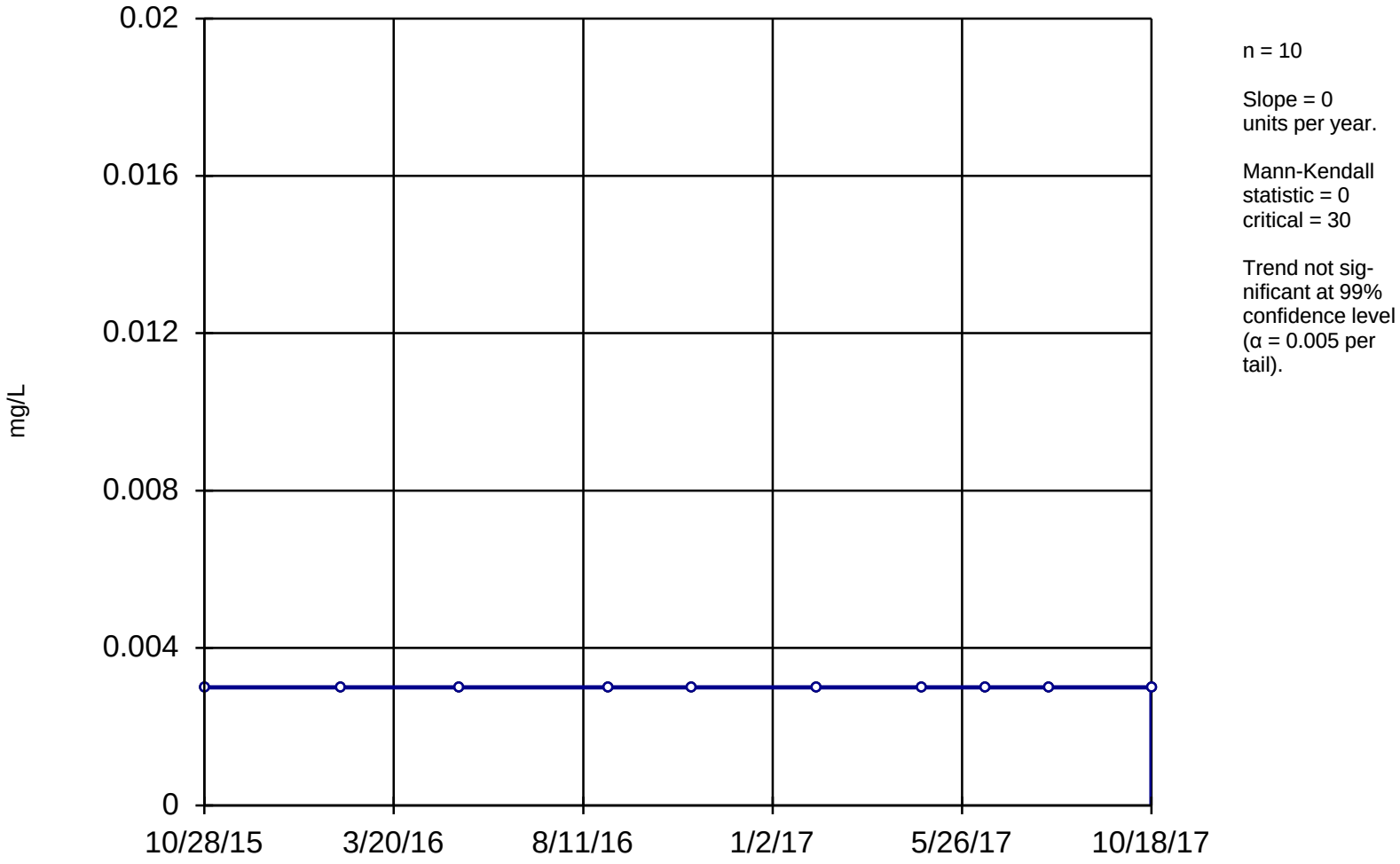
Constituent: Antimony, Total Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



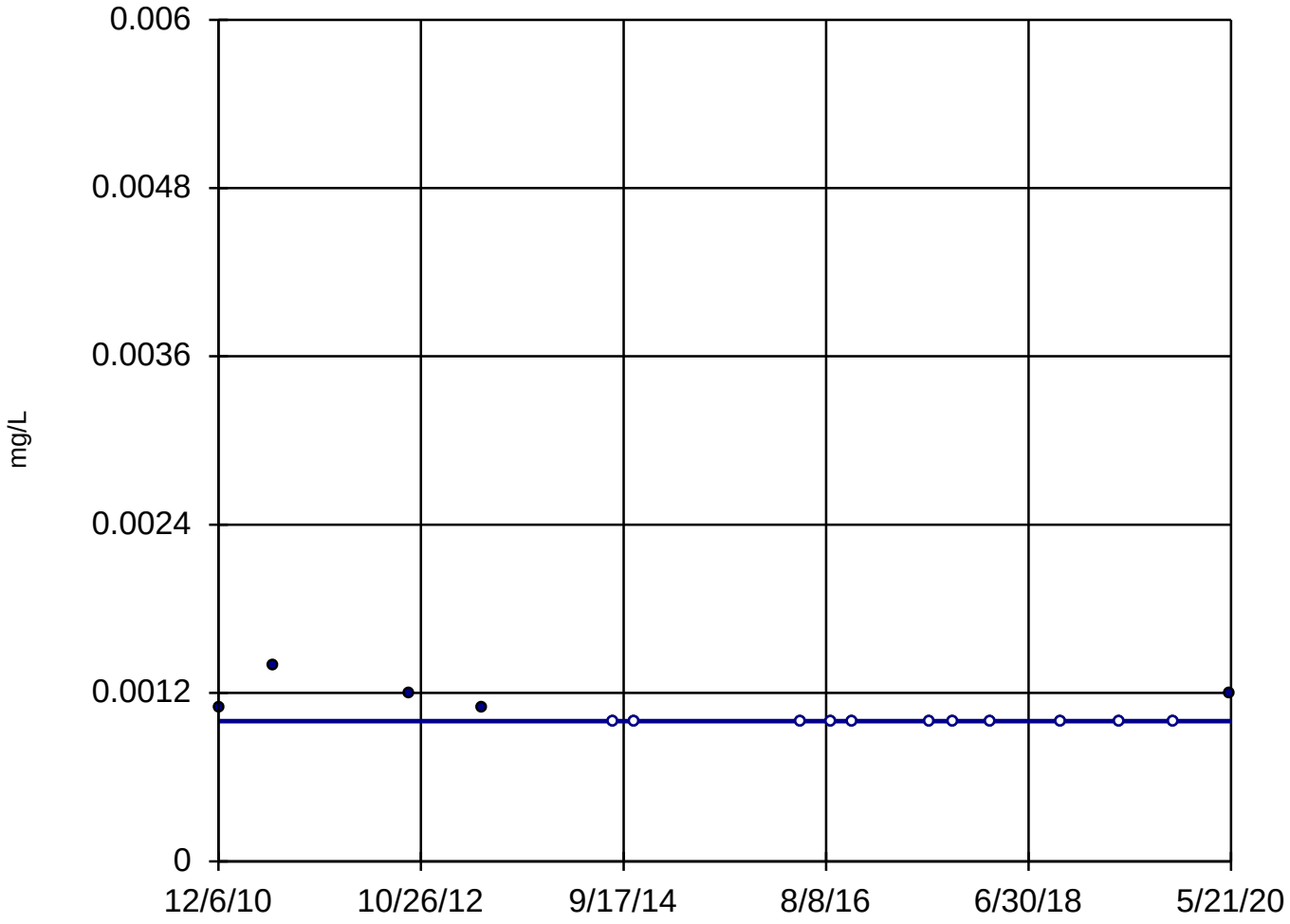
Constituent: Antimony, Total Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-01



n = 16

Slope = 0
units per year.

Mann-Kendall
statistic = -33
critical = -58

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

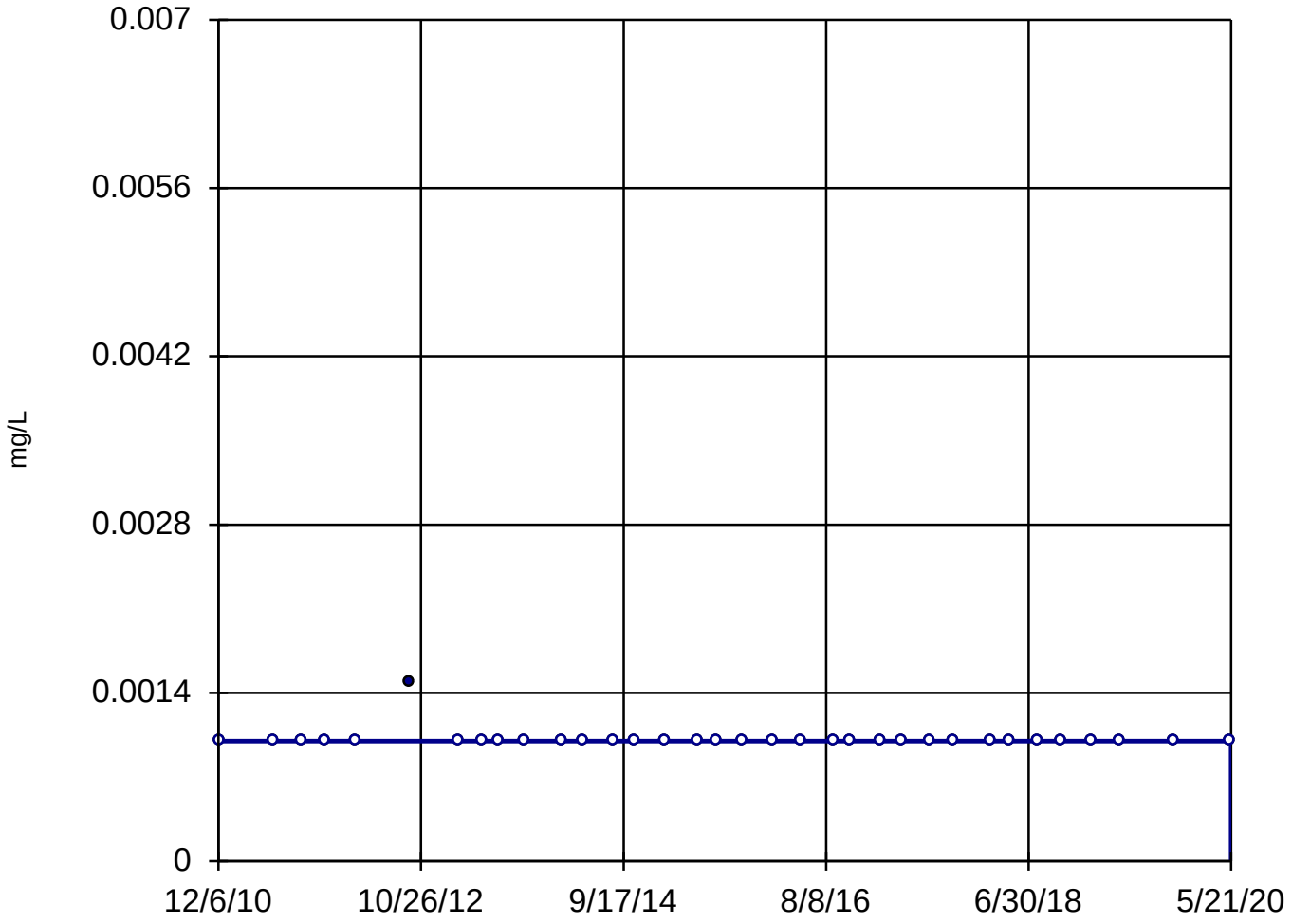
Constituent: Arsenic, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = -23
critical = -176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

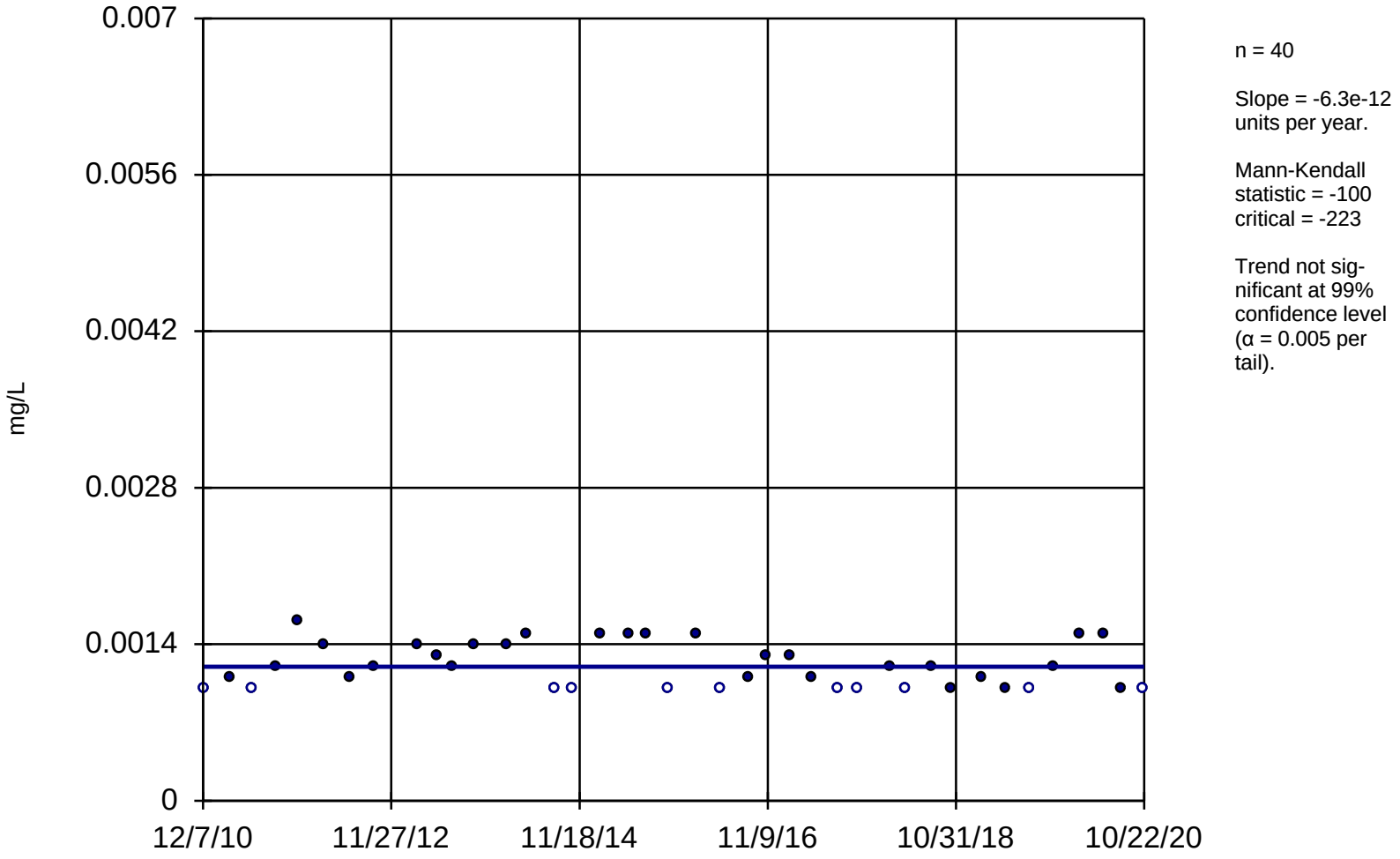
Constituent: Arsenic, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 40

Slope = -6.3e-12 units per year.

Mann-Kendall statistic = -100
critical = -223

Trend not significant at 99% confidence level (α = 0.005 per tail).

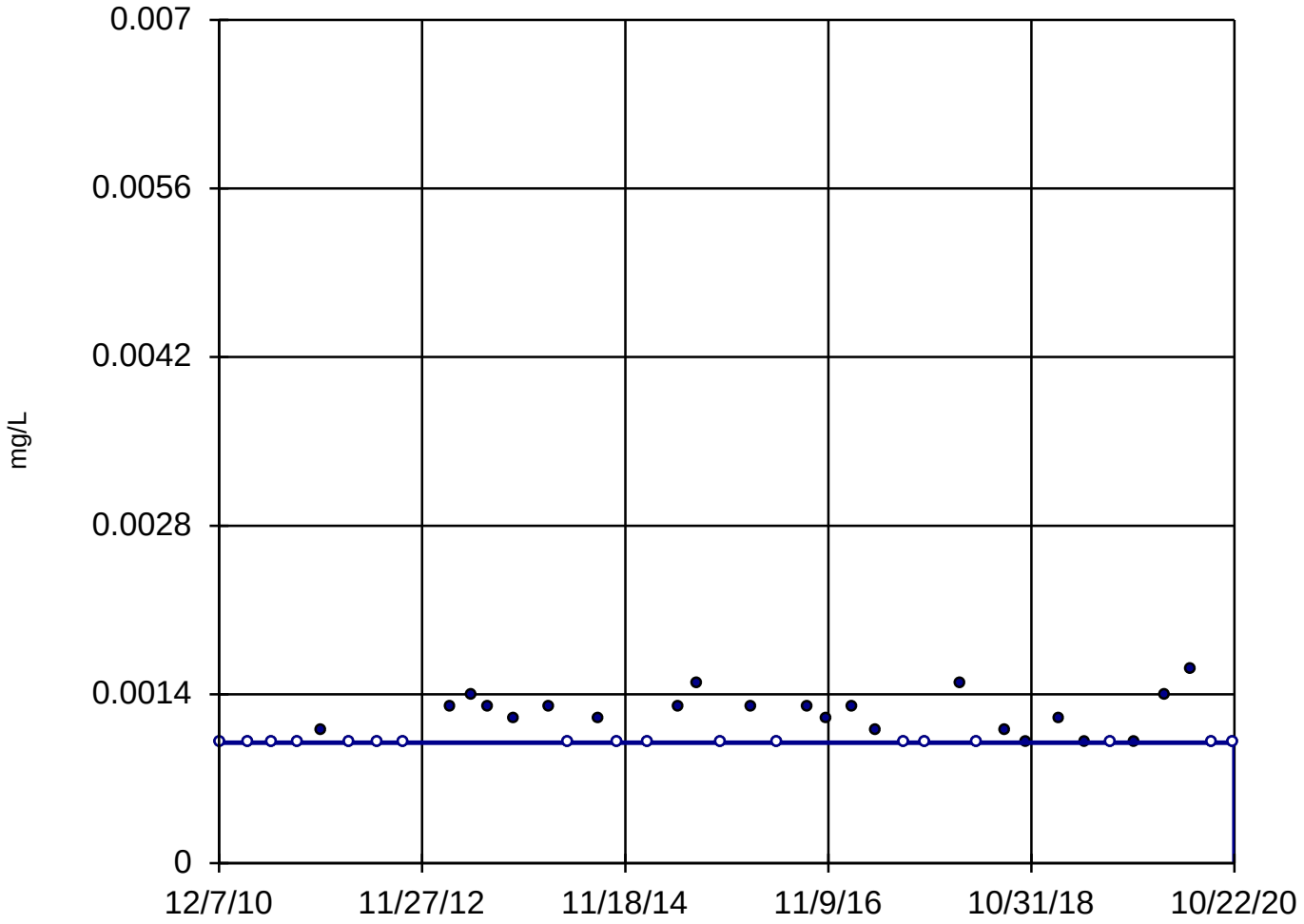
Constituent: Arsenic, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 36
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

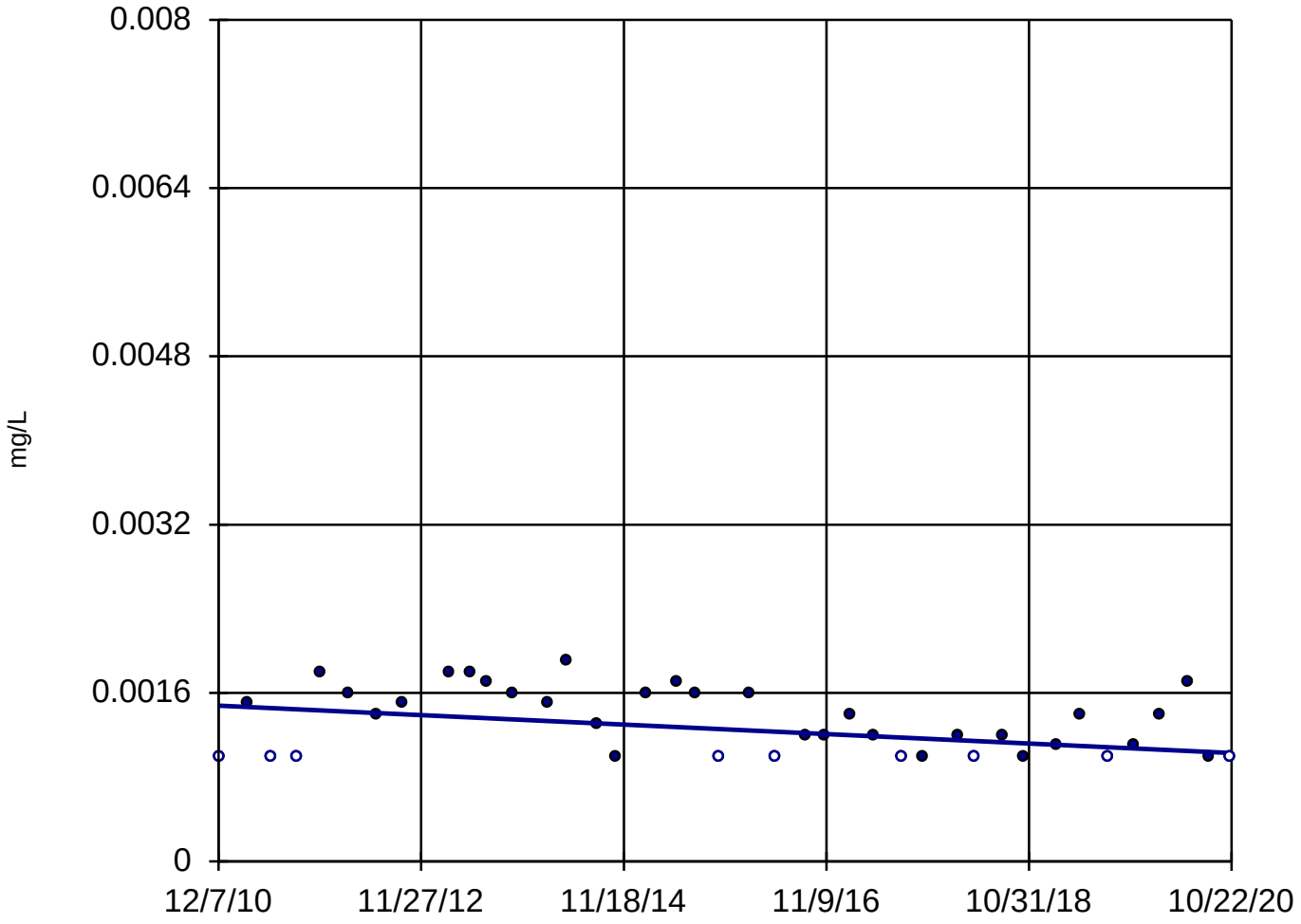
Constituent: Arsenic, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = -0.00004546 units per year.

Mann-Kendall statistic = -196
critical = -223

Trend not significant at 99% confidence level (α = 0.005 per tail).

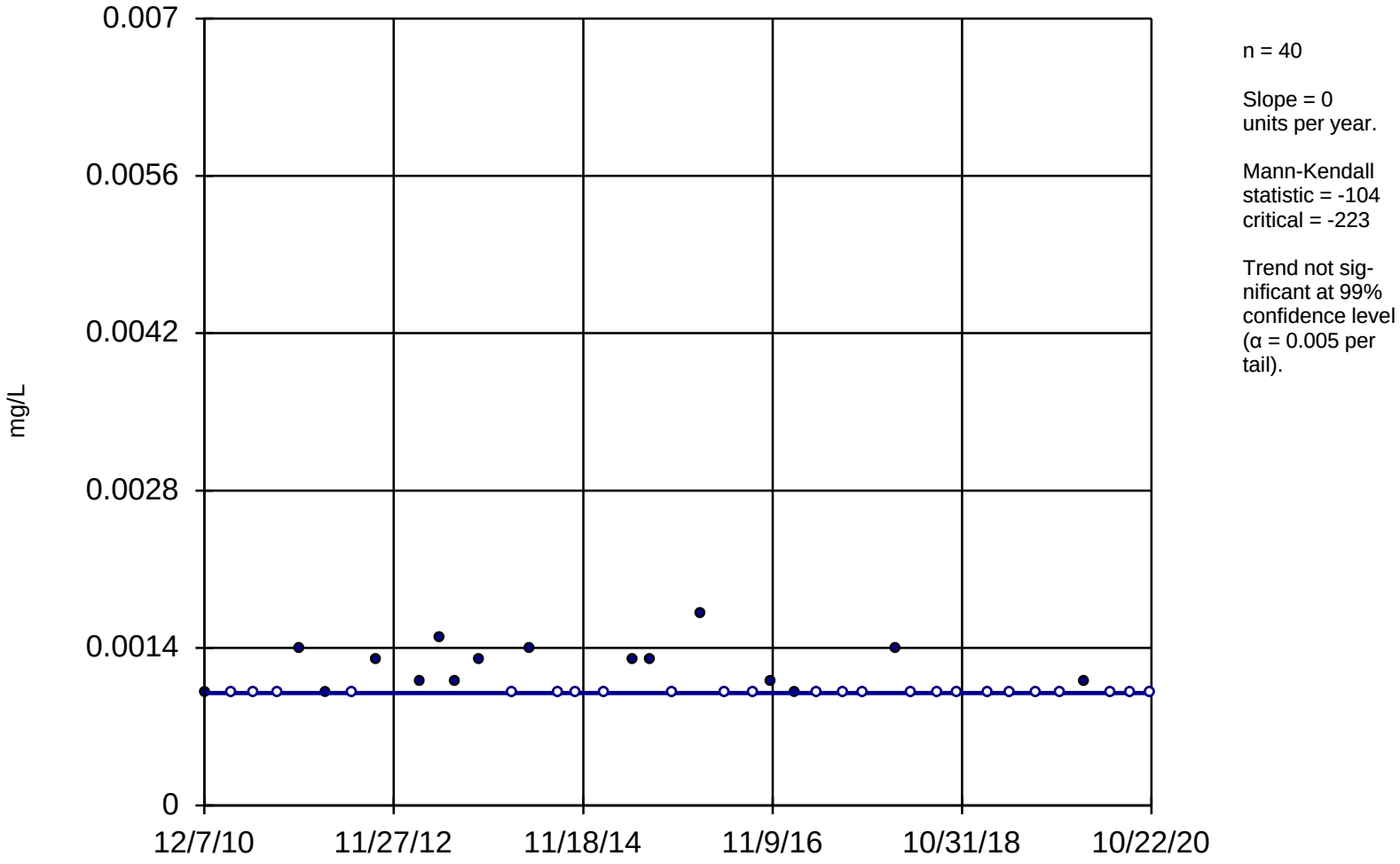
Constituent: Arsenic, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -104
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

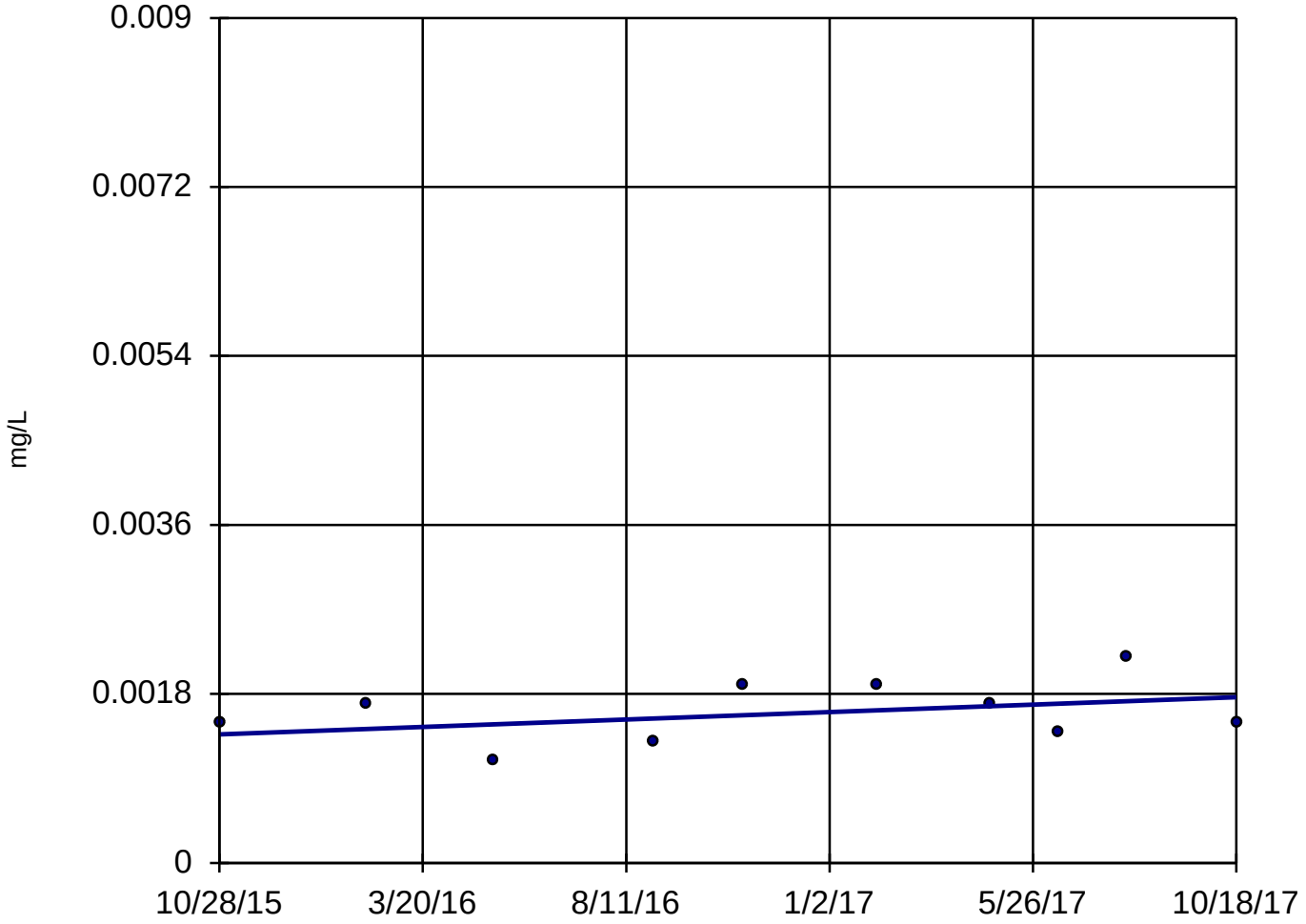
Constituent: Arsenic, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-03



n = 10

Slope = 0.0002017 units per year.

Mann-Kendall statistic = 10
critical = 30

Trend not significant at 99% confidence level (α = 0.005 per tail).

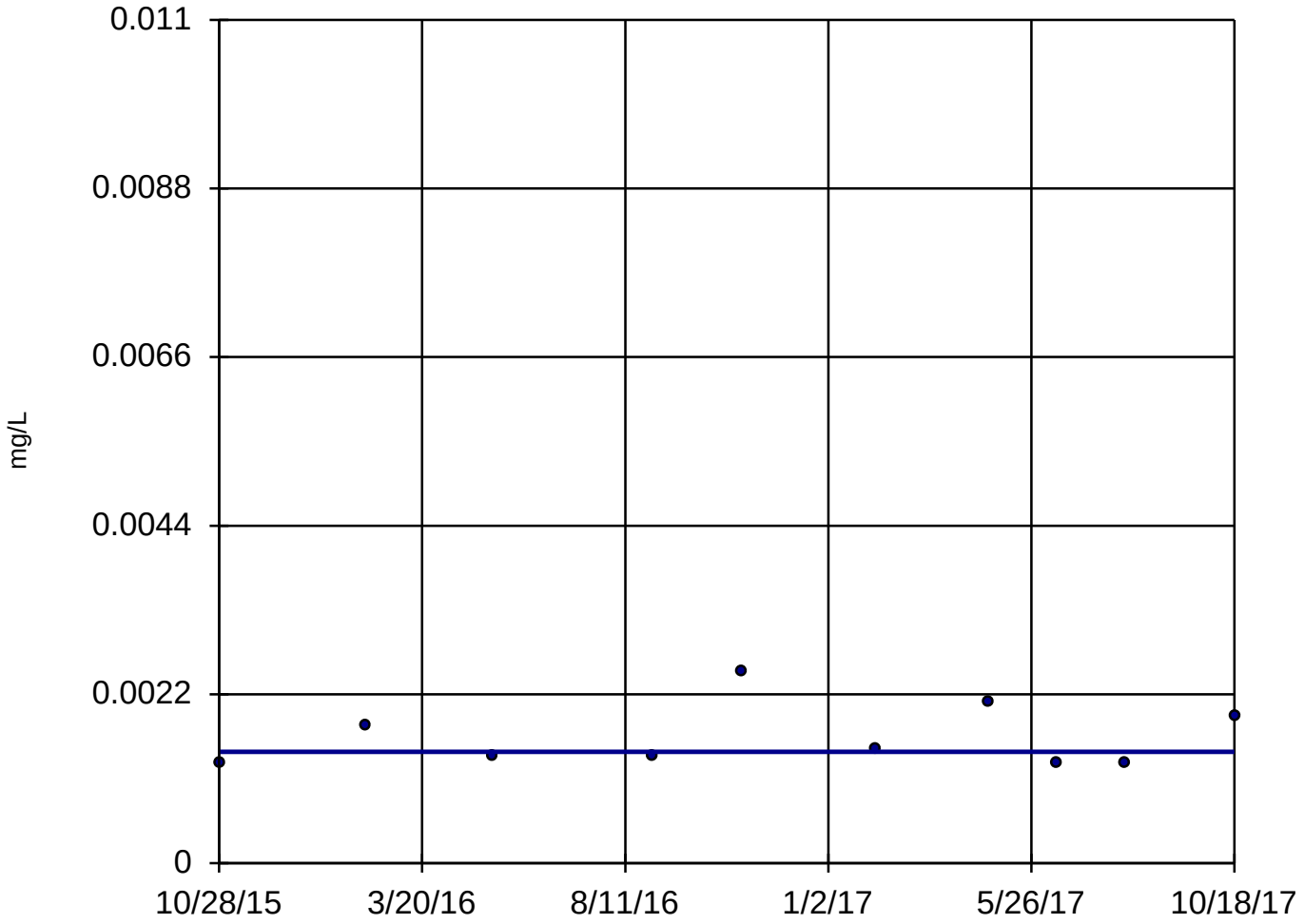
Constituent: Arsenic, Total Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-04



n = 10

Slope = 0
units per year.

Mann-Kendall
statistic = 3
critical = 30

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

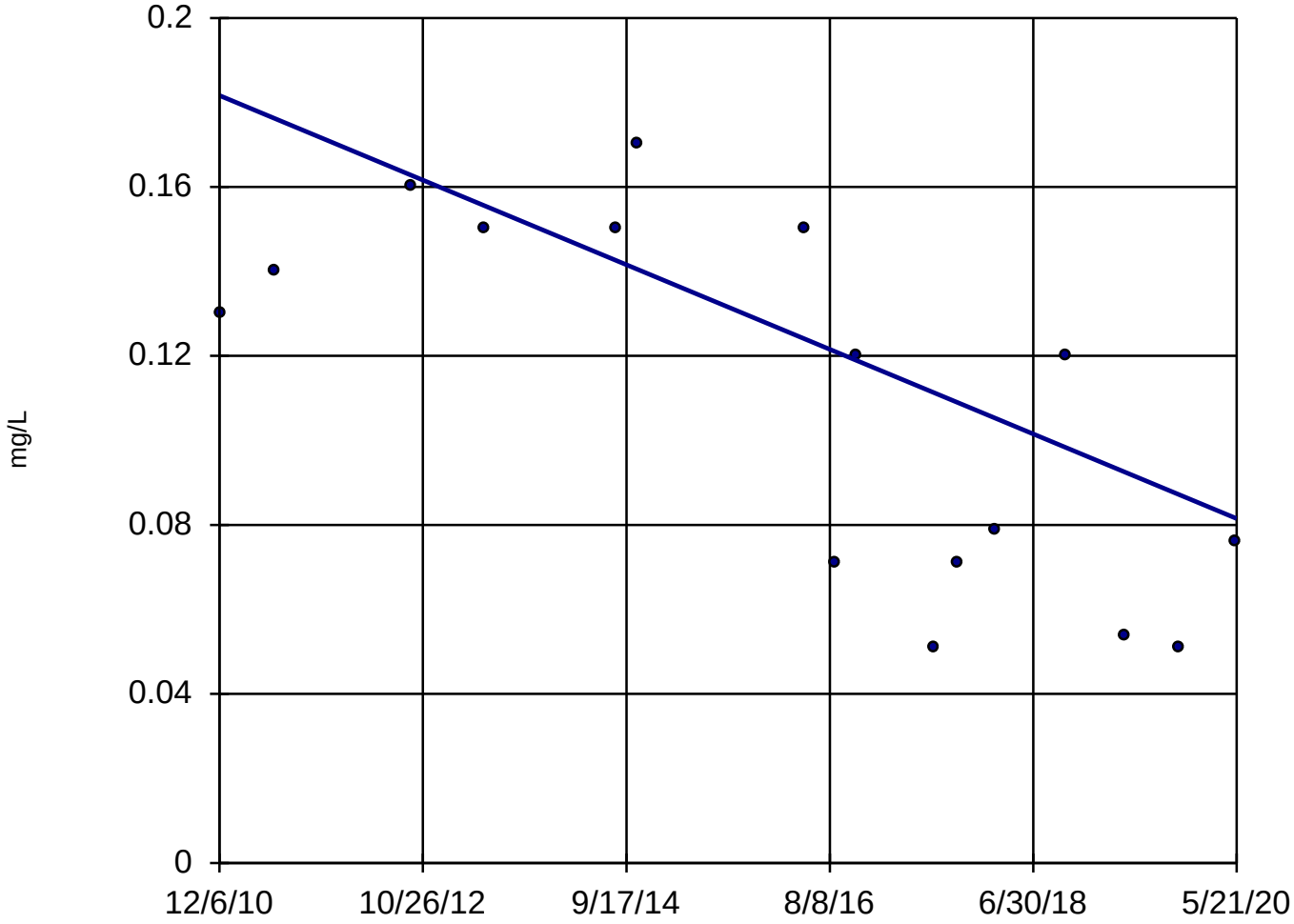
Constituent: Arsenic, Total Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-01



n = 16

Slope = -0.01058 units per year.

Mann-Kendall statistic = -56
critical = -58

Trend not significant at 99% confidence level (α = 0.005 per tail).

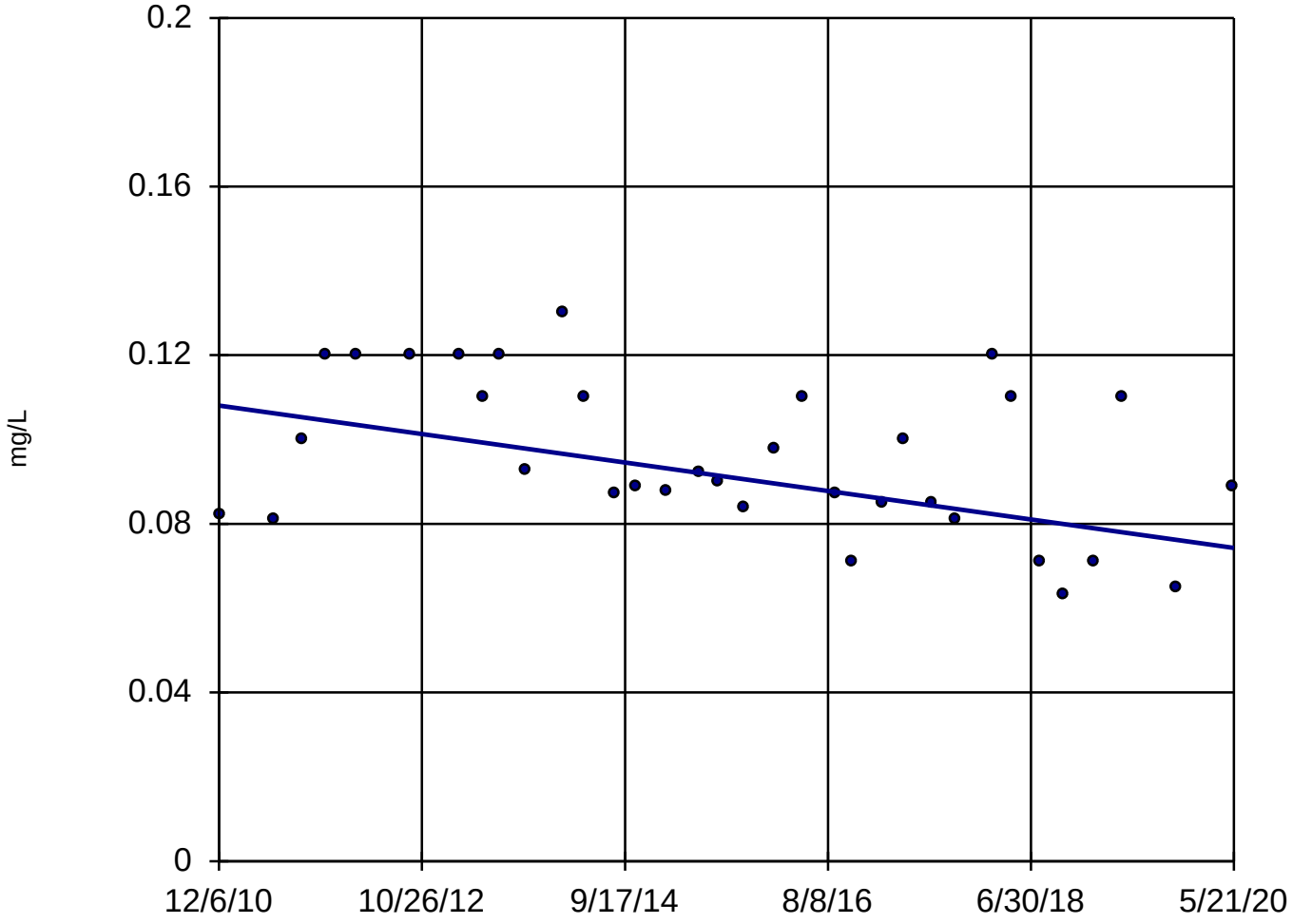
Constituent: Barium, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-02



n = 34

Slope = -0.003564 units per year.

Mann-Kendall statistic = -178
critical = -176

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

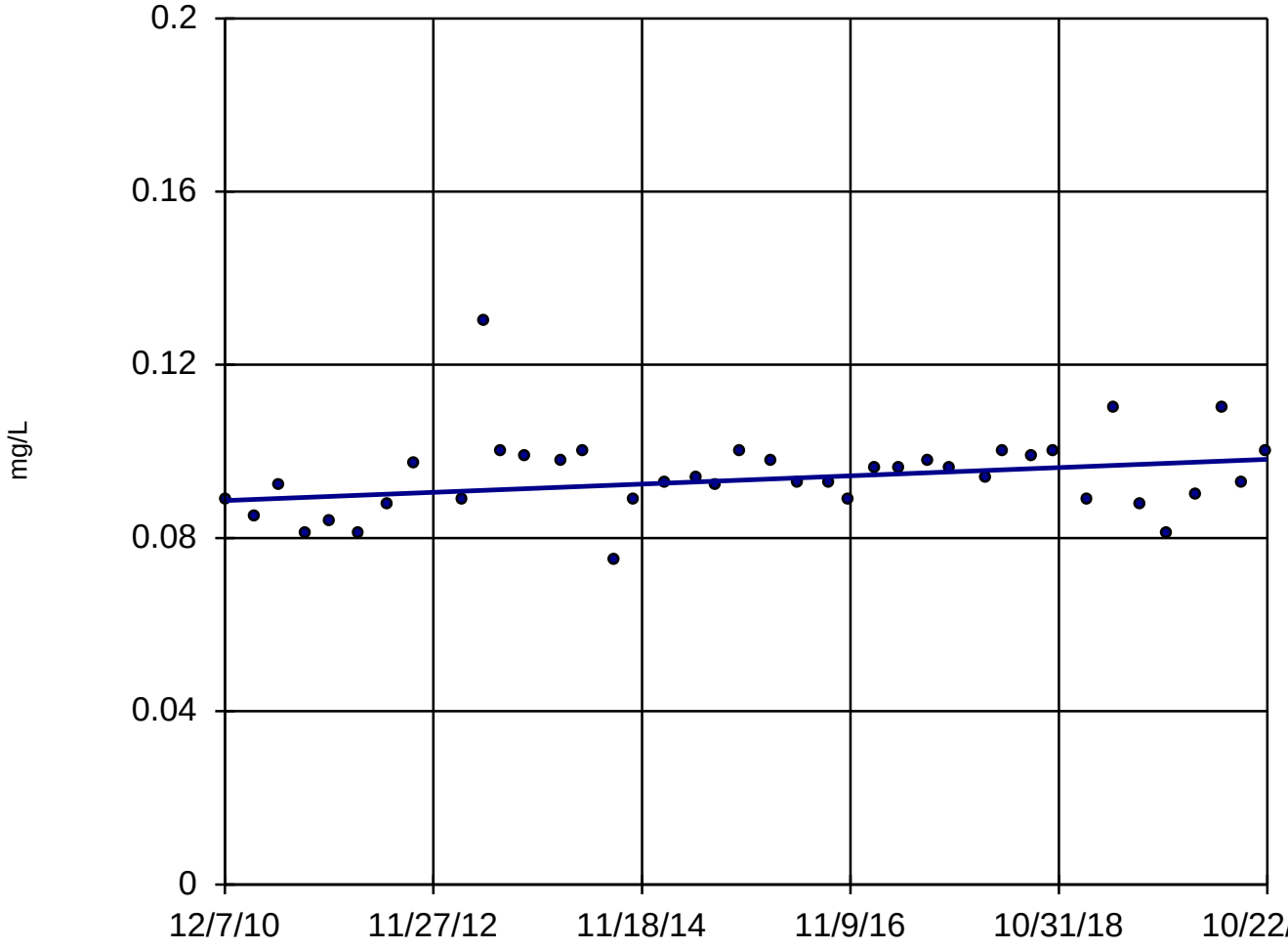
Constituent: Barium, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-03



n = 40

Slope = 0.0009656 units per year.

Mann-Kendall statistic = 177
critical = 223

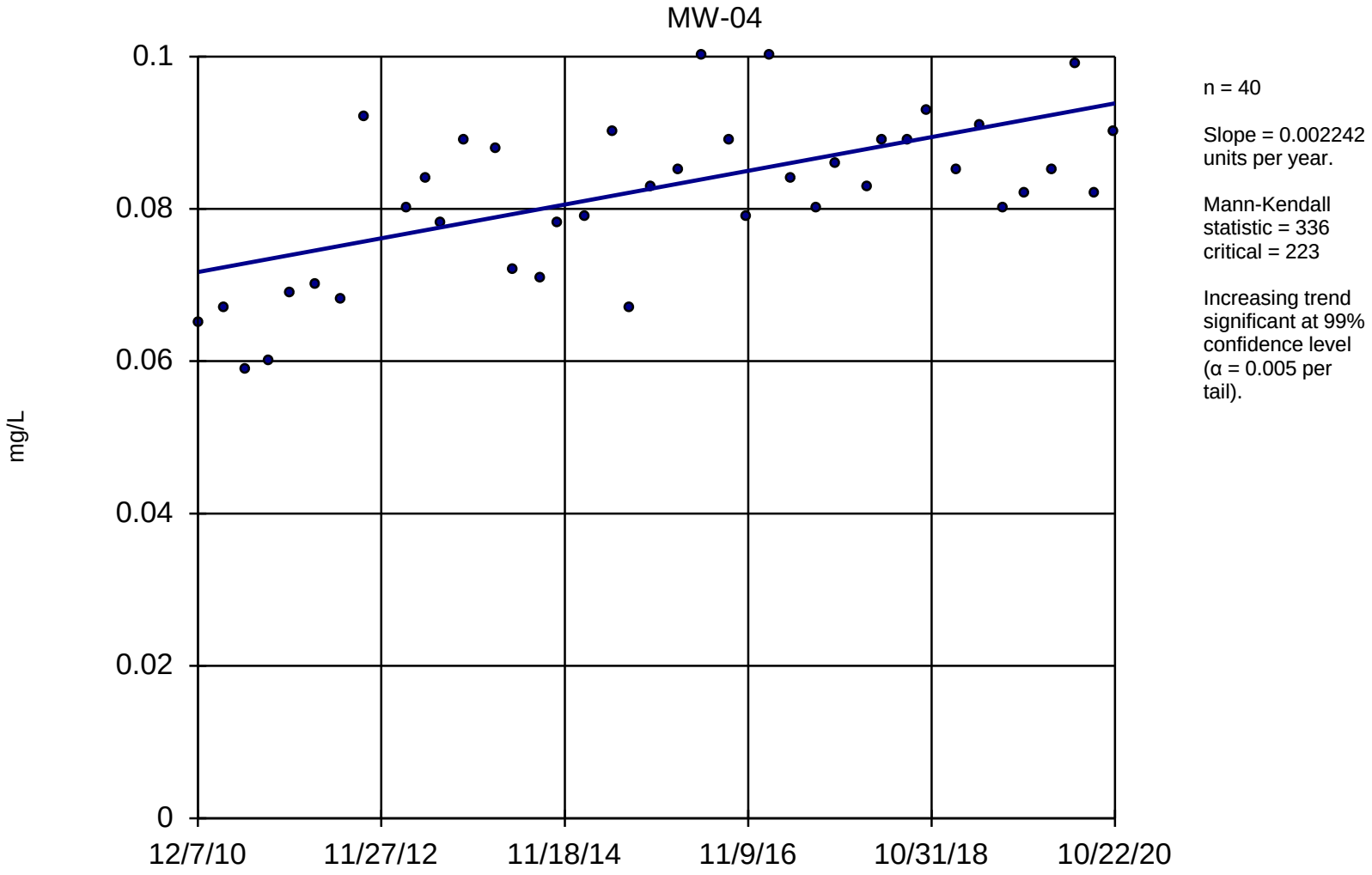
Trend not significant at 99% confidence level (α = 0.005 per tail).

Constituent: Barium, Dissolved Analysis Run 4/2/2021 11:00 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator



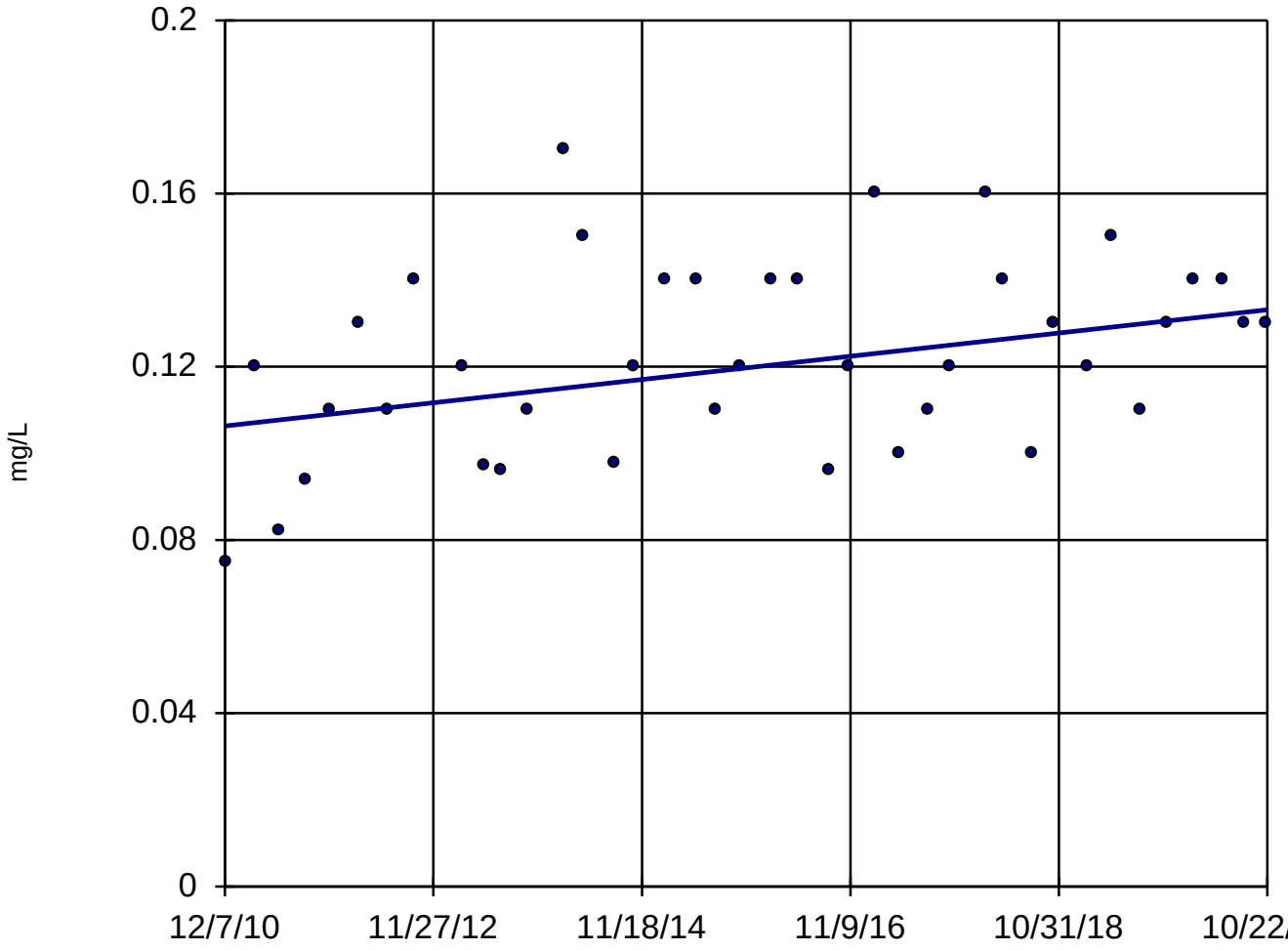
Constituent: Barium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-06



n = 40

Slope = 0.002711 units per year.

Mann-Kendall statistic = 206
critical = 223

Trend not significant at 99% confidence level (α = 0.005 per tail).

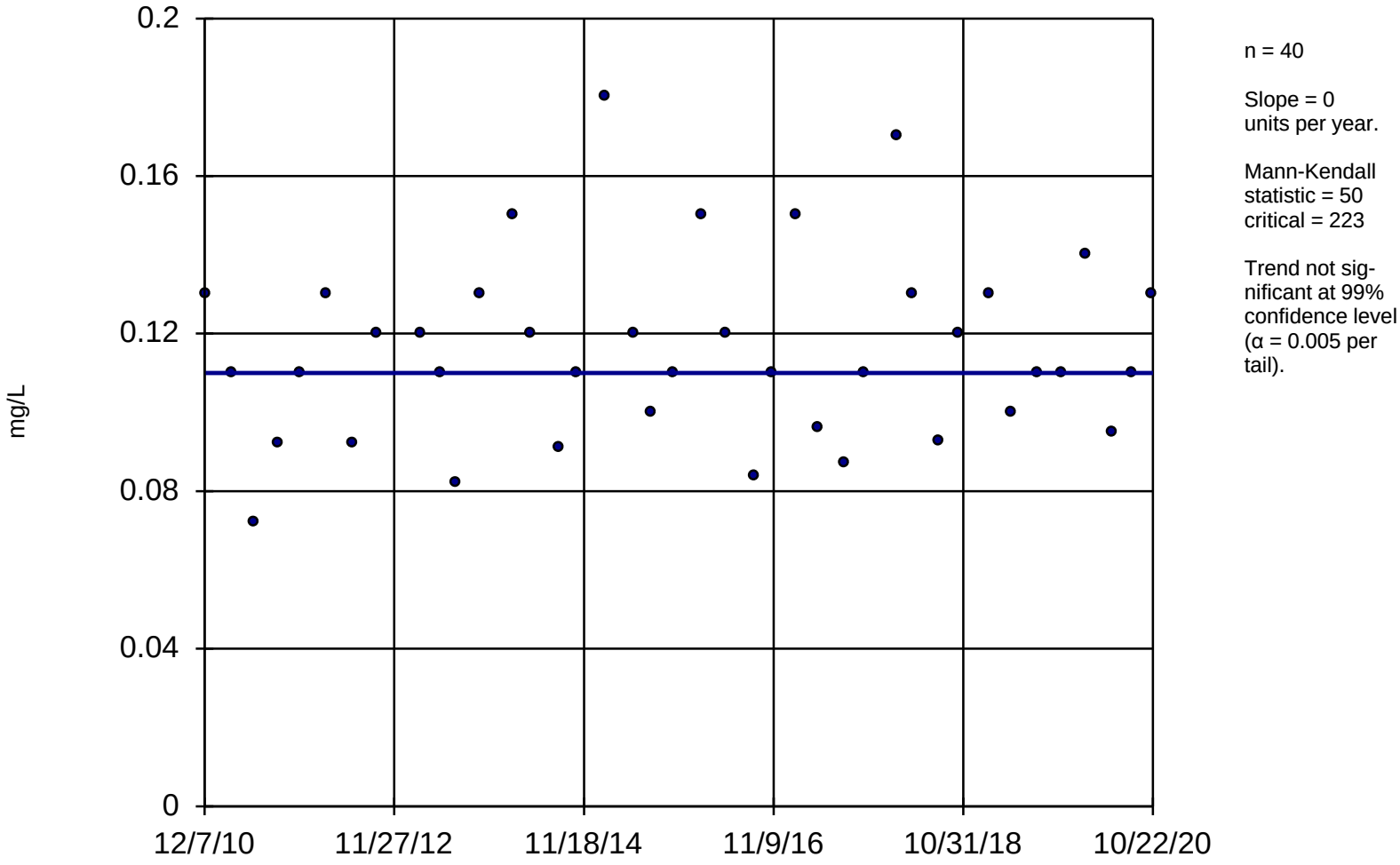
Constituent: Barium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 50
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

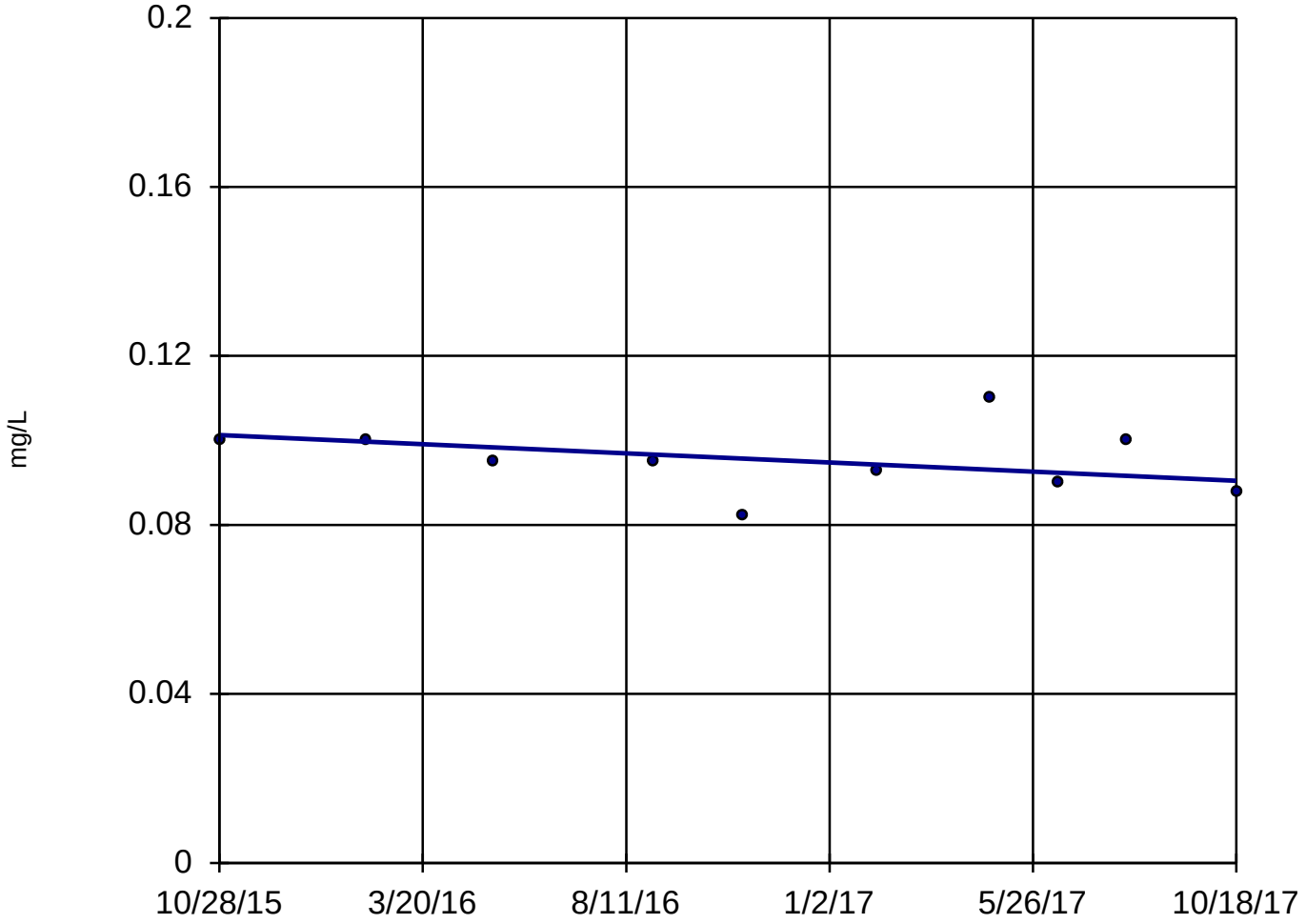
Constituent: Barium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-03



n = 10

Slope = -0.005471 units per year.

Mann-Kendall statistic = -13
critical = -30

Trend not significant at 99% confidence level (α = 0.005 per tail).

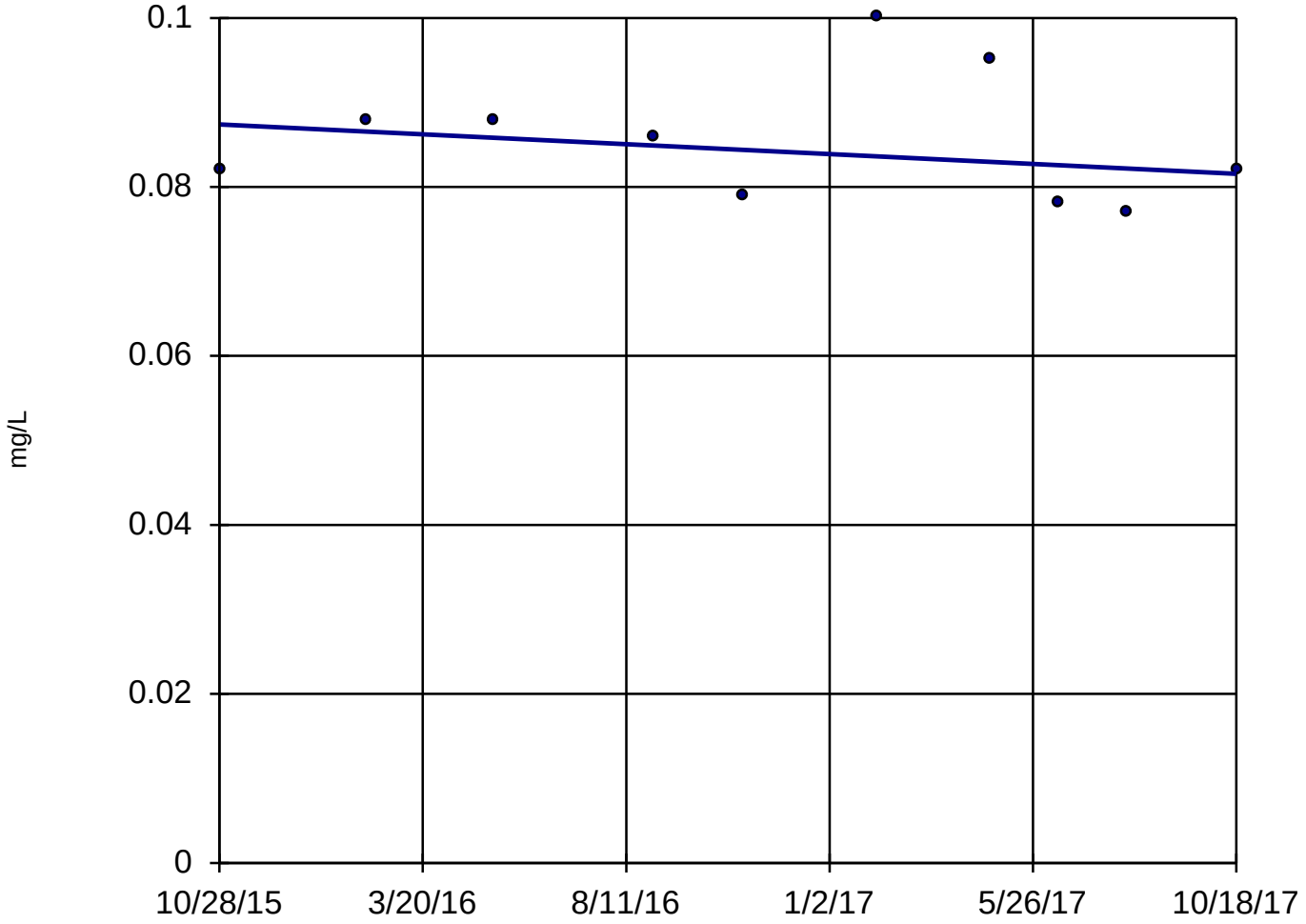
Constituent: Barium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-04



n = 10

Slope = -0.002951 units per year.

Mann-Kendall statistic = -11
critical = -30

Trend not significant at 99% confidence level (α = 0.005 per tail).

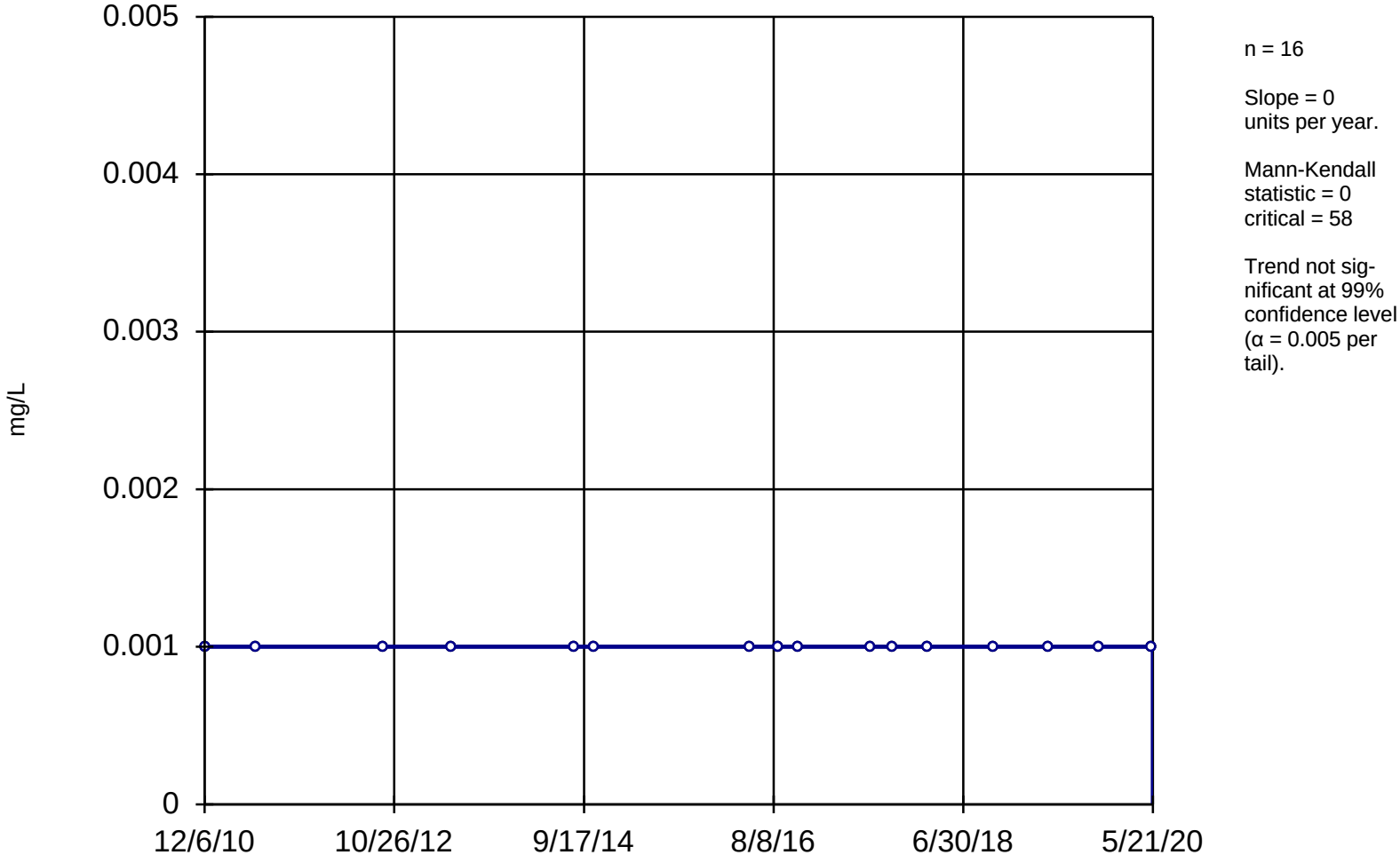
Constituent: Barium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-01



n = 16

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 58

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

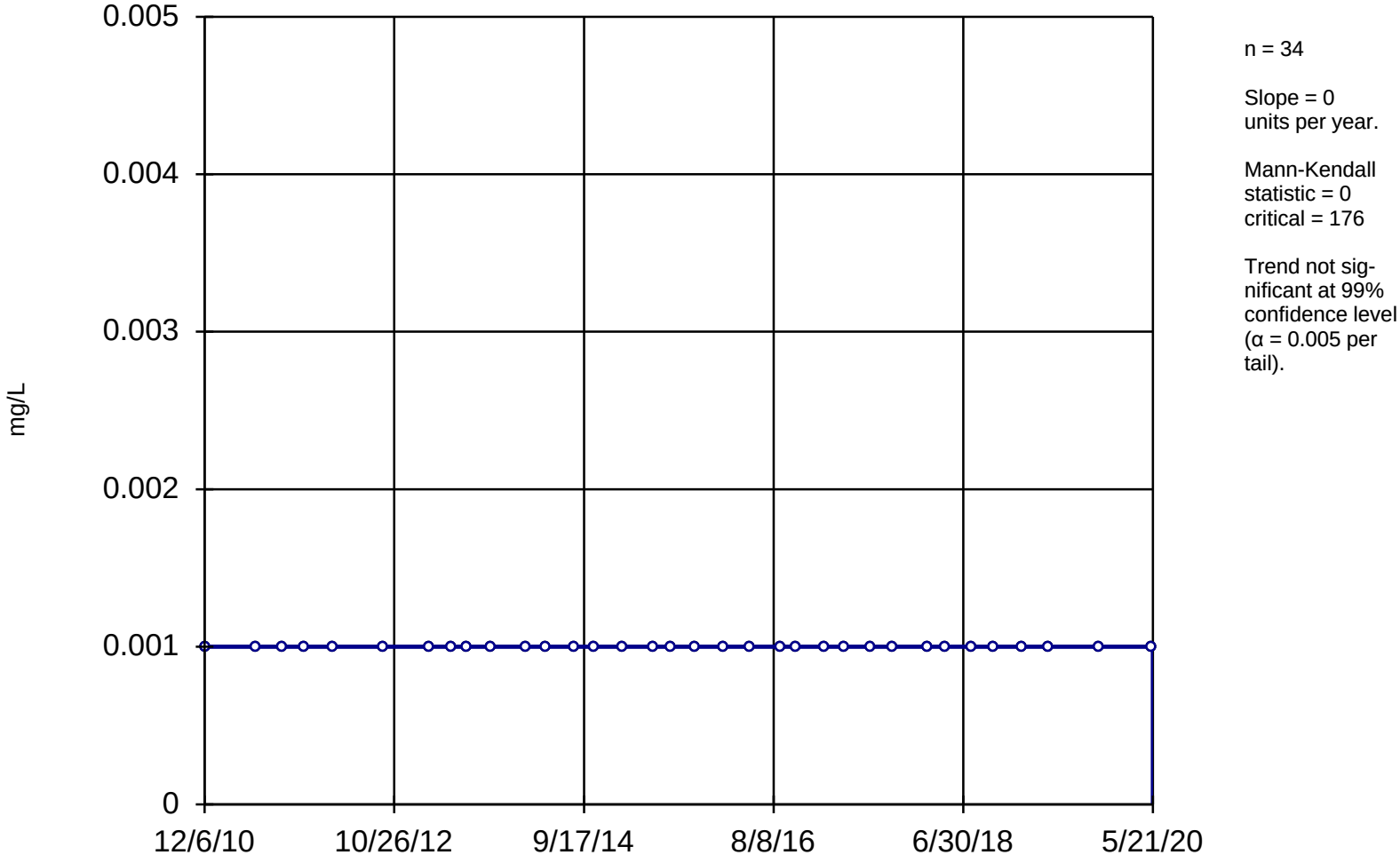
Constituent: Beryllium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

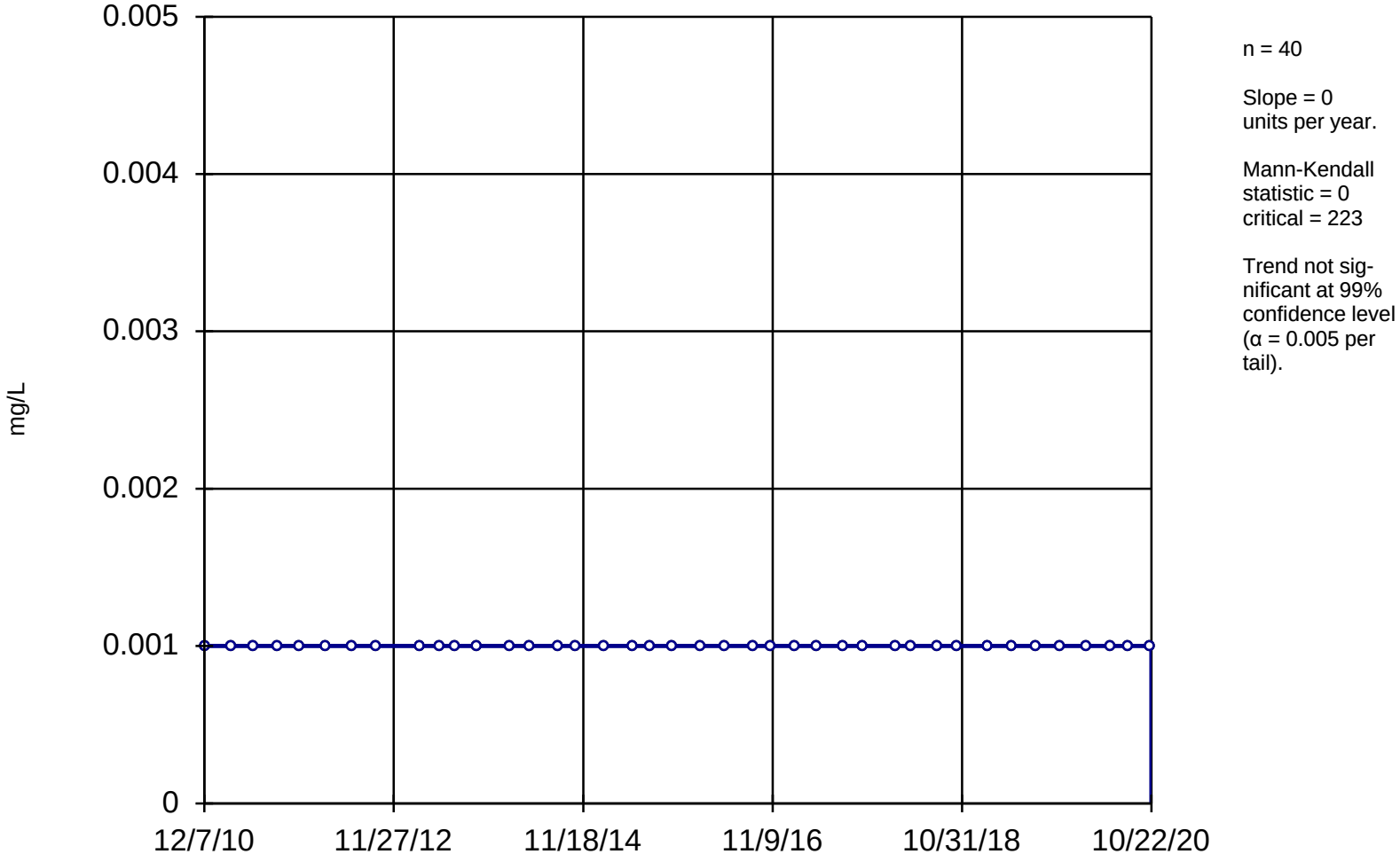
Constituent: Beryllium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



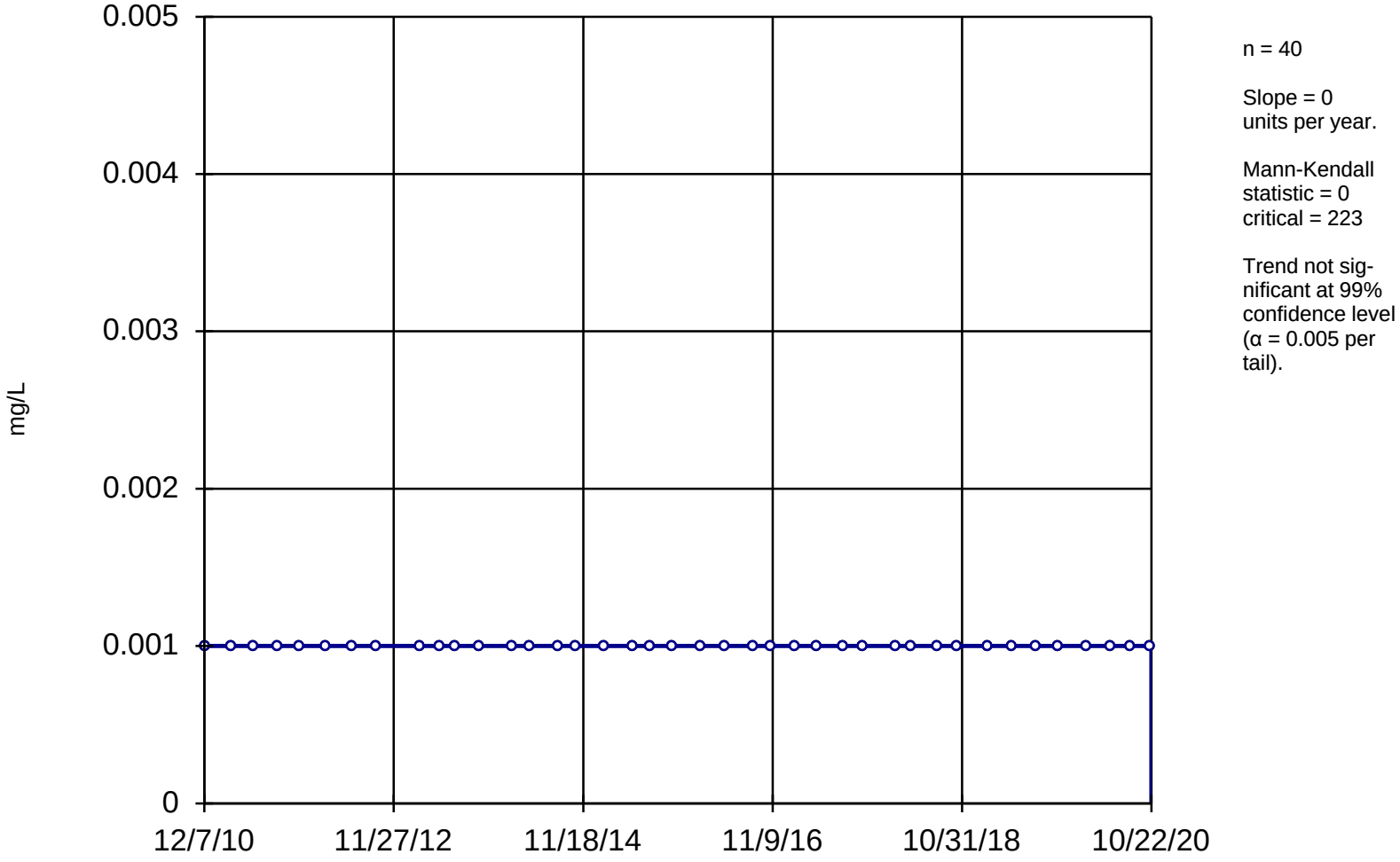
Constituent: Beryllium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

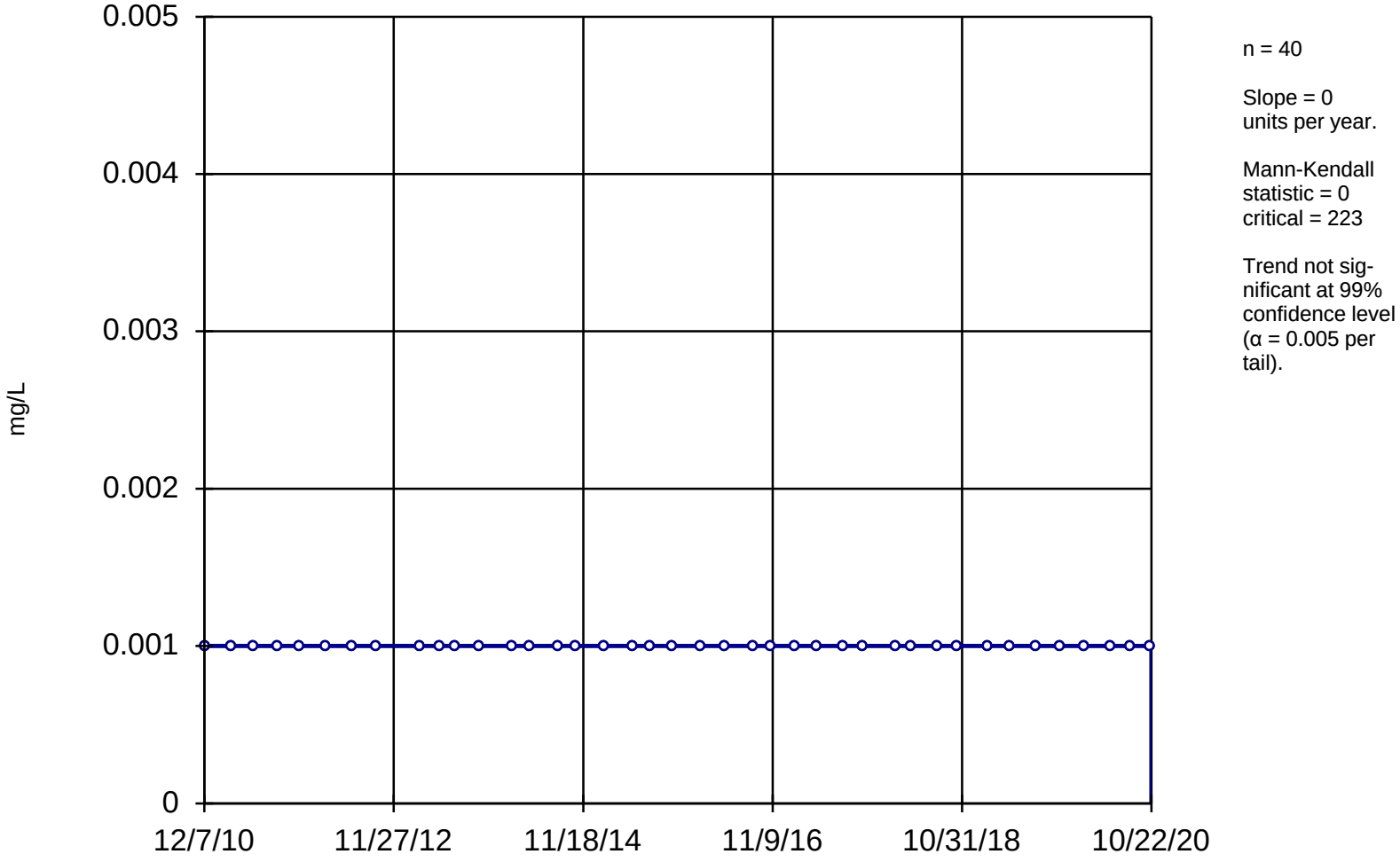
Constituent: Beryllium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

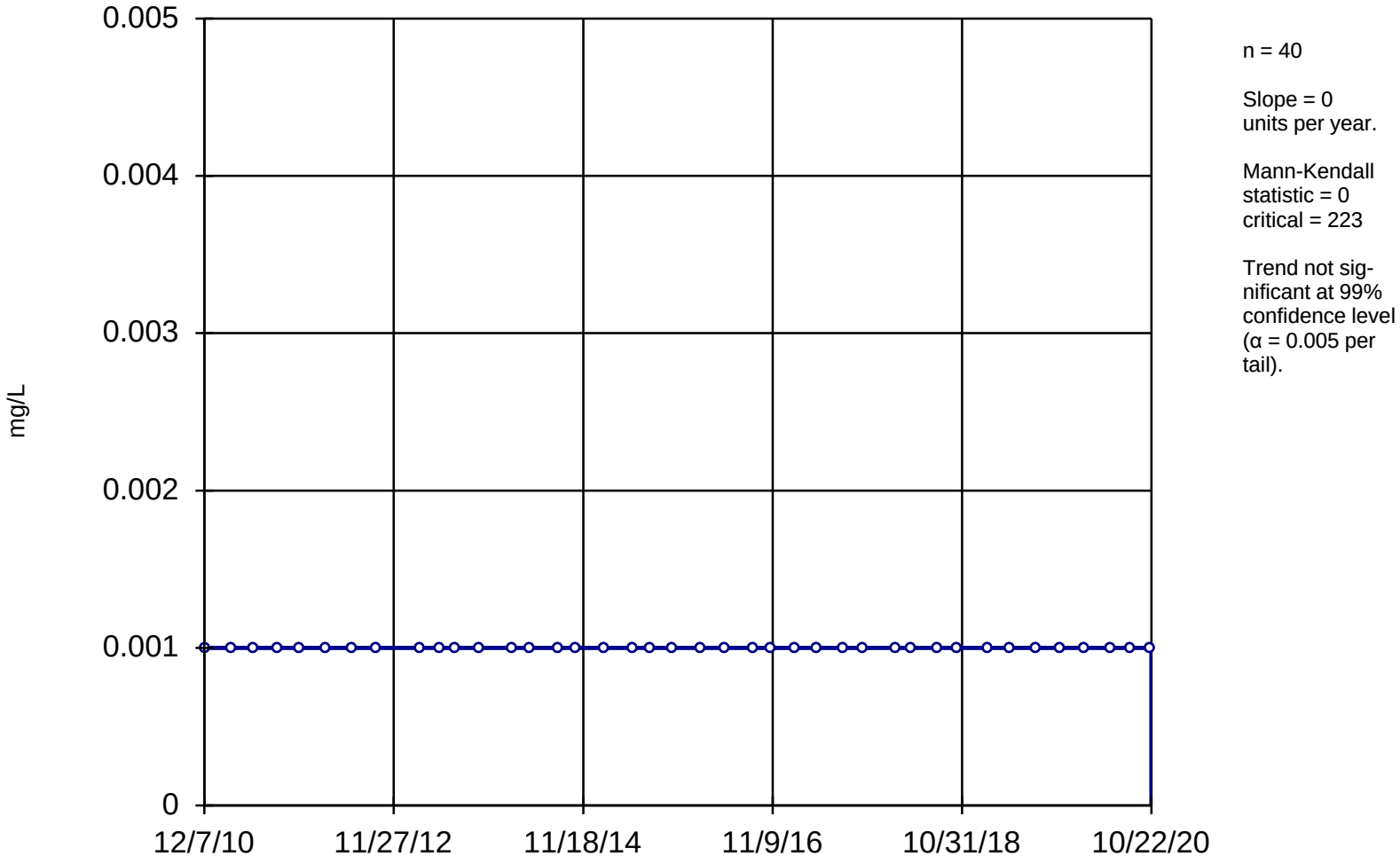
Constituent: Beryllium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

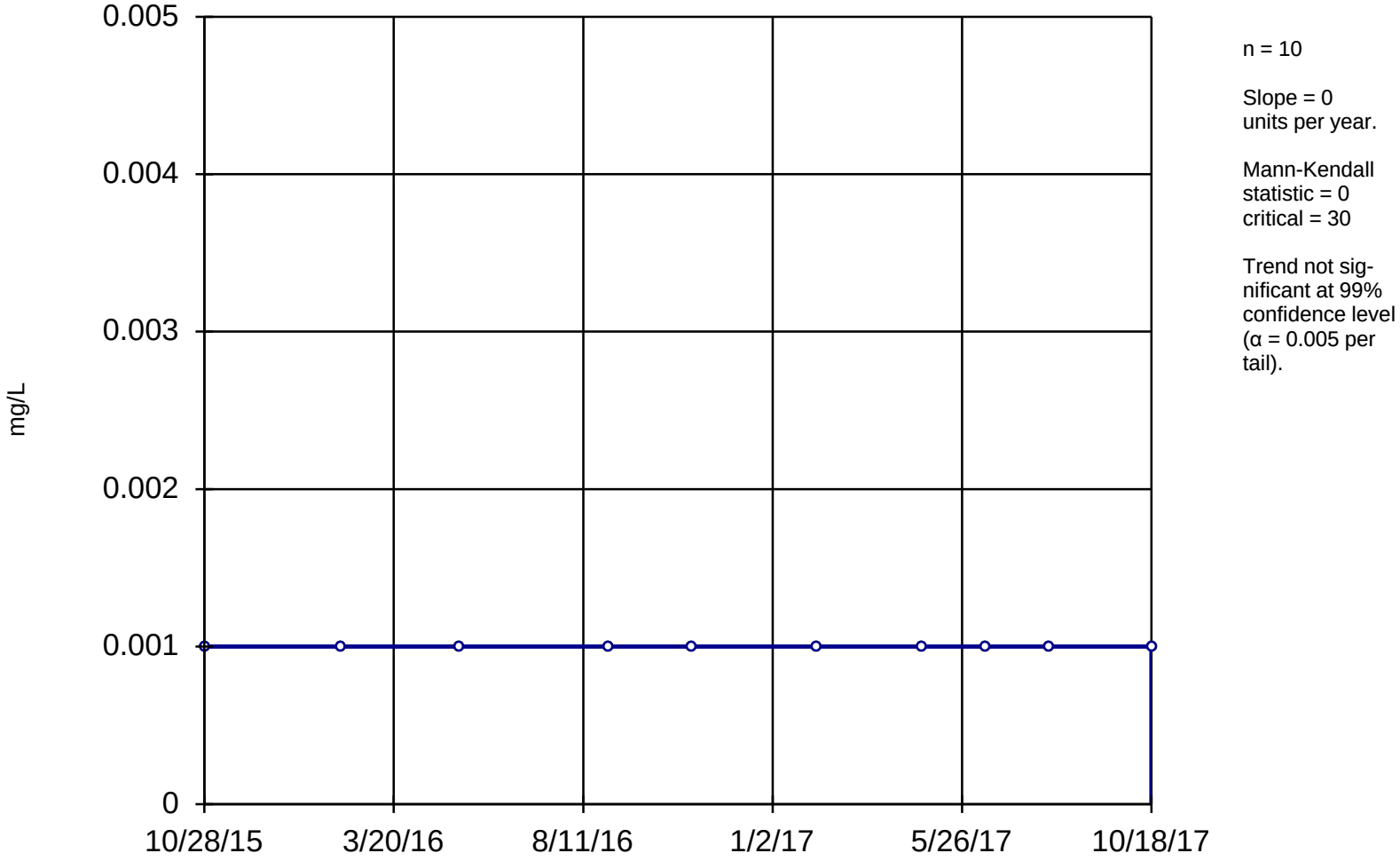
Constituent: Beryllium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



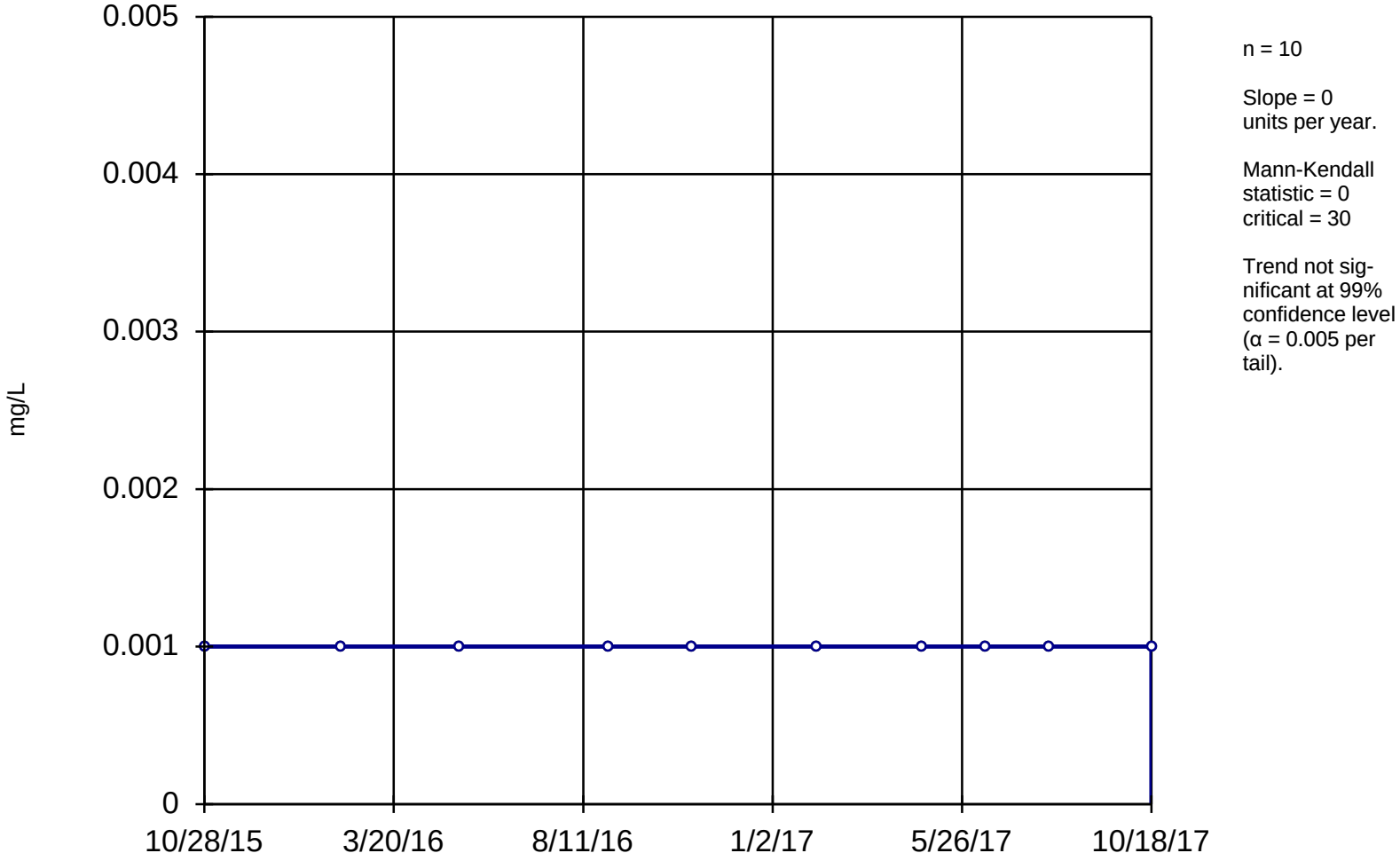
Constituent: Beryllium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



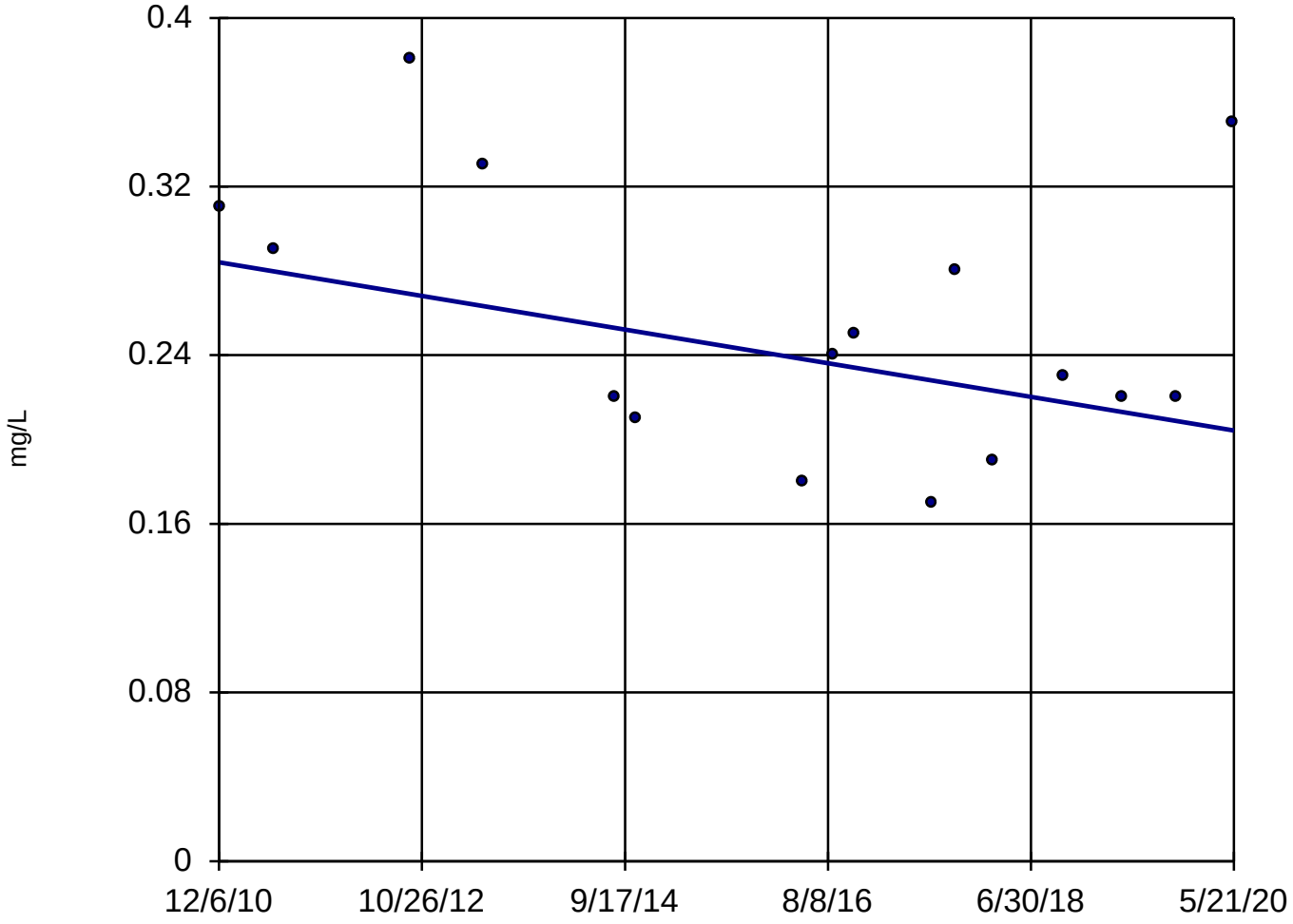
Constituent: Beryllium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-01



n = 16

Slope = -0.008431 units per year.

Mann-Kendall statistic = -25
critical = -58

Trend not significant at 99% confidence level (α = 0.005 per tail).

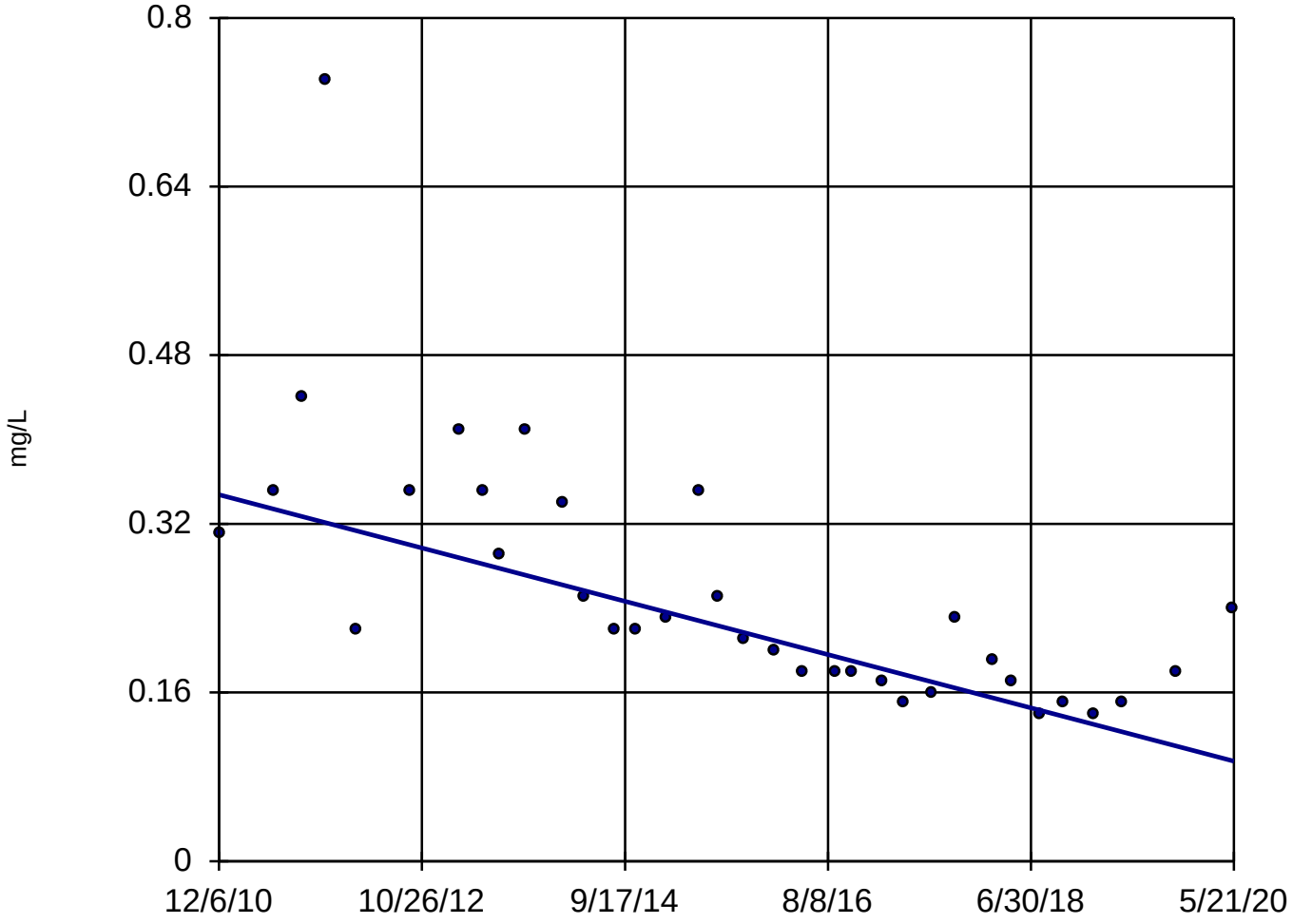
Constituent: Boron, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-02



n = 34

Slope = -0.02673 units per year.

Mann-Kendall statistic = -356
critical = -176

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

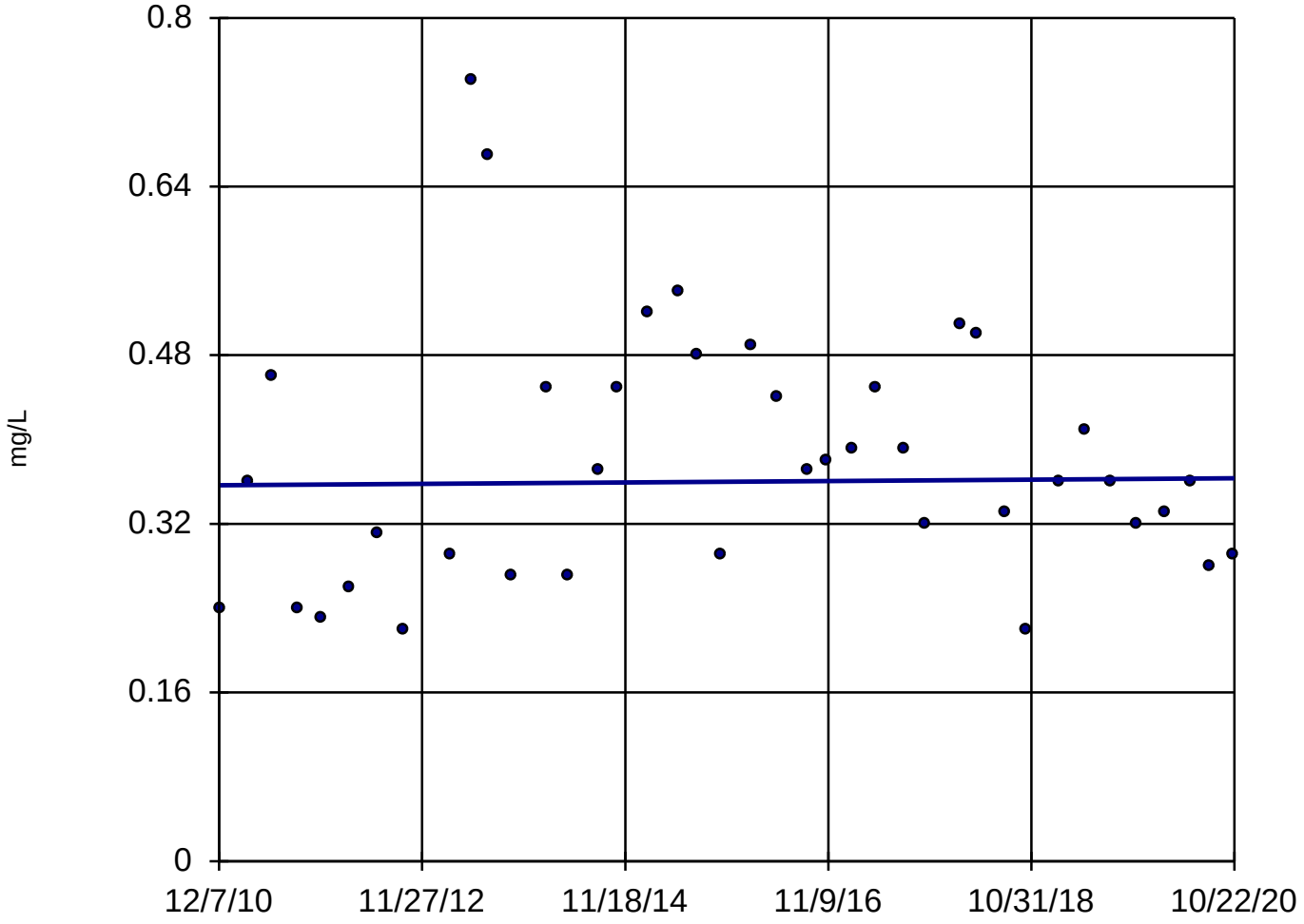
Constituent: Boron, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-03



n = 40

Slope = 0.0006767 units per year.

Mann-Kendall statistic = 19
critical = 223

Trend not significant at 99% confidence level (α = 0.005 per tail).

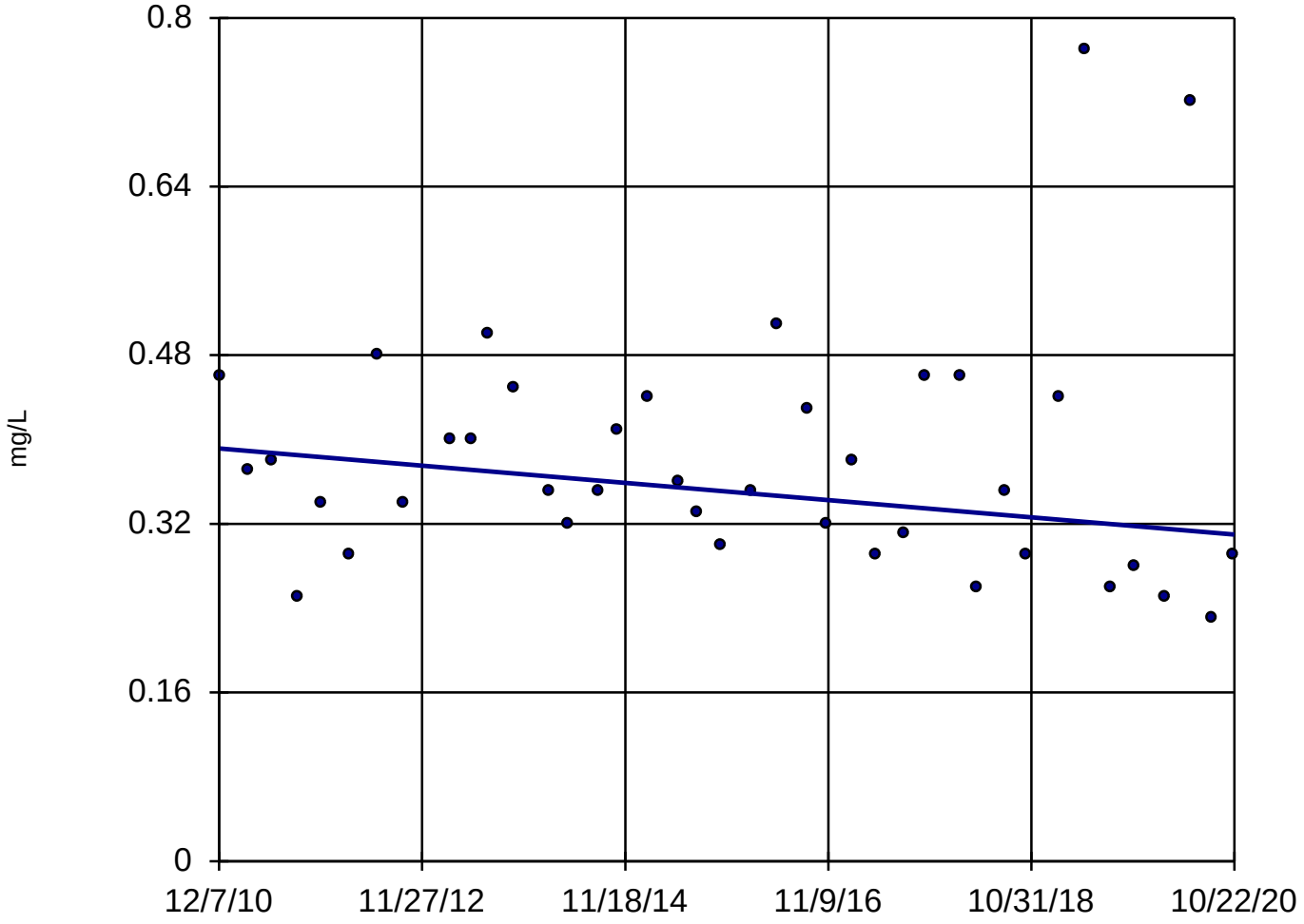
Constituent: Boron, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-04



n = 40

Slope = -0.008279 units per year.

Mann-Kendall statistic = -128
critical = -223

Trend not significant at 99% confidence level (α = 0.005 per tail).

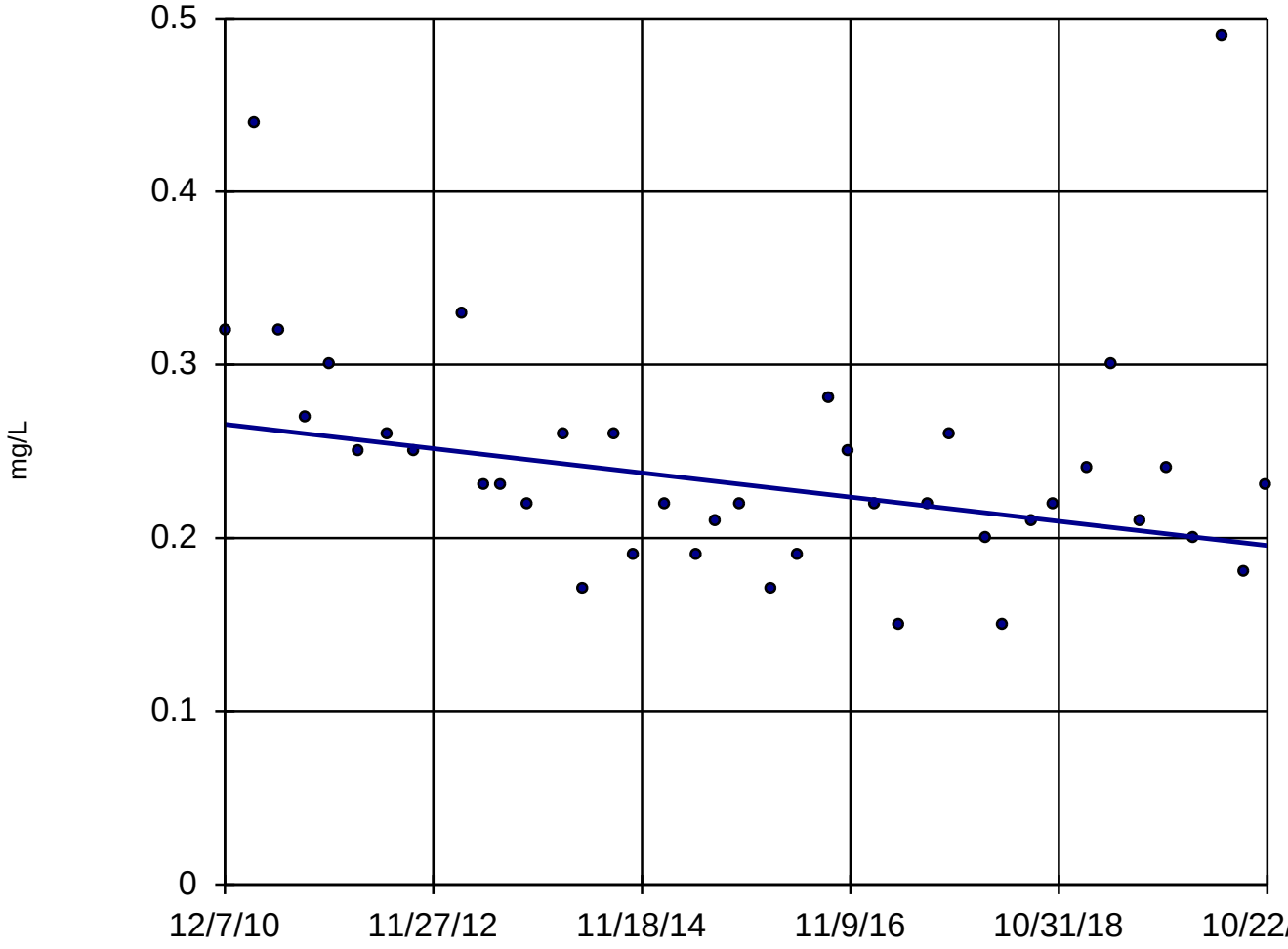
Constituent: Boron, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-06



n = 40

Slope = -0.007079 units per year.

Mann-Kendall statistic = -229
critical = -223

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

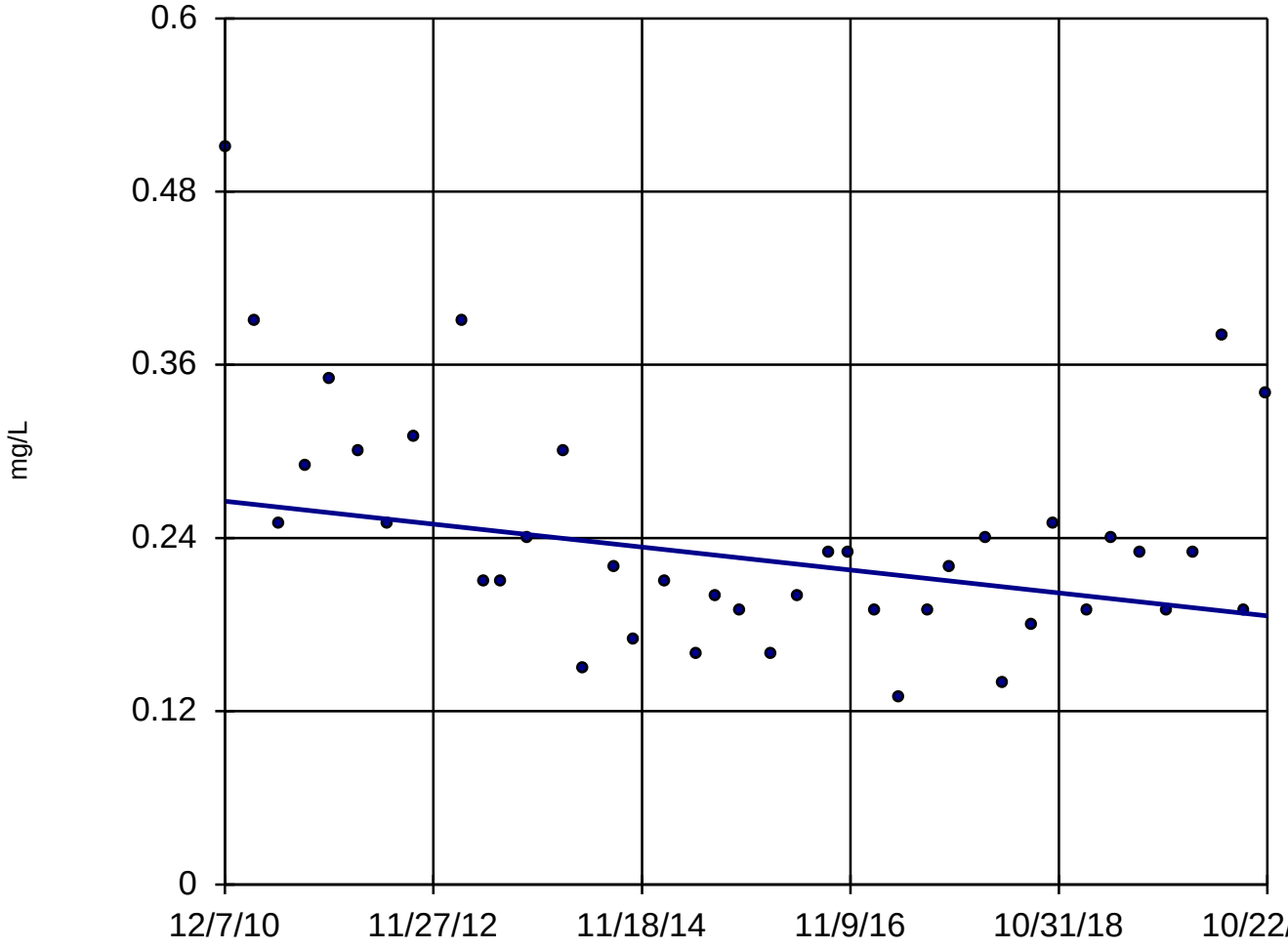
Constituent: Boron, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-07



n = 40

Slope = -0.008027 units per year.

Mann-Kendall statistic = -191
critical = -223

Trend not significant at 99% confidence level (α = 0.005 per tail).

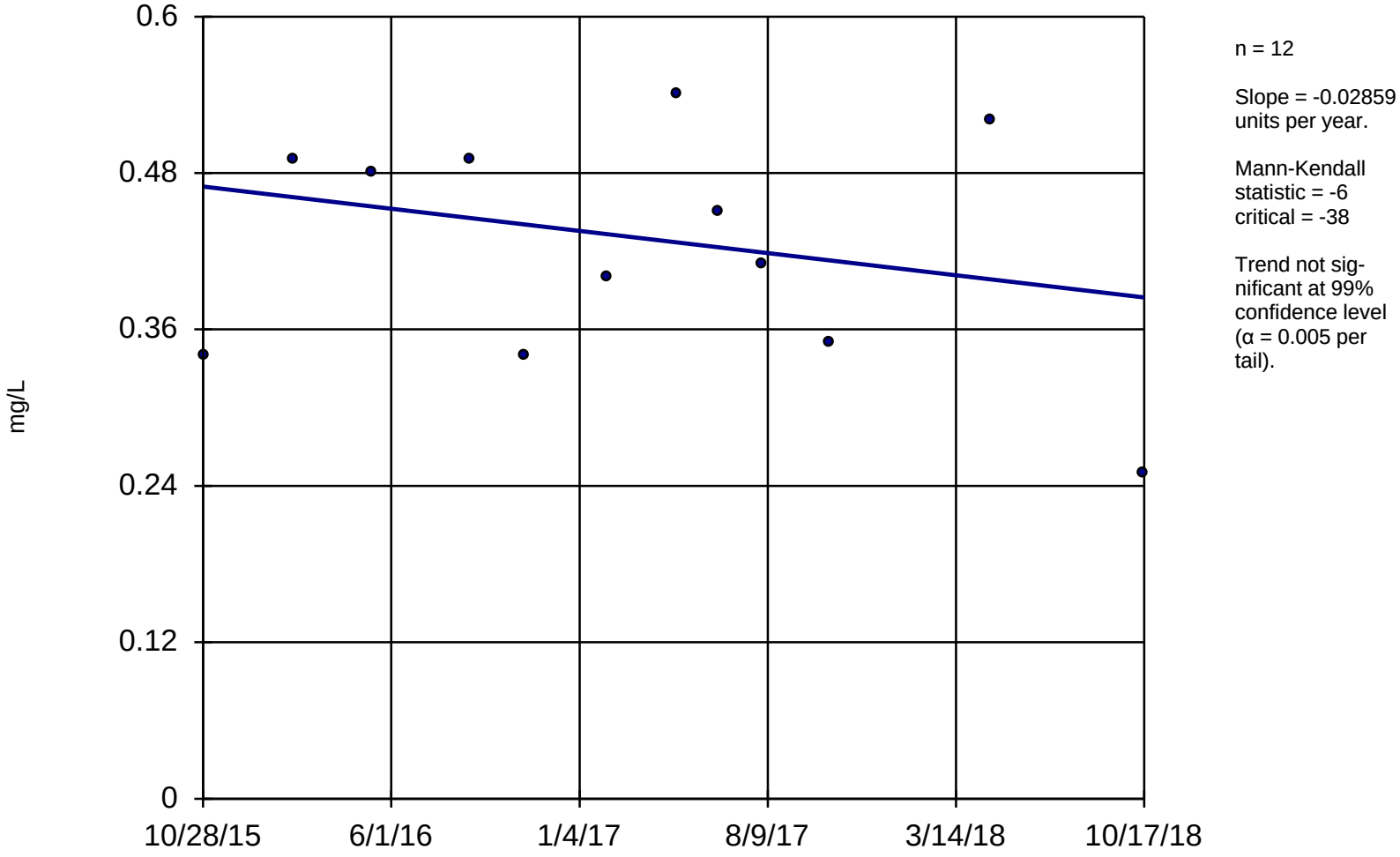
Constituent: Boron, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-03



n = 12

Slope = -0.02859 units per year.

Mann-Kendall statistic = -6
critical = -38

Trend not significant at 99% confidence level (α = 0.005 per tail).

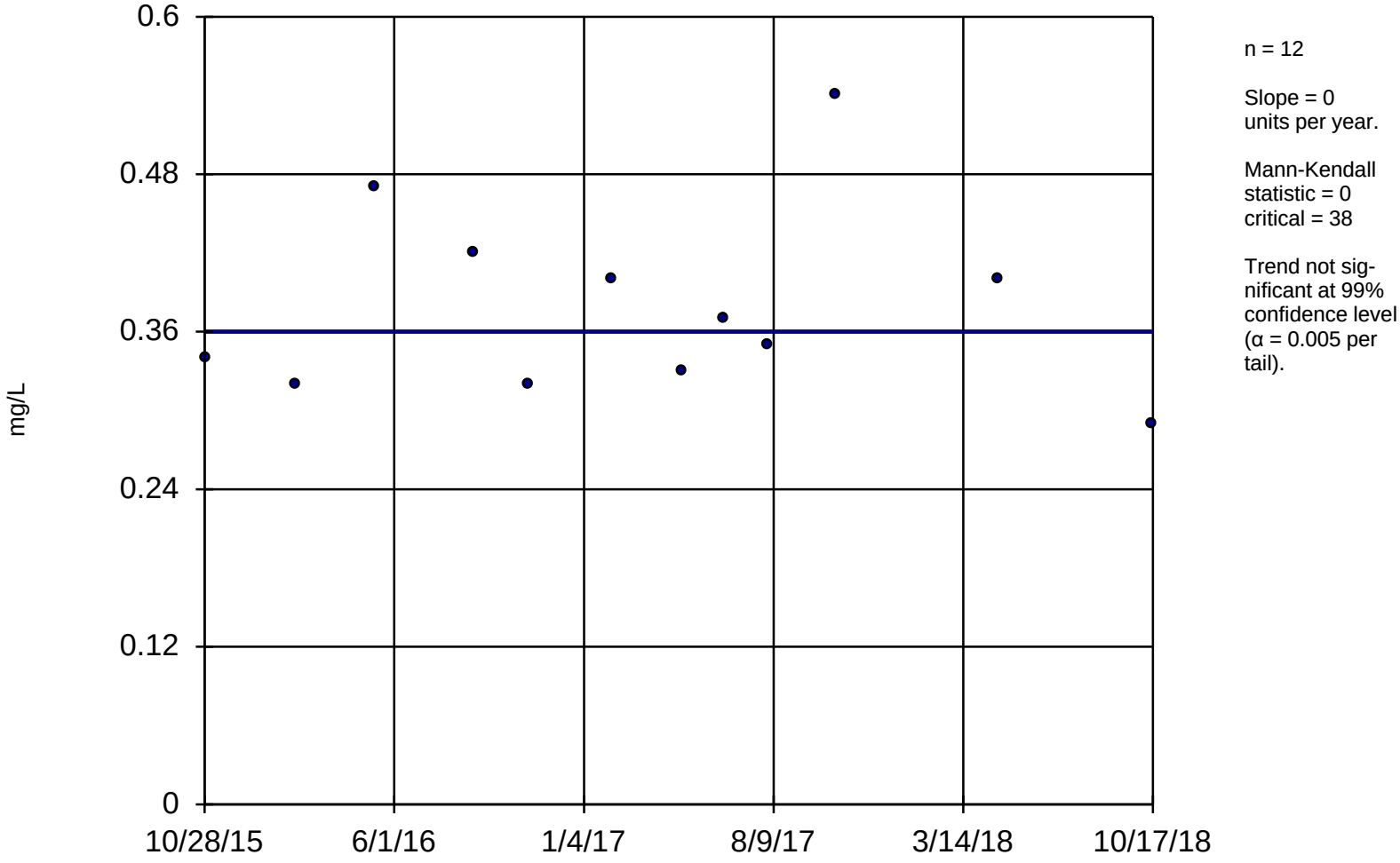
Constituent: Boron, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-04



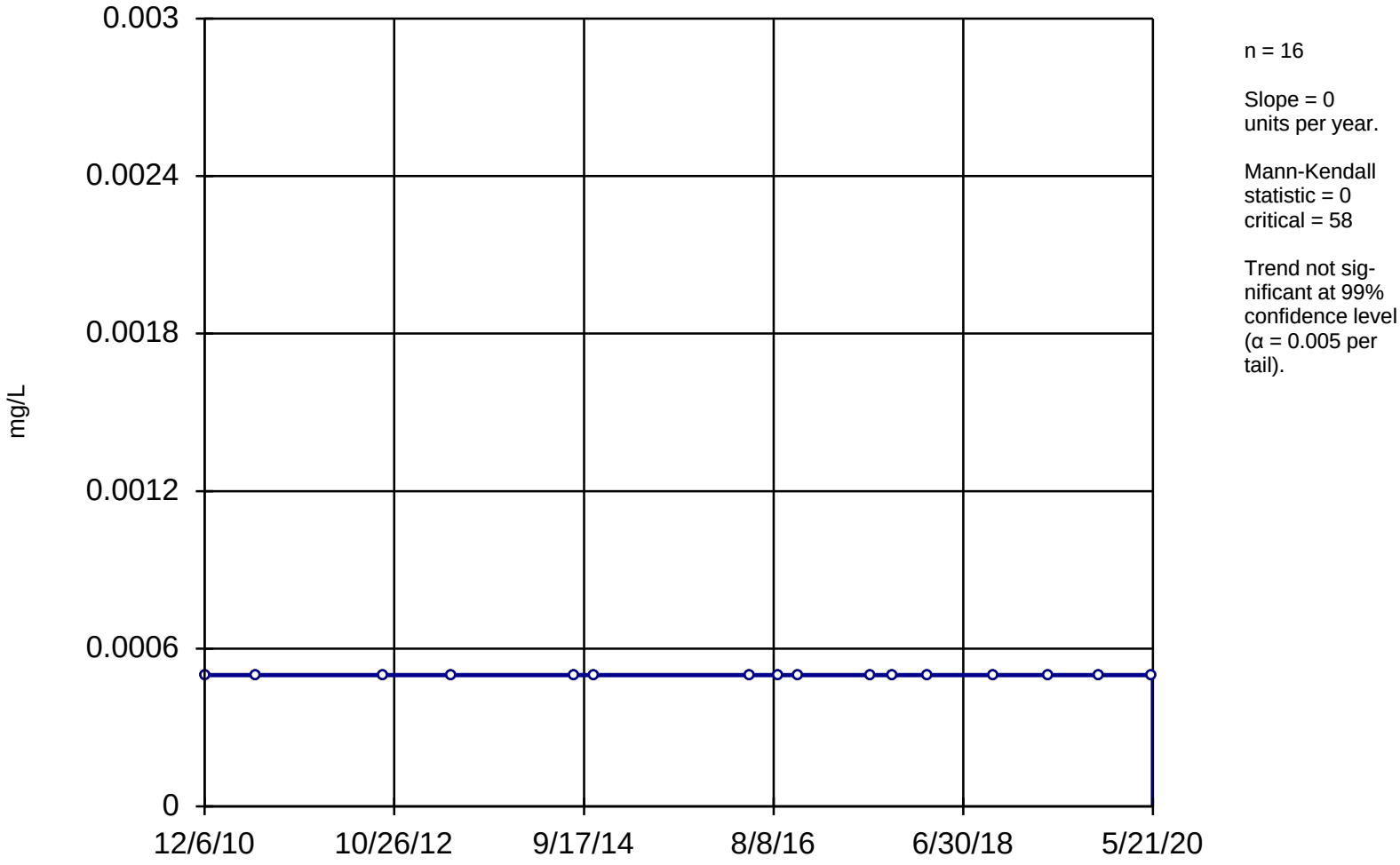
Constituent: Boron, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-01



n = 16

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 58

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

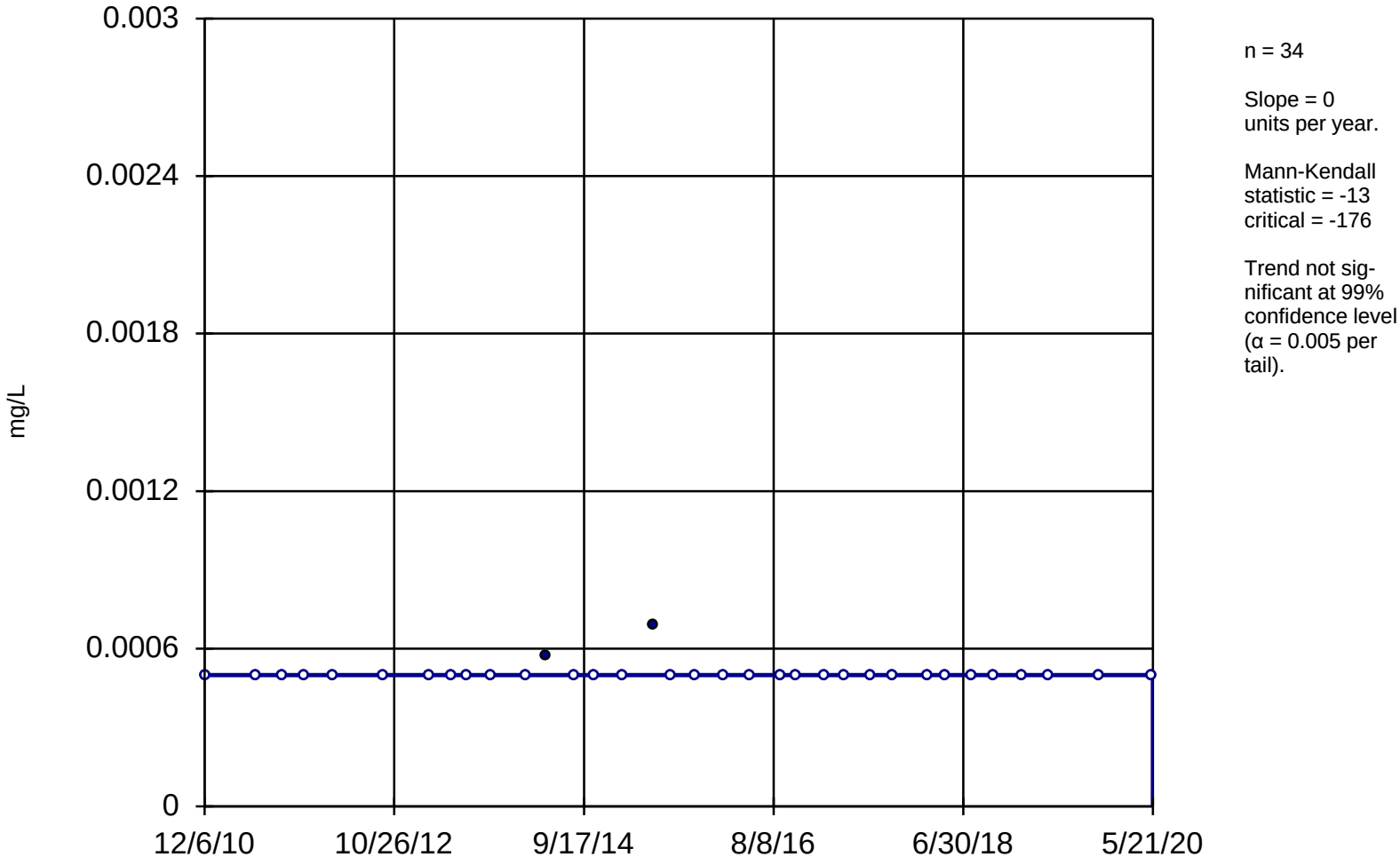
Constituent: Cadmium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = -13
critical = -176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

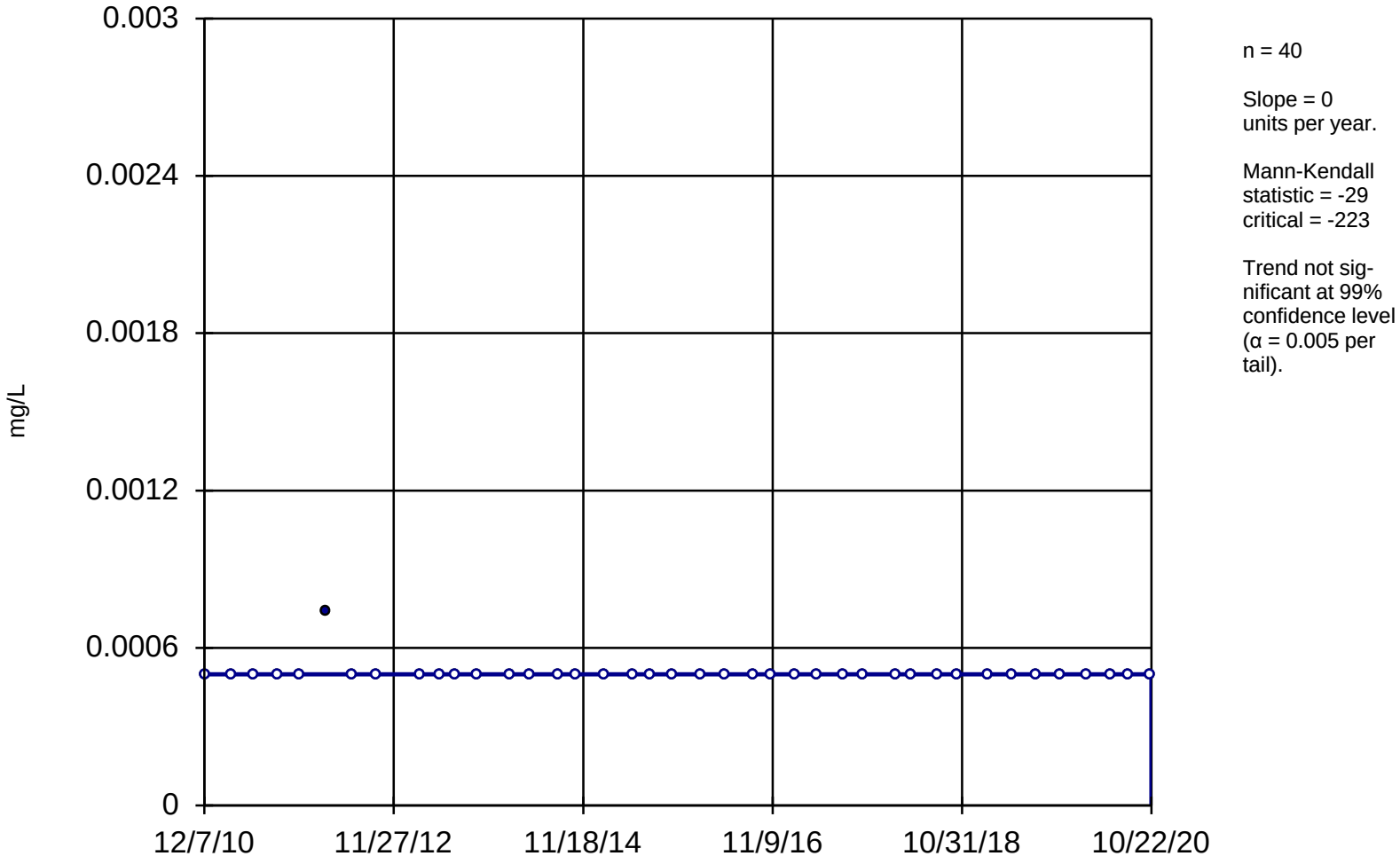
Constituent: Cadmium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -29
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

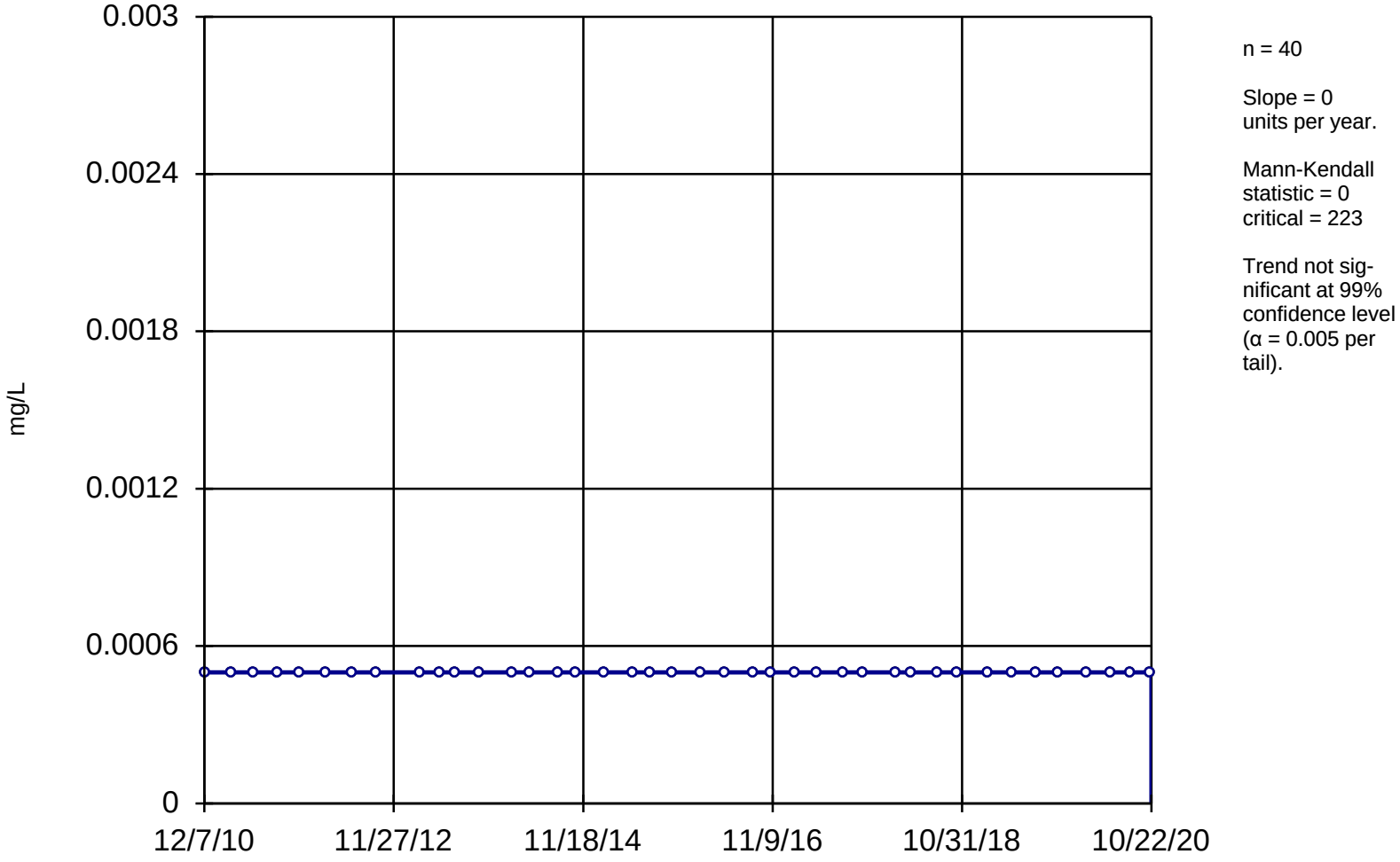
Constituent: Cadmium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

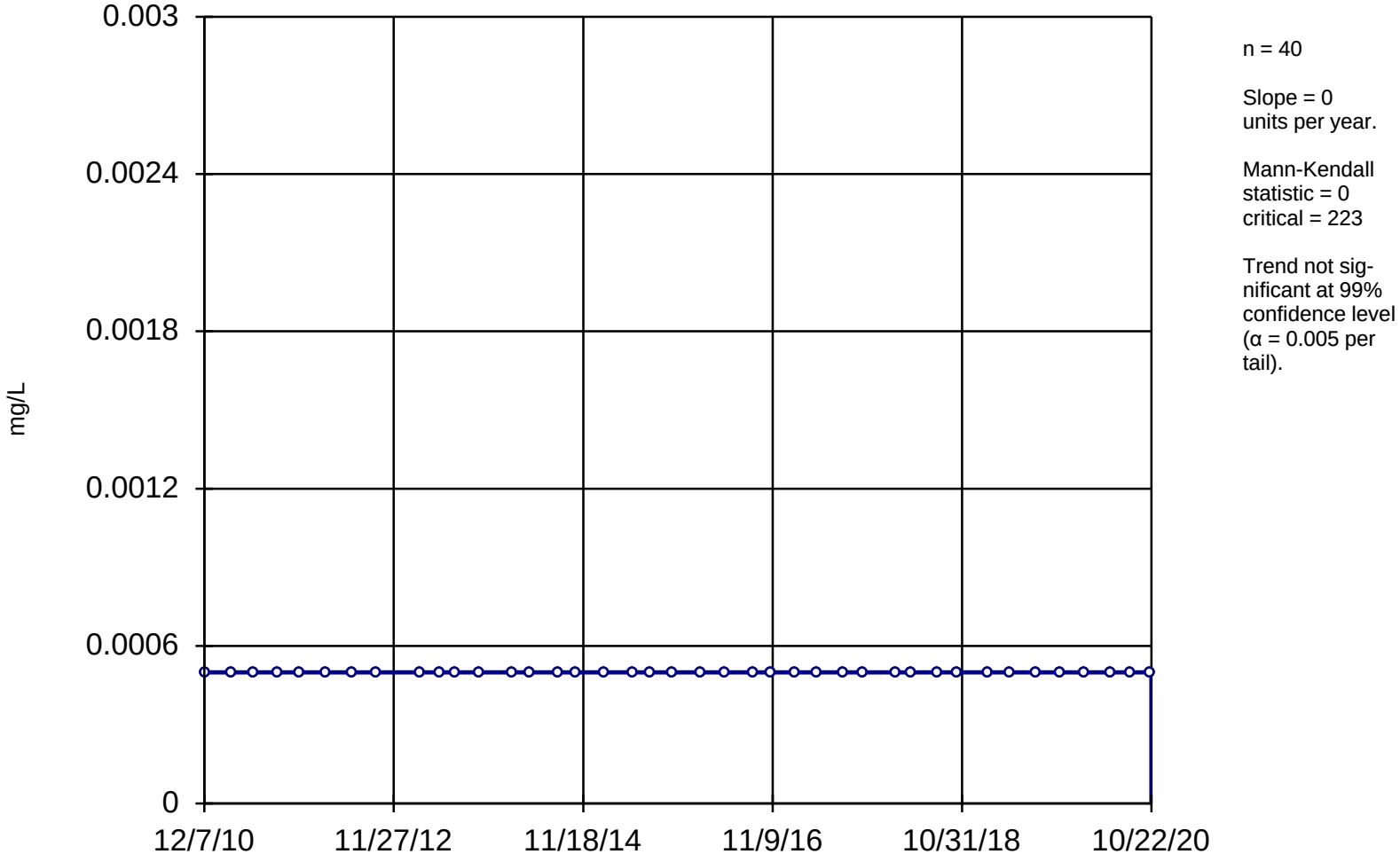
Constituent: Cadmium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

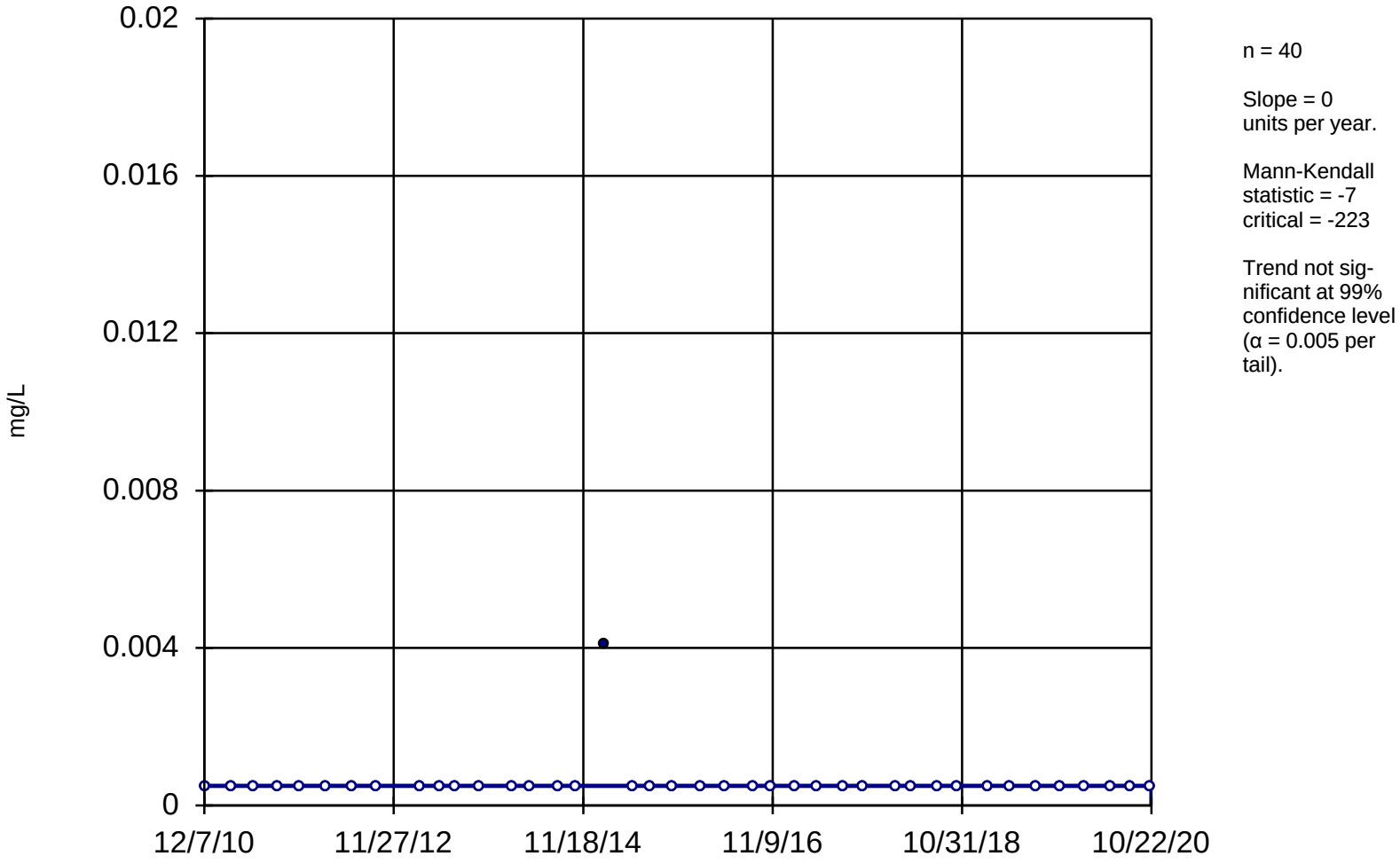
Constituent: Cadmium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -7
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

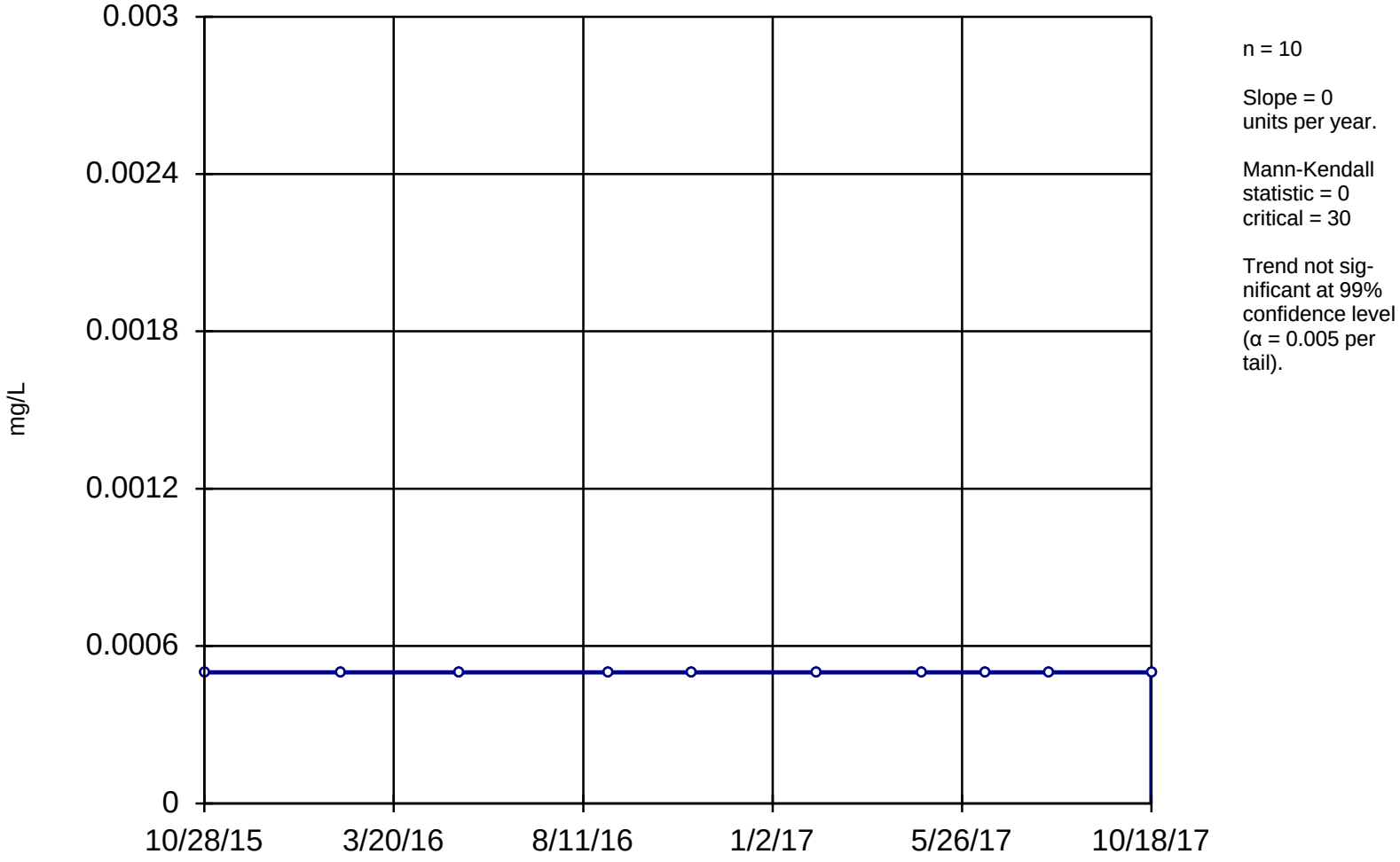
Constituent: Cadmium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



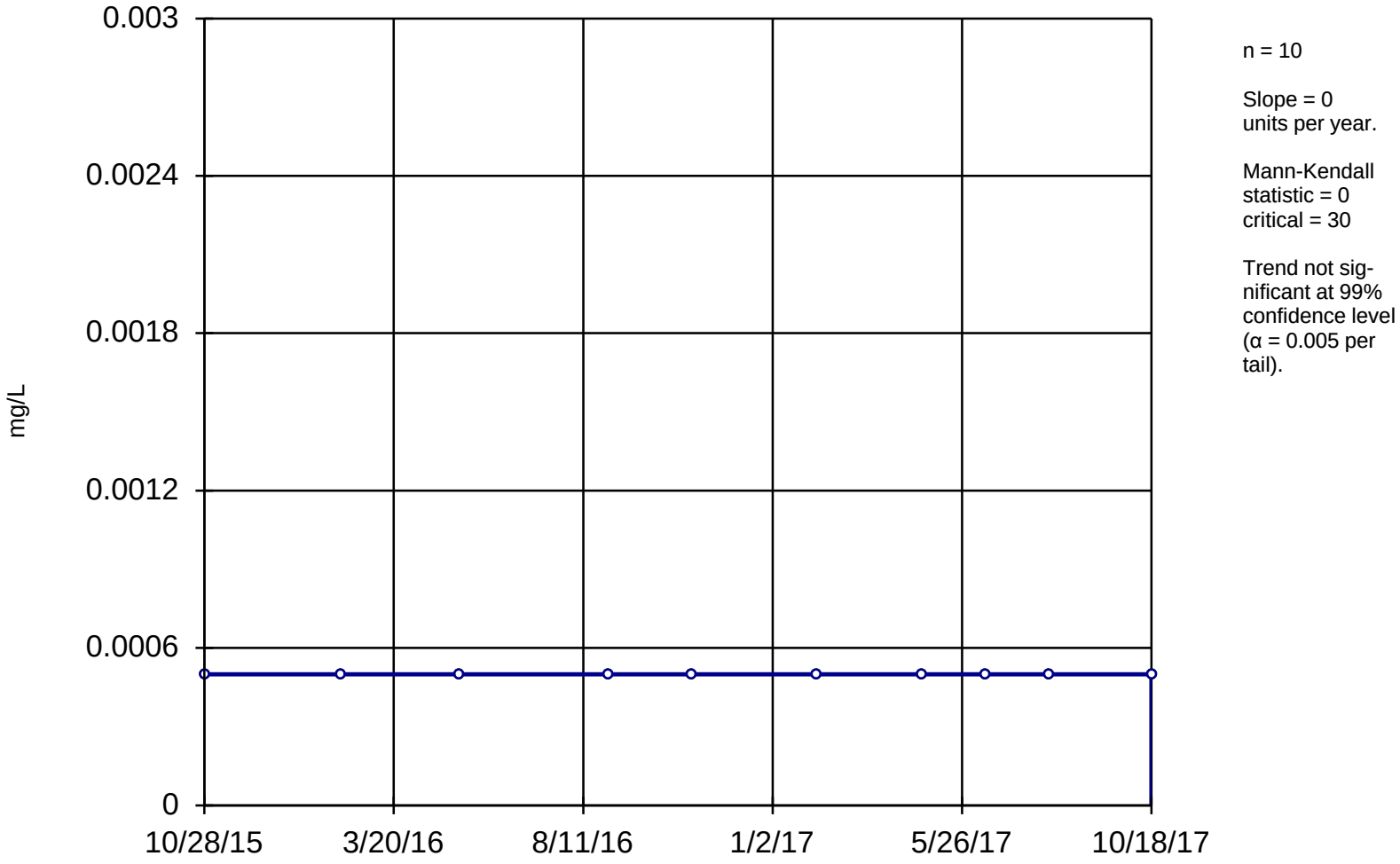
Constituent: Cadmium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



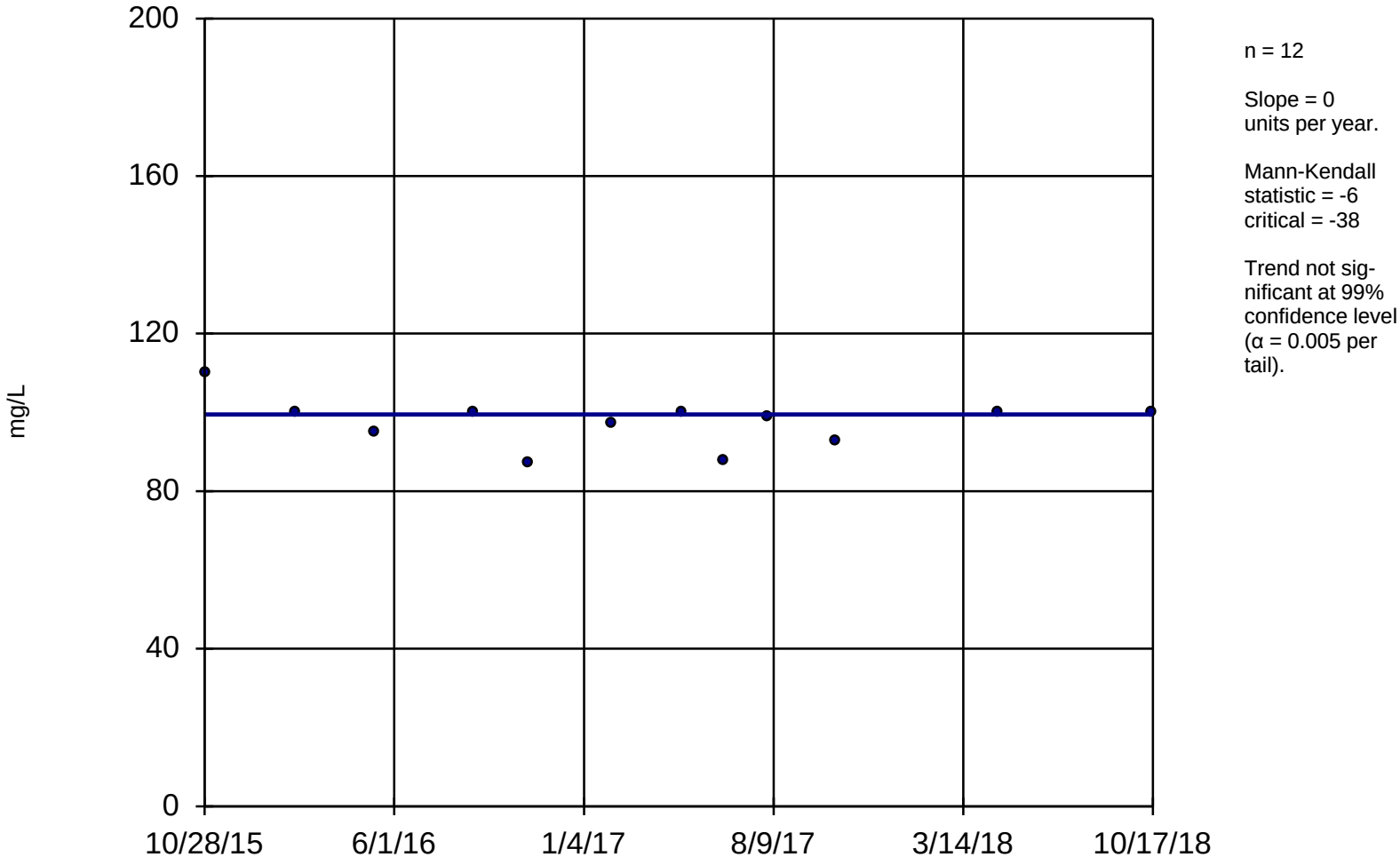
Constituent: Cadmium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-03



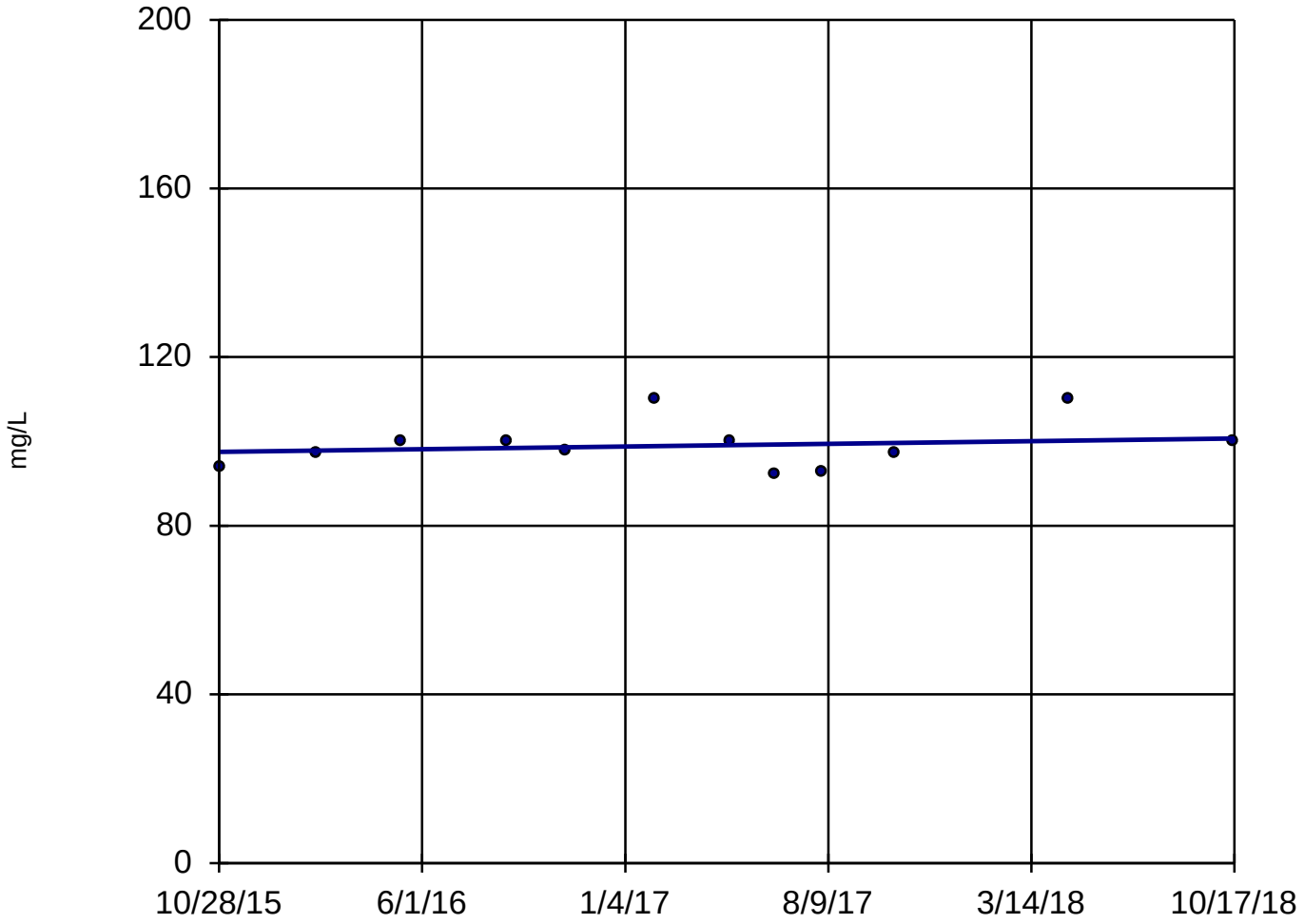
Constituent: Calcium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-04



n = 12

Slope = 1.07 units per year.

Mann-Kendall statistic = 10
critical = 38

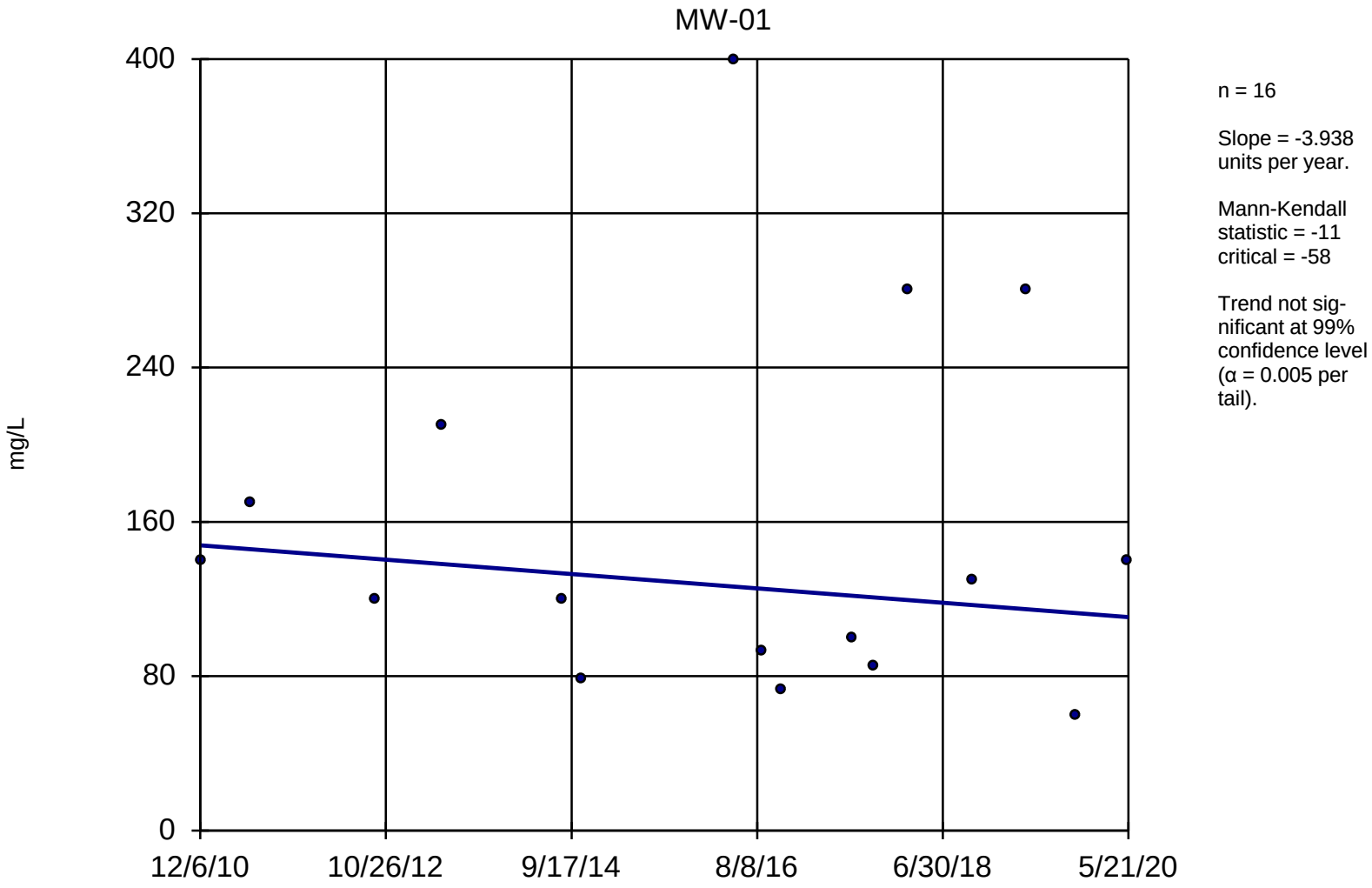
Trend not significant at 99% confidence level (α = 0.005 per tail).

Constituent: Calcium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator



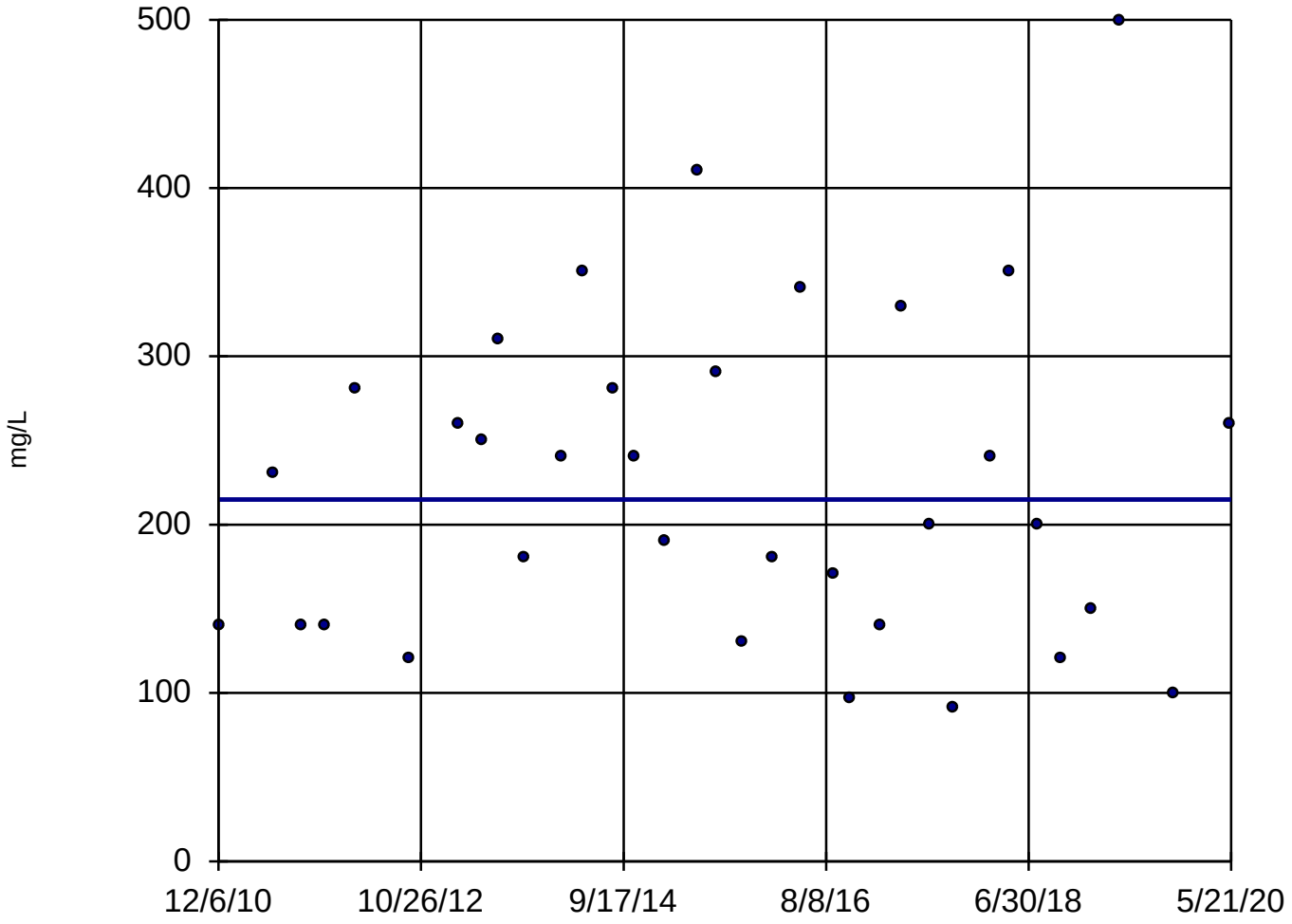
Constituent: Chloride Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = -4
critical = -176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

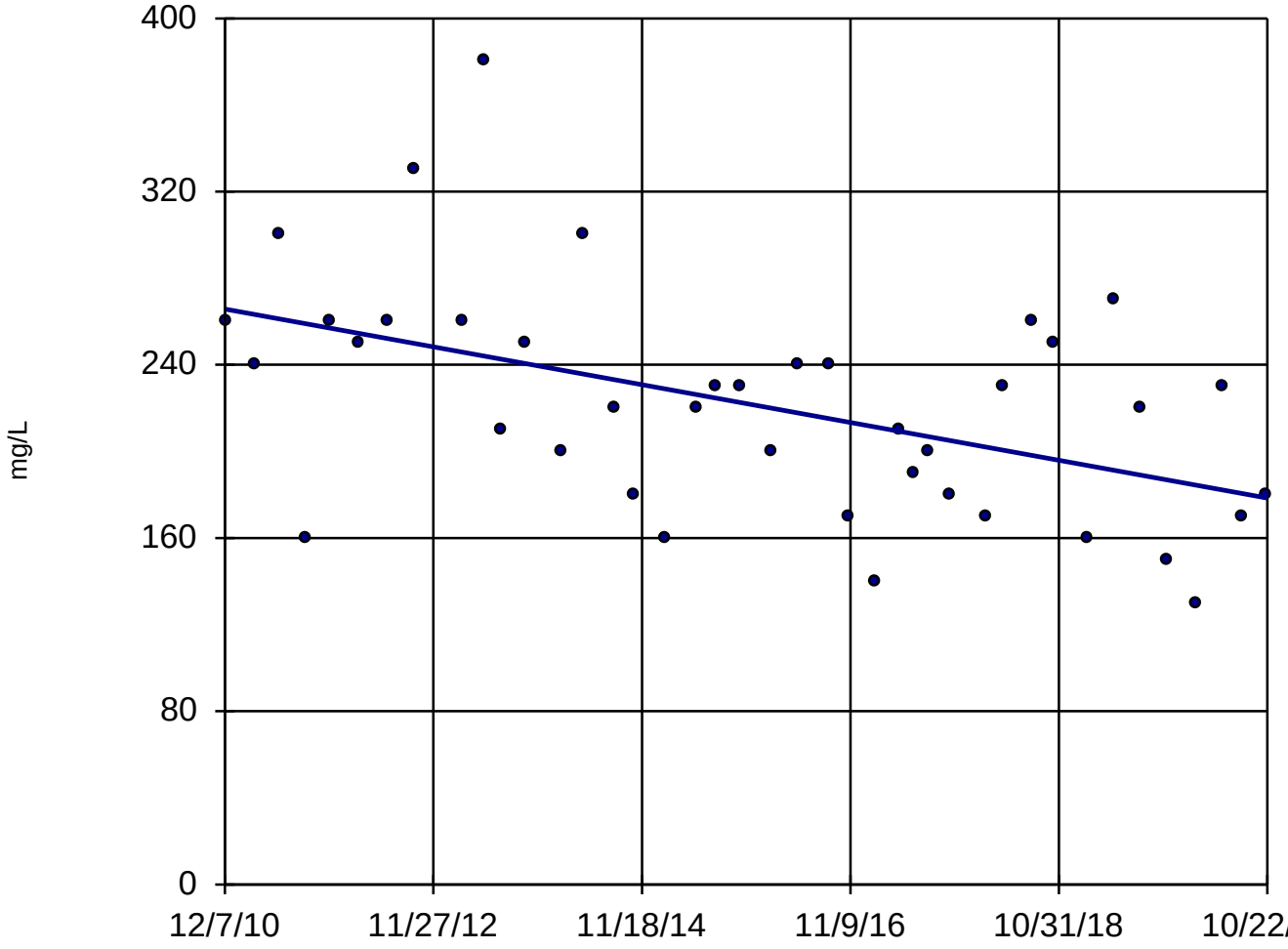
Constituent: Chloride Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-03



n = 41

Slope = -8.834 units per year.

Mann-Kendall normal approx. = -3.043
critical = -2.58

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

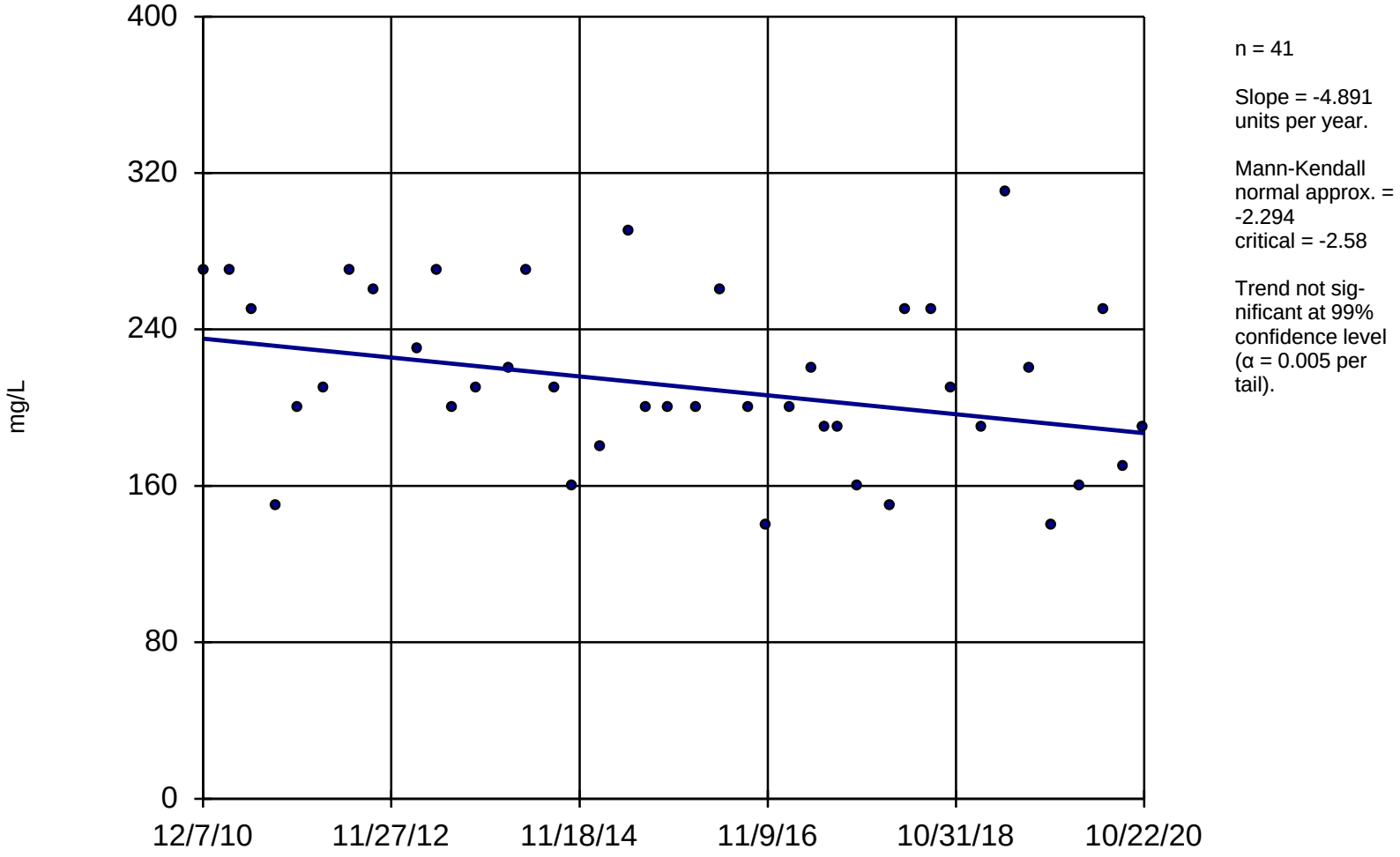
Constituent: Chloride Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-04



n = 41

Slope = -4.891 units per year.

Mann-Kendall normal approx. = -2.294
critical = -2.58

Trend not significant at 99% confidence level (α = 0.005 per tail).

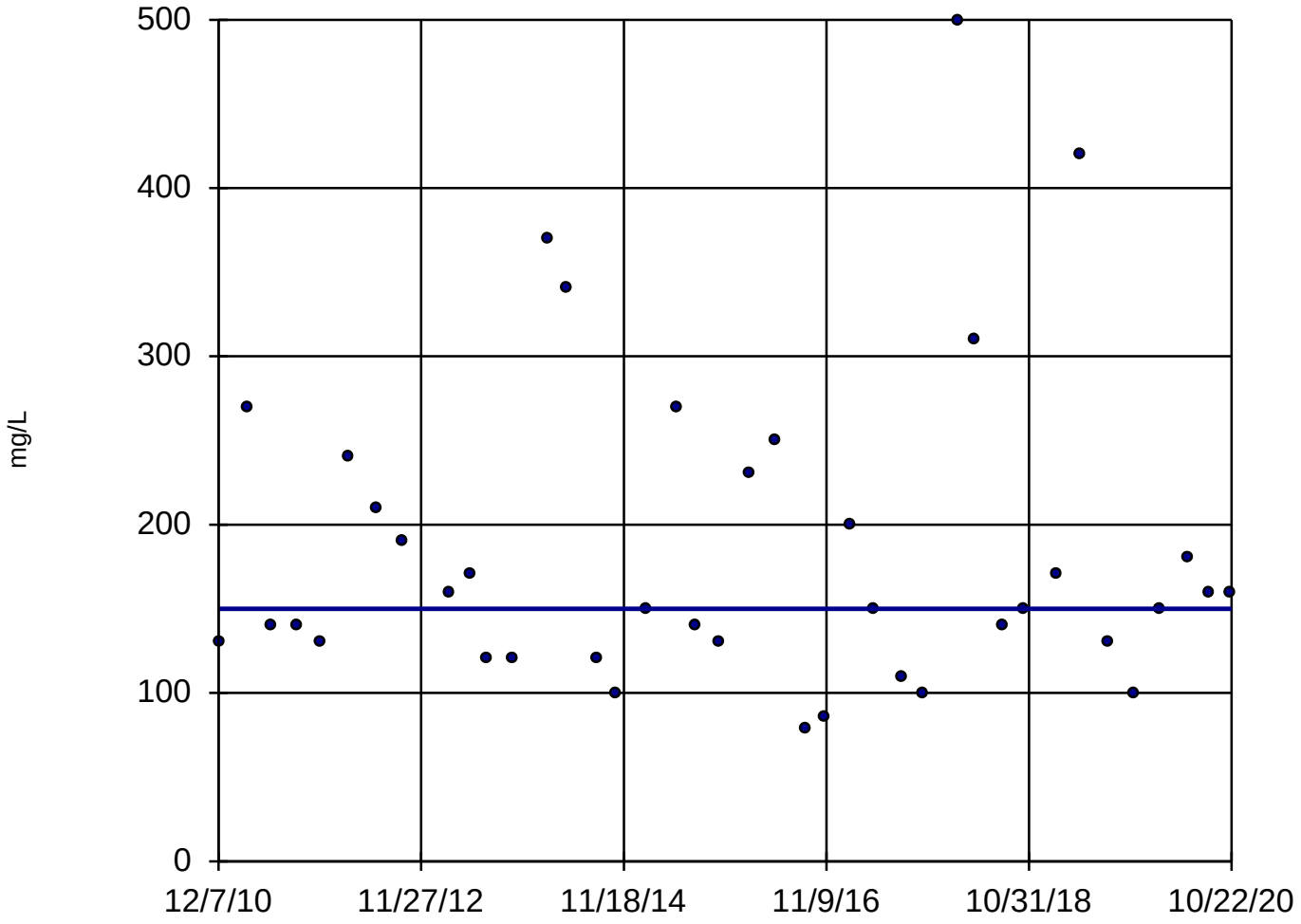
Constituent: Chloride Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -13
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

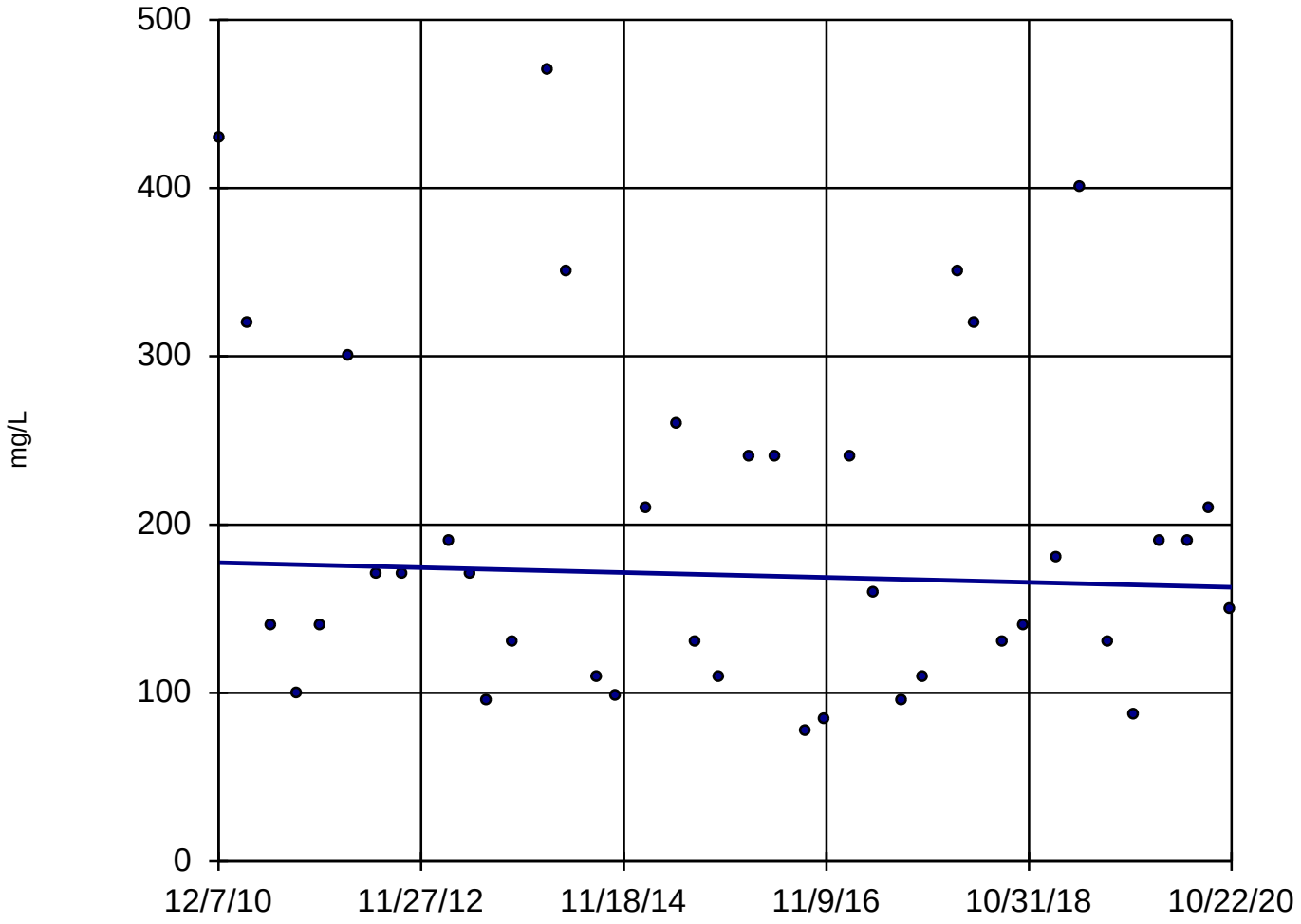
Constituent: Chloride Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-07



n = 40

Slope = -1.487 units per year.

Mann-Kendall statistic = -40
critical = -223

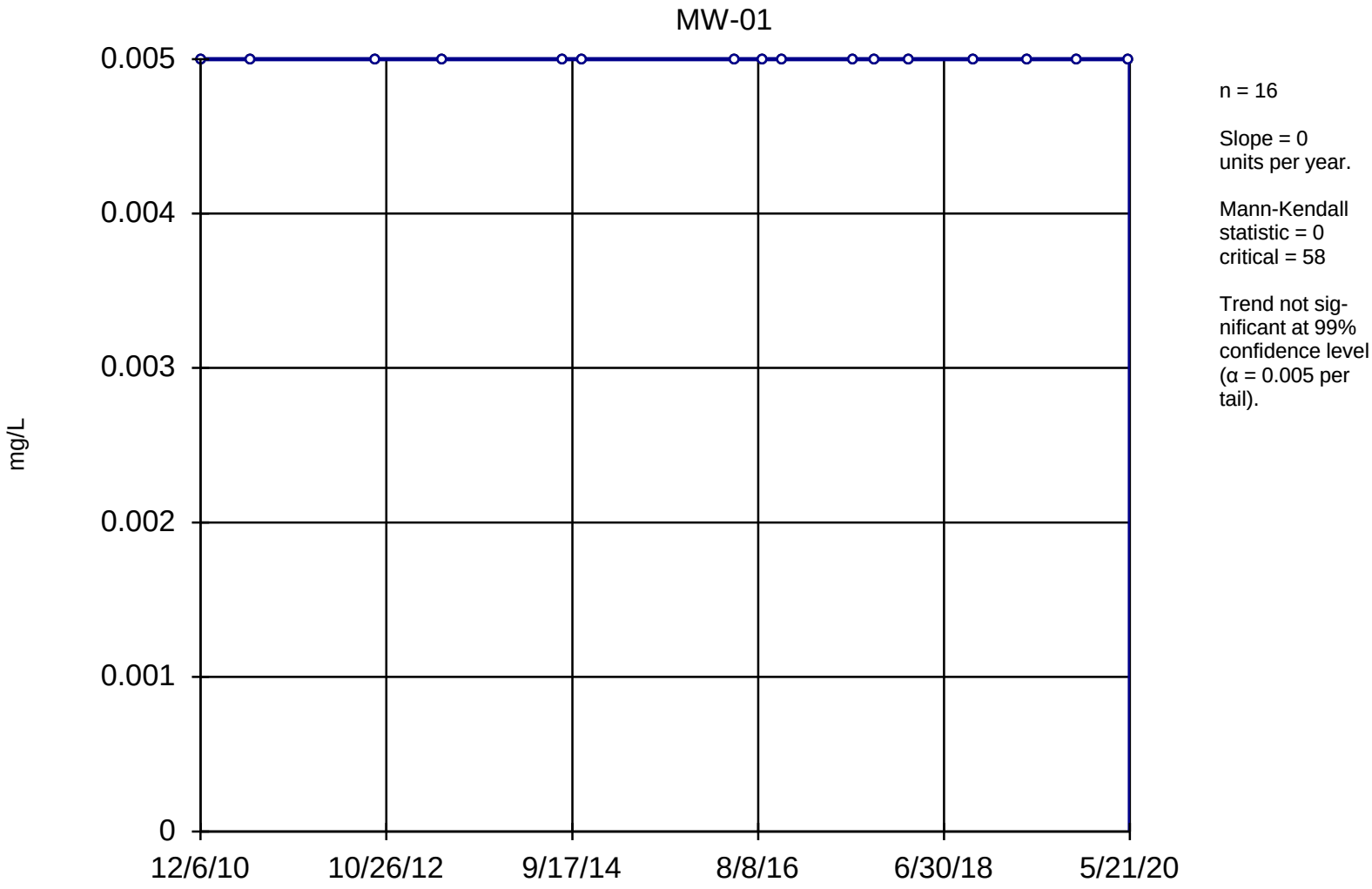
Trend not significant at 99% confidence level (α = 0.005 per tail).

Constituent: Chloride Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator



Constituent: Chromium, Dissolved Analysis Run 4/2/2021 11:01 AM

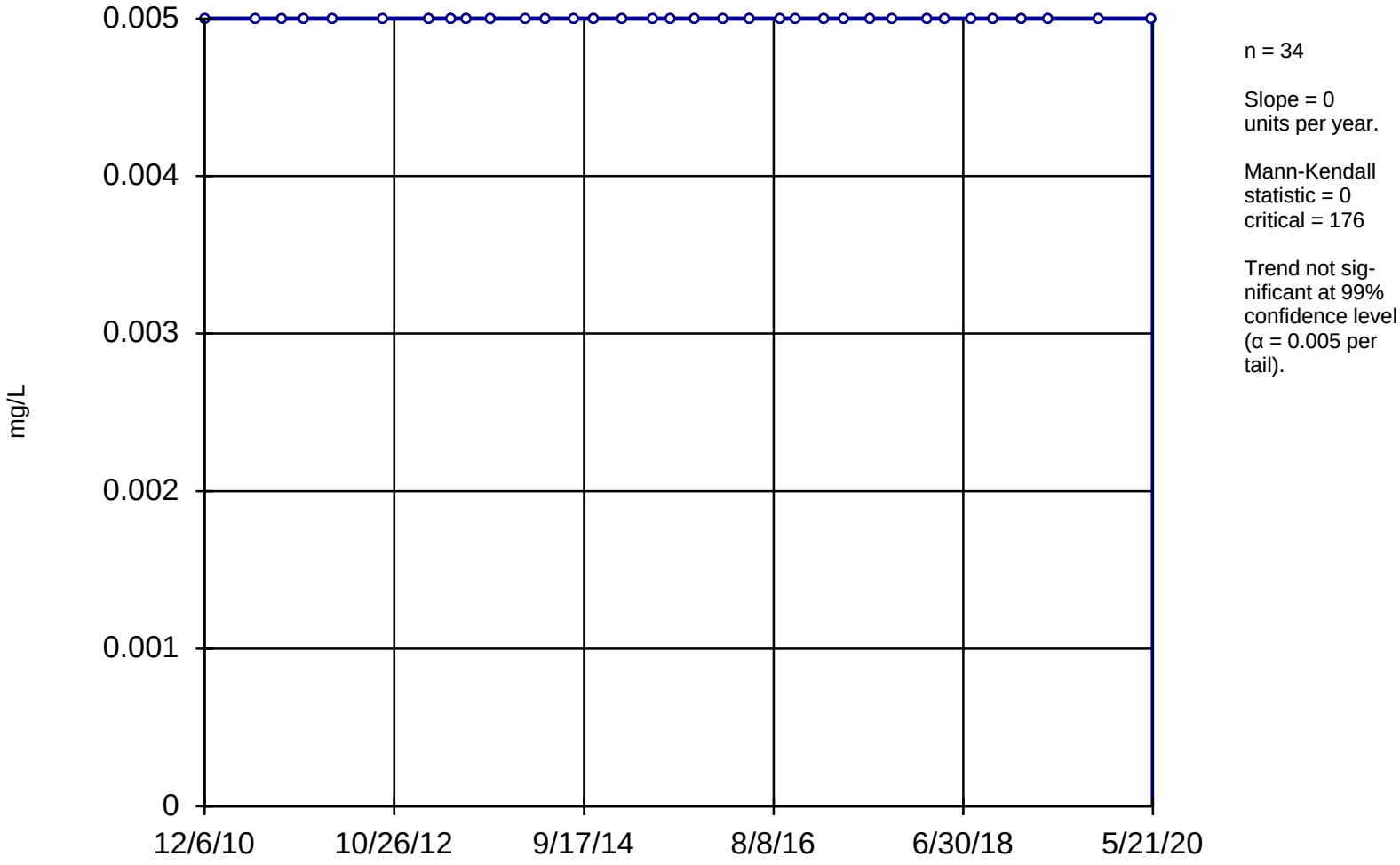
Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 176

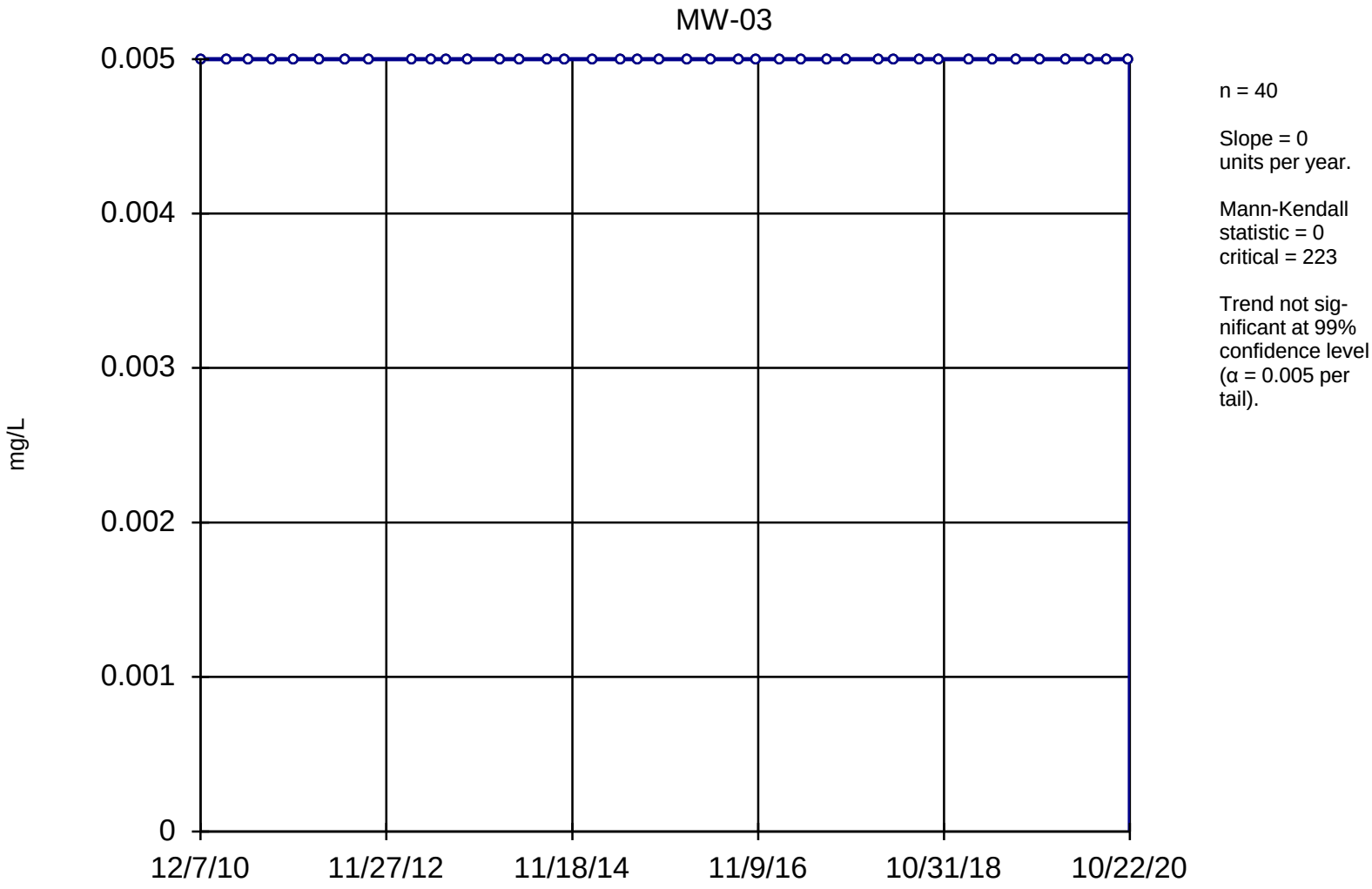
Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

Constituent: Chromium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator



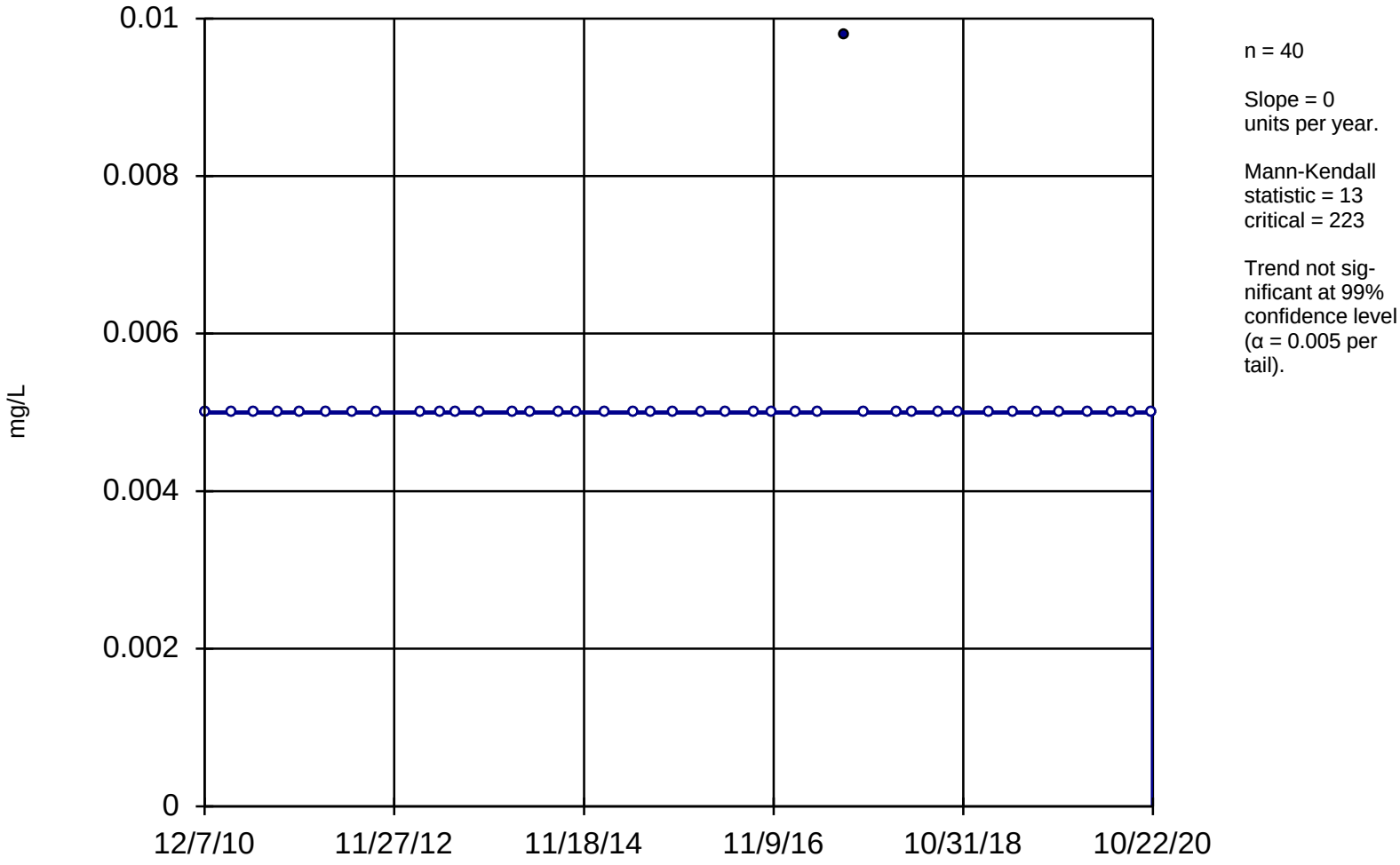
Constituent: Chromium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 13
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

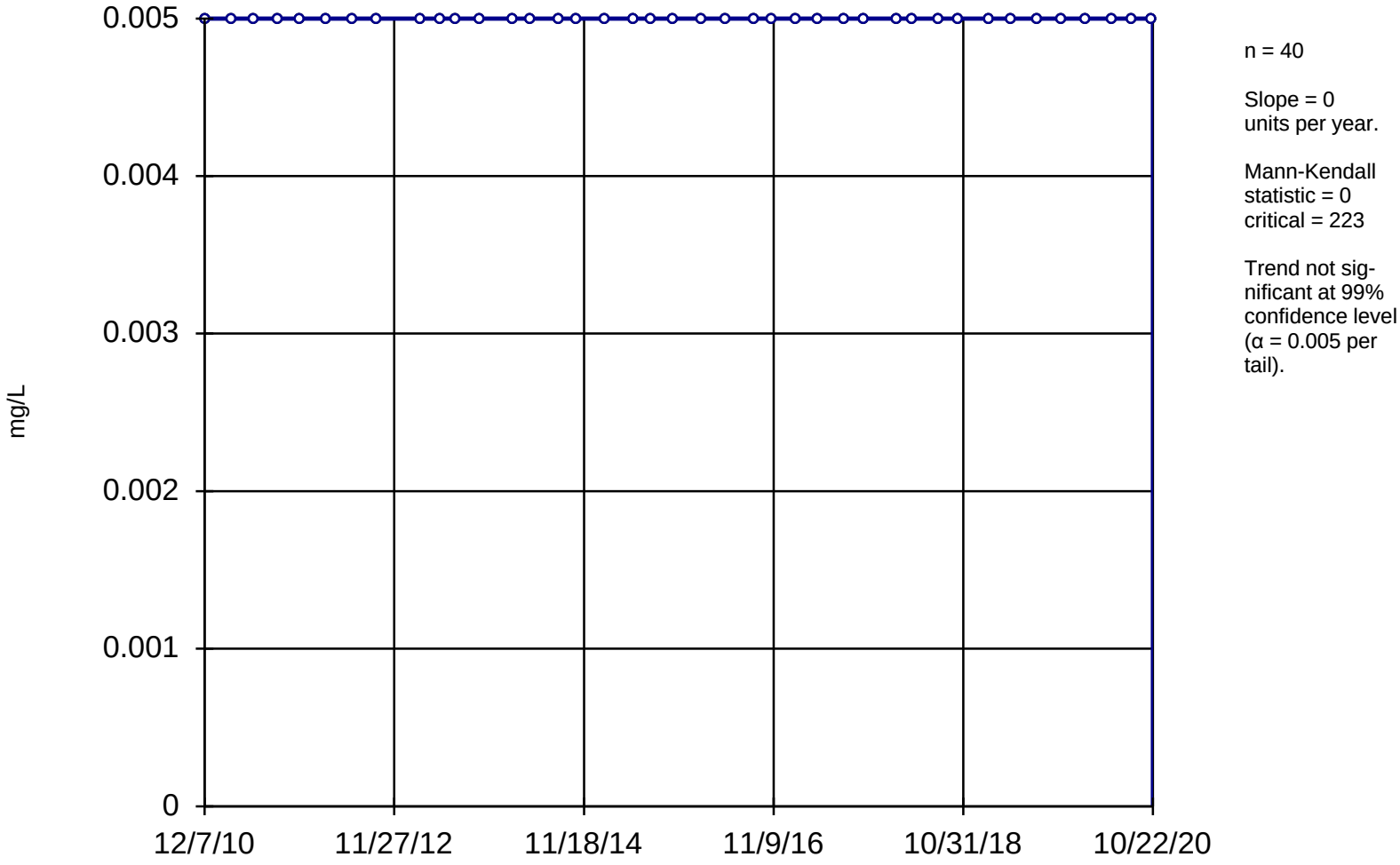
Constituent: Chromium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

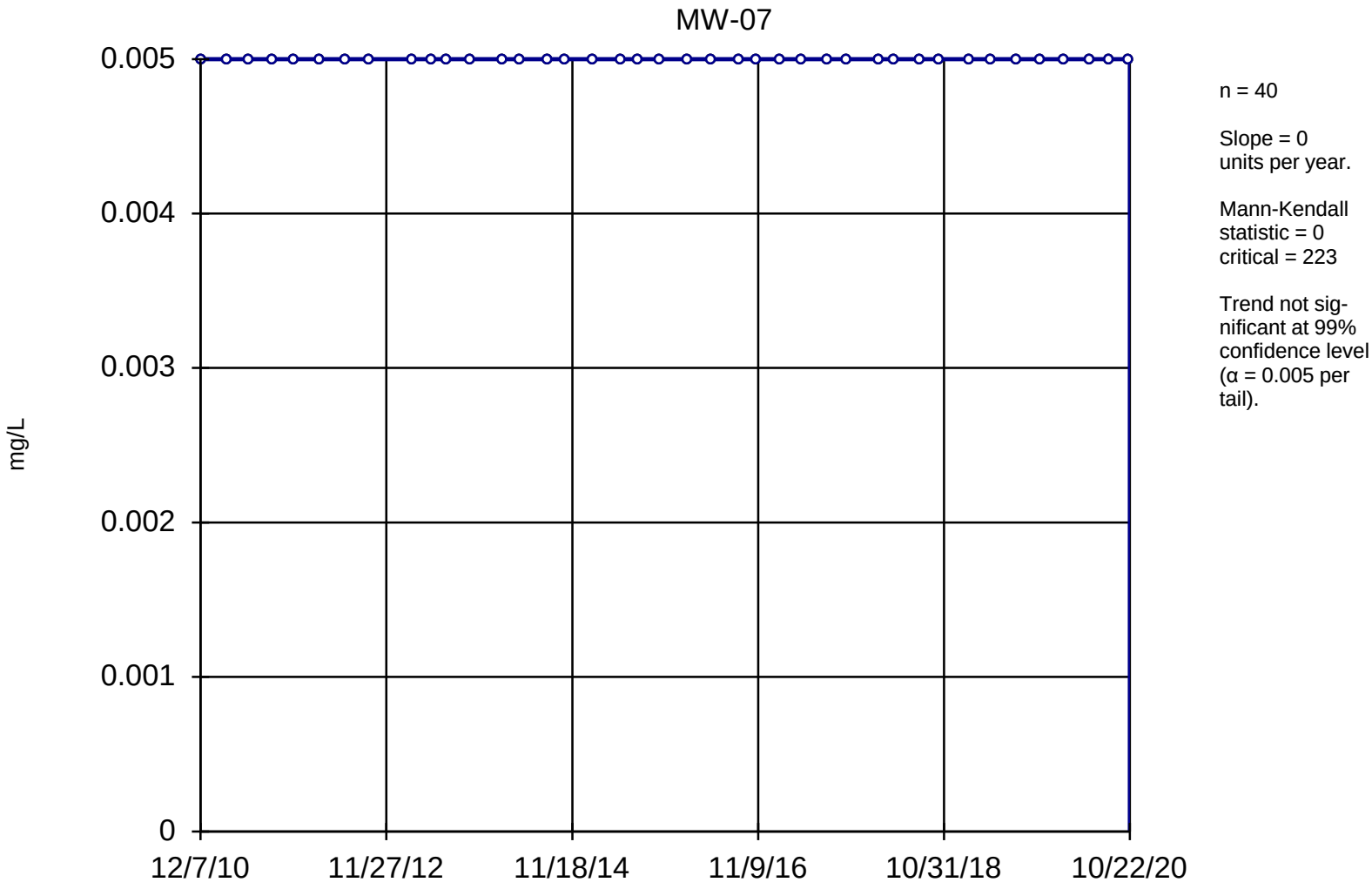
Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

Constituent: Chromium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator



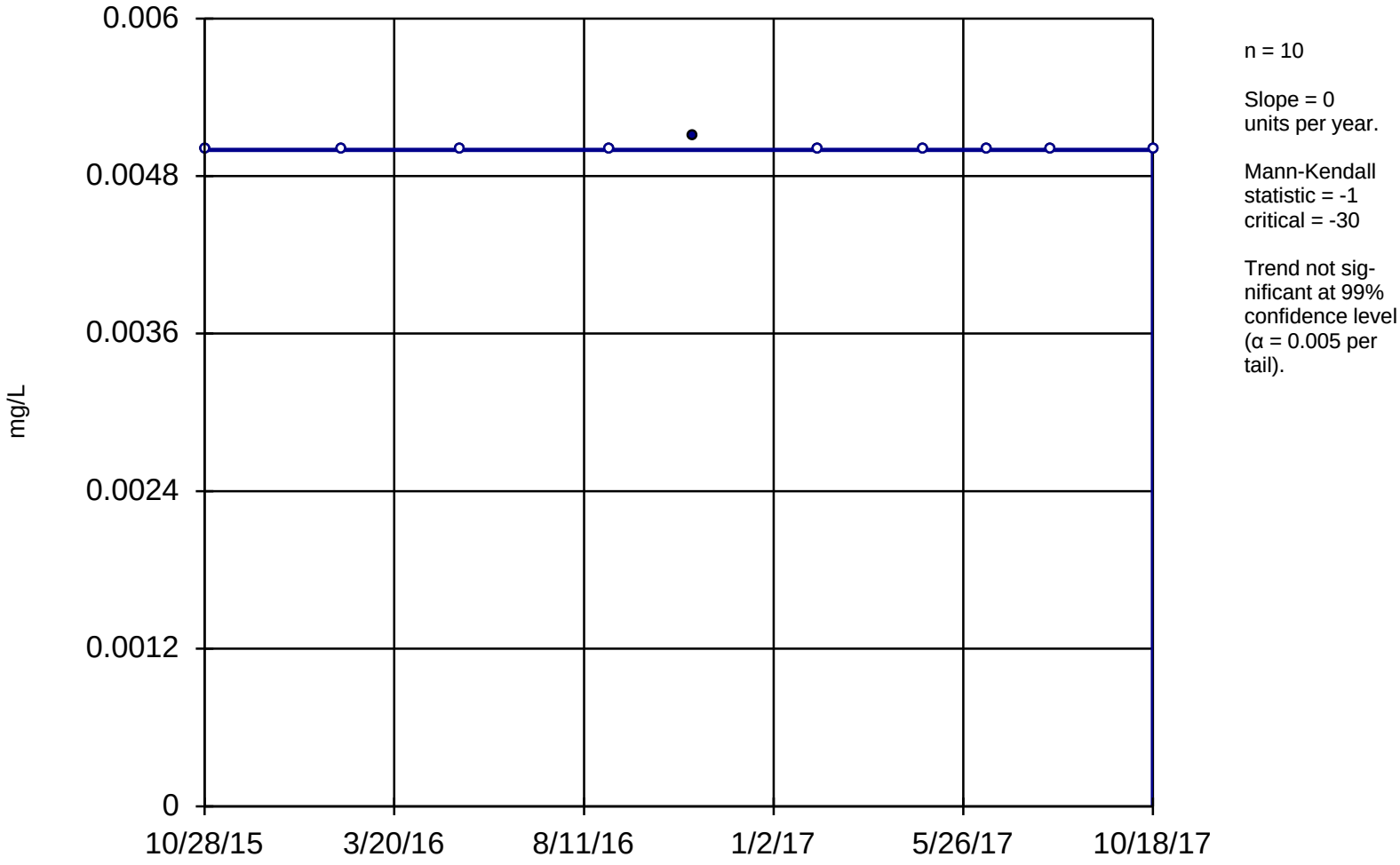
Constituent: Chromium, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



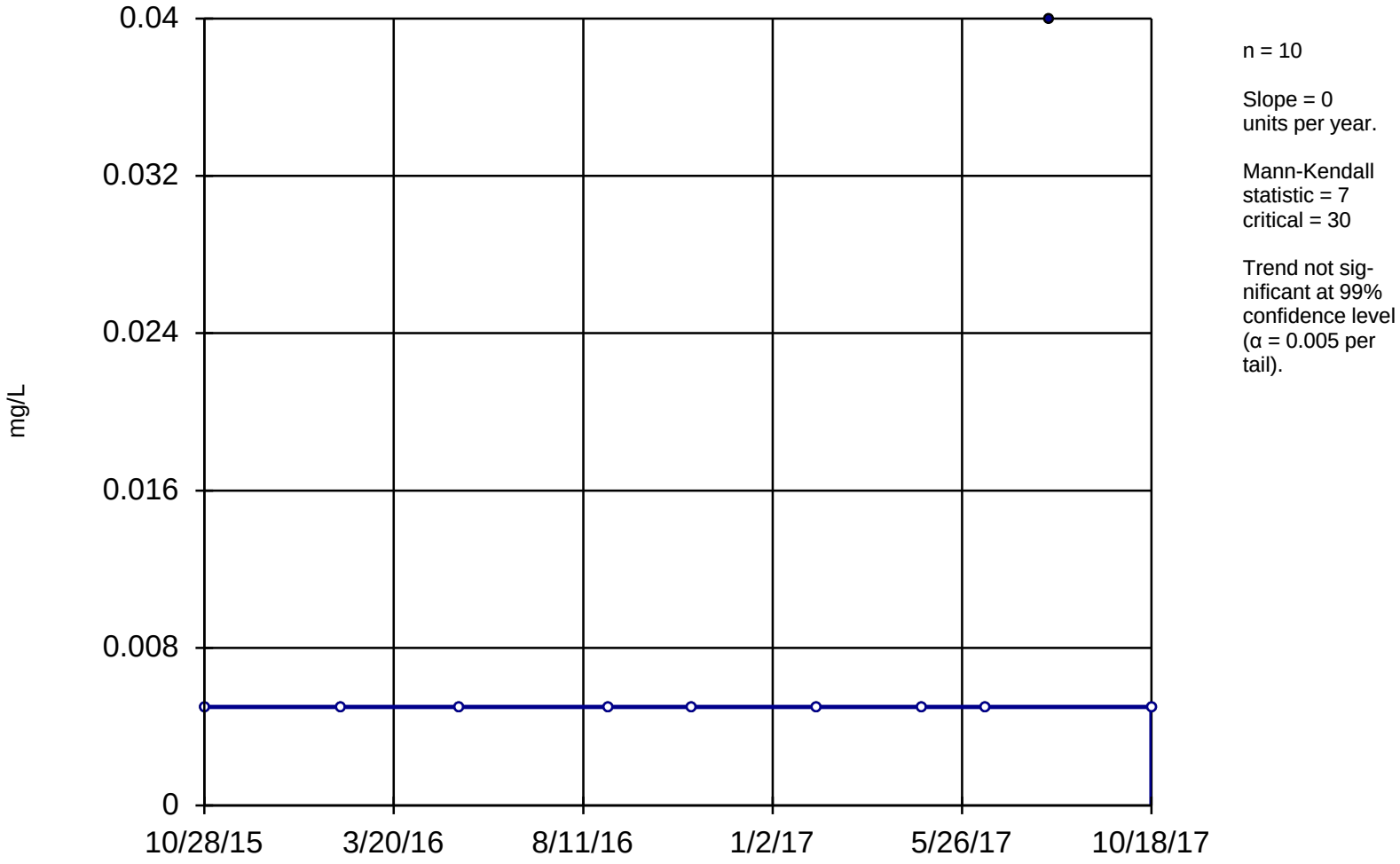
Constituent: Chromium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 10

Slope = 0
units per year.

Mann-Kendall
statistic = 7
critical = 30

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

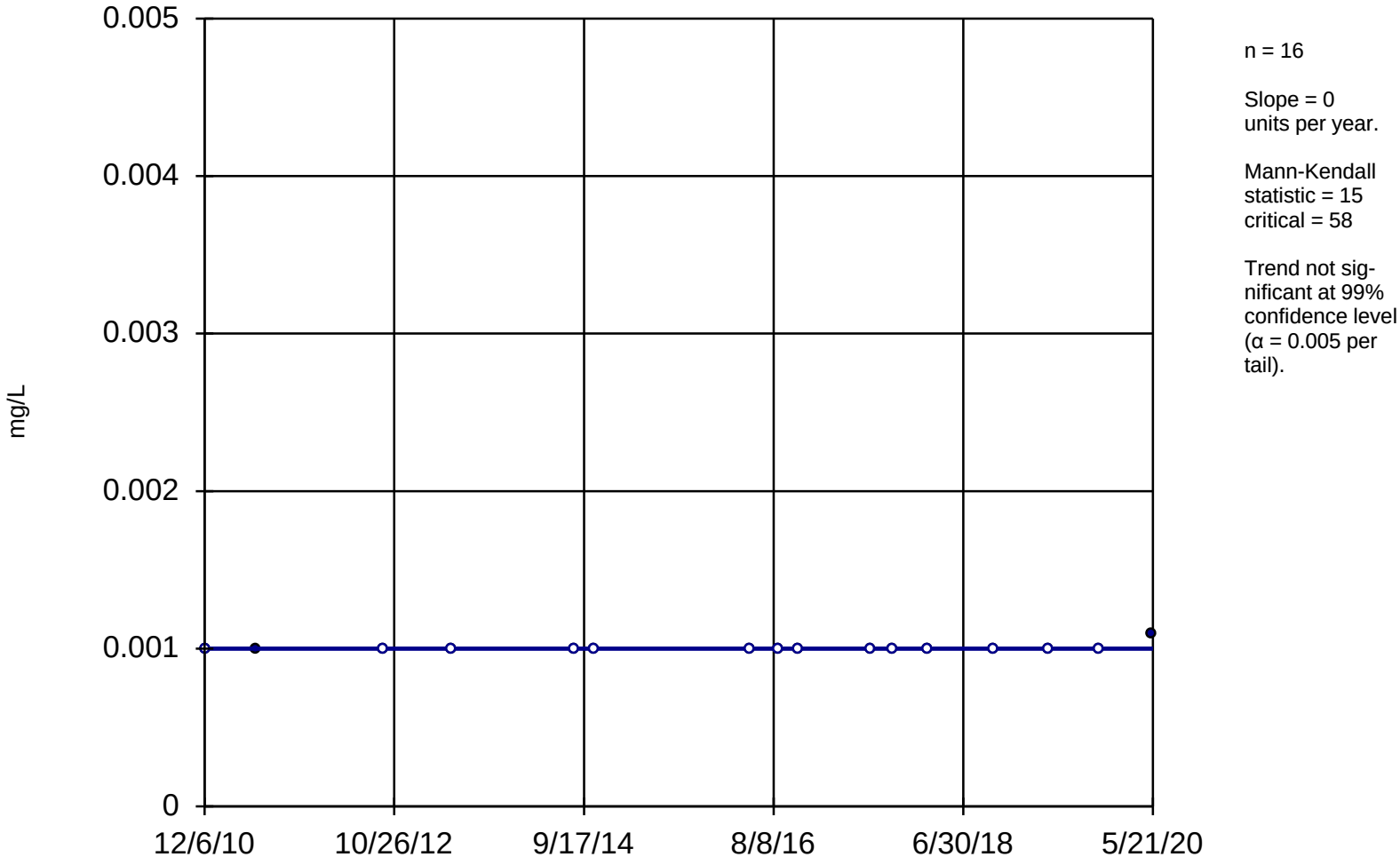
Constituent: Chromium, Total Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-01



n = 16

Slope = 0
units per year.

Mann-Kendall
statistic = 15
critical = 58

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

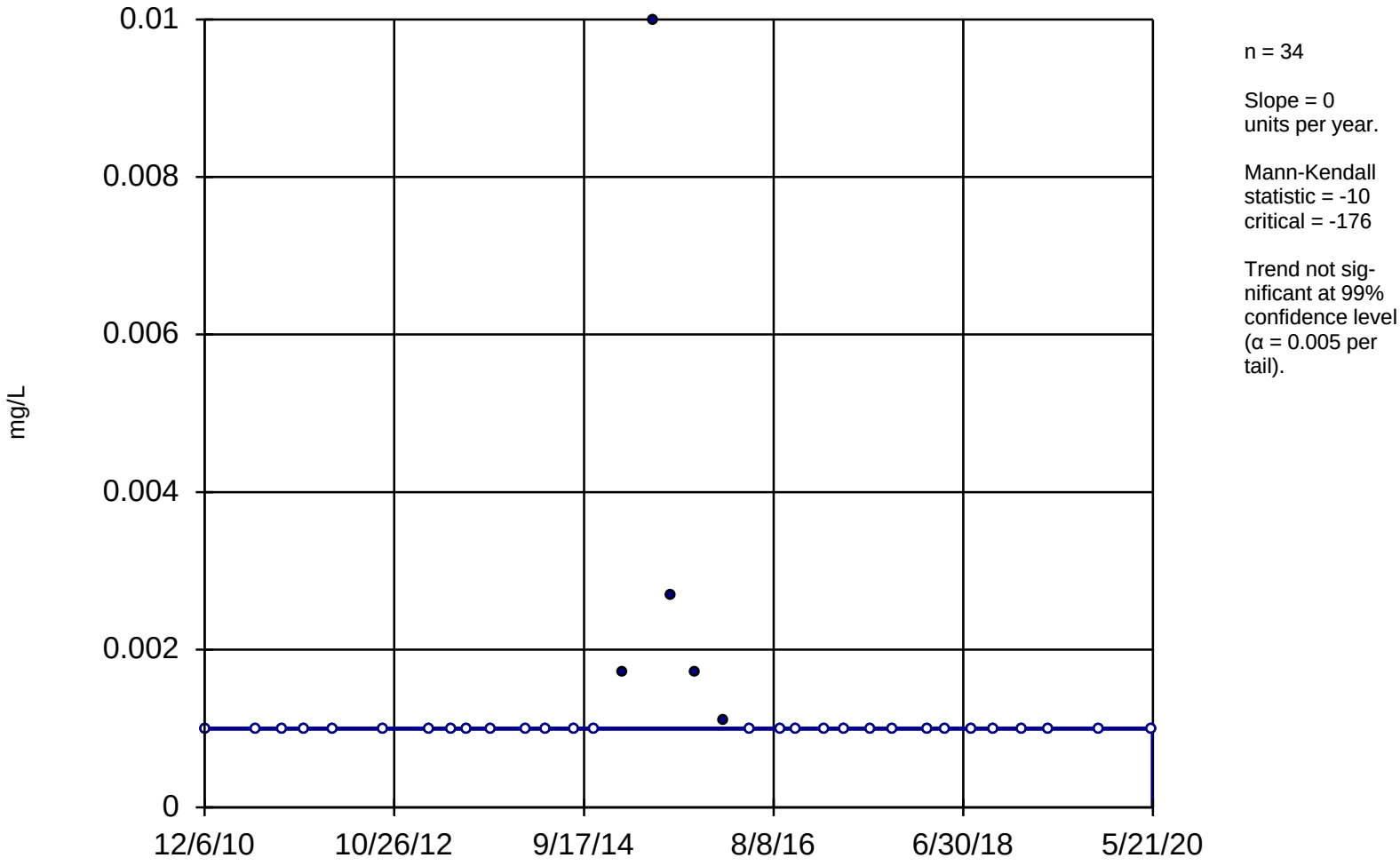
Constituent: Cobalt, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = -10
critical = -176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

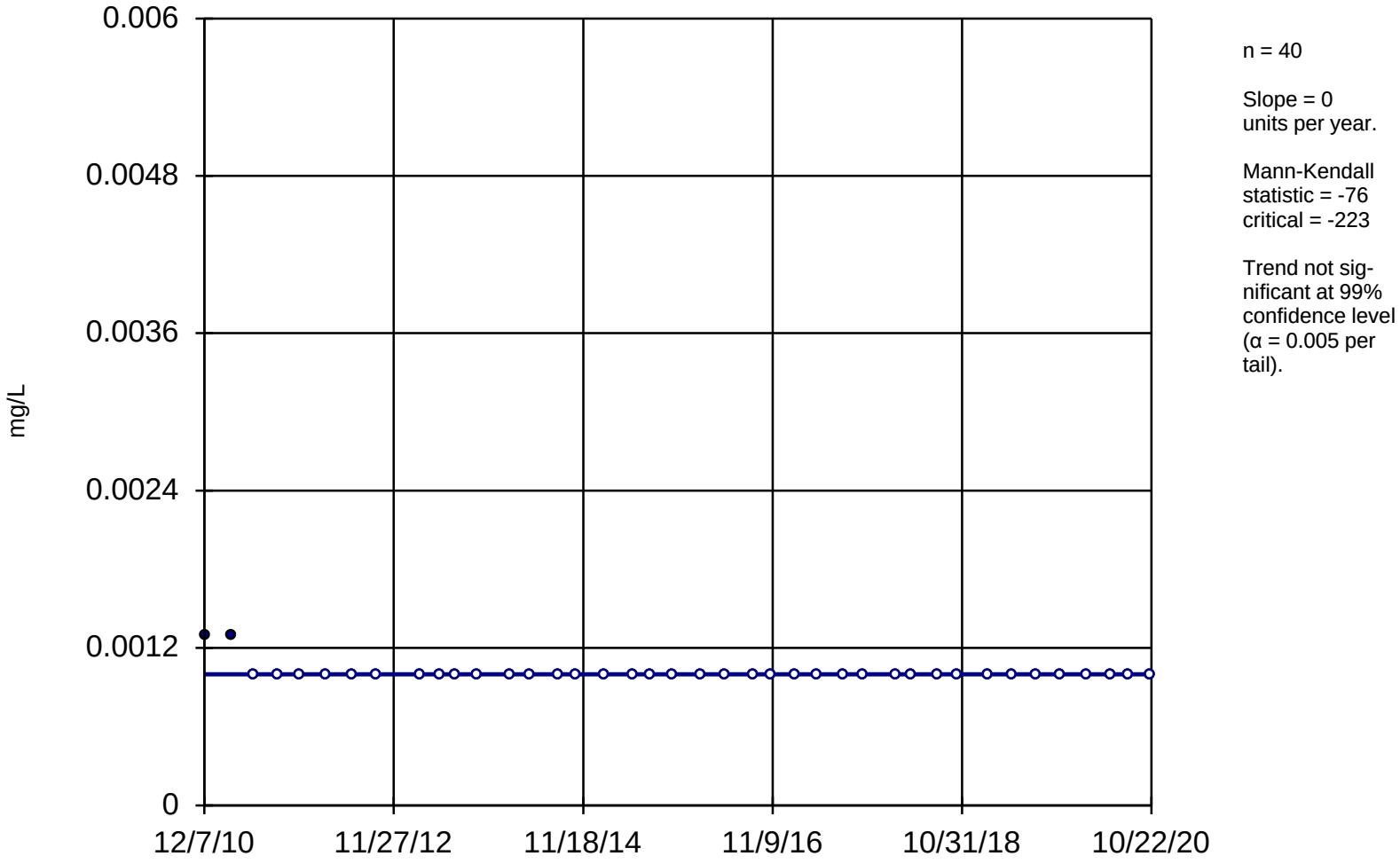
Constituent: Cobalt, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -76
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

Constituent: Cobalt, Dissolved Analysis Run 4/2/2021 11:01 AM

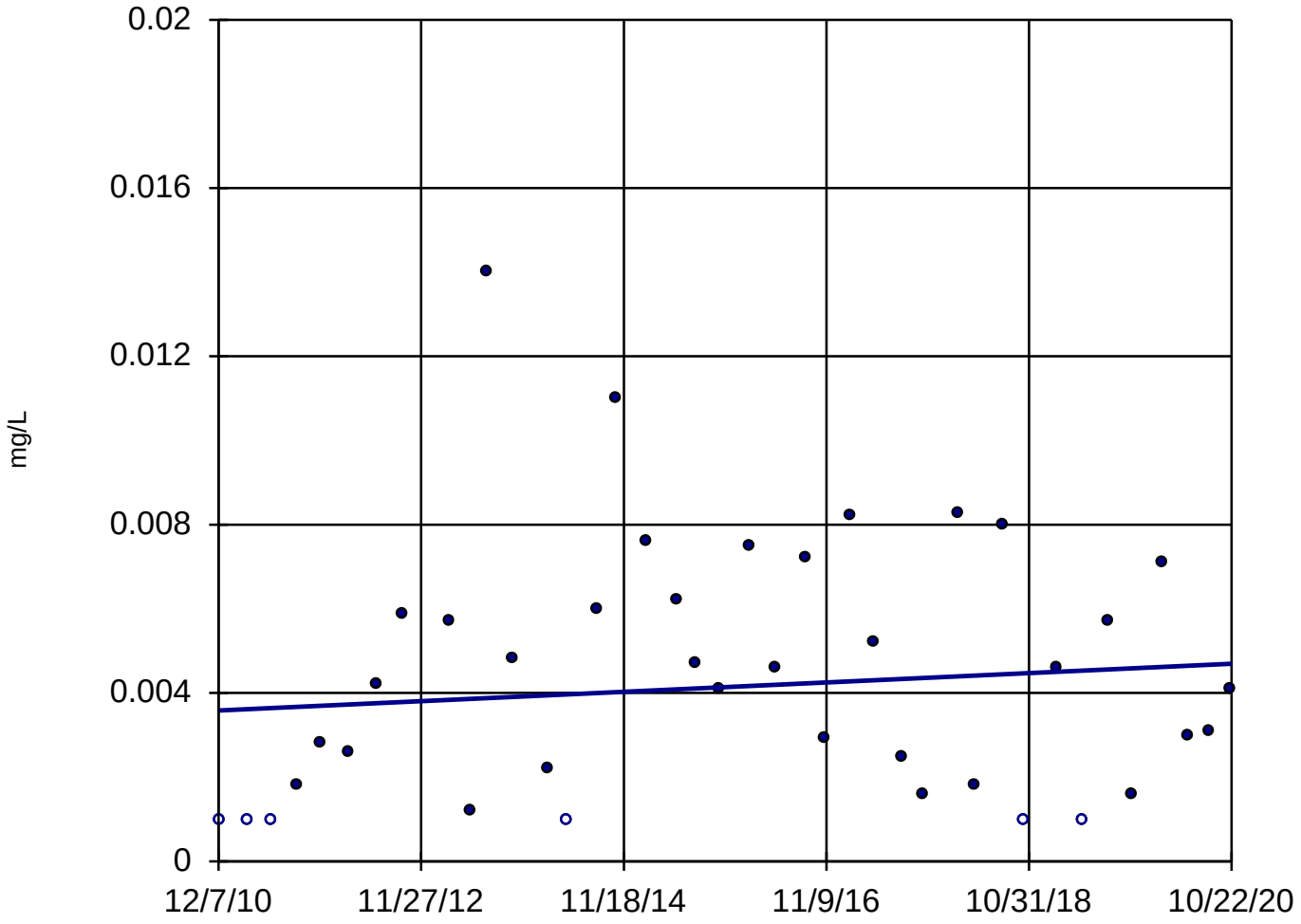
Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0.0001123 units per year.

Mann-Kendall statistic = 74
critical = 223

Trend not significant at 99% confidence level (α = 0.005 per tail).

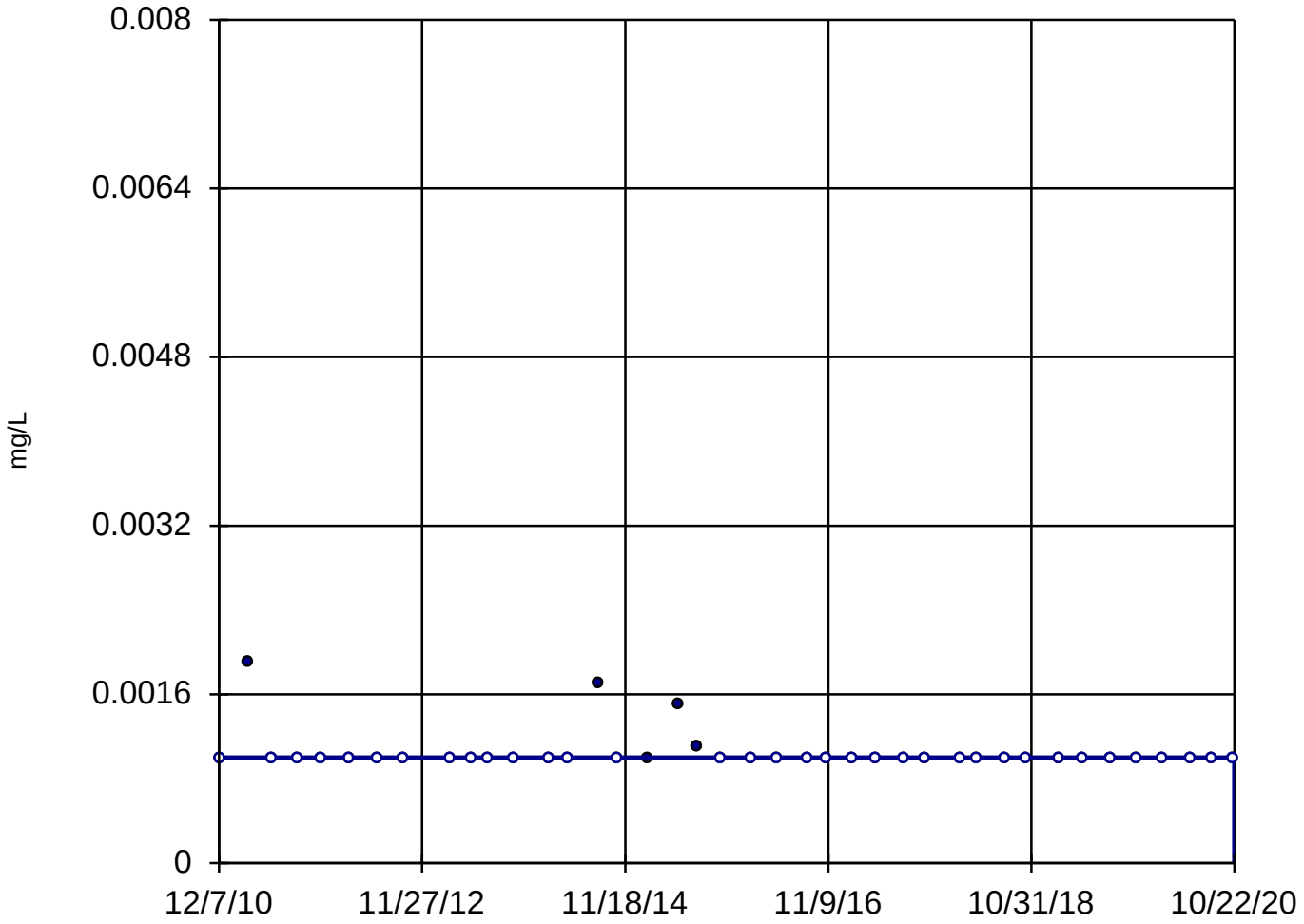
Constituent: Cobalt, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -62
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

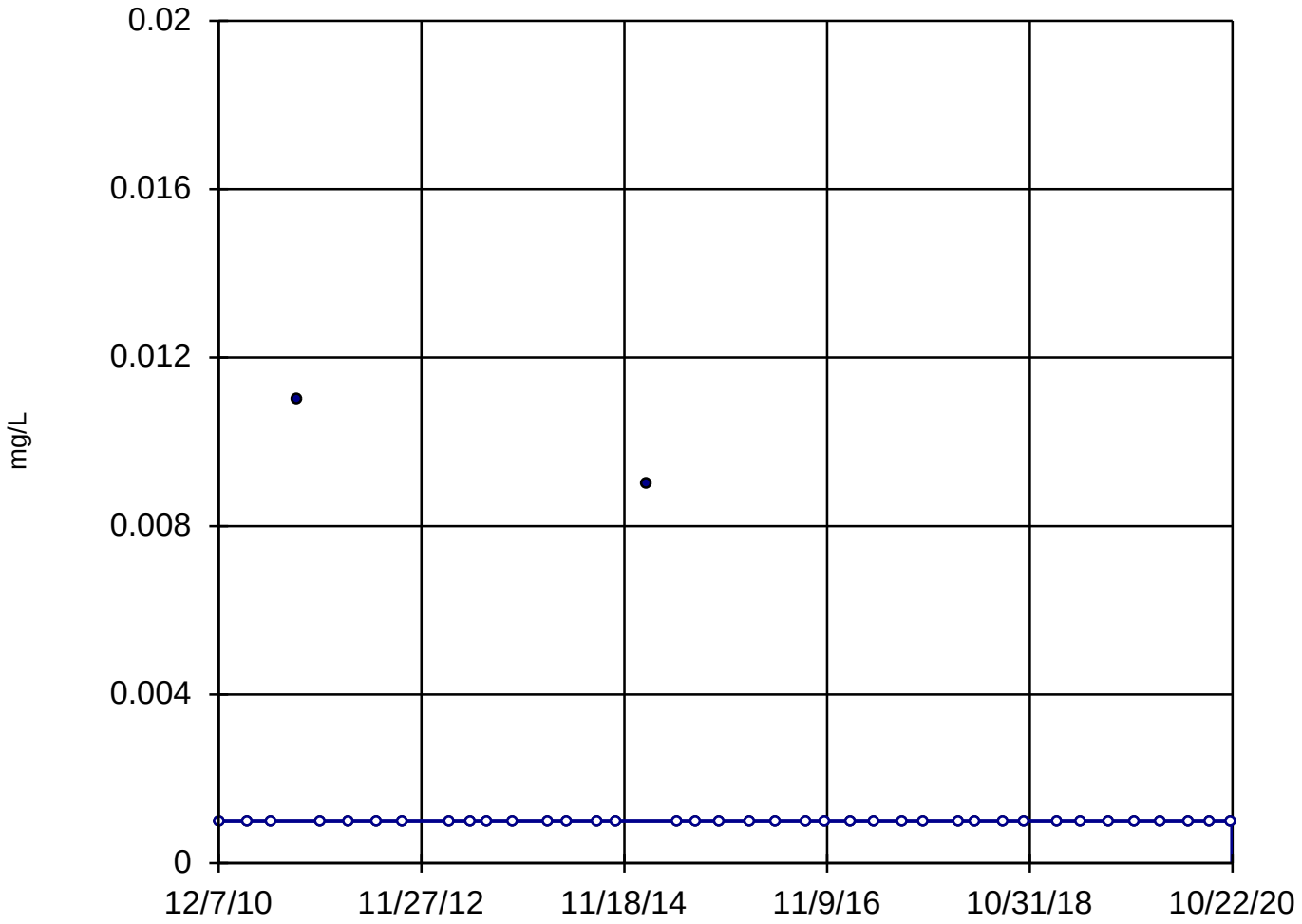
Constituent: Cobalt, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -41
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

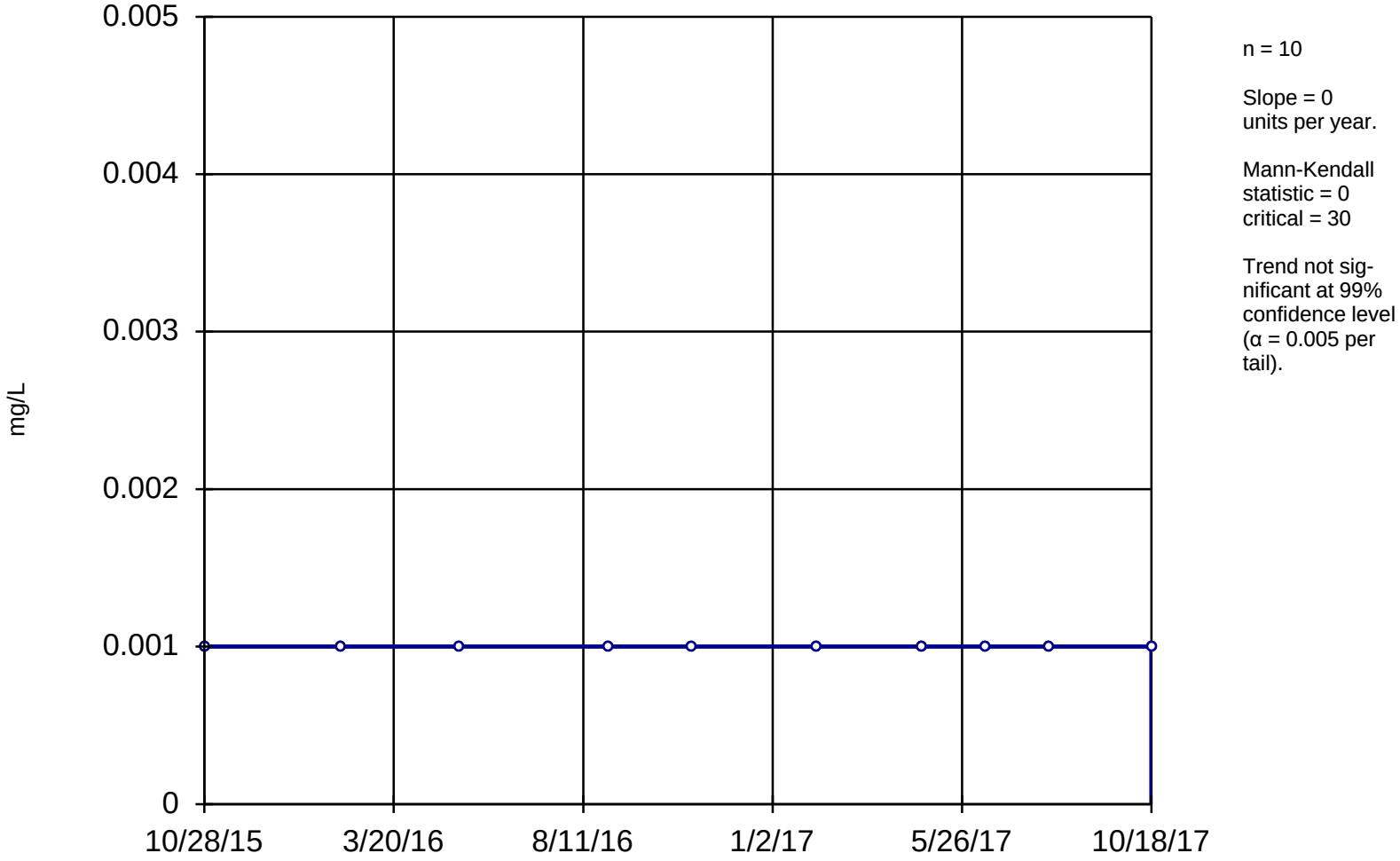
Constituent: Cobalt, Dissolved Analysis Run 4/2/2021 11:01 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



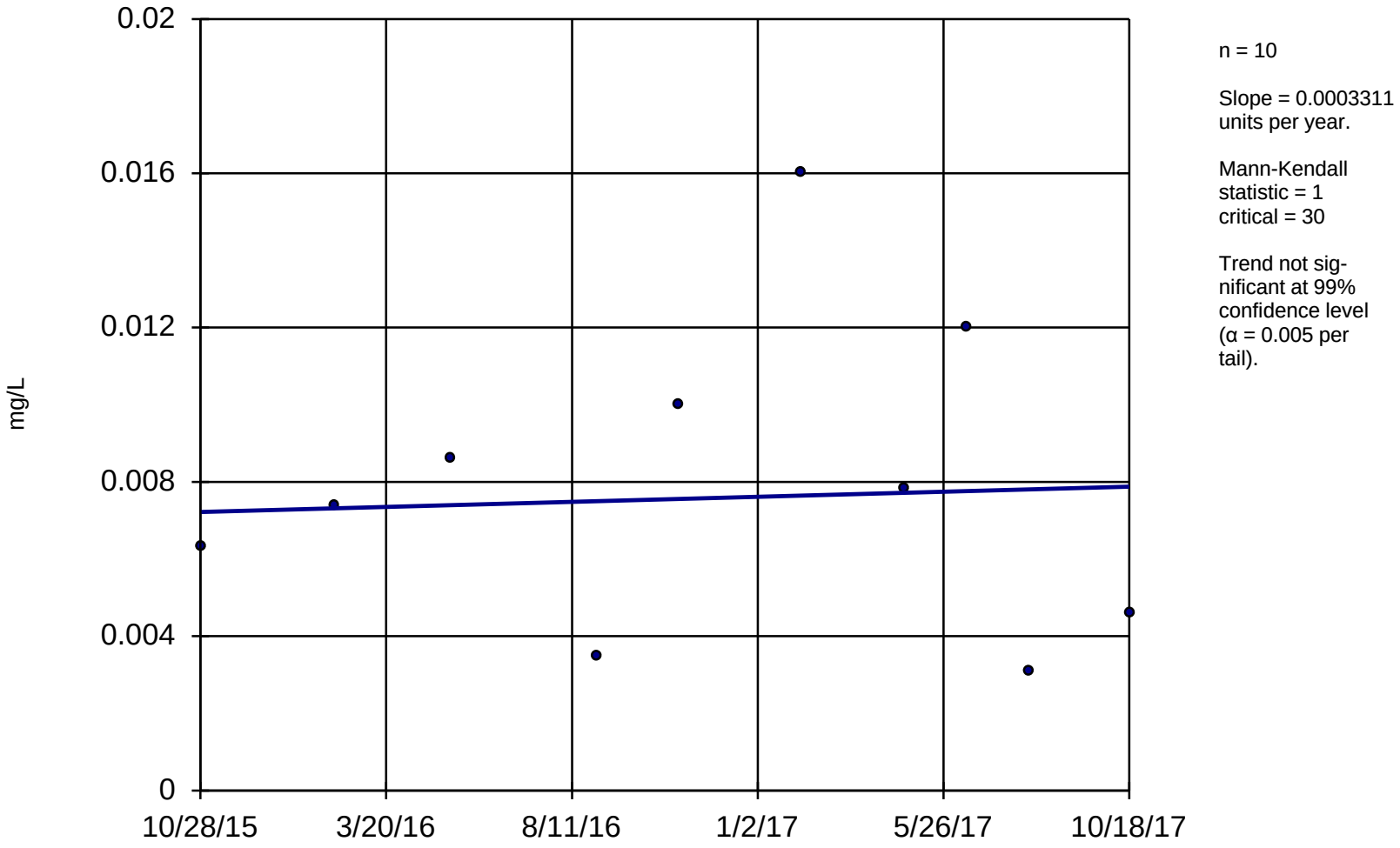
Constituent: Cobalt, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-04



n = 10

Slope = 0.0003311 units per year.

Mann-Kendall statistic = 1
critical = 30

Trend not significant at 99% confidence level (α = 0.005 per tail).

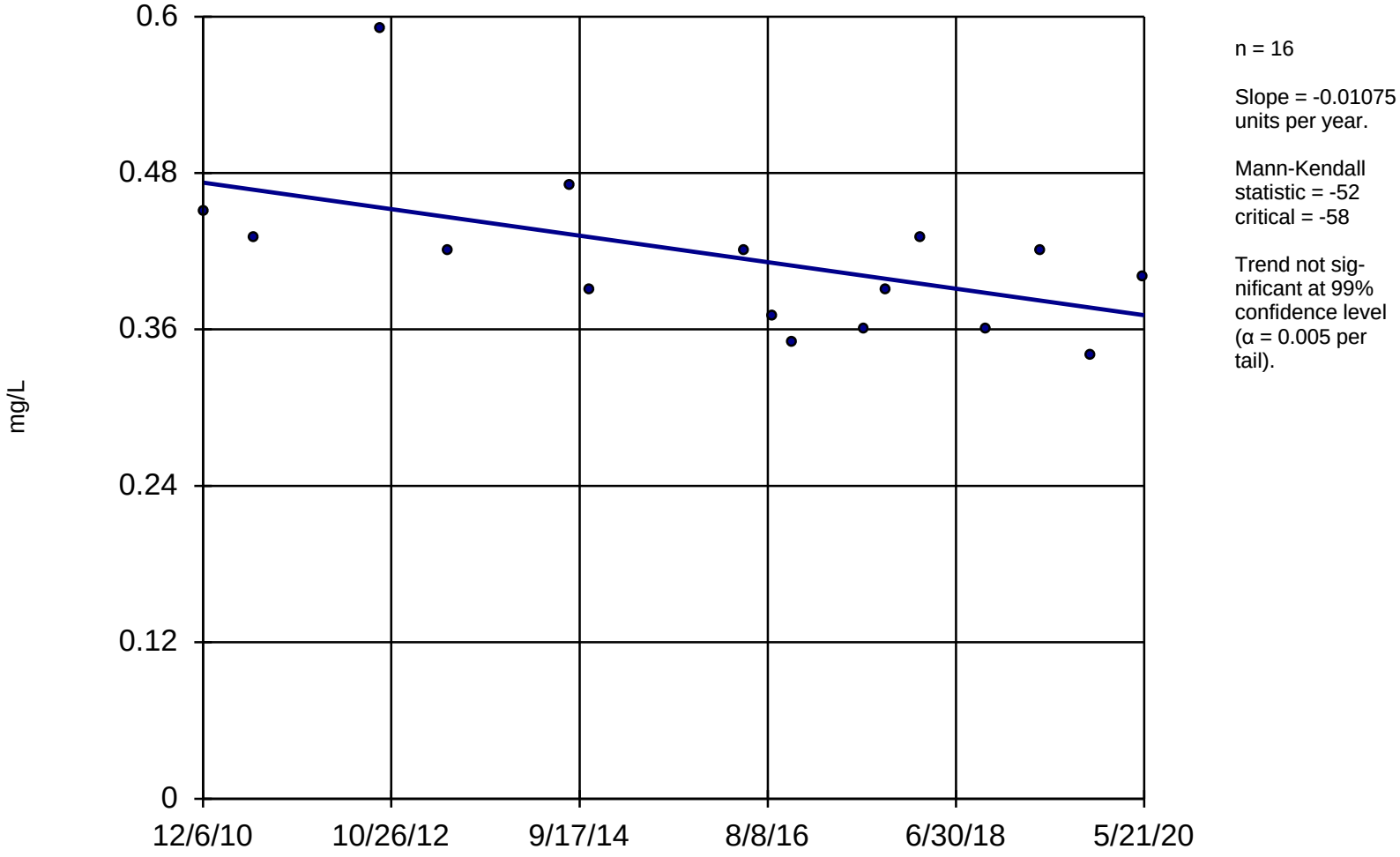
Constituent: Cobalt, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-01



n = 16

Slope = -0.01075 units per year.

Mann-Kendall statistic = -52
critical = -58

Trend not significant at 99% confidence level (α = 0.005 per tail).

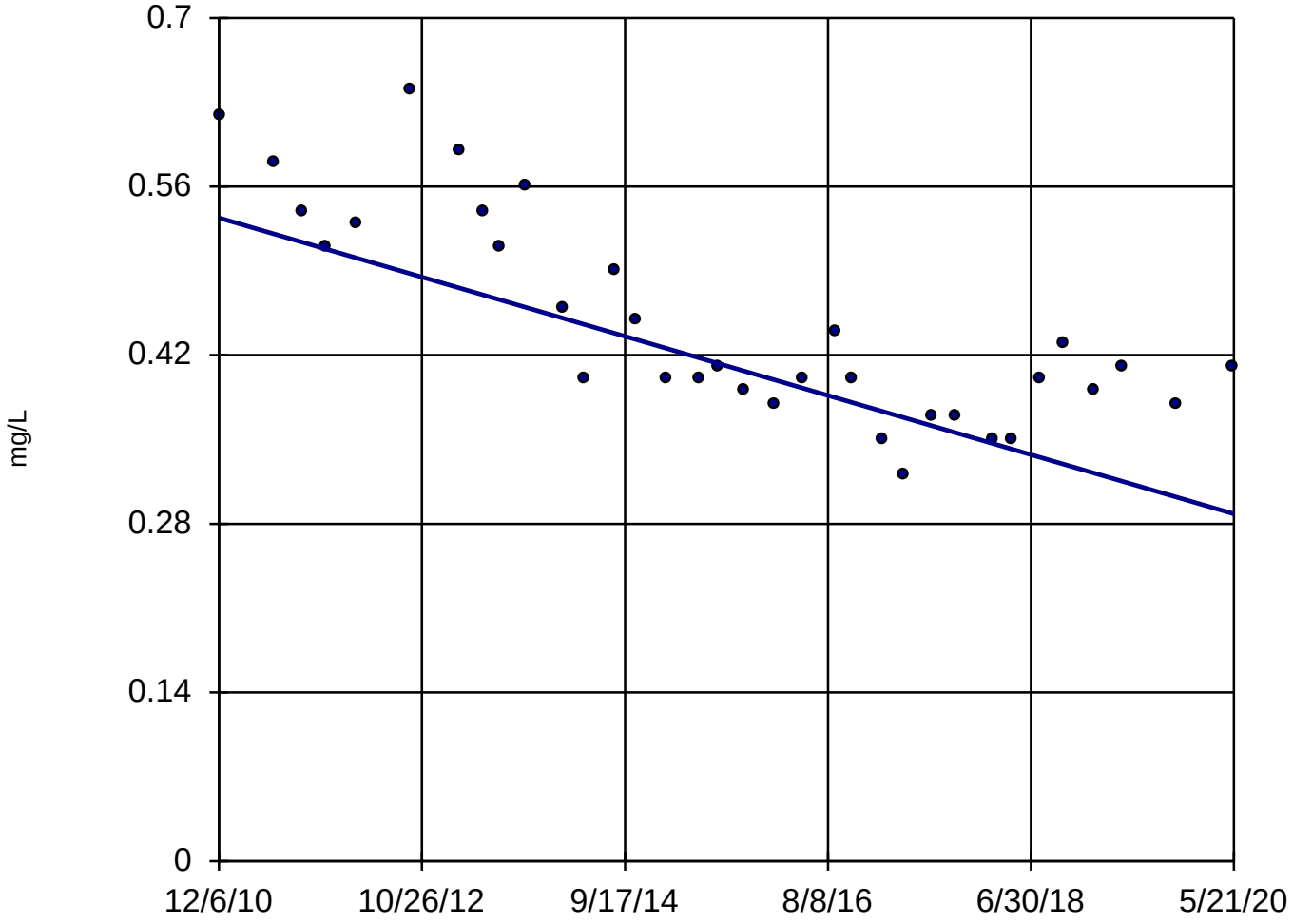
Constituent: Fluoride Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-02



n = 34

Slope = -0.02597 units per year.

Mann-Kendall statistic = -321
critical = -176

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

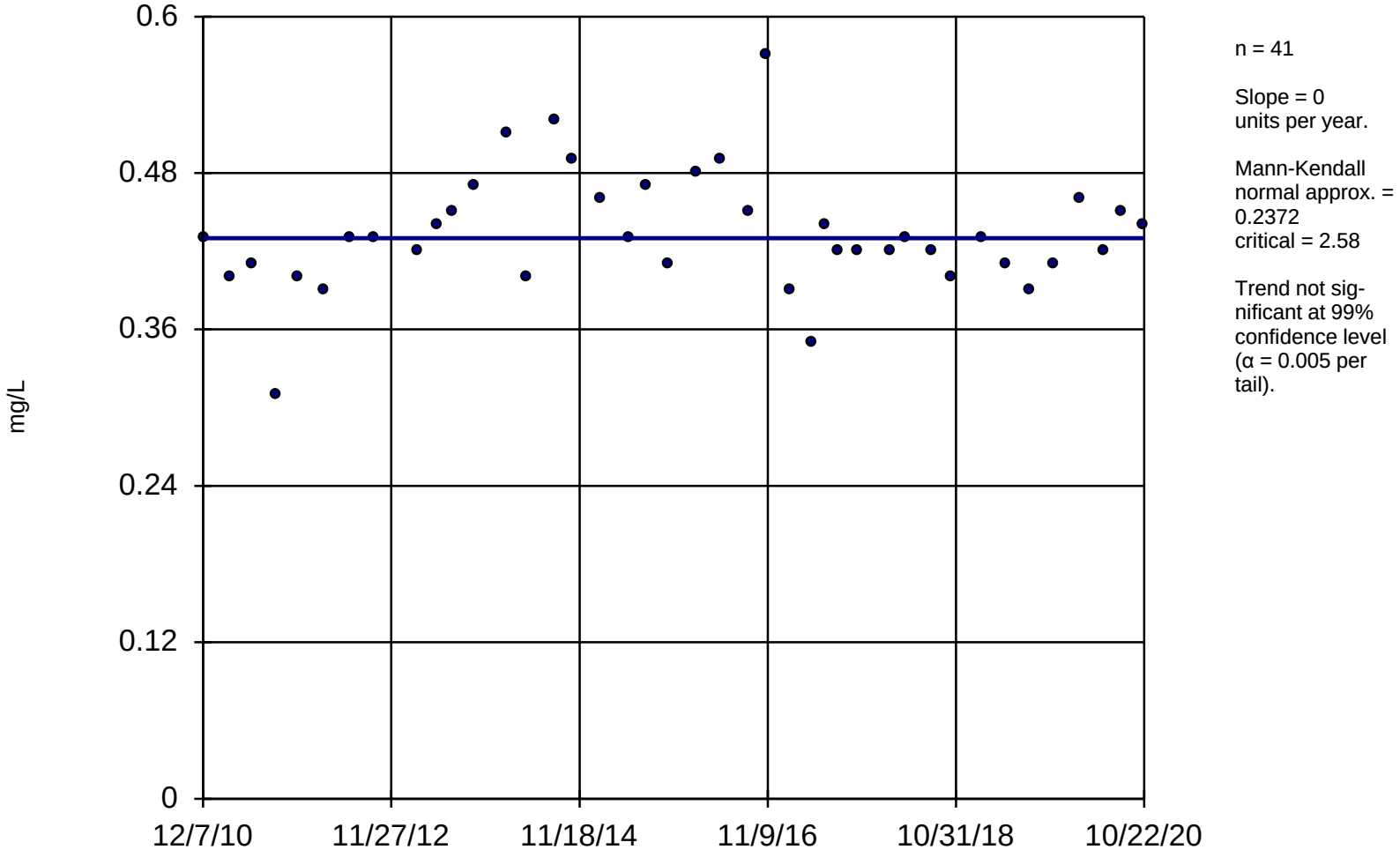
Constituent: Fluoride Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-03



n = 41

Slope = 0
units per year.

Mann-Kendall
normal approx. =
0.2372
critical = 2.58

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

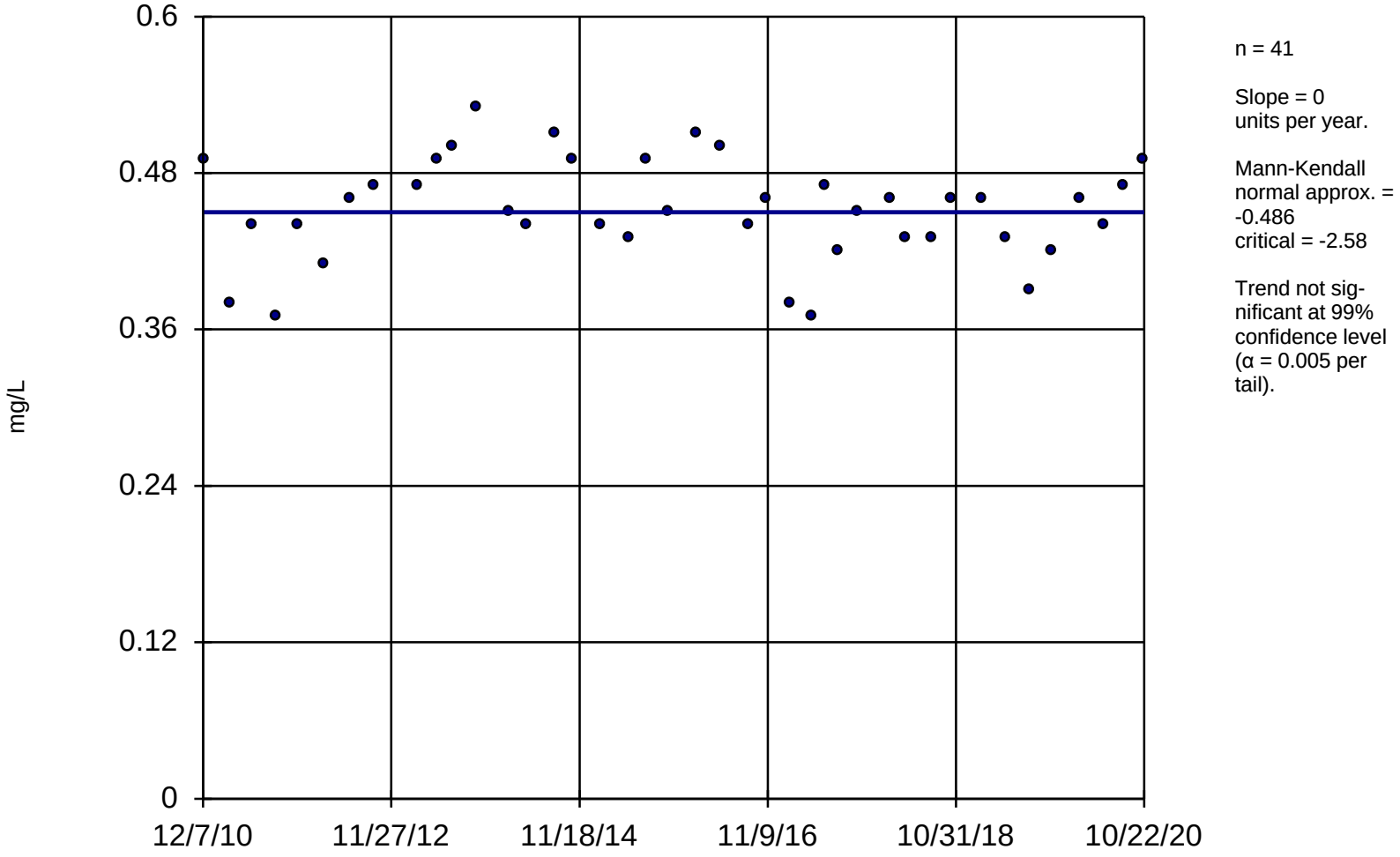
Constituent: Fluoride Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-04



n = 41

Slope = 0
units per year.

Mann-Kendall
normal approx. =
-0.486
critical = -2.58

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

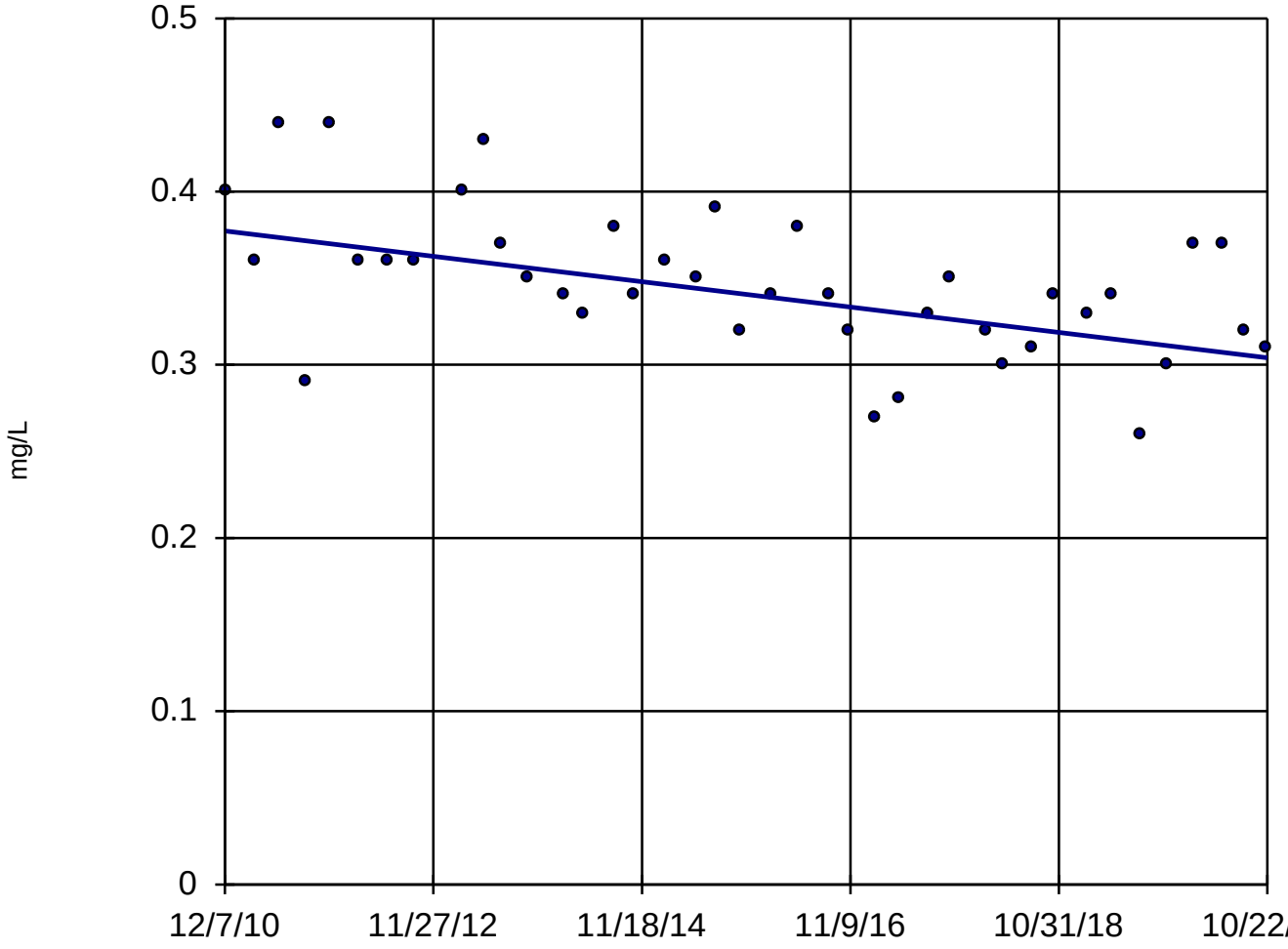
Constituent: Fluoride Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-06



n = 40

Slope = -0.0074 units per year.

Mann-Kendall statistic = -315
critical = -223

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

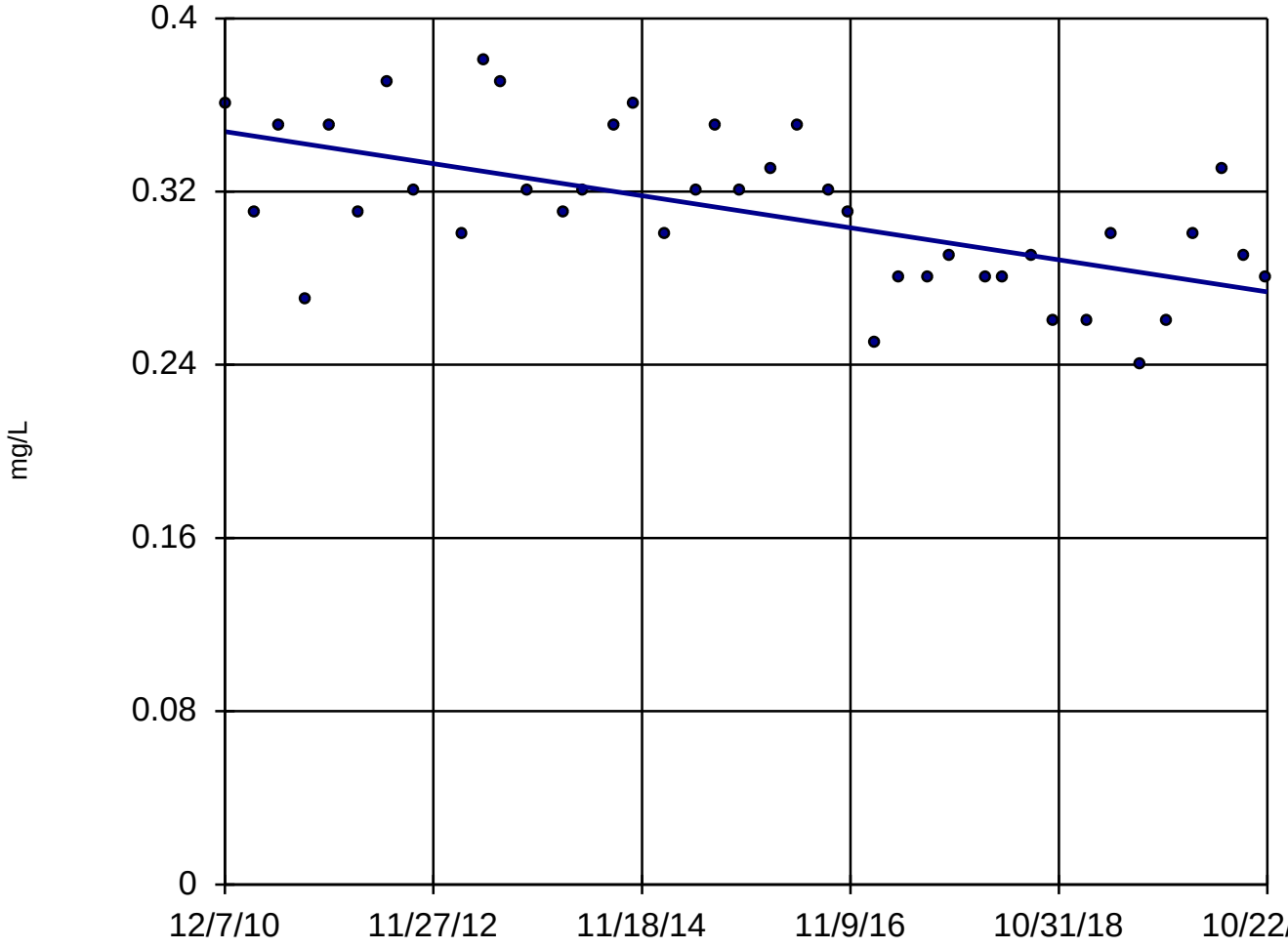
Constituent: Fluoride Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-07



n = 40

Slope = -0.007482 units per year.

Mann-Kendall statistic = -320
critical = -223

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

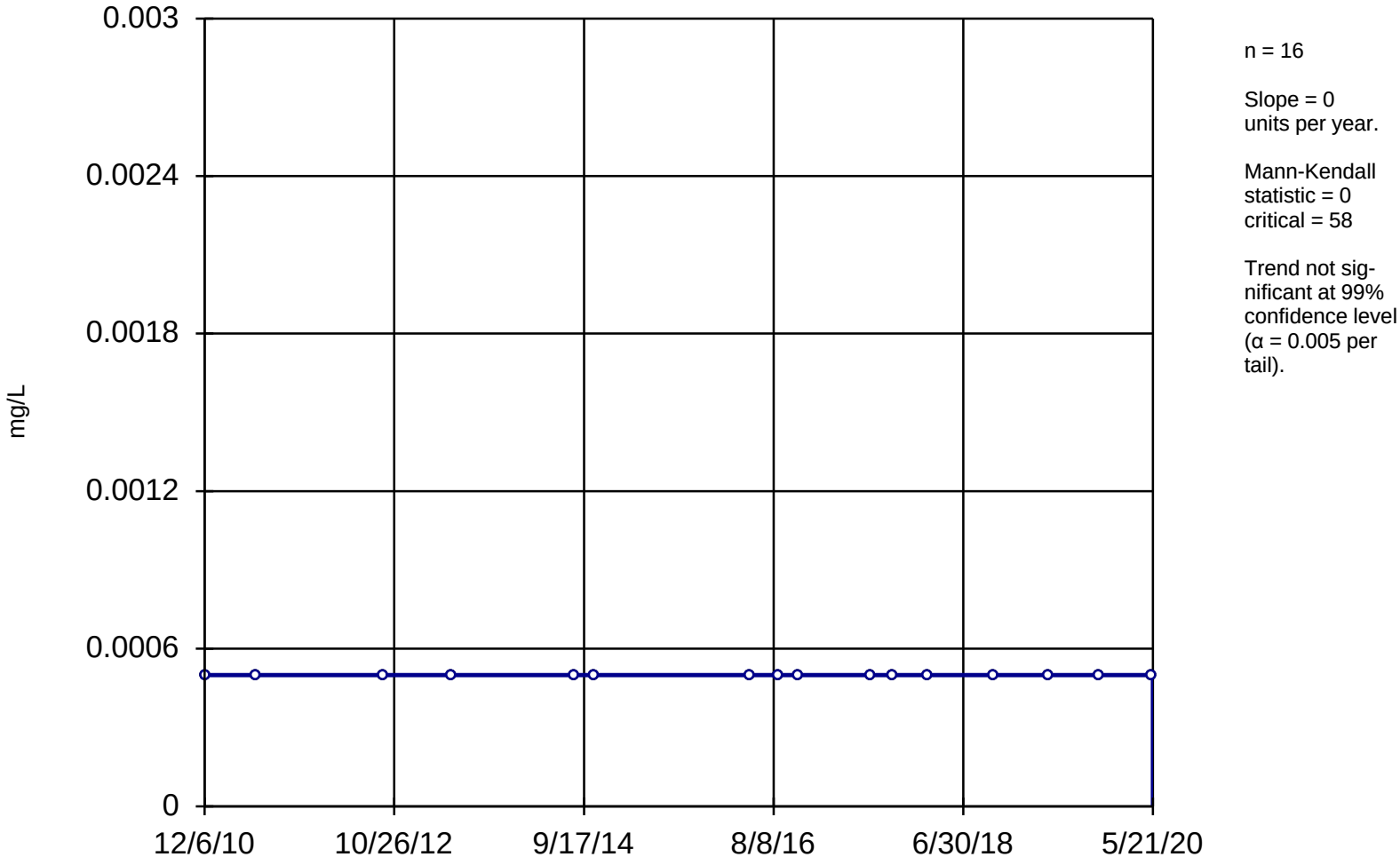
Constituent: Fluoride Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-01



n = 16

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 58

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

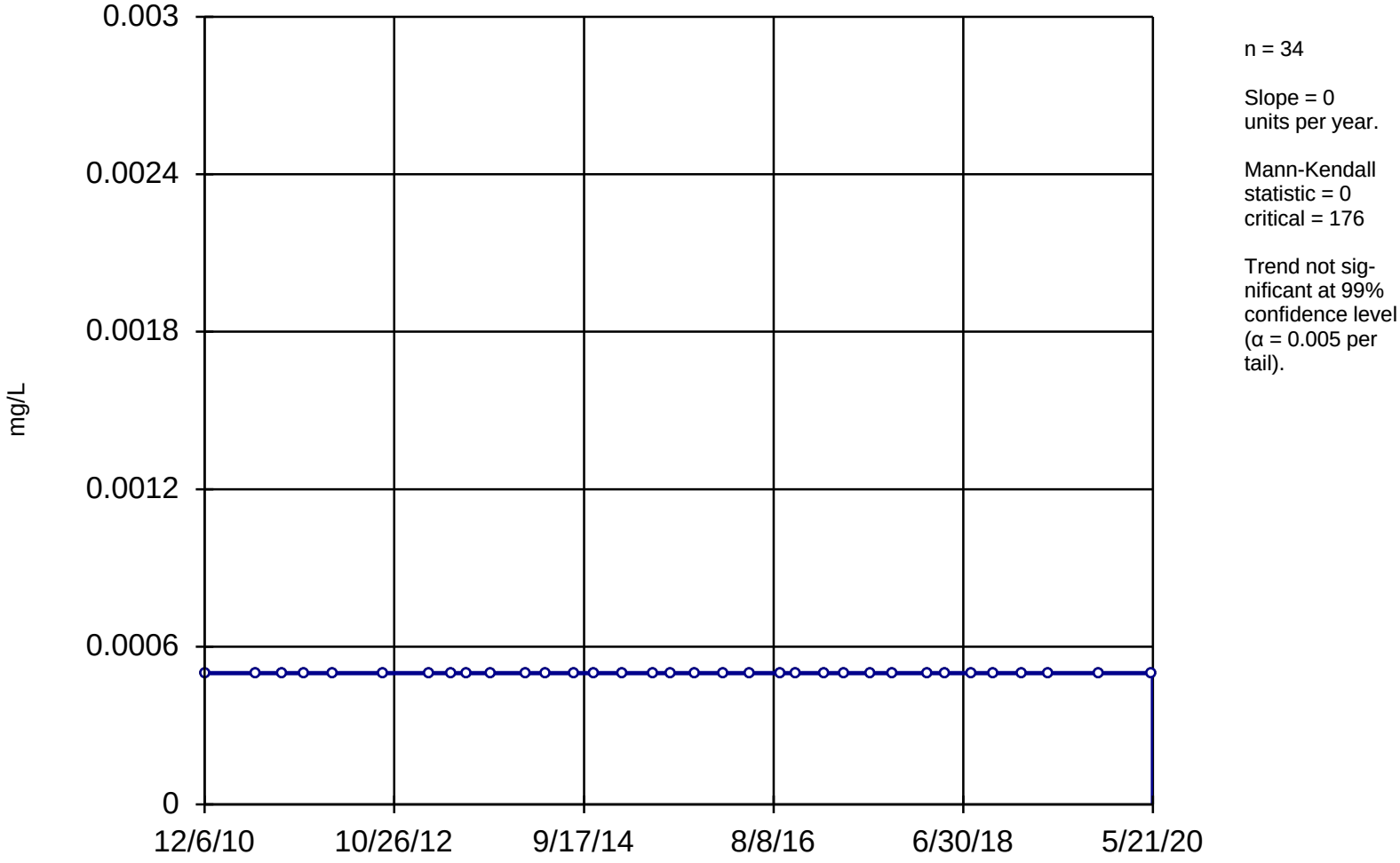
Constituent: Lead, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

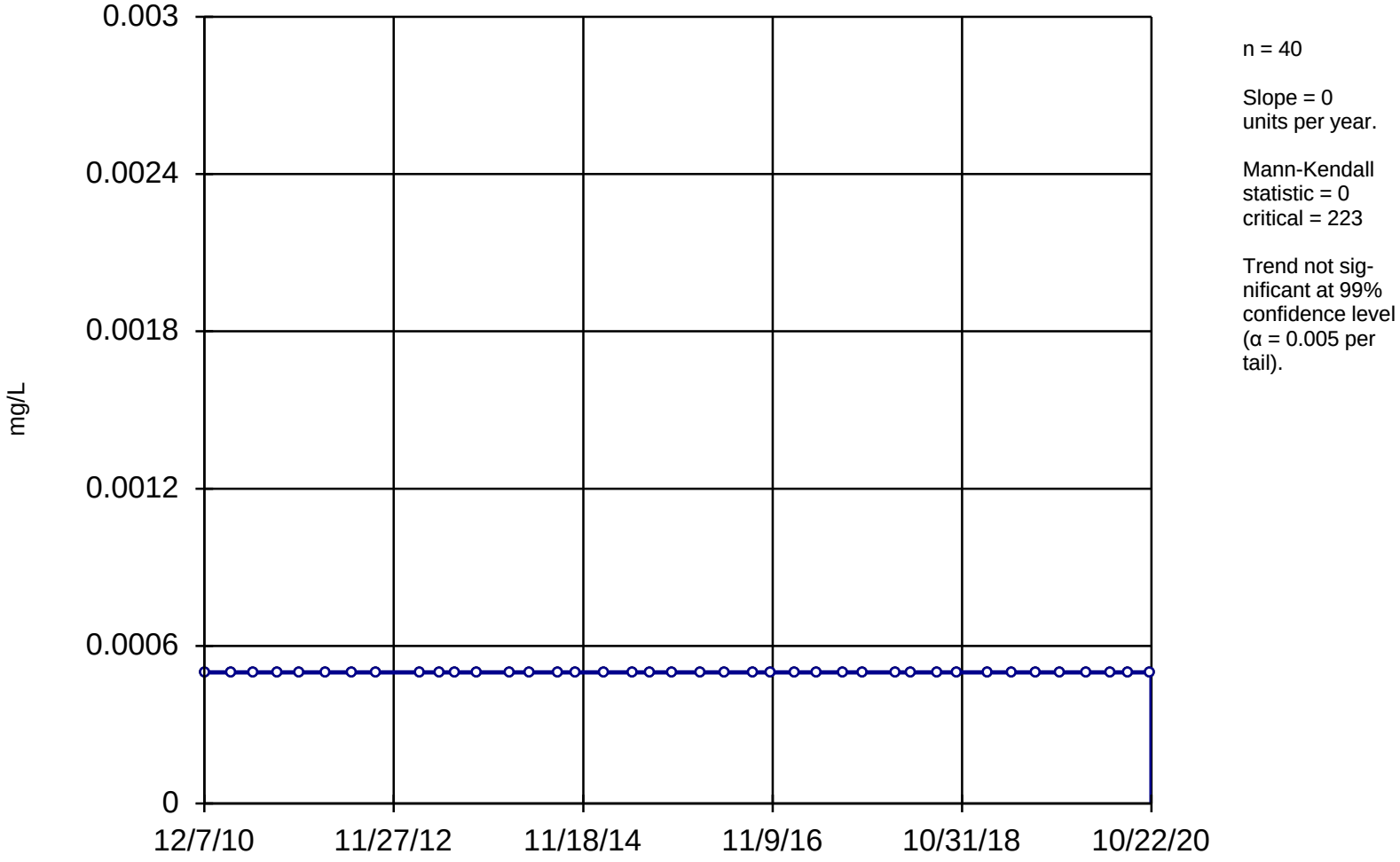
Constituent: Lead, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

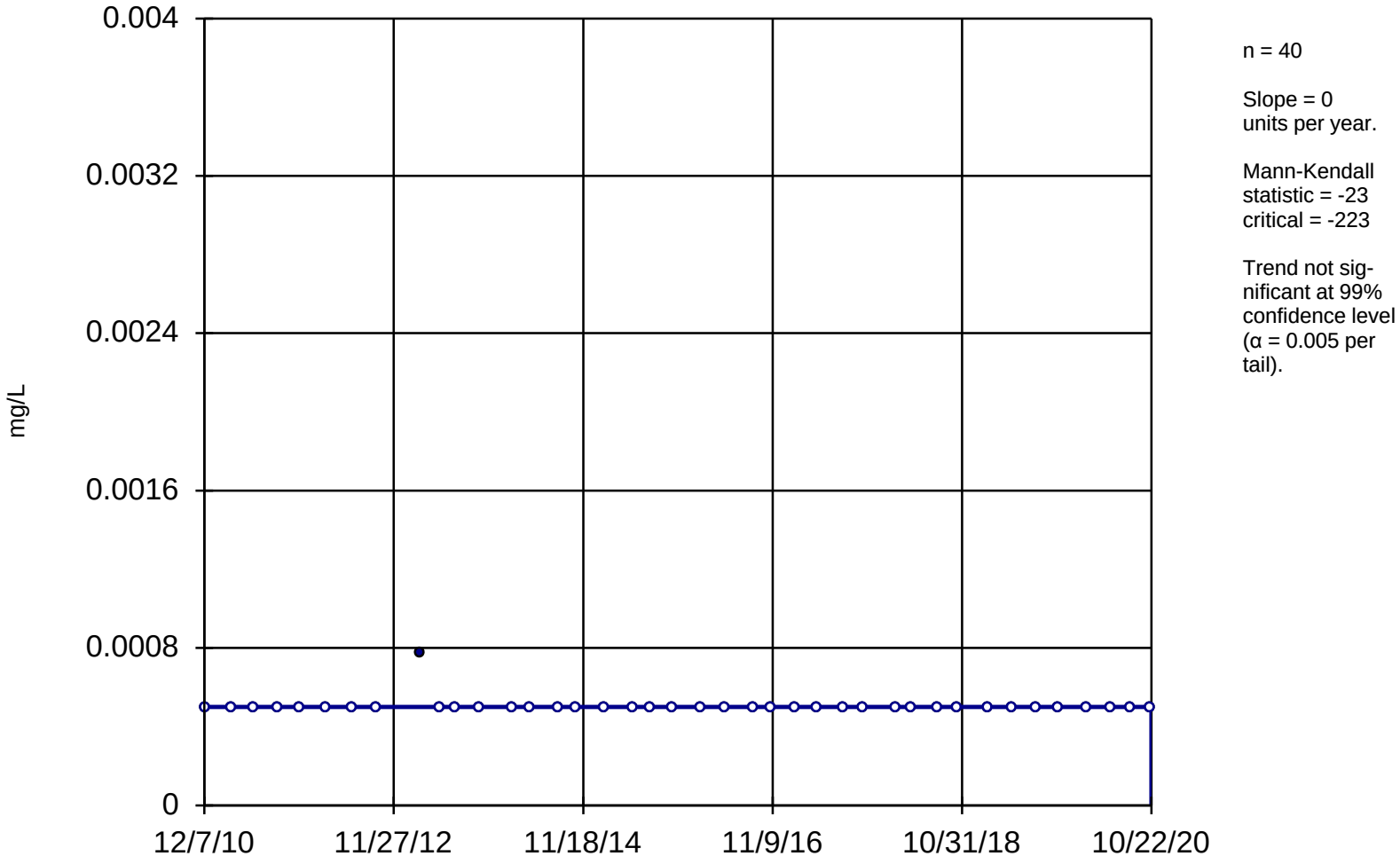
Constituent: Lead, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -23
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

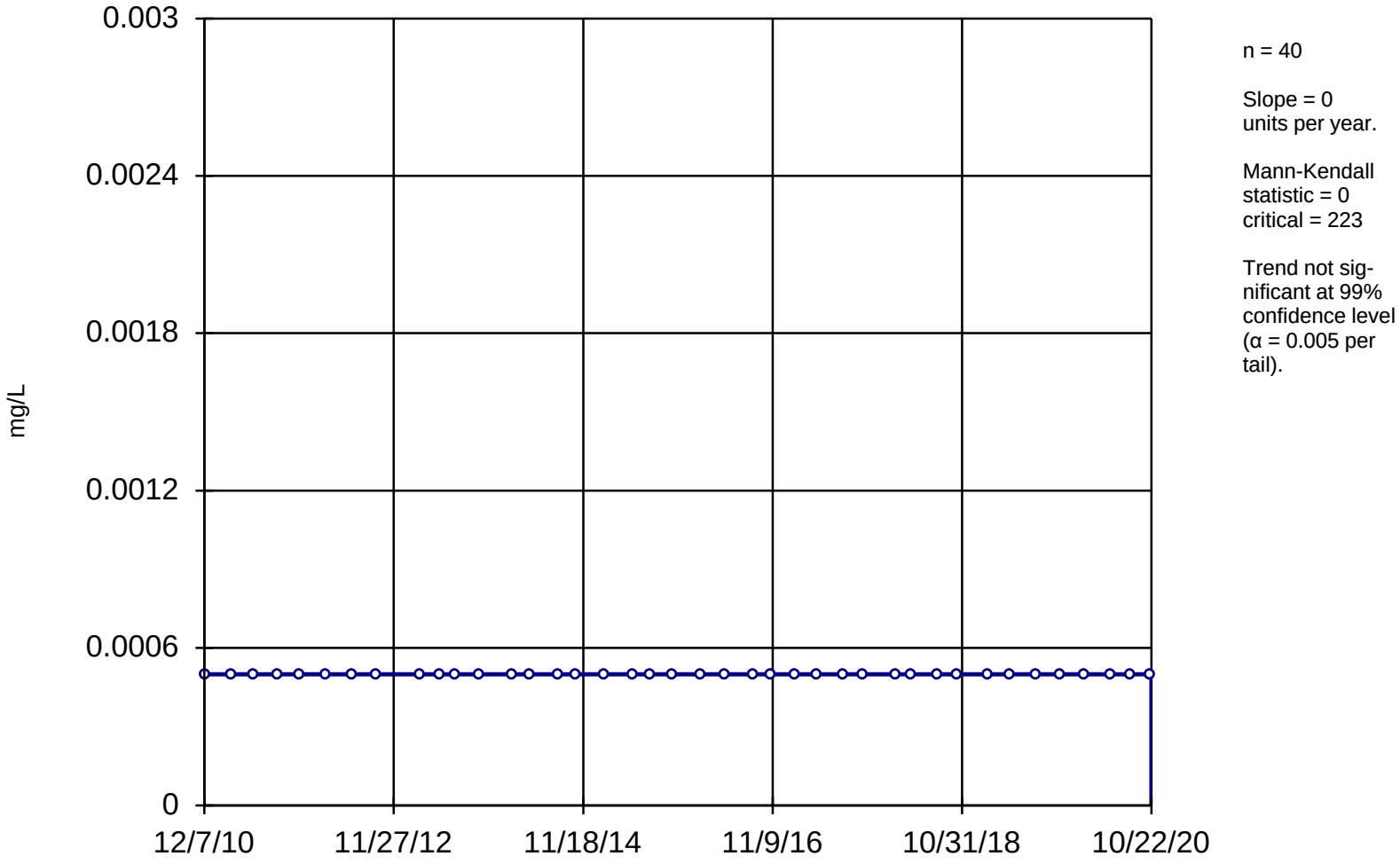
Constituent: Lead, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

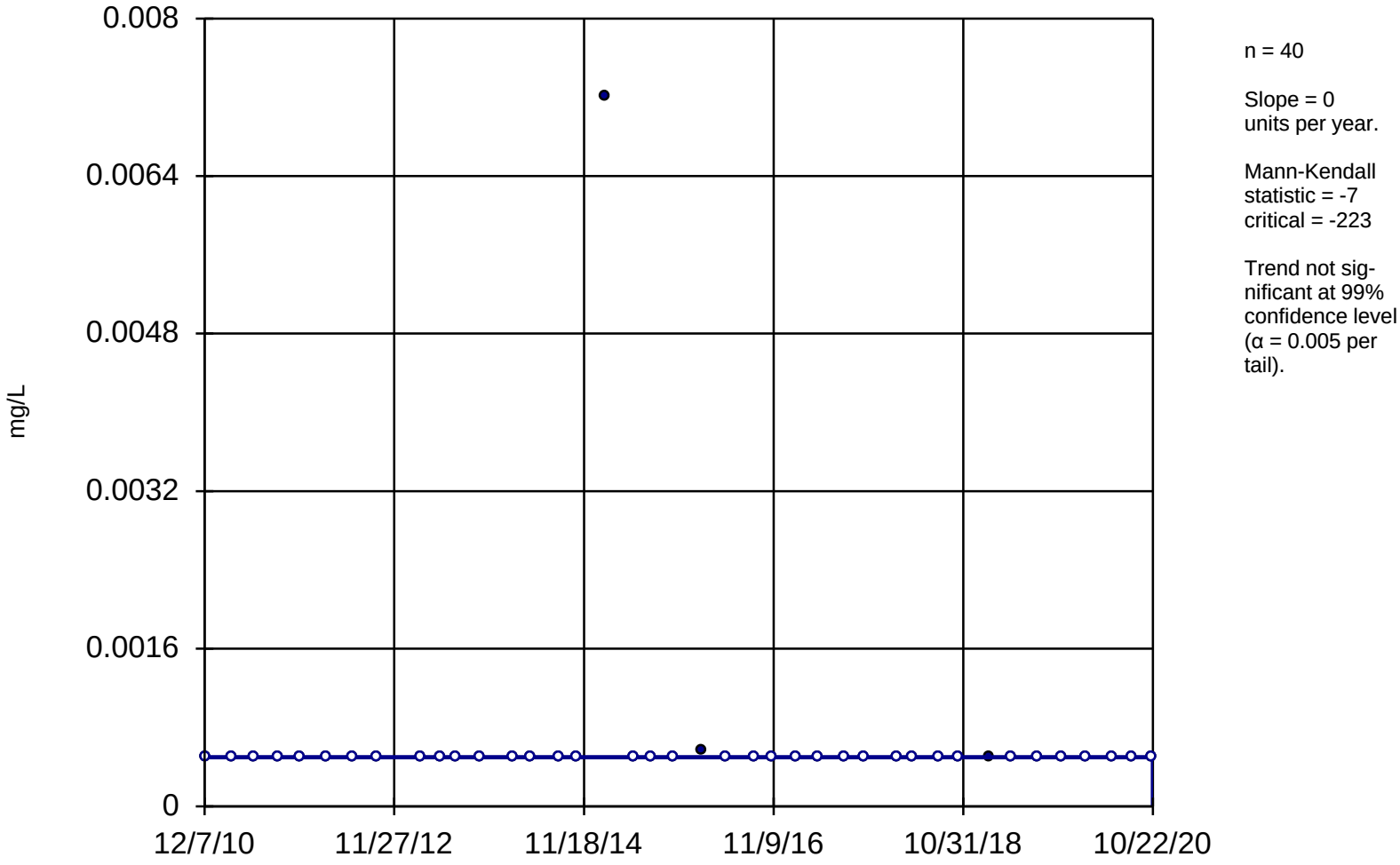
Constituent: Lead, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -7
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

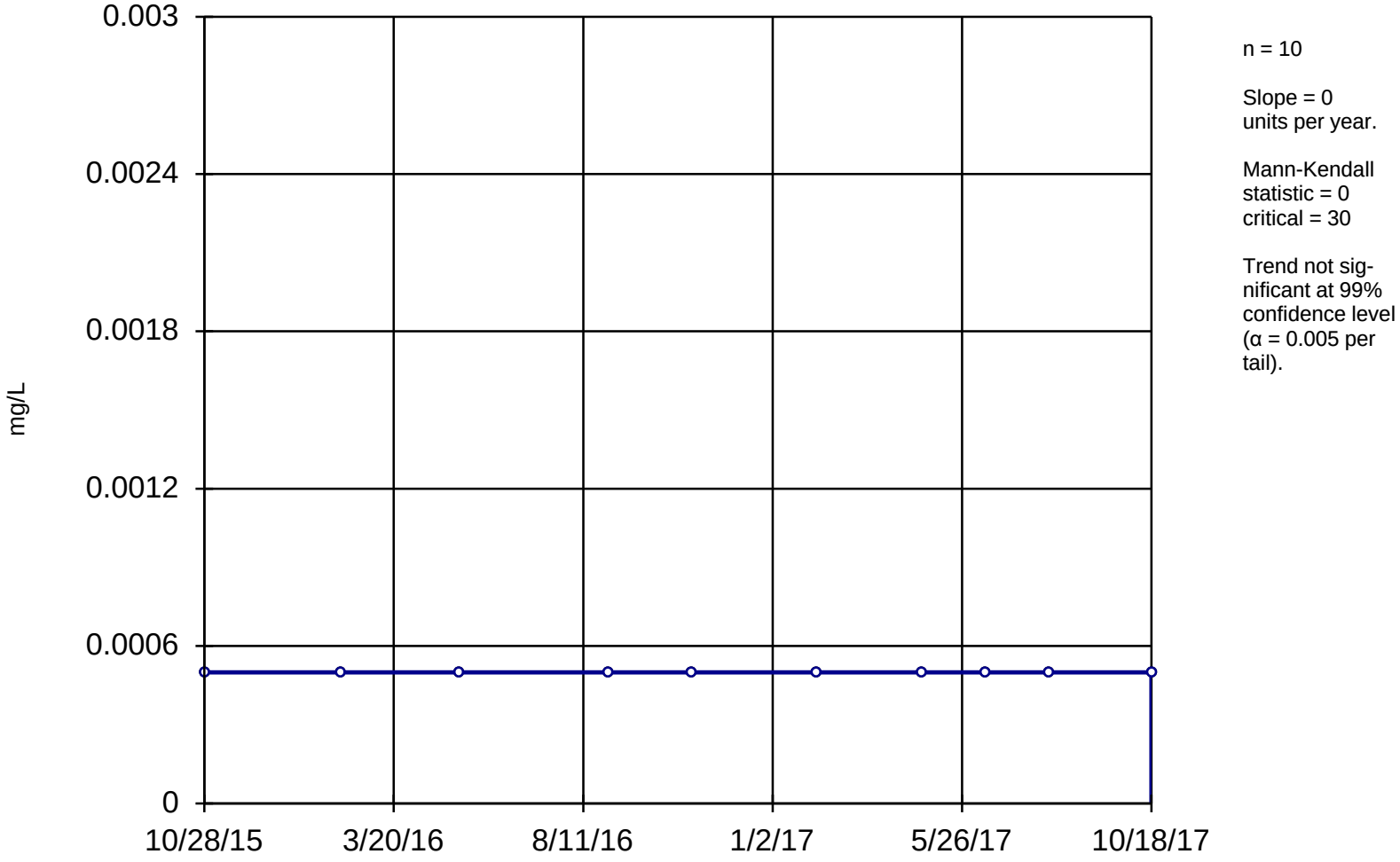
Constituent: Lead, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



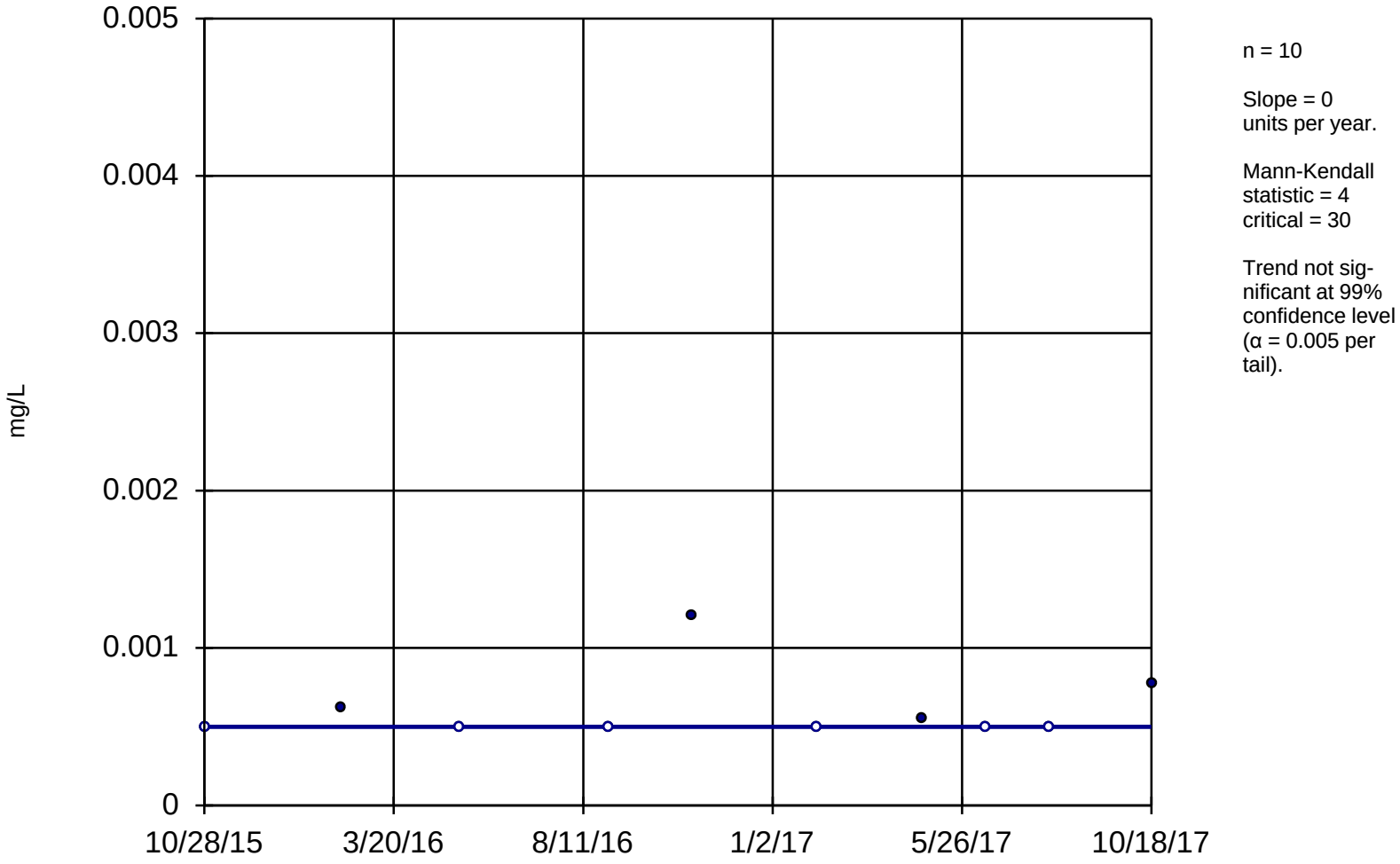
Constituent: Lead, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 10

Slope = 0
units per year.

Mann-Kendall
statistic = 4
critical = 30

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

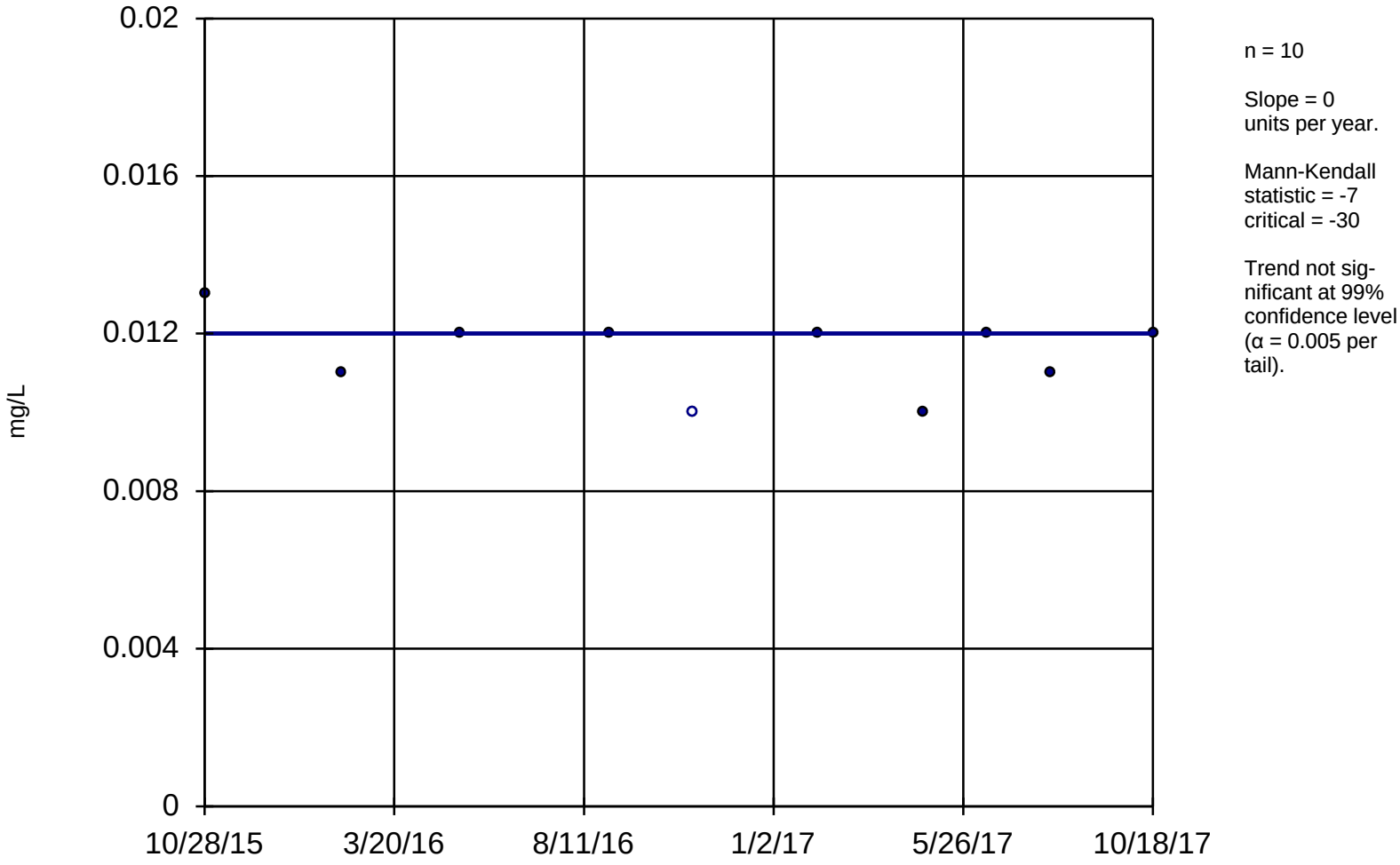
Constituent: Lead, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 10

Slope = 0
units per year.

Mann-Kendall
statistic = -7
critical = -30

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

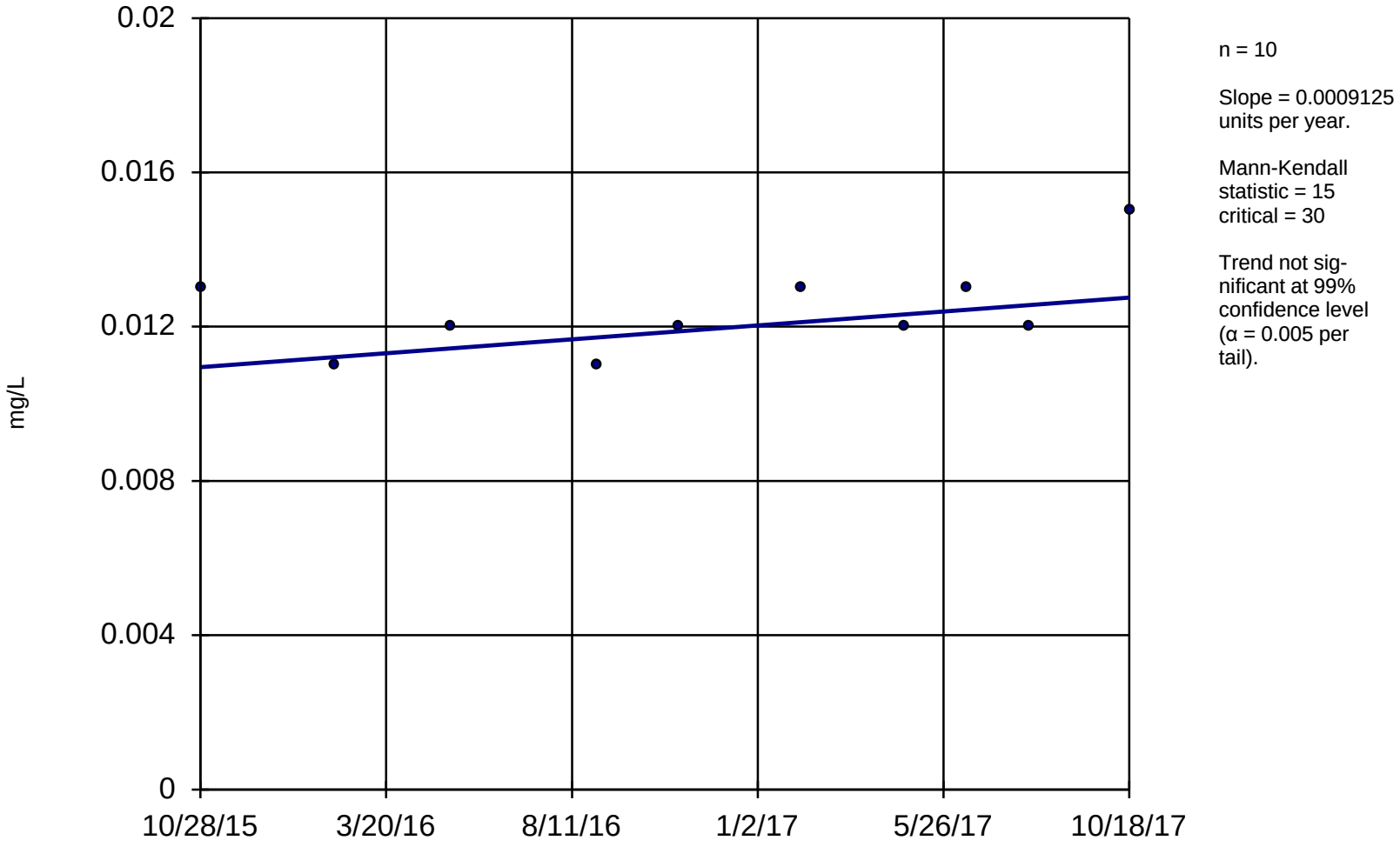
Constituent: Lithium, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-04



n = 10

Slope = 0.0009125 units per year.

Mann-Kendall statistic = 15
critical = 30

Trend not significant at 99% confidence level (α = 0.005 per tail).

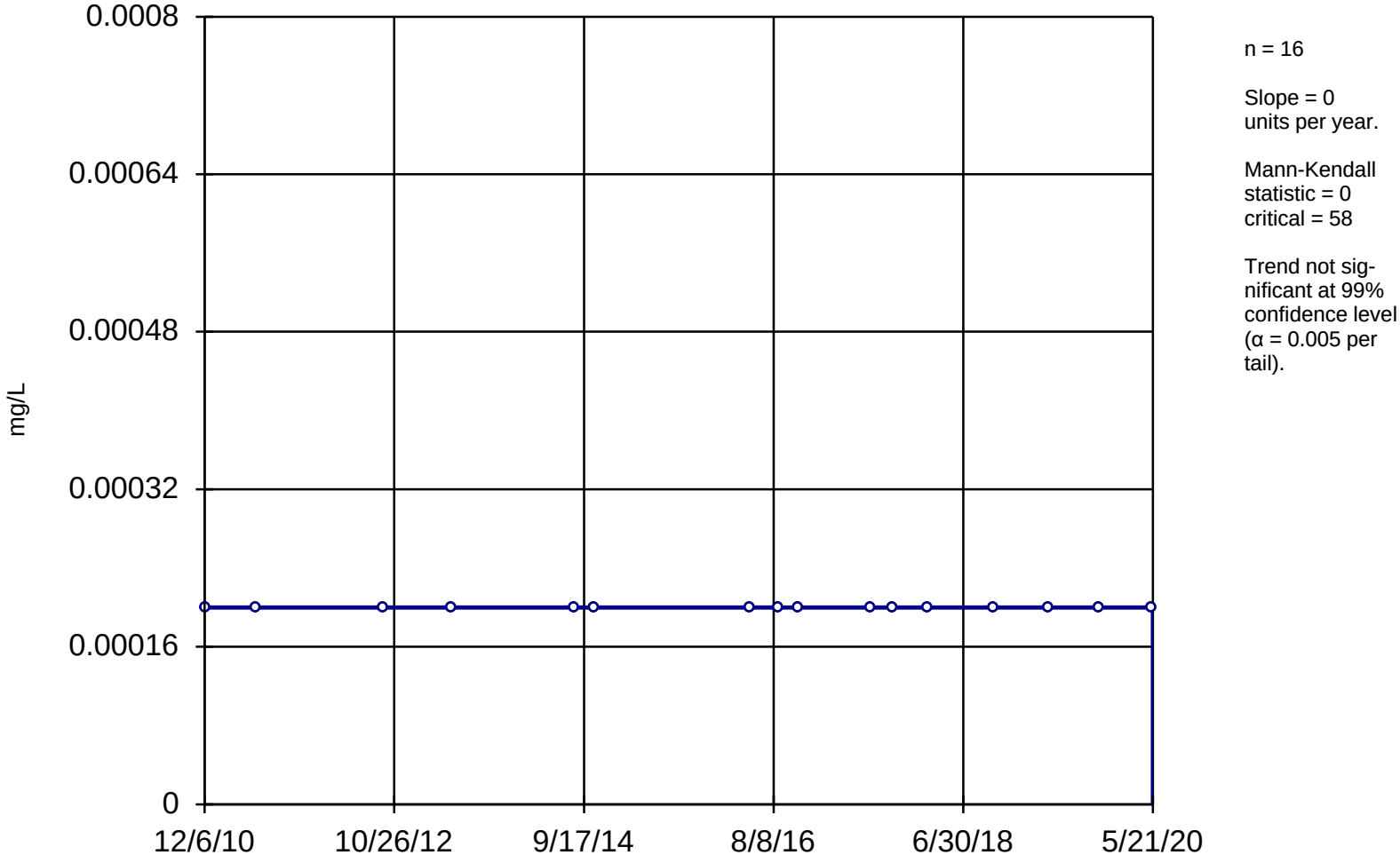
Constituent: Lithium, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-01



n = 16

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 58

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

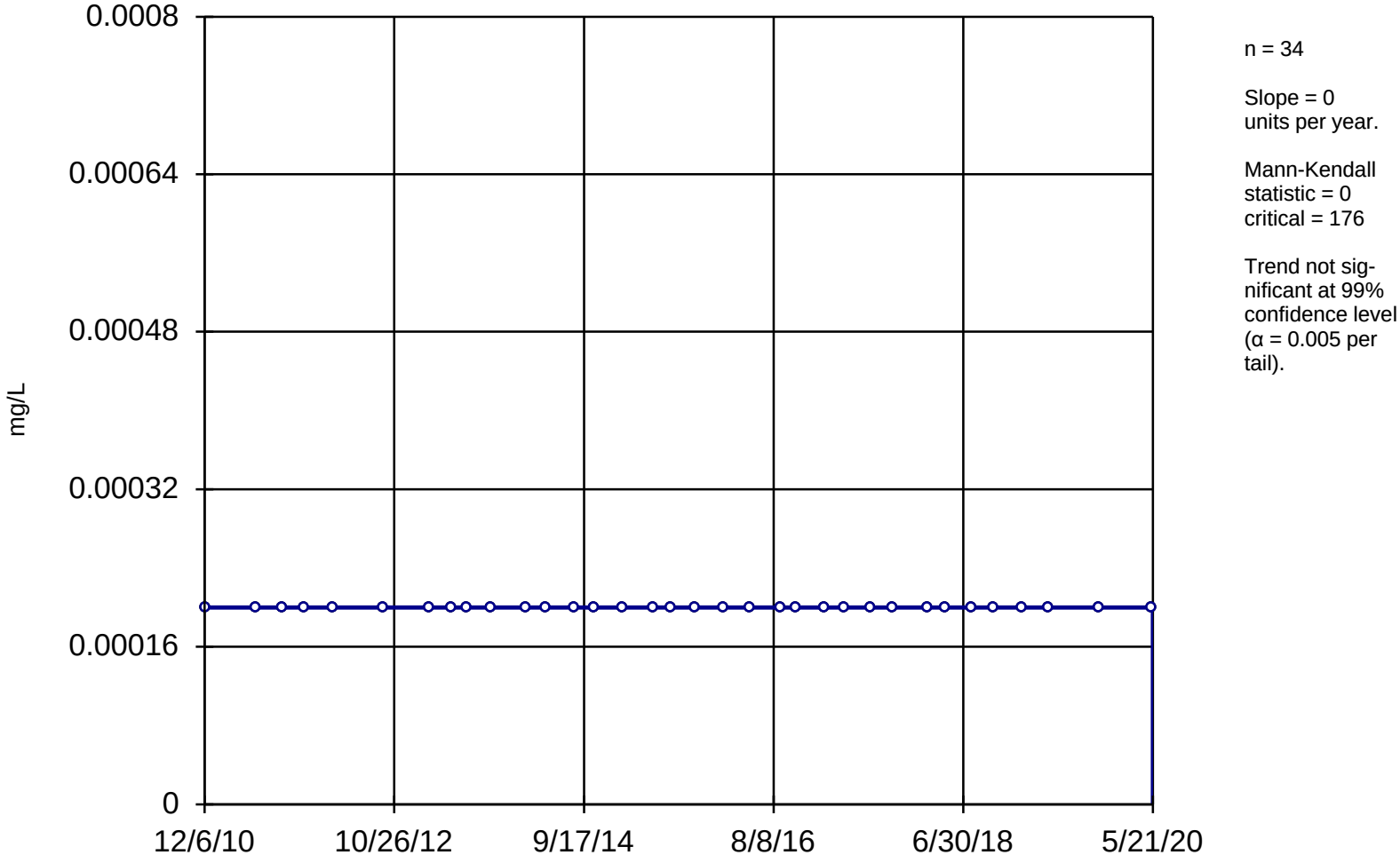
Constituent: Mercury, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

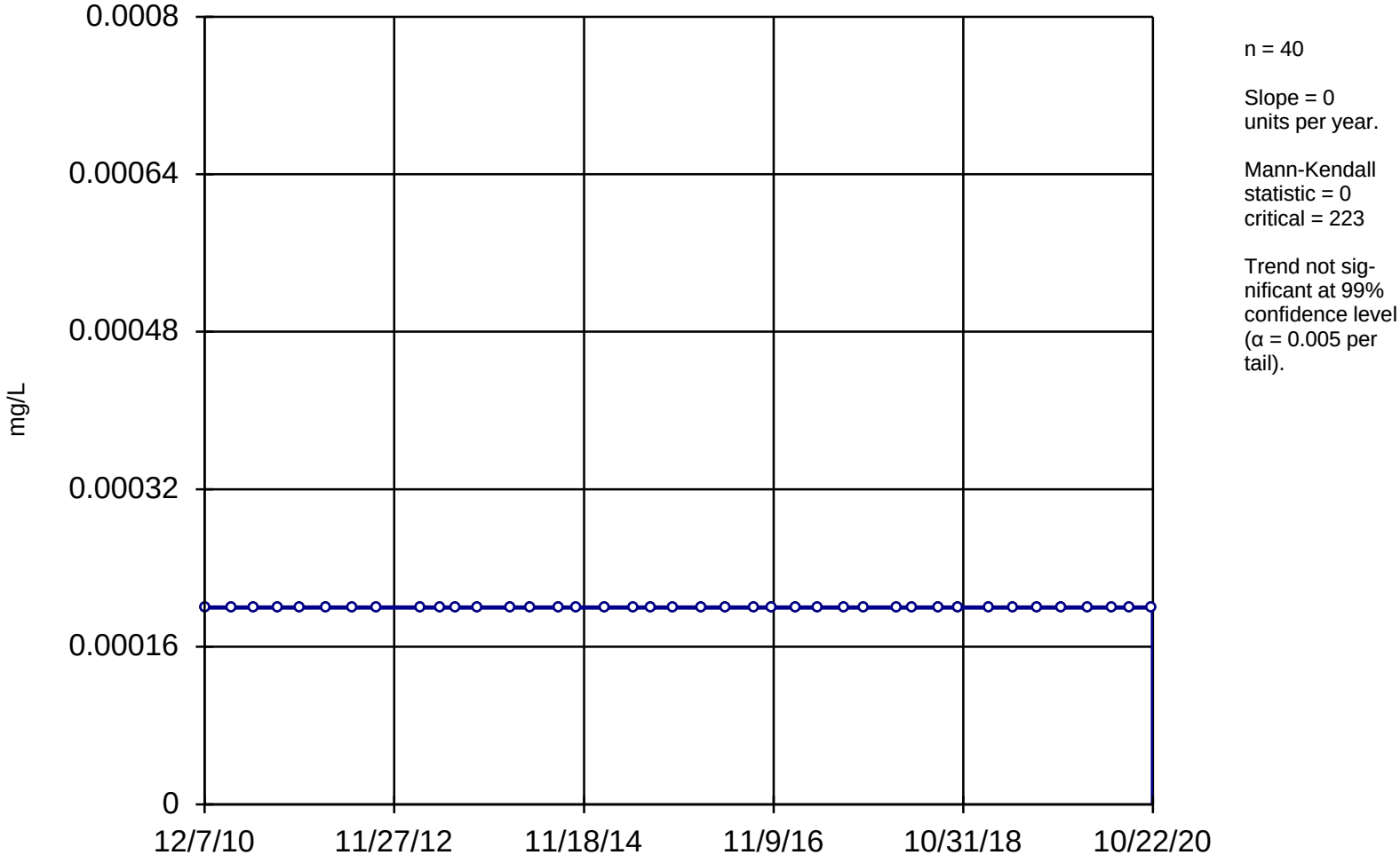
Constituent: Mercury, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



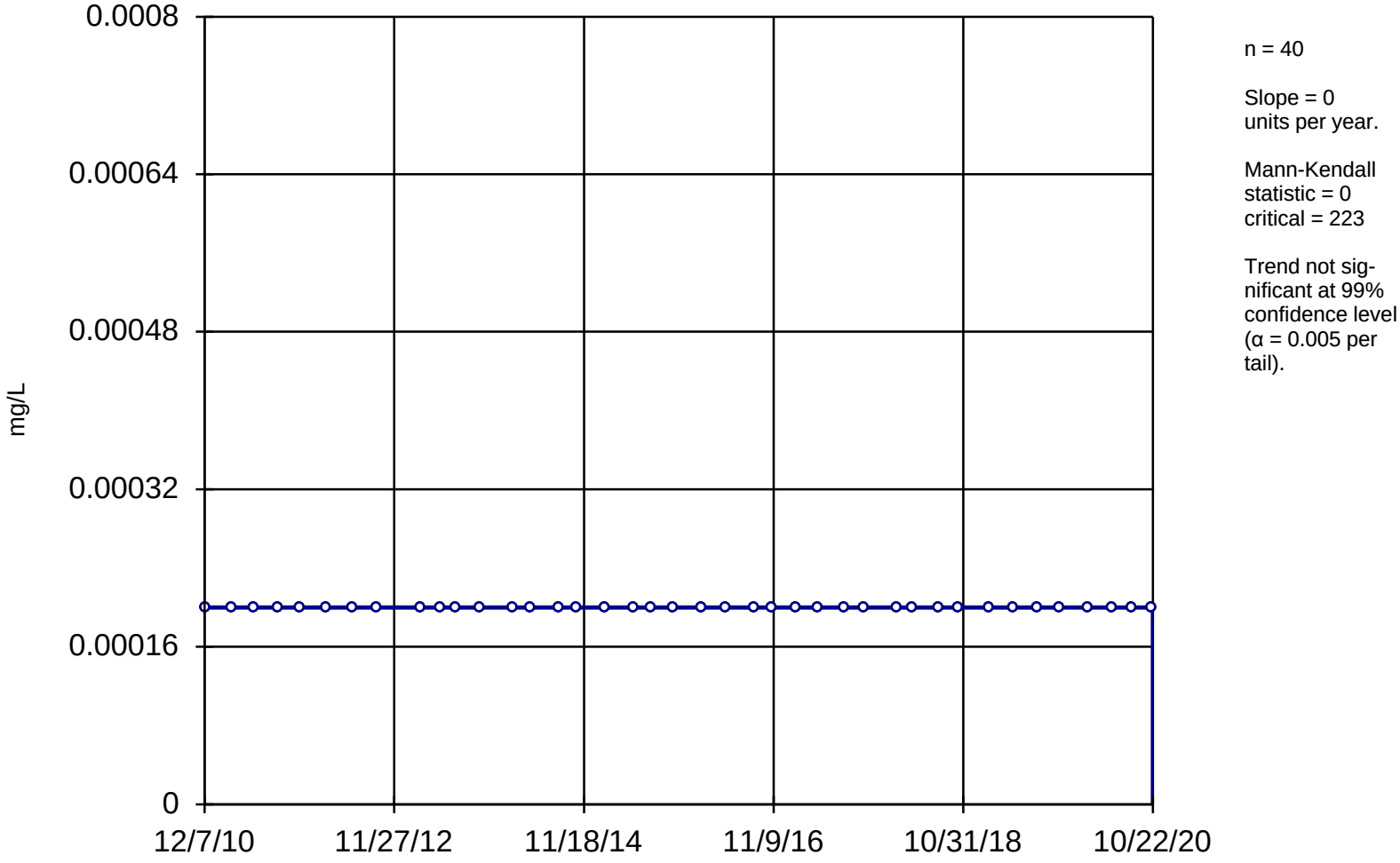
Constituent: Mercury, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

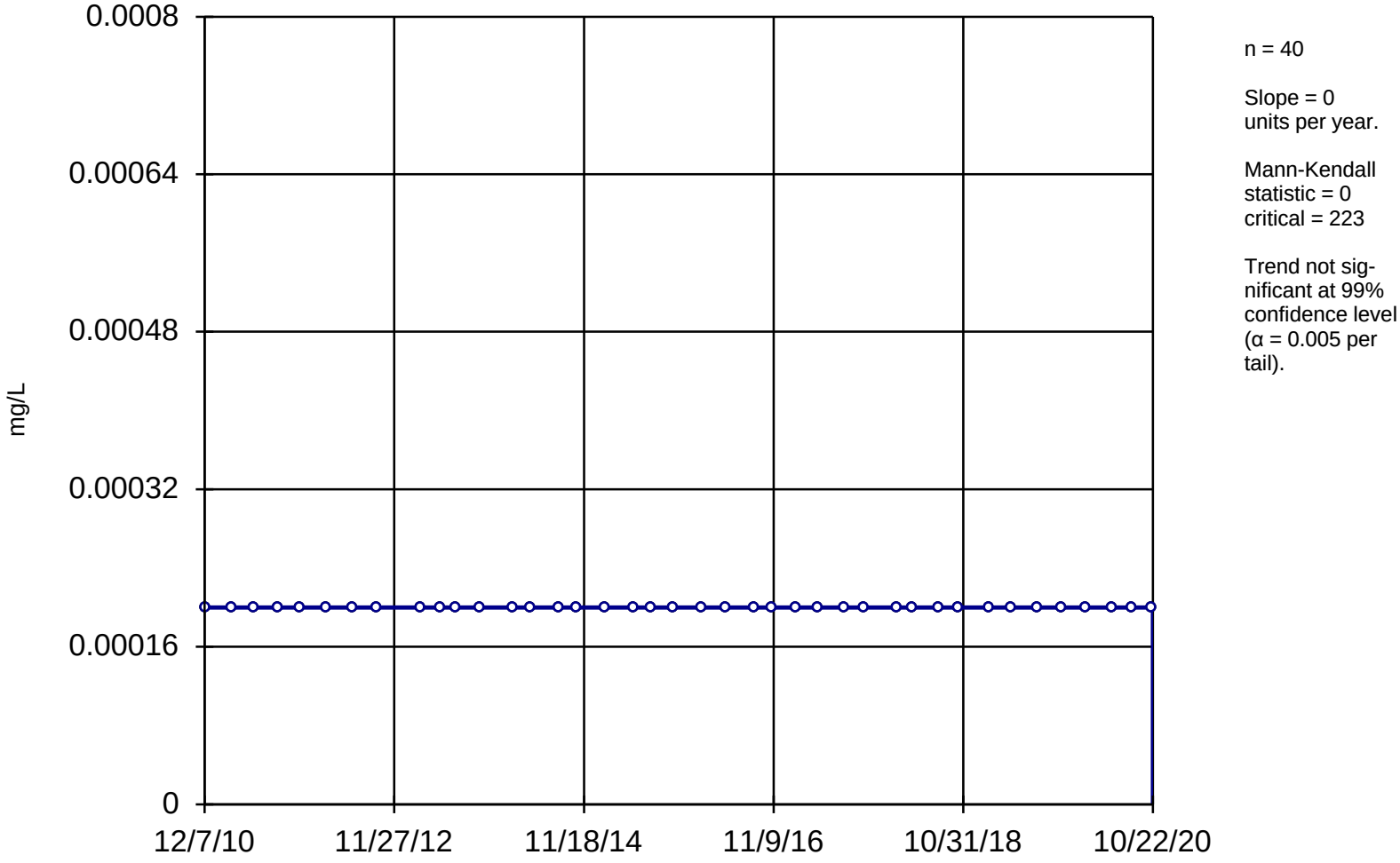
Constituent: Mercury, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

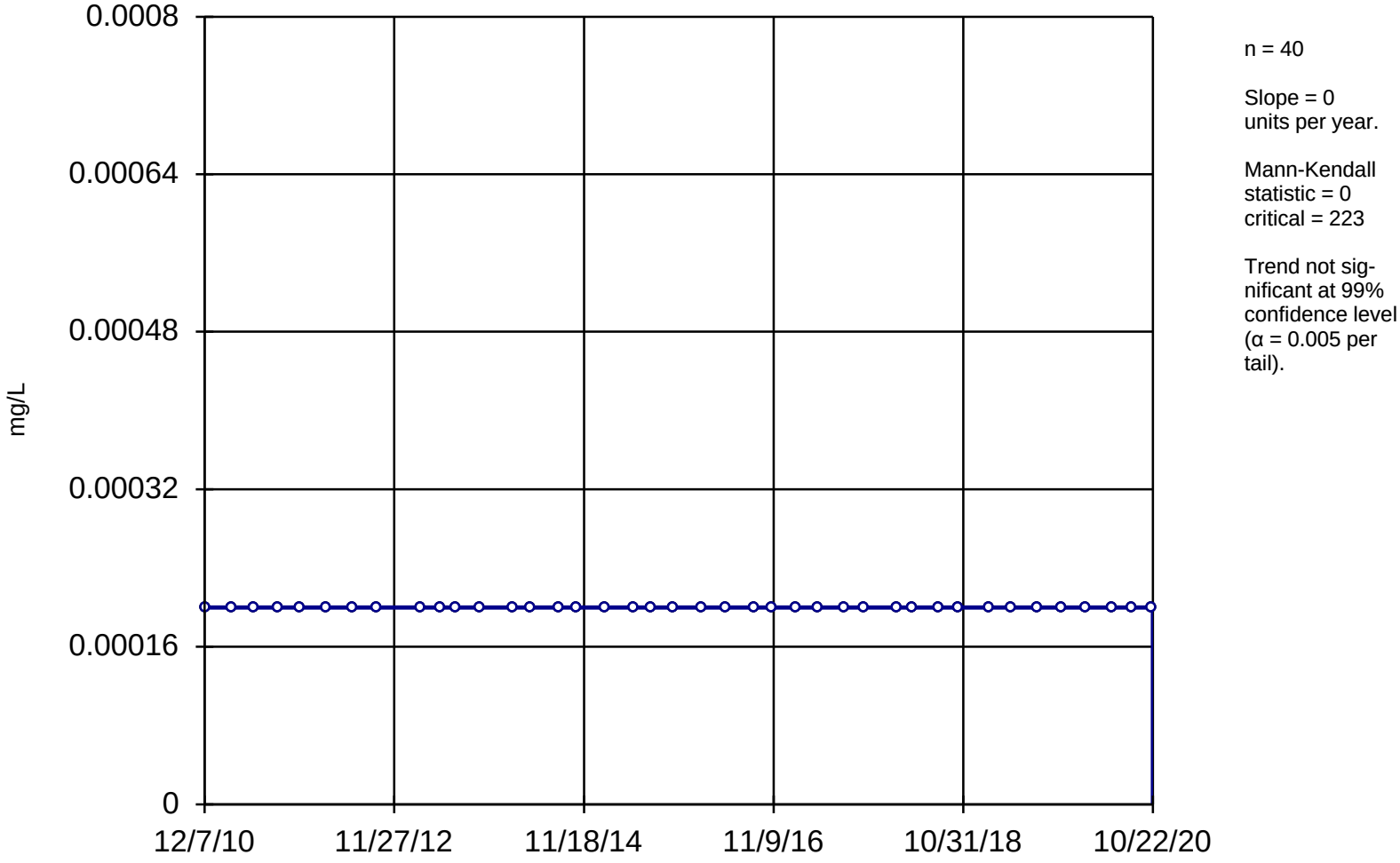
Constituent: Mercury, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

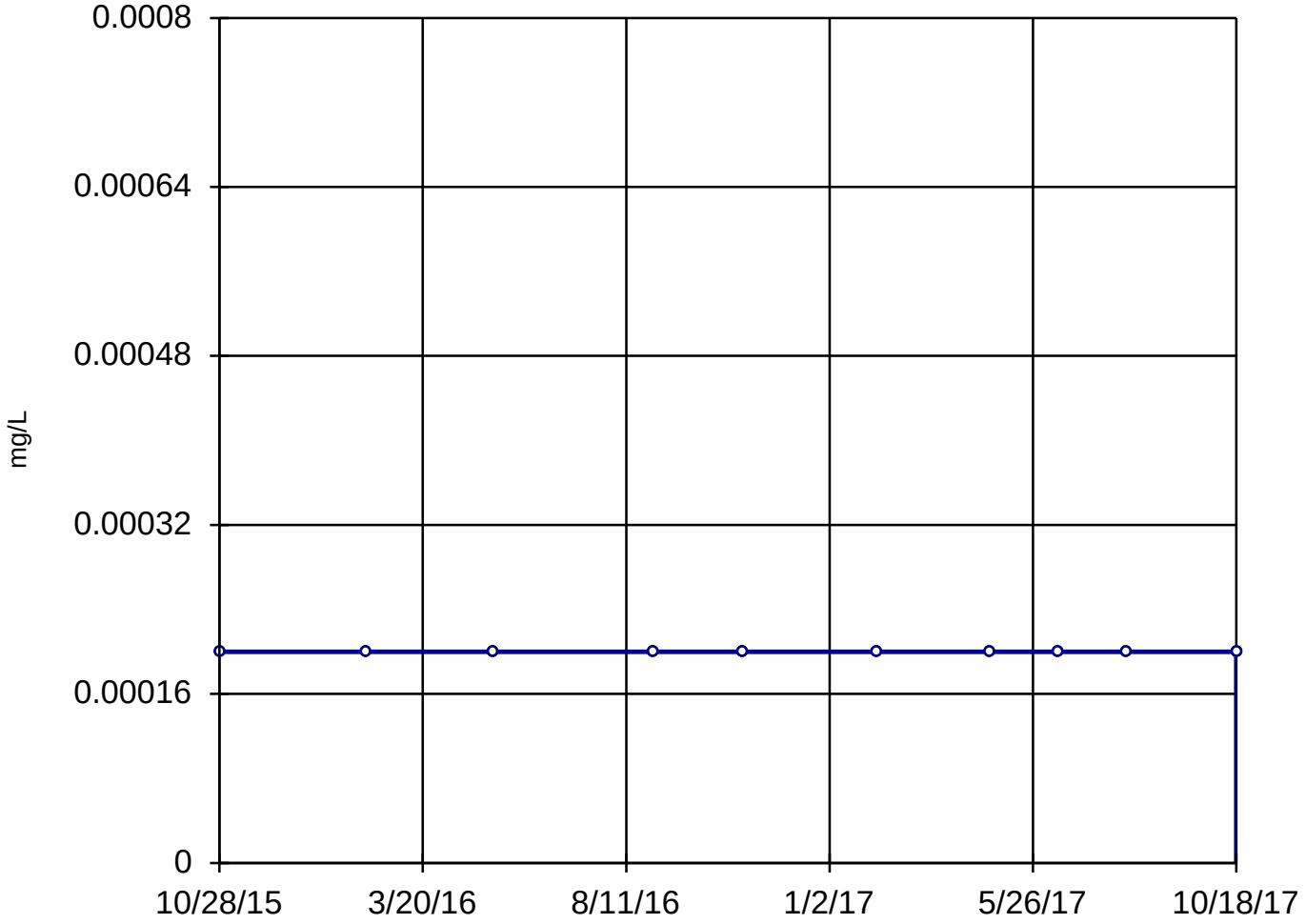
Constituent: Mercury, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 10

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 30

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

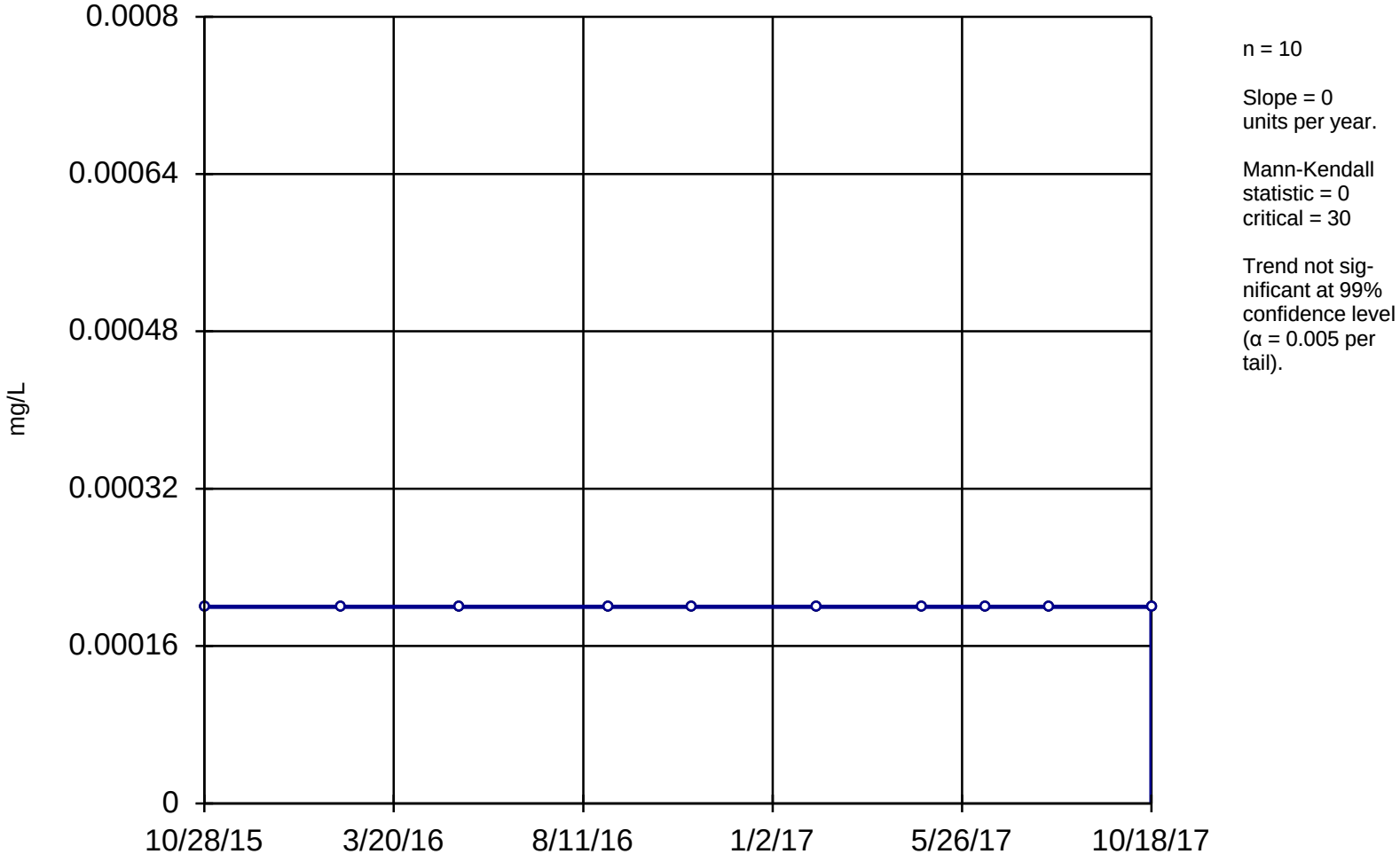
Constituent: Mercury, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 10

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 30

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

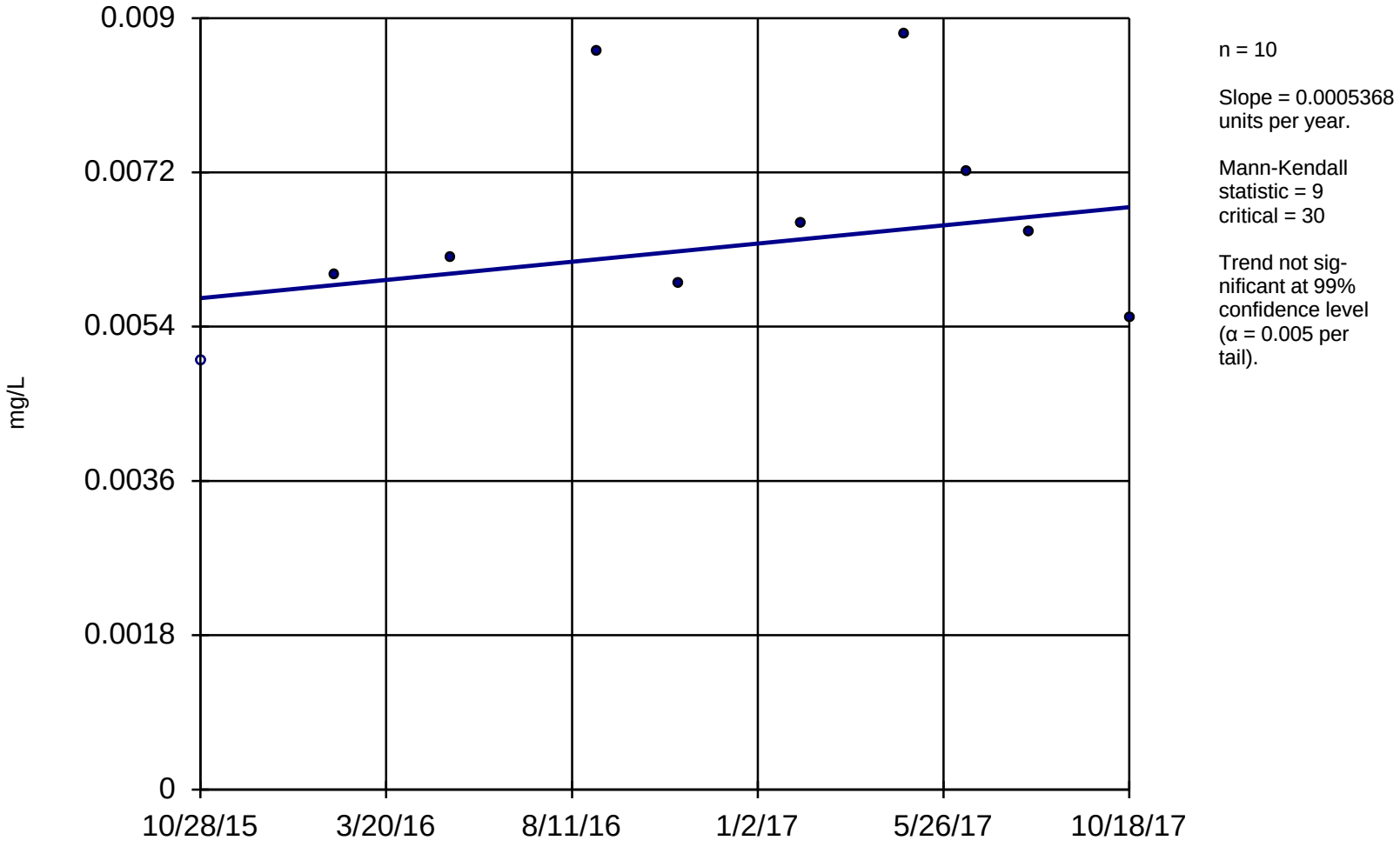
Constituent: Mercury, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 10

Slope = 0.0005368 units per year.

Mann-Kendall statistic = 9
critical = 30

Trend not significant at 99% confidence level (α = 0.005 per tail).

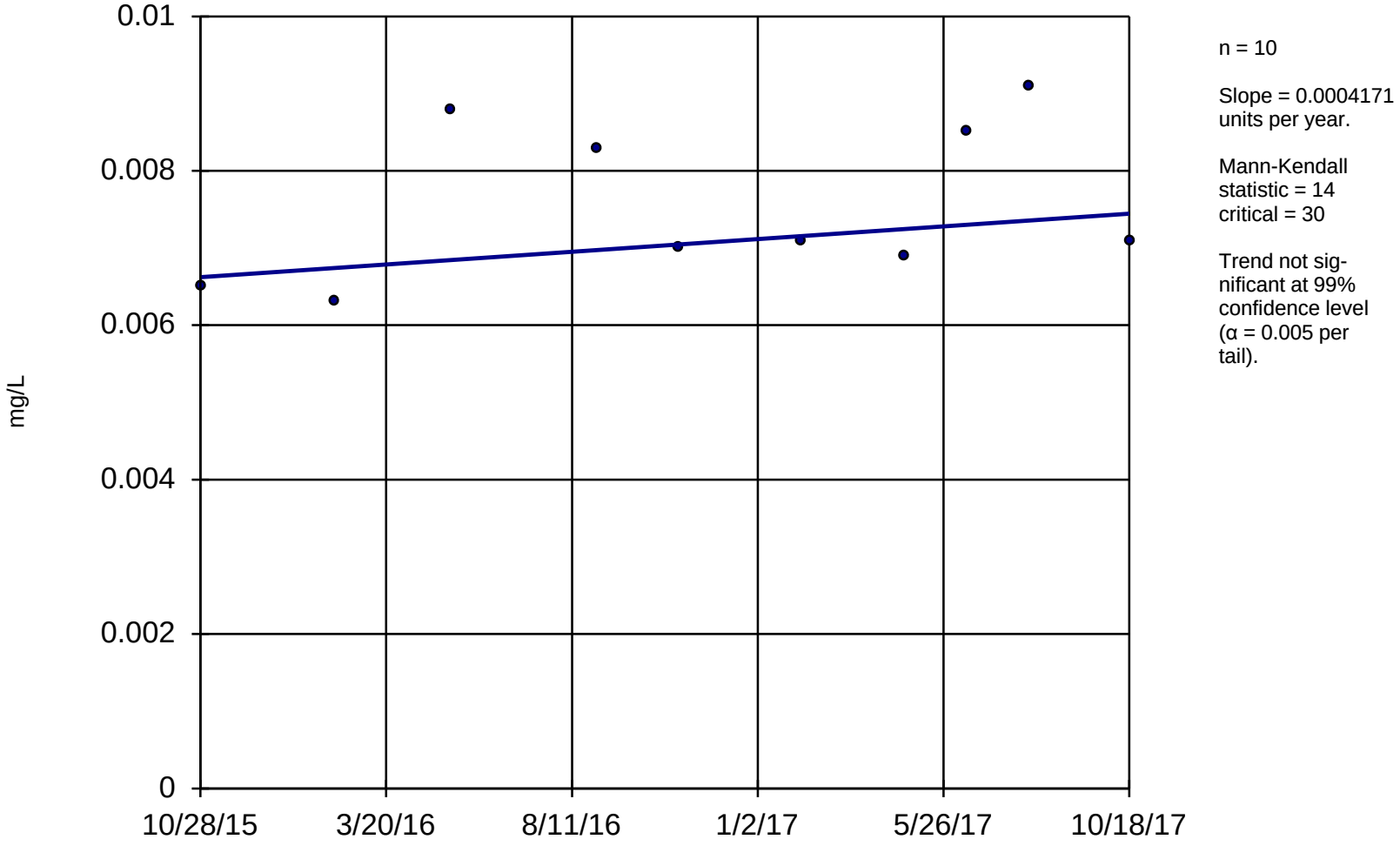
Constituent: Molybdenum, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-04



n = 10

Slope = 0.0004171 units per year.

Mann-Kendall statistic = 14
critical = 30

Trend not significant at 99% confidence level (α = 0.005 per tail).

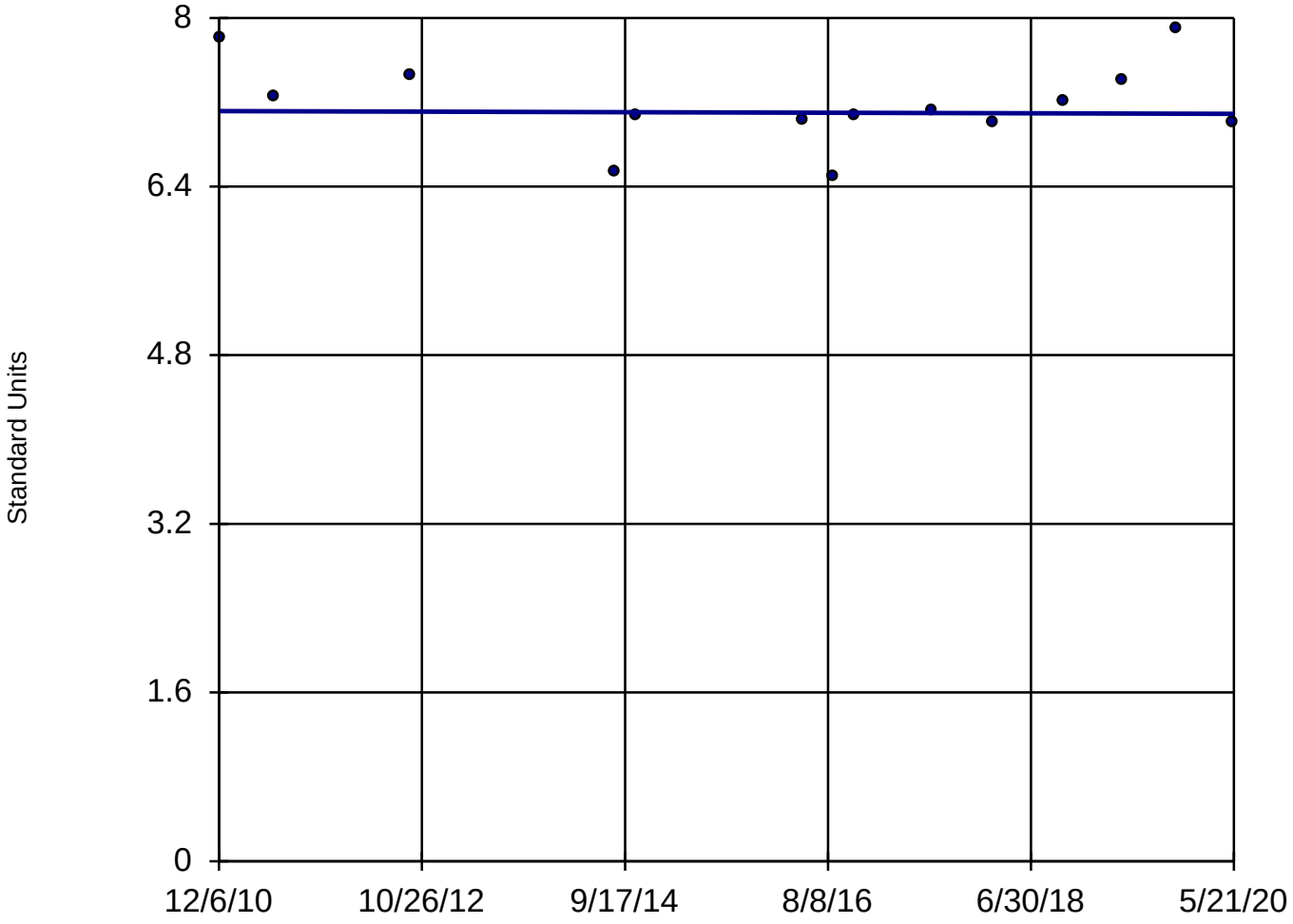
Constituent: Molybdenum, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-01



n = 14

Slope = -0.002481 units per year.

Mann-Kendall statistic = -2
critical = -48

Trend not significant at 99% confidence level (α = 0.005 per tail).

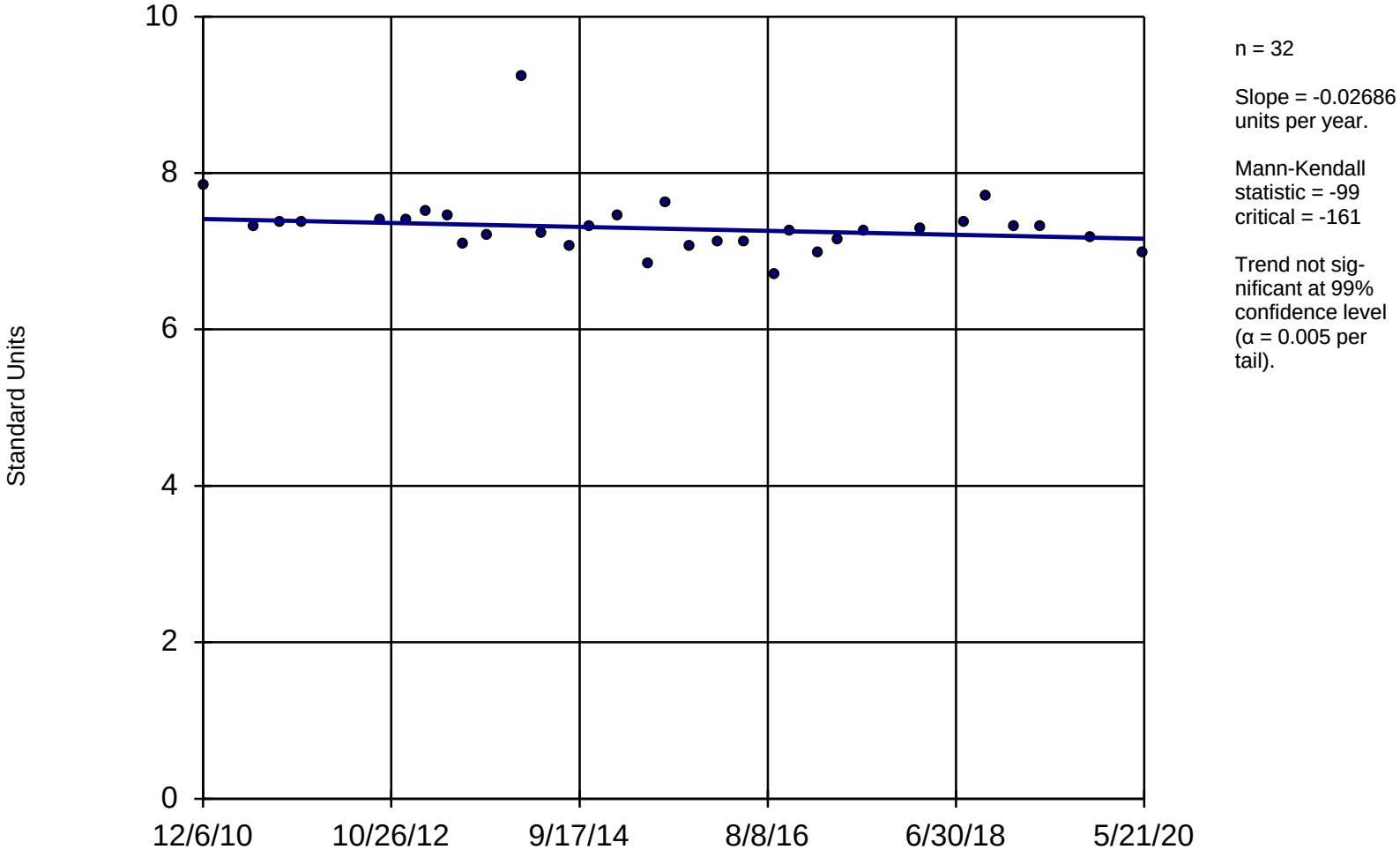
Constituent: pH, Field Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-02



n = 32

Slope = -0.02686 units per year.

Mann-Kendall statistic = -99
critical = -161

Trend not significant at 99% confidence level (α = 0.005 per tail).

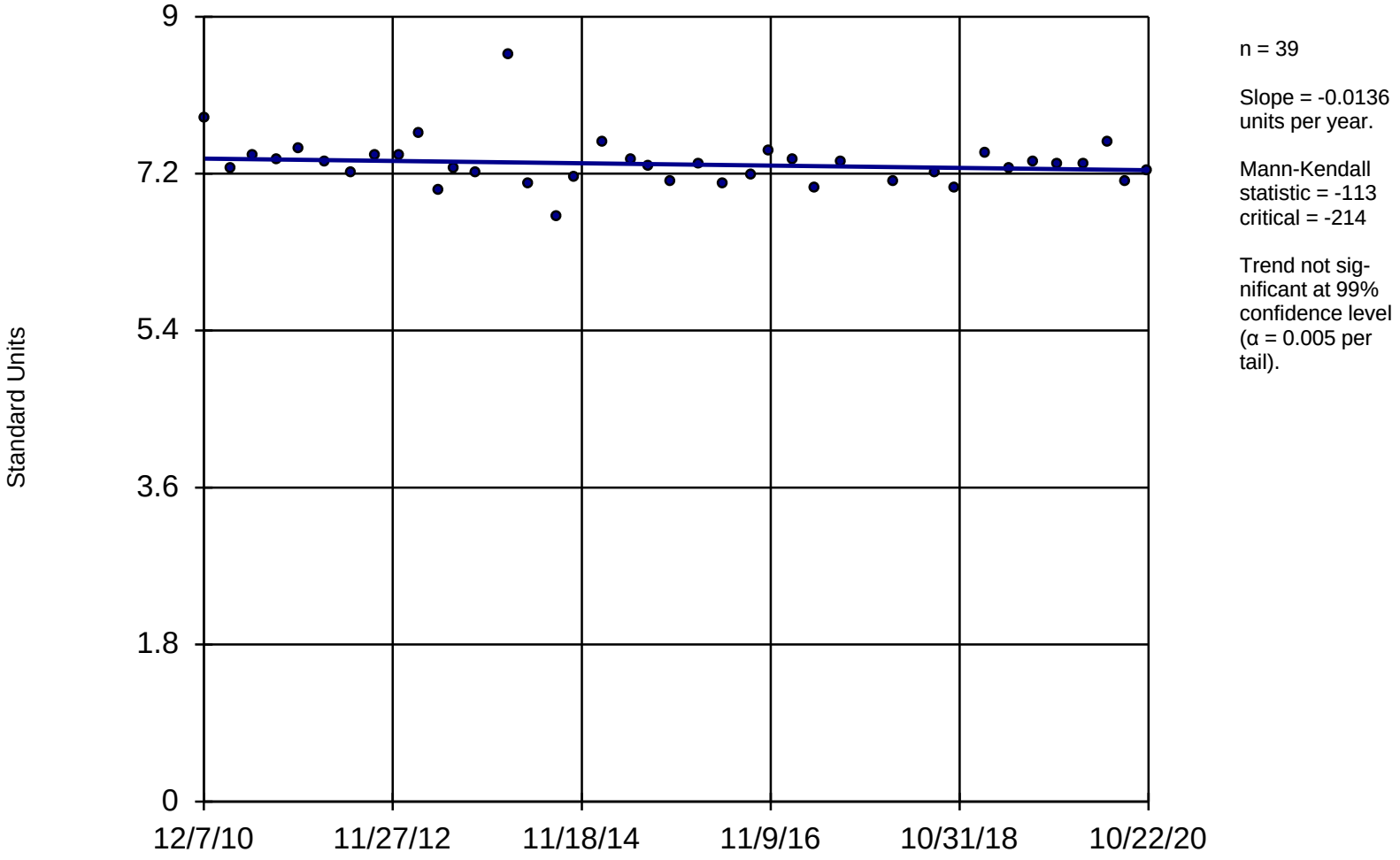
Constituent: pH, Field Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-03



n = 39

Slope = -0.0136 units per year.

Mann-Kendall statistic = -113
critical = -214

Trend not significant at 99% confidence level (α = 0.005 per tail).

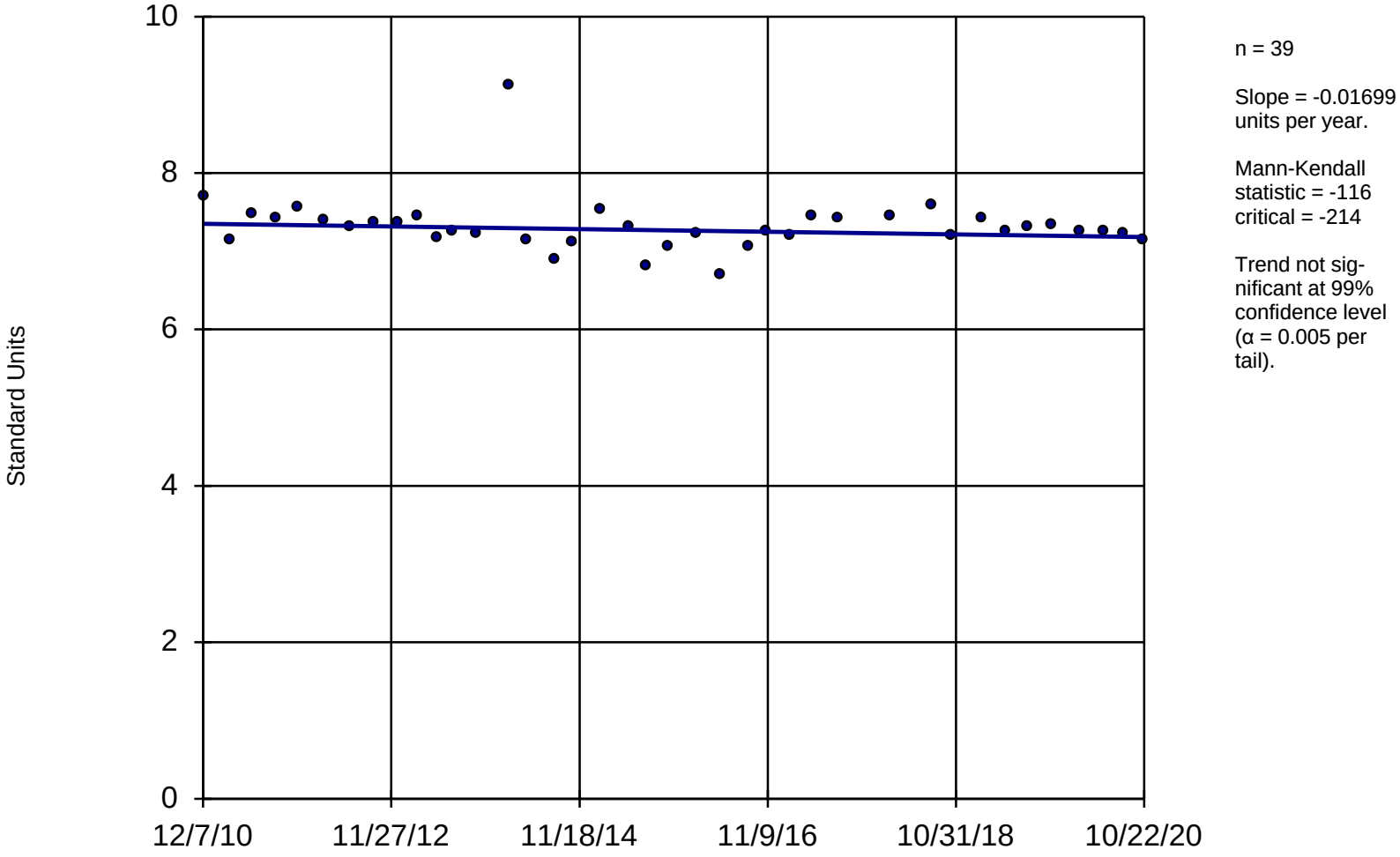
Constituent: pH, Field Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-04



n = 39

Slope = -0.01699 units per year.

Mann-Kendall statistic = -116
critical = -214

Trend not significant at 99% confidence level (α = 0.005 per tail).

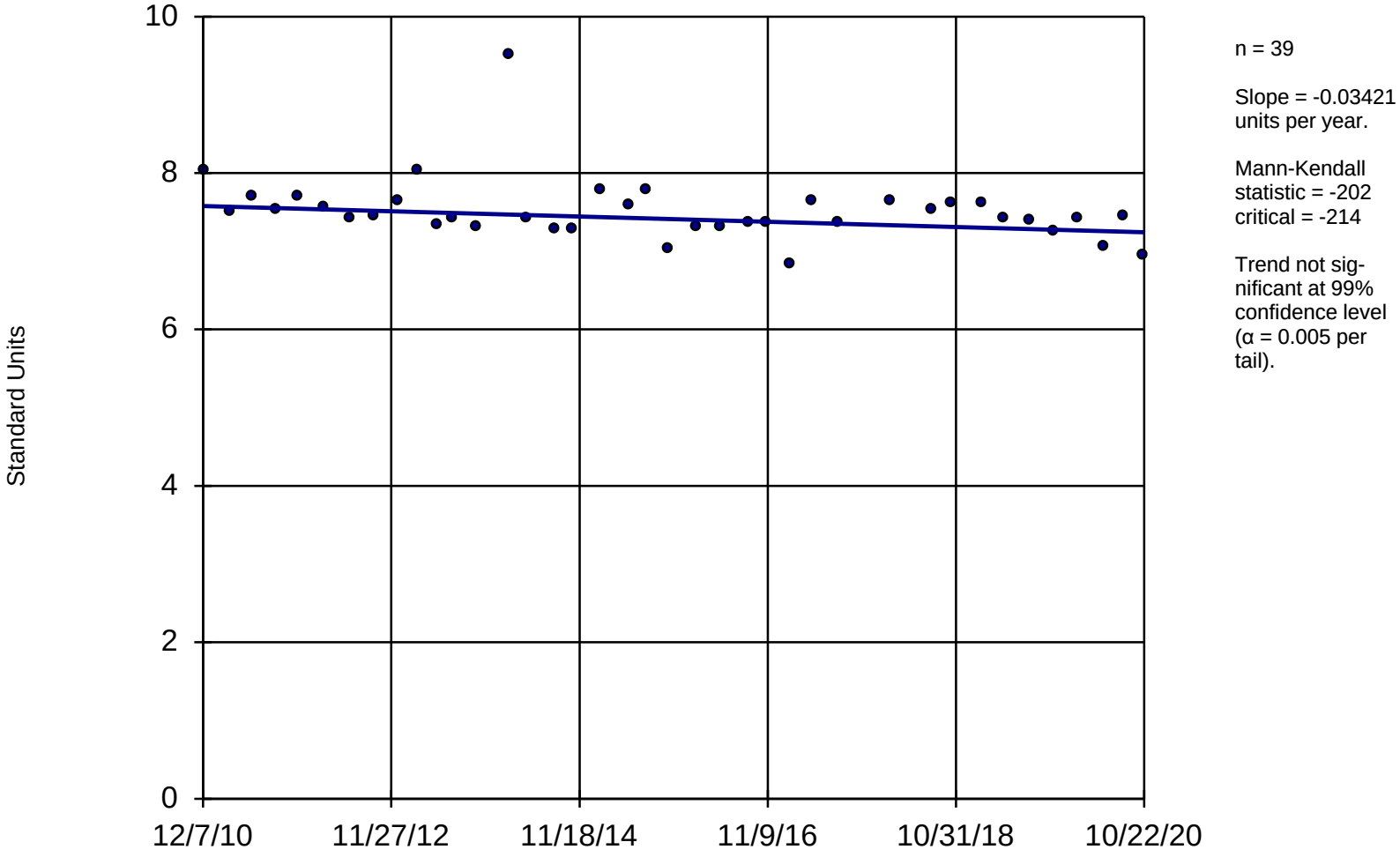
Constituent: pH, Field Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-06



n = 39

Slope = -0.03421 units per year.

Mann-Kendall statistic = -202
critical = -214

Trend not significant at 99% confidence level (α = 0.005 per tail).

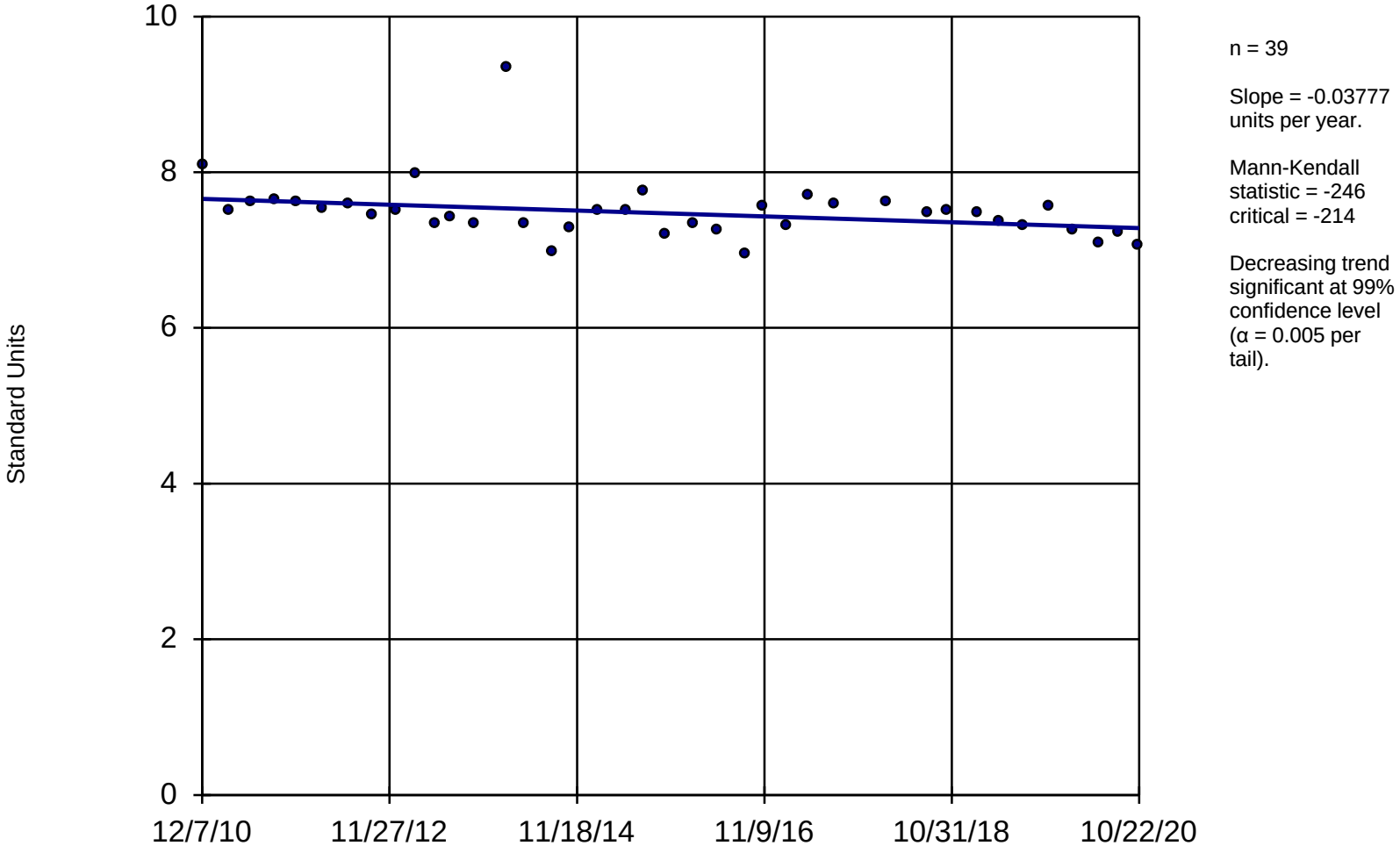
Constituent: pH, Field Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-07



n = 39

Slope = -0.03777 units per year.

Mann-Kendall statistic = -246
critical = -214

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

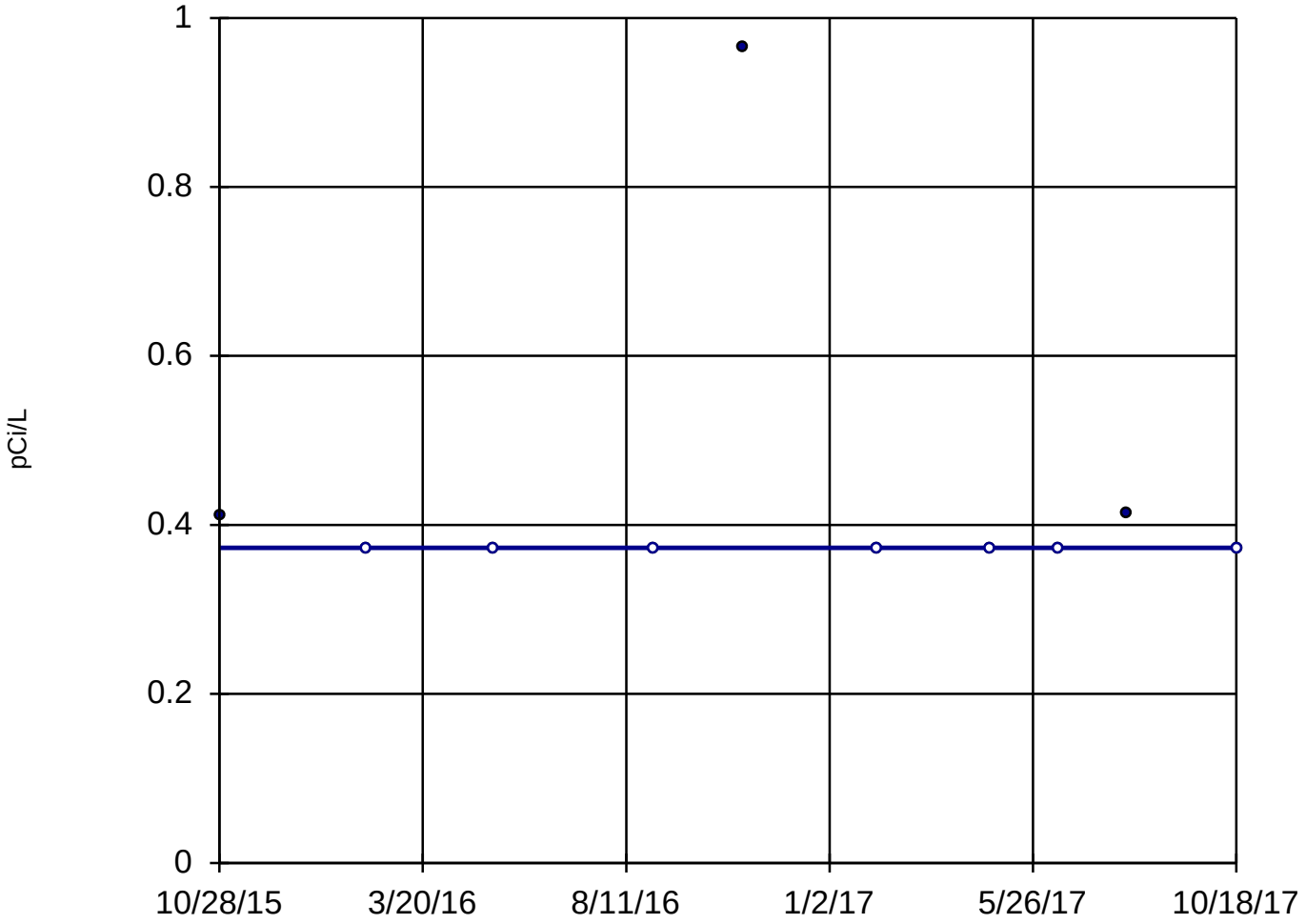
Constituent: pH, Field Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 10

Slope = 0
units per year.

Mann-Kendall
statistic = -2
critical = -30

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

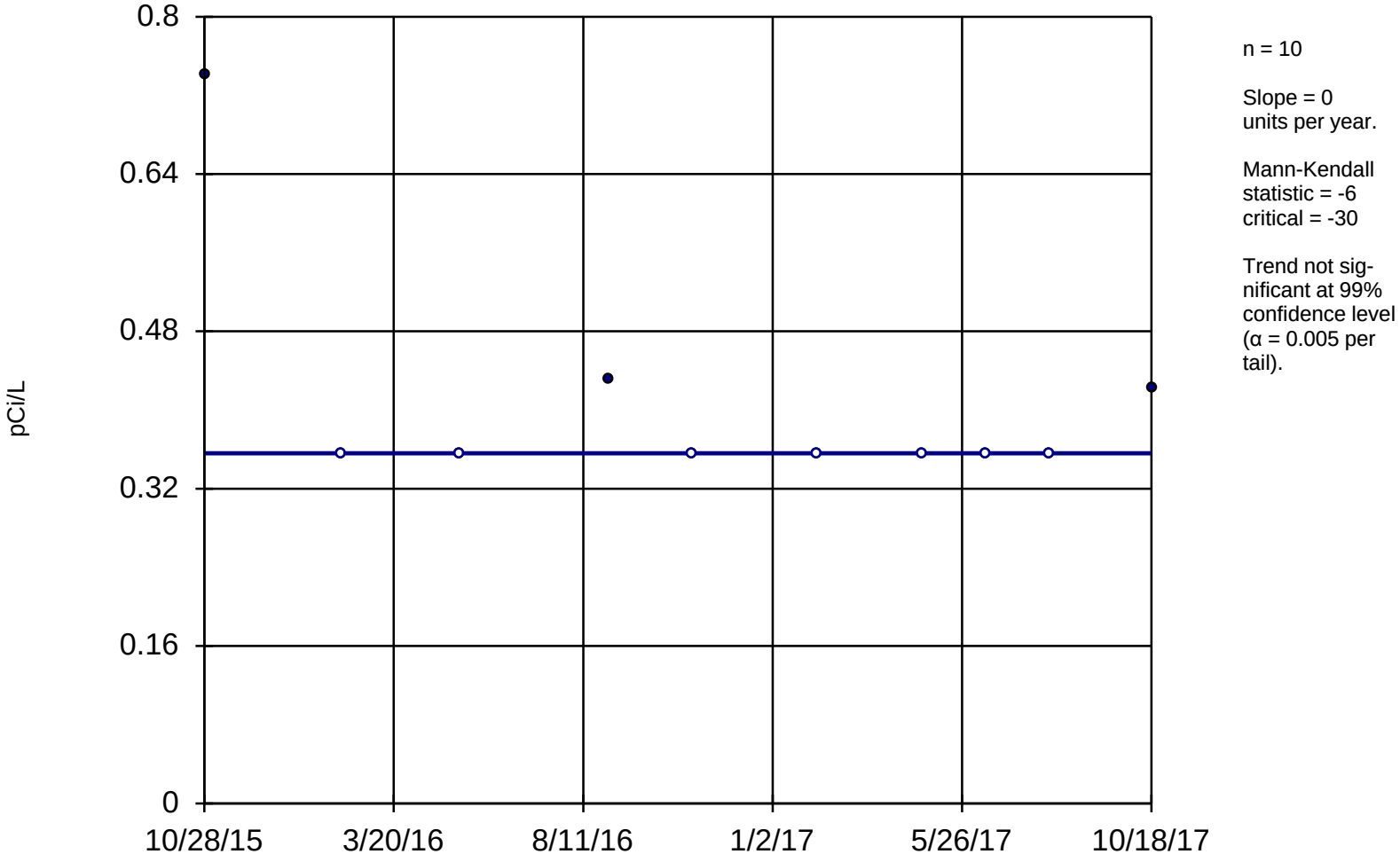
Constituent: Radium 226 + Radium 228, Combined Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



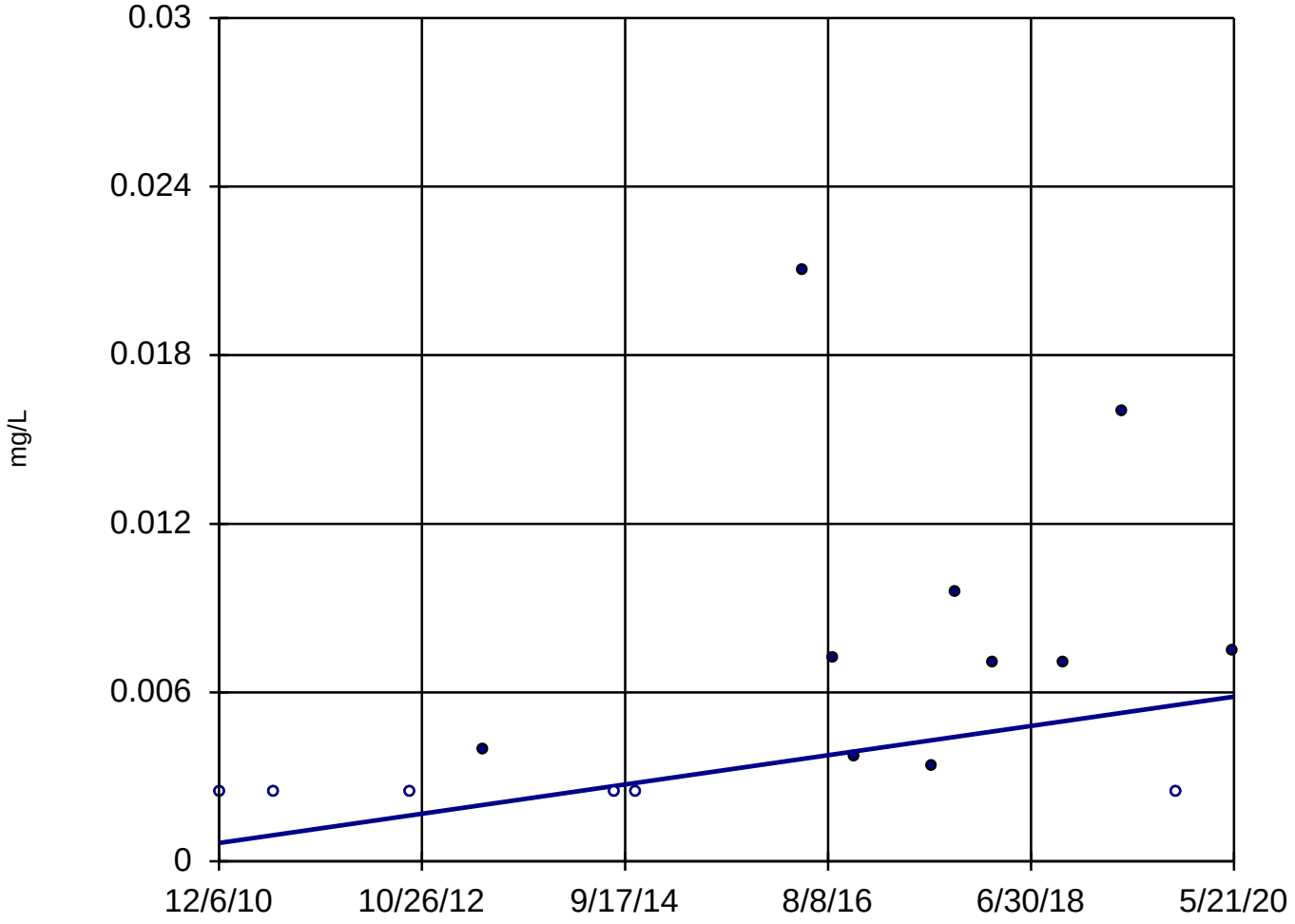
Constituent: Radium 226 + Radium 228, Combined Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-01



n = 16

Slope = 0.0005506 units per year.

Mann-Kendall statistic = 44
critical = 58

Trend not significant at 99% confidence level (α = 0.005 per tail).

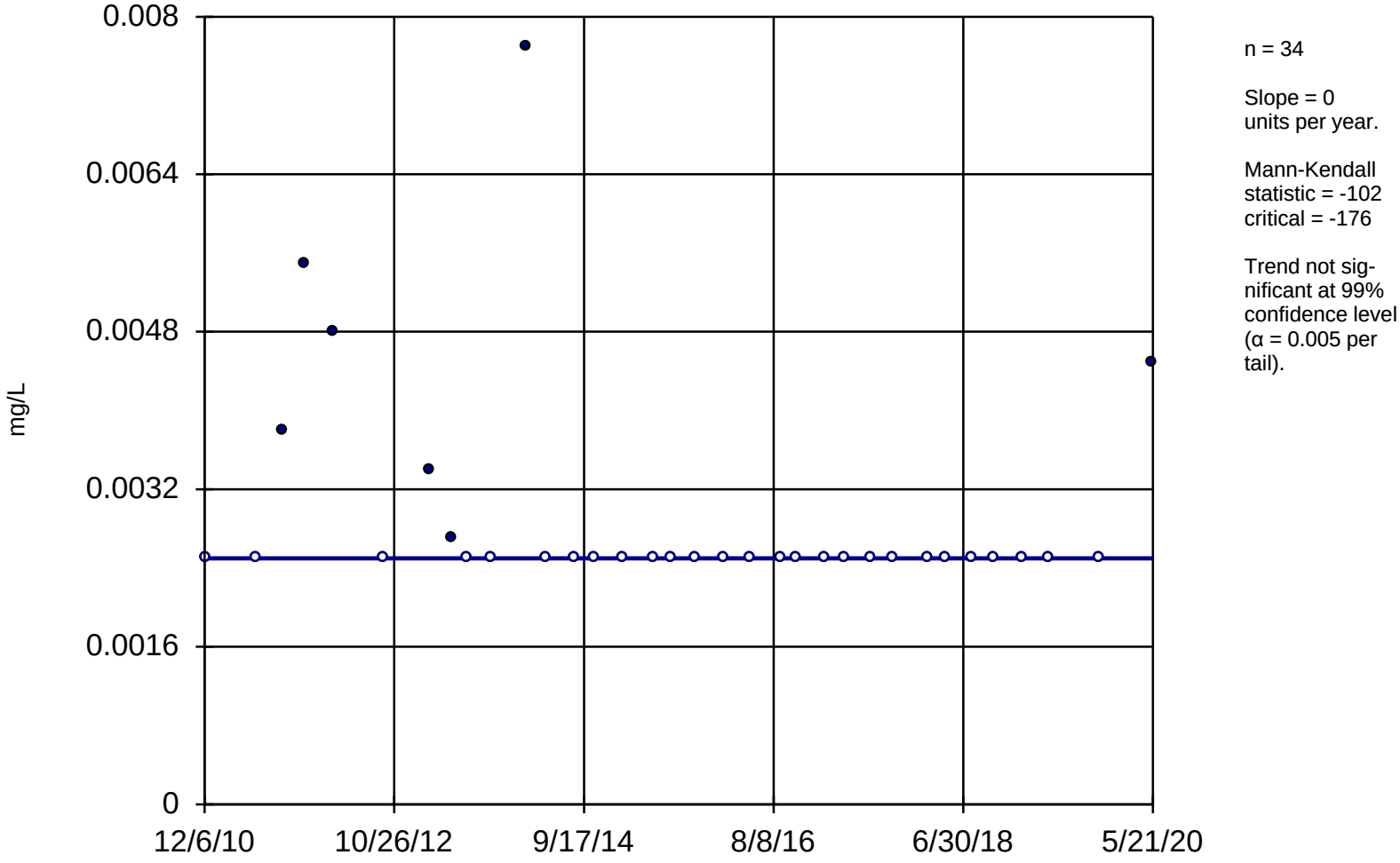
Constituent: Selenium, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = -102
critical = -176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

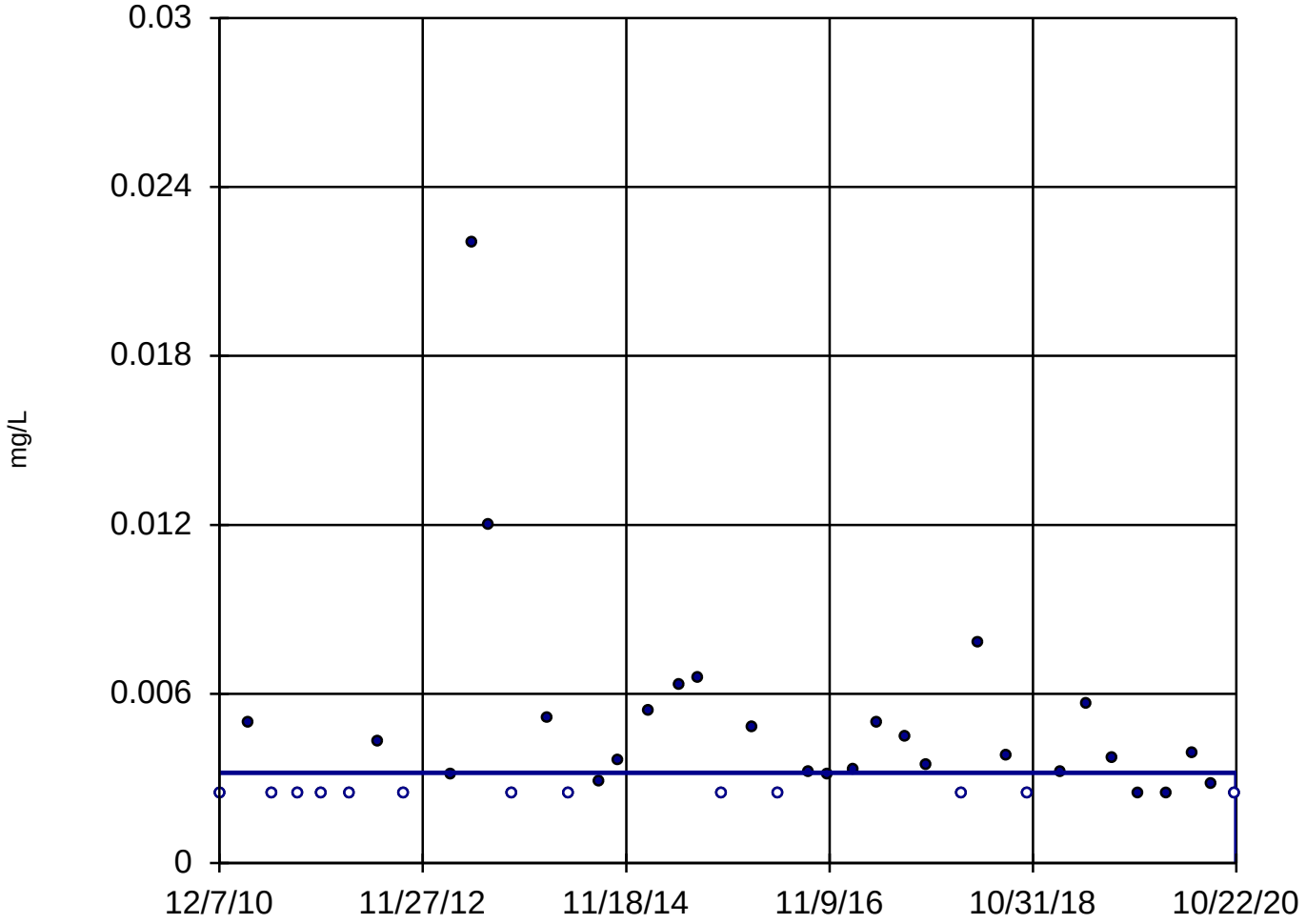
Constituent: Selenium, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 26
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

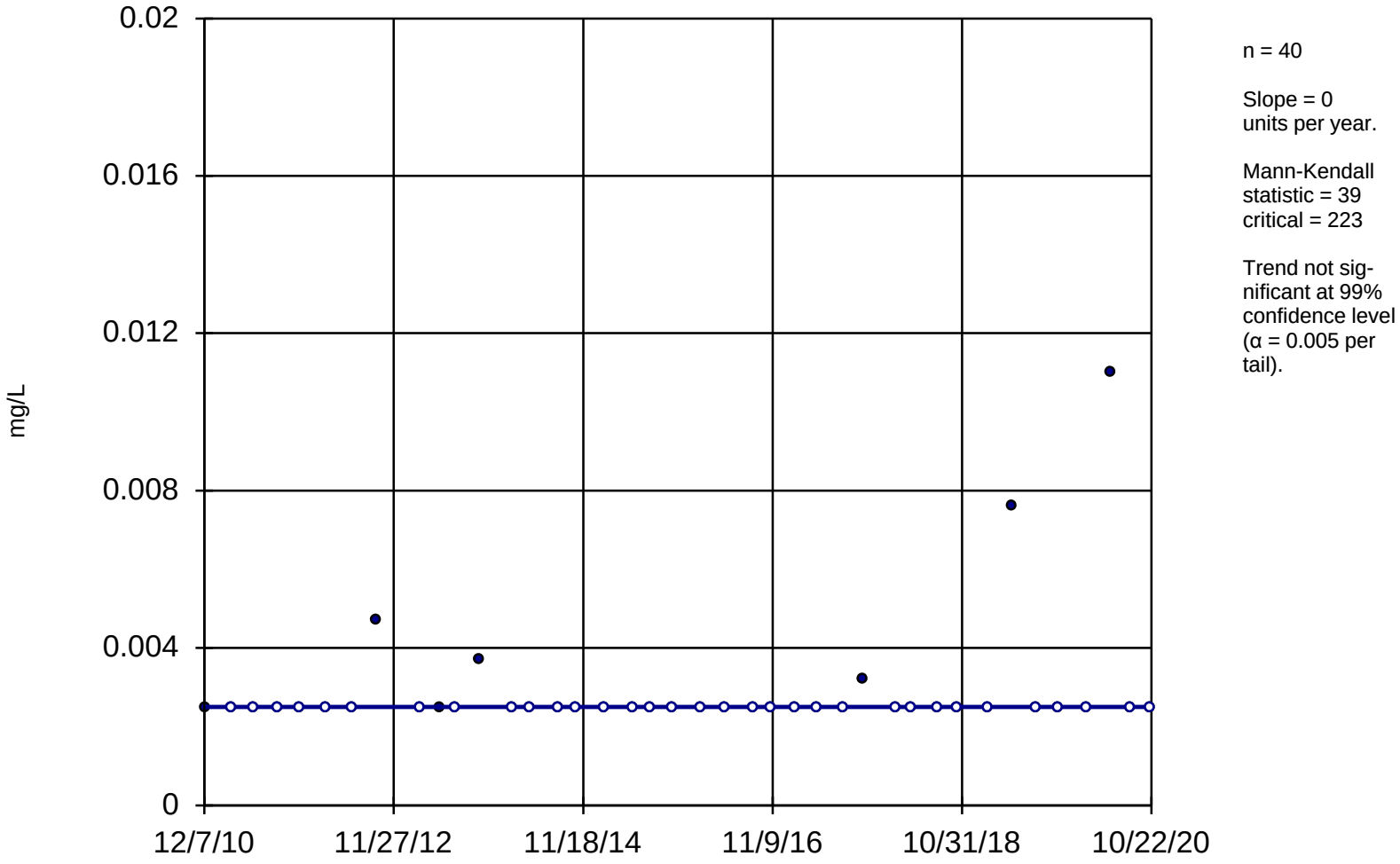
Constituent: Selenium, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 39
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

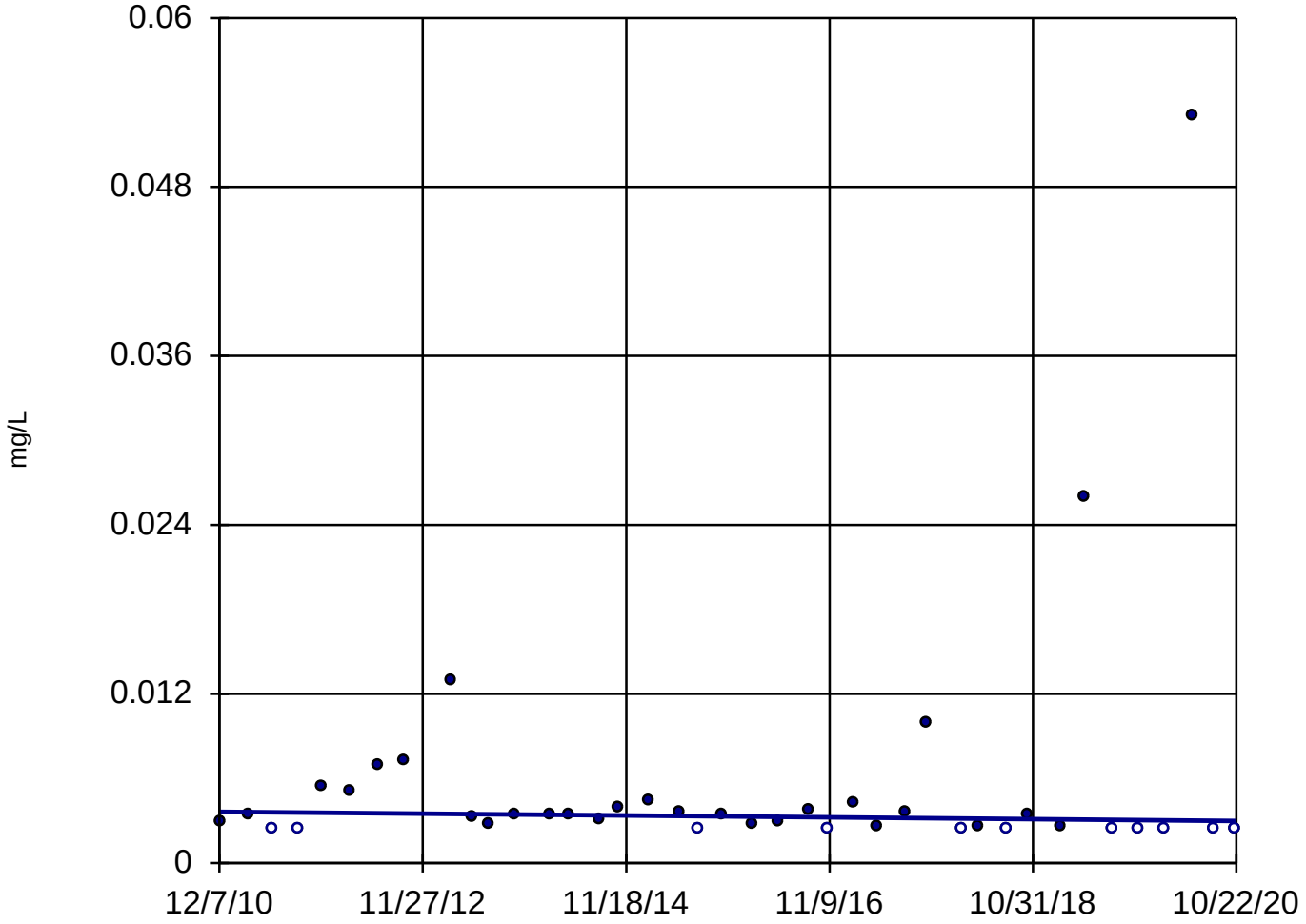
Constituent: Selenium, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = -0.00006728 units per year.

Mann-Kendall statistic = -155
critical = -223

Trend not significant at 99% confidence level (α = 0.005 per tail).

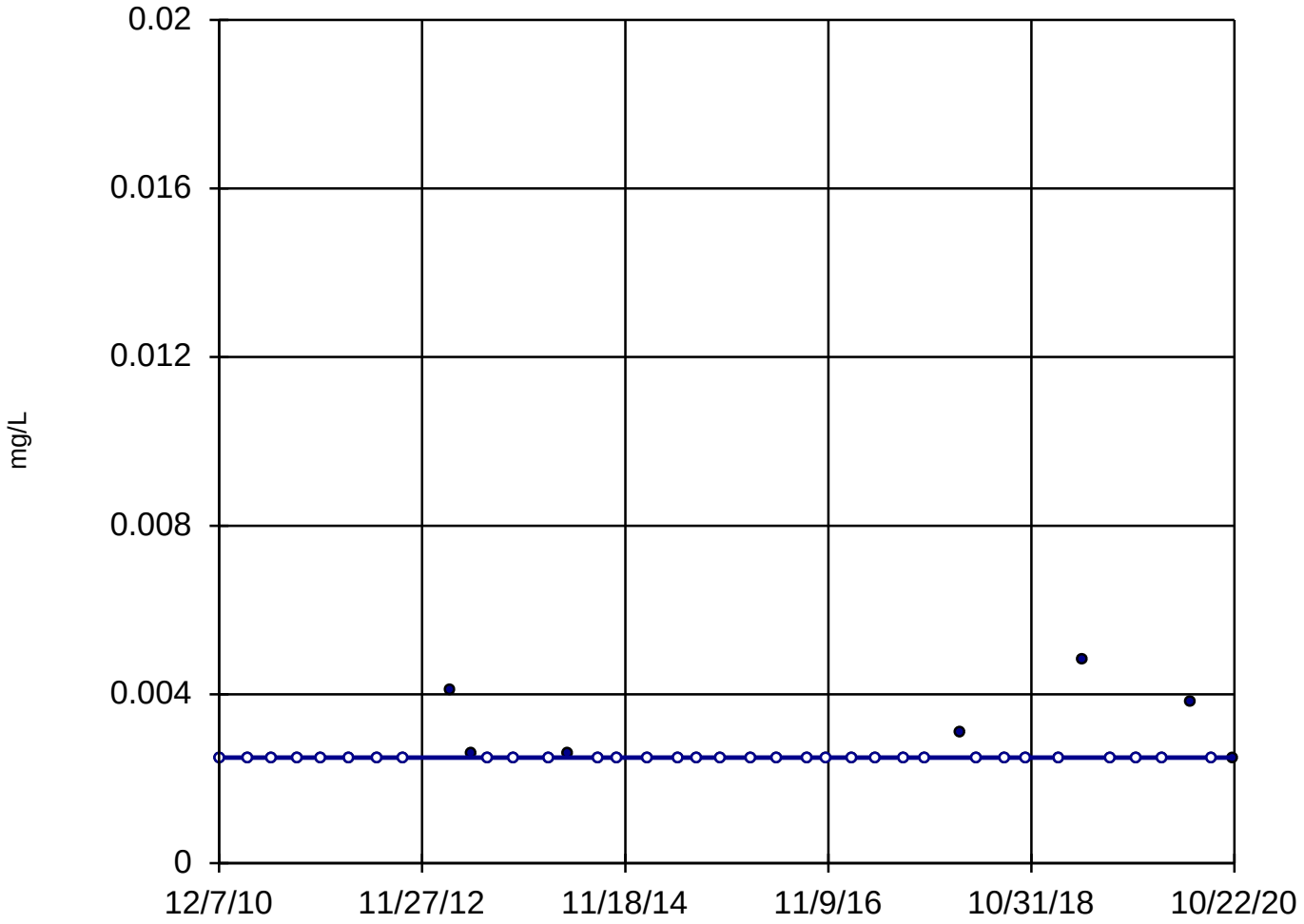
Constituent: Selenium, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 26
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

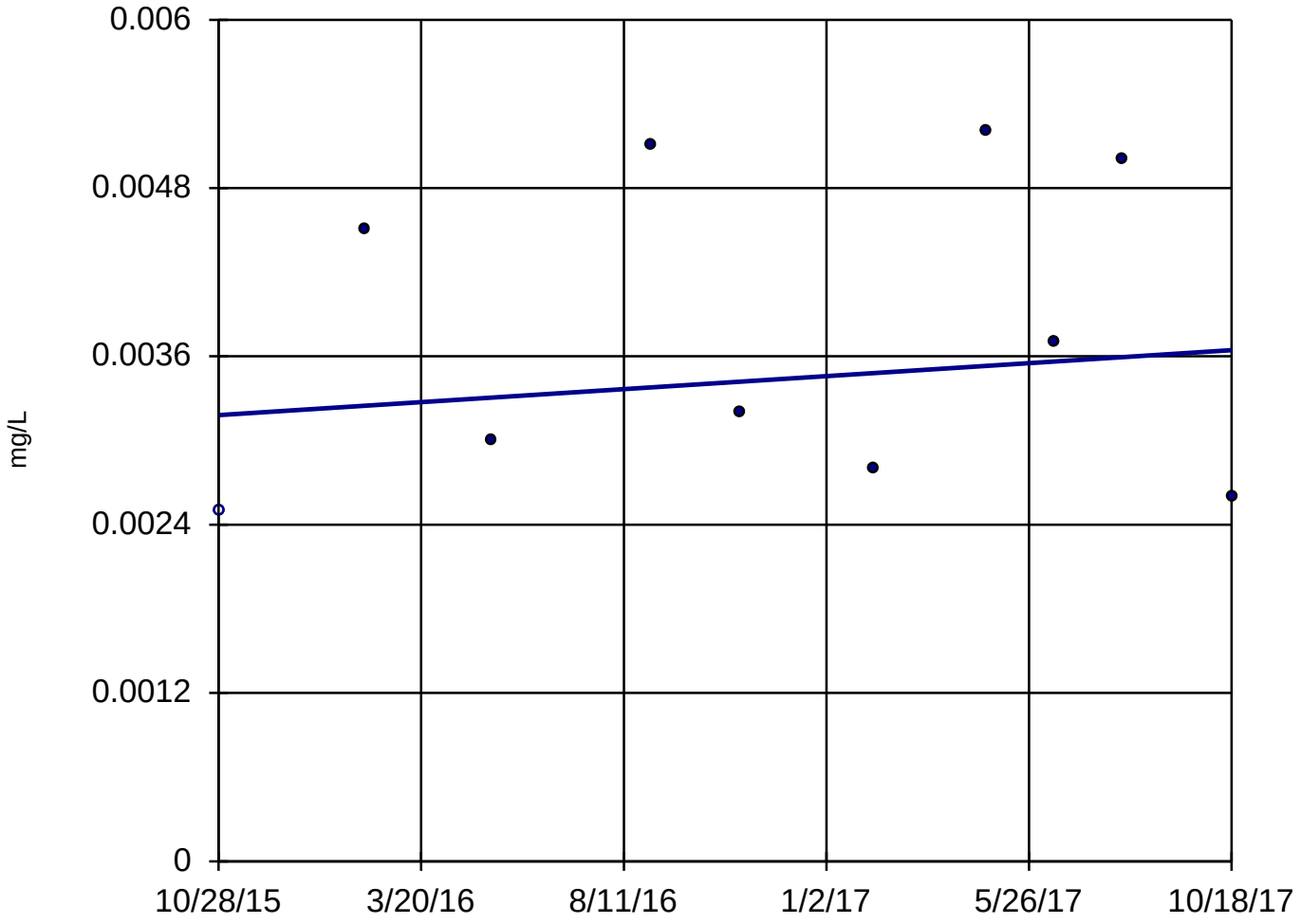
Constituent: Selenium, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 10

Slope = 0.0002345 units per year.

Mann-Kendall statistic = 5
critical = 30

Trend not significant at 99% confidence level (α = 0.005 per tail).

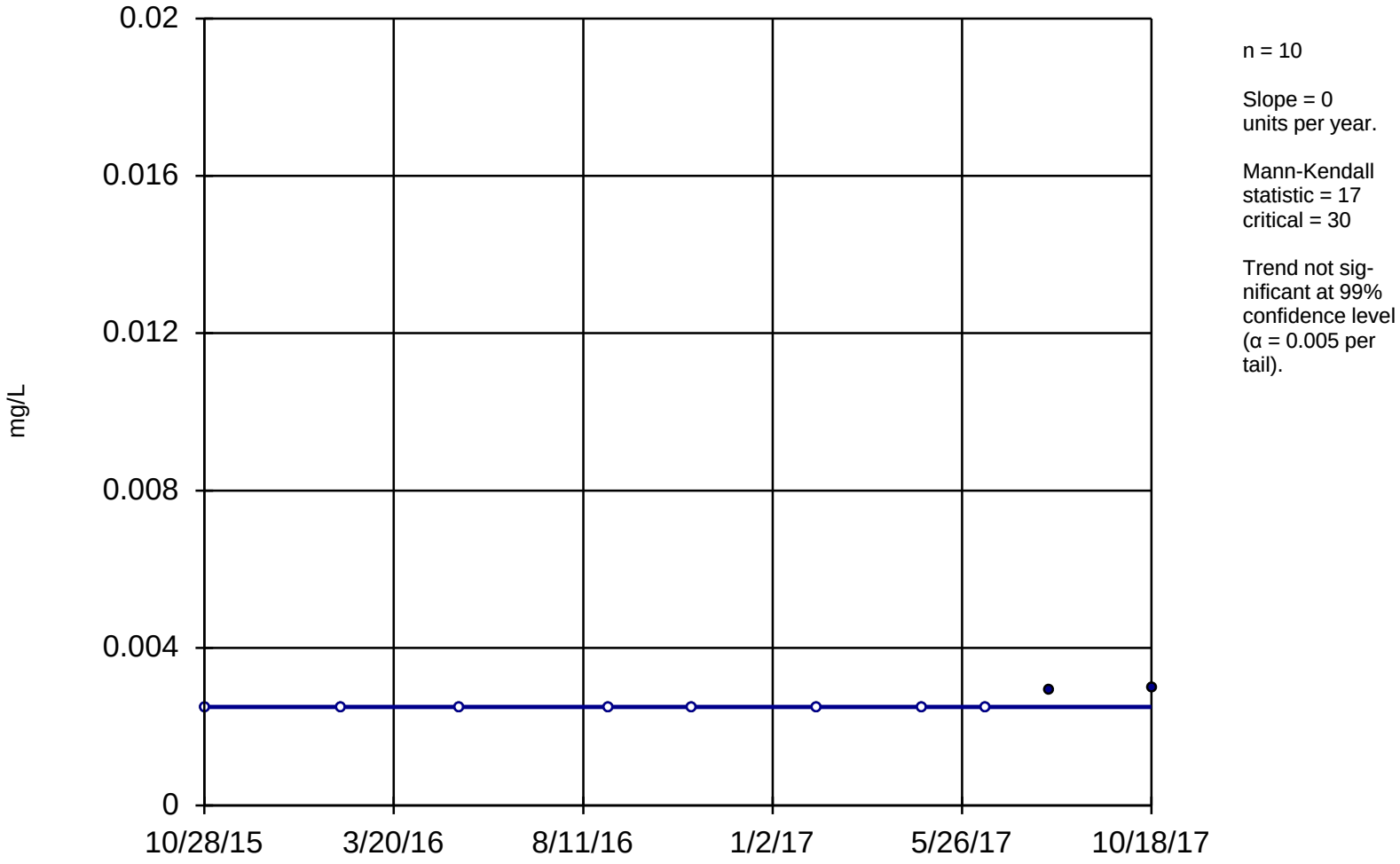
Constituent: Selenium, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 10

Slope = 0
units per year.

Mann-Kendall
statistic = 17
critical = 30

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

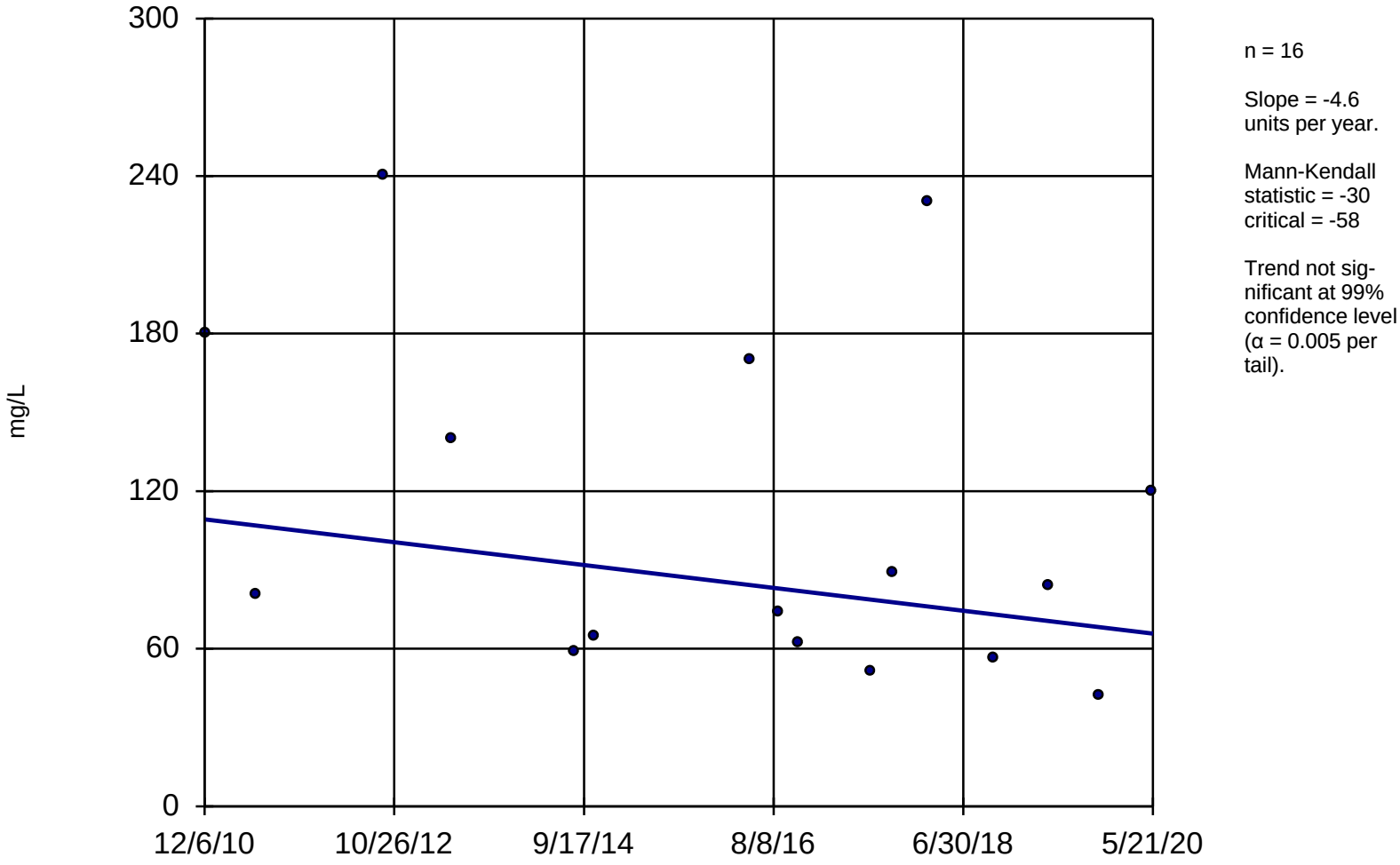
Constituent: Selenium, Total Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-01



n = 16

Slope = -4.6 units per year.

Mann-Kendall statistic = -30
critical = -58

Trend not significant at 99% confidence level (α = 0.005 per tail).

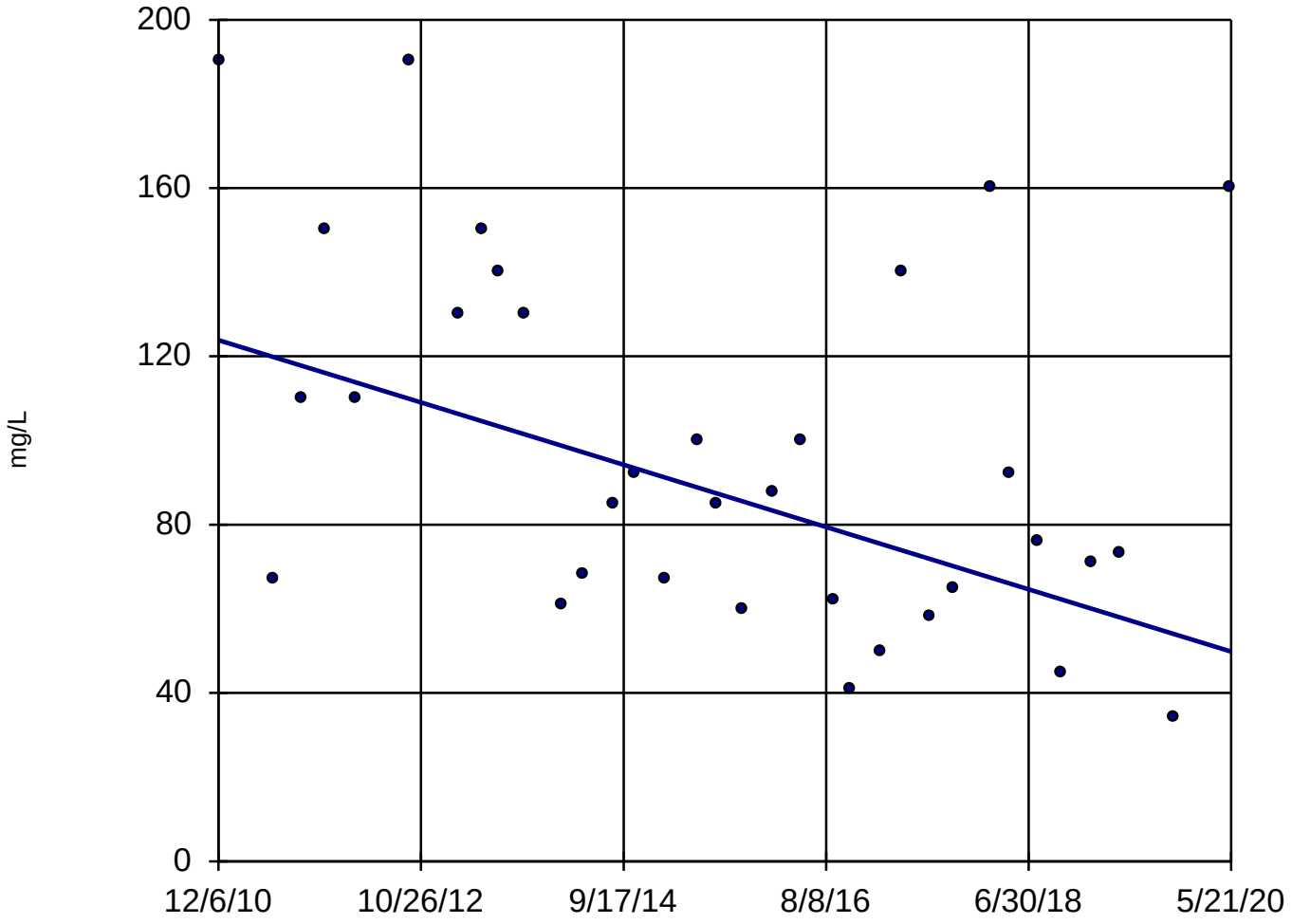
Constituent: Sulfate Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-02



n = 34

Slope = -7.826 units per year.

Mann-Kendall statistic = -175
critical = -176

Trend not significant at 99% confidence level (α = 0.005 per tail).

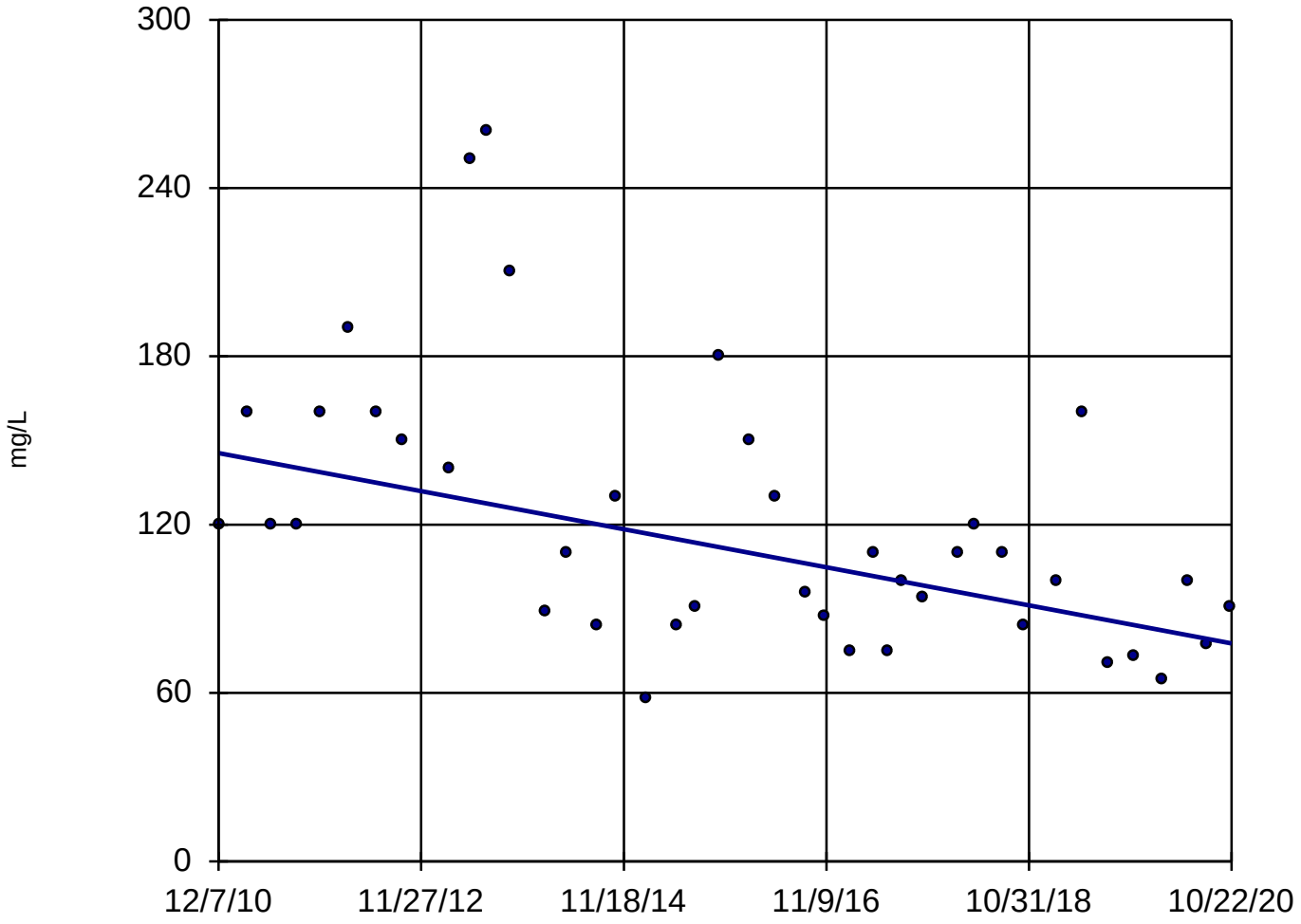
Constituent: Sulfate Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-03



n = 41

Slope = -6.868 units per year.

Mann-Kendall normal approx. = -3.501
critical = -2.58

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

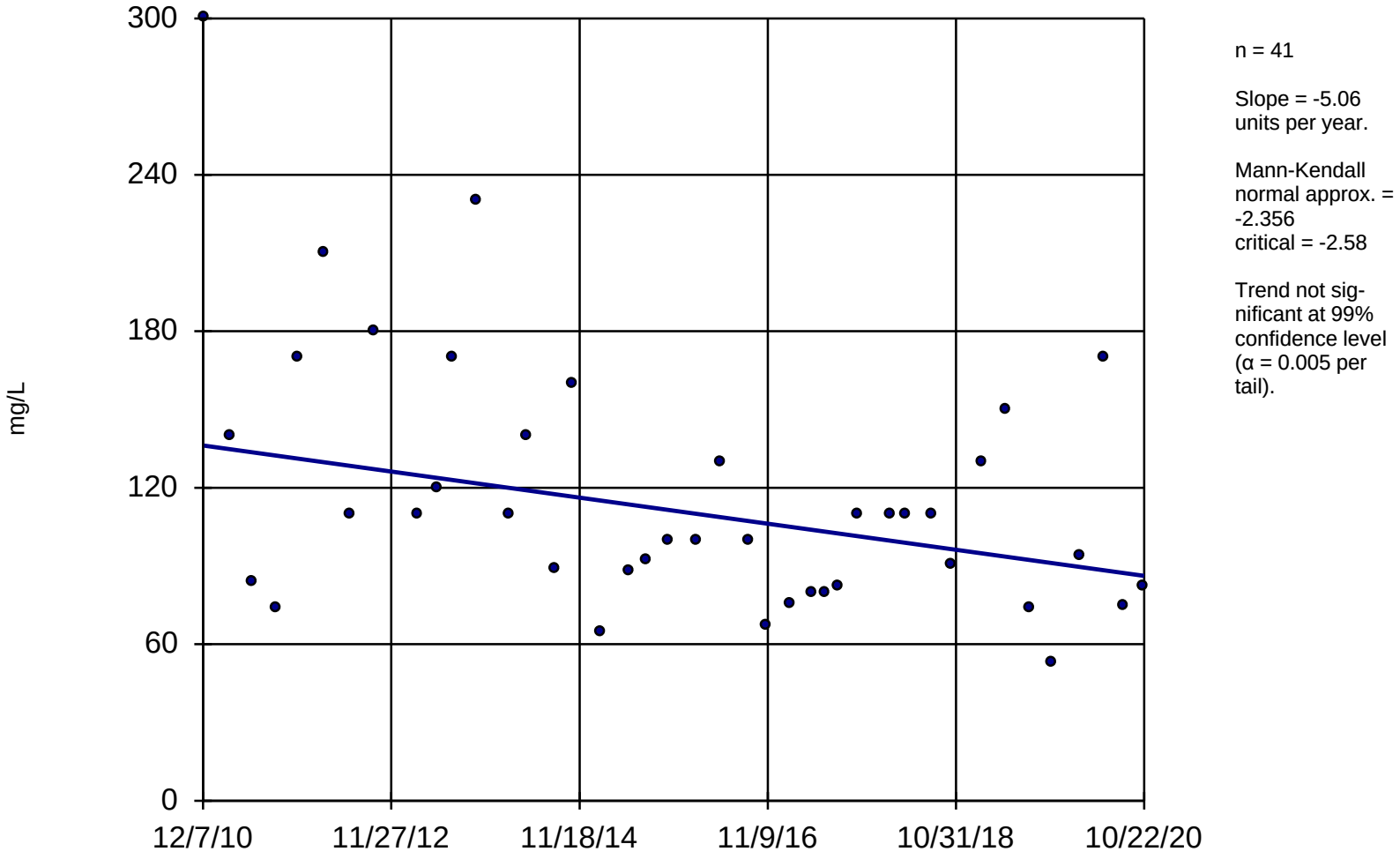
Constituent: Sulfate Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-04



n = 41

Slope = -5.06 units per year.

Mann-Kendall normal approx. = -2.356
critical = -2.58

Trend not significant at 99% confidence level (α = 0.005 per tail).

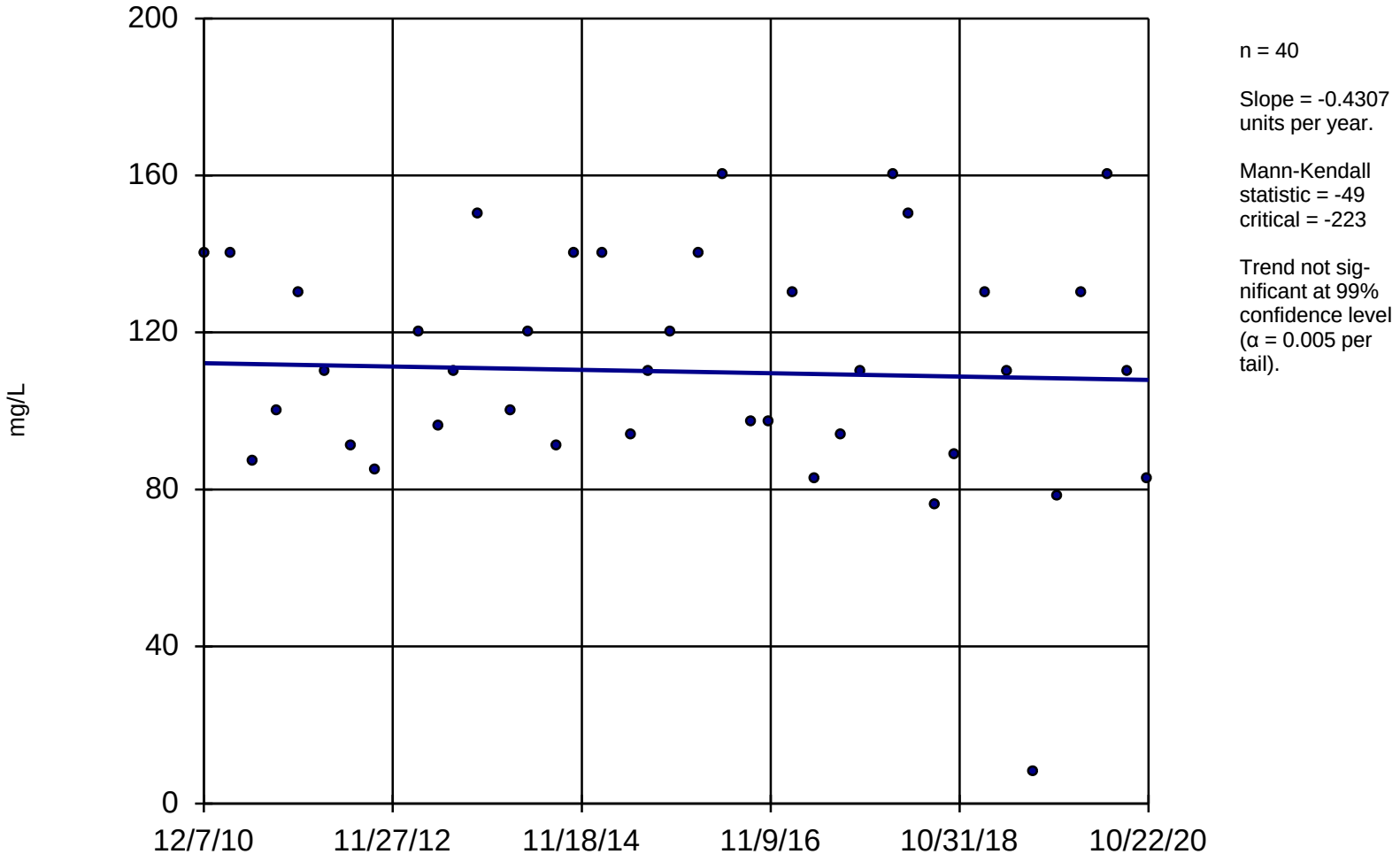
Constituent: Sulfate Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-06



n = 40

Slope = -0.4307 units per year.

Mann-Kendall statistic = -49
critical = -223

Trend not significant at 99% confidence level (α = 0.005 per tail).

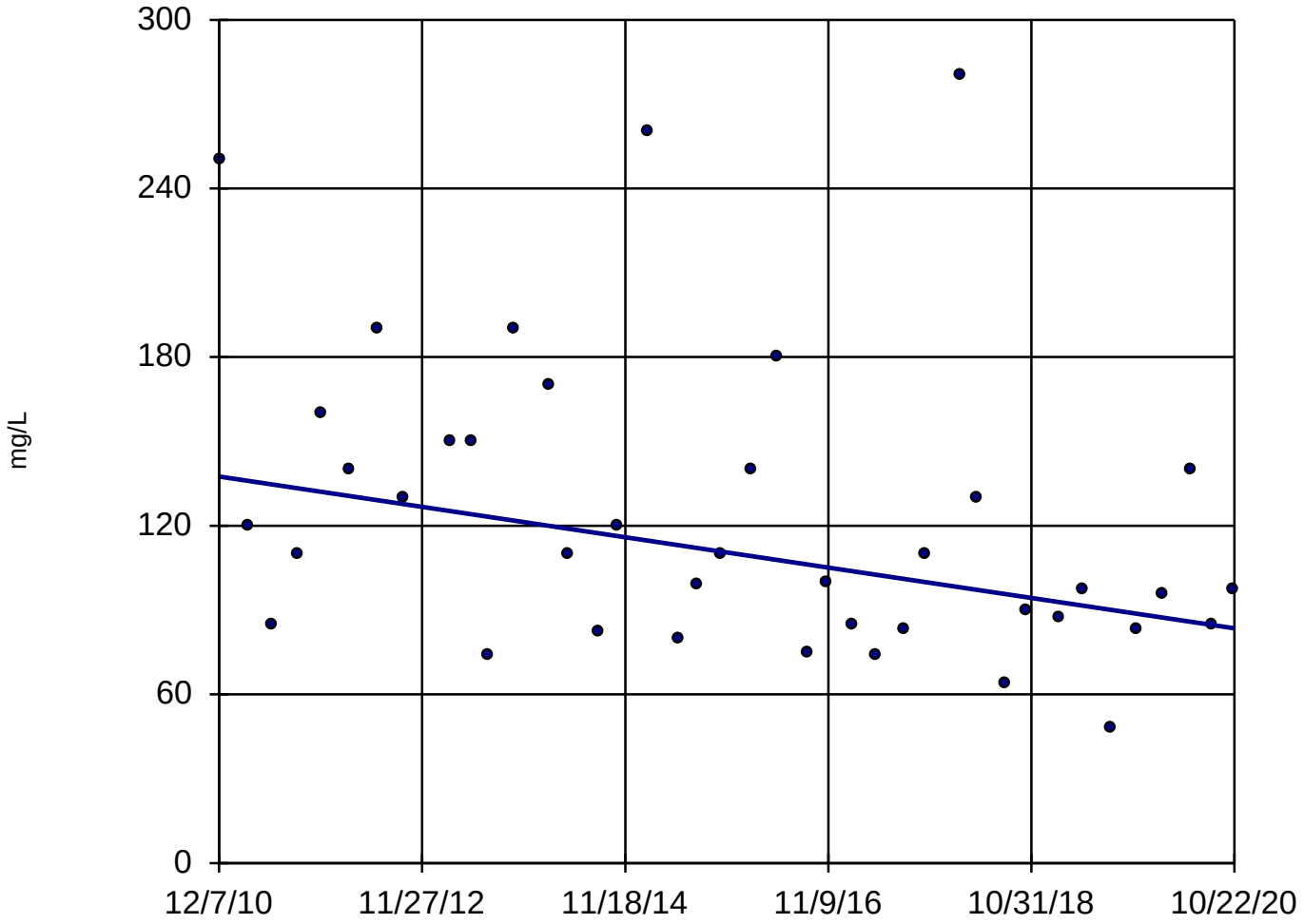
Constituent: Sulfate Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-07



n = 40

Slope = -5.456 units per year.

Mann-Kendall statistic = -215
critical = -223

Trend not significant at 99% confidence level (α = 0.005 per tail).

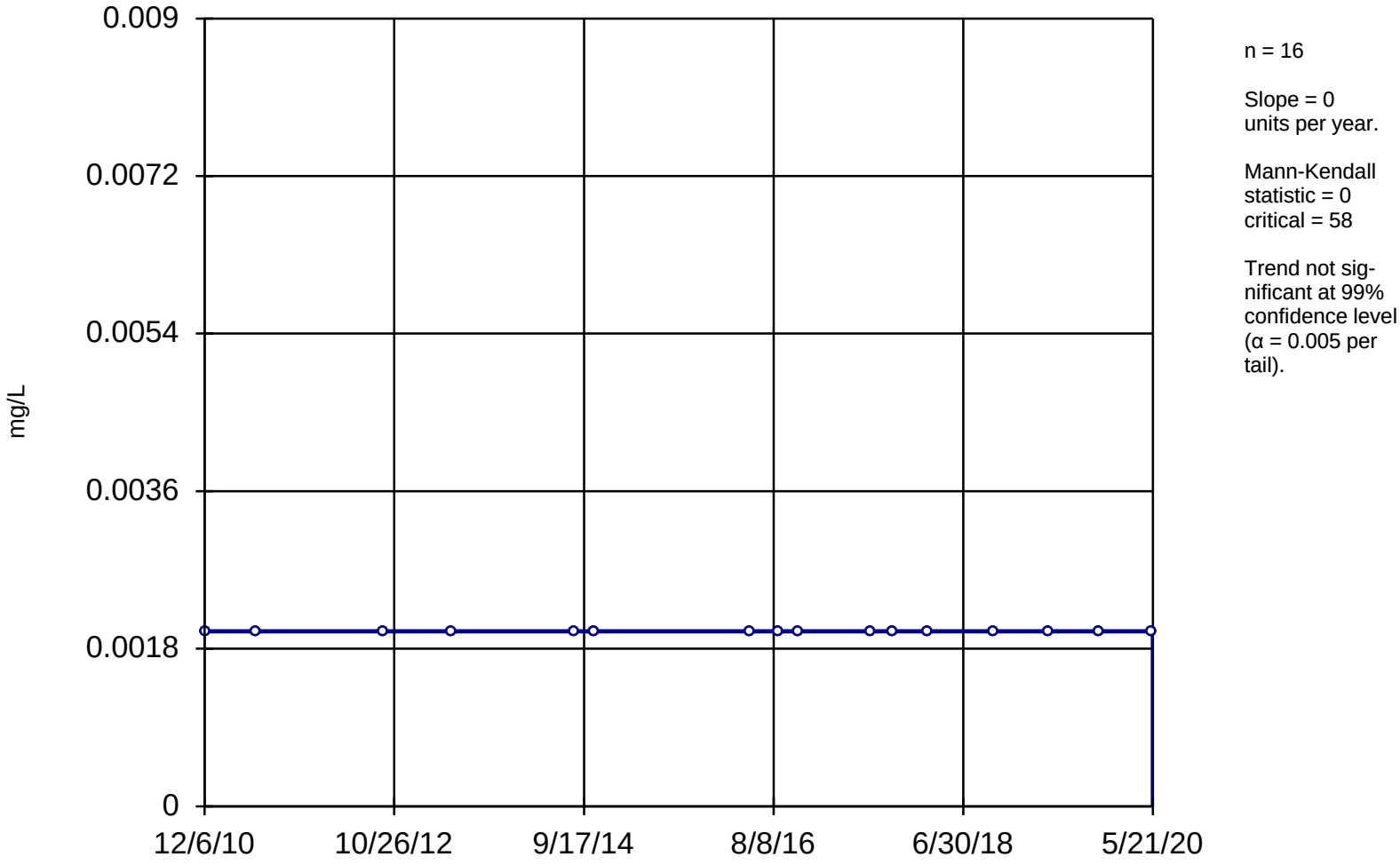
Constituent: Sulfate Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-01



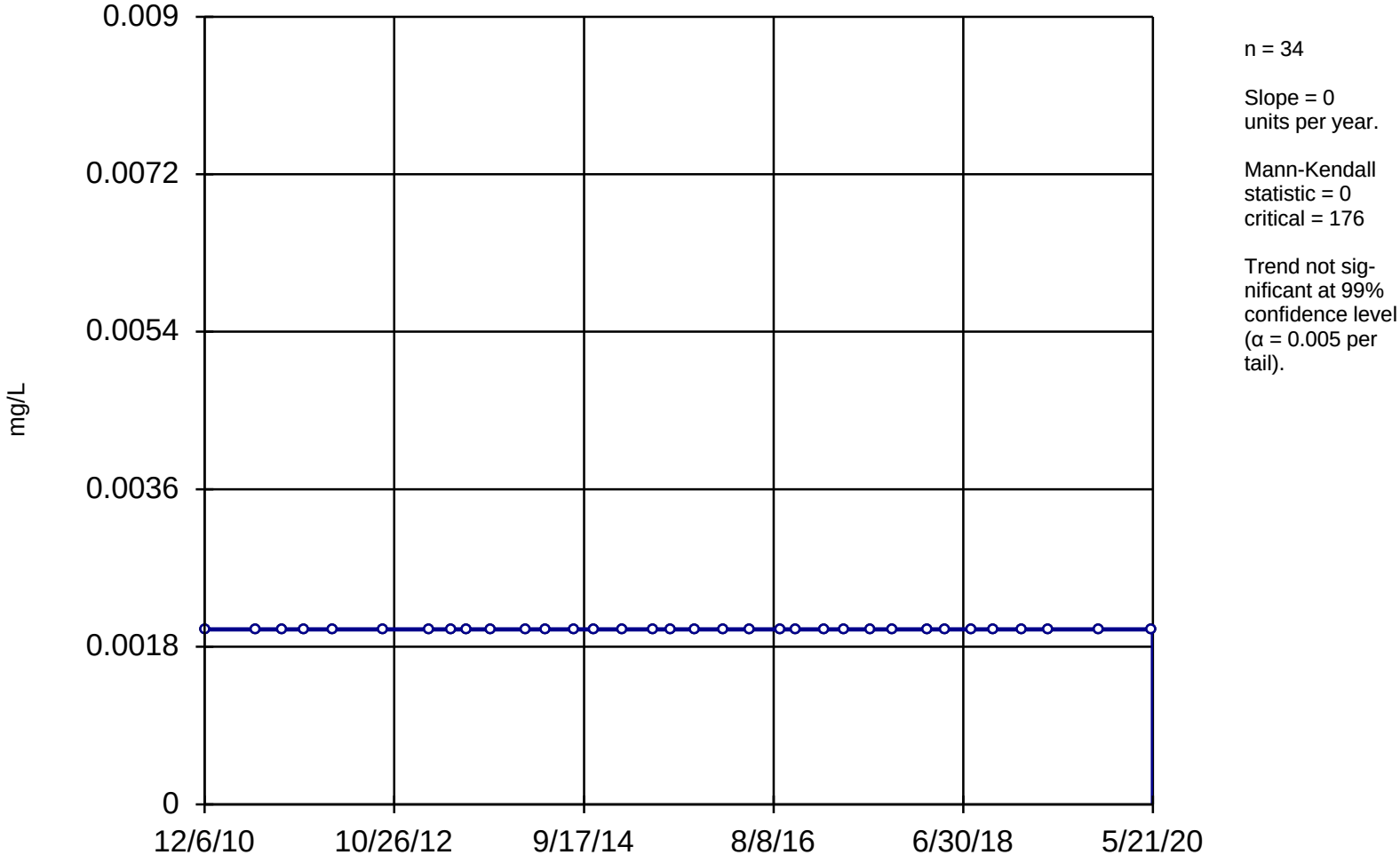
Constituent: Thallium, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-02



n = 34

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 176

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

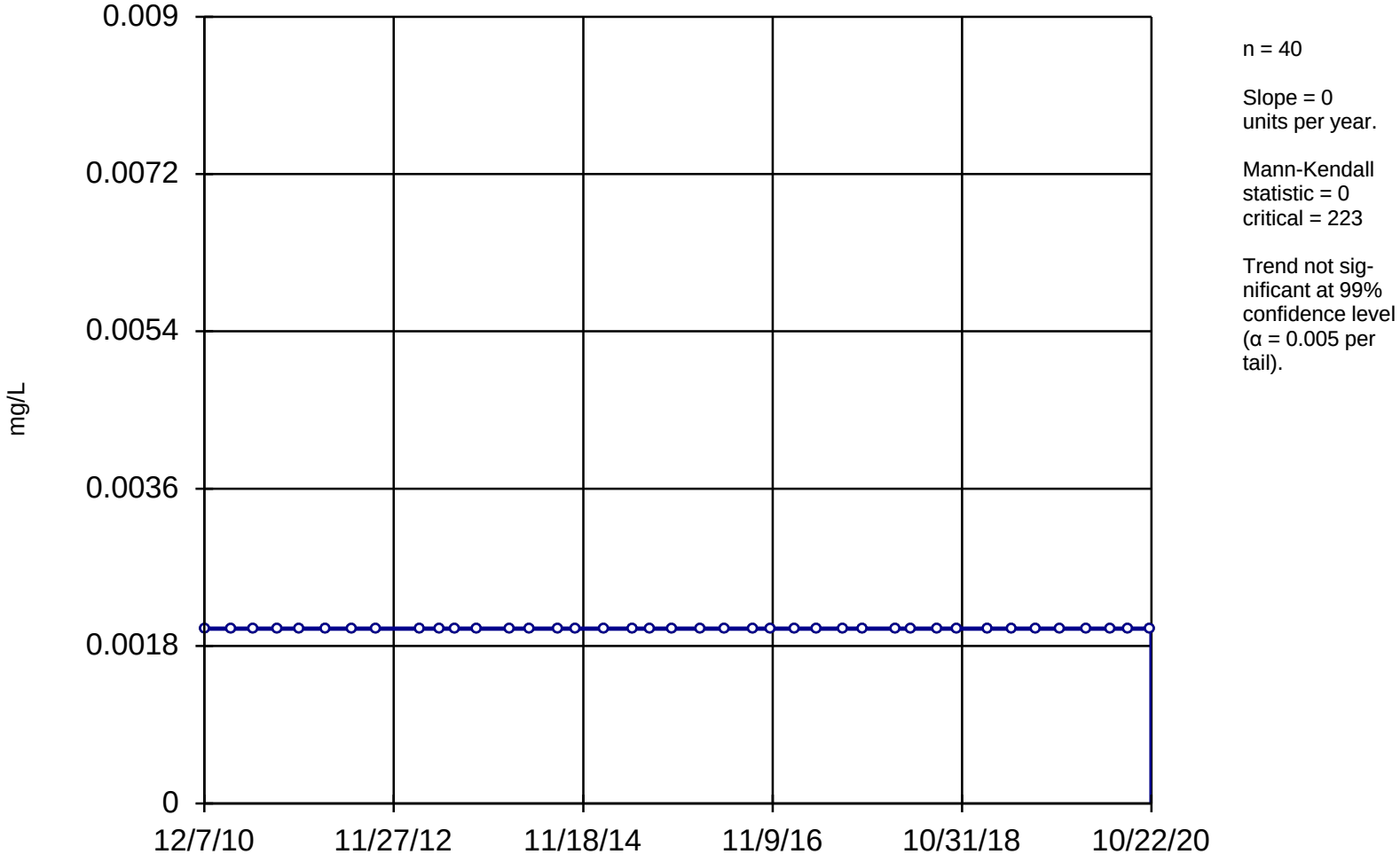
Constituent: Thallium, Dissolved Analysis Run 4/2/2021 11:02 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

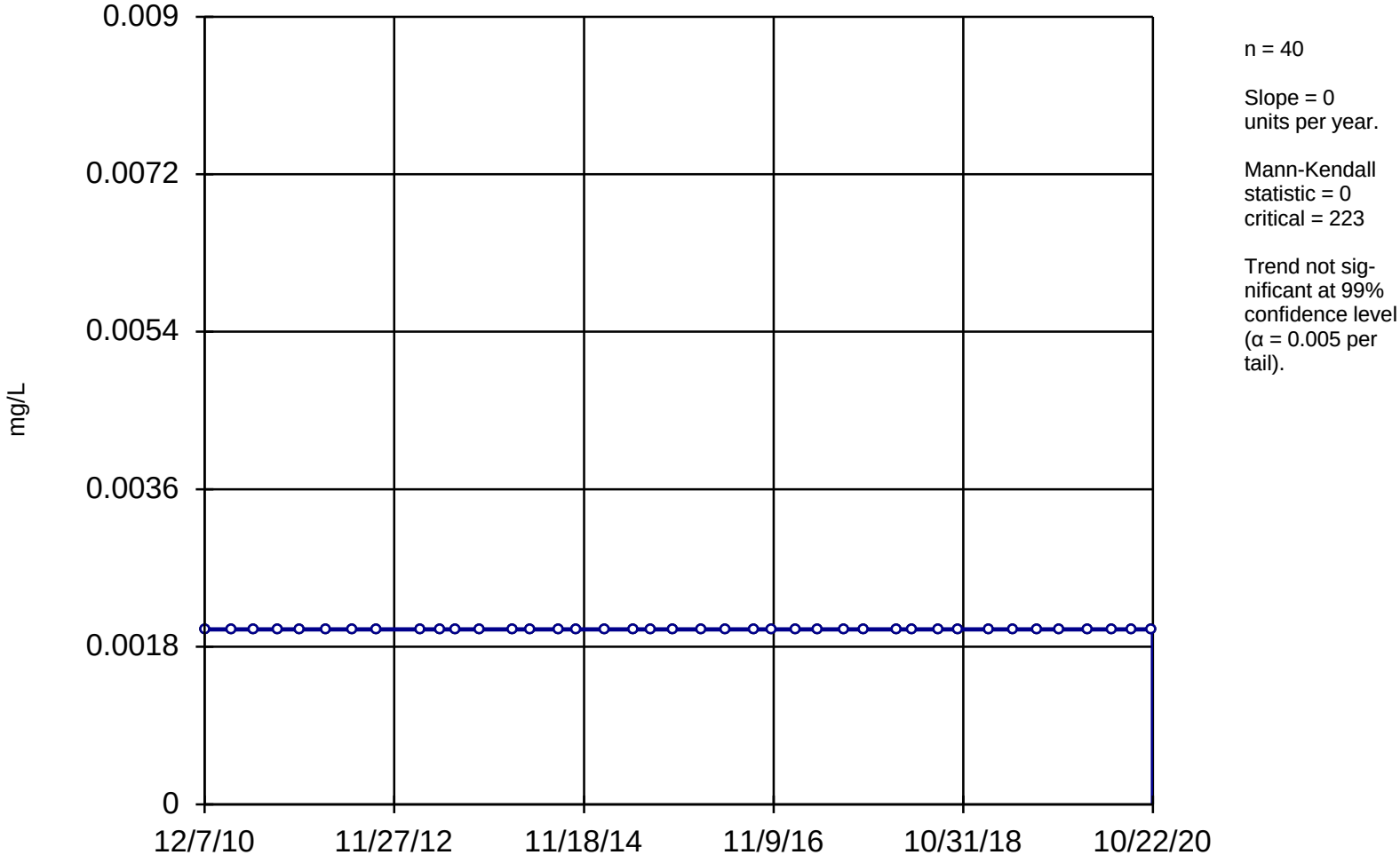
Constituent: Thallium, Dissolved Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

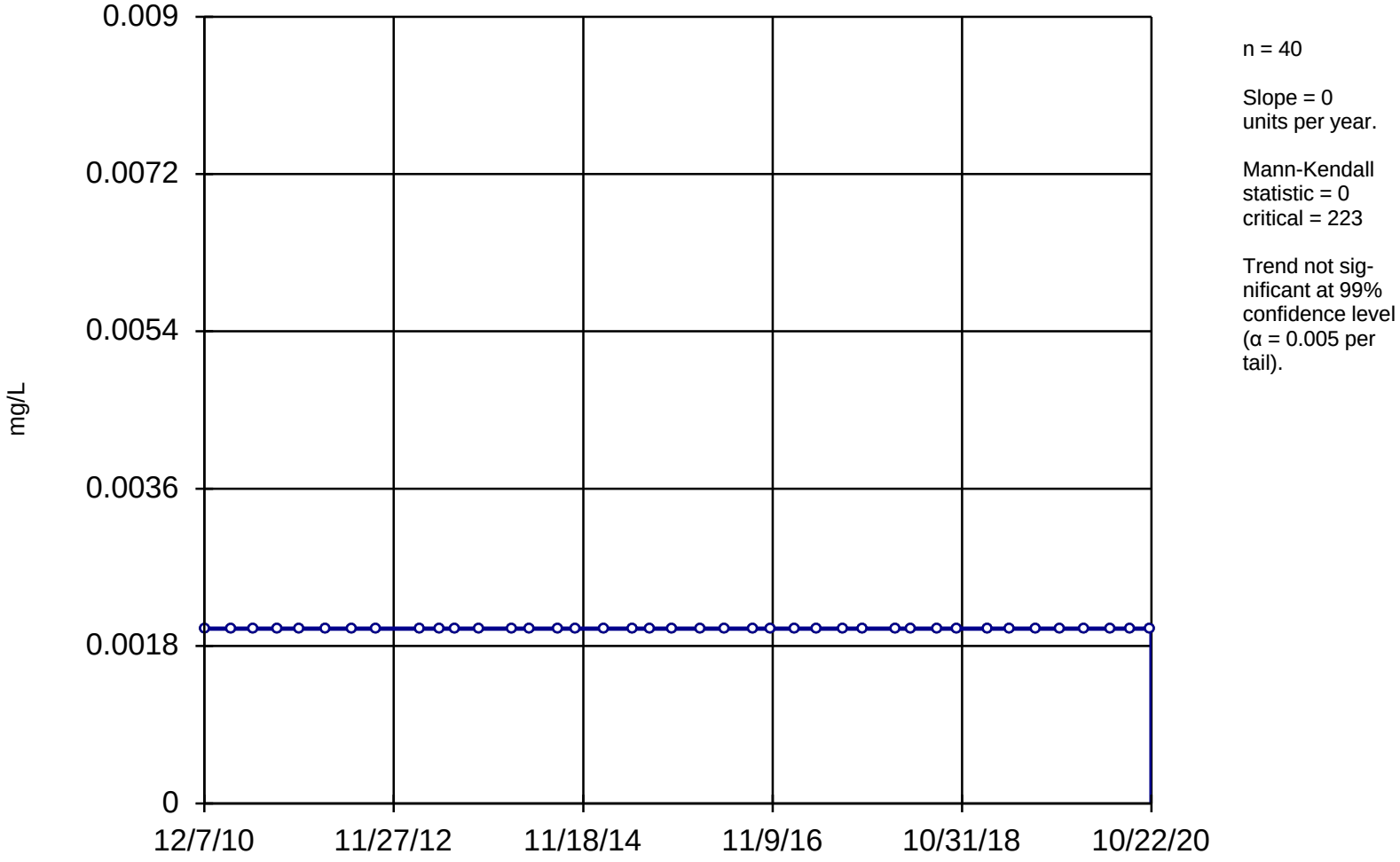
Constituent: Thallium, Dissolved Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

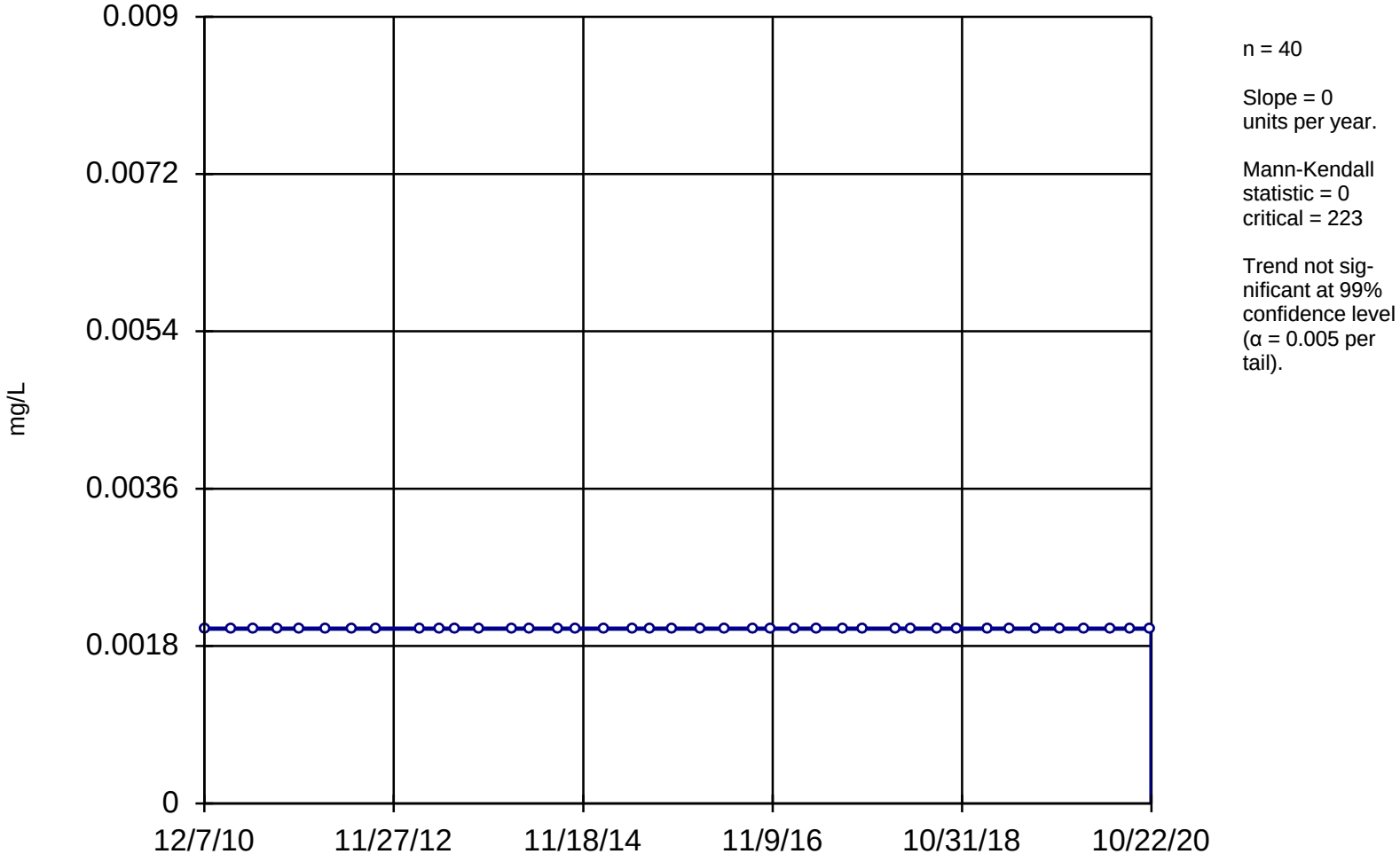
Constituent: Thallium, Dissolved Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-07



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = 0
critical = 223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

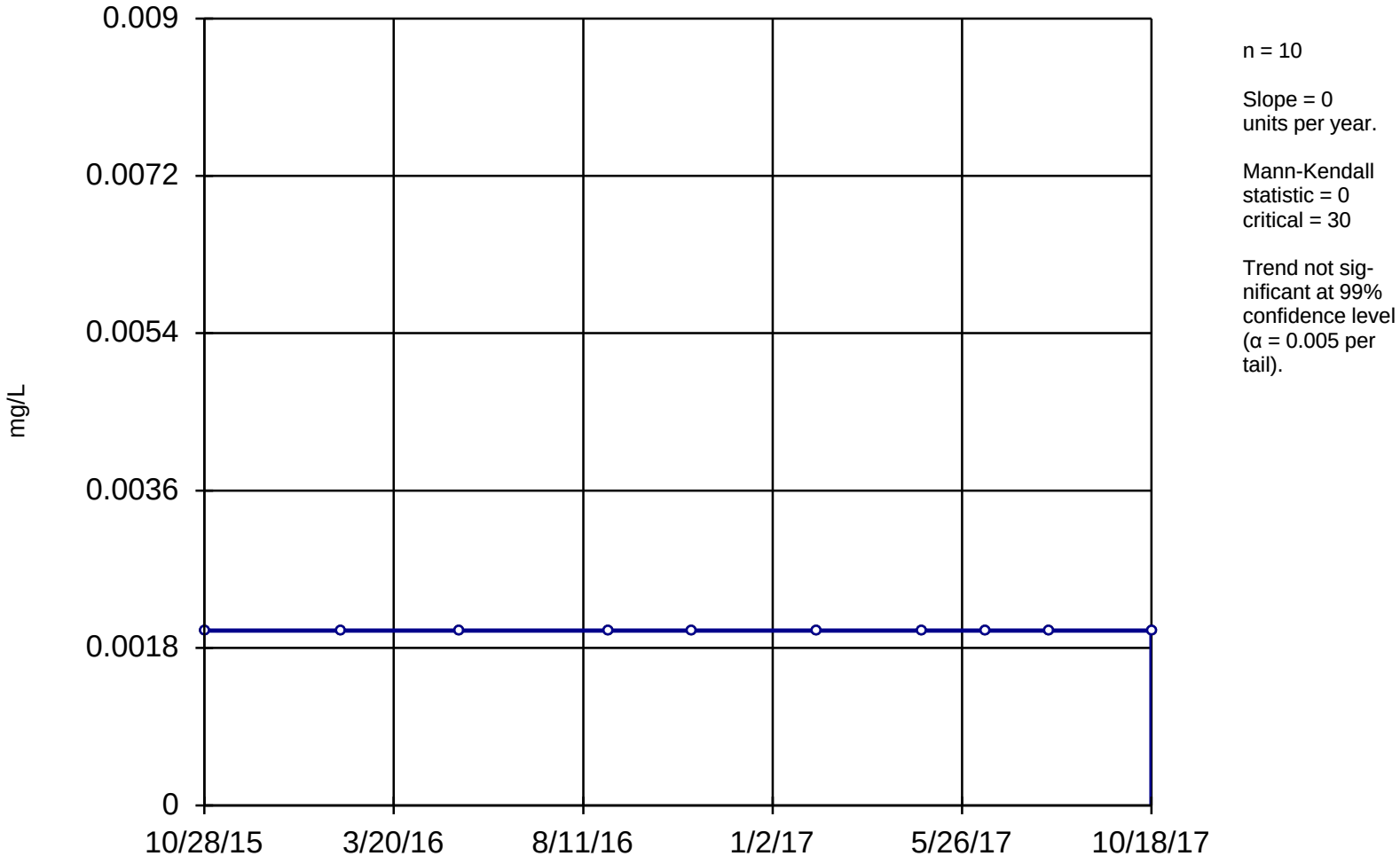
Constituent: Thallium, Dissolved Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-03



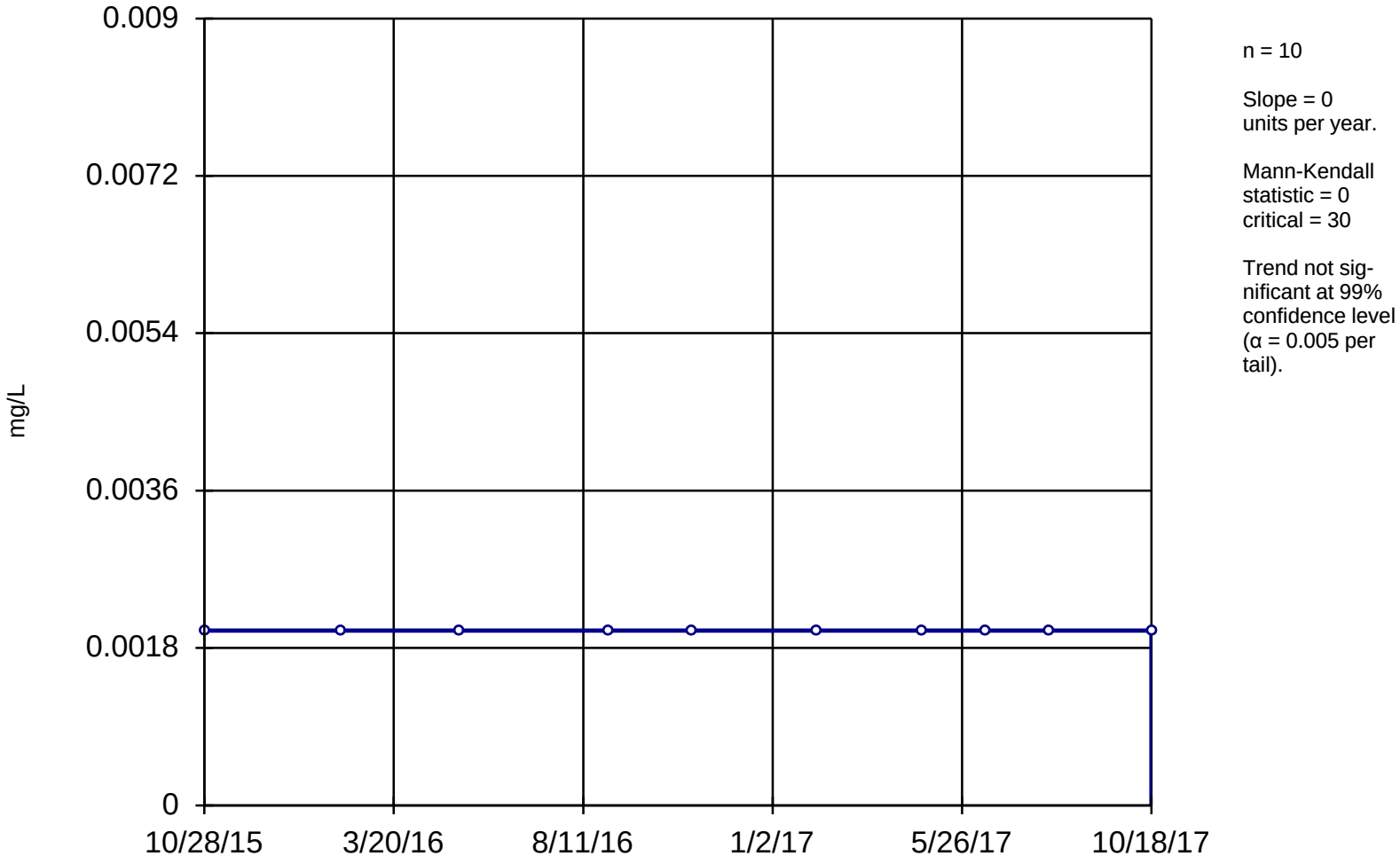
Constituent: Thallium, Total Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA
Hollow symbols indicate censored values.

Sen's Slope Estimator

MW-04



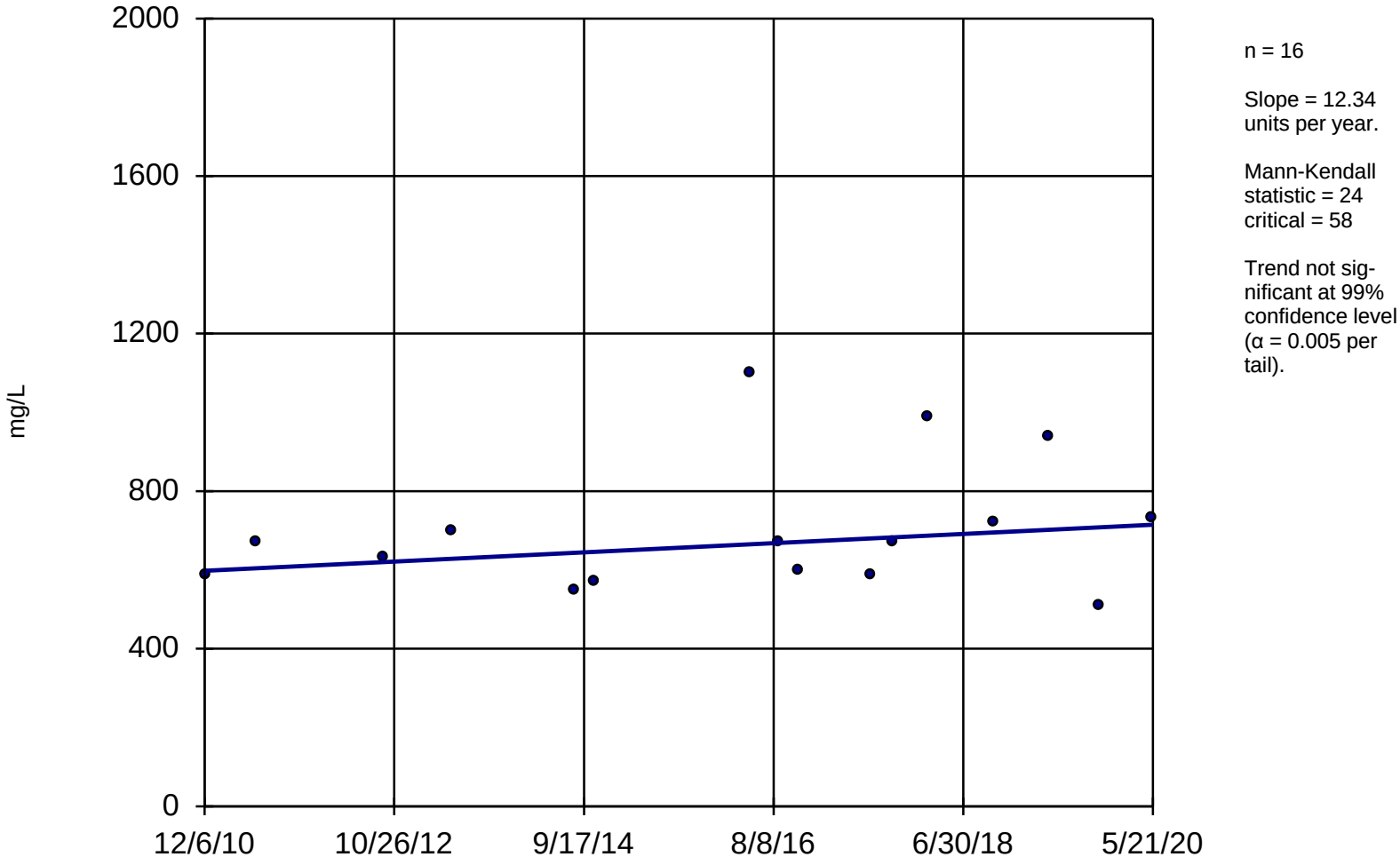
Constituent: Thallium, Total Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

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Sen's Slope Estimator

MW-01



n = 16

Slope = 12.34 units per year.

Mann-Kendall statistic = 24
critical = 58

Trend not significant at 99% confidence level (α = 0.005 per tail).

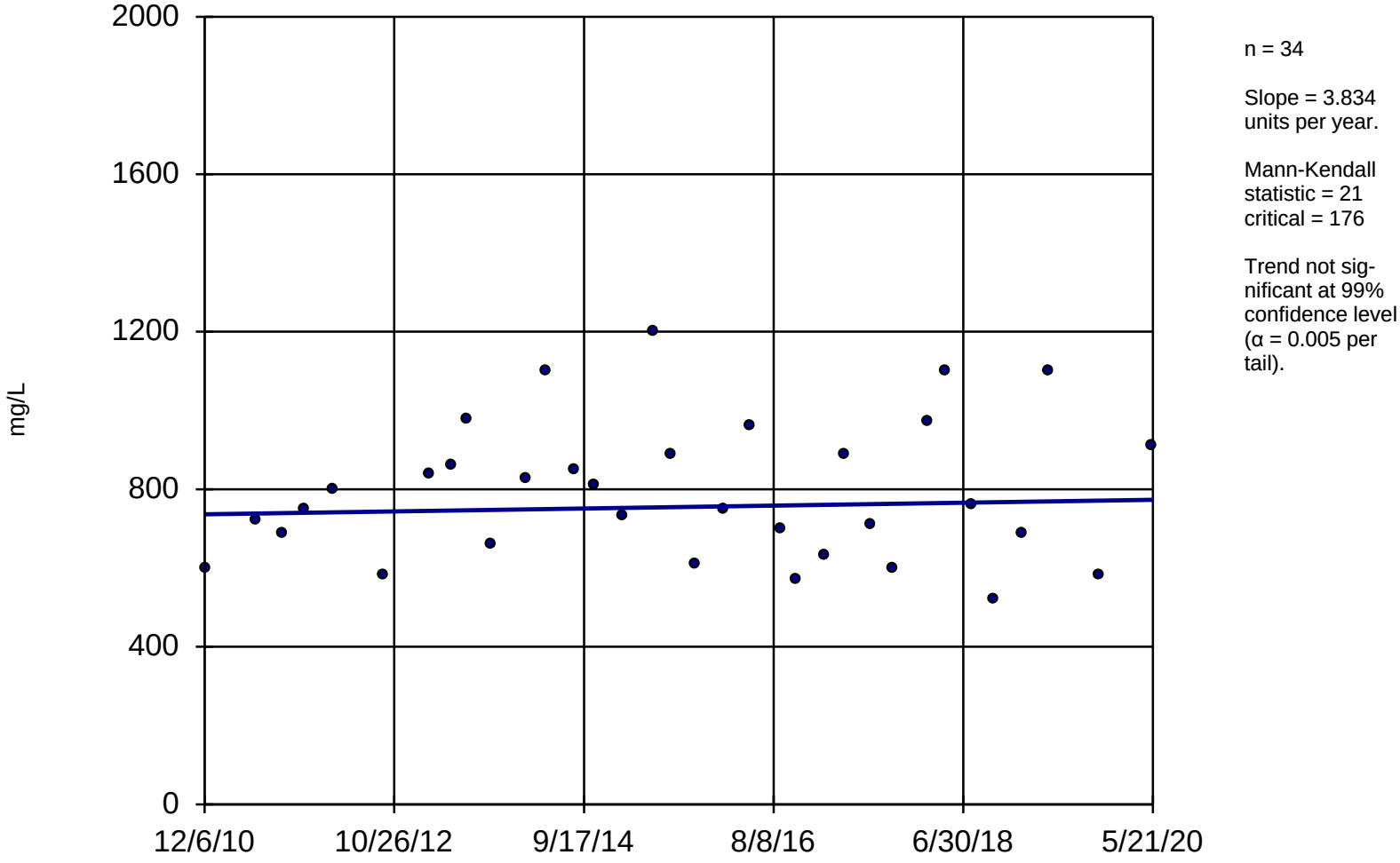
Constituent: Total Dissolved Solids Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-02



n = 34

Slope = 3.834 units per year.

Mann-Kendall statistic = 21
critical = 176

Trend not significant at 99% confidence level (α = 0.005 per tail).

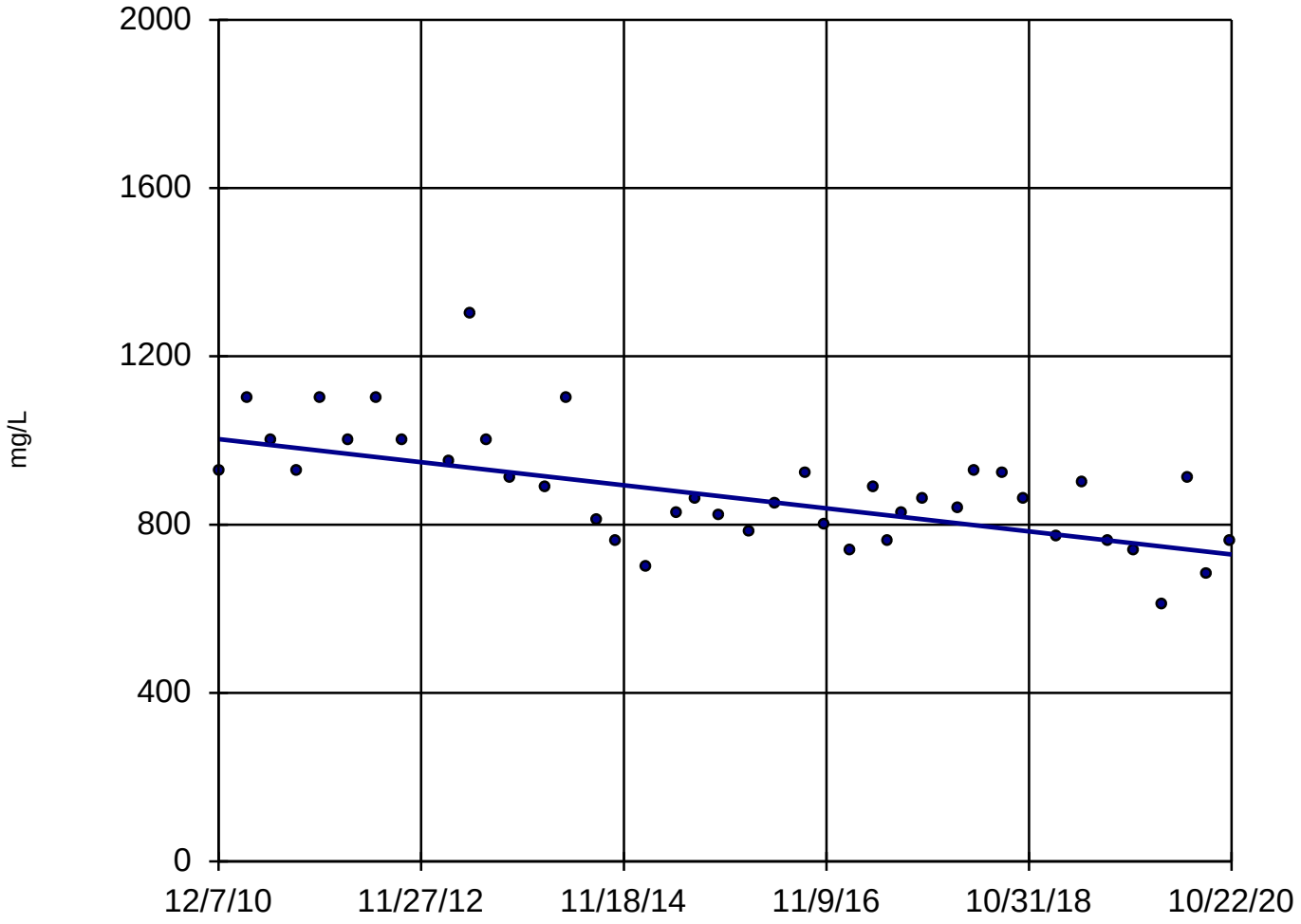
Constituent: Total Dissolved Solids Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-03



n = 41

Slope = -27.74 units per year.

Mann-Kendall normal approx. = -4.189
critical = -2.58

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

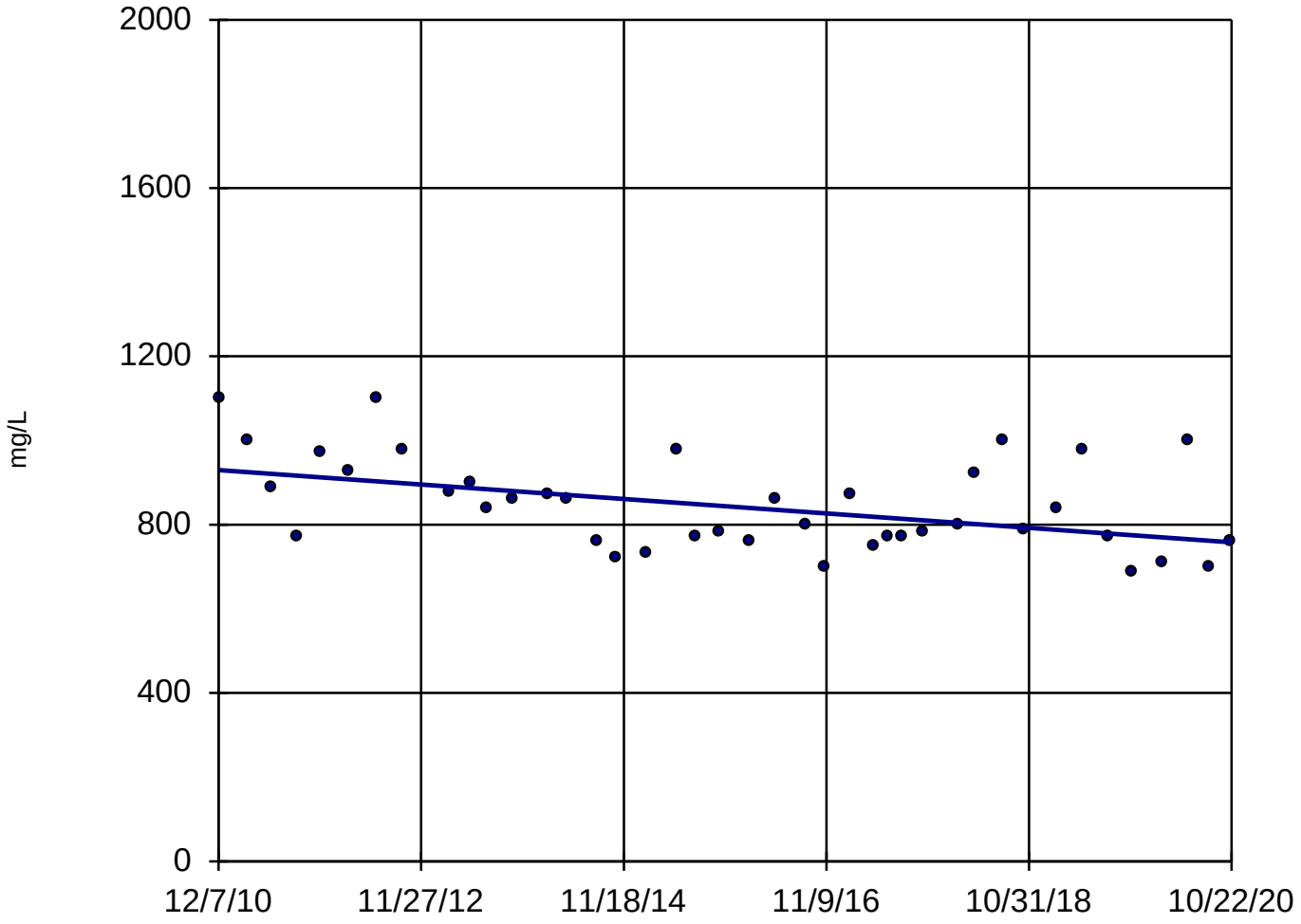
Constituent: Total Dissolved Solids Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-04



n = 41

Slope = -17.39 units per year.

Mann-Kendall normal approx. = -2.826
critical = -2.58

Decreasing trend significant at 99% confidence level (α = 0.005 per tail).

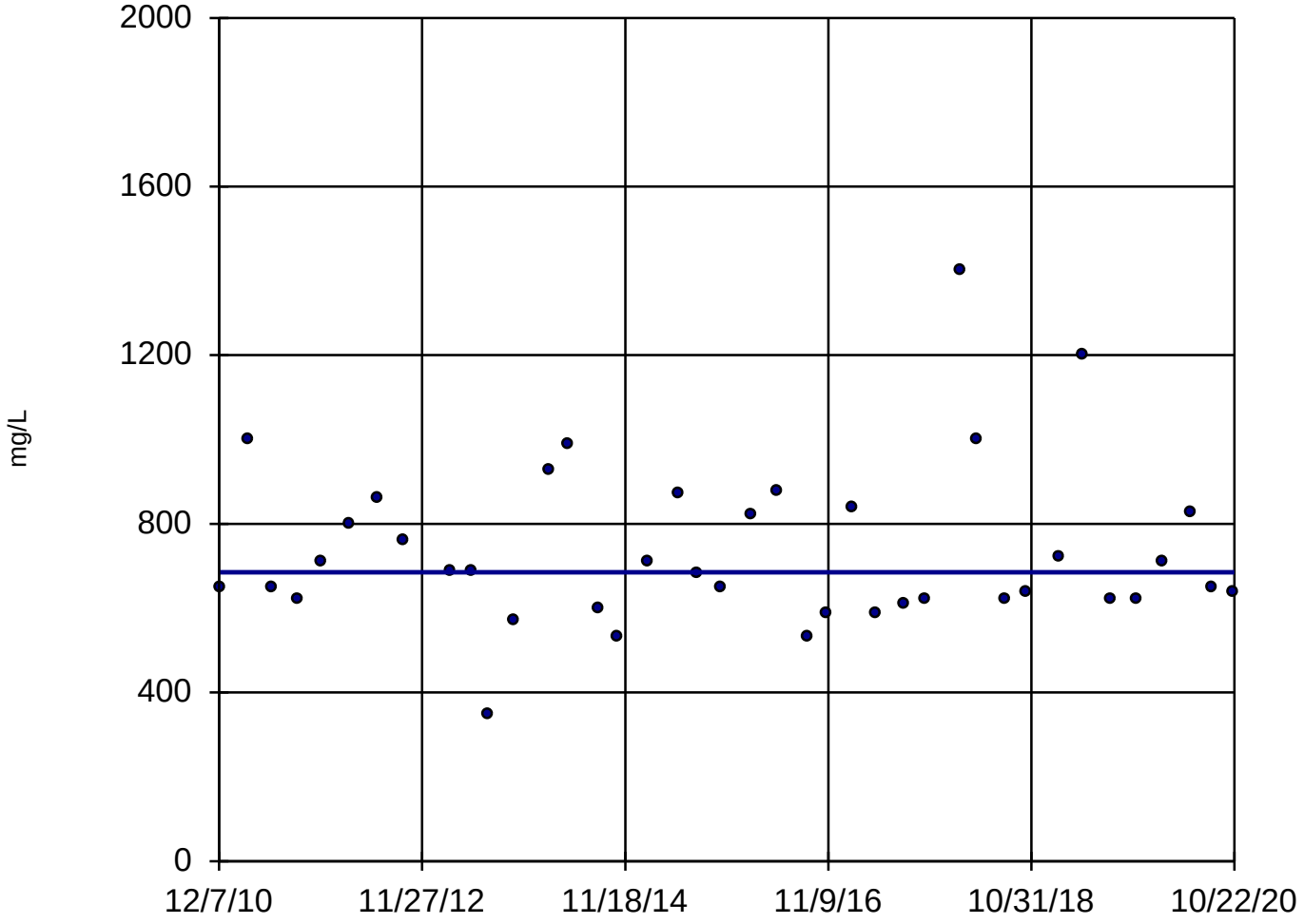
Constituent: Total Dissolved Solids Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-06



n = 40

Slope = 0
units per year.

Mann-Kendall
statistic = -4
critical = -223

Trend not sig-
nificant at 99%
confidence level
(α = 0.005 per
tail).

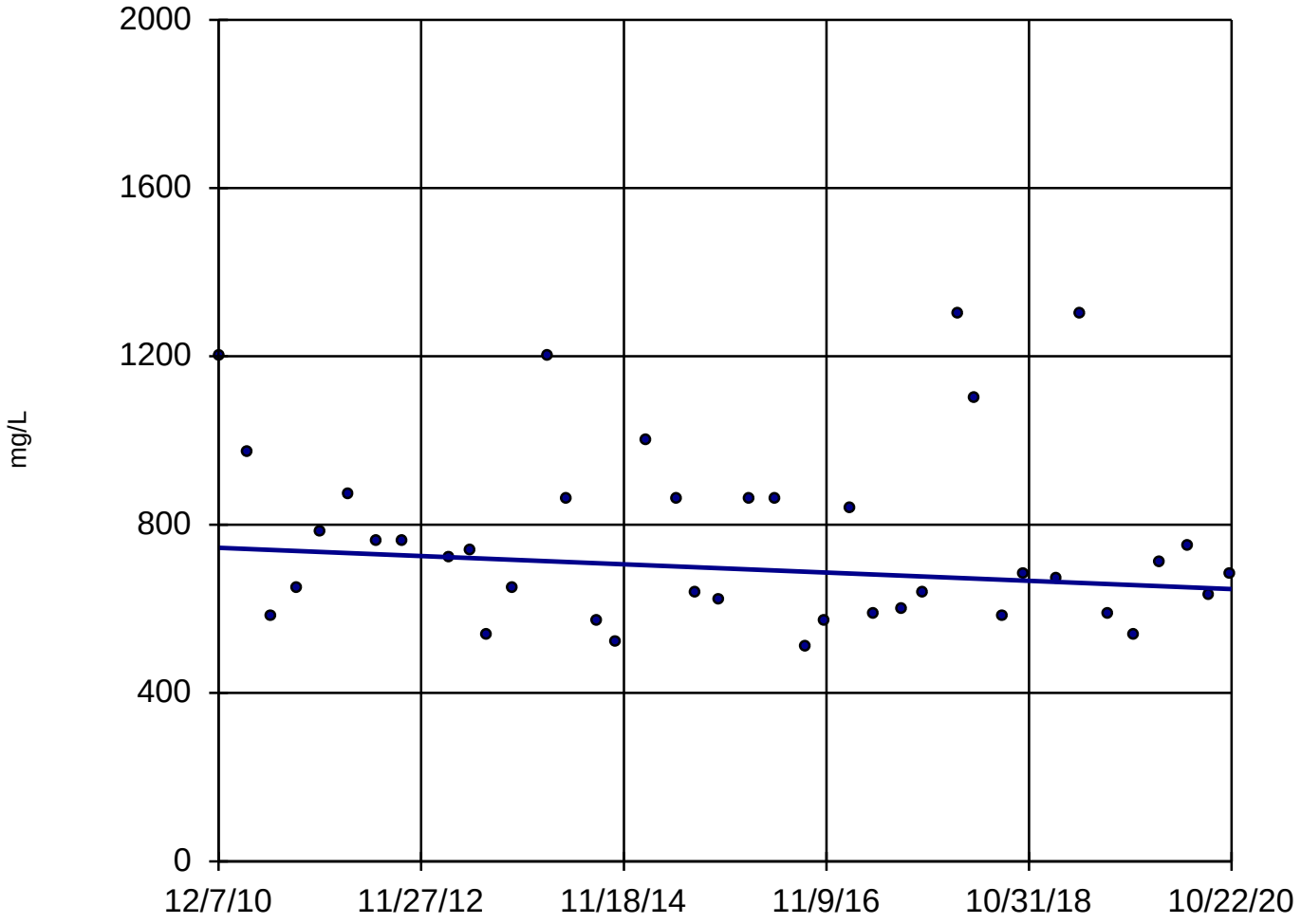
Constituent: Total Dissolved Solids Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

Sanitas™ v.9.6.28 Software licensed to Weaver Consultants Group. EPA

Sen's Slope Estimator

MW-07



n = 40

Slope = -9.923 units per year.

Mann-Kendall statistic = -96
critical = -223

Trend not significant at 99% confidence level (α = 0.005 per tail).

Constituent: Total Dissolved Solids Analysis Run 4/2/2021 11:03 AM

Utility Site J Client: Weaver Consultants Group Data: Joliet 29 Sanitas Database

APPENDIX C

Data from November 2020 Soil Borings Near MW-09

Electronic Filing: Received, Clerk's Office 2/04/2022

DRAFT	Boring Number: SB-1	Page 1 of 1
Site Name: NRG Joliet Station #29 Address: 1800 Channahon Road Joliet, IL 60436	Boring Location	Date: 11/11/2020 Start 12:30 PM Finish 12:50 PM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		42"		1–5	Dark Brown Sand and Gravel with some Clay, slightly moist Tan Silty Sand and Gravel, slightly moist				
		22"		6–10					
		30"		11–14	----- 6" gray medium sand layer, slightly moist				
		4"		15–17	End of Boring at 17 ft. bgs.				
				18–19					

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

The Agency is authorized to require this information under 415 ILCS 5/4 and 21. Disclosure of this information is required. Failure to do so may result in a civil penalty up to $25,000.00 for each day failure continues, a fine up to $50,000.00 and imprisonment up to five years. This form has been approved by the Forms Management Center.

Electronic Filing: Received, Clerk's Office 2/04/2022

DRAFT

Boring Number: SB-2

Site Name: NRG Joliet Station #29

Address: 1800 Channahon Road Joliet, IL 60436

Boring Location

Date: 11/11/2020 Start 11:20 PM

Finish 11:50 PM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		45"		1–5	Brown Clay with Silty Sand and Gravel, moist --Increase Tan Silty Sand --Dark brown/black silty clay layer Tan Silty Sand and Gravel, moist				
		32"		5–10					
		12"		10–13					
				13	End of Boring at 13 ft. bgs.				
				14–19					

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

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DRAFT

Boring Number: SB-3

Page 1 of 1

Site Name: NRG Joliet Station #29
Address: 1800 Channahon Road Joliet, IL 60436

Boring Location

Date: 11/11/2020 Start 10:55 AM

Finish 11:15 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		40"		1–5	Brown Silty Sand and Gravel, slightly moist --trace rust-colored mottling				
		30"		5–10	Yellow/Tan Silty Sand and Gravel, slightly moist				
		18"		10–15	--Increased cobbles				
		12"		15–17					
				17–19	End of boring at 17 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

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Electronic Filing: Received, Clerk's Office 2/04/2022

DRAFT	Boring Number: SB-4	Page 1 of 1
Site Name: NRG Joliet Station #29 Address: 1800 Channahon Road Joliet, IL 60436	Boring Location	Date: 11/11/2020 Start 10:35 AM Finish 10:50 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		42"		1–5	Tan Silty Sand and Gravel with some Brown Clay, Slightly Moist Black/Brown Silty Clay, slightly moist Yellow/Tan Silty Silty Sand and Gravel, slightly moist				
		26"		5–10	--Increased cobbles				
		12"		10–14	--Trace pink-colored gravel				
				14–19	End of boring at 14 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

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DRAFT

Boring Number: SB-5

Page 1 of 1

Site Name: NRG Joliet Station #29

Address: 1800 Channahon Road Joliet, IL 60436

Boring Location

Date: 11/11/2020 Start 10:05 AM

Finish 10:30 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		36"		1	Gray Sand and Gravel with Brown Clay, slightly moist				
				2	Tan Silty Sand and Gravel, slightly moist				
				3	Black/Brown Clay, slightly moist				
				4	Yellow/Tan Silty Sand and Gravel, slightly moist				
				5	--coarse gravel				
		30"		6	Tan Sand and Gravel, some Coarse Gravel, slightly moist				
				7					
				8					
				9					
				10					
		31"		11					
				12					
				13					
				14					
				15					
		18"		16					
				17					
				18					
				19	End of boring at 18 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

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Electronic Filing: Received, Clerk's Office 2/04/2022

DRAFT	Boring Number: SB-6	Page 1 of 1
Site Name: NRG Joliet Station #29 Address: 1800 Channahon Road Joliet, IL 60436	Boring Location	Date: 11/11/2020 Start 12:55 PM Finish 13:20 PM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		44"		1 2 3 4 5	Brown Silty Clay with Sand and Gravel, slightly moist ---some rust-colored mottling Yellow/Tan Silty Sand and Gravel, slightly moist				
		36"		6 7 8 9	-6" black/brown sandy clay layer Tan Sand and Gravel, slightly moist				
				10 11 12 13 14 15 16 17 18 19	End of boring at 9 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

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DRAFT

Boring Number: SB-7

Page 1 of 1

Site Name: NRG Joliet Station #29

Address: 1800 Channahon Road Joliet, IL 60436

Boring Location

Date: 11/11/2020 Start 13:15 PM

Finish 13:40 PM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		32"		1–5	Brown Silty Clay with Sand and Gravel, slightly moist ---increase coarse gravel				
		26"		5–10	---increase clay content				
		20"		10–15	---increase yellow/tan silty sand content				
		12"		15–17					
				17–19	End of boring at 17 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

IL 532-2275
LPC 501 Rev June 2004

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326"

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DRAFT

Boring Number: SB-8

Page 1 of 1

Site Name: NRG Joliet Station #29

Address: 1800 Channahon Road Joliet, IL 60436

Boring Location

Date: 11/11/2020 Start 13:50 PM

Finish 14:20 PM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		34"		1–5	Brown Silty Sand and Gravel, very moist ---increase clay content				
		24"		6–10					
		14"		10–12	Tan Silty Sand and Gravel, trace Clay				
				12–19	End of boring at 12 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

IL 532-2275
LPC 501 Rev June 2004

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326"

Electronic Filing: Received, Clerk's Office 2/04/2022

DRAFT	Boring Number: SB-9	Page 1 of 1
Site Name: NRG Joliet Station #29 Address: 1800 Channahon Road Joliet, IL 60436	Boring Location	Date: 11/12/2020 Start 08:45 AM Finish 09:00 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		30"		1–5	Gray/Tan Silty Sand and Gravel with Clay, very moist Gray/Black/Tan Sand and Gravel, very moist. Brown Clay with Silty Sand and Gravel, moist.				
		26"		6–10	---Increase coarse gravel and sand				
		6"		11	` End of boring at 11 ft. bgs.				
				12–19					

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

The Agency is authorized to require this information under 415 ILCS 5/4 and 21. Disclosure of this information is required. Failure to do so may result in a civil penalty up to $25,000.00 for each day failure continues, a fine up to $50,000.00 and imprisonment up to five years. This form has been approved by the Forms Management Center.

326"

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DRAFT

Boring Number: SB-10

Page 1 of 1

Site Name: NRG Joliet Station #29

Address: 1800 Channahon Road Joliet, IL 60436

Boring Location

Date: 11/11/2020 Start 14:15 PM

Finish 14:35 PM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		22"		1–5	Gray/Tan Silty Sand with Trace Clay, moist Brown Clay with Silty Sand and Gravel, Very Moist				
		12"		6–10					
		17"		11–15	---Increase Clay content				
		16"		16–18	Tan Silty Sand and Gravel, moist ` End of boring at 18 ft. bgs.				
				19					

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

IL 532-2275
LPC 501 Rev June 2004

The Agency is authorized to require this information under 415 ILCS 5/4 and 21. Disclosure of this information is required. Failure to do so may result in a civil penalty up to $25,000.00 for each day failure continues, a fine up to $50,000.00 and imprisonment up to five years. This form has been approved by the Forms Management Center.

326"

Electronic Filing: Received, Clerk's Office 2/04/2022

DRAFT

Boring Number: SB-11

Page 1 of 1

Site Name: NRG Joliet Station #29

Address: 1800 Channahon Road Joliet, IL 60436

Boring Location

Date: 11/12/2020 Start 08:20 AM

Finish 08:40 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		21"		1–5	Brown Clay with Tan Silty Sand and Gravel, slightly moist --Increase tan sand				
		21"		5–10	---coarse gravel				
		12"		10–13	---very moist ` End of boring at 13 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

IL 532-2275
LPC 501 Rev June 2004

The Agency is authorized to require this information under 415 ILCS 5/4 and 21. Disclosure of this information is required. Failure to do so may result in a civil penalty up to $25,000.00 for each day failure continues, a fine up to $50,000.00 and imprisonment up to five years. This form has been approved by the Forms Management Center.

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DRAFT

Boring Number: SB-12

Page 1 of 1

Site Name: NRG Joliet Station #29

Address: 1800 Channahon Road Joliet, IL 60436

Boring Location

Date: 11/12/2020 Start 09:40 AM

Finish 09:55 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		27"		1–5	Tan Silty Sand and Gravel, slightly moist --Increase clay content				
		28"		5–9	-Increase sand and gravel content End of boring at 9 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

IL 532-2275
LPC 501 Rev June 2004

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DRAFT	Boring Number: SB-13	Page 1 of 1
Site Name: NRG Joliet Station #29 Address: 1800 Channahon Road Joliet, IL 60436	Boring Location	Date: 11/12/2020 Start 10:15 AM Finish 10:40 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		7"		1–5	Brown Clay with Sand and Gravel, slightly moist				
		38"		6–9	Tan Silty Sand and Gravel, slightly moist				
		14"		10–13					
				13	End of boring at 13 ft. bgs.				
				14–19					

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

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DRAFT

Boring Number: SB-14

Page 1 of 1

Site Name: NRG Joliet Station #29

Address: 1800 Channahon Road Joliet, IL 60436

Boring Location

Date: 11/11/2020 Start 09:53 AM

Finish 10:00 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		37"		1–5	Light Gray/Tan Silty Sand and Gravel, slightly moist Brown Clay with Yellow Sand and Gravel, slightly moist ---some rust-colored mottling				
		12"		6	End of boring at 6 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

IL 532-2275
LPC 501 Rev June 2004

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DRAFT	Boring Number: SB-15	Page 1 of 1
Site Name: NRG Joliet Station #29 Address: 1800 Channahon Road Joliet, IL 60436	Boring Location	Date: 11/12/2020 Start 09:20 AM Finish 09:45 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		34"		1–5	Brown/Gray Silty Sand and Gravel with Clay, slightly moist. --6" tan fine sand layer				
		30"		5–10	---Increase clay content				
		15"		10–15	Tan Fine Sand and Gravel, moist				
		10"		15–16	End of boring at 16 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

IL 532-2275
LPC 501 Rev June 2004

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DRAFT	Boring Number: SB-16	Page 1 of 1
Site Name: NRG Joliet Station #29 Address: 1800 Channahon Road Joliet, IL 60436	Boring Location	Date: 11/12/2020 Start 10:50 AM Finish 11:05 AM

Sample Number	Sample Device	Sample Recovery	Lithology Symbol	Depth (feet)	Detailed Soil and Rock Description	Natural Moisture Content %	Hand Penetrometer	OVA/PID/FID/OVM	Remarks
		36"		1–5	Dark Brown Silty Sand and Gravel, slightly moist Brown Clay with Sand and Gravel, slightly moist Tan Silty Sand and Gravel, slightly moist				
		36"		6–10	Tan Fine Sand and Gravel, moist ---coarse gravel				
		30"		11–14					
				15	End of boring at 14.5 ft. bgs.				

Note: Stratification lines are approximate; in-situ transition between soil types may be gradual.

Groundwater Data

▼ Depth While Drilling N/A

▽ Depth After Drilling N/A

Auger Depth N/A Rig Geoprobe

Rotary Depth N/A Geologist Erin Bulson

Driller/Co Cabeno Environmental

Note: Boring backfilled unless otherwise noted

Illinois Environmental Protection Agency

The Agency is authorized to require this information under 415 ILCS 5/4 and 21. Disclosure of this information is required. Failure to do so may result in a civil penalty up to $25,000.00 for each day failure continues, a fine up to $50,000.00 and imprisonment up to five years. This form has been approved by the Forms Management Center.

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eurofins | Environment Testing TestAmerica



ANALYTICAL REPORT

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Tel: (708)534-5200

Laboratory Job ID: 500-180157-1
Client Project/Site: Joliet Station 29 - NPDES

For:
Midwest Generation EME LLC
1800 Channahon Road
Joliet, Illinois 60436

Attn: Harrison Estepp

Diana Mockler

Authorized for release by:
4/8/2020 11:33:41 AM

Diana Mockler, Project Manager I
(219)252-7570
diana.mockler@testamericainc.com

LINKS

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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.

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Case Narrative

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Job ID: 500-180157-1

Laboratory: Eurofins TestAmerica, Chicago

Narrative

Job Narrative
500-180157-1

Comments
No additional comments.

Receipt
The samples were received on 4/2/2020 12:55 PM; the samples arrived in good condition, properly preserved and, where required, on ice. The temperature of the cooler at receipt was 6.8º C.

Metals
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

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Method	Method Description	Protocol	Laboratory
200.7 Rev 4.4	Metals (ICP)	EPA	TAL CHI
300.0	Anions, Ion Chromatography	MCAWW	TAL CHI
9045C	pH	SW846	TAL CHI
Moisture	Percent Moisture	EPA	TAL CHI
SM 4500 H+ B	pH	SM	TAL CHI
200.7	Preparation, Total Metals	EPA	TAL CHI
300_Prep	Anions, Ion Chromatography, 10% Wt/Vol	MCAWW	TAL CHI

Protocol References:

EPA = US Environmental Protection Agency

MCAWW = "Methods For Chemical Analysis Of Water And Wastes", EPA-600/4-79-020, March 1983 And Subsequent Revisions.

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 = Eurofins TestAmerica, Chicago, 2417 Bond Street, University Park, IL 60484, TEL (708)534-5200

Sample Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received	Asset ID
500-180157-1	East Clarifier	Water	04/02/20 10:20	04/02/20 12:55	
500-180157-2	West Clarifier	Water	04/02/20 10:50	04/02/20 12:55	
500-180157-3	TW-1 3-4	Solid	04/02/20 08:40	04/02/20 12:55	
500-180157-4	TW-1 12-14	Solid	04/02/20 08:40	04/02/20 12:55	
500-180157-5	TW-2 3-4	Solid	04/02/20 09:30	04/02/20 12:55	
500-180157-6	TW-2 10-14	Solid	04/02/20 09:30	04/02/20 12:55	
500-180157-7	TW-3 3-4	Solid	04/02/20 09:05	04/02/20 12:55	
500-180157-8	TW-3 12-14	Solid	04/02/20 09:05	04/02/20 12:55	

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: East Clarifier

Date Collected: 04/02/20 10:20
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-1

Matrix: Water

Method: 200.7 Rev 4.4 - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	0.68		0.20		mg/L		04/02/20 17:40	04/03/20 08:49	1
Manganese	0.10		0.010		mg/L		04/02/20 17:40	04/03/20 08:49	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	87		5.0		mg/L			04/02/20 23:04	25
pH	7.6	HF	0.2		SU			04/03/20 13:17	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: West Clarifier

Date Collected: 04/02/20 10:50
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-2

Matrix: Water

Method: 200.7 Rev 4.4 - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	<0.20		0.20		mg/L		04/02/20 17:40	04/03/20 09:06	1
Manganese	<0.010		0.010		mg/L		04/02/20 17:40	04/03/20 09:06	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	**63**		2.0		mg/L			04/02/20 23:17	10
pH	**7.6**	**HF**	0.2		SU			04/03/20 13:21	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: TW-1 3-4
Date Collected: 04/02/20 08:40
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-3
Matrix: Solid

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	400		20		mg/Kg		04/03/20 23:49	04/05/20 01:21	10
pH	7.5		0.2		SU			04/03/20 16:01	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: TW-1 12-14
Date Collected: 04/02/20 08:40
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-4
Matrix: Solid

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	180		9.4		mg/Kg		04/03/20 23:49	04/05/20 01:58	5
pH	8.4		0.2		SU			04/03/20 16:03	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: TW-2 3-4
Date Collected: 04/02/20 09:30
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-5
Matrix: Solid

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	11000		390		mg/Kg		04/03/20 23:49	04/05/20 02:10	200
pH	7.1		0.2		SU			04/03/20 16:08	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: TW-2 10-14
Date Collected: 04/02/20 09:30
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-6
Matrix: Solid

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	620		19		mg/Kg		04/03/20 23:49	04/05/20 02:22	10
pH	8.0		0.2		SU			04/03/20 16:11	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: TW-3 3-4
Date Collected: 04/02/20 09:05
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-7
Matrix: Solid

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	37		1.8		mg/Kg		04/03/20 23:49	04/04/20 03:52	1
pH	9.3		0.2		SU			04/03/20 16:13	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: TW-3 12-14
Date Collected: 04/02/20 09:05
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-8
Matrix: Solid

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	89		2.0		mg/Kg		04/03/20 23:49	04/04/20 04:29	1
pH	9.1		0.2		SU			04/03/20 16:16	1

Definitions/Glossary

Client: Midwest Generation EME LLC
Job ID: 500-180157-1
Project/Site: Joliet Station 29 - NPDES

Qualifiers

General Chemistry

Qualifier	Qualifier Description
E	Result exceeded calibration range.
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

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Metals

Prep Batch: 536544

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-1	East Clarifier	Total/NA	Water	200.7	
500-180157-2	West Clarifier	Total/NA	Water	200.7	
MB 500-536544/1-A	Method Blank	Total/NA	Water	200.7	
LCS 500-536544/2-A	Lab Control Sample	Total/NA	Water	200.7	
500-180157-1 MS	East Clarifier	Total/NA	Water	200.7	
500-180157-1 DU	East Clarifier	Total/NA	Water	200.7	

Analysis Batch: 536716

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-1	East Clarifier	Total/NA	Water	200.7 Rev 4.4	536544
500-180157-2	West Clarifier	Total/NA	Water	200.7 Rev 4.4	536544
MB 500-536544/1-A	Method Blank	Total/NA	Water	200.7 Rev 4.4	536544
LCS 500-536544/2-A	Lab Control Sample	Total/NA	Water	200.7 Rev 4.4	536544
500-180157-1 MS	East Clarifier	Total/NA	Water	200.7 Rev 4.4	536544
500-180157-1 DU	East Clarifier	Total/NA	Water	200.7 Rev 4.4	536544

General Chemistry

Analysis Batch: 536567

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-1	East Clarifier	Total/NA	Water	300.0	
500-180157-2	West Clarifier	Total/NA	Water	300.0	
MB 500-536567/3	Method Blank	Total/NA	Water	300.0	
LCS 500-536567/4	Lab Control Sample	Total/NA	Water	300.0	
500-180157-2 MS	West Clarifier	Total/NA	Water	300.0	
500-180157-2 MSD	West Clarifier	Total/NA	Water	300.0	

Analysis Batch: 536665

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-3	TW-1 3-4	Total/NA	Solid	Moisture	
500-180157-4	TW-1 12-14	Total/NA	Solid	Moisture	
500-180157-5	TW-2 3-4	Total/NA	Solid	Moisture	
500-180157-6	TW-2 10-14	Total/NA	Solid	Moisture	
500-180157-7	TW-3 3-4	Total/NA	Solid	Moisture	
500-180157-8	TW-3 12-14	Total/NA	Solid	Moisture	

Analysis Batch: 536714

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-1	East Clarifier	Total/NA	Water	SM 4500 H+ B	
500-180157-2	West Clarifier	Total/NA	Water	SM 4500 H+ B	
LCS 500-536714/5	Lab Control Sample	Total/NA	Water	SM 4500 H+ B	
LCSD 500-536714/6	Lab Control Sample Dup	Total/NA	Water	SM 4500 H+ B	
500-180157-1 DU	East Clarifier	Total/NA	Water	SM 4500 H+ B	
500-180157-2 DU	West Clarifier	Total/NA	Water	SM 4500 H+ B	

Analysis Batch: 536761

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-7	TW-3 3-4	Total/NA	Solid	300.0	536765
500-180157-8	TW-3 12-14	Total/NA	Solid	300.0	536765
MB 500-536765/1-A	Method Blank	Total/NA	Solid	300.0	536765
LCS 500-536765/2-A	Lab Control Sample	Total/NA	Solid	300.0	536765

QC Association Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

General Chemistry (Continued)

Analysis Batch: 536761 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-8 MS	TW-3 12-14	Total/NA	Solid	300.0	536765
500-180157-8 MSD	TW-3 12-14	Total/NA	Solid	300.0	536765

Prep Batch: 536765

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-3	TW-1 3-4	Total/NA	Solid	300_Prep	
500-180157-4	TW-1 12-14	Total/NA	Solid	300_Prep	
500-180157-5	TW-2 3-4	Total/NA	Solid	300_Prep	
500-180157-6	TW-2 10-14	Total/NA	Solid	300_Prep	
500-180157-7	TW-3 3-4	Total/NA	Solid	300_Prep	
500-180157-8	TW-3 12-14	Total/NA	Solid	300_Prep	
MB 500-536765/1-A	Method Blank	Total/NA	Solid	300_Prep	
LCS 500-536765/2-A	Lab Control Sample	Total/NA	Solid	300_Prep	
500-180157-8 MS	TW-3 12-14	Total/NA	Solid	300_Prep	
500-180157-8 MSD	TW-3 12-14	Total/NA	Solid	300_Prep	

Analysis Batch: 536782

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-3	TW-1 3-4	Total/NA	Solid	300.0	536765
500-180157-4	TW-1 12-14	Total/NA	Solid	300.0	536765
500-180157-5	TW-2 3-4	Total/NA	Solid	300.0	536765
500-180157-6	TW-2 10-14	Total/NA	Solid	300.0	536765
MB 500-536765/1-A	Method Blank	Total/NA	Solid	300.0	536765
LCS 500-536765/2-A	Lab Control Sample	Total/NA	Solid	300.0	536765

Analysis Batch: 536857

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-180157-3	TW-1 3-4	Total/NA	Solid	9045C	
500-180157-4	TW-1 12-14	Total/NA	Solid	9045C	
500-180157-5	TW-2 3-4	Total/NA	Solid	9045C	
500-180157-6	TW-2 10-14	Total/NA	Solid	9045C	
500-180157-7	TW-3 3-4	Total/NA	Solid	9045C	
500-180157-8	TW-3 12-14	Total/NA	Solid	9045C	
LCS 500-536857/2	Lab Control Sample	Total/NA	Solid	9045C	
LCSD 500-536857/3	Lab Control Sample Dup	Total/NA	Solid	9045C	
500-180157-4 DU	TW-1 12-14	Total/NA	Solid	9045C	

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Method: 200.7 Rev 4.4 - Metals (ICP)

Lab Sample ID: MB 500-536544/1-A
Matrix: Water
Analysis Batch: 536716

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 536544

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	<0.20		0.20		mg/L		04/02/20 17:40	04/03/20 08:41	1
Manganese	<0.010		0.010		mg/L		04/02/20 17:40	04/03/20 08:41	1

Lab Sample ID: LCS 500-536544/2-A
Matrix: Water
Analysis Batch: 536716

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 536544

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Iron	1.00	0.971		mg/L		97	85 - 115
Manganese	0.500	0.447		mg/L		89	85 - 115

Lab Sample ID: 500-180157-1 MS
Matrix: Water
Analysis Batch: 536716

Client Sample ID: East Clarifier
Prep Type: Total/NA
Prep Batch: 536544

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Iron	0.68		1.00	1.79		mg/L		111	70 - 130
Manganese	0.10		0.500	0.555		mg/L		90	70 - 130

Lab Sample ID: 500-180157-1 DU
Matrix: Water
Analysis Batch: 536716

Client Sample ID: East Clarifier
Prep Type: Total/NA
Prep Batch: 536544

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Iron	0.68		0.768		mg/L		12	20
Manganese	0.10		0.106		mg/L		3	20

Method: 300.0 - Anions, Ion Chromatography

Lab Sample ID: MB 500-536567/3
Matrix: Water
Analysis Batch: 536567

Client Sample ID: Method Blank
Prep Type: Total/NA

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<0.20		0.20		mg/L			04/02/20 20:00	1

Lab Sample ID: LCS 500-536567/4
Matrix: Water
Analysis Batch: 536567

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	5.00	5.26		mg/L		105	90 - 110

Lab Sample ID: 500-180157-2 MS
Matrix: Water
Analysis Batch: 536567

Client Sample ID: West Clarifier
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	63		25.0	89.7		mg/L		108	80 - 120

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Method: 300.0 - Anions, Ion Chromatography (Continued)

Lab Sample ID: 500-180157-2 MSD — **Client Sample ID: West Clarifier**
Matrix: Water — **Prep Type: Total/NA**
Analysis Batch: 536567

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Sulfate	63		25.0	89.5		mg/L		107	80 - 120	0	20

Lab Sample ID: MB 500-536765/1-A — **Client Sample ID: Method Blank**
Matrix: Solid — **Prep Type: Total/NA**
Analysis Batch: 536761 — **Prep Batch: 536765**

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<2.0		2.0		mg/Kg		04/03/20 23:49	04/04/20 02:38	1

Lab Sample ID: MB 500-536765/1-A — **Client Sample ID: Method Blank**
Matrix: Solid — **Prep Type: Total/NA**
Analysis Batch: 536782 — **Prep Batch: 536765**

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<2.0		2.0		mg/Kg		04/03/20 23:49	04/05/20 00:56	1

Lab Sample ID: LCS 500-536765/2-A — **Client Sample ID: Lab Control Sample**
Matrix: Solid — **Prep Type: Total/NA**
Analysis Batch: 536761 — **Prep Batch: 536765**

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	50.0	52.6		mg/Kg		105	90 - 110

Lab Sample ID: LCS 500-536765/2-A — **Client Sample ID: Lab Control Sample**
Matrix: Solid — **Prep Type: Total/NA**
Analysis Batch: 536782 — **Prep Batch: 536765**

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	50.0	52.7		mg/Kg		105	90 - 110

Lab Sample ID: 500-180157-8 MS — **Client Sample ID: TW-3 12-14**
Matrix: Solid — **Prep Type: Total/NA**
Analysis Batch: 536761 — **Prep Batch: 536765**

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	89		24.8	113	E	mg/Kg		96	80 - 120

Lab Sample ID: 500-180157-8 MSD — **Client Sample ID: TW-3 12-14**
Matrix: Solid — **Prep Type: Total/NA**
Analysis Batch: 536761 — **Prep Batch: 536765**

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Sulfate	89		24.8	114	E	mg/Kg		101	80 - 120	1	20

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Method: 9045C - pH

Lab Sample ID: 500-180157-4 DU
Matrix: Solid
Analysis Batch: 536857

Client Sample ID: TW-1 12-14
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier		DU Result	DU Qualifier	Unit	D			RPD	RPD Limit
pH	8.4			8.5		SU				1	

Method: SM 4500 H+ B - pH

Lab Sample ID: 500-180157-1 DU
Matrix: Water
Analysis Batch: 536714

Client Sample ID: East Clarifier
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier		DU Result	DU Qualifier	Unit	D			RPD	RPD Limit
pH	7.6	HF		7.6		SU				0.1	

Lab Sample ID: 500-180157-2 DU
Matrix: Water
Analysis Batch: 536714

Client Sample ID: West Clarifier
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier		DU Result	DU Qualifier	Unit	D			RPD	RPD Limit
pH	7.6	HF		7.6		SU				0.1	

Chain of Custody Record

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Phone: 708-534-5200 Fax: 708-534-5211

eurofins | Environment Testing TestAmerica

Client Information
Client Contact: Peter O'Day
Company: Midwest Generation EME LLC
Address: 1800 Channahon Road
City: Joliet
State, Zip: IL, 60436
Phone: 773-617-7515(Tel)
Email: peter.o'day@nrgenergy.com
Project Name: Joliet Station 29 -
Site:

500-180157 COC

Sampler: Mitchel Dolan
Phone: 262-781-0475
Lab PM: Mockler, Diana J
E-Mail: diana.mockler@testamericainc.com
Carrier Tracking No(s):
COC No: 500-80622-36959.1
Page: Page 1 of 1
Job #: 500-180157

Due Date Requested:
TAT Requested (days):
PO #: 4502012471
WO #:
Project #: 50000292
SSOW#:

Analysis Requested

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)
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)	300 - pH, Sulfate	200.7 - (MOD) Fe, Mn	300, 9045C	300, 6010B, 9045C	Total Number of containers	Special Instructions/Note:
				Preservation Code:				N	D	N	N		
1	East Clarifier	4/2/20	1020	G	Water	N	N	X	X				
2	West Clarifier	4/2/20	1050	G	Water	N	N	X	X				
					Water								
					Water								
					Water								
3	TW-1 3-4	4/2/20	0840	G	Solid					X	Z		
4	TW-1 12-14	4/2/20	0840	G	Solid					X	Z		
5	TW-2 3-4	4/2/20	0930	G	Solid					X			
6	TW-2 10-14	4/2/20	0930	G	Solid					X			
7	TW-3 3-4	4/2/20	0905	G	Solid					X			
8	TW-3 12-14	4/2/20	0905	G	Solid					X			

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: Mo 02	Date/Time: 4/2/20 1	Company: KPRG	Received by:	Date/Time: 4/2/20 1255	Company: TAEKI
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: 6.8

Login Sample Receipt Checklist

Client: Midwest Generation EME LLC

Job Number: 500-180157-1

Login Number: 180157
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	6.8
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	

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: East Clarifier
Date Collected: 04/02/20 10:20
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-1
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	200.7			536544	04/02/20 17:40	BDE	TAL CHI
Total/NA	Analysis	200.7 Rev 4.4		1	536716	04/03/20 08:49	JEF	TAL CHI
Total/NA	Analysis	300.0		25	536567	04/02/20 23:04	EAT	TAL CHI
Total/NA	Analysis	SM 4500 H+ B		1	536714		SMO	TAL CHI
					(Start)	04/03/20 13:17		
					(End)	04/03/20 13:19		

Client Sample ID: West Clarifier
Date Collected: 04/02/20 10:50
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-2
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	200.7			536544	04/02/20 17:40	BDE	TAL CHI
Total/NA	Analysis	200.7 Rev 4.4		1	536716	04/03/20 09:06	JEF	TAL CHI
Total/NA	Analysis	300.0		10	536567	04/02/20 23:17	EAT	TAL CHI
Total/NA	Analysis	SM 4500 H+ B		1	536714		SMO	TAL CHI
					(Start)	04/03/20 13:21		
					(End)	04/03/20 13:23		

Client Sample ID: TW-1 3-4
Date Collected: 04/02/20 08:40
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-3
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	300_Prep			536765	04/03/20 23:49	EAT	TAL CHI
Total/NA	Analysis	300.0		10	536782	04/05/20 01:21	EAT	TAL CHI
Total/NA	Analysis	9045C		1	536857	04/03/20 16:01	SMO	TAL CHI
Total/NA	Analysis	Moisture		1	536665	04/03/20 09:12	LWN	TAL CHI

Client Sample ID: TW-1 12-14
Date Collected: 04/02/20 08:40
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-4
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	300_Prep			536765	04/03/20 23:49	EAT	TAL CHI
Total/NA	Analysis	300.0		5	536782	04/05/20 01:58	EAT	TAL CHI
Total/NA	Analysis	9045C		1	536857	04/03/20 16:03	SMO	TAL CHI
Total/NA	Analysis	Moisture		1	536665	04/03/20 09:12	LWN	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Client Sample ID: TW-2 3-4
Date Collected: 04/02/20 09:30
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-5
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	300_Prep			536765	04/03/20 23:49	EAT	TAL CHI
Total/NA	Analysis	300.0		200	536782	04/05/20 02:10	EAT	TAL CHI
Total/NA	Analysis	9045C		1	536857	04/03/20 16:08	SMO	TAL CHI
Total/NA	Analysis	Moisture		1	536665	04/03/20 09:12	LWN	TAL CHI

Client Sample ID: TW-2 10-14
Date Collected: 04/02/20 09:30
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-6
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	300_Prep			536765	04/03/20 23:49	EAT	TAL CHI
Total/NA	Analysis	300.0		10	536782	04/05/20 02:22	EAT	TAL CHI
Total/NA	Analysis	9045C		1	536857	04/03/20 16:11	SMO	TAL CHI
Total/NA	Analysis	Moisture		1	536665	04/03/20 09:12	LWN	TAL CHI

Client Sample ID: TW-3 3-4
Date Collected: 04/02/20 09:05
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-7
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	300_Prep			536765	04/03/20 23:49	EAT	TAL CHI
Total/NA	Analysis	300.0		1	536761	04/04/20 03:52	EAT	TAL CHI
Total/NA	Analysis	9045C		1	536857	04/03/20 16:13	SMO	TAL CHI
Total/NA	Analysis	Moisture		1	536665	04/03/20 09:12	LWN	TAL CHI

Client Sample ID: TW-3 12-14
Date Collected: 04/02/20 09:05
Date Received: 04/02/20 12:55

Lab Sample ID: 500-180157-8
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	300_Prep			536765	04/03/20 23:49	EAT	TAL CHI
Total/NA	Analysis	300.0		1	536761	04/04/20 04:29	EAT	TAL CHI
Total/NA	Analysis	9045C		1	536857	04/03/20 16:16	SMO	TAL CHI
Total/NA	Analysis	Moisture		1	536665	04/03/20 09:12	LWN	TAL CHI

Laboratory References:
TAL CHI = Eurofins TestAmerica, Chicago, 2417 Bond Street, University Park, IL 60484, TEL (708)534-5200

Electronic Filing: Received, Clerk's Office 2/04/2022

Accreditation/Certification Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - NPDES

Job ID: 500-180157-1

Laboratory: Eurofins TestAmerica, Chicago

The accreditations/certifications listed below are applicable to this report.

Authority	Program	Identification Number	Expiration Date
Illinois	NELAP	IL00035	04-30-20

eurofins | Environment Testing America



ANALYTICAL REPORT

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Tel: (708)534-5200

Laboratory Job ID: 500-190983-1
Client Project/Site: Joliet Station 29 - Soils

For:
Midwest Generation EME LLC
1800 Channahon Road
Joliet, Illinois 60436

Attn: Harrison Estepp

Diana Mockler

Authorized for release by:
11/27/2020 10:49:26 AM

Diana Mockler, Project Manager I
(219)252-7570
Diana.Mockler@Eurofinset.com

LINKS

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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.

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Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Job ID: 500-190983-1

Laboratory: Eurofins TestAmerica, Chicago

Narrative

Job Narrative
500-190983-1

Comments
No additional comments.

Receipt
The samples were received on 11/12/2020 11:50 AM; the samples arrived in good condition, and where required, properly preserved and on ice. The temperatures of the 2 coolers at receipt time were 6.1º C and 7.6º C.

Receipt Exceptions

The following sample was received at the laboratory outside the required temperature criteria: SB-14 3-4" (500-190983-1). The samples were covered with small bag of ice, the temp was 7.6. Samples that were collected on 11/12 are fine, the cooling process has begun.

Metals
Method 6010B: The following samples were diluted due to the abundance of non-target analytes: SB-9 7-9' (500-190983-23), SB-12 3-4' (500-190983-26), SB-12 7-9' (500-190983-27), SB-13 1-3' (500-190983-28), SB-13 11-13' (500-190983-29), SB-16 3-4' (500-190983-30) and SB-16 12-14' (500-190983-31). Elevated reporting limits (RLs) are provided.

Method 6010B: The following samples were diluted due to the abundance of non-target analytes: SB-5 12-14' (500-190983-2), SB-3 12-14' (500-190983-7), SB-2 11-13' (500-190983-9), SB-1 3-4' (500-190983-10), SB-1 12-14' (500-190983-11), SB-6 7-9' (500-190983-13) and SB-7 12-14' (500-190983-15). Elevated reporting limits (RLs) are provided.

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: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Method	Method Description	Protocol	Laboratory
6010B	Metals (ICP)	SW846	TAL CHI
300.0	Anions, Ion Chromatography	MCAWW	TAL CHI
9045C	pH	SW846	TAL CHI
Moisture	Percent Moisture	EPA	TAL CHI
300_Prep	Anions, Ion Chromatography, 10% Wt/Vol	MCAWW	TAL CHI
3050B	Preparation, Metals	SW846	TAL CHI

Protocol References:

EPA = US Environmental Protection Agency

MCAWW = "Methods For Chemical Analysis Of Water And Wastes", EPA-600/4-79-020, March 1983 And Subsequent Revisions.

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

TAL CHI = Eurofins TestAmerica, Chicago, 2417 Bond Street, University Park, IL 60484, TEL (708)534-5200

Electronic Filing: Received, Clerk's Office 2/04/2022

Sample Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received	Asset ID
500-190983-1	SB-14 3-4"	Solid	11/11/20 10:00	11/12/20 11:50	
500-190983-2	SB-5 12-14'	Solid	11/11/20 10:25	11/12/20 11:50	
500-190983-3	SB-5 3-4'	Solid	11/11/20 10:15	11/12/20 11:50	
500-190983-4	SB-4 3-4'	Solid	11/11/20 10:40	11/12/20 11:50	
500-190983-5	SB-4 12-14'	Solid	11/11/20 10:50	11/12/20 11:50	
500-190983-6	SB-3 3-4'	Solid	11/11/20 11:05	11/12/20 11:50	
500-190983-7	SB-3 12-14'	Solid	11/11/20 11:20	11/12/20 11:50	
500-190983-8	SB-2 3-4'	Solid	11/11/20 11:30	11/12/20 11:50	
500-190983-9	SB-2 11-13'	Solid	11/11/20 11:45	11/12/20 11:50	
500-190983-10	SB-1 3-4'	Solid	11/11/20 12:40	11/12/20 11:50	
500-190983-11	SB-1 12-14'	Solid	11/11/20 12:45	11/12/20 11:50	
500-190983-12	SB-6 3-4'	Solid	11/11/20 13:00	11/12/20 11:50	
500-190983-13	SB-6 7-9'	Solid	11/11/20 13:10	11/12/20 11:50	
500-190983-14	SB-7 3-4'	Solid	11/11/20 13:30	11/12/20 11:50	
500-190983-15	SB-7 12-14'	Solid	11/11/20 13:35	11/12/20 11:50	
500-190983-16	SB-8 3-4'	Solid	11/11/20 13:50	11/12/20 11:50	
500-190983-17	SB-8 10-12'	Solid	11/11/20 14:10	11/12/20 11:50	
500-190983-18	SB-10 3-4'	Solid	11/11/20 14:20	11/12/20 11:50	
500-190983-19	SB-10 12-14'	Solid	11/11/20 14:35	11/12/20 11:50	
500-190983-20	SB-11 3-4'	Solid	11/12/20 08:30	11/12/20 11:50	
500-190983-21	SB-11 11-13'	Solid	11/12/20 08:35	11/12/20 11:50	
500-190983-22	SB-9 2-4	Solid	11/12/20 08:55	11/12/20 11:50	
500-190983-23	SB-9 7-9'	Solid	11/12/20 09:00	11/12/20 11:50	
500-190983-24	SB-15 3-4'	Solid	11/12/20 09:30	11/12/20 11:50	
500-190983-25	SB-15 6-8'	Solid	11/12/20 09:35	11/12/20 11:50	
500-190983-26	SB-12 3-4'	Solid	11/12/20 09:50	11/12/20 11:50	
500-190983-27	SB-12 7-9'	Solid	11/12/20 10:00	11/12/20 11:50	
500-190983-28	SB-13 1-3'	Solid	11/12/20 10:30	11/12/20 11:50	
500-190983-29	SB-13 11-13'	Solid	11/12/20 10:40	11/12/20 11:50	
500-190983-30	SB-16 3-4'	Solid	11/12/20 10:55	11/12/20 11:50	
500-190983-31	SB-16 12-14'	Solid	11/12/20 11:00	11/12/20 11:50	

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-14 3-4"

Date Collected: 11/11/20 10:00
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-1

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	19000		18		mg/Kg		11/20/20 07:32	11/20/20 18:32	1
Manganese	250		0.89		mg/Kg		11/20/20 07:32	11/20/20 18:32	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	4000		200		mg/Kg		11/20/20 10:10	11/21/20 13:31	100
pH	7.4		0.2		SU			11/19/20 11:41	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-5 12-14'
Date Collected: 11/11/20 10:25
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-2
Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	7500		90		mg/Kg		11/20/20 07:32	11/24/20 10:48	5
Manganese	270		0.90		mg/Kg		11/20/20 07:32	11/20/20 18:58	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	140		9.5		mg/Kg		11/20/20 10:10	11/21/20 13:44	5
pH	8.2		0.2		SU			11/19/20 11:43	1

Electronic Filing: Received, Clerk's Office 2/04/2022

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-5 3-4'

Date Collected: 11/11/20 10:15
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-3

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	14000		17		mg/Kg		11/20/20 07:32	11/20/20 19:01	1
Manganese	530		0.86		mg/Kg		11/20/20 07:32	11/20/20 19:01	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	67		1.9		mg/Kg		11/20/20 10:10	11/20/20 16:04	1
pH	7.9		0.2		SU			11/19/20 11:46	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-4 3-4'

Date Collected: 11/11/20 10:40
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-4

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	11000		20		mg/Kg		11/20/20 07:32	11/20/20 19:04	1
Manganese	530		0.99		mg/Kg		11/20/20 07:32	11/20/20 19:04	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	94		2.0		mg/Kg		11/20/20 10:10	11/20/20 16:18	1
pH	8.0		0.2		SU			11/19/20 11:53	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-4 12-14'
Date Collected: 11/11/20 10:50
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-5
Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	10000		19		mg/Kg		11/20/20 07:32	11/20/20 19:07	1
Manganese	270		0.94		mg/Kg		11/20/20 07:32	11/20/20 19:07	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	14		1.9		mg/Kg		11/20/20 10:10	11/20/20 16:32	1
pH	8.5		0.2		SU			11/19/20 11:48	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-3 3-4'

Date Collected: 11/11/20 11:05
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-6

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	14000		18		mg/Kg		11/20/20 07:32	11/20/20 19:10	1
Manganese	450		0.91		mg/Kg		11/20/20 07:32	11/20/20 19:10	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	32		1.9		mg/Kg		11/20/20 10:10	11/20/20 16:45	1
pH	8.3		0.2		SU			11/19/20 11:58	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-3 12-14'

Date Collected: 11/11/20 11:20
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-7

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	6800		94		mg/Kg		11/20/20 07:32	11/24/20 11:01	5
Manganese	300		0.94		mg/Kg		11/20/20 07:32	11/20/20 19:14	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	7.4		1.9		mg/Kg		11/20/20 10:10	11/20/20 16:59	1
pH	8.4		0.2		SU			11/19/20 12:03	1

Electronic Filing: Received, Clerk's Office 2/04/2022

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-2 3-4'

Date Collected: 11/11/20 11:30
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-8

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	14000		18		mg/Kg		11/20/20 07:32	11/20/20 19:17	1
Manganese	480		0.90		mg/Kg		11/20/20 07:32	11/20/20 19:17	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	26		2.0		mg/Kg		11/20/20 10:10	11/20/20 17:12	1
pH	8.0		0.2		SU			11/19/20 12:06	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-2 11-13'
Date Collected: 11/11/20 11:45
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-9
Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	7300		89		mg/Kg		11/20/20 07:32	11/24/20 11:05	5
Manganese	450		0.89		mg/Kg		11/20/20 07:32	11/20/20 19:20	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	6.5		1.9		mg/Kg		11/20/20 10:10	11/20/20 17:26	1
pH	8.4		0.2		SU			11/19/20 12:01	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-1 3-4'

Date Collected: 11/11/20 12:40
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-10

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	8600		86		mg/Kg		11/20/20 07:32	11/24/20 11:08	5
Manganese	260		0.86		mg/Kg		11/20/20 07:32	11/20/20 19:24	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	15		2.0		mg/Kg		11/20/20 10:10	11/20/20 17:40	1
pH	8.4		0.2		SU			11/19/20 12:08	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-1 12-14'

Date Collected: 11/11/20 12:45
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-11

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	8500		84		mg/Kg		11/20/20 07:32	11/24/20 11:11	5
Manganese	180		0.84		mg/Kg		11/20/20 07:32	11/20/20 19:38	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	30		1.9		mg/Kg		11/20/20 10:10	11/20/20 18:20	1
pH	8.2		0.2		SU			11/19/20 12:11	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-6 3-4'

Lab Sample ID: 500-190983-12

Date Collected: 11/11/20 13:00

Matrix: Solid

Date Received: 11/12/20 11:50

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	10000		20		mg/Kg		11/20/20 07:32	11/20/20 19:41	1
Manganese	300		0.98		mg/Kg		11/20/20 07:32	11/20/20 19:41	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	150		9.4		mg/Kg		11/20/20 10:10	11/21/20 13:56	5
pH	7.6		0.2		SU			11/19/20 12:13	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-6 7-9'

Date Collected: 11/11/20 13:10
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-13

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	14000		93		mg/Kg		11/20/20 07:32	11/24/20 11:14	5
Manganese	300		0.93		mg/Kg		11/20/20 07:32	11/20/20 19:44	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	97		1.9		mg/Kg		11/20/20 10:10	11/20/20 18:48	1
pH	8.1		0.2		SU			11/19/20 12:16	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-7 3-4'

Lab Sample ID: 500-190983-14

Date Collected: 11/11/20 13:30

Matrix: Solid

Date Received: 11/12/20 11:50

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	12000		19		mg/Kg		11/20/20 07:32	11/20/20 19:48	1
Manganese	270		0.97		mg/Kg		11/20/20 07:32	11/20/20 19:48	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	48		2.0		mg/Kg		11/20/20 10:10	11/20/20 19:01	1
pH	8.7		0.2		SU			11/19/20 12:21	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-7 12-14'

Date Collected: 11/11/20 13:35
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-15

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	7500		94		mg/Kg		11/20/20 07:32	11/24/20 11:18	5
Manganese	210		0.94		mg/Kg		11/20/20 07:32	11/20/20 19:51	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	57		1.9		mg/Kg		11/20/20 10:10	11/20/20 19:15	1
pH	8.2		0.2		SU			11/19/20 12:23	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-8 3-4'

Lab Sample ID: 500-190983-16

Date Collected: 11/11/20 13:50

Matrix: Solid

Date Received: 11/12/20 11:50

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	14000		20		mg/Kg		11/20/20 07:32	11/20/20 19:54	1
Manganese	270		0.99		mg/Kg		11/20/20 07:32	11/20/20 19:54	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	59		1.8		mg/Kg		11/20/20 10:10	11/20/20 19:28	1
pH	8.4		0.2		SU			11/19/20 12:26	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-8 10-12'

Lab Sample ID: 500-190983-17

Date Collected: 11/11/20 14:10

Matrix: Solid

Date Received: 11/12/20 11:50

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	11000		17		mg/Kg		11/20/20 07:32	11/20/20 19:58	1
Manganese	350		0.85		mg/Kg		11/20/20 07:32	11/20/20 19:58	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	100		3.7		mg/Kg		11/20/20 10:10	11/21/20 14:09	2
pH	8.0		0.2		SU			11/19/20 12:28	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-10 3-4'

Date Collected: 11/11/20 14:20
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-18

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	19000		17		mg/Kg		11/20/20 07:32	11/20/20 20:01	1
Manganese	240		0.85		mg/Kg		11/20/20 07:32	11/20/20 20:01	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	30		2.0		mg/Kg		11/20/20 10:10	11/20/20 19:56	1
pH	8.5		0.2		SU			11/19/20 12:31	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-10 12-14'
Date Collected: 11/11/20 14:35
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-19
Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	12000		18		mg/Kg		11/20/20 07:32	11/20/20 20:04	1
Manganese	180		0.92		mg/Kg		11/20/20 07:32	11/20/20 20:04	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	230		9.9		mg/Kg		11/20/20 10:10	11/21/20 14:22	5
pH	8.6		0.2		SU			11/19/20 12:33	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-11 3-4'
Date Collected: 11/12/20 08:30
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-20
Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	10000		19		mg/Kg		11/20/20 07:32	11/20/20 20:07	1
Manganese	270		0.94		mg/Kg		11/20/20 07:32	11/20/20 20:07	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	14		1.8		mg/Kg		11/20/20 11:35	11/20/20 15:46	1
pH	8.5		0.2		SU			11/19/20 12:36	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-11 11-13'

Lab Sample ID: 500-190983-21

Date Collected: 11/12/20 08:35
Matrix: Solid
Date Received: 11/12/20 11:50

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	17000	V	19		mg/Kg		11/20/20 07:52	11/20/20 15:05	1
Manganese	290	V	0.94		mg/Kg		11/20/20 07:52	11/20/20 15:05	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	2000		96		mg/Kg		11/20/20 11:35	11/21/20 15:25	50
pH	7.7		0.2		SU			11/19/20 12:38	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-9 2-4

Date Collected: 11/12/20 08:55
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-22

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	17000		20		mg/Kg		11/20/20 07:52	11/20/20 15:28	1
Manganese	280		0.98		mg/Kg		11/20/20 07:52	11/20/20 15:28	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	45		1.9		mg/Kg		11/20/20 11:35	11/20/20 16:12	1
pH	8.9		0.2		SU			11/19/20 12:41	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-9 7-9'

Date Collected: 11/12/20 09:00
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-23

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	16000		93		mg/Kg		11/20/20 07:52	11/23/20 12:27	5
Manganese	330		0.93		mg/Kg		11/20/20 07:52	11/20/20 15:32	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	40		1.9		mg/Kg		11/20/20 11:35	11/20/20 16:24	1
pH	8.2		0.2		SU			11/19/20 12:44	1

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Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-15 3-4'

Date Collected: 11/12/20 09:30
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-24

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	15000		18		mg/Kg		11/20/20 07:52	11/20/20 15:35	1
Manganese	320		0.90		mg/Kg		11/20/20 07:52	11/20/20 15:35	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	64		1.9		mg/Kg		11/20/20 11:35	11/20/20 16:37	1
pH	9.1		0.2		SU			11/19/20 12:49	1

Electronic Filing: Received, Clerk's Office 2/04/2022

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-15 6-8'

Lab Sample ID: 500-190983-25

Date Collected: 11/12/20 09:35
Matrix: Solid
Date Received: 11/12/20 11:50

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	34000		20		mg/Kg		11/20/20 07:52	11/20/20 15:38	1
Manganese	220		0.99		mg/Kg		11/20/20 07:52	11/20/20 15:38	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	16000		500		mg/Kg		11/20/20 11:35	11/21/20 15:38	250
pH	7.4		0.2		SU			11/19/20 12:54	1

Electronic Filing: Received, Clerk's Office 2/04/2022

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-12 3-4'

Lab Sample ID: 500-190983-26

Date Collected: 11/12/20 09:50
Matrix: Solid
Date Received: 11/12/20 11:50

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	14000		89		mg/Kg		11/20/20 07:52	11/23/20 12:30	5
Manganese	300		0.89		mg/Kg		11/20/20 07:52	11/20/20 15:41	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	26		1.9		mg/Kg		11/20/20 11:35	11/20/20 17:03	1
pH	8.9		0.2		SU			11/19/20 12:56	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-12 7-9'

Date Collected: 11/12/20 10:00
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-27

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	9100		98		mg/Kg		11/20/20 07:52	11/23/20 12:34	5
Manganese	310		0.98		mg/Kg		11/20/20 07:52	11/20/20 15:45	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	19		1.9		mg/Kg		11/20/20 11:35	11/20/20 17:15	1
pH	9.0		0.2		SU			11/19/20 12:58	1

Electronic Filing: Received, Clerk's Office 2/04/2022

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-13 1-3'

Lab Sample ID: 500-190983-28

Date Collected: 11/12/20 10:30
Matrix: Solid
Date Received: 11/12/20 11:50

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	12000		86		mg/Kg		11/20/20 07:52	11/23/20 12:47	5
Manganese	280		0.86		mg/Kg		11/20/20 07:52	11/20/20 15:48	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	7.7		1.9		mg/Kg		11/20/20 11:35	11/20/20 17:53	1
pH	8.1		0.2		SU			11/19/20 13:01	1

Electronic Filing: Received, Clerk's Office 2/04/2022

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-13 11-13'

Lab Sample ID: 500-190983-29

Date Collected: 11/12/20 10:40
Matrix: Solid
Date Received: 11/12/20 11:50

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	7900		86		mg/Kg		11/20/20 07:52	11/23/20 12:51	5
Manganese	300		0.86		mg/Kg		11/20/20 07:52	11/20/20 15:51	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	6.1		2.0		mg/Kg		11/20/20 11:35	11/20/20 18:06	1
pH	8.3		0.2		SU			11/19/20 13:03	1

Electronic Filing: Received, Clerk's Office 2/04/2022

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-16 3-4'

Date Collected: 11/12/20 10:55
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-30

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	16000		87		mg/Kg		11/20/20 07:52	11/23/20 12:54	5
Manganese	310		0.87		mg/Kg		11/20/20 07:52	11/20/20 16:01	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	62		1.9		mg/Kg		11/20/20 11:35	11/20/20 18:44	1
pH	8.7		0.2		SU			11/19/20 13:06	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-16 12-14'

Date Collected: 11/12/20 11:00
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-31

Matrix: Solid

Method: 6010B - Metals (ICP)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	10000		92		mg/Kg		11/20/20 07:52	11/23/20 12:58	5
Manganese	340		0.92		mg/Kg		11/20/20 07:52	11/20/20 16:04	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	9.8		1.9		mg/Kg		11/20/20 11:35	11/20/20 18:57	1
pH	8.5		0.2		SU			11/19/20 13:09	1

Definitions/Glossary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Qualifiers

Metals

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.
F3	Duplicate RPD exceeds the control limit
V	Serial Dilution exceeds the control 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: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Metals

Prep Batch: 573218

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-1	SB-14 3-4"	Total/NA	Solid	3050B	
500-190983-2	SB-5 12-14'	Total/NA	Solid	3050B	
500-190983-3	SB-5 3-4'	Total/NA	Solid	3050B	
500-190983-4	SB-4 3-4'	Total/NA	Solid	3050B	
500-190983-5	SB-4 12-14'	Total/NA	Solid	3050B	
500-190983-6	SB-3 3-4'	Total/NA	Solid	3050B	
500-190983-7	SB-3 12-14'	Total/NA	Solid	3050B	
500-190983-8	SB-2 3-4'	Total/NA	Solid	3050B	
500-190983-9	SB-2 11-13'	Total/NA	Solid	3050B	
500-190983-10	SB-1 3-4'	Total/NA	Solid	3050B	
500-190983-11	SB-1 12-14'	Total/NA	Solid	3050B	
500-190983-12	SB-6 3-4'	Total/NA	Solid	3050B	
500-190983-13	SB-6 7-9'	Total/NA	Solid	3050B	
500-190983-14	SB-7 3-4'	Total/NA	Solid	3050B	
500-190983-15	SB-7 12-14'	Total/NA	Solid	3050B	
500-190983-16	SB-8 3-4'	Total/NA	Solid	3050B	
500-190983-17	SB-8 10-12'	Total/NA	Solid	3050B	
500-190983-18	SB-10 3-4'	Total/NA	Solid	3050B	
500-190983-19	SB-10 12-14'	Total/NA	Solid	3050B	
500-190983-20	SB-11 3-4'	Total/NA	Solid	3050B	
MB 500-573218/1-A	Method Blank	Total/NA	Solid	3050B	
LCS 500-573218/2-A	Lab Control Sample	Total/NA	Solid	3050B	
500-190983-1 MS	SB-14 3-4"	Total/NA	Solid	3050B	
500-190983-1 MSD	SB-14 3-4"	Total/NA	Solid	3050B	
500-190983-1 DU	SB-14 3-4"	Total/NA	Solid	3050B	

Prep Batch: 573236

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-21	SB-11 11-13'	Total/NA	Solid	3050B	
500-190983-22	SB-9 2-4	Total/NA	Solid	3050B	
500-190983-23	SB-9 7-9'	Total/NA	Solid	3050B	
500-190983-24	SB-15 3-4'	Total/NA	Solid	3050B	
500-190983-25	SB-15 6-8'	Total/NA	Solid	3050B	
500-190983-26	SB-12 3-4'	Total/NA	Solid	3050B	
500-190983-27	SB-12 7-9'	Total/NA	Solid	3050B	
500-190983-28	SB-13 1-3'	Total/NA	Solid	3050B	
500-190983-29	SB-13 11-13'	Total/NA	Solid	3050B	
500-190983-30	SB-16 3-4'	Total/NA	Solid	3050B	
500-190983-31	SB-16 12-14'	Total/NA	Solid	3050B	
MB 500-573236/1-A	Method Blank	Total/NA	Solid	3050B	
LCS 500-573236/2-A	Lab Control Sample	Total/NA	Solid	3050B	
500-190983-21 MS	SB-11 11-13'	Total/NA	Solid	3050B	
500-190983-21 MSD	SB-11 11-13'	Total/NA	Solid	3050B	
500-190983-21 DU	SB-11 11-13'	Total/NA	Solid	3050B	

Analysis Batch: 573529

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-21	SB-11 11-13'	Total/NA	Solid	6010B	573236
500-190983-22	SB-9 2-4	Total/NA	Solid	6010B	573236
500-190983-23	SB-9 7-9'	Total/NA	Solid	6010B	573236
500-190983-24	SB-15 3-4'	Total/NA	Solid	6010B	573236

QC Association Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Metals (Continued)

Analysis Batch: 573529 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-25	SB-15 6-8'	Total/NA	Solid	6010B	573236
500-190983-26	SB-12 3-4'	Total/NA	Solid	6010B	573236
500-190983-27	SB-12 7-9'	Total/NA	Solid	6010B	573236
500-190983-28	SB-13 1-3'	Total/NA	Solid	6010B	573236
500-190983-29	SB-13 11-13'	Total/NA	Solid	6010B	573236
500-190983-30	SB-16 3-4'	Total/NA	Solid	6010B	573236
500-190983-31	SB-16 12-14'	Total/NA	Solid	6010B	573236
MB 500-573236/1-A	Method Blank	Total/NA	Solid	6010B	573236
LCS 500-573236/2-A	Lab Control Sample	Total/NA	Solid	6010B	573236
500-190983-21 MS	SB-11 11-13'	Total/NA	Solid	6010B	573236
500-190983-21 MSD	SB-11 11-13'	Total/NA	Solid	6010B	573236
500-190983-21 DU	SB-11 11-13'	Total/NA	Solid	6010B	573236

Analysis Batch: 573644

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-1	SB-14 3-4"	Total/NA	Solid	6010B	573218
500-190983-2	SB-5 12-14'	Total/NA	Solid	6010B	573218
500-190983-3	SB-5 3-4'	Total/NA	Solid	6010B	573218
500-190983-4	SB-4 3-4'	Total/NA	Solid	6010B	573218
500-190983-5	SB-4 12-14'	Total/NA	Solid	6010B	573218
500-190983-6	SB-3 3-4'	Total/NA	Solid	6010B	573218
500-190983-7	SB-3 12-14'	Total/NA	Solid	6010B	573218
500-190983-8	SB-2 3-4'	Total/NA	Solid	6010B	573218
500-190983-9	SB-2 11-13'	Total/NA	Solid	6010B	573218
500-190983-10	SB-1 3-4'	Total/NA	Solid	6010B	573218
500-190983-11	SB-1 12-14'	Total/NA	Solid	6010B	573218
500-190983-12	SB-6 3-4'	Total/NA	Solid	6010B	573218
500-190983-13	SB-6 7-9'	Total/NA	Solid	6010B	573218
500-190983-14	SB-7 3-4'	Total/NA	Solid	6010B	573218
500-190983-15	SB-7 12-14'	Total/NA	Solid	6010B	573218
500-190983-16	SB-8 3-4'	Total/NA	Solid	6010B	573218
500-190983-17	SB-8 10-12'	Total/NA	Solid	6010B	573218
500-190983-18	SB-10 3-4'	Total/NA	Solid	6010B	573218
500-190983-19	SB-10 12-14'	Total/NA	Solid	6010B	573218
500-190983-20	SB-11 3-4'	Total/NA	Solid	6010B	573218
MB 500-573218/1-A	Method Blank	Total/NA	Solid	6010B	573218
LCS 500-573218/2-A	Lab Control Sample	Total/NA	Solid	6010B	573218
500-190983-1 MS	SB-14 3-4"	Total/NA	Solid	6010B	573218
500-190983-1 MSD	SB-14 3-4"	Total/NA	Solid	6010B	573218
500-190983-1 DU	SB-14 3-4"	Total/NA	Solid	6010B	573218

Analysis Batch: 573645

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-23	SB-9 7-9'	Total/NA	Solid	6010B	573236
500-190983-26	SB-12 3-4'	Total/NA	Solid	6010B	573236
500-190983-27	SB-12 7-9'	Total/NA	Solid	6010B	573236
500-190983-28	SB-13 1-3'	Total/NA	Solid	6010B	573236
500-190983-29	SB-13 11-13'	Total/NA	Solid	6010B	573236
500-190983-30	SB-16 3-4'	Total/NA	Solid	6010B	573236
500-190983-31	SB-16 12-14'	Total/NA	Solid	6010B	573236

QC Association Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Metals

Analysis Batch: 573861

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-2	SB-5 12-14'	Total/NA	Solid	6010B	573218
500-190983-7	SB-3 12-14'	Total/NA	Solid	6010B	573218
500-190983-9	SB-2 11-13'	Total/NA	Solid	6010B	573218
500-190983-10	SB-1 3-4'	Total/NA	Solid	6010B	573218
500-190983-11	SB-1 12-14'	Total/NA	Solid	6010B	573218
500-190983-13	SB-6 7-9'	Total/NA	Solid	6010B	573218
500-190983-15	SB-7 12-14'	Total/NA	Solid	6010B	573218

General Chemistry

Analysis Batch: 572835

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-1	SB-14 3-4"	Total/NA	Solid	Moisture	
500-190983-2	SB-5 12-14'	Total/NA	Solid	Moisture	
500-190983-3	SB-5 3-4'	Total/NA	Solid	Moisture	
500-190983-4	SB-4 3-4'	Total/NA	Solid	Moisture	
500-190983-5	SB-4 12-14'	Total/NA	Solid	Moisture	
500-190983-6	SB-3 3-4'	Total/NA	Solid	Moisture	
500-190983-7	SB-3 12-14'	Total/NA	Solid	Moisture	
500-190983-8	SB-2 3-4'	Total/NA	Solid	Moisture	
500-190983-9	SB-2 11-13'	Total/NA	Solid	Moisture	
500-190983-10	SB-1 3-4'	Total/NA	Solid	Moisture	
500-190983-11	SB-1 12-14'	Total/NA	Solid	Moisture	
500-190983-12	SB-6 3-4'	Total/NA	Solid	Moisture	
500-190983-13	SB-6 7-9'	Total/NA	Solid	Moisture	
500-190983-14	SB-7 3-4'	Total/NA	Solid	Moisture	
500-190983-15	SB-7 12-14'	Total/NA	Solid	Moisture	
500-190983-16	SB-8 3-4'	Total/NA	Solid	Moisture	
500-190983-17	SB-8 10-12'	Total/NA	Solid	Moisture	
500-190983-18	SB-10 3-4'	Total/NA	Solid	Moisture	
500-190983-19	SB-10 12-14'	Total/NA	Solid	Moisture	
500-190983-20	SB-11 3-4'	Total/NA	Solid	Moisture	
500-190983-1 DU	SB-14 3-4"	Total/NA	Solid	Moisture	

Analysis Batch: 572870

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-21	SB-11 11-13'	Total/NA	Solid	Moisture	
500-190983-22	SB-9 2-4	Total/NA	Solid	Moisture	
500-190983-23	SB-9 7-9'	Total/NA	Solid	Moisture	
500-190983-24	SB-15 3-4'	Total/NA	Solid	Moisture	
500-190983-25	SB-15 6-8'	Total/NA	Solid	Moisture	
500-190983-26	SB-12 3-4'	Total/NA	Solid	Moisture	
500-190983-27	SB-12 7-9'	Total/NA	Solid	Moisture	
500-190983-28	SB-13 1-3'	Total/NA	Solid	Moisture	
500-190983-29	SB-13 11-13'	Total/NA	Solid	Moisture	
500-190983-30	SB-16 3-4'	Total/NA	Solid	Moisture	
500-190983-31	SB-16 12-14'	Total/NA	Solid	Moisture	
500-190983-23 DU	SB-9 7-9'	Total/NA	Solid	Moisture	

QC Association Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

General Chemistry

Analysis Batch: 573101

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-1	SB-14 3-4"	Total/NA	Solid	9045C	
500-190983-2	SB-5 12-14'	Total/NA	Solid	9045C	
500-190983-3	SB-5 3-4'	Total/NA	Solid	9045C	
500-190983-4	SB-4 3-4'	Total/NA	Solid	9045C	
500-190983-5	SB-4 12-14'	Total/NA	Solid	9045C	
500-190983-6	SB-3 3-4'	Total/NA	Solid	9045C	
500-190983-7	SB-3 12-14'	Total/NA	Solid	9045C	
500-190983-8	SB-2 3-4'	Total/NA	Solid	9045C	
500-190983-9	SB-2 11-13'	Total/NA	Solid	9045C	
500-190983-10	SB-1 3-4'	Total/NA	Solid	9045C	
500-190983-11	SB-1 12-14'	Total/NA	Solid	9045C	
500-190983-12	SB-6 3-4'	Total/NA	Solid	9045C	
500-190983-13	SB-6 7-9'	Total/NA	Solid	9045C	
500-190983-14	SB-7 3-4'	Total/NA	Solid	9045C	
500-190983-15	SB-7 12-14'	Total/NA	Solid	9045C	
500-190983-16	SB-8 3-4'	Total/NA	Solid	9045C	
500-190983-17	SB-8 10-12'	Total/NA	Solid	9045C	
500-190983-18	SB-10 3-4'	Total/NA	Solid	9045C	
500-190983-19	SB-10 12-14'	Total/NA	Solid	9045C	
500-190983-20	SB-11 3-4'	Total/NA	Solid	9045C	
500-190983-21	SB-11 11-13'	Total/NA	Solid	9045C	
500-190983-22	SB-9 2-4	Total/NA	Solid	9045C	
500-190983-23	SB-9 7-9'	Total/NA	Solid	9045C	
500-190983-24	SB-15 3-4'	Total/NA	Solid	9045C	
500-190983-25	SB-15 6-8'	Total/NA	Solid	9045C	
500-190983-26	SB-12 3-4'	Total/NA	Solid	9045C	
500-190983-27	SB-12 7-9'	Total/NA	Solid	9045C	
500-190983-28	SB-13 1-3'	Total/NA	Solid	9045C	
500-190983-29	SB-13 11-13'	Total/NA	Solid	9045C	
500-190983-30	SB-16 3-4'	Total/NA	Solid	9045C	
500-190983-31	SB-16 12-14'	Total/NA	Solid	9045C	
LCS 500-573101/2	Lab Control Sample	Total/NA	Solid	9045C	
LCSD 500-573101/3	Lab Control Sample Dup	Total/NA	Solid	9045C	
500-190983-4 DU	SB-4 3-4'	Total/NA	Solid	9045C	
500-190983-24 DU	SB-15 3-4'	Total/NA	Solid	9045C	

Prep Batch: 573283

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-1	SB-14 3-4"	Total/NA	Solid	300_Prep	
500-190983-2	SB-5 12-14'	Total/NA	Solid	300_Prep	
500-190983-3	SB-5 3-4'	Total/NA	Solid	300_Prep	
500-190983-4	SB-4 3-4'	Total/NA	Solid	300_Prep	
500-190983-5	SB-4 12-14'	Total/NA	Solid	300_Prep	
500-190983-6	SB-3 3-4'	Total/NA	Solid	300_Prep	
500-190983-7	SB-3 12-14'	Total/NA	Solid	300_Prep	
500-190983-8	SB-2 3-4'	Total/NA	Solid	300_Prep	
500-190983-9	SB-2 11-13'	Total/NA	Solid	300_Prep	
500-190983-10	SB-1 3-4'	Total/NA	Solid	300_Prep	
500-190983-11	SB-1 12-14'	Total/NA	Solid	300_Prep	
500-190983-12	SB-6 3-4'	Total/NA	Solid	300_Prep	
500-190983-13	SB-6 7-9'	Total/NA	Solid	300_Prep	

QC Association Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

General Chemistry (Continued)

Prep Batch: 573283 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-14	SB-7 3-4'	Total/NA	Solid	300_Prep	
500-190983-15	SB-7 12-14'	Total/NA	Solid	300_Prep	
500-190983-16	SB-8 3-4'	Total/NA	Solid	300_Prep	
500-190983-17	SB-8 10-12'	Total/NA	Solid	300_Prep	
500-190983-18	SB-10 3-4'	Total/NA	Solid	300_Prep	
500-190983-19	SB-10 12-14'	Total/NA	Solid	300_Prep	
MB 500-573283/1-A	Method Blank	Total/NA	Solid	300_Prep	
LCS 500-573283/2-A	Lab Control Sample	Total/NA	Solid	300_Prep	

Prep Batch: 573285

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-20	SB-11 3-4'	Total/NA	Solid	300_Prep	
500-190983-21	SB-11 11-13'	Total/NA	Solid	300_Prep	
500-190983-22	SB-9 2-4	Total/NA	Solid	300_Prep	
500-190983-23	SB-9 7-9'	Total/NA	Solid	300_Prep	
500-190983-24	SB-15 3-4'	Total/NA	Solid	300_Prep	
500-190983-25	SB-15 6-8'	Total/NA	Solid	300_Prep	
500-190983-26	SB-12 3-4'	Total/NA	Solid	300_Prep	
500-190983-27	SB-12 7-9'	Total/NA	Solid	300_Prep	
500-190983-28	SB-13 1-3'	Total/NA	Solid	300_Prep	
500-190983-29	SB-13 11-13'	Total/NA	Solid	300_Prep	
500-190983-30	SB-16 3-4'	Total/NA	Solid	300_Prep	
500-190983-31	SB-16 12-14'	Total/NA	Solid	300_Prep	
MB 500-573285/1-A	Method Blank	Total/NA	Solid	300_Prep	
LCS 500-573285/2-A	Lab Control Sample	Total/NA	Solid	300_Prep	
500-190983-29 MS	SB-13 11-13'	Total/NA	Solid	300_Prep	
500-190983-29 MSD	SB-13 11-13'	Total/NA	Solid	300_Prep	

Analysis Batch: 573319

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-3	SB-5 3-4'	Total/NA	Solid	300.0	573283
500-190983-4	SB-4 3-4'	Total/NA	Solid	300.0	573283
500-190983-5	SB-4 12-14'	Total/NA	Solid	300.0	573283
500-190983-6	SB-3 3-4'	Total/NA	Solid	300.0	573283
500-190983-7	SB-3 12-14'	Total/NA	Solid	300.0	573283
500-190983-8	SB-2 3-4'	Total/NA	Solid	300.0	573283
500-190983-9	SB-2 11-13'	Total/NA	Solid	300.0	573283
500-190983-10	SB-1 3-4'	Total/NA	Solid	300.0	573283
500-190983-11	SB-1 12-14'	Total/NA	Solid	300.0	573283
500-190983-13	SB-6 7-9'	Total/NA	Solid	300.0	573283
500-190983-14	SB-7 3-4'	Total/NA	Solid	300.0	573283
500-190983-15	SB-7 12-14'	Total/NA	Solid	300.0	573283
500-190983-16	SB-8 3-4'	Total/NA	Solid	300.0	573283
500-190983-18	SB-10 3-4'	Total/NA	Solid	300.0	573283
MB 500-573283/1-A	Method Blank	Total/NA	Solid	300.0	573283
LCS 500-573283/2-A	Lab Control Sample	Total/NA	Solid	300.0	573283

Analysis Batch: 573343

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-20	SB-11 3-4'	Total/NA	Solid	300.0	573285
500-190983-22	SB-9 2-4	Total/NA	Solid	300.0	573285

QC Association Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

General Chemistry (Continued)

Analysis Batch: 573343 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-23	SB-9 7-9'	Total/NA	Solid	300.0	573285
500-190983-24	SB-15 3-4'	Total/NA	Solid	300.0	573285
500-190983-26	SB-12 3-4'	Total/NA	Solid	300.0	573285
500-190983-27	SB-12 7-9'	Total/NA	Solid	300.0	573285
500-190983-28	SB-13 1-3'	Total/NA	Solid	300.0	573285
500-190983-29	SB-13 11-13'	Total/NA	Solid	300.0	573285
500-190983-30	SB-16 3-4'	Total/NA	Solid	300.0	573285
500-190983-31	SB-16 12-14'	Total/NA	Solid	300.0	573285
MB 500-573285/1-A	Method Blank	Total/NA	Solid	300.0	573285
LCS 500-573285/2-A	Lab Control Sample	Total/NA	Solid	300.0	573285
500-190983-29 MS	SB-13 11-13'	Total/NA	Solid	300.0	573285
500-190983-29 MSD	SB-13 11-13'	Total/NA	Solid	300.0	573285

Analysis Batch: 573419

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-190983-1	SB-14 3-4"	Total/NA	Solid	300.0	573283
500-190983-2	SB-5 12-14'	Total/NA	Solid	300.0	573283
500-190983-12	SB-6 3-4'	Total/NA	Solid	300.0	573283
500-190983-17	SB-8 10-12'	Total/NA	Solid	300.0	573283
500-190983-19	SB-10 12-14'	Total/NA	Solid	300.0	573283
500-190983-21	SB-11 11-13'	Total/NA	Solid	300.0	573285
500-190983-25	SB-15 6-8'	Total/NA	Solid	300.0	573285
MB 500-573283/1-A	Method Blank	Total/NA	Solid	300.0	573283
MB 500-573285/1-A	Method Blank	Total/NA	Solid	300.0	573285
LCS 500-573283/2-A	Lab Control Sample	Total/NA	Solid	300.0	573283
LCS 500-573285/2-A	Lab Control Sample	Total/NA	Solid	300.0	573285

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Method: 6010B - Metals (ICP)

Lab Sample ID: MB 500-573218/1-A
Matrix: Solid
Analysis Batch: 573644

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 573218

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	<20		20		mg/Kg		11/20/20 07:32	11/20/20 18:25	1
Manganese	<1.0		1.0		mg/Kg		11/20/20 07:32	11/20/20 18:25	1

Lab Sample ID: LCS 500-573218/2-A
Matrix: Solid
Analysis Batch: 573644

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 573218

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Iron	100	92.3		mg/Kg		92	80 - 120
Manganese	50.0	45.3		mg/Kg		91	80 - 120

Lab Sample ID: 500-190983-1 MS
Matrix: Solid
Analysis Batch: 573644

Client Sample ID: SB-14 3-4"
Prep Type: Total/NA
Prep Batch: 573218

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Iron	19000		95.0	12200	4	mg/Kg		-6787	75 - 125
Manganese	250		47.5	296	4	mg/Kg		106	75 - 125

Lab Sample ID: 500-190983-1 MSD
Matrix: Solid
Analysis Batch: 573644

Client Sample ID: SB-14 3-4"
Prep Type: Total/NA
Prep Batch: 573218

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Iron	19000		88.0	13000	4	mg/Kg		-6351	75 - 125	7	20
Manganese	250		44.0	285	4	mg/Kg		90	75 - 125	4	20

Lab Sample ID: 500-190983-1 DU
Matrix: Solid
Analysis Batch: 573644

Client Sample ID: SB-14 3-4"
Prep Type: Total/NA
Prep Batch: 573218

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Iron	19000		11900	F3	mg/Kg		44	20
Manganese	250		246		mg/Kg		0.2	20

Lab Sample ID: MB 500-573236/1-A
Matrix: Solid
Analysis Batch: 573529

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 573236

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	<20		20		mg/Kg		11/20/20 07:52	11/20/20 14:59	1
Manganese	<1.0		1.0		mg/Kg		11/20/20 07:52	11/20/20 14:59	1

Lab Sample ID: LCS 500-573236/2-A
Matrix: Solid
Analysis Batch: 573529

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 573236

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Iron	100	103		mg/Kg		103	80 - 120
Manganese	50.0	48.2		mg/Kg		96	80 - 120

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Method: 6010B - Metals (ICP)

Lab Sample ID: 500-190983-21 MS
Matrix: Solid
Analysis Batch: 573529

Client Sample ID: SB-11 11-13'
Prep Type: Total/NA
Prep Batch: 573236

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Iron	17000	V	98.3	16200	4	mg/Kg		-860	75 - 125
Manganese	290	V	49.2	311	4	mg/Kg		51	75 - 125

Lab Sample ID: 500-190983-21 MSD
Matrix: Solid
Analysis Batch: 573529

Client Sample ID: SB-11 11-13'
Prep Type: Total/NA
Prep Batch: 573236

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Iron	17000	V	97.4	14000	4	mg/Kg		-3158	75 - 125	15	20
Manganese	290	V	48.7	282	4	mg/Kg		-7	75 - 125	10	20

Lab Sample ID: 500-190983-21 DU
Matrix: Solid
Analysis Batch: 573529

Client Sample ID: SB-11 11-13'
Prep Type: Total/NA
Prep Batch: 573236

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Iron	17000	V	18100		mg/Kg		6	20
Manganese	290	V	310		mg/Kg		8	20

Method: 300.0 - Anions, Ion Chromatography

Lab Sample ID: MB 500-573283/1-A
Matrix: Solid
Analysis Batch: 573319

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 573283

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<2.0		2.0		mg/Kg		11/20/20 10:10	11/20/20 14:02	1

Lab Sample ID: MB 500-573283/1-A
Matrix: Solid
Analysis Batch: 573419

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 573283

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<2.0		2.0		mg/Kg		11/20/20 10:10	11/21/20 13:06	1

Lab Sample ID: LCS 500-573283/2-A
Matrix: Solid
Analysis Batch: 573319

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 573283

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	50.0	53.2		mg/Kg		106	90 - 110

Lab Sample ID: LCS 500-573283/2-A
Matrix: Solid
Analysis Batch: 573419

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 573283

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	50.0	54.3		mg/Kg		109	90 - 110

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Method: 300.0 - Anions, Ion Chromatography (Continued)

Lab Sample ID: MB 500-573285/1-A
Matrix: Solid
Analysis Batch: 573343

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 573285

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<2.0		2.0		mg/Kg		11/20/20 11:35	11/20/20 15:21	1

Lab Sample ID: MB 500-573285/1-A
Matrix: Solid
Analysis Batch: 573419

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 573285

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Sulfate	<2.0		2.0		mg/Kg		11/20/20 11:35	11/21/20 14:35	1

Lab Sample ID: LCS 500-573285/2-A
Matrix: Solid
Analysis Batch: 573343

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 573285

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	50.0	52.5		mg/Kg		105	90 - 110

Lab Sample ID: LCS 500-573285/2-A
Matrix: Solid
Analysis Batch: 573419

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 573285

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	50.0	53.5		mg/Kg		107	90 - 110

Lab Sample ID: 500-190983-29 MS
Matrix: Solid
Analysis Batch: 573343

Client Sample ID: SB-13 11-13'
Prep Type: Total/NA
Prep Batch: 573285

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Sulfate	6.1		24.3	30.3		mg/Kg		100	80 - 120

Lab Sample ID: 500-190983-29 MSD
Matrix: Solid
Analysis Batch: 573343

Client Sample ID: SB-13 11-13'
Prep Type: Total/NA
Prep Batch: 573285

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Sulfate	6.1		23.6	30.1		mg/Kg		102	80 - 120	1	20

Method: 9045C - pH

Lab Sample ID: 500-190983-4 DU
Matrix: Solid
Analysis Batch: 573101

Client Sample ID: SB-4 3-4'
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
pH	8.0		7.9		SU		2	

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Method: 9045C - pH (Continued)

Lab Sample ID: 500-190983-24 DU
Matrix: Solid
Analysis Batch: 573101

Client Sample ID: SB-15 3-4'
Prep Type: Total/NA

Analyte	Sample Result	Sample Qualifier		DU Result	DU Qualifier	Unit	D			RPD	RPD Limit
pH	9.1			9.1		SU				0.1	

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: 500-86776-39133.1
Client Contact: Erin Bulson	Phone: 262-278-0621	E-Mail: Diana.Mockler@Eurofinset.com		Page: Page 1 of 4
Company: KPRG and Associates, Inc.				Job #: 500-190983
Address: 14665 West Lisbon Road, Suite 1A	Due Date Requested:			
City: Brookfield	TAT Requested (days):			
State, Zip: WI, 53005				
Phone: 773-617-7515(Tel)	PO #: 4502012471			
Email: erinb@kprginc.com	WO #:			
Project Name: Joliet Station 29 -	Project #: 50000292			
Site:	SSOW#:			

Analysis Requested

500-190983 COC

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)	300 - pH, Sulfate	300, 6010B, 9045C	Total Number of containers	Special Instructions/Note:
				Preservation Code:				N	N		
1	SB-14 3-4'	11-11	1000	C	Water			X	X		
2	SB-5 12-14'	11-11	1025		Water						
3	SB-5 3-4'	11-11	1015		Water						
4	SB-4 3-4'	11-11	1040		Water						
5	SB-4 12-14'	11-11	1050		Solid						
6	SB-3 3-4'	11-11	1105		Solid						
7	SB-3 12-14'	11-11	1120		Solid						
8	SB-2 3-4'	11-11	1130		Solid						
9	SB-2 11-13'	11-11	1145		Solid						
10	SB-1 3-4'	11-11	1240		Solid						
11	SB-1 12-14'	11-11	1245	↓	Solid			↓	↓		

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
		11/12/2020 1150			11/12/20 1150	ETA
	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: 7.8 → 7.6, 6.3 → 6.1

Electronic Filing: Received, Clerk's Office 2/04/2022

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: 500-86776-39133.2
Client Contact: Erin Bulson	Phone:	E-Mail: Diana.Mockler@Eurofinset.com		Page: Page 2 of 4
Company: KPRG and Associates, Inc.				Job #: 500-190983
Address: 14665 West Lisbon Road, Suite 1A	Due Date Requested:			
City: Brookfield	TAT Requested (days):			
State, Zip: WI, 53005				
Phone: 773-617-7515(Tel)	PO #: 4502012471			
Email: erinb@kprginc.com	WO #:			
Project Name: Joliet Station 29 -	Project #: 50000292			
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	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)	300 - pH, Sulfate	300, 6010B, 9045C	Total Number of containers	Special Instructions/Note:
				Preservation Code:				N	N		
12	SB-6 3-4'	11-11-20	1300		Solid			X	X		
13	SB-6 7-9'	11-11-20	1310		Solid						
14	SB-7 3-4	11-11-20	1330		Solid						
15	SB-7 12-14'	11-11-20	1335		Solid						
16	SB-8 3-4'	11-11-20	1350		Solid						
17	SB-8 10-12'	11-11-20	1410		Solid						
18	SB-10 3-4'	11-11-20	1420		Solid						
19	SB-10 12-14'	11-11-20	1435		Solid						
20	SB-11 3-4'	11-12-20	0830		Solid						
21	SB-11 11-13'	11-12-20	0845		Solid						
22	SB-9 2-4'	11-12-20	0855		Solid						

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:

	Date/Time:	Company		Date/Time:	Company
Relinquished by:	11/12/2020 1140		Received by:	11/12/20 1150	ETA
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: 7.8 → 7.6, 6.3 – 6.1

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: 500-86776-39133.3
Client Contact: Erin Bulson	Phone: 262 - 278-1622	E-Mail: Diana.Mockler@Eurofinset.com		Page: Page 3 of 4
Company: KPRG and Associates, Inc.				Job #: 500-190983
Address: 14665 West Lisbon Road, Suite 1A	Due Date Requested:			
City: Brookfield	TAT Requested (days):			
State, Zip: WI, 53005				
Phone: 773-617-7515(Tel)	PO #: 4502012471			
Email: erinb@kprginc.com	WO #:			
Project Name: Joliet Station 29 -	Project #: 50000292			
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	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)	300 - pH, Sulfate	300, 6010B, 9045C	Total Number of containers	Special Instructions/Note:
				Preservation Code:				N	N		
23	SB-9 7-9'	11-12-20	0900		Solid						
24	SB-14 3-4'	11-12-20	0930		Solid						
25	SB-14 6-8'	11-12-20	0935		Solid						
26	SB-12 3-4'	11-12-20	0950		Solid						
27	SB-12 7-9'	11-12-20	1000		Solid						
28	SB-13 1-3'	11-12-20	1030		Solid						
29	SB-13 11-13'	11-12-20	1040		Solid						
30	SB-16 3-4'	11-12-20	1095		Solid						
31	SB-16 12-14'	11-12-20	1100		Solid						
					Solid						
					Solid						

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: 11/12/2020 1150	Company	Received by:	Date/Time: 11/12/20 1150	Company ETA
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: 7.8 → 7.6, 6.3 - 6.1

Login Sample Receipt Checklist

Client: Midwest Generation EME LLC

Job Number: 500-190983-1

Login Number: 190983
List Number: 1
Creator: Buckley, Paula M

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.	False	Received same day of collection; chilling process has begun.
Cooler Temperature is recorded.	True	7.6, 6.1
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").	N/A	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-14 3-4"
Date Collected: 11/11/20 10:00
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-1
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 18:32	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		100	573419	11/21/20 13:31	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 11:41	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-5 12-14'
Date Collected: 11/11/20 10:25
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-2
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 18:58	EEN	TAL CHI
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573861	11/24/20 10:48	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		5	573419	11/21/20 13:44	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 11:43	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-5 3-4'
Date Collected: 11/11/20 10:15
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-3
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:01	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 16:04	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 11:46	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-4 3-4'
Date Collected: 11/11/20 10:40
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-4
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:04	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 16:18	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 11:53	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-4 12-14'
Date Collected: 11/11/20 10:50
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-5
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:07	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 16:32	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 11:48	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-3 3-4'
Date Collected: 11/11/20 11:05
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-6
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:10	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 16:45	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 11:58	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-3 12-14'
Date Collected: 11/11/20 11:20
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-7
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:14	EEN	TAL CHI
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573861	11/24/20 11:01	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 16:59	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:03	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-2 3-4'
Date Collected: 11/11/20 11:30
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-8
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:17	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 17:12	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:06	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-2 11-13'
Lab Sample ID: 500-190983-9
Date Collected: 11/11/20 11:45
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:20	EEN	TAL CHI
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573861	11/24/20 11:05	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 17:26	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:01	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-1 3-4'
Lab Sample ID: 500-190983-10
Date Collected: 11/11/20 12:40
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:24	EEN	TAL CHI
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573861	11/24/20 11:08	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 17:40	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:08	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-1 12-14'
Lab Sample ID: 500-190983-11
Date Collected: 11/11/20 12:45
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:38	EEN	TAL CHI
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573861	11/24/20 11:11	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 18:20	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:11	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-6 3-4'
Lab Sample ID: 500-190983-12
Date Collected: 11/11/20 13:00
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:41	EEN	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-6 3-4'
Lab Sample ID: 500-190983-12
Date Collected: 11/11/20 13:00
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		5	573419	11/21/20 13:56	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:13	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-6 7-9'
Lab Sample ID: 500-190983-13
Date Collected: 11/11/20 13:10
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:44	EEN	TAL CHI
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573861	11/24/20 11:14	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 18:48	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:16	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-7 3-4'
Lab Sample ID: 500-190983-14
Date Collected: 11/11/20 13:30
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:48	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 19:01	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:21	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-7 12-14'
Lab Sample ID: 500-190983-15
Date Collected: 11/11/20 13:35
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:51	EEN	TAL CHI
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573861	11/24/20 11:18	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 19:15	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:23	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-8 3-4'

Lab Sample ID: 500-190983-16
Matrix: Solid
Date Collected: 11/11/20 13:50
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:54	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 19:28	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:26	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-8 10-12'

Lab Sample ID: 500-190983-17
Matrix: Solid
Date Collected: 11/11/20 14:10
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 19:58	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		2	573419	11/21/20 14:09	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:28	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-10 3-4'

Lab Sample ID: 500-190983-18
Matrix: Solid
Date Collected: 11/11/20 14:20
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 20:01	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573319	11/20/20 19:56	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:31	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-10 12-14'

Lab Sample ID: 500-190983-19
Matrix: Solid
Date Collected: 11/11/20 14:35
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 20:04	EEN	TAL CHI
Total/NA	Prep	300_Prep			573283	11/20/20 10:10	EAT	TAL CHI
Total/NA	Analysis	300.0		5	573419	11/21/20 14:22	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:33	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-11 3-4'
Lab Sample ID: 500-190983-20
Date Collected: 11/12/20 08:30
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573218	11/20/20 07:32	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573644	11/20/20 20:07	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573343	11/20/20 15:46	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:36	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572835	11/18/20 11:50	LWN	TAL CHI

Client Sample ID: SB-11 11-13'
Lab Sample ID: 500-190983-21
Date Collected: 11/12/20 08:35
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 15:05	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		50	573419	11/21/20 15:25	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:38	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Client Sample ID: SB-9 2-4
Lab Sample ID: 500-190983-22
Date Collected: 11/12/20 08:55
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 15:28	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573343	11/20/20 16:12	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:41	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Client Sample ID: SB-9 7-9'
Lab Sample ID: 500-190983-23
Date Collected: 11/12/20 09:00
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 15:32	EEN	TAL CHI
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573645	11/23/20 12:27	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573343	11/20/20 16:24	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:44	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-15 3-4'
Lab Sample ID: 500-190983-24
Date Collected: 11/12/20 09:30
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 15:35	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573343	11/20/20 16:37	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:49	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Client Sample ID: SB-15 6-8'
Lab Sample ID: 500-190983-25
Date Collected: 11/12/20 09:35
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 15:38	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		250	573419	11/21/20 15:38	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:54	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Client Sample ID: SB-12 3-4'
Lab Sample ID: 500-190983-26
Date Collected: 11/12/20 09:50
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 15:41	EEN	TAL CHI
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573645	11/23/20 12:30	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573343	11/20/20 17:03	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:56	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Client Sample ID: SB-12 7-9'
Lab Sample ID: 500-190983-27
Date Collected: 11/12/20 10:00
Matrix: Solid
Date Received: 11/12/20 11:50

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 15:45	EEN	TAL CHI
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573645	11/23/20 12:34	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573343	11/20/20 17:15	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 12:58	LWN	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-12 7-9'
Date Collected: 11/12/20 10:00
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-27
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Client Sample ID: SB-13 1-3'
Date Collected: 11/12/20 10:30
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-28
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 15:48	EEN	TAL CHI
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573645	11/23/20 12:47	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573343	11/20/20 17:53	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 13:01	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Client Sample ID: SB-13 11-13'
Date Collected: 11/12/20 10:40
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-29
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 15:51	EEN	TAL CHI
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573645	11/23/20 12:51	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573343	11/20/20 18:06	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 13:03	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Client Sample ID: SB-16 3-4'
Date Collected: 11/12/20 10:55
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-30
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 16:01	EEN	TAL CHI
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573645	11/23/20 12:54	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
Total/NA	Analysis	300.0		1	573343	11/20/20 18:44	EAT	TAL CHI
Total/NA	Analysis	9045C		1	573101	11/19/20 13:06	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

Job ID: 500-190983-1

Client Sample ID: SB-16 12-14'

Date Collected: 11/12/20 11:00
Date Received: 11/12/20 11:50

Lab Sample ID: 500-190983-31

Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		1	573529	11/20/20 16:04	EEN	TAL CHI
Total/NA	Prep	3050B			573236	11/20/20 07:52	LMN	TAL CHI
Total/NA	Analysis	6010B		5	573645	11/23/20 12:58	EEN	TAL CHI
Total/NA	Prep	300_Prep			573285	11/20/20 11:35	EAT	TAL CHI
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Total/NA	Analysis	9045C		1	573101	11/19/20 13:09	LWN	TAL CHI
Total/NA	Analysis	Moisture		1	572870	11/18/20 14:56	LWN	TAL CHI

Laboratory References:

TAL CHI = Eurofins TestAmerica, Chicago, 2417 Bond Street, University Park, IL 60484, TEL (708)534-5200

Electronic Filing: Received, Clerk's Office 2/04/2022

Accreditation/Certification Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet Station 29 - Soils

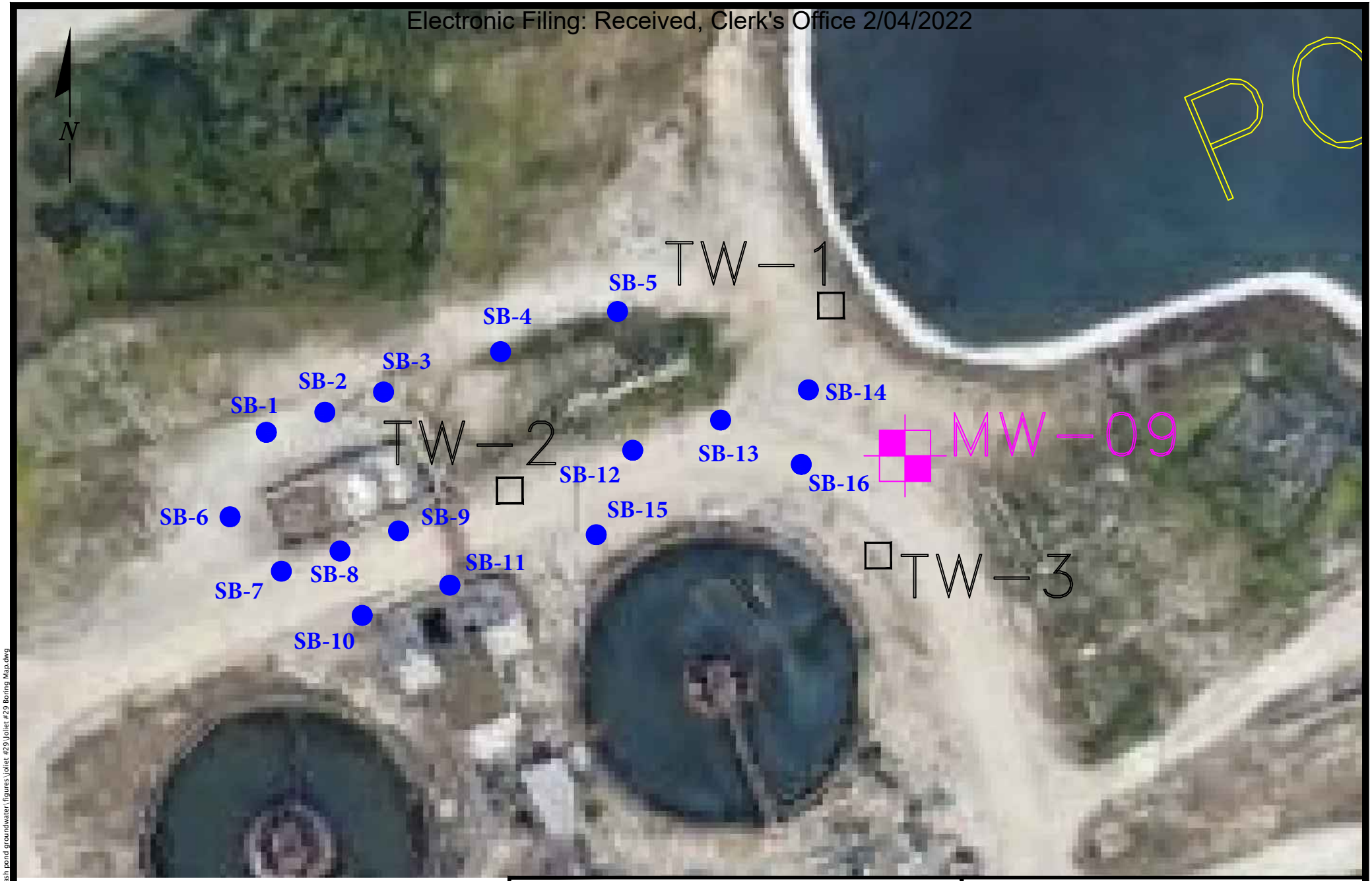
Job ID: 500-190983-1

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

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LEGEND:

- PROPOSED BORING LOCATION
- TW-2 TEMPORARY WELL LOCATION
- MW-9 MONITORING WELL LOCATION

0 40'

APPROXIMATE SCALE

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

PROPOSED BORING LOCATIONS

JOLIET #29 GENERATING STATION
JOLIET, ILLINOIS

Scale: 1" = 48' | Date: July 17, 2020

KPRG Project No. 11020.0 | FIGURE 1

W:\projects\midwest generation\12313 ash pond groundwater figures\joliet #29\joliet #29 Boring Map.dwg

Attachment 6

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U.S. ROUTE 6

EAST ENTRANCE

MAIN ENTRANCE

ASH IMPOUNDMENT 2
(WATER ELEVATION 530.99' ON 04/05/07)
APPROXIMATE BOTTOM ELEVATION: 516.0'

ASH IMPOUNDMENT 1
(WATER ELEVATION 532.36' ON 04/05/07)
APPROXIMATE BOTTOM ELEVATION: 516.0'

FOUND "PK" MASONRY NAIL

SITE BENCHMARK 1

SITE BENCHMARK 2

INV.= 529.88

OUTLET WEIR

INV.= 530.03

OUTLET WEIR

RAMP SLOPE 10%

RAMP SLOPE 10%

TOP OF SLOPE

TOP OF SLOPE

TOP OF SLOPE

3:1 SLOPE

3:1 SLOPE

3:1 SLOPE

2:1 SLOPE

2:1 SLOPE

INLET DISTRIBUTION TROUGH

INLET DISTRIBUTION TROUGH

INLET APRON

INLET APRON

GRAVEL DRIVE

GRAVEL DRIVE

GRAVEL DRIVE

WOODEN PIPE RACKS

CONCRETE RETAINING WALL

1 C031

LEGEND

- GROUND SURFACE CONTOURS
- UNDERGROUND DISCHARGE PIPE
- FENCE
- EDGE OF PIPE RACK
- ABOVE GROUND PIPELINES
- OVERHEAD ELECTRIC LINE
- POWER POLE
- LIGHT POLE
- MARKER POST
- CONCRETE

0 20 40 80
SCALE IN FEET

N

CONTRACTOR NOTES:
1. CONTRACTOR SHALL BEGIN CONSTRUCTION SEQUENCE WITH ASH IMPOUNDMENT 2.
2. CLEAR AND GRUB ALL BRUSH ALONG TOP OF SLOPE OF IMPOUNDMENT.
3. CONTRACTOR SHALL STORE ALL GEOSYNTHETICS AND SUBGRADE MATERIALS IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS.
4. CONTRACTOR SHALL STORE AND STAGE EQUIPMENT AT LOCATION APPROVED BY THE OWNER.
5. CONTRACTOR SHALL REMOVE EXISTING LINER FROM IMPOUNDMENTS AND DISPOSE AT AN APPROVED LANDFILL.
6. CONTRACTOR SHALL REMOVE VEGETATION, ROCKS AND OTHER DEBRIS GREATER THAN 3 INCHES FROM IMPOUNDMENT SUBGRADE AND DISPOSE AT AN APPROVED LANDFILL.
7. CONTRACTOR SHALL REMOVE AT LEAST 18 INCHES OF EXISTING RAMP MATERIAL FOR PLACEMENT OF SUBGRADE LAYER AND FINAL LAYER OF RAMP.
8. CONTRACTOR TO FIELD VERIFY LOCATION OF UNDERGROUND DISCHARGE PIPES WITH ASSISTANCE OF OWNER'S UTILITY LOCATOR.
9. CONTRACTOR SHALL INSTALL MARKER POSTS ALONG THE BASE OF THE IMPOUNDMENTS AS SHOWN AND IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS AND DETAIL 1 ON SHEET C031.
10. CONTRACTOR SHALL PLACE SUBGRADE MATERIAL IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS.
11. SUBGRADE LAYER MUST BE APPROVED BY ENGINEER PRIOR TO INSTALLATION OF GEOMEMBRANE.
12. CONTRACTOR SHALL PROVIDE MEANS TO PROTECT SUBGRADE LAYER FROM EROSION, STORM WATER AND HEAVY EQUIPMENT TRAFFIC. DAMAGE TO SUBGRADE LAYER SHALL BE REPAIRED AT THE CONTRACTOR'S EXPENSE.
13. PROTECT ALL CONCRETE AND UTILITY STRUCTURES THROUGHOUT PROJECT DURATION.

SOURCE NOTES:
1. THIS DRAWING WAS DEVELOPED FROM A SURVEY MAP BY RUETTIGER, TONELLI & ASSOCIATES, INC., JOLIET, ILLINOIS, PLAT OF PARTIAL TOPOGRAPHY OF MIDWEST GENERATION JOLIET 29 POWER PLANT ASH IMPOUNDMENTS, SHEET 1 OF 1, DATED APRIL 7, 2007, FILE NO: 064B7.DWG. COORDINATE SYSTEM IS ILLINOIS STATE PLANE EAST ZONE, (NAD 83).
2. ASH IMPOUNDMENTS 1 AND 2 WERE DEVELOPED FROM DRAWINGS BY NGS CORPORATION, DRAWING NUMBERS: 5079C5102 AND 5079C5103, DATED JANUARY 23, 1979.
3. TOPOGRAPHY OUTSIDE OF ASH IMPOUNDMENTS 1 AND 2 WAS DEVELOPED FROM DIGITAL-ORTHO FILES, 030750.DWG, 040750.DWG, AND 040760.DWG ILLINOIS STATE PLANE EAST NAD 83 COORDINATE SYSTEM, DATED APRIL, 1997 DOWNLOADED FROM http://www.ellinois.org.

DRAFT

NOT FOR CONSTRUCTION

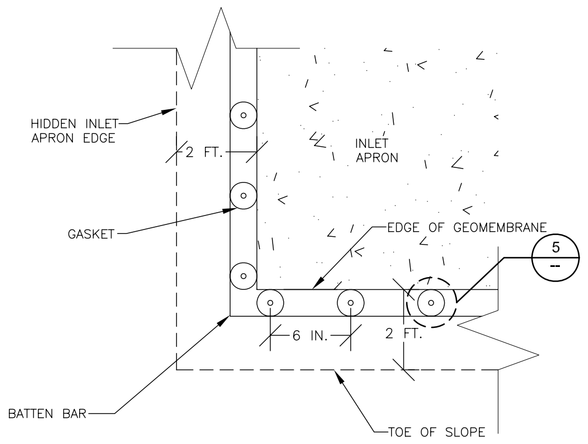
REVISION:	DATE:	APP'D BY:
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NATURAL RESOURCE TECHNOLOGY

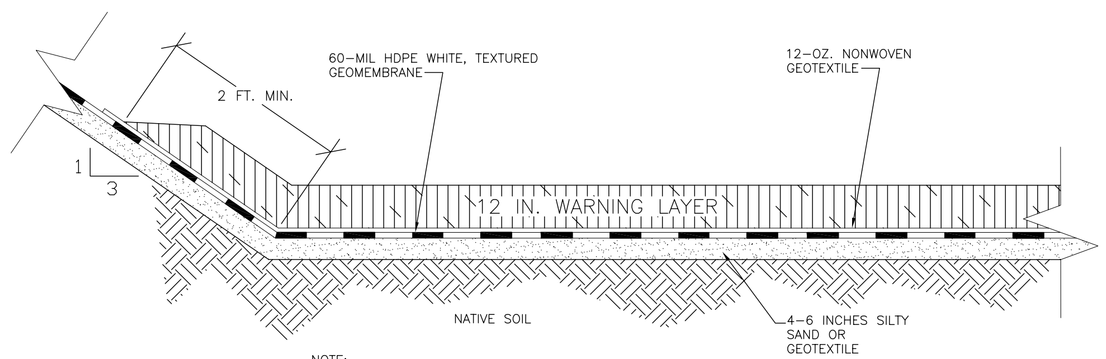
PROJECT NO. 1862/2.0	LINER SUBGRADE PREPARATION
DRAWN BY: BJK 05/03/07	ASH IMPOUNDMENT LINER DESIGN MIDWEST GENERATION JOLIET STATION NO. 29 JOLIET, ILLINOIS
CHECKED BY: EJT 05/04/07	
APPROVED BY: XX/XX/XX	DRAWING NO: D1862C020-00
	REFERENCE: .

SHEET NO. C020

Electronic Filing: Received, Clerk's Office 2/04/2022

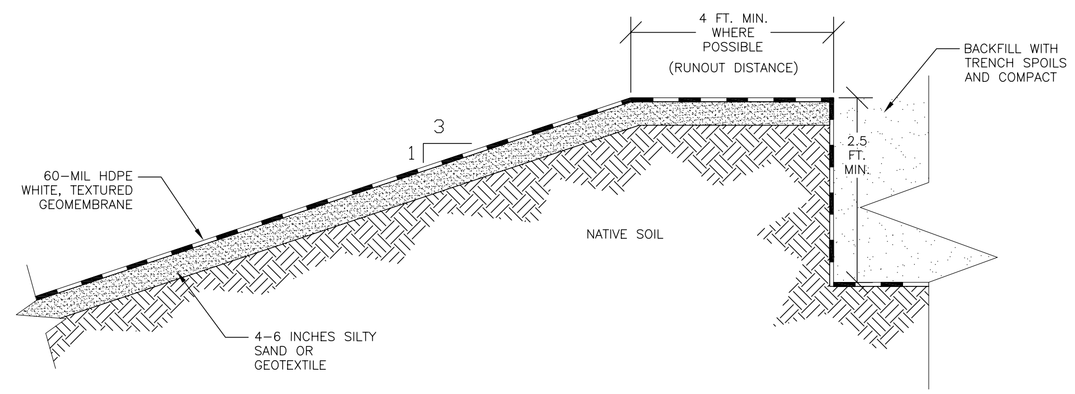


2 / C030 INLET APRON DETAIL PLAN
NOT TO SCALE



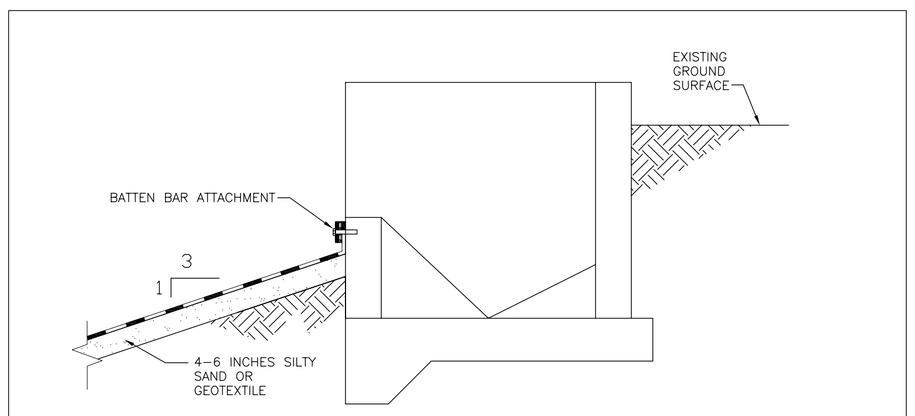
NOTE:
1. WELD'S SHALL BE PLACED 5 FT. FROM TOE OF SLOPE AT A MINIMUM.
2. CONTRACTOR SHALL PLACE 12-OZ. NONWOVEN GEOTEXTILE ON TOP OF THE GEOMEMBRANE AT THE BASE OF THE IMPOUNDMENTS AND 2 FT. UP THE INLET APRON AND SIDE SLOPES.

A / C030 SLOPE TRANSITION SECTION
NOT TO SCALE

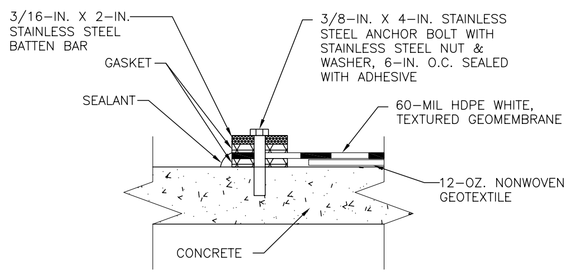


4 / C030 ANCHOR TRENCH DETAIL
NOT TO SCALE

DRAFT

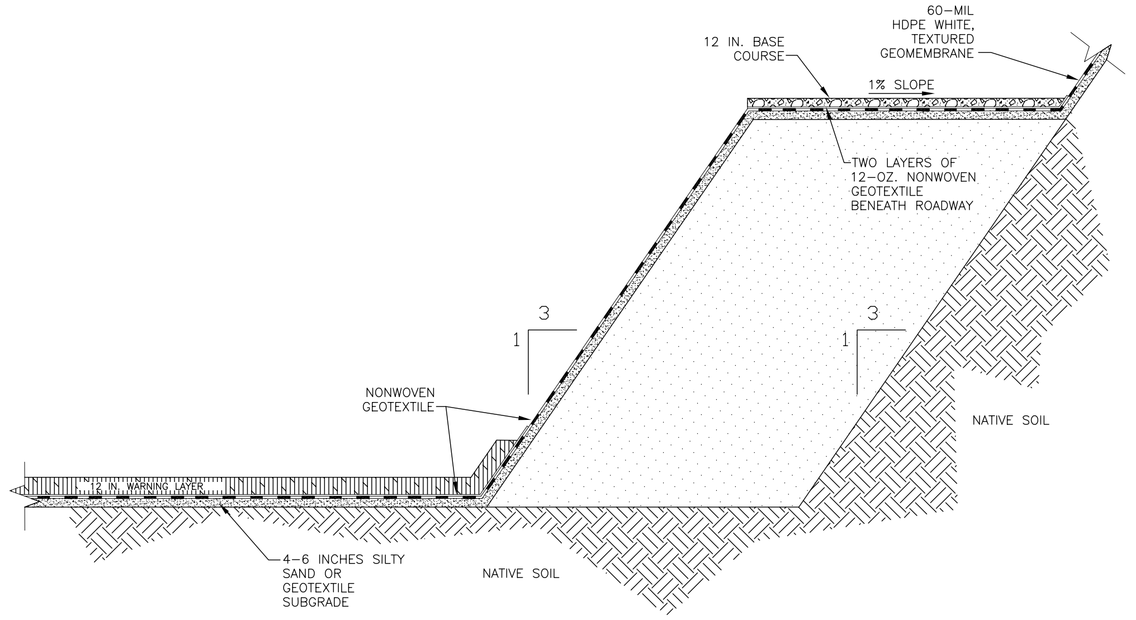


3 / C030 OUTLET WEIR DETAIL
NOT TO SCALE

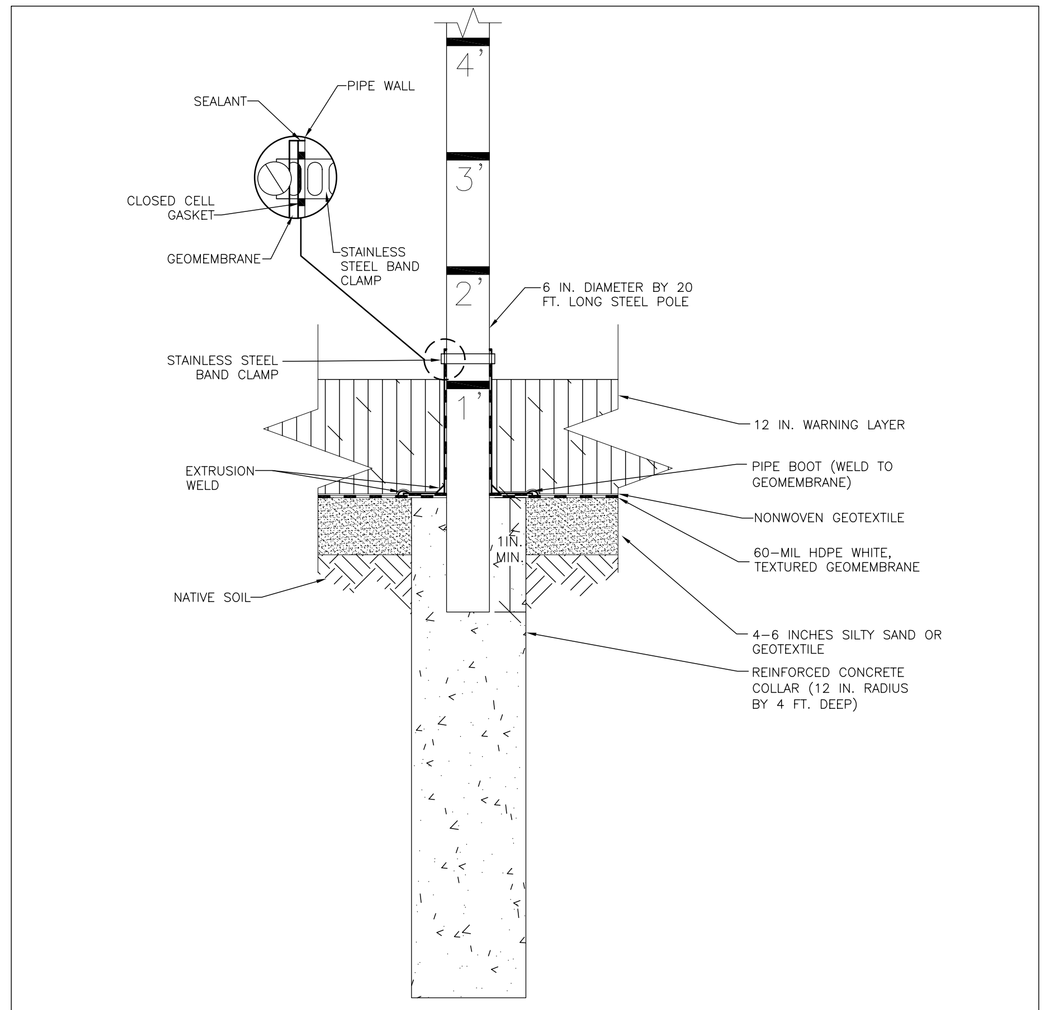


NOTE:
1. ANCHOR BOLTS 6 IN. OFF CENTER.

5 / -- BATTEN BAR ATTACHMENT
NOT TO SCALE



B / C030 RAMP SECTION
NOT TO SCALE



1 / C020 MARKER POST DETAIL
NOT TO SCALE

NOT FOR CONSTRUCTION

REVISION:	DATE:	APP'D BY:
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0. ISSUED FOR PERMIT	.	.

NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/2.0	DETAILS AND SECTIONS
DRAWN BY: RJG BJK 05/04/07	ASH IMPOUNDMENT LINER DESIGN MIDWEST GENERATION JOLIET STATION NO. 29 JOLIET, ILLINOIS
CHECKED BY: EJT 05/04/07	
APPROVED BY: XX/XX/XX	DRAWING NO: D1862C031-00
	REFERENCE: .
	SHEET NO. C031

Attachment 7

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WATER-N6B1

NATURAL RESOURCE TECHNOLOGY

MIDWEST GENERATION

Technical Specifications for Ash Impoundment #2 Liner Replacement

Joliet 29 Generation Station
1800 Channanhon Road
Joliet, Illinois

August 3, 2007

Project No: 1862

MWG13-15_18654

Electronic Filing: Received, Clerk's Office 2/04/2022

NATURAL RESOURCE TECHNOLOGY

MIDWEST GENERATION

Technical Specifications for Ash Impoundment #2 Liner Replacement

Joliet 29 Generation Station
1800 Channanhon Road
Joliet, Illinois

August 3, 2007

Project No: 1862

Electronic Filing: Received, Clerk's Office 2/04/2022

NATURAL RESOURCE TECHNOLOGY

www.naturalrt.com

TRANSMITTAL

To:	**Midwest Generation, LLC**	**Date:**	**August 3, 2007**
	Joliet 29 Station	**Project #:**	**1862**
	1800 Channanhon Road	**From:**	**Eric Tlachac**
	Joliet, IL 60436		
Attn:	**Elsie Briette**	**Direct No:**	**262-522-1214**
Cc:	**Len Johnson, Midwest Generation**		
Re:	**Draft Specifications and Drawings for Ash Impoundment #2 Liner Replacement**		

For Your Files ____ **As Requested** ____ **For Review** X **Approve & Return** ____

Copies:	Description
1	Draft Technical Specifications for Ash Impoundment #2 Liner Replacement, Midwest Generation Joliet 29 Station, 1800 Channahon Road, Joliet, Illinois.

Message:

Please find enclosed draft technical specifications and drawings for the replacement liner for Ash Impoundment #2 at the Joliet 29 Station. Please review and contact me with your comments. Following receipt of your comments, we will finalize the technical specifications and drawings, and send you an adequate number of copies to include in your Request For Proposal for the project.

Thanks for the opportunity to provide continued support to Midwest Generation on this project.

EJT

23713 W. Paul Rd., Ste. D • Pewaukee, WI 53072 • Phone: 262.523.9000 • Fax: 262.523.9001 • www.naturalrt.com

[1862 EBriette Draft Specs trans 070803]

Electronic Filing: Received, Clerk's Office 2/04/2022

NATURAL RESOURCE TECHNOLOGY

DRAFT

(DRAFT)
TECHNICAL SPECIFICATIONS FOR ASH IMPOUNDMENT #2 LINER REPLACEMENT

JOLIET 29 GENERATION STATION
1800 CHANNANHON ROAD
JOLIET, ILLINOIS

Project No. 1862

Prepared For:

Midwest Generation, LLC
1800 Channahon Road
Joliet, Illinois

Prepared By:

Natural Resource Technology, Inc.
23713 West Paul Road, Suite D
Pewaukee, WI 53072

August 3, 2007

_____	_____
Signature **(Seal)**	**Signature** **(Seal)**

MWG13-15_18657

TABLE OF CONTENTS

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SECTION 00001
SPECIFICATION DATA SHEET

INTRODUCTORY PAGE

SPECIFICATION TITLE:	Ash Impoundment #2 Liner Replacement Midwest Generation, LLC Joliet 29 Generation Station Joliet, Illinois
REVISION NO.:	0
DATE:	August 1, 2007
MIDWEST GENERATION PROJECT MANAGER:	Elsie Briette– (815) 207-5489
NATURAL RESOURCE TECHNOLOGY, INC. (NRT) ENGINEERS:	Eric J. Tlachac, PE – Project Manager–(262) 522-1214 Heather M. Simon, PE – Project Engineer–(262) 522-1207

DESCRIPTION OF WORK SUMMARY:

Replacement of liner in Ash Impoundment #2 at Joliet 29 Generation Station in Joliet, Illinois. Site activities will consist of subgrade preparation, including minimal grading, excavation, transport, stockpiling and disposal, installation of marker posts, excavation of anchor trench, installation of white, 60-mil HDPE geomembrane and surrounding geotextile, placement of warning layer material, ramp reconstruction, and leak location survey of geomembrane.

END OF SECTION

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DIVISION 1

DIVISION 1

GENERAL REQUIREMENTS

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SECTION 01010
SUMMARY OF WORK

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Definitions

B. Location of Project

C. Existing Site Conditions and Uses

D. Work by Contractor

E. Work by Owner

F. Work by Others

1.02 DEFINITIONS

A. Owner: Midwest Generation, LLC.

B. Engineer: Natural Resource Technology, Inc. (NRT).

C. Contractor: The Contractor performing the Work described herein.

D. Contract Drawings: Set of construction drawings titled, "Ash Impoundment #2 Liner Replacement, Midwest Generation, Joliet Station No. 29, Joliet, Illinois."

E. Specifications: Exhibit A – Technical specifications of which this is the first Section.

F. Work: All labor, supplies, and materials for completing liner construction, as shown and specified.

1.03 LOCATION OF PROJECT

A. The project is located at Ash Impoundment #2 at the Joliet Station No. 29 in Joliet, Illinois.

B. Site is easily accessible by truck but security clearance is required for access. All contractor personnel must sign in at gate house.

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1.04 EXISTING SITE CONDITIONS AND USES

A. Ash Impoundments #1 and #2 both receive wastewater from the plant and individually discharge to Ash Impoundment #3 (east of the plant East Entrance, not shown on Contract Drawings). They operate in parallel to one another with only one impoundment in service at any given time. Currently, Ash Impoundment #1 is operating. Ash Impoundment #2 is not operating and undergoing fly ash removal. The condition of the current liner is unknown. The base of the impoundment is approximately 19 feet from the top bank. Ash fine deposits are distributed throughout the base of the impoundment. The total approximate volume of the impoundment is 14.5 million gallons.

B. The Illinois Environmental Protection Agency (IEPA) is reviewing the Water Pollution Control Construction Permit Application for the project.

C. Access to the Site will be provided at the Main Entrance.

D. Overhead and underground utilities are present at the site.

1.05 WORK BY CONTRACTOR:

A. The Contractor shall perform the following Work:

1. Furnish all labor, materials, services, equipment, and perform all necessary work for the excavating, loading, and hauling of brush and excess material from Ash Impoundment #2 to an approved recycling/disposal facility; construction of geomembrane anchor trench; installation of geomembrane liner; excavating, stockpiling, loading, and hauling ramp material to an Owner approved location; and transporting and placing imported soil at the site; quality control activities including leak location survey; documentation surveys; and completing site restoration activities as indicated on the Contract Drawings and as specified herein.

B. It shall be the Contractor's responsibility to obtain complete information as to the work involved in the project in order to submit a complete and comprehensive bid. Under no circumstances, shall the Contractor make any claims for any additional expenses incurred due to his failure to obtain a complete understanding of the complete and detailed scope of work involved during the bid period, after award, or after the Work is in progress. The summary of work described above is an overall summary of work to be performed and is the responsibility of the Contractor. It does not supersede specific requirements of other Contract Documents.

1.06 WORK BY OWNER

A. Work to be performed by the Owner or Owner's designated representatives is as follows:

1. Construction inspection and construction quality assurance (CQA) activities.

2. Public relations.

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3. Relocation of southern aboveground piping adjacent o Ash Impoundment #2.

4. Dredging of ash deposits from Ash Impoundment #2, and transportation of ash for disposal.

PART 2 - PRODUCTS **(NOT USED)**

PART 3 - EXECUTION **(NOT USED)**

END OF SECTION

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SECTION 01015
GENERAL REQUIREMENTS

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Abbreviations

B. Contractor's Responsibilities

C. Other's Responsibilities

D. Permits

E. Measurement and Payment

F. Estimates of Plan Quantities

G. Construction Limits

H. Work on Properties Owned by Others

1.02 ABBREVIATIONS

A. Abbreviations: ANSI – American National Standard Institute
ASTM – American Society for Testing and Materials
IDOT – Illinois Department of Transportation
IEPA – Illinois Environmental Protection Agency
NEC – National Electric Code; latest edition
NEMA – National Electrical Manufacturers Association
NPFA – National Fire Protection Association
OSHA – Occupational Safety and Health Administration

1.03 CONTRACTOR'S RESPONSIBILITIES

A. Become familiar with conditions relating to execution of Work. Neglect of this requirement will not be accepted as a basis for additional compensation.

B. Schedule operations to coordinate work of Contractor's forces, subcontractors, and suppliers to meet project schedule and completion date.

C. Obtain complete data of site and inspect areas scheduled to receive Work before proceeding with such Work.

D. Obtain any permits necessary to haul materials or equipment on public streets and highways. Obey load restrictions at all times.

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E. Take all precautions required to maintain the integrity and structural stability of the existing structures and utilities.

F. Maintain vehicle access on private roads for plant personnel.

G. Repair or clean public or private roads or driveways following damage or spillage.

H. Be solely responsible for obtaining and verifying accuracy of measurements and layout of Work.

I. Correct deficiencies, errors, or defects due to faulty measurements, information, layout, or due to failure to report discrepancies.

J. Immediately notify Owner and/or Engineer in writing in case of discrepancies between existing work and drawings or defects on such surfaces that are to receive work prior to commencing work. Failure to notify Owner and/or Engineer of such discrepancies and/or defects shall be done at expense of Contractor who applied work to defective surfaces.

K. Location of existing underground and aboveground utilities, structures, and other obstructions shown on Contract Drawings are taken from existing information and are approximate only. Obstructions not shown on the Drawings may exist and shall be exposed by Contractor without damage. Contractor shall be responsible for damage to existing facilities and utilities resulting from Contractor's operations and shall repair or replace damaged items to Owner's satisfaction.

1.04 OTHER'S RESPONSIBILITIES

A. Owner and/or Engineer shall be responsible for scheduling performance of Work by Owner or others.

B. Owner and/or Engineer shall be responsible to maintain daily contact with Contractor during progress of work.

1.05 PERMITS

A. Permits

1. Owner has obtained IEPA Water Pollution Control Construction Permit required for project.

2. Copies of permits and approvals provided by the Owner will be made available to the Contractor.

3. Copies of Permits obtained by the Contractor shall be provided to the Owner.

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1.06 ESTIMATES OF PLAN QUANTITIES

A. Quantities of materials provided in these plans and specifications are estimates and are to be verified by the Contractor prior to use in preparing the bid.

1.07 CONSTRUCTION LIMITS

A. Contractor shall restrict operations and storage of materials and equipment to the area within the project site as shown on the Contract Drawings unless otherwise approved by the Owner. Owner will further define the construction limits in the field when the Contractor believes it is appropriate or upon reasonable request of Contractor. Contractor shall restore all disturbed areas within the construction limits as necessary to match pre-existing conditions.

1.08 WORK ON PROPERTIES OWNED BY OTHERS

A. Contractor shall be familiar with property boundaries and those of the adjacent properties at the site where work is to be conducted.

B. Storage of materials or equipment on property owned by others is not allowed unless as authorized by the Owner.

C. Notify and receive advance approval of the Owner of need to remove or disturb materials not addressed by these documents.

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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SECTION 01040
PROJECT ADMINISTRATION

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Contractor Supervision and Subcontracted Work

B. Submittals

C. Project Meetings

D. Construction Schedule

E. Work Hours and Coordination

F. Reports

1.02 RELATED SECTIONS

A. Section 01050-Field Engineering and Surveying

B. Section 01300-Submittals

C. Section 01400-Quality Assurance and Control

1.03 CONTRACTOR SUPERVISION AND SUBCONTRACTED WORK

A. Assign one superintendent or foreman to be on site continuously during working hours from start to finish of project. Submit site superintendent/foreman's name and phone number prior to project start. The superintendent shall be the primary contact with the Owner and/or Engineer and shall be responsible for all negotiated change orders. If Contractor changes foreman assigned to site, Contractor shall make transition seamless to avoid lost work. In the event of a change in supervisory staff, the Owner shall be provided a minimum of two weeks notice prior to making the change.

B. Use an adequate number of skilled workers who are thoroughly trained and experienced and who are completely familiar with specified requirements and methods needed for performance of Work.

C. Use experienced professional personnel for that work which requires judgment, knowledge, and expertise of qualified professionals, and who are familiar with all aspects of Work.

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D. Contractor's superintendent/foreman shall maintain communication between subcontracted personnel and Contractor's personnel, and shall be on site when subcontractors are on site performing work.

E. Contractor shall direct and supervise all Subcontractors.

F. Contractor shall submit names of all Subcontractors who will be performing any work with bid.

1.04 SUBMITTALS

A. As required in accordance with this Section, Section 01300 and Table 2.

1.05 PROJECT MEETINGS

A. A pre-construction meeting will be conducted by the Owner and/or Engineer. Contractor shall submit all submittals required prior to the project start prior to the pre-construction meeting. Meeting shall be held at the site unless otherwise announced. At a minimum, the following personnel shall attend: Contractor, including site superintendent/foreman, geosynthetics installer's site superintendent / foreman, Owner and/or Engineer. The agenda for the meeting shall include, but not be limited to:

1. Review work scope.

2. Review status of submittals required to be transmitted prior to project commencement.

3. Discuss project administration prior to start of work.

4. Determine frequency and schedule for progress meetings.

5. Discuss the coordination and scheduling of each major element of the construction, including but not be limited to, site preparation, excavation and grading, anchor trench, geomembrane installation, backfilling, leak location survey, and site restoration.

6. Discuss Owner's emergency notification and operating practices for emergency situations.

B. The Owner and/or Engineer will conduct regular progress meetings for the purpose of coordinating and inspecting Work. All parties will agree upon the frequency and schedule for progress meetings at the pre-construction meeting. Contractor and subcontractors shall attend weekly progress meetings during the duration of each subcontractor's work.

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C. Owner and/or Engineer will conduct a final inspection meeting for purpose of confirming project is complete and consistent with Contract Documents. Meeting will be scheduled when Contractor has submitted written certification to Owner that the Contract Documents have been reviewed, Work has been inspected, and that Work is Substantially Complete in accordance with Contract Documents and ready for final inspection (Section 01700).

D. A principal member of Contractor's staff, authorized to make decisions on his behalf, shall represent Contractor at each meeting. Owner and/or Engineer may direct certain subcontractors to attend meetings as needed. Failure to attend a meeting does not relieve Contractor from acting on contents of meetings.

E. Owner and/or Engineer will record all pertinent topics discussed and any resulting action items in the minutes of the project meetings. Meeting minutes will be distributed prior to the next meeting to all parties in attendance and responsible for action items.

F. Special meetings may be called at discretion of the Owner and/or Engineer for the purpose of resolving problems or other purposes concerning Work. Attendance at special meetings is mandatory for Contractor and other parties requested by Owner and/or Engineer to attend.

1.06 CONSTRUCTION SCHEDULE

A. Overall work is to be completed as indicated in these Technical Specifications.

B. A Baseline Construction Schedule is required to be submitted with the Contractor's bid. Within 10 working days of date of contract award, Contractor shall submit to Company and/or Engineer for review one updated copy of the Baseline Construction Schedule. Schedule shall be time-scaled and show work activities, including sequence of performance and interdependency. Each activity shall be labeled and include an estimated duration in working days. Baseline Construction Schedule shall comply with required completion date stated in Contract Documents and any work restrictions, including restrictions on days or hours of work, stated in Technical Specifications. Baseline Construction Schedule shall be discussed at pre-construction meeting.

C. The Contractor shall update the Baseline Construction Schedule during Construction to indicate actual progress in percent completion for each activity and submit one updated copy to the Owner and/or Engineer one work day prior to the regularly scheduled progress meeting. This updated schedule is termed "Progress Schedule". In addition to indicating actual progress, the Progress Schedule shall also indicate any changes in completion times or dates for any of activities shown on previous version.

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D. Each Progress Schedule shall be submitted with a written narrative describing revisions, if any, from the previous version, the effects of these revisions upon remaining Work and schedule, and corrective actions taken or proposed by Contractor.

E. Owner and/or Engineer shall review the Contractor's Baseline Construction Schedule and Progress Schedules. Comments made by Owner and/or Engineer on Schedule, lack of such comments, rejection, or acceptance of Contractor's Schedule does not relieve Contractor from compliance with Contract Documents, nor create any responsibility or duty for scheduling owed from Owner and/or Engineer to Contractor. This review, whether accompanied by comments, rejection, or neither, is only for general conformance with information provided in the Contract Documents.

F. Any contingency within Schedule (i.e., a difference in time between project's early completion and required completion dates) will belong to Project and not any parties to Contract.

G. Contractor shall furnish material and labor at proper time and in sufficient quantities to correspond with actual job progress whether or not such actual progress is in conformance with subsequent Progress Schedules.

H. Should Contractor fail to adhere to the Baseline Construction Schedule or revised Progress Schedules, Contractor shall promptly take measures necessary to regain conformance with such schedules at no additional cost to Owner. Addition of equipment or construction forces, increase in working hours, or any other method, manner, or procedure to return to Schedule shall not be considered justification for a request for additional compensation or treated as an acceleration order. If, in opinion of the Owner, methods prove unsuccessful in compensating for lost time, Owner shall have right to pursue remedies, as described in Agreement and General Conditions of Contract Documents.

1.07 WORK HOURS AND COORDINATION

A. Contractor shall perform work during a regular workweek of ten hours per day, Monday through Friday. Working hours will be 7:00 a.m. to 5:00 p.m. Saturday work and hours shall be reviewed with the Owner on a case by case basis.

B. Contractor shall keep the Owner and/or Engineer informed, at reasonable time in advance or as required by specific sections of Technical Specifications, of times and places where work is to be done, so that any inspection or oversight deemed necessary may be done with minimum inconvenience to the Owner and/or Engineer.

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1.08 REPORTS

A. Contractor shall be responsible for submitting to the Owner and/or Engineer a progress report one work day prior to a regularly scheduled progress meeting. Progress report shall include following:

1. A brief description of work completed during the current reporting period.

2. Quantities and volumes of work completed during the current reporting period.

3. Contractor's summary of work completed and estimate of percentage of completion for each work item.

4. Erosion control inspection records, as necessary.

5. A list of work scheduled for the next reporting period.

6. Quantities and volumes of work anticipated for the next reporting period.

7. A list and number of supervision and craft people on site by craft.

8. A review of conditions affecting execution of work, including encountered or anticipated problem areas, including delays and causes.

B. Contractor shall be required to submit the following special reports:

1. Accident Reports

2. Work Stoppage/Dispute Records

3. Contractor's Invoices

4. Schedule of Values

5. Test Report Records

6. Equipment Check Reports

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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SECTION 01050
FIELD ENGINEERING AND SURVEYING

PART 1 – GENERAL

1.01 SECTION INCLUDES

A. Work by Contractor

B. Contractor's Responsibilities and Submittals

C. Survey Data for Construction Documentation

D. Construction Documentation Drawings

1.02 WORK BY CONTRACTOR: Contractor shall provide field engineering and surveying services as required for proper completion of work including:

A. Documenting location of anchor trench.

B. Documenting location and elevation of geomembrane panels.

C. Documenting location of marker posts.

D. Documenting topography of warning layer.

1.03 CONTRACTOR'S RESPONSIBILITIES AND SUBMITTALS

A. Upon commencement of construction work, become familiar with the location of existing benchmarks, control points, and other necessary reference points. Maintain their accuracy and prevent disturbance or destruction. Contractor is responsible for re-establishing control points and benchmarks if such items are damaged and/or destroyed at no cost to Owner.

B. Establish and verify grades, lines, levels, locations and dimensions as shown on Drawings and report any errors or inconsistencies to Owner and/or Engineer before commencing work.

C. Initial staking of discharge pipe and anchor trench.

D. Lay out own work and be responsible for all surveys, lines, elevations, and measurements of structures and other work executed under Contract. Exercise proper preparation to verify figures on Drawings within construction limits before laying out work. Any error resulting from failure to exercise such precautions or work done without being properly located may be removed at Owner's direction and corrected or replaced at Contractor's expense.

F. Contractor shall verify its own work with respect to required grades prior to documentation surveys. Areas deficient will be corrected and resurveyed at Contractor's expense.

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1.04 SURVEY DATA FOR CONSTRUCTION DOCUMENTATION

A. Survey work performed by Contractor shall be certified by a registered land surveyor (RLS), and will include items identified in Table 1.

B. Frequency of surveys for each item is summarized in Table 1 and relevant Sections of the Technical Specifications.

C. Survey data shall be supplied to Owner and/or Engineer in one of the following formats within two working days after completion of survey:

1. Topographic map (hard copy and electronic file compatible with AutoCAD).

2. Tabular (according to Table 1).

3. ASCII files (northing, easting, elevation).

D. Contractor will be notified by Owner and/or Engineer of areas to be adjusted or will be given written approval of surveyed area within two working days of receiving survey data.

E. Contractor shall obtain written approval from Owner and/or Engineer for each surveyed area prior to placement of any overlying materials.

1.05 CONSTRUCTION DOCUMENTATION DRAWINGS

A. Contractor shall distribute record drawings to Owner and/or Engineer based on results of documentation survey within four working days following completion of survey for a particular surface or set of features as supplied by the RLS.

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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SECTION 01300
SUBMITTALS

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. General Requirements

B. Submittal Format

C. Submittal Procedures

1.02 GENERAL REQUIREMENTS

A. Procedures and format for submittals required by the Technical Specifications that may include but are not limited to:

1. Soil and/or material test data
2. Survey data
3. Product test data
4. Progress reports
5. Shop drawings
6. Manufacturers instructions, certificates, guarantees and warranties
7. Management, staging and sequencing plans
8. Schedules

B. Refer to Technical Specifications and Table 2 for list of submittals.

1.03 SUBMITTAL FORMAT

A. All submittals shall be transmitted by Contractor with the following identified on the cover sheet:

1. Project name and contract number.
2. Applicable Technical Specification (Section) and submittal number.

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3. Date (or revision number).

4. Sequential page numbers.

B. Submittals shall be made in triplicate.

C. Stamp, sign, or initial submittal certifying products or field dimensions, whichever pertains, are in accordance with requirements of Work and Contract Documents.

1.04 SUBMITTAL PROCEDURES

A. Provide all submittals and information as identified in Technical Specifications to named parties in the time frames indicated in Table 2. Payments may be withheld, in whole or in part, at discretion of the Owner in the event that submittals are not made within times specified unless previously requested in writing by the Contractor (to Owner and/or Engineer) and approved in writing by Owner and/or Engineer.

B. Transmit submittals by appropriate means to expedite review of submittal. Submittals delivered by hand, facsimile, or mail service are acceptable. Business addresses of project representatives will be provided at the pre-construction meeting.

C. Submittals shall be made far enough in advance of the scheduled approval dates to allow adequate time for reviews, approvals, and revisions.

D. Submittals shall identify variations from Contract Documents and product or system limitations that may be detrimental to successful performance of completed work.

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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SECTION 01400
QUALITY ASSURANCE AND CONTROL

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Construction Quality Assurance

B. Contractor's Role

C. Engineer's Role

D. Owner's Role

1.02 CONSTRUCTION QUALITY ASSURANCE

A. Owner shall arrange for and inform Contractor of inspection and testing activities to confirm that the construction activities and completed Work complies with Technical Specifications and Contract Drawings.

B. Owner's inspection and testing activities shall consist of following activities:

1. Daily observation and record of Contractor activities.

2. Arrange for in-place soil compaction testing, as necessary.

3. Obtain material samples and transport samples to laboratory, as necessary.

4. On-site visual material inspection and testing.

5. Verifying compliance with Technical Specifications and Drawings.

1.03 CONTRACTOR'S ROLE

A. Perform work in strict accordance with Technical Specifications and Drawings, using necessary construction procedures and techniques. Coordinate, supervise, and oversee subcontractors as needed to perform construction activities.

B. Perform testing as deemed necessary to satisfy requirements of Technical Specifications related to off-site materials prior to delivery to site. Materials that do not meet specifications shall be removed from site at Contractor's expense.

C. Contractor shall replace and/or recompact material at Contractor's expense, if soil compaction not acceptable per compaction requirements.

D. Furnish material samples and provide assistance in on-site inspection and test activities.

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E. Provide submittals required by Contract Documents within times specified. Failure to do so will result in withholding of payment.

F. Perform or arrange survey and layout work to construct Work in accordance with Drawings and applicable sections of Technical Specifications.

G. If manufacturer's instructions and/or standard industry practice conflicts with Technical Specifications or Drawings request clarification from Owner and/or Engineer before proceeding.

H. Communicate any pertinent issues with the Owner and/or Engineer.

1.04 ENGINEER'S ROLE

A. Provide clarifications to Technical Specifications and Drawings, as well as any necessary design changes requested by the Owner.

B. Issue a Field Directive in cases where deviation from specified design, Technical Specifications and Drawings is necessary.

C. Communicate any pertinent issues with the Owner and/or Contractor.

D. Confirm construction compliance with Technical Specifications and Drawings by performing observations, inspections, verifications, and documentation activities, as directed by Owner.

E. Provide photo documentation and daily written reports documenting construction according to the Technical Specifications and Drawings, as directed by Owner.

F. Perform or observe soil and/or geosynthetic inspections and testing to confirm materials meet requirements herein, as directed by Owner.

1.05 OWNER'S ROLE

A. Perform Owner's engineering review and monitor construction progress, progress payment approval, and approval of field job orders.

B. Confirm construction compliance with Technical Specifications and Drawings by performing observations, inspections, verifications, and documentation activities, as necessary.

C. Perform Owner's administrative and managerial responsibilities. Owner has authority to accept/reject materials and workmanship, and for dispute resolution.

D. Communicate any pertinent issues with Contractor and/or Engineer. Maintain communication with IEPA, as necessary.

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PART 2 - PRODUCTS **(NOT USED)**

PART 3 - EXECUTION **(NOT USED)**

END OF SECTION

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SECTION 01500
CONSTRUCTION FACILITIES AND TEMPORARY CONTROLS

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Use of Site Facilities

B. Security

C. Parking

D. Telephone Service

E. Temporary Utilities

F. Sanitary Facilities

G. Equipment Storage Locations

H. Dust and Mud Controls

I. Fugitive Emissions Controls

J. Construction Noise

K. Water and Erosion Controls

L. Barriers and protection of installed work.

M. Site Progress Cleaning

N. Fuel Storage and Handling

O. Protection of the environment

P. Public Road Requirements

Q. Additional Requirements

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1.02 USE OF SITE FACILITIES

A. Use of Site

1. Contractor shall consult with the Owner and/or Engineer regarding locations for offices, trailers, material storage, access roads, fences, gates, and areas within construction limits for use by Contractor.

2. Contractor shall conduct construction activities in a manner to minimize interference with plant operations.

3. Confine equipment, storage of materials, and operations of workmen to areas designated by the Owner. Do not bring materials onto site until reasonably required for progress of work. No area outside of construction limit or staging area may be used for any purpose by Contractor or subcontractors unless expressly approved by the Owner in writing.

4. Store, place, and handle material and equipment to protect from any damage. Contractor shall move materials, sheds, or storage platforms, as necessary or when required for continuing construction at Contractor's expense.

5. Owner assumes no responsibility for project material or equipment stored on site or off site. Contractor assumes full responsibility for damage due to storage of materials.

6. Contractor is responsible to schedule work, storage of materials, etc., to minimize interference with construction activities.

7. Contractor is responsible for all snow removal as necessary during duration of project, as necessary.

8. Contractor is responsible for controlling sediment migration, reventing tracking of sediment onto site access roads and public roads along haul routes, and cleaning site access roads and public right-of-ways and streets daily or as deemed necessary by Owner with commercial street sweepers.

B. Contractor shall inspect site with Owner and/or Engineer prior to start of work to determine existing conditions in conjunction with preconstruction meeting (Section 01040).

1.03 SECURITY

A. Security is not provided by Owner for Contractor's property.

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B. Contractor is responsible for loss or injury to persons or property where his work is involved, and shall provide security and take precautionary measures as deemed necessary to protect Contractor's and Owner's interests.

1.04 ACCESS ROADS AND PARKING

A. Contractor shall maintain the service road accessing the construction areas and stockpile areas as necessary, or as directed by Owner and/or Engineer.

B. Parking areas on site shall be within the work area or area designated by Owner

1.05 TELEPHONE SERVICE

A. Contractor shall provide, maintain and pay for cellular phone service for Contractor's designated on-site superintendent or foreman. In addition, subcontractor's designated on-site personnel shall have cellular phones.

1.06 TEMPORARY UTILITIES

A. Electricity

1. Contractor shall arrange and pay for temporary electrical service as needed.

3. OSHA regulations require that employers shall use either ground fault circuit interrupters or an assured equipment grounding conductor program in addition to any other regulations for equipment grounding conductors.

4. Utilize and remove upon completion of project an electrical distribution system for temporary light and power during construction, if necessary.

B. Water

1. Water is not available on site.

2. Contractor shall provide clean water to be used for dust suppression in work areas. Dust suppression will be necessary for haul roads, stockpile areas, and within construction limits. Submit source of clean water to be used for dust suppression to Owner and/or Engineer for approval prior to project commencement.

3. Contractor shall provide potable water for Contractor's employees, as necessary.

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1.07 SANITARY FACILITIES

A. Contractor shall provide sanitary facilities on site conforming to state and local health and sanitation regulations in sufficient number for use of Contractor's employees.

B. Contractor shall maintain on-site facilities in sanitary condition at all times.

1.08 EQUIPMENT STORAGE LOCATIONS

A. Contractor shall park equipment and store materials only in areas proposed by Contractor and approved by Owner.

B. Restore disturbed areas to pre-construction condition upon project completion.

1.09 DUST AND MUD CONTROLS

A. Conduct operations and maintain site at all times to minimize creation and dispersion of dust and mud.

B. Provide equipment necessary to control dust generation resulting from wind effects on open stockpiles, excavations, and from Contractor's vehicle and equipment traffic at all times. Control dust by application of water to affected areas, such that surfaces are moistened to prevent dust from becoming a nuisance to public, neighbors, and concurrent performance of other work at site. Contractor shall prevent dusting 24 hours a day from project commencement to substantial completion of the work.

C. Control mud and tracking of mud on site access roads and public roads along haul routes. Maintain surfaces in proper condition to facilitate removal efficiency.

D. The Owner and/or Engineer shall monitor site conditions related to dust and mud generation on a daily basis and direct Contractor to take actions as necessary to address deficient practices or conditions deleterious to construction and/or public.

E. Clean public right-of-ways and streets as deemed necessary by Owner with commercial street sweepers.

1.10 CONSTRUCTION NOISE

A. The Owner shall decide on the adequacy of provision and maintenance of noise reduction equipment. When so instructed by the Owner, the Contractor shall immediately withdraw any item of plant or equipment from service and carry out all necessary additions, replacements, or repairs to the noise reduction equipment to the satisfaction of the Owner.

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1.11 WATER AND EROSION CONTROLS

A. Contractor shall install and maintain erosion control measures necessary to prevent runoff, tracking, or loss of soil materials by water or mechanical action from disturbed portions of the site or excavation areas(s).

B. No direct discharge shall be allowed into Ash Impoundment #1 without the approval from Owner.

1.12 BARRIERS AND PROTECTION OF INSTALLED WORK

A. Contractor shall protect installed work and provide special protection as needed.

B. Construction traffic shall be prohibited on completed and/or landscaped areas.

C. Protect existing facilities and adjacent properties from damage during construction operations.

1.13 SITE PROGRESS CLEANING

A. Maintain areas free of waste materials, debris, and rubbish. Site shall be maintained in clean and orderly condition.

B. Remove waste materials, debris, and rubbish from site weekly and dispose off-site at Contractor's expense and in accordance with federal, state and local regulations.

C. Contractor shall provide a dumpster on site for general waste materials and rubbish during site activities.

1.14 FUEL STORAGE

A. Store fuel according to local, state, and federal laws.

1.15 FUEL HANDLING

A. At no time shall overtopping fuel tanks or spillage to the ground surface be allowed.

1.16 PROTECTION OF THE ENVIRONMENT

A. Minimize air pollution by use of properly operating emission control devices on construction vehicles and equipment. Encourage shutdown of motorized equipment not in use.

B. Trash burning not permitted on site.

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C. All areas for handling and storage of fuels, oils, and other potentially hazardous liquids shall have spill containment or release prevention measures. Maintenance of equipment on site shall be with prior approval of the Owner and/or Engineer.

D. All waste materials shall be recycled, hauled to a licensed solid waste landfill, or otherwise disposed of in an environmentally sound manner and in compliance with all applicable local, state, and federal rules.

E. All hazardous waste shall be stored, handled, and disposed of in compliance with applicable local, state and federal rules.

F. Other measures shall be taken, as necessary, to maintain work site in an environmentally sound matter.

G. All spills or leaks of fuels, oil, or other IEPA-reportable liquids resulting from handling or equipment malfunctions shall be reported immediately to Owner and/or Engineer. Affected soils shall be properly removed from limits of construction and disposed in accordance with applicable local, state and federal rules at the sole expense of the Contractor and as agreed by the Owner and/or Engineer. Copies of manifests, if necessary, shall be provided to Owner and/or Engineer within five working days of disposal. Waste Generator Manifests shall not state Owner as Generator. Owner reserves right to order leaking equipment removed from site.

1.17 PUBLIC ROAD REQUIREMENTS

A. Contractor shall comply with Local Weight Limits. Local roads shall be cleaned daily, as necessary, to maintain their condition free of mud and dirt.

B. The Contractor shall conduct his operations on the site in a manner that will minimize interference with the normal operation of plant, adjoining public and private roads and parking lots, and shall implement all specified and other appropriate measures to ensure the safety of all users of the adjoining public and private roads and parking lots.

C. Contractor shall provide flag person(s) as necessary and at request of Owner and/or Engineer.

1.18 ADDITIONAL REQUIREMENTS

A. No cameras are allowed on the site without permission from the Owner.

B. No firearms or explosives are allowed on site.

C. Possession and/or use of intoxicating beverages and nonprescription drugs are prohibited at all times. Persons caught in possession or under the influence of drugs or alcohol will be immediately dismissed and removed from the site.

D. Smoking will be allowed in designated areas only.

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E. No horseplay is permitted on the job site.

F. Visitors or personnel not employed by the Contractor or his approved Subcontractors shall not be permitted on site without prior approval by the Owner.

G. Owner and/or Engineer reserve the right to require that any of the Contractor's personnel be excluded from work at the site at any time.

PART 2 – PRODUCTS (NOT USED)

PART 3 – EXECUTION (NOT USED)

END OF SECTION

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SECTION 01700
PROJECT CLOSEOUT

PART 1 - GENERAL

1.01 SECTION INCLUDES

A. Description of Work

B. Procedures

C. Record Documents

1.02 DESCRIPTION OF WORK

A. To provide an orderly and efficient transfer of the completed Work to the Owner.

1.03 PROCEDURES

A. Remove temporary above grade or buried utilities, equipment, materials, prior to final application or payment inspection, and clean and repair damage caused by installation or use of temporary facilities.

B. Substantial Completion: When all work described in the contract documents is completed:

1. Owner and/or Engineer will prepare and submit a list of items to be completed for Contractor review and completion.

2. Should the Owner and/or Engineer determine that the Work is not substantially complete; Contractor will remedy the deficiencies and notify the Owner and/or Engineer when ready for re-inspection.

C. Final Completion:

1. Remove waste and surplus materials, rubbish, and construction facilities from site.

2. Prepare and submit the notice that all Work is complete.

3. Certify in writing that the Work is complete and ready for final inspection.

4. Owner and/or Engineer will make a final inspection to verify status of completion.

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1.04 RECORD DOCUMENTS

A. Contractor will maintain on site one set of following record documents of all items of work; record actual revisions of all items of work:

1. Drawings.

2. Technical Specifications.

3. Change orders and other modifications to contract.

4. A copy of approvals of work performed.

5. Record documents.

B. Engineer, as directed by Owner, will record information concurrent with construction progress including changes made by addenda and modifications.

C. Contractor will maintain a Daily Field Log including work times, personnel on site, equipment used, and other essential information of the operation's progress.

PART 2 - PRODUCTS (NOT USED)

PART 3 - EXECUTION (NOT USED)

END OF SECTION

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DIVISION 2

DIVISION 2

SITE WORK

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SECTION 02300
EARTHWORK

PART 1 - GENERAL

1.01 WORK INCLUDES

A. Preparation of Ash Impoundment 2 liner subgrade by clearing and grubbing vegetation and removing rocks and other debris greater than 3 inches in diameter along side slopes and base of impoundment, and excavating at least 18 inches of existing ramp surface material.

B. Load and transport rocks and other debris removed from liner subgrade to an approved recycling or disposal facility.

C. Load and transport excavated ramp material to a stockpile area on site, as directed by Owner, for reuse at project completion.

D. Installation of marker posts along toe of the Ash Impoundment side slopes, as shown on Contract Drawings, prior to installation of geomembrane.

E. Trenching, backfilling, and compaction for anchoring geomembrane and geotextile including field verifying the location of discharge pipes, protection and maintenance of trench, and support of existing structures (i.e., aboveground piping, outlet and inlet).

F. Load and transport excess trench spoils to an approved recycling or disposal facility.

G. Placement, grading and compaction of sand material including weighting and transporting to site following installation of geomembrane.

H. Placement, grading and compaction of warning layer material including weighing and transporting to site following placement of sand material.

I. Placement of riprap at base of inlet apron.

J. Placement, grading, and compaction of excavated ramp material, including loading and transporting from on-site stockpile area to the ash impoundment ramp following installation of geomembrane.

1.02 RELATED SECTIONS

A. Section 01050 – Field Engineering and Surveying

B. Section 02600 – HDPE Geomembrane

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1.03 DEFINITIONS

A. Structures and Surface Features: Existing structures and surface features including buildings, signs, posts, utility poles, monitoring wells, fences, trees, shrubs, landscaped surface features, and other miscellaneous items.

B. Utilities: Existing gas mains, water mains, electric lines, storm sewers and conduits, telephone and other communication lines and conduits, sewer pipe, cable television, other utilities, and appurtenances.

C. Clearing and Grubbing: cutting, removal and disposal of trees, roots, brush, stumps, windfalls, logs, and other vegetation.

1.04 REFERENCES

A. ASTM D422-63 – Standard Test Method for Particle-Size Analysis of Soils.

B. ASTM D2487-93 – Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System).

C. ASTM D2940 – Standard Specifications for Graded Aggregate Material for Bases or Subbases for Highways or Airports

D. State of Illinois, Department of Transportation, Standard Specifications for Road and Bridge Construction, current edition.

E. OSHA 29 CFR Part 1926, Occupational Safety and Health Standards Excavations.

1.05 PERFORMANCE REQUIREMENTS

A. Excavation and grading shall be done without damage to adjacent property or structures and without interference to public and/or plant pedestrian and vehicular traffic.

B. Provide adequate backup systems to accomplish the excavation.

C. Complete Work to required grades as indicated in the Contract Drawings.

1.06 SUBMITTALS

A. In accordance with Section 01300.

B. Submit with bid a description of proposed Earthwork Plan, including but not limited to:

1. Methods and equipment.

2. Temporary staging facilities and stockpile locations.

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3. Methods of advancing and stabilizing anchor trenches.

4. Sequence of liner subgrade preparation, shoring, grading, material staging and replacement.

If changes occur, submittal shall be revised no later than five days prior to project start. Re-submittals shall be made during course of construction if plan is modified during construction.

C. Submit prior to start of construction the name and location of all sources that will be used to obtain the materials specified in this Section.

D. Provide Owner and/or Engineer written notice of construction start date at least five working days prior to beginning site activities.

E. Submit for documentation certificates and/or test results for one sample of each material obtained from off-site sources indicating compliance with Specifications prior to start of construction. Owner and/or Engineer may take random samples of the material upon delivery or placement to verify compliance with the Specifications.

F. Submit with bid name and location of the recycling and/or disposal facility that will be used to dispose of excess material specified in this Section.

PART 2 - PRODUCTS

2.01 GENERAL SOIL MATERIALS

A. Provide borrow soil materials when sufficient satisfactory soil materials are not available from excavations.

B. Satisfactory Soils: ASTM D2487 soil classification groups GW, GP, GM, SW, SP, and SM, or a combination of these group symbols; free of rock or gravel larger than 3 inches (75 mm) in any dimension, debris, waste, frozen materials, vegetation, and other deleterious matter.

C. Unsatisfactory Soils: ASTM D2487 soil classification groups GC, SC, MH, CH, OL, OH, and PT, or a combination of these group symbols.

1. Unsatisfactory soils also include satisfactory soils not maintained within 2 percent of optimum moisture content at time of compaction.

D. Unclassified Imported Fill: Satisfactory soil materials.

E. Excavated Ramp Material: Excavated material from the existing ramp surface that does not require disposal and may be reused as backfill, subject to Owner's and/or Engineer's approval.

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F. Anchor Trench Backfill: Trench spoils free of rock or gravel larger than 3 inches in any dimension, debris, waste, frozen materials, vegetation and other deleterious matter.

G. Riprap at Base of Inlet Apron: Riprap shall be durable field or quarry stone between 4 and 12 inches in diameter.

2.02 BASE COURSE MATERIAL (AS NEEDED)

A. Imported base course material shall be obtained from an off-site borrow source of the Contractor's choice and shall at a minimum satisfy the following specifications:

1. Naturally or artificially graded mixture of natural or crushed gravel, crushed stone, and natural or crushed sand; ASTM D 2940; with at least 95 percent passing a 1-1/2-inch sieve and not more than 8 percent passing a No. 200 sieve; and

2. Other materials with greater or equal bearing characteristics with the written approval of the Owner and/or Engineer. Verify the materials meet and/or exceed the materials specified in 2.02.A.1.

B. Contractor shall provide to Owner and/or Engineer a representative gradation (ASTM D422) and classification (ASTM D2487) for the base course material proposed for use in the project two weeks prior to delivery to site.

2.03 SAND MATERIAL

A. Conform to Section 1003.01, Fine Aggregates of Standard Specifications for Road and Bridge Construction:

a. Grade No. FA 1 or FA 2 shall be used; and

b. Other materials with greater or equal characteristics with the written approval of the Owner and/or Engineer.

B. Contractor shall provide Owner and/or Engineer a representative gradation (ASTM D422) and classification (ASTM D2487) for the sand layer two weeks prior to delivery to site.

2.04 WARNING LAYER MATERIAL

A. Imported Warning Layer Material shall be obtained from an off-site borrow source of the Contractor's choice and shall at a minimum satisfy the following specifications:

1. Conform to Section 1004.04, Coarse Aggregate for Stabilized Subbase of Standard Specifications for Road and Bridge Construction:

a. Grade No. CA 6 shall be used; and

b. Other materials with greater or equal characteristics with the written approval of the Owner and/or Engineer.

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B. Contractor shall provide Owner and/or Engineer a representative gradation (ASTM D422) and classification (ASTM D2487) for the warning layer two weeks prior to delivery to site.

PART 3 - EXECUTION

3.01 PROTECTION OF UTILITIES AND STRUCTURES

A. At least ten business days before beginning Work, coordinate utility locate with Owner and Owner's utility locator for locating Owner's private utilities near the ash impoundments.

B. Protect existing utilities not specified for removal against damage.

C. Locate existing underground utilities by hand excavation.

D. If unmarked utilities are encountered during excavation, stop work, place work in a safe condition, and notify Owner and/or Engineer.

E. Preserve and protect benchmarks and other structures. If damaged during construction, notify Owner and/or Engineer immediately. If determined by Owner and/or Engineer that the integrity of the structure is compromised, Contractor shall repair damaged benchmarks or other structures at Contractor's expense under observation of Owner and/or Engineer.

F. Protect, support, and maintain conduits, wires, pipes, or other utilities that are to remain in place during work as indicated in the Contract Drawings.

3.02 PREPARATION

A. Contractor shall perform, as necessary, additional survey and layout to establish location, line and grades for controlling the work.

B. Vicinity Controls

1. Surface Water: Contractor is responsible for management of surface water and maintaining adequate berms and drainage to control surface water run-on into the Ash Impoundment, as needed. Surface water and run-on water may be directed to Ash Impoundment 1, as needed to complete work and as approved by Owner.

2. Dust Controls: Dust shall be minimized at all times. Appropriate engineering controls shall be maintained that include using a light water spray with or without additives as approved by the Owner to minimize off-site migration of fugitive dust from stockpiles, truck routes, and other Contractor disturbed areas.

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3.03 ON-SITE MATERIAL GRADING, GENERAL

A. Uniformly grade all areas to a smooth surface, free from irregular surface changes. Provide a smooth transition between adjacent existing grades and new grades.

B. Comply with compaction requirements and grade to cross sections, lines, and elevations indicated.

C. Flatten or shore and brace slopes as required to maintain stability.

D. Removal of debris or other deleterious material encountered during excavations is to be managed as required under this Section.

E. Notify Owner and/or Engineer of unexpected subsurface conditions and discontinue work in affected area until notified to resume Work.

3.03 BACKFILLING, GENERAL

A. Material used to construct surface water diversion berms, as needed, may be reused for backfill as directed by the Owner and/or Engineer.

B. Imported backfill materials shall be pre-approved by the Owner and/or Engineer before delivery to the site in accordance with this Section.

C. Materials placed, which are not conforming to the Technical Specifications, shall be re-worked or removed. Replacement material and fill surfaces upon which it is placed shall conform to all requirements of this specification. All reworking or removal and replacement will be performed at Contractor's expense.

D. Mechanical tamping around structures shall be done in no greater than 6-inch lifts.

3.04 STOCKPILING, GENERAL

A. Stockpile materials on site at locations specified by Owner and consistent with the Contractor's Earthwork Plan.

B. Stockpile in sufficient quantities to meet project schedule and requirements.

C. Separate differing materials and stockpile separately to prevent mixing.

D. Direct surface water away from stockpiles to prevent erosion or deterioration of materials, as needed.

3.05 LINER SUBGRADE

A. Liner subgrade surface shall be graded to 3 horizontal to 1 vertical (3H:1V) along side slopes, or as approved by the Owner and/or Engineer. The base of the impoundment subgrade surface shall not exceed a 1% slope (to be relatively flat).

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B. Contractor shall prepare the liner subgrade by clearing and grubbing vegetation and removing rocks and other debris greater than 3 inches in diameter along side slopes and base of impoundment, and excavating at least 18 inches of existing ramp surface material.

C. Proof roll subgrade with smooth-drum compactor to identify soft pockets and areas of excess yielding. Do not proof roll wet or saturated subgrade.

D. Reconstruct liner subgrade damaged by freezing temperatures, frost, rain, accumulated water, or construction activities, as directed by the Owner and/or Engineer and Geomembrane Installer.

E. Cut out soft spots, fill low spots, and trim high spots to comply with required surface tolerances.

F. The surface of the subgrade shall be to the satisfaction of the Owner and/or Engineer and Geomembrane Installer, graded so it is free of irregularities, protrusions, loose soil, and abrupt changes in grade. Rocks with sharp protrusions and rocks or other debris grater than 3 inches in any dimension shall be removed.

G. Vegetation, rocks and other debris removed during subgrade preparation shall be loaded and transported to an approved recycling or disposal facility.

H. Excavated ramp material shall be loaded and transported to a stockpile area on-site, as directed by Owner.

I. Ramp subgrade shall be have a maximum 10% slope, and a minimum 1% slope toward the side slopes of the impoundment to divert water away from the outboard slopes of the ramp, as indicated on Contract Drawings.

3.06 ANCHOR TRENCH

A. Excavate to required alignment and grade. Where feasible, Contractor shall place anchor trench at least 4 feet from top of side slopes. If not feasible, Contractor shall provide Owner and/or Engineer with proposed alignment (i.e., 2 feet from top of side slope near the aboveground pipes) for approval.

B. Contractor shall not excavate more than the amount of anchor trench required for one day of geosynthetics deployment, unless otherwise specified by the Owner and/or Engineer. Rounded corners shall be provided in the trenches where the geosynthetics enter the trench to allow them to be uniformly supported by the subgrade and to avoid sharp bends. The geosynthetics shall not be supported by loose soils in anchor trenches.

C. Remove water which may accumulate in trench. Water shall be pumped to Ash Impoundment 1 (active impoundment), as directed by Owner and/or Engineer.

D. Owner and/or Engineer may limit amount of open trench where field conditions require.

E. Owner and/or Engineer may order additional excavation where unsuitable soil conditions are encountered.

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F. Excavations shall be filled with trench spoils, as directed by Owner and/or Engineer. Care shall be taken when backfilling to prevent any damage to Geomembrane or other geosynthetics that may be placed prior to backfilling.

G. Anchor Trench Backfill shall be mechanically compacted to a hard durable surface with no evidence of pumping or ponding of water. Backfill shall be compacted to the degree that no further appreciable consolidation is evident under the action of compaction equipment.

H. Anchoring, backfilling, and compaction of anchor trench will be observed by Owner and/or Engineer. .

3.07 INSTALLATION OF MARKER POSTS

A. Prior to deployment of the geomembrane liner, Contractor shall install marker posts along the toe of the impoundment side slopes, as shown on Contract Drawings.

B. Contractor shall construct 4 feet deep, 1 foot diameter holes. The hole shall be backfilled with concrete and 12 foot long steel poles.

C. Marks spaced every foot from the top of the subgrade layer shall be inscribed in the steel poles to the top of the pole, as indicated on the Contract Drawings.

3.08 PLACEMENT OF SAND AND WARNING LAYER MATERIALS

A. Prior to placement of the sand and warning layer materials, the Owner and/or Engineer and Geomembrane Installer shall verify the area of geomembrane completion and provide Contractor notification to proceed with placement of sand and warning layers.

B. Contractor shall place sand material to achieve 12-inch thickness over the 12-oz non woven geotextile within the Ash Impoundment, as indicated on Contract Drawings. The sand material shall be placed at least 4 feet along the impoundment's side slopes over the non woven geotextile.

C. Contractor shall place warning layer material to achieve 6-inch thickness over the sand material within the Ash Impoundment, as indicated on Contract Drawings. The warning layer material shall be placed at least 4 feet along the impoundment's side slopes over the sand material.

D. Sand and warning layer materials shall not be placed directly on geomembrane.

E. Place materials evenly on all sides of structures to required elevation,

F. Compact with tracked equipment to a hard, durable surface with no evidence of pumping or ponding of water. Materials shall be compacted to the degree that no further appreciable consolidation is evident under the action of compaction equipment.

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G. Apply following general criteria for covering of the 12-oz non woven geotextile and geomembrane liner:

1. Do not place soils on the geomembrane at an ambient temperature below 32 degrees F, (0 degrees C) nor above 104 degrees F (40 degrees C), unless otherwise specified.

2. Do not drive equipment used for placing soil directly on the geomembrane.

3. A minimum thickness of 1 foot of soil shall be between tracked equipment and the geomembrane.

4. Do not compact soils placed directly on geomembrane.

5. Damage to the geomembrane resulting from placement of cover soils shall be repaired in accordance with Part 3.07 by the Geomembrane Installer at the Contractor's expense.

6. Do not push soil downslope. Soil shall be placed over the geomembrane starting from base of the slope, up to top of the slope.

3.09 PLACEMENT OF RIPRAP

A. Place 18-inch thick layer of riprap at the base of the inlet apron over 12 oz non woven geotextile. The non woven geotextile shall cover the geomembrane batten bar attachment.

B. Riprap shall be placed cautiously to prevent damage to the batten bar attachment and geomembrane. Any damages to the batten bar or geomembrane shall be repaired at Contractor's expense.

3.11 RECONSTRUCTION OF RAMP

A. Following installation of the geomembrane and 12-oz non woven geotextile, Contractor shall load and transport excavated ramp material from stockpile area to the impoundment. Contractor shall place and compact excavated ramp material to achieve 18 inch thickness over the 12-oz non woven geotextile to construct final ramp surface.

B. The ramp final surface shall be a maximum 10% slope toward the base of the ramp, and a minimum 1% slope towards the 3H:1V side slopes, as indicated on Contract Drawings.

C. Compaction shall be conducted with tracked equipment only.

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3.12 MOISTURE CONTROL

A. Do not place backfill or fill material on surfaces that are muddy, frozen, or contain frost or ice.

B. Remove and replace, or scarify and air-dry, otherwise satisfactory soil material that is too wet to compact to specified dry unit weight.

3.10 GRADE TOLERANCE

A. Sand layer shall have minimum thickness of 12-inches, shall have a tolerance of 0 to +0.1 feet of design grade.

B. Warning layer shall have a minimum thickness of 6-inches, shall have a tolerance of 0 to +0.3 feet of design grade.

C. Top of ramp surface is to be a minimum thickness of 18-inches, shall have a tolerance of 0 to +0.1 feet of design grade.

D. Layer thickness shall be measured vertically. Minimum thickness shall be measured against previous layer grades.

3.11 PROTECTION

A. Protecting Graded Areas: Protect newly graded areas from traffic, freezing, and erosion. Keep free of trash and debris.

B. Repair and re-establish grades to specified tolerances where completed or partially completed surfaces become eroded, rutted, settled, or where they lose compaction due to subsequent construction operations or weather conditions.

1. Scarify or remove and replace soil material to depth as directed by Owner and/or Engineer, reshape and recompact.

C. Where settling occurs before Project correction period elapses, remove finished surfacing, backfill with additional soil material, compact, and reconstruct surfacing.

1. Restore appearance, quality, and condition of finished surfacing to match adjacent work, and eliminate evidence of restoration to the greatest extent possible.

3.13 SITE RESTORATION AND CLEANUP

A. Remove surplus soil and waste material, including unsatisfactory soil, trash, and debris, and transport off-site for disposal as directed by the Owner.

B. Restore pavement, base course, topsoil, landscaping, and utilities which are disturbed during the performance of the Work to preconstruction condition.

C. Temporary erosion control measures shall be removed.

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D. Contractor shall correct, at no expense to the Owner, any damage to buildings, telephone or other cables, overhead and underground utilities or their structures as a result of his construction, whether or not the item is shown on the Contract Drawings.

E. All Contractor equipment and materials shall be removed from the site.

END OF SECTION

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SECTION 02600
HIGH DENSITY POLYETHYLENE (HDPE) GEOMEMBRANE

PART 1 - GENERAL

1.01 WORK INCLUDES

A. Furnish all labor, materials, tools, supervision, transportation, and installation equipment necessary for installation of 60-mil High Density Polyethylene (HDPE) geomembrane, as specified herein, and as shown on Contract Drawings.

1.02 REFERENCE STANDARDS

A. ASTM D1004 – Test Method for Initial Tear Resistance of Plastic Film and Sheeting.

B. ASTM D1238 – Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.

C. ASTM D1505 – Test Method for Density of Plastics by the Density-Gradient Technique.

D. ASTM D1603 – Test Method for Carbon Black in Olefin Plastics.

E. ASTM D4833 – Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.

F. ASTM D5199 – Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

G. ASTM D5397 – Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test.

H. ASTM D5596 – Test Method for Microscopic Evaluation of Dispersion of Carbon Black in Polyolefin Geosynthetics.

I. ASTM D5994 Standard Test Method for Measuring Core Thickness of Textured Geomembranes.

J. ASTM D6392 –Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced Using Thermo-Fusion Methods.

K. ASTM D6693 Standard Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes.

L. ASTM D7007 Standard Practice for Locating Leaks in Geomembranes Covered with Water or Earthen Materials.

M. GRI Test Method, GM 13 - Test Methods, Test Properties and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes

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N. GRI Test Method, GM 14 – Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes.

O. GRI Test Method, GM 19 – Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes.

1.03 DEFINITIONS

A. Geomembrane Installer: hired by Contractor responsible for field handling, transporting, storing, deploying, seaming and testing of the geomembrane seams.

B. Geomembrane Manufacturer: hired by Geomembrane Installer to provide HDPE geomembrane.

C. Leak Location Contractor: hired by Contractor and responsible for locating potential holes in the installed geomembrane using electrical methods.

D. Geosynthetic Quality Assurance Laboratory (Testing Laboratory): Party, independent from the Owner, Manufacturer and Installer, responsible for conducting laboratory tests on samples of geosynthetics obtained at the site or during manufacturing, usually under the direction of the Owner.

E. Lot: A quantity of resin (usually the capacity of one rail car) used in the manufacture of geomembranes. Finished roll will be identified by a roll number traceable to the resin lot used.

F. Resin Supplier: selected by Geomembrane Manufacturer to provide resin used in manufacturing geomembrane.

G. Panel: Unit area of a geomembrane that will be seamed in the field that is larger than $100ft^2$.

H. Patch: Unit area of a geomembrane that will be seamed in the field that is less than $100ft^2$.

I. Subgrade Surface (Bedding Layer): Soil Layer surface which immediately underlies the geosynthetic material(s).

1.04 QUALITY ASSURANCE

A. Qualifications:

1. Geomembrane Installer:

a. 5 years of continuous experience in installation of HDPE geomembrane.

b. Experience totaling a minimum of 5,000,000 square feet of installed HDPE geomembrane on some combination of at least 10 completed facilities.

c. Personnel performing seaming operations qualified by experience or by successfully passing seaming tests. Master seamer shall have experience seaming a minimum of 3,000,000 square feet of geomembrane using same type of seaming apparatus to be used on this project.

2. Leak Location Contractor:

a. 3 years of continuous experience in performing leak location surveys using electrical methods.

b. Experience totaling a minimum of 2,000,000 square feet of geomembrane leak location surveys on some combination of at least 5 completed facilities.

c. Personnel performing survey qualified by experience with at least 2 years of geomembrane testing experience using the leak location survey electrical method.

d. Leak Location Contractors that are qualified and approved by Engineer are listed below:

i. Leak Location Services, Inc.
San Antonio, TX
210-408-1241

ii. The Hutchinson Group, Ltd.
Murrysville, Pennsylvania
724-325-3996

iii. Or other approved by Owner and/or Engineer.

B. Quality Assurance Program:

1. Geomembrane Manufacturer/Installer shall conform with requirements of these Technical Specifications.

2. The Owner and/or Engineer may document geomembrane installation including panel placement, seaming, pre-qualification seam testing, non-destructive seam and repair testing, repair size and locations, and weather conditions.

3. The Owner may engage and pay for the services of Engineer and QA Laboratory to monitor geomembrane installation.

1.05 SUBMITTALS

A. Prior to project start, submit the following to Owner and/or Engineer in accordance with Section 01300, Submittals:

1. Raw Materials:

a. Name of Resin Supplier, location of supplier's production plant(s), resin brand name and product number.

b. Source and nature of plasticizers, fillers, carbon black and any other additives along with their percent addition to geomembrane material.

c. Test results documenting conformance with the "index properties" of GRI Test Method, GM 13.

2. Geomembrane Manufacturer's Certification:

a. Written certification that Geomembrane Manufacturer's Quality Control Plan was fully implemented during production of geomembrane material supplied for this project. (Submittal shall be made within 5 working days of delivery to site).

3. Geomembrane Manufacturer Production Information:

a. Corporate background information indicating compliance with qualification requirements.

b. Quality control plan for manufacturing.

c. Copy of quality control certificates demonstrating compliance with the quality control plan for manufacturing and the test property requirements of GRI Test method, GM 13 (i.e., mill certificates).

4. Contractor shall provide the Engineer a certificate stating the name of the geotextile manufacturer, product name, chemical composition of the filaments and other pertinent information to fully describe the geotextile.

5. Geomembrane Installer's Seaming Personnel

a. Corporate background information indicating compliance with qualification requirements.

b. Training completed by personnel.

c. Seaming experience for each personnel.

6. Geomembrane Installer's Information:

a. Corporate background information indicating compliance with qualification requirements.

b. List of completed facilities, totaling 5,000,000 square feet minimum for which Geomembrane Installer has completed installation of a HDPE geomembrane. Include name and purpose of facility, location, date of installation, and quantity installed.

c. Resumes of personnel performing field seaming operation, along with pertinent experience information. Include documentation regarding which seamers are qualified to use thermal fusion welding apparatus.

d. Installation quality control plan.

7. Installation panel layout diagram identifying placement of geomembrane panels, seams, and any variance or additional details which deviate from Contract Drawings or Technical Specifications. Layout shall be drawn to scale and shall be adequate for use as a construction plan. Layout shall include dimensions and pertinent seam and anchorage details.

8. Installation Sequence and Schedule shall be included as part of Construction Progress Schedule.

9. Description of seaming apparatus to be used indicating compliance with specified requirements.

B. With bid, submit the following to Owner and/or Engineer in accordance with Section 01300, Submittals

1. Leak Location Contractor's Work Plan:

a. Corporate background information indicating compliance with qualification requirements.

b. List of completed facilities, totaling 2,000,000 square feet minimum of geomembrane leak location surveys on some combination of at least 5 completed facilities. Include name and purpose of facility, location, date of survey, survey method, and quantity surveyed.

c. Resumes of personnel performing leak location survey, along with pertinent experience information.

d. Leak Location Contractor quality control plan including description of the proposed survey methods and procedures, and field calibration procedures.

e. Leak Location Contractor's required site preparations to be completed to perform the proposed leak location survey, and estimated duration to complete the survey.

f. An example of a final report (per ASTM D 7007) provided by the Leak Location Contractor following the completion of the survey.

C. During installation, submit the following to the Owner and/or Engineer:

1. Daily records/logs prepared by Geomembrane Installer documenting work performed, personnel involved, general working conditions, and any problems encountered or anticipated on project. Submit on a weekly basis.

2. Copy of subgrade acceptance signed by Geomembrane Installer for areas to be covered with geomembrane each day.

D. Within 10 days of geomembrane installation completion, submit the following to Owner and/or Engineer:

1. Geomembrane installation certification that Work was performed under Geomembrane Installer's approved quality control plan and in substantial compliance with Technical Specifications and Contract Drawings.

2. As-built panel diagram identifying placement of geomembrane panels, seams, repairs, and destructive seam sample locations.

3. Copy of warranty for material (including factory seams) and installation covering both for a period of 2 years from the date of substantial completion.

E. The Owner and/or Engineer will review and inspect geomembrane installation upon completion of all Work specified in this Section. Deficiencies noted shall be corrected at no additional cost to the Owner.

F. The Owner and/or Engineer will provide written final acceptance of the geomembrane installation after completion of the leak location survey. Written conditional geomembrane installation acceptance can be provided to the Contractor prior to completion of the leak location survey when the following conditions are satisfied, if necessary, and requested by the Contractor:

1. The entire geomembrane installation is completed or any pre-determined subsection if the project is phased.

2. All installation quality assurance/control documentation has been completed and submitted to the Owner and/or Engineer.

3. Verification of the adequacy of all field seams, repairs and associated testing is complete.

G. Within 14 days of completion of the leak location survey, submit final written report (per ASTM D 7007) of the leak location survey provided by Leak Location Contractor.

1.06 DELIVERY, STORAGE, AND HANDLING

A. Transportation:

1. Geomembrane rolls shall be transported, unloaded and handled at the job site in accordance with manufacturer recommendations. Damaged material may be rejected by the Owner and/or Engineer. Manufacturer packaging shall be labeled in accordance with Section 02700, 2.02G.

B. On-site Storage:

1. Geomembrane rolls which have been delivered to job site shall be unloaded and stored in original, unopened packaging in a secure location, determined by Owner and/or Engineer.

2. Store geomembrane rolls to ensure adequate protection against exposure to the following:

   a. Equipment;

   b. Strong oxidizing chemicals, acids, or bases;

   c. Flames, including welding sparks;

   d. Temperatures in excess of 160 deg. F;

   e. Dust;

   f. Ultraviolet radiation (i.e. sunlight); and

   g. Inclement weather.

3. Whenever possible, provide a 6-inch minimum air space between rolls.

4. Containers/rolls shall not be stacked.

C. On-Site Handling:

1. Handle rolls per Geomembrane Manufacturer's recommendations and as necessary to prevent damage.

PART 2 - PRODUCTS

2.01 MATERIALS

A. Geotextile to be used for cushioning between subgrade and geomembrane shall be polyester or polypropylene, non-woven needlepunched fabric and shall conform to the following requirements:

GEOTEXTILE PROPERTIES

Property	Units	Value	Test	Criterion
Mass Per Unit Area	oz/yd^2	16	ASTM D5261	MARV
Puncture Strength	lb	170	ASTM D4833	MARV
Trapezoid Tear	lb	145	ASTM D4533	MARV
Grab Tensile Strength	lb	370	ASTM D4632	MARV
Grab Elongation	%	50	ASTM D4632	MARV
UV Resistance @500 hours	% retained	70	ASTM D4355	Minimum

B. Geotextile to be used for separation between geomembrane and sand material shall be polyester or polypropylene, non-woven needlepunched fabric and shall conform to the following requirements:

GEOTEXTILE PROPERTIES

Property	Units	Value	Test	Criterion
Mass Per Unit Area	oz/yd^2	12	ASTM D5261	MARV
Apparent Opening Size	US Sieve	100	ASTM D4751	MARV
Puncture Strength	lb	210	ASTM D4833	MARV
Trapezoid Tear	lb	125	ASTM D4533	MARV
Grab Tensile Strength	lb	320	ASTM D4632	MARV
Grab Elongation	%	50	ASTM D4632	MARV
UV Resistance @500 hours	% retained	70	ASTM D4355	Minimum

C. High Density Polyethylene (HDPE) White Textured Geomembrane

1. HDPE geomembrane shall be white, textured (both sides), 60-mil product approved by the Owner and/or Engineer.

2. The Contractor shall submit, with the bid, written certification from the proposed Geomembrane Manufacturer that geomembrane products proposed in the bid satisfy the following requirements:

   a. The proposed Geomembrane Manufacturer shall have a minimum of 5 years of continuous experience manufacturing HDPE geomembrane totaling 1,000,000 square feet.

   b. The proposed HDPE compound shall be comprised entirely of virgin materials. Compliance with this specification shall be documented in accordance with Geomembrane Manufacturer's quality control program and submitted to the Owner and/or Engineer with the written conformance certification.

   c. The proposed Geomembrane Manufacturer shall certify that any plasticizers, fillers and additives incorporated into the manufacturing process for the proposed HDPE geomembrane have demonstrated acceptable performance on past projects.

   d. The proposed geomembrane shall meet the requirements of Geosynthetic Research Institute's test method GM 13.

   e. The nominal thickness of proposed geomembrane shall be 60 mil., or as approved by the Owner and/or Engineer.

3. Geomembrane sheets shall be visually consistent in appearance and shall contain no holes, blisters, undisbursed raw materials or other signs of contamination by foreign material. Geomembrane must have no striations, roughness or bubbles on the surface.

B. Seaming Apparatus

1. Thermal fusion welding machines used for joining geomembrane surfaces may be either extrusion or hot wedge. These machines shall include sufficient temperature and rate-of-travel monitoring devices to allow continuous monitoring of operating conditions.

2. One spare, operable thermal fusion seaming device shall be maintained on site at all times.

C. Field Test Equipment

1. Field Tensiometer: the field tensiometer shall be calibrated within three months prior to project start date over the range of field test values.

2. Air Channel Test Equipment: air channel test equipment shall consist of hoses, fittings, valves and pressure gauge(s) needed to deliver and monitor the pressure of compressed air through an approved pressure feed device.

3. Air Compressor: the air compressor utilized for field testing shall be capable of producing and maintaining an operating pressure of at least 50 psi.

4. Vacuum Box: the vacuum box shall consist of a vacuum gage, valve, and a gasket around the edge of the open bottom needed to apply vacuum to a surface.

2.02. CONFORMANCE TESTING REQUIREMENTS

A. Geomembrane shipped to site shall undergo conformance testing. Manufacturer's roll certificates may be used for conformance evaluation at the option of the Owner and/or Engineer. Nonconforming material shall either be retested at the direction of the Owner and/or Engineer or removed from site and replaced at Contractor's expense.

B. Conformance Test Methods

1. Samples will be located and collected by the Owner and/or Engineer at a rate of one sample per 100,000 square feet of geomembrane delivered to site.

2. One sample will be obtained from each geomembrane production batch delivered to the site.

3 Samples shall be cut by Geomembrane Installer and be at least 45 square feet in size.

4. Samples shall be tested in accordance with Table 1 (Smooth) or Table 2 (Textured) specified in GRI Test Method GM13.

5. Geomembrane thickness shall be measured a minimum of three times per panel during deployment to verify conformance with GRI Test Method GM13.

C. Role of Testing Laboratories

1. The Owner and/or Engineer will be responsible for acquiring samples of the geomembrane for conformance testing. The Owner or Engineer will retain an independent, third party laboratory to perform conformance testing on samples of geomembrane.

2. Retesting of geomembrane panels by the Geomembrane Installer because of failure to meet any of the conformance specifications can only be authorized by the Owner and/or Engineer. Non-conforming panels may be retested in accordance with Subsection 2.03(B) and 2.03(D) under authorization of the Owner and/or Engineer.

3. The Geomembrane Manufacturer and/or Geomembrane Installer may perform independent tests in accordance with methods and procedures specified in Subsection 2.03(B). Results shall not be substituted for quality assurance testing described herein.

D. Procedures for Determining Conformance Test Failures

1. If conformance test results fail to meet specifications, the roll and/or batch may be retested using specimens from either the original roll sample or from another sample collected by the Owner and/or Engineer. Two additional tests (retests) shall be performed for each failed test procedure. Each retest shall consist of multiple specimen tests if multiple specimens are specified in the test procedure. If the results of both retests meet specifications, the roll and batch will be considered to have passed conformance testing.

2. Failure of any retest shall be cause for rejection of the entire roll or batch depending on the type of failing test. The Owner and/or Engineer reserves the right to collect samples from other roll of a particular batch for further conformance testing. The Owner and/or Engineer may choose to accept only a portion of the batch on the basis of the results of conformance testing of samples collected from other rolls.

3. If retesting does not result in conformance with the specifications as defined in preceding paragraph, or if there are any other nonconformities with the material specifications, the Contractor shall remove the rolls from use in project. The Contractor shall also be responsible for removal of rejected geomembrane from the site and replacement with acceptable geomembrane at no additional cost to the Owner.

PART 3 - EXECUTION

3.01 PRE-CONSTRUCTION MEETING

A. A Pre-Construction Meeting shall be held at the site in accordance with Section 01040, Project Administration, to discuss and plan the details of geomembrane installation. This meeting shall be attended by the Geomembrane Installer, Owner, Engineer and the Contractor.

B. The following topics relating to geomembrane installation shall be addressed:

1. Responsibilities of each party.
2. Lines of authority and communication.
3. Methods for documenting, reporting and distributing documents and reports.
4. Procedures for packaging and storing archive samples.
5. Review of the schedule for all installation and quality assurance testing, including third-party testing turnaround times.
6. Review of panel layout, access and numbering systems for panels and seams including details for marking on the HDPE geomembrane.
7. Procedures and responsibilities for preparation and submittal of as-built drawings.
8. Temperature and weather limitations, installation procedures for adverse weather conditions and defining acceptable subgrade or ambient moisture and temperature conditions for working during liner installation.
9. Subgrade conditions, dewatering responsibilities and subgrade maintenance plan.
10. Deployment techniques including allowable subgrade for geomembrane.
11. Procedures for covering of the geomembrane to prevent damage.
12. Plan for minimizing wrinkles in the geomembrane.
13. Measurement and payment schedules.
14. Site health and safety procedures/protocols.

3.02 SUBGRADE PREPARATION

A. The Geomembrane Installer shall visually inspect the subgrade immediately prior to geomembrane deployment. Inspection shall verify that there are no potentially harmful foreign objects present, such as sharp rocks and other deleterious debris. Any foreign objects encountered shall be removed by Geomembrane Installer or Contractor. All subgrade damaged by construction equipment and deemed unsuitable for geomembrane

deployment shall be repaired prior to geomembrane deployment. All repairs shall be approved by the Owner and/or Engineer and Geomembrane Installer. The responsibility for preparation, repairs, and maintenance of the subgrade shall be defined in the preconstruction meeting. The Geomembrane Installer shall provide the Owner and/or Engineer with written acceptance of subgrade surface over which 16 oz non woven geotextile and geomembrane is deployed (Part 1 .05B) for each day of deployment.

3.03 GEOMEMBRANE LINER DEPLOYMENT

A. Geomembrane Installer shall deploy 16-oz non woven geotextile following applicable certifications/quality control certificates listed in subsection 1.05 of this section and conformance testing in subsection 2.02 or this section are submitted and approved by the Owner and/or Engineer. Any 16-oz non woven geotextile placed prior to approval by the Owner and/or Engineer shall be at the sole risk of the Contractor. If geotextile installed prior to approval by the Owner and/or Engineer does not meet the requirements of this specification, it shall be removed from the site at no additional cost to the Owner.

B. Geomembrane will be deployed following installation of 16-oz non woven geotextile according to submitted panel layout drawing as approved by the Owner and/or Engineer. The Owner and/or Engineer is to be notified of and approve any revisions or modifications to the approved panel layout drawing prior to deploying geomembrane in the area of review.

C. Adequate temporary anchoring (sand bags, tires, etc.) that will not damage the geomembrane shall be placed on a deployed panel to prevent uplift by wind.

D. Geomembrane shall not be deployed if:

1. Ambient temperatures are below 41 degrees F (5 degrees C) or above 104 degrees F (40 degrees C) measured six inches above geomembrane surface unless approved by the Owner and/or Engineer.

2. Precipitation is expected or in the presence of excessive moisture or ponded water on the subgrade surface.

3. Winds are excessive as determined by Geomembrane Installer in agreement with the Owner and/or Engineer.

4. The Owner and/or Engineer will have the authority to suspend work during such conditions.

E. The Geomembrane Installer shall be responsible for conformance with the following requirements:

1. Equipment utilized for installation/quality assurance testing does not damage geomembrane. Such equipment shall have rubber tires and a ground pressure not exceeding 5 psi or total weight exceeding 750 lbs. Only equipment necessary for installation and quality assurance testing is allowed on the deployed geomembrane.

2. Personnel working on geomembrane do not damage geomembrane (activities such as smoking or wearing damaging clothing shall not be allowed).

3. Method of deployment does not damage geomembrane.

4. Method of deployment minimizes wrinkles.

5. Temporary loading or anchoring does not damage geomembrane.

6. Direct contact with geomembrane is minimized.

F. Geomembrane Installer shall place 12-oz non woven geotextile on the geomembrane at the base of the impoundment and at least 4 feet up side slopes, as indicated on Contract Drawings. Geomembrane Install shall cover the inlet apron batten bar attachment with the 12-oz non woven geotextile.

G. No vehicles shall be allowed on deployed geomembrane under any circumstances.

3.04 FIELD SEAMS

A. Seam Layout

1. In general, seams shall be oriented parallel to the line of the maximum slope. In corners and at other odd-shaped geometric intersections, number of seams should be minimized. If at all possible, seams shall not be located at low points in the subgrade unless geometry requires seaming to be done at these locations.

2. A seam numbering system compatible with the panel numbering system shall be agreed upon at the Pre-Construction Meeting.

B. Seaming Processes/Equipment

1. Approved processes for field seaming (panel to panel) are extrusion or hot wedge fusion-type seam methods. No other processes can be used without prior written authorization from the Owner and/or Engineer. Only equipment which has been specifically approved by make and model shall be used, if applicable.

3. The Geomembrane Installer will meet following requirements regarding use, availability, and cleaning of welding equipment at job site:

a. Intersecting hot wedge seams shall be patched using extrusion welding process.

b. Electric generator for equipment shall be placed on a smooth base such that no damage occurs to geomembrane. A smooth insulating plate or fabric shall be placed beneath hot equipment after usage.

3. The Geomembrane Installer shall keep records for performance and testing of all seams.

C. Seaming Requirements/Procedures

1. Weather Conditions - Range of weather conditions under which geomembrane seaming can be performed are as follows:

   a. Unless otherwise authorized in writing by Owner and/or Engineer, no seaming shall be attempted or performed at an ambient temperature below 41 degrees F (5 degrees C) or above 104 degrees F (40 degrees C).

   b. Between ambient temperatures of 32 degrees F (0 degrees C) and 41 degrees F (5 degrees C), seaming shall be performed only if geomembrane is preheated by either sun or a hot air device, provided there is no excessive ambient cooling resulting from high winds. Pre-qualification seams shall be produced under identical conditions.

   c. Above 41 degrees F (5 degrees C), no preheating of geomembrane will be required.

   d. Geomembrane shall be dry and protected from wind.

   e. Seaming shall not be performed during any precipitation event.

   f. Seaming shall not be performed in areas where ponded water has collected below surface of geomembrane.

2. If the Geomembrane Installer chooses to use methods which may allow seaming at ambient temperatures below 41 degrees F or above 104 degrees F, the Geomembrane Installer shall demonstrate and submit certification to Owner and/or Engineer that methods and techniques used to perform seaming produce seams that are equivalent to seams produced at temperatures above 41 degrees F and below 104 degrees F. The Owner and/or Engineer may deny approval for use of the proposed technique regardless of demonstration results.

3. Overlapping - Geomembrane panels shall have finished overlap as follows:

   a. Minimum of 6 inches for thermal fusion welding.

   b. Insufficient overlap will be considered a failed seam.

4. Pre-qualification tests for geomembrane fusion welding shall be conducted by a minimum of 2 pre-qualification seams conducted per day per welding machine by each seaming technician performing welding with that machine. At least one test shall be performed at the start of each work day, with tests at intervals of no greater than 5 hours and additional pre-qualification tests following work interruptions, weather changes, changes to machine settings, or as directed by the Owner and/or Engineer. Pre-qualification seams shall be made under the same conditions as the actual seams.

a. Pre-qualification seam samples shall be 5 feet long by 1-foot wide (minimum) after seaming, with seam centered along its length. Each pre-qualification seam shall be labeled with the date, geomembrane temperature, seaming unit identifier, seam number or test location, technician performing the test seam and description of testing results.

b. Seam overlap shall be in accordance with subsection 3.04(C)(3).

c. Pre-qualification seams shall be inspected for proper squeeze-out, footprint pressure, and general appearance.

d. Four specimens, each 1-inch in length, shall be cut from opposite ends of the pre-qualification seam sample by the Geomembrane Installer. The remainder of pre-qualification seam shall be retained by the Owner and/or Engineer and may be submitted for laboratory testing.

e. The Geomembrane Installer shall complete two shear tests and two peel tests.

f. Pre-qualification seams failed by inspection or testing may be retested at request of the Geomembrane Installer. If the second pre-qualification seam fails, then the seaming apparatus or seaming technique shall be disqualified from use until two consecutive, satisfactory pre-qualification seams are obtained.

5. Seam Preparation

a. Prior to seaming, seam area shall be clean and free of moisture, dust, dirt, debris of any kind, and foreign material.

b. Seams shall be aligned so as to minimize number of wrinkles and fishmouths.

6. General Seaming Procedures

a. Fishmouths or wrinkles at seam overlaps shall be cut along ridge of the wrinkle to achieve a flat overlap. Cut fishmouths or wrinkles shall be repaired, and/or patched in accordance with Part 3.07.

b. Seaming shall extend to the outside edge of geomembrane panels including material placed in anchor trenches.

c. For cross seams, the intersecting thermal fusion seams shall be patched using the extrusion welding process.

3.05 NON-DESTRUCTIVE TESTING

A. Each field seam shall be non-destructively tested over its entire length by the Installer. Testing shall be conducted as field seaming progresses, not at completion of all seams, unless specifically agreed to by the Owner and/or Engineer in writing.

B. Vacuum Testing – shall be performed in accordance with ASTM D5641, Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber.

C. Air Pressure Testing – shall be performed in accordance with ASTM D5820, Standard Practice for Pressurized Air Channel Evaluation of Dual Seamed Geomembranes, and GRI GM 6, Pressurized Air Channel Test for Dual Seamed Geomembranes.

D. Each seam tested non-destructively shall be marked with the date of the test, name of the testing technician, length of the seam, test method and results. The same shall also be recorded by the Owner and/or Engineer on the appropriate CQA documentation.

E. Non-Destructive Seam Test Failures

1. Seams failing non-destructive testing shall be repaired by the Geomembrane Installer according to Part 3.07. Seams shall be non-destructively retested. If the seam defect cannot be located, the entire section of seams affected shall be repaired and retested.

3.06 ELECTRONIC LEAK LOCATION SURVEY

A. Leak Location Contractor shall identify actions required by Contractor to prepare the site for the leak location survey.

B. Contractor shall ensure that the sand and warning layers, and 12 oz non woven geotextile above and 16 oz non woven geotextile below the geomembrane contains sufficient moisture to conduct a leak location survey. Typically, a moisture content of earth materials of 1% to 2% by weight is sufficient to conduct the survey. If the moisture content of the sand layer, warning layer and subgrade is not sufficient per the requirements of the Leak Location Contractor, Contractor shall add sufficient water the layers, as required.

C. Contractor shall provide electrical isolation of the metal marker posts, batten bars, and concrete structures, as requested by Leak Location Contractor.

D. Leak Location Contractor shall inspect the site prior to commencing the survey to ensure all site preparations are completed and the site conditions are appropriate for conducting the leak location survey.

E. Any discrepancy in the required site preparation detailed in the Leak Location Contractor's Work Plan or site conditions shall be reported to the Contractor for corrective or appropriate action.

F. After the warning layer is placed, conduct a leak location survey on the warning layer material using the procedures for surveys with earth materials covering the Geomembrane as described in ASTM D 7007.

G. A leak detection sensitivity test using an artificial leak shall be conducted on the geomembrane for each set of equipment used before the equipment is used on for the leak location survey, as described in ASTM D 7007 to determine the detection distance for the survey.

H. The leak location survey shall be taken on survey lines or on a grid spaced no farther apart than twice the leak detection distance as determined in the leak detection sensitivity test.

I. The Leak Location Contractor shall inform the Owner and/or Engineer and mark the locations of all identified or indicated leaks with a flag or spray paint. The Geomembrane Installer shall repair the defect/hole as detailed in Part 3.08 of this Section.

3.07 DEFECTS AND REPAIRS

A. The geomembrane shall be examined by the Geomembrane Installer and the Owner and/or Engineer for defects, holes, blisters, undispersed raw materials, and any signs of contamination by foreign matter. The geomembrane surface shall be swept and/or washed by the Geomembrane Installer if the amount of dust or mud inhibits examination. The Contractor shall provide a water truck, an operator, clean water and hoses as reasonably necessary to assist the Geomembrane Installer in this activity.

B. Portions of geomembrane exhibiting flaws, or failing a non-destructive or destructive (if conducted) test, shall be repaired or replaced by the Geomembrane Installer. Repair procedures available include:

1. Patching - used to repair large holes, tears, undispersed raw materials, contamination by foreign matter, holes resulting from destructive sampling (if conducted), and locations where seam overlap is insufficient;

2. Capping - used to repair large lengths of failed seams; and

3. Additional Procedures - used upon recommendation of the Geomembrane Installer if agreed to by the Owner and/or Engineer.

C. Patches or caps.

1. Extend patch or cap 6 inches (minimum) beyond the edge of the defect.

2. Round corners of patch and/or cap (suggest 3-inch radius).

3. Repair procedures, equipment, materials, and techniques will be approved by the Owner and/or Engineer prior to repair.

4. Geomembrane below large caps shall be appropriately cut to avoid water or gas collection between two sheets.

D. The Geomembrane Installer shall mark on the geomembrane (using a non-puncturing writing utensil), repair date, time, and personnel involved.

E. Each repair shall be non-destructively tested in accordance with Part 3.05. Large caps may require destructive test sampling at the discretion of the Owner and/or Engineer (in accordance with Part 3.06).

F. Repairs which fail testing shall be redone and retested until a passing result is obtained. The Geomembrane Installer will perform non-destructive testing or repairs and will document retesting of repairs.

G. The Owner and/or Engineer will document repairs, repair testing, and retesting results.

H. The Geomembrane Installer shall cut and seam wrinkles which may adversely affect long-term integrity of the geomembrane, hinder subsequent construction of overlying layers, or impede drainage off of the geomembrane after it is covered by soil. Seaming shall be done in accordance with procedures described in Parts 3.04(B) and 3.04(C), and it shall be subject to test provisions of Parts 3.05 (non-destructive testing) and 3.06 (destructive testing – if conducted).

3.08 PROTRUSIONS AND CONNECTIONS TO GEOMEMBRANE

A. If required, the Geomembrane Installer shall install geomembrane around utility poles, guy wires, and other structures according to the Contract Drawings and the following requirements:

1. Use minimum 2-ft long membrane pipe boots and steel straps to seal the geomembrane around pole or structure.

2. Use standard welding procedures to seam the membrane boot to the geomembrane.

3. Seaming performed on and around penetrations, and other appurtenances shall be non-destructively tested using the vacuum testing method.

3.09 SURVEY DOCUMENTATION

A. Prior to covering the geomembrane, the Geomembrane Installer shall provide the Contractor , Owner and/or Engineer with 24-hour notification to conduct a survey. The Contractor shall survey the location of all seams (panel corners acceptable), and repairs. The Contractor shall provide survey data to the Owner and/or Engineer within one working day of survey completion and in accordance with Section 01050.

3.10 DAILY FIELD INSTALLATION REPORTS

A. At the beginning of each day, the Geomembrane Installer shall provide the Owner and/or Engineer with a report for all work completed the previous day.

B. The Daily Field Installation Report shall include the following:

1. The total amount and location of geomembrane placed.

2. The total length and location of seams completed, technician name and welding unit numbers.

3. A drawing or sketch depicting the geomembrane installed the previous day including the panel number, seam number and locations of non-destructive and destructive testing (if conducted).

4. Results of pre-qualification test seams, if available.

5. Results of non-destructive testing.

C. Destructive test results (if conducted) shall be reported within 48 hours or prior to covering the geomembrane, whichever is practical.

END OF SECTION

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Section 01500 – Construction Facilities and Temporary Controls ..... 01500-1 to 7
Section 01700 – Project Closeout ..... 01700-1 to 2

DIVISION 2 - SITE WORK

Section 02300 – Earthwork ..... 02300-1 to 11
Section 02600 – HDPE Geomembrane ..... 02600-1 to 19

FIGURES

Figure 1 Site Location Map (1862-A01C)

TABLES

Table 1 List of Documentation Surveys
Table 2 List of Submittals

SHEETS

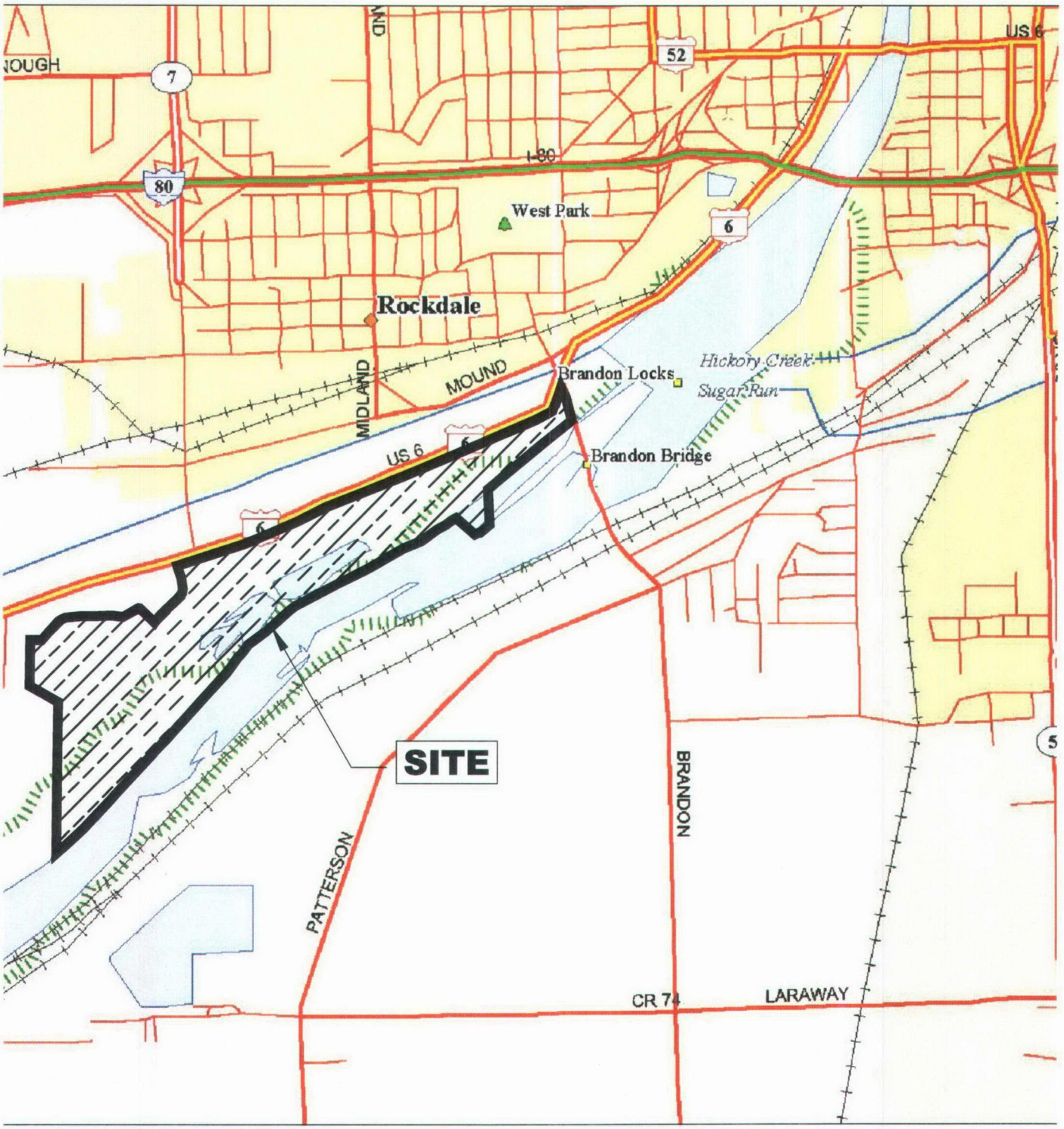
TS Title Sheet (D1862-TS-00)

C010 Existing Conditions (D1862 C010-01)
C020 Liner Subgrade Preparation (D1862 C020-01)
C030 Warning Layer Plan (D1862 C030-01)
C031 Details and Sections (D1743 C031-01)

MWG13-15_18721

FIGURES

FIGURE



SOURCE: DELORME MAP EXPERT (TM)
VERSION 2.0
COPYRIGHT 1993, DELORME MAPPING
JOLIET. DATED 1993.



QUADRANGLE LOCATION

N

0 2000 4000

SCALE IN FEET

SITE LOCATION MAP

MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

NATURAL RESOURCE TECHNOLOGY

DRAWN BY: BJK 05/08/07 APP'D BY: HMS DATE: 06/04/07

PROJECT NO. 1862

DRAWING NO. 1862–A01C

FIGURE NO. 1

MWG13-15_18724

Electronic Filing: Received, Clerk's Office 2/04/2022

TABLES

TABLES

Table 1. List of Documentation Surveys
Ash Impoundment #2 Liner Replacement Specifications
Midwest Generation – Joliet 29

Survey	Responsible Party	Frequency	Technical Specification Reference
Location of anchor trench alignment	Contractor	Every 25 ft intervals	Section 01050, 1.02B
Location and elevation geomembrane panels	Contractor	At panel corners and repairs, as necessary	Section 01050, 1.02C Section 02600, 1.05C, 3.10A
Location of marker post	Contractor	As necessary	Section 01050, 1.02E
Topographic survey of warning layer	Contractor	50 ft square grid and at grade changes	Section 01050, 1.02F

Notes
1. Contractor shall provide Owner and/or Engineer results of survey within 2 working days after completion.
2. Owner and/or Engineer acceptance or rejection will be provided within 2 working days following receipt of documentation survey.

MWG13-15_18727

Table 2 - List of Submittals
Ash Impoundment #2 Liner Replacement Specifications
Midwest Generation – Joliet 29

	Submittal	From	To	Time Frame	Reviewer	Technical Specification	
						Section	Part
1	Subcontractor List	Contractor	Owner and/or Engineer	**With bid documents**	Owner	01040	1.03F
2	Baseline Construction Schedule	Contractor	Owner and/or Engineer	**With bid documents** and update within 10 calendar days of the date of the Contract award	Owner and/or Engineer	01040	1.06B
3	Earthwork Plan	Contractor	Owner and/or Engineer	**With bid documents**	Owner and/or Engineer	02300	1.06B
4	Name and Location of Recycling / Disposal Facility	Contractor	Owner and/or Engineer	**With bid documents**	Owner and/or Engineer	02300	1.06E
5	Leak Location Contractor's Work Plan	Contractor	Owner and/or Engineer	**With bid documents**	Owner and/or Engineer	02600	1.05B
6	Construction Start Date	Contractor	Owner and/or Engineer	5 Working days prior to construction start	Owner and/or Engineer	02300	1.06D
7	IEPA Water Pollution Control Construciton Permit	Owner through Engineer	Contractor	Prior to project start	Contractor	01015	1.05A
8	Site Superintendant/Foreman's Name & Phone Number	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	01040	1.03A
9	Location of Off-site Fill Material Sources	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02300	1.06C
10	Off-site Fill Material Certificates/Test Results	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02300	1.06E
11	Resin Supplier, Address, Brand Name, Product Number and Test Results	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02600	1.05A
12	Source and nature of additives	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02600	1.05A
13	Geomembrane Installer's Information, Layout Diagram, Schedule, Seaming Equipment	Contractor	Owner and/or Engineer	Prior to project start	Owner and/or Engineer	02600	1.05A

Table 2 - List of Submittals
Ash Impoundment #2 Liner Replacement Specifications
Midwest Generation – Joliet 29

	Submittal	From	To	Time Frame	Reviewer	Technical Specification	
						Section	Part
14	Progress Meeting Minutes	Owner and/or Engineer	Owner, Contractor, Engineer, and Subcontractors (as necessary)	Prior to subsequent progress meeting	Owner and/or Engineer	01040	1.05E
15	Progress Schedule	Contractor	Owner and/or Engineer	Weekly one working day prior to regular scheduled progess meeting	Owner and/or Engineer	01040	1.06C 1.06D
16	Progress Reports	Contractor	Owner and/or Engineer	Weekly one working day prior to regular scheduled progess meeting	Owner and/or Engineer	01040	1.08A
17	Accident Reports, Work Stoppage/Dispute Records, Contractor Invoices, Schedule of Values, Test Report Records, and Equipment Check Records	Contractor	Owner and/or Engineer	As Necessary	Owner and/or Engineer	01040	1.08B
18	Sand Material Representative Sample	Contractor	Owner and/or Engineer	Two weeks prior to delivery	Owner and/or Engineer	02300	2.03
19	Warning Layer Representative Sample	Contractor	Owner and/or Engineer	Two weeks prior to delivery	Owner and/or Engineer	02300	2.04
20	Geomembrane Manufacture's Certification-PGI Standards	Contractor	Owner and/or Engineer	5 working days prior to delivery to site	Owner and/or Engineer	02600	1.05A
21	Geotextile - Product Information	Contractor	Owner and/or Engineer	5 working days prior to delivery to site	Owner and/or Engineer	02600	1.05A
22	Geomembrane Manufacturer's Certification - Product Information	Contractor	Owner and/or Engineer	5 working days prior to delivery to site	Owner and/or Engineer	2600	1.05A
23	Certification of Geomembrane Manufacturer's Quality Control Plan	Contractor	Owner and/or Engineer	5 working days prior to delivery to site	Owner and/or Engineer	2600	1.05A

Table 2 - List of Submittals
Ash Impoundment #2 Liner Replacement Specifications
Midwest Generation – Joliet 29

	Submittal	From	To	Time Frame	Reviewer	Technical Specification	
						Section	Part
24	Geomembrane Installer's Daily Logs and Quality Control Documentation	Contractor	Owner and/or Engineer	During geomembrane installation	Owner and/or Engineer	02600	1.05C
25	Geomembrane Installer's Subgrade Acceptance	Contractor	Owner and/or Engineer	Each day prior to geomembrane installation	Owner and/or Engineer	02600	1.05C 3.02A
26	Geomembrane Installation Certificate, As-Builts, and Warranties	Contractor	Owner and/or Engineer	Within 10 working days of geomembrane installation completion	Owner and/or Engineer	02600	1.05D
27	Written Certification for Project	Contractor	Owner and/or Engineer	Upon completion of work	Owner and/or Engineer	01700	1.03B & C
28	Conditional and/or Final Geomembrane Installation Acceptance	Owner and/or Engineer	Contractor	Upon completion of geomembrane installation and submittals	Contractor	2600	1.05F
29	Record Documents	Contractor	Owner and/or Engineer	Prior to submittal of final invoice	Owner and/or Engineer	01700	1.04
30	Survey Data	Contractor	Owner and/or Engineer	Within 4 days following completion of survey	Owner and/or Engineer	01050	1.05
31	Final Leak Location Survey Report	Contractor	Owner and/or Engineer	Within 14 days following completion of leak location survey	Owner and/or Engineer	02600	1.05G

SHEETS

ASBUILT OF
MIDWEST GENERATION JOLIET 29 POWER PLANT
WEST-ASH IMPOUNDMENTS

GRAPHIC SCALE
40 0 40
(IN FEET)
1 inch = 40 ft.



LEGEND

meas.	MEASURED
rec.	RECORDED
calc.	CALCULATED
●	FOUND SURVEY MONUMENT
■	SET 5/8" REBAR UNLESS OTHERWISE NOTED
	6' HIGH CHAIN LINK FENCE
	UTILITY POLE
	LIGHT
	UNDERGROUND PIPELINE LOCATED BY OTHERS
XXX	EXISTING CONTOUR
XXX.XX	EXISTING ELEVATION
	OVERHEAD UTILITY LINES

ASBUILT NOTE:

THE POND ASBUILT EXTENDS TO THE OUTSIDE OF THE NEW LINER, AS SHOWN HEREON. AREAS OUTSIDE THE NEW LINER AND SHOWN HEREON HAVE NOT BEEN REVERIFIED

SITE BENCHMARK 1:

SET CONCRETE NAIL IN WESTERLY FACE OF UTILITY POLE, WEST SIDE OF EAST ENTRANCE ROAD, 4TH UTILITY POLE SOUTH OF U.S. ROUTE 6.

ELEVATION: 536.39 (NGVD 29)

SITE BENCHMARK 2:

SET REBAR 2' S & 2.5' E OF 6' HIGH CHAIN LINK FENCE CORNER AT SOUTHEAST CORNER OF MAIN ENTRANCE ROAD & U.S. ROUTE 6.

ELEVATION: 536.71 (NGVD 29)

BENCHMARK:

WILL COUNTY CONTROL MONUMENT STATION 6274 CUT SQUARE ON CENTERLINE OF SOUTH HEADWALL IN THE SOUTHEAST CORNER OF THE INTERSECTION OF BRANDON ROAD AND MEADOW AVENUE.

ELEVATION: 550.33 (NGVD 29)

FIELD VERIFY BENCHMARKS WITH BENCHMARK LIST.

STATE OF ILLINOIS)
)SS
COUNTY OF WILL)

RUETTIGER, TONELLI & ASSOCIATES, INC., ILLINOIS PROFESSIONAL DESIGN FIRM No. 184-001251, HEREBY CERTIFIES THAT IT HAS TOPOGRAPHICALLY SURVEYED THE POND AREA NOTED HEREON AND AS SHOWN ON THE ANNEXED PLAT, WHICH IS A TRUE AND CORRECT REPRESENTATION OF SAID TOPOGRAPHY.

SURVEY FIELD WORK COMPLETED 10/20/08

GIVEN UNDER MY HAND AND SEAL THIS 10th DAY OF MAY, 2008.

BY _____
ILLINOIS PROFESSIONAL LAND SURVEYOR (MY LICENSE EXPIRES 11-30-2008)

REVISIONS

No.	DATE	DESCRIPTION	BY
1	12/2/08	ADDED NEW ASBUILT INFORMATION	MJ

R&T Ruettiger, Tonelli & Associates, Inc.
Surveyors •Engineers •Planners •Landscape Architects •G.I.S. Consultants
2174 ONEIDA STREET, JOLIET, ILLINOIS 60435, PH. (815) 744-6600 FAX (815) 744-0101
2603 S. WASHINGTON STREET - SUITE 170, NAPERVILLE, ILLINOIS 60565, PH. (630) 420-7740 FAX (630) 420-7741

DATE: 6/9/08	SCALE: 1" = 40'	DRAWN BY: MJ	CHECKED BY: EC

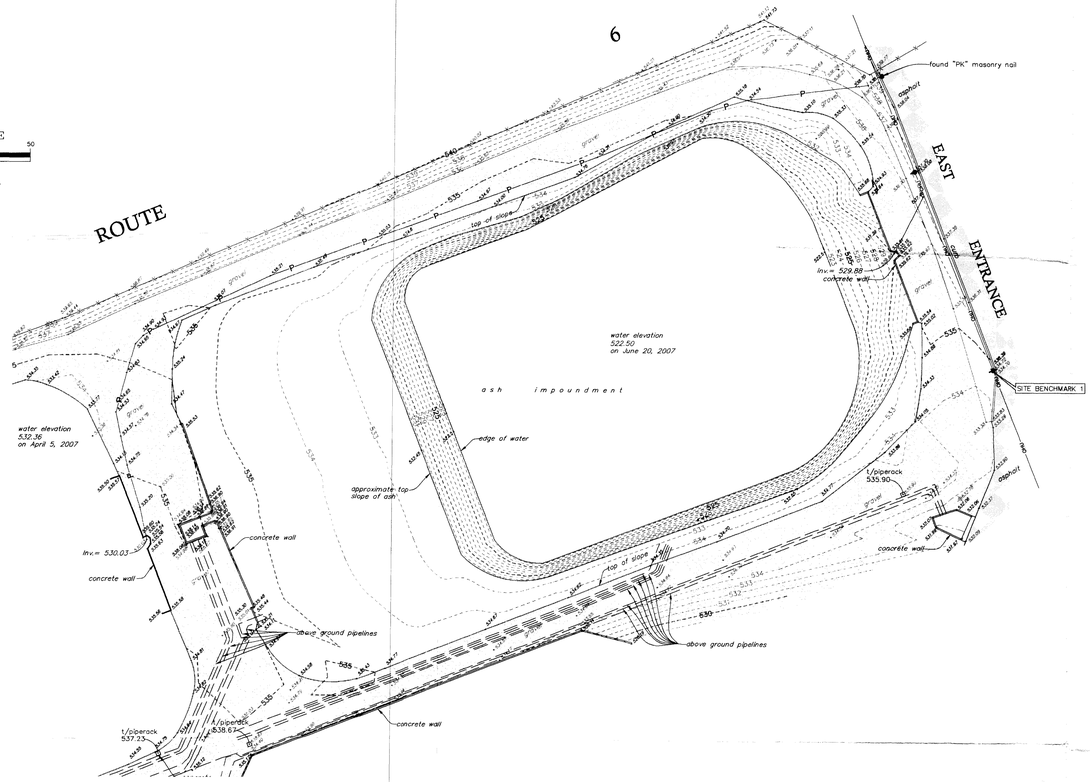
PREPARED FOR: BREISER CONSTRUCTION COMPANY
24101 S. MUNICIPAL DRIVE
CHANNAHON, IL

FIELD BOOK: MIDWEST GEN.
PAGE: 11-13

DRAWING No.:
308-0363 ASBUILT WEST-ASH IMP.

DRAWING TITLE: ASBUILT

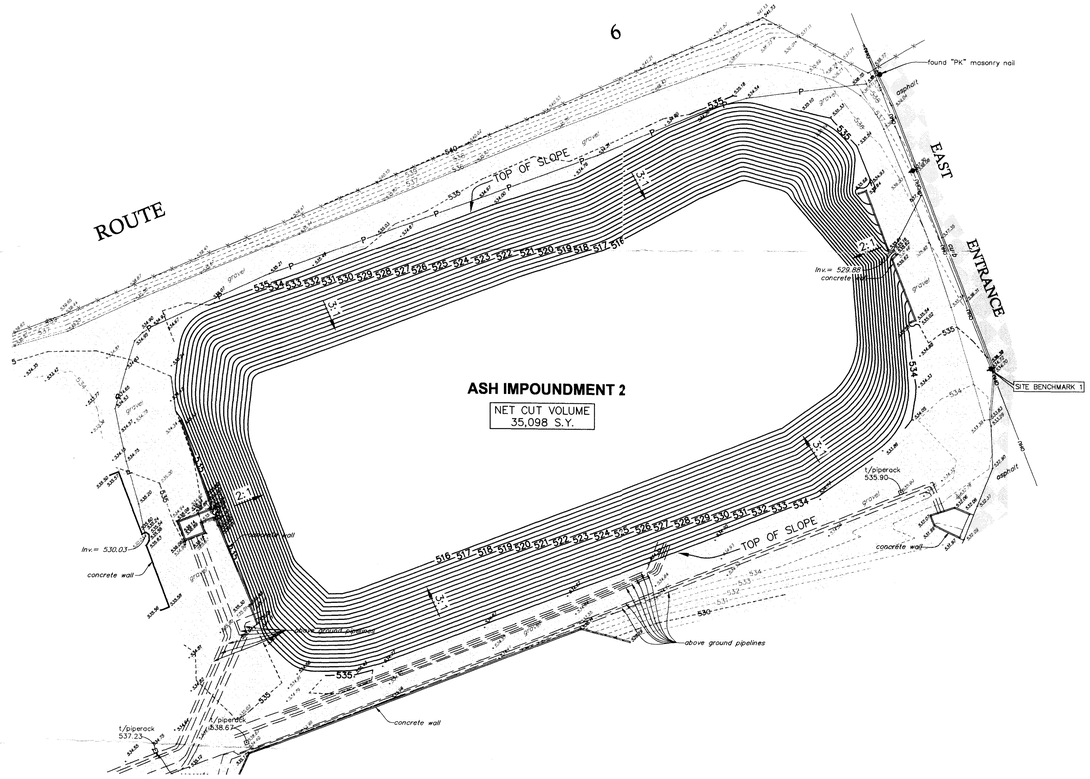
GRAPHIC SCALE
50 0 50
(IN FEET)
1 inch = 50 ft.



EXISTING CONDITONS

LEGEND

meas.	MEASURED
rec.	RECORDED
calc.	CALCULATED
●	FOUND SURVEY MONUMENT
■	SET 5/8" REBAR UNLESS OTHERWISE NOTED
x—x—x—x	6' HIGH CHAIN LINK FENCE
◆	UTILITY POLE
☼	LIGHT
—P—	UNDERGROUND PIPELINE LOCATED BY OTHERS
XXX	EXISTING CONTOUR
XXX.XX	EXISTING ELEVATION
OHU	OVERHEAD UTILITY LINES



ASH IMPOUNDMENT 2

NET CUT VOLUME
35,098 S.Y.

CONCEPTUAL DESIGN CONTOURS FOR PROPOSED EXCAVATION

NOTE: THIS DESIGN IS BASED UPON INFORMATION OBTAINED IN NATURAL RESOURCE TECHNOLOGY'S DRAWING No. D1862C010-00, DATED 05-04-07.

REVISIONS

No.	DATE	DESCRIPTION	BY	No.	DATE	DESCRIPTION	BY

DOCUMENTATION:
PROJECT No.: 20070648
DATE: 06-27-07
FIELD BOOK: MIDWEST GEN.
DRAWN BY: NW
CHECKED BY: JPH

R T & A
Ruettiger, Tonelli & Associates, Inc.
Surveyors • Engineers • Planners • Landscape Architects • G.I.S. Consultants
2174 ONEIDA STREET JOLIET, ILLINOIS 60435 PH. (815) 744-6600 FAX (815) 744-0101
2603 S. WASHINGTON STREET - SUITE 170 NAPERVILLE, ILLINOIS 60565 PH. (630) 420-7740 FAX (630) 420-7741

PROJECT TITLE:
MIDWEST GENERATION JOLIET STATION No. 29 ASH IMPOUNDMENT

DRAWING TITLE:
ASH REMOVAL EXHIBIT

DRAWING No. 307-0648-E1
SCALE: 1" = 50'
"DEPARTMENT"
SHEET 1 OF 1

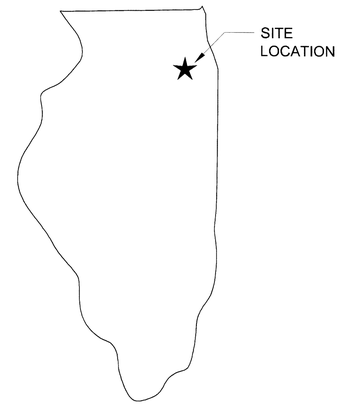
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MWG13-15_18733

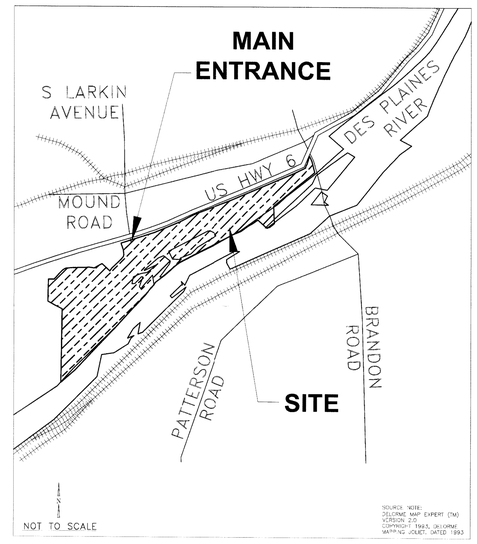
ASH IMPOUNDMENT DESIGN
JOLIET STATION NO. 29
MIDWEST GENERATION
JOLIET, WILL COUNTY, ILLINOIS

LIST OF DRAWINGS

SHEET NO.	TITLE	DRAWING NO.
TS	TITLE SHEET	D1862TS-00
C010	EXISTING CONDITIONS	D1862C010-01
C020	LINER SUBGRADE PREPARATION	D1862C020-01
C030	WARNING LAYER PLAN	D1862C030-01
C031	DETAILS AND SECTIONS	D1862C031-01



ILLINOIS



SITE VICINITY

NOT FOR CONSTRUCTION

TITLE SHEET

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

SHEET NO. TS

PROJECT NO. 1862/3.0
DRAWN BY: BJK 07/12/07
CHECKED BY: HMS 08/02/07
APPROVED BY:
DRAWING NO: D1862TS-00
REFERENCE: 1862/3/BID-CON/

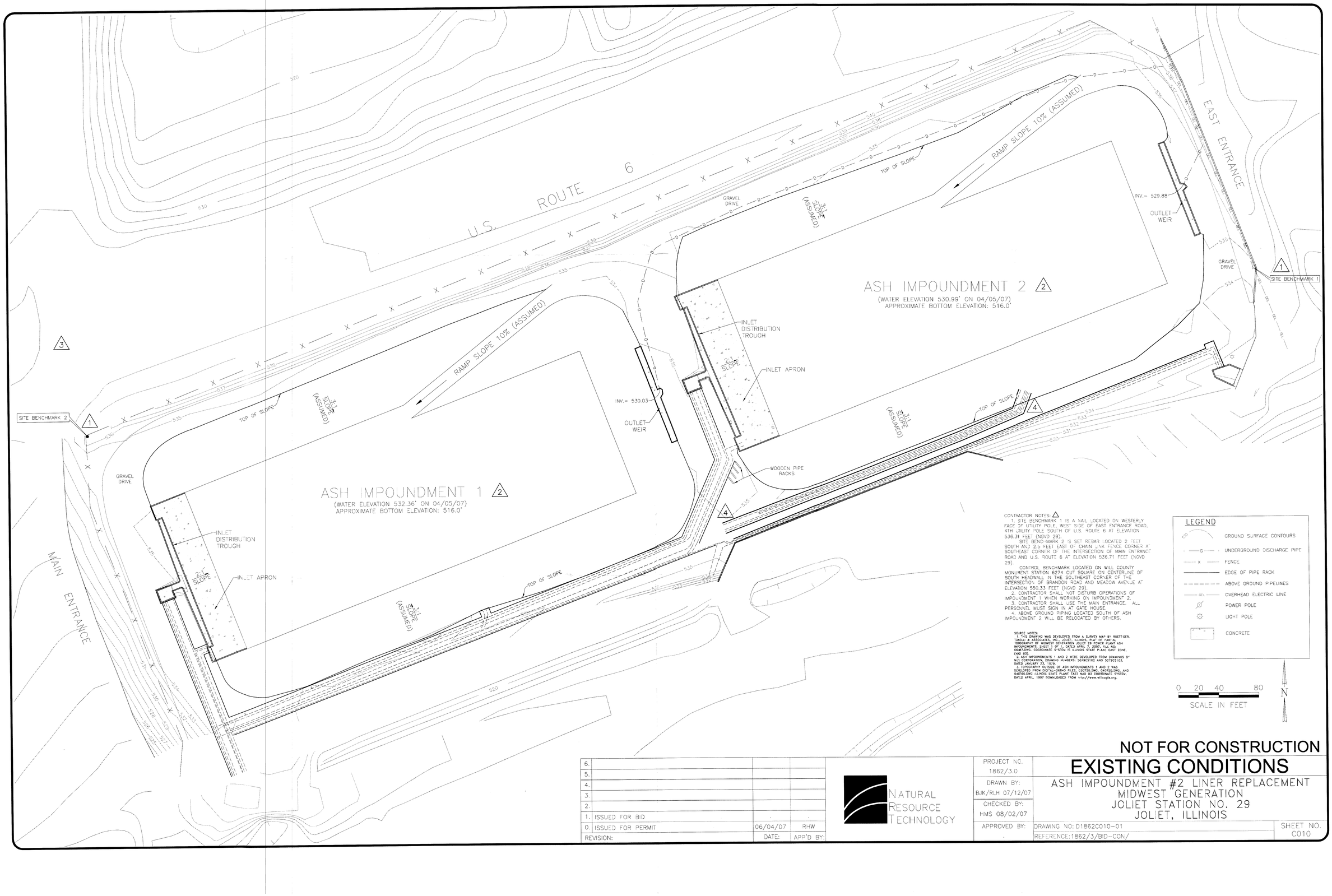
NATURAL RESOURCE TECHNOLOGY

NO.	REVISION:	DATE:	APP'D BY:
0.	ISSUED FOR BID		
1.			
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6.			

AUGUST 2007

PREPARED FOR:

MIDWEST GENERATION, LLC
1800 CHANNAHON ROAD
JOLIET, ILLINOIS 60436



CONTRACTOR NOTES: △

1. SITE BENCHMARK 1 IS A NAIL LOCATED ON WESTERLY FACE OF UTILITY POLE, WEST SIDE OF EAST ENTRANCE ROAD, 41M UTILITY POLE SOUTH OF U.S. ROUTE 6 AT ELEVATION 536.39 FEET (NGVD 29).

SITE BENCH-MARK 2 IS SET REBAR LOCATED 2 FEET SOUTH AND 2.5 FEET EAST OF CHAIN LINK FENCE CORNER AT SOUTHEAST CORNER OF THE INTERSECTION OF MAIN ENTRANCE ROAD AND U.S. ROUTE 6 AT ELEVATION 536.71 FEET (NGVD 29).

CONTROL BENCHMARK LOCATED ON WILL COUNTY MONUMENT STATION 6274 CUT SQUARE ON CENTERLINE OF SOUTH HEADWALL IN THE SOUTHEAST CORNER OF THE INTERSECTION OF BRANDON ROAD AND MEADOW AVENUE AT ELEVATION 550.33 FEET (NGVD 29).

2. CONTRACTOR SHALL NOT DISTURB OPERATIONS OF IMPOUNDMENT 1 WHEN WORKING ON IMPOUNDMENT 2.

3. CONTRACTOR SHALL USE THE MAIN ENTRANCE. ALL PERSONNEL MUST SIGN IN AT GATE HOUSE.

4. ABOVE GROUND PIPING LOCATED SOUTH OF ASH IMPOUNDMENT 2 WILL BE RELOCATED BY OTHERS.

SOURCE NOTES:

1. THIS DRAWING WAS DEVELOPED FROM A SURVEY MAP BY: RUETT-GER, TONELLI & ASSOCIATES, INC., JOLIET, ILLINOIS, PLAT OF PARTIAL TOPOGRAPHY OF MIDWEST GENERATION JOLIET 29 POWER PLANT ASH IMPOUNDMENTS, SHEET 1 OF 1, DATED APRIL 7, 2007, FILE NO. D1862DWG. COORDINATE SYSTEM IS ILLINOIS STATE PLANE EAST ZONE, NAD 83.

2. ASH IMPOUNDMENTS 1 AND 2 WERE DEVELOPED FROM DRAWINGS BY NUS CORPORATION, DRAWING NUMBERS: 5079C5102 AND 5079C5103, DATED JANUARY 23, 1979.

3. TOPOGRAPHY OUTSIDE OF ASH IMPOUNDMENTS 1 AND 2 WAS DEVELOPED FROM DIGITAL-ORTHO FILES, D30750.DWG, D43750.DWG, AND D40760.DWG ILLINOIS STATE PLANE EAST NAD 83 COORDINATE SYSTEM, DATED APRIL, 1997 DOWNLOADED FROM http://www.wiliogis.org

LEGEND

- GROUND SURFACE CONTOURS
- UNDERGROUND DISCHARGE PIPE
- FENCE
- EDGE OF PIPE RACK
- ABOVE GROUND PIPELINES
- OVERHEAD ELECTRIC LINE
- POWER POLE
- LIGHT POLE
- CONCRETE

0 20 40 80
SCALE IN FEET

N

NOT FOR CONSTRUCTION

EXISTING CONDITIONS

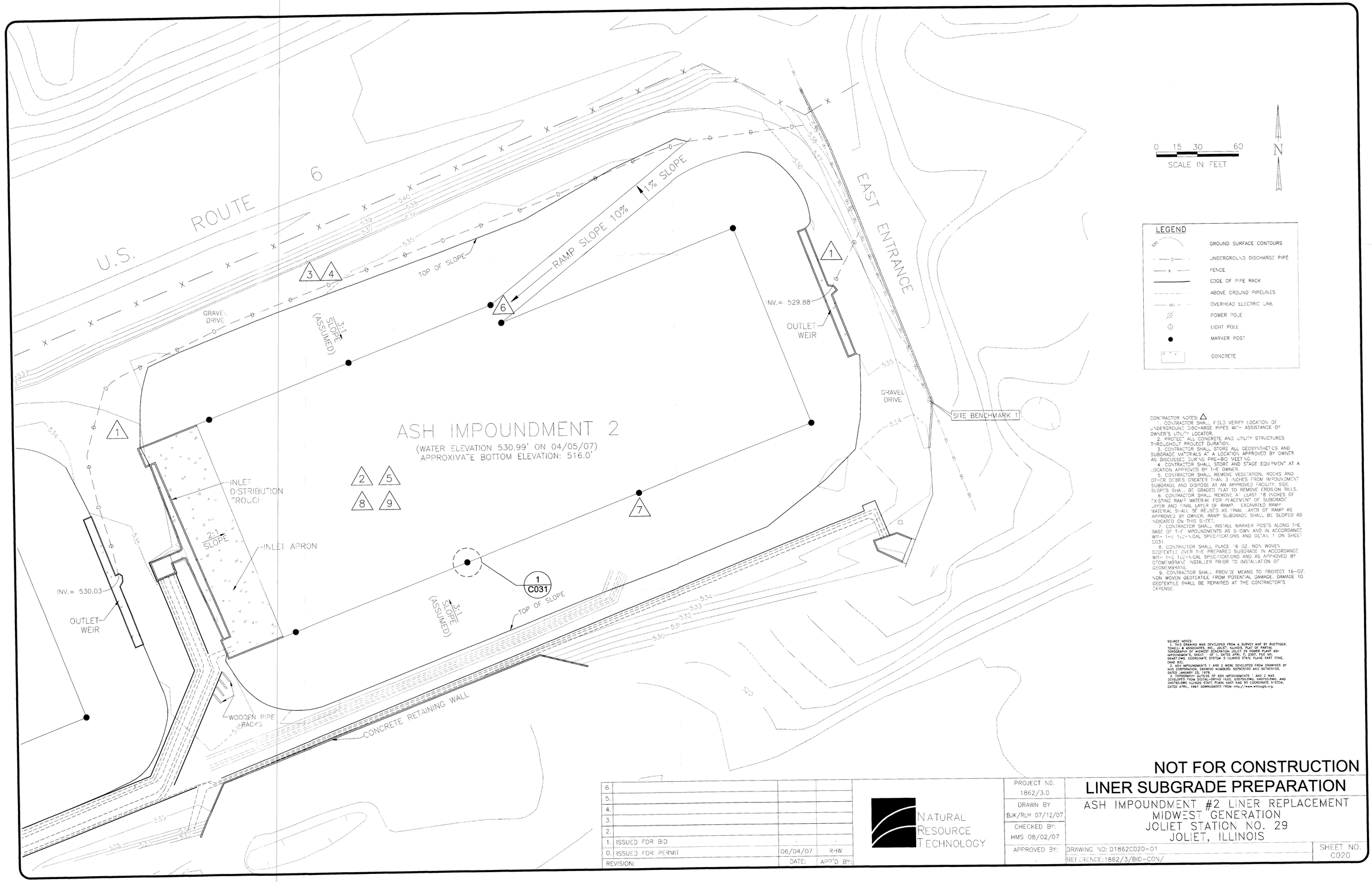
ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

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1.	ISSUED FOR BID	.	.
0.	ISSUED FOR PERMIT	06/04/07	RHW
REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.	1862/3.0
DRAWN BY:	BJK/RLH 07/12/07
CHECKED BY:	HMS 08/02/07
APPROVED BY:	.
DRAWING NO:	D1862C010-01
REFERENCE:	1862/3/BID-CON/
SHEET NO.	C010

MWG13-15_18735



CONTRACTOR NOTES:
1. CONTRACTOR SHALL FIELD VERIFY LOCATION OF UNDERGROUND DISCHARGE PIPES WITH ASSISTANCE OF OWNER'S UTILITY LOCATOR.
2. PROTECT ALL CONCRETE AND UTILITY STRUCTURES THROUGHOUT PROJECT DURATION.
3. CONTRACTOR SHALL STORE ALL GEOSYNTHETICS AND SUBGRADE MATERIALS AT A LOCATION APPROVED BY OWNER AS DISCUSSED DURING PRE-BID MEETING.
4. CONTRACTOR SHALL STORE AND STAGE EQUIPMENT AT A LOCATION APPROVED BY THE OWNER.
5. CONTRACTOR SHALL REMOVE VEGETATION, ROCKS AND OTHER DEBRIS GREATER THAN 3 INCHES FROM IMPOUNDMENT SUBGRADE AND DISPOSE AT AN APPROVED FACILITY. SIDE SLOPES SHALL BE GRADED FLAT TO REMOVE EROSION RILLS.
6. CONTRACTOR SHALL REMOVE AT LEAST 18 INCHES OF EXISTING RAMP MATERIAL FOR PLACEMENT OF SUBGRADE LAYER AND FINAL LAYER OF RAMP. EXCAVATED RAMP MATERIAL SHALL BE REUSED AS FINAL LAYER OF RAMP AS APPROVED BY OWNER. RAMP SUBGRADE SHALL BE SLOPED AS INDICATED ON THIS SHEET.
7. CONTRACTOR SHALL INSTALL MARKER POSTS ALONG THE BASE OF THE IMPOUNDMENTS AS SHOWN AND IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS AND DETAIL 1 ON SHEET C031.
8. CONTRACTOR SHALL PLACE 16 OZ. NON WOVEN GEOTEXTILE OVER THE PREPARED SUBGRADE IN ACCORDANCE WITH THE TECHNICAL SPECIFICATIONS AND AS APPROVED BY GEOMEMBRANE INSTALLER PRIOR TO INSTALLATION OF GEOMEMBRANE.
9. CONTRACTOR SHALL PROVIDE MEANS TO PROTECT 16-OZ. NON WOVEN GEOTEXTILE FROM POTENTIAL DAMAGE. DAMAGE TO GEOTEXTILE SHALL BE REPAIRED AT THE CONTRACTOR'S EXPENSE.

SOURCE NOTES:
1. THIS DRAWING WAS DEVELOPED FROM A SURVEY MAP BY RUETTIGER, TONELLI & ASSOCIATES, INC., JOLIET, ILLINOIS, TITLED BY PARTIAL TOPOGRAPHY OF MIDWEST GENERATION ASH IMPOUNDMENT #2 AND ADJACENT AREAS, SHEET 1 OF 1, DATED APRIL 23, 2007, FILE NO. D0607-TOPO. COORDINATE SYSTEM IS ILLINOIS STATE PLANE EAST ZONE, (NAD 83).
2. ASH IMPOUNDMENTS 1 AND 2 WERE DEVELOPED FROM DRAWINGS BY NUS CORPORATION, DRAWING NUMBERS: 5079C5103 AND 5079C5105, DATED JANUARY 23, 1979.
3. TOPOGRAPHY OUTSIDE OF ASH IMPOUNDMENTS 1 AND 2 WAS DEVELOPED FROM DIGITAL CONTOUR FILES, 530750.DWG, 540750.DWG, AND 540760.DWG, ILLINOIS STATE PLANE EAST NAD 83 COORDINATE SYSTEM, DATED APRIL, 1997 DOWNLOADED FROM http://www.willcogis.org.

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1.	ISSUED FOR BID	.	.
0.	ISSUED FOR PERMIT	06/04/07	RHW
REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.	1862/3.0
DRAWN BY	BJK/RLH 07/12/07
CHECKED BY:	HMS 08/02/07
APPROVED BY:	.

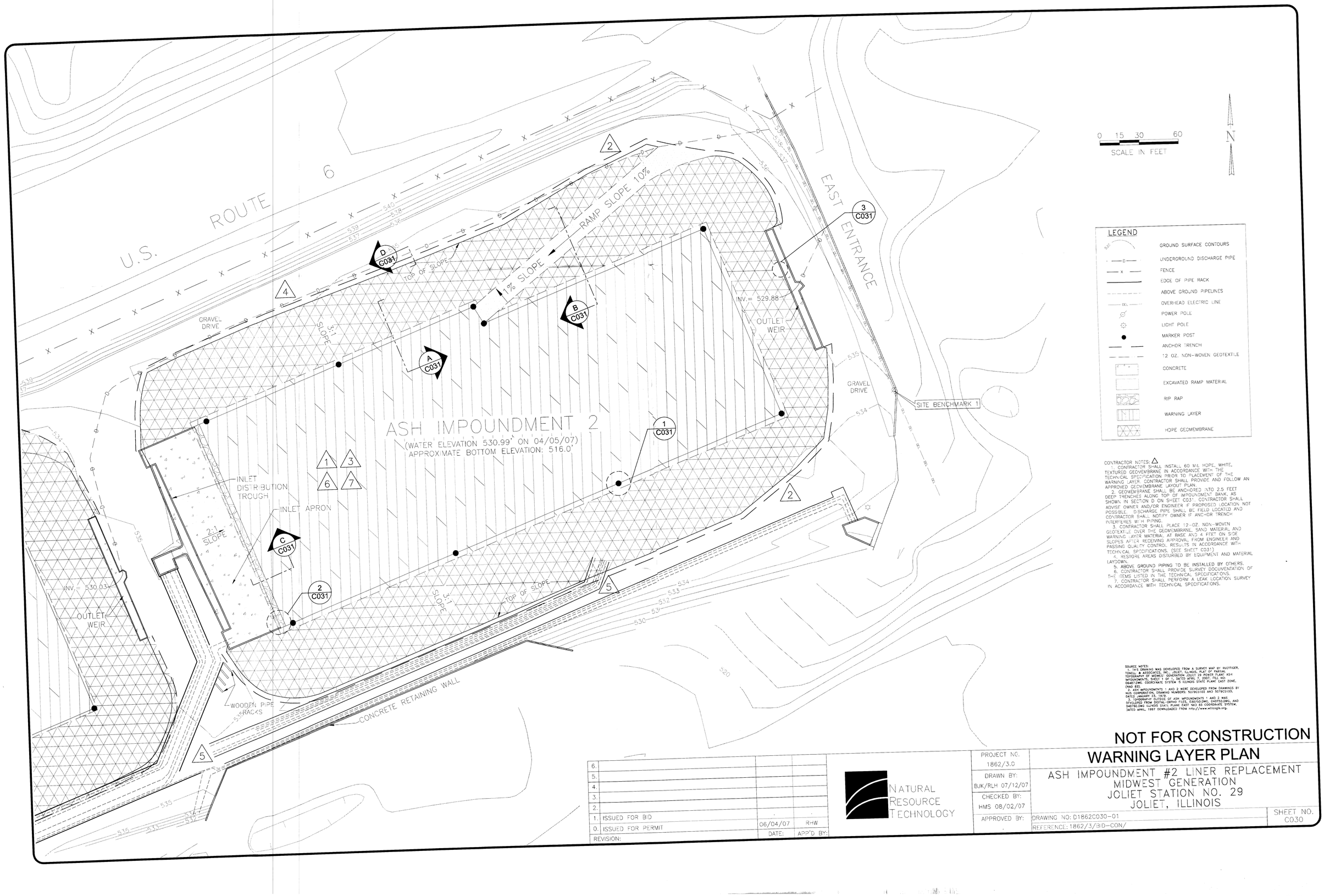
NOT FOR CONSTRUCTION

LINER SUBGRADE PREPARATION

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

DRAWING NO: D1862C020-01
REFERENCE:1862/3/BID-CON/

SHEET NO. C020



CONTRACTOR NOTES: △
1. CONTRACTOR SHALL INSTALL 60 MIL HDPE, WHITE, TEXTURED GEOMEMBRANE IN ACCORDANCE WITH THE TECHNICAL SPECIFICATION PRIOR TO PLACEMENT OF THE WARNING LAYER. CONTRACTOR SHALL PROVIDE AND FOLLOW AN APPROVED GEOMEMBRANE LAYOUT PLAN.
2. GEOMEMBRANE SHALL BE ANCHORED INTO 2.5 FEET DEEP TRENCHES ALONG TOP OF IMPOUNDMENT BANK, AS SHOWN IN SECTION D ON SHEET C031. CONTRACTOR SHALL ADVISE OWNER AND/OR ENGINEER IF PROPOSED LOCATION NOT POSSIBLE. DISCHARGE PIPE SHALL BE FIELD LOCATED AND CONTRACTOR SHALL NOTIFY OWNER IF AND/OR TRENCH INTERFERES WITH PIPING.
3. CONTRACTOR SHALL PLACE 12-OZ. NON-WOVEN GEOTEXTILE OVER THE GEOMEMBRANE, SAND MATERIAL AND WARNING LAYER MATERIAL AT BASE AND 4 FEET ON SIDE SLOPES AFTER RECEIVING APPROVAL FROM ENGINEER AND PASSING QUALITY CONTROL RESULTS IN ACCORDANCE WITH TECHNICAL SPECIFICATIONS. (SEE SHEET C031)
4. RESTORE AREAS DISTURBED BY EQUIPMENT AND MATERIAL LAYDOWN.
5. ABOVE GROUND PIPING TO BE INSTALLED BY OTHERS.
6. CONTRACTOR SHALL PROVIDE SURVEY DOCUMENTATION OF THE ITEMS LISTED IN THE TECHNICAL SPECIFICATIONS.
7. CONTRACTOR SHALL PERFORM A LEAK LOCATION SURVEY IN ACCORDANCE WITH TECHNICAL SPECIFICATIONS.

SOURCE NOTES:
1. THIS DRAWING WAS DEVELOPED FROM A SURVEY MAP BY KUETTIGER, TONELL & ASSOCIATES, INC., JOLIET, ILLINOIS, PLAT OF PARTIAL TOPOGRAPHY OF MIDWEST GENERATION JOLIET 29 POWER PLANT ASH IMPOUNDMENTS, SHEET 1 OF 1, DATED APRIL 7, 2007, T&L NO. 06487.DWG. COORDINATE SYSTEM IS ILLINOIS STATE PLANE EAST ZONE, (NAD 83).
2. ASH IMPOUNDMENTS 1 AND 2 WERE DEVELOPED FROM DRAWINGS BY NCR CORPORATION, DRAWING NUMBERS: 9023G102 AND 5079C3103, DATED JANUARY 23, 1978.
3. TOPOGRAPHY OUTSIDE OF ASH IMPOUNDMENTS 1 AND 2 WAS DEVELOPED FROM DIGITAL-ORTHO FILES, D80250.DWG, D40730.DWG, AND D40760.DWG ILLINOIS STATE PLANE EAST NAD 83 COORDINATE SYSTEM, DATED APRIL 1997 DOWNLOADED FROM http://www.ntlsonb.org.

NOT FOR CONSTRUCTION

WARNING LAYER PLAN

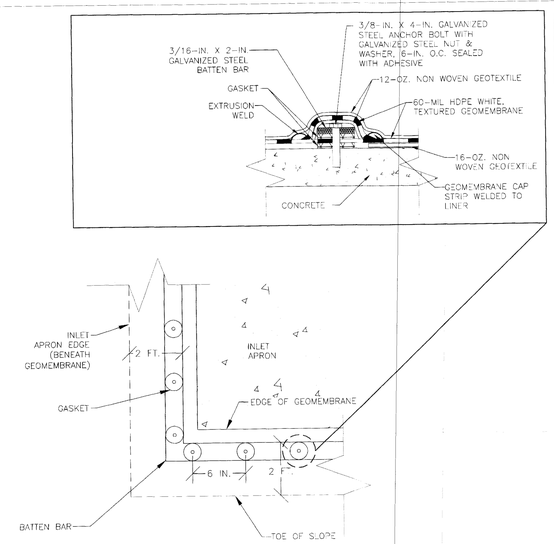
ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

REVISION:	DATE:	APP'D BY:
6.		
5.		
4.		
3.		
2.		
1. ISSUED FOR BID	06/04/07	RHW
0. ISSUED FOR PERMIT		

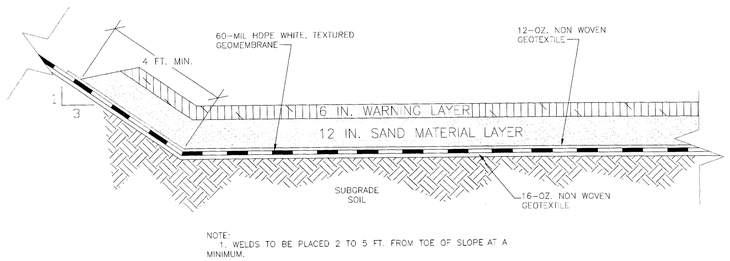
NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/3.0	
DRAWN BY: BJK/RLH 07/12/07	DRAWING NO: D1862C030-01
CHECKED BY: HMS 08/02/07	REFERENCE: 1862/3/3D-CON/
APPROVED BY:	SHEET NO. C030

MWG13-15_18737

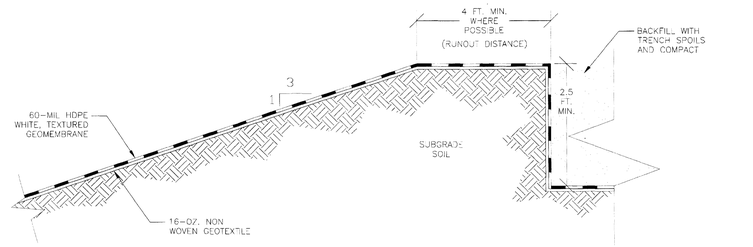


2 / C030 INLET APRON DETAIL PLAN
NOT TO SCALE

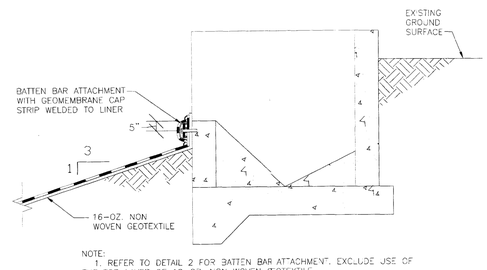


NOTE:
1. WELDS TO BE PLACED 2 TO 5 FT. FROM TOE OF SLOPE AT A MINIMUM.

A / C030 SLOPE TRANSITION SECTION
NOT TO SCALE

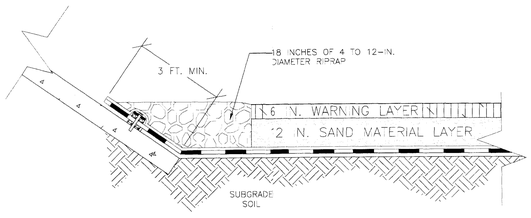


D / C030 ANCHOR TRENCH SECTION
NOT TO SCALE

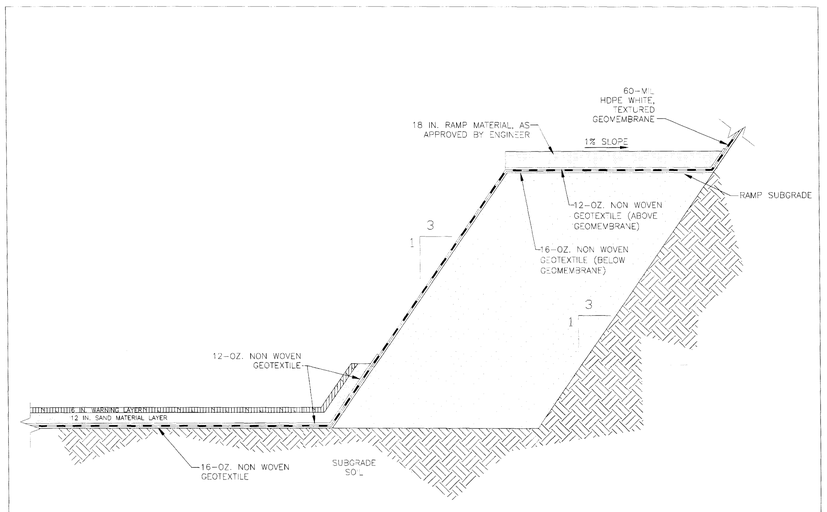


NOTE:
1. REFER TO DETAIL 2 FOR BATTEN BAR ATTACHMENT. EXCLUDE USE OF THE TOP LAYER OF 12-OZ. NON WOVEN GEOTEXTILE.

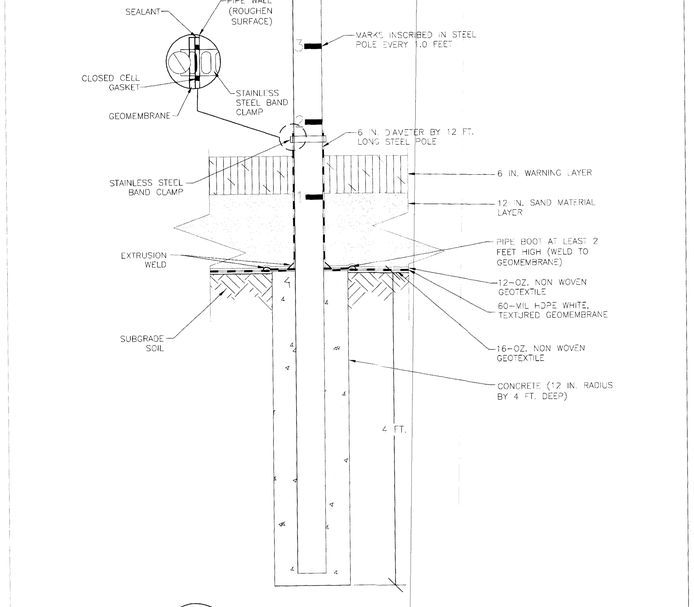
3 / C030 OUTLET WEIR DETAIL
NOT TO SCALE



C / -- INLET APRON SECTION
NOT TO SCALE



B / C030 RAMP SECTION
NOT TO SCALE



1 / C020 MARKER POST DETAIL
NOT TO SCALE

NOT FOR CONSTRUCTION

6.			
5.			
4.			
3.			
2.			
1.	ISSUED FOR BID	-	-
0.	ISSUED FOR PERMIT	06/04/07	RHW
REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

DETAILS AND SECTIONS

ASH IMPOUNDMENT #2 LINER REPLACEMENT
MIDWEST GENERATION
JOLIET STATION NO. 29
JOLIET, ILLINOIS

PROJECT NO. 1862/3.0		
DRAWN BY: BJK/RLH 07/12/07		
CHECKED BY: HMS 08/02/07		
APPROVED BY: -	DRAWING NO: D1862C031-01	SHEET NO. C031
	REFERENCE: 1862/3/BID-CON/	

Attachment 8

Electronic Filing: Received, Clerk's Office 2/04/2022

04/13/2008 19:43 8155210999 BRIESER CONSTRUCTION PAGE 02

MIDWEST GENERATION EME, LLC
An EDISON INTERNATIONAL℠ Company

FCR # 1

Field Change Request (FCR)

Contractor: Brieser Construction MWGen PO # 4500007560

Description of Change/Information Requested: The 9 Marker Posts require drilling into bedrock in lieu of soil. Drilling into rock requires specialized equipment and more time. We will hire a subcontractor for this work.

Affected Design/Contract Documents: N/A

Reason for Change: We were not aware of bedrock height when project was bid.

Requested by: Todd Mills Date: 4-14-08

MWGen Response:

Response by: Date:

Does this Request require a contract change? ☒ YES ☐ NO
If YES, complete the following:

Requisition Number: PO # / Line Item: 4500007560

Cost of Change: $4,000.00

Cost Basis: ☒ Firm Lump Sum Quote ☐ T&M estimate ☐ T&M estimate not to exceed

Schedule Impact: None

Change Approved by: Authorized MWGen Signature 4-22-08 Approval Date

Change Approved by: Todd Mills Authorized Contractor Signature 4-22-08 Approval Date

FCR Form Revision 0, dated 3/4/08

Electronic Filing: Received, Clerk's Office 2/04/2022

MIDWEST GENERATION EME, LLC
An EDISON INTERNATIONAL Company

FCR # 2

Field Change Request (FCR)

Contractor: Briceser Construction MWGen PO # 4500007560

Description of Change/Information Requested: Bottom of Ash Pond #2 has unsuitable material that has been deposited in the pond. The material will not dry out and needs to be removed. We have estimated that 1200 cubic yards of material may have to be removed.

Affected Design/Contract Documents:

Reason for Change: Material is not acceptable for a base to install the new liner upon.

Requested by: Todd Mills Date: 4-17-08

MWGen Response:

Response by: Date:

Does this Request require a contract change? ☒ YES ☐ NO
If YES, complete the following:

Requisition Number: PO # / Line Item:

Cost of Change: $18,000.00 - estimated
Cost Basis: ☐ Firm Lump Sum Quote ☒ T& M estimate ☐ T& M estimate not to exceed

Schedule Impact: None

Change Approved by: Brian Delvos — Authorized MWGen Signature — 4-22-08 Approval Date

Change Approved by: Todd Mills — Authorized Contractor Signature — 4-22-08 Approval Date

FCR Form Revision 0, dated 8/4/00

Attachment 9

Electronic Filing: Received, Clerk's Office 12/1/2015

Brieser Construction Co
24101 S. Municipal Drive
Channahon, IL 60410
(815) 521-0900
FAX (815) 521-0999

JOB INVOICE

35547

☐ DAY WORK ☐ CONTRACT ☒ EXTRA

Job Name: Pond liner #2

To: Midwest Generation

Order #: phase 1701

Job Number: 87188 Date: 4-21-08

DESCRIPTION OF WORK

Haul rest of material to coal pile w/ semis

EQUIPMENT CHARGES	HRS.	RATE	AMOUNT
#1 - Dozer w/ Ripper	8		
#1 Pulv	8		
TOTAL EQUIPMENT			

QTY.	MAT/SUBCONTRACTOR	PRICE	AMOUNT
-	Shuck - T300 w/ forks		
-	ILL. truck - 215 New Holland		
-	Debs way (T. Ref # 7530)		
-	MDI (T. Ref # 002065)		
-	MDI (T. Ref # 005997)		
-	MDI (T. Ref # 014459)		
-	MDI (T. Ref # 018578)		
100gals	Diesel fuel from shop		
TOTAL MAT/SUBS			

NAME	CLASS	HOURS	RATE	AMOUNT
Mike Schmidt	LF	ST 8		
		OT 1½		
		DT		
Brad Emanuelson	LJ	ST 8		
		OT		
		DT		
Billy Bringley	Oper	ST 8		
		OT		
		DT		
Mike Ackermann	GS	ST 1		
		OT		
		DT		
		ST		
		OT		
		DT		
		ST		
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TOTAL LABOR				
TOTAL MAT/SUBS				
TOTAL EQUIPMENT				
TOTAL				

WORK ORDERED BY

SIGNATURE Mike Nelson

CUSTOMER COPY

MWG13-15_18531

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Brieser Construction Co.
24101 S. Municipal Drive
Channahon, IL 60410
(815) 521-0900
FAX (815) 521-0999

JOB INVOICE

35546

☐ DAY WORK ☐ CONTRACT ☒ EXTRA

Job Name: Pond Liner #2

To: Midwest Generation

Order #: phase 1701

Job Number: 7188 Date: 4-18-08

DESCRIPTION OF WORK
Hauled in material w/ scrapers to road pile. Job is not complete

EQUIPMENT CHARGES	HRS.	RATE	AMOUNT
#1 - Push w/ tools	8		
#1 - Push	8		
TOTAL EQUIPMENT			

QTY.	MAT/SUBCONTRACTOR	PRICE	AMOUNT
8hrs	Smoke T300 w/ forks		
	ICE Smoke 210 New Holland		
	(Steer #11884)		
-	MDI (Unit # 14863)		
-	MDI (Unit # 14492)		
-	MDI (Unit # 13577)		
-	MDI (Unit # 02946)		
-	MDI (Unit # 02204)		
	Dobs way (Unit # 6998)		
TOTAL MAT/SUBS			

NAME	CLASS	HOURS	RATE	AMOUNT
Mike Schaefer	LF	ST 8		
		OT 3		
		DT		
Brad Emanuelson	LJ	ST 8		
		OT 2		
		DT		
Billy Bill [illegible]	Oper	ST 8		
		OT 2		
		DT		
Mike Adelmann	GS	ST 1		
		OT		
		DT		
Tom Gibbs	Sale	ST 1		
		OT		
		DT		
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TOTAL LABOR				

TOTAL MAT/SUBS	
TOTAL EQUIPMENT	
TOTAL	

WORK ORDERED BY

SIGNATURE BS Peters

CUSTOMER COPY

Electronic Filing: Received, Clerk's Office

Brieser Construction Co
24101 S. Municipal Drive
Channahon, IL 60410
(815) 521-0900
FAX (815) 521-0999

JOB INVOICE

35549

☐ DAY WORK ☐ CONTRACT ☒ EXTRA

Job Name: Pond Liner #2

To: Midwest Generation

Order #: phase #1701

Job Number: 87188 Date: 4-17-08

DESCRIPTION OF WORK
Push coal residue into piles

NAME	CLASS	HOURS	RATE	AMOUNT
Mike Schm.	LF	ST 4		
		OT 2½		
		DT		
Ralph Russ	Oper	ST 8		
		OT 2		
		DT		
		ST		
		OT		
		DT		
		ST		
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		DT		

EQUIPMENT CHARGES	HRS.	RATE	AMOUNT
#224 - D5 Dozer	8		
#1 Push	10		
TOTAL EQUIPMENT			

QTY.	MAT/SUBCONTRACTOR	PRICE	AMOUNT

Attachment 10

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NATURAL RESOURCE TECHNOLOGY

Mr. Brian Delcorio
Midwest Generation, LLC
Joliet Generating Station, Units 7/8
1800 Channahon Road
Joliet, IL 60436

December 23, 2008
(1862)

RE: Construction Documentation Transmittal
Ash Impoundment #1 and #2 Liner Replacement

Dear Mr. Delcorio:

Enclosed with this correspondence are construction record documents related to replacement of the liners in Ash Impoundments #1 and #2 at Joliet 29. Construction began on Impoundment #2 in early April 2008. Following Impoundment #2 construction, Impoundment #1 was dewatered and dredged. Liner replacement construction on Impoundment #1 began in late August 2008. The following information is enclosed:

- Select submittals from Contractor;

Attachment	Submittal Item # on Table 2[1]	Submittal Description
A1	10	Warning Layer and Cushion Layer Gradation Reports
A2	11	Geomembrane Resin Test Results
A3	21	Geosynthetic Product Information
A4	24	Geomembrane Installer's Daily Logs and QC Documentation (Impoundment #1 and #2)
A5	25	Geomembrane Installer's Subgrade Acceptance (Impoundment #1 and #2)
A6	26	Geomembrane Installation Certificate (Impoundment #1 and #2)
A7	26	Geomembrane Installation Warranties
A8	26	Geomembrane As-Built Panel Layout (Impoundment #1 and #2)
A9	31	Leak Location Survey Report (Impoundment #1and #2)

- Field Directives #1 and #2 (Attachment B);
- Drawings for both impoundments updated to reflect Contractor's documentation survey of the location of anchor trench alignment and marker posts, and topography of the warning layer (Attachment C);
- Natural Resource Technology, Inc. (NRT) Construction Quality Assurance (CQA) Daily Field Reports (Attachment D); and
- Record drawing containing liner details and sections (Sheet C031).

[1] Refer to Table 2 – List of Submittals from Specification No. 20007575

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If you have any questions or comments pertaining to this transmittal, please feel free to contact us. It has been a pleasure working with you on this project, and we look forward to working with you again in the future.

Sincerely,

NATURAL RESOURCE TECHNOLOGY, INC.

Heather M. Simon, PE
Project Engineer

Eric J. Tlachac, PE
Project Manager

Encls.: Attachment A: Contractor Submittals
Attachment B: Field Directives Attachment C: Ash Impoundment #1 and #2 Documentation Survey
Attachment D: NRT CQA Daily Field Reports
Sheet C031 – Details and Sections

cc: Ms. Maria Race (w/o attachments)

[1862 Construction Documentation 081223.doc]

Printed on paper containing 60% recycled fibers and 30% post-consumer waste

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ATTACHMENT A

CONTRACTOR SUBMITTALS

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ATTACHMENT A1

WARNING LAYER AND CUSHION LAYER GRADATION REPORTS

LAFARGE AGGREGATES & CONCRETE

Quality Test Report

Plant 30260-Joliet
Product CA-6-042CM06
Specification IDOT MODIFIED CM06 Spec

1641306362

Sample Information

Sample No 1641306362
Date Sampled 03/26/2008 10:30
Date Completed 03/27/2008 10:30
Sampled By Ken Sierzega
Tested By Ken Sierzega
Type Shipping
Method Bucket Blend/Sam Pad
Location
Process MAIN IDOT
Ledge Underground Bench
Other

Weather
Temp
Split Sample ☐ **Sequence**
Resample ☐ **Code**
Borehole
Depth Top/Bottom

Test Note

Gradation Results

Unit	Moist Mass	Dry Mass	Wash Mass	Moisture %	Wash Loss %	Procedure
g	6317.00	6203.00	5643.00	1.8	9.0	

Sieve	Mass Retained	Cum Mass Retained	Ind % Retained	% Retained	% Passing	Target	Specification	Comment
1 1/2" (37.5mm)	0.0	0.0	0	0	100		100-100	
1" (25mm)	528.0	528.0	8	8	92		90-100	
3/4" (19mm)	619.0	1147.0	10	18	82			
5/8" (16mm)	520.0	1667.0	8	27	73			
1/2" (12.5mm)	475.0	2142.0	8	35	65		60-90	
3/8" (9.5mm)	496.0	2638.0	8	43	57			
1/4" (6.3mm)	517.0	3155.0	8	51	49			
#4 (4.75mm)	284.0	3439.0	5	55	45		30-56	
#8 (2.36mm)	669.0	4108.0	11	66	34			
#16 (1.18mm)	473.0	4581.0	8	74	26		10-40	
#40 (0.425mm)	419.0	5000.0	7	81	19			
#200 (75um)	593.0	5593.0	9.6	90.2	9.8		4-12	
PAN (0um)	45.0	5638.0	9.8	100.0	0.0			

Other Test Results

Test Name	Date / Procedure	Result / Lab	Unit	Target	Specification / Tested By	Comment
FM	03/27/2008 10:30	5.57 Joliet			Ken Sierzega	
Grad Loss %	03/27/2008 10:30	0.081 Joliet	%		Ken Sierzega	
Wash Loss %	03/27/2008 10:30	9.0 Joliet	%		Ken Sierzega	

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LAFARGE AGGREGATES & CONCRETE

Quality Test Report

Plant 30260-Joliet
Product Stone Sand-013FM05
Specification 013FM05

1635349963

Sample Information

Sample No	1635349963	Weather	
Date Sampled	03/26/2008 08:29	Temp	
Date Completed	03/27/2008 08:29	Split Sample ☐	Sequence
Sampled By	Ken Sierzega	Resample ☐	Code
Tested By	Ken Sierzega	Borehole	
Type	Shipping	Depth Top/Bottom	
Method	Bucket Blend/Sam Pad	Test Note	
Location			
Process	MAIN IDOT		
Ledge	Underground Bench		
Other			

Gradation Results

Unit	Moist Mass	Dry Mass	Wash Mass	Moisture %	Wash Loss %	Procedure
g	805.30	769.70	640.20	4.6	16.8	

Sieve	Mass Retained	Cum Mass Retained	Ind % Retained	% Retained	% Passing	Target	Specification	Comment
3/8" (9.5mm)	0.0	0.0	0	0	100		100	
#4 (4.75mm)	18.5	18.5	2	2	98		84-100	
#8 (2.36mm)	142.3	160.8	19	21	79			
#16 (1.18mm)	181.1	341.9	24	45	55			
#30 (0.6mm)	116.1	458.0	15	60	40			
#50 (0.3mm)	77.2	535.2	10	70	30			
#100 (0.15mm)	50.6	585.8	7	76	24		0-40	
#200 (75um)	41.2	627.0	5.4	81.7	18.3		0-30	
PAN (0um)	11.5	638.5	18.3	100.0	0.0			

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ATTACHMENT A2

GEOMEMBRANE RESIN TEST RESULTS

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips Chemical Company LP

CoA Date: 08/23/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87473726
PO #: 40932
Weight: 188900 LB
Ship Date: 08/23/2007
Package: BULK
Mode: Hopper Car
Car #: PSPX009173
Seal No: 235847

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271106

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	9.8	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/22/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips Chemical Company LP

CoA Date: 08/23/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87473728
PO #: 40932
Weight: 192500 LB
Ship Date: 08/23/2007
Package: BULK
Mode: Hopper Car
Car #: PSPX005936
Seal No: 235760

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271118

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	12.9	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/25/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
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Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips Chemical Company LP

CoA Date: 08/23/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87473728
PO #: 40932
Weight: 192500 LB
Ship Date: 08/23/2007
Package: BULK
Mode: Hopper Car
Car #: PSPX005936
Seal No: 235760

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271118

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	12.9	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/25/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
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Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips

CoA Date: 08/27/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC 19103 GUNDLE ROAD WESTFIELD TX 77090 USA	CPC Delivery #: 87476502 PO #: 40931 Weight: 191700 LB Ship Date: 08/27/2007 Package: BULK
Recipient: Phouangsavanh Fax:	Mode: Hopper Car Car #: PSPX002351 Seal No: 235617

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271154

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	11.9	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/31/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

Chevron Phillips Chemical Company LP

CoA Date: 08/27/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87476504
PO #: 40931
Weight: 192500 LB
Ship Date: 08/27/2007
Package: BULK
Mode: Hopper Car
Car #: CHVX896642
Seal No: 235619

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271157

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	12.4	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		07/31/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Chevron Phillips Chemical Company LP

CoA Date: 08/29/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87477809
PO #: 40931
Weight: 190000 LB
Ship Date: 08/29/2007
Package: BULK
Mode: Hopper Car
Car #: GOCX058423
Seal No: 235771

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271162

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	12.1	g/10mi
Density	ASTM D1505	0.936	g/cm3
Production Date		08/02/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

CoA Date: 11/20/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87535160
PO #: 40931
Weight: 188700 LB
Ship Date: 11/20/2007
Package: BULK
Mode: Hopper Car
Car #: CHVX893140
Seal No: 246044

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271744

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	10.7	g/10mi
Density	ASTM D1505	0.936	g/cm3
Production Date		11/18/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

Electronic Filing: Received, Clerk's Office 2/04/2022

CoA Date: 11/20/2007

Certificate of Analysis

Shipped To: GSE LINING TECHNOLOGY INC: HC
19103 GUNDLE ROAD
WESTFIELD TX 77090
USA

Recipient: Phouangsavanh
Fax:

CPC Delivery #: 87535163
PO #: 40931
Weight: 192400 LB
Ship Date: 11/20/2007
Package: BULK
Mode: Hopper Car
Car #: PSPX003065
Seal No: 245929

Product:
MARLEX POLYETHYLENE K306 BULK

Lot Number: 8271747

Property	Test Method	Value	Unit
Melt Index	ASTM D1238	0.1	g/10mi
HLMI Flow Rate	ASTM D1238	11.2	g/10mi
Density	ASTM D1505	0.937	g/cm3
Production Date		11/19/2007	

The data set forth herein have been carefully compiled by Chevron Phillips Chemical Company LP.
However, there is no warranty of any kind, either expressed or implied, applicable to its use, and the user assumes all risk and liability in connection therewith.

Paul S. Newbold
Quality Systems Coordinator

For CoA questions contact Tom Scheirman at 832-813-4637

GSE Roll Allocation

Order 53376
Customer CAAWS
Site Midwest Generation LLC

Roll#	*Resin Lot*	*Product Code*	*Description*	*Mfg. Date*	*Length*
104137147	8271106	HDT060A010	HDT060A010	8/31/2007	520
104137238	8271118	HDT060A010	HDT060A010	9/6/2007	520
104137263	8271154	HDT060A010	HDT060A010	9/8/2007	520
104137264	8271154	HDT060A010	HDT060A010	9/8/2007	520
104137340	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137341	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137342	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137343	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137344	8271157	HDT060A010	HDT060A010	9/13/2007	520
104137406	8271162	HDT060A010	HDT060A010	9/17/2007	520
104137407	8271162	HDT060A010	HDT060A010	9/17/2007	520
105136345	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136346	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136347	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136353	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136354	8271744	HDT060A010	HDT060A010	12/4/2007	520
105136356	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136357	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136358	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136359	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136360	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136361	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136362	8271744	HDT060A010	HDT060A010	12/5/2007	520
105136363	8271747	HDT060A010	HDT060A010	12/5/2007	520
105136364	8271747	HDT060A010	HDT060A010	12/5/2007	520
105136365	8271747	HDT060A010	HDT060A010	12/5/2007	520
105136367	8271747	HDT060A010	HDT060A010	12/5/2007	520
105136368	8271747	HDT060A010	HDT060A010	12/5/2007	520

Electronic Filing: Received, Clerk's Office 2/04/2022

ATTACHMENT A3

GEOSYNTHETIC PRODUCT INFORMATION

Electronic Filing: Received, Clerk's Office 2/04/2022

Submittal #20

GSE Lining Technology, Inc.

19103 Gundle Road
Houston, Texas 77073
800-435-2008
281.230.6747

February 18, 2008

Matt Albert
Clean Air and Water Systems, LLC
123 Elm Street
Dousman, WI 53118

RE: Midwest Generation
Project No. 524244

Certification of Compliance

The undersigned, being qualified and authorized to do so, hereby certifies that GSE Lining Technologies Manufacturing Quality Assurance plan was fully implemented during production of the geosynthetic materials for the aforementioned project.

Sincerely,

Daniel Semanisin
GSE Technical Support Specialist

cc: Karen Dennison, GSE Lining Technology Inc.

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE®

GSE Lining Technology, Inc.

LETTER OF TRANSMITTAL

Brian McKeown
Clean Air and Water Systems, LLC.
123 Elm Street
Dousman, WI 53118-0337

DATE: December 11, 2007
JOB NO: SO 53376
JOB NAME: Midwest Generation, LLC
RE: QC/QA Certificate

COPIES	DESCRIPTION
1	QC/QA Documentation as per Bill of Lading # 72674 & 72671

TRANSMIT VIA:

U.S. Mail

If enclosures are not as noted kindly notify us at once.

SIGNED: Janet M Valadez
DATE: December 11, 2007

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at HOUSTON, TEXAS

Shippers No. 72671

Received at Houston, Texas from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Roll Certifications Included

Date: 12/10/07

Branch Plant: 1500

Shipping Instructions: Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order 53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	FREIGHTSHT001 DOM. SHIPPING CHARGE DOMESTIC SHEET NON TAXABLE	
2	105136353	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,973.00
3	105136356	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,920.00
4	105136357	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,930.00
5	105136358	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,920.00
6	105136359	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,920.00
7	105136360	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,920.00
8	105136362	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,980.00
9	105136363	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,922.00
10	105136364	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,940.00
11	105136365	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,970.00
12	105136367	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,990.00
13	105136368	11700	SF	HDT060A010 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,004.00

Deliver on 12/12/07

Total Quantity 140,401 **Total Weight:** 47,389.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up # 18406RR

Seal #

Truckers P.O. # PO183780

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (281) 230-6781 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: BENNETT

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Lining Technology, Inc

Roll Test Data Report

Bill of Lading: 72671

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	HDT060A010	12/10/2007

GSE QC APPROVED

*Modified

	ASTM D 5994		ASTM D638, Type IV / D6693								ASTM D 1004		ASTM D 4833	ASTM D 1505	ASTM D 4218/1603	ASTM D 5596	GRI GM 12	
	Average Thickness	Minimum Thickness	TD Strength @ Yield	MD Strength @ Yield	TD Strength @ Break	MD Strength @ Break	TD Elongation @ Yield	MD Elongation @ Yield	TD Elongation @ Break	MD Elongation @ Break	TD Tear Resistance	MD Tear Resistance	Puncture Resistance	Density	Carbon Black Content	Carbon Black Dispersion	Asperity Height Side A	Asperity Height Side B
	(mils)	(mils)	(ppi)	(ppi)	(ppi)	(ppi)	(%)	(%)	(%)	(%)	(lbs)	(lbs)	(lbs)	(g/cc)	(%)	Views in Cat1 - Cat2	(mils)	(mils)
Roll No.	every roll		every 4th								every 4th		every 4th	every 4th	every 4th	every 4th	every 2nd	
105136353	62	59	165	161	184	218	17	18	440	554	53	55	151	0.945	2.59	10	32	18
105136356	62	60	162	159	176	205	15	18	448	518	51	54	147	0.944	2.59	10	24	22
105136357	62	60	162	159	176	205	15	18	448	518	51	54	147	0.944	2.59	10	24	22
105136358	63	60	168	161	172	213	15	17	417	545	51	53	142	0.945	2.66	10	24	19
105136359	62	60	168	161	172	213	15	17	417	545	51	53	142	0.945	2.66	10	24	19
105136360	62	58	168	161	172	213	15	17	417	545	51	53	142	0.945	2.66	10	23	24
105136362	61	57	170	166	184	214	16	18	436	541	53	57	156	0.945	2.56	10	23	21
105136363	61	58	170	166	184	214	16	18	436	541	53	57	156	0.945	2.56	10	23	21
105136364	62	59	170	166	184	214	16	18	436	541	53	57	156	0.945	2.56	10	24	19
105136365	62	57	170	166	184	214	16	18	436	541	53	57	156	0.945	2.56	10	24	19
105136367	61	59	162	160	214	202	18	18	588	553	51	55	152	0.944	2.75	10	24	23
105136368	63	61	162	160	214	202	18	18	588	553	51	55	152	0.944	2.75	10	24	23

Approved By:

This test report shall not be reproduced, except in full, without written approval of the laboratory.

GSE-8.2.4-029 Rev - - 03/05

19103 Gundle Road - Houston, Texas 77073

Dec 10 07 03:31p Lab 2812336797 P.1

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at HOUSTON, TEXAS

Shippers No. 72674

Received at Houston, Texas from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Roll Certifications Included

Date: 12/10/07

Branch Plant: 1500

Shipping Instructions:

Call 24 hours before delivery

Tedd Mills @ 815-521-0900

Sales Order 53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	**FREIGHTSHT001** DOM. SHIPPING CHARGE DOMESTIC SHEET NON TAXABLE	
2	104137263	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,000.00
3	104137264	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,972.00
4	104137340	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,932.00
5	104137341	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,952.00
6	104137342	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,940.00
7	104137343	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,932.00
8	104137344	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,936.00
9	105136345	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,028.00
10	105136346	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,078.00
11	105136347	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	4,000.00
12	105136354	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,976.00
13	105136361	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,934.00

Deliver on 12/12/07

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up # 18407AR

Seal #

Truckers P.O. # PO176633

Total Quantity 140,401 Total Weight: 47,880.00

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (281) 230-6781 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: TMC

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Lining Technology, Inc

Roll Test Data Report

Bill of Lading: 72674

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	HDT060A010	12/10/2007 *Modified

GSE QC APPROVED

	ASTM D 5994		ASTM D638,Type IV / D6693								ASTM D 1004		ASTM D 4833	ASTM D 1505	ASTM D 4218/1603	ASTM D 5596	GRI GM 12	
	Average Thickness (mils)	Minimum Thickness (mils)	TD Strength @ Yield (ppi)	MD Strength @ Yield (ppi)	TD Strength @ Break (ppi)	MD Strength @ Break (ppi)	TD Elongation @ Yield (%)	MD Elongation @ Yield (%)	TD Elongation @ Break (%)	MD Elongation @ Break (%)	TD Tear Resistance (lbs)	MD Tear Resistance (lbs)	Puncture Resistance (lbs)	Density (g/cc)	Carbon Black Content (%)	Carbon Black Dispersion Views in Cat1 - Cat2	Asperity Height Side A (mils)	Asperity Height Side B (mils)
Roll No.	every roll		every 4th								every 4th		every 4th	every 4th	every 4th	every 4th	every 2nd	
104137263	61	58	128	134	155	175	16	17	494	535	47	45	137	0.946	2.51	10	29	21
104137264	61	57	153	165	210	200	18	17	565	518	54	54	151	0.946	2.52	10	29	21
104137340	61	58	161	148	198	240	16	18	531	622	51	55	153	0.947	2.44	10	18	22
104137341	62	56	162	158	189	229	18	17	552	634	51	55	153	0.947	2.41	10	18	22
104137342	61	57	162	158	189	229	16	17	552	634	51	55	153	0.947	2.41	10	17	21
104137343	61	58	162	158	189	229	16	17	552	634	51	55	153	0.947	2.41	10	17	21
104137344	61	58	162	158	189	229	16	17	552	634	51	55	153	0.947	2.41	10	22	22
105136345	63	59	168	170	207	208	15	16	549	519	54	57	148	0.946	2.59	10	26	18
105136346	60	55	163	155	205	212	16	18	559	538	53	55	151	0.946	2.58	10	26	21
105136347	62	59	163	155	205	212	16	18	559	538	53	55	151	0.946	2.58	10	23	21
105136354	61	58	162	159	176	205	15	18	448	518	51	54	147	0.944	2.59	10	24	21
105136361	61	58	168	161	172	213	15	17	417	545	51	53	142	0.945	2.66	10	23	24

Approved By:

This test report shall not be reproduced, except in full, without written approval of the laboratory.

19103 Gundle Road - Houston, Texas 77073

Dec 10 07 04:14p Lab 2812306787 p.1

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE®

GSE Lining Technology, Inc.

LETTER OF TRANSMITTAL

Brian McKeown
Clean Air and Water Systems, LLC.
123 Elm Street
Dousman, WI 53118-0337

DATE: December 12, 2007
JOB NO: SO 53376
JOB NAME: Midwest Generation, LLC
RE: QC/QA Certificate

COPIES	DESCRIPTION
1	QC/QA Documentation as per Bill of Lading # 72695

TRANSMIT VIA:

U.S. Mail

If enclosures are not as noted kindly notify us at once.

SIGNED: Janet M Valadez
DATE: December 12, 2007

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at HOUSTON, TEXAS

Shippers No. 72695

Received at Houston, Texas from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Roll Certifications Included

Date: 12/11/07

Branch Plant: 1500

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order: 53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	**FREIGHTSHT001** DOM. SHIPPING CHARGE DOMESTIC SHEET NON TAXABLE	
2	104137147	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,994.00
3	104137238	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,934.00
4	104137406	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,978.00
5	104137407	11700	SF	**HDT060A010** 60 mil Avg GSE HDW Textured Blk/Wht, HD, 2 Side Tex, 22.5'	3,964.00

Del. 12/13/07

Total Quantity 46,801 — Total Weight: 15,870.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Signature of Consignor

Local Verification Signed:

X

Pick Up # 18408RR

Seal #

Truckers P.O. # P0187869

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (281) 230-6781 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: IIE

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Lining Technology, Inc

Roll Test Data Report

Bill of Lading: 72695

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	HDT060A010	12/11/2007 *Modified

GSE QC APPROVED

	ASTM D 5994		ASTM D638,Type IV / D6693								ASTM D 1004		ASTM D 4833	ASTM D 1505	ASTM D 4218/1603	ASTM D 5596	GRI GM 12	
	Average Thickness (mils)	Minimum Thickness (mils)	TD Strength @ Yield (ppi)	MD Strength @ Yield (ppi)	TD Strength @ Break (ppi)	MD Strength @ Break (ppi)	TD Elongation @ Yield (%)	MD Elongation @ Yield (%)	TD Elongation @ Break (%)	MD Elongation @ Break (%)	TD Tear Resistance (lbs)	MD Tear Resistance (lbs)	Puncture Resistance (lbs)	Density (g/cc)	Carbon Black Content (%)	Carbon Black Dispersion Views in Cat1 - Cat2	Asperity Height Side A (mils)	Asperity Height Side B (mils)
Roll No.	every roll		every 4th								every 4th		every 4th	every 4th	every 4th	every 4th	every 2nd	
104137147	62	59	154	147	209	221	16	18	561	558	51	54	143	0.945	2.54	10	23	23
104137238	60	57	156	147	181	226	16	18	469	616	52	55	150	0.946	2.52	10	24	23
104137406	62	55	161	153	188	209	15	17	502	548	52	55	124	0.946	2.31	10	29	22
104137407	61	57	161	153	188	209	15	17	502	548	52	55	124	0.946	2.31	10	28	25

Approved By: Jane Allan

This test report shall not be reproduced, except in full, without written approval of the laboratory.

19103 Gundle Road - Houston, Texas 77073

Dec 11 07 01:29p Lab 2812306787 p.2

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE® GSE Lining Technology, Inc.

LETTER OF TRANSMITTAL

Brian McKeown
Clean Air and Water Systems, LLC.
123 Elm Street
Dousman, WI 53118-0337

DATE: January 2, 2008
JOB NO: SO 53376
JOB NAME: Midwest Generation, LLC
RE: QC/QA Certificate

COPIES	DESCRIPTION
1	QC/QA Documentation as per Bill of Lading # 72947

TRANSMIT VIA:

U.S. Mail

If enclosures are not as noted kindly notify us at once.

SIGNED: Janet M Valadez
DATE: January 2, 2008

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72947

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/27/07

Branch Plant: 1503

Shipping Instructions: ETA 12-31-07

Call 24 hours before delivery

Tedd Mills @ 815-521-0900

Sales Order 53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	FREIGHTGEO001 DOM. SHIPPING CHARGE DOMESTIC GEOTEXTILE NONTAXABLE	
2	130288407	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
3	130288408	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	398.00
4	130288410	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	398.00
5	130288411	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	400.00
6	130288412	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
7	130288413	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
8	130288414	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	389.00
9	130288415	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	392.00
10	130288416	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	400.00
11	130288417	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	403.00
12	130288418	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	401.00
13	130288419	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	399.00
14	130288420	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
15	130288421	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	401.00
16	130288422	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	403.00
17	130288423	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	399.00
	19,001			*Continued on next page.....*	15,037.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Signature of Consignor

Local Verification Signed:

Pick Up # 10937KS

Seal #

Truckers P.O. #

Driver Requirements: TRL# 53205

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: Landstar

Carrier Signature:

Date: 12-27-07

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72947

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/27/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery

Tedd Mills @ 815-521-0900

Sales Order
53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
18	130288424	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	398.00
19	130288425	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	392.00
20	130288426	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
21	130288427	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
22	130288428	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
23	130288429	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	392.00
24	130288430	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	393.00
25	130288431	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	393.00
26	130288432	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	397.00
27	130288433	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	392.00
28	130288434	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
29	130288435	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	390.00
30	130288436	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	393.00
31	130288437	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
32	130288438	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
33	130288439	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
34	130288440	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
	19,001			*Continued on next page.....*	15,037.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number:
1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72947

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/27/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order

53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
35	130288441	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	396.00
36	130288442	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
37	130288443	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	395.00
38	130288444	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00
39	130288445	500	SY	GEO1208002 Geotextile 12 oz/yd2 MARV	394.00

Total Quantity 19,001 Total Weight: 15,037.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72947

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1208002	12/27/2007

GSE QC APPROVED

*Modified

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallon-min/ft2)	Water permeability (cm sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength (D) (lbs)	Trap Tear Strength (MD) (lbs)	Grab Elongation (D) (%)	Grab Elongation (MD) (%)	Grab Strength (D) (lbs)	Grab Strength (MD) (lbs)	Thickness (mils)	Mass per Unit Area (oz./yd2)
Roll No.	every 60th			every roll	every 20th	every 20th	every 20th		every 20th				every 20th	every 20th
130288407	115	0.80	1.6	0.150	718	236	395	252	122	109	451	364	186	13.6
130288408	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288410	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288411	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288412	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288413	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288414	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288415	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288416	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288417	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288418	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288419	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288420	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288421	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288422	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288423	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288424	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288425	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288426	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288427	115	0.80	1.6	0.150	668	246	373	238	126	104	406	333	169	12.9
130288428	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288429	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288430	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7

Approved By: Nate T. Dawson

This test report shall not be reproduced, except in full, without written approval of the laboratory.

Roll Test Data Report

Bill of Lading: 72947

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1208002	12/27/2007 *Modified

GSE OC APPROVED

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallon/min/ft2)	Water permeability (cm/sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength (CD) (lbs)	Trap Tear Strength (MD) (lbs)	Grab Elongation (CD) (%)	Grab Elongation (MD) (%)	Grab Strength (CD) (lbs)	Grab Strength (MD) (lbs)	Thickness (mils)	Mass per Unit Area (oz/yd2)
Roll No.	every 80th			every roll	every 20th	every 20th	every 20th		every 20th				every 20th	every 20th
130288431	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288432	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288433	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288434	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288435	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288436	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288437	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288438	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288439	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288440	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288441	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288442	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288443	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288444	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7
130288445	115	0.80	1.6	0.150	654	246	282	195	118	96	414	357	154	12.7

Approved By: Nicole T. Dawson

This test report shall not be reproduced, except in full, without written approval of the laboratory.

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE®

GSE Lining Technology, Inc.

LETTER OF TRANSMITTAL

Brian McKeown
Clean Air and Water Systems, LLC.
123 Elm Street
Dousman, WI 53118-0337

DATE: January 2, 2008
JOB NO: SO 53376
JOB NAME: Midwest Generation, LLC
RE: QC/QA Certificate

COPIES	DESCRIPTION
1	QC/QA Documentation as per Bill of Lading # 72923 & 72926

TRANSMIT VIA:

U.S. Mail

If enclosures are not as noted kindly notify us at once.

SIGNED: Janet M Valadez
DATE: January 2, 2008

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72926

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions: ETA 12-28-07
Call 24 hours before delivery
Tedd Mills @ 815-521-0900

Sales Order
53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	FREIGHTGEO001 DOM. SHIPPING CHARGE DOMESTIC GEOTEXTILE NONTAXABLE	
2	130288335	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	506.00
3	130288336	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
4	130288337	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
5	130288338	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
6	130288339	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
7	130288340	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	506.00
8	130288341	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	506.00
9	130288342	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
10	130288343	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
11	130288344	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
12	130288345	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
13	130288346	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
14	130288347	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
15	130288348	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
16	130288349	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
17	130288350	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	507.00
		17,501			17,721.00

Continued on next page.....

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number:
1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Wendy Kessler
Signature of Consignor

Local Verification Signed:

X

Pick Up # 10939KS

Seal #

Truckers P.O. #

Driver Requirements:

TRL# 76607

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: RGT

Carrier Signature:

Date: 12-28-07

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72926

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order

53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
18	130288351	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
19	130288352	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
20	130288353	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
21	130288354	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	507.00
22	130288355	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
23	130288356	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
24	130288357	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
25	130288359	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	506.00
26	130288360	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
27	130288361	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
28	130288362	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	507.00
29	130288363	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
30	130288364	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
31	130288365	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	505.00
32	130288366	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	507.00
33	130288367	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
34	130288369	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	514.00
		17,501		*Continued on next page.....*	17,721.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72926

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order

53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
35	130288404	500	SY	**GEO1608002** Geotextile 16 oz/yd2 MARV	505.00
36	130288405	500	SY	**GEO1608002** Geotextile 16 oz/yd2 MARV	509.00

Total Quantity 17,501 — Total Weight: 17,721.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72926

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1608002	12/21/2007 *Modified

GSE QC APPROVED

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallon/min/ft2)	Water permeability (cm/sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength CD (lbs)	Trap Tear Strength MD (lbs)	Grab Elongation CD (%)	Grab Elongation MD (%)	Grab Strength CD (lbs)	Grab Strength MD (lbs)	Thickness (mils)	Mass per Unit Area (oz/yd2)
Roll No.		every 20th		every roll	every 11th	every 11th	every 11th			every 11th			every 11th	every 11th
130288335	87	0.60	1.2	0.150	822	304	446	226	121	121	517	411	196	16.1
130288336	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288337	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288338	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288339	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288340	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288341	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288342	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288343	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288344	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288345	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288346	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288347	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288348	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288349	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288350	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288351	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288352	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288353	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288354	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288355	87	0.60	1.2	0.150	840	300	399	253	103	114	550	403	195	16.4
130288356	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288357	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8

Approved By: Vicky T. Parrott

This test report shall not be reproduced, except in full, without written approval of the laboratory.

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72926

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1608002	12/21/2007 "Modified

GSE QC APPROVED

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallmin/sq ft)	Water permeability (cm/sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength CD (lbs)	Trap Tear Strength MD (lbs)	Grab Elongation CD (%)	Grab Elongation MD (%)	Grab Strength CD (lbs)	Grab Strength MD (lbs)	Thickness (mils)	Mass per Unit Area (oz/sq.yd)
Roll No.	every 20th			every roll	every 11th	every 11th	every 11th		every 11th				every 11th	every 11th
130288359	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288360	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288361	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288362	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288363	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288364	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288365	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288366	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288367	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288369	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288404	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288405	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0

Approved By: Vicky T. Powell

This test report shall not be reproduced, except in full, without written approval of the laboratory.

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72923

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:
Call 24 hours before delivery

ETA 12-28-07
Tedd Mills @ 815-521-0900

Sales Order
53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
1		1	EA	FREIGHTGEO001 DOM. SHIPPING CHARGE DOMESTIC GEOTEXTILE NONTAXABLE	
2	130288368	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
3	130288370	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	515.00
4	130288371	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	515.00
5	130288372	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	513.00
6	130288373	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	512.00
7	130288374	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	511.00
8	130288375	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
9	130288376	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
10	130288377	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
11	130288378	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	509.00
12	130288379	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	508.00
13	130288380	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
14	130288381	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	503.00
15	130288382	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
16	130288383	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	539.00
17	130288384	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	531.00
		17,501			17,747.00

Continued on next page.....

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number:
1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Signature of Consignor

Local Verification Signed:

Pick Up # 10938KS

Seal #

Truckers P.O. #

Driver Requirements:
TRL# 74608
1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: RGT
Carrier Signature:
Date: 12-21-07

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC

Shippers No. 72923

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery — Tedd Mills @ 815-521-0900

Sales Order

53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
18	130288385	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	539.00
19	130288386	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00
20	130288387	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	502.00
21	130288388	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
22	130288389	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
23	130288390	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
24	130288391	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
25	130288392	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
26	130288393	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	502.00
27	130288394	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
28	130288395	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
29	130288396	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
30	130288397	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
31	130288398	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	502.00
32	130288399	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
33	130288400	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	500.00
34	130288401	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
	17,501			*Continued on next page.....*	17,747.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number: 1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

_____
Signature of Consignor

Local Verification Signed:

X _____

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

Shipping Order - Packing List - Original - Not Negotiable

GSE Lining Technology, Inc. at Kingstree, SC Shippers No. 72923

Received at Kingstree, SC from GSE Lining Technology, Inc. the property described below, in apparent good order, except as noted (contents and condition of packages unknown), marked, consigned, and destined as indicated below, which said Carrier agrees to carry to the place of delivery at said destination. It is mutually agreed as to each Carrier of all or any said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service performed hereunder shall be subject to the rates and contract agreed to in writing by GSE Lining Technology, Inc. and Carrier. GSE Lining Technology, Inc.'s obligation to pay freight charges for the shipment is conditioned on (1) the existence of a separate written contract with the carrier transporting the freight and (2) the carrier's name appearing on this Bill of Lading, and other carriers must look solely to a party other than GSE Lining Technology, Inc. for payment.

Ship To: CAAWS/Midwest Generation LLC
C/O Brieser Construction Co.
1800 Channahon Road
Joliet IL 60436

Date: 12/21/07

Branch Plant: 1503

Shipping Instructions:

Call 24 hours before delivery Tedd Mills @ 815-521-0900

Sales Order
53376 SO

No. Line	Roll #	QTY Shipped	UM	Kind of Package, Description of Articles, Special Marks and Exceptions	Weight
35	130288402	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	501.00
36	130288403	500	SY	GEO1608002 Geotextile 16 oz/yd2 MARV	504.00

Total Quantity 17,501 Total Weight: 17,747.00

Project# 524244

Freight charges are prepaid unless marked collect.

Check box if collect ☐

Customer P.O. Number:
1113-07

If this shipment is to be delivered to consignor, consignor shall sign the following statement.

Carrier may decline to deliver this shipment without payment of freight and all other lawful charges.

Signature of Consignor

Local Verification Signed:

X

Pick Up #

Seal #

Truckers P.O. #

Driver Requirements:

1) Driver must pre call 24 hrs prior to delivery and on Friday for Monday delivery.
2) Driver must call (843) 201-1520 when unloaded.
3) Driver must call and advise any delay in transit.
4) A copy of this bill of lading must accompany Freight Invoice.

Carrier Name: _____

Carrier Signature: _____

Date: _____

Electronic Filing: Received, Clerk's Office 2/04/2022

GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72923

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1608002	12/21/2007

GSE QC APPROVED

*Modified

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate	Water permeability	Permittivity	Apparent Opening Size	Mullen Burst Strength	Puncture Resistance	Trap Tear Strength CD	Trap Tear Strength MD	Grab Elongation CD	Grab Elongation MD	Grab Strength CD	Grab Strength MD	Thickness	Mass per Unit Area
	(gallon/min/ft2)	(cm/sec)	(Sec-1)	(mm)	(psi)	(lbs)	(lbs)	(lbs)	(%)	(%)	(lbs)	(lbs)	(mils)	(oz./yd2)
Roll No.	every 20th			every roll	every 11th	every 11th	every 11th		every 11th				every 11th	every 11th
130288368	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288370	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288371	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288372	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288373	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288374	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288375	87	0.60	1.2	0.150	864	312	553	283	113	121	583	431	197	16.8
130288376	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288377	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288378	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288379	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288380	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288381	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288382	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288383	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288384	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288385	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288386	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288387	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288388	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288389	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288390	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288391	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8

Approved By: Vicky T. Parrott

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GSE Nonwoven Technology

Roll Test Data Report

Bill of Lading: 72923

Sales Order No.	Project Number	Customer Name	Project Location	Product Name	Report Date
53376	524244	CAAWS	Joliet, IL	GEO1608002	12/21/2007 *Modified

GSE QC APPROVED

	ASTM D 4491			ASTM D 4751	ASTM D 3786	ASTM D 4833	ASTM D 4533		ASTM D 4632				ASTM D 5199	ASTM D 5261
	Average Sample Flow Rate (gallons/min/ft2)	Water permeability (cm/sec)	Permittivity (Sec-1)	Apparent Opening Size (mm)	Mullen Burst Strength (psi)	Puncture Resistance (lbs)	Trap Tear Strength (T) (lbs)	Trap Tear Strength (MD) (lbs)	Grab Elongation (T) (%)	Grab Elongation (MD) (%)	Grab Strength (T) (lbs)	Grab Strength (MD) (lbs)	Thickness (mils)	Mass per Unit Area (oz/yd2)
Roll No.	every 20th			every roll	every 11th	every 11th	every 11th		every 11th				every 11th	every 11th
130288392	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288393	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288394	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288395	87	0.60	1.2	0.150	810	282	536	286	112	123	644	420	198	16.8
130288396	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288397	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288398	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288399	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288400	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288401	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288402	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0
130288403	87	0.60	1.2	0.150	832	272	483	286	125	119	580	408	198	16.0

Approved By: Vicky T. Parrott

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ATTACHMENT A4

GEOMEMBRANE INSTALLER'S DAILY LOGS AND QC DOCUMENTATION (IMPOUNDMENT #1 AND #2)

A4

IMPOUNDMENT #1

Electronic Filing: Received, Clerk's Office 2/04/2022 Submittal #24

CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	Q.C. NAME:
PROJECT NAME: Midwest Gen Ash Pond 1	MAT. TYPE:
PROJECT NUMBER: 0	TRUCK NUMBER:
LOCATION Joliet, IL	BILL OF LADING #

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
365	22.50 x 520	11,700	
357	22.50 x 520	11,700	
362	22.50 x 520	11,700	
359	22.50 x 520	11,700	
356	22.50 x 520	11,700	
360	22.50 x 520	11,700	
368	22.50 x 520	11,700	
353	22.50 x 520	11,700	
367	22.50 x 520	11,700	
344	22.50 x 520	11,700	
364	22.50 x 520	11,700	
134	x		partial
116	x		partial
346	22.50 x 520	11,700	
356	x		partial
357	x		partial
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	TOTAL =	140,400	

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Submittal

GAAWP Systems

TRIAL WELD TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB NUMBER:	0	MAT'L TYPE:

TENSIOMETER ID:	0

DATE	SAMPLE I.D. (TW#)	TIME	AMB. TEMP (ºF)	WEATHER (CLOUDY/ SUNNY)	QC INT	MACH NO.	SEAMER INT	EXTRUSION BARREL/ PREHEAT	FUSION WEDGE/ SET SPEED	FIELD WELD VALUES PEEL (PPI)					SHEAR (PPI)			P/F	Comments
10/1/2008	1	08:27	54	cloudy	ss	138	hn	B:	W: 850	167	162	155			184	188	183	P	
								P:	S: 350	162	151	154							
10/1/2008	2	08:25	54	cloudy	ss	427	kk	B:	W: 850	152	147	158			179	183	188	P	
								P:	S: 350	164	156	155							
10/1/2008	3	13:30	68	cloudy	ss	427	kk	B:	W: 850	130	133	126			164	166	160	P	
								P:	S: 350	128	124	124							
10/1/2008	4	13:00	68	cloudy	ss	138	hn	B:	W: 850	130	140	133			160	158	155	P	
								P:	S: 350	129	132	129							
10/2/2008	1	08:05	58	cloudy	ss	138	hn	B:	W: 850	142	154	157			178	172	183	P	
								P:	S: 350	133	148	149							
10/2/2008	2	08:00	58	cloudy	ss	427	kk	B:	W: 850	151	143	148			181	167	188	P	
								P:	S: 350	156	164	155							
10/2/2008	3	08:45	65	cloudy	ss	175	vk	B: 545	W:	134	138	142			189	182	190	P	
								P: 245	S:										
10/2/2008	4	13:05	65	cloudy	ss	175	vk	B: 545	W:	128	136	132			174	180	177	P	
								P: 245	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

TRIAL WELD TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB NUMBER:	0	MAT'L TYPE:

TENSIOMETER ID:	0	EXTRUSION	FUSION	FIELD WELD VALUES										
DATE	SAMPLE I.D. (TW#)	TIME	AMB. TEMP (ºF)	WEATHER (CLOUDY/ SUNNY)	QC INT	MACH NO.	SEAMER INT	BARREL/ PREHEAT	WEDGE/ SET SPEED	PEEL (PPI)				SHEAR (PPI)			P/F	Comments
10/3/2008	1	07:20	57	cloudy	ss	175	vk	B: 545	W:	129	130	140		168	163	170	P	
								P: 245	S:									
10/3/2008	2	10:30	57	cloudy	ss	427	kk	B:	W: 850	128	128	140		175	157	168	P	
								P:	S: 350	145	130	147						
10/3/2008	3	10:27	57	cloudy	ss	138	hn	B:	W: 850	145	153	139		173	171	170	P	
								P:	S: 350	153	142	145						
10/3/2008	4	13:20	64	cloudy	ss	427	kk	B:	W: 850	139	144	128		160	159	159	P	
								P:	S: 350	142	132	126						
10/3/2008	5	13:19	64	cloudy	ss	138	hn	B:	W: 850	136	125	133		165	157	163	P	
								P:	S: 350	145	143	136						
10/3/2008	6	13:35	64	cloudy	ss	175	vk	B: 515	W:	115	102	123		165	162	151	P	
								P: 235	S:									
10/4/2008	1	07:03	41	sunny	ss	138	hn	B:	W: 850	151	170	158		198	191	190	P	
								P:	S: 350	148	164	163						
10/4/2008	2	07:30	41	sunny	ss	427	kk	B:	W: 850	167	184	167		188	190	185	P	
								P:	S: 350	173	190	163						
10/4/2008	3	07:35	41	sunny	ss	175	vk	B: 545	W:	162	154	171		201	200	198	P	
								P: 245	S:									
10/4/2008	4	13:05	69	sunny	ss	175	vk	B: 515	W:	148	132	137		154	150	163	P	
								P: 215	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									

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Submitted 2/2

GeoSynthetics

PANEL PLACEMENT FORM

PROJECT NAME:			Midwest Gen Ash Pond 1			JOB NUMBER: 0	Material Type:
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
10/1/2008		P1	58	22.00	1,276	365	
10/1/2008		P2	58	22.00	1,276	365	
10/1/2008		P3	58	22.00	1,276	365	
10/1/2008		P4	58	22.00	1,276	365	
10/1/2008		P5	58	22.00	1,276	365	
10/1/2008		P6	58	22.00	1,276	365	
10/1/2008		P7	58	22.00	1,276	365	
10/1/2008		P8	58	22.00	1,276	365	
10/1/2008		P9	58	22.00	1,276	357	
10/1/2008		P10	58	22.00	1,276	357	
10/1/2008		P11	58	22.00	1,276	357	
10/1/2008		P12	58	22.00	1,276	357	
10/1/2008		P13	58	22.00	1,276	357	
10/1/2008		P14	58	22.00	1,276	357	
10/1/2008		P15	58	22.00	1,276	357	
10/1/2008		P16	58	22.00	1,276	357	
10/1/2008		P17	58	22.00	1,276	362	
10/1/2008		P18	58	22.00	1,276	362	
10/1/2008		P19	52	22.00	1,144	362	
10/1/2008		P20	52	22.00	1,144	362	
10/1/2008		P21	17	17.00	145	362	
10/1/2008		P22	52	22.00	1,144	362	
10/1/2008		P23	76	22.00	1,518	362	
10/1/2008		P24	76	22.00	1,672	362	
				Total Area (SF) This Page Only =	29,735		

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C a a W Systems

PANEL PLACEMENT FORM

PROJECT NAME:		Midwest Gen Ash Pond 1				JOB NUMBER: 0	Material Type:
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
10/1/2008		P25	58	22.00	968	362	
10/1/2008		P26	30	15.00	225	362	
10/1/2008		P27	35	22.00	385	359	
10/1/2008		P28	53	22.00	968	359	
10/1/2008		P29	417	22.00	9,174	359	
10/2/2008		P30	470	22.00	10,340	356	
10/2/2008		P31	478	22.00	10,516	360	
10/2/2008		P32	478	22.00	10,516	362	
10/2/2008		P33	478	22.00	10,516	368	
10/2/2008		P34	478	22.00	10,516	353	
10/3/2008		P35	55	22.00	1,210	367	
10/3/2008		P36	26	18.00	234	367	
10/3/2008		P37	26	16.00	208	367	
10/3/2008		P38	58	22.00	792	367	
10/3/2008		P39	113	22.00	2,486	367	
10/3/2008		P40	50	22.00	1,100	367	
10/3/2008		P41	113	22.00	2,486	344	
10/3/2008		P42	113	22.00	2,486	344	
10/3/2008		P43	113	22.00	2,486	344	
10/3/2008		P44	113	22.00	2,486	344	
10/3/2008		P45	113	22.00	2,486	344	
10/3/2008		P46	65	22.00	1,430	344	
10/3/2008		P47	48	22.00	1,056	364	
10/3/2008		P48	113	22.00	2,486	364	
				Total Area (SF) This Page Only =	87,556		

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CAAW Systems

PANEL PLACEMENT FORM

PROJECT NAME:			Midwest Gen Ash Pond 1			JOB NUMBER: 0	Material Type:
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
10/3/2008		P49	113	22.00	2,486	364	
10/3/2008		P50	113	22.00	2,486	364	
10/3/2008		P51	113	22.00	2,486	364	
10/3/2008		P52	113	22.00	2,486	134	
10/4/2008		P53	113	22.00	2,486	134	
10/4/2008		P54	51	22.00	1,122	134	
10/4/2008		P55	62	22.00	1,364	116	
10/4/2008		P56	113	22.00	2,486	116	
10/4/2008		P57	100	22.00	2,200	346	
10/4/2008		P58	100	22.00	2,200	346	
10/4/2008		P59	100	22.00	2,200	346	
10/4/2008		P60	100	22.00	2,200	346	
10/4/2008		P61	100	22.00	1,529	346	
10/4/2008		P62	44	22.00	484	344	
10/4/2008		P63	27	13.00	176	344	
10/4/2008		P64	54	13.00	351	346	
10/4/2008		P65	51	22.00	1,122	346	
10/4/2008		P66	47	22.00	1,034	356	
10/4/2008		P67	50	22.00	1,100	357	
				Total Area (SF) This Page Only =	31,998		

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Submittal #24

CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/1/2008	08:40	P1/P2	58	kk	850	350	427	10MPH/54		
10/1/2008	08:38	P2/P3	58	hn	850	350	138	10MPH/54		
10/1/2008	08:50	P3/P4	58	kk	850	350	427	10MPH/54		
10/1/2008	08:56	P4/P5	58	hn	850	350	138	10MPH/54		
10/1/2008	09:10	P6/P7	58	kk	850	350	427	10MPH/54		
10/1/2008	09:13	P7/P8	58	hn	850	350	138	10MPH/54		
10/1/2008	09:45	P9/P10	58	kk	850	350	427	10MPH/54		
10/1/2008	09:51	P10/P11	58	hn	850	350	138	10MPH/54		
10/1/2008	10:00	P11/P12	58	kk	850	350	427	10MPH/54		
10/1/2008	10:08	P12/P13	58	hn	850	350	138	10MPH/54		
10/1/2008	10:27	P14/P15	58	hn	850	350	138	10MPH/54		
10/1/2008	10:30	P15/P16	58	kk	850	350	427	10MPH/54		
10/1/2008	09:35	P8/P9	58	hn	850	350	138	10MPH/54		
10/1/2008	09:14	P5/P6	58	hn	850	350	138	10MPH/54		
10/1/2008	10:15	P13/P14	58	kk	850	350	427	10MPH/54		
10/1/2008	10:53	P16/P17	58	hn	850	350	138	10MPH/54		
10/1/2008	11:00	P17/P18	58	kk	850	350	427	10MPH/54		
10/1/2008	11:10	P18/P19	58	hn	850	350	138	10MPH/54		
10/1/2008	12:10	P19/P20	52	kk	850	350	427	10MPH/54		
10/1/2008	11:27	P20/P21	17	hn	850	350	138	10MPH/54		
10/1/2008	11:58	P21/P22	17	hn	850	350	138	10MPH/54		
10/1/2008	12:00	P22/P23	52	kk	850	350	427	10MPH/54		
10/1/2008	11:44	P23/P24	69	hn	850	350	138	10MPH/54		
10/1/2008	12:26	P20/P22	28	kk	850	350		10MPH/54		

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CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/1/2008	14:10	P25/P28	21	kk	850	350	427	10MPH/54		
10/1/2008	14:10	P25/P27	5	hn	850	350	138	10MPH/54		
10/1/2008	13:35	P1/P25	58	kk	850	350	427	10MPH/54		
10/1/2008	13:48	P25/P26	30	hn	850	350	138	10MPH/54		
10/1/2008	14:10	P26/P27	29	hn	850	350	138	10MPH/54		
10/1/2008	14:00	P27/P28	35	kk	850	350	427	10MPH/54		
10/1/2008	14:50	P29/P25	10	kk	850	350	427	10MPH/54		
10/1/2008	14:25	P29/P30	417	hn	850	350	138	10MPH/54		
10/1/2008	15:05	P29/P1	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P2	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P3	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P4	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P5	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P6	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P7	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P8	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P9	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P10	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P12	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P13	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P14	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P15	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P16	22	kk	850	350	427	10MPH/54		
10/1/2008	15:05	P29/P17	22	kk	850	350	427	10MPH/54		

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CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/1/2008	15:05	P29/P18	22	kk	850	350	427	10MPH/54		
10/2/2008	08:40	P31/P30	470	kk	850	350	427	10MPH/54		
10/2/2008	08:47	P31/P32	470	hn	850	350	138	10MPH/54		
10/2/2008	09:02	P32/P33	470	kk	850	350	427	10MPH/54		
10/2/2008	10:34	P33/P34	470	hn	850	350	138	10MPH/54		
10/2/2008	09:25	P31/P24	58	kk	850	350	427	10MPH/54		
10/3/2008	13:35	P40/P35	13	hn	850	350	138	10MPH/68		
10/3/2008	11:37	P38/P37	24	hn	850	350	138	10MPH/68		
10/3/2008	11:37	P38/P36	8	hn	850	350	138	10MPH/68		
10/3/2008	11:37	P38/P35	24	hn	850	350	138	10MPH/68		
10/3/2008	11:03	P38/P39	58	hn	850	350	138	10MPH/68		
10/3/2008	11:37	P39/P40	50	hn	850	350	138	10MPH/68		
10/3/2008	11:25	P36/P37	26	hn	850	350	138	10MPH/68		
10/3/2008	11:25	P36/P35	37	kk	850	350	427	10MPH/68		
10/3/2008	11:30	P39/P41	108	kk	850	350	427	10MPH/68		
10/3/2008	13:30	P41/P42	108	kk	850	350	427	10MPH/68		
10/3/2008	14:05	P43/P42	108	hn	850	350	138	10MPH/68		
10/3/2008	14:00	P43/P44	108	kk	850	350	427	10MPH/68		
10/3/2008	14:42	P44/P45	108	hn	850	350	138	10MPH/68		
10/3/2008	15:00	P45/P46	60	kk	850	350	427	10MPH/68		
10/3/2008	15:00	P45/P47	48	kk	850	350	427	10MPH/68		
10/3/2008	15:00	P46/P47	22	hn	850	350	138	10MPH/68		
10/3/2008	15:07	P46/P48	60	hn	850	350	138	10MPH/68		
10/3/2008	15:07	P47/P48	48	hn	850	350	138	10MPH/68		

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CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/3/2008	15:25	P48/P49	108	kk	850	350	427	10MPH/68		
10/3/2008	15:41	P49/P50	108	hn	850	350	138	10MPH/68		
10/3/2008	15:50	P50/P51	108	kk	850	350	427	10MPH/68		
10/3/2008	16:15	P51/P52	108	kk	850	350	427	10MPH/68		
10/3/2008	16:19	P52/P53	108	hn	850	350	138	10MPH/68		
10/3/2008	16:42	P53/P54	46	hn	850	350	138	10MPH/68		
10/3/2008	16:42	P53/P55	62	hn	850	350	138	10MPH/68		
10/3/2008	16:40	P55/P54	22	kk	850	350	427	10MPH/68		
10/3/2008	16:45	P54/P56	46	kk	850	350	427	10MPH/68		
10/3/2008	16:45	P55/P56	62	kk	850	350	427	10MPH/68		
10/4/2008	07:40	P67/P56	22	hn	850	350	138	10MPH/68		
10/4/2008	07:52	P56/P57	95	hn	850	350	138	10MPH/68		
10/4/2008	08:10	P57/P58	95	hn	850	350	138	10MPH/68		
10/4/2008	08:20	P58/P59	95	kk	850	350	427	10MPH/68		
10/4/2008	08:35	P59/P60	95	hn	850	350	138	10MPH/68		
10/4/2008	08:50	P60/P61	95	kk	850	350	427	10MPH/68		
10/4/2008	09:40	P61/P62	44	kk	850	350	427	10MPH/68		
10/4/2008	10:15	P62/P63	27	kk	850	350	427	10MPH/68		
10/4/2008	10:25	P63/P64	13	kk	850	350	427	10MPH/68		
10/4/2008	10:25	P64/P62	22	kk	850	350	427	10MPH/68		
10/4/2008	09:30	P64/P65	54	kk	850	350	427	10MPH/68		
10/4/2008	10:25	P61/P64	27	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P61/P66	9	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P60/P66	22	kk	850	350	427	10MPH/68		

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PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
10/4/2008	10:50	P59/P66	16	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P59/P67	6	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P58/P67	22	kk	850	350	427	10MPH/68		
10/4/2008	10:50	P57/P67	22	kk	850	350	427	10MPH/68		
10/4/2008	07:40	P67/P66	22	kk	850	350	427	10MPH/68		
10/4/2008	08:00	P34/P67	50	kk	850	350	427	10MPH/68		
10/4/2008	08:00	P34/P66	47	hn	850	350	138	10MPH/68		
10/4/2008	10:15	P66/P65	22	hn	850	350	138	10MPH/68		
10/4/2008	10:00	P45/P65	43	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P40/P34	10	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P39	11	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P41	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P42	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P43	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P44	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P45	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P47	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P48	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P49	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P50	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P51	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P52	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P53	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P55	22	kk	850	350	427	10MPH/68		
10/3/2008	16:50	P34/P56	22	kk	850	350	427	10MPH/68		

Submittal #21

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PAGE NO.: 1

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/1/2008	58	P1/P2	ss	11:01	11:06	30	30	P		
10/1/2008	58	P2/P3	ss	11:02	11:07	30	30	P		
10/1/2008	58	P3/P4	ss	11:04	11:09	30	29	P		
10/1/2008	58	P4/P5	ss	11:05	11:10	30	30	P		
10/1/2008	58	P6/P7	ss	11:13	11:18	30	30	P		
10/1/2008	58	P7/P8	ss	11:14	11:19	30	29	P		
10/1/2008	58	P9/P10	ss	11:15	11:20	30	30	P		
10/1/2008	58	P10/P11	ss	11:16	11:21	30	30	P		
10/1/2008	58	P11/P12	ss	11:18	11:23	30	30	P		
10/1/2008	58	P12/P13	ss	11:30	11:35	30	30	P		
10/1/2008	58	P14/P15	ss	11:31	11:36	30	30	P		
10/1/2008	58	P15/P16	ss	11:32	11:37	30	29	P		
10/1/2008	58	P8/P9	ss	11:33	11:38	30	30	P		
10/1/2008	58	P5/P6	ss	11:37	11:42	30	28	P		
10/1/2008	58	P13/P14	ss	11:39	11:44	30	30	P		
10/1/2008	58	P16/P17	ss	11:41	11:46	30	30	P		
10/1/2008	58	P17/P18	ss	11:43	11:48	30	29	P		
10/1/2008	58	P18/P19	ss	11:52	11:57	30	30	P		
10/1/2008	52	P19/P20	ss	12:02	12:07	30	30	P		
10/1/2008	17	P20/P21	ss	13:03	13:08	30	29	P		
10/1/2008	17	P21/P22	ss	13:04	13:09	30	30	P		
10/1/2008	52	P22/P23	ss	13:05	13:10	30	28	P		
10/1/2008	69	P23/P24	ss	13:06	13:11	30	29	P		
10/1/2008	28	P20/P22	ss	13:08	13:13	30	30	P		

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CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/2/2008	21	P25/P28	ss	7:02	7:07	30	29	P		
10/2/2008	5	P25/P27	ss	07:03	7:08	30	30	P		
10/2/2008	58	P1/P25	ss	07:04	7:09	30	30	P		
10/2/2008	30	P25/P26	ss	07:06	7:11	30	30	P		
10/2/2008	29	P26/P27	ss	07:10	7:15	30	30	P		
10/2/2008	35	P27/P28	ss	07:11	7:16	30	29	P		
10/2/2008	10	P29/P25	ss	07:12	7:17	30	30	P		
10/2/2008	417	P29/P30	ss	07:15	7:20	30	30	P		
10/2/2008	22	P29/P1	ss	07:21	7:26	30	29	P		
10/2/2008	22	P29/P2	ss	07:22	7:27	30	28	P		
10/2/2008	22	P29/P3	ss	07:23	7:28	30	30	P		
10/2/2008	22	P29/P4	ss	07:24	7:29	30	30	P		
10/2/2008	22	P29/P5	ss	07:33	7:38	30	29	P		
10/2/2008	22	P29/P6	ss	07:34	7:39	30	30	P		
10/2/2008	22	P29/P7	ss	07:35	7:40	30	28	P		
10/2/2008	22	P29/P8	ss	07:36	7:41	30	30	P		
10/2/2008	22	P29/P9	ss	07:37	7:42	30	29	P		
10/2/2008	22	P29/P10	ss	08:02	8:07	30	30	P		
10/2/2008	22	P29/P12	ss	08:03	8:08	30	28	P		
10/2/2008	22	P29/P13	ss	08:05	8:10	30	29	P		
10/2/2008	22	P29/P14	ss	08:07	8:12	30	30	P		
10/2/2008	22	P29/P15	ss	08:09	8:14	30	28	P		
10/2/2008	22	P29/P16	ss	08:10	8:15	30	30	P		
10/2/2008	22	P29/P17	ss	08:11	8:16	30	30	P		

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CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/4/2008	22	P29/P18	ss	7:00	7:05	30	29	P		
10/4/2008	470	P31/P30	ss	07:01	7:06	30	30	P		
10/4/2008	470	P31/P32	ss	07:03	7:08	30	29	P		
10/4/2008	470	P32/P33	ss	07:05	7:10	30	30	P		
10/4/2008	470	P33/P34	ss	07:06	7:11	30	30	P		
10/4/2008	58	P31/P24	ss	07:07	7:12	30	29	P		
10/4/2008	13	P40/P35	ss	07:13	7:18	30	28	P		
10/4/2008	24	P38/P37	ss	07:14	7:19	30		F	P	ext welded
10/4/2008	8	P38/P36	ss	07:15	7:20	30		F	P	ext welded
10/4/2008	24	P38/P35	ss	07:16	7:21	30		F	P	ext welded
10/4/2008	58	P38/P39	ss	07:17	7:22	30	30	P		
10/4/2008	50	P39/P40	ss	07:24	7:29	30	29	P		
10/4/2008	26	P36/P37	ss	07:25	7:30	30	28	P		
10/4/2008	37	P36/P35	ss	07:28	7:33	30	30	P		
10/4/2008	108	P39/P41	ss	07:29	7:24	30	30	P		
10/4/2008	108	P41/P42	ss	07:30	7:35	30	30	P		
10/4/2008	108	P43/P42	ss	07:33	7:38	30	30	P		
10/4/2008	108	P43/P44	ss	07:35	7:40	30	28	P		
10/4/2008	108	P44/P45	ss	07:36	7:41	30	30	P		
10/4/2008	60	P45/P46	ss	07:44	7:49	30	29	P		
10/4/2008	48	P45/P47	ss	07:45	7:50	30	29	P		
10/4/2008	22	P46/P47	ss	07:46	7:51	30	30	P		
10/4/2008	60	P46/P48	ss	07:47	7:48	30	30	P		
10/4/2008	48	P47/P48	ss	07:50	7:55	30	29	P		

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CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/4/2008	108	P48/P49	ss	8:04	8:09	30	30	P		
10/4/2008	108	P49/P50	ss	08:05	8:10	30	30	P		
10/4/2008	108	P50/P51	ss	08:06	8:11	30	30	P		
10/4/2008	108	P51/P52	ss	08:15	8:20	30	29	P		
10/4/2008	108	P52/P53	ss	08:16	8:21	30	30	P		
10/4/2008	46	P53/P54	ss	08:18	8:23	30	30	P		
10/4/2008	62	P53/P55	ss	08:20	8:25	30	30	P		
10/4/2008	22	P55/P54	ss	08:22	8:27	30	29	P		
10/4/2008	46	P54/P56	ss	08:23	8:28	30	30	P		
10/4/2008	62	P55/P56	ss	08:30	8:35	30	29	P		
10/4/2008	22	P67/P56	ss	14:02	14:07	30	30	P		
10/4/2008	95	P56/P57	ss	14:03	14:08	30	30	P		
10/4/2008	95	P57/P58	ss	14:04	14:09	30	30	P		
10/4/2008	95	P58/P59	ss	14:20	14:25	30	30	P		
10/4/2008	95	P59/P60	ss	14:24	14:29	30	30	P		
10/4/2008	95	P60/P61	ss	14:26	14:31	30	30	P		
10/4/2008	44	P61/P62	ss	14:28	14:33	30	30	P		
10/4/2008	27	P62/P63	ss	14:30	14:35	30	30	P		
10/4/2008	13	P63/P64	ss	14:40	14:45	30	30	P		
10/4/2008	22	P64/P62	ss	14:41	14:46	30	30	P		
10/4/2008	54	P64/P65	ss	14:42	14:47	30	30	P		
10/4/2008	27	P61/P64	ss	14:43	14:48	30	30	P		
10/4/2008	9	P61/P66	ss	14:48	14:53	30	29	P		
10/4/2008	22	P60/P66	ss	14:49	14:54	30	30	P		

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CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #: 0	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
10/4/2008	16	P59/P66	ss	15:02	15:07	30	30	P		
10/4/2008	6	P59/P67	ss	15:03	15:08	30	30	P		
10/4/2008	22	P58/P67	ss	15:04	15:09	30	30	P		
10/4/2008	22	P57/P67	ss	15:05	15:10	30	30	P		
10/4/2008	22	P67/P66	ss	15:12	15:17	30	30	P		
10/4/2008	50	P34/P67	ss	15:13	15:18	30	29	P		
10/4/2008	47	P34/P66	ss	15:15	15:20	30	28	P		
10/4/2008	22	P66/P65	ss	15:22	15:27	30	30	P		
10/4/2008	43	P45/P65	ss	15:23	15:28	30	29	P		
10/4/2008	10	P40/P34	ss	15:24	15:29	30	30	P		
10/4/2008	11	P34/P39	ss	15:32	15:37	30	30	P		
10/4/2008	22	P34/P41	ss	15:33	15:38	30	30	P		
10/4/2008	22	P34/P42	ss	15:34	15:39	30	30	P		
10/4/2008	22	P34/P43	ss	15:35	15:40	30	28	P		
10/4/2008	22	P34/P44	ss	15:36	15:41	30	30	P		
10/4/2008	22	P34/P45	ss	15:43	15:48	30	30	P		
10/4/2008	22	P34/P47	ss	15:44	15:49	30	29	P		
10/4/2008	22	P34/P48	ss	15:45	15:50	30	30	P		
10/4/2008	22	P34/P49	ss	15:46	15:51	30	30	P		
10/4/2008	22	P34/P50	ss	15:54	15:59	30	30	P		
10/4/2008	22	P34/P51	ss	15:55	16:00	30	28	P		
10/4/2008	22	P34/P52	ss	15:56	16:01	30	30	P		
10/4/2008	22	P34/P53	ss	15:58	16:03	30	29	P		
10/4/2008	22	P35/P55	ss	16:05	16:10	30	30	P		
10/4/2008	22	P34/P56	ss	16:06	16:11	30	29	P		

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Submittal #24

GAAW Systems

DESTRUCTIVE TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB NUMBER:	0	MATERIAL TYPE:

TENSIOMETER ID:	0	EXTRUSION	FUSION	FIELD WELD VALUES										
SAMPLE I.D. (DT#)	SEAM NO.	QC INT	MACH NO.	SEAMER INT	BARREL/ PREHEAT	WEDGE/ SET SPEED	PEEL (PPI)					SHEAR (PPI)			P/F	LOCATION OF DESTRUCTIVE TEST
DS1	P16/P17	ss	138	hn	B:	W: 850	135	141	137			178	180	172	P	neos 0'->3'
					P:	S: 350	128	146	144							
DS2	P17.P18	ss	427	kk	B:	W: 850	133	139	129			189	172	180	P	neos 0'->3'
					P:	S: 350	127	148	134							
DS3	P15/P29	ss	427	kk	B:	W: 850	141	142	127			169	173	177	P	weos 0'->5'
					P:	S: 350	123	130	138							
DS4	P29/P30	ss	138	hn	B:	W: 850	138	131	125			163	168	170	P	weos 0'->50'
					P:	S: 350	122	135	127							
DS5	P31/P30	ss	427	kk	B:	W: 850	136	122	138			172	163	169	P	weos 0'->150'
					P:	S: 350	129	126	122							
DS6	P31/P32	ss	138	hn	B:	W: 850	145	134	142			162	173	174	P	weos 0'->150'
					P:	S: 350	129	141	127							
DS7	P32/P33	ss	427	kk	B:	W: 850	137	135	139			167	169	172	P	weos 0'->200'
					P:	S: 350	131	127	124							
DS8	P33/P34	ss	138	hn	B:	W: 850	145	116	131			157	164	162	P	weos 0'->200'
					P:	S: 350	128	122	125							
DS9	P48/P49	ss	427	kk	B:	W: 850	133	128	132			167	162	169	P	neos 0'-76'
					P:	S: 350	127	123	127							
DS10	P49/P50	ss	138	hn	B:	W: 850	136	144	120			161	168	171	P	neos 0'->84'
					P:	S: 350	130	139	132							
DS11	P56/P34	ss	427	kk	B:	W: 850	121	134	125			158	166	165	P	weos 0'->8'
					P:	S: 350	122	128	134							
DS12	P58/P59	ss	427	kk	B:	W: 850	136	140	121			162	178	172	P	neos 0'->90'
					P:	S: 350	138	144	138							
DS13	P59/P60	ss	138	hn	B:	W: 850	126	137	131			167	173	165	P	neos 0'->90'
					P:	S: 350	134	127	130							

Electronic Filing: Received, Clerk's Office 2/04/2022

Submittal #2

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P21/P20		R1	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P20-P21-P22	P
P19/P20		R2	vk	175	sv	10/2/2008	patch 2x4	10/2/2008	int of P19-P20-P23	P
P20/P23		R3	vk	175	sv	10/2/2008	ext weld 4'	10/2/2008	eeos 0'->4'	P
P23/P22		R4	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P22-P23-P19	P
	P23	R5	vk	175	sv	10/2/2008	Boot patch 24"/ 3x5	10/2/2008	weop 0'->5' / neop 0'->14'	P
P23/P29		R6	vk	175	sv	10/2/2008	patch 3x8	10/2/2008	int of P29-P23-P19	P
P29/P30		R7	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P30-P29-P23-P24	P
P19/P18		R8	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P19-P18-P29	P
P18/P17		R9	vk	175	sv	10/2/2008	patch 2x3	10/2/2008	neos 0'->3' DS-2	P
P18/P17		R10	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P18-P17-P29	P
P17/P16		R11	vk	175	sv	10/2/2008	patch 2x3	10/2/2008	neos 0'->3' DS-1	P
P17/P16		R12	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P16-P17-P29	P
P16/P15		R13	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P16-P15-P29	P
P15/P29		R14	vk	175	sv	10/2/2008	patch 2x3	10/2/2008	weos 0'->5' DS-3	P
P15/P14		R15	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P15-P14-P29	P
P14/P13		R16	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P14/P13-P29	P
	P13	R17	vk	175	sv	10/2/2008	Boot patch 24"/ 3x9	10/2/2008	neop 0'->8' / weop 0'->6'	P
P13/P12		R18	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P13-P12-P29	P
P12/P11		R19	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P12-P11-P29	P
P12/P11		R20	vk	175	sv	10/2/2008	patch 2x2	10/2/2008	seos 0'-6"	P
P11/P10		R21	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P11-P10-P29	P
P10/P9		R22	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P10-P9-P29	P
P9/P8		R23	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P9-P8-P29	P
P9/P8		R24	vk	175	sv	10/2/2008	ext weld 5"	10/2/2008	neos 0'->30'	P
P8/P7		R25	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P8-P7-P29	P

Electronic Filing: Received, Clerk's Office 2/04/2022

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:		Midwest Gen Ash Pond 1					JOB #: 0		MATERIAL TYPE:	
FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P7/P6		R26	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P7-P6-P29	P
P7/P6		R27	vk	175	sv	10/2/2008	paych boot 24" 3x4	10/2/2008	neos 0'->8'	P
P6/P5		R28	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P6-P5-P29	P
P5/P4		R29	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P5-P4-P29	P
P4/P3		R30	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P4-P3-P29	P
P3/P2		R31	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P3-P2-P29	P
P2/P1		R32	vk	175	sv	10/2/2008	t-weld	10/2/2008	int of P2-P1-P29	P
	P25	R33	vk	175	sv	10/3/2008	patch boot 24" 3x7	10/3/2008	neop 0'->5' / eeop 0'->75'	P
P1/P25		R34	vk	175	sv	10/3/2008	t-weld	10/3/2008	int of P25-P1-P29	P
P25/P26		R35	vk	175	sv	10/3/2008	patch 2x4	10/3/2008	int of P25-P26-P27-P28	P
P25/P28		R36	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	int of P25-P28-P29	P
P24/P31		R37	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	int of P24-P20-P31	P
P31/P32		R38	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	eeos 0'-45'	P
P31/P32		R39	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	eeos 0'->72'	P
P30/P31		R40	vk	175	sv	10/3/2008	ext weld 2'	10/3/2008	weos 0'->129'	P
P33/P34		R41	vk	175	sv	10/3/2008	patch 2x2	10/3/2008	weos 0'->31'	P
P35/P38		R42	vk	175	sv	10/3/2008	ext weld 24'	10/3/2008	seos 0'->24' (ext whole seam)	P
P35/P36		R43	vk	175	sv	10/3/2008	patch 2x2	10/3/2008	int of P35-P36-P38	P
P36/P38		R44	vk	175	sv	10/3/2008	ext weld 8'	10/3/2008	seos 0'->8' (ext whole seam)	P
P37/P38		R45	vk	175	sv	10/3/2008	ext weld 24'	10/3/2008	seos 0'->24' (ext whole seam)	P
P38/P39		R46	vk	175	sv	10/3/2008	patch boot 24"3x5	10/3/2008	neos 0'->58'	P
P39/P41		R47	vk	175	sv	10/3/2008	patch 3x3	10/3/2008	int of P34-P39-P41	P
P42/P43		R48	vk	175	sv	10/3/2008	patch 2x5	10/3/2008	neos 0'->37'	P
P43/P44		R49	vk	175	sv	10/3/2008	patch 2x2	10/3/2008	neos 0'->55'	P
P44/P45		R50	vk	175	sv	10/3/2008	patch 2x2	10/3/2008	neos 0'->55'	P

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GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Ash Pond 1	JOB #:	0	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
	P44	R51	vk	175	10/4/2008	sv	patch boot 24"/ 3x3	10/4/2008	neop 0'->55' / weop 0'->10'	P
P45/P46		R52	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	int of P45-P46-P47	P
P48/P49		R53	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->44'	P
P48/P49		R54	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->76' DS-9	P
P48/P47		R55	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->55'	P
	P48	R56	vk	175	10/4/2008	sv	patch boot 24"/3x4	10/4/2008	neop 0'->55' / weop 0'->11'	P
P49/P50		R57	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->55'	P
P49/P50		R58	vk	175	10/4/2008	sv	patch boot 24"/3x3	10/4/2008	neos 0'-72'	P
P49/P50		R59	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->84' DS-10	P
P50/P51		R60	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->78'	P
P54/P53		R61	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	int of P53-P54-P55	P
P54/P56		R62	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	int ofP54-P55-P56	P
P56/P34		R63	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	weos 0'->8' DS-11	P
P67/P56		R64	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	int of P67-P34-P56	P
P57/P67		R65	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	int of P67-P57-P56	P
P56/P57		R66	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->29'	P
P56/P57		R67	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->51'	P
P58/P59		R68	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->90' DS-12	P
P59/P60		R69	vk	175	10/4/2008	sv	patch 3x3	10/4/2008	neos 0'->62'	P
P59/P60		R70	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->73'	P
P59/P60		R71	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	neos 0'->90' DS-13	P
P62/P61		R72	vk	175	10/4/2008	sv	patch 2x2	10/4/2008	neos 0'->21'	P
P62/P63		R73	vk	175	10/4/2008	sv	patch 6x3	10/4/2008	neos 0'->6'	P
P64/P63		R74	vk	175	10/4/2008	sv	patch 2x3	10/4/2008	eeos 0'->6'	P
P64/P63		R75	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P64-P63-P62	P

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Submittal =

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:		Midwest Gen Ash Pond 1			JOB #: 0				MATERIAL TYPE:	
FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P64/P62		R76	vk	175	10/4/2008	sv	patch 3x3	10/4/2008	int of P64-P62-P61	P
P64/P65		R77	vk	175	10/4/2008	sv	patch 2x4	10/4/2008	eeos 0'->6'	P
P64/P65		R78	vk	175	10/4/2008	sv	patch 3x5	10/4/2008	int of P65-P64-P66-P61	P
P64/P61		R79	vk	175	10/4/2008	sv	patch boot 24"/3x4	10/4/2008	seos 0'->7'	P
P61/P60		R80	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P60-P61-P66	P
P59/P60		R81	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P59-P60-P66	P
P66/P67		R82	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P66-P67-P59	P
P59/P58		R83	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P58-P59-P67	P
P58/P57		R84	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P57-P58-P67	P
P67/P34		R85	vk	175	10/4/2008	sv	t-weld	10/4/2008	int of P67-P66-P34	P
P15/P29		R86	vk	175	10/2/2008	sv	patch 2x3	10/2/2008	weos 0'->5' DS-3	P
P29/P30		R87	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'->50' DS-4	P
P31/P30		R88	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'->150' DS-5	P
P31/P32		R89	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'->150' DS-6	P
P32/P33		R90	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'->200' DS-7	P
P33/P34		R91	vk	175	10/2/2008	sv	patch 2x3	10/3/2008	weos 0'-.200' DS-8	P

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A4

IMPOUNDMENT #2

Electronic Filing: Received, Clerk's Office 2/04/2022 Submittal # 2

CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	4/29/2008	**Q.C. NAME:**	Sengratana Sengsay
PROJECT NAME:	Midwest Gen Station - Pond #2	**MAT. TYPE:**	60 Mil. HDPE Texture
PROJECT NUMBER:	200754	**TRUCK NUMBER:**	
LOCATION	Joliet, IL	**BILL OF LADING #**	

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
105136361	22.50 x 520	11,700	
105136347	22.50 x 520	11,700	
104137238	22.50 x 520	11,700	
104137340	22.50 x 520	11,700	
105136345	22.50 x 520	11,700	
104137407	22.50 x 520	11,700	
104137341	22.50 x 520	11,700	
104137342	22.50 x 520	11,700	
104137406	22.50 x 520	11,700	
104137147	22.50 x 520	11,700	
105136354	22.50 x 520	11,700	
105136346	22.50 x 520	11,700	
104137343	22.50 x 520	11,700	
184137263	22.50 x 520	11,700	
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	TOTAL =	163,800	

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CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	4/29/2008	**Q.C. NAME:**	Sengratana Sengsay
PROJECT NAME:	Midwest Gen Station - Pond #2	**MAT. TYPE:**	16 oz. Geotextile
PROJECT NUMBER:	200754	**TRUCK NUMBER:**	
LOCATION	Joliet, IL	**BILL OF LADING #**	

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
130288393	15.00 x 300	4,500	
130288390	15.00 x 300	4,500	
130288351	15.00 x 300	4,500	
130288383	15.00 x 300	4,500	
130288370	15.00 x 300	4,500	
130288381	15.00 x 300	4,500	
130288391	15.00 x 300	4,500	
130288397	15.00 x 300	4,500	
130288399	15.00 x 300	4,500	
130288389	15.00 x 300	4,500	
130288384	15.00 x 300	4,500	
130288395	15.00 x 300	4,500	
130288387	15.00 x 300	4,500	
130288401	15.00 x 300	4,500	
130288392	15.00 x 300	4,500	
130288372	15.00 x 300	4,500	
130288382	15.00 x 300	4,500	
130288373	15.00 x 300	4,500	
130288402	15.00 x 300	4,500	
130288386	15.00 x 300	4,500	
130288398	15.00 x 300	4,500	
130288352	15.00 x 300	4,500	
130288377	15.00 x 300	4,500	
130288379	15.00 x 300	4,500	
130288376	15.00 x 300	4,500	
130288394	15.00 x 300	4,500	
130288363	15.00 x 300	4,500	
130288400	15.00 x 300	4,500	
130288385	15.00 x 300	4,500	
130288365	15.00 x 300	4,500	
130288403	15.00 x 300	4,500	
	TOTAL =	139,500	

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	4/29/2008	Q.C. NAME:	Sengratana Sengsay
PROJECT NAME:	Midwest Gen Station - Pond #2	MAT. TYPE:	16 oz. Geotextile
PROJECT NUMBER:	200754	TRUCK NUMBER:	
LOCATION	Joliet, IL	BILL OF LADING #	

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
130288380	15.00 x 300	4,500	
130288369	15.00 x 300	4,500	
130288388	15.00 x 300	4,500	
130288396	15.00 x 300	4,500	
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	TOTAL =	18,000	

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CAAW Systems

MATERIAL DELIVERY / INVENTORY CHECKLIST

DATE:	4/29/2008	**Q.C. NAME:**	Sengratana Sengsay
PROJECT NAME:	Midwest Gen Station - Pond #2	**MAT. TYPE:**	12 oz. Geotextile
PROJECT NUMBER:	200754	**TRUCK NUMBER:**	
LOCATION	Joliet, IL	**BILL OF LADING #**	

Panel / Roll Number	Panel / Roll Size	Square Foot	Comments
130288410	15.00 x 300	4,500	
130288449	15.00 x 300	4,500	
130288429	15.00 x 300	4,500	
130288424	15.00 x 300	4,500	
130288430	15.00 x 300	4,500	
130288439	15.00 x 300	4,500	
130288418	15.00 x 300	4,500	
130288426	15.00 x 300	4,500	
130288428	15.00 x 300	4,500	
130288440	15.00 x 300	4,500	
130288421	15.00 x 300	4,500	
130288412	15.00 x 300	4,500	
130288425	15.00 x 300	4,500	
130288422	15.00 x 300	4,500	
130288423	15.00 x 300	4,500	
130288427	15.00 x 300	4,500	
130288420	15.00 x 300	4,500	
130288416	15.00 x 300	4,500	
130288438	15.00 x 300	4,500	
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	x		
	TOTAL =	85,500	

Electronic Filing: Received, Clerk's Office 2/04/2022

Submitted PC 1

GAW Systems

TRIAL WELD TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB NUMBER:	200754	MAT'L TYPE:	60 Mil. HDPE
TENSIOMETER ID:	T-062/06				

DATE	SAMPLE I.D. (TW#)	TIME	AMB. TEMP (ºF)	WEATHER (CLOUDY/ SUNNY)	QC INT	MACH NO.	SEAMER INT	EXTRUSION BARREL/ PREHEAT	FUSION WEDGE/ SET SPEED	FIELD WELD VALUES PEEL (PPI)					SHEAR (PPI)			P/F	Comments
4/30/2008	1	09:30	58	sunny	ss	428	ck	B:	W: 850	168	167	162			165	169		P	
								P:	S: 400	154	164	166							
4/30/2008	2	09:28	58	sunny	ss	138	vp	B:	W: 850	161	154	169			172	163		P	
								P:	S: 400	159	160	155							
4/30/2008	3	13:10	58	sunny	ss	428	ck	B:	W: 850	143	137	144			169	161		P	
								P:	S: 400	138	142	148							
4/30/2008	4	13:15	58	sunny	ss	138	vp	B:	W: 850	137	134	140			166	162		P	
								P:	S: 400	139	138	133							
5/1/2008	1	07:45	58	sunny	ss	428	ck	B:	W: 850	134	126	135			162	166		P	
								P:	S: 450	145	130	133							
5/1/2008	2	07:43	58	sunny	ss	138	vp	B:	W: 850	144	138	141			171	168		P	
								P:	S: 450	142	135	136							
5/1/2008	3	12:45	64	cloudy	ss	428	ck	B:	W: 850	137	141	144			167	162		P	
								P:	S: 450	154	135	138							
5/1/2008	4	12:40	64	cloudy	ss	138	vp	B:	W: 850	138	128	136			166	169		P	
								P:	S: 450	137	134	138							
5/2/2008	1	07:40	63	cloudy	ss	138	vp	B:	W: 850	136	144	137			161	157		P	
								P:	S: 450	148	139	142							
5/2/2008	2	07:42	63	cloudy	ss	428	ck	B:	W: 850	152	137	136			160	158		P	
								P:	S: 450	144	139	142							
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										
								B:	W:										
								P:	S:										

Electronic Filing: Received, Clerk's Office 2/04/2022

GAI Systems

TRIAL WELD TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB NUMBER:	200754	MAT'L TYPE:

TENSIOMETER ID:	T-062/06	EXTRUSION	FUSION	FIELD WELD VALUES										
DATE	SAMPLE I.D. (TW#)	TIME	AMB. TEMP (ºF)	WEATHER (CLOUDY/ SUNNY)	QC INT	MACH NO.	SEAMER INT	BARREL/ PREHEAT	WEDGE/ SET SPEED	PEEL (PPI)				SHEAR (PPI)			P/F	Comments
5/5/2008	1	08:40	67	Sunny	ss	428	ck	B:	W: 850	158	138	141		181	178		P	
								P:	S: 400	168	155	150						
5/5/2008	2	09:00	67	Sunny	ss	138	vp	B:	W: 850	135	137	133		183	180		P	
								P:	S: 400	130	130	140						
5/5/2008	3	13:05	67	Sunny	ss	428	ck	B:	W: 850	139	143	136		176	180		P	
								P:	S: 400	138	139	134						
5/5/2008	4	13:03	67	Sunny	ss	138	vp	B:	W: 850	144	137	141		188	183		P	
								P:	S: 400	139	134	138						
5/6/2008	1	07:07	58	Sunny	ss	428	ck	B:	W: 850	143	139	138		169	174		P	
								P:	S: 400	140	142	144						
5/6/2008	2	07:55	58	Sunny	ss	138	vp	B:	W: 850	152	138	139		178	174		P	
								P:	S: 400	139	144	145						
5/6/2008	3	08:00	58	Sunny	ss	175	vk	B: 550	W:	166	169	164		204	207		P	
								P: 350	S:									
5/6/2008	4	08:02	58	Sunny	ss	88	vp	B: 550	W:	165	173	167		198	203		P	
								P: 250	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									
								B:	W:									
								P:	S:									

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Submittal #24

GAAW Systems

PANEL PLACEMENT FORM

PROJECT NAME:		Midwest Gen Station - Pond #2				JOB NUMBER: 200754	Material Type: 60 Mil. HDPE
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
4/30/2008		P1	72	22.00	1,584	105136347	
4/30/2008		P2	75	22.00	1,650	105136347	
4/30/2008		P3	77	22.00	1,694	105136347	
4/30/2008		P4	77	22.00	1,694	105136347	
4/30/2008		P5	73	22.00	1,606	105136347	
4/30/2008		P6	75	22.00	1,650	105136347	
4/30/2008		P7	74	22.00	1,628	104137263	
4/30/2008		P8	71	22.00	1,562	104137263	
4/30/2008		P9	73	22.00	1,606	104137263	
4/30/2008		P10	75	22.00	1,650	104137263	
4/30/2008		P11	77	22.00	1,694	104137263	
4/30/2008		P12	75	22.00	1,650	104137263	
4/30/2008		P13	74	22.00	1,628	105136361	
4/30/2008		P14	74	22.00	1,628	105136361	
4/30/2008		P15	76	22.00	1,672	105136361	
4/30/2008		P16	75	22.00	1,650	105136361	
4/30/2008		P17	75	22.00	1,650	105136361	
4/30/2008		P18	72	22.00	1,584	105136361	
4/30/2008		P19	48	22.00	720	105136361	
4/30/2008		P20	24	22.00	192	105136361	
4/30/2008		P21	46	22.00	1,012	105136347	
4/30/2008		P22	72	22.00	1,584	104137407	
4/30/2008		P23	72	22.00	1,584	104137407	
4/30/2008		P24	24	22.00	264	104137407	
				Total Area (SF) This Page Only =	34,836		

Electronic Filing: Received, Clerk's Office 2/04/2022

PANEL PLACEMENT FORM

PROJECT NAME:		Midwest Gen Station - Pond #2				JOB NUMBER: 200754	Material Type: 60 Mil. HDPE
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
4/30/2008		P25	40	22.00	880	104137407	
4/30/2008		P26	65	22.00	1,430	104137407	
4/30/2008		P27	66	22.00	1,452	104137407	
5/1/2008		P28	58	22.00	1,276	104137407	
5/1/2008		P29	59	22.00	1,298	104137407	
5/1/2008		P30	61	22.00	1,342	105136345	
5/1/2008		P31	63	22.00	1,386	105136345	
5/1/2008		P32	62	22.00	1,364	105136345	
5/1/2008		P33	72	22.00	1,584	105136345	
5/1/2008		P34	60	22.00	1,034	105136345	
5/1/2008		P35	34	22.00	391	105136345	
5/1/2008		P36	74	22.00	1,628	105136345	
5/1/2008		P37	75	22.00	1,650	105136345	
5/1/2008		P38	76	22.00	1,672	104137341	
5/1/2008		P39	77	22.00	1,694	104137341	
5/1/2008		P40	76	22.00	1,672	104137341	
5/1/2008		P41	75	22.00	1,650	104137341	
5/1/2008		P42	76	22.00	1,672	104137341	
5/1/2008		P43	75	22.00	1,650	104137341	
5/1/2008		P44	75	22.00	1,650	104137104	
5/1/2008		P45	61	22.00	891	104137147	
5/1/2008		P46	20	22.00	220	104137147	
5/1/2008		P47	54	22.00	1,188	104137341	
5/1/2008		P48	55	22.00	1,210	104137342	
				Total Area (SF) This Page Only =	31,884		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

PANEL PLACEMENT FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB NUMBER: 200754	Material Type: 60 Mil. HDPE

DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
5/1/2008		P49	53	22.00	1,166	104137342	
5/1/2008		P50	53	22.00	1,166	104137342	
5/1/2008		P51	53	22.00	1,166	104137342	
5/1/2008		P52	53	22.00	1,166	104137342	
5/1/2008		P53	53	22.00	1,166	104137342	
5/1/2008		P54	53	22.00	1,166	104137342	
5/1/2008		P55	53	22.00	1,166	104137342	
5/2/2008		P56	405	22.00	8,910	104137340	
5/5/2008		P57	405	22.00	8,910	104137238	
5/5/2008		P58	108	22.00	2,376	104137264	
5/5/2008		P59	297	22.00	6,534	104137264	
5/5/2008		P60	202	22.00	4,444	104137264	
5/5/2008		P61	203	22.00	4,466	104137406	
5/5/2008		P62	303	22.00	6,666	104137406	
5/5/2008		P63	102	22.00	2,244	104137340	
5/5/2008		P64	405	22.00	8,910	105136346	
5/5/2008		P65	115	22.00	2,530	105136346	
5/5/2008		P66	67	22.00	1,474	184137263	
5/5/2008		P67	96	22.00	2,112	105136354	
5/5/2008		P68	96	22.00	2,112	105136354	
5/5/2008		P69	95	22.00	2,090	105136354	
5/5/2008		P70	96	22.00	2,112	105136354	
5/5/2008		P71	98	22.00	2,156	105136354	
5/5/2008		P72	98	22.00	2,156	104137343	
				Total Area (SF) This Page Only =	78,364		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAMP Systems

PANEL PLACEMENT FORM

PROJECT NAME:		Midwest Gen Station - Pond #2				JOB NUMBER: 200754	Material Type:
DATE	TIME	PANEL NO.	PANEL LENGTH (FT)	PANEL WIDTH (FT)	PANEL AREA (SF)	ROLL NO.	COMMENTS
5/5/2008		P73	98	22.00	2,156	104137343	
5/5/2008		P74	98	22.00	2,156	104137343	
5/5/2008		P75	98	22.00	2,156	104137343	
5/6/2008		P76	92	22.00	2,024	104137343	
5/6/2008		P77	71	22.00	1,562	104137343	
5/6/2008		P78	32	24.00	384	104137343	
				Total Area (SF) This Page Only =	10,438		

Electronic Filing: Received, Clerk's Office 2/04/2022

Submitted #24

CQA-w Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
4/30/2008	09:50	P1/P2	72	VP	850	400	148	10-15 MPH/58		
4/30/2008	10:05	P2/P3	75	CK	850	400	428	10-15 MPH/58		
4/30/2008	10:04	P3/P4	76	VP	850	400	148	10-15 MPH/58		
4/30/2008	10:24	P4/P5	73	CK	850	400	428	10-15 MPH/58		
4/30/2008	10:38	P5/P6	74	VP	850	400	148	10-15 MPH/58		
4/30/2008	10:43	P6/P7	73	CK	850	400	428	10-15 MPH/58		
4/30/2008	10:58	P7/P8	71	VP	850	400	148	10-15 MPH/58		
4/30/2008	11:14	P8/P9	71	CK	850	400	428	10-15 MPH/58		
4/30/2008	11:19	P9/P10	72	VP	850	400	148	10-15 MPH/58		
4/30/2008	11:31	P10/P11	75	CK	850	400	428	10-15 MPH/58		
4/30/2008	11:36	P11/P12	75	VP	850	400	148	10-15 MPH/58		
4/30/2008	13:20	P12/P13	74	CK	850	400	428	10-15 MPH/58		
4/30/2008	13:28	P13/P14	74	VP	850	400	148	10-15 MPH/58		
4/30/2008	13:35	P14/P15	74	CK	850	400	428	10-15 MPH/58		
4/30/2008	13:47	P15/P16	75	VP	850	400	148	10-15 MPH/58		
4/30/2008	13:48	P16/P17	75	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:04	P17/P18	72	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:18	P18/P19	48	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:28	P19/P20	24	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:40	P20/P21	16	CK	850	400	428	10-15 MPH/58		
4/30/2008	14:49	P21/P19	27	CK	850	400	428	10-15 MPH/58		
4/30/2008	15:00	P18/P21	13	CK	850	400	428	10-15 MPH/58		
4/30/2008	17:01	P1/P22	69	CK	850	400	428	10-15 MPH/58		
4/30/2008	17:05	P22/P23	72	VP	850	400	138	10-15 MPH/58		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAMP Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
4/30/2008	17:16	P26/P27	64	CK	850	400	428	10-15 MPH/58		
4/30/2008	17:20	P26/P25	40	VP	850	400	138	10-15 MPH/58		
4/30/2008	17:23	P24/P25	23	CK	850	400	428	10-15 MPH/58		
4/30/2008	17:26	P24/P23	24	VP	850	400	138	10-15 MPH/58		
4/30/2008	17:31	P23/P25	22	VP	850	400	138	10-15 MPH/58		
4/30/2008	17:36	P23/P26	27	VP	850	400	138	10-15 MPH/58		
5/1/2008	08:17	P27/P28	56	CK	850	450	428	10-15 MPH/68		
5/1/2008	08:30	P28/P29	59	CK	850	450	428	10-15 MPH/68		
5/1/2008	08:47	P29/P30	58	CK	850	450	428	10-15 MPH/68		
5/1/2008	08:57	P30/P31	62	CK	850	450	428	10-15 MPH/68		
5/1/2008	09:07	P31/P32	62	CK	850	450	428	10-15 MPH/68		
5/1/2008	09:17	P32/P33	63	CK	850	450	428	10-15 MPH/68		
5/1/2008	09:33	P33/P34	60	CK	850	450	428	10-15 MPH/68		
5/1/2008	09:44	P34/P35	34	CK	850	450	428	10-15 MPH/68		
5/1/2008	12:51	P36/P37	74	CK	850	450	428	10-15 MPH/68		
5/1/2008	13:10	P37/P38	75	CK	850	450	428	10-15 MPH/68		
5/1/2008	13:23	P38/P39	76	CK	850	450	428	10-15 MPH/68		
5/1/2008	13:40	P39/P40	75	VP	850	450	138	10-15 MPH/68		
5/1/2008	13:43	P40/P41	75	CK	850	450	428	10-15 MPH/68		
5/1/2008	13:55	P41/P42	76	VP	850	450	138	10-15 MPH/68		
5/1/2008	14:00	P42/P43	76	CK	850	450	428	10-15 MPH/68		
5/1/2008	14:20	P43/P44	75	VP	850	450	138	10-15 MPH/68		
5/1/2008	14:30	P44/P45	61	CK	850	450	428	10-15 MPH/68		
5/1/2008	14:35	P45/P46	20	VP	850	450	138	10-15 MPH/68		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAMWS Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/1/2008	14:57	P47/P46	22	CK	850	450	428	10-15 MPH/68		
5/1/2008	14:57	P47/P45	33	CK	850	450	428	10-15 MPH/68		
5/1/2008	16:18	P48/P21	42	CK	850	450	428	10-15 MPH/68		
5/1/2008	16:20	P48/P49	53	CK	850	450	428	10-15 MPH/68		
5/1/2008	16:18	P18/P48	16	CK	850	450	428	10-15 MPH/68		
5/1/2008	16:55	P49/P50	53	VP	850	450	138	10-15 MPH/68		
5/1/2008	17:03	P50/P51	53	CK	850	450	428	10-15 MPH/68		
5/1/2008	17:10	P51/P52	53	VP	850	450	138	10-15 MPH/68		
5/1/2008	17:20	P52/P53	53	CK	850	450	428	10-15 MPH/68		
5/1/2008	17:33	P53/P54	53	VP	850	450	138	10-15 MPH/68		
5/1/2008	17:50	P54/P55	53	CK	850	450	428	10-15 MPH/68		
5/1/2008	17:48	P55/P47	53	VP	850	450	138	10-15 MPH/68		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2			JOB #:	200754		MATERIAL TYPE:		
DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/2/2008	08:00	P56/P18	9	VP	850	450	138	10 MPH/65		
5/2/2008	08:04	P48/P56	12	VP	850	450	138	10 MPH/65		
5/2/2008	08:09	P49/P56	9	VP	850	450	138	10 MPH/65		
5/2/2008	08:13	P17/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:17	P16/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:21	P15/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:25	P14/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:29	P13/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:33	P12/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:37	P11/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:41	P10/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:45	P9/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:49	P8/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:53	P7/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	08:57	P6/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:01	P5/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:05	P4/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:09	P3/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:13	P2/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:17	P1/P56	22	VP	850	450	138	10 MPH/65		
5/2/2008	09:21	P22/P56	22	VP	850	450	138	10 MPH/65		

Electronic Filing: Received, Clerk's Office 2/04/2022

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/5/2008	08:47	P56/P57	405	CK	850	400	428	5-10 MPH / 59		
5/5/2008	09:30	P57/P58	108	VP	850	400	138	5-10 MPH / 59		
5/5/2008	09:44	P58/P59	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	09:46	P59/P57	297	VP	850	400	138	5-10 MPH / 59		
5/5/2008	10:48	P60/P61	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	10:33	P61/P59	311	CK	850	400	428	5-10 MPH / 59		
5/5/2008	11:16	P59/P60	94	CK	850	400	428	5-10 MPH / 59		
5/5/2008	11:25	P60/P62	202	VP	850	400	138	5-10 MPH / 59		
5/5/2008	11:40	P61/P62	101	VP	850	400	138	5-10 MPH / 59		
5/5/2008	11:35	P60/P58	108	CK	850	400	428	5-10 MPH / 59		
5/5/2008	13:10	P63/P61	102	VP	850	400	138	5-10 MPH / 59		
5/5/2008	13:11	P63/P64	102	CK	850	400	428	5-10 MPH / 59		
5/5/2008	13:26	P62/P64	303	CK	850	400	428	5-10 MPH / 59		
5/5/2008	14:00	P64/P66	67	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:15	P64/P65	115	VP	850	400	138	5-10 MPH / 59		
5/5/2008	13:45	P65/P66	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P65/P55	5	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P65/P54	13	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P64/P54	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P64/P53	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P62/P53	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P62/P52	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P60/P52	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P60/P51	12	VP	850	400	138	5-10 MPH / 59		

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAVU Systems

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/5/2008	14:40	P58/P51	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P58/P50	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P57/P50	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P57/P49	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P56/P49	10	VP	850	400	138	5-10 MPH / 59		
5/5/2008	14:40	P56/P48	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	15:11	P67/P36	76	CK	850	400	428	5-10 MPH / 59		
5/5/2008	15:33	P67/P68	95	CK	850	400	428	5-10 MPH / 59		
5/5/2008	16:00	P68/P69	95	CK	850	400	428	5-10 MPH / 59		
5/5/2008	16:26	P69/P70	95	CK	850	400	428	5-10 MPH / 59		
5/5/2008	16:26	P66/P36	15	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P66/P37	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P66/P38	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P66/P39	9	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P40	12	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P41	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P42	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P43	22	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:26	P65/P44	15	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:40	P70/P71	95	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:40	P71/P72	96	CK	850	400	428	5-10 MPH / 59		
5/5/2008	16:58	P72/P73	96	VP	850	400	138	5-10 MPH / 59		
5/5/2008	16:59	P73/P74	97	CK	850	400	428	5-10 MPH / 59		
5/5/2008	17:05	P74/P75	97	VP	850	400	138	5-10 MPH / 59		

Electronic Filing: Received, Clerk's Office 2/04/2022

PANEL SEAMING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	TIME	SEAM NO.	SEAM LENGTH (FT)	SEAMER INITIALS	SET TEMP	SET SPEED	MACHINE NUMBER	WEATHER WIND / TEMP (MPH / ºF)	BEGINNING SAMPLE TEST RESULT	ENDING SAMPLE TEST RESULT
5/6/2008	07:57	P75/P76	92	CK	850	400	428	5-10 MPH / 59		
5/6/2008	08:18	P76/P77	71	VP	850	400	138	5-10 MPH / 59		
5/6/2008	08:22	P77/P78	32	CK	850	400	428	5-10 MPH / 59		
5/6/2008	08:40	P78/P35	24	CK	850	400	428	5-10 MPH / 59		
5/6/2008	08:50	P77/P34	27	CK	850	400	428	5-10 MPH / 59		
5/6/2008	09:04	P77/P33	6	CK	850	400	428	5-10 MPH / 59		
5/6/2008	09:10	P76/P33	9	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P67/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P68/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P69/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P70/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P71/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P72/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P73/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P74/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P75/P64	22	CK	850	400	428	5-10 MPH / 59		
5/6/2008	10:00	P76/P64	22	CK	850	400	428	5-10 MPH / 59		

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Submittal #24

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
4/30/2008	72	P1/P2	ss	14:11	14:16	30	30	P	P	
4/30/2008	75	P2/P3	ss	14:12	14:17	30	28	P	P	
4/30/2008	76	P3/P4	ss	14:18	14:23	30	29	P	P	
4/30/2008	73	P4/P5	ss	14:19	14:24	30	28	P	P	
4/30/2008	65	P5/P6	ss	14:25	14:30	30	28	P	P	
4/30/2008	9	P5/P6	ss	14:24	14:29	30	28	P	P	
4/30/2008	73	P6/P7	ss	14:26	14:31	30	30	P	P	
4/30/2008	65	P7/P8	ss	14:28	14:33	30	30	P	P	
4/30/2008	9	P8/P9	ss	14:34	14:39	30	29	P	P	
4/30/2008	73	P9/P10	ss	14:40	14:45	30	30	P	P	
4/30/2008	71	P10/P11	ss	14:41	14:46	30	29	P	P	
4/30/2008	71	P11/P12	ss	14:43	14:48	30	30	P	P	
4/30/2008	72	P12/P13	ss	15:08	15:13	30	28	P	P	
4/30/2008	75	P12/P13	ss	15:09	15:14	30	29	P	P	
4/30/2008	75	P21/P20	ss	16:20	16:25	30	30	P	P	
4/30/2008	23	P21/P19	ss	16:21	16:26	30	28	P	P	
4/30/2008	50	P21/P18	ss	16:22	16:27	30	29	P	P	
4/30/2008	24	P19/P20	ss	16:33	16:38	30	30	P	P	
4/30/2008	48	P19/P18	ss	16:34	16:39	30	28	P	P	
4/30/2008	10	P18/P17	ss	16:36	16:41	30	30	P	P	
4/30/2008	62	P18/P17	ss	16:44	16:49	30	30	P	P	
4/30/2008	75	P17/P16	ss	16:50	16:55	30	29	P	P	
4/30/2008	75	P16/P15	ss	16:52	16:57	30	20	P	P	
4/30/2008	74	P15/P14	ss	16:54	16:59	30	28	P	P	
4/30/2008	74	P14/P13	ss	17:04	17:09	30	30	P	P	
5/1/2008	72	P1/P22	ss	07:40	7:45	30	30	P	P	
5/1/2008	72	P22/P23	ss	07:41	7:46	30	29	P	P	
5/1/2008	22	P23/P24	ss	07:42	7:47	30	28	P	P	
5/1/2008	24	P24/P25	ss	07:48	7:53	30	29	P	P	
5/1/2008	40	P25/P26	ss	07:49	7:54	30	30	P	P	
5/1/2008	65	P26/P27	ss	07:51	7:56	30	28	P	P	
5/1/2008	37	P26/P23	ss	08:00	8:05	30	29	P	P	
5/1/2008	22	P25/P23	ss	08:08	8:13	30	29	P	P	

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CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:	60 Mil. HDPE

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
5/1/2008	56	P27/P28	ss	8:46	8:51	30	30	P	P	
5/1/2008	59	P28/P29	ss	08:47	8:52	30	30	P	P	
5/1/2008	58	P29/P30	ss	09:06	9:11	30	28	P	P	
5/1/2008	62	P30/P31	ss	09:10	9:15	30	30	P	P	
5/1/2008	62	P31/P32	ss	09:48	9:53	30	30	P	P	
5/1/2008	63	P32/P33	ss	09:49	9:54	30	28	P	P	
5/1/2008	60	P33/P34	ss	10:01	10:06	30	30	P	P	
5/1/2008	34	P34/P35	ss	10:03	10:08	30	29	P	P	
5/1/2008	74	P36/P37	ss	13:22	13:27	30	28	P	P	
5/1/2008	75	P37/P38	ss	13:28	13:33	30	30	P	P	
5/1/2008	76	P38/P39	ss	13:45	13:50	30	29	P	P	
5/1/2008	75	P39/P40	ss	14:00	14:05	30	30	P	P	
5/1/2008	75	P40/P41	ss	14:04	14:09	30	28	P	P	
5/1/2008	76	P41/P42	ss	14:20	14:25	30	30	P	P	
5/1/2008	76	P42/P43	ss	14:24	14:29	30	30	P	P	
5/1/2008	75	P43/P44	ss	15:00	15:05	30	29	P	P	
5/1/2008	61	P44/P45	ss	15:04	15:09	30	30	P	P	
5/1/2008	20	P45/P46	ss	15:15	15:20	30	30	P	P	
5/1/2008	22	P46/P47	ss	16:02	16:07	30	28	P	P	
5/1/2008	33	P47/P45	ss	16:04	16:09	30	30	P	P	
5/1/2008	42	P21/P48	ss	16:10	16:15	30	3O	P	P	
5/1/2008	16	P18/P48	ss	16:20	16:25	30	28	P	P	
5/2/2008	53	P48/P49	ss	07:45	7:50	30	29	P	P	
5/2/2008	53	P49/P50	ss	07:47	7:52	30	30	P	P	
5/2/2008	53	P50/P51	ss	07:54	7:59	30	30	P	P	
5/2/2008	53	P51/P52	ss	07:55	8:00	30	29	P	P	
5/2/2008	53	P52/P53	ss	08:10	8:15	30	30	P	P	
5/2/2008	53	P53/P54	ss	08:11	8:16	30	29	P	P	
5/2/2008	53	P54/P55	ss	08:18	8:23	30	28	P	P	
5/2/2008	53	P55/P47	ss	08:31	8:36	30	30	P	P	

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CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
5/5/2008	9	P18/P56	SS	8:01	8:06	30	30	P	P	
5/5/2008	22	P17/P56	SS	08:02	8:07	30	28	P	P	
5/5/2008	22	P16/P56	SS	08:09	8:14	30	30	P	P	
5/5/2008	22	P15/P56	SS	08:11	8:16	30	29	P	P	
5/5/2008	22	P14/P56	SS	08:13	8:18	30	28	P	P	
5/5/2008	22	P13/P56	SS	08:19	8:24	30	30	P	P	
5/5/2008	22	P12/P56	SS	08:20	8:25	30	29	P	P	
5/5/2008	22	P11/P56	SS	08:26	8:31	30	29	P	P	
5/5/2008	22	P10/P56	SS	08:28	8:33	30	30	P	P	
5/5/2008	22	P9/P56	SS	08:34	8:39	30	28	P	P	
5/5/2008	22	P8/P56	SS	08:35	8:40	30	28	P	P	
5/5/2008	22	P7/P56	SS	08:41	8:46	30	30	P	P	
5/5/2008	22	P6/P56	SS	08:42	8:47	30	30	P	P	
5/5/2008	22	P5/P56	SS	08:48	8:53	30	30	P	P	
5/5/2008	22	P4/P56	SS	08:47	8:52	30	29	P	P	
5/5/2008	22	P3/P56	SS	08:58	9:03	30	30	P	P	
5/5/2008	22	P2/P56	SS	08:59	9:54	30	29	P	P	
5/5/2008	22	P1/P56	SS	09:10	9:15	30	30	P	P	
5/5/2008	22	P22/P56	SS	09:11	9:16	30	28	P	P	
5/5/2008	22	P48/P56	SS	09:20	9:25	30	28	P	P	
5/5/2008	22	P49/P56	SS	09:21	9:26	30	30	P	P	

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
5/5/2008	405	P56/P57	SS	10:48	10:53	30	28	P	P	
5/5/2008	108	P57/P58	SS	10:49	10:54	30	30	P	P	
5/5/2008	22	P58/P59	SS	14:02	14:07	30	30	P	P	
5/5/2008	297	P59/P57	SS	16:20	16:25	30	29	P	P	
5/5/2008	108	P58/P60	SS	16:21	16:26	30	30	P	P	
5/5/2008	94	P60/P59	SS	16:27	16:32	30	30	P	P	
5/5/2008	22	P60/P61	SS	16:28	16:33	30	29	P	P	
5/5/2008	203	P61/P59	SS	16:29	16:34	30	28	P	P	
5/5/2008	202	P60/P62	SS	16:35	16:40	30	30	P	P	
5/5/2008	101	P61/P62	SS	16:36	16:41	30	29	P	P	
5/5/2008	102	P61/P63	SS	16:42	16:47	30	30	P	P	
5/5/2008	22	P62/P63	SS	16:43	16:48	30	30	P	P	
5/5/2008	303	P64/P62	SS	16:49	16:54	30	29	P	P	
5/5/2008	102	P64/P63	SS	16:50	16:55	30	30	P	P	
5/5/2008	115	P64/P65	SS	16:56	17:01	30	29	P	P	
5/5/2008	67	P66/P64	SS	16:57	17:02	30	30	P	P	
5/5/2008	15	P66/P36	SS	16:58	17:53	30	28	P	P	
5/5/2008	22	P66/P37	SS	17:10	17:15	30	30	P	P	
5/5/2008	22	P66/P38	SS	17:11	17:16	30	29	P	P	
5/5/2008	9	P66/P39	SS	17:12	17:17	30	30	P	P	
5/5/2008	12	P65/P40	SS	17:13	17:18	30	29	P	P	
5/5/2008	22	P65/P41	SS	17:18	17:23	30	28	P	P	
5/5/2008	22	P65/P42	SS	17:25	17:30	30	30	P	P	
5/5/2008	22	P65/P43	SS	17:26	17:31	30	30	P	P	
5/5/2008	15	P65/P44	SS	17:33	17:38	30	29	P	P	
5/5/2008	95	P67/P68	SS	17:34	17:39	30	30	P	P	
5/5/2008	95	P68/P69	SS	17:41	17:46	30	28	P	P	
5/5/2008	96	P69/P70	SS	17:42	17:47	30	30	P	P	
5/5/2008	96	P70/P71	SS	17:49	17:54	30	28	P	P	
5/5/2008	96	P71/P72	SS	17:50	17:55	30	30	P	P	
5/5/2008	96	P72/P73	SS	17:56	18:01	30	29	P	P	
5/5/2008	96	P73/P74	SS	17:58	18:53	30	30	P	P	
5/5/2008	97	P74/P75	SS	18:10	18:15	30	29	P	P	

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CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE	SEAM LENGTH	SEAM #	TESTER	AIR PRESSURE TEST					VACUUM TEST	
				TIME		PRESSURE				
TESTED	TESTED		INITIALS	START	END	START	END	P/F	P / F	COMMENTS
5/6/2008	22	P64/P75	SS	9:08	9:13	30	30	P	P	
5/6/2008	22	P64/P74	SS	09:09	9:14	30	28	P	P	
5/6/2008	22	P64/P73	SS	09:15	9:20	30	29	P	P	
5/6/2008	22	P64/P72	SS	09:16	9:21	30	30	P	P	
5/6/2008	22	P64/P71	SS	09:17	9:22	30	30	P	P	
5/6/2008	22	P64/P70	SS	09:23	9:28	30	29	P	P	
5/6/2008	22	P64/P69	SS	09:24	9:29	30	28	P	P	
5/6/2008	22	P64/P68	SS	09:25	9:30	30	30	P	P	
5/6/2008	22	P64/P67	SS	09:31	9:36	30	30	P	P	
5/6/2008	13	P56/P27	SS	09:32	9:37	30	29	P	P	
5/6/2008	8	P57/P27	SS	09:33	9:38	30	30	P	P	
5/6/2008	12	P57/P28	SS	09:39	9:44	30	29	P	P	
5/6/2008	9	P59/P28	SS	09:47	9:52	30	30	P	P	
5/6/2008	12	P59/P29	SS	09:48	9:53	30	28	P	P	
5/6/2008	9	P61/P29	SS	09:56	10:01	30	30	P	P	
5/6/2008	12	P61/P30	SS	09:57	10:02	30	29	P	P	
5/6/2008	9	P63/P30	SS	10:08	10:13	30	30	P	P	
5/6/2008	12	P63/P31	SS	10:11	10:16	30	28	P	P	
5/6/2008	9	P64/P31	SS	10:12	10:17	30	30	P	P	
5/6/2008	12	P64/P32	SS	10:25	10:30	30	30	P	P	
5/6/2008	95	P67/P64	SS	10:35	10:40	30	30	P	P	
5/6/2008	95	P68/P64	SS	10:36	10:41	30	28	P	P	
5/6/2008	96	P69/P64	SS	10:42	10:47	30	29	P	P	
5/6/2008	95	P70/P64	SS	10:43	10:48	30	30	P	P	
5/6/2008	96	P71/P64	SS	10:45	10:50	30	29	P	P	
5/6/2008	95	P72/P64	SS	10:53	10:58	30	30	P	P	
5/6/2008	95	P73/P64	SS	10:55	11:00	30	28	P	P	
5/6/2008	96	P74/P64	SS	11:12	11:17	30	30	P	P	
5/6/2008	96	P75/P64	SS	11:15	11:20	30	30	P	P	
5/6/2008	96	P76/P74	SS	11:20	11:25	30	30	P	P	
5/6/2008	92	P75/P76	SS	11:21	11:26	30	30	P	P	
5/6/2008	71	P76/P77	SS	11:27	11:32	30	28	P	P	
5/6/2008	32	P77/P78	SS	11:28	11:33	30	29	P	P	
5/6/2008	24	P78/P35	SS	11:29	11:34	30	30	P	P	

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

NON-DESTRUCTIVE TESTING FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

DATE TESTED	SEAM LENGTH TESTED	SEAM #	TESTER INITIALS	AIR PRESSURE TEST					VACUUM TEST	COMMENTS
				TIME		PRESSURE				
				START	END	START	END	P/F	P / F	
5/6/2008	27	P77/P34	SS	11:35	11:40	30	30	P	P	
5/6/2008	6	P77/P33	SS	11:41	11:46	30	29	P	P	
5/6/2008	9	P76/P33	SS	11:43	11:48	30	28	P	P	

Electronic Filing: Received, Clerk's Office 2/04/2022

Submitted '24

DESTRUCTIVE TESTING REPORT FORM

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB NUMBER:	200754	MATERIAL TYPE:	60 Mil. HDPE

TENSIOMETER ID:	T-062/06	EXTRUSION	FUSION	FIELD WELD VALUES											
SAMPLE I.D. (DT#)	SEAM NO.	QC INT	MACH NO.	SEAMER INT	BARREL/ PREHEAT	WEDGE/ SET SPEED	PEEL (PPI)					SHEAR (PPI)			P/F	LOCATION OF DESTRUCTIVE TEST
DS1	P13/P14	ss	138	vp	B:	W: 850	146	151	138			165	162		P	NEOS 0'->14'
					P:	S: 400	140	139	137							
DS2	P14/P15	ss	428	ck	B:	W: 850	133	139	134			166	169		P	NEOS 0'->33'
					P:	S: 400	136	140	153							
DS3	P27/P28	ss	428	ck	B:	W: 850	138	135	131			169	168		P	WEOS 0'->10'
					P:	S: 450	140	134	137							
DS4	P37/P38	ss	428	ck	B:	W: 850	139	151	140			169	164		P	SEOS 0'->25'
					P:	S: 450	143	138	145							
DS5	P43/P44	ss	138	vp	B:	W: 850	132	136	138			171	168		P	SEOS 0'->20'
					P:	S: 450	142	144	135							
DS6	P50/P51	ss	428	ck	B:	W: 850	146	139	142			166	167		P	EEOS 0'->8'
					P:	S: 450	154	138	151							
DS7	P7/P56	ss	138	vp	B:	W: 850	138	137	134			180	165		P	WEOS 0'->10'
					P:	S: 450	132	139	132							
DS8	P56/P57	ss	428	ck	B:	W: 850	139	135	137			167	183		P	EEOS 0'->11'
					P:	S: 450	142	138	146							
DS9	P57/P59	ss	138	vp	B:	W: 850	138	138	132			165	174		P	EEOS 0'->102'
					P:	S: 450	136	132	143							
DS10	P60/P58	ss	428	ck	B:	W: 850	143	132	133			177	173		P	EEOS 0'->24'
					P:	S: 450	139	139	147							
DS11	P63/P61	ss	138	vp	B:	W: 850	133	135	132			171	179		P	EEOS 0'->5'
					P:	S: 450	137	133	136							
DS12	P63/P64	ss	428	ck	B:	W: 850	139	132	143			177	175		P	EEOS 0'->25'
					P:	S: 450	135	138	144							
DS13	P65/P43	ss	138	vp	B:	W: 850	143	146	137			172	178		P	EEOS 0'->10'
					P:	S: 450	138	133	139							

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Submitted #21

CAAW Systems

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P17/P56		R1	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P16/P56		R2	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P15/P56		R3	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P14/P56		R4	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P13/P56		R5	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P12/P56		R6	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P11/P56		R7	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P10/P56		R8	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P9/P56		R9	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P8/P56		R10	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P7/P56		R11	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P6/P56		R12	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P5/P56		R13	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P4/P56		R14	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P3/P56		R15	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P2/P56		R16	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P1/P56		R17	VK	175	5/6/2008	CK	ext weld	5/6/2008	NEOS 0'	P
P22/P56		R18	VK	175	5/6/2008	CK	patch 3x3	5/6/2008	NEOS 0'	P
P65/P55		R19	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P65/P54		R20	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P64/P54		R21	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P64/P53		R22	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P62/P53		R23	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P62/P52		R24	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P60/P52		R25	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P

Electronic Filing: Received, Clerk's Office 2/04/2022

CQA Systems

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:		Midwest Gen Station - Pond #2			JOB #: 200754			MATERIAL TYPE:		
FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P60/P51		R26	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P58/P51		R27	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P58/P50		R28	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P57/P50		R29	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P57/P49		R30	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P56/P49		R31	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P56/P48		R32	VK	175	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'	P
P66/P36		R33	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P66/P37		R34	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P66/P38		R35	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P66/P39		R36	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P40		R37	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P41		R38	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P42		R39	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P43		R40	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P65/P44		R41	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P67/P64		R42	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	SEOS 0'	P
P68/P64		R43	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P69/P64		R44	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P70/P64		R45	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P71/P64		R46	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	SEOS 0'	P
P72/P64		R47	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P73/P64		R48	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P74/P64		R49	VP	88	5/6/2008	CK	ext weld	5/6/2008	SEOS 0'	P
P75/P64		R50	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	SEOS 0'	P

Electronic Filing: Received, Clerk's Office 2/04/2022

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
P76/P64		R51	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	SEOS 0'	P
P58/P57		R52	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P60/P58		R53	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P60/P59		R54	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P60/P62		R55	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P61/P62		R56	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P64/P62		R57	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P65/P64		R58	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	EEOS 0'	P
P26/P25		R59	VK	175	5/6/2008	CK	ext weld	5/6/2008	anchor	P
P14/P13		R60	VK	175	5/6/2008	CK	bead	5/6/2008	anchor	P
P20/P21		R61	VK	175	5/6/2008	CK	patch 6x3	5/6/2008	anchor	P
P48/P21		R62	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	WEOS 0'	P
P18/P19		R63	VK	175	5/6/2008	CK	patch 1x1	5/6/2008	NEOS 0'	P
P50/P51		R64	VK	175	5/6/2008	CK	ext weld	5/6/2008	WEOS 0'	P
P51/P52		R65	VK	175	5/6/2008	CK	patch 1x1	5/6/2008	WEOS 0'	P
P55/P54		R66	VK	175	5/6/2008	CK	patch 1x1	5/6/2008	WEOS 0'	P
P47/P55		R67	VP	88	5/6/2008	CK	patch 6x8	5/6/2008	WEOS 0'	P
P46/P45		R68	VP	88	5/6/2008	CK	patch 1x1	5/6/2008	SEOS 0'	P
P45/P44		R69	VP	88	5/6/2008	CK	patch 3x3	5/6/2008	SEOS 0'	P
P42/P43		R70	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'->5'	P
P40/P41		R71	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	NEOS 0'->27'	P
P35/P34		R72	VP	88	5/6/2008	CK	patch 3x3	5/6/2008	WEOS 0'	P
P34/P33		R73	VP	88	5/6/2008	CK	patch 2x2	5/6/2008	WEOS 0'	P
P33/P32		R74	VK	175	5/6/2008	CK	patch 10x10	5/6/2008	EEOS 0'->5'	P
	P32	R75	VK	175	5/6/2008	CK	patch 1x1	5/6/2008	EEOP 0'->10'	P

Electronic Filing: Received, Clerk's Office 2/04/2022

CAAW Systems

GEOMEMBRANE REPAIR REPORT

PROJECT NAME:	Midwest Gen Station - Pond #2	JOB #:	200754	MATERIAL TYPE:

FIELD SEAM	PANEL NO.	REPAIR NO.	REPAIR CREW	MACH NO.	TEST DATE	TESTER INIT.	REPAIR TYPE AND SIZE (Patch, Bead, Ext Weld, Cap, DT, Boot, etc.)	REPAIR DATE	LOCTION OF REPAIR	V BOX PASS
	P28	R76	VK	175	5/6/2008	CK	bead	5/6/2008	EEOP 0'->10'	P
	P28	R77	VK	175	5/6/2008	CK	bead	5/6/2008	EEOP 0'->12'	P
P27/P28		R78	VK	175	5/6/2008	CK	patch 6x12	5/6/2008	EEOS 0'->15'	P
P13/P14		R79	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	NEOS 0'->14'(DS1)	P
P14/P15		R80	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	NEOS 0'->33'(DS2)	P
P27/P28		R81	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	WEOS 0'->10'(DS3)	P
P37/P38		R82	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	SEOS 0'->25'(DS4)	P
P43/P44		R83	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	SEOS 0'->20'(DS5)	P
P50/P51		R84	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->8'(DS6)	P
P7/P56		R85	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	WEOS 0'->10'(DS7)	P
P56/P57		R86	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->11'(DS8)	P
P57/P59		R87	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->102'(DS9)	P
P60/P58		R88	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->24'(DS10)	P
P63/P61		R89	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->5'(DS11)	P
P63/P64		R90	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->25'(DS12)	P
P65/P43		R91	VK	175	5/6/2008	CK	patch 2x3	5/6/2008	EEOS 0'->10'(DS13)	P
	P77	R92	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P69	R93	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P68	R94	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P39	R95	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P44	R96	VP	88	5/6/2008	CK	patch 3x3; pipe boot		SEOP	P
	P22	R97	VK	175	5/6/2008	CK	patch 3x3; pipe boot		NEOP	P
	P5	R98	VK	175	5/6/2008	CK	patch 3x3; pipe boot		NEOP	P
	P11	R99	VK	175	5/6/2008	CK	patch 3x3; pipe boot		NEOP	P
	P18	R100	VK	175	5/6/2008	CK	patch 3x3; pipe boot		NEOP	P

Electronic Filing: Received, Clerk's Office 2/04/2022

ATTACHMENT A5

GEOMEMBRANE INSTALLER'S SUBGRADE ACCEPTANCE (IMPOUNDMENT #1 AND #2)

Electronic Filing: Received, Clerk's Office 2/04/2022

CERTIFICATE OF ACCEPTANCE OF SUBGRADE SURFACE PREPARATION FOR GEOMEMBRANE INSTALLATION

PROJECT NAME: Midwest Generation Joliet Station Ash Pond 1

LOCATION: Joliet, IL

JOB NUMBER: 200754 CLIENT: Brieser Construction Company

AREA ACCEPTED: Entire area to be lined under panels P1 to P67

COMMENTS:

INSTALLER: The undersigned authorized representative of CAAW Systems certifies that he or she has visually inspected the subgrade surface of the area described above and has found the surface to be acceptable for installation of the geosynthetic materials.

CAAW Systems shall be responsible for the integrity of finished geosynthetic material until completion of the installation or demobilization from site.

This certification is based on observations of the subgrade surface conditions only. CAAW Systems has made no subterrain inspections or tests and makes no representations or warranties as to the conditions that may exist below the surface of the subgrade.

CERTIFICATE APPROVED BY:

Installers Acceptance		Inspectors Acceptance	
Company:	Clean Air And Water Systems, LLC	Company:	Brieser Construction Company
By:	Thong Ingels	By:	Mike Schmidt
Title:	Superintendent	Title:	Superintendent
Date:	10-6-08	Date:	10-6-08

Electronic Filing: Received, Clerk's Office 2/04/2022 Submittal #25

CERTIFICATE OF ACCEPTANCE OF SUBGRADE SURFACE PREPARATION FOR GEOMEMBRANE INSTALLATION

PROJECT NAME: Midwest Generation Joliet Station Ash Pond 2

LOCATION: Joliet, IL

JOB NUMBER: 200754 CLIENT: Brieser Construction Company

AREA ACCEPTED: Entire area to be lined under panels P1 to P78

COMMENTS:

INSTALLER: The undersigned authorized representative of CAAW Systems certifies that he or she has visually inspected the subgrade surface of the area described above and has found the surface to be acceptable for installation of the geosynthetic materials.

CAAW Systems shall be responsible for the integrity of finished geosynthetic material until completion of the installation or demobilization from site.

This certification is based on observations of the subgrade surface conditions only. CAAW Systems has made no subterrain inspections or tests and makes no representations or warranties as to the conditions that may exist below the surface of the subgrade.

CERTIFICATE APPROVED BY:

Installers Acceptance		Inspectors Acceptance	
Company:	Clean Air And Water Systems, LLC	Company:	Brieser Construction Company
By:	Thong Ingels	By:	Mike Schmidt
Title:	Superintendent	Title:	Superintendent
Date:	5-6-08	Date:	5-6-08

Electronic Filing: Received, Clerk's Office 2/04/2022

ATTACHMENT A6

GEOMEMBRANE INSTALLATION CERTIFICATE (IMPOUNDMENT #1 AND #2)

Electronic Filing: Received, Clerk's Office 2/04/2022

November 17, 2008

Tedd Mills
Brieser Construction Company
24101 S. Municipal Drive
Channahon, IL 60410

RE: Midwest Generation Joliet Station – Installation Certification for Ash Pond 1

To Whom It May Concern,

This letter shall act as a certification to the geomembrane and geotextile installation at the above referenced project. The HDPE geomembrane and geotextiles installed in Ash Pond 1 were installed in accordance with the project specifications.

Sincerely,

Brian McKeown
Member
Clean Air And Water Systems, LLC

Corporate Office
123 Elm Street
P.O. Box 337
Dousman, WI. 53118-0337
(262) 965-4366 Fax (262) 965-4369

www.caawsystem.com

Regional Office
2727 W. 2nd St., Ste 235
Hastings, NE 68901
(402) 463-0857 Fax (402) 463-0858

July 10, 2008

Tedd Mills
Brieser Construction Company
24101 S. Municipal Drive
Channahon, IL 60410

RE: Midwest Generation Joliet Station – Installation Certification for Ash Pond 2

To Whom It May Concern,

This letter shall act as a certification to the geomembrane and geotextile installation at the above referenced project. The HDPE geomembrane and geotextiles installed in Ash Pond 2 were installed in accordance with the project specifications.

Sincerely,

Brian McKeown
Member
Clean Air And Water Systems, LLC

Corporate Office
123 Elm Street
P.O. Box 337
Dousman, WI. 53118-0337
(262) 965-4366 Fax (262) 965-4369

www.caawsystem.com

Regional Office
2727 W. 2nd St., Ste 235
Hastings, NE 68901
(402) 463-0857 Fax (402) 463-0858

Electronic Filing: Received, Clerk's Office 2/04/2022

ATTACHMENT A7

GEOMEMBRANE WARRANTIES

Electronic Filing: Received, Clerk's Office 2/04/2022

INSTALLATION WARRANTY- GEOMEMBRANE LINERS

PROJECT NAME: Midwest Generation – Joliet Station

Subject to the terms and conditions set forth below, Clean Air And Water Systems, LLC warrants to Purchaser, Brieser Construction, that the 60 mil HDPE white liner installed at the Midwest Generation – Joliet Station, was installed by Clean Air And Water Systems, LLC, in accordance with specifications in a good and workmanlike manner and that the installation of the liner is free from defects in workmanship for a period of two (2) years from the date upon which the material was installed.

This warranty covers only defects in workmanship occurring during the installation of the liner. This warranty does not cover ay damage to, or defects in the liner found to have been a result of misuse, abuse or conditions existing after it was installed, including, but not limited to, rough handling; malicious mischief; vandalism; sabotage; fire; acts of God; acts of the public enemy; acts of war, public rebellion, severe weather conditions of all types; damage due to ice; excessive stress from any source; floating debris; damage due to machinery; foreign objects or animals. Nor does this warranty cover any defects which are found to have been a result of improper or defective design or engineering unless the design or engineering was performed by Clean Air And Water Systems, LLC. In the event circumstances are found to exist which purchaser believes may give rise to a claim under this warranty, the following procedure shall be followed:

a) Purchaser shall give Clean Air And Water Systems, LLC written notice of the facts and circumstances of said claim within ten (10) days of becoming aware of said facts and circumstances. Said notice shall be by registered or certified mail, return receipt requested, postage prepaid, addressed to Member, Clean Air And Water Systems, LLC, 123 Elm Street, PO Box 337, Dousman, Wisconsin 53118. The words "WARRANTY CLAIM" shall be clearly marked on the face of envelope in the lower right hand corner. Said notice shall contain, at a minimum, the name and address of the owner, the name and address of the installation, the name and address of the installer, the date upon which the material was purchased and the facts known to Purchaser upon which the claim is based. Failure to strictly comply with all the requirements of this paragraph shall void this warranty.

b) Within twenty days after receipt of the notice described in paragraph a., above, Clean Air And Water Systems, LLC shall notify Purchaser either that it will send a representative to inspect the allegedly defective liner or that it does not wish to do so. Purchaser shall pay the expenses incurred by Clean Air And Water Systems, LLC in making the inspection, including current per diem rates for personnel involved in making the inspection, in the event Clean Air And Water Systems, LLC determines that the claim is not covered by this warranty.

c) Purchaser SHALL NOT REPAIR, REPLACE, REMOVE, ALTER OR DISTURB ANY LINER, NOR SHALL Purchaser ALLOW ANYONE ELSE TO REPAIR, REPLACE, REMOVE, ALTER, OR DISTURB ANY LINER PRIOR TO SUCH INSPECTION OR RECEIPT OF CLEAN AIR AND WATER SYSTEMS, LLC.'S NOTICE THAT IT ELECTS NOT TO INSPECT. A FAILURE TO STRICTLY COMPLY WITH THIS PARAGRAPH SHALL VOID THIS WARRANTY OR MAY LEAD TO A DETERMINATION THAT THE ALLEGED DEFECTS ARE NOT WITHIN THE SCOPE OF THIS WARRANTY.

d) If Clean Air And Water Systems, LLC determines that the alleged defects are covered by this warranty, Clean Air And Water Systems, LLC shall, in its sole discretion, either repair the defective liner or provide Purchaser with replacement liner. THE REMEDIES PROVIDED HEREIN ARE THE EXCLUSIVE REMEDIES AVAILABLE UNDER THIS WARRANTY. Any determination as to whether a particular

defect is covered by this warranty will be made by Clean Air And Water Systems, LLC in its sole and complete discretion.

e) Purchaser agrees that it shall provide Clean Air And Water Systems, LLC with clean, dry and unobstructed access to the liner in order for Clean Air And Water Systems, LLC to perform the inspections and warranty work which may be required pursuant to this warranty.

THE REMEDIES PROVIDED TO Purchaser HEREIN ARE THE EXCLUSIVE REMEDIES AVAILABLE UNDER THIS WARRANTY AND ARE INTENDED FOR THE SOLE BENEFIT OF Purchaser. NEITHER THIS WARRANTY NOR ANY RIGHTS HEREUNDER SHALL BE ASSIGNABLE. CLEAN AIR AND WATER SYSTEMS, LLC SHALL HAVE NO LIABILITY UNDER THIS WARRANTY TO THIRD PARTIES OR STRANGERS TO THIS AGREEMENT. THE WARRANTY SET FORTH ABOVE IS THE ONLY WARRANTY APPLICABLE TO THE LINER AND ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL CLEAN AIR AND WATER SYSTEMS, LLC BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL OR CONSEQUENTIAL DAMAGES FOR, RESULTING FROM, OR IN CONNECTION WITH, ANY LOSS RESULTING FROM THE USE OF THE LINER. IN THE EVENT THE EXCLUSIVE REMEDY PROVIDED HEREIN FAILS IN ITS ESSENTIAL PURPOSE, AND IN THAT EVENT ONLY, Purchaser SHALL BE ENTITLED TO RETURN OF THE PURCHASE PRICE FOR SO MUCH OF THE MATERIAL AS CLEAN AIR AND WATER SYSTEMS, LLC DETERMINES IN ITS SOLE DISCRETION, TO HAVE VIOLATED THE WARRANTY PROVIDED HEREIN. EXCEPT FOR THE WARRANTY SET FORTH ABOVE, NO REPRESENTATION OR WARRANTY MADE BY ANY SALES OR OTHER REPRESENTATIVE CLEAN AIR AND WATER SYSTEMS, LLC, OR ANY OTHER PERSON, CONCERNING THE LINER SHALL BE BINDING UPON CLEAN AIR AND WATER SYSTEMS, LLC.

Any waiver of the terms and conditions of this warranty shall be in writing signed by CLEAN AIR AND WATER SYSTEMS, LLC the failure to insist upon strict compliance with any of the terms and conditions contained herein shall not act as a waiver of strict compliance with all of the remaining terms and conditions or this warranty and shall not operate as a waiver as to any of the terms and conditions of this warranty as to future claims under this warranty.

CLEAN AIR AND WATER SYSTEMS, LLC

BY: Brian McKeown, member

Brian K. McKeown/ Member

I have read and agree to be bound by the terms and conditions of the foregoing warranty.

By: Todd McC

Title: Vice President

Company: Bricar Construction

Date: 12-8-08

Electronic Filing: Received, Clerk's Office 2/04/2022

PRO RATA LIMITED MATERIAL WARRANTY
FOR GSE LINING TECHNOLOGY, INC.
Geomembrane Products
(U.S.A.)

Date:	11/19/2008	Warranty No.:	**524244**
Purchaser Name:	Midwest Generation	Project No.:	524244
Address:	1800 Channahon Rd.	Effective Date:	10/6/2008
City, State:	Joliet, IL 60436	Project Name:	Midwest Generation
Product Type/Description:	GSE HDT Geomembrane	Project Address:	1800 Channahon Rd., Joliet, IL 60436

GSE Lining Technology, Inc. ("GSE") warrants each GSE product described above to be free from material manufacturing defects (as described by the contract's material specifications) and to be able to withstand normal weathering for a period of **two (2) years** from the date of sale. This limited warranty does not include damages or defects in the GSE product resulting from acts of God, casualty or catastrophe, including but not limited to: earthquakes, floods, piercing hail, tornadoes or force majeure. The term "normal use" does not include, among other things, the exposure of GSE's product to harmful chemicals, abuse by machinery, equipment or people; improper site preparation or placement of cover materials; excessive pressures or stresses from any source. This warranty is intended for commercial use only and is not in effect for the consumer as defined in the Magnuson-Moss Warranty Act.

Should defects or premature loss of use within the scope of this warranty occur, GSE will, at its option, repair or replace the GSE product on a pro rata basis at the current price in such manner as to charge the Purchaser only for that portion of the warranted life which has elapsed since the purchase of the product. GSE shall have the right to inspect and determine the cause of the alleged defect in the product and to take appropriate steps to repair or replace the product if a defect exists that is covered under this warranty.

Any claim for any alleged breach of this warranty must be made in writing, by certified mail or courier, to GSE Lining Technology Co., 19103 Gundle Road, Houston, TX 77073, with the words "Warranty Claim" clearly marked on the face of the envelope, within ten (10) days of Purchaser becoming aware of the alleged defect. Should the required notice not be given, the defect and all warranties are waived by the Purchaser, and Purchaser shall not have rights under this warranty. GSE shall not be obligated to perform any inspection or obligated to perform any repair or replacement under this warranty until the area is made available free from all obstructions, water, dirt, sludge, residuals and liquids of any kind. If after inspection it is determined that there is no claim under this warranty, Purchaser shall reimburse GSE for its costs associated with the site inspection.

In the event the exclusive remedy provided herein fails in its essential purpose, and in that event only, the Purchaser shall be entitled to a return of the purchase price for so much of the product as GSE determines to have violated the warranty provided herein. GSE shall not be liable for direct, indirect, special, consequential or incidental damages resulting from a breach of this warranty including, but not limited to: damages for loss of production, lost profits, personal injury or property damage. GSE shall not be obligated to reimburse Purchaser for any repairs, replacement, modifications or alterations made by Purchaser to GSE's product, unless GSE specifically authorized, in writing, said repairs, replacements, modifications or alterations in advance. GSE liability under this warranty shall in no event exceed the replacement cost of the product sold to the Purchaser for the particular installation in which it failed.

GSE neither assumes nor authorizes any person other than an officer of GSE to assume for it any other or additional liability in connection with the GSE product made on the basis of the Limited Warranty. **GSE MAKES NO WARRANTY OF ANY KIND OTHER THAN THAT GIVEN HEREIN AND HEREBY DISCLAIMS ALL WARRANTIES, INCLUDING BOTH EXPRESS OR IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, AND BY ACCEPTING DELIVERY OF THE PRODUCT, PURCHASER WAIVES ALL OTHER POSSIBLE WARRANTIES. GSE's WARRANTY BECOMES AN OBLIGATION OF GSE TO PERFORM UNDER THE WARRANTY ONLY UPON RECEIPT OF FINAL PAYMENT.**

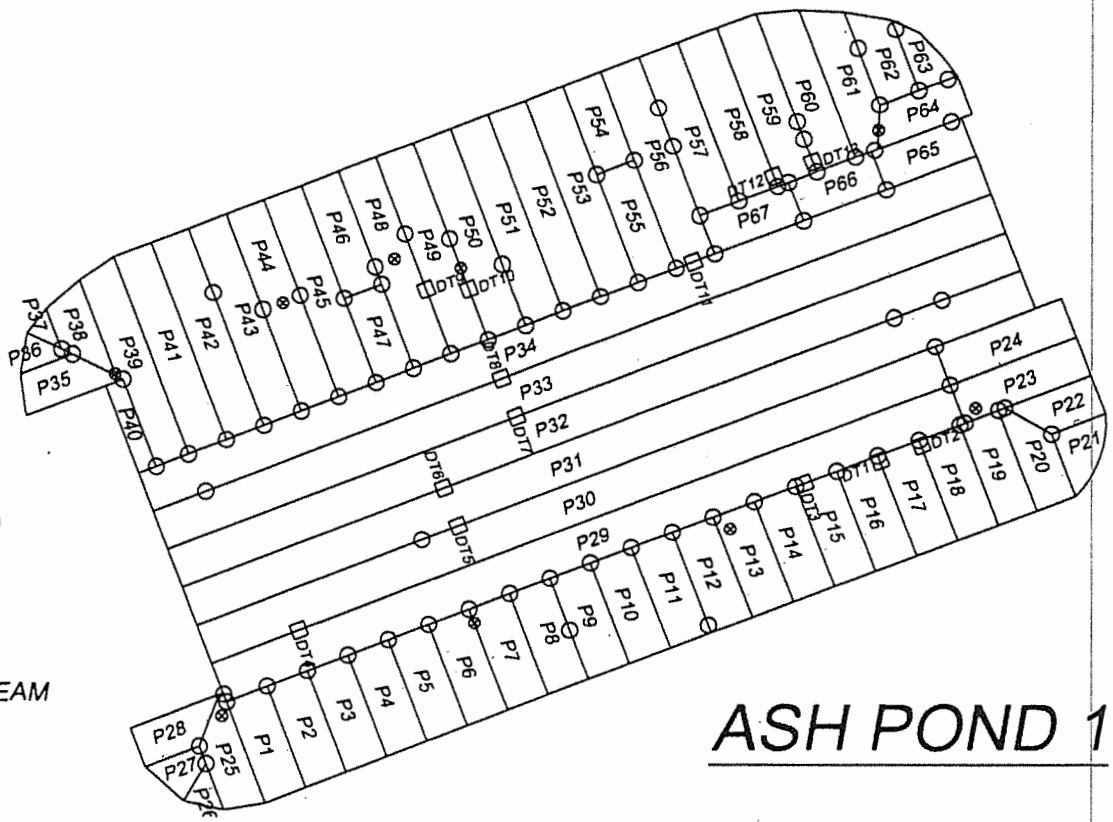
This warranty is extended to the Purchaser and is non-transferable and non-assignable, i.e. there are no third-party beneficiaries to this warranty.

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ATTACHMENT A8

GEOMEMBRANE AS-BUILT PANEL LAYOUT (IMPOUNDMENT #1 AND #2)

NORTH



ASH POND 1

LEGEND

○	PATCH / REPAIR WELD
□DT#	DESTRUCTIVE TEST
P#	PANEL NUMBER
⊗	PIPE BOOT
———	PANEL EDGE / FIELD SEAM

SCALE

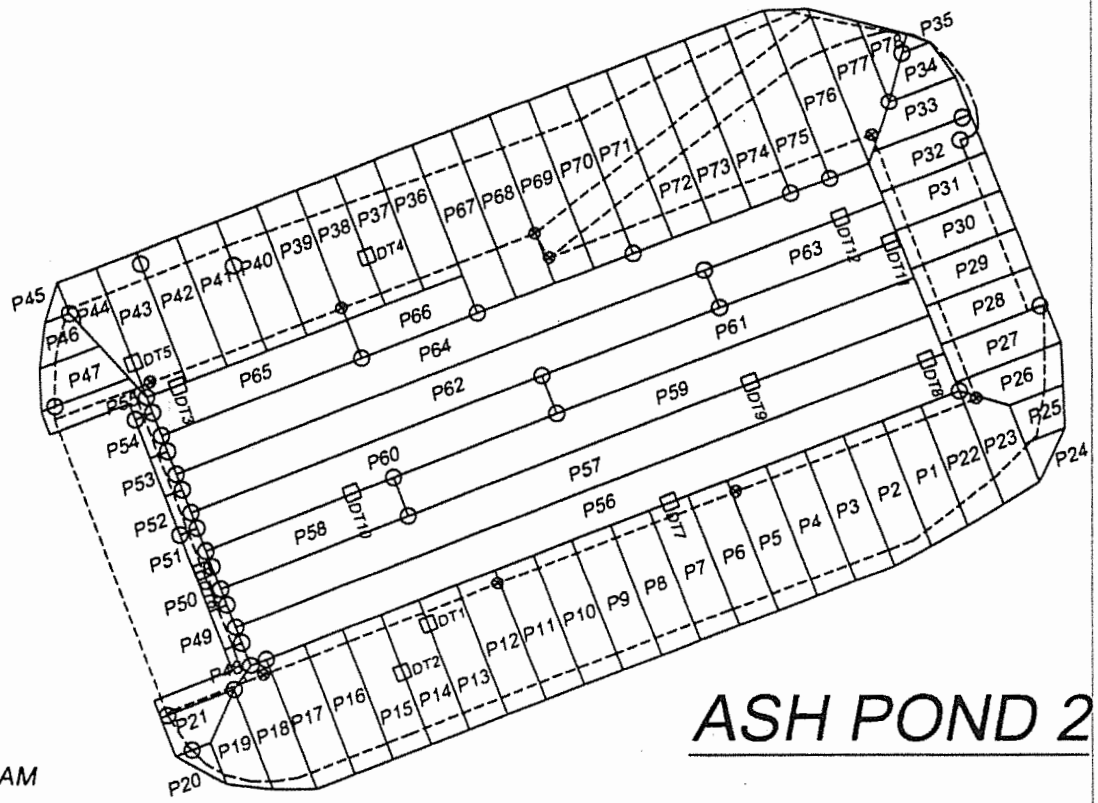
0 50 100

DRAWN BY M.A.		PROJECT NAME: MIDWEST GENERATION - JOLIET STATION #29 ASH IMPOUNDMENT CONSTRUCTION	
SCALE 1"=100'		DRAWING NAME: AS BUILT HDPE PANEL LAYOUT FOR ASH POND 1	
JOB #		LOCATION: JOLIET, IL	DRAWING NUMBER: ABPOND1
DATE 10-24-08			FILENAME: MIDWEST GENERATION

caawsystems.com
Clean Air And Water Systems, LLC
"You create it, we'll contain it"
123 ELM STREET
PO BOX 337
DOUSMAN, WI 53118
262-965-4366
FAX: 262-965-4369

Submittal # 26

NORTH



ASH POND 2

LEGEND

○	PATCH
□DT#	DESTRUCTIVE TEST
P#	PANEL NUMBER
⊗	PIPE BOOT
———	PANEL EDGE / FIELD SEAM

SCALE

0 50 100

DRAWN BY M.A.	PROJECT NAME: MIDWEST GENERATION - JOLIET STATION #29 ASH IMPOUNDMENT CONSTRUCTION	
SCALE 1"=100'	DRAWING NAME: AS BUILT HDPE PANEL LAYOUT FOR ASH POND 2	
JOB #	LOCATION: JOLIET, IL	DRAWING NUMBER: ABPOND2
DATE 6-6-08		FILENAME: MIDWEST GENERATION

caawsystems.com
Clean Air And Water Systems, LLC
"You create it, we'll contain it"
123 ELM STREET
PO BOX 337
DOUSMAN, WI 53118
· 262-965-4366
FAX: 262-965-4369

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ATTACHMENT A9

LEAK LOCATION SURVEY REPORT (IMPOUNDMENT #1 AND #2)

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LEAK LOCATION SERVICES, INC.

16124 UNIVERSITY OAK • SAN ANTONIO, TEXAS 78249 • (210) 408-1241 / FAX (210) 408-1242

October 23, 2008

Mr. Tedd Mills
Brieser Construction Company
24101 S. Municipal Drive
Channahon, IL 60410

Fax: (815) 521-0999

Subject: Report for "Geomembrane Leak Location Survey of a pond Located at the Midwest Generation Joliet Station"
LLSI Project 1165

Dear Mr. Mills:

On October 20 and 21, 2008, Martin Morales of Leak Location Services, Inc. (LLSI) conducted a leak location survey of the subject pond. The pond has an area of approximately 2 acres and has a geotextile under a single 60-mil HDPE geomembrane. The geomembrane is covered with a non-woven geotextile, a 12-inch sand layer and a 5-inch warming layer. This report documents the report of the survey.

I. SURVEY

A Results

No leaks were found in the primary geomembrane liner of the pond. The leak location equipment was tested for sensitivity and proper operation. A 0.25-inch diameter artificial leak was buried in the soil and leak location survey lines were run along both sides of the artificial leak.

Leak location survey measurements were collected to determine the maximum distance that the simulated leak could be reliably detected. This detection distance was approximately 7.5 feet. Figure 1 shows the artificial leak data for the instrument that was used.

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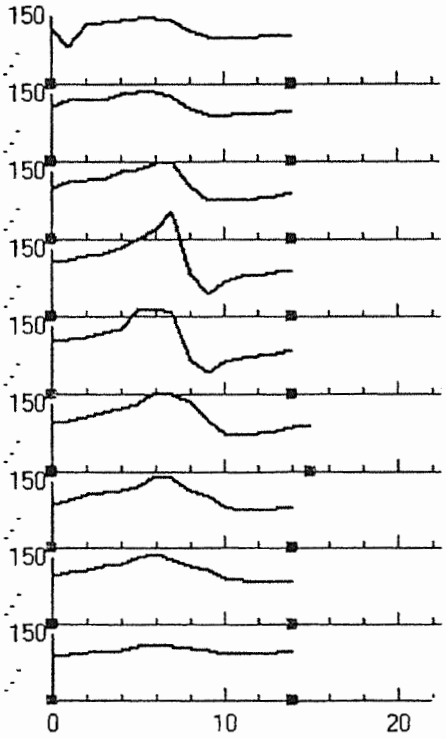


FIGURE 1. ARTIFICIAL LEAK DATA PLOT

II. TECHNIQUE

A. Principles of the Electrical Leak Location Method

The principle of the electrical survey method for geomembrane liners is to impress a high DC voltage across the liner and measure the resulting potential gradients on or in the conducting material on the liner. If any holes are present, characteristic anomalies in the potential measurements caused by electrical current flowing through the holes indicate their location.

B. Soil Covered Survey

A high voltage isolated DC power supply was used to impress a voltage across the liner using one electrode placed in the operations layer located on top of the primary liner and a second electrode placed in the electrically conducting material located beneath the liner. Therefore, the geomembrane liner provides an electrical barrier between the electrodes except where there are holes in the geomembrane liner. Electrical current flowing through the holes in the geomembrane liner produces localized anomalous areas of high current density near the holes. This electrical current path is provided by electrically conducting material such as water, sand, or soil.

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The survey of the pond was conducted by making potential gradient measurements on the moist warming layer with measurement electrodes spaced approximately 3 feet apart. These measurements were made approximately every 3 feet along numbered survey lines that were spaced approximately 5 feet apart. A portable digital data logger was used to collect the data. The data was then down-loaded into a portable computer for display, plotting, and analysis.

If there are any questions regarding the electrical surveys or this report, please contact us at (210) 408-1241. We appreciate the opportunity to have been of service to Brieser Construction Company.

Very truly yours,

John Ortiz
Project Manager

Approved by:

Daren L. Laine
President

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LEAK LOCATION SERVICES, INC.

16124 UNIVERSITY OAK • SAN ANTONIO, TEXAS 78249 • (210) 408-1241 / FAX (210) 408-1242

June 2, 2008

RECEIVED
JUN 10 2008
By

Ted Mills
Brieser Construction Company
24101 S. Municipal Drive
Channahon, IL 60410

Fax: 815-521-0999

Subject: Report for "Electronic Leak Location Survey for Ash Impoundment 2 at the Midwest Generation Joliet Station"
LLSI Project 1007

Dear Mr. Wells:

On May 22 and 23, 2008, Martin Morales of Leak Location Services, Inc. (LLSI) conducted the subject geomembrane leak location survey. The impoundment has an area of 3 acres and has a geotextile under a single 60-mil HDPE geomembrane. The geomembrane was covered with a non-woven geotextile, 12-inch sand layer and 5-inch warning layer. The geomembrane leak location survey was conducted after the warning layer was installed. This report documents the results of the leak location survey.

I. RESULTS

One leak was found. Figure 1 shows the approximate location of the leak. The leak was excavated and found to be an 8-inch by 4-inch tear. The leak was about 21 feet from the northwest edge of the floor and 245 feet from the northeast edge of the floor.

A 0.23-inch artificial leak was used to document the leak detection sensitivity. The artificial leak was a 0.23-inch electrode connected to an insulated wire. The other end of the wire was grounded. Leak location scans were made to determine the maximum distance that the artificial leak could be reliably detected. That distance was 10 feet.

II. TECHNIQUE

The electrical leak location method detects electrical paths through the liner caused by water or moisture in the leaks. A voltage is connected to one electrode in the material covering the liner and to an electrode connected to earth ground. Electrical current flowing through the leaks in the liner produces localized anomalous areas of high current density near the leaks. These areas are located by making electrical potential measurement scans on the material on the geomembrane liner.

Surveys with material covering the liner are conducted by making point-by-point potential measurements using special electrodes and a portable digital data acquisition system. The potential readings are made along survey lines with a fixed measurement electrode separation. The data is downloaded to a computer for storage and plotting. When a suspect area is located, manual measurements are made to further isolate the leak.

A systematic survey was conducted on the warning layer. Data was taken every 3 feet using a measurement electrode separation of 3 feet along survey lines spaced 5 feet apart. The data was

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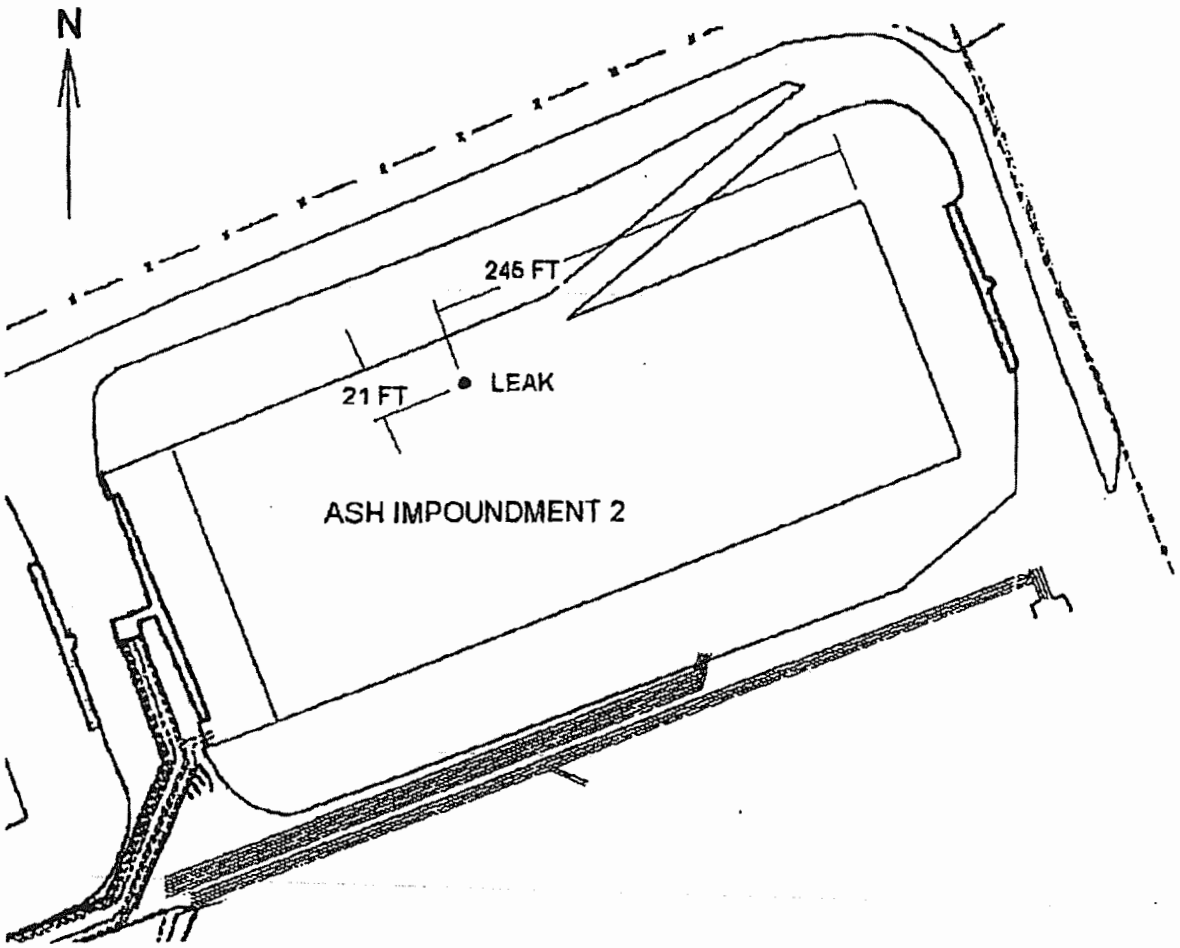


FIGURE 1. APPROXIMATE LOCATION OF THE LEAK

periodically downloaded to a computer for storage, plotting, and analysis for leak signals. Manual measurements were made to isolate the leak locations for excavation while the survey crew was on site. The leak was excavated and isolated from the materials on the geomembrane. Additional measurements were made to determine that there were no additional leaks in the area of the leak.

If there are any questions regarding the leak location survey or this report, please contact us at (210) 408-1241. We appreciate this opportunity to have been of service to Brieser Construction on this important service requirement.

Very truly yours,

Glenn T. Darilek

Glenn T. Darilek
Principal Engineer

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ATTACHMENT B

FIELD DIRECTIVES

Electronic Filing: Received, Clerk's Office 2/04/2022

NATURAL RESOURCE TECHNOLOGY

FIELD DIRECTIVE: NO. 1

DATE: April 25, 2008

TO: Brian Delcorio, Midwest Generation, LLC

FROM: Eric J. Tlachac, Natural Resource Technology, Inc.

SUBJECT: **Modifications to Section B, Sheet C031 (Access Ramp)**
Ash Impoundment #2 Liner Replacement, Joliet 29 Station

Due to existing site conditions with regard to the presence and depth of the Poz-o-Pac liner on the access ramp of Ash Impoundment #2, modifications are required to the layers of materials that will be placed above the geomembrane, as depicted in Section B on Sheet C031. A revised version of Sheet C031 (Rev. 2) is included as part of this field directive.

The contractor shall clean off the Poz-o-Pac surface to the extent practical to remove rocks that may pose a hazard to the geomembrane before placing the 16-ounce (oz) geotextile over the subgrade surface. The contractor shall also place 2 layers of the 12-oz geotextile over the geomembrane liner on the ramp, rather than the single layer originally specified. If sand bags are not adequate to hold the top layer of geotextile in place until it is covered, the contractor may heat bond the upper layer to the lower layer of geotextile with adequate precautions to avoid adversely affecting the underlying geomembrane.

Regarding the cover material on the ramp, the existing ramp material is not sufficient to be re-used, and there is question whether there is sufficient quantity, so the contractor shall place 6 inches of limestone screenings (approved replacement material for the specified sand) over the geosynthetics and 6 inches of the warning layer material (IDOT CA-6) over the limestone screenings. These layers will likely need to be blended into a smooth grade transition at the top of the ramp. If the ramp material needs to be thinned to 6 inches or less, the cover should be completely comprised of limestone screenings.

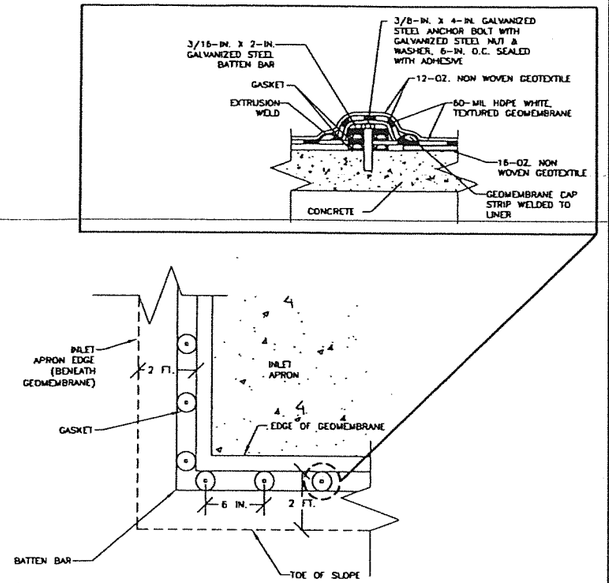
Minor modifications have also been made to Section C on Sheet C031 (Inlet Apron Section) to reflect discussion at the Job Start Meeting on March 28, 2008 regarding concerns about the "flap" of geomembrane that extends beyond the batten strip on the concrete inlet apron. As you may recall, there was concern that this "flap" will accumulate ash and other sediment if too long, and possibly cause uplift of the batten strip. Section C has been modified to remove the specified dimension for this flap so that it may be completed at the installer's discretion in the field.

As always, contractor comments are welcome and should be discussed / approved with the field construction quality assurance (CQA) engineer on site prior to modifying the approach described above. Should the field CQA engineer not be on site when concerns arise, please contact me at 262-522-1214.

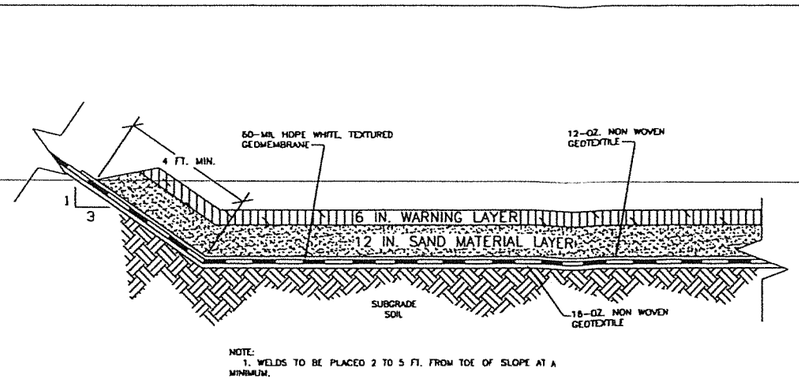
Enclosure: Sheet C031, Details and Sections, Rev. 2

23713 W. Paul Rd., Ste. D • Pewaukee, WI 53072 • Phone: 262.523.9000 • Fax: 262.523.9001 • www.naturalrt.com

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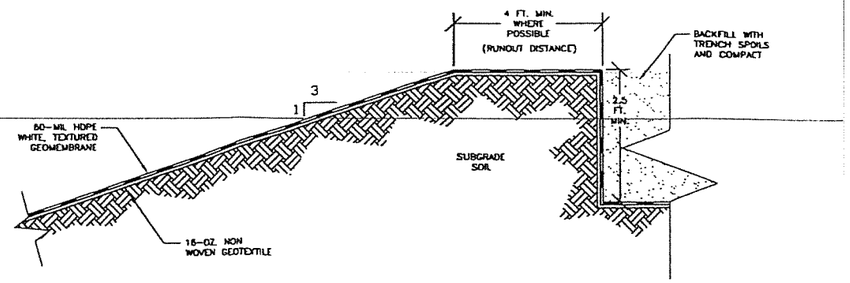


2 / C030 INLET APRON DETAIL PLAN
NOT TO SCALE

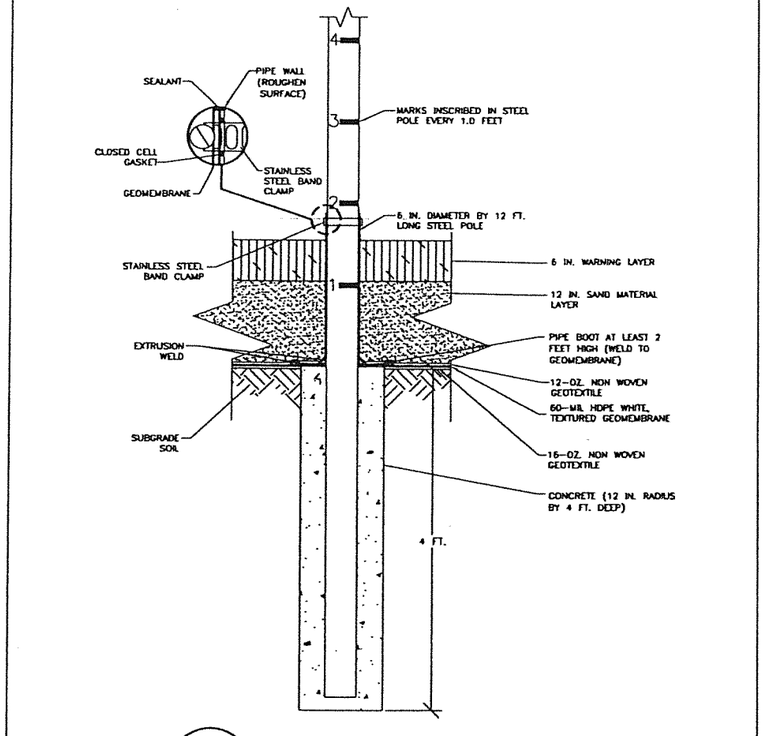


NOTE:
1. WELDS TO BE PLACED 2 TO 5 FT. FROM TOE OF SLOPE AT A MINIMUM.

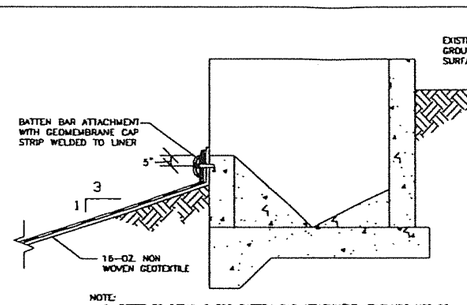
A / C030 SLOPE TRANSITION SECTION
NOT TO SCALE



D / C030 ANCHOR TRENCH SECTION
NOT TO SCALE

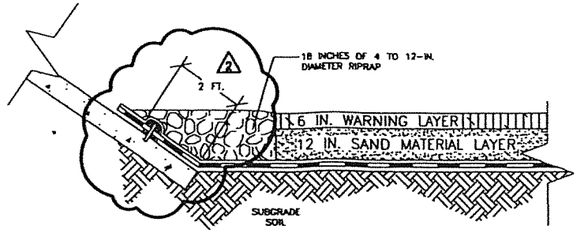


1 / C020 MARKER POST DETAIL
NOT TO SCALE

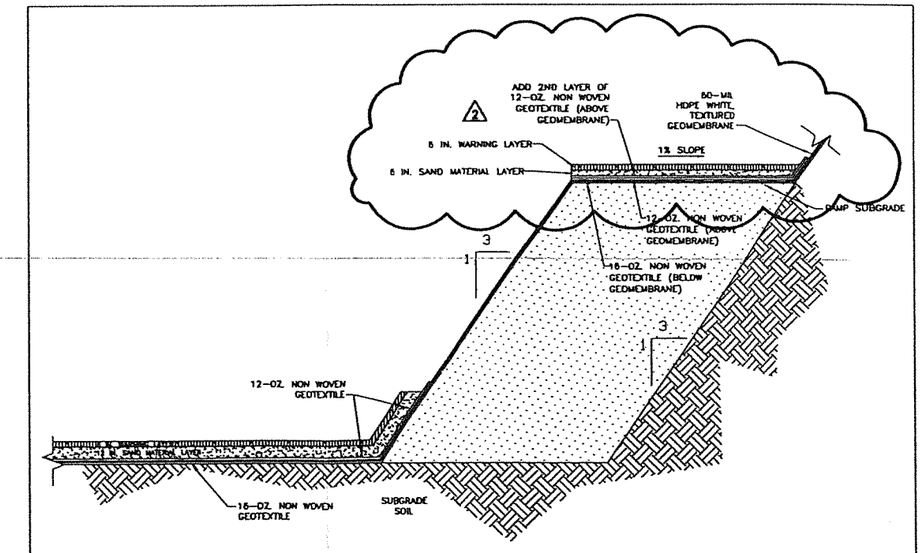


NOTE:
1. REFER TO DETAIL 2 FOR BATTEN BAR ATTACHMENT. EXCLUDE USE OF THE TOP LAYER OF 12-OZ. NON WOVEN GEOTEXTILE.

3 / C030 OUTLET WEIR DETAIL
NOT TO SCALE



C / -- INLET APRON SECTION
NOT TO SCALE



B / C030 RAMP SECTION
NOT TO SCALE

NOT FOR CONSTRUCTION

6.			
5.			
4.			
3.			
2.	ISSUED FOR FIELD DIRECTIVE #1	04/25/08	EJT
1.	ISSUED FOR BID	09/05/07	EJT
0.	ISSUED FOR PERMIT	06/04/07	RHW
REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/3.0	DETAILS AND SECTIONS
DRAWN BY: BJK/RLH 07/12/07	ASH IMPOUNDMENT #2 LINER REPLACEMENT MIDWEST GENERATION JOLIET STATION NO. 29 JOLIET, ILLINOIS
CHECKED BY: HMS 08/02/07	
APPROVED BY: EJT 09/05/07	DRAWING NO: D1862C031-02
	REFERENCE: 1862/3/BID-CON/
	SHEET NO C031

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NATURAL RESOURCE TECHNOLOGY

FIELD DIRECTIVE: NO. 2

DATE: September 10, 2008

TO: Brian Delcorio, Midwest Generation, LLC

FROM: Heather M. Simon, Natural Resource Technology, Inc.

SUBJECT: **Modifications to Geomembrane Anchor Trench**
Ash Impoundment # 1 Liner Replacement, Joliet 29 Station

Due to existing site conditions with regards to limited access and the presence of large stones along the south bank top of slope of Ash Impoundment #1, modifications are required to the anchor trench depicted in Section D, Sheet C031.

The contractor shall construct the anchor trench at the top of slope along the south bank, despite the fact that there will be less than 4 feet of horizontal runout distance for the geosynthetics. The contractor shall remove the large stones at the top of the slope to approximately 2 feet below the current ground surface in this area. The contractor shall construct berms at the top of slope using limestone screenings to create a minimum 2-foot deep anchor trench along the south bank. The limestone screenings shall be compacted in 12-inch lifts. Limestone screenings shall be compacted to a hard durable surface that exhibits no further noticeable consolidation under the action of compaction equipment and no evidence of pumping or ponding of water. Engineer will inspect compaction every 25 feet along the length of the anchor trench. The contractor shall place the geosynthetics in the constructed trench, as depicted on in Section D, Sheet C031. Limestone screenings shall be placed and compacted in the anchor trench following placement of the geosynthetics.

Areas where large stones are removed from the anchor trench along the east, west or north banks shall be backfilled with limestone screenings and compacted. Compaction requirements, as stated above. Contractor shall remove stones that protrude from the sides of the trench and may pose a hazard to the geomembrane. The large stones removed from the trench shall be disposed at MWG's direction.

As always, contractor comments are welcome and should be discussed / approved with the field engineer on site prior to modifying the approach described above. Should the field engineer not be on site when concerns arise, please contact me at 262-522-1207.

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ATTACHMENT C

ASH IMPOUNDMENT #1 AND #2
DOCUMENTATION SURVEY

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ASBUILT OF
MIDWEST GENERATION JOLIET 29 POWER PLANT
WEST-ASH IMPOUNDMENTS

GRAPHIC SCALE
(IN FEET)
1 inch = 40 ft.


6
U.S. ROUTE
EAST ENTRANCE
MAIN ENTRANCE
AS-BUILT AREA
SITE BENCHMARK 1
SITE BENCHMARK 2
found "PK" masonry nail
CUT CROSS @ ELEV.= 535.02 (NGVD 29)
CUT CROSS @ ELEV.= 536.30 (NGVD 29)
CUT CROSS @ ELEV.= 536.68 (NGVD 29)
concrete wall
above ground pipelines
edge of liner
edge of liner over concrete
edge of liner over geotextile
edge of liner over soil
edge of liner over riprap
edge of liner over gravel
edge of liner over asphalt
ridge of liner over concrete
ridge of liner over geotextile
ridge of liner over soil
ridge of liner over riprap
ridge of liner over gravel
ridge of liner over asphalt
concrete post (typ.)
metal post (typ.)
wood post (typ.)
metal rail (typ.)
concrete rail (typ.)
wood rail (typ.)
concrete pad (typ.)
asphalt
concrete
gravel
riprap
soil
geotextile
Electrical Manhole
Electrical Manhole
Electrical Manhole

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ATTACHMENT D

NRT CQA DAILY FIELD REPORTS

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.1
Project Names: Impoundment #2 liner replacement

Date:	April 28, 2008
Work Scope:	Subgrade Inspection and roll QC – Impoundment #2
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction and Clean Air and Water
Weather:	Rain and windy, low 40's (°F)
Equipment:	Digital camera
Field Comments:	• I arrive on site around 0800, checked in at gate house. • Gate house called Brian Delcorio to let him know I was here. • I went up to Brian's office and received the site specific training. • After meeting with Brian, I went over to pond #2 and walked the base and side slopes to inspect the subgrade (see photo). • The subgrade looked good, except one spot on the slope had a foot wide hole. I notified Brian and Brieser, Brieser said that they would fill it in. • Talked with Thong Ingels (Clean Air) and he said that the subgrade was fine just needed to get it dry. • Before leaving, I recorded the roll numbers for the geotextile and geomembrane (see photo). • Offsite around 1030, arrived at office 1330
Scope Changes: (Problems, Additional Hours, etc…)	• None
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	• Wet from Rain
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: _____ Date: 4-28-8
Ricky J. Guenther Jr.



Subgrade looking southwest



Rolls of HDPE liner

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FIELD NOTE SUMMARY

Project Number / Task: 1862/5.1
Project Names: Impoundment #2 liner replacement

Date:	April 30, 2008
Work Scope:	Discuss liner batten location on concrete inlet with Clean Air and Water and Brian Delcorio – Impoundment #2
NRT Staff:	Glenn Luke
Contractors:	Brieser Construction and Clean Air and Water
Weather:	Sunny, low 50's (°F)
Equipment:	Digital Camera
Field Comments:	• Arrived onsite at approximately 9:30 a.m. Had safety training and inspection at the Gate House. • Met with Brian for additional safety training in the Administrative building. • Met with Thong Ingels (Clean Air), Mike Schmidt (Brieser), and Brian regarding the batten on Pond #2 concrete inlet. • It was decided that the batten would be installed on the top of the concrete inlet on the flat section directly outside of the weir (see photos). Brieser, Clean Air, and Midwest Generation were all comfortable with this alignment for the batten. The liner will be carried to the top of the concrete for battening. The liner (and 16 oz. fabric) will be carried continuously over the curb on the edges of the concrete. The contractor (Brieser) indicated that they would put an extra strip of 16 oz. over the curb for added protection. • Brieser also expressed concern about placing the rip rap directly on the liner (and fabric). They asked if they could place a 4-6 inch layer of screenings prior to the rip rap, I discussed with Eric Tlachac and we agreed that this would be fine. • Obtained Mike Schmidt's (Brieser on-site supervisor) contact info so that he could contact Eric Tlachac directly to discuss overall liner installation procedures, etc. Mike Schmidt Phone: 815-693-3337. • Took photos of pond #1 as it was receiving water/bottom ash. • Contractor was installing 16 oz. fabric and 60 mil liner on the slopes. • Offsite approximately 13:00.
Scope Changes: (Problems, Additional Hours, etc…)	• Liner to be installed to the top of slope below the weir on the concrete inlet. Batten installed directly outside of the weir and to the top edge of concrete on the end wings. The liner will be carried over the curbs on the edge of the concrete. The contractor indicated that they would place and extra section of 16 oz. fabric over the curb for added protection. The contractor will place a 4-6 inch layer of screening beneath the rip rap.
Site Conditions: (Needed repairs, system condition, etc…)	• Subgrade at pond bottom improving.

Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: _____ Date: April 30, 2008

Glenn R. Luke.

Signature: _____ Date: _____



Inlet weir



Installation of liner at SE corner of Impoundment #2

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2

Project Names: Midwest Generation (MWG) Joliet 29 Ash Impoundment #2 Liner Replacement

Date:	May 6, 2008 (Tuesday)
Work Scope:	Site visit to observe / document geomembrane (GM) installation
NRT Staff:	Eric Tlachac
Contractors:	Brieser Construction (General Contractor) and Clean Air & Water Systems, LLC (CAAWS, subcontracted GM installer)
Weather:	Sunny, light winds, temps in the 70s (°F)
Equipment:	Digital Camera
Field Comments:	10:30 - Arrived at site at (following 3 hrs travel)

- CAAWS performing detail work (marker post boots, seam intersections, destructive sample patches), production seaming appears to be complete and tested
- Brieser loading out anchor trench spoils, backfilling anchor trench on north side of pond with limestone screenings utilizing Bobcat T300 skidsteer loader equipped with rubber tracks, and compacting with Bomag BMP-851 walk-behind sheepsfoot compactor
- Mike Schmidt (Brieser foreman) advised that he tentatively planned (weather dependent – rain forecasted for tonight / tomorrow) to begin placing limestone screenings on ramp tomorrow and will hold in place with sandbags from GM installation
- Other contractor equipment on site:
  - Brieser
    - CAT 420E-IT rubber-tired backhoe (for excavating anchor trench)
    - Airman PDS-185S air compressor (for drilling marker post holes)
  - CAAWS
    - Geomembrane seaming devices (wedge and extrusion welders), rubber-tired All Terrain Vehicle (for GM deployment), 5-kW portable generators
    - CAT TL943 forklift (for GM deployment)

12:45 - Met with Brian Delcorio (MWG PM) at his office to discuss project status and went out to pond to meet with Thong Ingels (CAAWS foreman), but Thong was off site to pick up additional sealant for boots and batten bar connections

	15:00 - Discussed GM connection to concrete inlet structure with Brian Delcorio, Mike Schmidt, and Thong Ingels o Design was modified last week to move GM connection from bottom of concrete inlet apron to top due to concerns expressed by CAAWS regarding quality of GM connection on rough concrete surface below water line. This change was mutually agreed to by CAAWS, Brieser, NRT, and MWG. MWG reported incurring a change order for this valued at approximately $10,000 for 1 additional roll of GM to cover the inlet apron. o MWG and NRT now concerned about ability of exposed GM to withstand inlet flows on apron before bottom ash accumulates. Both observed flows at Pond 1 (currently in service). NRT photographed same. o NRT continued discussions with Brieser and CAAWS regarding GM connection at inlet 17:45 – Leave site
Scope Changes: (Problems, Additional Hours, etc…)	None yet, but MWG has concerns over stability of GM against inlet flows, another design modification may be forthcoming
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	GM installed appears in good condition, CAAWS unable to produce quality control records (claimed they were left at hotel)
Soil/Water Stored On-site: (Prior & newly generated) (containers – conditions, labeling, location)	None – Brieser loading out anchor trench spoils and transporting to MWG disposal site (Lincoln Quarry)
Summary of Forms Attached:	Photos

Signature: Eric J. Tlachac Date: May 6, 2008

Eric J. Tlachac



Completed GM looking west



Completed marker posts (foreground) and anchor trench backfill (background)



GM inlet connection

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2

Project Names: Midwest Generation (MWG) Joliet 29 Ash Impoundment #2 Liner Replacement

Date:	May 8, 2008 (Thursday)
Work Scope:	Site visit to observe / document geomembrane (GM) installation and cushion layer placement
NRT Staff:	Eric Tlachac
Contractors:	Brieser Construction (General Contractor) and Clean Air & Water Systems, LLC (CAAWS, subcontracted GM installer)
Weather:	Cloudy, temps in the 50s (°F), NE winds 15-25 mph
Equipment:	Digital Camera
Field Comments:	7:45 - Arrived at site at (following 2.5 hrs travel) o Brieser pumping water from bottom of pond to facilitate placement of geotextile (GT). No work performed yesterday due to rain event. Also placing / compacting limestone screenings and dense-graded aggregate on ramp over double-layer of GT utilizing Bobcat T300 skidsteer loader equipped with rubber tracks and Case SV210 smooth-drum compactor o CAAWS continuing detail work (marker post boots, GM connection to outlet structure, re-working GM connection to inlet structure) and installing GT portion of cushion layer ▪ MWG decided yesterday to move GM connection from top of concrete inlet apron to back to bottom (as originally designed) due to concerns regarding ability of exposed GM to withstand inlet flows on apron before bottom ash accumulates. MWG reported incurring a change order for this to cover additional labor associated with re-working the batten bar. ▪ Observed gaps in batten bar on outlet structure, informed Thong Ingels (CAAWS foreman) and batten bars were re-positioned to minimize gaps 12:45 - Met with Brian Delcorio (MWG PM) at his office to discuss project status. Brian indicated that Brieser may seek a change order for additional limestone screenings due to the fact that the bottom of the pond is uneven (thus requiring additional material to construct a flat warning layer surface and meet minimum thickness requirements). In order to quantify the amount of limestone screenings included in Brieser's lump sum bid, Brian and I measured the dimensions of Pond 2 utilizing a measuring wheel provided by CAAWS, and I calculated the tonnage in a 1-ft layer of limestone screenings assuming a conversion of 1.8 tons / cubic yard (see attached calc). The result was approximately 5,000 tons. Brian then utilized this value in negotiations with Brieser, which resulted in the instruction to place the limestone screenings to the specified thickness regardless of the final pond elevation.

	Brieser expressed concern over the difficulty of executing this instruction given the variability in the bottom surface of the pond, and believed that, even with diligent grade control, they would still wind up placing more limestone screenings than allowed for in their bid. 14:30 – Mutually decided with CAAWS to attach the GM to the south side of the inlet apron approximately 10-12 ft north of (in from) the edge to avoid the large "pit" located at the south edge of the apron beneath an 18-inch pipe that discharges vertically onto the apron. This will require relocation of the pipe so that it does not discharge onto the GM. Advised Brian Delcorio accordingly, and he concurred with the modifications to the GM attachment and discharge pipe. Brian will arrange internally to have the discharge pipe relocated. 16:00 – observe / photograph completion of GM connection on inlet apron, placement of GT portion of cushion layer, and placement of limestone screenings at bottom of ramp. Discuss placement of limestone screenings with Mike Addenall (Brieser superintendant?). Traffic cones will be utilized to mark 12-inch thickness to aide the operator spreading the screenings with the skidsteer. I requested that trucks transporting screenings back down the ramp to dump to minimize turning on the GM. Mike Addenall and Mike Schmidt agreed. 18:45 – Leave site.
Scope Changes: (Problems, Additional Hours, etc…)	GM connection on concrete inlet apron was moved from top of apron back to the bottom of the apron (as originally designed) due to MWG concerns regarding ability of exposed GM to withstand inlet flows on apron before bottom ash accumulates.
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	Bolts from former batten bar attachment at top of concrete inlet apron need to be cut flush with the apron. Informed Brian Delcorio (MWG) via phone on 5/9.
Soil/Water Stored On-site: (Prior & newly generated) (containers – conditions, labeling, location)	None
Summary of Forms Attached:	Photos

Signature: Eric J. Tlachac Date: May 8, 2008

Eric J. Tlachac



GM attachment to outlet structure



Placement of limestone screenings on ramp



GM attachment to inlet structure

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.1
Project Names: Impoundment #2 liner replacement

Date:	May 22, 2008, May 23, 2008
Work Scope:	Leak detection survey and leak repair oversight – Impoundment #2
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction and Clean Air and Water
Weather:	Sunny, low 60's (°F) and Sunny, low 50's (°F)
Equipment:	Digital camera
Field Comments:	5/22 Leak Detection Survey • I arrive on site around 0800, checked in at gate house. • Talked with Brian (MWG), Mike (Brieser), and leak location surveyor at the pond. • Setup transects every 10 feet across the length of the pond. • The machine was calibrated to a ¼ inch hole. • The leak location surveyor walked transects at each line and at the half way point. Every hundred or fifty feet he downloaded the data to the laptop and checked for leaks. • One hole was found around 245 feet from the discharge weir. • Brieser and I dug out the leak after it was more precisely marked by the surveyor. It appeared that the liner was punctured by the construction equipment when placing the cushion layer/limestone screenings. • There was one other hole in the southeast corner of the pond where an operator hit the side slope with the construction equipment. • Offsite around 1530 5/23 Leak Repairs • I arrived on site around 0900, checked in at gate house. • Took a couple more photos of the two holes prior to Clean Air and Water arriving. • Clean Air and Water placed a patch on each location. • Offsite 1030
Scope Changes: (Problems, Additional Hours, etc…)	• None
Site Conditions: (Needed repairs, system condition, etc…)	• Good
Soil/Water Stored On-site:	• None
Summary of	• None

Summary of Forms Attached:

- None

Signature: Ricky J. Guenther Jr. Date: 5.23.8



Marker post



Warning layer looking west at inlet



Leak location surveyor and equipment

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Impoundment #1 liner replacement

Date:	September 12, 2008
Work Scope:	Subgrade Inspection – Impoundment #1
NRT Staff:	Rick Guenther
Contractors:	Brieser -Bill
Weather:	Rain and windy, low 70's (°F)
Equipment:	Digital camera
Field Comments:	• I arrive on site around 0930, checked in at gate house. • Gate house called Elsie to let her know I was here. • I went over to pond #1 and walked the base and side slopes to inspect the subgrade. • The subgrade was not complete at this time. • I talked with Bill (Brieser) and he said that he had stopped work until they could talk to us about the subgrade. He notified me that the material was wet under the top couple inches and equipment was sinking in when moving material around. He wanted to see if we had any suggestions or comments about the bottom being soft. Brieser doesn't want to be responsible if the liner gets ripped if the equipment hits a soft spot when placing the limestone screenings. • Offsite around 1100
Scope Changes: (Problems, Additional Hours, etc...)	• Brieser wanted to discuss wet material on subgrade not to do the subgrade inspection for approval.
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc...)	• Wet from Rain
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: _____ Date: 9.12.8

Ricky J. Guenther Jr.



Subgrade looking southwest



North side slope looking east

Electronic Filing: Received, Clerk's Office 2/04/2022

.FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Impoundment #1 liner replacement

Date:	September 25, 2008
Work Scope:	Subgrade Inspection – Impoundment #1
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction -Bill
Weather:	Rain and windy, low 70's (°F)
Equipment:	Digital camera
Field Comments:	• I arrive on site around 1100, checked in at gate house. • Walked the base and side slopes of pond #1 to inspect the subgrade. • Brieser was working on the anchor trench on the north side of the pond and working on the berm on the south end of the pond. • I talked with Bill (Brieser) and he said that they would be ready by Monday for the liner crew. • They will finish the anchor trench on the north side today and have the berm compacted and complete by Monday. • Once the berm is complete they will continue compaction of the bottom of the pond. • They will also be walking the site to remove large rocks. • I told him that they needed to fix the slope transition from the side slope to the bottom of the pond so the liner can lay down smooth. • Told him that they are responsible for completing the marker posts. • They will also be fixing some washouts in the NE corner side slopes. • Subgrade is looking good, mostly clean up and finish work left. • Offsite around 1530
Scope Changes: (Problems, Additional Hours, etc…)	• none
Site Conditions: (Needed repairs, system condition, etc…)	• In good condition, working on finishing up.
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: Rick J. Guenther Jr. Date: 9-25-8



Placement of anchor trench berm along top of south bank



North anchor trench



Prepared subgrade looking west

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Joliet 29 Impoundment #1 liner replacement

Date:	October 1 and 2, 2008
Work Scope:	Liner Installation Inspection – Impoundment #1
NRT Staff:	Heather Simon
Contractors:	Brieser Construction -Bill
Weather:	Partly Sunny 60s degree F
Equipment:	Digital camera
Field Comments:	10/1 • I arrive on site around 1100, checked in at gate house. • I went over to pond #1 to observe deployment of the liner on the southeast corner. • Liner installation was completed along the entire length of south bank today. At the end of day, liner was deployed at base of pond along southern edge up to the outlet. • Field seam tests were conducted. • Began installation of pipe boots. • Batten bars deployed along base of inlet apron. • Left site at 1600 10/2 • I arrive on site around 700 • Brieser backfilling south anchor trench with conveyor system. • I talked with Bill (Brieser) about compaction of the anchor trench backfill. • Crew deploying liner at base of pond. Left site at 1030
Scope Changes: (Problems, Additional Hours, etc…)	• None
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	• In good condition, compaction of anchor trench backfill required
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: Heather M Simon Date: 10/3/08
Heather Simon



Install of HDPE liner looking southwest



Thermal fusion welding apparatus

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Midwest Generation (MWG)
Joliet 29 Ash Impoundment #1
Liner Replacement

Date:	October 3, 2008 (Friday)
Work Scope:	Site visit to observe / document geomembrane (GM) installation and cushion layer placement
NRT Staff:	Eric Tlachac
Contractors:	Brieser Construction (General Contractor) and Clean Air & Water Systems, LLC (CAAWS, subcontracted GM installer)
Weather:	Partly cloudy, temps in the 50s (°F), E winds 5-10 mph
Equipment:	Digital Camera
Field Comments:	8:30 - Arrived at site at (following 3 hrs travel) , required to watch safety video by site security o Brieser excavating anchor trench at top of ramp with New Holland E150LC hydraulic excavator; later in day, Brieser assists CAAWS with GM and GT deployment and backfill of anchor trench on north side of pond ▪ Limestone screenings backfill in anchor trench on south side of pond not compacted. Advised Billy (Brieser foreman) that anchor trench backfill needed to be compacted. o CAAWS deploying geotextile (GT) portion of cushion layer and completing GM connections to outlet and inlet structures; later in day CAAWS deploys remaining GM on north side slopes ▪ Lower subgrade GT deployed on ramp following anchor trench excavation ▪ Observed edge of GM exposed at top of slope near inlet structure, advised Thong Ingels (CAAWS foreman) that edge of GM needs to be tucked into anchor trench ▪ AM and PM trial welds meet project specifications ▪ Several production seam air channel tests failed in NW corner of pond – much of the seams in this area extrusion welded. Seaming equipment adjusted accordingly. o Safety inspection conducted by Tim (Brieser safety officer) – CAAWS reprimanded for housekeeping o Discussed status with Brian Delcorio 17:15 – Leave site – GM deployed to NE corner of pond (ramp).
Scope Changes:	None

(Problems, Additional Hours, etc…)	
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	None
Soil/Water Stored On-site: (Prior & newly generated) (containers – conditions, labeling, location)	None
Summary of Forms Attached:	Photos

Signature: _____ Date: October 3, 2008

Eric J. Tlachac



Liner construction status upon arrival



Production seaming



GM deployment



Anchor trench backfill

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FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Impoundment #1 liner replacement

Date:	October 6, 2008
Work Scope:	Limestone screenings placement – Impoundment #1
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction-Bill
Weather:	Partly Cloudy, high 60's (°F)
Equipment:	Digital camera
Field Comments:	• I arrive on site around 1130, checked in at gate house. • I went over to pond #1 and verified that liner was complete and geotextile was installed. • Brieser was placing screens on the ramp using the rubber tracked skidster. • I instructed Bill that the warning layer needed to be placed on the ramp before any trucks drive on the ramp. • We also went over things that needed to be completed 1) place riprap at base of apron 2) cover up liner at inlet and discharge corners 3) place screenings 4 feet up side slope 4) compact north anchor trench 5) paint marker poles • Called Brian DelCorio. (MWG) before leaving to let him know what was left to be completed. • Offsite around 1400.
Scope Changes:	• none
Site Conditions: (Needed Well repairs,	• In good condition.
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

Signature: Ricky J. Guenther Jr. Date: 10.6.8



Placement of limestone screening on ramp



Top of southwest corner along anchor trench

Electronic Filing: Received, Clerk's Office 2/04/2022

FIELD NOTE SUMMARY

Project Number / Task: 1862/5.2
Project Names: Impoundment #1 liner replacement

Date:	October 21, 2008
Work Scope:	Leak detection survey – Impoundment #1
NRT Staff:	Rick Guenther
Contractors:	Brieser Construction-Billy
Weather:	Partly Sunny 60s degree F
Equipment:	none
Field Comments:	• I arrive on site around 0845, checked in at gate house. • I went over to pond #1 to observe the leak detection survey already in progress. • The survey was completed with one possible leak detection. Brieser removed the limestone screenings and visually inspected the linear, a hole was not detected. • The area was buried again and survyed again with and without an artificaial leak. The artificial leak was more visible with the software and it was ruled that there was no leak at this location. One possible cause for the intial leak signal is that the area below the screenings was very dry. • Brieser began final cleanup of the site. • Left site at 1115
Scope Changes: (Problems, Additional Hours, etc…)	• None
Site Conditions: (Needed Well repairs, borehole seals, system condition, etc…)	• Looks good
Soil/Water Stored On-site:	• None
Summary of Forms Attached:	• None

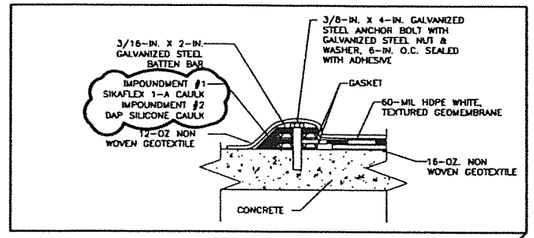
Signature: R. T. Guenther Jr. Date: 10·21·8

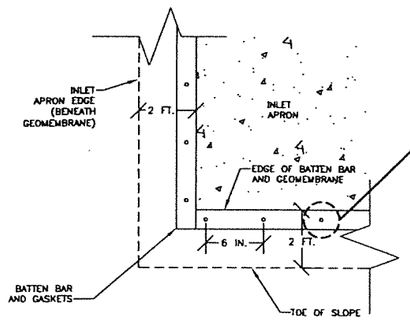
Rick Guenther

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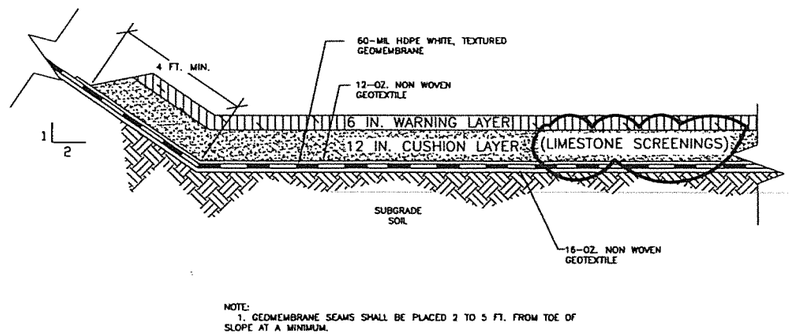
SHEETS

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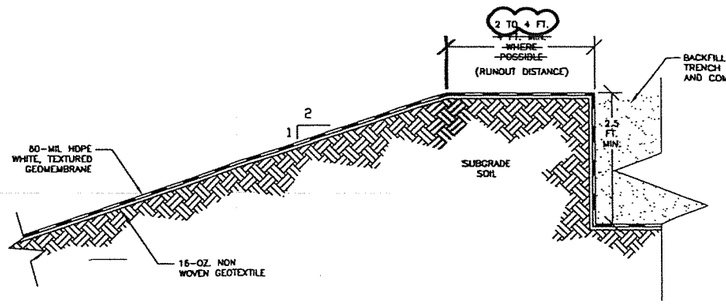


2 / C030 INLET APRON DETAIL PLAN
NOT TO SCALE

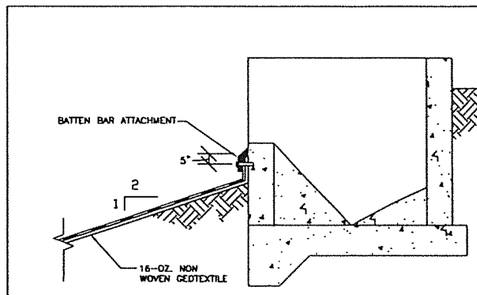


NOTE:
1. GEOMEMBRANE SEAMS SHALL BE PLACED 2 TO 5 FT. FROM TOE OF SLOPE AT A MINIMUM.

A / C030 SLOPE TRANSITION SECTION
NOT TO SCALE

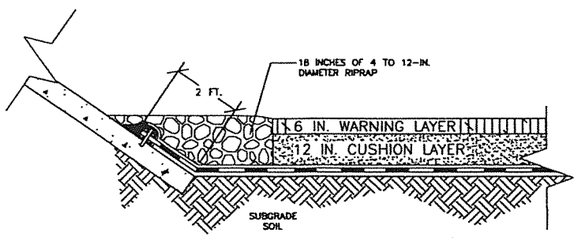


D / C030 ANCHOR TRENCH SECTION
NOT TO SCALE



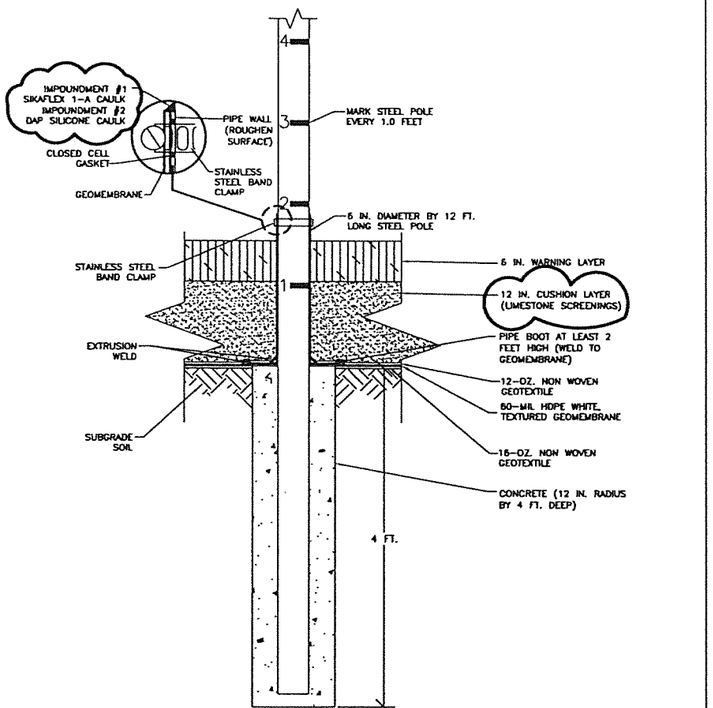
NOTE:
1. REFER TO DETAIL 2 FOR BATTEN BAR ATTACHMENT. EXCLUDE USE OF THE TOP LAYER OF 12-OZ. NON WOVEN GEOTEXTILE.

3 / C030 OUTLET WEIR DETAIL
NOT TO SCALE

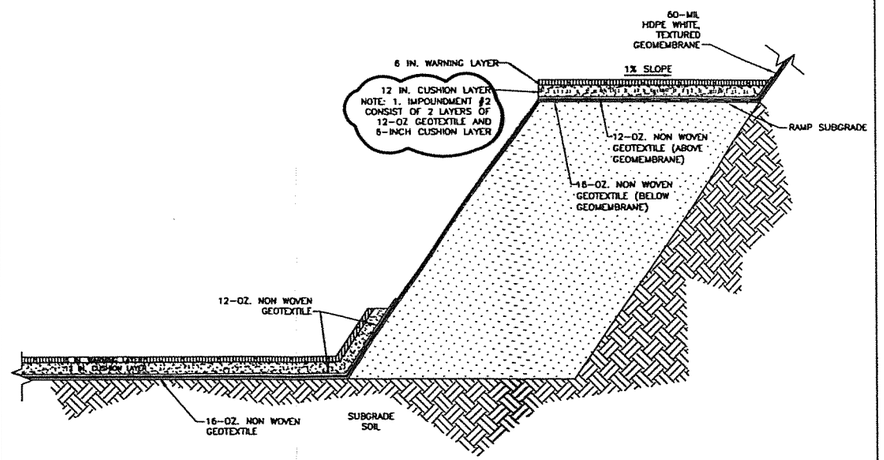


NOTE:
1. REFER TO DETAIL 2 FOR BATTEN BAR ATTACHMENT.

C / -- INLET APRON SECTION
NOT TO SCALE



1 / C020 MARKER POST DETAIL
NOT TO SCALE



B / C030 RAMP SECTION
NOT TO SCALE

6.			
5.			
4.			
3.			
2.			
1.			
0.	RECORD DRAWING	12/19/08	HMS
REVISION:		DATE:	APP'D BY:

NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1862/5.2	DETAILS AND SECTIONS
DRAWN BY: KNW 12/19/08	ASH IMPOUNDMENT #1 AND #2 LINER REPLACEMENT MIDWEST GENERATION, LLC JOLIET STATION NO. 29 JOLIET, ILLINOIS
CHECKED BY: HMS 12/19/08	
APPROVED BY: HMS 12/19/08	DRAWING NO: D1862C031-00 / REFERENCE:1862/RECORD DWGS/
	SHEET NO. C031

Attachment 11

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Exhibit H

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	AS 2021-001
Petition of Midwest Generation	)	
for an Adjusted Standard from 845.740(a)	)	
and Finding of Inapplicability of Part 845	)	(Adjusted Standard)
(Joliet 29 Station)	)	

AFFIDAVIT OF THOMAS HUBBARD

I, Thomas Hubbard, certify under penalty of perjury pursuant to Section 1-109 of the Illinois Code of Civil Procedure, 735 ILCS 5/1-109, that the statements set forth in this affidavit are true and correct, and further state that if called upon to testify in this matter, I would competently testify as follows:

1. I am employed by the Illinois Environmental Protection Agency ("Illinois EPA" or "Agency") as the Manager of the Disposal Alternative Unit within the Permit Section of the Bureau of Land, and I am located in Springfield, Illinois. I have been employed by the Illinois EPA since December 1, 1999.

2. As the Manager of the Disposal Alternative Unit, my duties include assigning permit applications for waste treatment and beneficial use determinations for reusing wastes and reviewing my employees' recommendations for approval or denial of said applications. In addition to other responsibilities, the Disposal Alternative Unit is charged with receiving notifications made to Illinois EPA, pursuant to Section 3.135 of the Illinois Environmental Protection Act, regarding beneficial reuse of coal combustion waste. 415 ILCS 5/3.135.

3. I have personal knowledge of the facts set forth in Illinois EPA's Recommendation to the Board as to the Petition of Midwest Generation, LLC ("MWG") for an Adjusted Standard from Section 845.740(a) and Finding of Inapplicability of Part 845 for the Joliet 29 Station, as stated below.

4. I have reviewed the records of the Permit Section within the Bureau of Land. I have not been able to locate any records that indicate MWG provided the Agency notification of the beneficial use or reuse of CCR material at the Joliet 29 Station.

FURTHER AFFIANT SAYETH NOT

_____
THOMAS HUBBARD

_____
DATE

State of Illinois
County of Sangamon

Subscribed and Sworn to before
me this _____ day of February, 2022.

_____
Notary Public

Exhibit

I

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Technical Paper submitted to *Geosynthetics International*, FINAL JULY 5, 2011

GEOMEMBRANE DAMAGE DUE TO STATIC AND CYCLIC SHEARING OVER COMPACTED GRAVELLY SAND

Patrick J. Fox, Jason D. Ross, Joseph M. Sura, and Richard S. Thiel

ABSTRACT: Several large-scale laboratory tests were conducted on multi-interface geomembrane liner specimens to assess damage effects from static pressure, cyclic loading, and large displacement static shear. The specimens consisted of compacted subgrade soil, a LLDPE or HDPE smooth geomembrane, and overlying potash salt. The subgrade soil was gravelly sand with 25 percent gravel content. Failure occurred at the geomembrane/soil interface for each shear test. Cyclic loading data indicated the LLDPE geomembrane had slightly lower values of interface shear stiffness and damping ratio than the HDPE geomembrane. Shear stiffness was essentially constant and damping ratio decreased with continued cycling for both geomembranes. Geomembrane damage for the static pressure and cyclic loading tests consisted of minor to moderate dimpling with no holes created. Damage was considerably more severe for the large displacement shear tests and consisted of deep scratching and gouging of the geomembranes. Two holes were created in the LLDPE specimen and no holes were created in the HDPE specimen as a result of shear displacement. The findings indicate that severe geomembrane damage can result from shear displacement against a compacted subgrade soil with gravel. Considering that shear displacements commonly occur within landfill liner systems due to such mechanisms as waste settlement, the findings suggest that additional research is needed on expected levels of shear-induced damage for geomembranes placed adjacent to soil layers with coarse particles, including compacted clay liners containing gravel.

KEYWORDS: Geomembrane, Compacted Soil, Interface Shear, Cyclic Loading, Damage

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1 INTRODUCTION

Geomembranes are critical components of hydraulic barrier systems in a large number of applications ranging from landfills to canals to heap leach pads. In order to provide an effective barrier, damage in the form of tears, holes, and bad seams must be minimized and great expense is often incurred to prevent, locate, and repair such damage. This includes stringent quality assurance/quality control procedures from factory to completed installation. As the risk of geomembrane damage is generally considered to be greatest after installation (Nosko and Touze-Foltz 2002, Giroud and Touze-Foltz 2003), protection layers are also often placed on geomembranes to limit damage during the process of covering with soil and from the weight of overlying materials. These protection layers include geotextiles, sand-filled cushions, rubber tire shreds, geonets, geocomposites, and GCLs (Heerten 1993, Darilek et al. 1995, Reddy et al. 1996, Guglielmetti et al. 1997). Considerable research has been conducted to assess potential damage due to sustained pressure after installation (Wilson-Fahmy et al. 1996, Narejo et al. 1996, Koerner et al. 1996, Tognon et al. 2000, Dickinson and Brachman 2008, Brachman and Gudina 2008); however, the potential for geomembrane damage due to interface shear has not received comparable attention.

Assessment of geomembrane integrity under interface shear conditions is important because relative displacements can occur due to common mechanisms such as waste settlement and stress transfer from nearby slopes. Some studies have investigated shear-induced damage effects for geomembranes placed against other geosynthetics (Frost and Lee 2001, Triplett and Fox 2001, Li and Gilbert 2006), and against soils including sands, silty sands, sand-clay mixtures, and pure clays (Ling et al. 2001, DeJong and Westgate 2005, Flemming et al. 2006); however, to the writers' knowledge no studies have been conducted to investigate shear-induced damage for geomembranes against soils containing gravel. Such applications are common. For example, geomembranes are often placed on gravelly subgrades or covered with gravelly overliner soils for heap leach pads, and landfill liner systems often contain drainage layers and compacted clay liners with appreciable gravel content. These applications typically involve high normal stress conditions, which may further increase risk to the integrity of the geomembrane.

The current paper presents a limited experimental study of damage to geomembranes placed on compacted soil containing gravel and subjected to static pressure, cyclic loading, and large displacement static shear. The study was motivated by an evaluation of geomembrane integrity

under expected operational conditions for a potash reclamation facility in New Mexico, USA. In this application, the liner system design consists of a single geomembrane placed on compacted subgrade soil. Brine solution is ponded on the liner and, after complete evaporation, the salts are recovered using construction equipment (i.e., scrapers). Although a scraper will not come closer than approximately 450 vertical mm of the geomembrane, design engineers were concerned about the ability of the geomembrane to withstand static and dynamic loads due to scraper operations during salt removal. To address this concern, several large-scale shear tests were conducted for two common types of geomembranes to assess potential damage. Results are presented for static pressure, cyclic loading, and static shear tests and the findings are discussed with regard to geomembrane performance for each loading condition.

2 MATERIALS

The experimental program was conducted using two geomembrane products manufactured by GSE Environmental (Houston, Texas, USA). The first product was a smooth linear low density polyethylene (LLDPE) geomembrane with a nominal thickness of 1.5 mm (60 mils). The second product was a smooth high density polyethylene (HDPE) geomembrane with a nominal thickness of 1.5 mm (60 mils). Table 1 provides a summary of material properties for both geomembranes.

Subgrade soil samples were obtained on site from two test pits (TP-1, TP-2). Initial moisture contents w are provided in Table 2. Each soil sample was passed through a 19 mm sieve to remove large particles and the subsequent particle size distribution curves are shown in Figure 1. The soils had similar textures consisting of gravelly sand with pieces of white caliche. A Standard Proctor test was conducted on each soil sample and the optimum moisture contents are provided in Table 2. Once the optimum moisture contents were established, each soil was prepared to a moisture content 2 percent dry of optimum and then the soils were mixed in a 1:1 ratio to create the final subgrade soil for the experimental program. The final subgrade had 25 percent gravel content.

Potash salt from the field site was passed through a 12.7 mm sieve and the subsequent particle size distribution curve is shown in Figure 1. The salt consisted almost entirely of sand-sized particles (3 percent gravel) and had an initial moisture content of 0.8 percent (Table 2).

3 EXPERIMENTAL PROGRAM

3.1 Specimen Preparation

Static normal stress, cyclic shear stress, and post-cyclic static shear tests were conducted on multi-interface specimens using the large dynamic direct shear machine described by Fox et al. (2006). The test chamber measures 305 × 1067 mm in plan and provides a shearing surface area of 0.325 m^2. Specimens were sheared between a rigid pullout plate and the floor of the test chamber, each of which is covered with an aggressive gripping surface. The shearing system is powered by a 245 kN hydraulic actuator that can impart bidirectional (i.e., back-and-forth) motion to the pullout plate with a maximum displacement amplitude of 254 mm. The maximum frequency for sinusoidal loading (± 25 mm) is 4 Hz. The actuator can also be used to conduct static shear tests at a constant slow displacement rate.

Each test specimen consisted of subgrade, geomembrane, and potash salt. Subgrade soil was compacted in three lifts to a final thickness of approximately 75 mm. New subgrade soil was used for each test. The first two lifts were heavily compacted using a hand tamper and, to be conservative, the final lift was moderately tamped to provide a rougher surface than would be normally expected in the field. Subgrade soil densities are not available due to the difficulty of measurement. Figure 2 shows a typical view of the subgrade soil after compaction in the test chamber. A specimen of either the LLDPE or HDPE geomembrane was placed on the subgrade with extra length provided on both ends to allow additional geomembrane material to enter the chamber during the shearing process and thus maintain constant shearing surface area. Approximately 50 mm of potash salt was then placed on the geomembrane and lightly tamped. The pullout plate was laid over the salt and a constant normal stress of 958 kPa was applied to the specimen for 24 h. No additional water was provided to the specimen during preparation or testing.

3.2 Geomembrane Integrity Tests

The integrity of geomembrane specimens was assessed at each stage of testing using a bright light integrity test and a water integrity test. For the bright light integrity test, the geomembrane specimen was held against a bright halogen lamp in a dark room and visually inspected for holes. The water integrity test was used to identify any non-visible holes that were missed during the bright light integrity test. For the water integrity test, the geomembrane was subjected to a static

water head of 150 mm for a minimum of 15 min. Paper towels placed underneath the geomembrane were used to detect leaks.

3.3 Test Procedures

The experimental program consisted of four tests. Test 5 (LLDPE) and Test 6 (HDPE) were static pressure tests in which geomembrane specimens were subjected to a constant normal stress of 958 kPa for 24 h. After the stress was released, the specimens were immediately photographed and subjected to bright light and water integrity tests.

Test 3 (LLDPE) and Test 4 (HDPE) were more comprehensive and included static pressure, cyclic loading, and static shearing stages. The static pressure stage was identical to Tests 5 and 6. After the static pressure stage, the normal stress remained constant and each specimen was subjected to 20 cycles of force-controlled sinusoidal loading with a nominal shear stress amplitude of 192 kPa and a frequency of 0.5 Hz. The level of cyclic loading corresponds to a mobilized interface friction angle of 11.3° and was intended to simulate the dynamic shear stress imposed on a geomembrane by salt removal activities. After cyclic loading, the normal stress was released and the geomembrane specimen was carefully removed from the test chamber while marking its precise location on the compacted subgrade soil. The specimen was immediately photographed, subjected to bright light and water integrity tests, and then repositioned on the subgrade to the same location. The normal stress (958 kPa) was reapplied and, after 2 h, a static shearing test was conducted at a rate of 10 mm/min. to a final displacement of 130 mm. At the conclusion of static shear, final moisture contents were taken from the subgrade soil (Table 2) and the geomembrane specimen was again photographed and subjected to bright light and water integrity tests.

4 RESULTS

4.1 Static Pressure Tests

The LLDPE and HDPE geomembranes were relatively undamaged in Tests 5 and 6. Bright light and water integrity tests indicated that no holes were created after the application of static pressure (958 kPa) for 24 h. Both tests produced minor to moderate dimpling of the geomembrane. The dimples resulted from stress concentrations over coarse particles in the subgrade soil. A typical photograph of this effect is shown in Figure 3.

4.2 Cyclic Loading Tests

Tests 3 and 4 produced cyclic loading data for the test specimens. Post-test inspections indicated that shear failure occurred at the geomembrane/subgrade interface in each case. Figures 4 and 5 present the measured cyclic loading data. The nominal shear stress amplitude of 192 kPa was approximately achieved for 20 sinusoidal cycles at 0.5 Hz. The average shear stress amplitude ranged from 185 to 190 kPa for LLDPE and from 188 to 194 kPa for HDPE. Shear displacements were also essentially sinusoidal and had nearly uniform amplitudes. Measured displacements correspond to shear of each multi-interface specimen as a whole and not specifically the geomembrane/subgrade failure surface. The average displacement amplitude was 1.29 mm for LLDPE and 1.05 mm for HDPE. For both geomembranes, displacement amplitude does not show a consistent trend with increasing number of cycles. The shear stress vs. shear displacement plots display similar hysteresis loops and indicate little change with continued cycling.

Cyclic shear parameters were calculated using the method of Nye and Fox (2007) and are shown in Figure 6. Values of shear stiffness were slightly higher for the HDPE geomembrane because shear displacements were slightly lower. Higher interface shear stiffness is also consistent with the higher density and stiffness of HDPE. Shear stiffness for both geomembranes was essentially constant with continued cycling because displacement amplitude was essentially constant, which is also indicated by constant values of stiffness degradation index. Damping ratios for both geomembranes decreased with increasing number of cycles and were consistently higher for HDPE than for LLDPE. Area reduction of the hysteresis loops with continued cycling is responsible for the decreases in damping ratio.

Figure 7 presents photographs of the LLDPE and HDPE specimens after cyclic loading. Visual inspections revealed moderate dimpling on both specimens that was only slightly more severe than for the static pressure tests (Tests 5 and 6). The bright light and water integrity tests indicated no holes for either geomembrane specimen.

4.3 Static Shearing Tests

After cyclic loading, the geomembranes were sheared to large displacement (130 mm). The shear stress-displacement relationships for both specimens are shown in Figure 8. Shear failure

occurred between the geomembrane and the subgrade soil in each case. Peak (τ_p) and large displacement (τ_{130}) shear strengths and corresponding secant interface friction angles are provided in Table 3. The curves show similar response with the LLDPE specimen yielding higher strengths, which is likely due to the greater ability of this geomembrane to conform to undulations of the rough soil subgrade. Peak and large displacement secant friction angles for LLDPE are larger than HDPE by approximately 3°.

Post-test visual inspections indicated that the underside of both geomembranes experienced significant damage as a result of interface shear. Damage included severe scratch and gouge marks approximately 130 mm in length and tearing of holes for the LLDPE. Each of the damage marks was associated with a gravel particle protruding from the soil subgrade. Figure 9 shows photographs of the geomembrane specimens. The bright light integrity test revealed two holes in the LLDPE geomembrane and the water integrity test did not reveal any additional holes. No holes were indicated by either integrity test for the HDPE geomembrane. The stiffer HDPE material did not conform as closely to protruding gravel particles and thus experienced less damage during shear. Throughout the testing program, all geomembrane damage was associated with the soil subgrade and no damage occurred from the overlying potash salt.

5 CONCLUSIONS AND IMPLICATIONS FOR PRACTICE

Geomembranes must be protected from stress concentrations to prevent puncture and to limit the potential for stress cracking over time. Stress concentrations commonly arise from coarse particles (e.g., gravel) in an underlying subgrade soil or overlying drainage layer. Previous research studies have generally focused on the effects of static pressure to assess the potential for geomembrane damage from such particles. Results from the foregoing large-scale laboratory tests have indicated that far greater damage can occur due to interface shear displacement. In the current study, both LLDPE and HDPE geomembranes experienced minor to moderate dimpling as a result of static pressure and cyclic loading over a subgrade soil consisting of gravelly sand. However, much more severe damage was observed after shear to large displacement. Shear-induced damage included deep scratch and gouge marks for both geomembranes and two holes formed for the LLDPE specimen. Damage was likely greater for LLDPE due to the greater ability of this material to conform more closely to the rough soil subgrade prior to shear. This is an interesting result considering that stiffer geomembranes are generally more susceptible to

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puncture damage than flexible geomembranes (Stark et al. 2008). Lower levels of damage to the HDPE geomembrane may have resulted from the short duration of tests conducted. If the static pressure was sustained for a longer period of time, the HDPE would be expected to creep and conform more closely with the soil subgrade and thus experience more damage during shear. The same mechanism may produce more shear-induced damage for the LLDPE geomembrane as well. Thus, long term sustained pressure prior to shear, such as for an actual liner system, may produce higher levels of damage for both geomembranes.

The observed physical damage would compromise containment function and result in stress concentrations that may increase the likelihood for stress cracking at those locations (Rowe and Sangam 2002). Considering that shear displacements can occur within a landfill liner system due to common mechanisms such as waste settlement, the findings suggest that additional research is needed on expected levels of shear-induced damage for geomembranes placed adjacent to soil layers with coarse particles, including compacted clay liners containing gravel.

The experimental program also provided information with regard to cyclic loading of a geomembrane/coarse soil interface. Cyclic loading data indicated the LLDPE geomembrane had slightly lower values of interface shear stiffness and damping ratio than the HDPE geomembrane. Shear stiffness was essentially constant and damping ratio decreased with continued cycling for both geomembranes. The limited amount of testing in this study is insufficient to discount the effects of material variability and additional work is needed to verify the foregoing results.

6 ACKNOWLEDGEMENTS

Financial support for this investigation was provided by Grant No. CMMI-0800030 from the Geotechnical Engineering Program of the U.S. National Science Foundation and by a grant from GSE Environmental Inc. of Houston, Texas, USA. Geosynthetic and soil materials were provided by GSE. This support is gratefully acknowledged. We also thank Dr. Craig H. Benson, Distinguished Professor at the University of Wisconsin-Madison, for helpful information with regard to typical gradation requirements for compacted clay liners.

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Table 1. Material properties for geomembranes.

Geomembrane	Average Thickness (mm)	Minimum Thickness (mm)	Density (g/cc)	MD Strength at Break (kN/m)	TD Strength at Break (kN/m)	MD Elongation at Break (%)	TD Elongation at Break (%)	MD Tear Resistance (N)	TD Tear Resistance (N)	Puncture Resistance (N)
LLDPE	1.57	1.47	0.926	60.9	58.5	1059	960	187	182	534
HDPE	1.55	1.50	0.943	48.2	53.6	761	859	214	205	636

MD = machine direction; TD = transverse direction

Table 2. Subgrade soil moisture contents for experimental program.

Soil	Standard Proctor Test		Final *w* (%)	
	Initial *w* (%)	Optimum *w* (%)	Test 3 - LLDPE	Test 4 - HDPE
TP-1	3.40	13.10	12.90	12.20
TP-2	3.69	15.70		
Salt	0.80	–	–	

Table 3. Shear strengths and secant interface friction angles for static shear tests.

Geomembrane	Peak shear strength (τ_p)	Large displacement shear strength (τ_{130})	Peak secant interface friction angle (δ_p)	Large displacement secant interface friction angle (δ_{130})
LLDPE	446 kPa	313 kPa	25.0°	18.1°
HDPE	385 kPa	263 kPa	21.9°	15.4°

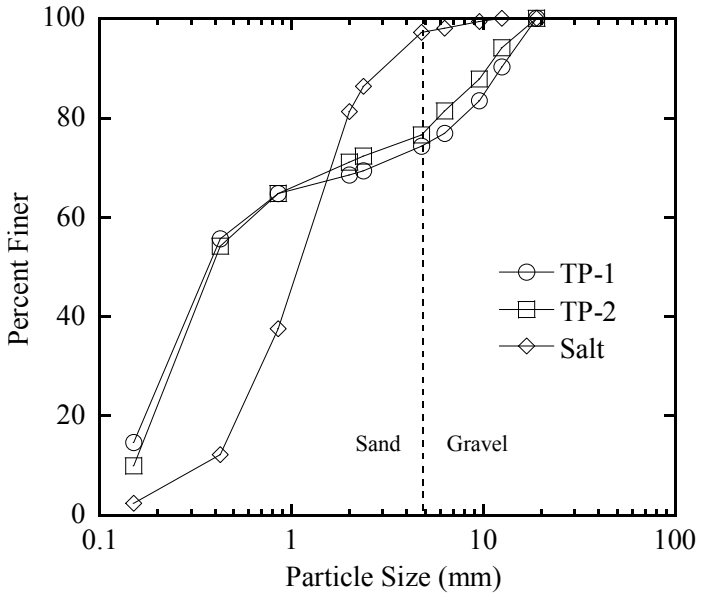


Figure 1. Particle size distribution curves.



Figure 2. Typical surface of subgrade soil prior to placement of geomembrane.

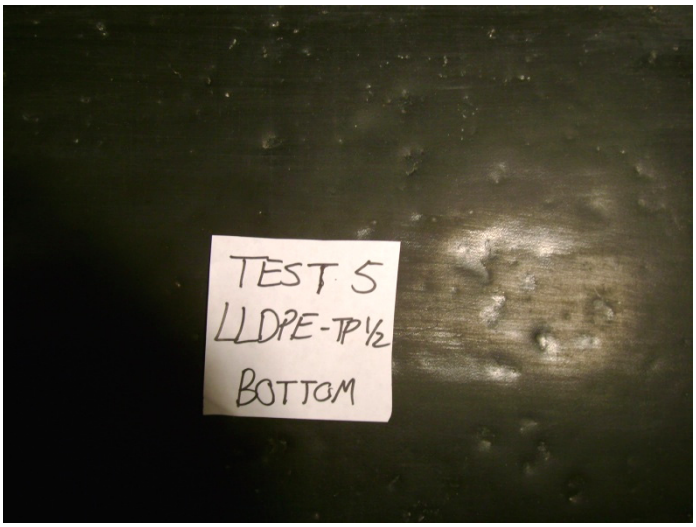


Figure 3. LLDPE geomembrane after static pressure test.

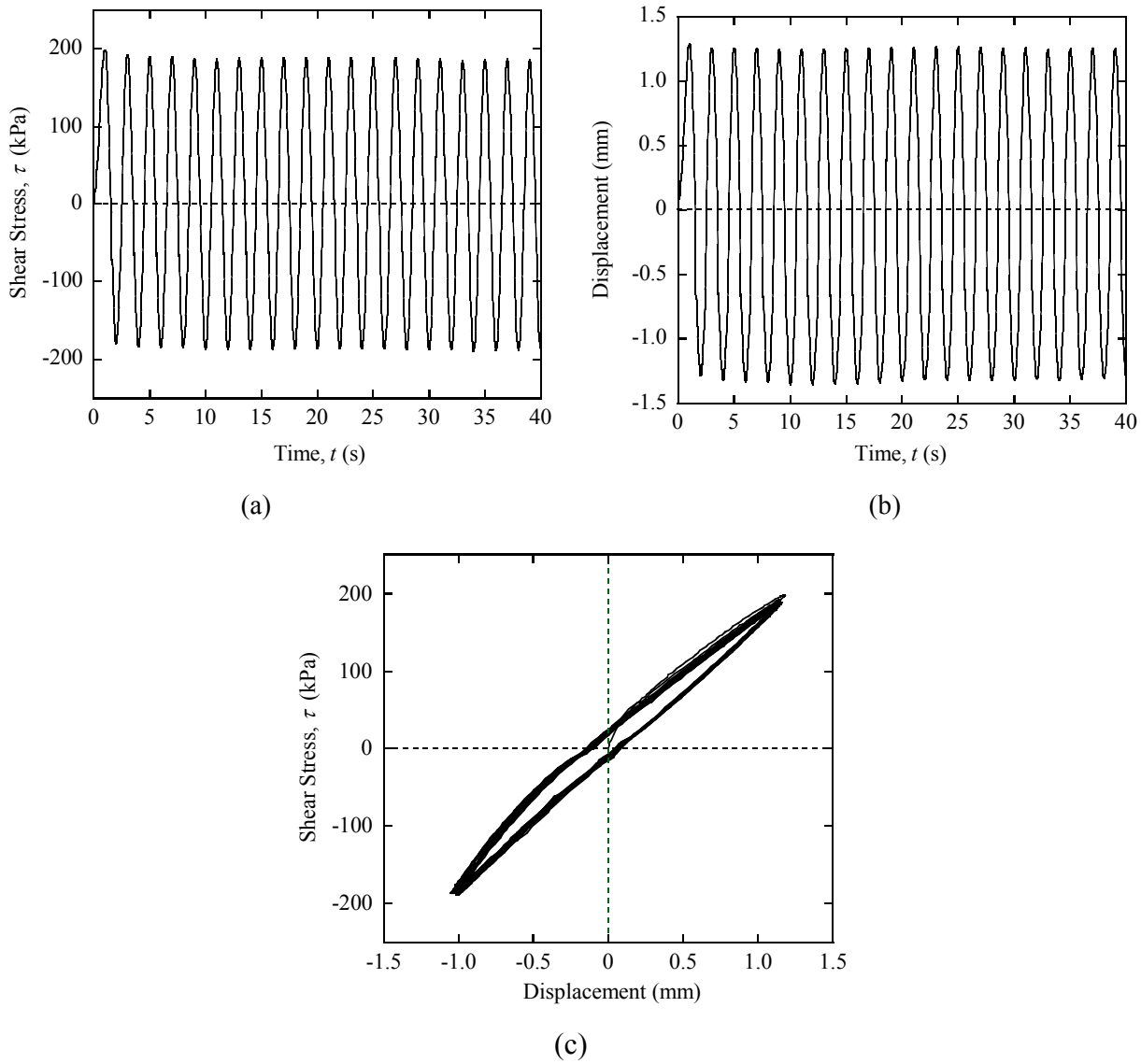


Figure 4. Cyclic loading measurements for LLDPE geomembrane: a) shear stress vs. time, b) shear displacement vs. time, and c) shear stress vs. shear displacement.

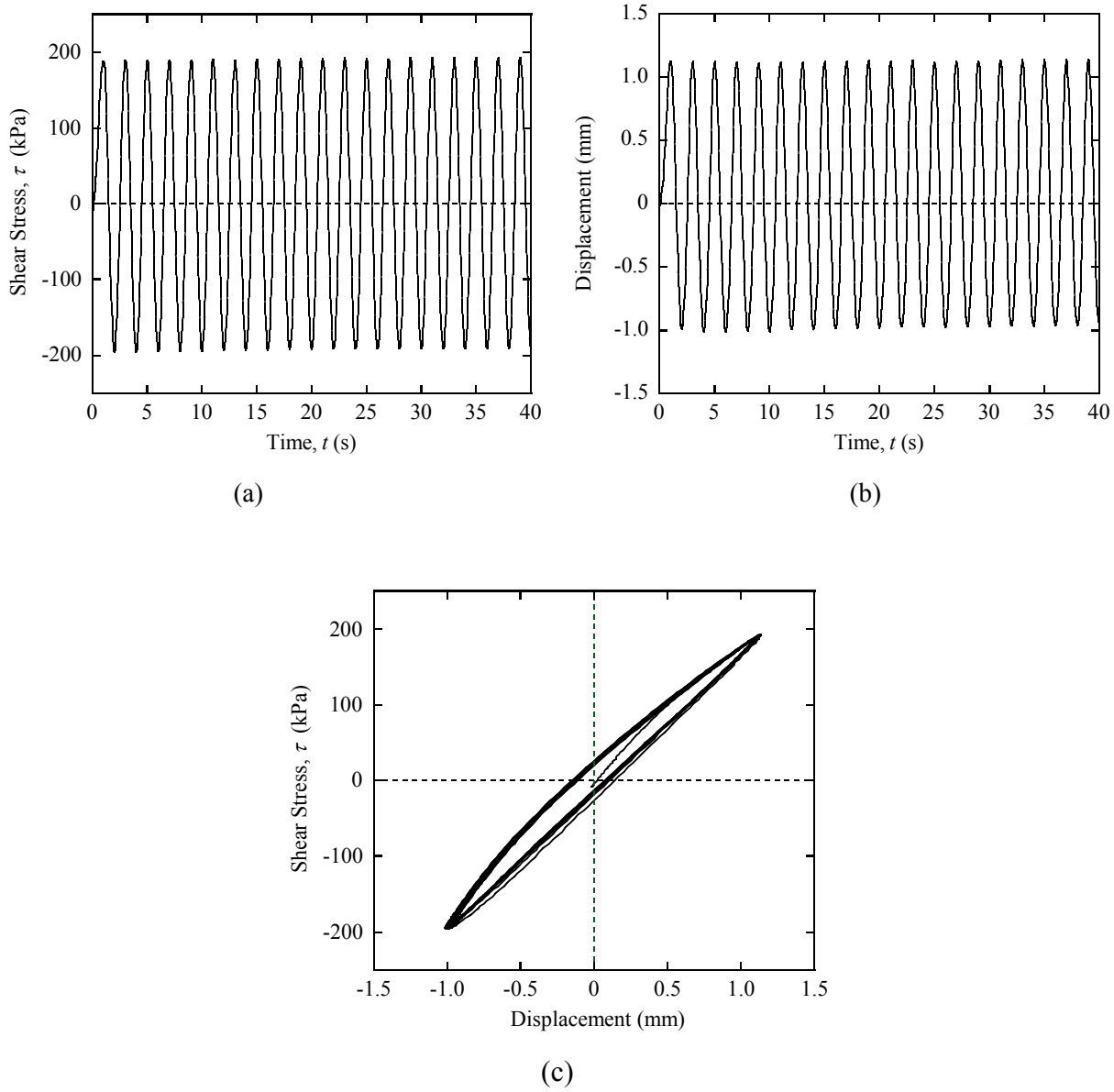


Figure 5. Cyclic loading measurements for HDPE geomembrane: a) shear stress vs. time, b) shear displacement vs. time, and c) shear stress vs. shear displacement.

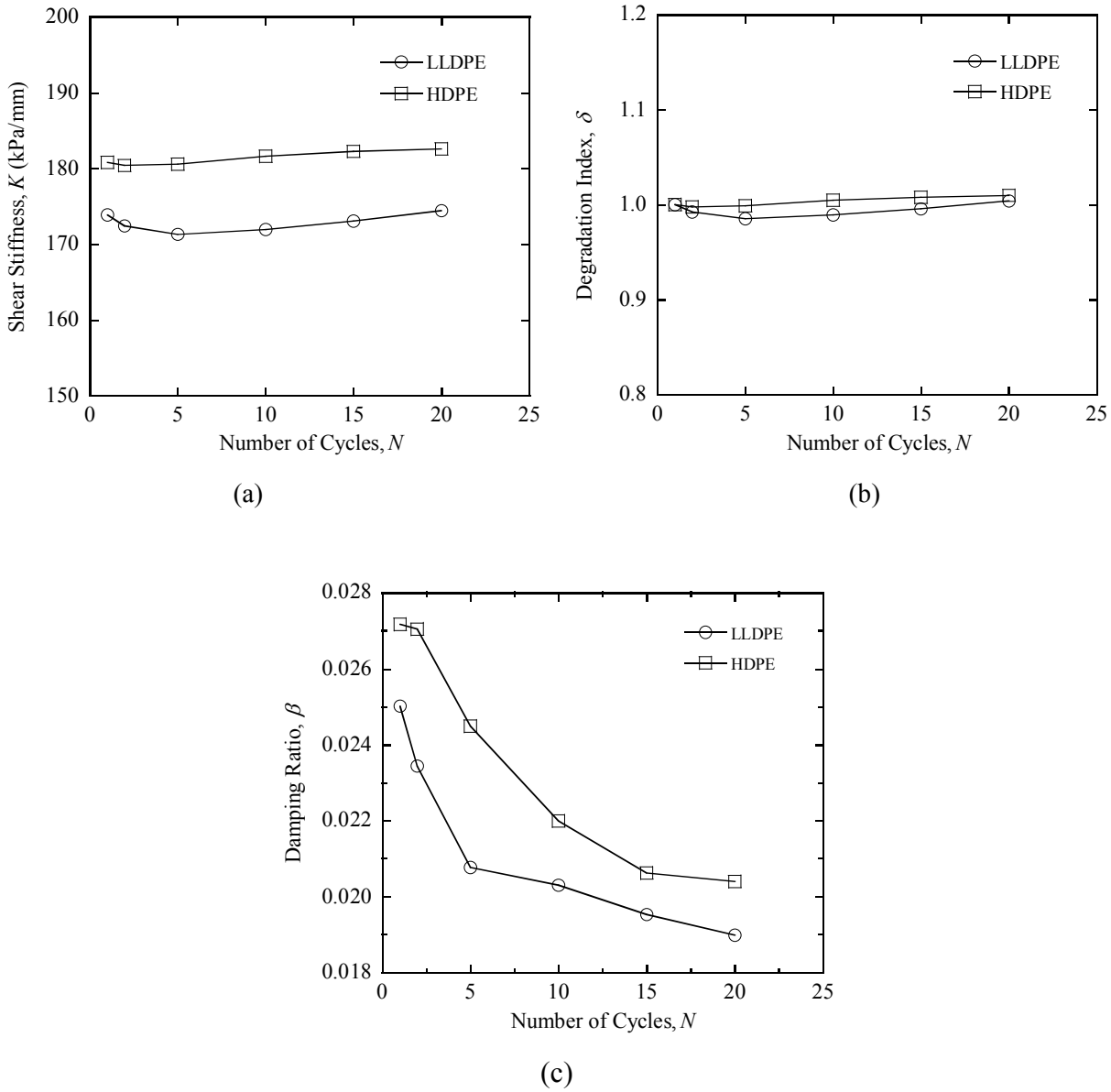
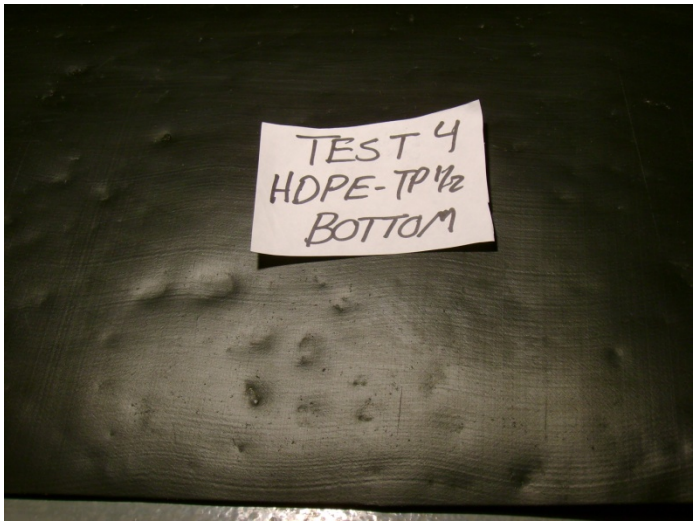


Figure 6. Cyclic loading parameters: a) shear stiffness, b) degradation index, and c) damping ratio.



(a)



(b)

Figure 7. Geomembrane specimens after cyclic loading: (a) LLDPE, (b) HDPE.

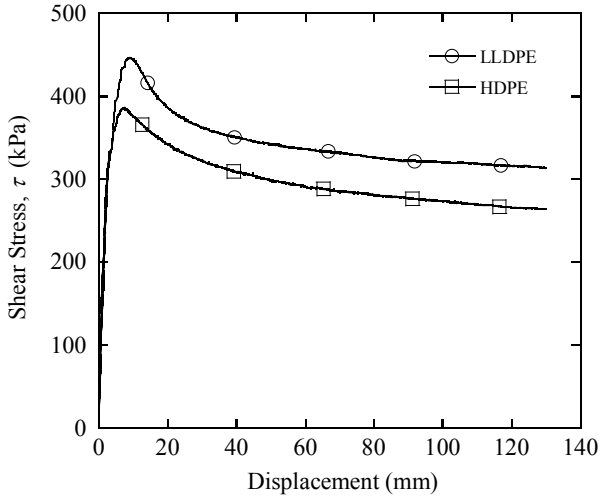
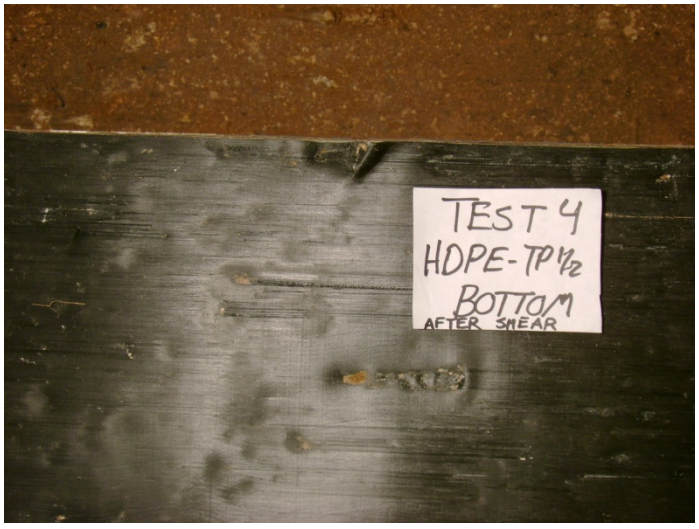


Figure 8. Stress-displacement curves for static shear tests.



(a)



(b)

Figure 9. Geomembrane specimens after cyclic loading and static shear: (a) LLDPE, (b) HDPE.

Exhibit J

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How long will my liner last?

Products (https://geosyntheticsmagazine.com/category/products/) | October 1, 2008 | By: IFAI (https://geosyntheticsmagazine.com/author/webteam/)

What is the remaining service life of my HDPE geomembrane?

By Ian D. Peggs, P.E., P.Eng., Ph.D.

Introduction

In his keynote lecture at the GeoAmericas-2008 conference last March, Dr. Robert Koerner (et al., 2008) of the Geosynthetic Institute (GSI) reported the ongoing Geosynthetic Research Institute (GRI) work to make the first real stab at assessing the service lives of high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), reinforced PE, ethylene propylene diene terpolymer (EPDM), and flexible polypropylene (fPP) exposed geomembranes.

The selected environment simulated that of Texas, USA, in sunny ambient temperatures between ~7°C (45°F) and 35°C (95°F). Of course, an exposed black HDPE geomembrane in the sun will achieve much higher temperatures, probably in excess of 80°C (176°F).

I do not know what the temperature would be at 150-300mm above the liner (for those still specifying this parameter), but it is quite immaterial. The only temperature of concern is the actual geomembrane temperature.

The lifetimes are shown in Table 1, but it must be recognized that these data are for specific manufactured products with specific formulations.  Table 1 | Estimated exposed geomembrane The "greater than" notation indicates that laboratory exposures (incubations) are still on-going, not

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that some samples have failed after the indicated time period. The PE-R-1 material is a thin LLDPE, so it might be expected to be the first to reach the defined end of life; the half-life—the time to loss of 50% of uniaxial tensile properties.

It is interesting to note that HDPE-1 and LLDPE-1 are proceeding apace, but it would be expected that the LLDPE-1 would reach its half-life earlier than HDPE-1. However, this does not automatically follow. With adequate additive formulations, perhaps LLDPE could be left exposed and demonstrate more weathering resistance than some HDPEs. This demonstrates the fact that all PEs, whether HD or LLD, are not identical—they can have different long-term performances dependent on the PE resin used and the formulation of the stabilizer package. However, such differences are not evident in the conventional mechanical properties such as tensile strength/ elongation, puncture and tear resistances, and so on.

The two fPPs are performing well. However, there had also been an fPP-1, one of the first PP geomembranes that did not perform well. This was due to a totally inappropriate stabilizer formulation. That particular product lasted 1.5 years in service. In the QUV weatherometer, it lasted 1,800 light hours at 70°C (158°F). Therefore, the lab/field correlation is that 1,000 QUV light hours is equivalent to a 0.83yr service life under those specific environmental conditions.

At another location in Texas, Koerner/ GRI found 1,000hr of QUV exposure was equivalent to 1.1 year actual field exposure. Consequently, for Texas exposures GRI is using a correlation of 1000hr QUV exposure as equivalent to Iyr of in-service exposure. Clearly, the correlation would be different in less sunny and colder environments.

The failed fPP-1 liner was replaced with a correctly stabilized fPP that, subsequently, performed well.

While estimated correlations might be made for other locations using historical weather station sunshine and temperature data, there is no question that the best remaining lifetime assessments will be obtained using samples removed from the field installation of interest.

A lifetime in excess of 28yr, demonstrated for a recently-made HDPE geomembrane, is comparable to the present actual service periods of as long as 30- 35yr. However, actual lifetimes of as low as ~15yr have also been experienced.

Do service lifetimes now exceeding 30yr mean that we might expect to see another round of stress cracking failures as exposed liners finally oxidize sufficiently on the surface to initiate stress cracking?

This would be frustrating after resolving the early 1980s problems with stress cracking failures at welds and stone protrusions when the liners contracted at low temperatures, but it is the way endof- life will become apparent. And will that be soon or in another 5-20 years? It would be useful to know.

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So how can we evaluate the condition of our exposed liners in a simple and practical manner to ensure they will continue to provide adequate service lifetimes and to get sufficient warning of impending expiration?

For each installation, a baseline needs to be established, and changes from that baseline need to be monitored.

A liner lifetime evaluation program

Rather than be taken by surprise when a liner fails or simply expires, it should be possible to monitor the condition of the liner to obtain a few years of notice for impending expiration. One can then plan for a timely replacement without the potential for accidental environmental damage and undesirable publicity. A program of periodic liner-condition assessment is proposed.

For baseline data, it would be useful to have some archive material to test, but that is not usually available. Manufacturers often discard retained samples after about 5 years. Perhaps facility owners should be encouraged to keep retained samples at room temperature and out of sunlight. The next best thing is to use material from the anchor trench or elsewhere that has not experienced extremes in temperature and that has not been exposed to UV radiation or to expansion/ contraction stresses.

Less satisfactory options are to use the original NSF 54 specifications, the manufacturer’s specifications, or the GRI-GM13 specifications at the appropriate time of liner manufacturing. The concern with using these specifications is that while aged material may meet them, there is no indication of whether the measured values have significantly decreased from the actual as-manufactured values that generally significantly exceed the specification.

A final option for the baseline would be to use the values at the time of the first liner assessment.

The first liner condition assessment would consist of a site visit during which a general visual examination would be done together with a mechanical probing of the edges of welds. A visual examination would include the black/gray shades of different panels that might indicate low carbon contents.

A closer examination should be done using a loupe (small magnifier) on suspect areas such as wrinkle peaks, the tops and edges of multiple extrusion weld beads, and the apex-down creases of round die-manufactured sheet.

The last detail is significant because the combination of oxidizing surface and exposed surface tension when the liner contracts at low temperatures and the crease is pulled flat can be one of the first locations to crack. The apex-up creases do not fail at the same time because the oxidized exposed surface is under compression (or less tension) when the crease is flattened out.

Appropriate samples for detailed laboratory testing will be removed.

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It may be appropriate to do a water lance electrical integrity survey on the exposed sideslopes, but this would only be effective on single liners, and on double liners with a composite primary liner, a conductive geomembrane, or a geocomposite with a conductive geotextile on top.

A sampling and testing regime

A liner lifetime evaluation program should be simple, meaningful, and cost-effective.

While it will initially require expert polymer materials science/engineering input to analyze the test data and to define the critical parameters, it should ultimately be possible to use an expert system to automatically make predictions using the input test data.

Small samples will be taken from deep in the anchor trench and from appropriate exposed locations. Potential sites for future sample removal by the facility owner for future testing will be identified and marked by the expert during the first site visit.

The baseline sample(s) will be tested as follows:

- Single-point stress cracking resistance (SCR) on a molded plaque by ASTM D5397
- High-pressure oxidative induction time (HP-OIT) by ASTM D5885
- Fourier transform infrared spectroscopy (FTIR-ATR) on upper surface to determine carbonyl index (CI) on nonarchive samples only
- Oven aging/HP-OIT (GRI-GM13)
- UV resistance/HP-OIT (GRI-GM13)

The exposed samples will be tested as follows:

- Carbon content (ASTM D1603)
- Carbon dispersion (ASTM D5596)
- Single-point SCR on molded plaque (ASTM D5397)
- Light microscopy of exposed surface, through-thickness cross sections, and thin microsections (~15 μm thick) as necessary
- HP-OIT on 0.5-mm-thick exposed surface layers from basic sheet and from sheet at edge of extruded weld bead (ASTM D5885), preferably at a double-weld bead
- FTIR-ATR on exposed surface to determine CI
- Oven aging/HP-OIT on 0.5mm surface layer (GRI-GM13)
- UV resistance/HP-OIT on 0.5 mm surface layer (GRI-GM13)

Carbon content is done to ensure adequate basic UV protection. Carbon dispersion is done to ensure uniform surface UV protection and to evaluate agglomerates that might act as initiation sites for stress cracking.

HP-OIT is used to assess the remaining amount of stabilizer additives, both in the liner panels and in the sheet adjacent to an extrusion weld. Most stress cracking is observed at the edges of extrusion weld beads in the lower sheet, so it is important to monitor this location.

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While standard OIT (ASTM D3895 at 200°C) better assesses the relevant stabilizers effective at processing (melting) and welding temperatures, the relevant changes in effective stabilizer content during continued service, including in the weld zone, will be provided by measurement of HP-OIT. There will be no future high temperature transient where knowledge of S-OIT will be useful. It is expected that the liner adjacent to the weld bead will be more deficient in stabilizer than the panel itself. Therefore, S-OIT is not considered in this program.

Note that HP-OIT is measured on a thin surface layer because the surface layer may be oxidized while the body of the geomembrane may not. If material from the full thickness of the geomembrane is used it could show a significant value of OIT, implying that there is still stabilizer present and that oxidation is far from occurring. However, the surface layer could be fully oxidized with stress cracks already initiated and propagating. A crack will then propagate more easily through unoxidized material than would initiation and propagation occur in unoxidized material.

The fact that the HP-OIT meets a certain specification value in the as-manufactured condition provides no guarantee that thermo- and photo-oxidation protection will be provided for a long time. Stabilizers might be consumed quickly or slowly while providing protection. They may also be consumed quickly to begin with, then more slowly, or vice versa. Hence, the need for continuing oven (thermal) aging and UV resistance tests. These two parameters, assessed by measuring retained HP- OIT, are critical to the assessment of remaining service life.

Oven (thermal) aging and UV resistance tests performed in this program will provide an extremely valuable data base that relates laboratory testing to in-service performance and that will further aid in more accurately projecting in-service performance from laboratory testing results.

Special considerations

Because we do not know, by OIT measurements alone, whether the surface layer is or is not oxidized (unless OIT is zero), and since we do not yet know at what level of OIT loss there might be an oxidized surface layer (the database has not yet been generated), FTIR directly on the surface of the geomembrane is performed using the attenuated total reflectance (ATR) technique to deny or confirm the presence of oxidation products (carbonyl groups).

Following the practice of Broutman, et al. (1989) and Duvall (2002) on HDPE pipes, if the ratio of the carbonyl peak at wave number 1760 cm-1 and the C-H stretching (PE) peak at wave number 1410 cm -1 is more than 0.10, there is a sufficiently oxidized surface layer that stress cracking might be initiated. For those familiar with the two slope stress rupture curve (Figure 1) where the brittle stress cracking region is the steeper segment below the knee, there is a third vertical part of the curve (Figure 2) where the material is fully oxidized and fracture occurs at the slightest stress.



Figure 1 | Standard stress rupture curves for five HDPE geomembranes (Hsuan, et al. 1998)

Figure 2 | Stress rupture curves showing third stage (Brittle no AO) oxidized limit. (Gaube, et al. 1985)

This is what will

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happen at the end of service life. But first note the times to initiation of stress cracking (the knees in the curves) in Figure 1—they range from ~10/hr to ~5,000/hr—clearly confirming that all HDPEs are not the same. Some are far more durable than others.

At the end of service life, at some level of OIT, there will be a critically oxidized surface layer that when stressed, such as at low temperatures by an upwards protruding stone, or by flexing due to wind uplift, will initiate a stress crack on the surface that will propagate downward through the geomembrane, as shown by the crack in Figure 3.


Figure 3 | Stress crack initiated by extruder die line at stone

This crack, initiated at a stress concentrating surface die mark, occurred when the liner contracted at low temperatures, and tightened over an upwardly protruding stone. The straight morphology of the crack, and the ductile break at the bottom surface as the stress in the remaining ligament rose above the knee in the stress rupture curve, are typical of a stress crack. Note the shorter stress cracks initiated along other nearby die marks.

Stress cracks are preferentially initiated along the edges of welds because the adjacent geomembrane has been more depleted of stabilizers during the high temperature welding process. Thus, under further oxidizing service conditions, it will become the first location to be oxidized to the critical level at which stress cracks will be initiated under any applied stress. In addition, the geometrical notches at grinding gouges and at the edges of the bead increase local stresses to critical levels for SC to occur.

I also believe that an internal microstructural flaw exists between the originally oriented geomembrane structure and the pool of more isotropic melted and resolidified material at the edge of the weld zone, as shown schematically in Figure 4.


Figure 4 | Schematic of microstructure at extrusion Most stress cracks occur at an off-normal angle at the edge of the weld bead that may be related to the angle of this molten-pool to oriented-structure interface (Figure 5).


Figure 5 | Typical off-normal angle of precursor crazes (left) and stress crack (right) at edge of extrusion It is also known that stress increases the extraction of stabilizers from polyolefin materials.

With all of these agencies acting synergistically, it is not surprising that stress cracking often first occurs adjacent to extrusion welds.

Looking ahead

With the first field assessment test results available to us, and the extent of changes from the baseline sample known, removal of a second set of samples by the facility owner (at locations previously identified and marked by the initial surveyor), will be planned for a future time, probably in 2 or 3 years.

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Why 2 or 3 years? In an extreme chemical environment, extensive reductions in S-OIT of studded HDPE concrete protection liners in mine solvent extraction facilities using kerosene/aromatic hydrocarbon/ sulfuric acid process solutions at 55°C (131°F) have been observed on the solution and concrete sides of the liner (Table 2) within 1 year (Peggs 2008).



Table 2 | S-OIT values on solution and concrete liner surfaces (Peggs, 2008)

But it is unlikely that such rapid decreases will be observed in air-exposed material.

With this second set of field samples, and with three sets of data points, practically reliable extrapolations of remaining lifetime can start to be made.

It is expected that a few years of notice for impending failures will be possible.

The key point to note in making these condition assessments is that, while all HDPE geomembranes have very similar conventional index properties, they can have widely variable photo-oxidation, thermal-oxidation, and stress-cracking resistances. Therefore, some HDPEs are more durable than others.

Thus, while one HDPE geomembrane manufactured in 1990 failed after 15 years in 2005, another HDPE geomembrane made in 1990 from a different HDPE resin (or more correctly a medium-density polyethylene [MDPE] resin), and with a better stabilizer additive package, could still have a remaining lifetime of 5, 20, or 30 years.

So, keep a close eye on those exposed liners and we'll learn a great deal more about liner performance and get notice of the end of service lifetime. And if owners can retain some archive material from new installations, so much the better.

Ian Peggs is president of I-CORP International Inc. and is a member of *Geosynthetics* magazine's Editorial Advisory Committee.

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Exhibit K

ANNUAL INSPECTION REPORT
ASH POND 2
JOLIET STATION
OCTOBER 2021

This annual inspection report has been prepared pursuant to both Title 35 IAC Part 845 Section 845.540(b) and Title 40 of the Code of Federal Regulations Part 257.83(b) for Ash Pond 2 (Pond 2) at Joliet Station in Joliet, Illinois (Station). The purpose of this project is to perform an annual inspection of Pond 2 by a licensed professional engineer to ensure that the design, construction, operation, and maintenance of the coal combustion residuals (CCR) unit is consistent with recognized and generally accepted good engineering standards. Civil & Environmental Consultants, Inc. (CEC) completed the following scope of services in preparing this annual inspection report:

- CEC reviewed the weekly and monthly inspection reports completed by qualified station personnel and the previous annual inspection report.

- CEC performed the annual inspection in accordance with the requirements of Part 845.540 and 40 CFR 257.83(b) including observations pertaining to the following:

    - Changes in Geometry: Observations of changes in the geometry of Ash Pond 2 since the previous annual inspection.

    - Instrumentation: Inspection of the location and type of existing instrumentation and documentation of the maximum recorded readings of each instrument since the previous annual inspection from records provided by the Station.

    - Capacity and Impounded Volume: Inspection observations for the approximate minimum, maximum, and present depth and elevation of the impounded water and CCR; storage capacity of the impounding structure at the time of the inspection; and the approximate volume of the impounded water and CCR at the time of the inspection.

    - Structural/Operational Observations: Inspection for actual or potential structural weakness of the CCR surface impoundment, in addition to any existing conditions that are disrupting or have the potential to disrupt the operation and safety of the CCR surface impoundment and appurtenant structures.

- Other Changes: Inspection including change(s) which may have affected the stability or operation of the impounding structure since the previous annual inspection.

Pond 2 is an inactive CCR surface impoundment. CEC inspected Pond 2 on October 6, 2021, and at the time of our inspection, Pond 2 contained no CCRs. CEC inspected the pond and found no signs of distress that would suggest the stability or operation of the impounding structure is compromised.

1.0 CHANGES IN GEOMETRY

The Pond 2geometry was observed to be unchanged since the October 2020 inspection.

2.0 INSTRUMENTATION

No instrumentation was reported or observed that would be associated with the hydraulic structures, impoundment embankments, and/or slope performance.

3.0 CAPACITY AND IMPOUNDED VOLUME

The capacity and impounded volume of the Pond 2 and estimated depth of impounded water and CCR are represented in Table 1, attached. Volumes and depths were determined by reviewing inspection reports, construction drawings, and from discussions with Station personnel.

4.0 STRUCTURAL/OPERATIONAL OBSERVATIONS

Pond 2 was inspected for signs of distress that would have the potential to disrupt operation and safety of the pond. None were observed. Prior to the inspection, CEC reviewed the previous annual inspection report. This report did not identify conditions that indicate an actual or potential structural weakness. Weekly and monthly inspection reports were also reviewed and did not indicate an actual or potential structural weakness.

5.0 OTHER CHANGES

Pond 2 was inspected for signs of other changes or distresses that would have the potential to disrupt operation and safety of the basins. Our inspection showed no distresses that would affect the operation and/or stability of Pond 2.

6.0 LIMITATIONS AND CERTIFICATION

This annual inspection report was prepared to meet the requirements of Section 845.540(b) and Part 257.83(b) and was prepared under the direction of Mr. M. Dean Jones, P.E.

By affixing my seal to this, I do hereby certify to the best of my knowledge, information, and belief that the information contained in this report is true and correct. I further certify I am licensed to practice in the State of Illinois and that it is within my professional expertise to verify the correctness of the information. I am aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment.

Seal:



Signature: _____

Name: M. Dean Jones, P.E.

Date of Certification: October 13, 2021

Illinois Professional Engineer No.: 062-051317

Expiration Date: November 30, 2021

Table 1: Inspection Summary - Pond 2

Category	Regulation Reference	Evaluation	Recommended Action
Change in Geometry	§845.450(b)(2)(A) §257.83(b)(2)(i)	None	None
Instrumentation	§845.450(b)(2)(B) §257.83(b)(2)(ii)	None	None
Water Depth	§845.450(b)(2)(C) §257.83(b)(2)(iii)	0 to 4 feet	None
CCR Depth	§845.450(b)(2)(C) §257.83(b)(2)(iii)	0 feet	None
Estimated Storage Capacity	§845.450(b)(2)(D) §257.83(b)(2)(iv)	38.4 Acre Feet	None
Impounded Water Volume	§845.450(b)(2)(E) §257.83(b)(2)(v)	6.8 Acre Feet	None
Impounded CCR Volume	§845.450(b)(2)(E) §257.83(b)(2)(v)	0 Acre Feet	None
Structural/Operational Observations	§845.450(b)(2)(F) §257.83(b)(2)(vi)	None	None
Other Changes	§845.450(b)(2)(G) §257.83(b)(2)(vii)	None	None

Exhibit

L

WEEKLY QUALIFIED PERSON CHECK LIST FOR JOLIET 29 STATION

INSTRUCTIONS:

1) An inspection of each ash pond and related embankments/berms at the Stations must be conducted **weekly and within 24 hours after a storm event greater or equal to 6.45 inches.**
2) The inspection must be conducted by a "qualified person" and the inspection records should be maintained at the Station for five years.
3) Every week, the qualified person must also inspect the CCR Unit Instrumentation.

Date: 10/10/21 **Time:** 0900 **Type of Inspection:** Weekly ☑ Storm Event ☐

GENERAL INFORMATION:	**POND 1 (see Note)**	**POND 2**	**POND 3 (see Note)**
1) Water Level in Pond	NORMAL ☑ HIGH ☐ LOW ☐	NORMAL ☑ HIGH ☐ LOW ☐	NORMAL ☑ HIGH ☐ LOW ☐
2) Is Ash Being Removed?	N/A	YES ☐ NO ☒	N/A
3) In Service?	YES ☑ NO ☐	YES ☐ NO ☑	YES ☑ NO ☐

PHYSICAL INSPECTION:

1) Seepage from or through embankment? Includes roads around ponds and outside fence.	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
2) Sinkholes/Depressions/Bulges in Pond or embankments?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
3) Signs of Piping/Channels or other Internal Erosion on embankments?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
4) Cracking on Embankments/Berms?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
5) Animal Burrows on embankments?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
6) Excessive or Lacking Vegetative Cover on embankments? (should be normal growth)	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
7) Slope Erosion on berms or embankments?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
8) Debris on embankments/berms?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑

9) Deterioration, malfunctions, or improper operation of overtopping control systems	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
10) Visible Releases	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑

11) If Yes to any of the above, or any other abnormalities are noted, please describe/explain: _____

_____

12) Is there any damage to Pond Liner: YES ☐ NO ☑

12.a) If YES, Describe in Detail: _____

_____

12.b) Specific Location: _____

_____

12.c) Is Water Level Below Damage? YES ☐ NO ☐

12.d) If No, Did You Reduce Pond Level? YES ☐ N/A ☐

12.e) Notified Shift Supervisor of Damage? YES ☐ Date Notified: _____ N/A ☐

12.f) Notified Station Management of Damage? YES ☐ Date Notified: _____ N/A ☐

12.g) Additional Comments: _____

Inspect[redacted]

Note: Joliet 29 Pond 1 and Pond 3 are not CCR surface impoundments. Inspections are conducted as part of good operating practices.

WEEKLY QUALIFIED PERSON CHECK LIST FOR JOLIET 29 STATION

INSTRUCTIONS:

1) An inspection of each ash pond and related embankments/berms at the Stations must be conducted **weekly and within 24 hours after a storm event greater or equal to 6.45 inches.**
2) The inspection must be conducted by a "qualified person" and the inspection records should be maintained at the Station for five years.
3) Every week, the qualified person must also inspect the CCR Unit Instrumentation.

Date: 10/13/21 **Time:** 0800 **Type of Inspection:** Weekly ☑ Storm Event ☐

GENERAL INFORMATION:	**POND 1 (see Note)**	**POND 2**	**POND 3 (see Note)**
1) Water Level in Pond	NORMAL ☑ HIGH ☐ LOW ☐	NORMAL ☑ HIGH ☐ LOW ☐	NORMAL ☑ HIGH ☐ LOW ☐
2) Is Ash Being Removed?	N/A	YES ☐ NO ☒	N/A
3) In Service?	YES ☑ NO ☐	YES ☐ NO ☑	YES ☑ NO ☐

PHYSICAL INSPECTION:

1) Seepage from or through embankment? Includes roads around ponds and outside fence.	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
2) Sinkholes/Depressions/Bulges in Pond or embankments?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
3) Signs of Piping/Channels or other Internal Erosion on embankments?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
4) Cracking on Embankments/Berms?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
5) Animal Burrows on embankments?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
6) Excessive or Lacking Vegetative Cover on embankments? (should be normal growth)	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
7) Slope Erosion on berms or embankments?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
8) Debris on embankments/berms?	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑

9) Deterioration, malfunctions, or improper operation of overtopping control systems	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑
10) Visible Releases	YES ☐ NO ☑	YES ☐ NO ☑	YES ☐ NO ☑

11) If Yes to any of the above, or any other abnormalities are noted, please describe/explain: _____

_____

12) Is there any damage to Pond Liner: YES ☐ NO ☑

12.a) If YES, Describe in Detail: _____

_____

12.b) Specific Location: _____

_____

12.c) Is Water Level Below Damage? YES ☐ NO ☐

12.d) If No, Did You Reduce Pond Level? YES ☐ N/A ☐

12.e) Notified Shift Supervisor of Damage? YES ☐ Date Notified: _____ N/A ☐

12.f) Notified Station Management of Damage? YES ☐ Date Notified: _____ N/A ☐

12.g) Additional Comments: _____

Inspector Signa[redacted]

Note: Joliet 29 Pond 1 and Pond 3 are not CCR surface impoundments. Inspections are conducted as part of good operating practices.

Exhibit M

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August 31, 2012

VIA E-MAIL AND OVERNIGHT MAIL

IEPA-DIVISION OF RECORDS MANAGEMENT
RELEASABLE

JAN 07 2013

REVIEWER JZJ

Illinois EPA
Division of Public Water Supplies
Attn: Andrea Rhodes, CAS #19
P.O. Box 19276
Springfield, IL 62794-9276

Re: Violation Notice: Midwest Generation, LLC, Joliet #29 Generating Station
Identification No.: 6284
Violation Notice No.: W-2012-00059

Dear Ms. Rhodes:

This letter is a supplemental response to the above-referenced June 11, 2012 Violation Notice ("VN") following the meeting between the Illinois Environmental Protection Agency ("Illinois EPA or the "Agency") and Midwest Generation, LLC ("MWG") on August 14, 2012.[1] MWG appreciated the opportunity to discuss the VNs and the underlying allegations with the Agency. The extensive participation at the August 14th meeting by Interim Director John Kim and Agency personnel was productive and helped to clarify the key issues. As a result, MWG believes it now has a better understanding of the Agency's views regarding resolution of this matter.

The August 14th meeting also helped MWG both to identify issues that warranted further attention and explanation in this supplemental response and to revise its proposed Compliance Commitment Agreement ("CCA") for the MWG Joliet #29 Generation Station ("Joliet #29") for the Agency's consideration. Accordingly, this supplemental response does not repeat all of the information contained in MWG's July 27, 2012 response to the VN, but rather focuses on responding to the questions and concerns raised by the Agency during the meeting. It also includes a revised, proposed CCA which MWG submits should be acceptable to resolve the VN allegations based on the discussion at the aforementioned August 14th meeting.

[1] The August 14, 2012 meeting was held at the request of MWG, pursuant to Section 31(a)(4) of the Illinois Environmental Protection Act. 415 ILCS 5/31(a)(4).

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A very significant revision has been made to the revised, proposed CCA to include a project to replace the existing liner in Pond 3 at the Joliet #29 Station. MWG made this decision based on Midwest Generation's understanding of Agency staff's concerns as expressed during the August 14th meeting, even though MWG continues to believe that groundwater monitoring well results do not indicate that Pond 3 is causing the alleged groundwater violations. These and other provisions of MWG's proposed CCA are summarized in Section II below.

By submitting this supplemental response, MWG does not waive any of its original objections to the VNs raised in our July 27th response. Moreover, MWG does not, by submitting this supplemental response, make any admissions of fact or law, or waive any of its defenses to those alleged violations.

I. Supplemental Response to Alleged Violations in the VN

To answer questions presented at the meeting and further explain why the ash ponds at Joliet #29 are not causing a release into the groundwater, MWG has set forth below additional information concerning: (1) the treatment purpose and function of the ash ponds; (2) the condition of the liners underlying the ash ponds; and (3) why the alleged groundwater exceedances are not the result of releases from the ash ponds. MWG believes the August 14th discussion provided important insights and clarifications by both parties concerning the relevant facts and issues raised by the VN. While we may not embrace the Agency's views on each of the issues discussed, the discussion provided MWG with information that enables us to present a revised CCA that we believe addresses the questions and concerns expressed by the Agency.

A. The Treatment Purpose and Function of the Ash Ponds

As stated in MWG's July 27, 2012 VN response, and discussed further during the August 14th meeting, the three ash ponds at Joliet #29 are not disposal sites, but are wastewater treatment ponds that remove ash from the ash wastewater. Ponds 1 and 2 are used intermittently and interchangeably with each other only when the regular method of ash wastewater treatment and disposal is unavailable.[2] When the treatment ponds are used, the ash wastewater enters either Pond 1 or 2 for settlement of suspended solids. Almost all of the ash settles out into one of these ponds and the effluent then flows into Pond 3 for additional treatment. Pond 3 acts as a finishing treatment for the wastewater by providing additional settling time for any residual ash solids in the wastewater. Consequently, because of the settling that occurs in Ponds 1 or 2, the amount of ash remaining in the effluent that settles out in Pond 3 is minimal. The treated effluent is

[2]Under normal station operations, the ash wastewater generated by Joliet #29 is conveyed mechanically directly to the on-site, permitted Lincoln Stone Quarry Landfill without entering any of the ash ponds. However, because there are temporary periods of time when the ash wastewater conveyance system is not operational, due to maintenance reasons, either Pond 1 or Pond 2 is temporarily used until the ash wastewater conveyance system is brought back on line.

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discharged from Pond 3 to the Des Plaines River through Outfall 001g pursuant to the Station's NPDES permit (NPDES Permit #IL0064254).[3]

Apparently, because the ash ponds perform a wastewater treatment function and are not disposal sites, it was suggested by Agency personnel during the August 14th meeting that the ash ponds may be subject to the design criteria for treatment works set forth in Part 370 of the Illinois Pollution Control Board Regulations, referencing generally section 370.930 thereof entitled "Waste Stabilization Ponds and Aerated Lagoons," and more specifically, section 370.930(d)(2)(D) entitled "Pond Bottom" as the relevant criteria for the liners that should be installed in ash ponds. 35 Ill. Adm. Code § 370.930. As a practical matter, this is unnecessary given that the existing liners in two of the Joliet #29 ash ponds provide an equivalent level of protection to that specified in section 370.930(d)(2)(D) and the Pond 3 Poz-o-Pac liner provides adequate protection given its minimal use and the minimal amount of ash which collects in it. Further, Part 370 is not applicable to existing treatment works like the ash ponds at the Joliet #29 Station. Rather, the Part 370 regulations only apply to new construction of waste collection and treatment works. As stated in section 370.100, the purpose of these regulations is to "establish criteria for the design and preparation of plans and specifications for wastewater collection and treatment systems." 35 Ill. Adm. Code § 370.100 (emphasis supplied; see also § 370.200). There are no provisions or requirements in the Part 370 regulations that require existing treatment works to be modified or replaced to meet Part 370 criteria.

B. The Liners in the Ash Ponds are Preventing Releases to Groundwater

As MWG explained in its July 27th letter and during the August 14th meeting, the Joliet #29 ash ponds are different from other ash impoundments in Illinois. They are neither disposal sites nor abandoned ponds. They are relatively small, active, treatment ponds from which ash is routinely removed. Moreover, they are fully lined to prevent releases to groundwater. MWG previously relined Ponds 1 and 2, the ponds that collect the bulk of the ash from the ash wastewater, with a high-density polyethylene ("HDPE") liner, overlain by a 12-inch sand cushion layer and a 6-inch limestone "warning" layer (to warn operators to the location of the underlying liner in order to prevent liner damage during ash removal). HDPE liners have a permeability of approximately 10^{-13} cm/sec. Pond 3, the finishing pond which does not collect much ash, is lined with a liner of two 6-inch lifts of Poz-o-Pac. MWG disagrees with Illinois EPA's conclusion that Pond 3 is the cause of the alleged groundwater exceedances and does not believe the factual evidence -- the existence of the Poz-o-Pac liner, the limited use of Pond 3 and the minimal ash that collects in it -- supports the Agency's conclusion. Moreover, as described further below, the groundwater data does not point to Pond 3 as the source of these impacts.

C. The Ash Ponds are not causing a Release to Groundwater

As stated in MWG's July 27th VN Response, the groundwater monitoring well data does not support the contention that the ash ponds are a source of the alleged groundwater impacts.[4]

[3] The effluent is subject to limits for pH and total suspended solids. To date, the limits have not been exceeded.

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For most parameters, the distribution and observation of concentrations is random and inconsistent. The data does not demonstrate, and is inconsistent with, the ash ponds being the source of the groundwater impacts. At least with regard to the chloride exceedances, MWG's understanding of the August 14th meeting discussion is that the Agency agreed with the conclusion that the chloride exceedances are more likely from dissolved road salt runoff (*e.g.*, from nearby U.S. Route 6) than from the ash ponds.

During the August 14th meeting, the Illinois EPA explained why it believes that Pond 3 is a source of the groundwater impacts at MW-9 and needs to be relined with a HDPE liner or its equivalent. The Agency explained that manganese and sulfate are indicators of coal ash, even in the absence of elevated boron levels in MW-9. MWG respectfully submits that the Agency is not giving sufficient consideration to the fact that the oxidation-reduction potential around MW-9 is consistently low, showing a strongly reducing environment. Typically in reducing environments, metals such as manganese can be elevated depending on the associated mineralogy of the local sediments.[5] Moreover, the sulfate exceedances, unaccompanied as they are here with an associated elevated boron concentration (let alone an exceedance), indicate that it is likely there are various, other potential sources, both natural and anthropogenic, that are wholly unrelated to coal ash. For these reasons, MWG maintains its position that the monitoring data does not provide an adequate, scientific basis on which to conclude that Pond 3 is causing the alleged violations. Nevertheless, in a good faith effort to resolve the VN, Midwest Generation is willing to agree to the Agency's request to reline Pond 3 with a HDPE liner or its equivalent.

II. Supplemental Compliance Commitment Agreement

Based on and in response to the August 14th meeting discussion, MWG has revised its proposed Compliance Commitment Agreement ("CCA") terms which were submitted in its July 27, 2012 VN response.

The revised CCA terms are set forth below and a draft CCA is enclosed for the Agency's review.

MWG believes this revised CCA should be an acceptable resolution to the VN issued to the Joliet #29 Station. As stated in the original VN response, there is no threat to human health presented by the alleged exceedances of the groundwater standards. Of the seventeen wells installed within 2,500 feet of the site, there are no downgradient wells. The two nearest wells are both wells owned by MWG and are located west and northeast of the main facility building, away from the location of the subject ash pond system. In addition, these wells are screened more than 1,500 feet deep, drawing from an aquifer below the Maquoketa shale confining unit.

---

[4] MWG incorporates by reference all of its discussion and explanation of the groundwater monitoring results in its July 27, 2012 VN response.

[5] "Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater" EPA/600/R-98/128, September 1998. Table B.3.3.

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The MWG wells are regularly sampled for potable water constituents, and the sampling results have consistently been in compliance with potable water regulations.[6] Shallow groundwater at the site discharges to the Des Plaines River, but the Des Plaines River is not used as a drinking water source near the station. In the absence of any potable groundwater receptors or use, groundwater at the Joliet #29 site does not pose any risk to human health.

The revised CCA terms are as follows:

A. The ash ponds will not be used as permanent disposal sites and will continue to function as treatment ponds to precipitate ash. Ash will continue to be removed from the ponds on a periodic basis.

B. The ash treatment ponds will 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 will 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 will 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, MWG will notify the Agency and will implement a corrective action plan for repair or replacement, as necessary, of the liner. Upon the Agency's approval, and the issuance of any necessary construction permit, MWG will implement the correction action plan

D. MWG will continue to monitor the groundwater through the existing eleven groundwater monitoring wells and report its findings to Illinois EPA.

E. MWG will apply for a construction permit to reline Pond 3 with a high-density polyethylene ("HDPE") liner within 6 months of the effective date of the CCA. A groundwater monitoring schedule will be included in the construction permit.

F. MWG will complete the work to reline Pond 3 with a high-density polyethylene ("HDPE") liner within 6 months of the receipt of the construction permit.

G. MWG reserves the right to request the Agency's approval of a cessation of all or some of the groundwater monitoring requirements based on future monitoring results.

This letter constitutes our supplemental response to, and modified CCA for, the Violation Notice W-2012-00059. MWG also reserves the right to raise additional defenses and mitigation arguments as may be necessary, in defense of the allegations listed in the Violation Notice in the

[6] See previously submitted Hydrogeologic Assessment of Midwest Generation Electric Generation Stations: Will County Station, Waukegan Station, Joliet 29 Station, Crawford Station, Powerton Station.

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event of any future enforcement. We believe that this supplemental response is responsive to all of the Agency's comments and concerns expressed in our meeting, and represents an appropriate resolution to the VN. Should you have any additional questions or concerns, please do not hesitate to contact me.

Very truly yours,

Susan M. Franzetti

Susan M. Franzetti
Counsel for Midwest Generation, LLC

Enclosure

cc: Maria L. Race, Midwest Generation, LLC

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ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

IN THE MATTER OF:	)	
	)	
Midwest Generation, LLC	)	
Joliet #29 Generating Station	)	
Joliet, Will County, Illinois	)	
IEPA ID #170000162525	)	
	)	
	)	**ILLINOIS EPA VN W-2012-00059**
	)	**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, Joliet #29 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 a coal-fired electrical generating station at 1800 Channahon Road in Joliet, Will County, IL.

3. Pursuant to Violation Notice ("VN") W-2012-00059, 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) Section 12 of the Illinois Environmental Protection Act, 415 ILCS 5/12

   b) 35 Ill. Adm. Code 620.115, 620.301, 620.401, 620.405, and 620.410

III. Compliance Activities

4. On July 27, 2012, the Illinois EPA received Respondent's response to VN W-2012-00059, which included proposed terms for a CCA. On August 14, 2011, the Parties met at the Illinois EPA offices to discuss the violation notice and the July 27th response. On _____, 2012, the Illinois EPA received Respondent's supplemental reply to the VN in response to Illinois EPA's comments at the meeting. The Illinois EPA has reviewed Respondent's proposed CCA terms, as well as considered whether any

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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-2012-00059:

a) The ash ponds will not be used as permanent disposal sites and will continue to function as treatment ponds to precipitate ash. Ash will continue to be removed from the ponds on a periodic basis.

b) The ash treatment ponds will 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 will 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 will 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, MWG will notify the Agency and will submit a corrective action plan for repair or replacement, as necessary, of the liner. Upon the Agency's approval, and the issuance of any necessary construction permit, MWG will implement the correction action plan.

d) MWG will continue to monitor the groundwater through the existing eleven groundwater monitoring wells and report its findings to Illinois EPA.

e) MWG will apply for a construction permit to reline Pond 3 with a high-density polyethylene ("HDPE") liner within 6 months of the effective date of the CCA. A groundwater monitoring schedule will be included in the construction permit.

f) MWG will complete the work to reline Pond 3 with a high-density polyethylene ("HDPE") liner within 6 months of the receipt of the construction permit.

g) MWG reserves the right to request the Agency's approval of a cessation of all or some of the groundwater monitoring requirements based on future monitoring results.

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-2012-00059.

7. This CCA is solely intended to address the violations alleged in Illinois EPA VN W-2012-00059. 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.

8. Respondent represents that it has entered into this CCA for the purpose of settling and compromising the alleged violations in VN W-2012-00059. By entering into this CCA and complying with its terms, Respondent does not admit the allegations of violation within VN W-2012-00059 and this CCA shall not be interpreted as including such admission.

9. 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.

10. 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 facility.

11. 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.

12. This CCA shall only become effective:

    a) If, within 30 days of receipt, Respondent executes this CCA and submits it, via certified mail, to Andrea Rhodes, CAS, CAS #19, Illinois EPA, Division of Public Water Supplies, P.O. Box 19276, Springfield, IL 62794-9276. 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.

13. 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: _____

Mike Crumly
Manager, Compliance Assurance Section
Division of Public Water Supplies
Bureau of Water

FOR RESPONDENT:

BY: _____ DATE: _____

Susan M. Franzetti
Counsel for Midwest Generation, LLC

Exhibit N

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EPA 120/R-07/001 | March 2007
www.epa.gov/osa

United States
Environmental Protection
Agency

Framework for Metals Risk Assessment







Office of the Science Advisor
Risk Assessment Forum

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EPA 120/R-07/001
March, 2007

Framework for Metals Risk Assessment

Office of the Science Advisor
Risk Assessment Forum
U.S. Environmental Protection Agency
Washington, DC 20460

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LIST OF ABBREVIATIONS AND ACRONYMS

1CFOK	One-Compartment, First-Order Kinetics model
ABA	Absolute bioavailability
aBLM	Aquatic Biotic Ligand Model
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resources Management Council of Australia and New Zealand
ATSDR	Agency for Toxic Substances and Disease Registry
AVS	Acid-volatile sulfide
AWQC	Ambient Water Quality Criteria
AWQS	Ambient Water Quality Standards
BAF	Bioaccumulation factor
BCF	Bioconcentration factor
BF	Bioaccessible fraction
BLM	Biotic Ligand Model
BSAF	Biota/sediment accumulation factor
CBR	Critical body residue
CCA	Chromated copper arsenate
CEC	Cation exchange capacity
CHESS	Chemical Equilibria in Soils and Solutions
CMAQ	Community Multiscale Air Quality model
DEPM	Dietary Exposure Potential Model
DHHS	U.S. Department of Health and Human Services
DL	Diffuse Layer model
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
EC_x	Effect concentration (for x percent of the study population)
ECOFRAM	Ecological Committee on FIFRA Risk Assessment Methods
Eh	Redox (reduction-oxidation) potential
EqP	Equilibrium partitioning
FDA	Food and Drug Administration
FIAM	Free Ion Activity Model
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FNB	Food and Nutrition Board (NAS)
GI	Gastrointestinal tract
HFO	Hydrous ferric oxide
HLA	Human leukocyte antigens
HSAB	Hard and soft acid and base
ICP-MS	Inductively coupled plasma-mass spectrometry
IEUBK	Integrated Exposure Uptake Biokinetic model
IRIS	Integrated Risk Information System
IUR	Inhalation Risk Unit
Kd	Partition distribution coefficient
Kow	Octanol-water partition coefficient
LC_{50}	Lethal concentration (for 50 percent of the study population)

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

MAP	Metals Action Plan
MCL	Maximum contaminant level
MPPD	Multipathway Particle Dosimetry Model
NAS	National Academy of Sciences
NASQAN	National Stream Quality Accounting Network
NOM	Natural organic matter
NRC	National Research Council
OM	Organic matter
OSWER	Office of Solid Waste and Emergency Response (EPA)
PBPD	Physiologically based pharmacodynamic
PBPK	Physiologically based pharmacokinetic
PBT	Persistent bioaccumulative toxic
PBTK	Physiologically based toxicokinetic
QSAR	Quantitative structure-activity relationship
RAGS	Risk Assessment Guidance for Superfund
RBA	Relative bioavailability
RDA	Recommended dietary allowance
RDDR	Regional Deposited Dose Ratio
RfC	Reference concentration
RfD	Reference dose
RTC	Report to Congress
SAB	Science Advisory Board
SEM	Simultaneously extracted metals
SHEDS	Stochastic Human Exposure and Dose Simulation model
SPC	Science Policy Council (EPA)
SRWG	Science and Research Working Group (SRWG) of the Non-Ferrous Metals Consultative Forum on Sustainable Development
STORET	Storage and Retrieval data system
TCLP	Toxicity Characteristic Leaching Procedure
TMDL	Total Maximum Daily Load
TRIM	Total Risk Integrated Methodology
TRV	Toxicity reference value
TSCA	Toxic Substances Control Act
U.S. EPA	U.S. Environmental Protection Agency
WER	Water-effect ratio
WHAM	Windermere Humic Aqueous Model
WHO	World Health Organization
WHO/IPCS	World Health Organization/International Programme on Chemical Safety

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PREFACE

Many U.S. Environmental Protection Agency (EPA or the Agency) programs are designed to develop guidelines on how to regulate metals. In this process, decisions can range from setting environmental release standards, to establishing protective levels in different environmental media, to setting priorities for programmatic or voluntary efforts. A fundamental input to the decision-making process for most EPA programs is an assessment of the potential risks to human health and the environment.

EPA's Science Policy Council (SPC) recognizes that metals present unique risk assessment issues. The SPC tasked an Agency workgroup, under the auspices of EPA's Risk Assessment Forum, the challenge of devising a Metals Action Plan (MAP) to establish a process for ensuring the consistent application of scientific principles to metals risk assessment. The MAP included brief descriptions of the Agency's current activities on metals, identified critical scientific issues that need addressing, and recommended the development of a metals risk assessment framework. The MAP stated that the Framework should offer general guidance to EPA programs for considering the various properties of metals, such as environmental chemistry, bioavailability, and bioaccumulation.

Because of the scientific complexity of metals-specific risk assessment, the Agency recognized the need to include stakeholders and the public in the Framework development process and to involve experts throughout the Agency. A stepwise process was initiated, beginning with the creation of MAP and continuing with framework development and review. Workshops and peer-review activities were conducted at regular intervals during development of the Framework to ensure that current, accurate science supports the program applications. To gain additional information, the Agency contracted for the development of issue papers on important topics in metals assessment. These activities, along with input from other federal agencies and review by EPA's Science Advisory Board (SAB), provided additional improvements to the Framework drafting process. Additional details on these activities are provided below.

MAP Stakeholder Input. In February 2002, MAP convened a meeting to gather stakeholder input to help EPA formulate the plan for developing the Framework for Metals Risk Assement. EPA solicited input on organization and content and received comments that were adopted into the document with the greatest practical extent. The meeting report and comments are available on EPA's Web site at

http://cfpub2.epa.gov/ncea/raf/recordisplay.cfm?deid=51737 and

http://cfpub2.epa.gov/ncea/raf/recordisplay.cfm?deid=51736.

Science Advisory Board Review. In September 2002, EPA's SAB reviewed the MAP and provided comments. By this point, MAP had some of the panel's recommendations are

summarized below; the full text of all recommendations is available at http://www.epa.gov/sab/pdf/ecl03001.pdf.

- The panel agreed that inorganic metals should be assessed differently from organic pollutants in a number of contexts. Metals are elements and, although they do not degrade, they have complex environmental chemistry. Moreover, some metals are essential for living organisms, and metals occur naturally in the environment.

- The panel agreed that chemical speciation, bioavailability, bioaccumulation, and toxicity are key issues in assessing the hazards of metals, with qualifications.

- The panel recommended consideration of stability and environmental residence times, as well as overall environmental chemistry, to determine temporal characteristics of metal hazards.

- The panel recommended greater emphasis on the combined effects of metals, including nutritional and toxicological considerations.

Issue Paper Topics and Science Questions. As part of the development of the Framework, issue papers were developed to discuss key scientific topics pertaining to metals. The issue paper authors were asked to expand on these topics, with focus on decision-making applications, Framework-specific uses, and research needs. The papers, available at http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=86119, address the following topics and primary questions:

- **Environmental chemistry.** How can environmental chemistry be better incorporated into assessments for inorganic metals?

- **Bioavailability and bioaccumulation of metals.** What methods or tools can be used now to reflect metal bioavailability? What scientifically based approaches can be used to determine metal bioaccumulation?

- **Metal exposure assessment.** What are the relevant exposure pathways for inorganic metals to humans and ecological endpoints?

- **Human health effects.** What populations are most susceptible to effects from inorganic metals? How should toxicity tests be conducted and interpreted, including issues of essential elements and dietary salts, among others?

- **Ecological effects.** What ecological system characteristics promote increased toxicity from metals?

Peer Consultation Workshop. A draft framework was completed in July 2004, and a peer consultation workshop was held from July 27-July 28 to seek input from expert scientists in the metals risk assessment field. Workshop participants were from academia; industry, state, federal, and Canadian agencies; and various EPA program offices. Stakeholder comments were

also received for consideration. Based on comments received at the workshop, the Agency contracted with a few workshop participants to explore several issues and insufficiencies identified in the human health and environmental chemistry discussions. The Framework draft was revised and made available for inter-Agency review.

Inter-Agency Review. Based on comments received, the framework was revised.

SAB Review and Public Comment. The SAB review was conducted in February 2005, and the final draft of the Framework for Metals Risk Assessment document was completed January 25, 2006. The SAB final report is available on the SAB Web site at http://www.epa.gov/sab/pdf/metals_sab-06-002.pdf. The SAB found that the framework covers the main areas of concern to risk assessors, that some technical corrections and additions were needed, and that the document should be restructured and revised to improve the clarity and precision of discussions. Based on these recommendations, the framework was revised to focus on principles and general metals assessment issues rather than tools.

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EXECUTIVE SUMMARY

The Framework for Metals Risk Assessment is a science-based document that addresses the special attributes and behaviors of metals and metal compounds to be considered when assessing their human health and ecological risks. The document describes basic principles to be considered in assessing risks posed by metals and is intended to foster consistency in how these principles are applied across the Agency's programs and regions when conducting these assessments. Although the audience for the Framework is primarily intended to be Agency risk assessors, it will also communicate principles and recommendations for metals risk assessment to the stakeholders and the public. This guidance will be used in conjunction with guidance developed by the programs and regions for use in site-specific risk assessments, criteria derivation, ranking or categorization and other similar Agency activities related to metals.

The purpose of this document is to present key guiding principles based on the unique attributes of metals (as differentiated from organic and organometallic compounds) and to describe how these metals-specific attributes and principles may then be applied in the context of existing EPA risk assessment guidance and practices. While organic compounds, for example, undergo bioaccumulation, there are unique properties, issues, and processes within these principles that assessors need to consider when evaluating metal compounds. Furthermore, the latest scientific data on bioaccumulation do not currently support the use of bioconcentration factors and bioaccumulation factors when applied as generic threshold criteria for the hazard potential of metals.

While the science surrounding the metals risk assessment principles continues to be studied intensively and evolving rapidly, some areas still lack sufficient information for a quantitative assessment to be carried out. Thus, specific approaches may become outdated or may otherwise require modification to reflect the best available science and others may be addressed only qualitatively until additional information becomes available. Regardless, the following principles are more generalized, fundamental properties of metals and should be addressed and incorporated into all inorganic metals risk assessments:

- Metals are naturally occurring constituents in the environment and vary in concentrations across geographic regions.
- All environmental media have naturally occurring mixtures of metals, and metals are often introduced into the environment as mixtures.
- Some metals are essential for maintaining proper health of humans, animals, plants, and microorganisms.
- Metals, unlike organic chemicals, are neither created nor destroyed by biological or chemical processes; although, these processes can transform metals from one species

to another (valence states) and can convert them between inorganic and organic forms.

- The absorption, distribution, transformation, and excretion of a metal within an organism, depends on the metal, the form of the metal or metal compound, and the organism's ability to regulate and/or store the metal.

This Framework document is not a prescriptive guide on how any particular type of assessment should be conducted within an EPA program office. Rather, it is intended to outline key metal principles and how they should be considered in existing human health and ecological risk assessment practices to foster consistency across EPA programs and regions. Chapter 1 identifies the purpose, audience, and scope of the Framework; includes a discussion of typical programmatic or regulatory contexts under which the Agency might undertake a metals risk assessment; and provides an overview of the metals principles. In particular, the context for risk assessment is an important factor in determining the type of analysis appropriate for a particular situation. To provide a context for discussion of the framework principles for metals, EPA has defined three general categories of assessments: national ranking and categorization, national-level assessments, and site-specific assessments. Each type of assessment can vary in level of detail from simple, screening analysis to complex, definitive assessments. Approaches and methodologies may be appropriate for some or all the risk assessment types and may be more or less applicable to screening or complex assessments. Here and elsewhere, the Framework acknowledges that data may not be available to implement all the steps in a metals risk assessment (e.g., lack of information about metal speciation in some environmental media), requiring use of assumptions and a discussion of how such uncertainty influences the risk outcome.

Chapter 2 reviews the human health and ecological risk assessment paradigm and applies the metals principles to each phase of the risk assessment process using assessment questions. The chapter presents a metals conceptual model showing the interrelationship between the metals or metal compounds of interest and the assessment process. Chapter 3 describes how environmental chemistry issues affect the assessment of metals. Chapter 4 describes how the metals principles should be considered when conducting human health risk assessments, and Chapters 5 and 6 describe how the metals principles should be considered in the context of aquatic and terrestrial risk assessments, respectively.

This document discusses scientific issues and scientific approaches. It is intended to foster the consistent application of methods and data to metals risk assessment in consideration of the unique properties of metals. The Agency will be analyzing the science policy implications and developing appropriate policy approaches that are protective of human health and the environment.

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The Framework is the result of contributions from a variety of individuals inside and outside the Agency. Their combined expertise and enthusiasm have improved the technical quality of the document and its applicability for various risk assessment activities.

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1. INTRODUCTION

Inorganic metals and metal compounds have unique characteristics that should be considered when assessing their risks. Some of these characteristics typically are not considered when assessing the risks of organic substances. For example, metals are neither created nor destroyed by biological or chemical processes; they are transformed from one chemical form to another. Native (zero valence) forms of most metals and some metal compounds are not readily soluble, and as a result, toxicity tests based on soluble salts may overestimate the bioavailability and toxicity of these substances. Some metals (e.g., copper [Cu], selenium [Se], and zinc[Zn]) are nutritionally essential elements at low levels but toxic at higher levels, and others (e.g., lead [Pb], arsenic [As], and mercury [Hg]) have no known biological functions. Because metals are naturally occurring, many organisms have evolved mechanisms to regulate accumulations, especially accumulations of essential metals. This metals risk assessment Framework identifies metals principles that are fundamental truths (or properties) of metals. The metals principles should be addressed and incorporated into inorganic metals risk assessments.

Metals Principles

- Metals are naturally occurring constituents in the environment and vary in concentrations across geographic regions.
- All environmental media have naturally occurring mixtures of metals, and metals are often introduced into the environment as mixtures.
- Some metals are essential for maintaining proper health of humans, animals, plants, and microorganisms.
- The environmental chemistry of metals strongly influences their fate and effects on human and ecological receptors.
- The toxicokinetics and toxicodynamics of metals depend on the metal, the form of the metal or metal compound, and the organism's ability to regulate and/or store the metal.

Because the majority of compounds assessed by the United States Environmental Protection Agency (EPA or the Agency) are organic substances, the various guidance documents provided for risk assessments of either human health or ecological receptors lack specificity on how to account for these and other metal attributes. This document attempts to fill this gap in current guidance.

1.1. PURPOSE AND AUDIENCE

The primary purpose of the Framework for Metals Risk Assessment is to identify key principles that should be addressed in any inorganic metals analysis and to provide EPA program

offices and regions with guidance on how to consider these principles in EPA risk assessment practices. Although the primary audience will be Agency risk assessors, the Framework will also communicate these principles to stakeholders and the public. The Framework relies on the draft Framework document, the issue papers, and Science Advisory Board (SAB) comments. The issue papers were developed, under EPA commission, to address key scientific topics pertaining to inorganic metals. The papers are available on EPA's Web site at http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=86119, which includes links to the draft framework (http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=88903). The SAB's comments are available at http://www.epa.gov/sab/pdf/metals_sab-06-002.pdf.

This Framework document has been developed to supplement previous guidance for use in site-specific risk assessments; criteria derivation, ranking, or categorization; and other similar Agency activities related to metals. The Framework is not a prescriptive guide on how any particular type of assessment should be conducted within an EPA program office. It is, however, intended to address issues that are unique to metals and frequently encountered when conducting a metals-specific risk assessment. This document does not address issues and methods that are common for both metals and organic compounds nor does it develop further guidance on issues that remain controversial or unresolved for assessments of risks from chemicals in general. Information on general risk assessment topics is available on EPA's Web site at http://cfpub.epa.gov/ncea/ and http://cfpub.epa.gov/ncea/raf/index.cfm.

The Framework is intended to be used for guidance only. It does not establish any substantive "rules" under the Administrative Procedure Act or any other law and will have no binding effect on EPA or any regulated entity. Rather, it represents a nonbinding statement of policy. EPA believes that the Framework provides a sound, up-to-date presentation of principles; provides guidance on how to consider these principles in assessing the risk posed by metals; and enhances application of the best available science in Agency risk assessments. However, EPA may conduct metals risk assessments using approaches that differ from those described in the Framework for many reasons, including, but not limited to, new information, new scientific understandings, and new science policy judgments. While the science surrounding metals risk assessment continues to be studied intensively and is evolving rapidly, some areas still lack sufficient information for a quantitative assessment. Thus, specific approaches may become outdated or may otherwise require modification to reflect the best available science and others may be addressed only qualitatively until additional information becomes available. Application of this Framework in future metals risk assessments will be based on EPA decisions that its approaches are suitable and appropriate. These judgments will be tested and examined through peer review, and any risk analysis will be modified as deemed appropriate.

1.2. METALS FRAMEWORK SCOPE

The Agency regulates metals and their inorganic and organometallic compounds (compounds exhibiting properties of both organic and metal compounds) because they have the potential to harm human health and the environment. The Agency's SAB has stressed the importance of environmental chemistry and its relevance to the assessment of both inorganic and organometallic compounds. However, the complexities of addressing all types of metal compounds within a single document would result in a framework that would be difficult to follow or to apply in specific cases. Because organometallic compounds exhibit properties common to both organic substances and metal compounds, the properties of both the organic moieties of these compounds and their components would need to be addressed. EPA has already developed frameworks and associated guidance documents for assessing properties of organic compounds. Therefore, this document addresses only the assessment issues associated with inorganic metal compounds. The Framework does discuss natural transformation pathways that form organometallic compounds and refers the reader to appropriate Agency documentation or research efforts related to relevant risk assessment issues.

Metals and Metalloids of Primary Interest

Aluminum	Manganese
Antimony	Mercury (inorganic)
Arsenic	Molybdenum
Barium	Nickel
Beryllium	Selenium
Boron	Silver
Cadmium	Strontium
Chromium	Tin
Cobalt	Thallium
Copper	Vanadium
Iron	Zinc
Lead	

In this Framework, the term "metals" refers to inorganic metals and metalloids that may pose a toxic hazard and are currently of primary interest to EPA. However, the principles and approaches set forth in the Framework are applicable to all metals. In some instances, metal-by-metal considerations are included, either as examples or as ways to highlight particular exceptions. Furthermore, in some cases, this document may discuss particular tools or methods that expand on a particular principle and its consideration in the context of EPA hazard and risk assessment. The discussions are intended to be illustrative and are not intended to provide a complete description of the applications and limitations of any particular tool or method, although proper citations to the open scientific literature are included. Nor does the Framework provide an exhaustive summary of all the tools and methods available to risk assessors, as this type of analysis is beyond the scope of this document.

1.3. METALS ASSESSMENT CONTEXT

The context for the risk assessment is a major factor in determining the type of analysis appropriate for any particular situation. The Agency conducts a variety of assessments, from

site-specific risk assessments to national criteria setting and ranking. To provide a context for discussion of the Framework principles for metals, this document has defined three general categories of metals assessments: national ranking and categorization, national-level assessments, and site-specific assessments. (See Figure 1-1 identifying the three categories of assessment in the context of the Agency's statutory authority.) As shown in the figure, national-scale and site-specific assessments can vary in level of detail—from simple screening analyses to complex definitive assessments. For example, in conducting a national-level screening analysis, EPA might undertake a screening-level review of a pesticide or new chemical under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) or the Toxic Substances Control Act (TSCA), and this may lead to a more definitive assessment if the screen cannot rule out a threat to health or the environment. Site-specific screening-level assessments might be sufficient to support an environmental impact statement, and a more complex analysis might be necessary as a part of a Superfund cleanup action. All three categories of assessments share common elements and rely on accurate information and knowledge about how metals behave in the environment and when they come into contact with humans or other organisms of concern. Metals have unique environmental and toxicological properties that may confound such assessments if they are not given consideration. Each of the three general assessment categories is discussed in more detail below.

1.3.1. National Ranking and Categorization

EPA may rank or categorize some chemicals based on their potential to cause risk to human health or the environment. Although there continue to be gaps in data to understanding the chemistry, environmental behavior, toxicity, and exposure potential for many chemicals, EPA is tasked with protecting and mitigating exposures and harmful effects associated with exposure to these chemicals. The Agency often is in a position, despite imperfect and incomplete databases, where methods and tools need to be developed to identify, characterize, and in some cases, rank and categorize chemicals.

With more than 80,000 chemicals currently listed on the TSCA inventory that can legally be used in commerce within the U.S. (not including pesticides or chemicals that are created as byproducts during industrial processes), the Agency needs a way to prioritize substances for review or action. Many of the statutes administered by EPA provide specific lists of chemicals that require consideration, but often those lists are based on information and analyses previously developed by EPA. In addition, the statutes generally provide for adding or deleting chemicals from the initial list on the basis of their potential threat to human health or ecological receptors. Consequently, a need exists for methods that rapidly screen chemicals for placement on lists or that prioritize potentially hazardous substances.

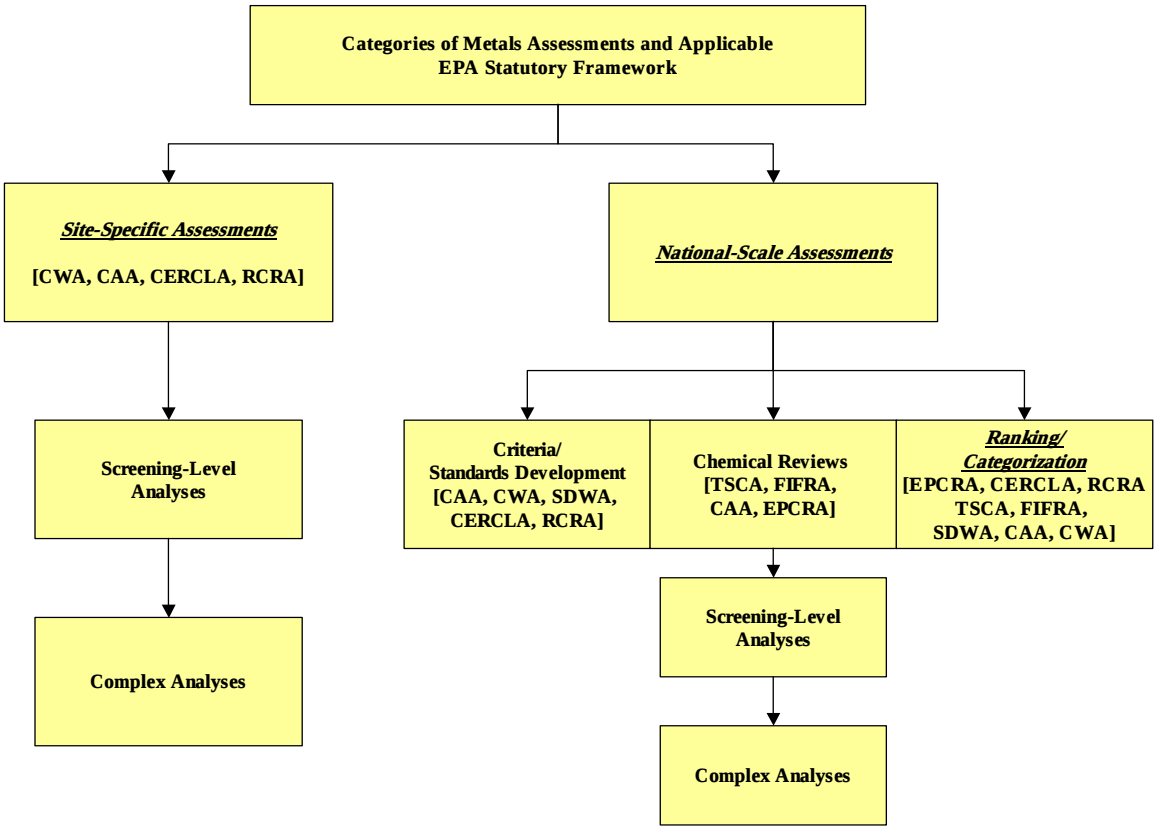


Figure 1-1. Categories of metals assessments under EPA statutory framework.

Some of the ranking and categorization methods used by EPA involve identifying certain attributes of chemicals that can then be used as indicators of potential human health or ecological risk. Example attributes include human and ecological toxicity, production volume, quantities released to the environment, persistence in the environment, mobility in the environment as indicated by volatility or solubility, and potential to bioaccumulate in the food chain. Other methods, which may be less quantitative, rely more on a combination of expert judgment, stakeholder input, and availability of information to determine the priority or categorization of chemicals for decision making or other action. Examples of programs where EPA identifies or categorizes chemicals for priority action based on human health or ecological concerns include the following:

- Selecting chemicals for the Agency's Toxicity Characteristic regulation (40 CFR 261.24) that defines hazardous wastes
- Establishing reporting thresholds for spills of hazardous materials under Superfund
- Setting priorities for revisions to the Ambient Water Quality Criteria (AWQC)

- Listing chemicals under the Toxics Release Inventory
- Determining priorities for developing drinking water standards
- Setting priorities for hazardous air pollutant data collection and assessment, and
- Setting priorities for reviewing existing chemicals under TSCA.

This list of needs for ranking or categorizing chemicals is not comprehensive but is illustrative of the activities that EPA conducts in this regard. In addition, the Agency may set national standards and guidelines for specific chemicals, including metals, as described in the next section.

Ambient Water Quality Criteria

EPA's Office of Water is charged with developing Ambient Water Quality Criteria (AWQC) to support the Clean Water Act goals of protecting and maintaining the physical, chemical, and biological integrity of U.S. waters. Examples of chemical-specific criteria include those designed to protect human health, aquatic life, and wildlife. Although AWQC are typically derived at a national level, there is a long history behind the development of methods to accommodate site-specific differences in metals bioavailability. For example, since the 1980s, aquatic life criteria for several cationic metals have been expressed as a function of water hardness to address the combined effect of certain cations (principally calcium and magnesium) on toxicity. Recognizing that water hardness adjustments did not account for other important ions and ligands that can alter metals bioavailability and toxicity, EPA developed the water effect ratio (WER) procedure as an empirical approach for making site-specific bioavailability adjustments to criteria (U.S. EPA, 1994a). This approach relies on comparing toxicity measurements made in site water with those made in laboratory water to derive a WER. The WER is then used to adjust the national criterion to reflect site-specific bioavailability. More recently, the Office of Water has been developing a mechanistic-based approach for addressing metals bioavailability using the Biotic Ligand Model (BLM) (Di Toro et al., 2001; Santore et al., 2001; U.S. EPA, 2000b). This model, discussed in Chapter 5, predicts acute toxicity to aquatic organisms on the basis of physical and chemical factors affecting speciation, complexation, and competition of metals for interaction at the biotic ligand (i.e., the gill in the case of fish). The BLM has been most extensively developed for copper and is being incorporated directly into the national copper aquatic life criterion. The BLM is also being developed for use with other metals, including silver. Conceptually, the BLM has appeal because metals criteria could be implemented to account for predicted periods of enhanced bioavailability at a site that may not be captured by purely empirical methods, such as the WER.

1.3.2. National-Level Assessments

National-level assessments may be performed when the Agency is setting media standards or guidelines for chemicals (e.g., Maximum Contaminant Levels [MCLs], National Ambient Air Quality Standards, AWQC, Superfund soil-screening levels) or when the Agency is using risk assessments to establish controls for environmental releases from industry or other sources (e.g., hazardous waste listings under the Resource Conservation and Recovery Act, residual risk determinations under the Clean Air Act, and pesticide registrations). These assessments can vary in level of detail from simple, screening analysis to complex, data-intensive definitive assessments. EPA also is charged with establishing controls on environmental releases based on the best available treatment technologies (e.g., maximum achievable control technology for air

emission and best available treatment technology for surface water discharges and for hazardous wastes). However, even though the standards are based on technological achievability, the Agency typically performs risk assessments in support of these regulations to help inform management decisions and for use in cost/benefit analyses.

Hazardous Waste Listing Determination

Under the Resource Conservation and Recovery Act, EPA is required to make formal decisions on whether to designate certain specific industry waste streams as hazardous. For waste streams that are listed as hazardous, the generators and handlers of those wastes must comply with a comprehensive set of management and treatment standards. In determining whether to list a waste as hazardous, the Agency evaluates the ways in which that waste is currently being managed or could plausibly be managed by the generators and handlers of the waste. The Agency also assesses the physical and chemical composition of the waste. Based on the waste characteristics and management practices, EPA then conducts an analysis to determine whether potentially harmful constituents in the waste might be released and transported to human or ecological receptors. In conducting these analyses, the Agency evaluates the potential for constituents in the waste material to be released to air, surface water, soil, and ground water. It then models the fate and transport of those constituents to potential receptors.

Differing environmental conditions across the country affect the biogeochemistry of metals, making it difficult to set single-value national criteria that represent the same risk level across the whole country (national standards that apply at the point of exposure, such as MCLs, are less affected by these factors). To conduct such assessments, the Agency commonly undertakes several approaches. One is to define one or more exposure scenarios and to conduct a relatively detailed analysis. The difficulty in this approach is in selecting the appropriate scenario; typically, the Agency tries to ensure that the scenario is sufficiently conservative to be protective of the population at highest risk (such as populations exposed above the 90th percentile) without being so conservative that the standards are protective of hypothetical individuals whose calculated risks are above the real risk distribution. In selecting the appropriate scenario, the Agency needs to consider all the factors that may affect potential risk, including environmental factors affecting the fate, transport, exposure potential, and toxicity of the chemicals released.

Another common approach for a national assessment or criteria derivation is to conduct a probabilistic analysis (such as a Monte Carlo analysis), wherein the variability of the key factors is described by parameter distributions used as inputs to the probability analysis procedure. The result is an integrated distribution of potential risk levels. The difficulties related to conducting this kind of analysis are in developing appropriate distributions for each parameter and in ensuring that adequate attention is paid to potential correlations among key parameters. These correlations often are more complex and difficult to describe for metals than for organic compounds.

1.3.3. Site-Specific Assessments

Site-specific assessments are conducted to inform a decision concerning a particular location and may also support some national regulatory decisions. They can also vary in detail from screening-level to complex, definitive-level analyses.

- Determining appropriate soil cleanup levels at a Superfund site
- Establishing water discharge permit conditions to meet AWQS, and
- Determining the need for emission standards for sources of hazardous air pollutants.

Establishing Water Discharge Permit Conditions

The Clean Water Act establishes a two-tier process for setting water discharge permit conditions. First, all dischargers must meet the technology-based effluent guidelines limitations requirements. Second, if those limitations are not adequate to allow the receiving stream to achieve its designated water quality standards (WQS), then more stringent limits are developed to ensure that those standards are met. WQS are established by the states and consist of a designated use for the water body and a set of criteria for individual chemicals that allow that use to be achieved. EPA has published national water quality criteria values for the states to use as guidance in setting their standards.

Once the standards that include the criteria have been established and it has been determined that the effluent guidelines alone will not be sufficient to allow those criteria to be met, the state prepares a wasteload allocation for all the dischargers to that stream segment, including, where appropriate, the nonpoint source discharges. The wasteload allocation generally consists of modeling the potential impact on the stream from each discharge of the chemicals of concern and then setting the allowable discharges to ensure that the criteria for the chemicals are met. The modeling process can be quite complex, potentially taking into account the interactions of the ambient stream conditions with the chemicals in the discharge, including dilution, chemical transformations, degradation, settling, resuspension, and other processes. For metals, stream characteristics such as pH, organic content, suspended solids levels, and numerous other factors can significantly affect how the metal will behave and affect aquatic life in the stream segment. Therefore, it is important to understand these processes in conducting the wasteload allocation.

An accurate site-specific assessment for an inorganic metal requires knowledge of the form (or forms) of the metal as it enters the environment, the environmental conditions affecting the metal (climatological conditions, soil geochemistry, water and sediment chemistry, etc.), the existence of plants and/or animals in which the metal might bioaccumulate as well as the uptake factors for whatever form(s) the metal may be in, plausible pathways and routes of exposures to the human or ecological receptors, and the effect the metal will have on target organisms in whatever form in which it reaches that organism and its target organ/system. Although many of these same principles also affect the risk potential of organic chemicals, models for predicting fate, transport, and toxic properties are generally better defined for organic chemicals than for metals.

1.4. KEY PRINCIPLES TO CONSIDER IN METALS RISK ASSESSMENT

One of the purposes of this Framework is to present key principles that differentiate inorganic metal compounds from other chemicals. These key principles, defined in subsequent subsections, warrant careful consideration when assessing the risks to human health and the environment associated with exposures to metals or metal compounds and should be addressed and incorporated into metals risk assessments to the extent practicable. For example, it is known that certain metal compounds bioaccumulate in human tissues and that this bioaccumulation can be related to the metals' toxicity (SAB, 2006). Contributors to the Metals Action Plan (MAP), members of the SAB, and external stakeholders, along with various contributors to and authors of this Framework, have discussed these metals principles for consideration in the assessment of metals. They are visible throughout this document. In Chapter 2, they are broadly discussed in the context of the Agency's risk assessment process. In Chapters 4 through 6, they are discussed in the context of human health, aquatic, or terrestrial risk assessment processes. The remainder of this chapter discusses these principles in more detail, focusing on the unique properties of metal compounds and why these principles are important for metals risk assessments.

1.4.1. Metals are Naturally Occurring Constituents in the Environment and Vary in Concentrations Across Geographic Regions

Implications for risk assessment include the following:

- Humans, other animals, and plants have evolved in the presence of metals and are adapted to various levels of metals. Many animals and plants exhibit geographic distributions that reflect variable requirements for and/or tolerance to certain metals. These regional differences in requirements and tolerances should be kept in mind when conducting toxicity tests, evaluating risks, and extrapolating across regions that differ naturally in metals levels.

- As a result of industrialization, current levels of metals may be elevated relative to levels occurring naturally. Depending on the purpose of the risk assessment, care should be taken to understand and distinguish among naturally occurring levels, current background levels (i.e., natural and anthropogenic sources), and contributions to current levels from specific activities of concern.

- Because the diets of humans and other animals are diverse, there may be wide variability in the dietary intake of some metals (e.g., in seafood), resulting in both temporal variability (e.g., spikes after a seafood meal or with life stage) and geographic or cultural variability.

1.4.2. All Environmental Media have Naturally Occurring Mixtures of Metals and Metals are Often Introduced into the Environment as Mixtures

Implications for risk assessment include the following:

- Some metals act additively when they are present together, others act independently of each other, and still others are antagonistic or synergistic. Such interactions are important aspects of assessing exposure and effects.

- Interactions among metals within organisms may occur when they compete for binding locations on specific enzymes or receptors during the processes of absorption, excretion, or sequestration, or at the target site.

- The presence of and amount of other metals are important when conducting and interpreting laboratory tests.

1.4.3. Some Metals are Essential for Maintaining Proper Health of Humans, Animals, Plants, and Microorganisms

Implications for risk assessment include the following:

- Adverse nutritional effects can occur if essential metals are not available in sufficient amounts. Nutritional deficits can be inherently adverse and can increase the vulnerability of humans and other organisms to other stressors, including those associated with other metals.

- Excess amounts of essential metals can result in adverse effects if they overwhelm an organism's homeostatic mechanisms. Such homeostatic controls do not apply at the point of contact between the organism and the environmental exposure.

- Essentiality thus should be viewed as part of the overall dose-response relationship for those metals shown to be essential, and the shape of this relationship can vary among organisms. For a given population, "reference doses" designed to protect from toxicity of excess should not be set below doses identified as essential. Essential doses are typically life-stage and gender specific.

1.4.4. The Environmental Chemistry of Metals Strongly Influences Their Fate and Effects on Human and Ecological Receptors

Unlike organic chemicals, metals are neither created nor destroyed by biological or chemical processes. However, these processes can transform metals from one species to another (valence states) and can convert them between inorganic and organic forms. Metals also are present in various sizes, from small particles to large masses. Implications for risk assessment include the following:

- The form of the metal (chemical species, compound, matrix, and particle size) influences the metal's bioaccessibility, bioavailability, fate, and effects.

- The form of the metal is influenced by environmental properties, such as pH, particle size, moisture, redox potential, organic matter, cation exchange capacity, and acid volatile sulfides.

- Certain forms of metals are used for evaluating exposure and effects. For example, the free metal ion is used for exposure assessments based on competitive binding of metal to specific sites of action.

- Metals attached to small airborne particles are of primary importance for inhalation exposures, although a few metals and metal compounds may exist as vapors (e.g., mercury).

- Information developed on the fate and effects of one form of a metal may not be directly applicable to other forms.

- Organometallic forms have different characteristics from inorganic metals and metal compounds, and the same general principles and approaches for risk assessment do not apply.

1.4.5. The Toxicokinetics and Toxicodynamics of Metals Depend on the Metal, the Form of the Metal or Metal Compound, and the Organism's Ability to Regulate and/or Store the Metal

These processes are often highly dynamic (e.g., vary according to exposure route and concentration, metal, and organism) and thus exert a direct influence on the expression of metal toxicity. Implications for risk assessment include the following:

- Certain metal compounds are known to bioaccumulate in tissues and this bioaccumulation can be related to their toxicity.

- The latest scientific data on bioaccumulation do not currently support the use of bioconcentration factor (BCF) and bioaccumulation factor (BAF) values when applied as generic threshold criteria for the hazard potential of inorganic metals in human and ecological risk assessment (e.g., for classification as a persistent bioaccumulative toxic [PBT] chemical).

- Single value BAF/BCFs hold the most value for site-specific assessments when extrapolation across different exposure conditions is minimized.

- For regional and national assessments, BAF/BCFs should be expressed as a function of media chemistry and metal concentration for particular species (or closely related organisms).

- Trophic transfer can be an important route of exposure for metals, although biomagnification of inorganic forms of metals in food webs is generally not a concern in metals assessments.

- Kinetic-based bioaccumulation models (e.g., DYNBAM) have been shown to accurately describe bioaccumulation resulting from different exposure routes for various metals and aquatic organisms and should be considered as alternatives to the BCF/BAF approach when appropriate data are available.

- Many organisms have developed physiological or anatomical means for regulating and/or storing certain metals up to certain exposure levels such that metals may not be present in organisms in a concentration, form, or place that can result in a toxic effect.

- The organ or tissue in which metal toxicity occurs may differ from the organ or tissue(s) in which the metal bioaccumulates and may be affected by the metal's kinetics. Target organs may differ by species, mainly owing to differences in absorption, distribution, and excretion. Effects at the portal of entry to an organism are less dependent on kinetic processes internal to an organism.

- Both the exposure route and the form of a metal can affect the metal's carcinogenic potential (assessed in the context of human health risk assessment) and its noncancer effects.

- Sensitivity to metals varies with age, sex, pregnancy status, nutritional status, and genetics (due to genetic polymorphisms).

2. FRAMEWORK FOR METALS RISK ASSESSMENT

The following discussion addresses issues that are unique to inorganic metals and routinely encountered during the inorganic metals risk assessment process. Discussions of issues generic to any chemical risk assessments are kept to a minimum because these are dealt with in other framework and guidance documents (e.g., U.S. EPA, 2003a, 2000a, 1998a; http://www.epa.gov/ncea/ and http://www.epa.gov/ncea/raf).

This chapter provides an overview of the risk assessment phases and assessment questions. Environmental chemistry issues and their implication in the assessment of inorganic metals are also discussed. The chapter is organized around the overall risk assessment paradigm. (See Figure 2-1, which broadly illustrates the overall risk assessment/risk management process and identifies some metals-specific considerations in the problem formulation and analysis steps.) An effective risk assessment for metals will account for the unique aspects of metals that differentiate them from other substances early and throughout the risk assessment process.

For assessments of human health or ecological risks at national, regional, or site-specific scales, the metals principles can be translated into sets of assessment questions. As appropriate, the risk assessor can use these questions to meet the needs of the assessment. The risk assessor should consider these questions throughout the risk assessment process; however, they are especially important in focusing the assessment during the Planning and Problem Formulation phase. Suggested assessment questions are given within this Framework for Problem Formulation, Analysis, and Risk Characterization. These questions are not exhaustive but provide the risk assessor with a feel for the proper questions to ask.

2.1. HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT: PLANNING AND PROBLEM FORMULATION

Planning and Problem Formulation are critically important for both human health and ecological risk assessments (U.S. EPA, 2003a, 2000a, 1998a). The concepts embodied in Planning and Problem Formulation are valuable starting points for any risk assessment involving metals. Planning and Problem Formulation provide an opportunity for initial consideration of the metals' characteristics and their chemistry. These considerations, along with other aspects of the assessment, contribute to the development of a conceptual model that conveys the important elements of the metals risk assessment.

Although Problem Formulation is not explicitly included in the human health risk assessment (HHRA) paradigm, as it is in the ecological risk assessment guidelines, current practice is to consider many of the issues in the planning stages that the assessor anticipates will be incorporated later in the HHRA. This is particularly true for more complex assessments that

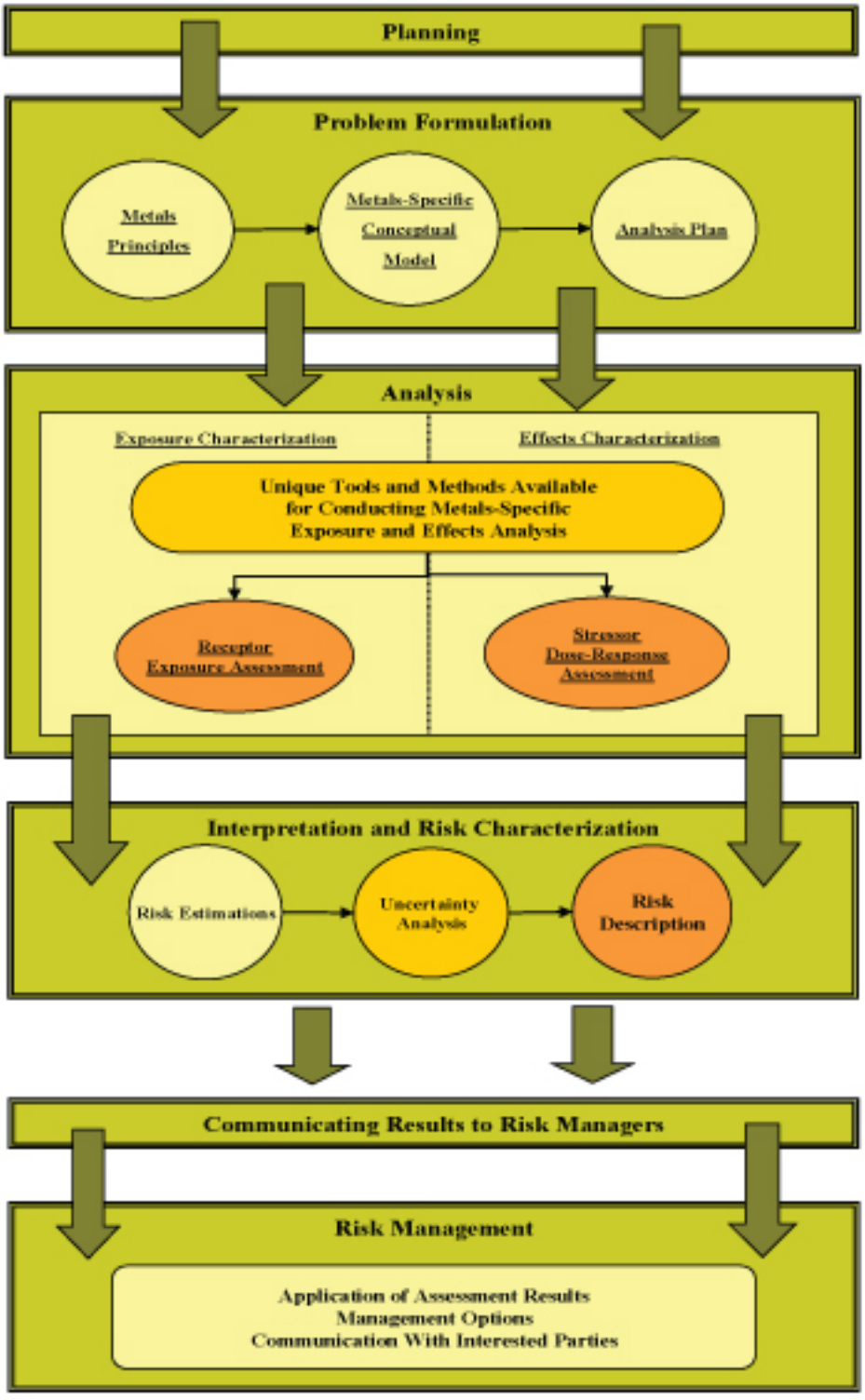


Figure 2-1. Risk assessment/risk management process for metals.

consider multiple metals, pathways/routes of exposure, etc., as is advised in EPA's Framework for Cumulative Risk Assessment (U.S. EPA, 2003e). These planning and scoping activities may include

- defining the geographic scale and scope (site, national-scale, etc.) of the assessment
- identifying potentially exposed populations and sensitive subpopulations
- characterizing exposure pathways and exposure routes (conceptual model)
- describing how exposure will be assessed
- determining how hazard and the receptor's dose-response will be assessed, and
- describing how risks will be characterized.

For metals, the type of assessment (i.e., screening or detailed) and the scale of the assessment (i.e., site specific, regional, or national) will determine how information on metals can be applied in the assessment. Site-specific assessments will involve only a single geographical area of concern and, therefore, can incorporate locally relevant aspects of environmental chemistry, background concentrations, and species sensitivities. For regional and national-scale assessments, more general assumptions about the form of the metal in the environment, deposition pathways, uptake and bioavailability parameters, and sensitive species or subpopulations are useful. These general assumptions frequently produce results that are conservative in their assumptions in an effort to be protective of sensitive species or locations. Regardless, the key principles in metals risk assessment should be considered in all risk assessments.

Translating the Metals Assessment Principles into Assessment Questions

Translating the metals principles into assessment questions should be stressed during planning and problem formulation. This step helps ensure that the principles have been appropriately considered.

For metals risk assessment, the risk assessor should consider the following examples of questions that should be considered during the planning and scoping of the Problem Formulation phases:

Background Concentrations

- How should background (natural and anthropogenic) levels for metals be characterized for the selected spatial scale of the assessment?

- Is ecoregion-specific information available or is the use of state averages, or distributions, compatible with the level of ecological relevance and certainty required by the risk analysis?

- For ecological risk assessments, are acclimation, adaptation, and tolerance data for organisms of concern available and are these issues being considered?

Mixtures and Interactions

- How will interactions affecting uptake and systemic effects be considered?
- Will issues be considered such as reduction of reactivity and increase in mobility by organic compounds that form complexes with metals and possible increases in toxic effects of organic compounds that form lipophilic complexes with metals?
- Will interactions with other metals and with organics (e.g., As and polycyclic aromatic hydrocarbons) be addressed?

Essentiality

- Are nutritional deficits, which can be inherently adverse and can increase the vulnerability of humans and other organisms to other stressors, be included in the assessment?
- How will both toxicity and deficiencies of essential metals be characterized?

Forms of Metals

- Since environmental chemistry is a primary factor influencing metal speciation and subsequent transport, uptake, and toxicity, how will it be included in the risk assessment?
- How will environmental conditions (e.g., pH and oxidation-reduction reactions) be addressed to determine metal speciation and mobility?

Toxicokinetics/Toxicodynamics of Metals

- What metal-related responses are of most concern in the health risk assessment?
- Which sensitive subpopulations should be considered for each metal of concern?
- How will biotic and abiotic factors that influence the bioavailability and bioaccumulation of metals be incorporated into the risk assessment?
- How will environmental factors that affect metal speciation and metabolic capacity of biota to regulate internal metal concentrations (homeostatic controls) be accounted for when calculating the bioaccumulation potential of metals?

2.2. METALS CONCEPTUAL MODEL

The relationships between the sources, exposure, and effects of metals to human and ecological receptors are complex and often are specific to a particular site, environmental condition, and receptor organism. Because metals are naturally occurring substances that undergo extensive biogeochemical cycling (i.e., are not destroyed but change form), transition functions between environmental loadings, media concentrations, exposed receptors, and the

final organismal or ecosystem responses are affected by natural processes to a much greater extent than those that occur with xenobiotic organic contaminants. The assessor should identify these transition functions in the conceptual model for all metals assessments.

The generic conceptual model depicted in Figure 2-2 shows the interrelationship between the metals or metal compounds of interest and the health risk assessment process. It is a representation of the actual and potential, direct and indirect relationships between stressors in the environment and exposed humans (or particular subpopulations) or ecological entities. The conceptual model depicts possible pathways from sources of metals and typical ways in which risk is assessed (e.g., on the basis of media concentrations, calculated dose, or residues in tissues). This model follows the same format as a typical chemical assessment, but it identifies areas (primarily in the transition states between environmental compartments) where metal-specific issues require additional consideration. For simplicity, the numerous environmental or biological processes that influence the predominant route of exposure or the physical/chemical properties of the metal compounds are not depicted in this model, but such processes would be used as inputs to models developed for specific assessments. The bidirectional arrows represent the fact that the transition functions (models) can be applied in a prospective manner (i.e., in a left-to-right direction to determine risks associated with a given load or exposure) or in a retrospective manner (in a right-to-left direction to determine the load or exposure associated with a predetermined level of risk). The latter is usually done for generating human and ecological quality criteria expressed as media concentrations.

The goals and scope of a health risk assessment, in addition to the availability of data, methods, and resources, are among the most important factors that determine the extent to which the key principles specific to metals (given in Section 1.4) can be incorporated into an assessment. Generally, health risk assessment endpoints are selected during the Problem Formulation phase of a risk assessment based on their relevance to risk management goals, societal values and laws, known adverse effects of metals, and endpoints of importance to stakeholders. Risk assessors will incorporate the metals principles to a lesser extent in screening-level assessments than in detailed risk assessments. Site-specific assessments can account for more metal-specific processes (particularly environmental chemistry) than can national-level assessments that require generalization across multiple ecoregions. Therefore, it is recommended that, when appropriate, regional- or national-level ecological risk assessments be subdivided into metal-related ecoregions, referred to as *metalloregions* (McLaughlin and Smolders, 2001), such that protection levels, mitigation goals, and ranking results will be appropriate for the suite of species naturally present within each type of controlling environment. This is directly analogous to the use of ecoregions when establishing water quality criteria (Griffith et al., 1999). The Problem Formulation phase of the assessment should clearly identify whether a regional approach is being used and, if so, how the metalloregions are defined in terms of species composition and environmental controlling factors.

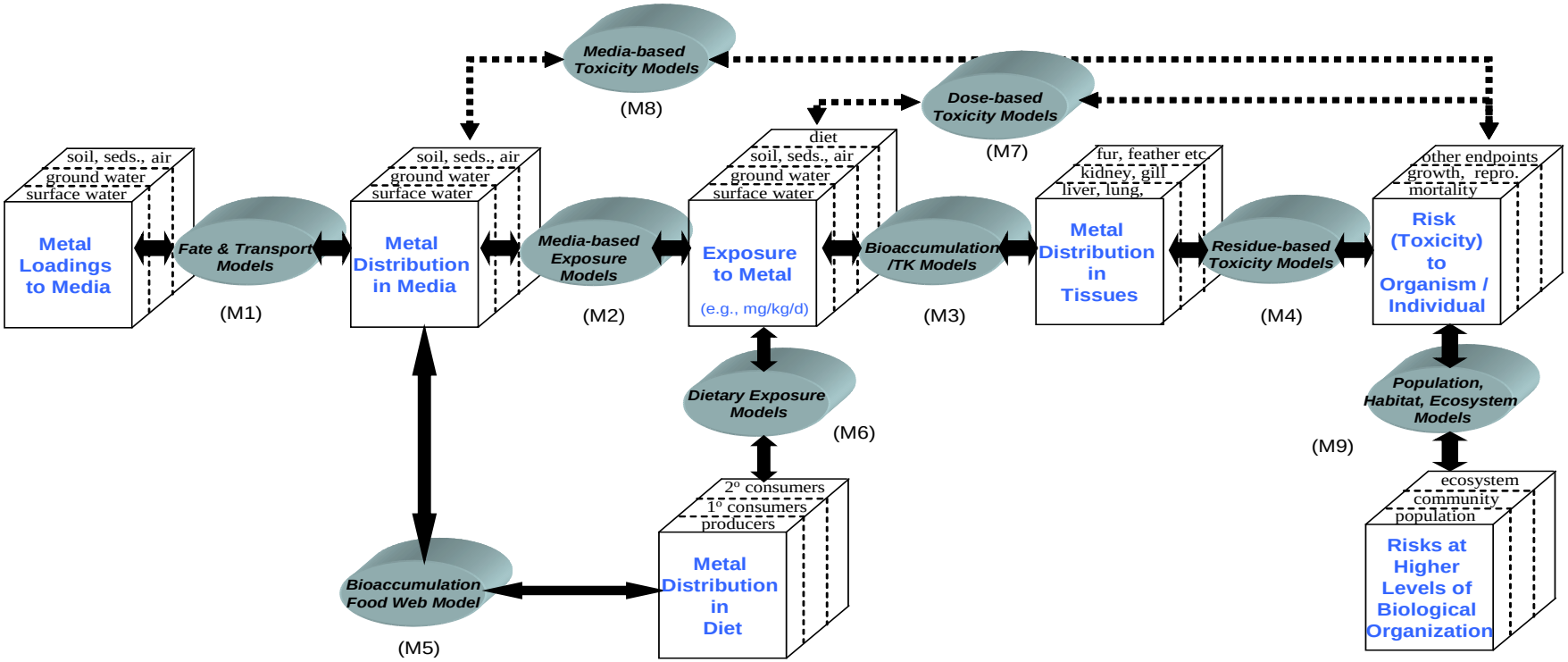


Figure 2-2. Generic conceptual model for metals risk assessment.

This concept of regional-based ecological assessments is significantly less important in *human health* assessments. In these assessments, the environmental controlling factors (pH, water hardness, etc.) may be important determinants in exposure calculations for dietary or drinking water exposures. However, **to our knowledge**, humans have not adapted to particular areas of metal enrichment or impoverishment but, rather, choose to live in all environments. Therefore, the differences in human sensitivity that should be considered are not geospatially correlated. Rather, the assessor should strive to identify potentially sensitive subpopulations, such as the very young or the elderly, subpopulations with genetic predispositions to metal sensitivity (e.g., Wilson's disease), or other similar groups. Again, the scope of the Problem Formulation phase should clearly address whether the risk results will be applied on a population-wide basis, such that protection is afforded to the most sensitive individuals, or whether these groups will be given additional scrutiny and separate risk analyses, such that results will be applicable only to the general population.

Figure 2-2 identifies areas in the conceptual model that stand out as metal-specific issues as the transitions between environmental loadings, media concentrations, exposure receptors, and the final organismal or ecosystem risk. Because metals are naturally-occurring substances with which organisms have evolved, it is particularly important to incorporate the natural processes that affect metal mobility, speciation, biogeochemical cycling, and sequestration into the health risk assessment. These may differ in details or approach, depending on the environment of concern (water, land, and air), the final receptor organisms (humans, animals, and plants), and the management goal (i.e., whether the management goal is the health of individuals or the maintenance of populations or communities). However, the same basic concepts always arise, regardless of the assessment context.

The conceptual model identifies the following issues, indicates the point within the health risk assessment process where they occur, and helps direct the remainder of the health risk assessment.

- **M1: Fate and transport models.** The partitioning and biogeochemical cycling of metals into the various environmental media from the loading source depend on the physical properties of the initial form of the material and the particular chemistry of the receiving environment. Fate and transport models are useful for estimating metal speciation, transition kinetics, partitioning, deposition, and potential resuspension within the context of environmental levels of the metal and other inorganic substances. These can be very detailed for site-specific assessments, or they can provide a potential range of processes that might occur over large, regional scales for assessments of a more generic nature (e.g., criteria development or ranking schemes). Reviews by Paquin et al. (2003), Allen (2002), and EPA (1997a) include up-to-date information with regard to the availability of models appropriate for use in evaluating fate and transport of metals in aquatic environments (see Chapter 3 on environmental chemistry).

- **M2: Media-based exposure models.** Media-specific exposure models are mathematical functions used to calculate the exposure of the organism to metals directly from abiotic media (i.e., excluding the food web). Estimating the uptake of metals from environmental media into biota follows many of the same processes used for organic substances, such as understanding dietary preferences, ingestion rates, inhalation rates, and movement patterns. Of particular concern with metals health risk assessments is accounting for the differing bioavailability of metal species to organisms from different environmental media. Exposure to existing environmental levels of metals is another issue of considerable importance in this modeling step. Exposure assessment issues are considered separately for human health, aquatic, and terrestrial receptors (see Chapters 3, 4, and 5, respectively).

- **M3: Bioaccumulation and toxicokinetic (TK) models.** Many organic substances require metabolic activation to become toxic or, conversely, to be detoxified and excreted. Metals do not. Metals may form complexes with proteins or other carrier molecules for distribution to target organs or for sequestration and excretion. Their bioaccumulation is tissue-specific (e.g., cadmium [Cd] in kidneys). The natural occurrence of metals has led to the development of specific mechanisms for uptake, metabolism, distribution/storage, and excretion of metals by organisms. These processes can impact the use and interpretation of bioaccumulation data and the toxicity of bioaccumulated metal.

- **M4: Residue-based toxicity models.** If risk to the organism(s) of concern is to be based on an estimate of internal dose, then information about the relationship of whole-body (or target organ) residue levels to toxic responses should be reviewed by the assessor, either from empirical data or physiologically based toxicokinetic (PBTK) models. Because of the processes discussed in the previous paragraph, this can be particularly challenging for inorganic metals. Metal speciation in the exposure matrix can especially influence this relationship because uptake and organ distribution kinetics are likely to differ. When available, critical body residues (CBRs) can be used to reduce uncertainties in health risk assessments because they account for site-specific bioavailability and multiple exposure pathways. However, CBRs for metals can vary widely depending on exposure pathway (food vs. water), rate of accumulation relative to the detoxification and sequestration processes, and form of bioaccumulated metal. Establishment of a valid residue-response relationship is critical for successful application of CBRs (see Sections 5.3 and 6.3).

- **M5: Bioaccumulation/food web model.** Movement of metals through the food web is complicated by factors of bioaccessibility, bioavailability, essentiality, regulation of metals (uptake and internal distribution), detoxification, and storage as well as accumulation and the natural adaptive capacity of organisms. While the ability to quantitatively address all these factors may be limited at present, the assessor should at least qualitatively address the potential impacts. Bioaccumulation and trophic transfer of metals does occur. However, biomagnification (i.e., increases in concentration through multiple levels of the food web) is rare, with the exception of certain organometallic compounds, such as methyl mercury, that can biomagnify many orders of magnitude in the aquatic food chain. Discussions of methods for estimating bioaccumulation in aquatic and terrestrial food webs are found in Sections 5.2.5.3 and 6.2.5.2, respectively.

- **M6: Dietary exposure models.** The assessor must carefully consider the bioavailability of metals from food items in models that estimate dietary exposure to metals. In ecological risk assessments, the wide variation in feeding modes and digestive physiology across species limits the ability to make generalizations with metals. Generalizations require knowledge of dietary preferences, trophic structure of the community, and ingestion and absorption rates. In human health risk assessments, the assessor should consider regional, social, and religious dietary preferences. Although this node of the conceptual model differs very little from risk assessment approaches for organic substances, some metal-specific generalities about the relative importance of exposure pathways can be applied to focus (and simplify) the process. For example, the highest accumulation of metals in plants generally occurs in the roots, and, except for hyperaccumulator species, most plant trophic transfer rates can be assumed to be <1. Therefore, direct toxicity to herbivores is less likely than for insectivores or from other dietary pathways, and risk to humans from most fruits and vegetables (except roots or green, leafy vegetables) is low. On the other hand, plants are quite sensitive to some metals and may die before achieving levels high enough to be toxic to animals, thereby affecting them indirectly through reduction in food availability. A discussion of dietary exposure assessment issues is found in Sections 5.2 and 6.2 for aquatic and terrestrial ecological receptors, respectively, and in Section 4.2.5.2 for humans.

- **M7: Exposure-based toxicity model.** Calculation of an external dose (oral intake, gill binding, etc.) for comparison with toxicity thresholds may depend on information about relative bioavailability (RBA), speciation of the metal or metal salt, dietary preferences and rates, environmental concentrations, essentiality, and metal interactions. Toxicity threshold considerations should be based on comparable information, such as appropriate metal species in exposure media, similarly acclimated or adapted organisms, similar exposure routes, and appropriate combinations of essential metals. Chemical equilibrium models such as MINTEQA2 (Brown and Allison, 1987) may be useful for characterizing the species of metal that is present in particular media, making exposure and effect comparisons more comparable. This forms the basis of the biotic ligand model (BLM) approach (Di Toro et al., 2001; Santore et al., 2001; Paquin et al., 1999) to defining acute aquatic toxicity.

- **M8: Media-based toxicity model.** This health risk assessment model compares environmental concentrations with organism response functions without calculating a body burden or internal dose. It is used more frequently for aquatic and soil-dwelling organisms, less frequently for wildlife, and very infrequently for human health assessments. Consideration of RBA, trophic transfer rates, dietary preferences, existing environmental concentrations, and organism adaptations is important for a metals assessment.

- **M9: Population, habitat, ecosystem models.** Assessors who carry out Ecological risk assessments often ask questions related to population growth, habitat change, or ecosystem functions in addition to questions related to risks to individual organisms. Most of the models and approaches are similar for both metal and organic substances. However, metals and other inorganic substances are among the fundamental determinants and delimiters of ecoregions (in conjunction with climate, elevation, and

day length associated with latitude). Therefore, knowledge of background levels and the adaptation of organisms to differing metal levels are essential in developing appropriate risk factors for naturally occurring species.

In summary, the conceptual model lays out a series of working hypotheses about how the metal(s) of concern might move through the environment to cause adverse effects in humans or ecological systems. These hypotheses are examined through data analyses, models, or other predictive tools to determine the probability and magnitude of the occurrence of unwanted effects. The approaches used to accomplish this assessement are discussed in general within various Agency risk assessment guidance documents.

2.3. ASSESSMENT PHASE

The assessment phase of a health risk assessment is the process of estimating exposure and understanding the dose-response relationship between biota and the chemical(s) of interest. The additional metals-specific factors should be considered during this phase. As with any assessment, at the beginning of the Analysis phase, the assessor should critically examine the data and models to ensure that they are appropriate to the level of detail and site-specific, regional, or national application of the assessment results. Most of the assessment questions in this chapter are directed toward assisting the assessor with the collection of the appropriate information to address metal-specific issues for conducting either exposure or effects characterizations.

Bioaccessibility, Bioavailability, and Bioaccumulation

Bioaccessibility refers to the amount of *environmentally available metal* that actually interacts with the organism's contact surface (e.g., membrane) and is potentially available for absorption (or adsorption if bioactive upon contact). *Environmentally available metal* is the total amount of metal that is available for physical, chemical, and biological modifying influences (e.g., fate and transport) and is not sequestered in an environmental matrix.

Bioavailability of metals is the extent to which bioaccessible metals absorb onto, or into, and across biological membranes of organisms, expressed as a fraction of the total amount of metal the organism is proximately exposed to (at the sorption surface) during a given time and under defined conditions.

Bioaccumulation of metals is the net accumulation of a metal in the tissue of interest or the whole organism that results from *all environmental exposure media*, including air, water, solid phases (i.e., soil, sediment), and diet, and that represents a net mass balance between uptake and elimination of the metal (SAB, 2006).

Bioconcentration is the net accumulation of metal in an organism resulting from direct uptake from water only, such as through gill membranes or other external surfaces.

2.3.1. Bioavailability

The bioavailability of metals and, consequently, the associated risk vary widely according to the physical, chemical, and biological conditions under which an organism is exposed. To the extent that available data and methods allow, the assessor should explicitly incorporate factors that influence the bioavailability of a metal into the health risk assessment. In situations where data or models are insufficient to address bioavailability rigorously, the assumptions made regarding

bioavailability should be clearly detailed in the health risk assessment as should the associated impact on results.

Although bioavailability may be a defined measurement when considered in certain vertebrate animals where metal uptake is directly a function of the concentration of metal in the diet, it is not as simple in many other aquatic and terrestrial organisms where food consumption is difficult to measure and where metals are present in the surrounding environment and available for uptake via nondietary pathways. In this case, as discussed in Meyer (2002), metal bioavailability may be more of a conceptual term and not a precisely measured parameter.

Environmental availability refers to the ability of a metal to interact with other environmental matrices and undergo various fate and transport processes. Environmentally available metal is not sequestered in an environmental matrix, and it represents the total pool of metal in a system that is *potentially* bioavailable at a particular time and under a particular set of environmental conditions (i.e., able to contact or enter into an organism). Environmental availability is specific to the existing environmental conditions and is a dynamic property, changing with environmental conditions. The *bioaccessible fraction* of metal is the portion (fraction or percentage) of environmentally available metal that actually interacts at the organism's contact surface and is potentially available for absorption or adsorption (if bioactive upon contact) by the organism.

The bioaccessibility, bioavailability, and bioaccumulation properties of inorganic metals in soil, sediments, and aquatic systems are interrelated and abiotic (e.g., organic carbon) and biotic (e.g., uptake and metabolism). Modifying factors determine the amount of an inorganic metal that interacts at biological surfaces (e.g., human digestive system, at the gill, gut, or root tip epithelium) and that binds to and is absorbed across these membranes. A major challenge is to consistently and accurately measure quantitative differences in bioavailability between multiple forms of inorganic metals in the environment.

The bioavailability issue paper authors (McGeer et al., 2004) provided EPA with some practical, standard, and defensible recommendations on concepts, terms, and definitions that can serve as a paradigm for studying inorganic metals and their bioavailability. Figure 2-3 presents a conceptual framework along with further discussion of metals bioavailability and bioaccumulation.

2.3.2. Exposure Characterization

Exposure characterization describes potential or actual contact or co-occurrence of stressors with receptors (U.S. EPA, 1998a). Metal factors incorporated into this portion of the health risk assessment include ecosystem and receptor characteristics that affect the movement of metals in the environment including atmospheric deposition, their uptake and accumulation in humans and other biota, and distribution into target organs. Specific assessment questions include the following:

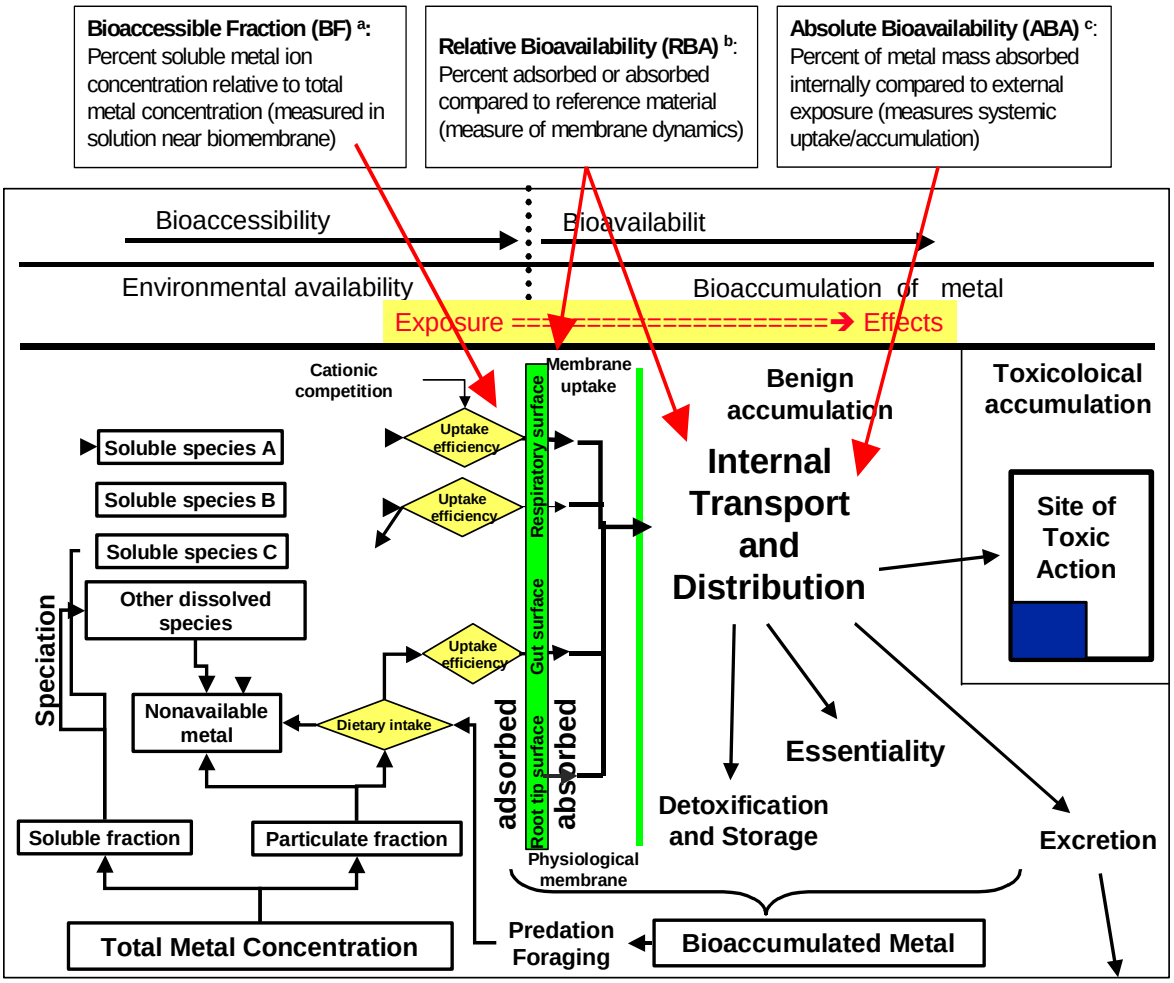


Figure 2-3. Conceptual diagram for evaluating bioavailability processes and bioaccessibility for metals in soil, sediment, or aquatic systems.

[a]BF is most often measured using *in vitro* methods (e.g., artificial stomach), but it should be validated by *in vivo* methods.
[b]RBA is most often estimated as the relative absorption factor, compared to a reference metal salt (usually calculated on the basis of dose and often used for human risk, but it can be based on concentrations).
[c]ABA is more difficult to measure and used less in human risk; it is often used in ecological risk when estimating bioaccumulation or trophic transfer.

Source: McGeer et al. (2004).

Background Concentrations

- What data sources are used to estimate background (natural and anthropogenic) concentrations?
- What are the ranges of background concentrations and how do they vary spatially?
- What degree of certainty exists in estimates of background concentrations?

Fate and Transport

- What environmental transport and air deposition models will be used and what are their assumptions, limitations, and uncertainties?
- How will the environmental chemistry (in air, water, and soils) of metals be addressed?
- What deposition scale (local, regional, or national) is important for the metal and receptors being considered?
- What meteorological factors impacting the fate and transport of metals should be considered in the health risk assessment?

Mixtures and Interactions

- Is exposure to metal mixtures being incorporated into the exposure assessment? If so, how is it being addressed? If not, what is the rationale for not addressing metal mixtures?
- What evidence exists to indicate exposure to the metal(s) of concern is affected by metal mixtures in the assessment?

Essentiality

- For essential metals, will exposure concentrations exceed the nutritional requirements (recommended dietary allowance [RDA])?
- How do the nutritional requirements vary across species and populations in the assessment?

Forms of Metals

- What forms (chemical species) of metals are likely to occur at the site(s) of interest?
- What biogeochemical speciation and transformation processes are relevant for the assessment?
- How might these biogeochemical processes impact exposure assessment for the metal(s) of concern?

- What transport and fate models are relevant for the environment and metals of concern?

Toxicokinetics/Toxicodynamics of Metals

- What environmental factors have the most influence on the bioavailability of the metals of concern?
- What methods will be used to address bioavailability in the assessment?
- How is bioaccumulation being assessed or predicted?
- To what extent are bioaccumulation predictions being extrapolated across species, exposure concentrations, locations, or environmental conditions?
- What are the key assumptions being used to address bioaccumulation and bioavailability and how accurate are these assumptions?

The objective is to produce a complete picture of how, when, and where exposure occurs or has occurred by evaluating sources and releases, the distribution of the stressor in the environment, and the extent and pattern of contact or co-occurrence with humans or ecologically relevant biota. The metal-specific exposure factors discussed in this framework contribute to the exposure characterization, but additional issues that are generally applied to all health risk assessments also should be considered (although they are not specifically discussed here). For the exposure profile to be useful, it should be comparable with the stressor-response relationship generated in the effects characterization.

2.3.3. Characterization of Effects/Hazard Analysis

To characterize effects or adverse responses to metals, the risk assessor should describe how the effects are elicited, link them to the human populations at greatest risk and/or the ecological assessment endpoints, and evaluate how they change with varying exposure levels. It is particularly important, especially for inorganic metals, to confirm that the conditions under which the exposure occurs are consistent with those of the conceptual model. This will ensure that the correct metal species is evaluated for its effects on the populations (including the vulnerable subpopulation) or endpoints of concern, or that appropriate models are used for extrapolating responses among metal species, biota (laboratory to field, or test species to humans), or for varying environments (e.g., metalloregions). Assessment questions regarding metal-specific factors for effects analyses or hazard assessments include the following:

Background Concentrations

- What is the relationship between environmental (natural and anthropogenic) concentrations and toxicologically relevant metal concentrations?

- For ecological risk assessments, how are acclimation, adaptation, and tolerance issues being addressed in the effects analysis?

- In human health assessments, have concentrations in locally grown or harvested foods been taken into account when estimating elevated metal exposures or estimating relative bioavailability of metals in foods, soil, or water?

- How representative are the toxicity test conditions of the environments being assessed?

Mixtures and Interactions

- Are toxicological effects of metal mixtures being incorporated in the effects assessment? If so, how are they being addressed? If not, what is the rationale for not addressing the toxicity of metal mixtures?

- For particular mixtures of inorganic metals, to what degree are their combined effects additive, antagonistic, or synergistic?

- Is mimicry (competitive interactions among chemically similar metals/metalloids) important in the assessment?

- For site-specific assessments, what evidence exists to indicate the toxicity of the metal(s) of concern is affected by the presence of other metals?

Essentiality

- For essential metals, are nutritional requirements known (e.g., RDA for humans)?

- What is the range between concentrations required nutritionally and those associated with toxicity reference values (e.g., reference concentration [RfC], Ambient Water Quality Criteria [AWQC]) or adverse effect levels used in the risk assessment?

- Are nutritional deficits that can increase the vulnerability of humans and other organisms to other stressors being addressed?

Forms of Metals

- Which forms of the metals are most toxicologically relevant?

- How toxicologically comparable are the forms of metals used in the effects and exposure assessment?

- How might assumptions regarding the toxicity of different metal forms impact the effects assessment? How accurate are these assumptions?

- How will the atmospheric chemistry, transport, and deposition of metals be addressed in the assessment?
- What meteorological factors impact the fate and transport of metals?

Toxicokinetics/Toxicodynamics of Metals

- How does toxicity vary for different metal forms found (or likely to be found) in the assessment?
- Which of these are most important and which are incorporated into the effects assessment?
- How are absorption, distribution, metabolism, and excretion addressed for individual metals or mixtures of concern?

Effects analysis results are summarized in a stressor-response profile. The analysis addresses the plausibility that effects may occur or are occurring as a result of exposure to the metal(s) of concern, and that linkages between measured effects and assessment endpoints can be made (this is especially important for ecological risk assessments). Many of these steps in effects assessments are not unique to inorganic metals, and so they are not addressed specifically in this Framework.

Although the prediction of toxicity due to dietary exposure to inorganic metals is complicated by wide variation in the bioavailability and toxicity of metals, it is a factor that risk assessors should consider in metals assessments. Direct approaches to accomplish this include quantifying the bioavailable fraction of bioaccumulated metals in consumers (e.g., analysis of tissue fractions such as cytosolic metals) and determining metal speciation in the media of concern (water, soil, or air). Comparisons of media values can then be made to toxicity reference values using the same metal species. Lacking such information, or for higher tier assessments, bioassay methods with field-collected media offer another way to assess bioavailability, although other than lead exposure in juvenile swine, such methods have not been widely standardized.

2.4. RISK CHARACTERIZATION

Risk Characterization is the final phase of the health risk assessment and is the culmination of the Planning, Problem Formulation, and Analysis of predicted or observed adverse effects. It combines the results of the exposure assessment with information on stressor-response profiles to estimate the likelihood of effects of specified magnitude(s). The risk assessor should describe available lines of evidence and conduct (and report) an uncertainty analysis. Conclusions presented in the Risk Characterization should provide clear information to risk managers that is useful for decision making. There are no metal-specific methods in the

Risk Characterization, other than revisiting the metal factors described above to verify that they were accorded proper consideration during the Analysis. However, because metal assessments are dependent on specific attributes of environmental chemistry and biological responses related to the natural occurrence of metals, it is particularly important that the Risk Characterization specify the conditions, locations, and time-frame within which the assessment results are applicable.

For risk assessments conducted for regional or national assessments, criteria development, or ranking purposes, it should be acknowledged that results will be based on organisms and soil types that result in greatest bioavailability and sensitivity. Care should be taken, however, that the organism-environment combinations assessed are, in fact, compatible with real-world conditions. Relevant assessment questions include the following:

Background Concentrations

- What assumptions are made regarding background (natural and anthropogenic) concentrations in characterizing metal risks?
- How sensitive are the risk assessment results to the presence of background concentrations (i.e., are background concentrations a major or minor component of the risk estimate)?
- Have metals with generally high background concentrations (e.g., aluminum (Al) and iron (Fe) in soil) been appropriately considered in ecological assessments?

Mixtures and Interactions

- How sensitive are the risk assessment results to assumptions regarding exposure and effects of metal mixtures?
- To what extent do the methods and assumptions regarding the exposure and effects of metal mixtures introduce intentional or unintentional bias in the Risk Characterization?

Essentiality

- How do risk assessment results compare to levels required to maintain nutritional health?
- How sensitive are the risk assessment results to methods and assumptions used to address essentiality?
- To what extent do the methods and assumptions regarding the exposure and effects of essential metals introduce intentional or unintentional bias in the Risk Characterization?

Forms of Metals

- How sensitive are the risk assessment results to methods and assumptions used to address the different metal forms?

- To what extent do the methods and assumptions regarding the exposure and effects of metal forms introduce intentional or unintentional bias in the risk assessment?

Toxicokinetics/Toxicodynamics of Metals

- How sensitive are the risk assessment results to methods and assumptions regarding factors affecting bioavailability and bioaccumulation of the metal?

- To what extent do the methods and assumptions regarding the factors affecting bioavailability and bioaccumulation of metals introduce intentional or unintentional bias in the risk assessment?

3. ENVIRONMENTAL CHEMISTRY, TRANSPORT AND FATE

3.1. INTRODUCTION AND TERMINOLOGY

A general review of factors pertaining to the chemistry of metals in sediments, soils, waters, and the atmosphere is presented in this chapter in the context of risk assessment. Because the behavior of metals defies simple generalities, understanding the chemistry of the particular metal and the environment of concern is necessary. However, the factors that control metal chemistry and the environmental characteristics used to produce estimates of metal fate and effects can be generalized.

Chemical Species

The International Union of Pure and Applied Chemistry (IUPAC) defines chemical species as chemical compounds that differ in isotopic composition, conformation, oxidation or electronic state, or that in the nature of their complexed or covalently bound substituents, can be regarded as distinct chemical species.

In environmental chemistry, the phase the species occurs in (gas, liquid, aqueous solution, mineral, or adsorbed on an interface between phases) generally is also included in a complete definition. In the context of the environmental chemistry of metals, chemists speak of a metal species as a "specific form of an element defined as to isotopic composition, electronic or oxidation state, complex or molecular structure" and phase (Templeton et al., 2000).

Metal speciation greatly determines the behavior and toxicity of metals in the environment. Speciation refers to the occurrence of a metal in a variety of chemical forms. These forms may include free metal ions, metal complexes dissolved in solution and sorbed on solid surfaces, and metal species that have been coprecipitated in major metal solids or that occur in their own solids. The speciation of a metal affects not only its toxicity but also its volatilization, photolysis, sorption, atmospheric deposition, acid/base equilibria, polymerization, complexation, electron-transfer reactions, solubility and precipitation equilibria, microbial transformations, and diffusivity (Bodek et al., 1988).

The following sections address the application of hard and soft acid and base (HSAB) concepts to metal behavior, including the formation of metal complexes, and the importance of pH and oxidation-reduction reactions to metal mobility. These sections also discuss the occurrence and interactions of the metals of concern in natural media (including surface and ground waters, soils and aquatic sediments, and the atmosphere). Metal sorption behavior, aging in soils, metal dissolution and transformation and transfer to plants, and methods of determining metal speciation in soils and sediments are important topics considered in these sections.

3.1.1. Hard and Soft Acids and Bases: The Stability of Complexes

Complexes are formed between metals (acids) and ligands (bases), both in solution and at the surfaces of minerals and organisms. The toxic reaction of organisms to metals can be directly related to the nature of the metal complexes formed in solution and at the surface of the organism.

Hard and Soft Acids and Bases

Hard acids and hard bases. Complexes formed between divalent hard acid cations and monovalent or divalent hard bases are ionic and relatively weak and are often termed "ion pairs." Complexes formed between Be^{2+} or trivalent hard acids and hard bases tend to be ionic and relatively strong.

Soft acids and soft bases. Relatively strong covalent bonds are formed in complexes between soft and borderline soft acid cations and soft bases. Ligand-binding sites on the external or internal surfaces of organisms are often soft base and thus bond strongly with soft and borderline soft acid cations.

A useful concept that helps to explain the strength of metal complexing and metal toxicity is that of HSAB, which was introduced by Pearson (1973). In this concept, metal cations are Lewis acids and ligands are Lewis bases, with the metal cation and ligand in a complex acting as electron acceptor and donor, respectively. "Soft" implies that the species' electron cloud is deformable or polarizable and the electrons are mobile and easily moved. Soft species prefer to participate in covalent bonding. Hard species are comparatively rigid and nondeformable, have low polarizability, hold their electrons firmly, and prefer to participate in ionic bonds in complex formation (Langmuir, 1997). Hard acids form strong, chiefly ionic bonds with hard bases, whereas soft acids and soft bases form strong, chiefly covalent bonds when they form complexes. In contrast, the bonds formed between hard-soft or soft-hard acids and bases are weak, such that their complexes tend to be rare. Table 3-1 summarizes hard and soft acid and base relationships for the metals of concern.

Ligands

Ligands are simply anions or molecules that form in coordination complexes with metal ions. Depending on whether a ligand shares one, two, three, or more electron pairs with metals, it is called a mono-, bi-, tri-, or multidentate ligand. For ligands composed of more than one atom, the atom that directly participates in metal-ligand binding is called the donor or ligand.

Hard metals (hard acids), which are the least toxic, preferentially bind with hard bases that contain oxygen, forming weaker bonds with soft nitrogen and sulfur species. The strength of binding between hard metals and hard ligands is usually a function of pH. Many of the hard metals are macronutrients. Soft metals (acids) bind preferentially with soft S and N ligands, forming weaker bonds with hard base species such as hydroxide and sulfate. Soft and borderline metals, and Mn^{2+}, which is hard, form bonds of decreasing strength with soft ligands such as sulfide, generally in the following order: $Pb^{2+} > Cu^{2+} > Cd^{2+} > Co^{2+} \cong Fe^{2+} > Ni^{2+} > Zn^{2+} > Mn^{2+}$. The tendency of metals to bind to soft ligands or to organic substrates (which are

Table 3-1. Hard and soft acids (metal cations) and bases (ligands)

Hard acids	Al^{3+}, Ba^{2+}, Be^{2+}, $Co^{3+,}$, Cr^{3+}, Fe^{3+}, Mn^{2+}, Sr^{2+}, U^{4+}, UO_2^{2+}, VO^{2+}
Borderline acids (between hard and soft)	Co^{2+}, Cu^{2+}, Fe^{2+}, Ni^{2+}, Pb^{2+}, Zn^{2+}
Soft acids	Ag^{+}, Cd^{2+}, Cu^{+}, Hg^{2+}, Hg^{+}, CH_3Hg^{+}, Tl^{3+}, Tl^{+}
Hard bases	F^{-}, H_2O, oxyanions: OH^{-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}, $C_2O_4^{2-}$, CrO_4^{2-}, MoO_4^{2-} $H_nPO_4^{n-3}$, $H_nAsO_4^{n-3}$, SeO_4^{2-}, $H_2VO_4^{-}$, NH_3, RNH_2, N_2H_4, ROH, RO^{-}, R_2O, CH_3COO^{-}, etc.
Borderline bases (between hard and soft)	Cl^{-}, Br^{-}, NO_2^{-}, SO_3^{2-}, $H_nAsO_3^{n-3}$, $C_6H_5NH_2$, C_5H_5N, N_3-, N_2
Soft bases	I^{-}, HS^{-}, S^{2-}, CN^{-}, SCN^{-}, Se^{2-}, $S_2O_3^{2-}$, -SH, $-SCH_3$, $-NH_2$, R-, C_2H_4, C_6H_6, RNC, CO, R_3P, $(RO)_3P$, R_3As, R_2S, RSH, RS^{-}

"R" refers to an organic molecule.

Source: Adapted from Langmuir (1997); Huheey et al. (1993).

usually soft) is greatest for soft and borderline metals (soft acids), followed by the hard metals (hard acids), typically in the order $Pb^{2+}>Cu^{2+}>Cd^{2+}>Zn^{2+}>Ca^{2+}>Mg^{2+}>> Na^{+}$ (Pickering, 1986).

The tendency of metals to form solid phases, such as sulfides in sediments, is also related to their HSAB qualities. For example, extremely insoluble metal sulfides are formed in anoxic sediments by soft acid metal cations, such as Hg^{2+} ($\log K_{sp} = -57.25$) or Ag^{+} ($\log K_{sp} = -49.7$), whereas borderline hard and hard metal cations such as Mn^{2+} ($\log K_{sp} = -19.25$) or Fe^{2+} ($\log K_{sp} = -22.39$) form slightly more soluble, although still highly insoluble, metal sulfides. Solubility products for all sulfides except Ag_2S are from Di Toro et al. (1990). The product for silver sulfide is from Stumm and Morgan (1970).

3.1.2. Transformations

As discussed previously, metals and metalloids can exist in the environment in several valence forms. They can also exist as organometallic compounds. Organometallic compounds are compounds that have a metal/metalloid-carbon bond. The bonds in organometallic compounds are generally covalent and between soft acid metals and soft ligands. Metal/metalloid transformation processes, such as metal methylation, occur through interactions with other chemicals and biota in the environment. Cycling and distribution of organometallic compounds between terrestrial, aquatic, and atmospheric phases may be physically, chemically,

or biologically mediated. Table 3-2 lists examples of some commonly occurring, environmentally stable organometallic compounds.

Table 3-2. Examples of organometallic compounds

Metal/metalloid	Organometallic compounds
AS	Methylarsenic acid, dimethyl arsenic acid, trimethyl arsine, trimethylarsine oxide
Pb	Tetramethyl/ethyl lead, trimethyl/ethyl lead, dimethyl/ethyl lead
Hg	Methyl mercury, dimethyl mercury
Se	Dimethyl selenide, dimethyl diselenide, seleno-amino acids
Sn	Tributyltin, bis(tributyltin) oxide

As discussed in this section, organometallic methylation and demethylation rates are influenced by both the speciation and bioavailability of the metal, the microbial community, and a large number of environmental factors, many of which are interrelated. Sulfide and organic matter are important environmental variables that significantly affect methylation; however, their effect on methylation/demethylation is poorly understood. The dominant variables differ among locations and between seasons, although it is clear that methylation is predominantly a biologically mediated process. Methylation/demethylation rates are strongly influenced by metal/metalloid speciation and bioavailability.

Environmental methyl-metal concentrations reflect the net methylation rather than simple rates of methyl-metal synthesis. Table 3-3 presents metals that are involved in abiotic or biotic methylation/demethylation processes. With the exception of As and Se, the metals in the table form stable complexes with either methyl or ethyl groups. In addition to methyl/ethyl compounds, metals can also be incorporated biochemically into stable organometallic compounds (e.g., As into lipids and Se into amino acids).

Organometallic environmental transformations may affect both the mobility and toxicity of metals. The transformation rates and the organometallic products are dependent on environmental conditions and the population of microorganisms available. For example, methylation/demethylation rates are dependent on the speciation of the metal, the microbial community, the environmental variables (e.g., pH, temperature, reduction oxidation potential, organic matter, dissolved oxygen, nutrient availability, salinity, complexing agents), and the distribution of the metal between compartments (sediment, water, gaseous). The inter-relatedness of these processes has made research into unraveling the factors controlling net methylation difficult and, to date, incomplete. However, some general trends can be predicted with some certainty, as discussed in this section.

Table 3-3. Metals/metalloids involved in methylation processes

Process	Metals affected
Environmentally stable organometallics	Si, Ge, Sn, Pb, Hg, As, Sb, Se
Abiotic chemical methylation	Hg, Pb, Sn
Abiotic demethylation	Sn, Pb
Biotic methylation	As, Cd, Hg, Pb, Se, Sn
Biotic demethylation	As, Hg, Sn, Pb

Source: Bodek et al. (1988).

3.1.2.1. *Biotic Methylation Transformations*

Biotic methylation occurs when organisms, primarily microorganisms, transfer alkyl groups to bioavailable metals. In general, it is thought that anaerobic sulfate-reducing bacteria are the principal methylators in freshwater and estuarine environments. However, methylation rates are not always correlated with sulfate-reducing bacteria. Not all sulfate-reducing bacteria are capable of methylating, and the efficiency of methylation is dependent on the activity and structure of the bacterial community. Other bacteria may be involved in methylation. Biotic methylation occurs predominantly in the sediment column; however, because the water column by volume is much larger, water column methylation is important.

Maximum methylation rates typically occur at the redox boundary, which varies seasonally and frequently coincides with the sediment-water interface (Ullrich et al., 2001). Methylation rates decrease with increasing sediment depth, probably due to a decrease in biotic habitat. Microorganisms may also demethylate (or dealkylate) organometallic compounds. Microbial-mediated transformations are frequently the most important environmental organometallic processes. Generally, as the amount of organic material increases in a system the microbial populations also increase.

High temperatures and anaerobic conditions generally favor metal-methylation formation, and demethylation processes are generally favored under low temperatures and/or aerobic conditions. Studies on the effects of pH are not consistent. Interconnected parameters include pH effects on the microbial communities and effects on the speciation distribution of the metals/metalloids in the water and the sediment as well as adsorption rates. Organometallic compounds appear to increase in the water column in low pH environments, but this may be due to release of methylated metals from the soil and subsequent depletion of organometallic compounds in the soil. Therefore, pH effects on net methylation in a system are not fully understood. In freshwater ecosystems, where sulfate concentrations are typically low, increase

in sulfate concentration increases methylation rates. However, in reducing environments, increasing sulfide concentration decreases methylation rates. General trends in methylation/demethylation rates are outlined in Table 3-4.

Table 3-4. General trends of environmental factors affecting rates of methylation/demethylation

Organometallic transformations	Temperature		pH		SO_4^{-2}	Organic matter	Redox		Salinity
	High	Low	High	Low	High		Oxic	Anoxic	High
Net methylation	↑	↓	?	**?**	**?**	**?**	↓	↑	↓
Methylation aq	↑	↓	↓**?**	↑**?**	↓	↓↑	↓	↑	↓
Methylation sed	↑	**?**	↑	↓	↓	**?**	**?**	**?**	**?**
Demethylation	↓	↑	↓	↑	**?**	**?**	↑	↓	**?**

↑ indicates an increase in rate.
↓ indicates a decrease in rate.
? indicates conflicting data or insufficient data to indicate a likely trend.

The inhibitory effect of sulfide is probably not due to metal sulfide formation but, rather, to the formation of less bioavailable metal-sulfur complexes. High organic matter may increase abiotic methylation through humic/fulvic metal reactions; however, this mechanism is poorly understood and confounded because biotic methylation rates may increase in environments with high organic matter. In ecosystems with high dissolved organic carbon (DOC) concentrations, DOC may bind with metals/metalloids, rendering them unavailable and thereby reducing biotic methylation rates.

3.1.2.2. *Abiotic Transformations*

Some organometallic compounds, those with electronegativities greater than 1.7, are stable under environmental conditions. In a few instances, metals can undergo abiotic methylation processes. Carbon-metal bonds with more polar (metal electronegatives <1.7) will undergo hydrolysis (reaction with water). Abiotic chemical methylation can occur by three mechanisms: transmethylation reactions between mercury and tin/lead alkyls, reactions with humic/fulvic substances, and photochemical reactions.

3.1.3. Aquatic Chemistry

Exposure and risks associated with metals in aquatic environments depend on the forms of the metals and on the factors that influence the presence of these forms as well as on the fate and transport of the metals.

3.1.3.1. *Processes*

Factors Affecting Sorption of Metals

Speciation/complexation
Precipitation
Colloid formation
Biofixation
Interactions with natural organic matter
Changes in pH
Oxidation potential
Salinity
Competing ions
Nature of sorbent phases
Surface site densities

A number of factors influence the sorption of metals in aquatic systems. Speciation/ complexation is the distribution of a given constituent among its possible chemical forms, including metal complexes, which have differing tendencies to be adsorbed or desorbed; precipitation is the process by which dissolved species exceed the solubility limits of their solids, so that some of the species precipitate from solution; colloid formation can result in metals being sorbed or coprecipitated with colloidal-sized particles; biofixation occurs when biological processes (usually involving microorganisms or plants) result in the binding of metals to solid materials; interactions with natural organic matter can also result in sorption. In addition to these factors, sorption is influenced by changes in pH, oxidation potential, salinity, concentrations of competing ions, the nature of sorbent phases and their surface areas, and surface site densities.

3.1.3.2. *Speciation and Complexes*

Metal species dissolved in water may occur as free ions, or aquo-ions, or as complexes. Free metal cations are generally surrounded by coordinating water molecules and so have been termed “aquocations,” although by convention the water molecules are ignored when writing chemical reactions involving metal cations.

The total analytical concentration of a given metal in water is the sum of the concentrations of its free ion and its complexes and any metal associated with suspended solids, whether organic or mineral. For example, the total molal concentration of lead, ΣPb, in a natural water might equal:

$$\Sigma Pb = mPb^{2+} + mPbOH^{+} + mPbCO_3^{o} + mPbHCO_3^{+} + mPbSO_4^{o} + mPb(suspended\ solids)$$

In most natural waters, the concentration of free lead ion, mPb^{2+}, is less than the sum of the concentrations of its complexes, which in this case are lead complexes with hydroxyl, carbonate, bicarbonate, and sulfate ions. Other metals that are found in natural waters most often

as complexes and not as free ions include Al^{3+}, Ag^{+}, Cu^{2+}, Fe^{3+}, and Hg^{2+}. The metalloids As and Se and the metals Cr, Mo, Sb, and V occur most often in aerobic waters and soils as covalently bonded to oxygen in oxyanions. Under oxidizing conditions, these include arsenate, selenate, chromate, molybdate, and vanadate, which themselves are complexes.

Complexes that incorporate metals play a major role in controlling the availability and fate of metals in the environment. Increasing the fraction of a metal that is complexed increases the solubility of minerals of that metal (Langmuir, 1997). For example, the solubility of lead sulfate is related to the molal concentrations of free lead and sulfate ions through the expression below:

$$K_{sp} = (\gamma_{Pb}.mPb^{2+})(\gamma_{SO4}.mSO_4^{2-})$$

where the terms γ_{Pb} and γ_{SO4} are the activity coefficients of the ions. The product of the ion activity coefficient and the molal concentration of each species equals the activity of the ion. This equation shows that for a given total Pb concentration, the greater the amount of Pb that is complexed, the lower the concentration of free Pb ion. This means that as the extent of Pb complexing increases, the total Pb concentration must also increase to reach saturation equilibrium with lead sulfate. In other words, metal complexing increases total metal solubility.

Metal complexing also has a direct influence on metal adsorption to organic matter or mineral surfaces. For example, metal carbonate, sulfate, and fluoride complexes are usually poorly adsorbed, whereas metal hydroxide complexes are strongly adsorbed (Langmuir, 1997). In summary, metal complexing generally increases the solubility and mobility of metals in surface and ground waters (with the exception of metal hydroxide complexes).

For many metals, the free metal ion is thought to be the primary metal species that causes toxicity to aquatic organisms. This is consistent with the free ion activity model (FIAM), which carries the assumption that the free or aquo-ion is the most biologically active form of the dissolved metal. If this is true, the key parameters that can modify the degree of toxicity are those that affect speciation, such as pH and the amount of inorganic and organic ligands (e.g., DOC) that can form metal complexes and so provide alternative binding sites for the metal ion. Metal toxicity also will be affected by other dissolved ions (e.g., Na, Ca) that compete with metals for binding sites on the gills of fish or on the respiratory surfaces of other aquatic organisms. However, it should be noted that many metal complexes (whether bound to organic or inorganic ligands) are reversible, particularly if environmental conditions change (e.g., pH decreases).

3.1.3.3. *Importance of pH and Redox Conditions*

The pH is probably the single most important variable that influences the behavior of metals in the environment. Thus, metal complexes with sulfate, fluoride, chloride, and phosphate are most stable and important below pH 7, whereas metal carbonate and hydroxide complexes become increasingly more important above pH 6–8.

Also, as discussed in Section 3.1.6, hydrogen ion competes with metal cations for adsorption sites, so that adsorption of metal cations by hydrous ferric oxide (HFO), for example, is low in acid systems but increases with increasing pH. In contrast, oxyanions of As, Mo, Se, and Cr tend to be desorbed from HFO with increasing pH because of competition between the oxyanions and OH- ion for sorption sites. Furthermore, the solubility of most metal-containing minerals is greatest under acid conditions, decreasing with increasing pH. Figure 3-1 shows the locus of measured values of oxidation potential (Eh) and pH in aquatic systems. The principal controls on Eh are atmospheric oxygen and organic matter. High Eh (oxidizing or aerobic) conditions are maintained in the atmosphere and in most surface waters and shallow soils in contact with atmospheric oxygen. The lowest Eh values and reducing or anaerobic conditions are found in water-logged soils and sediments that contain organic matter and in ground waters that contain a few milligrams per liter or more of DOC. Intermediate Eh conditions are found in waters and sediments that are only partially oxidized because of their relative isolation from the atmosphere. Measured Eh values may not agree with Eh values computed from the concentrations of redox-sensitive species. The difference between measured and computed Eh values is discussed at length by Stumm and Morgan (1996) and Langmuir (1997).

3.1.4. Ground Water and Metals Mobility

Site-specific nonorganic metal health risk assessments for EPA programs often are used to predict the rate of movement of metals through soils and their subsequent movement and concentrations in ground water. The primary processes governing the environmental fate and transport of metals in the subsurface are advection, dispersion, matrix diffusion, and retardation (U.S. EPA, 1994b). Advection and dispersion are functions of the system rather than of the contaminant. Matrix diffusion, which is a function of the contaminant, is relatively unimportant and is omitted in most model transport algorithms. Retardation depends on a number of factors (Langmuir, 1997; U.S. EPA, 1994b) and may involve or be affected by the following:

- **Sorption -** The attachment of metal species to mineral surfaces or other surfaces.
- **Speciation -** The distribution of a given constituent among its possible chemical forms, including metal complexes, which have differing tendencies to be adsorbed or desorbed.

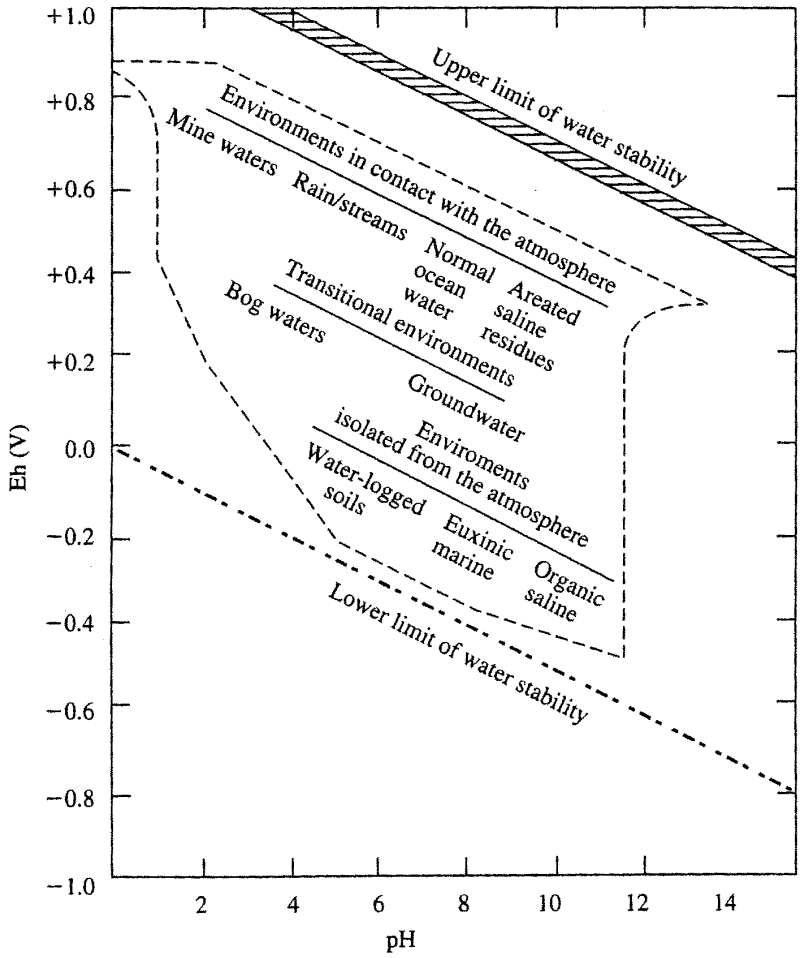


Figure 3-1. Approximate positions of some natural environments in terms of Eh and pH. The dashed line represents the limits of measurements in natural environments.

Source: Baas-Becking et al. (1960).

- **Precipitation -** The process by which dissolved species exceed the solubility limits of their solids, so that some of the species precipitate from solution. When a metal species reaches mineral saturation, addition of further amounts of the species to solution are precipitated, not adsorbed.

- **Colloid formation -** The process of forming colloids and the association of metal species with them. The metals may be sorbed or coprecipitated with colloidal-sized particles.

- **Biofixation** - The binding of metals to solid materials due to the interactions of microorganisms or plants.

- **Natural organic matter** - (NOM) interactions.

- **Other processes -** Other processes include changes in pH, oxidation potential, salinity, concentrations of competing ions, the nature of sorbent phases and their surface areas, and surface site densities.

3.1.4.1. *Application of Partition Coefficients to Metal Mobility in Ground Water*

Owing to the complexity and multiplicity of the processes involved, recourse is often made to the use of a single partition or distribution coefficient that describes the degree to which the contaminant's transport is retarded relative to water. This approach starts with defining the retardation factor:

$$R_f = \frac{v_p}{v_c}$$

where:

R_f = the retardation factor,
v_p i= the velocity of water through a control volume, and
v_c = the velocity of contaminant through a control volume.

Langmuir (1997) noted that the retardation factor is related to the distribution coefficient through the below expression:

$$R_f = 1 + \frac{\rho_b}{n_e} K_d$$

where:

ρ_b is the porous media bulk density, and
n_e is the effective porosity at saturation given as a volume fraction.

Laboratory adsorption studies often find that, in simple systems, the value of log K_d for metal adsorption increases linearly with pH. For example, for Zn^{2+} adsorption by HFO, Langmuir (1997) noted that adsorption followed the log equation:

$$log\ K_d = -5.48 + 1.77\ pH$$

The properties and applications of partition or distribution coefficients for metals are comprehensively reviewed in EPA (1999a). These coefficients may be obtained from the literature, estimated using mathematical models, or measured. Properly designed column

experiments generally give results more representative of the *in situ* behavior of soils and sediments than do batch tests (Langmuir, 1997).

Models using partition distribution coefficients (K_d) have significant inaccuracies for metals, and the application of single partition coefficient values for individual metals should be limited to site-specific assessments (when they can be calibrated for a specific site); to regional- and national-scale studies where bounds of potential K_d values are adequate; or reasonably representative single values that have sufficient functionality built in to account for variability due to pH and soil composition.

EPA (1999a) discusses the advantages and disadvantages of several methods for measuring partition coefficients, including laboratory batch testing, in situ field batch testing, flow-through testing, and field modeling. In many national assessments, EPA has used the MINTEQ model and its subsequent versions to generate generic partition coefficients that may be applied to regional or national mobility evaluations (http://www.epa.gov/ceampubl/mmedia/minteq/index.htm or http://www.lwr.kth.se/english/OurSoftware/Vminteq/).

For screening assessments:

- Partition coefficients have been tabulated as a function of pH by EPA (U.S. EPA, 1998b), and the Agency has also presented non-pH-dependent values for Pb (900) (Pb values have large variability and selecting meaningful values is difficult), mercuric chloride (58,000), and Hg (1,000) (U.S. EPA, 1999b).

- In simple systems, the value of log K_d for metal cation adsorption usually increases linearly with pH, whereas the value of log K_d generally decreases with pH for anion adsorption.

For definitive assessments:

- It may be possible to estimate metal adsorption with some accuracy without having to measure it in the field, depending on the information available on a specific soil, surface-water, or ground-water system. To do so, at minimum, the risk assessor will need to determine the amounts and surface areas of the potentially sorbing materials (e.g., metal oxides, clays, and organic matter [OM]) in a soil or sediment or in suspension in a stream, and the detailed chemical composition of the water, especially its pH and metal concentration. Literature information can then be used to estimate the sorption properties of these materials for use in the diffuse layer (DL) sorption model.

- If greater accuracy or site specificity is required, it may be necessary to measure metal adsorption in laboratory experiments designed to parameterize the DL model for application to a specific study area. The risk assessor could run experiments (batch tests) that attempt to reproduce the composition of waters and sorbing solids in the study area.

3.1.5. Sediment Chemistry

Sediments

Bed or bottom sediments are found at the bottom of lakes, rivers, and estuaries. Sediments have several sources that influence their composition and chemistry. The type and chemistry of sediments is also determined by their location in the water body as well as the characteristics of the water body. At any given site, metals can be associated with solid-phase minerals, organic matter, colloids, and pore water. The solid phase can vary from sand (>63 μm) to silt (2–63 μm) to clay (<2 μm). Because clays have more active binding sites than do the other grain sizes and because of their high surface area-to-volume ratio, clays –or fine-grained particles--are of greatest significance in terms of metal binding.

In addition to the challenges posed by metal chemistry, the sedimentary environment is complex and often highly heterogeneous. Fortunately, generalizations can be made about the sedimentary environment in order to progress toward a method for risk assessment. This brief review summarizes information on the composition of sediments; processes that act on sediments and their metal burden; and the chemistry of the sedimentary environment that influences the fate, bioavailability, and effects of metals. It is important to consider these factors in light of the aim of estimating potential biological effects of metals in sediments.

Sediment solids can hold up to a million times more metal than an equivalent volume of water. The exact proportion of a chemical held by sediment relative to water is a function of a metal's chemistry as well as the chemistry of the sediment solid and the surrounding environment. Further, this distribution is dynamic (Diamond and Mudroch, 1990). Because of their large capacity to "hold" metals, sediments have been characterized as "sinks." Sediments can serve as temporary sinks from which some of the metal can enter ecological and human food webs through several routes (e.g., Diamond, 1995), primarily through accumulation in benthic organisms. These organisms include those that fully or partially live in the sediments (e.g., tubificids, chironomids, trichopteran larvae) or those that feed from the sediment bed (e.g., suckers, carp). Some organisms obtain their chemical dose from both pelagic and benthic routes (e.g., lake whitefish, walleye), but because of high chemical concentrations in sediments, the benthic route can be the dominant route of uptake (Morrison et al., 2000).

For humans, the route of entry of metals from the sediments is through water used for drinking, bathing, and swimming. The availability of these metals is mediated by sediment-water exchange processes that can result in the release or remobilization of chemicals from the sediment bed. However, owing to the ability of Hg to bioaccumulate in its monomethyl form, fish consumption is the critical route of exposure to this metal for humans.[2]

Many important chemical reactions involving the metals of concern occur in the fine-grained materials that accumulate in the deep parts of water bodies. The controlling factors or master variables that influence metal chemistry are redox potential and pH. A depth profile of

[2] Marine biota can also be a significant route of exposure to arsenic in its organic forms, such as methylarsonic acid; however, these arsenic species are significantly less toxic than the inorganic forms (Fowler, 1983).

the sediments will reveal decreasing sediment porosity and concentrations of dissolved oxygen because oxygen is consumed as organic matter decomposes. The pH is often relatively constant or may decrease with depth, but alkalinity may increase owing to mineralization of organic matter (Stumm and Morgan, 1996). As dissolved oxygen is consumed, anaerobic microbes use other electron acceptors in redox or oxidation-reduction reactions in the order of nitrate, ferric iron, ammonium, sulfate, and bicarbonate to produce carbon dioxide, ammonia, sulfide, and methane.

The risk assessor can ascertain the redox status of the sediments by measuring the concentration of dissolved oxygen or other redox-sensitive species, by calculating pE (a measure of electron availability in solution), or by measuring Eh (millivolts) or the electromotive force of the pore water solution. The zone of transition from oxic to anoxic conditions is the redoxycline, which can migrate vertically, depending on the mixing of the overlying water column (e.g., Diamond and Mudroch, 1990). For example, the redoxycline may be 5-10 cm below the sediment-water interface in a well-oxygenated oligotrophic lake or river, but it may be above the sediment-water interface in a thermally stratified eutrophic lake or river.

3.1.5.1. *Metal Chemistry in Sediments*

In this discussion, the risk assessor should consider two pools of metals. The first pool consists of metals that exist as aqueous (or dissolved) species bound to colloids or DOM and those bound to sediment particles through an exchangeable binding process. This pool is often referred to as the “exchangeable” or “labile” pool. The second pool consists of metals found within the mineral matrix of the sediment solids. This pool is largely unavailable to biota, and its release will occur over geologic time scales, through diagenetic processes. Because the latter pool is largely unavailable, only the exchangeable pool of metals is considered. Note that the exchangeable pool will be composed of naturally occurring metals that are released into solution as a result of weathering and diagenetic processes as well as metals released into the environment as a result of anthropogenic activities.

The exchangeable pool of metals is subject to speciation in the aqueous phase (e.g., within the pore water) and sorption to solid phases, where sorption is a general term that includes adsorption (the accumulation of matter at the solid-water interface or a two-dimensional process) and absorption (inclusion in a three-dimensional matrix) (Stumm and Morgan, 1996). Here, speciation refers to the distribution of metal species in a particular sample or matrix or species distribution (Templeton et al., 2000). In the aqueous phase, metal will react or bind with dissolved ligands according to the pH, Eh, ionic strength, and abundance of ligands (see Section 3.1.3, Aquatic Chemistry).

The concentration of metal in the dissolved phase is controlled by sorption to the solid phase. Although sorption can occur rapidly, desorption or dissolution of metal from the solid phase may be a two-phase process, where the second phase is rate limiting (e.g., Nyffeler, 1986;

Santschi et al., 1986). If the kinetic limitation of reactions are not considered, the distribution of metals among aqueous species and between the aqueous phase and the solid phase can be estimated by using one of the speciation models. Several speciation/complexation models are available to perform this calculation, such as MINEQL+ (Schecher and McAvoy, 2001), the Windermere Humic Aqueous Model (WHAM) (Lofts and Tipping, 1998), and MINTEQA2 (Allison et al., 1991). These models work well under oxic conditions, but estimates of metal binding are less reliable under anoxic conditions, where metal concentrations are most often controlled by the solubility of metal sulfides. Furthermore, in some circumstances equilibrium may not be achieved, particularly when the redoxycline moves more quickly than the rate of metal reaction or when the reaction is governed by microbial processes, as occurs with the methylation of Hg or As.

In oxic sediment pore waters (above the redoxycline), metals will exist as aqueous species, that is, as freely dissolved ions or metal complexes (e.g., phosphate, sulfate, or carbonate complexes), and associated with colloids. Solid-phase reactions are controlled by iron oxyhydroxides and manganese oxides that may exist as colloids, sediment particles or surface coatings of particles, OM that may also exist as colloids or coat sediment particles, and clay colloids and particles.

As Eh declines, the solid-phase manganese oxides are the first to be reduced and thereby dissolve, which releases metals that have been sorbed or coprecipitated with these minerals. Some of the metals released into the pore water may then be adsorbed by iron(III) oxyhydroxides, which are the next to dissolve as the Eh continues to drop. Under reducing conditions, particularly as sulfate is consumed and the S is converted to sulfide, metal concentrations in pore waters again drop as solid-phase metal-sulfides are formed (see discussion below about the role of acid-volatile sulfides [AVSs] in regulating toxicity).

As a result of redox chemistry, metals can undergo seasonal redox-driven cycling between the water column and sediments or within the sediments, depending on the position of the redoxycline. The stages in the cycling are, first, the adsorption or coprecipitation of metals with iron and manganese hydroxides under oxidizing conditions; then with the development of moderately reducing conditions, the reduction and dissolution of the manganese and iron oxyhydroxides and consequent release of the associated metals into the water or pore water; followed by their diffusion upward toward the zone of low metal concentrations under oxidizing conditions. It is also possible for dissolved metals to diffuse downward toward the zone of low metal concentration owing to their precipitation as sulfides. As a result of this vertical cycling, the depth profile of metals in pore water may not match that of the solid phase (e.g., Carignan and Tessier, 1985). Moreover, it is possible, but less usual, that the cycling can occur relatively rapidly and involve a significant portion of the solid-phase metal. Under these conditions, the solid-phase sediment profile reflects this reworking rather than the historical record of metal loadings (MacDonald et al., 2000).

The pH controls metal speciation and binding by affecting the species distribution of dissolved ligands (e.g., phosphate, sulfate, carbonate, humic substances) and the surface charge of binding sites on DOM and solid phases such as iron oxyhydroxides. Generally, at low pH, when surface sites are protonated, the sorption of cationic metals decreases, and, hence, metal mobility increases. The converse occurs at high pH, which results in low metal solubility and greater sorption. The patterns of dissolution and sorption are reversed for metalloids, such as As, that exist as anionic species.

3.1.5.2. *Estimating Metal Distribution in Sediments*

A main objective in terms of assessing the hazard or risk posed by metals in sediments is estimating the amount of metal that is potentially bioavailable. The bioavailability of metals in sediments is a function of their distribution between the dissolved and solid phases, with dissolved metals in porewater generally considered to be the most bioavailable fraction. Accordingly, several methods have been developed to estimate the distribution of metals among dissolved and solid phases in sediments. These methods have been thoroughly reviewed by Mudroch et al. (1999, 1997). Although bioavailability is also a function of aqueous phase speciation, limited research has been conducted to estimate metal speciation in pore waters. Generally, for the purpose of ecological risk assessments, the exposure of benthic organisms to sediment-associated metal is assumed to be proportional to the metal concentrations in interstitial water, although some studies indicate that uptake from overlying water (Hare et al., 2003; Roy and Hare, 1999) or ingested sediment may be a significant source of body burdens of metals.

Distribution of metals in sediment pore waters may be determined by field measurements, experimental methods, and mathematical modeling, with the latter also requiring some field measurements. Concentrations of metals in pore waters may be determined in the field by using pore water dialysis chambers or peepers and by methods that separate the solid phase from the pore water, although the latter have been shown to be less reliable (Mudroch et al., 1997). Several extraction schemes have been developed to determine the distribution of metal among operationally defined fractions (e.g., Forstner, 1995; Tessier et al., 1979). However, sequential extraction methods do not cleanly distinguish the occurrence and speciation of different forms of metals in sediments and soils (Tye et al., 2003; Tack and Verloo, 1999). Other experimental methods include leaching tests (e.g., Reuther, 1999). The results of any of these methods are concentrations of metals in pore water, which can be related to toxicity benchmarks.

Because of the need to develop Sediment Quality Guidelines (SQGs) for metals that explicitly address toxicity and are based on readily measured parameters, several methods have been developed. For oxic sediments, Tessier et al. (1993, 1989, 1984; Tessier, 1992) compiled partition coefficients of metals that were derived from field studies of freshwater sediments. The

partition coefficients are dependent on pH (because Eh is held constant) and are generally linear over a range of pore water pH values (see above discussion under ground-water chemistry, Section 3.1.4 for the theoretical basis for development of partition coefficients). Speciation/complexation models also may be used to estimate fractions of dissolved and bound metal species. These models rely on measurements of pH, dissolved oxygen, or Eh to establish redox conditions. The models assume that solid-phase binding is governed by sorption to iron and manganese oxides. Model estimates are less reliable when other solid-phase substrates are dominant (e.g., clay minerals) and are a function of the availability and accuracy of the stability constants for the metal-ligand reactions that are used in the calculations. Model estimates are less reliable when other solid-phase substrates are dominant (e.g., clay minerals), and they are a function of the availability and accuracy of the stability constants for the metal-ligand reactions that are used in the calculations.

For anoxic sediments, the availability of sulfide controls metal distribution and solubility. Operationally, AVSs (mainly iron monosulfide) have been considered as a measure of reactive sulfides (Forstner, 1995). Studies have demonstrated an inverse relationship between sediment acute toxicity and AVSs for marine and freshwater sediments (Di Toro et al., 1992, 1990; Ankley et al., 1991) as well as between pore water concentrations and AVSs (Brumbaugh et al., 1994; Casas and Crecelius, 1994). As a screening-level tool, the acute toxicity of anoxic sediments can be assessed by determining the ratio of AVSs to simultaneously extracted metal (SEM). Low sediment toxicity is indicated when AVSs are in excess (AVS > SEM), which implies sufficient capacity of the AVS to bind essentially all free metal. This topic is further discussed in Section 5.

3.1.6. Soil Chemistry

The cationic metals occur naturally in soils as oxides and hydroxides (Fe, Mn, Al); to a lesser extent they can occur as carbonates, phosphates, and sulfates; and in reducing (usually wet or waterlogged) soils as sulfides, which are highly insoluble. The soil parameters important in affecting sorption and precipitation reactions and the extent of their influence—and thus contaminant bioavailability—depend on the intrinsic properties of the contaminants. In the soil environment, metals can exist as cations (having a positive charge), anions (having a negative charge), or neutral species (having a zero charge). Their form significantly affects their sorption, solubility, and mobility. For example, most soils are chiefly negatively charged; thus, metal cations have a higher propensity to be sorbed by soil particles than do metal anions (U.S. EPA, 2003e).

Cationic metals can react with inorganic soil constituents (e.g., carbonates, sulfates, hydroxides, sulfides), forming aqueous complexes, which may be adsorbed or precipitated in mineral form. Most complexation and precipitation reactions are pH dependent (U.S. EPA, 2003e).

As, Cr, Se, and V complex with O and typically exist as anionic species under most environmentally relevant scenarios (Bohn et al., 1985; Lindsay, 1979). The most common forms of As are arsenate (As(V)) and arsenite (arsenic(III)), which are present in soil solution in the form of AsO_4^{3-} and AsO_3^{3-}, respectively. The chemistry of arsenic resembles that of phosphate (Barber, 1995; Bohn et al., 1985). Cr can exist as chromate (Cr(VI) or CrO_4^{2-}), which is usually considered more soluble, mobile, and bioavailable than the sparingly soluble chromite (Cr(III)), which is normally present in soil as the precipitate $Cr(OH)_3$ (Barnhart, 1997; James et al., 1997). Similarly, Se can be present as selenates (SeO_4^{2-}) and selenites (SeO_3^{2-}). For V, vanadate (VO_4^{3-}) is the most common form (U.S. EPA, 2003e).

Metals can exist in the pore water as aquo-ions or soluble complexes. The bonding of metal species to soil particles can range from ionic to covalent. For most soils in the United States, negatively charged sites are more plentiful; less than 5% of the total available charge on the soil surface is positively charged. Metals existing as cationic species have a greater propensity to associate with such soils. This makes them less bioavailable, but it also results in greater loading of metals into the soil ecosystem. Anionic metals generally move into pore water—and so are more bioavailable—but leach out of the system much more rapidly. In summary, soil pH and availability of charged sites on soil surfaces are the primary soil factors controlling release of metals to pore water and, subsequently, bioavailability (U.S. EPA, 2003e).

3.1.6.1. *Key Parameters Affecting Metal Bioavailability in Soils*

From the preceding overview of how the metals and metal compounds interact with soil constituents, it is clear that soil plays a very significant role in reducing the potential bioavailability of metals in the environment. Given the types of contaminant-soil interactions presented, the primary soil factors controlling the potential bioavailability of metals are soil pH, the availability and character of sorption sites on soil surfaces, the content of Iron and aluminum oxyhydroxides and soil organic matter, and least important, the soil clay mineral content. The following discussion briefly details the key soil parameters affecting the various contaminants availability to the pore water.

Soil pH is often termed the master soil variable because it controls virtually all aspects of contaminant and biological processes in soil. These processes include dissolution and precipitation of metal solid phases, complexation and acid-base reactions of metal species, and metal sorption as well as microbial activity. Increasing soil pH also results in an increase in the number of negatively charged soil sites, with a concomitant decrease in the positively charged sites. Therefore, increasing the soil pH increases the sorption and removal from pore water (Bohn et al., 1985).

3.1.6.2. *Adsorption Behavior of the Metals of Concern*

3.1.6.2.1. ***Surface area and surface density.*** In porous media, the most important sorbent solids for metals are oxyhydroxides of iron and manganese. Their important surface properties are discussed in Langmuir et al. (2003). For a given weight of sorbent, metal sorption capacity is proportional to surface area and surface site density. The greatest surface site densities (positively or negatively charged sites) are those of organic material and the oxyhydroxides. These phases are the strongest and most important sorbents of trace metals. Except for kaolinite, the clays (0.02-2 mmol sites/g) have a surface charge that is largely independent of pH, whereas the surface charge of organic matter and the oxyhydroxides is strongly pH dependent.

3.1.6.2.2. ***Organic matter (organic carbon) content.*** Organic matter includes plant and animal remains in various stages of decomposition, cells and tissues of soil organisms, and substances exuded from plant roots and soil microbes (Sumner, 2000). Organic matter is primarily composed of carbon, oxygen, and minor amounts of nitrogen (N) and phosphorus (P). On average, approximately 58% of organic matter is organic carbon. Organic matter in soils ranges from <1% for a sandy soil to almost 100% for a peat soil, with most soils having organic matter contents <10% (Bohn et al., 1985). Also, organic matter content is usually higher in surface soils or in the root zone and decreases with depth in the soil profile. The organic acid functional groups typically present in organic matter have a high affinity for metal cations.

3.1.6.3. *Aging of Metals in Soil*

A distinction should be made between persistence of total metals in soil and persistence of bioavailable forms of the metal. As metals age in soils, they decrease in bioavailability. The aging process is partially reversible if environmental parameters change (e.g., pH decreases), although a portion of the metal ions will be securely entrapped in the soil particle lattice and not available to be resolubilized. It has been well documented that metal chemistry in solutions freshly added or spiked into soils vary from metal forms in field-contaminated soils. Typically, the metal contaminant pool requires time to diffuse into micro- or nanopores and to be absorbed into organic matter and soil particles. These slow reactions are attributed to micropore diffusion, occlusion in solid phases by (co)precipitation and (co)flocculation, and cavity entrapment. Although the slow reactions play a key role in metal bioavailability, their rates, mechanisms, and controlling factors have not been comprehensively elucidated. Evidence of aging processes is provided by studies of metal extractability and lability (Tye et al., 2003; Hamon et al., 1998). It has been frequently observed that easily extractable pools revert with time (~1 year) to more strongly bound forms. Isotopic dilution provides a useful way to quantify changes associated with progressive attenuation of metals in soil. After 1 year aging reactions are almost complete and are mostly reversible. At present, information regarding the aging reactions of different

metals and metalloids and sorbing solids, is very limited, so it is not possible to generalize which metal(s) age the fastest or with greater/less reversibility.

3.1.6.4. *Dissolution and Transformation of Metals*

The dissolution and transformation of a metal compound in soil is related to a series of chemical and physical properties characteristic of the compound itself and of the soil. Environmental parameters such as temperature and humidity have a strong influence on the rate of transformation. When assessing the transformation of a compound in soil, the risk assessor should keep in mind that aging reactions may take place at the same time as transformation and dissolution. When metal salts are added to soil, the form of the salt dictates the rate and amount of soluble metal that will form in the pore water. Insoluble forms of metals (e.g., vanadium pentoxide [V_2O_5]) will transform to soluble free ion (V) at a slower rate than will soluble metal salts (e.g., Na_3VO_4). However, the rate of formation of the free ion is not proportional to the dissolution rate of the salt because aging reactions will remove the free ion from the pore water. The risk assessor should consider the relative rates of dissolution and aging simultaneously to accurately predict pore water concentrations.

3.1.6.5. *Soil Metal Transfer to Plants*

The "soil-plant barrier" concept was introduced to communicate how metal addition, soil chemistry, and plant chemistry affect risk to animals from metals mixed in soil (Chaney, 1980). Reactions and processes that take place at the soil-plant barrier are influenced by the following factors: (1) soil solid phases (e.g., iron, aluminum, and manganese oxyhydroxides and organic matter) may have adsorptive surfaces that influence soil chemistry; (2) adsorption or precipitation of metals in soils or in roots limits uptake-translocation of most elements to shoots; and (3) the phytotoxicity of Zn, Cu, Ni, Mn, As, Bo, Al, and F, for example, limits residues of these elements in plant shoots. More recently, inductively coupled plasma-mass spectrometry (ICP-MS) and other very sensitive analytical methods have been used to examine soil solution and soil-plant transfer of 60 elements as a function of soil pH (Tyler and Olsson, 2001a, b). These studies provide evidence that further supports the concept of a soil-plant barrier

Several areas for potential errors in the research methodology should be avoided when making these comparisons:

- First, comparison of application rates is valid only after the system has been equilibrated using accepted methods.
- Second, soil pH levels should be equal across rates studied; co-variance of soil pH should be used to correct for unequal soil pH (Bell et al., 1988).

- Third, the metal concentration in the source applied affects the slope of metal uptake: higher metal concentration in the source means higher phytoavailability at equal metal applications (Jing and Logan, 1992).

Strongly acidic soils increase plant uptake of Zn, Cd, Ni, Mn, and Co and increase the potential for phytotoxicity from Cu, Zn, and Ni. In alkaline soils, the high pH increases uptake of Mo and Se. Pb and Cr are not absorbed by plants to any significant extent at any pH (Chaney and Ryan, 1993). However, each element should be considered separately because of its unique chemistry. For example, arsenate is more strongly adsorbed than is arsenite; when a soil is flooded to grow rice, soil microbes can reduce arsenate to arsenite, and the higher concentration of dissolved arsenite can be phytotoxic to rice in more highly contaminated soils. Most other elements have little potential for redox change with change in the redox status of soils. Reduced soils can form sulfide, and sulfide forms low-solubility compounds with most of the metals of concern in soils, including Pb, Zn, Cd, Cu, and Ni (see above discussion on sediment chemistry Section 3.1.5). For essential elements (e.g., Zn, Cu, Ni), low-solubility species can result in deficiency syndromes. Upon oxidation of the soil, sulfide is quickly oxidized, and the metals are returned to more normal equilibrium reactions of aerobic soils.

3.1.7. Atmospheric Behavior/Chemistry

Most metals and metal compounds exist in the solid phase under normal environmental conditions and thus occur almost exclusively in the particle phase of the atmosphere, where they are ubiquitous. Anthropogenic sources include combustion from fossil fuels and metal industries as well as industrial sources employing specific metal compounds in specific processes. Some airborne metals (e.g., manganese and nickel) may derive largely from crustal sources (U.S. EPA, 1996a). Richardson (2002) included volcanic eruptions and emissions, entrainment of soil and dust, entrainment of sea salt spray, and natural forest fires as significant natural metals emission sources.

For purposes of health risk assessment, particle size is important. The aerodynamic size and associated composition of particles determine their behavior in the human respiratory system. Furthermore, particle size is one of the most important parameters in determining the atmospheric lifetime of particles, which may be a key consideration in assessing inhalation exposures as well as exposures related to exposure pathways involving deposition onto soil or water (U.S. EPA, 1996a). Metals emitted by combustion processes (e.g., the burning of fossil fuels or wastes) generally occur in small particles or fine fraction, which is often characterized by particles less than 2.5 microns in diameter ($PM_{2.5}$). In contrast, the larger sized, coarse mode particles result from mechanical disruption, such as crushing, grinding, and evaporation of sprays, or suspensions of dust from construction and agricultural operations. Accordingly, metals in coarse mode particles (i.e., those larger than approximately 1–3 μm) are primarily those

of crustal origin, such as Silicon (Si), Al, and Fe (U.S. EPA, 1996a). The *fine* versus *coarse* distinction simply differentiates two relatively distinct size distributions of particles, the separation point of which occurs in the range of 1 to 3 μm. The distinction does not refer directly to particle sampling methods or size fractionations particular to health risk assessment (U.S. EPA, 1996a).

Fine and coarse particles typically exhibit different behavior in the atmosphere; fine mode particles exhibit longer atmosphere lifetimes (i.e., days to weeks) than coarse particles and tend to be more uniformly dispersed across a large geographic region (U.S. EPA, 1996a). Relatively lower dry deposition velocities of fine particles contribute to their persistence and uniformity throughout an air mass (U.S. EPA, 1997c). The larger coarse particles (i.e., greater than 10 μm) tend to rapidly fall out of the air and have atmospheric lifetimes on the order of minutes to hours, depending on their size and other factors (U.S. EPA, 1996a).

In most cases, metals do not undergo transformation while in the particle phase; thus, their removal from the atmosphere is regulated by the rate at which the particles themselves participate in wet and dry deposition processes. For example, metals such as As, Be, Cd, and Pb are generally found in airborne compounds with a single predominate oxidation state (As(III), Be(II), Cd(II), Pb(II)). Some metals (e.g., the transition metals Cr, Mn, and Ni) present the possibility of changing oxidation state *in situ* in the particle, although little is known of these processes (U.S. EPA, 2003d). This is an important consideration for health risk assessment as the different oxidation states also differ in toxicity (such as for Cr).

For metals that can change oxidation states, much of the atmospheric chemistry takes place in the aqueous phase, such as cloud droplets or water films on particles. Metal salts and oxides that dissolve in water can undergo several reversible reactions, including hydration, hydrolysis, polymerization, and reaction with other anions. The equilibrium between these forms depends on the atmospheric conditions, the equilibrium and solubility constants, and the concentrations of other chemicals. Transformations between oxidation states can occur either to increase the oxidation state (such as oxidizing Cr(III) to Cr(VI)) or to reduce it. These oxidation or reduction reactions can occur through reaction with other species, such as dissolved metals, reduced sulfur species, and organic compounds (Seigneur and Constantinou, 1995). Although models exist that can be used to estimate metal speciation in aerosols with liquid water, the reactions are still highly uncertain.

Hg is an exception among the commonly occurring metals; it exists primarily in the vapor phase under most conditions but can also occur in particle and aqueous phases. The risk assessor should consider at least three species of Hg: elemental Hg, which is largely present as a gas; divalent (Hg(II)) inorganic Hg compounds, which are more water soluble; and particulate-phase Hg (Schroeder and Munthe, 1998; U.S. EPA, 1997b). The behavior of Hg in the atmosphere depends strongly on the oxidation state. Elemental Hg is capable of being transported long distances, even globally; divalent Hg deposits within a few hundred kilometers of sources; and

particulate mercury is deposited at intermediate distances, depending on the particle size (Schroeder and Munthe, 1998). Elemental Hg that is deposited can be reemitted from the surface, as can divalent and particulate Hg after biological or chemical reduction to the elemental form.

In the gas phase, elemental Hg can be oxidized to divalent Hg by O_3, OH, H_2O_2, and molecular chlorine (Cl), although other halogen atoms also might be important (Schroeder and Munthe, 1998). In the aqueous phase, elemental Hg can be oxidized by OH, O_3, and dissolved chlorine, and divalent mercury can be reduced by processes such as reaction with HO_2 and S(IV). Both vapor-phase and aqueous atmospheric chemistry may involve multiple phases.

EPA has made a substantial effort to evaluate the atmospheric fate of Hg as a result of the requirements of the Clean Air Act. EPA (1997b) contains a comprehensive evaluation of mercury's atmospheric fate, but this is an area of ongoing research and controversy. EPA continues to actively investigate Hg behavior in the atmosphere (e.g., Landis and Stevens, 2003; Jaffe et al., 2003; Bullock and Brehme, 2002; U.S. EPA, 2001a; Bullock, 2000a, b).

Most sampling and analytical techniques published by EPA for metals in air are oriented toward evaluation of particular-phase total metals rather than metal species (U.S. EPA, 1999a). These methods involve collection of a particular size fraction of particles (e.g., $PM_{2.5}$, PM_{10}, and total suspended particulates), with subsequent analysis by x-ray fluorescence, atomic absorption, inductively coupled plasma, proton-induced x-ray emission, or neutron activation analysis gamma spectroscopy techniques. The one notable exception is a method for Hg(Method IO-5) that speciates vapor and particulate forms. To the extent that metals are sorbed to particulate phases, analysis of individual metal species can, at least theoretically, be accomplished by the same techniques used to analyze those species in other solid media.

Potential for Inhalation

Inhalation of metals is addressed in Section 4.2.5.1. Particle size is likely to be the most important determinant of potential exposure. Particle size also influences the overall fate of metals in the atmosphere.

3.2. METAL FATE AND TRANSPORT

Major metal sources to water and land include diverse manufacturing, mining, combustion, and pesticide activities. Major atmospheric sources are oil and coal combustion, mining and smelting, steel and iron manufacturing, waste incineration, phosphate fertilizers, cement production, and wood combustion (Haygarth and Jones, 1992). Metals from these atmospheric sources can find their way into soils, sediments, and water. Other major sources to aquatic and terrestrial systems include chloralkali, acid, pigment, electronics, and copper sulfate production.

Some exposure assessments do not involve anthropogenic releases of metals to the environment. Rather, they focus on changes in exposure to environmental metals that result from other aspects of human activities. For example, acidification of freshwater changes Al phase association and speciation, resulting in an increased dose of naturally occurring metals to aquatic biota (e.g., Campbell et al., 1992). Intensive irrigation mobilizes Se that is naturally present in relatively high concentrations in western soils, and consequent evaporative concentration in wetlands, impoundments, and other low-lying areas in arid regions of the U.S. can lead to toxic exposures (e.g., Wu et al., 1995).

3.2.1. Aquatic and Terrestrial Transport Pathways for Metals

When an exposure assessment is completed for a site, the available data are usually limited in their coverage with respect to the characterization of exposure levels over both time and space. Depending on the situation, it may be advantageous to use a transport and fate model (i.e., a computational model) to fill in the data gaps, such that an improved characterization of exposure levels is available for use by the risk assessor. Models are also useful in situations where it is desirable to have an estimate of future exposure levels that are expected to result from the implementation of remediation measures. These results can be used to quantitatively evaluate the effectiveness of alternative remediation scenarios that are being considered. The models can also be used to refine the design of the viable alternatives so that the risk assessor can develop an optimal remediation strategy.

Although numerous models are available for use, most are based on the same two fundamental principles: (1) metals are ubiquitous in the environment, as they are found in the aquatic, terrestrial, and atmospheric compartments; (2) within each compartment, they are present in association with water (freely dissolved metal or as organic and inorganic metal complexes), particles (sorbed, precipitated, or incorporated within a mineral phase), and air. The evaluation of metal transport therefore requires evaluation of the distribution of the metal among these phases, within each compartment (air, water, soil), as well as the movement (i.e., the transport) of each of these within and among the various compartments. It is important for the assessor’s model to simulate the movement of water and particles explicitly because this provides a way to evaluate differences in the degree to which various chemicals/metals may be transported in association with particles (i.e., via settling and resuspension) or in association with the dissolved phase (diffusive flux of dissolved metal). The analyst represents the environmental setting of interest as a series of discrete, interconnected volumes. Mass balance equations for air, water, solids, and metal are then formulated for each volume to obtain a system of mass balance equations that may then be solved for the concentrations of interest over both time and space. Including all compartments in every model is not necessary. For example, models for a site that is impacted by a smelter might call for use of a model of an atmospheric compartment (e.g., to simulate transport of a release from a stack) and a terrestrial compartment (to simulate fate of

atmospheric inputs to the soil). Alternatively, for an aquatic setting dominated by previously contaminated sediments, it may be sufficient to consider water and sediment transport alone and to neglect the atmospheric and terrestrial compartments.

Although the underlying principles of most models are similar, the included features vary widely from one model to the next. The output from a relatively simple model may be adequate for decision-making purposes in some instances. Some relatively simple models are limited in their applicability to steady-state analyses and spatially uniform conditions, but if this will provide a reasonable and/or conservative representation of conditions at a site, it may provide the analyst with a useful and cost-effective modeling alternative. In other cases, the analysis may require the completion of time-variable simulations to properly represent conditions that vary over time, such as daily or seasonal variations in flow and upstream boundary concentrations, point source loads, and pulse exposures. The analyst should select an appropriate model because not all models will be applicable to every situation. Although, in principle, the more sophisticated models provide the risk assessor with the capability to complete a more detailed and mechanistically based analysis than will a simple model, successful application of these models will require greater resources (data, time, and funding) than will the use of a simpler model. The analyst must also possess a relatively high level of modeling expertise to use the more sophisticated modeling approaches. It is for this reason that the more sophisticated models are usually reserved for use in higher level, definitive assessments.

Many of the models available for use in evaluating the transport and fate of metals were originally developed for application to neutral organic chemicals. As a result, these models frequently include a variety of reactions that are not necessarily relevant to an analysis of metal transport and fate (e.g., biodegradation, photo-oxidation, and volatilization). Although these models still may be of use in an exposure assessment for metals (the nonapplicable processes often may be bypassed), a more significant problem is that they often fail to represent some important metal-specific processes. For example, the evaluation of metal speciation and metal partitioning between dissolved and particulate phases will be represented only in a very simple manner in such models. This limitation may be overcome, at least in part, by performing the requisite metal-specific analyses with a stand-alone chemical equilibrium model, but this approach will place an added burden on the analyst to integrate the results of the two models in a technically defensible manner.

Although models that include some metal-specific capabilities will be discussed as part of this Framework, no single model that is currently available for use includes all the metal-specific features that would be desirable for use. More detailed discussions of these and other transport and fate models, as well as a number of chemical equilibrium models, may be found in Paquin et al. (2003) for aquatic systems and Allen (2002) for terrestrial systems. Additionally, work is in progress to develop updated models that will offer improved metal-specific capabilities (e.g., the

Unit World model (Di Toro et al., 2001). As a result, metal fate and transport models should be viewed as an evolving tool, and new models may be expected in the near future.

3.2.1.1. *Aquatic Transport Models*

Modeling of metal transport and fate within aquatic systems involves the representation of hydrodynamic transport to simulate movement of water, particulate transport to simulate the movement of particles, and chemical transfers and kinetics to simulate exchange of metal between dissolved and particulate phases and between the water column and benthic sediment (Figure 3-2). The risk assessor has the option of using independent hydrodynamic transport, sediment transport and chemical fate models, or an integrated model that incorporates all these processes.

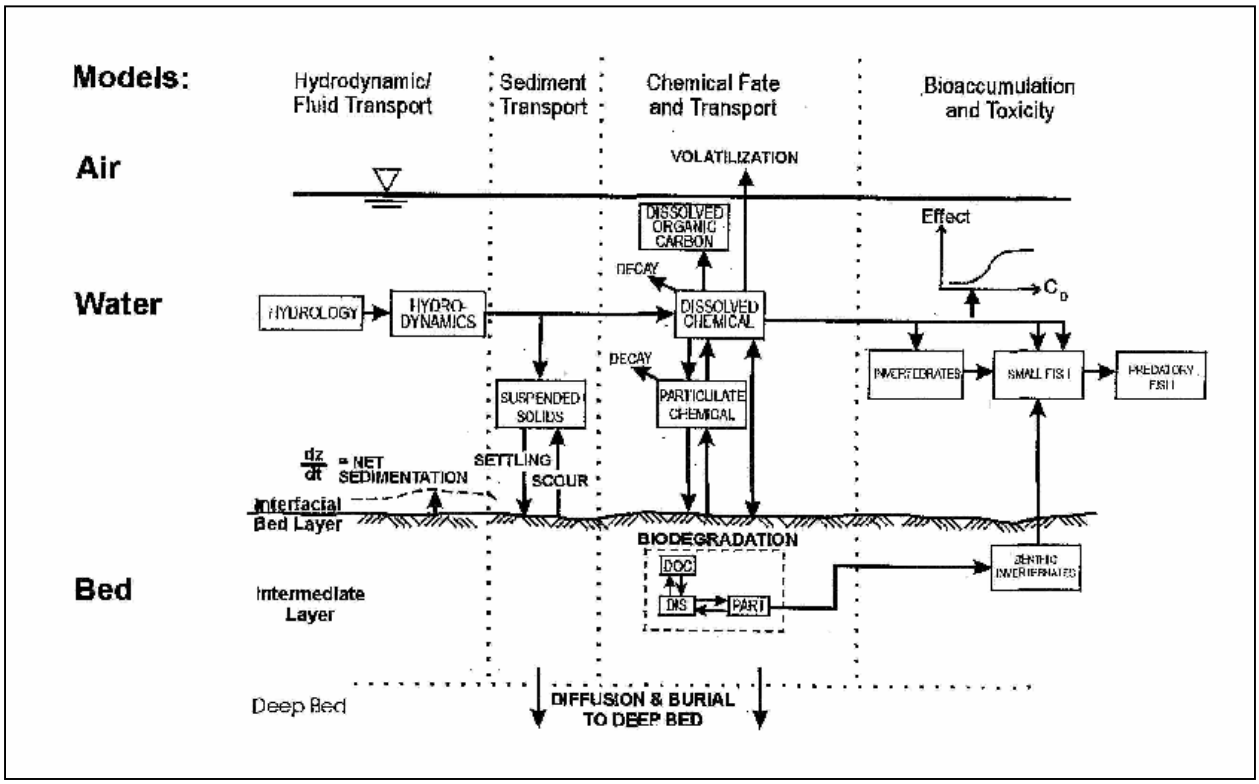


Figure 3-2. A generalized model framework for chemical fate and transport in an aquatic system.

Source: Paquin et al. (2003).

Modeling the movement of metals through an aquatic system begins with a characterization of the water movement through the system. The time scale for the hydrodynamic analysis should be represented in a way that will satisfy the needs of the sediment transport and chemical fate analyses that are also being performed. For example, low-flow

conditions associated with minimum dilution may be judged to be the most critical conditions in a setting involving a point source discharge, while peak flow conditions may need to be simulated in a setting where resuspension of contaminated sediments is the primary concern. A steady-state model might be appropriate for use in the former case, and a time-variable model would likely be needed in the latter case. Thus, the details of the specific problem setting will necessarily have an influence on both model selection and how the model will be used.

Integrated Models

The fate and transport of metals in aquatic systems is most reliably predicted using integrated models rather than stand-alone hydrodynamic or sediment transport models.

The risk assessor also should be aware of several reviews of fate and transport models that have been completed since the early 1980s. In earlier reviews, Delos et al. (1984) reviewed models for wastewater load allocations, and Mills et al. (1985) described screening-level analyses for water quality assessments of conventional pollutants. The Agency subsequently prepared an updated summary of the features included in the water quality models that were available for use in exposure assessments (U.S. EPA, 1987). Schnoor et al. (1987) simultaneously published their review and included detailed descriptions of fate and transport models and their required input parameters. Later, EPA published a review describing the use of modeling tools for the development of Total Maximum Daily Loads (TMDLs) in watersheds (U.S. EPA, 1997a). More recently, Paquin et al. (2003) completed a review of exposure, bioaccumulation, and toxicity models for aquatic systems, with a focus on their applicability to metals (exclusive of organometallics). Because of the advances that have been made since the mid-1990s with regard to the development of fate and transport models, including some recent efforts to couple these models with metal speciation models and more sophisticated stand-alone hydrodynamic and sediment transport models, the latter reviews by EPA (1997a) and Paquin et al. (2003) tend to include the most up-to-date information with regard to the availability of models that are appropriate for use. These reviews also include example applications of many of the models discussed.

Fate and transport analyses may be performed by using an integrated hydrodynamic, sediment, and chemical transport model or by employing what tend to be relatively sophisticated stand-alone versions of these three submodels. The advantage of the former approach is that integration of the hydrodynamic, sediment, and chemical transport results takes place in a seamless manner with limited need for an assessor’s intervention. This is in contrast to the use of stand-alone models, where the output of one model should be formatted in a way that ensures it is amenable to use with the other models that are to be applied. A distinct advantage of the latter approach is that it has the potential to reduce the time needed to complete a model run, an important consideration for a multiyear simulation of a large and complex problem setting. For example, it may not be necessary to repeat the simulation of hydrodynamic and sediment transport if the model input being modified affects only chemical transport (e.g., partition

coefficient). A similar line of reasoning would apply to the use of an integrated transport model that includes metal speciation versus one that uses a stand-alone chemical equilibrium model to satisfy this need.

Analytical Solution Models

Analytical solution models of aquatic system fate and transport are the simplest models with the lowest computational requirements. They are solved analytically to provide concentrations over metal of time or space.

The partition coefficient, which controls the distribution of metal between the dissolved and particulate phases, is considered to be a key model parameter in chemical/metal fate and transport evaluations (see Section 3.1.4). It is important for several reasons. First, the distribution of metal between the dissolved and particulate phases has a direct impact on the magnitude of particulate fluxes of metal that occur in association with the settling and resuspension of sorbed metal. Second, the partition coefficient also controls the magnitude of diffusive fluxes of metal between the sediment interstitial water and the overlying water column, as this flux is proportional to the concentration gradient of total dissolved metal (free ionic metal + metal-DOC and metal-inorganic ligand complexes) between these compartments. Partitioning reactions also affect the metal bioavailability and the route of exposure to a metal (food vs. water). Given its importance, the risk assessor should recognize that the assumption of equilibrium partitioning is a potential oversimplification in some situations (e.g., near a point source discharge to a receiving water or immediately following a pulse exposure, such as an overflow from a storm sewer system). Under these conditions, the assumption of equilibrium between the dissolved and particulate phases may be less appropriate than is otherwise the case and additional uncertainty will necessarily be associated with the model results. If this situation exists, consideration should be given to conducting special studies (e.g., measurement of free metal concentrations over time in a water sample) to test the validity of the equilibrium assumption.

Modeling of Hg and metalloids, such as As and Se, is complicated by transformation processes that change the form of the metal. Similarly, metals that readily change oxidation state (e.g., Cr) also require additional considerations in fate modeling. Many of the same transport models can be used, but input parameters will require modification. Such models are beyond the scope of this framework, which is focused on inorganic forms of metals. See, for example, the Hg cycling model by Hudson et al. (1994) for further guidance on fate and transport models for Hg. All modeling exercises are limited by the validity of the model Framework, the accuracy of input parameters, and the experience of the analyst (Dzombak and Ali, 1993). Therefore, all exposure assessments should include an explicit description of model assumptions and associated uncertainties.

3.2.2. Terrestrial Fate and Transport

Movement of metals through soils is dependent on the chemical properties controlling speciation, the presence of ligands that control complexation of metals within pore water (and ground water) and adsorption onto mineral surfaces, and the rate of water flux through the soil. Metals are lost from the soil by leaching into ground water and through metal specific uptake by plants (see Section 3.1.6.5). Sections 3.1.4 and 3.1.6 review the processes and models that predict movement of chemicals through soils or partitioning onto mineral surfaces (i.e., partition coefficients). These serve the same role as the fate and transport models discussed above for aquatic systems and therefore are not repeated here.

3.3. ATMOSPHERIC FATE AND TRANSPORT

Fine and coarse particles typically exhibit different behavior in the atmosphere: fine mode particles exhibit longer atmospheric lifetimes (i.e., days to weeks) than coarse particles and tend to be more uniformly dispersed across a large geographic region (U.S. EPA, 1996a). Relatively lower dry deposition velocities of fine particles contribute to their persistence and uniformity throughout an air mass (U.S. EPA, 1997c). The larger coarse particles (i.e., greater than 10 μm) tend to rapidly fall out of the air and have atmospheric lifetimes on the order of minutes to hours, depending on their size and other factors (U.S. EPA, 1996a).

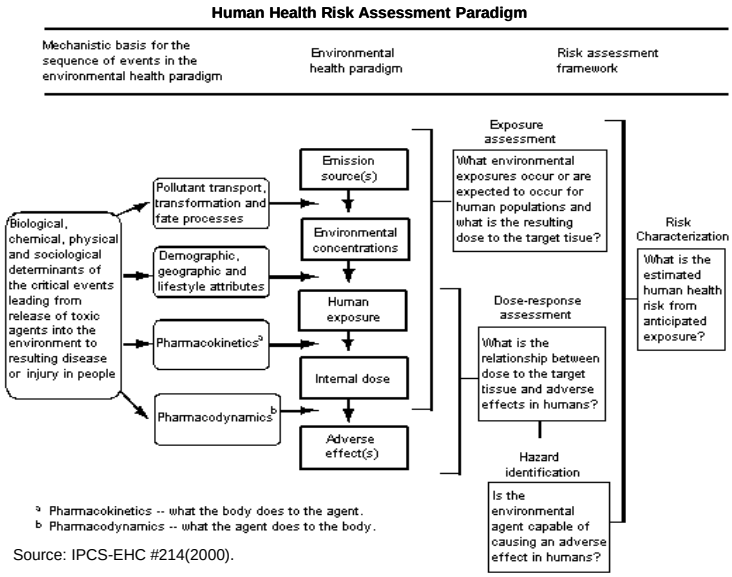
In the atmosphere, the behavior of Hg depends strongly on its oxidation state. Elemental Hg is capable of being transported long distances, even globally; divalent Hg deposits within a few hundred kilometers of sources; and particulate Hg is deposited at intermediate distances, depending on the particle size (Schroeder and Munthe, 1998). Elemental Hg that is deposited can be reemitted from the surface, as can divalent and particulate Hg after biological or chemical reduction to the elemental form.

Deposition

Because most metals occur as particulate matter (hereinafter referred to as *particulates*), their removal from the atmosphere is governed by the rates of wet and dry deposition. These deposition processes represent an important route of exposure for plants, animals, and humans. Some of the deposited metals can come to reside on the surfaces of vegetation, resulting in potential exposure to the plants and to animals that eat the plants. Metals deposited from the atmosphere also come to reside in the leaf litter and uppermost soil surfaces, where they can be a source of exposure for soil organisms, people, and wildlife.

4. HUMAN HEALTH RISK ASSESSMENT FOR METALS

The National Research Council (NAS/NRC, 1996, 1994b, 1983), of the National Academy of Sciences (NAS), described four phases to the human health risk assessment paradigm (Hazard Identification, Dose-response Assessment, Exposure Assessment, and Risk Characterization) and identified risk communication as a fifth area of study. These principles have been further addressed in EPA's *Risk Characterization Handbook* (U.S. EPA, 2000c). In brief, hazard identification (referred to as "hazard characterization" in recent EPA documents) involves the determination of whether a chemical is or is not causally linked to particular health effects. Dose-response involves the determination of the relationship between the magnitude of exposure and the probability of occurrence of the health effects in question. A parallel step in the process toward the hazard identification and dose-response assessment is exposure assessment. In Exposure Assessment, the risk assessor quantifies the total exposure to a toxic agent in the environment based on amount taken into the body, including any combination of the oral, inhalation, and dermal routes of exposure. For some assessments specific to a single exposure route, exposure may be expressed as an environmental concentration (e.g., ambient air or water concentrations). Depending on the application, the exposure assessment may be specific to a site, a population at a specific location, or it may broadly cover a region or an entire nation. Risk Characterization is the final step in the NAS paradigm. In this phase, the risk assessor summarizes and interprets the information from hazard identification, dose-response, and exposure steps, often by quantitatively comparing exposures with doses that are associated with potential health effects. Risk Characterization addresses the nature and often the magnitude of the human health risks, including attendant uncertainty. These steps are addressed in greater detail in the following sections, with particular attention to the aspects specific to metals.



Source: IPCS-EHC #214(2000).

The information provided here complements that given by the available Agency guidance for the risk assessment process, e.g., for carcinogen risk assessment (U.S. EPA, 2005, 1986), exposure assessment (U.S. EPA, 1992c), developmental toxicity (U.S. EPA, 1991), neurotoxicity (U.S. EPA, 1998c), chemical mixtures (U.S. EPA, 2000b, 1986), and cumulative risk (U.S. EPA,

2003e), and focuses on the unique and specific characteristics of metals and metal compounds that may be applied in metals risk assessments for human health.

4.1. METALS PRINCIPLES

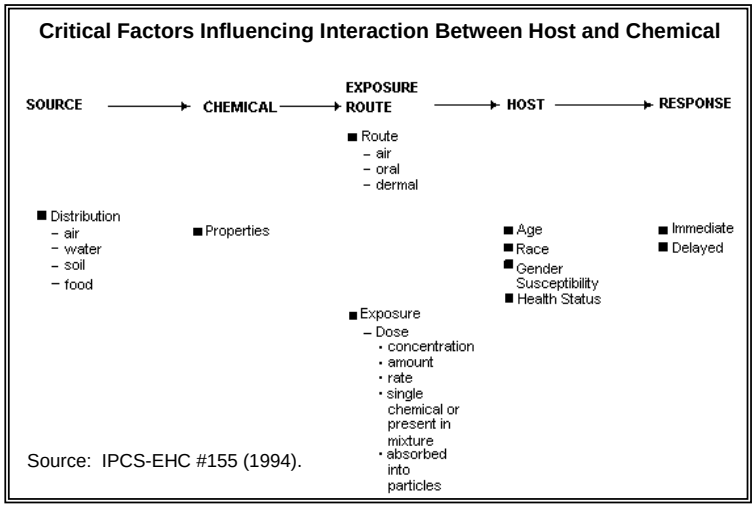
Metals are associated with a variety of health effects that are reviewed in detail in EPA's Integrated Risk Information System (IRIS) Toxicology Reviews, the Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profiles, the World Health Organization's International Programme for Chemical Safety (WHO/IPCS) Environmental Health Criteria Documents, and metal toxicology reviews (e.g., Lukaski, 1999; Hathcock, 1996; Mertz, 1995, 1993; Wallach, 1985). Metals have specific attributes that should be considered in all risk assessments. These principles for metals risk assessment (see Chapters 1 and 2) apply in various ways to human health risk assessments, depending on the scale of the assessment (site specific, regional, or national). This section describes applications of the metals principles to human health assessments within the standard risk assessment framework. Specifically, they fall into the risk assessment paradigm as follows:

Background levels	Exposure Assessment
Mixtures	Exposure and Effects Assessment
Essentiality	Effects Assessment
Forms of metals	Exposure Assessment (bioavailability) and Effects Assessment (absorption, distribution, metabolism, and excretion [ADME] and toxicity)
Toxicokinetics/toxicodynamics	

Often times, human health risk assessors start their analysis with a metal-specific reference value (RfD/RfC) and/or cancer potency factor that has been developed through a process separate from the health risk assessment. The role of the human risk assessor is to appropriately integrate the reference values and potency factors with the exposure assessment. Thus, the risk assessor needs an understanding of the toxicological endpoints and mechanisms of action that underlie the derivation of these values to ensure that, for example, the appropriate population and life stages are addressed, appropriate dietary aspects are taken into consideration, and the appropriate exposure pathways are considered. For metals, frequency and duration of exposure, as well as exposure concentrations and metal species, are important parameters for the risk assessor to consider for accurate dose assessments.

4.2. HUMAN EXPOSURE ASSESSMENT

NAS/NRC (1994b) defines exposure assessment as "the determination of the intensity, frequency, and duration of actual or hypothetical exposures of humans to the agent in question. In general, concentrations of the substance can be estimated at various points from its source." Although there is no specific guidance exclusively for metal exposure assessment, EPA has published guidelines for exposure assessment (U.S. EPA, 1992c), exposure factors (U.S. EPA, 1997e, 1989a), exposure factors for children (U.S. EPA, 2002b), and assessment of early lifestage exposure (U.S. EPA, 2005). Additional reports and principles have been published by the Centers for Disease Control and Prevention (CDC, 2003) and IPCS (2000, 1999, 1994b).



Assessment of human exposures to metals, as with any chemical agent, includes:

(1) identifying how people come into contact with metals in the environment

(2) determining the concentrations of specific forms (speciation) of the metal in specific medial (e.g., soil, water, air, and biota)

(3) identifying the pertinent exposure metric (via consideration of dose-response assessment)

(4) estimating the exposure metric (e.g., oral intake, inhalation exposure concentration, blood concentration), which may involve quantifying relationships between exposure concentrations and intakes and

(5) identifying sources of uncertainty and natural variability and, where possible, quantifying these in estimates of exposure.

4.2.1. Background Levels

Metals are naturally occurring constituents in the environment. As a result of industrialization, current environmental levels of metals can be elevated relative to naturally occurring levels. This may result in a wide variability in the intake of some metals in food (e.g., seafood), drinking water, or air. Strategies for estimating metal concentrations in air, soil, and

Background Metal Concentration

As a result of industrialization, current environmental levels of metals can be elevated relative to naturally occurring levels. Depending on the purpose of the risk assessment, assessors should distinguish among naturally occurring levels, existing background levels, and contributions from specific activities at the local or regional level.

water are discussed in Section 3. In human health risk assessments, the term "background" refers to all existing metal sources except the targeted source. A particular challenge for the risk assessor may be assessing the metal levels associated with the source(s) of interest in light of levels derived from natural and other anthropogenic sources.

4.2.2. Bioavailability

The term "environmentally available fraction" refers to the portion of total metal in soil, sediment, water, or air that is available for physical, chemical, and biological modifying influences (Lanno, 2003) and represents the total pool of metal at a given time in a system that is potentially able to contact or enter an organism. Of that portion, the bioaccessible fraction (BF) is the amount that actually interacts at the organism's contact surface and is potentially available for absorption or adsorption (if bioactive upon contact) by the organism. Bioavailability is the extent to which bioaccessible metals (see Section 2.3) cross biological membranes, expressed as a fraction of the total amount of metal the organism is proximately exposed to (at the sorption surface) during a given time and under defined conditions.

The concept of metal bioavailability includes metal species that are bioaccessible and are absorbed or adsorbed (if bioactive upon contact) with the potential for distribution, metabolism, elimination, and bioaccumulation in the organism. Metal bioavailability is specific to the metal salt and particulate size, the receptor and its specific pathophysiological characteristics, the route of entry, duration and frequency of exposure, dose, and the exposure matrix. The metal salt is influenced by properties of the environment such as pH, particle size, moisture, redox potential, organic matter, cation exchange capacity, and acid volatile sulfides. Depending upon the assessment, it may be appropriate for the risk assessor to consider metal bioavailability and compare the bioavailable fractions used to estimate reference doses (RfDs), or the equivalent, to those measured in the diet, drinking water, or air.

Prediction of toxicity due to exposure to inorganic metals is complicated by wide variations in the bioaccessibility and bioavailability of accumulated metals. The form of the metal (chemical species, compound, matrix, and particle size) influences its bioaccessibility. In turn, the metal form is impacted by properties of the environment such as pH, particle size, moisture, redox potential, organic matter, cation exchange capacity, and acid volatile sulfides. Bioavailability (how much of the ingested metal interacts at the target site) is influenced by nutritional state (deficiency versus excess), age, sex, physiological state, pathological conditions, and interactions with other substances present.

Bioavailability/Hazard Relationship

If two substances were equally toxic at comparable levels of target organ exposure, the substance with the higher intrinsic bioavailability would pose the greatest risk.

It is important that the Exposure Analysis describes the same bioavailable fraction of the metal(s) of concern as that used when estimating the reference value (e.g., the RfD). For

example, measuring total metals in dietary items may include insoluble forms of the metal (particularly if soil contamination is present on the foodstuff), so effective exposure is overestimated. There are both direct and indirect approaches to address the relative bioavailability of metals in the environment: (1) conduct new animal toxicology studies using the metal form encountered in the site assessment; (2) use adjunct scientific data to derive an adjustment to the effective dose identified in the animal study (e.g., data on the distribution of chemical forms of the metal in the environment or at a contaminated site); or (3) use a default assumption that the metal in the environmental samples is the same as that tested. Of the three approaches, the first is more scientifically sound. The second option might be available in some circumstances but is usually precluded by time and financial resource limitations, and the third option, is the most health-conservative.

A fourth alternative conducted for site-specific assessments is for the risk assessor to estimate bioavailability through solubility studies or limited bioavailability studies of specific samples from the site. For example, arsenic bioavailability has been estimated for soils from various contaminated sites (Ng et al., 1998; Freeman et al., 1995, 1993) and also through a series of solubility studies of soil from a site contaminated with mine tailings (Ng et al., 1998; Salocks et al., 1996). Additional examples are animal feeding studies with juvenile swine for lead bioavailability adjustments or *in vitro* tests, although the Agency currently requires additional validation of the latter approaches before they can be used as the sole basis for making bioavailability adjustments (U.S. EPA, 2006a).

4.2.3. Susceptible Populations

Risk assessors must specifically consider population subgroups, which may have a greater risk to metals than the general population (U.S. EPA, 2006b). Factors influencing susceptibility to metals include life stage, life style, gender, reproductive status, nutritional state, pre-existing health conditions or disease, and genetic polymorphisms. Children and elderly people do not regulate metal uptake and distribution efficiently and may be at higher risk of accumulating toxic levels (U.S. EPA, 2006b). Pregnant and lactating women have a higher demand for essential elements, and lack of adequate levels of protein in the diet can affect the bioavailability of essential elements (NAS/NRC, 2000). Individuals with chronic liver or kidney disease may have a lower threshold for effects because these are two of the major target organs of metal toxicity. Several well-known, heritable genetic alterations affect people's ability to regulate Cu or Fe, resulting in various deficiency or toxicity problems (WHO/IPCS, 2002). Although many of these same factors are considered in all human health risk assessments, each has attributes specific to metals-associated risks.

4.2.3.1. *Life Stage*

In addition to higher intake per kilogram of body weight (Plunkett et al., 1992), children may also be more sensitive than adults to metal irritants since sensitivity to skin irritants is generally considered to decrease with age. Infants in the immediate postnatal period can also be more susceptible to systemic effects of metals because absorption of essential metals is poorly regulated (WHO, 1996). At the other extreme, older adults are more sensitive to metals that target the kidney (e.g., Cd) because renal function declines with age. Efficiency of intestinal uptake of some trace metals, particularly Zn and Cu, also declines as people age (WHO, 1996; IPCS, 1994).

4.2.3.2. *Demographics*

Differences in lifestyle influence metal exposure. The risk assessor should explicitly investigate different lifestyles of the population of concern. For example, the use of dietary supplements and other consumer products containing essential elements has increased. In addition, folk remedies such as colloidal silver “cure-alls” and folk remedies containing lead tetroxide may contain high levels of metals (McKinney, 1999; Yanez et al., 1994; Pontifex and Garg, 1985; Trotter, 1985; Bose et al., 1983; CDC, 1983, 1982, 1981; Geffner and Sandler, 1980). Smoking provides significant exposure to some metals (e.g., Cd) and can potentiate the effects of exposures from other sources, and excessive alcohol consumption can exacerbate metal effects.

4.2.3.3. *Pregnancy and Lactation*

Pregnancy and lactation increase demand for some essential metals, particularly Cu, Zn, and Fe (NAS/IOM, 2003; Picciano, 1996). Because of physiological changes that include higher Fe and Ca requirements, hormonal changes, and susceptibility to respiratory disease, Zuurbier and Van den Hazel (2005) suggested that pregnant women could be predisposed to the toxic effects of beryllium (Be), Pb, and Mn (2005). Recommended dietary allowances (RDAs) specific to pregnant and lactating women have been developed for a number of essential elements (NAS/NRC, 2000, 2001) and should be considered by risk assessors looking at these metals. Additionally, women lose significant amounts of Fe during menstruation, which may lead to increased absorption and toxicity of Cd (Berglund et al., 1994).

4.2.3.4. *Concurrent Damage or Disease*

In general, people with allergies and those with pre-existing medical conditions have higher-than-average biological sensitivity to *environmental stressors.* For example, diseases or treatments that damage the kidney or liver may increase sensitivity to metals that target these organs. Damage to the lung from smoking can potentiate effects of simultaneously or

subsequently inhaled metals, particularly those that act directly on the lung (e.g., Be, Cd, Cr, and Ni). Skin abrasions or other irritations also can alter exposures to and subsequent effects of metals (although dermal absorption is not a primary route of metals exposure for intact skin).

4.2.3.5. *Nutritional State*

Risk assessors should be aware that dietary differences can affect the absorption of metals, thus changing internal target dose. For example, lack of protein (or the type of protein) can decrease metal uptake, thus reducing potential risk. However, relatively little is known about this risk factor and nutritional state is an area for further study.

4.2.3.6. *Genetic Polymorphisms and Variability*

Risk assessors should be aware of several well-known, heritable, genetic polymorphisms that affect susceptibility to metals. The best known of these are two disorders that affect Cu metabolism: Wilson's disease and Menkes syndrome. Wilson's disease is an autosomal recessive abnormality (prevalence of 1 in 30,000) that causes impaired biliary excretion of Cu, resulting in accumulation in and damage to various tissues, particularly the liver, brain, kidney, and cornea; hemolytic anemia also can result. Menkes syndrome is an X-linked recessive disorder of Cu metabolism (prevalence of 1 in 200,000) that resembles Cu deficiency regardless of level of Cu intake (WHO/IPCS, 2002).

Hemochromatosis is another common inherited disorder. It is characterized by excessive Fe absorption, elevated plasma Fe concentration, and altered distribution of Fe stores (altered iron kinetics). One long-term effect is liver cirrhosis, with increased risk of liver cancer (NAS/IOM, 2003). Another Fe-related genetic polymorphism affecting Pb metabolizing enzymes is delta-aminolevulinic acid dehydratase (ALAD), which has been found to affect the relationship of bone Pb to the cumulative blood index, suggesting that the transfer of Pb from blood to bone is altered. It is suspected that genetic polymorphisms also exist for As metabolism (NAS/NRC, 2001), but these have not yet been defined.

Risk assessors should consider the possibility of genetic differences when assessing potential sensitization reactions. Chronic beryllium disease (CBD) is an immune response, with sensitivity determined by major histocompatibility (MHC) class II genes (U.S. EPA, 1998d). Similarly, sensitivity to Ni is related to the genotype of human leukocyte antigens (HLA)[3] (ATSDR, 2003).

[3] The major histocompatibility complex is a group of genes on chromosome 6 that code for the antigens that determine tissue and blood compatibility. In humans, histocompatibility antigens are called human leukocyte antigens because they were originally discovered in large numbers on lymphocytes. There are thousands of combinations of HLA antigens.

4.2.4. Environmental Release, Transport, and Fate

The exposure component of a human health risk assessment includes source characterization and analysis of fate and transport of the chemical of interest through environmental media. Models for transport and fate of metals from emission points to environmental receptors of importance to humans (e.g., soils, plants, or animals used in food and fiber) are covered elsewhere in this Framework document (see Section 3.2), as they are similar for both human health and ecological risk assessments. It is recommended the risk assessor conduct this portion of the assessment simultaneously for both human health and ecological assessments to ensure appropriate integration of the results. Human activities that affect the contact time of people with contaminated media also influence the route(s) and total amount of exposure.

4.2.5. Route-Specific Differences in Effects

Risk assessors should consider how route of exposure affects metal bioavailability and whether effects will occur at portal-of-entry or will be due to systemic, target-organ responses. Interactions among metals or other exogenous or endogenous compounds also can affect bioaccessibility of metals and are route dependent. Thus, many metal exposure issues are specific to the route of entry and will be discussed separately in the following sections.

4.2.5.1. *Inhalation Exposure*

Most airborne metals, with a few important exceptions (e.g., Hg and arsine) occur in particulate form. This necessitates certain considerations for inhalation exposure assessment, e.g., how particle size affects respirability (i.e., how much of the pollutant enters the respiratory system). Additionally, inhalation dosimetry for particles involves some distinctly different processes than for gases (i.e., deposition, clearance, dissolution, etc.), which are also influenced by particle size (U.S. EPA, 2004, 1997c). Particle size is thus an important factor in assessing metals exposure, with the focus generally being on particles less than or equal to 10 microns (μ) in diameter (PM_{10}). Larger particles usually do not penetrate far into the respiratory tract and can be cleared to the ingestion route and swallowed. Larger particles may have a larger role as an irritant, affecting a person's eyes and nasal passages, and, if deposited in the uppermost reaches of the respiratory tract, may be transferred to the digestion tract. Thus, for exposure assessments involving measurements (e.g., using area or personal samples), the particle size is an important factor in determining inhalation exposure to metals.

Since inhalation is a primary route of exposure for metals, the risk assessor should have a good understanding of inhalation dosimetry methods and how inputs vary for metals. Key methods for inhalation dosimetry are described in EPA guidance documents (U.S. EPA, 2004, 1997c) and a number of models are available for calculating relative regional respiratory tract

deposition in rodents and humans (reviewed in U.S. EPA, 2004). The guidelines for reference concentration (RfC) development (U.S. EPA, 1990) cite the regional deposited dose ratio (RDDR) model, which has been used for development of a number of RfCs for metals. The multipathway particle dosimetry model (MPPD) developed by the Chemical Industry Institute for Toxicology (CIIT) and the Dutch National Institute of Public Health and the Environment (RIVM) was used in EPA's *Air Quality Criteria for Particulate Matter* (U.S. EPA, 2004). MPPD improves lung dose estimations by considering life-stage-specific parameters, particle clearance from the lung, and differences in oronasal breathing patterns with work load. The human equivalent concentration (HEC) is the concentration that is believed to result in the same dose to the respiratory tract region of interest as was received by the experimental animal species.

In developing inhalation exposure estimates, the risk assessor should pay careful attention to the form of the metal pertinent to the dose-response assessment (e.g., RfC, IUR). Simply measuring the total amount of a metal without regard to speciation may introduce uncertainties into inhalation exposure estimates or other exposure routes. Metal speciation affects a range of processes that change how the metal is deposited in the respiratory tract and subsequently distributed throughout the body and, consequently, its potential toxicity (Bailey and Roy, 1994; Oberdorster, 1992). For example, in assessing the risk of inhaled Cr, the assessor should consider speciation (e.g., Cr^{+3} vs. Cr^{+6}), as the dose-response assessment includes that specification. The bioavailability of metals via inhalation can be much higher than that of other intake routes. This may result in relatively high internal doses, even when intakes are similar to those from other routes. An example is the large contribution made by cigarette smoking to the body burden of Cd (e.g., Friis et al., 1998; Ellis et al., 1979). Variations in airway structure and respiratory conditions (e.g., as with age) may alter the deposition pattern of inhaled particles and contribute to variations in bioavailability (James, 1994; Xu and Yu, 1986; Phalen et al., 1985). For more information on the consideration of particle size in the dose-response assessment for RfCs and IURs, the risk assessor should refer to U.S. EPA, 1990. For metals having alternative Agency-developed dose-response metrics (e.g., blood Pb concentration), respirability, deposition, and clearance as well as absorption into the circulatory system may need to be addressed as part of the Exposure Assessment.

Risk assessors should be aware of emerging issues in inhalation dosimetry that may have important impacts on exposure assessments for metals (U.S. EPA, 2005). The developing literature suggests that current dosimetry models and traditional dose measures (such as concentration in mass/unit volume) may not adequately characterize human health risk to very small particles, such as particles $\leq$2.5 µm ($PM_{2.5}$) or <1 µm in diameter (nanoparticles). Much of the recent work on nanoparticle deposition has been conducted with metal oxide particles (e.g., titanium dioxide), and a growing body of literature is becoming available to the risk assessor. The bioavailability of Pb and other metals appears to increase with decreasing particle size,

particularly from the inhalation and oral routes of exposure, so risk assessors should be aware of the potential implications for bioavailability of metal nanoparticles.

Risk assessors should also consider exposure to metals in shower water, in which aerosolization can occur from the hot water tap. Though the magnitude of exposure from showering is unknown and comparable models do not exist for aerosolized metals (Wilkes, 1998), models have been developed to predict human inhalation exposures due to volatile organics from showering (e.g., Guo, 2002; Moya et al., 1999; McKone, 1987). Where appropriate, the risk assessor should address such inhalation exposures during the Risk Characterization phase.

4.2.5.2. *Dietary Exposure*

Dietary Exposure

Due to the diversity of the human diet, there may be wide variability in the intake of some metals in food (e.g., seafood), resulting in both temporal variability (e.g., spikes after a seafood meal) and geographic or cultural variability.

Risk assessors should be aware that dietary pathways represent a major exposure route for metals (Choudhury et al., 2001). Estimation of intakes of metals occurring in food requires information on the levels of metals in food and the amount of food consumed (NAS/IOM, 2003). A number of references provide assessors with national-scale information on dietary exposure to metals (Capar and Cunningham, 2000; Schoof et al., 1999a, b; Thomas et al., 1999; Bolger et al., 1996; Dabeka and McKenzie, 1995; Gunderson 1995; Tsuda et al., 1995; Dabeka et al., 1993). Although large-scale surveys of the metal contents of foods and food consumption patterns have been conducted (e.g., Egan et al., 2002; Ryan et al., 2001; U.S. FDA, 2001; O'Rourke et al., 1999; Thomas et al., 1999; U.S. DHHS, 1996), assessors should be aware that these surveys have several limitations for applications to human health risk assessment. Analysis is often conducted with "market basket" samples of packaged processed foods. With a few exceptions, such applications have not been empirically evaluated against biomarkers of exposure (Clayton et al., 2002, 1999; Choudhury et al., 2001). Risk assessors should be mindful that food consumption surveys are generally limited to short-term consumption (e.g., 1-3 days) and do not capture intra-individual variability that would affect long-term averages. Furthermore, dietary patterns may change over time (e.g., consumption of ethnic foods in childhood may change later), and, thus, patterns discerned at any given time may not accurately represent historical or future exposures. An additional challenge facing the risk assessor is integration of data from separate metal residue and food consumption surveys (e.g., Tomerlin et al., 1997). This leads to considerable uncertainty in estimates of metal exposure via the dietary route.

4.2.5.3. *Incidental Soil Exposure*

Infants and children can have enhanced exposures to metals through the pathway of surface dust because (1) they crawl and play in close proximity to surface dust and (2) they often mouth their hands (e.g., finger sucking) and objects in their environment. This causes an intake of surface dust that is generally greater than that which is normally found in adults (e.g., Barnes, 1990). On the other hand, infants have a large salivary response (i.e., they drool and spit up frequently), which may act to reduce overall dust intake. However, risk assessors should be aware that data are limited with regard to distinguishing between the quantity of dust ingested and the quantity of soil ingested. This parameter is important in connecting measured soil metal concentrations with surface dust ingestion that occurs in the indoor and outdoor environments (U.S. EPA, 1994a). Exposure assessment methods for direct soil ingestion are described in the Risk Assessment Guidance for Superfund (RAGS) (http://www.epa.gov/superfund/programs/risk/ragsa/index.htm). Additional guidance with respect to children (e.g., amount of soil a child may ingest) can be found in the *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2002b). Few studies of soil ingestion in adults have been conducted; however, the estimates support the assumption that average daily soil ingestion rates of adults who do not participate in activities in which intensive exposure to surface dust and soil occur (e.g., occupational gardening, construction work) are lower than those of children (Calabrese et al., 1990; Hawley, 1985). Because concentrations of the metal contaminants in soil can be expected to vary with depth, risk assessors should consider soil metal concentrations at the depth appropriate to the metal(s) of concern as well as human behaviors and activities.

4.2.5.4. *Drinking Water Exposure*

Treatment of surface and/or ground water for human consumption removes dissolved organic carbon and suspended organic sediments that can form complexes with metals (AWWA, 1999). Thus, inorganic forms of metals in treated drinking water will often consist of the more bioavailable, water-soluble species. Treatment also removes bacteria that can participate in organification reactions of toxicological significance to humans (e.g., methylation of inorganic mercuric mercury).

Risk assessors estimating the intake of metals in drinking water will require information about concentrations of metals in the water and the amount of water consumed. Data on the metal content of tap water can be obtained from EPA's Office of Drinking Water. EPA's *Exposure Factors Handbook* contains exposure information on daily drinking water ingestion and incidental ingestion of water during swimming and showering (U.S. EPA, 1997e).

Generally, water metal concentrations are measured at the distribution point for municipal water delivery systems. Distribution systems within homes (pipes, storage containers, etc.) can contribute significant amounts of metals (e.g., Pb, Cu) to the home drinking water

(Graziano et al., 1996); consequently, the contribution of metals from home-based pipes, etc., is a source of uncertainty in the human health risk assessment.

4.2.5.5. *Dermal Exposure*

Metals absorption through the skin is limited because the dermal route of exposure is of less concern during a health risk assessment. However, some metals (e.g., Ni and Cr) have the potential to induce toxic and sensitization effects directly on the skin (U.S. EPA, 2001, 1992). Dermal exposure can also lead to intakes via other routes, such as oral exposure via hand-to-mouth transfer or ocular contact.

Potential sources of dermal uptake that the risk assessor should consider include small particles in contact with the skin; metal exposure during bathing, showering, and swimming (NAS/NRC, 2002); and the uptake of metals through damaged skin (e.g., irritated skin, sunburn). Dermal contact with metals in soil also represents a potential route of exposure, but the relatively low lipid solubility of most metals limits absorption through the skin (Paustenbach, 2000; Hostynek et al., 1998). Few studies have actually attempted to quantify the extent or kinetics of the dermal penetration of metals deposited on the skin, and the applicability of these studies to metal species and complexes that occur in surface dust or soil is highly uncertain.

4.2.6. Integrated Exposure

Approaches to integrating exposure across pathways and physiological routes of uptake include modeling, estimates of relative bioavailability, and the use of biomarkers.

4.2.6.1. *Modeling*

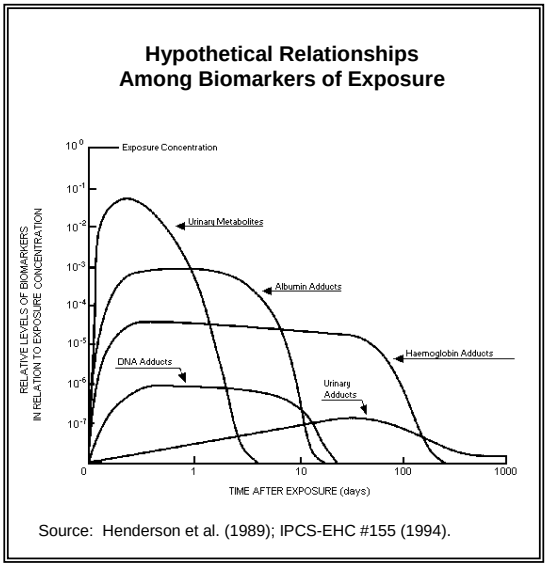
Risk assessors have access to only a few specific, integrated exposure models for metals. The Integrated Exposure Uptake Biokinetic (IEUBK) model for Pb in children (U.S. EPA, 1994a; White et al., 1998) was specifically developed for translating exposure measurements into risk estimates. The IEUBK model and background documentation are available on line at: http://www.epa.gov/superfund/lead/products.htm.

Risk assessors should not apply this model to other metals because it was derived using Pb-specific information and consequently is pertinent only to Pb. A multipathway exposure model specific for As has also been developed (Cohen et al., 1998). Less complex models linking adult exposures and blood Pb concentrations are available (Carlisle, 2000; Stern, 1996, 1994; U.S. EPA, 1996b; Bowers et al., 1994; Carlisle and Wade, 1992), and a stochastic human exposure model for Pb that is linked to a lead pharmacokinetics model may also be of use to the risk assessor (Beck et al., 2001; O'Flaherty, 1995).

Other models available to risk assessors are EPA's Total Risk Assessment Methodology (TRIM), which is being developed for multipathway risk assessment for air pollutants including

metals (http://www.epa.gov/ttn/fera/trim_gen.html); EPA's Stochastic Human Exposure and Dose Simulation (SHEDS) model, a probabilistic, physiologically based model that simulates aggregate human exposures and doses for various population cohorts of interest (Dang et al., 2003; Zartarian et al., 2000); EPA's Dietary Exposure Potential Model (DEPM) (Tomerline et al., 1997); RESRAD, a generic exposure model developed by the U.S. Department of Energy for risk assessment of radionuclides (U.S. DOE, 2001; LePoire et al., 2000); and 3MRA, a multimedia, multi-pathway, multi-receptor exposure model developed for screening-level risk-based assessment of chronic exposures to chemicals released from land-based hazardous waste management units (http://www.epa.gov/ceampubl/mmedia/3mra/).

4.2.7. Biomarkers



Source: Henderson et al. (1989); IPCS-EHC #155 (1994).

Risk assessors may find biomarkers of exposure, effect, and susceptibility useful as basic tools (IPCS, 2001, 1994). Centers for Disease Control (CDC) and the National Health and Nutrition Examination Survey (NHANES) are currently developing a national database to quantify and characterize body burdens (based on human blood and urine surveys) that includes Pb, Hg, Co, uranium (U), antimony (Sb), barium (Ba), Be, Cs Mo platinum (Pt), thallium (Tl), and tungsten (W) (CDC, 2005). Risk assessors can use this survey as a baseline measure against which the levels in receptor population individuals can be compared. The data are summarized in age, gender, and ethnicity categories. NAS also has completed a substantial amount of work in this area (NAS/NRC, 2006).

Integration of exposures across media, route, and time of exposure can be reflected in biomarkers of exposure. A biomarker of exposure is a measure of cumulative exposure to a metal and also of metal actually existing in the body, as occurs with chronic exposure to metals. However, such an approach may not be appropriate for metals that are not extensively bioaccumulated in tissues, and it does not differentiate between metal present in a tissue in a sequestered or inactive form and metal engaged in toxic or pathological processes. The approach also does not differentiate naturally occurring exposures from those due to added metals. For example, arsenobetaine is a nontoxic organic form of As found naturally in shrimp and other seafood. The analysis of total, unspeciated urinary As, without recognition of an individual's dietary history, could lead to an overestimation of exposure if the risk assessor does not account for seafood consumption (NAS/NRC, 1999). Thus, use of biomarkers increases the need for comprehensive, multipathway assessments of exposure. When available, reference or baseline levels of biomarkers of exposure should be incorporated into the assessment.

4.3. HAZARD CHARACTERIZATION

Hazard identification (or hazard characterization) is "the determination of whether exposure to an agent can cause an increased incidence of an adverse health effect, such as cancer or birth defects, and characterization of the nature and strength of the evidence of causation" (NAS/NRC, 1994b). This includes identification of the target organ(s), consideration of any route-specific issues, evaluation of the adversity of the effects observed, and consideration of relevance to humans. Key points and metals-specific concepts to be considered in hazard characterization are detailed in the following sections.

4.3.1. Mixtures and Interactions

In most settings, individual metals exist as components of mixtures with other metals and/or organic substances (ATSDR, 2004; NRC, 1988). Effects of the metals in mixtures may be synergistic, additive, subadditive, potentiating, and/or antagonistic. Interactions among metals occur by competition for binding locations on specific enzymes or on cellular receptors during the processes of absorption, excretion, or sequestration at the target site. The presence, amounts, and interactions of all inorganic metals are important when considering and evaluating the effects of exposure and resulting human health risk assessment.

Metals usually exist as components of mixtures with other metals and/or organic substances (ATSDR, 2004; NRC, 1988). Because the information or guidance on risks of metal mixtures is limited, risk assessors should follow published guidance for the human health risk assessment of chemical mixtures in general (U.S. EPA, 2000b, 1986) and cumulative risk guidance (U.S. EPA, 2003e).

Only a few controlled studies exist on the interactions of metals relevant to levels found in the environment (see ATSDR, 2004, on mixtures of (1)As, Cd, Cr, and Pb; and (2)Cu, Pb, Mn, and Zn). Risk assessors may use the current default approach, which assumes additivity of the doses for each metal as it will produce estimates that are overly-cautious. This approach, which involves calculation of a hazard index (HI), is most appropriate for chemicals that produce the same effects by similar modes of action (MOAs). However, differing potencies of metals with similar MOAs should be accounted for by converting chemical concentrations into an equitoxic dose using either toxic units (TUs) or toxicity equivalence factors (TEFs). In the case of chemicals with different MOAs, the risk assessor should consider estimating separate effect-specific HIs for each chemical in the mixture

Metal-Binding Proteins

Metallothioneins (Ag, Hg, Cu, Bi, Cd, Pb, Zn) **t**
Transferrin (Fe, Al, Mn) **t**
Ferritin (Fe, Cd, Zn, Al, Be) **s**
Ceruloplasmin (Cu, Fe) **tr**
Lead-binding protein(s) (Pb) **s**
Membrane carrier proteins **t**

s = storage; **t** = transport; **tr** = transform

using the RfD as the toxicity value for each effect. Newer EPA guidance provides a number of quantitative approaches for characterizing mixture risks (described in detail in U.S. EPA, 2000b, 1986).

The terms *molecular mimicry* and *ionic mimicry* have been applied to situations in which a metal forms a complex with an endogenous ligand and the resulting compound mimics the behavior of a normal substrate, disrupting normal function (Ballatori, 2002; Clarkson, 1993). Molecular or ionic mimicry may be viewed as a form of metal-metal interaction. Most examples involve the replacement of an essential metal with a nonessential metal. For example, Cd can mimic and substitute for Zn and Ca. Additionally, many different proteins in the body complex with metals which may modify their toxicity and kinetics (e.g., some metals bind with albumin for purposes of transport in the circulatory system and across cell membranes or within cells). Some proteins have different binding kinetics for the various metals, resulting in specific protein-metal interactions. Risk assessors should be familiar with these metal-binding proteins to correctly interpret the bioavailability of individual metals within a mixture and the potential use of protein expression as a biomarker of metal exposures.

Many of the interactions between essential metals are related to maintaining optimal nutritional levels by synergisms and antagonisms at both physiological and extrinsic (dietary) sites. World Health Organization (WHO) publications (IPCS, 2002; WHO, 1996) have summarized these homeostatic interactions, which are often complex (e.g., excess Ca in the diet may induce signs of Zn deficiency, even if the Zn intake is normal). Similarly, excess Zn in the diet may aggravate Fe deficiency.

Interactions between essential and nonessential metals are very common (e.g., Cd uptake can mimic that of Zn). Similarly, among anions, mimicry of the sulfate and phosphate ions occurs. However, the risk assessor should be aware that validated data in humans are rare, and that applications of this phenomenon are best limited to screening-level assessments. Two nonessential metals may compete for passive transport across common sites on a membrane or with an essential metal on an active binding site. These effects may not be additive and likely relate to relative binding strength. One metal may affect one site and another metal may affect a different site; this can include both active and passive transport or binding sites and may or may not include interactions with essential metals. These effects often will be additive. The risk assessor should be familiar with the MOAs of each metal of concern to develop at least a general understanding of whether the mixture effect is likely to be additive or more than additive.

Metals can be active at most cellular sites where organic toxicants have their effects and directly interfere with receptor activation (Stoica et al., 2000), ion channel regulation (Kiss and Osipenko, 1994), cell signaling (DeMoor and Koropatnick, 2000), cell adhesion (Prozialeck et al., 2002), and gene transcription (Meplan et al., 2000). Thus, metals are not readily distinguished from organic substances in the range of their potential mechanisms of action at the cellular and molecular level, so the risk assessor can transfer knowledge about toxicity across

chemicals. Additionally, co-occurrence of metals with organic substances can change the bioavailability and increase or decrease absorption. For example, in the diet, citrates and histidine are known to enhance Zn absorption, whereas ascorbate can modify Fe-Cu antagonisms. Low protein content may increase the absorption of Cd and Pb, and oral contraceptives may influence the metabolism of Fe, Cu, and Zn. The risk assessor should be aware of these conditions to avoid over- and underestimating risk.

4.3.2. Essentiality

Essentiality

Essentiality should be viewed as part of the overall dose-response relationship. The shape of this relationship can vary among organisms. For a given subpopulation, reference doses designed to protect from toxicity of excess should not be set below doses identified as essential for that subpopulation.

Certain elements are nutritionally essential to humans and play a key role in physiological or biochemical processes (NAS/IOM, 2003; IPCS, 2002; WHO, 1996). Elements essential to other organisms may not be essential to humans and vice versa. Adverse nutritional effects can occur if essential metals are not available in sufficient amounts, and nutritional deficits also can be adverse and increase the vulnerability of humans to other stressors, including those associated with other metals. Essentiality should be viewed as part of the overall dose-response relationship, and *reference doses* designed to protect from toxicity of excess should not be set below doses identified as essential.

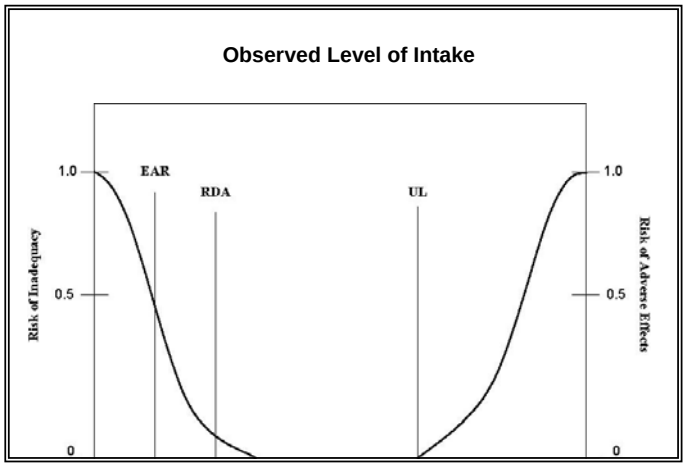
Metals that are currently deemed nutritionally essential for humans are Co, Cr III, Cu, Fe, Mg, Mn, Mo, Se and Zn (Table 4-1). Some metals (e.g., B, Ni, Si, V, and perhaps As), while not essential to human health, may have some beneficial effects at low levels of exposure (NAS/IOM, 2003). Risk assessors should consider the essential elements as comprising three groups: those that are cations (Zn, Fe, Cu, Mn, Cr), those that are anions (Mo, Se), and those that are a bio-inorganic complex (i.e., the Co complex, cobalamin). The homeostatic mechanisms differ for each group, and risk assessors can use this knowledge to generally classify the types of health effects that might occur and the potential bioavailability of the metal. In general, the gastrointestinal tract and the liver regulate the uptake and transfer of cations (e.g., Fe, Zn, Cu). The anionic group is more water-soluble and is less reactive with N, S, P, O, and hydroxide groups than are cations. They are absorbed very efficiently through the intestine and their subsequent compartmentalization and excretion is by manipulation of their oxidation and methylation states; total body burden is regulated by renal excretion. The risk assessor should be aware that homeostatic controls do not typically apply to effects at the portal of entry, so effects can be seen at lower doses than those required for systemic responses.

The risk assessor should view *essentiality* as part of the overall dose-response relationship. The risk assessor should use the entire dose-response relationship, from very low (inadequate) doses to high (toxic) doses (see text box) when determining an acceptable upper

Table 4-1. Metal essentiality for humans

Nutritionally essential metals	Nutritionally nonessential metals	
Cobalt II, III	Aluminum III	Nickel II
Chromium III	Antimony III, V	Niobium* V
Copper 0, I, II	Arsenic III, V	Palladium* 0, II
Iron II, III	Barium II	Platinum* 0, II, IV
Magnesium II	Beryllium II	Rubidium I
Manganese II, IV	Bismuth III, V	Silicon* IV
Molybdenum IV, VI	Boron III	Silver 0, I, II
Selenium II, IV, VI	Cadmium II	Strontium II
Zinc II	Cesium* I	Tellurium* II, IV, VI
	Chromium VI	Thallium I, III
	Gallium* III	Tin II, IV
	Germanium* IV	Titanium IV
	Gold 0, I, III	Tungsten VI
	Indium* III	Uranium IV, VI
	Lead II, IV	Vanadium III, V
	Lithium I	Zirconium* IV
	Mercury 0, I, II	

* Limited human data for these metals.



exposure limit. Several agencies have developed guidance for selecting a benchmark dose that is not too low (and, therefore, likely to result in deficiency) or too high (and likely to result in toxicity to some segment of the population). IPCS (2002) guidance describes the use of an "Acceptable Range of Oral Intake" (AROI), which estimates the minimal requirement to prevent deficiency and an upper limit that will produce toxicity. The NAS Food and Nutrition Board (FNB) in conjunction with the Institute of Medicine (IOM, 2001; NAS/IOM, 2000) developed the Dietary Reference Intakes (DRIs) program and reformulated RDAs (now known as RDIs) using the estimated average requirement (EAR) or adequate intakes (AIs). They also developed a tolerable upper intake level (UL), which is the highest level of daily nutrient intake that is likely to pose no risk of adverse health effects to almost all individuals in the general population. The UL is based on a risk assessment model similar to that used by EPA to set the RfDs and is intended to protect the population from adverse health effects resulting from excess exposure to a compound. ULs are available for all the essential metals and for B, Ni, and V. ULs do not take into account sensitive

or immuno-compromised populations. ULs may differ from RfDs because they are derived from human studies rather than animal studies and use smaller uncertainty factors. Additionally, the risk assessor should be cautioned that RfDs are intended to cover sensitive subpopulations, whereas RDAs are estimated to satisfy the nutritional needs of 97.5% of the healthy U.S. population. RDAs are specific to different age groups and genders, with listings for 16 different age-sex and six age-pregnancy combinations (NAS/IOM, 2003).

4.3.3. Forms of Metals

Unlike organic chemicals, metals are neither created nor destroyed by biological or chemical processes. However, these processes can transform metals from one valence state to another and can convert them between inorganic and organic forms. Information developed for one form of a metal may not be directly applicable to other forms. Different valence states (species) of the same metal affect bioaccessibility and bioavailability, and they elicit different responses in the human body. The particle size and environmental matrix (water, soil, air), within which the metal is embedded, influence exposure amount, rate, and route, particularly for the inhalation pathway, which can then result in different target organs and response levels. Therefore, the risk assessor should consider which form of the metal of interest is being assessed. If exposure or effects information has been developed for a different metal species, the risk assessor should either make appropriate adjustments or acknowledge this as a significant uncertainty in the Risk Characterization. For example, Cr(III) is essential in the diet, whereas inhaled Cr(VI) is carcinogenic.

Risk assessors should be aware that information developed on the health effects of one form of a metal may not be directly applicable to other forms, particularly organometallics; other guidance documents should be consulted when conducting risk assessments for organometallics.

4.3.4. Toxicokinetics/Toxicodynamics

Toxicokinetics

Toxicokinetics describes the series of processes that dictate the disposition of a substance in or on the body after exposure occurs and processes related to deposition on the body surfaces (also considered in exposure assessments), absorption, distribution, metabolism, and excretion (ADME).

Homeostatic mechanisms such as binding of metals to proteins can introduce significant complexities to hazard assessments for metals, with significant quantitative effects once these mechanisms are overwhelmed. Certain metal compounds bioaccumulate in human tissues, and it is important to recognize that such bioaccumulation is related to toxicity (SAB, 2006; see Section 2.3.1 for a definition and more detailed discussion of bioaccumulation). Since not all tissues may be of "interest" from a human health perspective, net accumulation in human tissues may or may not be relevant in the hazard characterization of metals (see, for example, Section 4.3.4.2 for a

discussion of metal sequestration and subsequent remobilization). Further, there are no available simple metrics that allow quantification of the potential for human bioaccumulation of metals, although a full pharmocokinetic model can be used to estimate metals bioaccumulation and distribution in human tissues. Additional discussion of the potential for remobilization of sequestered metals is in section 4.3.4.2. All these processes can be described through the use of physiologically based pharmacokinetic (PBPK) models. Integrated descriptions provide metrics of internal dose (including biological markers of exposure) that can be used by risk assessors to improve the quantitative basis of dose-response assessments. Unique features of metals that result in differences in toxicokinetic behavior of metals as compared to organic substances are shown in Table 4-2.

Bioaccumulation of metals is the net accumulation of a metal in the tissue of interest or the whole organism that results from *all environmental exposure media*, including air, water, solid phases (i.e., soil, sediment), and diet, and that represents a net mass balance between uptake and elimination of the metal (SAB, 2006).

Table 4-2. Summary of major differences in kinetic behavior of organic compounds compared to metals and inorganic metal compounds in humans

Organics	Metals
Tissue uptake is most commonly a blood flow-limited process, with linear portioning into tissues.	Metals and their complexes are often ionized, with *tissue uptake* (membrane transport) having greater potential to be diffusion-limited or to use specialized transport processes.
Metabolism is generally extensive and often species-specific.	*Metabolism* is usually limited to oxidation state transitions and alkylation/dealkylation reactions.
Persistence in body fat is common because of lipid solubility (not capacity-limited).	Often *sequestered*, bound to specific plasma or tissue proteins (intrinsically capacity-limited) or bone.
Due to complex metabolism, organics may be *eliminated* by excretion in urine after biotransformation from lipophilic forms to hydrophilic forms, in bile after conjugation to large organic molecules, or in exhaled air if not metabolized.	Predominantly *eliminated* in urine because metal compounds are generally small molecules and are hydrophilic. As a result of protein binding, may be excreted via hair and fingernails.
Generally substance-specific *homeostatic mechanisms* are not available.	Essential metals have *homeostatic mechanisms* that maintain optimum tissue levels over a range of exposures.
Interactions with other structurally similar compounds may occur, especially during metabolism.	*Interactions* among metals and between metals and organics are numerous and occur commonly during the processes of absorption, excretion, and sequestration.

Source: Adapted from Golub et al. (2004).

4.3.4.1. *Absorption*

Absorption is a process by which an administered substance enters the body. *Bioavailability* is a term often used to describe the degree of absorption. Two elements of the absorption process are critical for evaluating systemic doses of metal compounds, both the degree and rate of absorption. Although information on both of these parameters is ideal for developing a quantitative estimation of systemic doses, information on the degree of absorption is more commonly available for most chemicals. Metals have a number of unique properties that impact their absorption across biological membranes. Key factors affecting the absorption of metals include solubility, particle size, valence state, lipophilicity, and the exposure matrix. Soluble forms of the metal are more readily absorbed since the metal ion itself is typically the absorbed entity. The bioavailability of metals increases as particle size decreases. However, in the lung particle size also determines the site of deposition and thus the clearance mechanisms that can ultimately result in systemic uptake (via transport to the lymph system following macrophage engulfment) or the GI tract (via mucociliary transport). Chemical speciation in terms of valence state can affect absorption. Recent progress in identifying metal transporters suggests that generalizations are not appropriate, and each metal should be assessed in terms of its ability to access transporters and the presence of transporters in potential target organs. In general, lipophilic compounds will be absorbed more readily than hydrophilic ones. For example, human skin is not very permeable, and it provides a good barrier against dermal absorption of metals and metal compounds; elemental Hg and dimethyl Hg are notable exceptions. Risk assessors should note the complexities in absorption processes since they have direct implications on metals risk assessment, primarily in requiring detailed consideration in extrapolating across different exposure conditions or animal species. Absorption can vary dramatically for different forms of the same metal, for the same form of metal in different matrices, among different species, and across different routes of exposure. Therefore, it is not appropriate to assume concordance in absorption of metal compounds without a detailed evaluation (and documentation) of the scientific basis for such an assumption. For example, empirical information on dermal absorption of metals should be consulted when available (Stauber et al., 1994; Wester et al., 1992; Hursh et al., 1989; Ilyin et al., 1975), and similar considerations apply to other routes of exposure.

4.3.4.2. *Distribution*

The unique features of metals influence their distribution to potential target organs and the subsequent target tissue doses. The distribution of metals reflects their transport and accumulation in the body within tissues, blood or plasma, or other extracellular space. Partitioning to blood and cellular components, particularly via interactions with proteins, is of particular importance for metal risk assessment. Retention in tissues of metals or metal

compounds generally is related to formation of inorganic complexes or metal protein complexes (e.g., Pb in the bone compartment and Cd in tissues bound to low-molecular-weight metallothionein proteins). Risk assessors should be aware that retention of metals in the body by protein binding or sequestration in a nontoxic form allows the metal to reside in the body without producing a toxic or pathological effect. For example, As and Hg have relatively short biological half-lives that can be measured in days, whereas Cd and Pb can be bound or sequestered in inactive forms for years. Cd is retained in soft tissues (e.g., liver and kidney) for 10 to 20 years by intracellular binding with metallothionein. Metal binding to proteins is capacity-limited, and toxicity to target organs occurs when the binding capacity is exceeded. Thus, the potential for toxicity exists in older adults for metals with long half lives that are initially adequately sequestered. Conversely, retention in tissues is a dynamic equilibrium and can be a source of internal exposure long after the external exposure source has been removed. For example, Pb in bone can be mobilized during pregnancy and lactation or as a result of osteoporosis (USEPA IRIS, http://www.epa.gov/iris/subst/0277.htm). The risk assessor should consider all the aspects of metal distribution in the body (i.e., binding and sequestration plus release processes) when estimating likely target dose. The risk assessor should also note the uncertainty associated with lack of information to complete a quantitative analysis of these processes during the Risk Characterization.

4.3.4.3. *Metabolism*

Metabolism of metals is limited to oxidation-reduction reactions or alkylation/ dealkylation reactions. In these reactions, new inorganic species or metal organic complexes may be formed, but the metal ion persists. Nevertheless, differences in these transformation pathways among human populations or across species have practical implications for risk assessment because different species of the same metals often have very different toxicities. Because of this, the risk assessor should fully explore available data on metal metabolism. For example, As can be metabolized to organic forms that are less toxic than the inorganic As to which an individual is initially exposed.

4.3.4.4. *Excretion*

Risk assessors should be aware of the number of qualitative differences in metal excretion as compared to organic compounds. These include the greater likelihood for excretion in urine and the propensity for metals to be excreted via hair and nails. In addition to reducing the target dose, risk assessors can use these excretion routes to develop biological markers of exposure for many metals.

Although metals share many similar characteristics, their excretion kinetics can vary dramatically, primarily because of differences regarding sequestration in bone or binding to

specific proteins. This reduces the rate of excretion (or generates a biphasic excretion curve with two or more distinct excretion half-lives). Risk assessors should assess each metal individually to incorporate excretion rates in the calculations of target dose and subsequent hazard assessment.

4.3.4.5. *Kinetic Modeling*

Physiologically based pharmacokinetic/pharmacodynamic (PBPK/PBPD) modeling of metals entails the mathematical description and modeling of their absorption, distribution, metabolism, and excretion (ADME). A typical PBPK model consists of multiple compartments representing tissues or tissue groups that are linked by blood flow. PBPD models describe the relationship between target tissue dose and health endpoints or target tissue effects. Combined use of PBPK and PBPD models provides understanding of the complex relationships between exposure and target organ effects. Risk assessors may find that these models are valuable risk assessment tools for purposes of interspecies, high-dose/low-dose, route-to-route, and exposure scenario extrapolations (Krishnan and Andersen, 1994). A PBPK model allows the risk assessor to define the relationship between external exposure and an internal measure of a biologically effective or toxic dose in both experimental animals and humans, thus increasing the precision of extrapolating effects thresholds to humans. Use of PBPK models can account for nonlinear uptake, metabolism, and clearance; toxicity associated with products of metabolism rather than the parent chemical only; and tissue interactions. The underlying assumption of PBPK is tissue dose equivalence, i.e., that health effects are caused by the toxic form(s) of the chemical measured at the biological target (Krishnan and Andersen, 1994).

PBPK models historically have been developed and used for risk assessment mainly with volatile organic compounds (VOCs) (e.g., methylene chloride) (Andersen et al., 1987), but PBPK models have recently been applied to some metals (White et al., 1998; Clarke, 1995). There are currently three main Pb risk assessment PBPK models. *The O'Flaherty model* (O'Flaherty, 1995) is a PBPK model for children and adults. It includes the movement of Pb from exposure media (i.e., intake via ingestion or inhalation) to the lungs and gastrointestinal tract and subsequent exchanges between blood plasma, liver, kidneys, and richly and poorly perfused tissues; and excretion from liver and/or kidney. *The Leggett model* (Leggett, 1993) allows risk assessors to simulate lifetime exposures and can be used to predict blood Pb concentrations in both children and adults. The EPA has performed a comparison of these adult Pb risk assessment models (http://www.epa.gov/superfund/lead/products/adultrevie

Metal Toxicity

The organ or tissue in which metal toxicity occurs may differ from the organ or tissue(s) in which the metal accumulates and may be affected by the metal's kinetics. Effects at the portal of entry do not depend on bioavailability. Both the exposure route and the form of the metal can affect a metal's carcinogenic potential and its noncancer effects.

w.pdf) . EPA developed the Integrated Exposure Uptake Biokinetic (IEUBK) model to predict Pb levels in children (U.S. EPA, 1994a) and recommends that it be used as the primary tool for Pb risk assessment at Superfund and RCRA corrective action sites (OSWER Directive, 1998; http://www.epa.gov/superfund/lead/products/oswer98.pdf).

Risk assessors can review differences in kinetic behavior between metals and VOCs in O'Flaherty (1998). In brief, these include: (1) oral bioavailability, (2) inhalation bioavailability, (3) cellular uptake, (4) nutritionally essential and nonessential metal interactions, (5) protein-binding behavior and function, (6) incorporation into bone or hair, (7) metabolism, and (8) excretion. Moreover, risk assessors should keep in mind that many of the processes controlling the disposition of metals are intrinsically capacity-limited and can result in extended residence times. Risk assessors should use multiple lines of evidence to understand the kinetics and, therefore, the hazard of metal sequestration and elimination. The major challenge faced by the risk assessor when using PBTK models for metals is to balance the complexity of the biology with the data available to parameterize the model. Estimation of many parameters from the same data or insufficient data (over-parameterization) leads to greater uncertainty in model predictions and limits the utility of the model for regulatory purposes.

4.3.5. Metal Toxicity

Diversity in observed toxicities of different metals likely reflects the variety of biochemical mechanisms by which they exert their effects and variability in their toxicokinetic properties. At least five metals are known carcinogens, and several other effects of metals are also well documented, including effects on the neurological, cardiovascular, hematological, gastrointestinal, musculoskeletal, immunological, and epidermal systems.

4.3.5.1. *Noncancer Effects of Metals*

Metals and metal compounds have very diverse toxicological profiles. For risk assessment purposes, selected critical effects serve as the basis for deriving threshold or benchmark toxicity values (e.g., RfDs) and are defined as "the first adverse effect, or its known precursor that occurs to the most sensitive species as the dose rate of an agent increases" (U.S. EPA, 2005). Both the mechanism of toxicity and the critical effect may vary with the form of the metal. Additionally, short-term exposures may produce target organ effects very different from those produced by a similar dose over a longer period of time. Short-term, high-level exposure by ingestion may give rise to well-recognized acute toxicity syndromes, usually involving the gastrointestinal tract initially and possibly, secondarily involving the renal, cardiovascular, nervous, or hematopoetic systems. Survivors of acute high-dose As ingestion usually experience multiple organ effects, sometimes with long-term sequelae. Long-term, low-dose exposures from ingestion of metals in food and water generally cause an accumulation in

target organs over time. Such exposures can involve any organ system but do not usually produce overt gastrointestinal symptoms. For example, low-level, long-term exposure to Cd in food—sometimes combined with inhalation exposure from cigarette smoking—will cause Cd to accumulate in target organs (e.g., kidney) but will not produce any obvious clinical effects until "excess" capacity is diminished to a point where the normal function is lost (e.g., onset of renal disease and/or osteoporosis later in life).

In addition to considering systemic effects, the risk assessor should also examine portal-of-entry effects. Unlike systemic effects, which may be route-independent, portal-of-entry effects are not observed following other routes of exposure. For example, dermal irritation, sensitization, and allergic responses from metals can occur without absorption and systemic responses.

4.3.5.2. *Carcinogenic Effects of Metals*

At least five transition metals—As, Cd, Cr(VI), Be, and Nil—are accepted as human carcinogens in one form or another or in particular routes of exposure (IARC, 2004b; NTP, 2002) and inorganic Pb compounds are considered probable human carcinogens by EPA's IRIS program, while IARC (2004a) has concluded that there is limited evidence of carcinogenicity to humans (see: http://www.epa.gov/iris/subst/0277.htm#carc and http://monographs.iarc.fr/htdocs/announcements/vol87.htm). Other metals have mixed evidence regarding potential carcinogenicity. Therefore, risk assessors should pay careful attention to approaches for cancer risk assessment as applied to metals. Several guidance documents are available for use by the risk assessor in developing or interpreting cancer risk assessments (e.g., U.S. EPA, 2005), as are international efforts that provide guidance on assessing human relevance of tumors identified in animals (Cohen et al., 2004).

Nickel and Pb compounds and Cr and Cr compounds are well-established contact allergens. Other metals that have been cited as contact allergens include Cu (WHO/IPCS, 1998), Co salts (AIHA, 2003), organomercurials (AIHA, 2003), Be (IPCS, 1990b), palladium (Pd) (Kimber and Basketter, 1996), and gold (Au) (Kimber and Basketter, 1996). Although there is some connection between skin and respiratory sensitization, it does not follow exact rules, and the dermal mode is a much more common reaction to metals.

A key consideration for the risk assessor in cancer risk assessment is the determination of the MOA of carcinogenesis, a general description of how the chemical causes cancer. The MOA determines human relevance of observed animal tumors, any route-specific differences (e.g., carcinogenic at the portal of entry via the inhalation route, but not carcinogenic via the oral route), and the approach used for extrapolation from experimental doses in animals to environmentally relevant human doses. In particular, the MOA evaluation is a key consideration in whether a linear or nonlinear approach is used to extrapolate to low doses. The MOA is

known for some, but not all, metals. For those for which the MOA is unknown, the risk assessor should refer to the Cancer Guidelines (U.S. EPA, 2005) for guidance.

4.3.5.3. *Issues Related to Evaluation of Toxicity Tests for Metals*

As with any hazard assessment, risk assessors prefer a robust dataset on toxic responses of the metal(s) of concern for key endpoints (e.g., irritation and sensitization, systemic noncancer toxicity, and genotoxicity or tumorigenicity). In many cases, metals will be well-studied, and thus, human studies (epidemiology, controlled clinical studies, or case reports) will be available to aid in hazard characterization. For metal compounds for which adequate human data are not available, the risk assessor must rely on animal toxicity studies. U.S. EPA has established guidelines for assessing the adequacy of a database for derivation of chronic human health risk values such as RfDs and RfCs (U.S. EPA, 2002a) and has provided guidance for evaluating the "weight of evidence" for carcinogenicity (U.S. EPA, 2005). These generic guidelines are applicable to metals as well as organic compounds as long as the risk assessor considers the following metal-unique aspects of hazard determination:

- **Adequate controls.** When a salt of a metal is administered to the test animals, the risk assessor should evaluate that a suitable control group was used, specifically that any potential for salt-induced toxic responses is appropriately assigned probable cause.

- **Dosing solubility, ionization, hydration, and speciation of metals administered in water.** Metal compounds may be in suspension or in solution and may be differentially hydrated depending on the concentration in which they are prepared and the length of time the preparation stands, potentially resulting in different pharmacokinetic and toxic properties. Water pH and mineral content also are relevant factors to be considered by the risk assessor.

- **Trace element content of food and drinking water.** Because of the well-known interaction of metals with essential trace elements, the trace element content of animal feed and drinking water or of vehicles used for gavage or injection studies should be reported or controlled. Inconsistent results across experiments could be due to this factor.

- **Acute stress in the experiment**. A component of acute stress in the experiment can induce hepatic metal-binding proteins (acute phase proteins) and alter the toxicity of a given administered dose.

To achieve an adequate internal dose for the study of toxicity, animal toxicologists often use bioavailable forms of metals. For the initial characterization of a toxicity syndrome, it is not practical to simultaneously test all forms of a metal that may be involved in human exposures. For example, Al researchers commonly use aluminum lactate, which is known to reliably provide elevated tissue concentrations in laboratory animals, or aluminum maltolate, which

provides a stable ion pool in water solution. However, a risk assessor is very unlikely to conduct an assessment of Al in its lactate or maltolate form. Thus, the risk assessor should be aware that failure to adjust the toxicity data generated from water-soluble metal species to the appropriate, less soluble species of concern introduces uncertainty. There are both direct and indirect approaches to address the relative bioavailability of metals in the environment: (1) conduct new animal toxicology studies using the metal form encountered in the site assessment; (2) use adjunct scientific data to derive an adjustment to the effective dose identified in the animal study (e.g., data on the distribution of chemical forms of the metal in the environment or at a contaminated site); or (3) use a default assumption that the metal in the environmental samples is the same as that tested. The first approach is more scientifically sound but often is precluded by time and financial resource limitations; the third option generally is the most health-conservative.

A fourth alternative to conducting site-specific assessments is for the risk assessor to estimate bioavailability through solubility studies or limited bioavailability studies of specific samples from the site. For example, arsenic bioavailability has been estimated for soils from various contaminated sites (Ng et al., 1998; Freeman et al., 1995, 1993) and also through a series of solubility studies of soil from a site contaminated with mine tailings (Ng et al., 1998; Salocks et al., 1996).

4.3.6. Dose-Response Assessment

The result of the hazard characterization is a determination of the key noncancer and cancer endpoints related to exposure to the metal of interest. The risk assessor then uses these data as the input to the dose-response assessment to "characterize the relationship between exposure or dose and the incidence and severity of the adverse health effect" (NAS/NRC, 1994b). Assessors should consider the factors that influence dose-response relationships, such as intensity and pattern of exposure, age, and lifestyle variables. Traditionally, separate approaches have been used for dose-response assessment for noncancer and cancer endpoints. For noncancer endpoints, the result of the dose-response assessment is an RfD for oral or dermal exposure or an RfC for inhalation exposure. For cancer assessment, the approach depends on the chemical's MOA. Classically, the result of the cancer assessment is a measurement of the risk per unit dose, either as a slope factor or unit risk.

A key consideration for the risk assessor when deriving metal dose responses is to express the exposure potential and the toxic response as the same metal species. In general, for systemic effects of soluble metal salts, the risk assessor should express toxicity in terms of the dose of the metal ion rather than the metal salt. In contrast, if the toxicity is related to a specific compound, particularly for portal-of-entry effects, risk assessors should express it in terms of the compound, rather than the ion. These differences should be considered when applying toxicity values in risk assessments. For example, in IRIS, Se is listed as "selenium and compounds," and there are separate assessments for "nickel, soluble salts," "nickel subsulfide," "nickel refinery

dust" (a mixture), and "nickel carbonyl" (a highly reactive compound that behaves differently from other nickel compounds). In some situations, the toxicity of the anion needs to be considered. For example, there are separate IRIS documents for Ag and silver cyanide. However, careful consideration of the chemical form has not been applied historically to all such documents, and the risk assessor should carefully consider the applicability of the chosen toxicity values to the chemical forms of interest, paying close attention to solubility, bioavailability, and physical/chemical properties as well as available toxicity data.

Considerations in Risk Characterization

Variability. Inter-individual biological differences exist within an animal or human population, or measurement differences exist owing to method imprecision.

Uncertainty. Data are unavailable.

Incertitude. Knowledge about key relationships is not available.

A related issue is whether the toxic response is reported in terms of the added metal in the diet or the total metal (i.e., whether the amount of trace elements in the control diet in the animal studies is included in the dose calculations). Risk assessors should carefully review the supporting documentation for toxicity values to determine precisely what is being reported and to account for any potential interactions among dietary metals. The assessor also should consider whether the study provided adequate levels of trace elements so that the observed toxicity is not secondary to some unrelated deficiency.

Dose-response assessments for some metals are based on data from human occupational studies. While derivation of the dose-response value (e.g., the RfC, RfD, or cancer slope factor) will have included some steps to extrapolate the occupational study data to environmental exposures (e.g., dosimetric and duration adjustments), the form of the chemical may merit consideration. For example, the occupational exposure will have involved a particular range of particle sizes, which may influence the response observed (U.S. EPA, 2002a).

Risk assessors should review RfDs derived for essential elements to ensure that they are not below required daily intakes. The RfD should not be below the general population RDA. This means that the risk assessor should give careful consideration to the appropriate size of uncertainty factors, which is often made easier by the frequent (although not uniform) availability of human data for relatively large and diverse populations. The only exception to the comparison between the RfD and nutritional requirements is that certain populations (e.g., pregnant women) may have higher nutritional requirements, while these levels could theoretically be toxic to other populations. In such cases, the risk assessor should be careful to avoid logical inconsistencies and to identify the sensitive population on which the RfD is based.

4.4. RISK CHARACTERIZATION

Risk Characterization is the final phase of the risk assessment process. It is the phase in which information from hazard characterization, dose-response assessment, and exposure assessment is considered together to determine the actual likelihood of risk to exposed

populations (NAS/NRC, 1994b). For example, inorganic As occurs naturally in food and water; thus, a risk characterization would integrate the currently accepted dose-response information for inorganic As with the exposure assessment information for a particular food or drinking water source, or for the national distribution of intake from food and water, to determine whether a potential problem exists. During Risk Characterization the uncertainties in the dose-response assessment, the uncertainties in the estimate of exposure derived for the scenario under evaluation, and the level of confidence in the overall determination of risk should be laid out. At the same time, Risk Characterization is the first phase in the risk management process, in which information from the characterization is integrated into the consequences of rule-making or risk management, such as consideration of cost, alternative solutions, political considerations, and community interactions.

Risk Characterization

Have the qualitative assessment, quantitative assessment, and key uncertainties regarding metals been presented in accordance with EPA guidelines?

Do conclusions fully reflect risks in relation to ambient concentrations, essentiality of metals, chemical speciation, and information on human variability in sensitivity?

Have assumptions and uncertainties been documented adequately?

Have available data on mechanisms of action and metal interactions been fully explored in developing the quantitative assessment?

Risk assessors should refer to guidance on Risk Characterization (U.S. EPA, 2000c) that identifies key goals and steps for a Risk Characterization. Each Risk Characterization should include three components: a qualitative summary of each section of the risk assessment, a numerical risk estimate, and a description of uncertainties. Since metal exposures often occur in the context of mixtures (either mixtures of metals of the same form, mixtures of different metal elements, or mixtures with organics), risk assessors should consult additional Risk Characterization tools developed for mixtures (U.S. EPA, 2000b, 1986). These guidelines specify that the characterization of risks from mixtures of metals (and other compounds) be based primarily on information about the types of interactions that might be present.

Risk assessors should include a discussion in the Risk Characterization of the sources of variability and uncertainty in the risk assessment process. This is particularly important for metals risk assessments given all the components above. These are in addition to the variability and uncertainties that are inherent in all risk assessments (e.g., animal-to-human toxicity extrapolations). Because information, knowledge, and tools are lacking for many of the metal-specific uncertainties, risk assessors should be particularly diligent in documenting whether these may result in an over- or underestimation of risk (i.e., result in a conservative risk estimate or not). It is likely that site-specific risk assessments will have fewer uncertainties than regional- or national-scale assessments because risk assessors have access to local data on key issues such as specific metal species, relative bioavailability, or current metal levels. For national or regional assessments, selection of ranges or specific numbers for these values will depend on the degree

of conservatism desired by the risk assessor and, therefore, should be clearly documented during the Risk Characterization phase.

5. AQUATIC ECOLOGICAL RISK ASSESSMENT FOR METALS

This chapter describes how to incorporate the metals risk assessment principles described in Chapters 1 and 2 into ecological risk assessments involving aquatic-based receptors. Specifically, the following discussion focuses on the relationship between each metal principle and components of the EPA's Framework for Ecological Risk Assessment (U.S. EPA, 1992a) and subsequent guidelines (U.S. EPA, 1998a). These components include Problem Formulation, Characterization of Exposure, Characterization of Effects, and Risk Characterization. The Problem Formulation phase consists of defining assessment endpoints, risk hypotheses, and a conceptual model to produce an analysis plan for the risk assessment. Chapter 2 discussed the consideration of the metals principles in the Problem Formulation phase. In this chapter consideration of the metals principles in the characterization of exposure, effects, and risk to aquatic organisms is discussed.

Consistent with the previously stated scope and purpose of this Framework, not all aspects of the ecological risk assessment process are discussed. Only those aspects of the aquatic ecological risk assessment process and associated technical issues with the greatest relevancy to the metals principles are included. Also emphasized is how the geographic scale (e.g., site specific, regional, national) and analytical scope (e.g., screening vs. definitive analysis) of aquatic risk assessments affect the extent to which the metals principles can be incorporated. Although these principles apply equally to risk assessments involving terrestrial-based ecological receptors, many of the methods and tools that can be used to implement these principles differ between the aquatic and terrestrial environments. Thus, a separate discussion of how the metals principles apply to ecological risk assessment in the terrestrial environment is provided in Chapter 6.

5.1. METALS PRINCIPLES

Metals have specific environmental and biotic attributes that should be considered in all risk assessments. Specifically, these attributes fall into the risk assessment paradigm as follows:

Background levels	Exposure Assessment
Mixtures	Exposure and Effects Assessment
Essentiality	Effects Assessment
Forms of metals	Exposure and Effects Assessment
Toxicokinetics/toxicodynamics	Exposure Assessment (bioavailability) and Effects Assessment (absorption, distribution, metabolism, and excretion [ADME] and toxicity)

5.2. CHARACTERIZATION OF EXPOSURE

The Exposure Characterization phase describes the potential or actual contact or co-occurrence of stressors with receptors. It includes analysis of stressor sources, their distribution in the environment, and the extent and pattern of contact or co-occurrence to produce an exposure profile for the ecological receptor(s) of concern. Further guidance on characterizing exposure in ecological risk assessments is found in U.S. EPA (1998a, 1992a).

Exposure Profile

The exposure profile should describe the exposure pathways from stressor source to the receptor, the exposure intensity, its spatial and temporal distribution of co-occurrence, and the impact of variability and uncertainty on the exposure estimates.

5.2.1. Background Levels

Background levels refers to those concentrations of metals that derive from natural as well as anthropogenic sources that are not the focus of the risk assessment. In aquatic ecosystems, metal concentrations vary widely over space and time owing to differences in watershed geology, hydrology, anthropogenic and natural loads from "nontarget" sources, and other factors. Depending on the magnitude of the exposure associated with these factors, background metal concentrations can account for a significant portion of total metal exposure. Furthermore, certain essential metals can bioaccumulate to high levels in some aquatic organisms (e.g., Zn in barnacles, Cu in crayfish) due to species-specific physiological requirements, regardless of source. Even some nonessential metals can naturally bioaccumulate to significant levels as a result of mimicry of essential metals or sequestration and storage. Thus, the risk assessor needs knowledge of background concentrations in order to characterize exposure and to differentiate risk associated with metal sources already in the environment from risk associated with the metal sources of concern in the assessment.

Environmental Background in Exposure Assessment

What are the environmental background concentrations at the site(s) of interest? How do they vary over relevant spatial and temporal scales?

What is the relationship between environmental background and toxicologically relevant metal concentrations?

Can natural and anthropogenic metal be distinguished?

To what extent are background concentrations being extrapolated over space and time?

What level of confidence (uncertainty) exists in the estimate of environmental background concentrations?

Depending on the design and context for the assessment, the risk assessor needs to address several questions and issues pertaining to background concentrations of metals. Obtaining reliable estimates of background concentrations can be challenging, particularly at larger spatial scales. Risk assessors are cautioned against using background metals in soils as surrogates for sediments due to differences in the biogeochemical processes between these two environments. Metal concentrations in

sediments can be impacted by sediment physicochemical composition and localized sediment transport processes. Fractionation of sediment cores, in combination with careful estimates of sedimentation rates, has been used to distinguish pre- vs. post-industrialized contributions of metals via atmospheric transport (e.g., mercury) (U.S. EPA, 1997b). Risk assessors may find this type of sediment core analysis useful for differentiating natural levels versus levels associated with anthropogenic sources.

Concentrations of metals in the water column vary over time and are highly responsive to hydrological changes. In site-specific risk assessments, the risk assessor may quantify background levels by measuring metal concentrations at sites upstream from the area of concern. National databases of metal concentrations in various aquatic media (sediments, water, biota) include the following:

- The EPA STOrage and RETrieval (STORET) database (accessible at http://www.epa.gov/storet/);
- The National Sediment Quality Survey (NSQS) (accessible at http://www.epa.gov/waterscience/cs/nsidbase.html);
- Environmental Monitoring and Assessment Program (EMAP) (accessible at http://www.epa.gov/emap/);
- The National Stream Quality Accounting Network (NASQAN) (accessible at http://water.usgs.gov/nasqan/), and
- The Hydraulic Benchmark Network (HBN) (accessible at http://ny.cf.er.usgs.gov/hbn/).

The risk assessor should keep in mind that with the exception of the HBN, these databases have not been established to distinguish background concentrations from local, anthropogenic sources of metal loadings (e.g., industrial discharges, stormwater runoff) and, thus, may reflect significant anthropogenic loadings of metals to environmental media. The HBN was established to provide long-term measurements of streamflow and water quality in areas that are minimally affected by human activities. While the HBN contains long-term measurements of a number of parameters that are known to affect the bioavailability of metals (e.g., dissolved organic carbon [DOC], inorganic ions such as Ca and Mg, pH, conductivity), it does not contain information on metals of typical regulatory concern, with the exception of Al.

5.2.2. Forms of Metals

The physical and chemical forms of metals affect exposure, bioavailablity, and subsequent effects and are influenced by physicochemical environmental conditions. National-level assessments involve a broad range of environmental conditions; therefore, the risk assessor

should account for different metal species in different locations and water body types. As assessments transition from national, to regional, and to local, the assessor should incorporate site-specific sediment and water quality parameters that influence metal speciation, complexation, and sorption onto biological surfaces (e.g., pH, organic carbon, inorganic ligands, Ca, Mg, sulfide). Speciation models (e.g., MINEQL) combined with biotic ligand models offer a framework for addressing the differential occurrence and toxicity of various metal forms. Risk assessors should be aware of the difficulty in applying this approach to assessments involving large regional or national scales because of the variability in model parameter values (including covariance among parameters) that occurs across locations. Information about the range of the input parameters can be derived from available databases (see Section 5.2.1), and the risk assessor can decide what value to use (e.g., minimum, maximum, mean) depending on the degree of conservatism desired in the assessment. The risk assessor should include this information in the Risk Characterization as part of the overall discussion of assumptions and uncertainties in the assessment. Risk assessors can directly assess the metal forms for site-specific assessments or estimate what these would be based on sediment/water parameters (see Section 3.1.3, Environmental Chemistry).

5.2.3. Exposure Pathway Analysis

For aquatic organisms, potential routes of exposure to metals include absorption across (or in some cases adsorption to) respiratory organs, dermal absorption, sediment ingestion, and food ingestion. Quantifying exposure and uptake by the respitory route is a particular challenge to aquatic risk assessors because of the differing types of respiratory organs among aquatic species, the dynamic nature of the respiratory process in water, and the intimate contact between the receptor and metals dissolved in waters. Further complicating the issue, some respiratory organs can also be involved in locomotion, excretion, ion regulation and the capture, sorting, and ingestion of food. Similarly, risk assessors may find the ingestion route difficult to define for aquatic receptors because of the diversity of feeding modes and food sources, such as sediments, suspended solids, microflora, animal tissues, and plant tissues. The use of stable isotope techniques has contributed greatly to evaluating the role of diet in contaminant accumulation (including metals) by precisely defining trophic interactions (e.g., Kidd et al., 1995; Jarman et al., 1996). The absorption route can involve uptake across a phytoplankton cell membrane, amphibian skin, arthropod exoskeleton, the egg membrane, or the integument of an infaunal clam or annelid.

Exposure Routes

For aquatic organisms, pathways of exposure to metals include movement from water to sediments (and vice versa to a lesser extent) and through the food web; air deposition directly into aquatic systems or through run-off; and sedimentation from soils.

Despite the complexities associated with quantifying exposure of aquatic animals to metals from multiple routes of uptake, risk assessors can find a significant amount of information

on the relative importance of the different uptake pathways (Wang, 2002; Hook and Fisher, 2001b; Fisher et al., 1996; Bjerregaard et al., 1985). Applications of one-compartment biokinetic models using laboratory-based measurements of key model parameters (assimilation efficiency, metal uptake rates from water and food elimination rates) have been extended to field situations for populations of a diverse array of aquatic species, including freshwater and marine bivalves, various crustaceans such as copepods, amphipods, and crab, aquatic insects, and fish (e.g., Luoma and Rainbow, 2005; Stewart and Fisher, 2003; Griscom et al., 2002; Baines et al., 2002; Fisher et al., 2000, 1996; Roditi et al., 2000; Wang et al., 1996; Luoma et al., 1992). Site-specific model predictions for metal concentrations in animal tissues are strikingly close to independent field measurements for diverse water bodies, suggesting that it is possible for risk assessors to account for the major processes governing contaminant concentrations in aquatic animals and that laboratory-derived kinetic parameters are applicable to natural conditions (Luoma and Rainbow, 2005). Thus, these models provide tools for risk assessors to use when addressing metal exposure and uptake, and they can be used to determine the relative importance of different routes of exposure (Landrum et al., 1992; Wang et al., 1996).

Risk assessors should always consider temporal aspects of exposure, particularly in aquatic systems that respond to frequent shifts in hydrology. Rapid speciation and phase changes associated with changes in pH/Eh make temporal issues particularly germane to metals. Fluctuating or pulsed exposures occur in situations such as rapid changes in pH/Eh associated with photosynthesis and respiration, hypolimnetic discharge from stratified reservoirs, biocide (e.g., copper sulfate) spraying, ingestion of prey items with seasonally high metal concentrations, surface waters receiving wastewater treatment plant effluent, urban storm water, snowmelt, and acid precipitation runoff. Transient metal concentrations may be orders of magnitude higher than typical or average concentrations but last for only a few hours. These episodic exposure scenarios have been poorly characterized for metals (Butcher et al., 2006). Any risk assessment for metals should clearly state all assumptions about duration of exposure and what uncertainties are added to the risk model as a consequence.

5.2.4. Fate and Transport of Metals

Risk assessors routinely use transport and fate computational models to describe and quantify exposure pathways. Models also are useful in situations where risk assessors need an estimate of future exposure levels that are expected to result from the implementation of some permitting action or remediation measures at local, regional, or national scales. Numerous models are available for use; most are based on the same fundamental principles. Metals are ubiquitous in the environment and within each media compartment they are present in association with air, water (freely dissolved metal or as organic and inorganic metal complexes), and particles (sorbed, precipitated, or incorporated within a mineral phase). The risk assessor can find a detailed discussion of the fate and transport of metals in Section 3.2. No single,

currently available model includes all the desirable metal-specific features for aquatic systems. Discussions of the family of available aquatic transport and fate models, as well as a number of chemical equilibrium models, may be found in Paquin et al. (2003).

5.2.5. Toxicokinetics and Toxicodynamics (Bioavailability and Bioaccumulation Issues)

5.2.5.1. *Aqueous Phase*

In the dissolved phase, metals can exist as free ions as well as in a variety of complexed forms. These forms, or species, are of key importance in understanding bioavailability, and the hazard and risk assessments of waterborne metals are complicated by the fact that metal species differ in their toxicological properties. For many metals in aquatic systems, it is the free ionic form that is most responsible for toxicity. For example, Cu^{2+} has been directly linked to toxicity in fish and invertebrates while Cu complexed by dissolved organic matter does not induce toxicity to the same degree (Ma et al., 1999; Erickson et al., 1996) because of its reduced availability for uptake by the organism. However, the risk assessor should be aware that although toxicity of metals bound to DOC is reduced, it is not eliminated entirely and can contribute to the total metal loading to an ecosystem and subsequent toxic effects (McGeer et al., 2002; Erickson et al., 1996). On the other hand, there are cases where nontoxic metal species are bioavailable and taken up by the organism but cause no adverse response (e.g., Ag-Cl complexes in rainbow trout) (McGeer and Wood, 1998). Risk assessors should recognize that the presence of metal within an organism cannot always be used as a surrogate for toxic response.

Risk assessors can choose among a variety of methods to account for relative bioavailability of metals in aquatic systems, including hardness adjustments, water-effect ratio (WER), Free Ion Activity Model (FIAM), and aquatic Biotic Ligand Models (BLMs) (Paquin et al., 2002a). Each method contains strengths and limitations and may not be amenable to all types of assessments (e.g., ranking/classification, national, and site-specific assessments). For example, adjustment of aqueous metal concentrations for differences in water hardness was among the first computational methods to account for bioavailability differences between the laboratory and the field when applying EPA water quality criteria. Although these adjustments are relatively easy to apply, they require empirical data to define the toxicity-water hardness relationship. Thus, they are more amenable to site-specific risk assessments, although even in those cases they do not account for other water quality factors that affect bioavailability (e.g., DOC, pH). The water hardness approach has been applied at the national level through a statement of water quality criteria as hardness-based equations rather than as single values. Risk assessors can choose to use ranges, means, or median values when conducting large-scale (e.g., regional) assessments, but they will need to acknowledge this uncertainty during the risk characterization phase.

Bioavailability adjustments using WERs incorporate the combined effects of all water quality parameters present in site water on bioavailability of metals of interest relative to what was measured in laboratory tests (U.S. EPA, 1994c). Thus, compared to hardness adjustments, WERs encompass a broader array of water quality factors that can impact bioavailability. However, WERs are relatively resource intensive (requiring toxicity testing), are applicable only on a site-specific basis, and are not easily adjusted to account for temporal or spatial variability.

This relationship between speciation and bioavailability also has been explained through the free ion activity model (FIAM, Campbell, 1995). This model produces speciation profiles of a metal in an aquatic system and provides insight into the relative bioavailabilities of the different forms of metal as well as the importance of complexation. Models available for the calculation of metal speciation in natural waters are reviewed in Section 3.1.5, Sediment Chemistry, and include MINEQL (Schecher and McAvoy, 1994; Westall et al., 1976), MINTEQA2 (Brown and Allison, 1987), CHESS (Santore and Driscoll, 1995), WHAM (Tipping, 1994), and PHREEQ (Parkhurst et al., 1980). The risk assessor should review Paquin et al. (2003) for a more in-depth understanding of these models and how to select among them for particular places and types of assessments.

The BLM approach successfully combines the influences of speciation (e.g., free metal ion, DOC complexation) and cationic competition (e.g., K^{+}, Na^{+}, Ca^{+2}, Mg^{+2}) on metal toxicity in fish (De Schamphelaere and Janssen, 2004, 2002; De Schamphelaere et al., 2004, 2003, 2002; Heijerick et al., 2002a, b; Di Toro et al., 2001; Santore et al., 2001; McGeer et al., 2000). The model can be used to distinguish, at least conceptually, metals that will bioconcentrate at the site of toxicity (e.g., gill or other biotic ligand) from the total metal pools in an organism and the bioavailable metal pool in the exposure media. The model also can be applied to algae (De Schamphelaere et al., 2003; Heijerick et al., 2002) and *Daphnia* (De Schamphelaere and Janssen, 2004, 2002; De Schamphelaere et al., 2004, 2002). The BLM recently has been incorporated into draft revisions to EPA's national water quality criteria for Cu (it has been used in risk assessments at a range of geographic scales), and it is being applied as an alternative to the WER approaches for setting site-specific discharge objectives. The BLM has the potential to address spatial and temporal factors that affect bioavailability, provided that the variability in water quality parameters used as inputs to the model can be quantified or predicted (e.g., pH, DOC, K^{+}, Na^{+}, Ca^{+2}, Mg^{+2}). However, the risk assessor should be aware of the many limitations in applying the BLM (or any Free Ion model). For example, the development of the BLM has focused primarily on bioavailability and acute exposures. Work has begun to extend the BLM to chronic toxicity for some organism/metal combinations (e.g., De Schamphelaere and Janssen, 2004; Paquin et al., 2002a, b), and further development is expected. Also, the BLM is currently based on metal uptake through the dissolved phase; thus, additional research is needed to address metal uptake and toxicity via the diet.

5.2.5.2. *Sediment Phase*

Sediment-Associated Metals

When the molar concentrations of acid-volatile sulfide in sediment exceed the amount of simultaneously extracted metal, the metals are expected to be associated with the solid phase and not to be toxic.

Risk assessors have several approaches for estimating exposures to sediment-associated metals that account for bioavailability differences. The equilibrium partitioning approach (EqP) assumes that chemical activity in the sediment, as indexed by chemical concentration in the interstitial water, is proportional to the chemical's bioavailability to sediment-dwelling organisms. In anoxic sediments, sulfides provide the primary binding phase for many cationic metals. These metal sulfides are highly insoluble and are thought to have very low toxicity. Thus, in sediments where there is more sulfide than metal, most cationic metals should be present as insoluble sulfides and relatively nontoxic. The amount of reactive sulfide is quantified by measuring the amount of sulfide freed when sediment is extracted with 1 N HCl. This procedurally defined quantity is known as *acid volatile sulfide* (AVS). The amount of reactive metal is determined from the same extraction by measuring the metal concentration in the acid extract. This quantity is known as *simultaneously extracted metal* (SEM). The risk assessor then can determine the potential bioavailability of a metal by comparing the relative molar concentrations of the SEM and AVS. When SEM-AVS < 0, sufficient sulfide exists to bind all SEM, and metal toxicity is not expected. When SEM-AVS > 0, metal is present beyond the binding capacity of sulfide, and toxicity may occur if there is sufficient excess metal but not sufficient other binding phases to bind the metal. Use of this SEM-AVS as exposure estimates that are correlated with toxicity of metals in sediment has been explored closely for many metals (Ankley et al., 1996, 1991; Berry et al., 1996; Hansen et al., 1996; Carlson et al., 1991; Di Toro et al., 1990).

However, risk assessors should be aware that although the correspondence of SEM-AVS to toxicity was found, some questions remain about the applicability of the approach to all benthic organisms because it is based on the chemistry of bulk anoxic sediment, and many organisms live in oxygenated burrows. In addition, several studies have shown some degree of metal accumulation in organisms exposed to sediments where sulfide is in excess and metals are thought to be nonbioavailable, or at least nontoxic (Ankley et al., 1996). However, the lack of toxicity observed when AVS exceeds SEM suggests that this bioaccumulated metal may not be biologically available. A better understanding of the mechanisms of metal accumulation from sediment and their relationship to toxic effects is needed to help interpret these issues. Until such information becomes available, risk assessors can use the SEM-AVS model in exposure estimations as long as its shortcomings are acknowledged appropriately and uncertainties are recorded in the Risk Characterization phase of the assessment.

Other tools risk assessors can use to determine the bioavailable concentrations of sediment-bound metals include metal concentrations in the chemical extracts (Fan and Wang,

2001; Babukutty and Chacko, 1995; Tessier et al., 1984), acid extracts (Langston, 1980; Luoma and Bryan, 1978), or biomimetic extracts (Weston and Maruya, 2002; Mayer et al., 2001; Chen and Mayer, 1998). However, no consensus yet exists on their best use for different types of metals or metalloids. Several other methods have been proposed. Based on the premise that iron oxides in oxic sediments lower metal bioavailability, Fe in a 1 N HCl sediment extract has been used to normalize metal exposure concentrations (Luoma and Bryan, 1978). Increasing concentrations of organic carbon can decrease metal bioavailability (Crecelus et al., 1982), so normalization of sediment metal concentrations to organic carbon content has been conducted in other cases. The more readily extracted metals from sequential chemical extraction schemes tend to be the most bioavailable (Young and Harvey, 1991; Tessier et al., 1984) and have been used to estimate bioavailable metal.

5.2.5.3. *Dietary Phase*

Dietborne Metal Exposure

Risk assessors should consider dietborne metal exposure in two contexts: (1) dietborne exposure leading to accumulation and exposure to higher levels in the food chain (e.g., humans, wildlife) and (2) dietborne exposure leading to direct effects on exposed organisms.

As discussed in Section 5.2.3 (Exposure Pathway Analysis) and illustrated by the conceptual model for bioavailability (Figure 2-2), it is well established that dietary exposure to metals can result in accumulation of metals in aquatic organisms. What is less well established is the best way to express dietary exposure in a way that can be linked to potentially toxic effects (either directly to the aquatic organism or its predator). The main reason for this ambiguity is that the bioavailability of dietary metals varies widely across organisms and exposure conditions and standardized approaches are not available for predicting toxicity. The subsequent discussion elaborates on this point and provides some suggestions for how risk assessors might address dietary metals in different assessment contexts (screening vs. definitive).

After ingestion, some of the dietary metal can be released from the ingested particle into the gastrointestinal fluids of the animal (Chen and Mayer, 1999; Mayer et al., 1997; Gagnon and Fisher, 1997) and become available for assimilation into the tissues of the animal and the tissues of its consumer (i.e., trophic transfer). Assimilation efficiency (i.e., the net amount of metal retained in tissues relative to the amount ingested from food) is a common measure of the bioavailability of a chemical from food, and the risk assessor may find this to be a useful parameter for comparing the potential for toxicity among different types of organisms. Assimilation efficiency is also an important input parameter for estimating metal bioaccumulation using kinetic-based bioaccumulation models (e.g., Luoma and Rainbow, 2005). Assimilation efficiencies can vary widely depending on the metal, its form and distribution in prey, species digestive physiology (e.g., gut residence time), environmental conditions (e.g., temperature), food quality, food ingestion rate, and metal concentration in the diet. Thus, risk

assessors should consider likely ranges of assimilation efficiencies for a particular metal-animal combination when evaluating metal bioavailability from the diet. A number of reviews have summarized current knowledge of assimilation efficiencies of ingested metals among different aquatic animal species (Wang and Fisher, 1999; Fisher and Reinfelder, 1995).

The distribution and form of metals in dietary organisms is of critical importance for understanding the bioavailability of dietary metals and trophic transfer potential. For example, metals in the cytosolic fraction of phytoplankton and "soft parts" of zooplankton have been shown to correlate well with bioaccumulated metal in their predators (e.g., herbivores and plantivorous fish, respectively) (Wang and Fisher, 1996; Reinfelder and Fisher, 1994a, b). Metals sorbed to the cell wall of phytoplankton and the exoskeleton of zooplankton were poorly assimilated by consumers. The bioavailability of metal-enriched granules in prey (a detoxification and storage mechanism exhibited by some organisms) has been shown to be negligible or substantially reduced when consumed by certain predators (e.g., Wallace et al., 2003, 1998; Wang, 2002; Wang and Fisher, 1999; Nott and Nicolaidou, 1990). However, the risk assessor should be aware that the bioavailability of metal-enriched granules in prey can vary among metals and with type of granule (Wang, 2002; Mason and Jenkins, 1995; Nott and Nicolaidou, 1990) and may also depend somewhat on digestive physiology of the predator (e.g., gut pH, retention time). As a result of these findings, fractionating body burdens of metals (e.g., cytosolic metal vs. metal granules) has been suggested as a better means of identifying the bioavailable fraction of dietborne metals (Seebaugh and Wallace, 2004; Wallace et al., 2003; Fisher and Reinfelder, 1995; Reinfelder and Fisher, 1994). Although such techniques show promise for operationally defining the extent to which dietary metals may be bioavailable for trophic transfer in aquatic food webs, risk assessors should understand that broad-scale application of these techniques to metals risk assessments is presently limited by the relatively small number of metals and predator-prey relationships evaluated.

Despite the uncertainties associated with bioavailability and trophic transfer of dietary metals, the use of whole-body inorganic metal concentrations in prey species may have some utility to risk assessors for conservatively screening for exposure and potential risks to consumers (i.e., in cases where whole-body residues are below dietary toxic thresholds). For more definitive assessments, further research is needed to quantify the bioavailability and effects of inorganic dietary metals, with the exception of certain organometallics (e.g., methyl mercury) and metalloids (e.g., Se) where dietary toxicity has been well established.

Trophic Transfer

Trophic transfer is the transfer of a chemical from prey species to a predator species via dietary exposure.

Biomagnification is a type of trophic transfer where chemical concentrations increase in organisms from a lower trophic level to a higher trophic level within the same food web.

Biodilution represents a decrease in organism concentration with increasing trophic level.

5.2.5.4. *Bioaccumulation and Trophic Transfer*

Assessing and predicting the bioaccumulation of metals in aquatic ecosystems is a component of many Agency regulatory and nonregulatory activities (e.g., chemical ranking/classification, derivation of national water quality criteria, Superfund site risk assessments; see Section 2.3.1 for definitions and a conceptual model related to bioaccumulation). Interest in metals bioaccumulation originates from concerns regarding the direct impact of metals on organisms accumulating the metal and indirect impacts on their consumers (i.e., trophic transfer). Unlike certain persistent and bioaccumulative organic compounds, which tend to biomagnify in aquatic food webs (e.g., DDT/DDE, PCBs, PCDD/PCDF), inorganic metal compounds rarely biomagnify across three or more trophic levels (McGeer et al., 2004; Suedel et al., 1994); however, certain organometallics can biomagnify in aquatic food chains. Some metals (e.g., lead) tend to biodilute in aquatic food webs. Risk assessors should not interpret lack of biomagnification as lack of exposure or concern via trophic transfer (see text box). Even in the absence of biomagnification, aquatic organisms can bioaccumulate relatively large amounts of metals and become a significant source of dietary metal to their predators (Reinfelder et al., 1998).

For many nonionic organic chemicals, risk assessors can derive first-order approximations of bioaccumulation potential from information on chemical properties and organism attributes (e.g., K_{ow} and lipid content) and their use as inputs to simplified, fugacity-based models (e.g., Gobas et al., 1993). For metals, analogous methods to predict bioaccumulation based on simple chemical properties are not available or are not widely validated. The lack of analogous models for metals is likely due, at least in part, to the high degree of specificity exhibited by the mechanisms and processes underlying metals bioaccumulation (e.g., speciation, exposure conditions, and organism physiology) (see McGeer et al., 2004; Rainbow, 2002; Mason and Jenkins, 1995). As a result, risk assessors currently are limited to using an empirical approach for assessing and predicting metals bioaccumulation. Typically, this requires direct measurement of metal concentrations in the organism or experimentally-determined parameters for use as input to bioaccumulation models (e.g., gill uptake rate, elimination rate, assimilation efficiency).

Aquatic ecological risk assessors commonly use bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) to quantify chemical accumulation in tissue relative to concentration in water. BCFs and BAFs are determined as the ratio of the chemical concentration in tissue to its concentration in water (using the steady-state method) or as a ratio of uptake rate (k_u) and elimination rate (k_e) constants (using the kinetic method). Measurement of BCFs or BAFs usually is conducted for conditions that approximate steady-state (i.e., where accumulation remains relatively constant due to chemical uptake being offset by its elimination by the organism). It is assumed that the greater the BAF or BCF, the greater a chemical's bioaccumulation or bioconcentration potential.

Risk assessors should recognize that considerable uncertainty can be associated with the application of literature-derived BCFs and BAFs for assessing the risks of metals, as variability in BCFs and BAFs for metals is known to be high (e.g., 50-fold or higher within a metal). Most of this uncertainty results from bioavailability differences between the studies from which the BCF or BAF is measured and the site(s) to which it is being applied (e.g., water quality characteristics, metal speciation, exposure pathways).

Other sources of uncertainty that risk assessors should consider in the broad application of BCF/BAF data are rooted in the complex mechanisms of metal toxicokinetics (uptake, metabolism, distribution, elimination). For example, unlike hydrophobic, nonionic organic chemicals where uptake across biological membranes generally occurs via passive diffusion, the uptake of metals is believed to involve a number of specific transport mechanisms. Some of these transport mechanisms involve binding with membrane carrier proteins, transport through hydrophilic membrane channels, and endocytosis. Passive diffusion is thought to be reserved for certain lipid soluble forms of metals, such as alky-metal compounds and neutral, inorganically complexed metal species (e.g., $HgCl_2^0$). The implication of these specific transport mechanisms is that metal bioaccumulation can involve saturable uptake kinetics, such that BCFs and BAFs depend on exposure concentration. The existence of saturable uptake mechanisms, the presence of significant amounts of stored metal in organisms, and the ability of some organisms to regulate bioaccumulated metal within certain ranges are all thought to be responsible for the inverse relationship that has been frequently reported between BCFs/BAFs and metal exposure concentrations (McGeer et al., 2003; Borgman et al., 2004). In these cases, higher BCFs or BAFs are associated with lower exposure concentrations and also can be associated with lower tissue concentrations within a given BCF or BAF study. This is counter to the implicit assumption that higher BCFs or BAFs indicate higher metal hazard.

As a result of the aforementioned uncertainties, risk assessors must be careful in broad-scale application of BCF and BAF data for metals. Specifically, the current science does not support the use of a single, generic threshold BCF or BAF value as an indicator of metal hazard. Similarly for national risk assessments, use of a single BCF or BAF value holds little utility due to high uncertainty that results from differences in bioavailability, exposure conditions, and species-specific factors that influence metal bioaccumulation by aquatic organisms. When extrapolation across sites is necessary and limited data prevent application of alternative approaches (discussed below), uncertainty in the use of BCFs and BAFs can be reduced by expressing them as a function of media chemistry (i.e., to address bioavailable metal), exposure concentrations (i.e., to address concentration dependency issues), and limiting extrapolations to within a particular species or closely related species. The use of BCFs and BAFs for metals assessments appears to have most value for site-specific applications, when appropriate measurements are taken from the site(s) of interest and extrapolation of BCF/BAF values across differing exposure conditions and species is minimized.

Risk assessors should be aware of several alternatives for assessing metals bioaccumulation that address some of the concerns listed above. One of these is to develop regression relationships between tissue and exposure concentrations. Such regression relationships have been used to characterize bioaccumulation of metals by soil organisms (U.S. EPA, 2003c; Sample et al., 1999), but they have not yet been compiled for aquatic systems. The advantage of this technique is that it addresses the dependency of BCF or BAF on exposure concentration. However, it does not explicitly adjust for bioavailability differences that occur across sites. Another alternative is to use a kinetic-based model for describing bioaccumulation (Luoma and Rainbow, 2005; Wang and Zauke, 2004; Kahle and Zauke, 2003; Chang and Reinfelder, 2002; Reinfelder et al., 1998). These models can improve predictions of metal bioaccumulation in aquatic organisms because they incorporate different exposure routes (e.g., water vs. diet) and the dynamic nature of metal bioaccumulation processes. For example, Luoma and Rainbow (2005) reviewed the DYNBAM model (a single-compartment, kinetic-based bioaccumulation model) and found it to accurately predict metal bioaccumulation for a wide range of metals, organisms, and habitats based on data derived from 15 separate studies. Importantly, DYNBAM and similar such models require experimental data measured under environmentally-realistic conditions in order to derive model parameters for each metal-species combination (e.g., uptake and elimination rates, assimilation efficiency, food ingestion rates). Compilations of such data on model input parameters are available for some species and metals (e.g., Wang and Fisher, 1999, for aquatic invertebrates). Clason et al. (2004) and Kahle and Zauke (2003) have developed two-compartment bioaccumulation models for amphipod crustaceans that incorporate background metal and saturation of uptake kinetics. Currently, however, these models include only the dissolved phase and do not account for uptake from the diet.

The bioaccumulation models described above offer strong promise for improving bioaccumulation predictions in aquatic risk assessments for metals and should be considered by risk assessors. However, risk assessors should be aware of their limitations. For example, they currently do not account for differential partitioning and bioavailability of metal in organisms (see Figure 2-2). Empirical methods are being developed to predict metal compartmentalization in tissues of aquatic organisms (e.g., Wallace and Luoma, 2003; Wallace et al., 2003), but these have not been incorporated into bioaccumulation models. These models also do not explicitly address the impact of metal speciation on bioaccumulation or link bioaccumulated metal to toxic effects, although such models are under development (Paquin et al., 2002b). Regardless of the type of bioaccumulation model used, reductions in uncertainty in metals bioaccumulation assessments should be directed at achieving robust connections between the bioaccessible/bioavailable form(s) of metals in various exposure media, their accumulation, metabolism, and distribution in tissues, and the form(s) of metals that exert their toxicity directly to the organism or indirectly to its consumers.

5.3. CHARACTERIZATION OF EFFECTS

5.3.1. Essentiality

Essentiality refers to the nutritional requirements of an organism for normal metabolic function. A key difference between metals and organic chemical contaminants is that some metals are required either as macronutrients (e.g., Fe, Ca, Mg) or micronutrients (e.g., Cu, Zn, Ni) to maintain a healthy organism. Table 6-3 in Section 6.2.1 classifies the metals addressed in this Framework by their known essentiality to plants and animals.

Consideration of essentiality by the risk assessor is important for several reasons. First, the risk assessor should ensure that toxic effects thresholds calculated from an assessment are not lower than the nutritional requirements for the particular plant or animal species being evaluated. As discussed in Sections 4 and 6, the risk assessor should be aware that such elements exhibit classic bell-shaped or biphasic dose-response (or exposure effect) relationships, with adverse effects occurring at both high and low concentrations and an optimal mid-range dose or exposure (see Abernathy et al., 1993; Chapman and Wang, 1998). For aquatic organisms, information about nutritional requirements is available for many commonly tested or cultured species. Essentiality issues also impact the bioaccumulation and toxicity of metals since organisms have evolved various mechanisms to maintain homeostasis of essential metals. Such mechanisms may also impact the bioaccumulation and toxicity of nonessential metals, particularly those that share similar binding and uptake mechanisms. In these cases, accumulation is nonlinear with respect to exposure concentration, whereby greater uptake and retention of metals occurs at low concentrations and uptake rates decrease as exposure media concentrations increase. The impact of homeostatic and other mechanisms on bioaccumulation has been discussed in Section 5.2.

5.3.2. Toxicokinetics/Toxicodynamics (Toxicity Issues)

For organometallic compounds such as organo-selenium and methyl mercury, toxicity from dietary exposure has been shown to contribute substantially to ecological risk at environmentally-realistic concentrations and thus should be considered by the risk assessor when characterizing the effects of these compounds. Beyond those two organo-metal compounds, however, the importance of exposure to dietary metals is much less clear. Toxicity to aquatic organisms from dietary exposure to metals has been demonstrated where exposure is sufficiently high, although, in some cases, these concentrations are extreme (e.g., 10,000 g/g Cu) (Handy, 1993). In such cases, it is not clear that this pathway will drive ecological risk, as the environmental concentrations necessary to produce these exposures may be so extreme that ecological risk will occur first via other pathways (e.g., direct toxicity of waterborne metal).

In other studies, however, effects from dietary exposure have been demonstrated at relatively low exposure concentrations (e.g., zooplankton studies by Hook and Fisher, 2002,

2001a, b). This raises additional concern for metals assessment because it increases the potential for toxicologically significant exposures to occur in cases where risk via a waterborne pathway is low. However, other studies with the same organisms and metals, but somewhat different test methods, reached different conclusions regarding the significance of dietary exposure (e.g., De Schamphelaere and Janssen, 2004; Meyer et al. [in press]). Dietary exposure of aquatic organisms to metals is an active area of research, and it is likely that new data and insights will result in a more comprehensive understanding of dietary effects. Until that time, risk assessors should make decisions regarding potential risks of dietary metal exposure on a case-by-case basis.

5.3.3. Metal Mixtures

Mixtures of metals (including metalloids and organic substances) are commonly encountered in the natural environment as a result of anthropogenic inputs and should be considered by the risk assessor for all assessments. Metal interactions, according to Calamari and Alabaster (1980), occur at three levels:

- Chemical interactions with other constituents in the media
- Interactions with the physiological processes of the organism, and
- Interactions at the site of toxic action.

The joint action of metal mixtures may be expressed in different ways, including increasing or decreasing the toxicity relative to that predicted for individual components. As a result, the toxicity of metal mixtures has important consequences for metals risk assessments. For example, toxicity has been observed for mixtures of metals present individually at nontoxic levels (e.g., at levels corresponding to water quality guidelines) (Enserink et al., 1991; Spehar and Fiandt, 1986). Despite the importance of considering the effects and mixtures of metals to aquatic organisms, risk assessors will find that predicting the toxicity of metal mixtures has proven to be a difficult challenge in aquatic toxicology.

Much of the difficulty in predicting the toxicity of metal mixtures to aquatic organisms results from differences in the bioavailability and/or methods used to define the bioavailable fraction among toxicological studies and subsequent ambiguity in interpreting mixture toxicity data. As discussed in Chapter 2, the bioavailability of metals depends on a suite of factors that can affect their speciation, complexation with ligands, and interaction with biological systems (e.g., pH, DOC, inorganic anions, and cations). Apart from bioavailability differences, the joint action of metal mixtures to aquatic organisms (i.e., antagonism, additivity, synergism) has been reported to depend on other aspects of toxicity test design, including the degree of toxicity associated with the overall mixture concentration (Mowat and Bundy, 2002; Fargašová, 2001; Herkovits et al., 1999; Spehar and Fiandt, 1986), the relative proportion of constituent

concentrations (Norwood et al., 2003; Sharma et al., 1999), the duration of the exposure (Marr et al., 1998), and several other factors related to experimental design (Norwood et al., 2003). In a similar review, the European Centre for Ecotoxicology and Toxicology of Chemicals concluded that the acute and chronic toxicity to aquatic organisms of mixtures of metals could not be reliably predicted or generalized although they recommended that, in the interim, assuming additive effects is likely "a balanced approach" for acute toxicity of metal mixtures (ECTOC, 2001).

Given these difficulties in evaluating mixtures effects, risk assessors commonly use two simplifying models: concentration addition and effects (response) addition. These models are used to classify the combined effects of chemical mixtures as being antagonistic, additive, and synergistic (also referred to as "less than additive," "strictly additive," and "more than additive," respectively). Both models use metal concentrations in media to generate concentration-response curves for individual metals, and these data are then used to generate specific critical concentrations for mixture models. In the concentration addition model, all metals in a mixture are added together to predict toxicity; differing potencies are taken into account by converting chemical concentrations to an equitoxic dose, such as toxic units (TUs) or toxicity equivalence factors (TEFs), which converts all metals to one metal concentration. Concentration addition is often used when the constituents are known or assumed to act through the same or similar MOA. However, risk assessors should be aware that applying the concentration addition model to mixtures containing many metal constituents (particularly those well below toxic levels) can result in an upward bias in predicted mixture toxicity (Newman et al., 2004).

In the effects addition model, differing potencies are ignored, and the effect of each metal's concentration in a mixture is combined to predict mixture toxicity. The effects addition model is used when constituents act or are assumed to act independently (i.e., different MOAs). Thus, the risk assessor defines the nature of the metals' joint action (i.e., independent or similar MOA) to decide when to apply either the concentration addition or effects addition model. The risk assessor should consult information on the MOA, capacities to act as analogues for other metals, essentialities, and ligand binding tendencies to choose among these types of models.

The assumption of additivity has some regulatory precedence for use when addressing the toxicity of mixtures although not necessarily for metals. For example, the concentration addition approach is recommended for use by Australia and New Zealand for evaluating whether a mixture of less than six constituents exceeds their water quality guidelines (ANZECC and ARMGANZ, 2000). Similarly, additivity is assumed by EPA when evaluating the combined *acute* toxicity of multiple toxic effluents on the basis of whole-effluent toxicity data (U.S. EPA, 1991). Additivity is not assumed for *chronic* exposures due to lack of supporting data. For predicting the direct toxicity of mixtures of cationic metals in sediments to benthic organisms, EPA uses the ∑SEM-AVS approach described previously (see Section 5.2.5 Toxicokinetics and Toxicodynamics (Bioavailability and Bioaccumulation). Note, however, that this method is

limited to six cationic metals (Cd, Cu, Pb, Ni, Ag, and Zn). Furthermore, this method is considered a "no effect guideline," whereby the absence of toxicity can be predicted reliably (when ∑SEM<AVS) but the occurrence of toxicity (when ∑SEM>AVS) cannot be because of other factors that are not accounted for, which reduce metal toxicity.

Risk assessors should also consider the QICAR approach (described in Section 3.1.1) for addressing the toxicity of metal mixtures. Unsatisfied with the qualitative conclusions of Newman and McCloskey (1996), Ownby and Newman (2003) fit binary metal mixture data derived from the Microtox assay to develop a model of joint independent action (Finney, 1947). They predicted that the joint action of combined metals will increasingly deviate from independent action as their ligand-binding chemistries become more and more similar. Although Microtox is considered to be a useful tool for organic contaminants, its sensitivity for evaluating metal toxicity has been called into question (Willemson et al., 1995).

It is possible that receptor binding models (e.g., FIAM) may be expanded in the future to include mixtures. In theory, if two metals compete for binding to the same site of toxic action, it should be possible to model the total metal bound to that site and, hence, to predict metal toxicity using a mechanistic receptor binding approach in an effects addition model. Alternatively, if two metals do not compete for the same binding site, then these models may provide more reliable estimates of individual metal bioavailability, which then can be combined in more accurate effects addition models. However, at present, these possibilities remain theoretical. Furthermore, this approach, while improving the ability to assess the effects of metal mixtures, does not include temporal aspects (i.e., "time-to-response" versus concentration).

From the preceding discussion, it should be clear that the accurate prediction of the joint toxicity of metal mixtures to aquatic organisms remains a significant challenge for the risk assessor. For site-specific assessments, risk assessors are encouraged to assess mixture toxicity using *in situ* measurements (i.e., bioassays using site water or sediments). This approach is the foundation of the WER procedures used by EPA for making site-specific bioavailability adjustments to metals criteria. For site-specific assessments involving sediments, risk assessors should consider using the ∑SEM-AVS approach as a no-effect threshold. For national-level assessments, there is some precedence for assuming additive toxicity of mixture constituents, particularly when considering acute effects. However, the risk assessor should carefully consider the limitations to assuming strict additivity (i.e., potential for overprediction or underprediction of toxicity) and highlight these uncertainties in the Risk Characterization phase of the aquatic risk assessment.

5.3.4. Critical Body Residues

The bioavailability of metals from multiple exposure routes (water column, food, sediments) should be considered in aquatic risk assessments to account for relative contributions to overall toxicity. In concept, expressing toxicity on the basis of tissue residues is an attractive

approach to accomplishing this because it integrates chemical uptake from different routes of exposure, accounts for differences in bioavailability from exposure media, and addresses differences in toxicokinetics that occur for different species.

Expressing toxicological effects on the basis of internal (tissue) concentrations (e.g., use of critical body residues [CBR] or residue-response relationships) has gained significant attention in the aquatic ecotoxicology literature, particularly for organic chemicals (e.g., Landrum et al., 2005, 2004; Escher and Hermens, 2002; McCarty and Mackay, 1993; Cook et al., 1993, 1989; McCarty, 1986; Veith et al., 1983; Könemann, 1981). For many nonionic organic chemicals, available data indicate that whole-body burdens of chemical (normalized to lipid content) can serve as useful metrics of toxicological dose, and these relationships appear to be independent of whether exposure was via water or diet. A major strength of the CBR approach for organic chemicals is that it effectively integrates different exposure pathways into a single expression of dose and toxicological potency.

For metals (aside from organo-selenium and methyl mercury), the situation is far more complex and the CBR approach does not appear to be a robust indicator of toxic dose. One reason why the CBR approach currently appears more limited for metals relates to differences in their mechanisms of uptake, distribution, and disposition in aquatic organisms. Specifically, the distribution of nonionic organic chemicals in organisms is largely influenced by passive partitioning. In contrast, the uptake, distribution, and disposition of metals are typically governed by highly-specific biochemical processes that alter the metal form and involve facilitated or active transport. For example, some organisms take up metal and sequester it into "storage" compartments in chemical forms that have little toxicological potency, whereas other organisms actively excrete excess metals. As a basis for improving residue-response relationships, some studies have suggested that the metal concentration in the cellular cytosol (as opposed to that bound to cell walls or sequestered in nonbioavailable metal granules) may provide a better expression of internal metal dose associated with toxic effects (Wallace and Luoma, 2003; Wallace et al., 2003; Wallace and Lopez, 1996).

Other researchers have suggested that CBR relationships are confounded because the factor that determines the effects is not whole-body concentration per se, but the *rate* of metal uptake in relation to metabolic capacity for detoxification and storage; therefore, the effects are governed by factors that influence the rate of uptake. When uptake rate is elevated, the concentration of metabolically active metal at the site(s) of action increases (e.g., the spillover hypothesis) and effects ensue (Rainbow, 2002). Because different species of aquatic organisms invoke different "accumulation strategies" (i.e., involving combinations of regulation, detoxification, and storage), considerable difficulties arise among species when interpreting the toxicological significance of metal whole-body residues.

Therefore, risk assessors should ensure that a toxicologically valid residue-response relationship supports the CBR threshold before using tissue residues as indicators of toxicity.

Although many toxicological studies report measurements of metal residues in multiple tissues along with adverse effects, these tissue residue values may not be appropriate for use as a CBR threshold because metal concentrations in some tissues may have little or no relationship with toxicity. Furthermore, risk assessors are cautioned against extrapolating CBRs across differing exposure routes (food vs. water), durations, tissues, or species, because the potency of metal residues often differs depending on these factors.

5.3. RISK CHARACTERIZATION

As described in Section 2.4, Risk Characterization is the final phase of the risk assessment and is the culmination of the Planning, Problem Formulation, and Analysis of predicted or observed adverse effects. Risk Characterization produces a detailed description of the risk estimate(s), evaluates and summarizes the lines of evidence that support or refute the risk estimate(s), describes the uncertainties, assumptions and qualifiers in the risk assessment, and reports the conclusions of the assessment to risk managers (U.S. EPA, 2000c, 1998a).

While there are no metal-specific methods in the Risk Characterization, there are aspects that are important to metals risk assessments. For example, considering multiple lines of evidence such as results from *in situ* toxicity testing or biological assessments can be valuable for supporting the conclusions of a risk assessment. Care should be taken, however, to evaluate and present the limitations associated with each line of evidence, as discrepancies may not always indicate underlying differences; rather, they may reflect inherent limitations of each of the methods. For example, biological assessment methods may not be sufficiently sensitive to detect the level of effects or exposures that are of concern in the risk assessment. Documenting assumptions and uncertainties (e.g., use of background metal concentrations rather than added metal or specific metal species) becomes increasingly important the closer hazard thresholds are to background concentrations. Risk assessors also should document all assumptions and uncertainties in the methods used, such as how metals bioavailability was addressed. Because data may not be adequate to conduct a quantitative uncertainty analysis, risk assessors should describe the *sensitivity* of the risk assessment results to key assumptions and the *direction of bias* introduced by these assumptions (i.e., under- or overestimation of risks). This is particularly important for national or regional assessments, where results often are intentionally based on organisms and conditions that enhance exposure, bioavailability, and toxicological sensitivity. For essential metals, risk assessors should describe the relationship of the risk threshold to nutritionally required levels for the organisms of concern. Risk assessment results that fall below nutritionally required levels are an indication that some methods or assumptions require additional refinement. Risk assessors should carefully document the form(s) of metals used in the exposure and effects assessment, as they frequently differ due to data limitations. Additional issues and questions that should be addressed in the risk assessment are listed in Section 2.4.

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6. TERRESTRIAL ECOLOGICAL RISK ASSESSMENT FOR METALS

This section of the Framework provides an overview of how the principles for metals risk assessment apply to ecological risk assessments for terrestrial environments. Receptors typically considered in these assessments include soil invertebrates, plants, and wildlife species. Some assessments also examine effects on microbiota and soil processes. This section of the Framework builds on the information presented in Chapter 2 that lays out issues to be considered during Problem Formulation and that describes metal chemistry associated with soil systems. That information is not repeated here and the reader should refer to Chapter 2 for this information.

6.1. METALS PRINCIPLES

Metals have specific environmental and biotic attributes that should be considered in all risk assessments. These principles for metals risk assessment (see Chapters 1 and 2) apply in various ways to ecological risk assessments depending on the scale of the assessment (site specific, regional, or national). This section describes applications of the principles to terrestrial ecological assessments within the standard risk assessment framework. Specifically, they fall into the risk assessment paradigm as follows:

Background levels	Exposure Assessment
Mixtures	Exposure and Effects Assessment
Essentiality	Effects Assessment
Forms of metals	Exposure and Effects Assessment
Toxicokinetics/toxicodynamics	Exposure Assessment (bioavailability) and Effects Assessment (ADME and toxicity)

6.2. CHARACTERIZATION OF EXPOSURE

Metal exposure assessment includes characterization of the exposure routes and pathways specific to metals, the phase associations and chemical forms of the metals, and the expression of exposure and target doses in a manner consistent with defining hazard thresholds for particular organisms.

6.2.1. Natural Occurrence of Metals

At a national level, metal concentrations vary naturally in soils across the U.S. These variations pose challenges for conducting national assessments of risk to terrestrial ecological receptors. The assessor may decide to use a single toxicity level regardless of background concentrations for a screening type assessment (see text box on ecological soil screening levels or Eco SSLs) (U.S. EPA, 2003c) or may prefer to divide the country into regions of similar metal

background levels (metalloregions). Exposure assessments should consider metal levels inclusive of background.

At the regional and local (site) scales, risk assessors should account for the natural occurrence of metals either at the beginning of an assessment (i.e., during Problem Formulation), during the assessment, or when making risk management decisions about the implications of the predicted or observed levels of metals in soils. Because the national soil survey[4] is over 20 years old, risk assessors should consider the feasibility of generating site-specific concentrations for local risk assessments.

EPA's Ecological Soil Screening Levels

EPA's **Ecological Soil Screening Levels** (Eco SSLs) for metals are national-level concentrations of metals in soils that are protective of wildlife, plants, and soil organisms. These values are lower than naturally occurring levels in some parts of the country. Exceedences of such levels does not mean that a risk exists but does mean that a more regional or site-specific assessment may be needed.

More appropriately, risk assessors should avoid single-result assessments for the entire country. Rather, such assessments should be subdivided into metal-related ecoregions known as "metalloregions" (McLaughlin and Smolders, 2001) so that protection levels, mitigation goals, and ranking results will be appropriate for the suite of species naturally present within each type of controlling environment. This is directly analogous to the use of ecoregions when establishing water quality criteria (Griffith et al., 1999). The use of metalloregions provides the ability to account for the broad regional parameters affecting metal availability in soils and waters as well as for the differences in organism response to added metal.

The metalloregion concept (McLaughlin and Smolders, 2001), although intuitively appropriate, has not yet been fully developed for the U.S. The country has been divided into ecoregions for both aquatic and terrestrial systems (Bailey et al., 1994; Bailey, 1983). These are based on climactic and vegetation factors and form the basis of metalloregions. EPA is still working to complete ecoregion maps at much finer scales for each state (see EPA Web site at http://www.epa.gov/wed/pages/ecoregions/ecoregions.htm). To complete the metalloregion concept, soil properties that affect bioavailability (e.g., pH, cation exchange capacity [CEC], and organic matter [OM]) should be overlaid on the ecoregions, along with soil type (e.g., sandy loam, clay loam) and background concentrations of metals. Similar information is needed for water bodies. Although this type of information is fairly current and available, soil data have not been updated since the mid-1970s, which may limit their usefulness. Nevertheless, work is under way to develop metalloregions (e.g., McLaughlin and Smolders, 2001), although it is likely to be several years from the time of this writing before they are available for use in a decision-making capacity.

[4] Schacklette, HT; Boerngen, JG. (1984). Element concentrations in soils and surficial materials of the conterminous United States. U.S. Geological Survey Professional Paper 1270. 105 pp.

6.2.2. Forms of Metals

The physical and chemical forms of metals influence exposure and subsequent effects and can be influenced by physical/chemical conditions in the environment. National level assessments involve a broad range of environmental conditions and so the risk assessor should account for different metal species in different locations and soil types. As assessments transition from national, to regional, to local, the assessor should incorporate site-specific soil parameters that influence metal speciation (e.g., pH, CEC, clay content). National values (e.g., geometric mean values) of these parameters should be used, with the same recommendation as discussed in Section 5.1.3 on Natural Occurrence of Metals.

6.2.3. Exposure Routes

The major metal *exposure route* that the risk assessor should consider for wildlife is ingestion, with a minor (and often unknown) inhalation component. For plants, root uptake is the most important with leaf exposures secondary, with the exception of Hg where the majority is accumulated via foliar uptake; Cd and sometimes Pb also may be accumulated through foliage but amounts relative to soil exposure will vary depending upon soil conditions (e.g., pH). Plants may also lose metals through foliar leaching during precipitation events although to a significantly lesser extent than for other micronutrients such as potassium. Soil invertebrates are assumed to be exposed through direct contact. *Pathways* describe transport of the contaminant in the environment and include uptake and bioconcentration (e.g., dietary ingestion of a soil contaminant that has been taken up by plants). Principles of metal transport and fate in soils are applicable to assessments of risk to all terrestrial organisms and will be discussed first. However, because of significant differences in exposure routes and pathways between invertebrates, plants, and wildlife, it is more convenient to discuss exposure assessment methods by receptor group.

6.2.4. Soil Transport and Fate Models

Pathway of Exposure for Terrestrial Organisms

Pathways of exposure for terrestrial organisms to metals include movement from soils through the food web, and to a lesser extent, air deposition either into soils or directly onto terrestrial receptors (e.g., plants).

Risk assessors routinely use transport and fate models (i.e., a computational model) to describe and quantify exposure pathways. Models are also useful in situations where risk assessors are trying to estimate exposure levels that are expected to result from the implementation of some permitting action or remediation measures at local, regional, or national scales. Numerous models are available for use; most are based on the same fundamental principles: metals are ubiquitous in the environment and within each media compartment they are present in association with water (freely dissolved metal or as organic and inorganic metal complexes),

particles (sorbed, precipitated, or incorporated within a mineral phase), and air. The risk assessor can find a more detailed discussion of these processes in Section 3.2 on Fate and Transport. Currently, there is no single model available that encompasses all the desirable metal-specific features for terrestrial systems. Discussions of the available terrestrial transport and fate models, as well as a number of chemical equilibrium models, may be found in Allen (2002).

6.2.5. Toxicokinetics/Toxicodynamics

Target organ exposure levels and subsequent effects depend on how environmental conditions affect speciation of a metal (e.g., whether an organism actively takes up or excludes metals in soils and how an organism processes metals internally). See Section 3 for details on environmental chemistry and issues relating to bioaccumulation. Risk assessors should specifically address bioavailability and bioaccumulation for each metal of concern in each environment (either a local site for site-specific assessments or some larger estimate for regional and national level assessments).

6.2.5.1. *Bioavailability*

Risk assessors should adjust bulk soil metal concentrations by appropriate bioavailability factors to achieve comparable, actual uptake of metals by soil organisms. This will standardize exposure values across soil types and allow for more accurate comparisons with laboratory toxicity data. Cation exchange capacity (CEC) recently has been shown to be an important factor modifying zinc bioavailability in soils, and presumably it will be important for other cationic metals as well. However, CEC is strongly dependent on the type and amount of organic material (OM) and oxyhydroxides present in the soil, and is strongly pH dependent. Surface charge on OM and oxyhydroxides increases with pH, thereby increasing their sorptive capacity for metals (thus decreasing metal bioavailability). Conversely, positive surface charges increase as the pH drops, which increases sorption of anions (e.g., As or Se) under low pH conditions and decreasing sorption of cation ionic metals. Clays, on the other hand (except for kaolinite), have a surface charge that is largely independent of pH. Therefore, normalization of toxicity data to CEC can be done only within specific soil types and pH ranges, which frequently are not specified either in laboratory bioassays or many field studies. Furthermore, it is important for the risk assessor to note that most published values of CEC are measured at pH 7. In general, risk assessors can assume that cationic metals are more bioavailable at lower soil pH (<6) and less bioavailable at higher soil pH (>8). The opposite assumption holds for anionic metals.

Soil chemical models are being developed to predict how aging will modify bulk soil concentrations when soils are amended with soluble salts. Aging reduces the bioavailable fraction of metals over time. Preliminary studies suggest that consideration of aging may result in estimates of the bioavailable fraction as low as 0.1 × bulk soil concentrations (McLaughlin et

al., 2002). Until the data become available for metals of concern, toxicity values derived from soluble-salt amended soils (which have not simulated aging) cannot be reliably corrected to approximate aged metals in field situations and the risk assessor should acknowledge this as a significant uncertainty during the risk characterization.

Ideally, exposure should be expressed on the basis of pore water concentration, to account for all factors influencing bioavailabilty; however, there are currently significant limitations to collecting and interpreting metal-related data from soil pore waters and such information generally is not available (even at site-specific assessments and never for regional or national assessments). The risk assessor could estimate metal concentration in soil pore water using EqP theory (as with sediment pore water analyses; see Section 3.1.5). The risk assessor can use published soil binding coefficients (K_ds) to estimate partitioning between soil particles and pore water although these values also are inherently uncertain (published value depends on derivation method, soil type, etc.). Furthermore, toxicity threshold values generally are provided as bulk soil concentrations so the risk assessor would not be able to compare pore water exposure with any effects estimates.

6.2.5.2. *Bioaccumulation*

For terrestrial ecosystems, the concept of bioaccumulation is intended to capture the potential for two ecologically important outcomes: (1) direct toxicity to plants and wildlife and (2) secondary toxicity to animals feeding on contaminated plants and animals. This approach stresses the potential for trophic transfer of metals through the food web, so total exposure can be calculated, including dietary intake as well as intake from contaminated environmental media (soil and water). For vegetation or soil invertebrates, the bioaccumulation factor (BAF; or biota-soil accumulation factor, BSAF) is defined as field measurements of metal concentration in plant tissues divided by metal concentration in soil (or soil solution); the BCF is defined as the same measurement carried out in the laboratory (Smolders et al., 2003).

Risk assessors should be aware that data applicability is directly related to which tissue is sampled and how it is processed. BAFs for plants include metals aerially deposited on leaves as well as those in soil particles adhering to roots. Such metals will not be part of BCFs, which frequently are determined in hydroponic culture. Similar differences between BCFs and BAFs apply for earthworms exposed in soils versus laboratory studies using the filter paper substrate protocols. Furthermore, BCFs within earthworms may not include additional feeding of the animals during the study. Field studies are reflective of chronic exposures, whereas BCFs may be calculated from shorter time frames. Ideally, risk assessors should select BCFs reported at equilibrium (i.e., after sufficient exposure time to maximize the BCF). Whole-body BAFs generally are not calculated for birds and mammals, except for small mammals such as rodents (Sample et al., 1998b). Risk assessors should understand the conditions under which metal concentrations were measured and critically examine data to determine whether they are reported

as wet or dry weight (the ratio of tissue to soil concentrations must be done on the same wet/dry weight basis for both).

For soil invertebrates and most plants, metal BAFs are typically less than 1 and usually are based on the total metal in soil and tissue that do not account for bioavailability differences. The risk assessor might consider using a ratio of total metal in the organism to some measure of the bioavailable fraction of metal in the soil (e.g., free ion concentration or weak salt extractable) for expressing a BAF to allow comparison among different soils, although, in general, data are lacking for using this method.

Furthermore, the risk assessor is reminded that bioaccumulation of metals is not a simple linear relationship. Uptake is nonlinear, increasing at a decreasing rate as medium concentration increases. Models for predicting metal bioaccumulation by soil invertebrates are primarily statistical in nature, describing relationships between metal body burdens in oligochaetes and collembola, soil metal concentrations, and soil physical/chemical characteristics. Sample et al. (1998a) and Peijnenburg et al. (1999b) have each developed univariate uptake models for earthworms that are based on empirical data (metal concentrations in worms vs. the natural log of amount of metal in soils) that risk assessors can use as a first approximation for bioaccumulation in soil invertebrates; however, these models are not specific to soil type and, therefore, do not account for bioavailability factors. Furthermore, they do not adequately predict Cr or Ni uptake. An alternative approach that the risk assessor could consider is the use of multivariate statistical models to look for patterns of uptake of multiple metals to predict the potential bioconcentration of one metal of particular interest (Scott-Fordsmand and Odegard, 2002) or BAF as a function of soil characteristics (Saxe et al., 2001; Peijnenburg et al., 1999a, b). Path analysis has been suggested as an alternative for multiple regression in describing these relationships. It partitions simple correlations into direct and indirect effects, providing a numerical value for each direct and indirect effect and indicates the relative strength of that correlation or causal influence (Bradham, 2002; Basta et al., 1993).

The absolute level of metal accumulation is not as important as the rate of uptake (Hook and Fisher, 2002; Hook, 2001; Roesijadi, 1992). Adverse effects are avoided as long as the rate of metal uptake does not exceed the rate at which the organism is able to bind the metal, thereby preventing unacceptable increases in cytosolic levels of bioreactive forms of the metal. If the rate of uptake is too great, the complexation capacity of the binding ligand (e.g., metallothionein) could be exceeded; cytosolic metal levels then become unacceptably high, and adverse effects can ensue. Because measures of uptake rates are not available, static concentrations are used; the risk assessor should acknowledge this uncertainty during the Risk Characterization.

6.2.6. Soil Invertebrate Exposure

The soil ecosystem includes a complex food web of soil invertebrates (both hard- and soft-bodied) that feed on each other, decaying plant material, and bacteria or fungi. However,

the risk assessor should estimate exposure as a function of soil concentration, rather than as a detailed analysis of movement of metals through the food web, to generate data that will be comparable to effects concentrations. This is a reasonable approximation for soft-bodied invertebrates (e.g., earthworms) whose metal exposure is primarily through soil pore water (from both dermal absorption and soil ingestion) (Allen, 2002). There is more uncertainty in correlating soil metal concentrations with effects in hard-bodied invertebrates because they are primarily exposed through ingestion of food and incidental amounts of soil (Sample and Arenal, 2001). Regardless, risk assessors should estimate soil invertebrate exposure on the basis of total metal concentration in bulk soils (adjusted for relative bioavailability, where possible) collected in the top 0-12 cm of soil (U.S. EPA, 2003c, 1989b). In detailed, site-specific assessments, the organic matter on top of the soil (the "duff") may be analyzed separately to provide further detail on exposure to detritivores (such as Coll*embola*) and deeper-soil-dwelling organisms (e.g., various species of earthworms).

6.2.7. Plant Exposure

Plants access metals through the pore water although mycorrhyzae, protons, and phytosiderophores released by the root can significantly influence the microenvironment and change uptake rates of metals (George et al., 1994; Sharma et al., 1994; Laurie and Manthey, 1994; Arnold and Kapustka, 1993). Furthermore, plants have both active and passive mechanisms for taking up or excluding metals, depending on internal concentrations and whether or not the metal is an essential micronutrient, or whether it is mistaken for an essential micronutrient. Plants can be exposed to metals via aerial deposition onto leaf surfaces, trapping metals in hairs or rough cuticular surfaces. This might provide an exposure route for herbivores; it may also provide an exposure route for plants, as there are ion channels through the cuticle that are able to transport ionic metals from the leaf surface to other locations in the plant, depending on the inherent mobility of the metal in the xylem and phloem (Marschner, 1995).

The risk assessor should consider the default approach to estimating exposure of plants to metal as measuring metal concentrations in bulk soil (top 0-12 cm). However, as with soil invertebrates, this overestimates exposure because it does not account for differential bioavailability and aging. The risk assessor generally can categorize metal bioavailability and uptake based on soil pH and organic matter (see Section 3.1.6.5). It is very clear that strongly acidic soils increase plant uptake of Zn, Cd, Ni, Mn, and Co and increase the potential for phytotoxicity from Cu, Zn, and Ni. Alkaline soil pH increases uptake of Mo and Se, while Pb and Cr are not absorbed to any significant extent at any pH (Chaney and Ryan, 1993).

Table 6-1. Qualitative bioavailability of metal cations in natural soils to plants and soil invertebrates

Soil type	Soil pH		
	Low organic matter (<2%)	**Medium organic matter (2 <6%)**	**High organic matter (6 to 10%)**
4 ≤ Soil pH ≤ 5.5	Very high	High	Medium
5.5 < Soil pH ≤ 7	High	Medium	Low
7 ≤ Soil pH ≤ 8.5	Medium	Low	Very low

Table 6-2. Qualitative bioavailability of metal anions in natural soils to plants and soil invertebrates

Soil type	Soil pH		
	Low organic matter (< 2%)	**Medium organic matter (2 to <6%)**	**High organic matter (6 to 10%)**
4 ≤ Soil pH ≤5.5	Medium	Low	Very low
5.5 < Soil pH < 7	High	Medium	Low
7 ≤ Soil pH ≤ 8.5	Very high	High	Medium

Source: U.S. EPA (2003c).

Qualitative relationships between soil chemistry and bioavailability are appropriate for national-scale application. However, for site-specific or metals-specific applications, the risk assessor should use quantitative methods. Parker and Pedler (1997) and Lund (1990) have suggested that only uncomplexed, free ionic species of cations can be taken up by roots, and this has been described using a Free Ion Activity Model (FIAM) similar to the Biotic Ligand Model (BLM) used in aquatic systems. However, significant exceptions to the free-ion model have been identified; so until this theory is tested more thoroughly, the risk assessor should continue to estimate exposures using bulk soil values with qualitative estimates of bioavailability based on soil type (pH and OM). Again, the risk assessor should acknowledge these uncertainties during the Risk Characterization.

6.2.8. Wildlife Exposure

The relative importance of exposure pathways and routes varies by animal species and by metal, although, in general, wildlife exposure is primarily through diet and incidental ingestion

of soils or sediments. There are certain chemicals and exposure situations for which inhalation or dermal pathways are important, but in most situations the risk assessor can consider them to be insignificant contributors to total metal loads (U.S. EPA, 2003c).

Exposure Pathway for Terrestrial Wildlife

Food and the incidental ingestion of soil are the two most important exposure pathways for terrestrial wildlife.

Wildlife food chain exposures for metals are controlled by bioavailability, bioaccessibility, and bioaccumulation. Bioaccessibility of metals to animals and plants that live on or in the soils can be influenced by soil parameters, such as pH, CEC, and organic carbon. These soil parameters tend to be less important for soils that are incidentally ingested by wildlife species.

The relative importance of exposure pathways (soil vs. food chain) is dictated by the fraction of metal-contaminated soil in the diet and the amount of accumulation of metal in food items. In the absence of site-specific information, the risk assessor can use the following generalizations to determine the relative importance of incidental soil ingestion versus dietary metals:

1. Incidental soil ingestion is a proportionally more important pathway for herbivores than for carnivores or invertivores.

2. Uptake into soil invertebrates (e.g., earthworms) is a proportionally more important pathway for animals that feed on these organisms. (Note: This assessment reflects work done with earthworms and may not apply to hard-bodied soil invertebrates such as *Colembolla*.)

3. If bioaccumulation is low (<<1), importance of soil ingestion versus diet for metal exposure increases.

4. When bioaccumulation is greater (~1 or higher), the food pathway should dominate.

5. The closer the association an animal has to the ground, the greater the importance of soil ingestion. This association may be due to ground foraging, burrowing habits, etc.

6. The looser the association with the ground (e.g., piscivores, aerial/arboreal insectivores, raptors), the lower the importance of soil ingestion.

Figure 6-1 provides a simple scheme for the risk assessor to use for judging the relative contribution of food and soil before accounting for bioavailability. The assessor should assume that incidental ingestion of soil becomes proportionally more important for exposure to wildlife when (1) the bioaccumulation factor (BAF) from soil to food (e.g., to plants or soil invertebrates) is less than 1 and (2) the fraction of soil in the diet is greater than 1%. However, the risk assessor should use these generalizations with caution for site-specific assessments. As the risk assessor acquires more site-specific information, the relative importance of pathways may

change. For example, site-specific data may show that the accumulation of a chemical into plants or soil invertebrates is much lower than indicated by the default assumptions. In such cases, incidental ingestion of soil would become proportionally more important. The bioavailability of metals in incidentally ingested soil is also variable. Therefore, when the exposure is being driven by incidental soil ingestion, the risk assessor should consider refinements of exposure estimates through a better understanding of bioavailability, although very little information is available on this for most wildlife species.

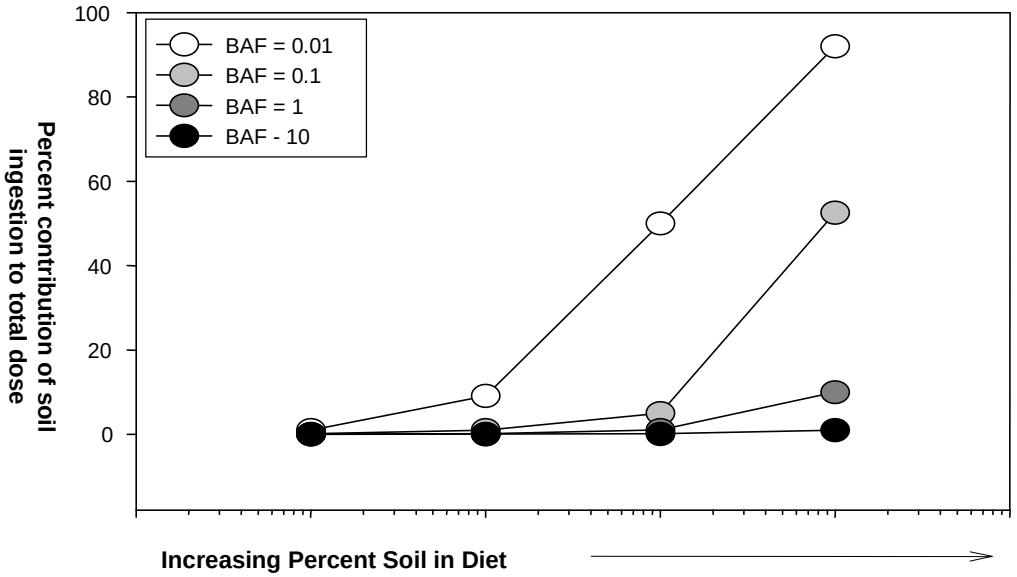


Figure 6-1. Generalized representation of percent contribution of incidental soil ingestion to oral dose for wildlife at different soil ingestion rates and bioaccumulation factors and a bioavailability of 100 percent.

The risk assessor should be cautious about extrapolating bioavailability adjustments for wildlife from models developed for estimation of bioavailability of metals in soils for incidental human exposures. There are significant variations in digestive physiology and anatomy across mammalian and avian species that alter the degree of assimilation and uptake of metals (Menzie-Cura and TN&A, 2000). For example, metals present in soils may be more or less bioavailable within the gut of an herbivore that relies on fermentation as compared to the simpler gut of a carnivore that is designed to break down proteins. These gut systems differ in chemistry (including pH) and residence time.

Food chain modeling can be used to estimate the exposure of wildlife to metals based on the ingestion of soil, food, and water. The risk assessor should use the same dietary uptake

model for metals as is used for organic substances, e.g., Eco SSLs; Ecological Committee on FIFRA Risk Assessment Methods (ECOFRAM) (Sample et al., 1997; U.S. EPA, 1997d). For national or regional risk assessments, the assessor may use trophic transfer rates to model food concentrations but only on the basis of soil measurements (rather than using direct measures of concentration of metals in food items). As with aquatic organisms, trophic transfer values for metals in terrestrial systems are an inverse function of soil concentrations. Therefore, the risk assessor should not use constants for this term but rather should generate regression equations of plant and invertebrate uptake rates as a function of soil concentrations and use which ever value(s) that are consistent with the degree of conservatism or amount of realism appropriate for the assessment. Sample et al. (1998a) developed uptake models to predict concentrations in earthworms from soil concentrations and Efroymson et al. (2001) provides similar information for plants (see Section 6.5.2.3 Bioaccumulation for a more detailed discussion).

With the exception of a few hyperaccumulator species, the risk assessor can reasonably assume that most plant species do not bioconcentrate metals (i.e., BAFs <1). Pb, As, Cr, and Co are not taken up by plants in measurable quantities, and the small amount that is taken up is mostly confined to root tissues (Chaney et al., 2000; McGrath, 1995; Chaney and Ryan, 1994; Xu and Thornton, 1985). In contrast, many plants are quite sensitive to some metals (Mn, Zn, Cu, for example); the risk assessor should be aware that plants frequently die before achieving high metal concentration levels that pose a threat to animals via food chain transfer (with the exception of the hyperaccumulator species, as noted above).

6.3. CHARACTERIZATION OF EFFECTS

When assessing metal toxicity to terrestrial organisms, the risk assessor should understand both the natural mechanisms of tolerance for (or, in the case of micronutrients, the use of) metals and the toxicological responses that occur when exposure exceeds the capacity of the organism to regulate its body burdens. The risk assessor should also consider interactions between metals in either their uptake or toxicity (such as Cd/Ca/Zn, Hg/Se, Cu/Mo). Risk assessments for metals are further complicated by the need to express the dose-response (or concentration-response) functions in bioavailable units that are functionally equivalent to measures of exposure. This section provides tools and approaches risk assessors can use when addressing issues of essentiality, metal mixtures, and appropriate use of toxicity tests; issues of how acclimation or adaptation to continued exposures may affect toxicity have been addressed in Sections 1.4.1 and 4.2.1 on Natural Occurrence of Metals.

Essentiality

Essentiality, or the requirement for normal organism metabolic function, of many metals is one of the primary factors that differentiates risk assessment for metals and metal compounds from that of synthetic organic chemicals.

6.3.1. Essentiality

Essentiality, or the requirement for normal organism metabolic function, of some metals is one of the primary factors that differentiates risk assessment for metals and metal compounds from that of synthetic organic chemicals (Janssen and Muyssen, 2001). Some trace elements, such as Co, Cu, Fe, Mn, Se, Mo, and Zn, are necessary for the normal development of plants and animals. Other metals, such as As, Cd, Pb, and Hg, have no known functions in plants and animals (Mertz, 1981). Table 6-3 classifies the metals addressed in this Framework by their known essentiality to organisms.

The risk assessor should be sure that effects thresholds such as Toxicity Reference Values (TRVs) are not lower than the nutritional requirements for the particular plant or animal species being evaluated. If TRVs are set too low (i.e., in the range where deficiency can occur), the determination of risk will be erroneous and deficiency effects will be mistaken for toxic responses. For wildlife, the risk assessor can consult the literature on dietary requirements of essential elements for livestock (McDowell, 2003; NAS/NRC, 1994a, 1980). Marschner (1995) summarizes the minimum concentrations required for plant growth.

Threshold Values

For essential elements, it is important to ensure that effects thresholds, such as Toxicity Reference Values (TRVs), are not lower than the nutritional requirements for the plant or animal species being evaluated. It may be difficult, however, for the risk assessor to directly compare toxicity threshold values with recommended dietary requirements because of differences in test conditions among published studies.

In screening-level assessments, toxicity threshold values can be used by the risk assessor, if they are not lower than estimated requirements. Detailed, higher level assessments may require additional bioassays to characterize the biphasic dose-response curve and determination of both required and excessive threshold levels.

Because of differences in test conditions among published studies, it may be difficult for the risk assessor to directly compare toxicity threshold values with recommended dietary requirements of essential elements. Extrapolation of data among species (e.g., from livestock to wildlife species) may also add uncertainty to the effects assessment. Furthermore, addition of safety factors when deriving protective values often results in concentrations significantly below required intake. The risk assessor should address these and similar uncertainties in toxicity threshold derivations as part of the Risk Characterization process. Detailed site-specific assessments, where more accurate estimates of effects thresholds are expected, may require the risk assessor to request additional bioassays to characterize the biphasic dose-response curve and determine both required and excessive threshold levels.

Table 6-3. Metals classified by their known essentiality

Metal	Essential (known requirement for health and function)		Beneficial (but not known to be essential)		Nonessential (and not known to be beneficial)
	Plants	Animals	Plants	Animals	
Aluminum (Al)					x
Antimony (Sb)					x
Arsenic (As)				X	
Barium (Ba)					x
Beryllium (Be)					x
Cadmium (Cd)					x
Chromium (Cr)		x			
Cobalt (Co)		x	x		
Copper (Cu)	X	x			
Lead (Pb)					x
Manganese (Mn)	X	x			
Mercury (Hg)					x
Molybdenum (Mo)	X	x			
Nickel (Ni)	X	x			
Selenium (Se)		x	x		
Silver (Ag)					X
Strontium (Sr)					X
Thallium (Tl)					X
Vanadium (V)				X	
Zinc (Zn)	X	x			

Source: Adapted from a table presented in SRWG (2002) and incorporating data from NAS/NRC (1980) and Barak (1999). Fairbrother and Kapustka (1997) discussed the roots of essentiality of naturally occurring elements.

6.3.2. Toxicity Tests

For assessments conducted for regional or national assessments, criteria development, or ranking purposes, risk assessors should acknowledge that results will be based on organisms and soil types that result in greatest bioavailability and sensitivity. The risk assessor should take great care to ensure that the organism-environment combinations that are assessed are, in fact,

compatible with real-world conditions. Thus, for site-specific assessments, species tested and water (or sediment) used in the test system should be similar to conditions at the site. In the absence of such information, risk assessors could use data from standard test species and conditions, but uncertainty factors may be warranted to adjust the final toxicity value.

6.3.3. Metal Mixtures

Mixtures of metals (including metalloids and other contaminants) are commonly encountered in the natural environment as a result of anthropogenic inputs and should be considered by the risk assessor for all assessments. Metal interactions, according to Calamari and Alabaster (1980), occur at three levels:

1. Chemical interactions with other constituents in the media,
2. Interactions with the physiological processes of the organism, and
3. Interactions at the site of toxic action.

The joint action of metal mixtures may be expressed in different ways, such as increasing or decreasing the toxicity relative to that predicted for individual components. As a result, the toxicity of metal mixtures has important consequences for metals risk assessments. However, predicting the toxicity of metal mixtures has proven to be a difficult challenge in ecotoxicology.

Much of the difficulty in interpreting the available information on the toxic effects of metal mixtures is due to differences in the bioavailability of metals (and measures used to define the bioavailable fraction) that occur across mixture studies. As discussed in Section 3, the bioavailability of metals depends on a suite of factors affecting their speciation, complexation with ligands, and interaction with biological systems. Nevertheless, the risk assessor needs some measure of the bioavailable metal fraction in the exposure media to accurately predict the effects of metals mixtures (Sauvé et al., 1998; Weltje, 1998; Posthuma et al., 1997). Besides bioavailability issues, the joint action of metal mixtures can depend on the overall mixture concentrations and the relative proportion of the constituent metals, as has been seen in aquatic studies (Norwood et al., 2003; Mowat and Bundy, 2002; Fargašová, 2001; Sharma et al. 1999).

The two most common classes of models used to predict mixture toxicity are the Concentration Addition and Effects Addition models. These models have been used to classify the combined effects of chemical mixtures as being *less than additive* (i.e., when the observed effect is less than the model prediction), *strictly additive* (i.e., matching model predictions), and *more than additive* (i.e., when the observed effect is greater than model predictions; Norwood et al., 2003). Both models use metal concentrations in media to generate concentration-response curves for individual metals, and these data are then used to generate specific critical concentrations for mixture models. In the Concentration Addition model, all metals in a mixture are added together to predict toxicity; differing potencies are taken into account by converting

chemical concentrations to an equitoxic dose (e.g., Toxic Units (TUs) or Toxicity Equivalence Factors (TEFs), which converts all metals to one metal concentration). Concentration Addition is used often when the constituents are known or assumed to act through the same or similar MOA. However, the risk assessor should use caution when applying the Concentration Addition model to mixtures containing many metal constituents (particularly those well below toxic levels) because of the potential for an upward bias in predicted mixture toxicity (Newman et al., 2004). In the Effects Addition model, differing potencies are ignored, and the effect of each metal's concentration is combined to predict mixture toxicity. The Effect Addition model is often used when constituents act independently (i.e., different modes of action). Only the Concentration Addition model allows detection of toxicity that is more than additive. Thus, a key issue in applying either the Concentration Addition or Effects Addition model is to define the nature of the metals' joint action (i.e., independent or similar mode of action). The risk assessor can use information on the MOA, capacities to act as analogues for other metals, essentialities and ligand binding tendencies to make this decision.

Risk assessors should keep in mind, however, that toxicities of certain metal elements are associated with deficiencies of others. For example, increased Zn, Cu, and Ni toxicities can be associated with Fe deficiencies (Bingham et al., 1986), and increased Pb and Zn toxicities can also be related to P deficiencies (Brown et al., 2000, 1999; Laperche et al., 1997). The behavior of plant species in response to nutrient deficiencies varies, and this behavior can affect the uptake of metal elements (Marschner, 1998). Similar interactions occur in wildlife; for example, Cu toxicity can be a result of Modeficiency and vice versa (McDowell, 2003; NAS/NRC, 1994a, 1980).

It is possible that receptor binding models (e.g., FIAM) may be expanded in the future to include mixtures. In theory, if two metals compete for binding to the same site of toxic action on an organism, it should be possible to model the total metal bound to that site and, hence, to predict metal toxicity using a mechanistic receptor binding approach in an Effects Addition model. Alternatively, if two metals do not compete for the same binding site on the organism, then these models may provide more reliable estimates of individual metal bioavailability, and these estimates can then be combined in more accurate Effects Addition models. However, at present, these possibilities remain theoretical. Additionally, this possibility, while improving the ability to assess the effects of metal mixtures, does not include temporal aspects (i.e., "time-to-response" versus concentration).

From the preceding discussion, it should be clear that the accurate prediction of joint toxicity of metal mixtures to terrestrial organisms remains a significant challenge.

6.3.4. Critical Body Residues

Critical body residues (CBRs) are internal concentrations of chemicals that are correlated with the onset of a toxic response (Conder et al., 2002; Lanno et al., 1998). CBRs can be based

on whole-body residues (see below for discussion of this approach in soil invertebrates) or concentrations in specific tissues. The risk assessor may choose to use CBRs instead of dietary TRVs to reduce uncertainties because they account for site-specific bioavailability and multipathway issues (Van Straalen, 1996; Van Wensem et al., 1994). Unfortunately, there are major data gaps in available CBRs for many species—metal combinations.

Risk assessors can use tissue-specific critical loads for some metals that have been established for several species of vertebrate wildlife, including Pb in liver, Cd in kidney, Hg in brains, and Se in eggs. See Beyer et al. (1996) for these figures. Only a few CBRs have been developed in soil invertebrates for metals (Conder et al., 2002; Crommentuijn et al., 1997, 1994; and Smit, 1997 for Cd and Zn).

For plants, the use of a tissue residue (CBR) approach is another method that risk assessors might use to address metal toxicity issues, based on the concept that a metal concentration must reach a threshold value in the organism or at the target site before effects begin to occur (McCarty and Mackay, 1993; Lanno and McCarty, 1997). For essential elements in plants, deficiency/sufficiency concentrations in foliage have been developed. However, the relationship between toxicity and tissue residues is complex and varies depending on tissue type (roots vs. shoots), plant species, and metal and there is little to no information available. Therefore, this approach, although conceptually sound, requires significant research before risk assessors will find it useful.

6.3.5. Plant and Soil Invertebrate Toxicity

The risk assessor can estimate TRVs (i.e., toxic thresholds) for plants and soil invertebrates from laboratory tests where metals are mixed with standard soils (Fairbrother et al., 2002). Variability among soil toxicity test results is due in part to the influence of soil properties on bioavailablity of metals (e.g., pH, organic matter and CEC). Additionally, acclimation and adaptation of test organisms can further complicate test results and aging and other physical/chemical processes that affect metal speciation and uptake are not represented. Because incorporation of sparingly soluble substances, such as many environmental forms of metals, into the soil matrix is difficult, tests generally are conducted using soluble metal salts with the addition of organism to the test matrix immediately after mixing. The risk assessor should be aware of how all these factors influence the test outcome and subsequent TRV derivation.

There is a large body of literature on toxicity of metals to soil organisms (e.g., van Straalen and Løkke, 1997), although often the objectives were to understand processes rather than to develop defensible toxicity thresholds. The challenge for the risk assessor, therefore, lies in how to use these data, taking into account the test-to-test variability in soil chemistry parameters, and how to develop a technically defensible means of extrapolating toxicity responses across soil type—in other words, how to adjust the toxicity threshold values for bioavailability differences in test conditions. One approach to addressing variability in soil

toxicity tests is to normalize test results by dividing the LC_{50} (or, more generally, the EC_x) by percent organic matter (Lock and Janssen, 2001). This approach is based on observed correlations between the LC_{50} of Cu to earthworms and soil organic matter content (Lock and Janssen, 2001). More recently, CEC has been shown to be the most important factor modifying Zn bioavailability in soils for both invertebrates and plants. Because CEC is a function, at least in part, of soil pH, normalization using this parameter should be done only among soils of similar pH ranges. However, comparison of field data with laboratory toxicity response information still is best accomplished by measuring metals in soil pore water from field assessments and comparing such data to spiked laboratory soils. Risk assessors can use the guidance document developed for establishing Ecological Soil Screening Levels or Eco SSL to judge the applicability of literature studies to plant or soil invertebrate toxicity threshold determinations. Eco SSLs have been developed for several metals, and the risk assessor should refer to these for national or regional assessments and for screening level, site-specific assessments.

6.3.6. Wildlife Toxicity

Toxicity in wildlife from metals exposures is generally poorly understood and is rarely quantified in field settings. A few notable exceptions are those mechanisms described in avian waterfowl exposure to Se (Adams et al., 2003), exposure of waterfowl to Pb-contaminated sediments (Henny et al., 2000; Beyer et al., 1998; Blus et al., 1991), and white-tailed ptarmigan exposure to Cd in vegetation (Larison et al., 2000). Most metals express multiorgan toxicity, resulting in a decrease in overall vigor, as opposed to well-defined mechanisms of action documented from organic xenobiotics such as pesticides. Typically, toxicological data used to assess the risk of many metals to wildlife are derived from laboratory species such as rats, mice, or domestic livestock species (e.g., cattle and chickens) exposed to soluble metal salts. Risk assessors will need to extrapolate the results of such tests to species of interest because of the paucity of data on the toxicity of metals to wildlife. However, risk assessors should approach this carefully due to the large amount of uncertainty that could be introduced into the risk assessment process (Suter, 1993).

Laboratory and domestic species may be more or less sensitive to chemicals than are the selected wildlife species. Toxicological responses vary among species because of many physiological factors that influence the toxicokinetics (absorption, distribution, and elimination) and toxicodynamics (relative potency) of metals after exposure has occurred. For example, differences in digestive tract physiology, renal excretion rates, and egg production influence the toxicokinetics of metals. The ability of some species to more rapidly produce protective proteins such as metallothionein after exposure to metals is a toxicodymamic features leading to interspecific extrapolation uncertainty. Thus, risk assessors should not extrapolate data from mammal studies to birds, and should be aware that extrapolation of data from rats (simple, monogastric digestive physiology) to ruminants introduces more uncertainty than does

extrapolation from rats to canids, and so on. In the case of metals, which some species are able to regulate or store in their tissues without experiencing toxic effects (i.e., biota-specific detoxification), extrapolations between species used to assess bioaccumulation and toxicity can be especially problematic. These difficulties in interspecific extrapolations are not unique to metals risk assessment except when dealing with essential elements. A review of potential extrapolation methodologies can be found in Kapustka et al. (2004).

Risk Characterization

Have the qualitative assessment, quantitative assessment, and key uncertainties regarding metals been presented in accordance with EPA guidelines?

Do conclusions fully reflect risks in relation to ambient concentrations, essentiality of metals, chemical speciation, and information on variability in species sensitivity?

Have assumptions and uncertainties been documented adequately?

Have available data on mechanisms of action and metal interactions been fully explored in developing the quantitative assessment in accordance with EPA Guidance on Mixtures Risk Assessment?

Currently, the best sources of information for the risk assessor on wildlife metal toxicity thresholds are NAS/NRC (1994a, 1980), McDowell (2003), and the documentation supporting development of Eco SSLs values. The Eco SSL document also includes an approach for screening studies for acceptability for use in derivation of toxicity thresholds for risk assessments, which can then be used for deriving site-specific TRVs for the most applicable endpoints. Risk assessors should apply uncertainty factors for extrapolation of data to species in a different taxonomic category (e.g., genus, family or class) with caution and include a discussion of uncertainty in the risk characterization. Summaries for some metals are available in Beyer et al. (1996) and Fairbrother et al. (1996).

6.4. RISK CHARACTERIZATION

Risk Characterization is the final phase of the risk assessment process, in which information from hazard characterization; dose-response assessment and exposure assessment are jointly considered to determine the actual likelihood of risk to exposed populations (U.S. EPA, 2000c, 1998a). The characterization also should discuss the uncertainties in the exposure and effects assessments, and the level of confidence in the overall determination of risk. At the same time, Risk Characterization is the first phase in the risk management process, in which information from the characterization is integrated into the consequences of rule-making or risk management, such as consideration of cost, alternative solutions, political considerations, community interactions.

Each Risk Characterization should include three components: a qualitative summary of each section of the risk assessment, a numerical risk estimate, and a description of assumptions and uncertainties. These descriptions of variability and uncertainty are particularly important for metals risk assessments given all the components and challenges discussed in this Framework document. These are in addition to the variability and uncertainties that are inherent in all risk

assessments (e.g., species to species toxicity extrapolations). Because information, knowledge, and tools are lacking for many of the metal-specific uncertainties, risk assessors should be particularly diligent in documenting whether these may result in an over- or under-estimation of risk (i.e., result in a conservative risk estimate or not). It is likely that site-specific risk assessments will have fewer uncertainties than regional or national scale assessments because risk assessors have access to local data on key issues such as specific metal species, relative bioavailability, or background metal levels. For national or regional assessments, selection of ranges or specific numbers for these values will depend upon the degree of conservatism desired by the risk assessor and, therefore, should be clearly documented during the Risk Characterization phase.

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[1] Information from the metals issue papers was used in the development of this framework

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Exhibit O

DATA SUMMARY POSTING

Station: Midwest Generation Joliet #29 Generating Station

Regulated Unit(s): Pond 2 (IEPA ID No. W1970450047-02)

In accordance with the new Ill. Adm. Code Title 35, Part 845: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (State CCR Rule) groundwater monitoring was completed during the 3rd quarter 2021 which includes the entire list of parameters specified under Section 845.600(a)(1) and (b). Table 1 is a summary table of all available CCR monitoring data to date including any data generated previously as part of the Federal CCR Rule monitoring. In addition, Table 2 provides a summary of turbidity data which was collected as part of State CCR Rule requirements which is a data parameter that was not required under the Federal CCR Rule.

No background statistics or proposed Groundwater Protection Standards are included on these tables as they will be calculated and proposed as part of the Operating Permit submittals due by October 31, 2021. Upon Illinois Environmental Protection Agency approval of the Operating Permit, the approved comparison values will be included for subsequent data comparisons/evaluations.

Table 1. Groundwater Analytical Results - Midwest Generation, LLC, Joliet Station #29, Joliet, IL.

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Well	Date	Boron	Calcium	Chloride	Fluoride	pH	Sulfate	Total Dissolved Solids	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Fluoride	Lead	Lithium	Mercury	Molybdenum	Radium 226 + 228	Selenium	Thallium
MW-10 up-gradient	10/28/2015	0.47	100	200	0.41	7.04	84	790	< 0.003	< 0.001	0.041	^ < 0.001	< 0.0005	< 0.005	< 0.001	0.41	< 0.0005	0.013	< 0.0002	0.0060	0.2981	< 0.0025	< 0.002
	2/10/2016	0.41	100	210	0.44	7.17	120	820	< 0.003	0.001	0.043	< 0.001	< 0.0005	< 0.005	< 0.001	0.44	< 0.0005	0.011	< 0.0002	0.0067	< 0.438	< 0.0025	< 0.002
	5/12/2016	0.29	100	300	0.42	7.02	110	920	< 0.003	< 0.001	0.046	< 0.001	< 0.0005	< 0.005	< 0.001	0.42	< 0.0005	0.012	< 0.0002	0.0051	< 0.414	< 0.0025	< 0.002
	8/31/2016	0.36	89	170	0.46	6.95	100	760	< 0.003	< 0.001	0.039	^ < 0.001	< 0.0005	< 0.005	< 0.001	0.46	< 0.0005	0.010	< 0.0002	0.0077	< 0.394	< 0.0025	< 0.002
	11/2/2016	0.48	100	130	0.45	6.99	95	720	< 0.003	0.0018	0.035	< 0.001	< 0.0005	< 0.005	< 0.001	0.45	0.0014	0.011	< 0.0002	0.0061	0.626	< 0.0025	< 0.002
	2/6/2017	0.44	120	190	0.36	6.99	88	820	< 0.003	0.0011	0.048	< 0.001	< 0.0005	< 0.005	< 0.001	0.36	0.00086	0.014	< 0.0002	0.0056	< 0.389	< 0.0025	< 0.002
	4/26/2017	0.35	120	200	0.35	7.27	87	760	< 0.003	0.0015	0.046	< 0.001	< 0.0005	< 0.005	< 0.001	0.35	0.0012	< 0.01	< 0.0002	0.006	< 0.34	< 0.0025	< 0.002
	6/14/2017	0.29	91	160	0.43	7.48	75	690	< 0.003	< 0.001	0.034	< 0.001	< 0.0005	< 0.005	< 0.001	0.43	< 0.0005	0.012	< 0.0002	0.0072	< 0.356	< 0.0025	< 0.002
	8/2/2017	0.45	97	170	0.38	7.23	110	750	< 0.003	0.0011	0.036	< 0.001	< 0.0005	< 0.005	< 0.001	0.38	< 0.0005	0.011	< 0.0002	0.0079	0.429	< 0.0025	< 0.002
	10/18/2017	0.61	120	140	0.41	7.11	130	820	< 0.003	0.0012	0.04	^ < 0.001	< 0.0005	< 0.005	< 0.001	0.41	0.00059	0.013	< 0.0002	0.0066	< 0.422	< 0.0025	^ < 0.002
	4/24/2018	0.4	110	260	0.39	7.28	120	910	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10/17/2018	0.63	120	180	0.42	7.30	110	810	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	11/24/2018 R	0.44	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5/7/2019	0.56	130	410	0.39	7.17	95	1,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	7/3/2019 R	NA	NA	230	NA	NA	NA	830	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	11/7/2019	0.35	90	130	0.36	7.40	59	650	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5/20/2020	0.85	120	250	0.41	6.90	100	960	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6/11/2020 R	0.26	NA	NA	NA	NA	NA	770	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10/22/2020	0.34	110	230	0.41	7.11	93	850	< 0.003	0.001	0.043	< ^ 0.001	< 0.0005	< 0.005	< 0.001	0.41	< 0.0005	0.011	< 0.0002	0.0057	NA	< 0.0025	< 0.002
	5/18/2021	0.33	140	350	0.39	7.16	210	1,200	< 0.003	0.0014	0.06	< 0.001	< 0.0005	< 0.005	< 0.001	0.39	< 0.0005	0.015	< 0.0002	0.0055	< 0.4800	< 0.0025	< 0.002
	6/29/2021 R	NA	160	420	NA	7.32	190	1,300	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	8/30/2021	0.28	120	330	0.37	7.56	170	990	< ^+ 0.003	0.0012	0.051	< 0.001	< 0.0005	< 0.005	< 0.001	0.37	< 0.0005	0.012	< 0.0002	0.0065	0.51	< 0.0025	< 0.002
MW-03 down-gradient	10/28/2015	0.34	110	230	0.41	7.11	110	960	< 0.003	0.0015	0.100	^ < 0.001	< 0.0005	< 0.005	< 0.001	0.41	< 0.0005	0.013	< 0.0002	< 0.0050	0.41	< 0.0025	< 0.002
	2/10/2016	0.49	100	220	0.44	7.31	130	790	< 0.003	0.0017	0.100	< 0.001	< 0.0005	< 0.005	< 0.001	0.44	< 0.0005	0.011	< 0.0002	0.0060	< 1.68	0.0045	< 0.002
	5/10/2016	0.48	95	240	0.44	7.07	130	800	< 0.003	0.0011	0.095	< 0.001	< 0.0005	< 0.005	< 0.001	0.44	< 0.0005	0.012	< 0.0002	0.0062	< 0.326	0.0030	< 0.002
	8/31/2016	0.49	100	250	0.45	7.18	120	920	< 0.003	0.0013	0.095	^ < 0.001	< 0.0005	< 0.005	< 0.001	0.45	< 0.0005	0.012	< 0.0002	0.0086	< 0.373	0.0051	< 0.002
	11/2/2016	0.34	87	190	0.44	7.45	94	780	< 0.003	0.0019	0.082	< 0.001	< 0.0005	< 0.0051	< 0.001	0.44	< 0.0005	< 0.010	< 0.0002	0.0059	0.965	0.0032	< 0.002
	2/6/2017	0.40	97	140	0.39	7.35	77	720	< 0.003	0.0019	0.093	< 0.001	< 0.0005	< 0.005	< 0.001	0.39	< 0.0005	0.012	< 0.0002	0.0066	< 0.356	0.0028	< 0.002
	4/26/2017	0.54	100	210	0.36	7.03	120	820	< 0.003	0.0017	0.11	< 0.001	< 0.0005	< 0.005	< 0.001	0.36	< 0.0005	0.010	< 0.0002	0.0088	< 0.411	0.0052	< 0.002
	6/14/2017	0.45	88	190	0.44	7.43	75	760	< 0.003	0.0014	0.09	< 0.001	< 0.0005	< 0.005	< 0.001	0.44	< 0.0005	0.012	< 0.0002	0.0072	< 0.358	0.0037	< 0.002
	8/2/2017	0.41	99	200	0.40	7.34	110	850	< 0.003	0.0022	0.10	< 0.001	< 0.0005	< 0.005	< 0.001	0.40	< 0.0005	0.011	< 0.0002	0.0065	0.414	0.005	< 0.002
	10/18/2017	0.35	93	160	0.42	7.11	100	850	< 0.003	0.0015	0.088	< ^ 0.001	< 0.0005	< 0.005	< 0.001	0.42	< 0.0005	0.012	< 0.0002	0.0055	< 0.417	0.0026	^ < 0.002
	4/24/2018	0.52	100	220	0.42	7.2	150	930	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	7/31/2018 R	NA	NA	NA	NA	NA	110	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10/17/2018	0.25	100	250	0.4	7.04	110	870	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5/7/2019	0.43	120	280	0.4	7.27	140	880	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	7/3/2019 R	NA	NA	NA	NA	NA	65	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	11/7/2019	0.34	100	150	0.4	7.32	65	660	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5/20/2020	0.38	100	230	0.42	7.56	78	960	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6/11/2020 R	NA	NA	NA	NA	NA	NA	930	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10/22/2020	0.32	110	180	0.43	7.23	90	770	< 0.003	0.0014	0.1	<^ 0.001	< 0.0005	< 0.005	< 0.001	0.43	< 0.0005	0.01	< 0.0002	< 0.005	NA	< 0.0025	< 0.002
	5/18/2021	0.28	130	290	0.4	7.13	190	1,200	< 0.003	0.0016	0.14	< 0.001	< 0.0005	< 0.005	0.0011	0.4	< 0.0005	0.014	< 0.0002	< 0.0050	1.1000	< 0.0025	< 0.002
	6/29/2021 R	NA	NA	NA	NA	7.34	210	1,300	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	8/30/2021	0.23	120	290	0.36	7.33	140	800	< ^+ 0.003	0.0018	0.12	< 0.001	< 0.0005	< 0.005	0.0014	0.36	< 0.0005	0.012	< 0.0002	< 0.005	0.641	< 0.0025	< 0.002
MW-04 down-gradient	10/28/2015	0.34	94	F1 200	0.45	7.07	83	740	< 0.003	0.0013	0.082	^ < 0.001	< 0.0005	< 0.005	0.0063	0.45	< 0.0005	0.013	< 0.0002	0.0065	0.741	< 0.0025	< 0.002
	2/10/2016	0.32	97	210	0.47	7.22	140	810	< 0.003	0.0018	0.088	< 0.001	< 0.0005	< 0.005	0.0074	0.47	0.00062	0.011	< 0.0002	0.0063	< 1.52	< 0.0025	< 0.002
	5/10/2016	0.47	100	260	0.46	6.71	150	900	< 0.003	0.0014	0.088	< 0.001	< 0.0005	< 0.005	0.0086	0.46	< 0.0005	0.012	< 0.0002	0.0088	< 0.365	< 0.0025	< 0.002
	8/31/2016	0.42	100	210	0.45	7.07	120	890	< 0.003	0.0014	0.086	^ < 0.001	< 0.0005	< 0.005	0.0035	0.45	< 0.0005	0.011	< 0.0002	0.0083	0.432	< 0.0025	< 0.002
	11/2/2016	0.32	98	160	0.43	7.25	83	750	< 0.003	0.0025	0.079	< 0.001	< 0.0005	< 0.005	0.0100	0.43	0.0012	0.012	< 0.0002	0.007	< 0.463	< 0.0025	< 0.002
	2/6/2017	0.40	110	200	0.37	7.19	98	790	< 0.003	0.0015	0.100	< 0.001	< 0.0005	< 0.005	0.0160	0.37	< 0.0005	0.013	< 0.0002	0.0071	< 0.356	< 0.0025	< 0.002
	4/26/2017	0.33	100	220	0.37	7.46	89	770	< 0.003	0.0021	0.095	< 0.001	< 0.0005	< 0.005	0.0078	0.37	0.00055	0.012	< 0.0002	0.0069	< 0.35	< 0.0025	< 0.002
	6/14/2017	0.37	92	190	0.47	7.45	80	770	< 0.003	0.0013	0.078	< 0.001	< 0.0005	< 0.005	0.0120	0.47	< 0.0005	0.013	< 0.0002	0.0085	< 0.309	< 0.0025	< 0.002
	8/2/2017	0.35	93	180	0.43	7.41	100	770	< 0.003	0.0013	0.077	< 0.001	< 0.0005	0.04	0.0031	0.43	< 0.0005	0.012	< 0.0002	0.0091	< 0.282	0.0029	< 0.002
	10/18/2017	0.54	97	140	0.45	7.2	120	790	< 0.003	0.0019	0.082	^ < 0.001	< 0.0005	< 0.005	0.0046	0.45	0.00077	0.015	< 0.0002	0.0071	0.423	0.003	^ < 0.002
	4/24/2018	0.4	110	240	0.43	7.21	160	940	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	7/31/2018 R	NA	NA	NA	NA	NA	120	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10/17/2018	0.29	100	230	0.45	7.2	130	840	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5/7/2019	0.76	120	340	0.42	7.27	120	1,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	7/3/2019 R	0.23	NA	250	NA	NA	NA	870	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	11/6/2019	0.3	77	140	0.41	7.33	53	670	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5/20/2020	0.79	110	250	0.45	7.3	110	1,100	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	6/11/2020 R	0.28	NA	NA	NA	NA	NA	850	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10/22/2020	0.33	100	190	0.48	7.15	83	770	< 0.003	0.0015	0.089	< ^ 0.001	< 0.0005	< 0.005	0.0082	0.48	< 0.0005	0.013	< 0.0002	0.0061	NA	< 0.0025	< 0.002
	5/18/2021	0.22	120	280	0.42	7.3	190	1,100	< 0.003	0.0019	0.12	< 0.001	< 0.0005	< 0.005	0.0037	0.42	< 0.0005	0.014	< 0.0002	< 0.005	< 0.4450	< 0.0025	< 0.002
	6/29/2021 R	NA	NA	NA	NA	7.36	190	1,200	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	8/30/2021	0.33	120	330	0.4	7.46	170	1,000	<^+ 0.003	0.0016	0.12	< 0.001	< 0.0005	< 0.005	0.0034	0.4	< 0.0005	0.013	< 0.0002	0.0057	0.877	0.003	< 0.002
MW-05 down-gradient	10/28/2015	0.64	100	160	0.39	7.12	120	790	< 0.003	0.0011	0.057	^ < 0.001	< 0.0005	< 0.005	0.0013	0.39	< 0.0005	0.018	< 0.0002	0.0088	0.6231	0.0031	< 0.002
	2/10/2016	0.46	110	220	0.39	7.25	120	790	< 0.003	0.0028	0.071	< 0.001	< 0.0005	0.0062	0.0013	0.39	0.0022	< 0.02	< 0.0002	F1 0.0053	1.09	< 0.0025	< 0.002
	5/10/2016	0.8	150	220	0.46	6.88	290	950	< 0.003	0.0023	0.075	< 0.001	< 0.0005	< 0.005	< 0.001	0.46	0.0022	0.014	< 0.0002	0.008	< 0.40	0.019	< 0.002
	8/31/2016	1.0	140	99	0.56	6.81	260	820	< 0.003	< 0.001	0.07	^ < 0.001	< 0.0005	< 0.005	< 0.001	0.56	< 0.0005	< 0.01	< 0.0002	0.012	< 0.42	0.02	< 0.002
	11/2/2016	0.41	98	130	0.37	7.26	100	700	< 0.003	0.0022	0.056	< 0.001	< 0.0005	0.0051	< 0.001	0.37	0.0017	0.015	< 0.0002	0.0061	0.438	< 0.0025	< 0.002
	2/6/2017	0.48	150	180	0.30	7.22	120	790	< 0.003	0.0016	0.082	< 0.001	< 0.0005	< 0.005	< 0.001	0.30	0.0016	0.021	< 0.0002	< 0.005	0.564	0.0029	< 0.002
	4/26/2017	0.67	110	F1 190	0.37	7.28	170	770	< 0.003	0.0014	0.063	< 0.001	< 0.0005	< 0.005	< 0.001	0.37	0.0008	< 0.01	< 0.0002	0.0066	< 0.411	0.013	< 0.002
	6/14/2017	0.44	75	150	0.46	7.47	110	670	< 0.003	0.0012	0.044	< 0.001	< 0.0005	< 0.005	< 0.001	0.46	< 0.0005	0.013	< 0.0002	0.0076	< 0.316	0.0029	< 0.002
	8/2/2017	0.28	83	170	0.35	7.30	99	770	< 0.003	< 0.001	0.054	< 0.001	< 0.0005	< 0.005	< 0.001	0.35	< 0.0005	0.014	< 0.0002	0.0053	0.659	< 0.0025	< 0.002
	10/18/2017	0.42	110	110	0.38	7.16	95	720	< 0.003	0.002	0.067	< ^ 0.001	< 0.0005	< 0.005	< 0.001	0.38	0.0023	0.018	< 0.0002	< 0.005	< 0.371	0.0029	^ < 0.002
	4/24/2018	0.31	110	300	0.34	7.33	130	1,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	7/31/2018 R	NA	NA	NA	NA	NA	NA	940	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10/17/2018	0.31	110	210	0.36	7.29	93	810	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5/6/2019	0.38	130	500	0.31	7.11	84	1,300	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	7/3/2019 R	NA	NA	150	NA	NA	NA	890	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	11/7/2019	0.31	180	130	0.3	7.44	64	590	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	12/4/2019 R	NA	89	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5/20/2020	0.32	100	270	0.37	7.03	67	890	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	10/22/2020	0.52	92	180	0.38	7.16	85	720	< 0.003	0.0012	0.069	<^ 0.001	< 0.0005	< 0.005	< 0.001	0.38	< 0.0005	0.013	< 0.0002	0.0054	NA	0.003	< 0.002
	5/18/2021	0.37	130	410	0.3	7.00	160	1,300	< 0.003	0.0015	0.1	< 0.001	< 0.0005	< 0.0050	< 0.0010	0.3	< 0.0005	0.023	< 0.0002	< 0.005	< 0.5970	< 0.0025	< 0.002
	6/29/2021 R	NA	NA	430	NA	7.33	150	1,300	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	8/27/2021	0.36	100	300	0.3	6.94	140	960	< ^+ 0.003	0.0014	0.069	< 0.001	< 0.0005	< 0.005	< 0.001	0.3	< 0.0005	0.015	< 0.0002	< 0.005	0.528	0.0027	< 0.002

Notes: All units are in mg/l except pH is in standard units and radium is in pCi/L

DNYA - Data not yet available.

F1 - MS and/or MSD Recovery outside of limits.

NA - Not analyzed. No confirmation resample required.

^+ - Continuing calibration verification is outside acceptance limits, high biased.

Table 2. Turbidity Measurement Data, Midwest Generation, LLC, Joliet #29 Generating Station

Well ID	Date	Turbidity (NTU)
MW-03	3/2/2021	0.45
	4/10/2021	22.9
	4/25/2021	2.40
	5/18/2021	2.53
	6/11/2021	2.34
	6/29/2021	2.86
	7/19/2021	37.40
	8/9/2021	2.71
	8/30/2021	5.70
	9/27/2021	10.27
MW-04	3/2/2021	81.89
	4/10/2021	5.96
	4/25/2021	3.02
	5/18/2021	2.52
	6/11/2021	2.8
	6/29/201	3.34
	7/19/2021	47.4
	8/9/2021	4.13
	8/30/2021	18.3
	9/27/2021	1.76
MW-05	2/25/2021	1.57
	4/10/2021	8.36
	4/25/2021	2.42
	5/17/2021	5.2
	6/11/2021	14.22
	6/29/2021	5.33
	7/19/2021	26.9
	8/9/2021	3.69
	8/27/2021	8.7
	9/27/2021	14.92
MW-10	3/2/2021	26.07
	4/10/2021	7.31
	4/25/2021	5.21
	5/18/2021	3.73
	6/11/2021	6.65
	6/29/2021	9.49
	7/19/2021	14.5
	8/9/2021	10.08
	8/30/2021	9.3
	9/27/2021	16.3

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ANALYTICAL REPORT

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Tel: (708)534-5200

Laboratory Job ID: 500-204479-1
Client Project/Site: Joliet #29 CCR

For:
Midwest Generation EME LLC
1800 Channahon Road
Joliet, Illinois 60436

Attn: DeAndre Cooley

Diana Mockler

Authorized for release by:
9/21/2021 3:23:38 PM

Diana Mockler, Project Manager I
(219)252-7570
Diana.Mockler@Eurofinset.com

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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.

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Electronic Filing: Received, Clerk's Office 2/04/2022

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Job ID: 500-204479-1

Laboratory: Eurofins TestAmerica, Chicago

Narrative

Job Narrative
500-204479-1

Comments
No additional comments.

Receipt
The samples were received on 8/27/2021 6:00 PM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperatures of the 4 coolers at receipt time were 1.3º C, 2.5º C, 2.6º C and 3.2º C.

Receipt Exceptions
The following sample(s) was submitted for analysis; however, it was not listed on the Chain-of-Custody (COC): "Duplicate" Client did not check analysis off on COC and didn't not provide date. Logged as sample #5 and logged date per container label (8/30/21). Analysis logged per container labels (same as all previous samples).

Metals
Method 6020A: The continuing calibration verification (CCV) at line 64, associated with batch 500-617878 recovered above the upper control limit for Antimony. The samples associated with this CCV were non-detects for the affected analyte; 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: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Method	Method Description	Protocol	Laboratory
6010C	Metals (ICP)	SW846	TAL CHI
6020A	Metals (ICP/MS)	SW846	TAL CHI
7470A	Mercury (CVAA)	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
3005A	Preparation, Total Recoverable or Dissolved Metals	SW846	TAL CHI
7470A	Preparation, Mercury	SW846	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 = Eurofins TestAmerica, Chicago, 2417 Bond Street, University Park, IL 60484, TEL (708)534-5200

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Sample Summary

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
500-204479-1	MW-05	Water	08/27/21 12:36	08/27/21 18:00
500-204479-2	MW-03	Water	08/30/21 10:53	08/31/21 10:57
500-204479-3	MW-04	Water	08/30/21 12:15	08/31/21 10:57
500-204479-4	MW-10	Water	08/30/21 14:30	08/31/21 10:57
500-204479-5	Duplicate	Water	08/30/21 00:00	08/31/21 10:57

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Client Sample ID: MW-05

Date Collected: 08/27/21 12:36
Date Received: 08/27/21 18:00

Lab Sample ID: 500-204479-1

Matrix: Water

Method: 6010C - Metals (ICP) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lithium	**0.015**		0.010		mg/L		09/07/21 08:35	09/08/21 19:05	1

Method: 6020A - Metals (ICP/MS) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030	^+	0.0030		mg/L		09/07/21 08:35	09/08/21 19:23	1
Arsenic	**0.0014**		0.0010		mg/L		09/07/21 08:35	09/08/21 19:23	1
Barium	**0.069**		0.0025		mg/L		09/07/21 08:35	09/08/21 19:23	1
Beryllium	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 19:23	1
Boron	**0.36**		0.050		mg/L		09/07/21 08:35	09/08/21 19:23	1
Cadmium	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:23	1
Calcium	**100**		0.20		mg/L		09/07/21 08:35	09/08/21 19:23	1
Chromium	<0.0050		0.0050		mg/L		09/07/21 08:35	09/08/21 19:23	1
Cobalt	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 19:23	1
Lead	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:23	1
Molybdenum	<0.0050		0.0050		mg/L		09/07/21 08:35	09/08/21 19:23	1
Selenium	**0.0027**		0.0025		mg/L		09/07/21 08:35	09/08/21 19:23	1
Thallium	<0.0020		0.0020		mg/L		09/07/21 08:35	09/08/21 19:23	1

Method: 7470A - Mercury (CVAA)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		09/02/21 10:10	09/03/21 08:41	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**960**		10		mg/L			08/31/21 05:22	1
Chloride	**300**		40		mg/L			09/20/21 14:59	20
Fluoride	**0.30**		0.10		mg/L			09/20/21 10:33	1
Sulfate	**140**		25		mg/L			09/20/21 15:21	5

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Client Sample ID: MW-03

Date Collected: 08/30/21 10:53
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-2

Matrix: Water

Method: 6010C - Metals (ICP) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lithium	**0.012**		0.010		mg/L		09/07/21 08:35	09/08/21 19:09	1

Method: 6020A - Metals (ICP/MS) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030	^+	0.0030		mg/L		09/07/21 08:35	09/08/21 19:27	1
Arsenic	**0.0018**		0.0010		mg/L		09/07/21 08:35	09/08/21 19:27	1
Barium	**0.12**		0.0025		mg/L		09/07/21 08:35	09/08/21 19:27	1
Beryllium	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 19:27	1
Boron	**0.23**		0.050		mg/L		09/07/21 08:35	09/08/21 19:27	1
Cadmium	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:27	1
Calcium	**120**		0.20		mg/L		09/07/21 08:35	09/08/21 19:27	1
Chromium	<0.0050		0.0050		mg/L		09/07/21 08:35	09/08/21 19:27	1
Cobalt	**0.0014**		0.0010		mg/L		09/07/21 08:35	09/08/21 19:27	1
Lead	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:27	1
Molybdenum	<0.0050		0.0050		mg/L		09/07/21 08:35	09/08/21 19:27	1
Selenium	<0.0025		0.0025		mg/L		09/07/21 08:35	09/08/21 19:27	1
Thallium	<0.0020		0.0020		mg/L		09/07/21 08:35	09/08/21 19:27	1

Method: 7470A - Mercury (CVAA)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		09/02/21 10:10	09/03/21 08:44	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**800**		10		mg/L			09/02/21 03:16	1
Chloride	**290**		40		mg/L			09/20/21 14:59	20
Fluoride	**0.36**		0.10		mg/L			09/20/21 10:36	1
Sulfate	**140**		25		mg/L			09/20/21 15:21	5

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Client Sample ID: MW-04

Date Collected: 08/30/21 12:15
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-3

Matrix: Water

Method: 6010C - Metals (ICP) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lithium	**0.013**		0.010		mg/L		09/07/21 08:35	09/08/21 19:13	1

Method: 6020A - Metals (ICP/MS) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030	^+	0.0030		mg/L		09/07/21 08:35	09/08/21 19:30	1
Arsenic	**0.0016**		0.0010		mg/L		09/07/21 08:35	09/08/21 19:30	1
Barium	**0.12**		0.0025		mg/L		09/07/21 08:35	09/08/21 19:30	1
Beryllium	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 19:30	1
Boron	**0.33**		0.050		mg/L		09/07/21 08:35	09/08/21 19:30	1
Cadmium	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:30	1
Calcium	**120**		0.20		mg/L		09/07/21 08:35	09/08/21 19:30	1
Chromium	<0.0050		0.0050		mg/L		09/07/21 08:35	09/08/21 19:30	1
Cobalt	**0.0034**		0.0010		mg/L		09/07/21 08:35	09/08/21 19:30	1
Lead	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:30	1
Molybdenum	**0.0057**		0.0050		mg/L		09/07/21 08:35	09/08/21 19:30	1
Selenium	**0.0030**		0.0025		mg/L		09/07/21 08:35	09/08/21 19:30	1
Thallium	<0.0020		0.0020		mg/L		09/07/21 08:35	09/08/21 19:30	1

Method: 7470A - Mercury (CVAA)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		09/02/21 10:10	09/03/21 08:46	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**1000**		10		mg/L			09/02/21 03:19	1
Chloride	**330**		40		mg/L			09/20/21 15:00	20
Fluoride	**0.40**		0.10		mg/L			09/20/21 10:39	1
Sulfate	**170**		25		mg/L			09/20/21 15:22	5

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Client Sample ID: MW-10

Date Collected: 08/30/21 14:30
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-4

Matrix: Water

Method: 6010C - Metals (ICP) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lithium	**0.012**		0.010		mg/L		09/07/21 08:35	09/08/21 19:17	1

Method: 6020A - Metals (ICP/MS) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030	^+	0.0030		mg/L		09/07/21 08:35	09/08/21 19:34	1
Arsenic	**0.0012**		0.0010		mg/L		09/07/21 08:35	09/08/21 19:34	1
Barium	**0.051**		0.0025		mg/L		09/07/21 08:35	09/08/21 19:34	1
Beryllium	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 19:34	1
Boron	**0.28**		0.050		mg/L		09/07/21 08:35	09/08/21 19:34	1
Cadmium	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:34	1
Calcium	**120**		0.20		mg/L		09/07/21 08:35	09/08/21 19:34	1
Chromium	<0.0050		0.0050		mg/L		09/07/21 08:35	09/08/21 19:34	1
Cobalt	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 19:34	1
Lead	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:34	1
Molybdenum	**0.0065**		0.0050		mg/L		09/07/21 08:35	09/08/21 19:34	1
Selenium	<0.0025		0.0025		mg/L		09/07/21 08:35	09/08/21 19:34	1
Thallium	<0.0020		0.0020		mg/L		09/07/21 08:35	09/08/21 19:34	1

Method: 7470A - Mercury (CVAA)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		09/02/21 10:10	09/03/21 08:48	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**990**		10		mg/L			09/02/21 03:22	1
Chloride	**330**		40		mg/L			09/20/21 15:00	20
Fluoride	**0.37**		0.10		mg/L			09/20/21 10:42	1
Sulfate	**170**		25		mg/L			09/20/21 15:22	5

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Client Sample ID: Duplicate

Date Collected: 08/30/21 00:00
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-5

Matrix: Water

Method: 6010C - Metals (ICP) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lithium	**0.012**		0.010		mg/L		09/07/21 08:35	09/08/21 19:22	1

Method: 6020A - Metals (ICP/MS) - Total Recoverable

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030	^+	0.0030		mg/L		09/07/21 08:35	09/08/21 19:37	1
Arsenic	**0.0013**		0.0010		mg/L		09/07/21 08:35	09/08/21 19:37	1
Barium	**0.051**		0.0025		mg/L		09/07/21 08:35	09/08/21 19:37	1
Beryllium	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 19:37	1
Boron	**0.26**		0.050		mg/L		09/07/21 08:35	09/08/21 19:37	1
Cadmium	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:37	1
Calcium	**120**		0.20		mg/L		09/07/21 08:35	09/08/21 19:37	1
Chromium	<0.0050		0.0050		mg/L		09/07/21 08:35	09/08/21 19:37	1
Cobalt	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 19:37	1
Lead	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 19:37	1
Molybdenum	**0.0061**		0.0050		mg/L		09/07/21 08:35	09/08/21 19:37	1
Selenium	<0.0025		0.0025		mg/L		09/07/21 08:35	09/08/21 19:37	1
Thallium	<0.0020		0.0020		mg/L		09/07/21 08:35	09/08/21 19:37	1

Method: 7470A - Mercury (CVAA)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		09/02/21 10:10	09/03/21 08:50	1

General Chemistry

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Total Dissolved Solids	**870**		10		mg/L			09/02/21 03:24	1
Chloride	**330**		40		mg/L			09/20/21 15:00	20
Fluoride	**0.37**		0.10		mg/L			09/20/21 10:45	1
Sulfate	**160**		25		mg/L			09/20/21 15:22	5

Definitions/Glossary

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Qualifiers

Metals

Qualifier	Qualifier Description
^+	Continuing Calibration Verification (CCV) is outside acceptance limits, high biased.

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

Electronic Filing: Received, Clerk's Office 2/04/2022

QC Association Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Metals

Prep Batch: 617084

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total/NA	Water	7470A	
500-204479-2	MW-03	Total/NA	Water	7470A	
500-204479-3	MW-04	Total/NA	Water	7470A	
500-204479-4	MW-10	Total/NA	Water	7470A	
500-204479-5	Duplicate	Total/NA	Water	7470A	
MB 500-617084/12-A	Method Blank	Total/NA	Water	7470A	
LCS 500-617084/13-A	Lab Control Sample	Total/NA	Water	7470A	

Analysis Batch: 617281

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total/NA	Water	7470A	617084
500-204479-2	MW-03	Total/NA	Water	7470A	617084
500-204479-3	MW-04	Total/NA	Water	7470A	617084
500-204479-4	MW-10	Total/NA	Water	7470A	617084
500-204479-5	Duplicate	Total/NA	Water	7470A	617084
MB 500-617084/12-A	Method Blank	Total/NA	Water	7470A	617084
LCS 500-617084/13-A	Lab Control Sample	Total/NA	Water	7470A	617084

Prep Batch: 617441

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total Recoverable	Water	3005A	
500-204479-2	MW-03	Total Recoverable	Water	3005A	
500-204479-3	MW-04	Total Recoverable	Water	3005A	
500-204479-4	MW-10	Total Recoverable	Water	3005A	
500-204479-5	Duplicate	Total Recoverable	Water	3005A	
MB 500-617441/1-A	Method Blank	Total Recoverable	Water	3005A	
LCS 500-617441/2-A	Lab Control Sample	Total Recoverable	Water	3005A	

Analysis Batch: 617834

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total Recoverable	Water	6010C	617441
500-204479-2	MW-03	Total Recoverable	Water	6010C	617441
500-204479-3	MW-04	Total Recoverable	Water	6010C	617441
500-204479-4	MW-10	Total Recoverable	Water	6010C	617441
500-204479-5	Duplicate	Total Recoverable	Water	6010C	617441
MB 500-617441/1-A	Method Blank	Total Recoverable	Water	6010C	617441
LCS 500-617441/2-A	Lab Control Sample	Total Recoverable	Water	6010C	617441

Analysis Batch: 617878

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total Recoverable	Water	6020A	617441
500-204479-2	MW-03	Total Recoverable	Water	6020A	617441
500-204479-3	MW-04	Total Recoverable	Water	6020A	617441
500-204479-4	MW-10	Total Recoverable	Water	6020A	617441
500-204479-5	Duplicate	Total Recoverable	Water	6020A	617441
MB 500-617441/1-A	Method Blank	Total Recoverable	Water	6020A	617441
LCS 500-617441/2-A	Lab Control Sample	Total Recoverable	Water	6020A	617441

QC Association Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

General Chemistry

Analysis Batch: 616592

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total/NA	Water	SM 2540C	
MB 500-616592/1	Method Blank	Total/NA	Water	SM 2540C	
LCS 500-616592/2	Lab Control Sample	Total/NA	Water	SM 2540C	

Analysis Batch: 617000

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-2	MW-03	Total/NA	Water	SM 2540C	
500-204479-3	MW-04	Total/NA	Water	SM 2540C	
500-204479-4	MW-10	Total/NA	Water	SM 2540C	
500-204479-5	Duplicate	Total/NA	Water	SM 2540C	
MB 500-617000/1	Method Blank	Total/NA	Water	SM 2540C	
LCS 500-617000/2	Lab Control Sample	Total/NA	Water	SM 2540C	

Analysis Batch: 619345

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total/NA	Water	SM 4500 F C	
500-204479-2	MW-03	Total/NA	Water	SM 4500 F C	
500-204479-3	MW-04	Total/NA	Water	SM 4500 F C	
500-204479-4	MW-10	Total/NA	Water	SM 4500 F C	
500-204479-5	Duplicate	Total/NA	Water	SM 4500 F C	
MB 500-619345/3	Method Blank	Total/NA	Water	SM 4500 F C	
LCS 500-619345/4	Lab Control Sample	Total/NA	Water	SM 4500 F C	

Analysis Batch: 619403

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total/NA	Water	SM 4500 SO4 E	
500-204479-2	MW-03	Total/NA	Water	SM 4500 SO4 E	
500-204479-3	MW-04	Total/NA	Water	SM 4500 SO4 E	
500-204479-4	MW-10	Total/NA	Water	SM 4500 SO4 E	
500-204479-5	Duplicate	Total/NA	Water	SM 4500 SO4 E	
MB 500-619403/15	Method Blank	Total/NA	Water	SM 4500 SO4 E	
LCS 500-619403/16	Lab Control Sample	Total/NA	Water	SM 4500 SO4 E	

Analysis Batch: 619404

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total/NA	Water	SM 4500 Cl- E	
500-204479-2	MW-03	Total/NA	Water	SM 4500 Cl- E	
500-204479-3	MW-04	Total/NA	Water	SM 4500 Cl- E	
500-204479-4	MW-10	Total/NA	Water	SM 4500 Cl- E	
500-204479-5	Duplicate	Total/NA	Water	SM 4500 Cl- E	
MB 500-619404/16	Method Blank	Total/NA	Water	SM 4500 Cl- E	
LCS 500-619404/17	Lab Control Sample	Total/NA	Water	SM 4500 Cl- E	

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Method: 6010C - Metals (ICP)

Lab Sample ID: MB 500-617441/1-A
Matrix: Water
Analysis Batch: 617834

Client Sample ID: Method Blank
Prep Type: Total Recoverable
Prep Batch: 617441

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lithium	<0.010		0.010		mg/L		09/07/21 08:35	09/08/21 17:56	1

Lab Sample ID: LCS 500-617441/2-A
Matrix: Water
Analysis Batch: 617834

Client Sample ID: Lab Control Sample
Prep Type: Total Recoverable
Prep Batch: 617441

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Lithium	0.750	0.754		mg/L		101	80 - 120

Method: 6020A - Metals (ICP/MS)

Lab Sample ID: MB 500-617441/1-A
Matrix: Water
Analysis Batch: 617878

Client Sample ID: Method Blank
Prep Type: Total Recoverable
Prep Batch: 617441

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Antimony	<0.0030		0.0030		mg/L		09/07/21 08:35	09/08/21 17:55	1
Arsenic	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 17:55	1
Barium	<0.0025		0.0025		mg/L		09/07/21 08:35	09/08/21 17:55	1
Beryllium	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 17:55	1
Boron	<0.050		0.050		mg/L		09/07/21 08:35	09/08/21 17:55	1
Cadmium	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 17:55	1
Calcium	<0.20		0.20		mg/L		09/07/21 08:35	09/08/21 17:55	1
Chromium	<0.0050		0.0050		mg/L		09/07/21 08:35	09/08/21 17:55	1
Cobalt	<0.0010		0.0010		mg/L		09/07/21 08:35	09/08/21 17:55	1
Lead	<0.00050		0.00050		mg/L		09/07/21 08:35	09/08/21 17:55	1
Molybdenum	<0.0050		0.0050		mg/L		09/07/21 08:35	09/08/21 17:55	1
Selenium	<0.0025		0.0025		mg/L		09/07/21 08:35	09/08/21 17:55	1
Thallium	<0.0020		0.0020		mg/L		09/07/21 08:35	09/08/21 17:55	1

Lab Sample ID: LCS 500-617441/2-A
Matrix: Water
Analysis Batch: 617878

Client Sample ID: Lab Control Sample
Prep Type: Total Recoverable
Prep Batch: 617441

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Antimony	0.750	0.780		mg/L		104	80 - 120
Arsenic	0.150	0.144		mg/L		96	80 - 120
Barium	3.00	2.97		mg/L		99	80 - 120
Beryllium	0.0750	0.0744		mg/L		99	80 - 120
Boron	1.50	1.40		mg/L		93	80 - 120
Cadmium	0.0750	0.0734		mg/L		98	80 - 120
Calcium	15.0	15.0		mg/L		100	80 - 120
Chromium	0.300	0.294		mg/L		98	80 - 120
Cobalt	0.750	0.745		mg/L		99	80 - 120
Lead	0.150	0.161		mg/L		108	80 - 120
Molybdenum	1.50	1.45		mg/L		97	80 - 120
Selenium	0.150	0.146		mg/L		97	80 - 120
Thallium	0.150	0.158		mg/L		105	80 - 120

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Method: 7470A - Mercury (CVAA)

Lab Sample ID: MB 500-617084/12-A
Matrix: Water
Analysis Batch: 617281

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 617084

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Mercury	<0.00020		0.00020		mg/L		09/02/21 10:10	09/03/21 08:37	1

Lab Sample ID: LCS 500-617084/13-A
Matrix: Water
Analysis Batch: 617281

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 617084

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Mercury	0.00200	0.00211		mg/L		106	80 - 120

Method: SM 2540C - Solids, Total Dissolved (TDS)

Lab Sample ID: MB 500-616592/1
Matrix: Water
Analysis Batch: 616592

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			08/31/21 04:33	1

Lab Sample ID: LCS 500-616592/2
Matrix: Water
Analysis Batch: 616592

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	278		mg/L		111	80 - 120

Lab Sample ID: MB 500-617000/1
Matrix: Water
Analysis Batch: 617000

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			09/02/21 02:51	1

Lab Sample ID: LCS 500-617000/2
Matrix: Water
Analysis Batch: 617000

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	246		mg/L		98	80 - 120

Method: SM 4500 Cl- E - Chloride, Total

Lab Sample ID: MB 500-619404/16
Matrix: Water
Analysis Batch: 619404

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			09/20/21 14:36	1

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Method: SM 4500 Cl- E - Chloride, Total (Continued)

Lab Sample ID: LCS 500-619404/17
Matrix: Water
Analysis Batch: 619404

Client Sample ID: Lab Control Sample
Prep Type: Total/NA

Analyte			Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits		
Chloride			20.0	19.9		mg/L		99	85 - 115		

Method: SM 4500 F C - Fluoride

Lab Sample ID: MB 500-619345/3
Matrix: Water
Analysis Batch: 619345

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			09/20/21 09:40	1

Lab Sample ID: LCS 500-619345/4
Matrix: Water
Analysis Batch: 619345

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	10.6		mg/L		106	90 - 119		

Method: SM 4500 SO4 E - Sulfate, Total

Lab Sample ID: MB 500-619403/15
Matrix: Water
Analysis Batch: 619403

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			09/20/21 13:41	1

Lab Sample ID: LCS 500-619403/16
Matrix: Water
Analysis Batch: 619403

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	20.5		mg/L		102	88 - 123		

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: Mark Wilson	Lab PM: Mockler Diana J	Carrier Tracking No(s):	COC No: 500-94078-41749 1
Client Contact: Erin Bulson	Phone: 630-325-1300	E-Mail: Diana Mockler@Eurofinset com	State of Origin:	Page: Page 1 of 1
Company: KPRG and Associates, Inc.	PWSID:			Job #: 500-204479
Address: 14665 West Lisbon Road Suite 1A	Due Date Requested			
City: Brookfield	TAT Requested (days)			
State, Zip: WI 53005	Compliance Project: Δ Yes Δ No			
Phone:	PO #: 4502042860			
Email: erinb@kprginc.com	WO #:			
Project Name: Joliet #29 CCR/ Event Desc. Quarterly MWG Joliet #29 CCR	Project #: 50011568			
Site: Illinois	SSOW#:			

Analysis Requested

500-204479 COC

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)	6010C, 6020A, 7470A	2540C, 4500_F_C, SM4500_Cl_E, SM4500_SO4_E	903.0, 904.0	Total Number of containers	Special Instructions/Note:
			Preservation Code:				D	N	D		
MW-03				Water							
MW-04				Water							
MW-05	8-27-21	0736	G	Water	Y		X	X	X		
MW-10	~~8-27-21~~		G	Water	Y		X	X	X		
Duplicate				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
Mark Wilson	8/27/21 1800	KPRG	Paula Buckley	8/27/21 1800	EETA CHI
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: 2.6

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park IL 60484
Phone (708) 534-5200 Phone (708) 534-5211

Chain of Custody Record

eurofins

500-204479 COC

Client Information	Sampler: Mark Wilson	Lab PM: Mockler Diana J	King No(s):	COC No. 500-91207-40679 1
Client Contact: Erin Bulson	Phone: (630) 325-1300	E-Mail: Diana.Mockler@Eurofinset.com	State of Origin:	Page: Page 1 of 1
Company: KPRG and Associates Inc.	PWSID:			Job #: 500-204479
Address: 14665 West Lisbon Road Suite 1A	Due Date Requested:			
City: Brookfield	TAT Requested (days):			
State, Zip: WI, 53005	Compliance Project: Δ Yes Δ No			
Phone:	PO #: 4502042860			
Email: erinb@kprginc.com	WO #:			
Project Name: Quarterly MWG Joliet #29 CCR	Project #: 50011568			
Site: Illinois	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	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)	6010C - Lithium, 6020A - '13 elements, 7470A - Mercury	2540C - TDS	4500FC - Fluoride	SM600CLE - Chloride	SM4500SO4 - Sulfate	903- Rad 226	904 - Rad 228	Rad Combined							Total Number of containers	Special Instructions/Note
				Preservation Code:		X	X	D	N	D													
2	MW-03	8-30-21	1053	G	Water	Y		X	X	X	X	X	X	X	X								*Metals List: Sb,As,Ba,Be,B,Cd,Ca,Cr,Co,Pb,Mo,SeTl
3	MW-04	8-30-21	1215	G	Water	Y		X	X	X	X	X	X	X	X								
	MW-05				Water																		
4	MW-10	8-30-21	1430	G	Water	Y		X	X	X	X	X	X	X	X								
5	Duplicate				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
1	Mark Wilson/KPRG	8-31-21/0930	KPRG	[illegible]	8/31/21 0930	ETA
2	[illegible]	8/31/21 1057	ETA	Stephanie Hernandez	8/31/21 1057	ETA-CHI
3						

Custody Seals Intact: Δ Yes Δ No | Custody Seal No.

Cooler Temperature(s) °C and Other Remarks: 13, 3 2, 2 5

Ver: 01/16/2019

Login Sample Receipt Checklist

Client: Midwest Generation EME LLC

Job Number: 500-204479-1

Login Number: 204479
List Number: 1
Creator: Hernandez, Stephanie

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	2.6,1.3,3.2,2.5
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").	N/A	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Client Sample ID: MW-05
Date Collected: 08/27/21 12:36
Date Received: 08/27/21 18:00

Lab Sample ID: 500-204479-1
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6010C		1	617834	09/08/21 19:05	JJB	TAL CHI
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6020A		1	617878	09/08/21 19:23	FXG	TAL CHI
Total/NA	Prep	7470A			617084	09/02/21 10:10	MJG	TAL CHI
Total/NA	Analysis	7470A		1	617281	09/03/21 08:41	MJG	TAL CHI
Total/NA	Analysis	SM 2540C		1	616592	08/31/21 05:22	CLB	TAL CHI
Total/NA	Analysis	SM 4500 Cl- E		20	619404	09/20/21 14:59	MS	TAL CHI
Total/NA	Analysis	SM 4500 F C		1	619345	09/20/21 10:33	MS	TAL CHI
Total/NA	Analysis	SM 4500 SO4 E		5	619403	09/20/21 15:21	MS	TAL CHI

Client Sample ID: MW-03
Date Collected: 08/30/21 10:53
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-2
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6010C		1	617834	09/08/21 19:09	JJB	TAL CHI
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6020A		1	617878	09/08/21 19:27	FXG	TAL CHI
Total/NA	Prep	7470A			617084	09/02/21 10:10	MJG	TAL CHI
Total/NA	Analysis	7470A		1	617281	09/03/21 08:44	MJG	TAL CHI
Total/NA	Analysis	SM 2540C		1	617000	09/02/21 03:16	CLB	TAL CHI
Total/NA	Analysis	SM 4500 Cl- E		20	619404	09/20/21 14:59	MS	TAL CHI
Total/NA	Analysis	SM 4500 F C		1	619345	09/20/21 10:36	MS	TAL CHI
Total/NA	Analysis	SM 4500 SO4 E		5	619403	09/20/21 15:21	MS	TAL CHI

Client Sample ID: MW-04
Date Collected: 08/30/21 12:15
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-3
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6010C		1	617834	09/08/21 19:13	JJB	TAL CHI
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6020A		1	617878	09/08/21 19:30	FXG	TAL CHI
Total/NA	Prep	7470A			617084	09/02/21 10:10	MJG	TAL CHI
Total/NA	Analysis	7470A		1	617281	09/03/21 08:46	MJG	TAL CHI
Total/NA	Analysis	SM 2540C		1	617000	09/02/21 03:19	CLB	TAL CHI
Total/NA	Analysis	SM 4500 Cl- E		20	619404	09/20/21 15:00	MS	TAL CHI
Total/NA	Analysis	SM 4500 F C		1	619345	09/20/21 10:39	MS	TAL CHI
Total/NA	Analysis	SM 4500 SO4 E		5	619403	09/20/21 15:22	MS	TAL CHI

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-1

Client Sample ID: MW-10

Lab Sample ID: 500-204479-4
Matrix: Water
Date Collected: 08/30/21 14:30
Date Received: 08/31/21 10:57

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6010C		1	617834	09/08/21 19:17	JJB	TAL CHI
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6020A		1	617878	09/08/21 19:34	FXG	TAL CHI
Total/NA	Prep	7470A			617084	09/02/21 10:10	MJG	TAL CHI
Total/NA	Analysis	7470A		1	617281	09/03/21 08:48	MJG	TAL CHI
Total/NA	Analysis	SM 2540C		1	617000	09/02/21 03:22	CLB	TAL CHI
Total/NA	Analysis	SM 4500 Cl- E		20	619404	09/20/21 15:00	MS	TAL CHI
Total/NA	Analysis	SM 4500 F C		1	619345	09/20/21 10:42	MS	TAL CHI
Total/NA	Analysis	SM 4500 SO4 E		5	619403	09/20/21 15:22	MS	TAL CHI

Client Sample ID: Duplicate

Lab Sample ID: 500-204479-5
Matrix: Water
Date Collected: 08/30/21 00:00
Date Received: 08/31/21 10:57

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6010C		1	617834	09/08/21 19:22	JJB	TAL CHI
Total Recoverable	Prep	3005A			617441	09/07/21 08:35	BDE	TAL CHI
Total Recoverable	Analysis	6020A		1	617878	09/08/21 19:37	FXG	TAL CHI
Total/NA	Prep	7470A			617084	09/02/21 10:10	MJG	TAL CHI
Total/NA	Analysis	7470A		1	617281	09/03/21 08:50	MJG	TAL CHI
Total/NA	Analysis	SM 2540C		1	617000	09/02/21 03:24	CLB	TAL CHI
Total/NA	Analysis	SM 4500 Cl- E		20	619404	09/20/21 15:00	MS	TAL CHI
Total/NA	Analysis	SM 4500 F C		1	619345	09/20/21 10:45	MS	TAL CHI
Total/NA	Analysis	SM 4500 SO4 E		5	619403	09/20/21 15:22	MS	TAL CHI

Laboratory References:

TAL CHI = Eurofins TestAmerica, Chicago, 2417 Bond Street, University Park, IL 60484, TEL (708)534-5200

eurofins | Environment Testing America



ANALYTICAL REPORT

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park, IL 60484
Tel: (708)534-5200

Laboratory Job ID: 500-204479-2
Client Project/Site: Joliet #29 CCR

For:
Midwest Generation EME LLC
1800 Channahon Road
Joliet, Illinois 60436

Attn: DeAndre Cooley

Diana Mockler

Authorized for release by:
10/21/2021 2:46:38 PM

Diana Mockler, Project Manager I
(219)252-7570
Diana.Mockler@Eurofinset.com

LINKS

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Have a Question? Ask The Expert

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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.

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Electronic Filing: Received, Clerk's Office 2/04/2022

Job ID: 500-204479-2

Laboratory: Eurofins TestAmerica, Chicago

Narrative

Job Narrative
500-204479-2

Comments
No additional comments.

Receipt
The samples were received on 8/27/2021 6:00 PM. Unless otherwise noted below, the samples arrived in good condition, and where required, properly preserved and on ice. The temperatures of the 4 coolers at receipt time were 1.3º C, 2.5º C, 2.6º C and 3.2º C.

Receipt Exceptions
The following sample(s) was submitted for analysis; however, it was not listed on the Chain-of-Custody (COC): "Duplicate" Client did not check analysis off on COC and didn't not provide date. Logged as sample #5 and logged date per container label (8/30/21). Analysis logged per container labels (same as all previous samples).

RAD
Method 903.0: Radium-226 prep batch 160-526228:

Any minimum detectable concentration (MDC), critical value (DLC), or Safe Drinking Water Act detection limit (SDWA DL) is sample-specific unless otherwise stated elsewhere in this narrative. Radiochemistry sample results are reported with the count date/time applied as the Activity Reference Date. MW-04 (500-204479-3) and MW-10 (500-204479-4)

Methods 903.0, 9315: Radium 226 prep batch 160-526228
Duplicate precision (RPD/RER/DER) is outside the established QC criteria for (500-204479-D-2-A DU), associated with radium-226 batch 160-526228. However, both the sample and duplicate results are below the requested limit (RL); therefore, the data does not appear to be adversely affected. Results are reported as achieved.

Methods 903.0, 9315: Radium-226 prep batch 160-526228:

Any minimum detectable concentration (MDC), critical value (DLC), or Safe Drinking Water Act detection limit (SDWA DL) is sample-specific unless otherwise stated elsewhere in this narrative. Radiochemistry sample results are reported with the count date/time applied as the Activity Reference Date. MW-05 (500-204479-1), MW-03 (500-204479-2), MW-04 (500-204479-3), MW-10 (500-204479-4), Duplicate (500-204479-5) and (500-204479-D-2-A DU)

Methods 904.0, 9320: Radium-228 prep batch 160-526247:

The method blank was counted on a detector that failed the daily background check high. The detector passed the background check the day prior to and after the sample count. The method blank activity is below the MDC and RL. The lab does not believe this excursion adversely affects the data. The data have been reported with this narrative. (MB 160-526247/1-A)

Methods 904.0, 9320: Radium-228 prep batch 160-526247:

Any minimum detectable concentration (MDC), critical value (DLC), or Safe Drinking Water Act detection limit (SDWA DL) is sample-specific unless otherwise stated elsewhere in this narrative. Radiochemistry sample results are reported with the count date/time applied as the Activity Reference Date. MW-05 (500-204479-1), MW-03 (500-204479-2), MW-04 (500-204479-3), MW-10 (500-204479-4), Duplicate (500-204479-5), (LCS 160-526247/2-A), (MB 160-526247/1-A) and (500-204479-D-2-B DU)

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

Method Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Method	Method Description	Protocol	Laboratory
903.0	Radium-226 (GFPC)	EPA	TAL SL
904.0	Radium-228 (GFPC)	EPA	TAL SL
Ra226_Ra228	Combined Radium-226 and Radium-228	TAL-STL	TAL SL
PrecSep_0	Preparation, Precipitate Separation	None	TAL SL
PrecSep-21	Preparation, Precipitate Separation (21-Day In-Growth)	None	TAL SL

Protocol References:

EPA = US Environmental Protection Agency

None = None

TAL-STL = TestAmerica Laboratories, St. Louis, Facility Standard Operating Procedure.

Laboratory References:

TAL SL = Eurofins TestAmerica, St. Louis, 13715 Rider Trail North, Earth City, MO 63045, TEL (314)298-8566

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Sample Summary

Job ID: 500-204479-2

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
500-204479-1	MW-05	Water	08/27/21 12:36	08/27/21 18:00
500-204479-2	MW-03	Water	08/30/21 10:53	08/31/21 10:57
500-204479-3	MW-04	Water	08/30/21 12:15	08/31/21 10:57
500-204479-4	MW-10	Water	08/30/21 14:30	08/31/21 10:57
500-204479-5	Duplicate	Water	08/30/21 00:00	08/31/21 10:57

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Client Sample ID: MW-05
Date Collected: 08/27/21 12:36
Date Received: 08/27/21 18:00

Lab Sample ID: 500-204479-1
Matrix: Water

Method: 903.0 - Radium-226 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-226	0.136	U	0.105	0.106	1.00	0.155	pCi/L	09/09/21 17:37	10/11/21 21:24	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*93.6*		*40 - 110*	*09/09/21 17:37*	*10/11/21 21:24*	*1*

Method: 904.0 - Radium-228 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-228	**0.393**		0.253	0.256	1.00	0.389	pCi/L	09/10/21 09:05	10/07/21 12:45	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*93.6*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:45*	*1*
Y Carrier	*85.6*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:45*	*1*

Method: Ra226_Ra228 - Combined Radium-226 and Radium-228

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Combined Radium 226 + 228	**0.528**		0.274	0.277	5.00	0.389	pCi/L		10/12/21 18:39	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Client Sample ID: MW-03
Date Collected: 08/30/21 10:53
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-2
Matrix: Water

Method: 903.0 - Radium-226 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-226	0.109	U	0.109	0.110	1.00	0.174	pCi/L	09/09/21 17:37	10/12/21 17:52	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*89.0*		*40 - 110*	*09/09/21 17:37*	*10/12/21 17:52*	*1*

Method: 904.0 - Radium-228 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-228	**0.532**		0.280	0.284	1.00	0.417	pCi/L	09/10/21 09:05	10/07/21 12:46	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*89.0*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:46*	*1*
Y Carrier	*83.4*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:46*	*1*

Method: Ra226_Ra228 - Combined Radium-226 and Radium-228

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Combined Radium 226 + 228	**0.641**		0.300	0.305	5.00	0.417	pCi/L		10/12/21 18:39	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Client Sample ID: MW-04
Date Collected: 08/30/21 12:15
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-3
Matrix: Water

Method: 903.0 - Radium-226 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-226	**0.542**		0.312	0.316	1.00	0.426	pCi/L	09/09/21 17:37	10/07/21 21:59	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*82.1*		*40 - 110*	*09/09/21 17:37*	*10/07/21 21:59*	*1*

Method: 904.0 - Radium-228 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-228	0.335	U	0.296	0.297	1.00	0.476	pCi/L	09/10/21 09:05	10/07/21 12:34	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*82.1*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:34*	*1*
Y Carrier	*84.5*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:34*	*1*

Method: Ra226_Ra228 - Combined Radium-226 and Radium-228

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Combined Radium 226 + 228	**0.877**		0.430	0.434	5.00	0.476	pCi/L		10/12/21 18:39	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Client Sample ID: MW-10
Date Collected: 08/30/21 14:30
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-4
Matrix: Water

Method: 903.0 - Radium-226 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-226	**0.381**		0.228	0.230	1.00	0.300	pCi/L	09/09/21 17:37	10/07/21 21:59	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*95.4*		*40 - 110*	*09/09/21 17:37*	*10/07/21 21:59*	*1*

Method: 904.0 - Radium-228 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-228	0.129	U	0.217	0.217	1.00	0.367	pCi/L	09/10/21 09:05	10/07/21 12:34	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*95.4*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:34*	*1*
Y Carrier	*84.5*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:34*	*1*

Method: Ra226_Ra228 - Combined Radium-226 and Radium-228

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Combined Radium 226 + 228	**0.510**		0.315	0.316	5.00	0.367	pCi/L		10/12/21 18:39	1

Client Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Client Sample ID: Duplicate

Date Collected: 08/30/21 00:00
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-5

Matrix: Water

Method: 903.0 - Radium-226 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-226	0.292	U	0.285	0.286	1.00	0.452	pCi/L	09/09/21 17:37	10/07/21 22:00	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*87.7*		*40 - 110*	*09/09/21 17:37*	*10/07/21 22:00*	*1*

Method: 904.0 - Radium-228 (GFPC)

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-228	0.186	U	0.261	0.261	1.00	0.435	pCi/L	09/10/21 09:05	10/07/21 12:34	1

Carrier	*%Yield*	*Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*87.7*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:34*	*1*
Y Carrier	*84.1*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:34*	*1*

Method: Ra226_Ra228 - Combined Radium-226 and Radium-228

Analyte	Result	Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Combined Radium 226 + 228	**0.478**		0.386	0.387	5.00	0.452	pCi/L		10/12/21 18:39	1

Definitions/Glossary

Client: Midwest Generation EME LLC
Job ID: 500-204479-2
Project/Site: Joliet #29 CCR

Qualifiers

Rad

Qualifier	Qualifier Description
F	Duplicate RPD exceeds the control limit
U	Result is less than the sample detection limit.

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: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Rad

Prep Batch: 526228

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total/NA	Water	PrecSep-21	
500-204479-2	MW-03	Total/NA	Water	PrecSep-21	
500-204479-3	MW-04	Total/NA	Water	PrecSep-21	
500-204479-4	MW-10	Total/NA	Water	PrecSep-21	
500-204479-5	Duplicate	Total/NA	Water	PrecSep-21	
MB 160-526228/1-A	Method Blank	Total/NA	Water	PrecSep-21	
LCS 160-526228/2-A	Lab Control Sample	Total/NA	Water	PrecSep-21	
500-204479-2 DU	MW-03	Total/NA	Water	PrecSep-21	

Prep Batch: 526247

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
500-204479-1	MW-05	Total/NA	Water	PrecSep_0	
500-204479-2	MW-03	Total/NA	Water	PrecSep_0	
500-204479-3	MW-04	Total/NA	Water	PrecSep_0	
500-204479-4	MW-10	Total/NA	Water	PrecSep_0	
500-204479-5	Duplicate	Total/NA	Water	PrecSep_0	
MB 160-526247/1-A	Method Blank	Total/NA	Water	PrecSep_0	
LCS 160-526247/2-A	Lab Control Sample	Total/NA	Water	PrecSep_0	
500-204479-2 DU	MW-03	Total/NA	Water	PrecSep_0	

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Method: 903.0 - Radium-226 (GFPC)

Lab Sample ID: MB 160-526228/1-A
Matrix: Water
Analysis Batch: 530631

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 526228

Analyte	MB Result	MB Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-226	0.09496	U	0.121	0.121	1.00	0.200	pCi/L	09/09/21 17:37	10/11/21 21:21	1

Carrier	*MB %Yield*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*68.3*		*40 - 110*	*09/09/21 17:37*	*10/11/21 21:21*	*1*

Lab Sample ID: LCS 160-526228/2-A
Matrix: Water
Analysis Batch: 530631

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 526228

Analyte			Spike Added	LCS Result	LCS Qual	Total Uncert. (2σ+/-)	RL	MDC	Unit	%Rec	%Rec. Limits		
Radium-226			11.3	10.94		1.22	1.00	0.224	pCi/L	96	75 - 125		

Carrier	*LCS %Yield*	*LCS Qualifier*	*Limits*
Ba Carrier	*72.9*		*40 - 110*

Lab Sample ID: 500-204479-2 DU
Matrix: Water
Analysis Batch: 531123

Client Sample ID: MW-03
Prep Type: Total/NA
Prep Batch: 526228

Analyte	Sample Result	Sample Qual		DU Result	DU Qual	Total Uncert. (2σ+/-)	RL	MDC	Unit			RER	RER Limit
Radium-226	0.109	U		0.6035	F	0.217	1.00	0.238	pCi/L			1.51	1

Carrier	*DU %Yield*	*DU Qualifier*	*Limits*
Ba Carrier	*62.1*		*40 - 110*

Method: 904.0 - Radium-228 (GFPC)

Lab Sample ID: MB 160-526247/1-A
Matrix: Water
Analysis Batch: 530525

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 526247

Analyte	MB Result	MB Qualifier	Count Uncert. (2σ+/-)	Total Uncert. (2σ+/-)	RL	MDC	Unit	Prepared	Analyzed	Dil Fac
Radium-228	0.05123	U	0.328	0.328	1.00	0.576	pCi/L	09/10/21 09:05	10/07/21 12:29	1

Carrier	*MB %Yield*	*MB Qualifier*	*Limits*	*Prepared*	*Analyzed*	*Dil Fac*
Ba Carrier	*68.3*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:29*	*1*
Y Carrier	*83.0*		*40 - 110*	*09/10/21 09:05*	*10/07/21 12:29*	*1*

QC Sample Results

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Method: 904.0 - Radium-228 (GFPC) (Continued)

Lab Sample ID: LCS 160-526247/2-A
Matrix: Water
Analysis Batch: 530525

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 526247

Analyte			Spike Added	LCS Result	LCS Qual	Total Uncert. (2σ+/-)	RL	MDC	Unit	%Rec	%Rec. Limits		
Radium-228			9.26	10.88		1.30	1.00	0.480	pCi/L	117	75 - 125		

Carrier	*LCS %Yield*	*LCS Qualifier*	*Limits*
Ba Carrier	*72.9*		*40 - 110*
Y Carrier	*82.2*		*40 - 110*

Lab Sample ID: 500-204479-2 DU
Matrix: Water
Analysis Batch: 530487

Client Sample ID: MW-03
Prep Type: Total/NA
Prep Batch: 526247

Analyte	Sample Result	Sample Qual		DU Result	DU Qual	Total Uncert. (2σ+/-)	RL	MDC	Unit			RER	RER Limit
Radium-228	0.532			0.01577	U	0.343	1.00	0.610	pCi/L			0.82	1

Carrier	*DU %Yield*	*DU Qualifier*	*Limits*
Ba Carrier	*62.1*		*40 - 110*
Y Carrier	*83.7*		*40 - 110*

Electronic Filing: Received, Clerk's Office 2/04/2022

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: Mark Wilson	Lab PM: Mockler Diana J	Carrier Tracking No(s):	COC No: 500-94078-41749 1
Client Contact: Erin Bulson	Phone: 630-325-1300	E-Mail: Diana Mockler@Eurofinset com	State of Origin:	Page: Page 1 of 1
Company: KPRG and Associates, Inc.	PWSID:			Job #: 500-204479

Address: 14665 West Lisbon Road Suite 1A	Due Date Requested	Analysis Requested	Preservation Codes.
City: Brookfield	TAT Requested (days)		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:
State Zip: WI 53005	Compliance Project: Δ Yes Δ No		
Phone:	PO #: 4502042860		
Email: erinb@kprginc.com	WO #:		
Project Name: Joliet #29 CCR/ Event Desc. Quarterly MWG Joliet #29 CCR	Project #: 50011568		
Site: Illinois	SSOW#:		

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)	6010C, 6020A, 7470A	2540C, 4500_F_C, SM4500_Cl_E, SM4500_SO4_E	903.0, 904.0	Total Number of containers	Special Instructions/Note:
			Preservation Code:				D	N	D		
MW-03				Water							
MW-04				Water							
MW-05	8-27-21	0736	G	Water	N		X	X	X		
MW-10	~~8-27-21~~		G	Water	N		X	X	X		
Duplicate				Water							

500-204479 COC

Possible Hazard Identification	Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☐ Non-Hazard ☐ Flammable ☐ Skin Irritant ☐ Poison B ☐ Unknown ☐ Radiological	☐ 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: 8/27/21 1800	Company: KPRG	Received by:	Date/Time: 8/27/21 1800	Company: EUA CHI
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: 2.6

10/21/2021

Eurofins TestAmerica, Chicago
2417 Bond Street
University Park IL 60484
Phone (708) 534-5200 Phone (708) 534-5211

Chain of Custody Record

eurofins

500-204479 COC

Client Information	Sampler: Mark Wilson	Lab PM: Mockler Diana J	King No(s):	COC No. 500-91207-40679 1
Client Contact: Erin Bulson	Phone: (630) 325-1300	E-Mail: Diana.Mockler@Eurofinset.com	State of Origin:	Page: Page 1 of 1
Company: KPRG and Associates Inc.	PWSID:			Job #: 500-204479
Address: 14665 West Lisbon Road Suite 1A	Due Date Requested:			
City: Brookfield	TAT Requested (days):			
State, Zip: WI, 53005	Compliance Project: Δ Yes Δ No			
Phone:	PO #: 4502042860			
Email: erinb@kprginc.com	WO #:			
Project Name: Quarterly MWG Joliet #29 CCR	Project #: 50011568			
Site: Illinois	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	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)	6010C - Lithium, 6020A - '13 elements, 7470A - Mercury	2540C - TDS	4500FC - Fluoride	SM600CLE - Chloride	SM4500SO4 - Sulfate	903- Rad 226	904 - Rad 228	Rad Combined							Total Number of containers	Special Instructions/Note
				Preservation Code:		X	X	D	N	D												X	
2	MW-03	8-30-21	1053	G	Water	Y		X	X	X	X	X	X	X	X								*Metals List: Sb,As,Ba,Be,B,Cd,Ca,Cr,Co,Pb,Mo,SeTl
3	MW-04	8-30-21	1215	G	Water	Y		X	X	X	X	X	X	X	X								
	MW-05				Water																		
4	MW-10	8-30-21	1430	G	Water	Y		X	X	X	X	X	X	X	X								
5	Duplicate				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
1	Mark Wilson/KPRG	8-31-21/0930	KPRG	[illegible]	8/31/21 0930	ETA
2	[illegible]	8/31/21 1057	ETA	Stephanie Hernandez	8/31/21 1057	ETA-CHI
3						

Custody Seals Intact: Δ Yes Δ No | Custody Seal No.

Cooler Temperature(s) °C and Other Remarks: 13, 3 2, 2 5

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: 500-152006.1
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 #: 500-204479-2
Address: 13715 Rider Trail North,	Due Date Requested: 9/30/2021			
City: Earth City	TAT Requested (days):			
State, Zip: MO, 63045				
Phone: 314-298-8566(Tel) 314-298-8757(Fax)	PO #:			
Email:	WO #:			
Project Name: Joliet #29 CCR	Project #: 50011568			
Site: NRG Midwest Generation LSQ Joliet#29 CCR	SSOW#:			

Analysis Requested

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)

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)	903.0/PrecSep_21 Standard Target List	904.0/PrecSep_0 Standard Target List	Ra226Ra228_GFPC	Total Number of containers	Special Instructions/Note:
			Preservation Code:								
MW-05 (500-204479-1)	8/27/21	12:36 Central		Water			X	X	X	3	Batch QC must be performed (dup, spikes, etc) - no NCMs concerning limited volume;

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 TestAmenca 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	Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
Unconfirmed	☐ 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: [signature]	Date/Time: 8/30/21 1130	Company ETA CHL	Received by: FED EX	Date/Time:	Company	
Relinquished by: FED EX	Date/Time:	Company	Received by: [signature]	Date/Time: 8/31/21 1005	Company ETA STL	
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:			

10/21/2021

Electronic Filing: Received, Clerk's Office 2/04/2022

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: 500-152054.1
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 #: 500-204479-1
Address: 13715 Rider Trail North, ,	Due Date Requested: 9/21/2021			
City: Earth City	TAT Requested (days):			
State, Zip: MO, 63045	PO #:			
Phone: 314-298-8566(Tel) 314-298-8757(Fax)	WO #:			
Email:	Project #: 50011568			
Project Name: Joliet #29 CCR	SSOW#:			
Site: NRG Midwest Generation LSQ Joliet#29 CCR				

Analysis Requested

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)

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)	903.0/PrecSep_21 Standard Target List	904.0/PrecSep_0 Standard Target List	Ra226Ra228_GFPC	Total Number of containers	Special Instructions/Note:
			Preservation Code:								
MW-03 (500-204479-2)	8/30/21	10:53 Central		Water			X	X	X	3	Batch QC must be performed (dup, spikes, etc) - no NCMs concerning limited volume;
MW-04 (500-204479-3)	8/30/21	12:15 Central		Water			X	X	X	3	Batch QC must be performed (dup, spikes, etc) - no NCMs concerning limited volume;
MW-10 (500-204479-4)	8/30/21	14:30 Central		Water			X	X	X	3	Batch QC must be performed (dup, spikes, etc) - no NCMs concerning limited volume;
Duplicate (500-204479-5)	8/30/21	Central		Water			X	X	X	3	Batch QC must be performed (dup, spikes, etc) - no NCMs concerning limited volume;

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	Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
Unconfirmed	☐ 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: [signature]	Date/Time: 8/31/21 1445	Company: EA-CHI	Received by: [signature] Date/Time: 9/1/21 08:37 Company: EA SR
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: 06/08/2021

Electronic Filing: Received, Clerk's Office 2/04/2022

Login Sample Receipt Checklist

Client: Midwest Generation EME LLC

Job Number: 500-204479-2

Login Number: 204479
List Number: 1
Creator: Hernandez, Stephanie

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	2.6,1.3,3.2,2.5
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").	N/A	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Login Sample Receipt Checklist

Client: Midwest Generation EME LLC

Job Number: 500-204479-2

Login Number: 204479
List Number: 2
Creator: Mazariegos, Leonel A

List Source: Eurofins TestAmerica, St. Louis
List Creation: 08/31/21 12:02 PM

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.	N/A	
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	

Login Sample Receipt Checklist

Client: Midwest Generation EME LLC

Job Number: 500-204479-2

Login Number: 204479
List Number: 3
Creator: Korrinhizer, Micha L

List Source: Eurofins TestAmerica, St. Louis
List Creation: 09/01/21 05:44 PM

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.	N/A	
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	

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Client Sample ID: MW-05
Date Collected: 08/27/21 12:36
Date Received: 08/27/21 18:00

Lab Sample ID: 500-204479-1
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	PrecSep-21			526228	09/09/21 17:37	MLK	TAL SL
Total/NA	Analysis	903.0		1	530630	10/11/21 21:24	EMH	TAL SL
Total/NA	Prep	PrecSep_0			526247	09/10/21 09:05	MJ	TAL SL
Total/NA	Analysis	904.0		1	530479	10/07/21 12:45	ANW	TAL SL
Total/NA	Analysis	Ra226_Ra228		1	531331	10/12/21 18:39	EMH	TAL SL

Client Sample ID: MW-03
Date Collected: 08/30/21 10:53
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-2
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	PrecSep-21			526228	09/09/21 17:37	MLK	TAL SL
Total/NA	Analysis	903.0		1	531123	10/12/21 17:52	FLC	TAL SL
Total/NA	Prep	PrecSep_0			526247	09/10/21 09:05	MJ	TAL SL
Total/NA	Analysis	904.0		1	530479	10/07/21 12:46	ANW	TAL SL
Total/NA	Analysis	Ra226_Ra228		1	531331	10/12/21 18:39	EMH	TAL SL

Client Sample ID: MW-04
Date Collected: 08/30/21 12:15
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-3
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	PrecSep-21			526228	09/09/21 17:37	MLK	TAL SL
Total/NA	Analysis	903.0		1	530476	10/07/21 21:59	ANW	TAL SL
Total/NA	Prep	PrecSep_0			526247	09/10/21 09:05	MJ	TAL SL
Total/NA	Analysis	904.0		1	530476	10/07/21 12:34	ANW	TAL SL
Total/NA	Analysis	Ra226_Ra228		1	531331	10/12/21 18:39	EMH	TAL SL

Client Sample ID: MW-10
Date Collected: 08/30/21 14:30
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-4
Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	PrecSep-21			526228	09/09/21 17:37	MLK	TAL SL
Total/NA	Analysis	903.0		1	530476	10/07/21 21:59	ANW	TAL SL
Total/NA	Prep	PrecSep_0			526247	09/10/21 09:05	MJ	TAL SL
Total/NA	Analysis	904.0		1	530476	10/07/21 12:34	ANW	TAL SL
Total/NA	Analysis	Ra226_Ra228		1	531331	10/12/21 18:39	EMH	TAL SL

Lab Chronicle

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Client Sample ID: Duplicate

Date Collected: 08/30/21 00:00
Date Received: 08/31/21 10:57

Lab Sample ID: 500-204479-5

Matrix: Water

Prep Type	Batch Type	Batch Method	Run	Dilution Factor	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	PrecSep-21			526228	09/09/21 17:37	MLK	TAL SL
Total/NA	Analysis	903.0		1	530476	10/07/21 22:00	ANW	TAL SL
Total/NA	Prep	PrecSep_0			526247	09/10/21 09:05	MJ	TAL SL
Total/NA	Analysis	904.0		1	530476	10/07/21 12:34	ANW	TAL SL
Total/NA	Analysis	Ra226_Ra228		1	531331	10/12/21 18:39	EMH	TAL SL

Laboratory References:

TAL SL = Eurofins TestAmerica, St. Louis, 13715 Rider Trail North, Earth City, MO 63045, TEL (314)298-8566

Tracer/Carrier Summary

Client: Midwest Generation EME LLC
Project/Site: Joliet #29 CCR

Job ID: 500-204479-2

Method: 903.0 - Radium-226 (GFPC)

Matrix: Water

Prep Type: Total/NA

		Percent Yield (Acceptance Limits)
		Ba
Lab Sample ID	Client Sample ID	(40-110)
500-204479-1	MW-05	93.6
500-204479-2	MW-03	89.0
500-204479-2 DU	MW-03	62.1
500-204479-3	MW-04	82.1
500-204479-4	MW-10	95.4
500-204479-5	Duplicate	87.7
LCS 160-526228/2-A	Lab Control Sample	72.9
MB 160-526228/1-A	Method Blank	68.3

Tracer/Carrier Legend

Ba = Ba Carrier

Method: 904.0 - Radium-228 (GFPC)

Matrix: Water

Prep Type: Total/NA

		Percent Yield (Acceptance Limits)	
		Ba	Y
Lab Sample ID	Client Sample ID	(40-110)	(40-110)
500-204479-1	MW-05	93.6	85.6
500-204479-2	MW-03	89.0	83.4
500-204479-2 DU	MW-03	62.1	83.7
500-204479-3	MW-04	82.1	84.5
500-204479-4	MW-10	95.4	84.5
500-204479-5	Duplicate	87.7	84.1
LCS 160-526247/2-A	Lab Control Sample	72.9	82.2
MB 160-526247/1-A	Method Blank	68.3	83.0

Tracer/Carrier Legend

Ba = Ba Carrier
Y = Y Carrier