Documentation and Certification of Existing Surface Impoundment Liner, Scrubber Ponds

Lewis & Clark Station

Prepared for
Montana-Dakota Utilities Co.

October 2018

234 West Century Avenue
Bismarck, ND 58503
701.255.5460
www.barr.com

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October 2018

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Certifications

I hereby certify that the flow rate through the lower component of the alternative composite liner described in this report is no greater than the liquid flow rate through two feet of compacted soil with a hydraulic conductivity of 1×10^{-7} cm/sec. Furthermore, I hereby certify that the documentation demonstrating that the CCR unit, including alternative composite liner design, meets the requirements of § 257.71(a) is accurate.

Paul T. Swenson
Barr Engineering Co.
MT Registration Number 12805PE

Dated this 11th day of October 2018

1.0 Purpose

Montana-Dakota Utilities Co. (MDU) operates the Lewis & Clark Station (Lewis & Clark), a coal-fired steam-electric generating plant, near Sidney, Montana to produce electrical energy. Coal combustion residuals (CCR) is a by-product of plant operation. Management of CCR produced by electric utilities is subject to the requirements of 40 CFR 257 Subpart D, Disposal of Coal Combustion Residuals From Electric Utilities (CCR Rule).

Flue-gas desulfurization solids and fly ash are captured by the plant's air quality control equipment, which is then slurried to a surface impoundment, referred to as the Scrubber Ponds, for settling and further CCR management. The Scrubber Ponds are subdivided into the West and East Scrubber Ponds, and are defined as a single, multi-unit CCR unit, which has been designated an existing surface impoundment under the CCR Rule.

The CCR Rule requires that liners for existing surface impoundments be evaluated in accordance with the following provisions:

> *"§257.71 Liner design criteria for existing CCR surface impoundments.*
>
> *(a)(1) No later than October 17, 2016, the owner or operator of an existing CCR surface impoundment must document whether or not such unit was constructed with any one of the following:*
>
> *(i) A liner consisting of a minimum of two feet of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec;*
>
> *(ii) A composite liner that meets the requirements of § 257.70(b); or*
>
> *(iii) An alternative composite liner that meets the requirements of § 257.70(c).*
>
> *(2) The hydraulic conductivity of the compacted soil must be determined using recognized and generally accepted methods.*

This report is provided to comply with requirements in CCR Rule § 257.71(b) stating that the owner or operator of an existing surface impoundment obtains a certification from a qualified professional engineer attesting that the liner documentation is accurate and meets the provisions of paragraph (a).

Lewis & Clark Station is a 50-MW, coal-fired power plant located approximately 2.5 miles south of Sidney, Montana on the north bank of the Yellowstone River in Richland County. The Scrubber Ponds consist of two basins, the West and East Scrubber Ponds, located near the plant (Figure 1). The West Scrubber Pond is approximately 2.0 acres in size. A splitter berm was constructed within the pond creating a primary cell of approximately 1.4 acres and a secondary cell of 0.5 acres. The East Scrubber Pond is approximately 2.3 acres in size. A splitter berm was constructed within the pond creating a primary cell of approximately 1.7 acres and a secondary cell of 0.5 acres.

2.0 Alternative Composite Liner System Design Criteria

The Scrubber Ponds are designed and constructed with an alternative composite liner system that covers all surrounding earth that otherwise would likely be in contact with CCR. The liner system is considered an alternative composite liner, consisting of two layers of geosynthetic clay liner (GCL) overlain by a 60-mil high-density polyethylene (HDPE) geomembrane, as shown on Figure 1. The alternative composite liner is equivalent to the composite liner and satisfies the design requirements of §257.70(c) and §257.70(b)(1) through (4), as documented in this report.

3.0 Scrubber Ponds Liner Evaluation

The following paragraphs provide evaluation of design characteristics of the alternative composite liner compared to the liner system described in §257.70(b). CCR Rule §257.70(c) establishes the criteria to conduct the evaluation.

3.1 Design Criteria

The alternative composite liner consists of two components, as required by §257.70 (c)(1): an upper component that is a 60-mil textured HDPE (meeting the minimum requirement in the CCR Rule), and a lower component of two layers of GCL, with a liquid flow rate no greater than the liquid flow rate of two feet of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec, as demonstrated in Sections 3.2 and 3.3. Design and compatibility information was provided by CETCO for the GCL used as the lower component of the alternative composite liner (provided in Appendix 1).

Calculations were prepared (provided in Appendix 2) to demonstrate that the lower component of the alternative composite liner hydraulic conductivity satisfies the requirements of §257.70(c)(1), which states that the lower component must have "a liquid flow rate no greater than the liquid flow rate of two feet of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec." Calculations provided in Appendix 2 demonstrate that the hydraulic conductivity of the lower component of the alternative composite liner must be no greater than 2.5×10^{-9} cm/sec (assuming that two layers of GCL are used) for the lower component to exhibit a liquid flow rate no greater than the liquid flow rate through two feet of compacted soil with a hydraulic conductivity of 1×10^{-7} cm/sec. Calculations were conducted using Equation 1 presented in §257.70(c)(2).

GCL used in the construction of the West and East Scrubber Ponds is CETCO Resistex 200 FLW9. CETCO conducted hydraulic conductivity testing of the material using water from the Scrubber Ponds. A May 8, 2018 letter from CETCO (provided in Appendix 1) provides documentation that the hydraulic conductivity of the material does not exceed 1.9×10^{-9} cm/sec for chemical conditions that are expected at Lewis & Clark.

Based on the calculations in Appendix 2 and the hydraulic conductivity test results provided by CETCO, it is determined that the liquid flow rate through the GCL component of the alternative composite liner is no greater than the liquid flow rate through two feet of compacted soil with a hydraulic conductivity of 1×10^{-7} cm/sec.

3.2 Chemical Compatibility and Construction Conditions

CCR Rule §257.70(c)(3) requires that the alternative composite liner meet the requirements specified in §257.70(b)(1) through (4). Compliance with these criteria are described below.

3.2.1 Chemical Compatibility Characteristics of GCL

CCR Rule §257.70(b)(1) requires that the alternative composite liner exhibit properties that are compatible with the CCR and leachate they contact, and other site conditions.

The HDPE geomembrane that provides the upper component of the alternative composite liner is commonly used for such applications, and meets the requirements for the upper component as stated in §257.70(b).

The lower component (two GCL layers) of the alternative composite liner for the Scrubber Ponds was tested for chemical compatibility by the manufacturer, CETCO Lining Technologies. A May 8, 2018, letter from CETCO (included in Appendix 1) describes the testing procedures and results, and shows that the GCL used in the project has appropriate chemical properties as tested by the index flux and hydraulic conductivity testing performed using water from the Scrubber Ponds for testing. The final reported permeability of 1.9×10^{-9} cm/sec maintained during the test provides demonstration of chemical compatibility.

Hydrogeologic forces on the liner will be negligible as separation to groundwater will be maintained, eliminating potential uplift or other forces that might otherwise damage the liner.

3.2.2 Physical Compatibility Characteristics of GCL

CCR Rule §257.70(b)(2) requires that liner materials provide appropriate shear resistance of the upper and lower component interface to prevent sliding of the upper component, including on slopes. The GCL used is specifically designed for deployment and use in the physical environment found in the Scrubber Ponds. The bonding geotextile component of the GCL and the needle-punching and stich-bonding between the upper and lower geotextiles provide containment for the encapsulated bentonite layer. This also provides resistance for the stresses of moving and deploying during construction activities.

During construction activities the following Construction Quality Assurance (CQA) methods were employed:

- Compacted subgrade was uniform in slope and grade with no deleterious materials or sharp rocks.
- GCL deployment was observed for proper overlap, placement of bentonite powder on all the seams, no gaps between layers and no overlapping seams on both layers of the GCL.
- 60-mil textured HDPE was observed placed and seamed over the two layers of GCL to assure no damage to the bottom layers of GCL occurred.
- Seaming of all panels and patches of the 60-mil HDPE were observed along with both non-destructive and destructive seam testing.

Resistex 200 FLW9 GCL by CETCO is needle-punched, which provides internal shear strength suitable for the 3H:1V slopes of the berms. The interface shear resistance between the GCL and the overlying textured 60-mil HDPE geomembrane is sufficient to maintain stability on a 3H:1V slope. The granular buffer soils above the liner have internal friction angles that are greater than the angle of the perimeter slope and will serve as ballast to maintain system stability.

A slope stability model was conducted with GeoStudio SLOPE/W to evaluate liner system stability. The model determined that the internal shear resistance of the liner system and overlying buffer layers provides a factor of safety of 1.9 against sliding (see model results in Appendix 3).

3.2.3 Foundation Conditions

CCR Rule §257.70(b)(2) requires that liner is placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift. The Scrubber Ponds alternative liner system was constructed on imported common fill consisting of sandy lean clay, which was compacted and smooth rolled during construction. Subgrade testing for compaction was performed during construction to ensure that settlement after construction would be minimized.

3.3 Extent of Liner Coverage

Finally, CCR Rule §257.70(b)(2) requires that the liner is installed to cover all surrounding earth likely to be in contact with the CCR or leachate. The liner system for the Scrubber Ponds covers all surrounding earth likely to be in contact with CCR by extending to an elevation that is a minimum of one foot higher than pond operating elevations. The result is full containment of CCR materials and leachate within the Scrubber Pond liner extents. The record survey extent of liner for the Scrubber Ponds is shown on Figure 2.

4.0 Conclusion

The Scrubber Ponds at the Lewis & Clark Electric Generating Station are lined with an alternative composite liner that complies with the requirements of 40 CFR §257.71(a)(1)(iii). As demonstrated by information provided in this report, the alternative composite liner in both the West and East Scrubber Ponds meets or exceeds the criteria presented in §257.71.

Figures

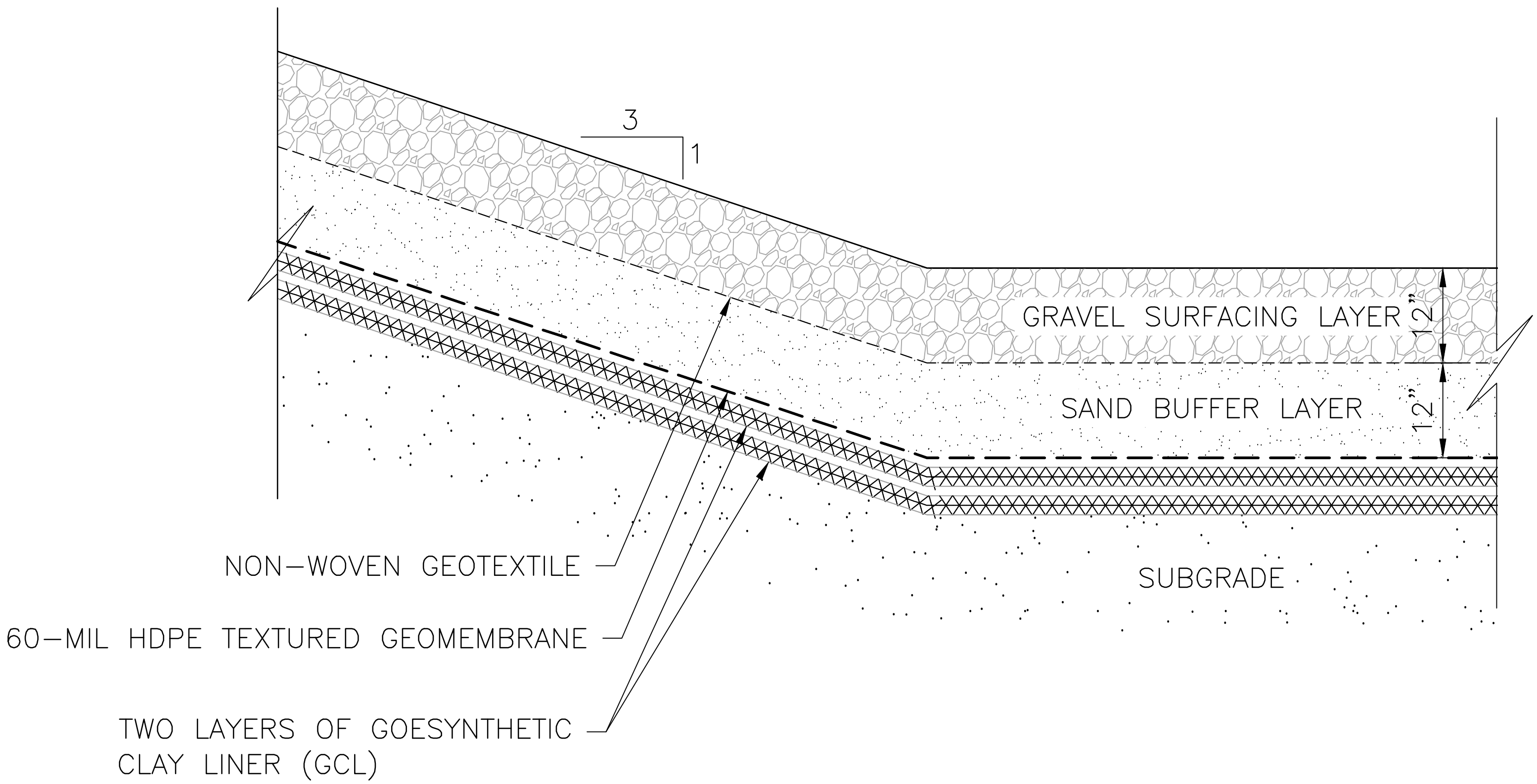


FIGURE 1
TYPICAL LINER SECTION

LEWIS AND CLARK STATION
MONTANA-DAKOTA UTILITIES
BISMARCK, ND

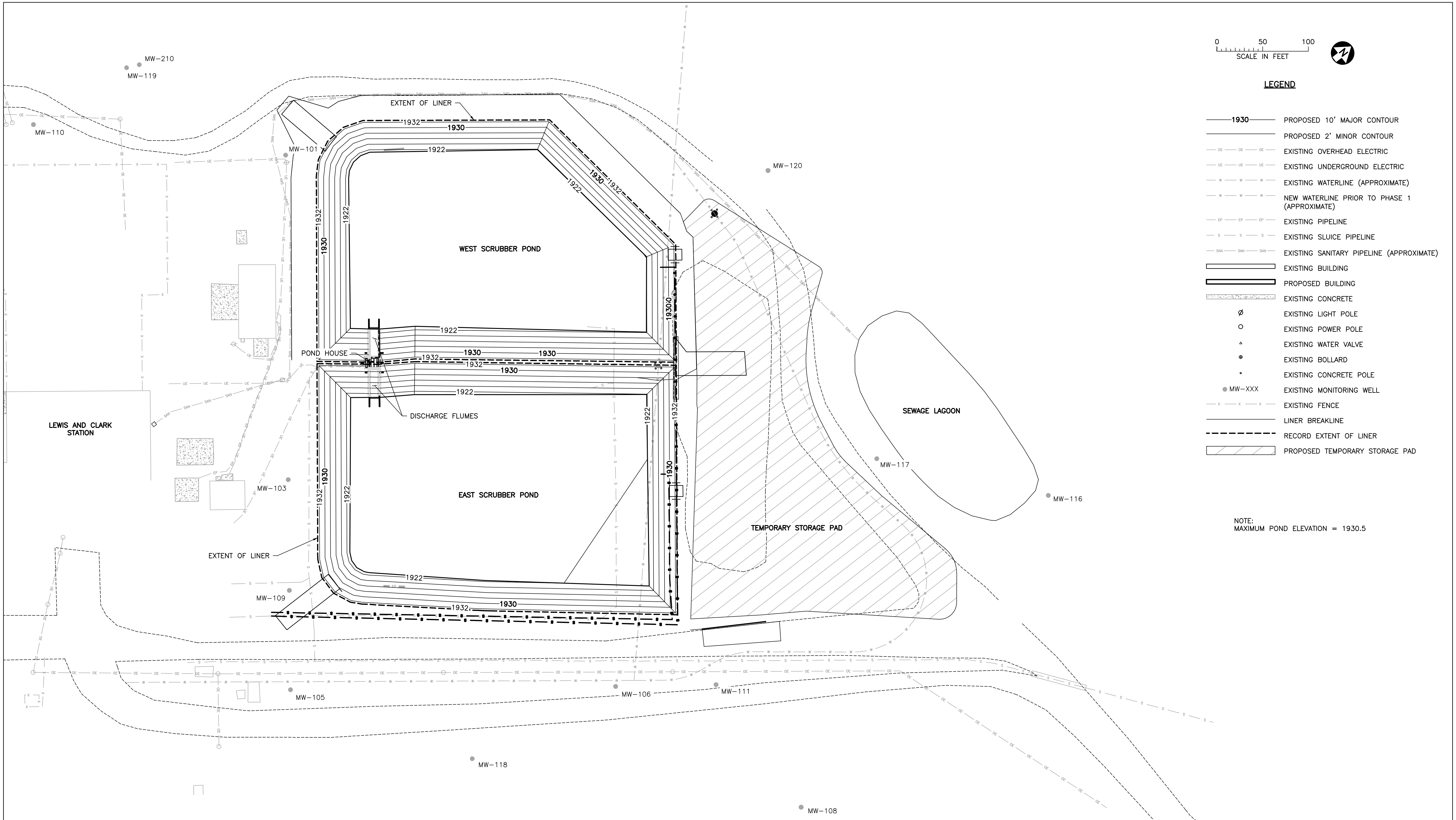


FIGURE 2
SCRUBBER POND LINER EXTENTS

LEWIS & CLARK STATION
MONTANA-DAKOTA UTILITIES
BISMARCK, ND

CADD USER: Amanda Ramnandon FILE: M:\DESIGN\26411015.00\26411015_FIGURE 2-REPORT.DWG PLOT SCALE: 1:2.0116 PLOT DATE: 10/9/2018 3:42 PM

Appendices

Appendix 1

CETCO Resistex 200 FLW9 Compatibility Testing

CETCO 2870 Forbs Avenue Hoffman Estates, IL 60192
847.851.1800 800.527.9948 Fax 847.851.1339 www.cetco.com

April 13, 2017

RE: Montana-Dakota Utilities, Lewis and Clark Station
Geosynthetic Clay Liner – Compatibility Testing

To Whom It May Concern:

The purpose of this letter is to present the preliminary results of compatibility testing of the CETCO® CG-50® bentonite used to make our Bentomat® products and the Resistex® geosynthetic clay liner for the above mentioned project. This preliminary report is being made prior to the completion of the permeability testing for either of the two aforementioned products. All testing was performed by CETCO®'s in-house GAI-LAP accredited laboratory located in Hoffman Estates, Illinois.

Per your request, CETCO® initiated a geosynthetic clay liner (GCL) chemical compatibility evaluation as outlined in our Technical Reference (TR-345, attached) in April 2017 after receiving a representative sample of leachate. Completion of Tier I and II evaluations (see TR-345) indicated that a standard GCL (Bentomat®) in the presence of the leachate would likely not provide suitable performance as defined by permeability. CETCO®'s Resistex® GCLs were also evaluated for its Tier II performance and is CETCO®'s recommended product for Tier III testing.

At your request CETCO® can initiate Tier III testing of the Resistex® 200 and 300 products to determine the performance of the product via permeability testing using the site leachate. Permeability testing will be completed in general accordance with ASTM D6766, Scenario II using the site leachate. For this testing, a cell pressure of 80 pounds per square inch (psi), 77 psi headwater pressure, and 75 psi tailwater pressure will be utilized in evaluating our GCL products. It should be noted that testing utilizing field condition pressures could yield different results.

We appreciate your interest in CETCO® products. Please contact Chuck Hornaday, CETCO® Technical Sales Manager, at (224) 365-9207 if you have any further questions.

Very truly yours,

John M. Allen, P.E.
Technical Services Manager
CETCO® Environmental Products

Enclosures (1)

CETCO Lining Technologies 2870 Forbs Avenue Hoffman Estates, IL 60192
847.851.1800 800.527.9948 Fax 847.851.1899 www.cetco.com

GEOSYNTHETIC CLAY LINER COMPATIBILITY ANALYSIS

ASTM D6141 - 09

Project:	Montana-Dakota Utilities, Lewis and Clark Station	Date:	April 4, 2017
Location:		Project Type and Citation:	Liner Compatibility BMG/LT-12-25
Requested By:	John M. Allen, P.E.	Sample ID:	LT17-5
Sample Type(s)[1]:	Leachate		

Test Results:

Leachate Used for Testing	Site Leachate	
Bentonite/Product	Resistex® 200	Resistex® 300
Fluid Loss (mL), ASTM D5891 modified[1]	171.3	51.1
Free Swell (mL/2g), ASTM D5890 modified[1]	8.5	10.5
Conductivity (μS/cm)	15,240	
pH	7.820	
Chloride (ppm)	288	

Note:

1) Test method modified for use with site specific hydration fluid in place of deionized water.

CETCO Lining Technologies 2870 Forbs Avenue Hoffman Estates, IL 60192
847.851.1800 800.527.9948 Fax 847.851.1899 www.cetco.com

ICP Elemental Analysis

Element	ppm
Silver	0.007
Aluminum	0.654
Arsenic*	0.066
Boron	58.753
Barium	0.223
Calcium	476.658
Cadmium	0.029
Chromium	0.053
Copper	0.059
Iron*	0.109
Mercury*	2.518
Potassium	10.557
Magnesium	3359.876
Manganese	6.146
Molybdenum	0.283
Sodium	199.386
Nickel	0.197
Phosphorus	0.842
Lead*	0.471
Sulfur	5026.027
Antimony	0.065
Selenium*	0.899
Titanium	0.028
Zinc	0.049
Zircon	0.098

1) Accuracy is ±0.005 ppm except for arsenic, iron, mercury, lead and selenium which have accuracy limits of 0.02 ppm.
2) The sample was diluted 1:9 prior to testing and the results were scaled up by 10x.

Analyst: GP

Report Template 1/11/17

CETCO 2870 Forbs Avenue Hoffman Estates, IL 60192
847.851.1800 800.527.9948 Fax 847.851.1339 www.cetco.com

May 8, 2018

RE: Montana-Dakota Utilities, Lewis and Clark Station
Geosynthetic Clay Liner – Compatibility Testing

To Whom It May Concern:

The purpose of this letter is to present the results of compatibility testing of the CETCO® CG-50® bentonite used to make our Bentomat® products and the Resistex® geosynthetic clay liner (GCL) for the above mentioned project. This report is being made at the completion of the permeability testing for Resistex® 200 FLW9 GCL. All testing was performed by CETCO®'s in-house GAI-LAP accredited laboratory located in Hoffman Estates, Illinois.

Per your request, CETCO® initiated a geosynthetic clay liner (GCL) chemical compatibility evaluation as outlined in our Technical Reference (TR-345, attached) in June 2017 after receiving a representative sample of leachate. Completion of Tier I and II evaluations (see TR-345) indicated that a standard GCL (Bentomat®) in the presence of the leachate would likely not provide suitable performance as defined by permeability. CETCO®'s Resistex® 200 FLW9 GCL was also evaluated for its Tier II performance and is CETCO®'s recommended product for Tier III testing.

Permeability testing was completed in general accordance with ASTM D6766, Scenario II. For this testing, a cell pressure of 80 pounds per square inch (psi), 77 psi headwater pressure, and 75 psi tailwater pressure were utilized and represent test conditions that CETCO® utilizes in evaluating our GCL products. Permeability testing of the Resistex® 200 FLW9 product was terminated upon your request after 8771 hours and 14.95 pore volumes of flow through the sample. The final average permeability for the Resistex® 200 FLW9 product was 1.8×10^{-9} cm/sec.

In addition to our Tier I & II results please find enclosed a copy of our Technical Data Sheet and Technical Reference. We appreciate your interest in CETCO® products. Please contact Chuck Hornaday, CETCO® Technical Sales Manager, at (224) 365-9207 if you have any further questions.

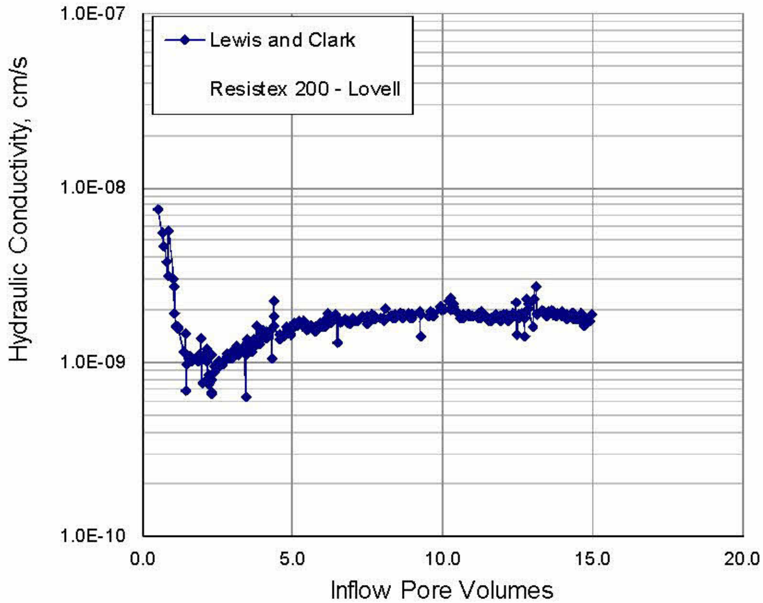
Table 1. Summary of final three measurements for the Resistex® 200 fLW9 product

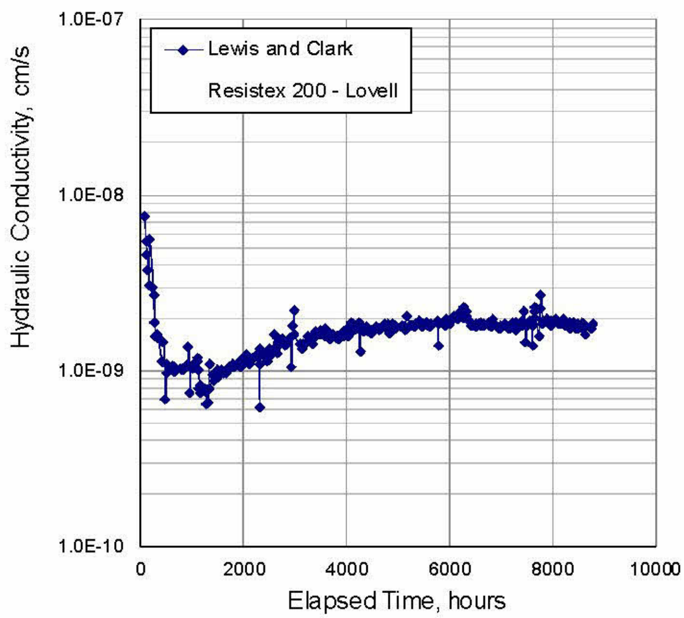
Elapsed Time (hr)	Pore Volumes	Inflow/ Outflow	Permeability (cm/sec)
8634	14.70	1.0	1.8×10^{-9}
8747	14.91	1.0	1.8×10^{-9}
8771	14.95	1.1	1.9×10^{-9}

Very truly yours,

John M. Allen, P.E.
Technical Services Manager
CETCO® Environmental Products

Attachments (3)





Permeability with pore volumes and time for the Resistex® 200 FLW9 GCL using site specific leachate per ASTM D6766, Scenario II, for the Montana Dakota Utility, Lewis and Clark CCR Scrubber Ponds

EVALUATING GCL CHEMICAL COMPATIBILITY

Sodium bentonite is an effective barrier primarily because it can absorb water (i.e., hydrate and swell), producing a dense, uniform layer with extremely low hydraulic conductivity, on the order of 10^{-9} cm/sec. Water absorption occurs because of the unique physical structure of bentonite and the complementary presence of sodium ions in the interlayer region between the bentonite platelets. Sodium bentonite's exceptional hydraulic properties allow GCLs to be used in place of much thicker soil layers in composite liner systems.

Sodium bentonite which is hydrated and permeated with relatively "clean" water will perform as an effective barrier indefinitely. In addition, past testing and experience have shown that sodium bentonite is chemically compatible with many common waste streams, including Subtitle D municipal solid waste landfill leachate (TR-101 and TR-254), some petroleum hydrocarbons (TR-103), deicing fluids (TR-109), livestock waste (TR-107), and dilute sodium cyanide mine wastes (TR-105).

In certain chemical environments, the interlayer sodium ions in bentonite can be replaced with cations dissolved in the water that comes in contact with the GCL, a process referred to as ion exchange. This type of exchange reaction can reduce the amount of water that can be held in the interlayer, resulting in decreased swell. The loss of swell usually causes increased porosity and increased GCL hydraulic conductivity. Experience and research have shown that calcium and magnesium are the most common source of compatibility problems for GCLs (Jo et al, 2001, Shackelford et al, 2000, Meer and Benson, 2004, Kolstad et al, 2004/2006). Examples of liquids with potentially high calcium and magnesium concentrations include: leachates from lime-stabilized sludge, soil, or fly ash; extremely hard water; unusually harsh landfill leachates; and acidic drainage from calcareous soil or stone. Other cations (ammonium, potassium, and sodium) may contribute to compatibility problems, but they are generally not as prevalent or as concentrated as calcium (Alther et al, 1985), with the exception of brines and seawater. Even though these highly concentrated solutions do not necessarily contain high levels of calcium, their high ionic strength can reduce the amount of bentonite swelling, resulting in increased GCL hydraulic conductivity.

This reference discusses the tools that can be used by a design engineer to evaluate GCL chemical compatibility with a site-specific leachate or other liquid.

HOW IS GCL CHEMICAL COMPATIBILITY EVALUATED?

Ideally, concentration-based guidelines would be available for determining GCL compatibility with a site-specific waste. Unfortunately, considering the variety and chemical complexity of the liquids that may be evaluated, as well as the many variables that influence chemical compatibility (e.g., prehydration with subgrade moisture [TR-222], confining stress [TR-321], and repeated wet-dry cycling [TR-341]), it is not possible to establish such guidelines. Instead, a three-tiered approach to evaluating GCL chemical compatibility is recommended, as outlined below.

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Tier I

The first tier is a simple review of existing analytical data. The topic of GCL chemical compatibility has been the subject of much study in recent years, with several important references available in the literature. One of these references, Kolstad et al (2004/2006), reported the results of several long-term hydraulic conductivity tests involving GCLs in contact with various multivalent (i.e., containing both sodium and calcium) salt solutions. Based on the results of these tests, the researchers found that a GCL's long-term hydraulic conductivity (as determined by ASTM D6766) can be estimated if the ionic strength (I) and the ratio of monovalent to divalent ions (RMD) in the permeant solution are both known, using the following empirical expression:

$$\frac{\log K_c}{\log K_{DI}} = 0.965 - 0.976 \times I + 0.0797 \times RMD + 0.251 \times I^2 \times RMD$$

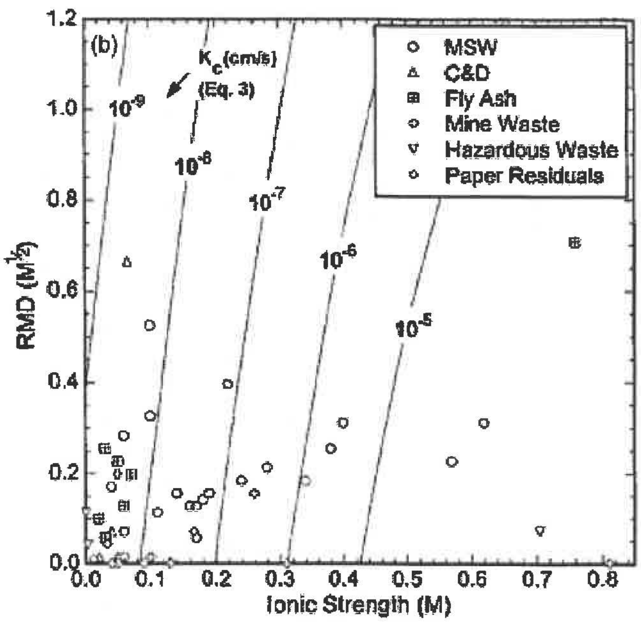
where:

I = ionic strength (M) of the site-specific leachate.

RMD = ratio of monovalent cation concentration to the square root of the divalent cation concentration ($M^{1/2}$) in the site-specific leachate.

K_c = GCL hydraulic conductivity when hydrated and permeated with site-specific leachate (cm/sec).

K_{DI} = GCL hydraulic conductivity with deionized water (cm/sec).



Using this tool, a Tier I compatibility evaluation can be performed if the major ion concentrations (typically, calcium, magnesium, sodium, and potassium) and ionic strength (estimated from either the total dissolved solids [TDS], or electrical conductivity [EC]) of the site leachate are known. For example, using the relationship above and MSW leachate data available in the literature, Kolstad et al. were able to conclude that high hydraulic conductivities (i.e., >10^{-7} cm/sec) are unlikely for GCLs in base liners in many solid waste containment facilities.

In many cases, the Tier I evaluation is sufficient to show that a site-specific leachate should not pose compatibility problems. However, if the analytical data indicate a potential impact to GCL hydraulic performance, or if there is no analytical data available, then it is necessary to proceed to the second tier, involving bentonite "screening" tests, which are described below.

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Tier II

The next tier of compatibility testing involves bentonite screening tests, performed in accordance with ASTM Method D6141. These tests are fairly straightforward, and can be performed at one of CETCO's R&D laboratories or at most commercial geosynthetics testing laboratories.

Liquid samples should be obtained very early in the project, such as during the site hydrogeological investigation. It is important that the sample collected is representative of actual site conditions. Synthetic leachate samples may also be considered for use in the compatibility tests. The objective is to create a liquid representative of that which will come in contact with the GCL. At least 1-gallon (4-Liter) of each sample should be submitted for testing. Samples should be accompanied by a chain-of-custody or information form. When a sample is received at the CETCO laboratory, the following screening tests are performed to assess compatibility:

- Fluid Loss (ASTM D5890) – A mixture of sodium bentonite and the site water/leachate is tested for fluid loss, an indicator of the bentonite's sealing ability.
- Swell Index (ASTM D5891) – Two grams of sodium bentonite are added to the site water/leachate and tested for swell index, the volumetric swelling of the bentonite.
- Water quality – The pH and EC of the site water/leachate are measured using bench-top water quality probes. pH will indicate if any strong acids (pH < 2) or bases (pH > 12) are present which might damage the bentonite clay. EC indicates the strength of dissolved salts in the water, which can hamper the swelling and sealing properties of bentonite if present at high concentrations.
- Chemistry – The site water/leachate is analyzed for major dissolved cations using ICP. The analytical results can then be used to perform a Tier I assessment, if one has not already been done.

As part of this testing, fluid loss and free swell tests are also performed on clean, deionized, or "DI" water for comparison to the results obtained with the site water/leachate sample. Sodium bentonite tested with DI water is expected to have a free swell of at least 24 mL/2g and a fluid loss less than 18 mL. Changes in bentonite swell and fluid loss indicate that the constituents dissolved in the site water may have an impact on GCL hydraulic conductivity. However, since it is only a screening tool, there are no specific values for the fluid loss and swell index tests that the clay must meet in order to be considered chemically compatible with the test liquid in question. Differences between the results of the baseline tests and those conducted with the site leachate may warrant further hydraulic testing.

A major drawback of the D6141 tests is the potential for a false "negative" result, meaning that the bentonite swell index or fluid loss might predict no impact to hydraulic performance, where in reality, there may be a long-term adverse effect. This is primarily a concern with dilute calcium or magnesium solutions, which may slowly affect GCL hydraulic performance over months or years. Short-term (2-day) bentonite screening tests would not be able to capture this type of long-term effect. This is not expected to be a concern with strong calcium or magnesium or high ionic strength solutions, which have been shown to impact GCL hydraulic conductivity almost immediately, and whose effects would therefore be captured by the short-term bentonite screening tests. Another limitation of the bentonite screening tests is their inability to simulate site conditions, such as clean water prehydration, increased confining pressure, and wet/dry cycling. These limitations can be in part addressed by moving to the third tier, a long-term GCL hydraulic conductivity test, discussed below.

Tier III

The third-tier compatibility evaluation consists of an extended GCL hydraulic conductivity test performed in accordance with ASTM D6766. This test method is essentially a hydraulic conductivity test, but instead of permeating the GCL sample with DI water, the site-specific leachate is used. Since leachates can often be hazardous, corrosive, or volatile, the testing laboratory must have permeant interface devices, such as bladder accumulators, to contain the test liquid in a closed chamber, and prevent contamination of the flow measurement and pressure systems, or release of chemicals to the ambient air.

Method D6766 provides some flexibility in specifying the testing conditions so that certain site conditions can be simulated. For example, in situations where the GCL will be deployed on a subgrade soil that is compacted wet of optimum, the GCL will very likely hydrate from the relatively clean moisture in the subgrade (TR-222), long before it comes in contact with the potentially aggressive site leachate. Lee and Shackelford (2005) showed that a GCL which is pre-hydrated with clean water before being exposed to a harsh solution is expected to exhibit a lower hydraulic conductivity than one hydrated directly with the solution. Depending on the expected site conditions, the D6766 test can be specified to pre-hydrate the GCL with either water (Scenario 1) or the site liquid (Scenario 2).

Another site-specific consideration is confining pressure. Certain applications, such as landfill bottom liners and mine heap leach pads, involve up to several hundred feet of waste, resulting in high compressive loads on the liner systems. Although the standard confining pressure for the ASTM D6766 test is 5 psi (representing less than 10 feet of waste), the test method is flexible enough to allow greater confining pressures,

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thus mimicking conditions in a landfill bottom liner or heap leach pad. Petrov et al (1997) showed that higher confining pressures will decrease bentonite porosity, and tend to decrease GCL permeability. TR-321 shows that higher confining pressures will improve hydraulic conductivity even when the GCL is permeated with aggressive calcium solutions.

ASTM D6766 has two sets of termination criteria: hydraulic and chemical. To meet the hydraulic termination criterion, the ratio of inflow rate to outflow rate from the last three readings must be between 0.75 and 1.25. It normally takes between one week and one month to reach the hydraulic termination criterion. To meet the chemical termination criterion, the test must continue until at least two pore volumes of flow have passed through the sample and chemical equilibrium is established between the effluent and influent. The test method defines chemical equilibrium as effluent electrical conductivity within ±10% of the influent electrical conductivity. This requirement was put in place to ensure that a large enough volume of site liquid passes through the sample to allow slow ion exchange reactions to occur. Two pore volumes can take approximately a month to permeate through the GCL sample. However, reaching chemical equilibrium (effluent EC within 10% of influent EC), may take more than a year of testing, depending on the leachate characteristics.

ASTM D6766 is a very useful tool which provides a fairly conclusive assessment of GCL chemical compatibility with a site-specific leachate. However, the major drawback of the D6766 test is the potentially long period of time required to reach chemical equilibrium. This limitation reinforces the need for upfront compatibility testing early in the project. Clearly, requiring the contractor to perform this testing during the construction phase is not recommended.

WHAT DO THE ASTM D6766 COMPATIBILITY TEST RESULTS MEAN?

ASTM D6766 is currently the state-of-the-practice in the geosynthetics industry for evaluating long-term chemical compatibility of a GCL with a particular site waste stream. An ASTM D6766 test that is properly run until both the hydraulic (inflow and outflow within ±25% over three consecutive readings) and chemical (effluent EC within ±10% of influent EC) termination criteria are achieved, provides a good approximation of the GCL's long-term hydraulic conductivity when exposed to the site leachate. Jo et al (2005) conducted several GCL compatibility tests with weak calcium and magnesium solutions, with some tests running longer than 2.5 years, representing several hundred pore volumes of flow. The intent of this study was to run the tests until complete ion exchange had occurred, which required even stricter chemical equilibrium termination criteria than the D6766 test. The study found that the final GCL hydraulic conductivity values measured after complete ion exchange were fairly close to (within 2 to 13 times) the hydraulic conductivity values determined by ASTM D6766 tests, which took much less time to complete.

The laboratory that performs the chemical compatibility test, whether it is the CETCO R&D laboratory or an independent third-party laboratory, is only reporting the test results under the specified testing conditions, and is not making any guarantees about actual field performance or the suitability of a GCL for a particular project. It is the design engineer's responsibility to incorporate the D6766 results into their design to determine whether the GCL will meet the overall project objectives. Neither the testing laboratory nor the GCL manufacturer can make this determination.

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Also, it is important to note that the results of D6766 testing for a particular project are only applicable for that site, for the specific waste stream that is tested, and only for the specific conditions replicated by the test. For instance, D6766 testing performed at high normal loads representative of a landfill bottom liner should not be applied to a situation where the GCL will only be placed under a modest normal load, such as a landfill cover or pond. Similarly, the results of a D6766 test where the GCL was pre-hydrated with clean water should not be applied to sites located in extremely arid climates where little subgrade moisture is expected, unless water will be applied manually to the subgrade prior to deployment. And finally, since D6766 tests are normally performed on continuously hydrated GCL samples, the test results should not be applied to situations where repeated cycles of wetting and drying of the GCL are likely to occur, such as in some GCL-only landfill covers, as desiccation can worsen compatibility effects.

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Appendix 2

Calculations

BARR ENGINEERING CO.

NAME JKH2
DATE 10/5/18
SHEET 1 IN SET
PAGE 2 IN FILE

CHECKED BY
DATE

Calculations for the liquid flow rate through the lower component of the Alternative Composite Liner for the West and East Scrubber ponds at Lewis & Clark Station alternative liner is no greater than the liquid flow rate through two feet of compacted soil with a hydraulic conductivity of 1×10^{-7} cm/sec. using (Eq. 1) of §257.70(c)(2)

(Eq. 1) $$\frac{Q}{A} = q = k\left(\frac{h}{t} + 1\right)$$

Provided by CETCO May 8, 2018 compatibility Testing Report $k_{GCL} = 1.9 \times 10^{-9}$ cm/sec

where:

Q = Flow Rate (cm^3/sec)
A = Surface Area of Liner (cm^2)
q = Flow Rate per unit area (cm^3/sec/cm^2)
k = hydraulic conductivity of the liner (cm/s)
h = hydraulic head above the liner (cm)
t = thickness of the liner (cm

Std: Soil Liner 2 ft thick

t_{STD} = 2 ft = 60.96 cm
h_{STD} = 11.53 ft = 351.43

k_{STD} = 1.0×10^{-7} cm/sec

t_{GCL} = 0.64 cm (Each layer of GCL)
h_{GCL} = 11.53 ft = 351.43

CETCO Testing $k_{GCL} = 1.9 \times 10^{-9}$ cm/s

$$k_{STD}\left(\frac{h_{STD}}{t_{STD}} + 1\right) = k_{GCL}\left(\frac{h_{GCL}}{t_{GCL}} + 1\right)$$

$$k_{GCL} = \frac{k_{STD}\left(\frac{h_{STD}}{t_{STD}} + 1\right)}{\left(\frac{h_{GCL}}{t_{GCL}} + 1\right)}$$

Using 2 layers of GCL: 0.64 cm + 0.64 cm = 1.28 cm

$$k_{GCL(2)} = (1.0 \times 10^{-7} \text{ cm/sec}) \left(\frac{\left(\frac{351.43}{60.96} + 1\right)}{\left(\frac{351.43}{1.28} + 1\right)} \right)$$

$$k_{GCL(2)} = 2.5 \times 10^{-9} \text{ cm/sec.}$$ ✓

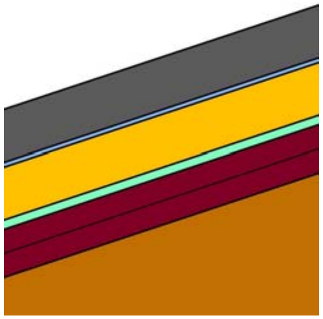
Therefore, with CETCO 1.9×10^{-9} cm/sec. need 2 layers of GCL in order to be equivalent to 2-feet compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec.

Appendix 3

Slope Analysis

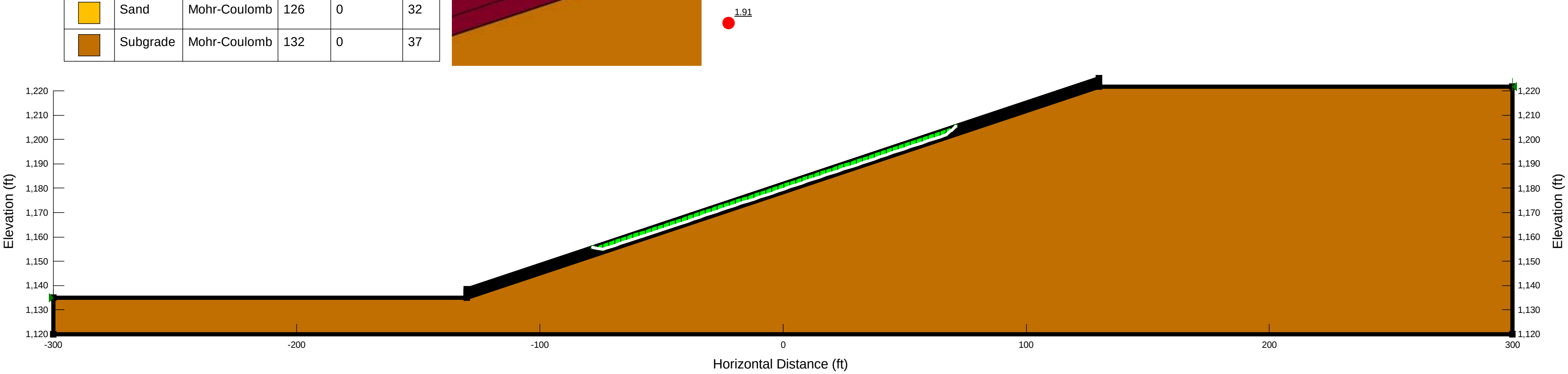
Stability Analysis
Cross Section 1
JCB Shear Resistance model
1.2 Fully specified
Last Saved Date: 10/4/2018

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)
	60-mm HDPE	Mohr-Coulomb	59	1,512	0
	GCL	Mohr-Coulomb	57.43	200	0
	Geotextile	Mohr-Coulomb	60	0	30
	Rock	Mohr-Coulomb	130	0	40
	Sand	Mohr-Coulomb	126	0	32
	Subgrade	Mohr-Coulomb	132	0	37



Factor of Safety: 1.91

Model as infinite slope.



P:\Mpls\34 ND\09\34091031 Swan Creek Watershed Plan\WorkFiles\Rush specific\Re-start Amenia focus\Alternatives\Geotech\Alts 1 and 2\Modeling