CHALLENGES TO APPLYING GEOMORPHIC AND STREAM RECLAMATION METHODOLOGIES TO MOUNTAINTOP MINING AND EXCESS SPOIL FILL CONSTRUCTION IN STEEP-SLOPE TOPOGRAPHY (E.G. CENTRAL APPALACHIA)[1]

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Abstract. Proponents of geomorphic mine land reclamation have criticized current reclamation practices in the coal fields of steep-sloped Central Appalachia as too narrowly focused on civil engineering principles and neglectful of the functional and aesthetic benefits of reclaiming mine sites in ways that mimic natural landforms and drainage patterns. They observe that current mining and reclamation practices are radically transforming the mountain-and-valley terrain into gigantic flat plateaus and, in doing so, disrupting the beauty and ecology of the natural landscape. Instead of designing and constructing linear or planar surfaces and unvarying slope gradients during the reclamation process, they recommend "landforming," i.e. the adoption of curvilinear, compound slope forms that blend well with the surrounding physiography and represent the result of naturally stabilizing geomomorphic processes. The authors feel that the concept of geomorphic mine land reclamation is sound, however, its application to the Central Appalachian coal fields faces significant--albeit not insurmountable--challenges. They include: (1) existing reclamation-enforcement regulations that are focused on civil engineering principles and not explicitly supportive of geomorphic methodologies; (2) regulatory agencies' current intent to limit the down-gradient reach of excess spoil fills in order to allay disruption or burial of natural streams; (3) actual or perceived increases in reclamation costs; and (4) the challenge of designing and constructing "natural" landforms that are mature and stable in an otherwise youthful, erosional landscape.

Additional Key Words: landforming, geomorphic reclamation, natural landscaping, mine reclamation.

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Introduction

Some of the most contentious issues related to coal surface mine reclamation surround the practice of mountaintop coal mining in the steep-slope topographic settings of Central Appalachia and the construction of excess spoil fills in valleys below the mine sites. Chief among them include: the flattening of the ridge and valley landscape that often results; the burial and pollution of headwater streams and riparian zones during and after the construction of fills; and extensive disruption the wide variety of biota unique to Appalachia. Proposed solutions vary from increasing environmental restrictions on surface mining in the region to the application of alternative approaches and methodologies to surface mining and reclamation. One approach to mine-land reclamation that has received keen interest in other parts of the U.S. over the last decade is the application of "landform grading" and stream restorative techniques. Broadly speaking the objective of this approach is to copy nature, i.e. reclaim the land and water in a way that reflects what geomorphic processes have already engendered in the surrounding environment. By doing so the hope is that the product of reclamation will approximate what natural processes would do to the land over geologic time anyway, thus restoring the land and ecology to its natural beauty, diversity, and stability in a relatively short period of time.

Relative to other parts of the country, interest in geomorphic reclamation, or "landforming" and stream restoration[1], has been slow to develop in Central Appalachia.[2] One likely reason for this pertains to the nature of the region's landscape. Unlike coal mining sites in the west, where landforms are nearly flat or gently undulating and excess spoil is not generated, the mountainous terrain in Central Appalachia presents significant challenges to earth-moving operations as mine sites are backfilled to achieve the approximate original contour (AOC) of the land and excess spoil fills (or "valley fills") are built on steep foundations. The perception in the mining industry has been that the practices of landforming and stream restoration would be uneconomical because of the extra time and skill required, especially in steep terrain, and the potential loss of storage volume in valley fills. Since the Federal regulations under the Surface Mining

[1] Henceforth, the meaning of "geomorphic reclamation" will include both stream restoration and "landforming." The term, landforming, which is borrowed from Schor and Gray (2007), will signify "natural" reclamation of upland terrain (land upslope and beyond the direct influence of, stream channels).

[2] One important exception is the important work of Agouridis et al. (2008), involving the restoration of a headwater stream system on a small hollow fill in eastern Kentucky.

Reclamation and Enforcement Act (SMCRA) do not explicitly reference geomorphic reclamation, there has been little impetus to utilize or encourage use of its methodologies.

Until recently, the authors and other members of the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) engaged with mountaintop mining and excess spoil disposal have focused on ensuring the exercise of prudent civil engineering practices in the design and construction of backfill structures and excess spoil fills. Important issues they have addressed include the long-term mass stability of fills; and drainage, erosion, and sedimentation control. Most of the attention has been focused on valley fills. In contrast to spoil backfills, valley fills are artificial landforms that are added to the natural landscape and that rest on inclined foundations. Several of them have been the sites of mass instability and dramatic occurrences of floods or mudflows. To date, nearly all site-specific problems took place on active mining and reclamation sites and were subsequently remediated by the mine operator. However, engineers and geologists of the OSM Appalachian Region offices remain concerned about the long-term stability of the fills and their drainage diversion channels. There is no provision in SMCRA for the maintenance or remediation of the structures once the mined land has been reclaimed to the satisfaction of the governing regulatory agency, and final bond moneys have been returned to the mine operator. The authors' concerns pertaining to long-term stability of the artificial structures are in large part behind their interest in landforming and stream restoration as alternative approaches to valley fill design and construction.

The objectives of this paper are to provide a brief summary of mountaintop mining and reclamation, with emphasis on valley fills; and identify aspects of SMCRA related regulations and policies, mining and reclamation practices, and regional geomorphic conditions that may affect landforming and stream-restoration applications on mined lands in Central Appalachia. The paper first summarizes how mountaintop mining results in excess spoil fills in valleys adjoining coal-extraction areas. It then describes longstanding issues that relate to the physical and hydrologic stability of the fills—and that may also influence the feasibility of applying geomorphic principles to their construction and reclamation. Finally, both the concept and challenges of applying geomorphic reclamation methodologies to mine-land reclamation (i.e. backfilling mined out areas, valley fill construction, and drainage control) in Central Appalachia are discussed. This work relies heavily on the pioneering work of Horst Schor and Donald Gray, which has recently been assembled in a reference guidebook (Schor and Gray, 2007). Other important references in this work include a study of valley fill long-term stability (U.S. OSM, 2002b) and a paper on the potential effects of recently promulgated regulations on fill stability by Michael and Superfesky (2007).

Generation of Excess Spoil and Valley Fill Construction

Mountaintop mining in the Appalachian coal fields removes overburden and interburden material to facilitate the extraction of coal seams. When coal is mined by surface mining methods, rock and soil that overlie the coal must be first temporarily removed and stored outside of the immediate mining area. The rock is blasted as it is removed. When sufficient storage space is available, the operator begins to transport the blasted rock, or spoil, back to the mine area for permanent storage. The operator grades the spoil so that it closely resembles the pre-mining topography or AOC and eliminates the highwall.

Mountaintop mining normally produces more spoil than can be stored in the mined out area. Because the angular blast rock comprising the spoil includes voids the volume of spoil removed during mining increases or "bulks" relative to the volume of rock that was in place prior to mining. Additional excess spoil can result from slope stability considerations in the mountaintop backfill if stable spoil slopes (i.e. with the slope-stability safety factor of 1.3) are not as steep as those of the natural, premined ridge top. Finally, relatively large volumes of excess spoil may be generated in steep-slope terrain when the operator proposes to reclaim the mining area to a flatter or more gently rolling topography in lieu of AOC so that a more economical viable land use may result. In these situations, the regulatory authority must approve the mountaintop removal AOC variance. Inadequate storage within the mine site requires placement of excess spoil into the adjacent narrow valleys, or hollows, of the Appalachian landscape.

Excess spoil generation and fill construction are almost exclusively limited to states in the Central Appalachian coal fields (Fig. 1). During the period October 1, 2001 to June 30, 2005, 1589 of the 1612 fills (98.6 %) approved to be constructed nationwide were located in Kentucky (1079), Tennessee (13), Virginia (125), and West Virginia (372), and only 23 fills outside of Central Appalachia. The valley fills vary greatly in size. For example, a sample of 128 valley fills were analyzed in a valley fill long-term stability study in support of the Mountaintop Mining/Valley Fill Programmatic Environmental Impact Statement. The sampled fills ranged in volume from 0.2 to more than 200 million cubic yards; and they varied in length from 300 to nearly 10,000 feet (USOSM, 2002b).

The Federal SMCRA regulations recognize several excess spoil fill construction methods. In most of the recognized construction methods, excess spoil is deposited in uniform and compacted horizontal lifts or layers (four feet or less in thickness). Prior to placement of the spoil, the foundation (i.e. valley floor and sides where the spoil will be placed) must be prepared and rock underdrains installed to accommodate groundwater seepage and surface-water infiltrations. The regulations require that the rock underdrain be durable (rock that will not slake in water nor degrade to soil material); non-acid or toxic forming; and free of coal, clay or other non-durable material.

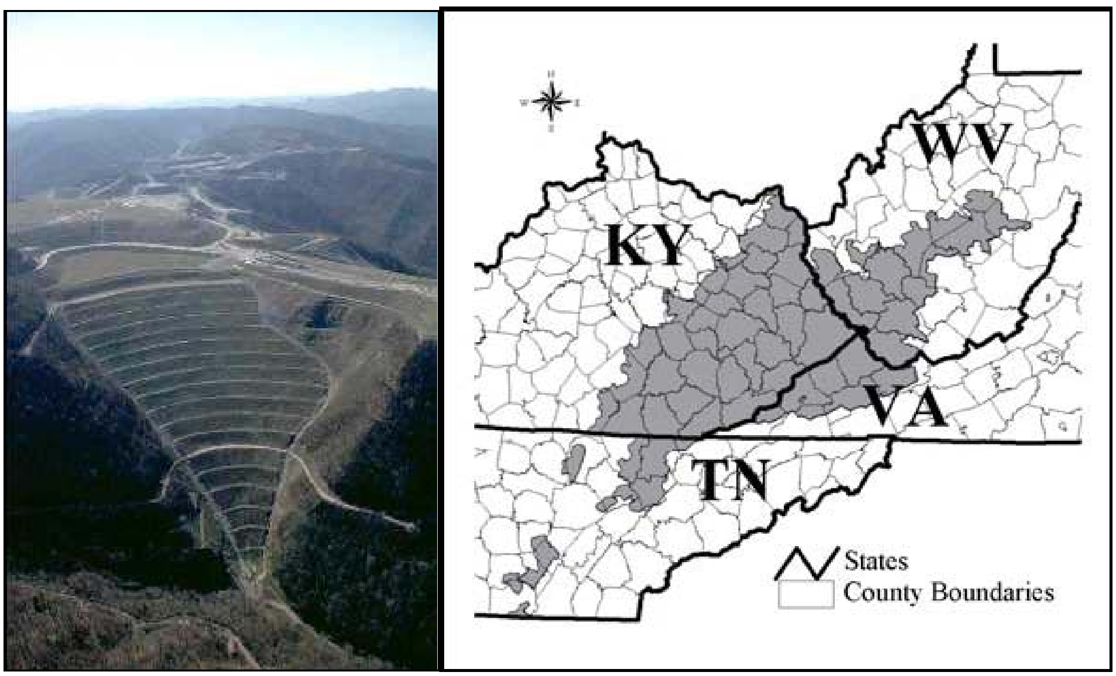

Figure 1: Valley Fills in Central Appalachia; (left) example of a valley fill at a mountaintop mining site; (right) counties with watersheds affected by mountaintop mining and valley fill construction (shown in gray).

The predominant valley fill construction technique employed in steep-sloped Appalachia is the *durable rock fill* method (Fig. 2). Unlike other fill construction techniques, this method does not require underdrain construction prior to spoil placement or spoil placement in thin lifts. Instead spoil is end-dumped into valleys in a single lift or multiple lifts (30 CFR 816 / 817.73). The fill construction begins at an elevation where the crown or top of the completed fill will occur. Dump trucks haul spoil to the center of the hollow and dump the material down slope.

This continues to take place, allowing a platform of spoil to lengthen down the hollow, and ends when the toe or bottom of the fill approaches its as-designed final location. Lifts of existing fills are known to range between 30 to over 400 feet in thickness. At the completion of spoil placement, the face of the fill is graded from its dumped angle of repose into a less steep, terraced configuration. The durable rock fill method can only be used if durable rock overburden is present and will comprise at least 80 percent (by volume) of the fill. The installation of a designed rock drain prior to spoil placement is not required for this type of fill, since it is assumed that the gravity segregation during dumping forms a highly permeable core and/or blanket drain at the interface between the natural ground and fill material.

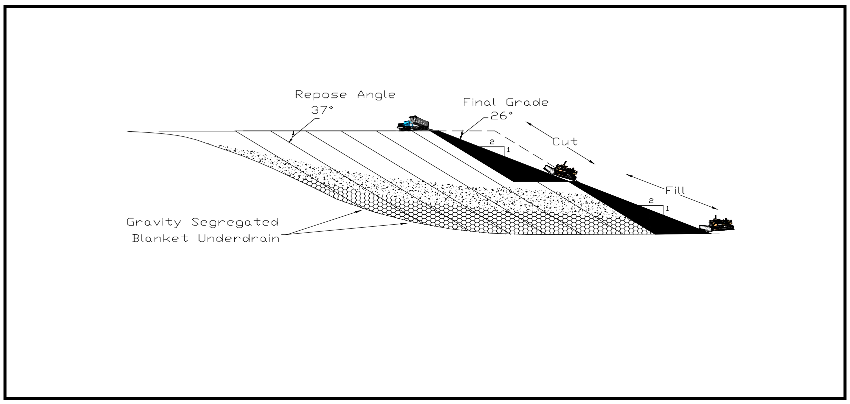

Figure 2: Schematic of durable rock fill construction.

The objective of most Federal regulatory requirements pertaining to excess spoil fills is to ensure long-term stability. Required steps to achieve stability include:

- A site investigation for each proposed excess spoil fill, specifically an investigation of the terrain and materials that will form the foundation of the fill. Important concerns include soil depth, the engineering strength of the soil or rock foundation materials, and the occurrence of seeps or springs.
- A stability analysis of the designed fill mass based on (1) accurate values representing the engineering strengths (i.e. internal friction angle and cohesion) of the placed spoil and foundation material and (2) anticipated pore-water pressures in the fill mass. The analysis must demonstrate a static safety factor (SF) of 1.5 and dynamic SF of 1.1.
- Following certain specific requirements in the design or construction of the fill body and appurtenant drainage structures, such as: removal of all vegetative and organic materials

from the disposal area (the fill foundation) prior to spoil placement; grading the final outslope of the valley fill to an inclination not steeper than 2h:1v (50 percent); the construction of keyway cuts or rock toe buttresses where the slope of the disposal area is in excess of 2.8h:1v (36 percent); construction of diversion ditches to keep uncontrolled drainage from flowing over the face of the fill; incorporation of flood control measures, e.g. designing and constructing drainage diversions adequate to safely pass runoff from a 100-year, 6-hour event for durable rock fills; and the protecting the fill slope from surface erosion.

- Professional engineer's certifications during the construction of the fills, quarterly and during critical phases of construction, to document that the fill is being constructed according to the permit plan. Critical construction phases include: foundation preparation; underdrain construction; surface drain construction; grading; and revegetation.

Valley Fill Design, Construction, and Inspection Issues

Several past and current issues pertaining to the long-term stability of valley fills, particularly durable rock fills, may also influence the application of geomorphic reclamation to those structures. The issues, in the original context of stability concerns, are briefly summarized below. More detailed discussions are available in USOSM (2002a&b) and Michael and Superfesky (2007).

Excess Spoil Minimization and Valley Fill Stability

OSM promulgated changes to the Code of Federal Regulations in the interest of minimizing the adverse effects of excess-spoil-fill construction on the "prevailing hydrologic balance, fish, wildlife and other environmental values" (73 *FR* 75814). Among other provisions, the proposed changes require: (1) minimizing the amount of excess spoil generated at a mine site; (2) restricting the volume of excess spoil fills constructed; and (3) avoiding placement of the fills within intermittent as well as perennial streams. Achieving those objectives can result in valley fills that toe out at higher elevations in the hollows (i.e. to prevent or limit burial of streams). Consequently, the slopes of fill foundations may generally be steeper than in the past. While OSM staff engineers and geologists have supported those measures to protect the hydrologic balance and general environment, they have also warned that placement of fills on steeper foundations can negatively impact the stability of the fills if proper care is not taken during their construction. An example of a failed durable rock fill on a steep foundation slope in eastern Kentucky is shown in Fig. 3.

Shear Strength of Foundation Materials

Several studies have emphasized that the identification of soil-like material in the foundation of a proposed excess spoil fill—and the use of accurate foundation shear strength properties—is essential for a realistic valley fill stability analysis (USOSM, 2002; and KYDNR and USOSM, 2006). They identified needed improvements to foundation investigations in support of the permit application process.

Figure 3: HNR durable rock fill in eastern Kentucky; (left) general view of landslide looking upslope from toe; (right) aerial view of fill during the post-landslide remediation.

Subsurface Drainage Control in a Durable Rock Fill

The effectiveness of gravity-segregated underdrain depends on whether the end-dumped material is sufficiently permeable to convey subsurface water out from the durable rock fill. An inadequate underdrain results in pore-water pressure build-up in the spoil, which diminishes the stabilizing effects of internal friction and cohesion. In the case of non- durable rock fills, underdrains can easily be designed and constructed to meet site-specific subsurface drainage conditions. In durable rock fills, however, the quality of the end-dumped underdrain completely depends on: the supply of durable rock; the selective use of durable rock during end-dumping (if necessary); and the effectiveness of the gravity segregation process. In most cases, as long as a permit application successfully demonstrates the on-site availability of 80 percent durable material in the coal overburden and interburden (through the use of Slake Durability Index or some other accepted lab testing protocol), construction of a durable rock fill is permitted.

However, the experience of Federal and State reclamationists over the years has indicated that the correlation between lab-tested rock durability and the formation of an effective underdrain is not strong (Welsh et al., 1991 and USOSM, 2002; see Fig. 4). Unfortunately, there is no consensus among geotechnical experts working for the industry, environmental groups, and government as to what constitutes a realistic rock durability testing protocol.

Figure 4: Gravity segregation of durable rock fill underdrains; (left) effective underdrain formation with durable sandstone boulders; (right) ineffective underdrain formation with "durable" shale fragments.

In response to this problem, OSM has established a Federal inspection protocol that emphasizes the importance of visible evidence of durable rock fill underdrain formation, i.e. that gravity segregation during end dumping visibly results in a graded fill face, with the largest particle size at the bottom and gradually decreasing particle sizes up the fill outslope (USOSM, 2008).

Another issue related to the durable rock fill underdrain is related to the required regrading of the fill outslope after the end dumping is completed. The outslope has to be regraded from the angle of repose to a more stable, 2:1 slope. This is commonly accomplished by grading spoil from upper sections of the fill outslope towards the toe, thus extending the toe downstream (Fig. 2). This reworked spoil is finer-grained than the gravity-segregated underdrain material. The placement of the fines downstream of the terminus of the blanket underdrain can retard free drainage from within the fill, and consequently increase pore pressures in the spoil, reducing fill stability. For this reason, several state regulatory authorities require machine placement of underdrains that are contiguous with the blanket drain and that extend beyond the final toe position of the outslope.

Surface Drainage Control Durable Rock Fills

Excess spoil fills other than durable rock fills are constructed from the bottom of the fill, or toe, upwards. As such, the final appurtenant surface drains are installed with each lift during fill construction. For durable rock fills constructed via end dumping of the excess spoil, final surface drains are not installed until the fill placement is complete and ready for final regrading. However, the mine operator, certifying engineer, and regulatory inspector are still charged with ensuring effective drainage control *throughout the construction of the fill*. Uncontrolled surface drainage over a barren outslope results in severe erosion and transport of fines towards the fill toe. Clogging or burying of the underdrain can result. Further, outwash deposits beyond the advancing toe can become weak foundation materials below the finished fill if not removed. In a worst case, severe, life-threatening floods or mud flows can occur during a storm event as in the Lyburn incident in West Virginia in 2002 (Fig. 5; USOSM, 2002a).

Contemporaneous Reclamation

Sometimes durable rock fills are abandoned for long periods of time following partial construction. Long exposure of spoil to the elements without the benefit of revegetation and surface drains could accelerate rapid spoil degradation and erosion. This can lead to rapid in-filling of sedimentation ponds near the toe of the fill and significant downstream sedimentation; and can also result in instability in the completed fill from internal weak zones parallel to the face of the completed fill. In the case of the 2002 Lyburn event, absence of contemporaneous reclamation and consequent spoil deterioration may have contributed to the heavily sediment-laden flood or mud flow.

Figure 5: Lyburn flood; (left) erosion and sloughing on the outslope of the durable rock fill following storm event; (right) property damages downstream of the fill.

Wing Dumping

A common problem in mountaintop mining has been the dumping of spoil across the valley from the mining bench on "points" down-valley of the toe of a developing fill. Ideally, all spoil is first transported up the valley and then dumped from the top of the fill in the down-valley direction. In this way, the end-dumped face of an advancing fill progresses uniformly down the valley and parallel to the fill face. This preferred procedure maximizes gravity segregation of competent (unweathered) rock for underdrain development; minimizes spoil exposure, and consequent breakdown and stream sedimentation; and ensures minimization of land disturbance. Several States authorities now have rules or policies that limit wing dumping.

The combination of wing dumping and unanticipated reductions in excess spoil volume has frequently resulted in a concave outslope on the completed fill (Fig. 6). A concave face typically includes over-steepened slopes at the side abutments with natural ground. It is also characterized by longer and less-inclined terrace drainage channels. Increased water transport distances and diminished channel gradients can cause ponding on the terraces. Ponding, in turn, may promote water infiltration into the fill material, fluvial erosion, and consequent fill instability.

Figure 6: Comparison of concave (left) and flat (right) valley fill outslopes.

Applying Geomorphic Reclamation to Mountaintop Mining: *The Concept*

Geomorphic reclamation involves the application of principles and insights gained from the study of geomorphology to land and stream modification and reclamation. Schor and Gray (2007) identify two primary benefits of landforming, namely: (1) the production, enhancement, or restoration of an aesthetically pleasing landscape; and (2) artificial landforms that are stable i.e. that experience minimal amounts of erosion and with virtually no or very little probability of large and rapid mass movements such as landslides. Objectives of the approach include: (1) constructing artificial landforms that blend in with the surrounding landscape; and (2) constructing landforms that nature itself would form or at least will accept without significant further modification through erosion and mass wastage. For reclaimed coal mined lands, we can rephrase the objectives as follows: to construct or modify landforms that look like they "belong" and that are stable in the <u>long-term,</u> thus <u>maintenance free</u> in the post-final-bond-release environment.

Schor and Gray (2007) contrast traditional methods of grading, drainage control, and landscaping with landforming as follows:

- Conventional grading results in slopes that generally have "…rectilinear- and planar-slope surfaces with unvarying gradients and angular slope intersections." The crests of the slopes are "…devoid of topographic relief…" and the "…bottom of the slope exhibits a linear and angular intersection with the base." Drainage diversion structures are usually "…constructed in a rectilinear configuration (parallel for surface drains, perpendicular for down-drains) in prominent and highly exposed positions, maximizing the negative visual impact on the slope face." Landscaping is "…applied in rigid, uniform patterns, and plant material such as trees and shrubs are placed at equal spacing to achieve the stated conventional objective of 'uniform coverage.'" This results in surfaces that are not aesthetic and are "devoid of creative opportunities for either the placement of drainage devices or plantings that would mimic the characteristic natural landscape of the area."
- Landforming, on the other hand, results in graded slopes "…characterized…by a continuous series of distinctive concave and convex forms interspersed with mounds that blend into the profiles—by nonlinearity in plan view and by varying slope gradients. The profile of slopes "…exhibits a concave form with steeper gradients near the top and with gradually decreasing, flatter inclinations near the bottom." Schor and Gray (2007) emphasize that a "…concave-slope profile is more stable than a linear profile, and it more closely resembles the equilibrium profile of natural slopes." The man-made slopes are smoothly transitioned with natural slopes to "…create a minimally perceptible blending of the two…." Surface runoff is directed into swales formed from the varying gradients across the slope face. This way, the channels are concealed. Also, their lengths are

increased, "…resulting in the reduction of gradient and flow velocity in the drain." The revegetation plan also mimics nature by concentrating trees and shrubs in the concave slope areas and swales (where moisture is concentrated), while planting grasses and other ground covers on the convex or interfluves areas.

The contrasts between conventional and landform grading and drainage control are illustrated in Fig. 7. In the case of coal-mine lands in steep-sloped Appalachia, Schor and Gray (2007) observe that reclamation is being carried out by conventional grading, drainage control, and revegetation methods, thus all too often producing landscapes characterized by broad, flat plateaus and adjoining or proximate fills in the hollows shaped like dam embankments. For both the backfill and excess spoil fill areas they recommend the construction of more complex, curvilinear forms (both in plan and cross section) that more closely achieve AOC and blend in with the natural topography. To exemplify their recommendations with respect to valley fills they offer the comparative photographs (shown in Fig. 7) of a valley fill built by current methods versus a preferred, natural topographic form in an adjacent natural slope. They also recommend that reclamation planners adapt designs and construction methods to natural watershed drainage and vegetation patterns.

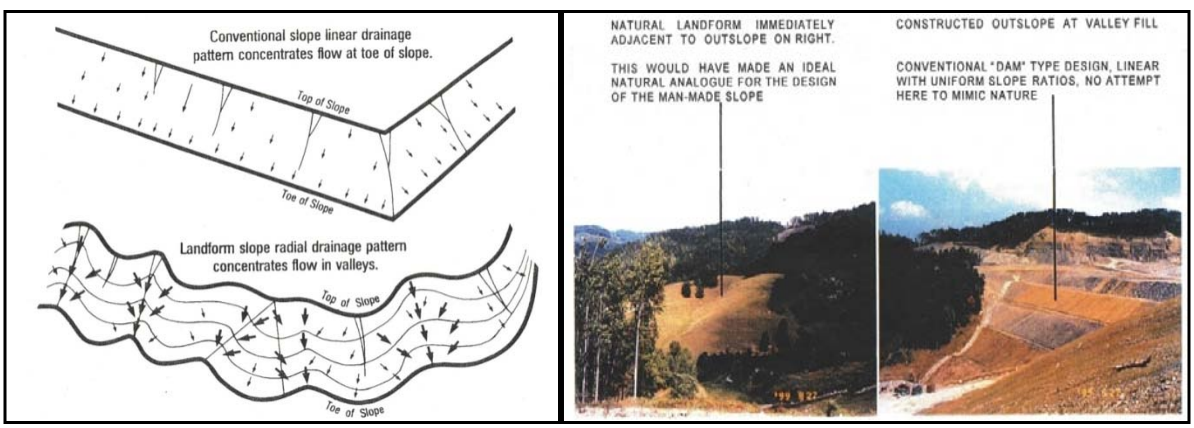

Figure 7: Comparisons between conventional and landform grading of fill slopes; (left) schematic illustration; (right) in-field comparison between a typical valley fill outslope and alternative "design" provided by natural geomorphic processes. (Left illustration from Schor and Gray, ©2007 John Wiley and Sons, Inc., reprinted with permission of John Wiley and Sons, Inc; right photograph from Schor, 1999)

Applying Geomorphic Reclamation to Mountaintop Mining: *The Challenges*

The authors find the concept of geomorphic reclamation to be sound and they generally support its application to coal mine land reclamation. However, they also recognize several potential challenges to its application to site conditions unique to the rugged topography of Central Appalachia. Those potential challenges are described below.

Lack of Support for Geomorphic Reclamation in the SMCRA Regulations

The terms, geomorphic reclamation, landforming, or stream restoration are not used in the Federal regulations. However, there are some important rules requiring the mine operator to take into account natural conditions that (1) existed on the mine site prior to mining and (2) surround the site. Most significant among them is the requirement that the mined and reclaimed land be returned to AOC. Specifically 30 CFR 701.5 defines AOC, in relevant part, as "…surface configuration achieved by backfilling and grading of the mined areas so that the reclaimed area, including any terracing or access roads, *closely resembles the general surface configuration of the land prior to mining and blends into and compliments the drainage pattern of the surrounding terrain*, with all highwalls, spoil piles and coal refuse piles eliminated." [Emphasis added]. Other rules referencing premining site conditions and the conditions of surrounding mine sites include:

- § 816.43 (a) (3), which requires designing and constructing permanent drainage diversion channels "…so as to restore or approximate the premining characteristics of the original stream channel including the natural riparian vegetation to promote the recovery and enhancement of the aquatic habitat."
- § 816.71 (a) (3), requiring that excess spoil fills are "…suitable for reclamation and revegetation compatible with the natural surroundings and approved postmining land use."
- §§ 816.111 (b) (2) and (4), respectively stipulating that reestablished plant species have "…the same seasonal characteristics of growth as the original vegetation," and be "…compatible with the plant and animal species of the area."

Finally, the practice of landforming is suggested in §§ 816.71 (e) (4) and 816.102 (h), which permit the construction of small depressions on excess spoil fills and spoil backfills, respectively. Those regulations state that the depressions are allowed if needed to "…retain moisture, minimize erosion, create and enhance wildlife habitat, or assist revegetation."

Most other regulations neither imply support for nor potentially impede geomorphic reclamation. However, there are several rules that are potential impediments. Those regulations pertain to alternative postmining land uses and to the application of certain civil engineering principles and practices to fill design. These rules are described below:

AOC variances. With respect to surface mining sites as a whole, the regulations do allow, under certain circumstances, backfilling of spoil to achieve surface configurations other than AOC. 30 CFR 785.14 (c) permits an AOC variance for "mountaintop removal" mining if the proposed postmining land use will be "…industrial, commercial, agricultural, residential, or public facility…" and if other, non-AOC, requirements in the regulations are met. Some of the same contingent allowances are available for "steep slope mining" (see § 785.16). Schor and Gray (2007, p. 196) acknowledge that there is some justification behind these variances: "There are certainly good reasons for a limited amount of level ground in mountainous terrain for such developments as housing, schools, shopping centers, golf courses, prisons, sports fields, and so forth." However, they warn that "…this level ground and associated land uses should not come…at the expense of damage to the beauty and environmental integrity of vast tracts of the original landscape that have attracted generations of residents and tourists alike."

The authors of this paper share Schor's and Gray's (2007) position; however, they also note that there is no programmatic mechanism for controlling how often AOC variances are approved or how much land area they effect. The frequency of variances only depends on how often a variance is requested by a mining company and granted by a regulatory authority (based on the merits of the specific request). Variances for "equal or better economic or public use of the affected land" invariably result in the permanent removal of original ridge tops and creation of plateaus. However, it is also noteworthy that, with sufficient amounts of backfill, the plateau surfaces themselves can be graded into landforms that are stable, and more supportive of healthy local environments and aesthetic than simple flattops. Figure 8 shows an example of alternative grading on a reclaimed ridgetop, in this case to construct a cattle watering hole. In like manner, grading can be designed to establish a "natural" landscape compatible with "equal or better" uses of the land.

References to engineering principles and practices. Rules in the SMCRA regulations based on engineering principles or practices include those that actually apply the words "engineer" or "engineering" to requirements relating to the design and construction of excess spoil fills. 30 CFR 816.71 (b) requires that "…current, prudent, engineering practices…" be applied to the design of fills and appurtenant structures and that a "…qualified registered professional engineer experienced in the design of earth and rock fills…" certify the design. Section 816.71 (h) stipulates that a "…qualified registered professional engineer, or other qualified professional specialist under the direction of the professional engineer…" periodically inspect the fill during its construction. Further, inspection reports must be certified by the "…qualified registered professional engineer…." These rules are necessary to ensure proper fill design and construction and none of them negate the practice of geomorphic reclamation. Nevertheless, mining and civil engineers are not normally educated in geomorphology. They are trained to design structures that are not only stable and functional, but also cost effective *to build*. For this reason, valley fills with simple, linear geometries are preferred. Future emphasis on the geomorphic reclamation of fills would require reorienting of most engineers and/or the added input of landforming and stream-restoration specialists. Further, if regular application of geomorphic reclamation to steep-slope surface mining is desired enforcement of the practice may require additional regulations.

Figure 8: Backfill grading to construct a cattle watering hole on a mountaintop mining site being reclaimed.

Other "engineering" regulations pertinent to excess spoil fills include the requirement for a valley fill outslope inclination of 2 horizontal to 1 vertical (2:1) or less, the allowance for terraces on the outslope, and stipulations relating to durable rock fill diversion channels. 30 CFR 816.71 (e) (3) states in part that the "grade of the outslope between terrace benches shall not be steeper than 2h:1v (50 percent)." The intent of the rule is to promote mass stability and minimize erosion. The rule does not address the *shape* of the outslope in cross section or in plan. However, the crest-to-toe profile of outslopes is typically straight. As stated above, straight slopes are simpler, less time consuming, and less costly to construct.

In contrast to outslope profiles, valley fill outslopes are often concave *in plan.* Concave outslopes commonly result from wing dumping and the placement of less excess spoil than anticipated for the designed fill. Although geomorphic reclamationists may favor concavity in plan as well as in profile, OSM engineers have historically promoted straight surfaces across the face slope in order to ensure: (1) 2:1 or gentler slopes where the fill face abuts the natural side slopes; (2) efficient transport of rainwater and snow melt along the outslope terraces to the side drains; and (3) minimization of land disturbance.

Another engineering practice that appears to contradict the geomorphic reclamation approach is related to the objective of minimizing water flow on the valley fill. The purpose of the objective is to: (1) control erosion; and (2) minimize seepage into the fill material and concomitant pore water pressure build-up and potential mass instability. Ideally, the top or "crown" of the fill is graded and the outslope is terraced to divert water off the fill into drainage diversion ditches located off the fill. 30 CFR 816.71 (e) (3) states in part that terraces "…may be constructed on the outslope of a fill if required for stability, control of erosion, to conserve soil moisture, or to facilitate the approved postmining land use." Although terraces are optional in the Federal regulations, they are constructed on valley fill outslopes on a regular basis.

The requirements of diversion ditches appurtenant to excess spoil fills are included in 30 CFR 816.71 (f), § 816.72 (a) (2), and § 816.73 (f). The first section contains, in part, the general requirements that "…the fill design shall include diversions and underdrains as necessary to control erosion, prevent water infiltration into the fill and ensure stability," and that the diversions comply with the requirements of § 816.43."[3] Section 816.72 (a) (2) applies to valley fills and "head-of-hollow" fills constructed in lifts and stipulates that runoff "…from areas above the fill and runoff from the surface of the fill shall be diverted into stabilized diversion channels designed to meet the requirements of § 816.43 and, in addition, to safely pass the runoff from a

[3] Section 816.43 contains specific requirements for the design and construction of all diversion channels on surface mines.

100-year, 6-hour precipitation event."[4] Section 816.73 (f), applicable to durable rock fills, is similar to the other sections, but is also unique in that it specifically states that surface water runoff "…from areas adjacent to and above the fill is not allowed to flow onto the fill…." Over the years OSM has advocated the use of grading and diversions to keep runoff from areas above and around the durable rock fill from flowing onto the fill, and terraces that direct precipitation off the outslope as efficiently as possible. This position reflects, in part, the intention to ensure that seepage into the fill mass is sufficiently limited so that gravity-fed underdrains can prevent the destabilizing build-up of a phreatic surface.

The stipulated means for minimizing erosion and preventing a phreatic surface in the fill clearly result in fill geometries that do not resemble natural landforms and streams. A geomorphically reclaimed valley fill would be characterized by complex curvilinear forms blending in with the surrounding terrain. The precise form of the fill would have to be carefully considered. For instance, simply converting a conventional, linear geometric shape to one that is concave in profile and/or plan could force a choice between reducing the volume of excess spoil storage and increasing the area of disturbance. Further, forming a concave outslope in profile in a durable rock fill would probably require more spoil regrading than what is currently done to achieve a straight, 2:1 slope. Extensive machine placement of durable material beyond the end-dumped toe may be necessary to maintain a continuous underdrain system.

Another potential outcome of geomomorphic reclamation is that one or several ephemeral-to-intermittent streams would flow on top of the fill's surface. The design and construction of the fill would have to ensure that seepage from the channels would not recharge a phreatic surface within the structure and consequently jeopardize its stability.

<u>Priority of Excess Spoil Fill Minimization</u>

The relationship between the interests of excess spoil fill minimization and geomorphic reclamation has at least two aspects. One aspect questions the placement of significant volumes of spoil in the most elevated positions within hollows. The natural analogue to spoil is colluvium. Natural geomorphic processes do not normally result in deep deposits of colluvium in the upper reaches of the Central Appalachian landscape. Exceptions occur where colluvial

[4] Section 816.72 allows for the use of rock core chimney drains in the center of the fill for surface and subsurface drainage for head-of-hollow fills and valley fills less than 250,000 cubic yards in volume.

deposits rest on natural or man-made topographic benches. Fully replicating the work of nature would usually entail placing excess spoil where nature tends to concentrate colluvium, i.e. within the lower topographic reaches where the underlying slopes are gentler. Natural landslides and earth or debris flows typically occur in the middle to upper reaches of hill sides; and they result in colluvial deposits in lower positions where a safety factor of at least one occurs and additional erosion is predominantly fluvial and, with sufficient vegetation, more gradual. Locating and building valley fills that replicate nature in this manner would clearly violate the current regulatory emphasis of minimization.

The other aspect allows the disposal of excess spoil at high elevations (in the interest of minimizing land and stream disturbance) but also entails grading an elevated fill into a complex, curvilinear configuration that blends in with the surrounding terrain. It may be possible to build such fills that not only look natural but are also more stable than fills as currently constructed. But, as stated previously, the landformed fills would probably store excess spoil less efficiently, forcing a choice between less volume in a particular hollow and greater terrain disturbance.

One potential advantage of geomorphic reclamation is that it would not necessarily result in stream burial no matter where a valley fill is constructed. More ephemeral or intermittent stream length may be disturbed during the construction of a landformed valley fill (relative to current construction methods), but only in the sense of being *modified*. Steams affected by excess spoil placement could be *restored*. One could argue that disturbance and subsequent (successful) restoration of longer stream lengths is a more environmentally efficacious practice than complete burial of shorter ones. Nevertheless, this viewpoint does not comport with current regulations and policies.

<u>Cost concerns</u>

Schor and Gray (2007) acknowledge that the practice of landforming, relative to more conventional methods of earth movement, is more costly. Some of the cost increase is restricted to initial applications of landforming where design engineers and surveyors are inexperienced in the methodology. Temporary cost increases for each of those services typically range between 10 and 15 percent, but reduce to 1 to 3 or 5 percent with training and greater familiarity. Cost increases related to earth movement involving 1 million cubic yards or more have historically been limited to 0.5 percent. This is because an average of approximately 90 percent of the total earth volume is placed by conventional methods. The actual landforming work is applied to only the outer slope layers which are 20 to 50 feet thick in thickness (Fig. 9).

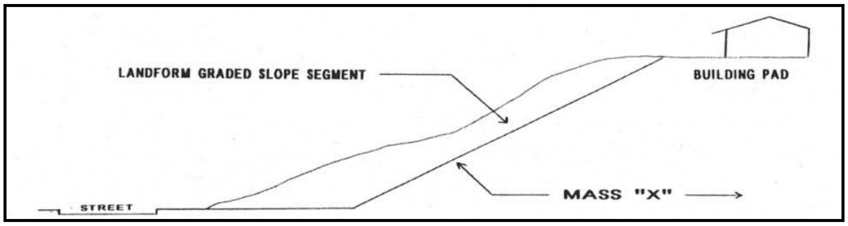

Figure 9: Relative amounts of earth moved by conventional vs. landform granding. (From Schor and Gray, ©2007 John Wiley and Sons, Inc., reprinted with permission of John Wiley and Sons, Inc.)

The temporary and permanent cost differentials with respect to engineering design and field survey control described by Schor and Gray (2007) may turn out to be true for mining reclamation in Central Appalachia. Minimal cost increases pertaining to earth movement may also apply to mine backfilling in accordance with AOC and the construction relatively large valley fills. The cost differential between landforming and more conventional earth movement could be significantly greater where mountaintop or steep-slope mining AOC variances apply and the thickness of spoil backfill is limited. The difference could also be marked in the case of small valley fills. Small fills can result from excess spoil minimization to avoid stream disturbance or from economic considerations, such as long transport distances between the points of excess spoil generation and disposal. Since these fills typically occur within the upper elevations of the hollow where slopes are relatively steep, they are thin. An example is the failed HNR durable rock fill in eastern Kentucky (Fig. 3 and 10). The maximum thickness of the structure, in its remediated condition, is 70 feet.

Contemporary Reclamation

The additional time and cost associated with a requirement for landform grading of durable rock fills may induce greater delays in their reclamation. Any additional reworking of the spoil to achieve a more complex, curvilinear surficial configuration could also increase the surface area relative to conventional practices and consequently increase the severity of erosion and flooding if a significant storm event occurred during the regrading process. Inspectors would need to be extra vigilant to ensure timely reclamation of the fills.

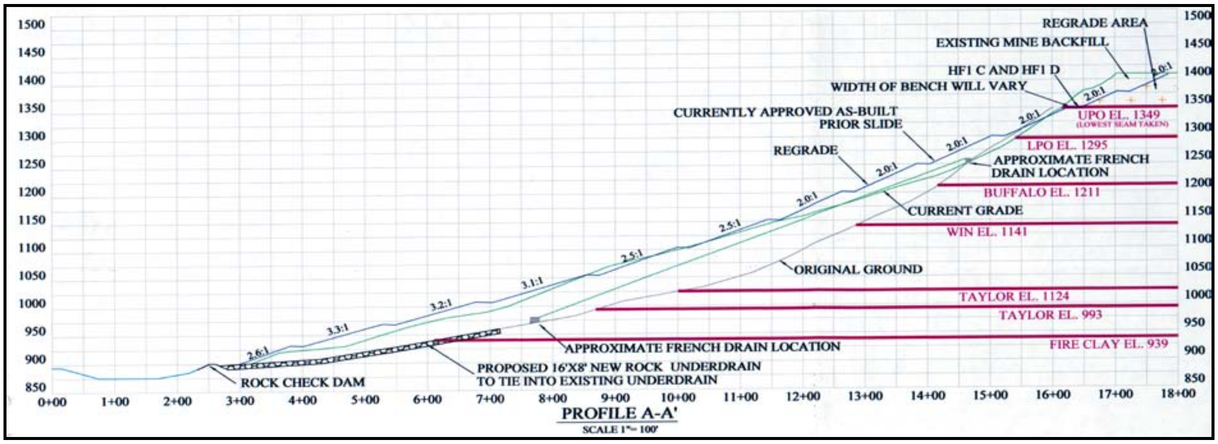

Figure 10: Profile of remediation plan for the HNR durable rock fill. (From CBC, 2005)

Building Stable Landforms in an Erosional Topography

Schor and Gray (2007) report that the available field, laboratory, and modeling evidence suggests that, all else being equal, concave slopes have greater fluvial and mass stability than uniform, planar slopes. They emphasize that greater stability is one of the benefits of landforming fill structures. Their description of successful applications of landform grading in housing and community development projects on steep and geologically unstable slopes in California suggests that the application of landforming to backfills and valley fills in the rugged, erosional terrain of Central Appalachia may be feasible. The authors of this paper wish to underline that naturally looking and well blending artificial landforms would not necessarily be stable. The unstable character of the natural Central Appalachian mountains and hills is very well documented on soil maps of the U.S. Natural Resources Conservation Service; in regional slope-instability mapping by Lessing et al. (1976) and Outerbridge (e.g. 1979, 1982); and numerous geotechnical investigations of natural landslides and other types of major mass movements (Fig. 11).

OSM provides annual training on spoil handling and disposal to State and Federal surface mine permit reviewers and inspectors under its National Technical Training Program; and much emphasis is placed on the identification of “landslide topography” to avoid fill construction on unstable foundation slopes. The overwhelming evidence demonstrates that nature is not patient with deep sequences of unconsolidated material on steep slopes, especially where subsurface drainage is at high discharge. The intention of SMCRA-related regulations is to ensure backfills and valley fills are stable indefinitely. The implication is that they should be at least *more* stable than the wide-spread, *natural* landslide-prone slopes in Central Appalachia. One means by which geomorphic reclamation can promote greater stability on valley fills is to anticipate or model the shape and position of a naturally-formed and stable distribution of unconsolidated material (i.e. one limited to gradual, equilibrated erosion and free of rapid mass movements). The result could be a series of gentle, concave slopes bounding a restored stream in the lower reach of a hollow. An alternative approach—that would be more in line with current attention to excess spoil fill minimization—would be to grade elevated valley fills into curvilinear slope forms while ensuring that measures to stabilize the fills are also performed. Most imperative are the preparation of a stable foundation and construction of adequate underdrains.

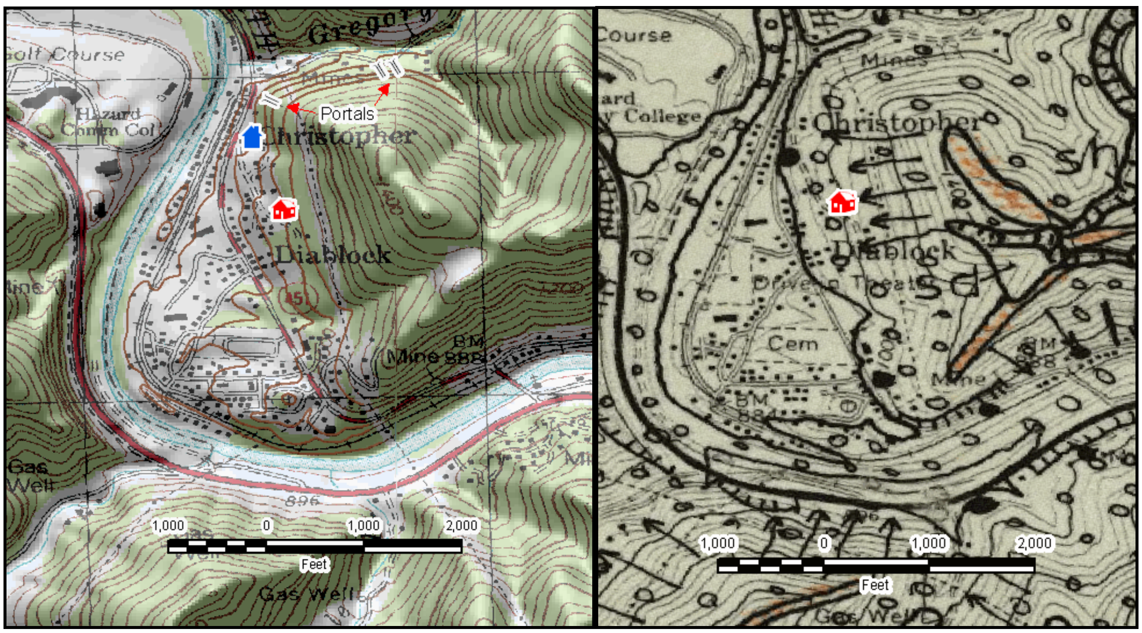

Figure 11: Site of OSM landslide investigation in Perry County, Kentucky; (left) site topography; (right) 1979 USGS survey of landslides and related features surrounding the site. Area covered with small circles represents colluvial slopes with landslides. Arrows delineate zones of debris flows and debris avalanches. Orange shading represents rock and soil susceptible to landslides. (Modified from USOSM, 2005).

Conclusions and Recommendations

The authors find the concept of geomorphic reclamation to be sound; and propose that the techniques of landform grading and stream restoration may have potential for coal mined lands in steep-sloped Appalachia as well as in other regions of the U.S. However, before the concept is applied to the coal fields of Central Appalachia, certain regulatory and practical bottlenecks will need to be addressed: Those bottlenecks are summarized as follows:

- The Federal SMCRA regulations as they currently stand include provisions that appear to be contrary to some of the objectives of geomorphic reclamation. These include: (1) AOC variances which turn natural ridges into broad plateaus; (2) references limited to expertise in rock- and earth-fill engineering (i.e., which do not include expertise in geomorphic reclamation); (3) lack of references to complex, curvilinear shapes (typical of natural landforms) for reclaimed surfaces; (4) and the requirements for or practices of constructing unnatural drainage control systems such as fill outslope terraces and steep diversion ditches on the sides of the fill.
- Recently promulgated regulations require, among other provisions, restrictions on the volume of excess spoil fills to avoid disturbance of natural streams. Placing excess spoil in naturally optimal locations (i.e. in lower topographic reaches) in the interest of stability as well as aesthetics could contravene these requirements. On the other hand, landform grading of a valley fill that is placed closer to a ridge top could either reduce spoil volume storage capacity or necessitate more land and stream disturbance relative to a conventional fill.
- Although cost increases connected with landforming have been shown to be minor after an adjustment period, they might still be enough to discourage its voluntary application to Central Appalachian mine sites on the part of the industry. The observation that earth-movement cost increases are minimized since only the surficial layers of a fill are landform graded probably would not apply to AOC variance sites and small valley fills.
- Requirements for more sophisticated and time-consuming regrading associated with landforming could motivate more delays in final reclamation relative to conventional earth-moving procedures. Inspectors would need to be especially vigilant to ensure contemporaneous reclamation of the valley fills.
- The terrain of Central Appalachia is erosional in nature and many of its steep slopes are prone to rapid mass movements. For this reason, constructing artificial landforms that look natural and blend well with the surrounding landscape will not necessarily satisfy all environmental objectives connected with coal mine land reclamation. One significant challenge will be to build valley fills that are stable as well as aesthetic.

Serious pursuance of landforming and stream restoration on valley fills in rugged topographic settings will require both workshops and in-field experimentation. The compatibility (or lack of which) between the objectives and procedures of geomorphic reclamation on the one hand and current regulations and enforcement policies on the other should be further assessed. However, rule changes to accommodate geomorphic reclamation should not be proposed without first determining the geotechnical feasibility of the approach to a variety of site conditions existing in Central Appalachia. This cannot be accomplished without experimental construction projects on mine sites.[5]

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[5] One potential but highly competitive source of funding for such projects is the OSM Technical Studies Program. Information on the program is available at: http://www.techtransfer.osmre.gov/NTTMainSite/appliedscience.htm .

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