Proceedings of Geosynthetics Mining Solutions, 2014
September 8—11, 2014, Vancouver, Canada
Published by InfoMine, © 2014 InfoMine, ISBN: 978-0-9917905-5-5

Advanced Geosynthetic Systems Mitigate Erosion at Mine Sites by Delivering Closure and Armoring Channels

Melissa Grace, Agru America, Inc., USA
Bradford Cooley, Watershed Geosynthetics LLC, USA

Abstract

Control of erosion is an ever-present mine challenge, and there are two areas of great concern at a mine when trying to control erosion: closures of waste piles and drainage channels. Since water quality and quantity is of primary importance today, final cover system designs and erosion protection of channels is defined by efforts to protect what is slowly becoming a limited resource. Therefore, many state-mandated mine-closure plans are developed by minimum-performance criteria to protect water resources. However, current practice of closures and stormwater conveyance at sites still put owners at high risk, resulting in increased financial liabilities in upkeep and maintenance associated with erosion prevention to preserve facility integrity. Balancing the well-being of the environment and economics continues to plague the industry, as erosion control activities impact profitability for mining companies.

Recently, the introduction of advanced geosynthetic systems has removed the need for large amounts of soil to construct covers for waste and erosion-protection applications. The technologies are Engineered Synthetic Turf (EST) Systems, and they perform better, look better, and are more economical when compared to traditional solutions. EST Systems are comprised of three main components: a high-friction structured geomembrane overlain by engineered synthetic turf, which is infilled with sand. Substite the sand for a high-strength, 5,000 psi (34 Mpa) cementitious material, and the system becomes a Concrete-Enhanced Synthetic Turf (CEST) Revetment System capable of outperforming traditional hard-armor when in application subjected to concentrated flows, extremely high velocities, or shear stresses (such as drainage channels). The EST/CEST Systems are virtually maintenance-free, have a design life exceeding one hundred years when properly maintained, and are new approaches to managing severe erosion challenges. This paper provides general discussion about the performance criteria of the systems, followed by a presentation of additional features and benefits, and concludes with a case study of the EST/CEST systems working in concert at a closed waste facility.

Introduction

The EST and CEST Systems represent a sophisticated approach to erosion prevention as they introduce the idea of a "geosynthetic erosion layer." Three components of the systems include: a high-friction structured geomembrane overlain by an engineered synthetic turf, which is infilled with sand or a binded infill depending upon the magnitude and type of erosive forces present in site specific locations. For final-closure applications, the EST Cover System is growing in acceptance since it meets regulatory requirements and can be less costly to construct (as it does not require large amounts of soil). Also, it provides for erosion and wind resistance, long-term geomembrane integrity, ease of accessibility, is quick and easy to install, and is very economical to maintain during the mandated thirty-year postclosure maintenance period. Since the technology's introduction to the industry in 2009, EST Cover Systems have been installed at over twenty facilities across the United States, totaling over 139 ha in service to date.

Additionally, the EST Cover System can be further enhanced for use in areas at mine sites where channelized flow of surface water exists. These areas may be an integral part of a heap leach or tails dam closures such as downchutes and bench drains, or may be unrelated to a closure, such as drainage channels used in daily operations or to mitigate gully erosion. By changing the infill from sand to a high-strength, 5,000 psi (34 MPa) cementitious material, the technology becomes a durable fiber-reinforced concrete-armoring solution, which still maintains the aesthetics of vegetation. The technology is then known as a Concrete-Enhanced Synthetic Turf (CEST) Revetment System as the fibers of the synthetic turf provide reinforcement for the cementitious infill material. A cross section of the EST and CEST Systems is shown in Figure 1 below.

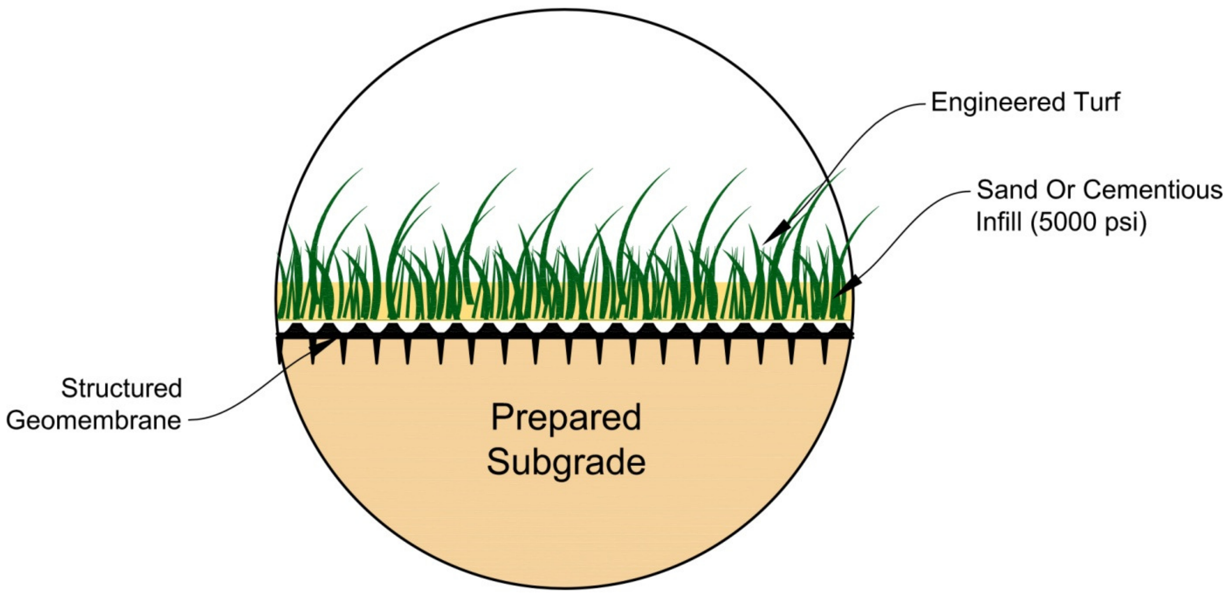

Figure 1: Section of Engineered Synthetic Turf (EST) System with Sand Infill OR Concrete-Enhanced Synthetic Turf (CEST) Revetment System with Cementitious Infill

Over the last five years alone, thirteen states in the United States have permitted the alternative EST and/or CEST Systems to be used at a variety of waste-containment facilities such as municipal solid waste, industrial waste, construction and demolition waste, and monofil waste. Key technical-performance properties of the systems and real-life application experiences will be discussed in the following sections. Furthermore, the testing program to determine the CEST System's performance thresholds will be presented, validating its potential for use in the most demanding erosion-protection applications located at mine facilities (outside of closure applications).

Key Performance Properties of EST and CEST Systems

Key performance properties discussed below demonstrate the improvement to performance levels the EST/CEST Systems offers when compared to that of the traditional solutions. Additionally, given the extreme performance capability of the CEST System when subjected to steady-state flow, the results presented in the following section validate the technology's use in other applications at mine sites to replace hard-armoring technologies such as articulate concrete blocks, rip rap, concrete channels, and other forms of armoring used to limit erosion on other storm-water management structures.

Stability

For mines, the long-term stability of steep side slopes of closures and steep channels are of primary concern, particularly after major storm events or in high seismic zones. The engineered turf systems have no soil and vegetation cover layer; therefore, the veneer stability is significantly greater than when compared to other alternatives that include a soil and vegetation layer. The engineered turf/structured geomembrane interface shear strength—tested in accordance with ASTM D 5321—has a peak interface friction value of 43 degrees, and a large deformation value of 38 degrees with calculated factors of safety of 1.4 and 1.2 on slopes as steep as 1.5:1 respectively. Results of the internal shear test can be seen in Figure 2.

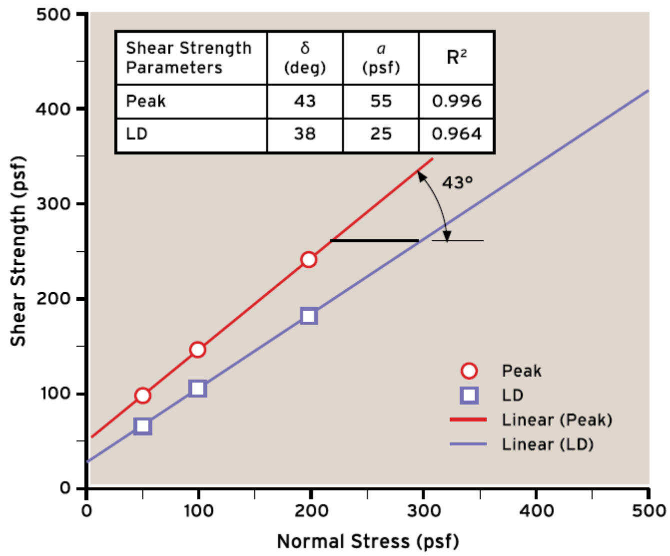

Figure 2: Internal Shear Test Results

In addition to internal system stability, the structured geomembrane provides a high level of interface shear strength at the subgrade/geomembrane interface due to the 175 mm spikes which are integrated into the structured geomembrane. At the Crazy Horse Landfill in Salinas Valley, CA, 27.5 ha of an EST cover system was installed in 2011. One of the important design factors for using the EST and CEST Systems was the high factor of safety offered by the system for seismic slope stability. The site is located approximately 6.5 km away from the highly active San Andreas Fault.

Resistance to Wind Uplift

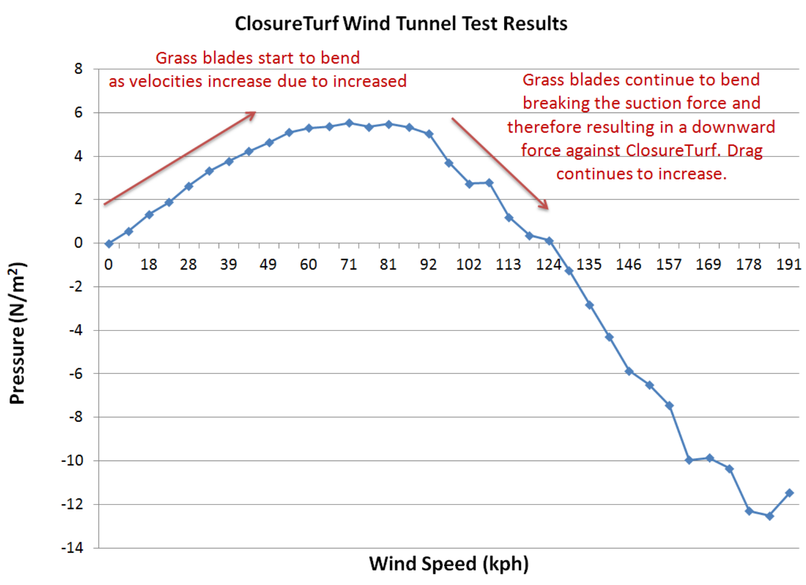

Figure 3: Wind Uplift Resistance of the EST and CEST Systems

The engineered-turf component of the EST system serves several purposes. One is providing an aesthetically pleasing solution, but another important function is protecting the EST from wind uplift while also covering the underlying geomembrane. An aerodynamic evaluation was performed on the wind uplift reactions of the EST technology by the Georgia Tech Research Institute (GTRI). The system experienced a maximum uplift of approximately 5.52 N/m^2 at 71 kph wind speed and a downward force of approximately −12.5 N/m^2 at 183 kph wind speed. The synthetic-turf component of the EST (without the sand infill) weighs approximately 0.73 kg/m^2. Therefore, this component will not uplift even when it is not infilled with sand. The results of the evaluation are presented in Figure 3 above.

This is in contrast with exposed geomembrane systems in cover applications, where extensive anchoring is required even for 50 kph winds (Giroud, 1995). The engineered-turf component provides features that help maximize wind resistance, such as a porous surface to break suction, and turf blades that will increase the aerodynamic boundary conditions as blades bend and react when velocity increases, eventually causing a downward force on the system. Real-life applications where this solution has been put to the test during high wind events include a 3.64 ha site in Jena, LA at the La Salle Grant Landfill installed in 2009. Three months after the first phase of the project was complete, a tornado producing shear winds of 113 kph travelled across the front of the landfill without damage.

Resistance to Rain Induced Erosion

The engineered-turf cover system was tested for resistance to rainfall-induced erosion per ASTM D-6459 as seen in Figure 4. Sand infill can resist over 150 mm/hr of rainfall intensity with only 0.04% loss. The rainfall penetrates quickly through an ASTM C-33 sand, and the porous engineered turf which rests on the stud-side of the structured geomembrane. Furthermore, the grass blades provide for further interlocking of the sand to keep it in place when subjected to sheet flow. The void space created by the engineered turf resting on the drainage studs of the structured geomembrane allow for storm water to percolate through the top two components and drain, with a transmissivity of 6.0E-03 m^2/sec.

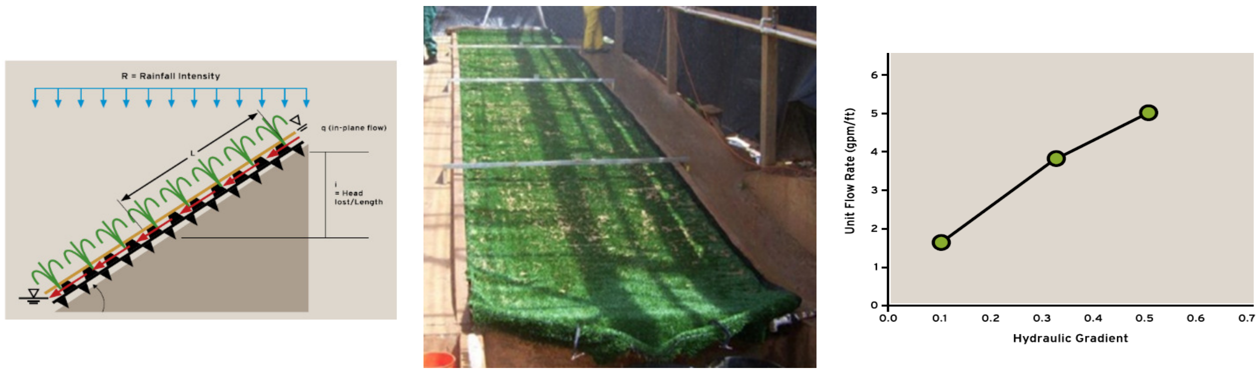

Figure 4: (Left to Right) Schematic of ASTM D-6459 with Hydraulic Force Evaluation, Picture of Rainfall-Induced Erosion Test, Flow Capacity

Resistance to Steady-state Flow (Protection for Channelized Applications)

As mentioned earlier in this paper, as part of the development of these innovative technologies, it was identified that additional erosion-protection applications were made possible by enhancing the infill component of the system. To validate this finding, full-scale hydraulic testing was performed on the CEST System at Colorado State University's Engineering Research Center for the purpose of establishing performance thresholds. The steady-state testing program was thorough, and involved three steady-state overtopping conditions of varying overtop depths. The overtop depths evaluated were 1.5, 3, and 5 ft (0.46, 0.91 and 1.52 m), respectively. These tests were performed in general accordance with ASTM D7277-08—the Standard Test Method for Performance Testing of Articulated Concrete Block (ACB) Revetment Systems for Hydraulic Stability in Open Channel Flow. The results of the test(s) were analyzed in accordance with ASTM D 7276—the Standard Guide for Analysis and Interpretation of Test Data for Articulating Concrete Block (ACB) Revetment Systems in Open Channel Flow.

During this test program, instability or failure of the CEST did not occur in over twenty hours of testing up to the maximum discharge capacity of the facility (5 ft [1.52 m] overtop depth). The testing described herein demonstrates CEST is able to withstand hydraulic loads resulting in a bed shear stress exceeding 8.8 psf (421 Pa) and velocity exceeding 29.2 fps (8.9 m/sec). The CEST was demonstrated to have a Manning's n value of 0.020 under the tested conditions.

Also of importance to note is that the test program included an evaluation of the technology when subjected to hydraulic jumps, debris loading, and performance in a damaged state. The system demonstrated the ability to withstand hydraulic loads caused by hydraulic jumps dissipating as much as

30 horsepower per foot of width (22.4 kW). Additionally, the qualitative tests performed established the ability of the CEST to withstand impact and abrasion caused by falling debris, as well as to withstand damage associated with puncture. As instability or failure of the system did not occur, these test results should not be taken as performance thresholds. The CEST performed exceptionally well in maintaining the underlying, highly erodible subgrade soils during these severe and varied tests, which validates its use in lieu of traditional hard-armoring technologies for the most severe erosion applications.

Features and Benefits

Weathering, Durability, and Design Life

The protective layers of the Systems include the engineered turf and infills. Their presence significantly reduces geomembrane exposure to environmental conditions which could lead to accelerated degradation of the impermeable layer of the systems, prematurely resulting in loss of system integrity.

The design life of both the EST and CEST Systems is in excess of one hundred years depending on the location of the systems in service. To determine the design life of any geosynthetic, the potential for degradation of the material in service, or weathering, must be evaluated over time because the presence of chemicals, extreme temperatures, or UV irradiation will accelerate degradation. (Geosynthetic research has been quite extensive on this discussion topic, and supplemental information is available from the Geosynthetic Research Institute in white paper 6)

For these systems however, the infill provides protection as it covers and insulates the geosynthetic components. However, the grass blades of the engineered turf are the most vulnerable part of the system. They are exposed and therefore receive the highest level of UV irradiation while in service. For this reason, understanding the turf yarn durability has become critical to determining the functional longevity of the technologies. An independent third party weathering study (results can be found in Figure 5) conducted at the Atlas Weathering Laboratory in New River, AZ, indicates that after one hundred years of exposure, the turf yarn will have three times the strength it needs to perform (resisting wheel loadings while trafficked). This is due to advancements made in polymer engineering over the last decade with the incorporation of a high-absorption UV stabilizer used in the yarns, and the initial high-tensile strength designed into the yarn during manufacturing. These two geosynthetic characteristics result in a high residual strength of the grass blades over time. The remaining synthetic parts (the engineered-turf backing and the geomembrane) are covered and insulated by either infill, providing redundancy and additional protection against heat and UV degradation, and thereby adding many years of functional life to these components well beyond one hundred years when properly maintained.

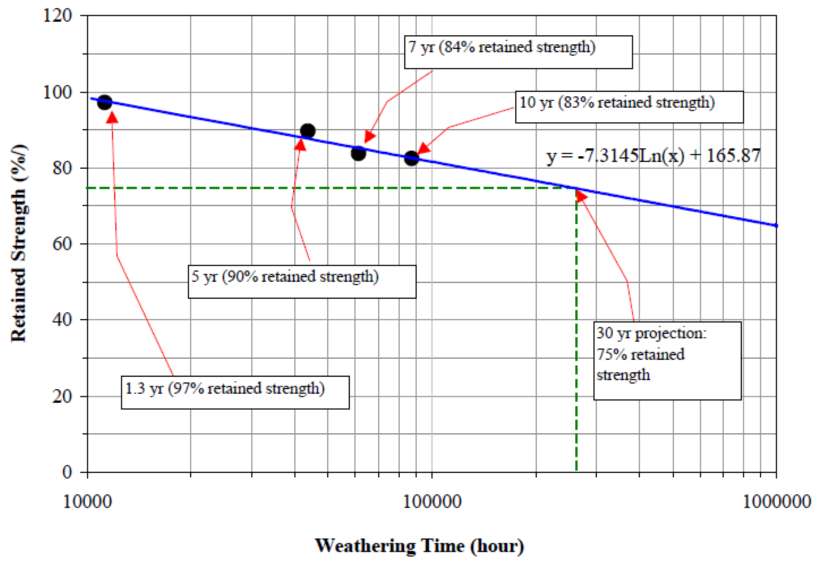

Figure 5: Weathering Resistance Test Results from the Atlas Weathering Lab in New River, AZ

Improved Water Quality

Quantifiably, exactly how much positive impact EST and CEST systems can have on storm water quality is somewhat unknown because data has been difficult to collect to date. However intuitively, without the presence of soil that can experience excessive erosion and sediment loss during a storm event, storm water runoff from these essentially soilless technologies is noticeably cleaner with less treatment required resulting in little impact on the environment. Figure 6 is a picture of storm water samples taken from the Tangipahoa Parish Landfill in Independence, Louisiana after 1 inch of rainfall over a 24 hour period earlier this year.

Figure 6: (Left) Closure Turf Storm Water Sample – 11NTU
(Right) Soil Cover Storm Water Sample –371 NTU

The jar on the left represents storm water collected from the portion of the site where 8 ha of an EST system is installed, and the jar on the right represents a sample where an intermediate vegetative soil cover is installed over an area of similar topography and size. Field tests estimate that the jar on the left has an NTU value of 11 and the jar on the right has an NTU value of 371. Even after an insignificant storm event, a visual difference can be seen, and the EST system's ability to lower turbidity levels of storm water is impressive.

Drivability

Mine closures will have to be accessed by persons on foot or in vehicles during their service life. The typical exposed geomembrane cover cannot handle this type of environmental condition. The infills placed into the EST and CEST systems allow for traffic access for vehicles with up to 415 KPa tire pressure on 3:1 slopes and up to 620 KPa tire pressure vehicles in flatter areas, without damage to the underlying geomembrane.

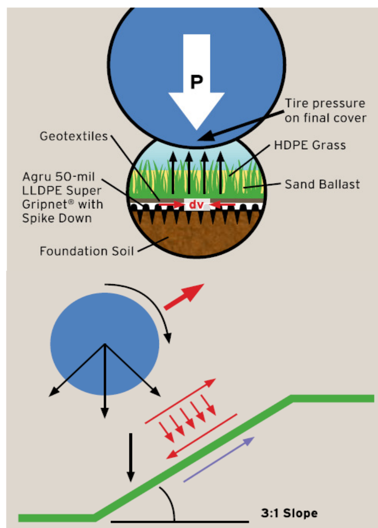

Figure 7: Schematic of the Traffic Loading Analysis

Calculations for equipment types analyzed the deformation of the engineered turf into the areas between the structured geomembrane drainage studs, puncture resistance of the engineered turf by the drainage studs, and loss of drainage stud height due to the traffic loading. Both static and dynamic (braking) forces were evaluated, and the calculated factors of safety are summarized in Table 1 for the static forces and Table 2 for dynamic forces (Giroud, 1981).

Table 1: Static Loading – Factors of Safety

Property	Light Vehicle	Heavy Vehicle
Geomembrane Puncture Resistance	4.2	1.6
Puncture Resistance – Geotextile	2,250	840
Geotextile Burst Resistance	4.4	1.6
Geotextile Tensile Strength	6.9	2.6

Table 2: Dynamic (Braking) Loading

Vehicle	Vehicle Speed	Slope Angle (degrees)	Static FS	Dynamic FS
Fire Engine	16 km/h	8	7.3	1.9
Pick Up Truck	16 km/h	18.4 (3H:1V)	1.8	1.2

Construction and Maintenance

With engineered-turf systems, it is also economically feasible to close smaller areas at a time, or install the system in hard-to-access areas, since large construction equipment is not needed for installation. The installation of the engineered turf systems is faster and can cost up to 40 percent less when compared to traditional solutions. Safe, rapid, low-impact development can be achieved with the engineered turf systems by eliminating the potential for thousands of truck trips. There is a much smaller carbon footprint, since the need for soil is significantly reduced. In some instances, the carbon footprint can be one-fifth of the traditional cover system or erosion prevention technology.

EST/ CEST System in Service at a Closed Facility

The 9.31 ha Saufley Field Road C&D Landfill located in the hurricane-prone area of Pensacola, FL was abandoned by its previous owner in 2008. Prior to the abandonment of the facility, the Florida Department of Environmental Protection (FDEP) documented numerous compliance issues since the site was permitted in 1990. The most severe noncompliance issues included operation of the facility at elevations higher than the permitted design height (approximately forty feet higher) and the presence of hydrogen sulfide emissions. In fact, the air pollution associated with the operation of the facility became so extreme in 2007 that the Florida Department of Health issued a Public Health Warning about the elevated levels of hydrogen sulfide around the facility affecting the local community. Additionally, the storm-water management design of the facility allowed both sediment and leachate to be released off-site, discharging into neighboring storm water systems maintained and operated by Escambia County, FL. Ground-water contamination was recorded with elevated levels of aluminum, arsenic, and manganese, which resulted in significant outrage in the community.

FDEP and Escambia County quickly realized that while this site remained open, it posed a threat to the environment and to the health of citizens living in the area. The only solution was to close the facility, which in itself posed several significant challenges: funds were not available to construct a closure and the closure plan would be required to implement necessary site improvements required to address the noncompliance issues previously mentioned.

Figure 8: EST/CEST System in Service at the Saufley Field Road Landfill in Pensacola, FL

After evaluating other traditional soil cover systems in 2012, a decision was made to complete the closure plan using the EST and CEST Systems in concert at the facility. A picture of the closed Saufley Field Landfill can be seen above in Figure 8. Both FDEP and Escambia County recognized that the geosynthetic erosion-control technologies presented the best solution for stakeholders because the technologies provided for:

- The most economical approach to performing a closure while also providing for the lowest long-term maintenance cost to maintain the facility once closed.
- A reduction on the impact to the environment since natural resources needed to construct this closure system were minimal due to the soilless nature of the technologies.
- Superior protection against erosion along slopes, in downchutes, and perimeter conveyance channels, which was important because of the location of the facility and the potential for extreme weather conditions.
- Reduced infiltration of storm water into the waste, thereby reducing impacts to groundwater quality, while also providing for an aesthetically pleasing and natural-looking enhanced viewscape.
- Enhanced emission control at the facility and greatly improved odor control.
- Reduced sediment loadings of storm-water run-off to the surrounding watershed.

Conclusion

One thing that is evident is that modern technology will continue the expansion and use of geosynthetics at mining facilities for a diverse range of applications. The EST and CEST systems are the most innovative technologies available for the mining and waste industries within the United States today. They serve as a catalyst to change the way that mine owners and engineers approach closures and defend against erosion at their facilities. These systems have endured extensive laboratory tests, research and development, and their growing implementation rate is proof that the technologies are performing in real-life applications and should become the new standard solutions for closure and erosion prevention at mine facilities.

References

ASTM. Standard Guide for Analysis and Interpretation of Test Data for Articulating Concrete Block (ACB) Revetment Systems in Open Channel Flow. D7276-08, developed by Subcommittee D18.25 of the American Society for Testing and Materials.

ASTM. Standard Test Method for Performance Testing of Articulating Concrete Block (ACB) Revetment Systems for Hydraulic Stability in Open Channel Flow. D7277-08, developed by Subcommittee D18.25 of the American Society for Testing and Materials.

Georgia Tech Research Institute. 2010. *Aerodynamic Evaluations of Closure Turf Ground Cover Materials*.

Giroud, J.P., and Noiray, L. 1981. "Geotextile-Reinforced Unpaved Road Design," *Journal of Geotechnical Engineering* 107, no. 9: 1233-1254.

Giroud, JP, et al. 1995. "Uplift of Geomembranes by Wind," *Geosynthetics International* 2, no. 6.

SGI Testing Services. 2009. *Final Report Critical Length and Influence of Seepage Force on Slope Stability Landfill Cover System*.

Thornton, C. I., Scholl, B. N., and Yaw, M.B. 2013. *Hydraulic Testing and Data Report for HydroTurf Revetment System*, Engineering Research Center, Colorado State University, Fort Collins, Colorado.

TRI Environmental. 2010. *Soil Loss Testing Report*.