THE EROSIONAL RESPONSE OF NATURAL AND RECLAIMED
HILLSLOPES AT THE GLENROCK COAL COMPANY[1]

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Abstract.--The objective of this research is a
comparison of sheet erosion rates on natural and
reclaimed hillslopes at the Glenrock in east-central
Wyoming. The study area is underlain by the sedimen-
tary rocks of the Wasatch Formation. The climate is
"semiarid interior continental," with about 380 mm. of
precipitation and 605 mm. of potential evapotranspira-
tion annually. Natural vegetation consists of short-
grasses and sagebrush, characteristic of the northern
Great Plains. Changes in surface elevation were
recorded at eight natural and ten reclaimed hillslopes
three times each year from 1980 to 1985, using the LEMI
technique. For natural hillslopes there was 2.74 mm.
of erosion while the reclaimed hillslopes experienced
4.08 mm. of erosion. The difference of 1.34 mm. is
within the accuracy of the measurement technique.
Based upon the similarity of erosion rates, it is con-
cluded that reclamation has been successful at this
mine from a geomorphic perspective.

INTRODUCTION

Perusal of relevant literature published
over more than a decade reveals that soil sta-
bility or erosion control is central to the
mission of surface-mine reclamation. Hodder
(1975) states that the first intent and obliga-
tion of reclamation is to achieve soil stability
and control soil erosion. Dollhopf et al (1977)
state that the control of runoff and erosion is
the initial basic prerequisite of mine-spoil
reclamation. Stiller et al (1980) state that
reclamation is complex and must involve erosion
control as a separate component as well as a
factor interdependent with revegetation. Hodder
(1983) states that erosion control is the first
obligation in the reclamation process. Colbert
(1983) states that soil stability could be con-
sidered the one comprehensive reclamation suc-
cess criterion. And, finally, Wells and Potter
(1986) state that a major goal of reclamation is
to reduce the amount of erosion and sediment
yield.

From a geomorphic perspective, erosion rates
provide a firm basis for evaluating the overall
success of reclamation programs. The work per-
formed by this process is a manifestation of
environmental conditions. Wiachmeier and Smith
(1978), among many others, demonstrate that ero-
sion rates reflect an integration of climate
(rainfall and runoff erosivity), soil (erodibil-
ity), topography (hillslope length and gradient),
and vegetation (cover) factors at a specific
site. If the erosion rates for natural and re-
claimed hillslopes are similar, then it seems
reasonable to conclude that the reclaimed area
is essentially stable and that the reclamation
program has been successful.

Comparisons of erosion rates could be devel-
oped from data: (1) secured by field measurement
at a particular location prior to disturbance and
again following reclamation, (2) obtained through
the use of estimating mathematical models for con-
ditions prior to disturbance and following recla-
mation, (3) collected from nearby natural areas
and reclaimed areas, or (4) simple observation of
rilling, gullying, or sedimentation on natural
and reclaimed lands. Generally, there is insuf-
ficient predisturbance data to permit utiliza-
tion of the first option. Mathematical models
are potentially very valuable; but in the absence
of onsite calibration (which itself requires

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field data), they may not be of sufficient accuracy to offer a trustworthy alternative. Observational information does not produce an accurate, quantitative basis for comparison. Hence, the third possibility above--comparison of data from nearby similar natural areas and reclaimed areas--is often the best choice. As long as both areas possess the same climatic characteristics, the results should be valid.

Given the significance of the erosion process in surface-mine reclamation, it is surprising that so little actual field data exist. The National Research Council lamented this deficiency in 1981, and the situation has not changed appreciably since then. Erosion studies conducted on mined lands have been undertaken for various purposes and utilize various measurement methods. Collier et al (1970) and Ringen et al (1979) measured sediment yields from small mined and unmined watersheds in Kentucky and Wyoming, respectively. Shown et al (1982), Frickel et al (1981), and Hadley et al (1981) used the Universal Soil Loss Equation to estimate soil loss from natural, actively-mined, and reclaimed lands in Alabama, Wyoming, and Montana, respectively. Lusby and Toy (1977), Gifford (1983), Gilley et al (1977), and Hofmann et al (1983) employed different types of rainfall simulation apparatus to generate erosion data from plots of different dimensions in Wyoming and North Dakota. Haigh (1979, 1980) and Haigh and Wallace (1982) assessed surface lowering of spoils by means of erosion pins in Wales, United Kingdom, and the State of Illinois.

Although the information contained in these and similar studies answers many questions concerning erosion processes and sediment yield on mined lands, it generally cannot be used to evaluate reclamation success with the necessary accuracy. Sediment yield rates include not only erosion rates but also sediment transport rates, which are influenced by numerous site and hydrologic characteristics. Estimates of erosion determined with the Universal Soil Loss Equation are significantly affected by the assumptions made concerning soil (K-factor) and vegetation cover (C-factor) on the reclaimed lands. Many rainfall-simulation investigations are conducted under experimental conditions that are not entirely reflective of site conditions. The plots are often rather small and situated on nearly-level land. Commonly, the intensity, duration, and drop-size distribution of water applications constitute rare natural precipitation events. Erosion pin data are probably imprecise and biased due to the presence of the pin itself at the point of measurement (Toy, 1983a).

There are three major categories of erosion by water that occur on the hillslopes comprising most of a reclaimed area: (1) gully erosion, (2) rill erosion, and (3) sheet erosion. As suggested by Toy (1984) and Curtis et al (1986), rilling and gullying are evidences of serious reclamation problems. The Permanent Program

Performance Standards for the Surface Mining Control and Reclamation Act of 1977 specify that "Rills and gullies, which form in areas that have been regraded and topsoiled and which either (1) disrupt the approved postmining land use or the reestablishment of the vegetation cover or (2) cause or contribute to a violation of water-quality standards for receiving streams, shall be filled, regraded, or otherwise stabilized; topsoil shall be replaced; and the area shall be reseeded or replanted" [Federal Register, 1983; 816.95, (b) 1, 2].

Fairbridge (1968) comments that sheet erosion is a major process in the denudation of land surfaces; it involves the impact of raindrops and their merging to form a near-continuous sheet which moves down hillslopes, gathering momentum and representing an erosive force of high potential. Stiller et al (1980) assert that most people think of erosion in terms of highly visible gullies; however, in a semiarid climate, sheet erosion accounts for most erosion on hillslopes.

From the foregoing, it is evident that: (1) erosion control is a primary objective of surface-mine reclamation; (2) knowledge of erosion rates on both reclaimed hillslopes and natural hillslopes in the vicinity is necessary in order to determine the extent to which this goal has been achieved by reclamation programs; (3) sheet erosion must be considered, in addition to rill and gully erosion; and (4) the data pertaining to sheet erosion are best collected in the field, under the actual environmental conditions at a particular locale. It is the purpose of the research reported herein to provide a comparison of sheet erosion rates on natural and reclaimed hillslopes at the Glenrock Coal Company near Glenrock, Wyoming.

THE STUDY AREA

The Dave Johnston Mine of the Glenrock Coal Company is located in east-central Wyoming, approximately 21 km. north of the town of Glenrock. This places the study area in the Northern Great Plains Physiographic Province, near the southern boundary of the Powder River Basin. A drainage divide passes through the mine, such that the northern part drains to the Cheyenne River while the southern part drains to the North Platte River.

The geology near the surface consists of nearly-horizontal sedimentary rocks of Eocene Age, known as the Wasatch Formation. The interbedded conglomerates, sandstone, siltstones, shales, and coal strata composing this formation were deposited in freshwater streams, lakes, and swamps. The School and Badger coal seams constitute the resource base for this mine.

The climate of this area is "semiarid interior continental." According to Toy and

Munson (1978), the average growing-season (frost-free period) extends for approximately 120 days each year, from about May 18 to September 19. Average annual precipitation is nearly 380 mm. with average growing-season precipitation of 220 mm. Potential evapotranspiration is estimated to average about 605 mm. per year, using the Blaney-Criddle method with a crop coefficient calibrated for natural vegetation in the Northern Great Plains (Toy, 1979). This produces an annual water deficiency of about 390 mm., based upon the Soil Conservation Service method (1970). Rainfall erosivity (R-factor) is given a value of 30 (U. S. Soil Conservation Service and U. S. Environmental Protection Agency, 1977).

The native soils are classified as belonging to coarse-loamy and sandy textural families derived from aeolian parent materials, and coarse-loamy to fine-loamy textural families derived from residual parent materials of sandstone, siltstone, and shale (Toy and Shay, in press). Erodibility (K-factor) is given values ranging from about 0.24 to 0.49 (U. S. Soil Conservation Service and U. S. Environmental Protection Agency, 1977).

The natural vegetation consists primarily of shortgrasses and sagebrush, characteristic of the Northern Great Plains. Typical species include blue grama grass (Bouteloua gracilis), western wheatgrass (Agropyron smithii), needle-and-thread grass (Stipa comata), and big sagebrush (Artemisia tridentata).

METHOD OF INVESTIGATION

Erosion data were collected on 18 hillslopes at this location. The eight natural hillslopes were distributed at both the northern and southern parts of the mine in order to provide representation in the sample of the soil series found within the permit area. The selected sites included hillslopes of both easterly and westerly aspects. Further, one-half of the natural hillslopes were periodically grazed by domestic livestock while the other one-half were no longer subjected to periodic grazing.

The 10 reclaimed hillslopes were distributed throughout the permit area. These also possessed both easterly and westerly aspects. A variety of reclamation practices had been utilized on these surfaces. Some were graded primarily with a dragline, others using motor-scrapers. Some had been seeded principally with wheatgrasses, others with a multi-species mix as approved by the regulatory authority. Taken together, the selection criteria provided samples of natural and reclaimed hillslopes that reflected the assorted site conditions at and adjacent to this mine.

A summary of hillslope properties is presented in table 1. The topography of both

Table 1.--Characteristics of Sampled Hillslopes

Property	Natural Sites	Reclaimed Sites
A. Topography		
Average Length (m)	64.12	61.21
Average Gradient (%)	14.10	13.50
B. Soil and Surface Material		
Particle Size Distribution[1]		
Gravel (%)	2.40	2.84
Sand (%)	72.34	56.97
Silt (%)	12.21	20.29
Clay (%)	13.11	20.19
Bulk Density (gm/cc)	1.42	1.44
Organic Matter (%)	2.19	2.80
Acidity-Alkalinity (pH)	6.31	5.18
C. Vegetation Cover (%)	67.03	54.42

[1]Do not total 100% because of rounding errors.

natural and reclaimed sites is quite similar, as shown by the measurements of length and gradient. However, there are some significant differences in the characteristics of soil and surface material at the natural and reclaimed sites. The surface soils of the natural sites contain substantially more sand but less silt and clay than the surface materials of the reclaimed sites. The average values of bulk density are virtually the same for the two site groups. The surface materials of the reclaimed sites appear to contain somewhat higher percentages of organic matter than the soils of the natural sites, but a part of the measured organic matter at a few reclaimed sites is actually waste coal rather than humus or root networks. The soils of the reclaimed sites tend to be more acidic than those of natural sites, perhaps as a consequence of the waste coal.

Finally, the average vegetation cover is greater on the natural sites than on the reclaimed sites, although the percentage for the reclaimed sites is reduced slightly by one site that was only seeded after initiation of the research project. Figure 1 shows the hillslope after about three growing seasons.

Figure 1.--Hillslope RNMW. Seeded after initiation
of research project.

MEASUREMENT OF SHEET EROSION

As indicated earlier, there are several approaches to the measurement of erosion rates. The LEMI (Linear Erosion/Elevation Measuring Instrument) technique was developed especially for this investigation. First, a series of support rods is implanted along each of the chosen hillslope profiles. The rods are 1.22 m. in length, 12.7 mm. in diameter, and driven until 60 cm. remains exposed above the surface. These rods should form a straight line downslope so that disturbance can be detected by misalignment.

The LEMI is constructed from two carpenter's levels connected through their centers by a thumb screw and set at right angles to each other. The lower level is fitted with three steel sleeves and braced. Measuring pins pass through the sleeves on either end of the lower carpenter's level. The larger central sleeve is mounted upon a support rod during the measuring process, and it is through this sleeve that a small orientation hole is drilled.

In order to document changes in surface elevation, the LEMI is placed on a support rod as shown in Figure 2. For the initial measurements, a small white dot is painted on the support rod through the orientation hole in the central sleeve. This series of white dots should also form a straight line downslope so that support rod disturbance will again be evidenced by the misalignment of these dots.

Once the LEMI is properly positioned in all three axes, with the centering of the white dot in the orientation hole and the leveling of both carpenter's levels, the measuring pin on one side of the LEMI is carefully lowered until it just touches the ground surface. Now the length of the measuring pin remaining above the lower carpenter's level can be measured to the nearest millimeter. This procedure is then repeated for the measuring pin on the other side of the carpenter's level.

The LEMI technique records changes in surface elevation relative to a fixed point, namely the top of the support rod. Erosion results in decreasing pin length above the carpenter's level while frost heave or deposition results in an increasing pin length. By taking measurements on either side of the support rods, changes in elevation are actually recorded along two paired and parallel profiles on the hillslope. The principal advantage of this technique, in contrast to erosion pins, is that measurements are obtained at a distance of 0.5 m. from the support rods on undisturbed surfaces. Complete discussion of the LEMI technique can be found in Toy (1983a, b).

In this study there were 273 support rods on the eight natural hillslopes and 312 rods on the ten reclaimed hillslopes. Measurements were taken at both sides of each rod during the three visits to the mine each year (March, June, September) over the five-year period. Hence, the comparison of erosion rates presented in the subsequent section is based upon more than 17,000 measurements. This may constitute the largest existing set of erosion data for natural and reclaimed lands.
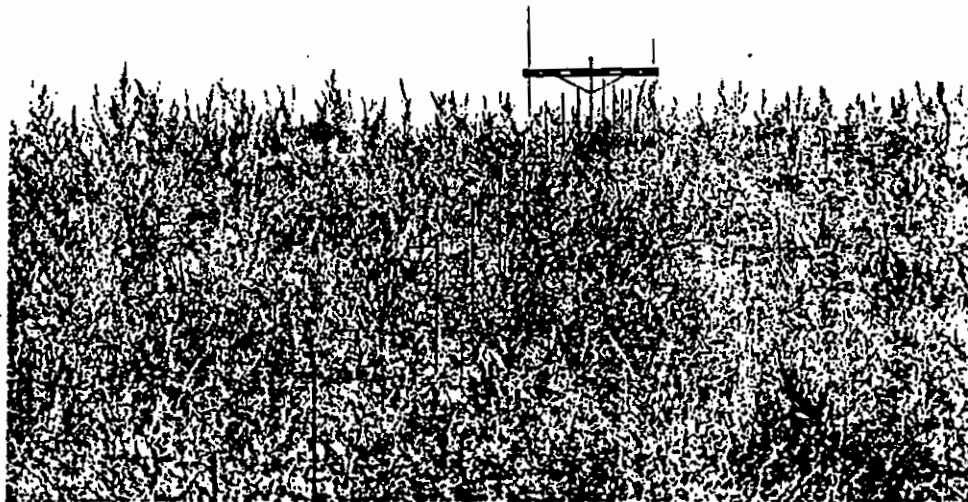
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Figure 2.--LEMI mounted on support rod.

THE RESULTS

The net change in surface elevation for the natural and reclaimed hillslopes is provided in table 2. The value for each site is the average for both hillslope profiles, on either side of the support rods, cumulated for the five-year period. The values for each set of sites, natural and reclaimed, are then averaged to produce the mean net change.

For the natural hillslopes, there was an average of 2.74 mm. of erosion during the five years of study. For the reclaimed hillslopes, there was an average of 4.08 mm. of erosion. Although the reclaimed hillslopes experienced somewhat greater erosion rates, the difference of 1.34 mm. (4.08-2.74) is comparable to the accuracy of the LEMI measurement technique. Thus, it seems permissible to submit that there is probably no significant difference between the erosion rates of natural and reclaimed hillslopes at this study area.

The net change data can also be expressed on an annual time-framework. Here, the erosion rate for natural hillslopes is 0.55 mm. per year while for reclaimed hillslopes the rate is 0.82 mm. per year. This yields a rate difference of only 0.27 mm. per year.

The positive change in surface elevation during the period of record at two natural and one reclaimed sites is noteworthy. Field observations at these sites suggest that the increase in elevation is due to the accumulation of aeolian material on the surface. Each location is downwind from a source of unconsolidated debris.

Table 2.--Summary of Net Change in Surface Elevation. (September 1980--June 1985)

Natural Hillslopes		Reclaimed Hillslopes	
Site[1]	Δ Elevation[2] (mm)	Site	Δ Elevation (mm)
5 NGSE	-4.1	1 RWW	-7.4
6 NGSW	-2.9	2 RWE	-4.0
7 NNSW	-3.7	3 RSE	-3.7
8 NNSE	-3.0	4 RSW	-3.1
9 NNNW	3.7	10 RSCW	-2.0
15 NGNE	-6.3	11 RSCE	-0.3
16 NGNW	-7.3	12 RNME	-5.6
17 NNNE	1.7	13 RDLW	-3.9
		14 RDLE	-11.7
		18 RNMW	0.9
Mean	-2.74	Mean	-4.08

[1]Alphabetic designations indicate selected attributes of sites; for example, first letter differentiates between natural and reclaimed sites while last letter shows hillslope aspect. Change (Δ) in elevation is the average for two profiles occurring on north and south side of LEMI.

[2]A negative sign indicates net ground retreat (erosion) while a positive value indicates net ground advance (deposition).

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CONCLUSION

The data amassed by this research project, and summarized in Table 2, indicate that the erosional response of both natural and reclaimed hillslopes to prevailing environmental conditions is quite similar at this mine. From a geomorphic perspective, this allows the conclusion that the reclamation program has successfully re-created a state of quasi-equilibrium or stability. The average age of the reclaimed hillslopes was more than eight years at the end of this investigation. So, barring extraordinary climatic conditions that would of course impact both natural and reclaimed hillslopes, it would appear that the quasi-equilibrium or stability state is likely to persist into the future.

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