THE LONG TERM STABILITY, LAND-USE POTENTIAL AND EROSIVITY OF SURFACE MINED LANDS RETURNED TO APPROXIMATE ORIGINAL CONTOUR IN THE CENTRAL APPALACHIANS[1]

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Abstract.-- The requirement for return of mine spoil to "approximate original contour" (AOC) is quite controversial in the Appalachians. Many AOC backfills are unstable and prone to failure, particulary in excessively steep topography. Alternatives to AOC exist which are more stable, environmentally and economically superior to complete AOC, and still eliminate the highwall, when properly constructed in appropriate locales. Widespread implementation of these alternative landforms would reduce sediment loss from mined areas.

INTRODUCTION

Federal legislation (Surface Mining Control and Reclamation Act of 1977--SMCRA) and resultant state Permanent Regulatory Programs require surface mine operators in the Appalachians to restore reclaimed land surfaces to their "approximate original contour" (AOC) or the most moderate slope possible to eliminate the highwall. In areas of steep relief, such as SW Virginia, this provision has been highly controversial. Many have alleged the AOC provision leads to unstable post-mining slope conditions, excessive mining costs, increased erosion, and loss of post-mining land-use value. Until now, little research, if any, has been conducted to objectively evaluate the AOC provision in the steeply sloping hard rock mining regions of Appalachia.

The Congressional Record indicates that Congress gave serious attention to the tradeoff between environmental quality and economics during the debate over SMCRA previous to its passage. The Act defines approximate original contour as:

> "Approximate original contour" means that surface configuration achieved by backfilling and grading of the mined area so that the reclaimed area, including any terracing of access roads, closely resembles the general surface configuration of the land prior to mining and blends into and complements the drainage pattern of the surrounding terrain, with all highwalls and spoil piles eliminated...(701(2))

The Act specifically requires surface mining operators to:

> ...grade in order to restore the approximate original contour of the land with all highwalls, spoil piles, and depressions eliminated ... (515(b)(3))

The same provision was specifically stated for areas of steep slope mining, i.e areas where the pre-mining ground slopes in excess of 20°.

In Virginia, the vast majority of mined lands are reclaimed to AOC. These lands are steeply sloping both before and after mining. The purpose of this research was to investigate the economic and environmental effects of the AOC provisions of SMCRA in the steeply sloping topography of the central Appalachian coal region. This report summarizes major results in researching and meeting three major objectives given below. A detailed discussion of each separate study is beyond the scope of this paper, but we hope that the reader will consult the indivudual referenced studies for more detail where needed.

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OVERALL OBJECTIVES

1. To investigate the long-term stability of AOC backfills, and to evaluate the engineering feasibility of this practice in the steeply sloping areas of the central Appalachians.
2. To determine the costs of returning spoil to AOC vs. placing it in alternative stable fills, and to identify, evaluate, and quantify potential land-use benefits foregone when spoil is returned to contour rather than placed in the alternative fills.
3. To estimate the differences in water quality, particularly sediment load, associated with AOC and alternative landforms.

METHODS, RESULTS AND DISCUSSION

I. AOC Backfill Stability

The specific objectives of this portion of the study were:

1. To evaluate factors contributing to slope failure of AOC backfills in SW Virginia by field observation of stable and unstable sites.
2. To determine the validity of commonly used slope stability models for predicting the factor of safety and locating critical failure surfaces.

The need for research to validate the use of the static factor of safety as a measurement of slope stability was documented by the Committee on Highwalls and Approximate Original Contour (COHAOC). This committee was created by the National Research Council (NRC) at the request of the Office of Surface Mining to study AOC reclamation in relation to removal of highwalls. The COHAOC did not find evidence of significant slope failures in regions of steep topography. However, it conceded that only 6 years had passed since enactment of SMCRA, an insufficient time to evaluate long-term slope stability (NRC, 1984). Also, the study was conducted as a general survey and therefore could not critically evaluate the slope stability issue from a scientific viewpoint. COHAOC recognized that situations may arise where complete highwall backfilling is undesirable for stability reasons and recommended provisions allowing partial highwall elimination.

Materials and Methods

<u>Field Investigations</u> During the course of this study, we observed stable and unstable sites reclaimed under the provisions of SMCRA to evaluate factors contributing to slope instability. All sites were located in Wise, Dickenson, and Buchanan Counties, Virginia. Local coal companies assisted in site selection and provided information on the mining techniques utilized.

The study area is located in the Appalachian Plateau physiographic region where the topography is characterized by strong relief with long ridges dissected by narrow winding streams. The SW Virginia coal fields are covered by 66 U. S. Geological Survey maps with the following distribution of average slopes per map: (VA DMLR, 1980)

Table 1. Distribution of slope classes in the SW Virginia coal fields.

% of Land In Slope Class	Approximate Average Slope (%)
5	25
8	30
9	35
27	40
27	45
24	≥50

The geology of the region is characterized by interbedded sandstone, siltstone, shales, and coal seams of the Pennsylvanian system. Units within the system include the Harlan Sandstone, Wise Formation, Gladeville Sandstone, Norton Formation, Lee Formation, and Pocahontas Formation in descending order.

We observed 24 AOC backfill sites of which 11 appeared stable, 9 were failing, and 4 showed signs of instability. We deliberately chose a range of unstable sites for study and the above figures are not intended to be representative of the frequency of AOC backfill slope failures. Since several sites were often on the same mine and composed of the same spoil material, we sampled on 12 different spoil types.

Our field investigations included detailed surveying of transects on maximum intervals of 20 feet to obtain accurate cross-sections for stability and to obtain accurate cross-sections for stability analyses. On sites where slope failure had significantly altered the original surface, we utilized transects of the adjacent undisturbed fill combined with the original mining plans to reconstruct the surface prior to slope failure. We surveyed areas of seepage and rock outcrop and made general field descriptions of the site and spoil characteristics. We took bulk spoil samples for strength analysis from the exposed scarp face at failed sites and from pits dug below the rooting zone on stable slopes.

<u>Laboratory Analyses</u> We determined the particle size distribution by passing the samples through 4.75-mm (No. 4) and 2.00-mm (No. 18) sieves and used the pipette method for analysis of the <2-mm fraction (Day, 1965). Compaction characteristics were by modified proctor (A.S.T.M., 1978). Direct shear tests were utilized to determine the shear strength parameters. Samples were recompacted to approximate field density conditions and strained at normal pressures of 24,48, and 96 kPa. Strain rates were calculated from consolidation characteristics to model drained conditions.

Therefore, the test yields effective strength parameters which are appropriate for modeling long-term strength conditions in spoil materials.

Computer Modeling REAME (Rotational Equilibrium Analysis of Multilayered Embankments) computer model was used in calculating slope stability (Huang, 1983). REAME is adaptable to a variety of surface mining situations and is widely used by the mining industry in the southern Appalachians. The program models rotational slope failures using the simplified Bishop method and is capable of handling several layers of different strength material. Seepage conditions may be defined by specifying the geometry of the phreatic surface or using the pore water pressure ratio (Ru) which is defined as:

$$Ru = \frac{\text{X-sect. area of fill below phreatic surface}}{\text{2 X total X-sectional area of fill}}$$

We utilized another computer model, SWASE (Sliding Wedge Analysis of Sidehill Embankments), for analysis of sites where planar foundation failures were also possible (Huang, 1983).

Results and Discussion

Slope failures commonly occur in AOC backfills in the Appalachian region, particularly in steep-slope contour mining situations. Small planar and rotational failures may occur immediately after mining, sometimes even before vegetation is established. Larger, massive failures usually are delayed for some time after site closure. All failures within 5 years endanger bond release, and beyond that time pose severe problems for regulatory agencies and landholders. It is difficult to estimate just how many AOC sites are failure-prone, but we believe the problem is significant on a regional basis.

The computer model (REAME) used to evaluate slope stability accurately predicted the location and occurrence of slope failures in the field Therefore, if properly used with accurate input parameters, REAME should provide accurate stability data. The planer failure model (SWASE) was also effective in predicting field failures under appropriate conditions. The variability of shear strength due to differences in compaction or material properties must always be considered when using REAME. We found considerable differences among the effective shear strength parameters (ϕ and c; angle of internal friction and cohesion) for differing materials (Bell and Daniels, 1985). Quite often, materials with nearly identical particle size distributions and field densities had grossly different strength values. These values are frequently estimated or extracted from accepted references in the mine planning and engineering process without actual testing. This is obviously a dangerous practice. Therefore, use of conservative values for shear strength parameters is essential when performing highwall backfill stability analyses, since an adequate number of strength tests to evaluate variablility are rarely performed.

Major factors which were identified (Bell and Daniels, 1985) as contributing to AOC slope failure included: 1) excessively steep ($>30^{\circ}$) slopes, 2) excessive seepage into the fill resulting in development of positive pore water pressures, 3) Placement of the toe of the fill beyond the edge of the mining bench, and 4) excessive acidic seepage causing rapid weathering and subsquent reduction in spoil shear strength.

All AOC backfills are required to meet a static safety factor of 1.3 based on standard geotechnical analyses. Steep backfills are often designed based on spoil strength parameters that are difficult or impossible to attain in the field. Uniform and complete spoil compaction is particularly difficult to obtain in AOC backfills since the spoil is essentially ramped up and dumped down into and over the backfill. Even under ideal conditions, spoils are seldom compacted in less than 1 m lifts, and recent research (Saxena et al., 1984) suggests that it may be necessary to compact spoils in much thinner lifts to achieve acceptable densities. Another design error may result from inaccurate estimation of spoil strength as previously discussed. The end result is that many AOC backfills have been constructed with slope angles in excess of the maximum that can be expected to remain stable, despite the requirement that stability analysis be performed and despite the required minimum safety factor of 1.3.

Most sites with slopes in excess of 30° displayed some degree of slope instability. Very shallow (6-12 inch) localized slides were common on these sites and early stages of large scale rotational slides were also observed. Another stability problem results from the construction of "pregnant" backfills with bulging convex slopes. This is common on long linear mountain slopes where hollows are not available for excess spoil disposal. This convex configuration leads to localized areas of instability due to steep slopes in the lower portion of the backfill.

Reductions in shear strength from weathering, compared to similar dry spoils, were observed in spoils high in siltstone. This, coupled with development of positive pore water pressures, led to extensive slope failures on only moderately steep ($<25^{\circ}$) slopes where seepage was a problem. Over time, considerable downslope subsurface water flow into the backfills occurs, particularly when long continuous slopes occur above the backfill. Settlement cracks are common where the top of the backfill meets the highwall, and serve as a conduit for water moving downslope into the fill. Small, unmapped local depressions and drainageways can also serve to concentrate water and move it into the fill. Backfills which are down dip can also receive considerable seepage through the highwall, and frequently the coal seam. It may take many years for sufficient water to accumulate in a fill and weaken it via development of pore water pressures or accelerated weathering.

Summary and Conclusions

The following factors were identified as contributing to slope failures at the sites studied, and in the region as a whole:

1. Excessively steep (>30°) final regraded surfaces.

2. Excessive seepage into fills causing development of positive pore water pressures and spoil strength reduction.

3. Placement of the toe of the fill beyond the edge of the mining bench. This practice does not meet current regulatory requirements.

4. Excessive seepage causing rapid weathering of siltstone spoils and subsequent reduction in shear strength.

5. Inaccurate estimation of spoil strength and compaction characteristics in fill design.

Additionally, the REAME computer model was able to accurately predict the location of failure surfaces and their occurence.

II. The Cost Of Return To AOC vs. Alternative Lanforms

Introduction

The Appalachian coal mining region is subject to a number of environmental and economic problems; many are a result of the steeply sloping topography. The extensive surface mining activities in the area appear to offer the opportunity to produce more favorable landforms at minimal marginal costs. Yet, despite this apparent opportunity and the success of research efforts to develop improved mine soil construction and revegetation techniques, the majority of the mining and reclamation activities in the Virginia coal region are carried out using conventional methods: reconstructing steeply sloping mining areas to AOC.

The purpose of this portion of the project was to estimate the costs of coal surface mine reclamation methods designed to prepare mined lands for improved use in areas of steeply sloping topography. The practice chosen for study was the production of a post-mining landform containing extensive near-level areas and surface soils suitable for agricultural use. This landform includes backfilled highwalls and meets all requirements of SMCRA other than the complete return to AOC. Since production of this landform required an alteration of the mining process, a computer simulation approach to cost estimation was chosen. Due to the fact that the most widely used mining and reclamation methods return sloping lands to AOC, the cost of the alternative studied was estimated as the change in overall mining cost resulting from implementation of the alternative landform (LA) vs. conventional AOC techniques.

Methods

In order to carry out this research, a computer-based mining and reclamation cost estimating system was developed. COSTSUM is a set of seven programs designed to analyze data from active surface mining sites, and determine spoil handling and reclamation costs (Zipper and Daniels, 1986). OPSIM is a surface mining simulator designed to estimate the differences in spoil handling costs among reclamation and postmining landform alternatives (Zipper et al., 1985a). In addition, Radian Corporation's CPS/PC was used to generate graphics and to perform volumetric analyses (Radian Corp., 1986). These techniques were applied to a case study, a surface mine at Amos Ridge in Wise County, Virginia, where the improved reclamation techniques under study were put into practice.

The pre-mining landform at the case study site consisted of a series of finger ridges protruding from a central "spine", Amos Ridge (Fig. 1). Nearly all of the land being mined had slopes in excess of 20°; this type of topography is common throughout the region. During the course of mining, three hollow fills are being constructed so that their upper surfaces are contiguous with flat areas on the tops of the finger ridges, which are not being returned to AOC. All highwalls are backfilled, but their slopes are considerabley less than would be formed under complete AOC mining. The final landform will include a broad, near-level bench extending over the stripped fingers and three filled hollows, which will support an agricultural land use (livestock). During the period of study, the first hollow fill was completed, associated areas were mined and reclaimed, and the second hollow fill was initiated. This mining method has been termed "Landform Alteration" (LA).

Results

During this study, data on machinery operation at the case-study site were recorded on a daily basis (Zipper and Daniels, 1984) and analyzed using the COSTSUM programs, which were developed for use in this study. The average cost of spoil handling at Amos Ridge between 1 January 1984 and 1 August 1985 was estimated to be $1.90 per bank cubic yard (Table 2). However, spoil handling costs varied widely between mining blocks. The detailed output of the COSTSUM programs allowed identification of high cost components and low cost components of spoil handling within each block, and thus the reasons for the sharp variations in spoil handling costs among the various mining blocks (Zipper et al., 1985).

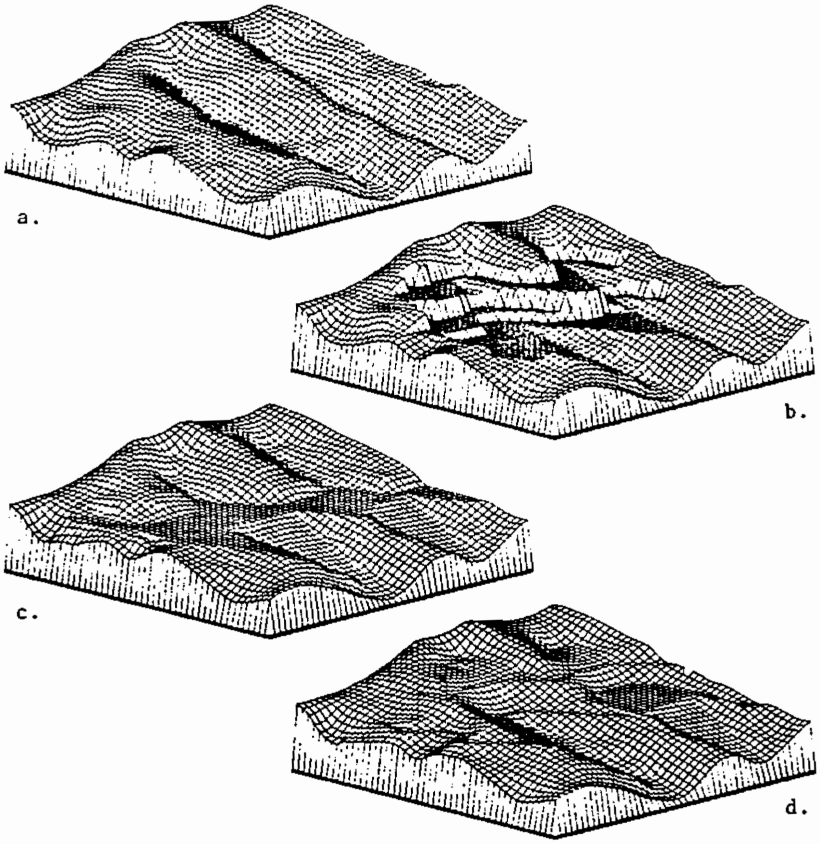

Figure 1. Isometric representations of actual and possible mined landforms at Amos Ridge. Each figure represents an area 1400 feet square. The figures are viewed from the southeast. (a.) The pre-mining topography, showing finger ridges protruding from the central "spine" of Amos Ridge at the western edge of the image. (b.) A representation of the portion of the topography disturbed by mining during the period of study. (c.) The post-mining landform currently under construction, the LA case. (d.) The probable post-mining landform, had the site been reclaimed to AOC.

Table 2. Components of average spoil handling cost at Amos Ridge

Component	\$ per bcy[1]
Clear and bench	0.01
Drill and blast	0.41
Carry and push	0.20
Load and haul	
Dozer feed	0.07
Loading	0.35
Hauling	0.38
Dumpsite	0.09
Total	0.89
Reclamation	0.08
Overhead	0.31
Total	\$1.90

[1]: a bank cubic yard is a measure of overburden volume before blasting and associated swell.

The daily operations data collected at the site formed a basis for simulation procedures (Zipper, 1986). First, the original model was extensively modified, in order to meet the modeling needs of this study. The modified model is called TOPSIM (TOPographically-based surface mining SIMulation). The first step of simulation was to duplicate the actual mining plan as closely as possible. Completion of this step showed that the TOPSIM program was able to simulate the drilling, dozer push, and loader carry operations so as to produce costs nearly identical the COSTSUM cost figures. The TOPSIM-estimated hauling cost was 84% of the COSTSUM figure (see Table 3).

The second step was to simulate mining of the area using conventional AOC techniques, without varying the input variables defining spoil movement rates unless such changes were clearly dictated by the change in mining plan. The simulated drilling cost did not change, due the assumption that identical areas would be mined in both cases. The total cost of dozer push and loader carry operations were estimated to decline with implementation of the AOC mining plan, since smaller quantities of spoil could be pushed or carried to disposal in areas adjacent to the mining block of origin. However, the hauling cost was judged to increase with implementation of the AOC mining plan, due to the increase in the quantity of material hauled and the increase in per-bank-cubic-yard hauling cost. The simulated spoil handling cost of the AOC mining and reclamation regime was $47,000 greater than the simulated spoil handling cost of observed practices (Table 3).

The third step of the cost comparison procedures was to manually adjust the simulated cost difference to compensate for non-modeled factors (Table 4). This procedure was carried out using both liberal and conservative assumptions; the estimated effect of post-mining landform on mining cost is between $0.14 and $0.58 per ton of coal produced; simulation procedures indicate that it is less expensive to mine using the alternative techniques under study than conventional AOC techniques.

The techniques under study also appear to offer additional benefits to mining operators, land owners, and residents of local communities (Bell et al., 1987). Primary among these are the increased land use potential and more favorable environmental impact of the LA topography, relative to the landform that would have been produced using conventional AOC techniques.

Conclusions

This study concludes that it is possible to perform economically and environmentally sound mining and reclamation procedures in steeply sloping topography, in spite of departure from conventional AOC practices. The efforts to develop site data collection and analysis procedures, and surface mine operation modeling procedures, appear to have been successful. Had mining at the Amos Ridge site been performed using conventional AOC practices, it is likely that less coal would have been recovered due to the increased costs of spoil disposal, relative to the alternative landform. Since the pre-mining landform at the case study site is similar to many others in the area, it is possible that additional opportunites for improved coal surface mining exist in the steeply-sloping central Appalachian coal mining region. Many of the factors preventing widespread implementation of these improved reclamation technologies could be eliminated through cooperation between the various firms of the industry and regulatory agencies (Zipper, 1987).

Table 3. Comparison of estimates of spoil handling costs at Amos Ridge: actual (COSTSUM) vs. simulated (TOPSIM), by postmining landform (LA vs. AOC).

Cost	Estimation Method		
Type	COSTSUM - LA	TOPSIM - LA	TOPSIM - AOC
Total			
Drill	$149,026	$150,041	$149,998
Carry and push	141,659	140,648	108,531
Carry		48,378	38,757
Push		92,270	69,774
Load and haul	574,184	483,070	563,370
Total cost	$864,869	$773,765	$821,904
Per-bcy			
Drill	$0.206	$0.207	$0.207
Carry and push	0.643	0.639	0.598
Push		0.471	0.447
Carry		0.785	0.735
Load and haul	1.134	0.954	1.034
Total	$1.190	$1.065	$1.131

Table 4. Adjustment of TOPSIM-estimated cost difference between landform alternatives due to non-modeled factors, liberal and conservative assumptions.

Factor	Liberal Assumption	Conservative Assumption
Spoil handling cost difference (AOC > LA)	$47,000	$39,000
Hollow fill 1 costs:		
Design (3 engineer work days plus one draftsman work day)	- 1000	- 1000
Bonding	- 200[2]	- 2000[3]
Construction and reclamation	- 31,000	- 32,000
Reclamation of mined area covered by HFl (approx. 1.3 acres, $2500 per acre)	+ 3250	+ 3250
Additional grading costs, AOC slopes south HFl (approx. 2.5 acres, $1000 per acre)	+ 2500	+ 2500
Work road and dumpsites, AOC slopes south HFl (approx. 130000 bcy)	+ 5500	+ 400
Weather-related hauling delays	+ 15,000	
Total	$41,000	$10,000
Total per ton of coal	$0.58	$0.14

[2]: partipation in Virginia Surface Mine Reclamation Fund (bonding pool) at $1500 per acre, assuming 60% release after 3 years, 80% release after 5 years, full release after 8 years; $12.50/$1000/annum bonding fee.

[3]: standard performance bond, $15000 per acre, other assumptions as above.

III. Potential Soil Erosion On AOC Slopes

The objectives of this portion of the study were to evaluate potential rates of soil loss from AOC backfills, to determine the primary factors affecting backfill erodibility and to compare expected soil loss among the AOC study sites.

Materials and Methods

We estimated soil erosion rates at each site using the Universal Soil Loss Equation (U.S.L.E.):

$$\text{Potential Soil Loss} = RKCP(LS)$$

Soil erodibility factors (K) were calculated from measured soil properties by the method of Wischmeier et. al. (1971). We obtained our annual rainfall erosivity value (R) from published tables by Wischmeier and Smith (1978) for SW Virginia. Site survey data was used to calculate the topographic factor (LS). No special management practices were assumed (P was set = 1 for all cases) and crop factors (C) corresponding to no vegetation, 75% cover by locust with 60% herbaceous cover, 20% and 80% herbaceous cover only, and native forest conditions were utilized. These vegetation conditions represent typical situations for surface-mined lands at various stages of revegetation. We obtained C values from published tables by Wischmeier and Smith (1978).

The U.S.L.E. was developed for application to agricultural situations and its extrapolation to soil and topographic conditions encounted in Appalachian surface mining is uncertain. While the equation may not produce accurate predictions of absolute quanitites of soil loss, it is a valuable tool for comparing relative rates of soil loss for various vegetation and topographic conditions encountered in surface-mining. Our goal in this portion of the project was to make relative comparisons of potential soil loss among the various study sites and not necessarily to predict absolute quantities of potential soil loss.

Many of the AOC slopes observed were irregular in shape and therefore were broken down into several segments requiring different LS factors. We calculated the contribution of each slope segment to the total LS factor by the method outlined by Wischmeier and Smith (1978) and Castro and Zobeck (1986) for irregular slopes utilizing soil loss fractions. Since our segment lengths were frequently unequal, we weighted the calculated fractions by segment length. Overall LS was calculated by summing the products of the LS values for each segment and the weighted soil loss fraction.

Results and Discussion

Predicted Soil Loss: Predicted rates of soil loss were highest for AOC sites with spoils high in siltstone and on excessively steep (>30x) sites. Estimations of soil loss are shown in Table 5 and are based on average annual rainfall conditions (EI = 150) conditions for southwestern Virginia. General topographic features for each site are given in Table 6 and spoil mechanical properties in Table 7. The minimum and maximum slopes are for the 20-foot segments we surveyed at each site.

Table 5 - Predicted annual soil loss by vegetative cover and site.

	Vegetative Cover Cases				
Site	A	B	C	D	E
	Mg/Ha/Yr				
A	1233	247	44	16	14
B	1560	312	56	20	17
C	548	110	20	7	6
D	652	130	23	8	7
E	1498	300	54	19	16
F	921	184	33	12	10
G	501	100	18	7	6
I	546	109	20	7	6
J	811	162	29	11	9
K	738	148	27	10	8
L	786	157	28	10	9
M	1586	317	57	21	17

A - No Vegetation. B - 20% Grass Cover
C - 75% Cover by Black Locust Canopy and 60% Grass Cover
D - 80% Grass Cover E - Native Forest

Calculated soil-K factors were generally low (0.07 - 0.22) reflecting the high coarse fragment content of the mine spoils. The higher K-factors were associated with spoils higher in silt. We would expect the K-factors of unvegetated slopes to decrease with successive rainfall events as soil sized material is eroded away and the relative coarse fragment content of the surface soil increases. This process will also seriously reduce the productivity of the surface soil by diminishing the water and nutrient holding capacities within the rooting zone. Therefore, rapid vegetation establishment is essential to maintain the ability of mine soils on steeply sloping AOC backfills to sustain permanent vegetation.

Table 6: Topographic data and soil-K factors by site.

Site	Minimum Slope	Maximum Slope	Slope Length	Soil K-Factor
	degrees		meters	
A	21.0	33.9	62.2	.22
B	29.8	37.9	111.0	.22
C	28.5	35.5	131.2	.07
D	18.4	23.6	120.2	.16
E	25.0	39.0	26.1	.22
F	26.0	26.0	67.5	.15
G	28.0	32.0	95.8	.07
I	22.3	26.7	42.7	.12
J	28.0	32.2	107.8	.11
K	32.0	32.0	53.1	.10
L	32.4	55.8	91.9	.09
M	32.0	37.5	81.4	.18

The importance of establishing long-term vegetation is dramatically illustrated in Table 5 by observing the rates of soil loss under various vegetative conditions. Establishment of only a 20% grass cover should, theoretically, result in an 80% reduction in annual soil loss. An 80% grass cover should reduce soil loss to approximately the same level as existed prior to mining under native forest, assuming topographic conditions are identical.

The quantity of soil which may be lost from an unvegetated AOC backfill in a single rainfall event can be significant and, depending on rainfall intensity and spoil composition, may seriously reduce the capacity of the surface soil to support long-term vegetation. Therefore, the rapid establishment of an annual cover crop, such as rye, millet, buckwheat, or crimson clover, immediately after final regrading is essential to maintain adequate soil productivity. Establishment of vegetation on steeply sloping surfaces is more effective at controlling soil erosion than any of the previously mentioned factors and should be the primary concern in erosion management. The establishment of a successful vegetative cover will incorporate organic matter into the soil which, when combined with chemical and physical weathering, will promote aggregation and further reductions in soil erodibility.

We predict, under the assumptions of the Universal Soil Loss Equation, that the highest rates of soil loss will occur on sites A, B, E, and M. These sites all share the following two

Table 7: Particle size distribution and compaction characteristics of mine spoils by site.

Site	>4.75-mm	2.00 - 4.75-mm	Sand	Silt	Clay	Optimum Moisture Content	Maximum Dry Density
	%						Mg/m^3
A	31.3	7.3	9.6	33.2	18.6	9.8	2.04
B	31.8	6.9	10.4	32.8	18.1	9.8	2.03
C	66.6	8.5	12.1	9.8	2.9	8.8	2.18
D	45.9	11.2	5.1	24.7	13.1	7.0	2.07
E	32.1	8.2	9.2	33.0	17.5	9.9	2.06
F	58.0	8.0	9.5	17.8	6.7	10.2	2.02
G	42.3	21.8	5.0	13.0	17.9	8.9	2.17
I	46.5	6.6	22.7	15.3	8.8	7.8	2.14
J	47.0	6.3	24.1	15.0	7.6	NA	NA
K	60.5	12.6	8.0	13.7	5.3	9.2	2.06
L	61.9	13.0	4.5	13.6	7.1	9.1	2.04
M	38.7	12.5	16.3	23.5	8.9	10.1	1.98

conditions: 1) excessively steep maximum slopes (33.9 - 39.0°) and 2) high spoil silt contents (23.5 - 33.2%). These two factors in combination create highly erodible soil conditions. Therefore, to reduce sedimentation and revegetation problems, predominantly sandstone spoil or topsoil should be used as a surface application on excessively steep slopes if possible. Conversely, slopes should be minimized in mining areas where siltstone spoils are the only available topsoiling material.

We observed localized areas of excessively steep (>30°) slopes on many sites. This situation often results from the creation of convex backfills which have localized areas of excessively steep slopes on the lower portion of the fill. Convex shaped slopes are more erodible than concave or straight slopes and failure to account for slope shape can cause considerable error in soil loss estimations. (Castro and Zobeck, 1986). Convex slopes are frequently generated due to two factors in combination : 1) Blasted, unconsolidated spoil requires more volume than consolidated overburden, therefore a greater volume of material is replaced in a backfill than existed prior to mining; and 2) the economics of many mining situations require placement of maximum quantities of spoil on the mining bench, rather than in hollow fills or other non-bench spoil disposal areas.

Conclusions

Based on measured conditions in the field and resultant calculations of potential soil loss under the assumptions of the Universal Soil Loss Equation we conclude that:

1. Rapid establishment of a vegetative cover is essential to prevent loss of soil productivity and excessive sedimentation on AOC backfills. Vegetative establishment is the most effective method for controlling soil erosion.

2. High rates of soil loss were associated with high spoil silt contents. Therefore, siltstone spoils should not be used as a topsoil substitute on steep AOC backfills if an alternative material of suitable quality and quantity, which is lower in silt content, can be economically utilized.

3. Localized areas of excessively steep slopes, predominantly resulting from convex slope shapes, contribute to higher rates of soil loss. Straight or concave slope shapes should be utilized if possible.

4. Compared to steep AOC backfills, the generation of stable alternative landforms such as the LA landform shown in Fig. 2 would reduce total sediment loss due to reduced slope angle and lengths, and the presence of flat bench terraces to intercept water flow.

IV. OVERALL SUMMARY AND CONCLUSIONS

The major conclusions to be drawn from this study are:

1. Widespread construction of AOC backfills in steep slope topography with inherent slope stability problems will likely have negative environmental and economic consequences in future years.

2. Situations exist where contour surface mining spoil can be placed in stable fills, thereby producing large areas of level lands capable of improved use, at less cost than the mining spoil can be placed in AOC backfills.

3. The erosive potential of steeply sloped mining areas can be reduced by minimizing slope and siltstone contents of backfilled spoils, rapid revegetation, and by placing mining spoil

in stable fills with extensive near-level areas, rather than returning such lands to AOC.

The first purpose of SMCRA, as written into the Act by Congress, is:

> [to]... protect society and the environment from the adverse effects of surface coal mining operations (Sec. 102(a)).

The conclusions of this research indicate that near-universal use of AOC mining and reclamation techniques in the steeply sloping topography of SW Virginia and the central Appalachians does not meet this purpose. There are situations where construction of AOC backfills is not an appropriate form of reclamation, given SMCRA's primary purpose. In order to assure that future mining in steeply sloping regions meets the purpose of SMCRA and serves the interests of mining communities, a number of changes are in order.

First of all, mining firms and regulatory authorities should work together to see that AOC backfills are constructed only in locales where they can be expected to remain stable.

Secondly, mining firms should construct backfills in a manner which is sensitive to site conditions. Modeling of potential slope stability during permit preparation should be performed rigorously, based on actual data. Construction techniques should be adapted to conditions at the site which were not anticipated in the drawing room, such as seeps and localized excessively steep areas. Regulatory authorities should be cooperative with mining firm attempts to meet unanticipated site conditions.

Thirdly, when evaluating variance requests for mining plans to produce landforms capable of supporting improved land uses, regulatory authorities should recognize that environmental (improved hydrologic effects) and economic (increased coal recovery) benefits may result from properly constructed alternatives to AOC. These benefits will occur regardless of the land-use to be implemented at the immediate conclusion of mining, if revegetation is accomplished rapidly and thoroughly.

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