GEOSYNTHETIC CLAY LINERS UTILIZED FOR ENHANCING CONSTRUCTED WETLANDS

Over 5 million square feet of geosynthetic clay liner (GCL) has been installed in constructed wetlands since these products were commercialized in the early 1980s. The use of GCLs has been predicated largely on the advantages they offer over traditional compacted clay liners in wetland projects. This paper outlines the benefits of utilizing a GCL instead of compacted clay in engineered / constructed wetlands. Benefits discussed include the GCL's superior hydraulic performance, its resistance to desiccation, its ability to withstand differential settlement and root penetration, and finally, the ease and speed of construction. Also included in the paper is a summary of several projects where GCLs have been utilized on wetlands projects in the USA.

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ABSTRACT: Geosynthetic clay liners (GCLs) are manufactured barrier layers containing a competent layer of high-quality sodium bentonite clay attached or adhered to geotextiles or a geomembrane. The GCL's low permeability and high strength make it an ideal replacement for low permeability soil or clay liners for the containment of water and/or wastewater in engineered/constructed wetlands.

This paper will discuss the benefits of utilizing a GCL versus compacted clay in constructed wetlands. Some of the benefits to be compared include the GCL's lower permeability [5 x 10^{-9} centimeters per second (cm/sec)], the GCL's greater resistance to desiccation, differential subsidence, freeze-thaw, and root penetration, and lastly, the ease and speed of installing the GCL.

This paper will also detail a number of important case studies related to using GCLs in both rural and urban constructed wetlands. These case studies are summarized below:

- Wetlands and stormwater control in the urban Seattle metropolitan area.
- Wetlands and stormwater control in a developing community in the North Natomas area of Sacramento, California.
- Wetlands preservation for a state correctional facility in Buckeye, Arizona.
- Wetlands preservation at a precious metals mine reclamation project in Colorado Rocky Mountains.
- Wastewater treatment using wetlands at a rural American Indian community in Wyoming.

INTRODUCTION

A GCL is a high quality, high-swelling sodium bentonite clay adhered or attached to manufactured geotextiles or flexible geomembranes. GCLs have been manufactured since the mid-1980's, initially used in double-lined landfill liner systems (Koerner, R.M., 1996). The structure of interlayer sodium cations makes sodium bentonite hydrophilic (water attracting). The sodium cation clay structure readily accepts water molecules so that little free-water space is available in the clay voids, hence, maximum water permeabilities of 5 x 10^{-9} cm/sec are readily obtained using GCLs. GCLs contain clays that contain swell index characteristics of at least 24 ml per 2 grams of bentonite using ASTM Method D-5890, and maximum fluid loss values of 18 ml using ASTM Method D-5891. All GCLs contain an industry standard minimum of 0.75 pounds of sodium bentonite clay per square foot (3.65 kilograms per square meter) of material as measured using ASTM Method D-5993.

There are unreinforced and reinforced GCLs available for use. Unreinforced products are manufactured using either adhesives and/or pressure.

These products incorporate the use of a geotextile or flexible geomembrane to carry the bentonite layer. The unreinforced GCL is used on slopes gentler than 10:1, such as on the flat areas of reclamation caps, leaching facilities, and fluid containment basins. The reinforced GCLs are manufactured by needlepunching or stitch-bonding the top and bottom geotextiles together to encapsulate the sodium bentonite layer. The physical bonding of the geotextiles enhances the GCLs internal resistance to shearing and creep.

Construction Issues. GCL is typically manufactured in rolls 13.8 to 15.5 feet (4.2 to 4.7 meters) wide and 150 feet (45.7 meters) long, and weigh upwards of 2,800 pounds (1,200 kilograms), so applicable offloading and installing equipment should be used that can withstand the heavy roll loads. The panels are overlapped typically 6 to 12 inches (150 to 300 mm) depending upon the application. If the GCL is not self-seaming (i.e., needlepunched products), then a thin layer of granular sodium bentonite is applied in the overlap seam at a typical rate of 0.25 pounds (375 grams) per lineal foot of seam. Self-seaming GCLs do not require additional sodium bentonite.

GCLs are covered with a minimum of 12 inches (300 mm) of soil to protect the liner and provide confinement to the sodium bentonite layer (Figure 1). The 12-inch minimum soil cover is deployed onto the GCL in a single lift using standard earthwork equipment. Many constructed wetlands will utilize additional growth sustaining soil layers on top of the initial 12-inch (300 mm) protective layer to optimize aquatic fauna and flora development.

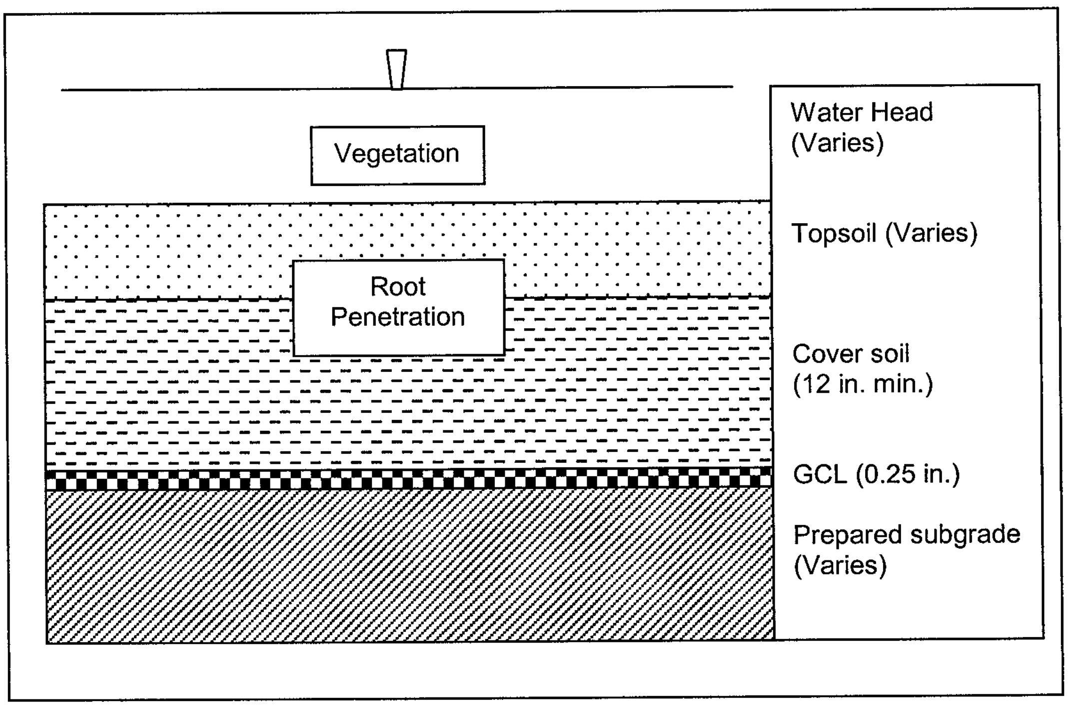

FIGURE 1. Typical GCL barrier layer cross section

Design Issues. Designing wetland seepage control using GCL is a simple process. Table 1 summarizes some of the design issues that are common to both GCLs and compacted clay liners. A discussion of liner leakage follows Table 1.

TABLE 1. GCL design issues for constructed wetlands.

Design issues	Suggested design activities
Freeze-thaw	Freeze-thaw has been proven not to affect the performance of the GCL, unlike compacted clay (see Kraus, et al., 1997; Hewitt and Daniel, 1997).
Desiccation	Desiccation has been proven not to affect the performance of the GCL, unlike compacted clay (see Boardman and Daniel, 1996).
Root penetration	Normal root growth has been shown to have minimal impacts on the performance of a GCL in a wetlands system. If deep-rooted shrubs or trees are needed for enhancing a riparian environment, CETCO recommends digging a pilot hole first through the GCL, installing the vegetation, then backfilling with granular bentonite at the junction of the GCL and trunk.
Differential settlement	Most GCLs can withstand over 10 percent tensile strain before hydraulic conductivity increases (see LaGatta et al., 1997), therefore, this should not be a critical design issue for wetlands. If settlement is still a concern, increase overlap of panels to 12 to 18 inches to minimize panel overlap "pullout."
Subgrade preparation	Subgrade needs to be prepared so that protrusions greater than ½ to 1-inch are minimized. Additionally, the subgrade should contain minimal voids caused by too much coarse-grained soil material.
Chemical compatibility	Design using cover soils or water that do not have elevated leachable Calcium and Magnesium cations (i.e. limestone or dolomite). If a problem persists, you can design a GCL with a chemical resistant bentonite, or possibly a composite laminate.

Leakage Assessment. GCL and compacted clay liner leakage rates can be estimated using one or a combination of methods as summarized below. GCL leakage is most commonly estimated by converting laboratory Index Flux measurements (ASTM D-5887) in cubic meters per square meters per second ($m^3/m^2/s$) to gallons per day per acre (gpd/acre) of leakage. For example, a GCL Index Flux measurement of 1×10^{-8} $m^3/m^2/s$, translates into a panel leakage of 925 gallons per acre per day at a water head of 4.5 feet (1.37 m).

Compacted clay liner leakage can be measured either in the field or in the laboratory. A sealed double ring infiltrometer (SDRI) using ASTM D-5093 (U.S. EPA, 1988) is the most accurate measurement of field "in situ" permeability. This apparatus, unfortunately, is expensive and time consuming.

Consequently, the most common approach to measuring permeability is to collect relatively undisturbed compacted clay samples in the field and measure the samples in the laboratory using a fixed or flexible wall permeameter. These results can be extrapolated into an "in-situ" permeability by using a multiplier of at least 5-fold, since researchers have determined that laboratory-measured clay layers always exhibit a lower permeability than what is measured in field "in-situ" tests (Rogowski, 1990). The leakage through the clay liner can then be estimated using the measured permeability and Darcy's Law. Darcy's Law (Equation 1) is a one-dimensional equation estimating the flow of fluids through a soil layer.

$$Q = kiA \qquad (1)$$

Where Q = Flow (cm^3/sec)
i = Hydraulic Gradient ($((l+h)/l)$) (unitless) where l = liner thickness (cm) and h = water head or water depth (cm).
A = Area in squared centimeters (cm^2)
k = Hydraulic conductivity (cm/sec)

Q/A, also known as flux, can be further converted from $cm^3/cm^2/sec$ to gpd/acre using a 9.225×10^8 conversion factor.

Figure 2 contains a leakage comparison between two GCL products and two different compacted clay liners. The y-axis is gpd/acre, and the x-axis is water head in feet. The two GCL products are a standard GCL product (referred to as "Bentomat ST") with a maximum index flux ASTM D5887 of 1×10^{-8} $m^3/m^2/sec$, and an enhanced GCL product or composite laminate (referred to as "Bentomat CL") that contains a maximum index flux per ASTM D5887 of 1×10^{-9} $m^3/m^2/sec$. The two compacted clay liners are a 12-inch thick layer (referred to as "Pond Clay") containing a maximum "in-situ" hydraulic conductivity of 1×10^{-6} cm/sec, and a 24-inch thick layer (referred to as "Landfill Clay") containing a maximum "in-situ" hydraulic conductivity of 1×10^{-7} cm/sec.

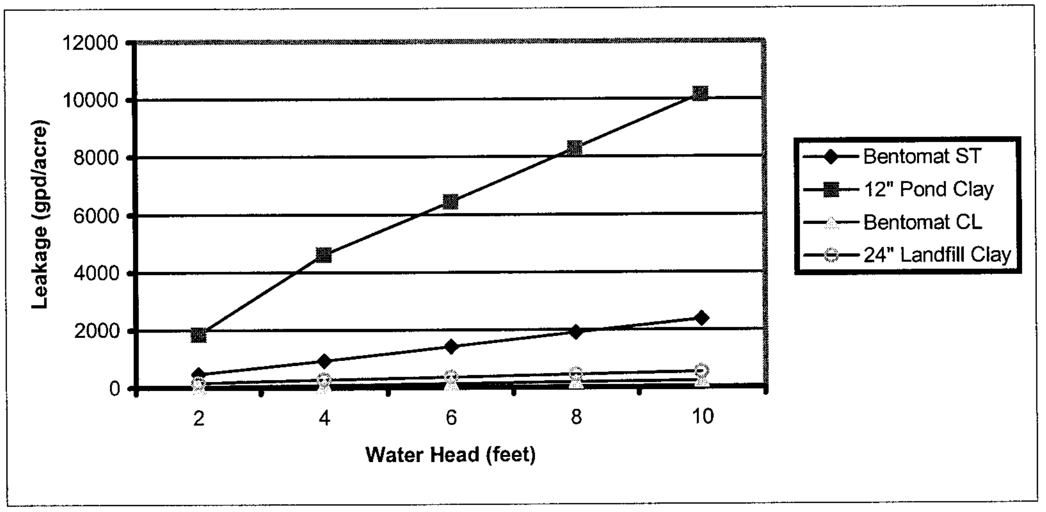

FIGURE 2. Leakage estimates for GCL and Compacted Clay

Figure 2 indicates that the 12" pond compacted clay leakage rate is substantially greater than the Bentomat leakage rate. For instance, the leakage of a pond clay system at a nominal water head of 6 feet is 4 times greater than Bentomat ST and 45 times greater than Bentomat CL. The 24-inch thick landfill clay system has lower leakage rates than the Bentomat ST, however, the cost to construct this liner is likely more expensive than the Bentomat depending on whether clay is available on site, off site, or bentonite is needed to amend the soil layer to achieve the desired permeability.

APPLICATIONS

GCLs have been specified or used in enhancing constructed wetlands for the following applications.

- Municipal wastewater treatment wetlands.
- Septage treatment wetlands.
- Municipal stormwater runoff containment and filtration.
- Wetlands mitigation driven by Section 404 of the Federal Clean Water Act.
- Wetlands for waterfowl and fishery enhancement.
- Riparian corridor enhancement.
- Transportation corridor runoff control.
- Estuarine ecosystem enhancement.

CASE STUDIES

Below is a summary of 22 case studies where GCL has been used in wetlands across the United States. The majority of the case studies are for satisfying wetlands mitigation objectives, enhancing transportation corridors with wetlands, or for containing wastewater during wetlands treatment.

<u>Celebration Park Wetlands</u>. About 185,000 ft^2 of GCL was installed in drainage channel and detention ponds for a major sports complex in Federal Way, Washington. Detention ponds are used to filter stormwater and create wetlands environment. Project completed in 1998.

<u>Clark Tailings Wetlands</u>. Wetlands constructed on top of reclaimed mine tailings facility in Butte, Montana. The wetlands were constructed with 310,000 ft^2 GCL to contain runoff, reduce seepage to the tailings facility, and provide a water feature for future parkland. Project completed in 1998.

<u>Burlington NJ DOT Wetlands</u>. GCL was used to replace compacted clay for a 170,000 ft^2 wetlands basin adjacent to a major transportation corridor in Burlington, New Jersey. Project completed in 1997.

Fort Washakie Wetlands Treatment System. About 96,000 ft^2 of composite laminate GCL was used to control seepage in wetlands treatment cells constructed in Fort Washakie, Wyoming. Project completed in 1998.

Great Plains Wetlands. About 113,000 ft^2 of composite laminate GCL was used to repair leaking wetlands pond for wastewater treatment project serving rural American Indian community in Riverton, Wyoming. Project completed in 1999.

Henderson Mill Wetlands. About 99,000 ft^2 of GCL used to enhance wetlands as part of a reclamation program at a toxic metals millsite in the Colorado Rocky Mountains. Project completed in 1999.

Lewis Correctional Facility Wetlands. About 376,000 ft^2 of GCL used in wetlands restoration project in Buckeye, Arizona. Project completed in 1999 using inmate day labor to install the GCL.

Lower Arroyo Seco Wetlands. About 280,000 ft^2 of GCL used to restore a streambed and create a wetlands in Pasadena, California. 1996 project was part of a wetlands mitigation project by a major waste disposal company.

Mahwah NJ DOT Wetlands. About 1,300,000 ft^2 of GCL was installed in a wetlands mitigation project along the Interstate 287 in Mahwah, New Jersey. A geocomposite drainage blanket (GDB) was placed underneath the GCL in areas where free drainage of marsh water was needed. A geogrid was placed above the GCL so cover soil could be placed on top of the liner system using standard earthmoving equipment. The project was completed in 1994 after 18 months of construction (Trauger and Burgio, 1994).

NE 124th Street Stream Restoration. About 125,000 ft^2 of GCL installed below an engineered stream channel that discharges into the Sammamish River, Renton, Washington. Root wads and logs were placed above GCL cover soil to provide native fish habitat. Project completed in 1999.

Newport North Wetlands. About 50,000 ft^2 of GCL used in Newport, Delaware to restore a wetlands during a major site remediation project for a major chemical company. Project completed in 1997.

Oakley School Wetlands. About 44,000 ft^2 of GCL installed in an Oakley, Utah elementary school wetlands mitigation project. Project completed in 1998.

Pennsylvania DOT Wetlands. Various projects have been completed using GCL in roadside ditches and wetlands. Over 500,000 ft^2 of GCL has been used since 1992.

Ramapo Landfill Wetlands. About 32,000 ft^2 of composite laminate GCL was used for wetlands adjacent to a Hillburn, New York solid waste landfill. Project completed in 1997.

Quantico Wetlands Restoration. About 100,000 ft^2 of GCL was installed to restore a wetlands at a major marine base. The installation contractor received a value engineering alternative (VEA) to install GCL in lieu of compacted clay. Project completed in 1997.

Santa Fe Sports Complex. About 382,000 ft^2 of GCL was used to reduce seepage in a wetlands/pond network containing secondary treated wastewater. 1997 project constructed at a Santa Fe, New Mexico sports complex that includes ball fields and a championship golf course.

Starno Road Site Improvements. Over 1,100,000 ft^2 of GCL was used in a constructed stormwater/wetlands detention basin at a road construction project in Melbourne, Florida. The GCL was found to be substantially lower cost than compacted clay. Project completed in 1996.

Stow Botanical Gardens. About 150,000 ft^2 of composite laminate GCL was used in aesthetic holding ponds and wetlands in a major botanical gardens in Charlotte, North Carolina. Project completed in 1996.

UDOT Bangerter Rd. Wetlands. About 60,000 ft^2 of GCL installed during transportation improvement project in Salt Lake City, Utah. Project completed in 1998.

Wal Mart Detention Wetlands. About 42,000 ft^2 of GCL installed in a detention wetlands pond in Chambersburg, Pennsylvania. Project was constructed adjacent to major retail store parking lot in 1997.

Westchester Airport Wetlands. About 131,000 ft^2 of GCL installed in a shallow wetlands mitigation project in Westchester, New York. Project was completed in 1997.

Woodward Meadows Wetlands. About 70,000 ft^2 of GCL installed in shallow wetlands mitigation project at Federal Highway Administration project outside of Chewelah, Washington. Project completed in 1999.

SUMMARY

Over 5 million ft^2 of GCL has been installed in constructed wetlands because it is easy to install, cost effective, meets leakage performance requirements, and is resistant to many physical and climatic issues that may affect the performance of compacted soil or clay liners. Additionally, GCLs are accepted by Federal and State Regulatory Agencies as an equivalent substitute to compacted clay for containing water and wastewater in wetlands.

The use of GCLs for enhancing constructed wetlands should continue to increase as more demands are placed on conserving water in wetlands mitigation projects, and lastly, for meeting leakage requirements for wetlands wastewater treatment and urban stormwater filtration and treatment systems.

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