DESIGNER'S FORUM

Geosynthetics in mining reclamation final covers

By Gregory N. Richardson

I AM PLEASED THAT THE RARE MINing-related article in this month's *GFR* was written by Allan Breitenbach (page 38). I have had the pleasure of reviewing projects that he was involved in, and his presence always made the process easy. Through him, I also gained a new respect for the meaning of "travel mileage"! With work scattered all over the world, someone in Allan's position must accumulate frequent-flyer miles faster than their body can recuperate.

I will leave the discussion of heap-leach pads to Allan and discuss what I feel will have an even greater impact on the mining industry and society: economical, yet effective, methods of reclaiming lands damaged by mining activities. For the past five years, mining reclamation has been a hobby of mine, as well as a good way to revisit western lands with historical ties to my family. While heap-leach pads are essential for today's operations, I feel the political and economic future of mining in this country lies in the development of economical and functional reclamation of mined lands.

Much of this reclamation requires more than simply recontouring and revegetating affected areas. Most copper and gold surface mines must move enormous quantities of waste rock to reach the producing ore bodies. Frequently, this waste rock contains metal sulfide minerals (remember fools gold?). Acid generation occurs when metal sulfide minerals are oxidized through exposure to both water and oxygen. The chemistry occurs according to the following general equation:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \Rightarrow Fe(OH)_3 + 2SO_4^{-2} + 4H^+$$

Water that drains from such waste rock piles, commonly referred to as acid rock drainage (ARD), is very acidic. It kills the vegetation that it touches and can destroy all life in the streams or rivers which it flows into.

To protect the environment, we attempt to slow this drainage process by limiting the amount of water that reaches the waste rock. For this we can use conventional final cover technology developed by the U.S. Environmental Protection Agency (EPA) for Resource Conservation and Recovery Act (RCRA) landfills. However, these covers are very expensive (approximately $80,000 to $120,000 per acre) and have questionable life spans in the arid and semiarid west. This high cost affects mines in both the initial capital required for the reclamation and in increased bonding costs related to financial-assurance requirements (cover cost is typically included in initial construction costs).

Roles for geosynthetics in reclamation covers

The potential roles played by geosynthetics in mine-reclamation covers depends upon the soils available for construction, the regional climate, and the topography of the site. The availability of suitable construction soils is the most consistent problem that I encounter. Reclamation cover designs are never performed early in the life of a mine, so the mine operations group has no idea of the material types that will be needed after the mine ceases operation. This is unfortunate, since the group has operations expertise in the processing of natural materials, and, in many cases, it has flexibility in the segregation and processing of waste materials.

Table 1 provides a functional breakdown of reclamation cover types according to climate and soil-type availability. The barrier reclamation cover is an extension of RCRA final cover systems. The evapo-transpiration (ET) and enhanced run-off reclamation covers are water-balance covers generally assumed to be suitable for the arid and semiarid west.

Note that significant research has been performed on the agricultural and ecological aspects of land reclamation. I particularly recommend a review of Munshower (1993) for a detailed, general discussion of these aspects and Ray Brown's classic works (1990) on high-altitude revegetation. The design of successful reclamation systems is interesting, in part, because of the need for so many aspects of engineered and ecological systems to function in harmony.

Barrier reclamation covers

If annual precipitation exceeds 25 in. or if limited topsoil/loam stockpiles exist at the mining location, some type of a barrier will be required. **Figure 1** (page 18) shows three reclamation cover profiles proposed for a recent Montana reclamation project that I reviewed. These examples are a good vehicle for discussing the current state-of-practice "confusion" and the potential roles for geosynthetics in mining reclamation.

Barrier systems in the arid or semi-arid west generally are needed only when there is insufficient quantity of vegetative support soils, i.e., loams. All of the reclamation covers on Figure 1 reflect such a shortage of vegetative support material. Let's examine each of the proposals.

Table 1 FUNCTIONAL TYPES OF RECLAMATION COVERS—SLOPE < 8%

Climate	Soil Inventory	Cover Mechanism	Role of Geosynthetic
Arid or semi-arid annual precipitation barrier less 25 in.	Crushed rock with limited topsoil	Barrier	GCL barrier or GM barrier
	Crushed rock with adequate supply topsoil or loam	Evapotranspiration (ET)	GT @ capillary break
	No crushed rock but processed soil with high fines	Evapotranspiration (ET)	GN capillary break
Temperate or Humid Regions	Crushed rock with limited topsoil	Barrier	GCL barrier or GM barrier
(Annual precipitation greater than 25 in.)	Crushed rock with adequate supply topsoil or loam	Barrier	GCL barrier or GM barrier

GCL–Geosynthetic Clay Liner, GT–Geotextile, GM–Geomembrane, GN–Geonet

Reclamation Cover A

Two significant problems exist with the design of Reclamation Cover A. The 12-in. vegetative layer is too thin to support even grasses, and the clay layer is too thin and is exposed to dessication cracking. In most parts of the west, a minimum of 18 to 24 in. of vegetative support layer is required to allow even grasses to survive through the late summer. Additionally, a minimum thickness of 12 in. of compacted clay barrier is required for construction reasons. Note that at this site, the clay had to be hauled in from a pit ten miles away. If this section is really needed, my vote would be to replace the compacted clay with any form of soil (like the "previous surface") and add a GCL over the previous surface. Doing so provides more water storage for the plants and a more durable barrier, at no increase in cost.

Reclamation Cover B

This side-slope cover adds 36 in. of a blast-rock capillary break and the requisite 12 in. of clay to the design. The blast rock is very coarse with less than 15% rock fines. The topsoil and the blast rock do not satisfy Terzaghi's (1967) filter criteria and would require a geotextile separator to limit loss of the already insufficient thickness of topsoil into the blast rock. The blast-rock capillary break will act more as a lateral drain and remove water required for survival of the vegetation.

A better design would 1) increase the vegetative support system by adding 12 in. of any soil beneath the topsoil, and 2) add a geotextile between the vegetative layer and the blast rock to create a real capillary break or ET cover. The resulting cover would allow successful vegetation of the cover and limit infiltration, at a much lower cost, with a higher potential for long-term survivability.

Unfortunately, the available soils typically would not allow such a design change. A more viable side-slope alternative is to abandon the goal of a "green" solution and instead use a GCL or geomembrane barrier beneath an erosion-resistant layer of the blast rock. Such hardened final covers are not welcomed by typical ecologists but do provide the most effective, long-lived and economical covers.

Reclamation Cover C

The specified 3-in. compacted clay layer is for real. Design details like this provide a quick means of evaluating the designer's competence. This "flatland" cover suffers from many of the same faults as Cover B. Replacing the capillary-break blast rock with a loam-type soil would help this cover dramatically. As is frequently the case, the site has a significant volume of non-ARD blast rock, little topsoil, and large flat expanses to be covered. These flat surfaces present minimal erosion potential. In such locations, I prefer to use the topsoil and vegetative support soils removed from the side slopes.

If sufficient quantities of topsoil and vegetative soils can be gathered, then the ET cover described above would be my first choice for this application. If the quantity of topsoil and vegetative soils is not sufficient to provide adequate storage of anticipated precipitation, then a GCL could be substituted for the geotextile. This will prevent moisture breakthrough when the vegetative layers approach saturation, not only providing more moisture for the vegetation but limiting ARD development

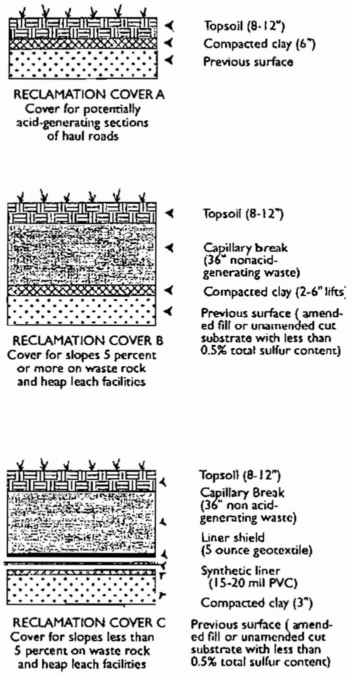
ET reclamation covers

These ecological covers use both natural evaporation and the transpiration potential of vegetation to limit penetration of moisture. I was introduced to these covers almost 12 years ago while serving on an advisory panel reviewing long-term isolation research at the Department of Energy's Hanford facility. Glendon Gee of Pacific Northwest Labs (1997) has set the standard for quality development in this area. Outstanding civil engineering research in this area has been published by Craig Benson (1995) of the University of Wisconsin and John Stormont (1997) of the University of New Mexico. The basic water balance equation is

$$\Delta S = P - Q - ET - L$$

where ΔS is the change in water storage in the upper soil layer, P is precipitation, Q is the runoff, ET is evapo-transpiration, and L is seepage or percolation through the final cover. The design objective is to minimize L.

As shown on **Figure 2**, water-balance covers rely on a two-layered system to limit penetration of surface waters. The upper layer consists of a well-graded loamy soil that will support vegetation and provide sufficient water storage to typically hold more than a full season's precipitation. The premise is simple: If we can hold all of the infiltration in the upper loam layer when the ET is minimal, the water will be removed by ET when the vegetative growth is maximum. Most arid and semi-arid vegetation is limited by the amount of stored water



RECLAMATION COVER A
Cover for potentially acid-generating sections of haul roads

RECLAMATION COVER B
Cover for slopes 5 percent or more on waste rock and heap leach facilities

RECLAMATION COVER C
Cover for slopes less than 5 percent on waste rock and heap leach facilities

Figure 1. The three types of reclamation covers for mining.

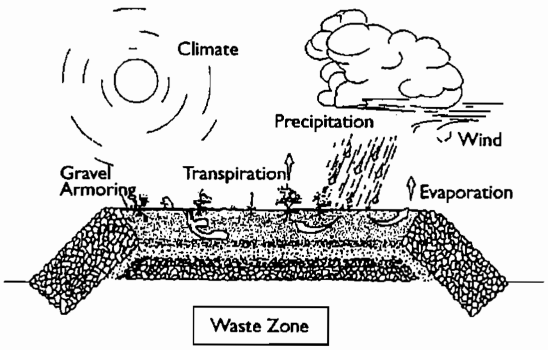


Figure 2. Final cover system with two-layer water balance.

typically available in the ground; it runs out of moisture in late summer or fall and becomes stressed.

To hold the moisture in the loam layer in a water-balance cover, apply simple phenomena first explored by L.A. Richards in the '30s. He observed that loamy soil layers underlain by a coarse-grained soil layer were always wetter that those underlain by a fine-grained layer. His explanation, now known as Richards' Effect, is that water is held in the loam by capillary tension. The coarse lower layer forms a capillary break that prevents moisture from being drawn downward by capillary forces and aids in retention of moisture in the upper loam.

The engineer must look for the simplest and most economical means of establishing the capillary break. I believe that this is a natural role for a geotextile separator. Naturally graded filters between the loam and typical blast rock may require two to three layers of graded-soil filters. This dulls the capillary break and is very expensive. A geotextile separator allows a very sharp capillary break at a very reasonable cost. I have done some preliminary work related to this application (1997) but am hopeful that it will be examined by others.

Summary

Geosynthetic materials can play a cost-effective role in reclamation covers that must limit vertical migration of water. The bottom line for the geosynthetics industry is that, while potential heap leach pad applications, i.e., liners, are measured in hundreds of acres, possible reclamation acreage due to ARD is measured in tens of thousands of acres. The mining industry currently lacks the Glendon Gees, Craig Bensons and John Stormonts to develop technology for, and educate the designers of, such covers. Seems to me that this is a good opportunity for the geosynthetics industry! GR

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