Evaluations of engineered cover systems for mine waste rock and tailings

Geosynthetics for mining waste rock and tailings.

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Introduction
Waste rock dumps and tailings impoundments are common features at mine sites. Many of these waste disposal facilities contain sulfide-rich minerals that generate acid mine drainage (AMD) when they oxidize in the presence of oxygen and water. Control of AMD is achieved by removing one or more of the three essential components in the acid-generating process: sulfides, air, or water. An AMD prevention measure with a good history is to properly cap the waste and thereby minimize the infiltration of water and diffusion of air into the system.

Common cap designs include:

- Compacted clay, or low-permeability soil, liners (CCLs).

- Store-and-release covers (also known as evapotranspiration, ET, or water balance covers). These covers require climate conditions where there is greater evapotranspiration than precipitation, both annually and seasonally.

- Composite covers (a geomembrane liner over either a CCL or a geosynthetic clay liner (GCL). These systems have been commonly used for capping solid waste landfills for more than 30 years. In contrast, there has historically been very limited use of geosynthetics in mine closures. For example, of the approximately 150 technical papers presented at the Mine Closure 2011 conference in Alberta, Canada, only three mentioned geosynthetics. The paucity of geosynthetics usage in mine closures appears to be due to lack of regulatory drivers, perceived higher costs, perceived benefits of soil-only covers, and longevity concerns.

Comparisons of these different cover systems, both in terms of performance and cost, are presented in this article.

Performance of different cover systems
In 1998, the U.S. Environmental Protection Agency (EPA) initiated the Alternative Cover Assessment Program (ACAP) to evaluate the field-scale performance of conventional and alternative landfill covers (Albright et al., 2010). Test facilities were constructed and monitored
at 12 sites throughout the U.S. The ACAP study provides an excellent reference for comparing the relative field performance of the three different types of cover systems referenced above.

Compacted clay covers were among the worst performers (three sites, with measured percolation rates of 7.4 to 156 mm/yr, and increasing with time). These observations are consistent with those of Suter et al. (1993) and Benson et al. (2007) who noted that during a four-year monitoring period, the permeability of cover soils increased by as much as a factor of 10,000.

ET covers, installed at all 12 sites, showed highly variable performance, from 0 to 207 mm/yr of percolation. Performance was strongly linked to climate, with excellent performance at sites located in arid or semiarid climates, and poor performance at sites located in subhumid and humid climates.

One of the ACAP study’s conclusions was: “Low percolation rates (1 mm/yr or less) cannot be achieved with water balance covers at all sites. Stringent percolation objectives are unlikely to be achieved at more humid sites” (Albright et al., 2010). Two exceptions—in Monticello, Utah, and Sacramento, Calif.—produced very low percolation, but required much thicker and more complex (namely, more expensive) covers to do so. (For example, at Monticello the capping system consisted of 5 layers and was nearly 9 ft thick).

Two of the sites—in Boardman, Ore., and Apple Valley, Calif.—used geomembrane/GCL cover systems. ACAP data showed that the geomembrane/GCL cover systems were the best performing covers in the entire study, allowing 0 mm/yr percolation, compared to 0 to 207 mm/yr for the ET covers and 7.4 to 156 mm/yr for the CCLs.

Costs of cover systems

Koerner (2002) estimated that the total constructed cost of a geosynthetic composite cover system at between $300,000 and $470,000/ha. This range is consistent with the senior author’s experience with leach pad liner systems, which use the same geosynthetic components and, on average, cost approximately $350,000/ha to construct.

Wilson et al. (2011) estimated that soil-only covers cost about $100,000/ha. However, Rykaart et al. (2006) discussed the traditional approach of handling mine waste covers as little more than landscaping projects, with limited attention to design, construction, or quality control.

This, in part, may explain the low construction costs cited previously. This attitude is now changing, with the industry realizing that covers are engineered systems. ET covers also require thoughtful design, careful construction, and quality control, which tend to increase cover costs; Rykaart et al. (2006) provided an example of the ET covers built by Syncrude, where exceptional control is achieved, but at much higher cost.

The U.S. Air Force Center for Engineering and the Environment (AFCEE, 1999) compiled construction cost data for landfill covers at several Air Force bases. Its survey showed a geomembrane/CCL cover cost ranged from $788,000 to $1.41 million/ha. A CCL at one base
cost $1.235 million/ha to construct, while an ET cover cost $365,000/ha. Dwyer (1998) presented cost data from the U.S. Department of Energy for the construction of six large-scale landfill cover sections in Albuquerque, N.M. Costs reported were: $514,000/ha (CCL), $738,900/ha (monolithic ET), $752,600/ha (anisotropic), $926,400/ha (capillary), and $1,575,400/ha (geomembrane/CCL).

Although both the AFCEE and DOE cost estimates appear high compared to past experience and other literature references, they are presented here to provide an upper range of conceivable values for the probabilistic cost evaluation presented in the following section.

**DCF/NPV comparison**

An economic evaluation using discounted cash flow (DCF) and net present value (NPV at 8%) methodologies was also performed to compare total life cycle costs. The analysis considers a hypothetical 100-ha closure, located in a temperate climate. The following three cover systems were evaluated:

1. A 0.6-m compacted clay liner, underlying a 0.3-m vegetated topsoil layer.

2. An ET cover consisting of a 0.5-m stone capillary barrier, underlying a 1-m sandy loam soil layer, underlying a vegetated topsoil layer.

3. A composite cover, consisting of a geomembrane/GCL barrier layer, underlying a drainage geocomposite, underlying a 0.3m-thick vegetated topsoil layer.

Capital costs and estimated annual AMD management costs were calculated based on the expected performance (i.e., percolation allowed) of each cover system. Since there is uncertainty in both the constructed cost of the cover and its performance, a statistical approach was used to better capture these uncertainties and to allow for a more comprehensive comparison of the different cover systems.

The probabilistic methods originally developed by Duncan (2000) for geotechnical engineering problems, and later applied to mine containment applications by Thiel et al. (2005), were applied for each cover scenario. The values selected, shown in Table 1, represent best estimates for cover systems from the authors’ mining and landfill engineering experience, as well as published data.
The technical and economic effectiveness of the three cover systems were compared by using ratios of the net present or discounted life cycle costs (e.g., NPV_clay/NPV_GM/GCL and NPV_ET/NPV_GM/GCL). Using the method in Duncan (2000), the probability that the discounted cost ratio would be greater than 1 was calculated.

The results of these calculations found that, for the example ranges provided, it would be economically beneficial to construct a geosynthetic composite cover in lieu of a compacted clay liner or an ET/capillary cover. The probability that the discounted costs of a compacted clay liner and an ET cover would exceed that of a geosynthetic composite cover are 75% and 88%, respectively.

These results support the use of a more robust cover system—even one with a potentially higher initial capital cost—to decrease long-term AMD collection and treatment costs, and to reduce overall discounted costs. The authors recommend this type of analysis for mine owners.
evaluating different closure options, using site-specific values to ensure that the option with truly the best technical and economic value (i.e., lowest discounted life cycle cost) is selected. Where life cycle costs are similar (ratios near 1), then other factors should also be considered, such as long-term risks related to the various infiltration rates and the reliability of the cover to perform without unforeseen intervention.

**Summary and conclusion**

Although geosynthetic materials have been commonly used in final cover systems at solid-waste landfills for more than 30 years, they have seen much less use in cover systems for mine waste closures.

Possible reasons for this include lack of regulatory drivers, concerns over cost and longevity, as well as perceived benefits of soil-only covers. Case studies were presented highlighting the advantages and disadvantages of various cover systems, including compacted clay, ET covers, and geosynthetic composite covers.

Using information from the literature and from the authors’ experience, an economic evaluation of various types of cover systems for mine closures using discounted cash flow and statistical methodologies was performed for a hypothetical mine waste rock site in a temperate climate. The DCF analyses included not only capital costs but also long-term AMD management costs, which are frequently underestimated in mine closure plans. Example calculations found that it would be economically beneficial to construct a geosynthetic composite cover in lieu of a compacted clay liner or an ET/capillary cover.

These results support the use of a more robust cover system to decrease long-term AMD collection and treatment costs, and reduce overall discounted life cycle costs. It is important to note that the analysis above does not consider the risks or costs of environmental degradation due to uncontrolled AMD release. If these unquantifiable risks could be included in the analysis, the results would favor cover options with lower percolation rates over time.
Additionally, since mines often must both bond their closure costs and recognize the liability on their balance sheets, the capital cost of an upgraded cover system can be partially (or fully) offset. The DCF/NPV analysis above does not recognize this; if this consideration was included in the analysis, the result would be even more favorable to the lower life-cycle cost option.

The analysis presented here serves as an example for a hypothetical mine site located in a temperate climate. It is recommended that when evaluating different closure options, the analysis above be performed using site-specific values to ensure that the option with truly the best technical and economic value (i.e., lowest discounted cost over the life of the mine) is selected.

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