Closure Plan

Columbia Dry Ash Disposal Facility

Phase 1 Module 1
Phase 1 Module 2
Phase 1 Module 3
Phase 1 Module 4
Phase 1 Module 5
Phase 1 Module 6
Phase 2 Module 10
Phase 2 Module 11

Prepared for:

Wisconsin Power and Light Company
Columbia Energy Center
W8375 Murray Road
Pardeeville, Wisconsin 53954

SCS ENGINEERS

25222260.00 | February 1, 2023

2830 Dairy Drive
Madison, WI 53718-6751
608-224-2830

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Appendices

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PE CERTIFICATION

I, Phillip Gearing, hereby certify that I am a licensed professional engineer in the State of Wisconsin in accordance with the requirements of ch. A–E 4, Wis. Adm. Code; that this document has been prepared in accordance with the Rules of Professional Conduct in ch. A–E 8, Wis. Adm. Code; and that, to the best of my knowledge, all information contained in this document is correct and the document was prepared in compliance with all applicable requirements in chs. NR 500 to 538, Wis. Adm. Code.

Specifically,

- This Closure Plan was prepared by me or under my direct supervision and meets the requirements of 40 CFR 257.102(b) and NR 514.07(10)(c)

February 1, 2023

(signature) (date)

Phillip E. Gearing

(printed or typed name)

License number E-45115

My license renewal date is July 31, 2024.

Pages or sheets covered by this seal:

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1.0 INTRODUCTION AND PROJECT SUMMARY

On behalf of Wisconsin Power and Light Company (WPL), SCS Engineers (SCS) has prepared this Closure Plan for the Columbia (COL) Dry Ash Disposal Facility Phase 1, Modules 1 through 6 and Phase 2, Modules 10 and 11 as required by 40 Code of Federal Regulations (CFR) 257.102(b) and Wisconsin Administrative Code NR 514.07(10)(c), as stated below.

<u>40 CFR 257.102(b)</u> *"Written closure plan – (1) Content of the plan. The owner or operator of a CCR unit must prepare a written closure plan that describes the steps necessary to close the CCR unit at any point during the active life of the CCR unit consistent with recognized and generally accepted good engineering practices. The written closure plan must include, at a minimum, the information specified in paragraphs (b)(1)(i) through (vi) of this section."*

<u>NR 517.07(10)(c)</u> *"A written closure plan in accordance with the requirements under s. NR 514.06 (10) and all of the following: (1) A narrative description of how the CCR landfill will be closed, including a description of the steps necessary to close the CCR unit at any point during the active life of the CCR unit, consistent with recognized and generally accepted good engineering practices."*

The COL facility includes an active coal combustion residual (CCR) landfill, which currently consists of the following modules, located in Phase 1 and Phase 2 of the facility.

- **Phase 1, Module 1** – This module has received final cover over outer sideslope areas that will no longer receive additional CCR; intermediate cover has been placed over remaining areas. The final cover placed complies with the CCR Rule.
- **Phase 1, Module 2** – This module has received intermediate cover over a majority of the in-place CCR.
- **Phase 1, Module 3** – This module has received intermediate cover over a majority of the in-place CCR.
- **Phase 1, Module 4** – This module is currently being filled and also has received intermediate cover over areas of the in-place CCR.
- **Phase 1, Module 5** – This module is currently being filled and has received intermediate cover over areas of the in-place CCR.
- **Phase 1, Module 6** – This module is currently being filled and has received intermediate cover over areas of the in-place CCR.
- **Phase 2, Module 10** – Construction of the Module 10 liner began in 2022. The new module will be used for disposal following approval of the liner Construction Documentation Report, which will be submitted for WDNR review early in 2023. Filling is anticipated to begin in 2023.
- **Phase 2, Module 11** – Construction of the Module 11 liner began in 2022. The new module will be used for disposal following approval of the liner Construction Documentation Report, which will be submitted for WDNR review early in 2023. Filling is anticipated to begin in 2023.

Phase 1, Modules 1-3 were previously described as separate existing CCR landfills although they are contiguous and are managed as a single landfill by the facility and by the WDNR. WPL has clarified in the operating record for the Columbia facility that Modules 1-3 are one existing CCR landfill as defined in 40 CFR 257.53 of the federal CCR Rule. Phase 1, Modules 4-6 are considered to be a new CCR landfill that initiated construction after October 19, 2015, and is therefore managed as a separate CCR unit under the CCR Rule even though they are contiguous to the existing CCR landfill (Modules 1-3). In addition, the new CCR landfill will include Phase 2, Modules 10 and 11, once the liner construction documentation is approved by the WDNR in 2023. Construction of additional modules is not currently planned prior to retirement of the Columbia Energy Center, which is currently scheduled to occur no later than June 1, 2026.

Figure 1 shows the site location. **Figure 2** shows the closure areas. A detail of the final cover system is shown on **Figure 3.**

2.0 PROPOSED CLOSURE PLAN NARRATIVE

40 CFR 257.102(b)(1)(i) *"A narrative description of how the CCR unit will be closed in accordance with this section."*

NR 517.07(10)(c)(1) *"A narrative description of how the CCR landfill will be closed, including a description of the steps necessary to close the CCR unit at any point during the active life of the CCR unit, consistent with recognized and generally accepted good engineering practices."*

When CCR placement is completed in the CCR unit, or if early closure is required, the unit will be closed by covering the CCR with the final cover system described in **Section 3.0**. Prior to final cover system construction, the CCR surfaces will be graded and compacted to establish a firm subgrade for final cover construction. In addition, all required notifications will be submitted to the Wisconsin Department of Natural Resources (WDNR, or "Department"), and WPL will obtain all additional necessary permits (for example, general permit coverage for construction storm water management). WPL may also engage in procurement activities to secure services for installing the final cover system.

The timing for completion of CCR placement in the units that are addressed with this closure plan will depend on CCR generation and disposal rates. Future CCR unit development will also impact the timing of closure. Each of the existing CCR units is designed to receive additional CCR once adjacent units are constructed and overlay airspace is available for filling. Based on the current CCR units alone, if early closure of all units is required, final cover will be placed in the active landfill areas shown on **Figure 2.** A closure schedule is discussed in **Section 6.0** and presented in **Appendix B.**

The initiation of closure activities will commence no later than 30 days after the known final receipt of CCR as required by 40 CFR 257.102(e)(1) and NR 506.083(2)(a), or in accordance with 40 CFR 257.102(e)(2) and NR 506.083(2)(b).

3.0 FINAL COVER SYSTEM AND PERFORMANCE

40 CFR 257.102(b)(1)(iii) *"If closure of the CCR unit will be accomplished by leaving CCR in place, a description of the final cover system, designed in accordance with paragraph (d) of this section, and the methods and procedures to be used to install the final cover. The closure plan must also discuss how the final cover system will achieve the performance standards specified in paragraph (d) of this section."*

40 CFR 257.102(d) *"Closure performance standard when leaving CCR in place."*

40 CFR 257.102(d)(1) *"The owner or operator of a CCR unit must ensure that, at a minimum, the CCR unit is closed in a manner that will:"*

> 40 CFR 257.102(d)(1)(i) *"Control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground or surface waters or to the atmosphere;"*

NR 514.07(10)(c)(3) *"A demonstration, including a narrative discussion, of how final closure will meet the performance standards under s. NR 506.083(6)."*

NR 506.083(6) *"Closure performance standards when leaving CCR in place. An owner or operator of a CCR landfill shall ensure that, at a minimum the CCR landfill is closed in a manner that will achieve all of the following performance standards:"*

> NR 506.083(6)(a) *"Control, minimization or elimination, to the maximum extent feasible, of post-closure infiltration of liquids into the waste and of releases of CCR, leachate, or contaminated run-off to the ground or surface waters or to the atmosphere."*

The final cover system design will minimize or eliminate infiltration, as further described below.

> 40 CFR 257.102(d)(1)(ii) *"Preclude the probability of future impoundment of water, sediment, or slurry;"*
>
> NR 506.083(6)(b) *"Prevention of the impoundment of water, sediment or slurry."*

The final cover system will meet these criteria, as further described below.

> 40 CFR 257.102(d)(1)(iii) *"Include measures that provide for major slope stability to prevent the sloughing or movement of the final cover system during the closure and post-closure care period;"*
>
> NR 506.083(6)(c) *"Slope stability to prevent the sloughing or movement of the final cover system during the closure and long-term care period.*

The final cover system is designed to provide slope stability and to prevent sloughing or movement during the closure and post-closure care period. Stability of the final cover system was assessed as part of the WDNR landfill permitting process and is further addressed below.

> 40 CFR 257.102(d)(1)(iv) *"Minimize the need for further maintenance of the CCR unit; and"*
>
> NR 506.083(6)(d) *"Minimization of the need for long-term maintenance of the CCR landfill."*

Maintenance of the final cover will be minimized by the establishment of vegetative cover and the erosion control systems, which are further described below.

> 40 CFR 257.102(d)(1)(v) *"Be completed in the shortest amount of time consistent with recognized and generally accepted good engineering practices."*
>
> NR 506.083(6)(e) *"Complete closure in the shortest amount of time consistent with recognized and generally accepted good engineering practices."*

All closure activities for the CCR units will be completed within 6 months, as stated in **Section 7.0** below.

40 CFR 257.102(d)(2) *"Drainage and stabilization of CCR surface impoundments."*

This does not apply to the COL CCR landfill units.

40 CFR 257.102(d)(3) *"Final cover system"*

NR 517.07(10)(c)(2) *"A description of the final cover system, designed in accordance with s. NR 504.07, and the methods and procedures to be used to install the final cover."*

NR 504.12(4)(b) *"The owner or operator of a new or existing CCR landfill or a lateral expansion of a CCR landfill may propose an alternative final cover system design within a written closure plan in accordance with s. NR 504.10 and all of the following:"*

The alternative final cover design has been developed to meet the requirements of NR 504.12(4)(b) and is discussed in detail below.

The existing final cover system (see **Figure 3** for details) in place on part of Module 1 will be extended to cover the remaining portion of Module 1. The Module 1 final cover system is as follows from the bottom up:

- 3-inch grading layer
- Geosynthetic clay liner (GCL)
- 40-millimeters (mil) linear low-density polyethylene (LLDPE) geomembrane
- 12 inches of drainage material
- 12 inches of rooting zone
- 6 inches of topsoil

This final cover meets and exceeds the minimum requirements of 40 CFR 257.102(d)(3)(i)(A) through (D) and NR 504.12(4)(b)(1) through (4) as follows:

- Per 257.102(d)(3)(i)(A) and NR 504.12(4)(b)(1), the permeability of the final cover system is less than or equal to the permeability of the bottom liner system and is less than $1x10^{-5}$ centimeters per second (cm/sec) required by the rule. The COL cover system contains a GCL with a permeability of $5x10^{-9}$ cm/sec. The geomembrane above the GCL makes the cover system even less permeable.

The bottom liner system for the existing CCR landfill in Module 1 is as follows:

- Phase 1, Module 1 South:
  - GCL
  - 40-mil high density polyethylene (HDPE) geomembrane
  - The layers of the liner system are less than the cover system layers; therefore, infiltration will be more than the cover system.

- Phase 1, Module 1 North:
  - 3 feet of compacted ash
  - The liner here does not include a geomembrane, and therefore the infiltration through the cover system will be less than this base liner.

An alternate final cover system will be installed in future remaining areas of final cover north of Module 1 (Phase 1, Modules 2, 3, 4, 5, and 6 and Phase 2, Modules 10 and 11). The alternate cover consists of the following components, from bottom to top:

- 3-inch-thick grading layer
- GCL
- 40-mil polyethylene geomembrane
- Geocomposite drainage layer
- 24-inch-thick rooting zone layer
- 6-inch-thick topsoil layer

This alternative final cover meets and exceeds the minimum requirements of 40 CFR 257.102(d)(3)(i)(A) through (D) and NR 504.12(4)(b)(1) through (4) as follows:

- Per 257.102(d)(3)(ii)(A), 257.102(d)(3)(i)(A), and NR 504.12(4)(b)(1), the permeability of the final cover system is less than or equal to the permeability of the bottom liner system and is less than $1x10^{-5}$ centimeters per second (cm/sec) required by the rule. The COL cover system contains a GCL with a permeability of $5x10^{-9}$ cm/sec. The geomembrane above the GCL makes the cover system even less permeable.

The bottom liner system for the existing CCR landfill is as follows:

- Phase 1, Modules 2 and 3:
  - 2 feet of compacted clay
  - GCL
  - 60-mil HDPE geomembrane

The bottom liner system for the new CCR landfill is as follows:

- Phase 1, Modules 4, 5, and 6 and Phase 2, Modules 10 and 11:
  - 2 feet of compacted clay
  - GCL
  - 60-mil HDPE geomembrane

Based on a comparison of the design slopes and drainage system components in the liner system and final cover system (described in greater detail below), the final cover system is at least equivalent in permeability when compared to the liner system in Phase 1, Modules 1, 2, 3, 4, 5, and 6 and Phase 2, Modules 10 and 11.

- Per 257.102(d)(3)(i)(B), the existing final cover system includes 2.5 feet of soil, which is greater than the 18 inches of earthen material required to minimize infiltration.

- Per 257.102(d)(3)(ii)(A) and 257.102(d)(3)(i)(B), the alternative final cover system includes 2.5 feet of soil, which is greater than the 18 inches of earthen material required to minimize infiltration.

- Per NR 504.12(4)(b)(2), the proposed final cover contains a GCL infiltration layer. Water infiltrating the final cover will be contained in the drainage layers (sand, geocomposite, and high capacity geocomposite), which will limit infiltration further through the final cover system. Based on our understanding of the regulations, it is unclear if the WDNR will require a soil barrier layer to be added below the final cover GCL. Further discussions with the WDNR will be needed to determine if the current final cover design is acceptable or if updates to the design are required.

- Per 257.102(d)(3)(i)(C) and NR 504.12(4)(b)(3), erosion of the existing final cover system is minimized with a vegetative support layer consisting of 12 inches of uncompacted rooting zone material and 6 inches of topsoil. This provides more than the required 6-inch thickness for plant growth.

- Per 257.102(d)(3)(ii)(B), 257.102(d)(3)(i)(C), and NR 504.12(4)(b)(3), erosion of the alternative final cover system is minimized with a vegetative support layer consisting of 24 inches of uncompacted rooting zone material and 6 inches of topsoil. This provides more than the required 6-inch thickness for plant growth.

Also, the existing final cover system and alternative final cover system limits infiltration while promoting surface water run-off in a controlled manner to minimize erosion and promote stability. The surface layer of 18 inches (existing) or 30 inches (alternative) of soil supports vegetation that assists with erosion control. Water that infiltrates will be collected by the 12-inch drainage layer (existing) or geocomposite drainage layer (alternate) and will be routed to the perimeter drainage system.

In addition, the surface has intermediate drainage swales to reduce the flow lengths down the final cover slope, also aiding in erosion control. Where needed, the intermediate drainage swales are connected to downslope channels to control storm water runoff and prevent erosion of the final cover.

- Per 257.102(d)(3)(i)(D) and NR 504.12(4)(b)(4), the design of the existing final cover system minimizes disruptions to the final cover system. Stability of the final cover system was assessed as part of the WDNR landfill permitting process. The stability calculations are included in **Appendix A1**.

- Per 257.102(d)(3)(ii)(C) and NR 504.12(4)(b)(4), the design of the alternative final cover system minimizes disruptions to the final cover system. Stability of the final cover system was assessed as part of the WDNR landfill permitting process. The stability calculations are included in **Appendix A2**.

The design of the final cover system accommodates settling and subsidence of the CCR fill below the cover. The CCR at COL is placed dry and is compacted in place. CCR continues to consolidate and gain strength as filling progresses prior to final cover placement. The final cover system is designed with a maximum slope of 25 percent (4 horizontal to 1 vertical). Because the final cover has a relatively large positive slope and the CCR has been gaining strength over time, the final cover is expected to easily accommodate the remaining relatively minor settlement potential of the CCR fill when fill placement ends and the landfill is closed.

All final cover materials will be tested to confirm they meet specifications, and construction will be overseen and documented by a licensed engineer. Rooting zone and topsoil layers will be checked for thickness. All areas will be restored after final cover is placed. Vegetation will be monitored and maintained.

4.0 MAXIMUM INVENTORY OF CCR

40 CFR 257.102(b)(1)(iv) *"An estimate of the maximum inventory of CCR ever on-site over the active life of the CCR unit."*

NR 514.07(10)(c)(4) *"An estimate of the maximum volume in cubic yards of CCR that will be disposed on–site over the active life of the CCR landfill."*

The following table reflects the estimated maximum volume of CCR disposed on site at the COL facility.

Area	Maximum Capacity (cy)
Phase 1, Modules 1-6, Phase 2, Modules 10-11	2,583,692

The estimated maximum inventory of CCR ever on site over the active life of the CCR landfill units is based on the design capacity of the landfill. The maximum design capacity was submitted in the WDNR approved 2022 Plan of Operation Update.

5.0 LARGEST AREA OF CCR UNIT REQUIRING FINAL COVER

40 CFR 257.102(b)(1)(v) *"An estimate of the largest area of the CCR unit ever requiring a final cover as required by paragraph (d) of this section at any time during the CCR unit's active life."*

NR 514.07(10)(c)(5) *"An estimate of the largest area of the CCR landfill that will require a final cover at any time during the CCR landfill's active life."*

The largest area of each CCR unit requiring final cover is the open area shown on **Figure 2**, with areas as follows:

Areas Requiring Final Cover (acres)	
Phase 1, Modules 1- 3	12.9
Phase 1, Modules 4-6	12.0
Phase 2, Modules 10-11	7.3
Total	**32.2**

6.0 SCHEDULE OF SEQUENTIAL CLOSURE ACTIVITIES

40 CFR 257.102(b)(1)(vi) *"A schedule for completing all activities necessary to satisfy the closure criteria in this section, including an estimate of the year in which all closure activities for the CCR unit will be completed."*

NR 514.07(10)(c)(6) *"A schedule for completion of all closure activities, including an estimate of the year in which all closure activities for the CCR landfill will be completed."*

CCR placement is anticipated to permanently end at this facility following retirement of the Columbia Generating Station by June 2026, as announced by WPL. Some CCR disposal activity may be necessary following retirement of Columbia as part of decommissioning efforts (for example, cleaning of ducts and other equipment that may contain CCR following retirement). Closure activities are expected to be complete by the end of 2027.The potential schedule for closure of the existing CCR modules is provided in **Appendix B.**

7.0 COMPLETION OF CLOSURE ACTIVITIES

40 CFR 257.102(f)(1) *"Except as provided for in paragraph (f)(2) of this section, the owner or operator must complete closure of the CCR unit:*

(i) For existing and new CCR landfills and any lateral expansion of a CCR landfill, within six months of commencing closure activities."

NR 506.083(3)(a) *"The owner or operator shall complete closure of the CCR landfill within 6 months of commencing closure activities."*

As shown on the enclosed schedule, closure of each CCR unit will be completed within 6 months of commencing closure activities.

40 CFR 257.102(f)(3) *"Upon completion, the owner or operator of the CCR unit must obtain a certification from a qualified professional engineer verifying that closure has been completed in accordance with the closure plan specified in paragraph (b) of this section and the requirements of this section."*

NR 506.083(1)(b) *"Within 30 days following completion of closure of a CCR landfill under sub. (3), the owner or operator shall prepare and submit a notification of closure to the department and place a copy in the facility's operating record. The notification shall include the certification required under s. NR 516.04(3)(d)."*

A qualified licensed engineer will oversee the final cover construction. The engineer will verify final cover materials and methods and oversee material testing. At the end of construction, the engineer will provide a report summarizing and documenting construction and will certify compliance with the requirements.

8.0 CERTIFICATION

40 CFR 257.102(b)(4) *"The owner or operator of the CCR unit must obtain a written certification from a qualified professional engineer that the initial and any amendment of the written closure plan meets the requirement of this section."*

NR 500.05 *"Unless otherwise specified, all submittals for review and approval of any initial site report, feasibility report, plan of operation site investigation report, remedial action options report, construction documentation report, or closure plan, or any modifications to those plans, shall include all of the following:*

(4) CERTIFICATION. (a) The reports and plan sheets shall be under the seal of a licensed professional engineer."

Phillip Gearing, PE, a licensed professional engineer in the State of Wisconsin has overseen the preparation of this Closure Plan. A certification statement is provided on page iii of this plan.

40 CFR 257.102(d)(2)(iii) *"The owner or operator of the CCR unit must obtain a written certification from a qualified professional engineer that the design of the final cover system meets the requirement of this section."*

Phillip Gearing, PE, a licensed professional engineer in the State of Wisconsin has overseen the design of the final cover system and certifies that the design meets the requirements of 40 CFR 257.102(d). The certification statement is provided on page iii of this plan.

9.0 RECORDKEEPING AND REPORTING

40 CFR 257.102(b)(vi)(2)(iii) *"The owner or operator has completed the written closure plan when the plan including the certification required by paragraph (b)(4) of this section, has been placed in the facility's operating record as required by Section 257.105(i)(4)."*

NR 506.17(2)(e) *"The written operating record shall contain the plan of operation, plan modifications, construction documentation, department approvals, annual reports, inspection records, monitoring and corrective action records, notifications to the department, and records of public comments received during any public comment period."*

The Closure Plan will be placed in the facility's operating record and on Alliant Energy's CCR Rule Compliance Data and Information website.

Amendments to the written Closure Plan will be done when a new module is constructed, when there is a change in the operation of the CCR unit that affects the plan, or when unanticipated events warrant revision to the written Closure Plan as required by 40 CFR 257.102(b)(3) and NR 514.07(10)(c)(7).

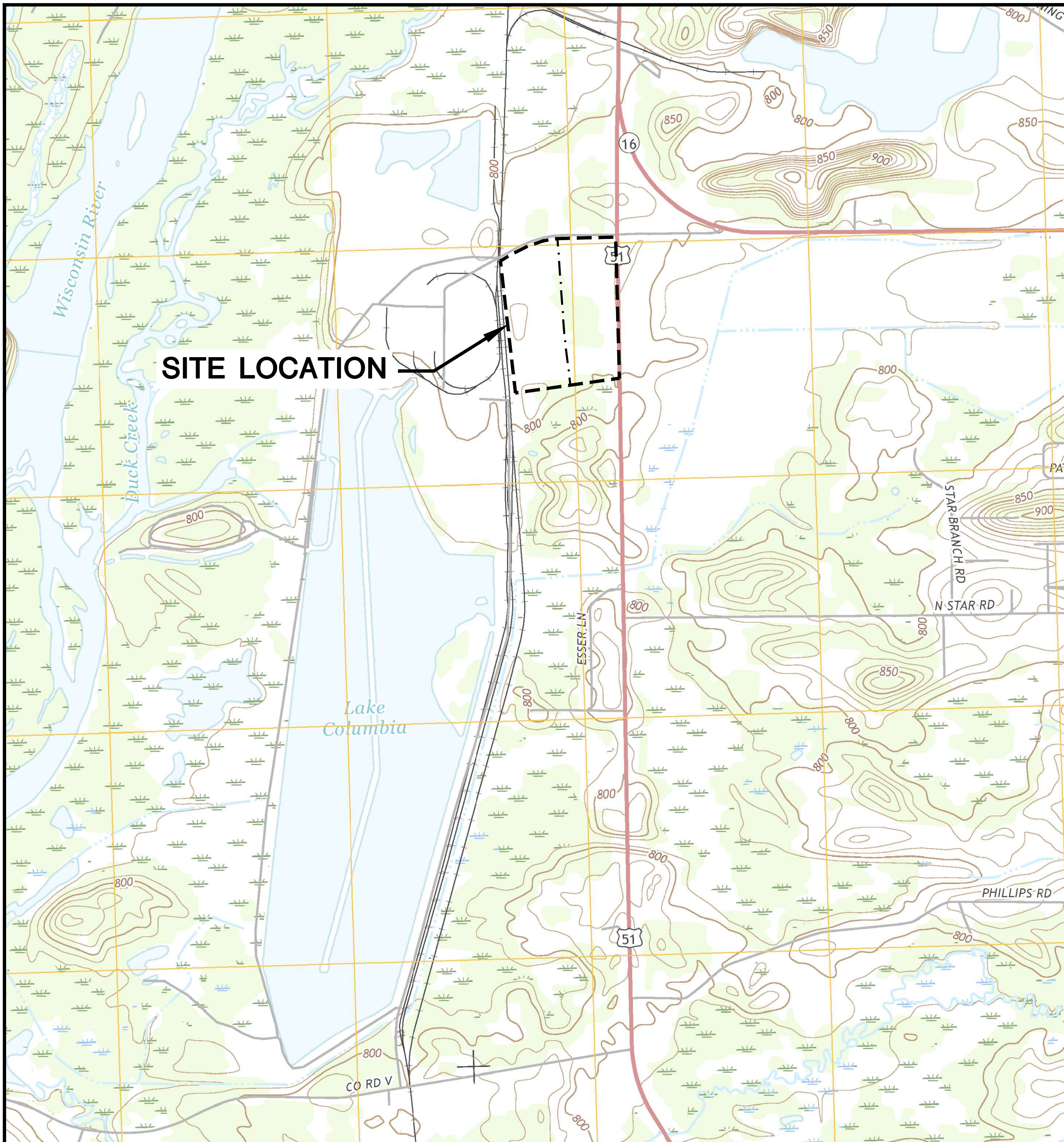
WPL will provide notification as follows:

- Intent to initiate closure
- Closure completion

- Availability of the written Closure Plan and any amendments

All notifications will be placed in the facility's operating record and on the website per 40 CFR 257.105(i), 257.106(i), 257.107(i), and NR 506.17(2).

Figures



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POYNETTE QUADRANGLE
WISCONSIN–COLUMBIA CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
2016
SCALE: 1" = 2,000'

CLIENT	WISCONSIN POWER AND LIGHT COLUMBIA ENERGY CENTER W8375 MURRAY ROAD PARDEEVILLE, WISCONSIN 53954	SITE	CLOSURE PLAN COLUMBIA DRY ASH DISPOSAL FACILITY TOWN OF PACIFIC, WISCONSIN

SITE LOCATION MAP

PROJECT NO.	25222260.00	DRAWN BY:	AHB	ENGINEER: SCS ENGINEERS 2830 DAIRY DRIVE MADISON, WI 53718-6751 PHONE: (608) 224-2830	FIGURE
DRAWN:	08/09/2016	CHECKED BY:	RJG		1
REVISED:	12/28/2022	APPROVED BY:	PEG 01/31/23		

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LEGEND

- ASH DISPOSAL FACILITY LIMITS
- APPROVED LIMITS OF ASH FILL
- PHASE/MODULE LIMIT
- EXISTING GRADE (5' CONTOUR)
- EXISTING GRADE (1' CONTOUR)
- PAVED ROAD
- UNPAVED ROAD
- RAILROAD TRACKS
- VEGETATION
- FENCE
- SWALE
- EDGE OF WATER
- APPROXIMATE LIMITS OF EXISTING LEACHATE/SURFACE WATER POND LINER
- CULVERT
- TRANSMISSION TOWER
- WATER SUPPLY WELL
- STAFF GAUGE
- WATER TABLE WELL
- PIEZOMETER
- SURFACE WATER SAMPLE LOCATION
- LYSIMETER
- ABANDONED WATER TABLE WELL
- ABANDONED PIEZOMETER
- BENCHMARK
- PROPOSED FINAL GRADE (2' CONTOUR)
- PROPOSED FINAL GRADE (10' CONTOUR)
- ACTIVE LANDFILL AREA
- PROPOSED DIVERSION BERM
- PROPOSED DOWNSLOPE CHANNEL
- PROPOSED DOWNSLOPE FLUME
- CLOSED AREA
- AREA TO BE CLOSED WITH FINAL COVER (SAND DRAINAGE LAYER)
- AREA TO BE CLOSED WITH FINAL COVER (GEOCOMPOSITE DRAINAGE LAYER)
- AREA WITH HIGH CAPACITY GEOCOMPOSITE

NOTES:

1. BASE MAP CREATED FROM AERIAL SURVEY BY KBM, FLOWN DECEMBER 1, 2014, AND GROUND SURVEY BY SCS ENGINEERS IN DECEMBER 2020, AND BY DRONE SURVEY BY AMES ON JANUARY 17, 2023.
2. MONITORING WELL LOCATIONS AND ELEVATIONS SURVEYED BY WISCONSIN POWER AND LIGHT, INC. IN DECEMBER 1994, NOVEMBER 1996, APRIL 2003, AUGUST 2012, JANUARY 2016, AND BY SCS ENGINEERS IN MAY 2019.

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SCALE: 1" = 200'

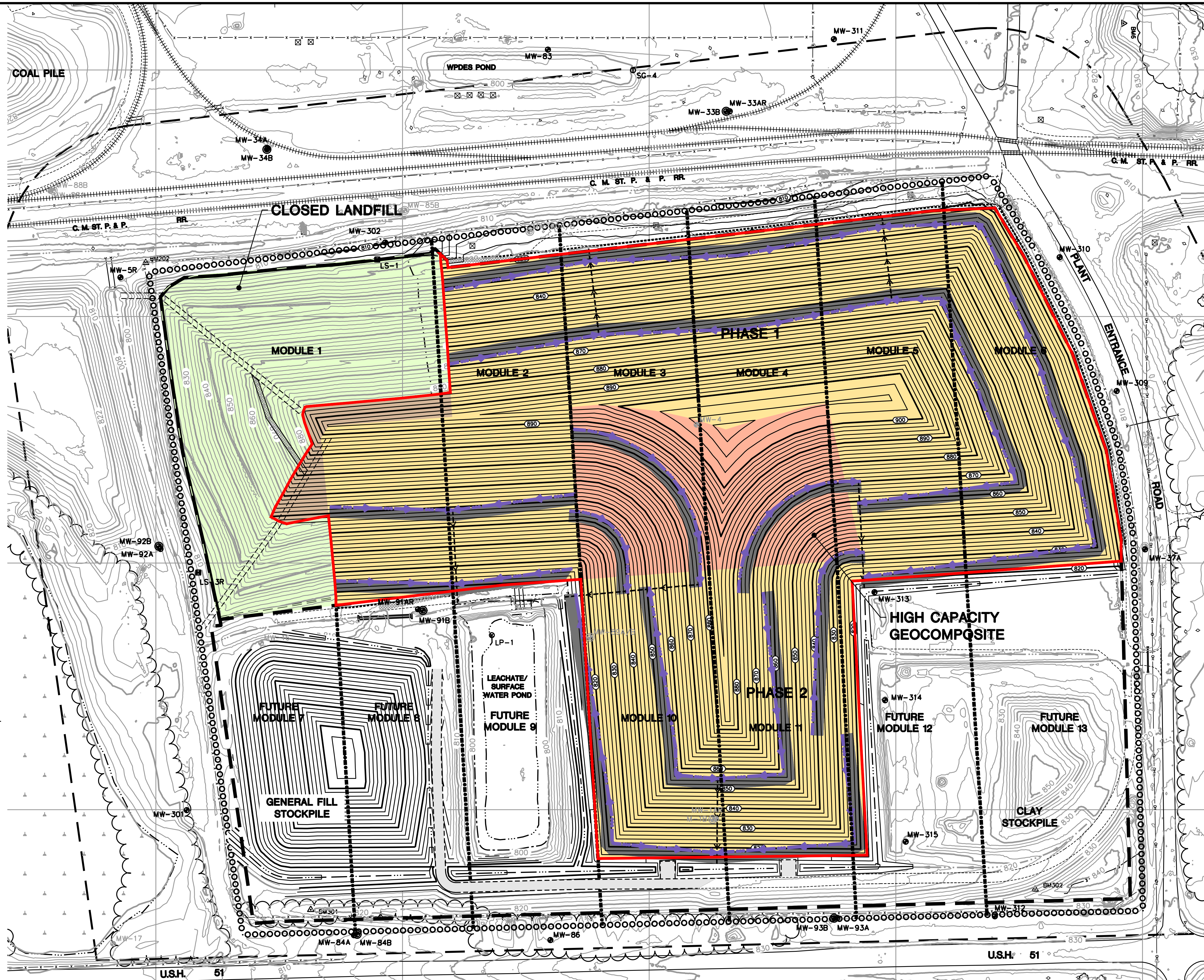

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FIGURE 2

CLOSURE PLAN

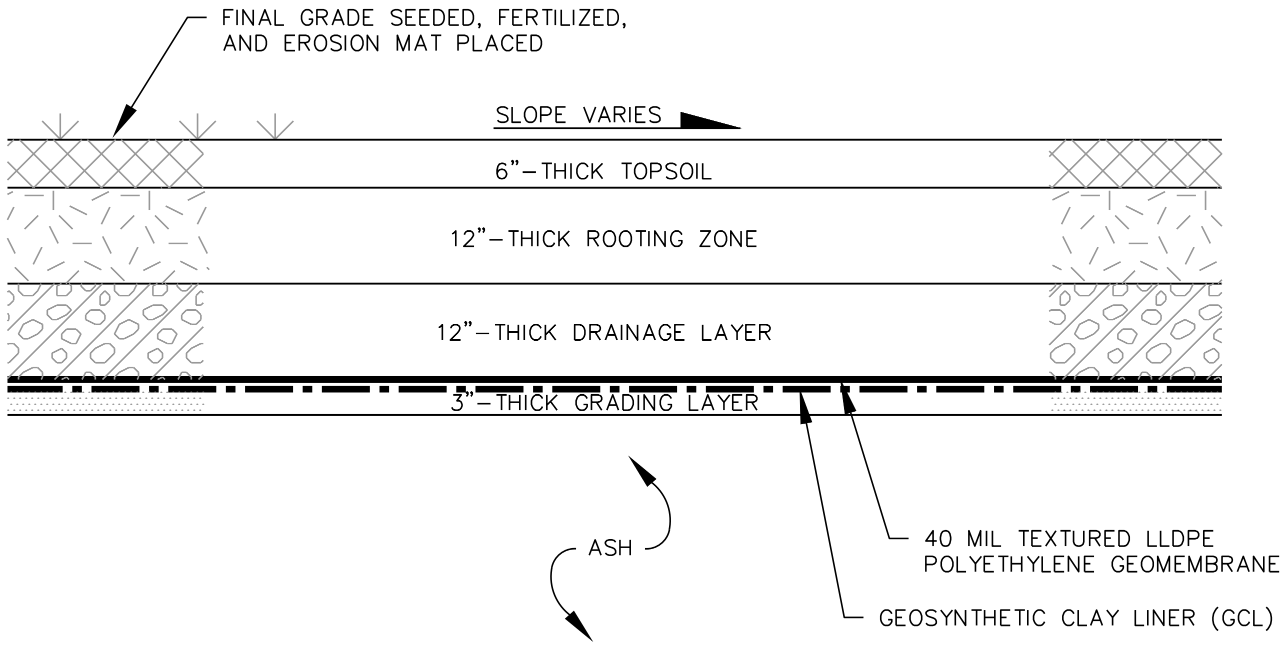
SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

ENGINEER

SITE
CLOSURE PLAN
COLUMBIA DRY ASH DISPOSAL FACILITY
TOWN OF PACIFIC, WISCONSIN

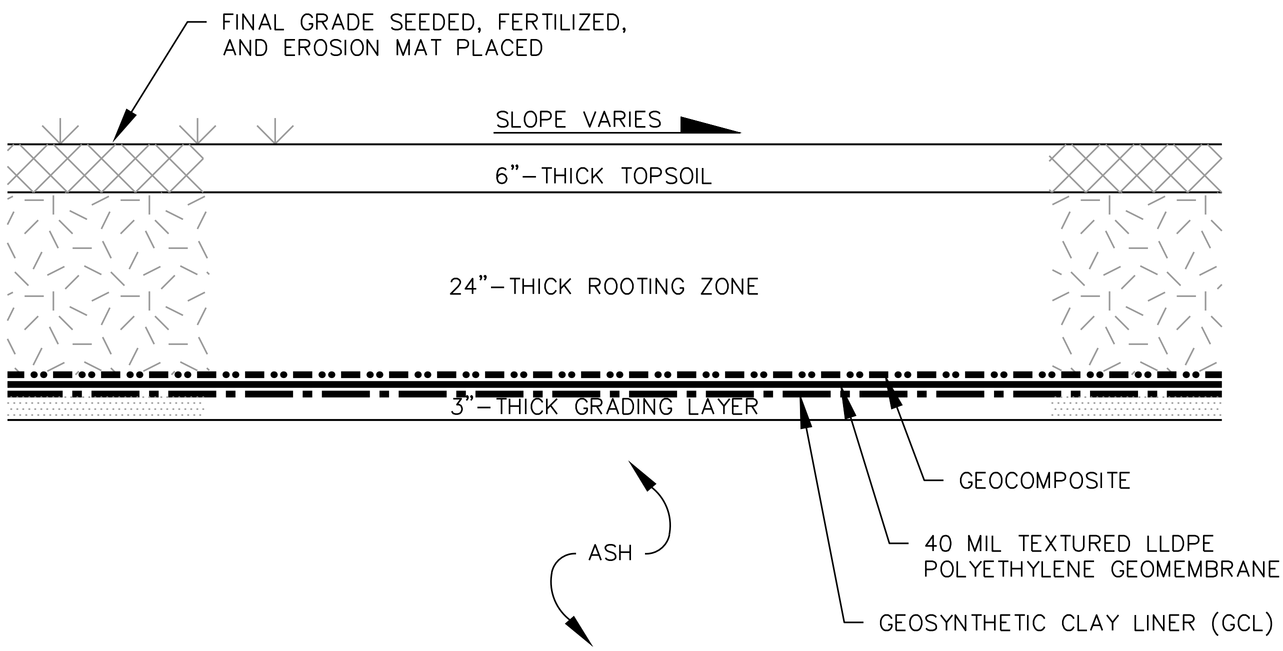
CLIENT
WISCONSIN POWER AND LIGHT
COLUMBIA ENERGY CENTER
W8375 MURRAY ROAD
PARDEEVILLE, WISCONSIN 53954

PROJECT NO.	25222260.00	DRAWN BY:	KP/MJT
DRAWN:	11/30/2021	CHECKED BY:	RJG
REVISED:	01/25/2023	APPROVED BY:	PEG 01/31/23



FINAL COVER SYSTEM (SAND DRAINAGE LAYER)

SCALE: 1" = 2'



FINAL COVER SYSTEM (GEOCOMPOSITE DRAINAGE LAYER)

SCALE: 1" = 2'

CLIENT	SITE	
WISCONSIN POWER AND LIGHT COLUMBIA ENERGY CENTER W8375 MURRAY ROAD PARDEEVILLE, WISCONSIN 53954	CLOSURE PLAN COLUMBIA DRY ASH DISPOSAL FACILITY TOWN OF PACIFIC, WISCONSIN	FINAL COVER SYSTEM

				ENGINEER	FIGURE
PROJECT NO.	25222260.00	DRAWN BY:	KP/MJT	SCS ENGINEERS 2830 DAIRY DRIVE MADISON, WI 53718-6751 PHONE: (608) 224-2830	3
DRAWN:	08/17/2016	CHECKED BY:	RJG		
REVISED:	01/25/2023	APPROVED BY:	PEG 01/31/23		

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Appendix A

Stability Calculations

Appendix A1

Existing Final Cover Stability Calculations

EVALUATION:

Evaluate the Phase 1 landfill liner side slope drainage layer for static veneer slope stability.

The side slope on the modules base runs at a 3:1 slope for an approximate maximum of 80 feet.

The following calculations evaluate the static veneer slope stability of the 3:1 slope.

REFERENCES:

1.) Koerner, Robert M. & Te-Yang Soong, Analysis and Design of Veneer Cover Soils, Geosynthetic Research Institute.
2.) U.S. Department of Transportation - Federal Highway Administration Recycled Materials, Coal Bottom Ash User's Guide

EQUATIONS:

$FS = (-b+(b^2-4*a*c)^{1/2})/(2*a)$

$a = (W_A-N_A*\cos\beta)*\cos\beta$

$b = -((W_A-N_A*\cos\beta)*\sin\beta*\tan\phi+(N_A*\tan\delta+C_a)*\sin\beta*\cos\beta+(C+W_P*\tan\phi)*\sin\beta)$

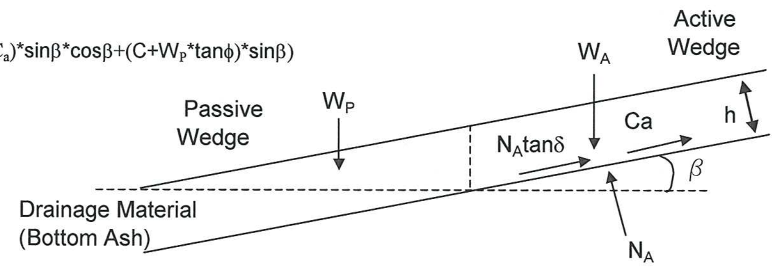
$c = (N_A*\tan\delta+C_a)*(\sin\beta)^2*\tan\phi$

$N_A = W_A*\cos\beta$

$W_A = \gamma*h^2*(L/h-1/\sin\beta-\tan\beta/2)$

$W_P = (\gamma*h^2)/\sin2\beta$

$C_a = c_a(L-h/\sin\beta)$



DEFINITIONS OF VARIABLES:

FS = Factor of Safety

a, b, & c = intermediate variables (= calculated variable)

N_A = Effective force normal to the failure plane of the active wedge (= calculated variable)

W_A = Total weight of active wedge (= calculated variable)

W_P = Total weight of passive wedge (= calculated variable)

β = Soil slope angle beneath the geomembrane (= 18.42 degrees or 0.322 radians based on liner slope of 3 to 1)

ϕ = Friction angle of the drainage layer material (= 35 degrees 0.611 radians based on Ref #2)

δ = Interface friction angle for liner system geosynthetics (to be determined)

c_a = Adhesion for liner system geosynthetics at active wedge (to be determined) , Variable

γ = Unit weight of the drainage layer material (= 135 pcf based on conservative wet density of bottom ash).

C = Cohesive force along the failure plane of the passive wedge (assumed 0 for drainage layer material)

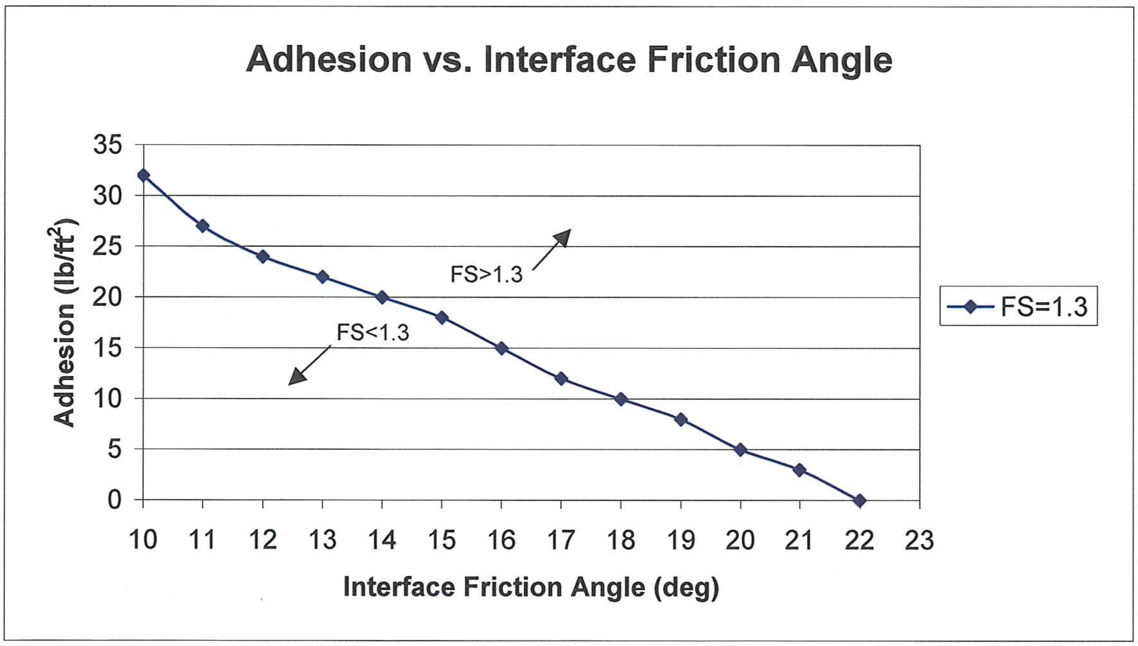
C_a = Adhesive force of the active wedge for the liner system geosynthetics

h = Thickness of the drainage layer material(= 1.0 foot based on base design)

L = Length of slope measured along the geomembrane (= 80 feet based on base design)

CALCULATIONS:

δ		c_a	W_A	W_P	N_A	C_a	a	b	c	FS
(deg)	(rad)	(lb/ft^2)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	
10	0.175	32	10,350	225	9,820	2,459	981	-1,535	293	**1.3**
11	0.192	27	10,350	225	9,820	2,075	981	-1,473	279	**1.3**
12	0.209	24	10,350	225	9,820	1,844	981	-1,457	275	**1.3**
13	0.227	22	10,350	225	9,820	1,690	981	-1,465	277	**1.3**
14	0.244	20	10,350	225	9,820	1,537	981	-1,473	279	**1.3**
15	0.262	18	10,350	225	9,820	1,383	981	-1,482	281	**1.3**
16	0.279	15	10,350	225	9,820	1,153	981	-1,468	277	**1.3**
17	0.297	12	10,350	225	9,820	922	981	-1,455	274	**1.3**
18	0.314	10	10,350	225	9,820	768	981	-1,465	277	**1.3**
19	0.332	8	10,350	225	9,820	615	981	-1,477	279	**1.3**
20	0.349	5	10,350	225	9,820	384	981	-1,465	277	**1.3**
21	0.367	3	10,350	225	9,820	231	981	-1,478	280	**1.3**
22	0.384	0	10,350	225	9,820	0	981	-1,468	277	**1.3**



CONCLUSION:

The landfill liner side slope drainage layer was evaluated for static veneer slope stability along its longest slope. Calculations were performed to determine the minimum adhesion necessary for a range of interface friction angles to reach a FS of 1.3 or greater. Each interface friction angle and the coinciding adhesion was graphed in order to easily determine if a material interface is acceptable along the side slope.

BT SQUARED

		Sheet No.	1 of 1
		Calc. No.	
		Rev. No.	
Job No. 4071	Job: Columbia Ash Generation Landfill	By PEG	Date 9/27/10
Client: Alliant	Subject: GCL Internal Shear for Liner System	Chk'd DLN	Date 9/29/10

Purpose: Determine the maximum shear stress acting on a Geosynthetic Clay Liner (GCL) and the GCL internal shear strength required to provide a minimum slope stability safety factor (FS) of 1.5 for the liner system.

Approach: Use maximum shear stress formula and assumed values.

References: **Design of GCL Barrier for Final Cover Side Slope Applications**
Gregory N. Richardson, Ph.D., P.E. Geosynthetics '97 - 541

Calculation: The maximum shear stress acting on the GCL can be calculated as follows:

$$\tau_{act} = W_T \sin \beta$$

$$\beta = 18.4^{\circ}$$

$$W_T = \gamma * h$$

Where,

γ = Ash Unit Weight = 135 pcf

h = drainage layer thickness = 1 ft

$$W_T = 135 \text{ psf}$$

$$\tau_{act} = 42.6 \text{ psf}$$

$$FS = \frac{\tau_{resist}}{\tau_{act}} = 1.5$$

$$\tau_{resist} = FS * \tau_{act} = 1.5 * 42.6 = 64 \text{ psf}$$

Assumptions: 1. Slope angle, $\beta=18.4^{\circ}$ (3:1 horizontal/vertical liner side slope).

2. Ash unit weight, γ = 135 pcf

Conclusions: For a total weight of the leachate drainage layer of 135 psf and a slope angle of 3:1, the maximum shear stress will be 42.6 psf. A minimum GCL internal shear strength of 64 psf is required to provide a slope stability safety factor of 1.5.

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Job No. 25220183.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 03/31/22
Client: WPL	Subject: Sand Drainage Layer - Unit Gradient	Chk'd: DLN	Date: 05/04/22

Purpose: To determine the maximum length of slope that the final cover drainage layer (sand) can carry infiltrating water and remain stable.

Approach: Use the unit gradient method to determine the maximum slope length.

References:

1. Landfilldesign.com

2. "GRI-GC8, Determination of the Allowable Flow Rate of a Drainage Geocomposite". Geosynthetics Research Institute, 2001

3. "Beyond a factor-of-safety value, i.e., the proabability of failure". GRI Newsletter/Report, Vol. 15, no. 3

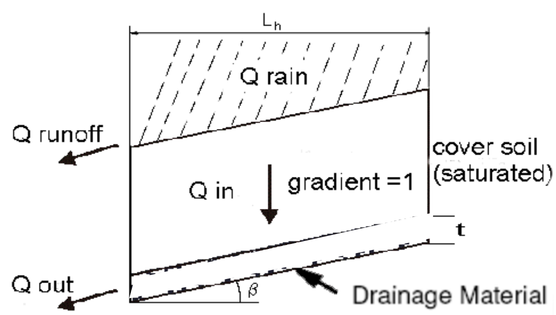
4. "Designing with Geosynthetics". R.M. Koerner, Prentice Hall Publishing Co., Englewood Cliffs, NJ, 1998

5. "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers". J. P. Giroud, J. G. Zornberg and A. Zhao, Geosynthetics International, Vol. 7, Nos 4-5

6. "Lateral Drainage Design update - part 2". G. N. Richardson, J. P. Giroud and A. Zhao, Geotechnical Fabrics Report, March 2002

7. HELP Model "User's Guide", Table 4: Default Soil, Waste, and Geosynthetic Characteristics

8. SCS Engineers, Plan Modification Request/Plan of Operation Update, Dry Ash Disposal Facility, COL Energy Center, Final Grades Plan Sheet, May 2022



With Darcy's Law:

$$Q = k \times i \times A$$

Inflow of water in the Drainage Material

$$Q_{in} = k_{veg} \times i \times A = k_{veg} \times 1 \times L_h \times 1$$

Outflow of water from the geocomposite at the toe of the slope

$$Q_{out} = k_{drain} \times i \times A = k_{drain} \times t \times \sin\beta$$

This results in a required k_{drain} of:

$$k_{drain} = \frac{k_{veg} \times L_h}{t \times \sin\beta} \times FS$$

Assumptions: 1. Soil hydraulic gradient i = 1.0.

2. Top soil will be clay. Soil permeability is 4.2×10^{-5} cm/sec for a CL clay from HELP model user's guide.
3. Drainage Layer hydraulic gradient = sinβ where β=14° (4:1 horizontal/vertical final cover slope).
4. Maximum horizontal final cover slope length from crest to toe drain is 368 feet as shown in Module 1 on the final grades plan sheet.
5. The minimum hydraulic conductivity ($k_{drain,ave}$) is 1.0×10^{-2} cm/s for the sand.
6. Cover drainage layer thickness t = 1 foot.

Calculation: Constants

L_h	=	Drainage pipe spacing or length of slope measured horizontally	=	See Below	
k_{veg}	=	Permeability of the vegetative supporting soil	=	0.000042	cm/sec
S	=	The liner's slope, **S** = tan **b**	=	25%	b = 14°
FS_{slope}	=	Minimum factor of safety against sliding, for drainage layer/geomembrane interface	=	1.5	
$\delta_{req'd}$	=	Minimum interface friction angle = $\tan^{-1}$(FS*tan(b))	=	20.6	degrees

Determine the maximum slope length for the given minimum required drainage layer permeability

L_h (feet)	L_h (meter)	$k_{drain, req}$ (cm/s)	
30	9.1	7.69E-03	Design

Conclusions: The design has an intermediate pipe every 30 feet spaced evenly up the slope. The intermediate pipe spacing design with the sand material has a factor of safety of 1.95.

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		Sheet No.	1 of 1
		Calc. No.	
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Job No. 25220183.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 04/25/22
Client: WPL	Subject: GCL Internal Shear on Final Cover	Chk'd: DLN	Date: 04/26/22

Purpose: Determine the maximum shear stress acting on a Geosynthetic Clay Liner (GCL) and the GCL internal shear strength required to provide a minimum slope stability safety factor (FS) of 1.5 for the final cover.

Approach: Use maximum shear stress formula and assumed values.

References: Design of GCL Barrier for Final Cover Side Slope Applications, Gregory N. Richardson, Ph.D., P.E., Geosynthetics '97-541

Calculation: The maximum shear stress acting on the GCL can be calculated as follows:

$$\tau_{act} = W_T \sin \beta$$

$$\beta = 14 ^\circ$$

$$W_T = \gamma \times h$$

Where:

γ	=	Soil Unit Weight	=	120	pcf
h	=	Cover Thickness	=	2.5	ft

$$W_T = 300 \text{ psf}$$

$$\tau_{act} = 72.6 \text{ psf}$$

$$FS = \frac{\tau_{resist}}{\tau_{act}} = 1.5$$

$$\tau_{resist} = FS \times \tau_{act} = 1.5 \times 72.6 = 109 \text{ psf}$$

Assumptions: Slope angle, $\beta = 14^\circ$ (4:1 horizontal / vertical final cover slope)

Soil unit weight, $\gamma = 120$ pcf

Conclusion: For a total weight of the final cover system of 300 psf and a slope angle of 4:1, the maximum shear stress will be 72.6 psf. A minimum GCL internal shear strength of 109 psf is required to provide a slope stability safety factor of 1.5.

Appendix A2

Alternative Final Cover Stability Calculations

Purpose: Evaluate the Module 10 and 11 landfill liner side slope drainage layer for static veneer slope stability. The following calculations evaluate the static veneer slope stability of the 3:1 slope.

References:

1. Koerner, Robert M. & Te-Yang Soong, Analysis and Design of Veneer Cover Soils, Geosynthetic Research Institute.
2. U.S. Department of Transportation - Federal Highway Administration Recycled Materials, Coal Bottom Ash User's Guide

Calculation:

$FS = (-b + (b^2 - 4 * a * c)^{1/2}) / (2 * a)$

$a = (W_A - N_A * \cos\beta) * \cos\beta$

$b = -((W_A - N_A * \cos\beta) * \sin\beta * \tan\phi + (N_A * \tan\delta + C_a) * \sin\beta * \cos\beta + (C + W_P * \tan\phi) * \sin\beta)$

$c = (N_A * \tan\delta + C_a) * (\sin\beta)^2 * \tan\phi$

$N_A = W_A * \cos\beta$

$W_A = \gamma * h^2 * (L / h - 1 / \sin\beta - \tan\beta / 2)$

$W_P = (\gamma * h^2) / \sin 2\beta$

$C_a = c_a (L - h / \sin\beta)$

<u>Where:</u>

FS = Factor of Safety

a, b, & c = intermediate variables (calculated variable)

N_A = Effective force normal to the failure plane of the active wedge (calculated variable)

W_A = Total weight of active wedge (calculated variable)

W_P = Total weight of passive wedge (calculated variable)

β = Soil slope angle beneath the geomembrane = 18.421 degrees = 0.3215 radians
based on liner slope of 3 to 1

ϕ = Friction angle of the sand drainage layer material = 30 degrees = 0.5236 radians
based on experience

δ = Interface friction angle for liner system geosynthetics (to be determined)

c_a = Adhesion for liner system geosynthetics at active wedge (to be determined), Variable

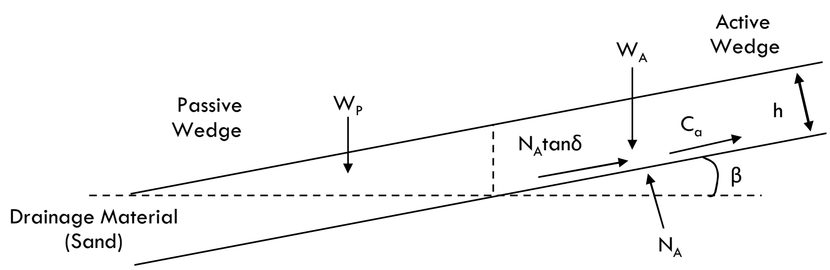
γ = Unit weight of the drainage layer material = 125 pcf
based on conservative wet density of sand

C = Cohesive force along the failure plane of the passive wedge, assumed
= 0 for drainage layer material

C_a = Adhesive force of the active wedge for the liner system geosynthetics

h = Thickness of the drainage layer material = 1 foot, based on base design

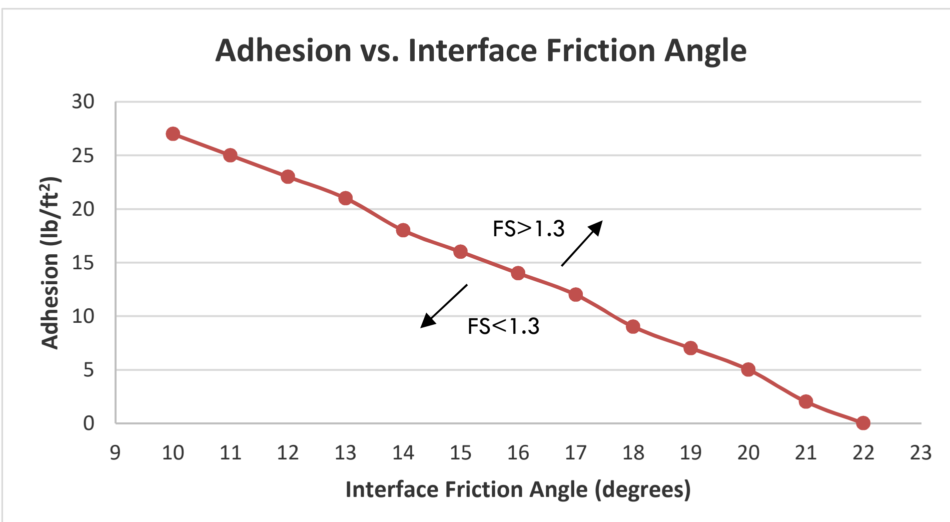
L = Length of slope measured along the geomembrane = 49 feet, based on base design



Calculation:

(cont.)

δ		c_a	W_A	W_P	N_A	C_a	a	b	c	FS
(deg)	(rad)	(lb/ft^2)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	(lb/ft)	
10	0.1745	27	5,709	208	5,416	1237.6	541	-799	126	1.3
11	0.192	25	5,709	208	5,416	1,146	541	-801	127	1.3
12	0.2094	23	5,709	208	5,416	1,054	541	-803	127	1.3
13	0.2269	21	5,709	208	5,416	963	541	-805	128	1.3
14	0.2443	18	5,709	208	5,416	825	541	-794	125	1.3
15	0.2618	16	5,709	208	5,416	733	541	-797	126	1.3
16	0.2793	14	5,709	208	5,416	642	541	-800	127	1.3
17	0.2967	12	5,709	208	5,416	550	541	-803	127	1.3
18	0.3142	9	5,709	208	5,416	413	541	-793	125	1.3
19	0.3316	7	5,709	208	5,416	321	541	-797	126	1.3
20	0.3491	5	5,709	208	5,416	229	541	-802	127	1.3
21	0.3665	2	5,709	208	5,416	92	541	-793	125	1.3
22	0.384	0	5,709	208	5,416	0	541	-798	126	1.3



Conclusion: The landfill liner side slope drainage layer was evaluated for static veneer slope stability along its longest slope. Calculations were performed to determine the minimum adhesion necessary for a range of interface friction angles to reach a FS of 1.3 or greater. Each interface friction angle and the coinciding adhesion was graphed in order to easily determine if a material interface is acceptable along the side slope.

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		Sheet No.	1 of 1
		Calc. No.	
		Rev. No.	
Job No. 25220183.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 03/02/22
Client: WPL	Subject: GCL Internal Shear for Liner System	Chk'd: DLN	Date: 04/13/22

Purpose: Determine the maximum shear stress acting on a Geosynthetic Clay Liner (GCL) and the GCL internal shear strength required to provide a minimum slope stability safety factor (FS) of 1.5 for the liner system.

Approach: Use maximum shear stress formula and assumed values.

References: Design of GCL Barrier for Final Cover Side Slope Applications, Gregory N. Richardson, Ph.D., P.E., Geosynthetics '97-541

Calculation: The maximum shear stress acting on the GCL can be calculated as follows:

$$\tau_{act} = W_T \sin\beta$$

$$\beta = 18.4^\circ$$

$$W_T = \gamma \; X \; h$$

Where:

γ	=	Sand Unit Weight	=	125	pcf
h	=	Drainage Layer Thickness	=	1	ft

$$W_T = 125 \text{ psf}$$

$$\tau_{act} = 39.5 \text{ psf}$$

$$FS = \frac{\tau_{resist}}{\tau_{act}} = 1.5$$

$$\tau_{resist} = FS \; X \; \tau_{act} = 1.5 \; X \; 39.5 = 59 \text{ psf}$$

Assumptions: Slope angle, $\beta = 18.4^\circ$ (3:1 horizontal / vertical liner side slope

Sand unit weight, $\gamma = 125$ pcf

Conclusion: For a total weight of the leachate drainage layer of 125 psf and a slope angle of 3:1, the maximum shear stress will be 39.46 psf. A minimum GCL internal shear strength of 59.19 psf is required to provide a slope stability safety factor of 1.5.

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		Sheet No.	1 of 2
		Calc. No.	
		Rev. No.	
Job No. 25220183.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 3/14/22
Client: WPL	Subject: Geocomposite Unit Gradient	Chk'd: DLN	Date: 4/19/22

Purpose: To determine the maximum length of slope that the final cover drainage geocomposite can carry infiltrating water and remain stable. Also determine the recommended minimum friction angle for final cover side slope stability. Note: This calculation does not include the flow convergence areas where a separate calculation is required.

Approach: Use the unit gradient method to determine the maximum slope length.

References:

1. Landfilldesign.com - Lateral Drainage System - Single Slope, Unit Gradient Method

2. "GRI-GC8, Determination of the Allowable Flow Rate of a Drainage Geocomposite". Geosynthetics Research Institute, 2001.

3. "Beyond a factor-of-safety value, i.e., the proabability of failure". GRI Newsletter/Report, Vol. 15, no. 3.

4. "Designing with Geosynthetics". R.M. Koerner, Prentice Hall Publishing Co., Englewood Cliffs, NJ, 1998.

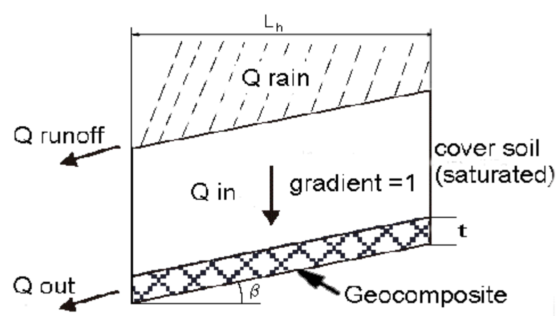
5. "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers". J. P. Giroud, J. G. Zornberg and A. Zhao, Geosynthetics International, Vol. 7, Nos 4-5.

6. "Lateral Drainage Design update - part 2". G. N. Richardson, J. P. Giroud and A. Zhao, Geotechnical Fabrics Report, March 2002.

7. Giroud, Zornberg, and Zhao, 2000, "Hydraulic Design of Liquid Collection Layers", Geosynthetics International

8. SCS Engineers, Plan Modification Request/Plan of Operation Update, Dry Ash Disposal Facility, COL Energy Center, Final Grades Plan Sheet, May 2022

9. HELP Model "User's Guide" in conjunction with GRI report #19, pages 34-37 (Leachate Collection System)



With Darcy's law:

$$Q = k * i * A$$

Inflow of water in the geocomposite

$$Q_{in} = k_{veg} * i * A = k_{veg} * 1 * L_h * 1$$

Outflow of water from the geocomposite at the toe of the slope

$$Q_{out} = k_{comp} * i * A = k_{comp} * i * t * 1 = \theta_{required} * \sin\beta \quad = \theta * i * 1 \text{ where } \theta = k_{comp} * t$$

Inflow equals outflow (Factor of Safety = 1)

$$Q_{in} = Q_{out}$$

This results in a required transmissivity of the geocomposite of:

$$\theta_{required} = \frac{k_{veg} * L_h}{\sin\beta}$$

Which results in the ultimate transmissivity after multiplying by the Total Serviceability Factor (TSF)

$$\theta_{ultimate} = \theta_{required} * FS_d * RF_{in} * RF_{cr} * RF_{cc} * RF_{bc}$$

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		Sheet No.	2 of 2
		Calc. No.	
		Rev. No.	
Job No. 25220183.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 3/14/22
Client: WPL	Subject: Geocomposite Unit Gradient	Chk'd: DLN	Date: 4/19/22

Assumptions:
1. Soil hydraulic gradient *i* = 1.0.
2. Top soil will be clay. Soil permeability is 4.2 x 10^{-5} cm/sec for a CL clay from HELP model user's guide.
3. Geocomposite hydraulic gradient = sinβ where β=14° (4:1 horizontal/vertical final cover slope).
4. Factor of safety and transmissivity reduction factors are from recommended values in GRI report #19 (Leachate collection system example) and HELP model "Users Guide"
5. Maximum horizontal final cover slope length from crest to toe drain is 397 feet as shown on Module 10 and 11 Final Grades plan sheet. This includes 58' of 10:1 slope length at the peak.

Calculation: Constants

L_h	=	Drainage pipe spacing or length of slope measured horizontally	=	See Below	
k_{veg}	=	Permeability of the vegetative supporting soil	=	0.000042	cm/sec
S	=	The liner's slope, **S** = tan **b**	=	25%	b = 14°
FS_{slope}	=	Minimum factor of safety against sliding, for soil/geocomposite or geocomposite/geomembrane interfaces	=	1.5	
$\delta_{req'd}$	=	Minimum interface friction angle = $\tan^{-1}$(FS*tan(b))	=	20.6	degrees
FS_d	=	Overall factor of safety for drainage	=	2.0	
RF_{in}	=	Intrusion Reduction Factor	=	1.1	
RF_{cr}	=	Creep Reduction Factor	=	1.2	
RF_{cc}	=	Chemical Clogging Reduction Factor	=	1.1	
RF_{bc}	=	Biological Clogging Reduction Factor	=	1.4	

Determine the maximum slope length for a given ultimate transmissivity

Θ_{ult} (m^2/sec)	L_h (meter)	L_h (feet)
1.00E-03	141.7	465

Determine the ultimate transmissivity based on a given slope length

L_h (feet)	L_h (meter)	Θ_{ult} (m^2/sec)	
397	121.0	8.55E-04	~ Total slope length
199	60.5	4.27E-04	~ 1/2 of total slope length
132	40.3	2.85E-04	~ 1/3 of total slope length

Conclusions: If no intermediate drainage outlets were constructed on the final cover, a minimum transmissivity of 8.55 x 10^{-4} m^2/sec would need to be obtained.

A minimum interface friction angle of 20.6 degrees between cover soil and geocomposite is required to achieve a minimum recommended final cover slope stability safety factor of 1.5.

Purpose: To determine the geocomposite drainage requirements in the final cover where flow converges in the north and south corners of Modules 10 and 11so the final cover drainage geocomposite can carry infiltrating water and remain stable. Also to determine the recommended minimum interface friction angle for final cover stability.

Approach: Use the unit gradient method and flow path geometry to determine the geocomposite transmissivity required at locations within the converging flow area.

References:

1. Landfilldesign.com - Lateral Drainage System - Single Slope, Unit Gradient Method

2. "GRI-GC8, Determination of the Allowable Flow Rate of a Drainage Geocomposite". Geosynthetics Research Institute, 2001.

3. "Beyond a factor-of-safety value, i.e., the proabability of failure". GRI Newsletter/Report, Vol. 15, no. 3.

4. "Designing with Geosynthetics". R.M. Koerner, Prentice Hall Publishing Co., Englewood Cliffs, NJ, 1998.

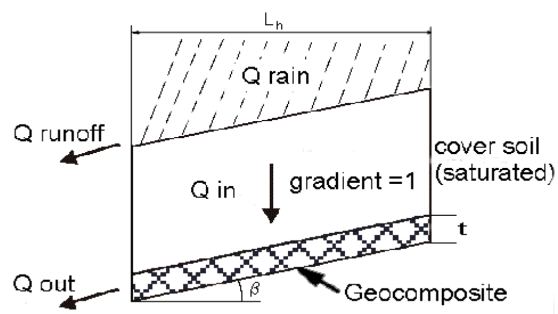
5. "Hydraulic Design of Geosynthetic and Granular Liquid Collection Layers". J. P. Giroud, J. G. Zornberg and A. Zhao, Geosynthetics International, Vol. 7, Nos 4-5.

6. "Lateral Drainage Design update - part 2". G. N. Richardson, J. P. Giroud and A. Zhao, Geotechnical Fabrics Report, March 2002.

7. Giroud, Zornberg, and Zhao, 2000, "Hydraulic Design of Liquid Collection Layers", Geosynthetics International

8. SCS Engineers, Plan Modification Request/Plan of Operation Update, Dry Ash Disposal Facility, COL Energy Center, Final Grades Plan Sheet, April 2022

9. HELP Model "User's Guide" in conjunction with GRI report #19, pages 34-37 (Leachate Collection System)



With Darcy's law:

$$Q = k * i * A$$

Inflow of water in the geocomposite

$$Q_{in} = k_{veg} * i * A = k_{veg} * 1 * L_h * 1$$

Outflow of water from the geocomposite at the toe of the slope

$$Q_{out} = k_{comp} * i * A = k_{comp} * i * t * 1 = \theta_{required} * \sin\ \beta$$

= θ*i*1 where $\theta = k_{comp} * t$ (minimum allowable outflow to keep head within geocomposite)

Inflow equals outflow (Factor of Safety = 1)

$$Q_{in} = Q_{out}$$

This results in a required transmissivity of the geocomposite of:

$$\theta_{required} = \frac{k_{veg} * L_h}{\sin\ \beta}$$

Which results in the ultimate transmissivity after multiplying by the Total Serviceability Factor (TSF)

$$\theta_{ultimate} = \theta_{required} * FS_d * RF_{in} * RF_{cr} * RF_{cc} * RF_{bc}$$

Assumptions: 1. Soil hydraulic gradient *i* = 1.0.

2. Top soil will be clay. Soil permeability is 4.2 x 10^{-5} cm/sec for a CL clay from HELP model user's guide.

3. Geocomposite hydraulic gradient = sinβ where β=14° (4:1 horizontal/vertical final cover slope).

4. Factor of safety and transmissivity reduction factors are from recommended values in GRI report #19 (Leachate collection system example) and HELP model "Users Guide"

5. Flow paths A-E and F-J are as shown on attached drawing. Assume circular arc with radius measured from the corner of the toe drain.

6. Intermediate drainage piping will be used at 3 locations along the slope in each area to divert flow from the drainage layer to the diversion berms and downslope flume.

Calculation: Constants

L_h = Drainage pipe spacing or length of slope measured horizontally = See Below

k_{veg} = Permeability of the vegetative supporting soil = 0.000042 cm/sec

S = The liner's slope, **S** = tan **b** = 25% b = 14°

FS_{slope} = Minimum factor of safety against sliding, for soil/geocomposite or geocomposite/geomembrane interfaces = 1.5

$\delta_{req'd}$ = Minimum interface friction angle = $\tan^{-1}$(FS*tan(b)) = 20.6 degrees

FS_d = Overall factor of safety for drainage = 2.0

RF_{in} = Intrusion Reduction Factor = 1.1

RF_{cr} = Creep Reduction Factor = 1.2

RF_{cc} = Chemical Clogging Reduction Factor = 1.1

RF_{bc} = Biological Clogging Reduction Factor = 1.4

w = Geocomposite width at drainage outlet

A = Final cover plan area upslope of geocomposite drainage outlet

Determine the maximum slope length for a given ultimate transmissivity

Min. Θ_{req} = A X k_{veg} / (w X sinβ)

For the outlet at the corner, use minimum 5 foot width and 2 foot width of geocomposite to connect the toe drain to drain the converging flow area:

Area	A (sq. feet)	w (feet)	w (meter)	Min. Θ_{ult} (m^2/sec)	Proposed Θ_{ult} (m^2/sec)
1	420	5	1.52	1.81E-04	1.00E-03
4	70	2	0.61	7.53E-05	1.00E-03

The toe drainage areas, Area 1 and Area 4, include only converging flow below the lowest intermediate drainage piping, as flow above this area is diverted. There are intermediate drainage pipes in Areas 1 and 4 which divert flow from the outlet corner to the downslope flume.

For converging flow in a circular arc, from radius R-top to radius R-bottom:

L = R-top - R-bottom

w-bot = w-top * (R-bot/R-top)

A = L* (1+ (R-bot/R-top))/2 (assuming unit width at top and trapezoid vs arc to simplify)

Θult-bot = (Θult calculated for L) * R-top/R-bot * (1+ (R-bot/R-top))/2

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Calc. No.	
Rev. No.	

Job No. 25220183.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 04/06/22
Client: WPL	Subject: Unit Gradient - Converging Flow Area	Chk'd: DLN	Date: 05/02/22

Calculation: (Cont.) For the southern convergence area, flow paths A-E, calculate Θult for selected R-bot values to determine appropriate geocomposite products as flow converges down the slope:

Flow Path	R-top (feet)	R-bot (feet)	L_h (feet)	L_h (meters)	Θ_{ult} (m^2/sec)	Proposed Θ_{ult} (m^2/sec)
Area 1						
A1	138	26	112	34	7.57E-04	1.00E-03
B1	132	24	108	32	7.34E-04	1.00E-03
C1	129	23	106	32	7.47E-04	1.00E-03
D1	126	21	105	32	7.91E-04	1.00E-03
E1	122	20	102	31	7.77E-04	1.00E-03
Area 2						
A2	306	138	168	51	5.79E-04	1.00E-03
B2	294	132	162	49	5.58E-04	1.00E-03
C2	286	129	157	47	5.34E-04	1.00E-03
D2	278	126	152	46	5.21E-04	1.00E-03
E2	270	122	148	45	5.11E-04	1.00E-03
Area 3						
A3	328	306	22	6	4.39E-05	1.00E-03
B3	357	294	63	19	1.49E-04	1.00E-03
C3	419	286	133	40	3.48E-04	1.00E-03
D3	319	278	41	12	9.10E-05	1.00E-03
E3	285	270	15	4	2.91E-05	1.00E-03

Conclusions: For the southern area proposed design with intermediate slope outlets and a toe-of-slope drainage outlet, placement of geocomposite with the required transmissivities to the minimum lengths/areas shown in the table above and on the attached drawing will provide adequate drainage for the converging flow.

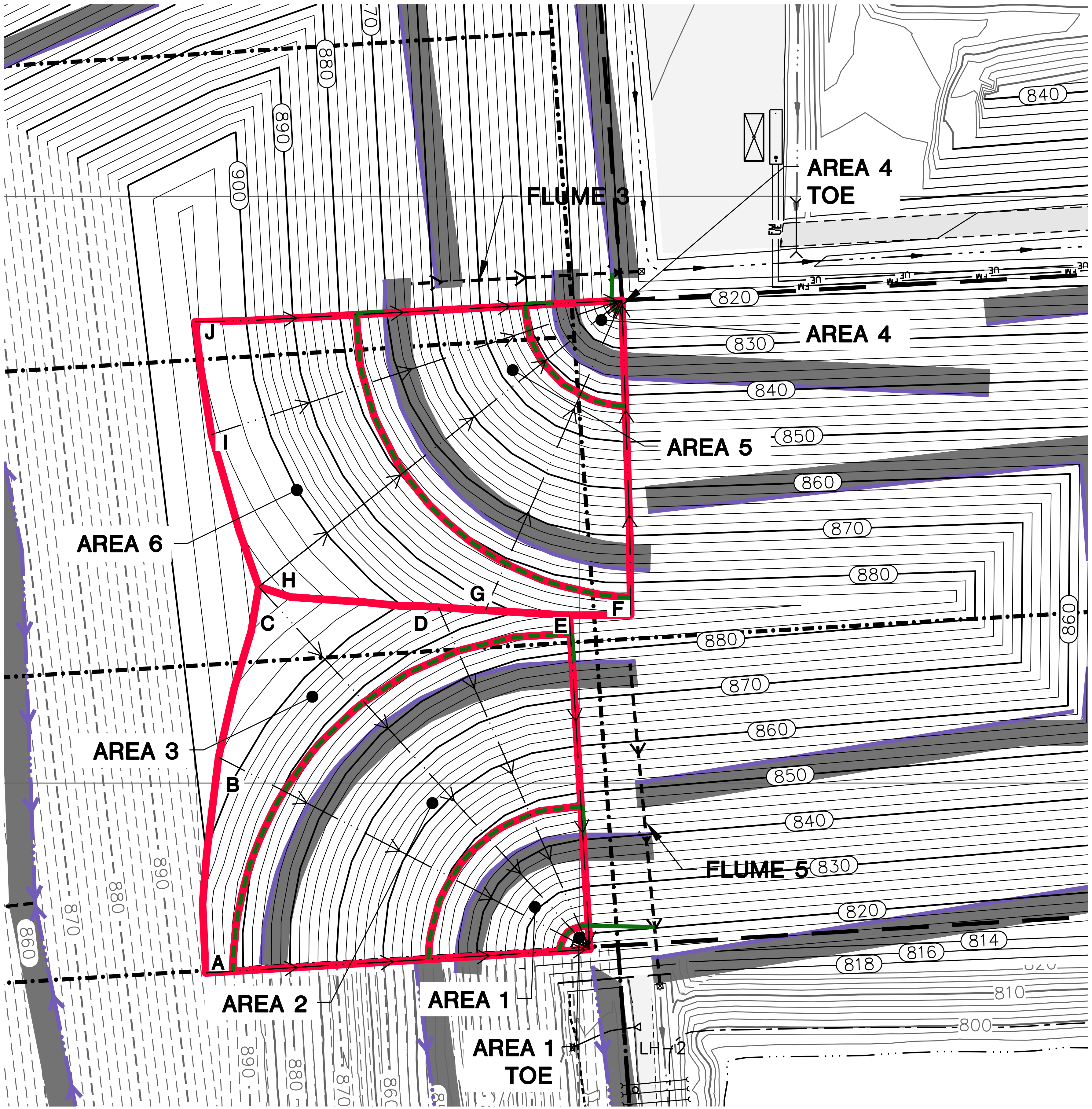
A minimum interface friction angle of 20.6 degrees for the geocomposite, geomembrane, and GCL interfaces is required to achieve a minimum recommended final cover slope stability safety factor of 1.5.

Calculation: (Cont.) For the northern convergence area, flow paths F-J, calculate Θult for selected R-bot values to determine appropriate geocomposite products as flow converges down the slope:

Flow Path	R-top (feet)	R-bot (feet)	L_h (feet)	L_h (meters)	Θ_{ult} (m^2/sec)	Proposed Θ_{ult} (m^2/sec)
Area 4						
F4	91	11	80	24	7.86E-04	1.00E-03
G4	87	10	77	23	7.88E-04	1.00E-03
H4	86	9	77	23	8.57E-04	1.00E-03
I4	84	9	75	22	8.03E-04	1.00E-03
J4	83	9	74	22	7.94E-04	1.00E-03
Area 5						
F5	254	91	163	49	6.56E-04	1.00E-03
G5	245	87	158	48	6.47E-04	1.00E-03
H5	237	86	151	46	6.10E-04	1.00E-03
I5	231	84	147	44	5.83E-04	1.00E-03
J5	227	83	144	43	5.67E-04	1.00E-03
Area 6						
F6	268	254	14	4	2.90E-05	1.00E-03
G6	289	245	44	13	1.00E-04	1.00E-03
H6	395	237	158	48	4.52E-04	1.00E-03
I6	368	231	137	41	3.75E-04	1.00E-03
J6	365	227	138	42	3.87E-04	1.00E-03

Conclusions: For the northern area proposed design with intermediate slope outlets and a toe-of-slope drainage outlet, placement of geocomposite with the required transmissivities to the minimum lengths/areas shown in the table above and on the attached drawing will provide adequate drainage for the converging flow.

A minimum interface friction angle of 20.6 degrees for the geocomposite, geomembrane, and GCL interfaces is required to achieve a minimum recommended final cover slope stability safety factor of 1.5.



LEGEND

- LIMITS OF WASTE
- LINER PHASE/MODULE LIMIT
- 810 — EXISTING GRADE (10' INTERVAL)
- EXISTING GRADE (2' INTERVAL)
- SWALE
- EDGE OF WATER
- WETLAND
- 840 — PROPOSED PHASE 1 FINAL GRADE (10' INTERVAL)
- PROPOSED PHASE 1 FINAL GRADE (2' INTERVAL)
- 840 — PROPOSED GRADE (10' INTERVAL)
- PROPOSED GRADE (2' INTERVAL)
- PROPOSED PERIMETER ROAD
- PROPOSED SWALE
- PROPOSED CULVERT
- PROPOSED LEACHATE COLLECTION SYSTEM CLEANOUT
- PROPOSED LEACHATE VAULT
- FM — PROPOSED LEACHATE FORCEMAIN
- UE — PROPOSED UNDERGROUND ELECTRIC
- PROPOSED DIVERSION BERM
- PROPOSED DOWNSLOPE FLUME
- PROPOSED ENERGY DISSIPATOR
- PROPOSED RIPRAP
- CONVERGENCE FLOW PATH
- PERFORATED SUBSURFACE PIPING
- SOLID SUBSURFACE PIPING

10 0 10

SCALE: 1" = 10'

GEOTECHNICAL CALCULATION – FLOW CONVERGENCE

FIGURE 1

SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

ENGINEER

PLAN OF OPERATION
2022 UPDATE
COLUMBIA DRY ASH DISPOSAL FACILITY
TOWN OF PACIFIC, WISCONSIN

SITE

DRAWN BY: KP/MJT
CHECKED BY: DN
APPROVED BY:

WISCONSIN POWER AND LIGHT
COLUMBIA ENERGY CENTER
W8375 MURRAY ROAD
PARDEEVILLE, WISCONSIN 53954

CLIENT

PROJECT NO. 25220183.00
DRAWN: 01/25/2022
REVISED: 05/02/2022

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SCS ENGINEERS

Sheet No.	1 of 1
Calc. No.	
Rev. No.	

Job No. 25220183.00	Job: Columbia Dry Ash Disposal Facility	By: MJT	Date: 04/25/22
Client: WPL	Subject: GCL Internal Shear on Final Cover	Chk'd: DLN	Date: 04/26/22

Purpose: Determine the maximum shear stress acting on a Geosynthetic Clay Liner (GCL) and the GCL internal shear strength required to provide a minimum slope stability safety factor (FS) of 1.5 for the final cover.

Approach: Use maximum shear stress formula and assumed values.

References: Design of GCL Barrier for Final Cover Side Slope Applications, Gregory N. Richardson, Ph.D., P.E., Geosynthetics '97-541

Calculation: The maximum shear stress acting on the GCL can be calculated as follows:

$$\tau_{act} = W_T \sin \beta$$

$$\beta = 14\ ^\circ$$

$$W_T = \gamma \ \text{X} \ h$$

Where:

γ	=	Soil Unit Weight	=	120	pcf
h	=	Cover Thickness	=	2.5	ft

$$W_T = 300 \text{ psf}$$

$$\tau_{act} = 72.6 \text{ psf}$$

$$FS = \frac{\tau_{resist}}{\tau_{act}} = 1.5$$

$$\tau_{resist} = FS \ \text{X} \ \tau_{act} = 1.5 \ \text{X} \ 72.6 = 109 \text{ psf}$$

Assumptions: Slope angle, $\beta = 14^\circ$ (4:1 horizontal / vertical final cover slope)

Soil unit weight, $\gamma = 120$ pcf

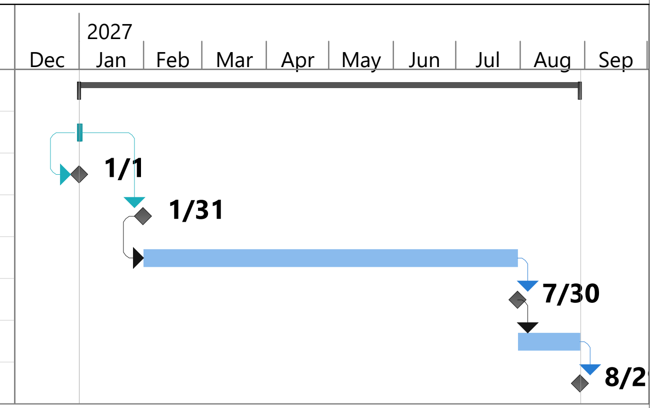
Conclusion: For a total weight of the final cover system of 300 psf and a slope angle of 4:1, the maximum shear stress will be 72.6 psf. A minimum GCL internal shear strength of 109 psf is required to provide a slope stability safety factor of 1.5.

Appendix B

Schedule

Closure Plan - Columbia Ash Disposal Facility

ID	Task Name	Duration	Start	Finish
1	**Closure of Columbia Ash Disposal Facility**	**241 days**	**Fri 1/1/27**	**Sun 8/29/27**
2	Ash Filling Ceases	1 day	Fri 1/1/27	Fri 1/1/27
3	Other Regulatory Permits - None	0 days	Fri 1/1/27	Fri 1/1/27
4	Notification of Intent to Close	0 days	Sun 1/31/27	Sun 1/31/27
5	Construction Activities	180 days	Mon 2/1/27	Fri 7/30/27
6	Notification of Closure Completion	0 days	Fri 7/30/27	Fri 7/30/27
7	Documentation of Closure	30 days	Sat 7/31/27	Sun 8/29/27
8	State Submittal of Documentation Report	0 days	Sun 8/29/27	Sun 8/29/27



Date: Tue 1/31/23

Task		Inactive Summary		External Tasks	
Split		Manual Task		External Milestone	
Milestone		Duration-only		Deadline	
Summary		Manual Summary Rollup		Progress	
Project Summary		Manual Summary		Manual Progress	
Inactive Task		Start-only			
Inactive Milestone		Finish-only			