SOLMAX

TECHNICAL NOTE

HYDRAULIC EQUIVALENCY COMPARISON

CFR Prescriptive Liner System vs. Coal Ash Barrier System

The Code of Federal Regulations (CFR) defines performance based technical criteria for solid waste landfill liner design alternatives in terms of predicted impacts on groundwater as the basis for approval by the Director of an approved State.

This approach first requires the designer to estimate the amount of leakage through the liner system into the unsaturated subsurface vadose zone below the lining system. Next, the movement of leachate from leaks in the liner system to an assumed point of compliance (e.g. a groundwater monitoring well) is modeled. Analysis of this kind is required in order to demonstrate that potential leakage through the alternative liner system will keep groundwater concentrations of certain chemical constituents below regulatory thresholds (often called Maximum Contaminant Levels, or MCL's) at the point of compliance.

The objective of a hydraulic equivalency evaluation is to demonstrate that the environmental performance (i.e. leak prevention) of the alternative liner system will be equal or superior to that of the prescriptive composite liner system design as prescribed in CFR Title 40: Part 258, Subpart D. The following calculations will estimate the leakage rates for the CFR prescriptive liner system as compared to the Coal Ash Barrier System as manufactured by GSE Environmental, LLC. The Coal Ash Barrier System consists of Coal Drain Geocomposite, Leak Location Liner Geomembrane, and Coal Ash Resistant Geosynthetic Clay Liner (GCL) elements which overlay the subgrade foundation. The purpose of these calculations is to demonstrate that the Coal Ash Barrier System design provides equivalent or superior performance to the minimum performance standard as set forth in CFR Title 40: Part 258, Subpart D *Design Criteria.*

Equivalency parameters

The Giroud leakage equation is currently the accepted industry model for the evaluation of leakage through defects in composite lining systems. The basis of this equation is referenced in the *U.S. EPA Technical Manual (1993)*, and is incorporated into the latest versions of the HELP computer model *(U.S. EPA, 1994)* used for predicting leachate generation and leakage. Please note that the "Giroud" leakage equation is empirical in nature. This equation can only be used with the dimensional units indicated. For the purpose of this Technical Note, the terms "hole" and "defect" will be used interchangeably to describe liner damage which occurs during protective cover placement activities.

$$Q = C\,[1 + 0.1\,(hw/t)^{0.95}]\,a^{0.1}\,h_w^{0.9}\,k_s^{0.74} \text{ per defect}$$

Q = Rate of leakage through a defect (m^3/s)

C = A dimensionless constant related to the quality of the intimate contact between the geomembrane and underlying clay liner or Geosynthetic Clay Liner (GCL)

hw = Liquid head on top of the geomembrane (m)

t = Clay soil or GCL element thickness of the composite liner (m)

a = defect area in geomembrane (m^2)

ks = Clay soil or GCL element hydraulic conductivity of the composite liner (m/s)

Parameters typically considered for a hydraulic equivalency demonstration are the liquid head, the number and size of defects in the geomembrane, the clay or GCL bentonite permeability and thickness, and the degree of intimate contact and composite action between the geomembrane and the underlying compacted clay or GCL. Each of these parameters is briefly discussed below.

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Liquid Head – Drainage is relevant here to the extent that it affects the assumed hydraulic head build-up above the liner system. Liquid head build-up is a primary controlling factor affecting potential leakage rates. CFR allows no more than 12 inches of liquid head build-up above the liner. Therefore, this is a conservative value to use for leakage calculations. Since assuming the maximum allowable head can significantly affect the calculation, the hydraulic head that will actually occur above the lining system can also be estimated utilizing the HELP model (*U.S. EPA, 1994*).

Geomembrane Defects – The number and size of defects that are assumed to occur in the geomembrane above a compacted clay or GCL will directly influence the volume of liquid that will presumably migrate through and below the liner. Please note that the number of defects is critical in regard to the resulting leakage rate. Solmax geomembranes are 100% spark tested for pinholes (defects with a diameter equal or smaller than the geomembrane thickness) during manufacturing to ensure that there are no manufacturing defects in Solmax membranes.

As a matter of practice in estimating the number of defects per unit area in an installed geomembrane, industry guidelines suggest that 1 to 4 defects per acre exist after a geomembrane is placed and covered with soil. Studies by *Giroud and Bonaparte (1989)* have shown that geomembrane liners installed with strict construction quality assurance could have as few as 1 to 2 defects per acre. State regulatory agency regulations require inspection for uniformity, damage, and imperfections immediately after construction or installation; therefore we can assume that a strict quality assurance program will be followed. Assuming strict quality assurance, a defect area of 1 sq.cm per defect is appropriate (*Giroud et all., 1994*) for both the CFR prescriptive liner system and the Coal Ash Barrier System.

In this equivalency demonstration, it is appropriate and conservative to assume that the number of defects per acre in the geomembrane will not be the same for both the CFR prescriptive liner system and the Leak Location Liner Geomembrane element of the Coal Ash Barrier System. An Electrical Liner Integrity (ELI) survey is typically performed to identify and repair liner installation defects after the protective cover soil has been placed over the geomembrane liner. Recent studies by *Gallagher and Beck (2012)* document that ELI surveys, performed in accordance with ASTM method D7007, more accurately identify liner installation defects over a wider variety of soil-moisture conditions and liner-contact situations when utilizing an electrically conductive geomembrane such as Leak Location Liner Geomembrane. Table 1 can be referenced to estimate the defects per acre.

Hydraulic Conductivity – Hydraulic conductivity has a significant influence on leakage rates. The compacted clay liner or GCL is incorporated into the composite liner system to act as a back-up to potential breaches through the geomembrane. For the CFR prescriptive liner system, this maximum value ($1x10^{-7}$ cm/s) is determined by the regulations for the compacted clay liner. The bentonite component function in a GCL is to swell and seal against potential liquid migration through the liner. Therefore, the inquiry into the hydraulic conductivity of GCL is focused on the bentonite portion of it. For GCL's, the hydraulic conductivity is dependent upon the normal service load above the lining system, and the bentonite's chemical compatibility with project specific leachate. As the normal service load on the GCL increases, the GCL's hydraulic conductivity and thickness decrease as it is compressed. This statement is accurate as long as the bentonite is chemically compatible with the project specific leachate.

Installation quality	Defect density per acre	CFR Prescriptive Liner System	Coash Ash Barrier System
Excellent	Up to 1		X
Good	1 to 4	X	
Fair	4 to 10		
Poor	10 to 20		

Table 1: Defect density based on installation quality

The subgrade conditions will be the same for both the CFR prescriptive liner system and the Coal Ash Barrier System. Therefore, it has not been included in the following hydraulic equivalency calculations.

Intimate Contact – When there is a defect in the geomembrane, the liquid first passes through the defect, then it flows laterally some distance between the geomembrane and the underlying material until it finally infiltrates into the low permeability soil or GCL component of the composite liner system. Flow between the geomembrane and underlying clay soil or GCL is called interface flow, and is highly dependent upon the contact quality between the two elements (*Bonaparte et al., 1989*). The fundamental basis for the difference in flow between various levels of intimate contact can be related to the transmissivity at the interface zone between the geomembrane and underlying clay soil or GCL. The potential for lateral seepage between the geomembrane and a GCL has proven to be much less than that between a geomembrane and compacted clay (*Rowe 1998*).

As illustrated in Figure 1, good intimate contact between the geomembrane and underlying clay soil or GCL minimizes lateral seepage at the interface, thus reducing overall leakage.

Poor contact conditions correspond to a geomembrane that has been installed with a certain number of wrinkles, and/or placed on a low-permeability soil that has not been well compacted and does not appear smooth.

Good contact conditions correspond to a geomembrane that has been installed with as few wrinkles as possible on top of a low permeability soil that has been adequately compacted and has a smooth surface. This is typical of a compacted clay liner and fabric encased GCL when installed under strict construction quality assurance.

Excellent contact conditions correspond to a geomembrane supported GCL that has been placed on top of an adequately compacted soil with a smooth surface. This is typical of a geomembrane supported GCL when installed under strict quality assurance.

Figure 1: Comparison of a) Good and b) Poor Intimate Contact between geomembrane and clay elements of a composite liner system.

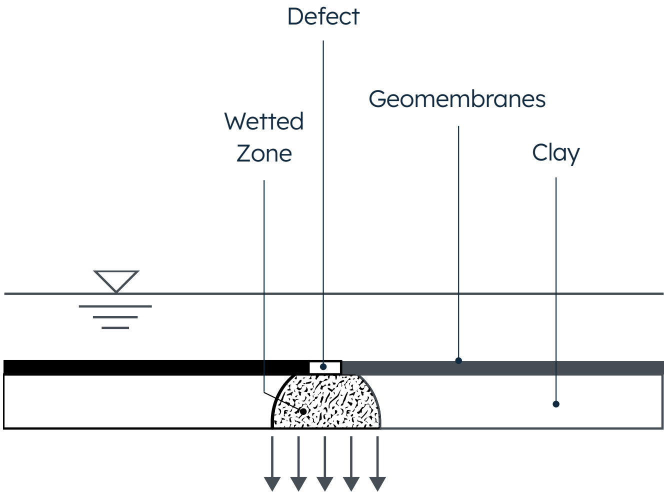


Figure 1a: Good intimate contact

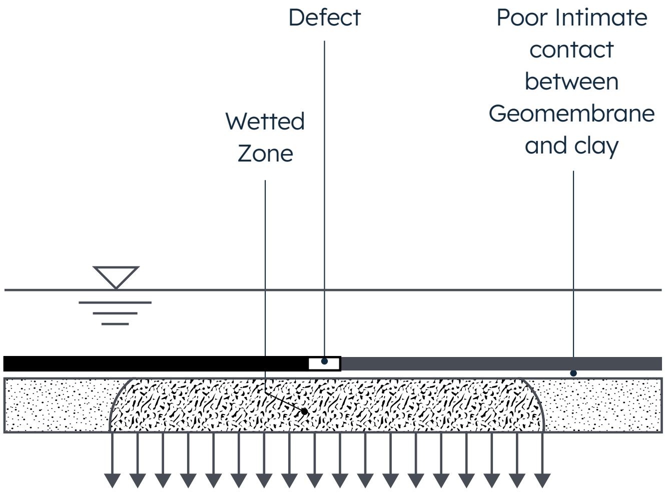


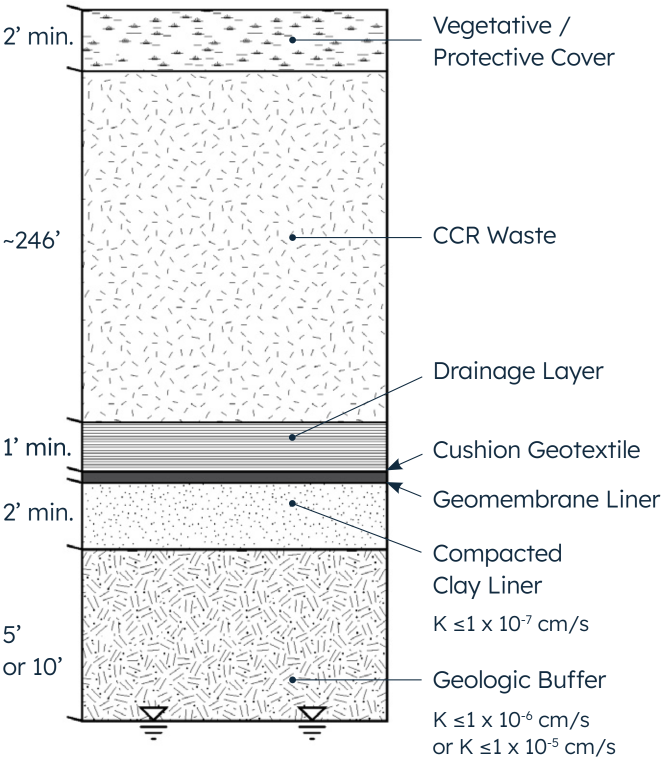
Figure 1b: Poor intimate contact

Interface	Contact quality	Contact factor (C)
Geomembrance/Compacted Clay Liner	Good	0.21
	Poor	1.15
Geomembrance/Fabric Encased GCL	Good	0.10
	Poor	0.50
Geomembrance Supported GCL	Excellent	0.01

Table 2: Defect density based on installation quality

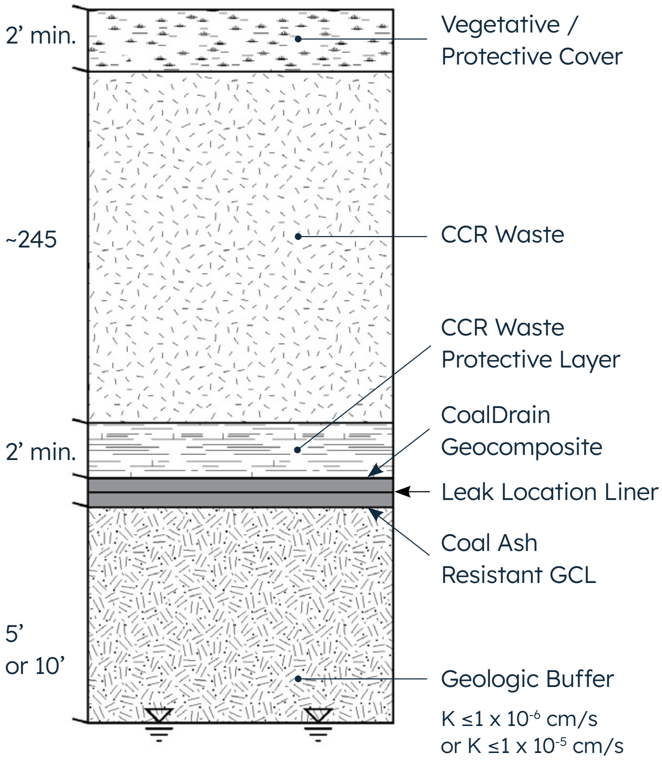
Hydraulic equivalency calculations example

Example calculations are presented below which compare leakage rates between the prescriptive CFR composite bottom liner system (geomembrane/compacted clay soil) and the Coal Ash Barrier System alternative liner system for a typical CCR waste containment application. Figure 2 illustrates the cross-sections for each liner system. The design parameters modeled are as follows:



NOTE: To arrive at 25,000 psf maximum normal load, 100 psf was assumed for the CCR Waste Unit weight.

Figure 2a: CFR Prescriptive Liner System



NOTE: To arrive at 25,000 psf maximum normal load, 100 psf was assumed for the CCR Waste Unit weight.

Figure 2b: Coal Ash Barrier System

The challenge

Given a CCR waste landfill where the designer wishes to use Coal Ash Barrier System as an alternative single composite liner, provide hydraulic equivalency calculations to demonstrate that potential leakage will be no greater than that of a prescriptive CFR composite liner.

The situation

1. Strict construction quality assurance is maintained over the liner system installation.
2. Maximum normal load on the bottom liner system in the landfill is 25,000 psf (~ 1,200 kPa).
3. "Good" Installation Quality (Table 1) and Intimate Contact (Table 2) for the CFR prescriptive liner system. Therefore, it is appropriate to select two (2) defects per acre in the CFR prescriptive liner system with a typical defect area of 1 cm^2 (0.0001 m^2).
4. "Excellent" IInstallation Quality (Table 1) and "good" Intimate Contact (Table 2) for the Coal Ash Barrier System. Therefore, it is appropriate to select one (1) defect per acre in the Coal Ash Barrier System with a typical defect area of 1 cm^2 (0.0001 m^2).
5. Giroud leakage equation to determine leakage through defect.
6. Liquid head: Maximum allowable = 12 in (300 mm) for CFR prescriptive liner system.
7. Liquid head: Maximum allowable = 7.5 mm (300 mil CoalDrain Geocomposite thickness) for Coal Ash Barrier System.
8. The Coal Ash Resistant GCL element in the Coal Ash Barrier System has demonstrated satisfactory chemical compatibility performance with the site specific leachate when tested in accordance with ASTM D6766, Scenario 2 for a minimum 6-month time duration.

Design assumptions

The CFR prescriptive liner consists of a welded 60 mil (1.5 mm) HDPE geomembrane overlying a 2 ft (600 mm) thick compacted clay liner having a hydraulic conductivity k ≤ 1 x10^{-7} cm/s = 1 x10^{-9} m/s.

Analysis

First, determine the hydraulic conductivity of the GCL bentonite under the operational conditions. The specified maximum hydraulic conductivity for the Coal Ash Resistant GCL elemeProblent in the Coal Ash Barrier System is 5x10^{-9}cm/s. Because the Coal Ash Resistant GCL hydraulic conductivity will decrease as the normal load increases, we can assume the bentonite specified maximum hydraulic conductivity value k = 5x10^{-9} cm/s = 5x10^{-11} m/s for the purpose of this design example. As noted previously, as the normal load increases the GCL thickness will decrease. Based on the normal load ranging from 20 psf to 25,000 psf, the bentonite thickness will range from 8 mm down to 2.5mm at the maximum 25,000 psf normal load. To be conservative, we will use a 2.5 mm bentonite thickness in the Coal Ash Barrier System leakage rate calculations.

Leakage through holes in the geomembrane is calculated as follows (from Giroud Leakage Equation):

$$Q = C\,[1 + 0.1\,(hw/t)^{0.95}]\,a^{0.1}\,h_w^{\,0.9}\,k_s^{\,0.74} \text{ per defect}$$

From Table 2, the C-value for “good” contact quality using a geomembrane/compacted clay liner interface is 0.21.
If hw = 1 ft (300 mm), then leakage through the CFR prescriptive composite liner would be estimated as:

$$Q = 0.21\left[1 + 0.1\left(\frac{0.3}{0.6}\right)^{0.95}\right](0.0001)^{0.1}\,(0.3)^{0.9}\,(1x10^{-9})^{0.74}$$

$$Q = 6.5x10^{-9}\ m^3/s = 0.149\ gpd \text{ per defect}$$

From Table 2, the C-value for “good” contact quality using a geomembrane/fabric encased GCL is 0.10. If h = 7.5 mm, then leakage through the Coal Ash Barrier System alternative liner design would be estimated as:

$$Q = 0.10\left[1 + 0.1\left(\frac{0.0075}{0.0025}\right)^{0.95}\right](0.0001)^{0.1}\,(0.0075)^{0.9}\,(5x10^{-11})^{0.74}$$

In this scenario, there is significantly less leakage through a defect in the Coal Ash Barrier System as compared to a defect in the CFR prescriptive liner. Table 3 provides a summary of the leakage rate per acre for the given design scenario.

Liner system	No. of holes (per acre)	Leakage per hole (gallons per day per acre)	Total leakage (gallons per day per acre)
GCFR Prescriptive	2	0.149	0.298
Coash Ash Barrier	1	0.00034	0.00034

Table 3: Calculated leakage rate comparison for the bottom liner design

Given two defects per acre (Table 1), the total leakage rate for the CFR prescriptive liner system would be:

$$Q_{TDEC} = (2\ defects)\ (0.149\ gpd) = 0.298\ gpd$$

Given 1 defect per acre (Table 1), the total leakage rate for the Coal Ash Barrier System would be:

$$Q_{TDEC} = (1\ defect)\ (0.00034\ gpd) = 0.00034\ gpd$$