GEOMORPHIC RESPONSES OF NATURAL AND RECLAIMED HILLSLOPES TO PRECIPITATION EVENTS IN WYOMING[1,2]

by

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Abstract. Runoff and sediment data were collected from plots on two natural and reclaimed hillslopes at the Glenrock Coal Company. Runoff from the newly reclaimed site exceeded that from the natural sites despite lower average precipitation intensities; however, runoff from the older reclaimed site was less than from the natural sites. Sediment yield from the newly reclaimed site was much higher than from the natural sites while sediment yield from the older reclaimed site was within the range of that from the natural sites. Sediment concentration of flows from the newly reclaimed site were very high, especially at the beginning of the record, and greatly exceeded those from the natural sites. Again, sediment concentrations from the older reclaimed site were within the range of those from the natural sites. There were significant statistical relations between runoff and sediment yield. The comparison of sediment and soil particle-size distributions suggested selective entrainment and transportation of soil separates. Lastly, available evidence suggested that reclaimed surfaces may approach a semblance of equilibrium, analogous to natural surfaces, in about five years.

ADDITIONAL KEY WORDS: Reclamation success; Geomorphological assessment.

Introduction

Much pertinent literature identifies erosion control as central to the mission of surface-mine reclamation (Hodder, 1975; Dollhopf et al, 1977; Vogel, 1981; Toy and Hadley, 1987). However, the evaluation of reclamation success is commonly based upon qualitative or visual evidence. Herein, rill development on finish-graded surfaces, channel or gullies at the midpoints or toes of hillslopes, and deposits of eroded material at the base of hillslopes, are generally taken as

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indicators of reclamation problems (Curtis et al, undated). The National Research Council (1981) laments the paucity of actual erosion data for the mined lands of the western United States and the state of affairs is not markedly better for the eastern region.

It is the purpose of this report to present the results of a runoff and sediment yield study conducted on two natural and two reclaimed hillslopes at a surface mine in east-central Wyoming. This research was part of a larger project, also measuring sheetwash erosion and soil creep rates at this same locale; the results of the sheetwash erosion investigation will be available elsewhere (Toy, in press).

The Study Area

Runoff and sediment yield data were collected at the Dave Johnston Mine of the Glenrock Coal Company in east-central Wyoming. This operation is situated near the southern border of the Powder River Basin in the Northern Great Plains Physiographic Province. The surface geology consists of nearly horizontal strata of conglomerates, sandstones, siltstones, shales, and interbedded coal seams deposited in freshwater streams, lakes and swamps, and designated as the Wasatch Formation.

The climate is classified as semiarid, continental with an annual precipitation of approximately 380 mm, of which about 57% is received during the May-September growing season (Toy and Munson, 1978). The estimated rainfall erosivity (R-factor) is 30, according to the U.S. Soil Conservation Service and U.S. Environmental Protection Agency (1977).

The natural vegetation cover consists primarily of shortgrasses and sagebrush, typical of the Northern Great Plains. Common plant species include blue gramma grass (<u>Bouteloua gracilis</u>), western wheatgrass (<u>Agropyron smithii</u>), needle-and-thread grass (<u>Stipa comata</u>), and big sagebrush (<u>Artemisia tridentata</u>).

The undisturbed soils are classified as coarse-loamy and sandy in texture when derived from aeolian parent materials and coarse-loamy to fine-loamy in texture when derived from residual parent materials (Toy and Shay, 1987). Soil erodibility (K-factor) ranges from about 0.24 to 0.49, according to the U.S. Soil Conservation Service and U.S. Environmental Protection Agency (1977).

Method of Investigation

Within this study area, runoff and sediment collection plots were established on two natural and two reclaimed hillslopes. For each pair, one plot was situated on a surface of easterly aspect while the other was situated on a surface of westerly aspect. Both of the reclaimed hillslopes had been graded with a motorscraper. There was no grazing by domestic livestock at any site, although the entire area is subject to periodic grazing by wildlife.

The collection plots were oriented orthogonal to the hillslope contours with a width of 0.75 m and varied in length, in accordance with total hillslope length. To prevent the outflow or inflow of runoff and sediment, plastic tubing with an outside diameter of 2.54 cm (1 in.) was used to delineate each plot. The tubing was fastened to the hillslope surface with wire staples. Soil or surface materials were used to construct a small berm abutting the tubing on the outside of each plot. Lastly, asphalt spray (sold commercially as automobile undercoating) was applied on the inside of the plot to create a seal between the tubing and the soil or surface material. Consequently, the effective plot width was found to average 0.70 m.

A trough was implanted at the downslope terminus of each plot, approximately two-thirds of the distance from the crest of the hillslope. Such troughs or traps vary somewhat in design but most are similar to those described by Young (1960) and Gerlach (1967). Further discussion of this measurement apparatus can be found in Carson and Kirkby (1972), De Ploey and Gabriels (1980), and Dunne (1977). Here, the trough was constructed from roof gutter material with a sheet metal cover and downpipe in the base. The asphalt spray was also used to seal the contact between the trough and the soil or surface material; plot length was reduced by the surface rendered impervious by this spray.

Four runoff and sediment collection barrels were constructed from 208 l (55 gal.) drums and fitted inside with a staff gage. Each barrel was calibrated individually so that the staff gage readings could be accurately converted to volume measurements. These barrels were implanted at the base of the hillslopes upon which the plots were located and leveled so that the staff gages would produce valid readings.

The troughs were connected to the barrels by means of suction hoses. This type of hose is preferable because it will not collapse when empty and, hence, water and sediment will not back up in the hose and trough at the beginning of a runoff event, but flow into the barrel with minimum resistance.

The barrel lids were fitted with a metal "snap-ring" to hold them in place and a slot was cut into the lids to receive the suction hose. Sheet rubber material was used to create a gasket to seal the gap between the lid slot and the suction hose.

Small plastic collector rain gages were placed adjacent to the plots so that the depth of precipitation received at the site could be measured. Precipitation intensity was determined by dividing this depth by the storm duration measured with a recording rain gage at a meteorology station operated by the mine company that averaged a distance of approximately 2 km from the collection plots. It would have been preferable to have a recording rain gage at each site but this was precluded by budgetary constraints.

The runoff and sediment produced from individual precipitation events were transported from the plots, through the troughs, to the collection barrels. Thereafter, and before the next precipitation event, each barrel staff gage and rain gage was read, usually by mine company personnel. At this time, the suction hose was removed from the barrel and the rubber gasket was used to cover the lid slot so that the sample would not be contaminated by other precipitation events or aeolian material. During the next visit to the mine by the principal investigator, the barrels were excavated and the sediment was transferred to small buckets for transport to the laboratory for analysis. Here, the oven-dry weight and particle-size distribution of the sediment samples were determined.

While at the mine the collection barrels were cleaned, replaced, and leveled in preparation for the next runoff event. Likewise, the rain gages were emptied and cleaned. Finally, the plot borders were serviced and new asphalt spray applied at the contacts between the tubing and trough contacts with the soil or surface materials, as needed.

The collection plots were visited in March, June, and September each year throughout the research project. During the March visit, the apparatus was installed and maintained in readiness for the Spring precipitation. Samples were collected during the June and September visits, if a runoff event had occurred. At the end of the September visit, the equipment was winterized.

Characteristics of the Sites

The attributes of the land at the collection plots are summarized in Table 1. The soils of the natural sites contain more sand and less silt and clay than those of the reclaimed sites. The bulk densities of the soils are approximately the same for all sites. It appears that the soils of the reclaimed sites contain slightly more organic matter than those of the natural sites, but a part of the organic matter at the former sites is actually waste coal rather than humus or plant rootlets (Toy and Shay, 1987). The soils of the reclaimed sites are somewhat more acidic than those of the natural sites and this may be due to waste coal as well.

The vegetation cover was measured annually at each site using the point-frame method (Levy and Madden, 1933). The values recorded include both live vegetation and surface litter because each is of geomorphic significance in deterring runoff and erosion. The average cover of the natural sites tends to exceed that of the reclaimed sites, although the highest average cover occurs at one reclaimed site while the lowest average cover occurs at the other reclaimed site. It should be noted

TABLE 1: Site Characteristics

Property	Natural Sites		Reclaimed Sites	
	NNNE	NNNW	RSCE	RNMW
A. Surface Material (top dm)				
1. Particle Size				
Gravel (%)	0.40	1.40	3.44	1.20
Sand (%)	81.82	71.97	49.91	52.82
Silt (%)	6.93	12.37	22.91	19.52
Clay (%)	10.90	14.30	25.82	26.53
2. Bulk Density (gm/cc)	1.427	1.309	1.494	1.294
3. Organic Matter (%)	1.50	1.84	2.34	2.39
4. Soil Reaction (pH)	6.71	7.39	5.59	5.60
B. Vegetation Cover* (%)	63.2	57.4	64.0	33.0
C. Date of Reclamation			1976	1981

* includes live vegetation plus organic litter

that the reclaimed site with the lowest average vegetation cover was planted after commencement of this project and the cover developed from 0 to 59 percent over the five-year period of record.

The dimensions of the runoff and sediment collection plots are compiled in Table 2. Plot length varied depending upon hillslope length. Plot width was constant at 0.70 m. As a result, plot area ranged from 19.60 m^2 to 34.09 m^2. The inclination of the plots on the reclaimed sites were somewhat greater than those on the natural sites. Three plots were installed in July, 1980 with the fourth installed on the newly reclaimed surface in April, 1981.

Results

During the period of record, from 1980 to 1984, runoff and sediment samples were obtained following 7-9 events on the collection plots. The number of samples varies due to the installation of the equipment at the newly reclaimed site after seeding in 1981, and barrel overflow at three locations during a storm in August, 1983. Other runoff events sometimes occurred prior to servicing of the plots, but it was not possible to secure additional samples on these occasions with this apparatus. The measurements for precipitation, runoff, and sediment at each plot are summarized in Table 3. There is considerable variation in the data from plot to plot and from event to event; however, it is only possible to present and discuss the average values at this time.

Precipitation

The average total precipitation per runoff event ranged from 18 to 27 mm. Likewise, average precipitation intensity for these storms ranged from 20.8 to 28.3 mm/hr. Recall that there was probably some error in the intensity data because storm duration was taken from the records at the meteorology station rather than measured on-site.

Runoff

The plots on natural hillslopes, NNNE and NNNW, averaged 2.90 l/m^2 and 3.71 l/m^2 of runoff respectively. Because the totals and the intensities were similar, it does not seem likely that precipitation is responsible for the difference. Hillslope aspect, the particle-size distribution of soils, and vegetation cover are probably responsible for much of the variation. In this geographic region, storms and accompanying winds commonly travel from west to east, driving rain into the

TABLE 2: Runoff/Sediment Collection Plot Dimensions

Dimension	Natural Sites		Reclaimed Sites	
	NNNE	NNNW	RSCE	RNMW
A. Plot length (m)	28.0	48.7	46.2	40.0
B. Plot width (m)	0.70	0.70	0.70	0.70
C. Plot area (m^2)	19.60	34.09	32.34	28.00
D. Plot gradient (%)	11	12	15	18
E. Date of installation	7/80	7/80	7/80	4/81

TABLE 3: Geomorphic Response of Natural and Reclaimed Hillslopes (Mean Values)

	Runoff/Sediment Collection Sites			
	Natural Sites		Reclaimed Sites	
	NNNE	NNNW	RSCE	RNMW
Number of Events	9	8	8	7
Precipitation				
Total (mm)	26	27	18	21
Intensity (mm/hr)	26.2	25.3	28.3	20.8
Runoff (l/m^2)	2.90	3.71	1.70	3.59
Sediment				
Per unit area (g/m^2)	4.5	14.6	6.0	203.9
Concentration (mg/l)	1490.1	3746.3	3516.7	26,377.8
Particle size				
Sand (%)	39.6	30.6	19.5	30.3
Silt (%)	32.9	36.5	34.6	25.8
Clay (%)	26.3	31.5	44.5	43.8

westerly-facing hillslopes. As a result, it seems likely that average droplet impact energy is higher on the hillslopes of westerly aspect than on those of easterly aspect. If so, then surface sealing should be more effective on the westerly-facing hillslope. The particle size analyses show that the soils of the westerly-facing site contain more silt and clay than the soils of the easterly-facing site. Lastly, the vegetation cover on the westerly-facing site is less than on the easterly-facing site. Collectively, it would seem that the westerly-facing surface should possess a lower infiltration capacity than the easterly-facing surface and, therefore, should generate runoff at a faster rate.

The plots on the reclaimed hillslopes, RSCE and RNMW, averaged 1.70 l/m^2 and 3.59 l/m^2 of runoff respectively. It is more difficult to explain the differences in average runoff between these two sites because there were also some differences in the average total and intensity of precipitation. However, it seems unlikely that the dissimilarities in precipitation characteristics are sufficient to account for the two-fold variation in runoff. As with the natural hillslopes, the westerly-facing hillslope again generated the greater volume of runoff. Here, however, the particle-size distributions of the surface materials are quite similar and so this factor can be eliminated as a possible cause. The average vegetation cover is considerably higher on the easterly-facing site. Recall that the westerly site was barren at the initiation of the project but developed a cover of 59% by the end of record. Collectively, it again would seem that the westerly-facing surface should possess a lower infiltration capacity than the easterly-facing surface and, therefore, should generate runoff at a faster rate.

Comparison of runoff generation between the natural and reclaimed sites is complicated by the differences in precipitation characteristics. Additionally, the reclaimed hillslopes are slightly steeper in gradient than the natural hillslopes. Nevertheless, it is interesting to observe the general similarity in runoff rates between the two groups, despite the differences in hillslope gradient, vegetation cover, and surface material properties. In fact, the lowest rate of runoff was recorded at one of the reclaimed sites. The findings are similar to the results of the rainfall simulation experiments of Lusby and Toy (1976) at this study area, but at different field locations.

Sediment Yield

The plots on natural hillslopes, NNNE and NNNW, yielded an average of 4.5 g/m^2 and 14.6 g/m^2 of sediment respectively. Because the westerly-facing hillslope generated the greater volume of runoff, it might be expected that it would likewise produce the greater volume of sediment. With greater volumes of runoff, one would expect greater depth and velocity of runoff, and hence, greater tractive force impinging upon the surface materials of the westerly-facing surface.

There is also some evidence that surface erodibility is higher on the westerly-facing site. The relative paucity of vegetation cover and higher silt content of the soils favor higher erosion rates. However, the Soil Conservation Service (1977) nomograph for estimating soil erodibility (K-Factor) does not indicate substantial differences between these two sites.

The plots on reclaimed hillslopes, RSCE and RNMW, yielded an average of 6.0 g/m^2 and 203.9 g/m^2 of sediment respectively. The average for the latter site was heavily weighted by very high sediment yields early in the period of record while vegetation cover was minimal. Again, the westerly-facing hillslope generated the greater volume of runoff, possessed the lower vegetation cover, and produced the greater volume of sediment. Here, the particle-size distribution and organic matter content of surface materials are similar and so there should not be much difference in soil erodibility at the two sites.

The comparison of sediment yields from the natural and reclaimed sites is again complicated by the difference in precipitation characteristics. However, it is interesting to observe that the older reclaimed site (RSCE) produced sediment at an average rate within the range of the natural sites, while the newly reclaimed site (RNMW) produced sediment at a much higher rate. Scrutiny of the data for individual storms reveals that the plot on hillslope RNMW was producing sediment at a rate similar to the other reclaimed and natural sites toward the end of the period of record. This suggests that hillslopes in this region may achieve a semblance of geomorphic stability in about five years following the application of reclamation practices.

These results differ from those of Lusby and Toy (1976), wherein the reclaimed sites always produced more sediment than the natural sites. According to the memory of the mine company personnel, the surfaces tested in the Lusby and Toy (1976) experiments would have been only a couple of years beyond reclamation at the time.

The runoff (l/m^2) and sediment yield (g/m^2) data from the individual storm events were subjected to simple regression and correlation analyses, with runoff serving as the independent variable (X) and sediment yield serving as the dependent

(Y) variable. Results significant at the 5% level are found for three sites:

NNNE $Y = -0.483 + 1.720X$ (1)

$N = 9$

$r = 0.975$

$Sxy = 1.175$

NNNW $Y = -3.599 + 4.907X$ (2)

$N = 8$

$r = 0.819$

$Sxy = 10.362$

RSCE $Y = -1.414 + 4.344X$ (3)

$N = 8$

$r = 0.987$

$Sxy = 1.692$

The relation between runoff and sediment yield for the plot on hillslope RNMW is not significant. However, examination of the data suggests that extreme values, from storms at the beginning of the record when the surface was barren, likely skew the distribution of sediment yield values. The $\log_{10}$ transformation is employed for this variable with the following result, significant at the 5% level:

RMNW $\log_{10} Y = -0.320 + 0.365X$ (4)

$N = 7$

$r = 0.908$

$Sxy = 0.621$

Sediment Concentration

The sediment concentration can be computed from the volume of runoff and weight of sediment collected. The plots on natural hillslopes, NNNE and NNNW, produced average sediment concentrations of 1,490.1 mg/l and 3,746.3 mg/l respectively, while the plots on reclaimed hillslopes, RSCE and RNMW, produced average sediment concentrations of 3,516.7 mg/l and 26,377.8 mg/l respectively. The same environmental conditions that caused the variabilities in runoff and sediment yield should be responsible for the variabilities in sediment concentration. The average concentration from the older reclaimed site, RSCE, lies within the range from the natural sites; however, that from the newly reclaimed site, RNMW, is much higher. The average from this latter site was heavily weighted by the data for an event in July, 1981, when the concentration approached that of a mudflow.

Particle-Size Distribution of Sediment

The plots on natural hillslopes, NNNE and NNNW, yielded sediments composed of rather similar proportions of sand, silt and clay. However, the plots on the reclaimed hillslopes, RSCE and RNMW, yielded sediments composed principally of clay, with lesser amounts of sand and silt. These sediment data in Table 3 can be compared with the information concerning the particle-size distributions of the soils and surface materials for the natural and reclaimed sites in Table 1. This suggests that the hydrologic processes on hillslopes entrain and transport materials in the silt and clay fractions with the greatest efficiency. The percentages of silt and clay in the sediment are always greater than in the soil or surface material, while the percentage of sand is always less. Here, it seems that particles in the clay fraction are entrained and transported more readily than indicated by the experiments of Wischmeier and Mannering (1969). This might be due to the high sand contents resulting in little soil aggregation.

Conclusion

Runoff and sediment samples from two natural and two reclaimed hillslopes were collected over a 5-year period at the Glenrock Coal company in east-central Wyoming. The average rate of runoff from the reclaimed sites were similar to that from the natural sites, despite differences in hillslope gradient, vegetation cover, and the characteristics of soils and surface materials. These data suggest that hillslope aspect influences runoff generation because the westerly-facing hillslopes produced more runoff than their easterly-facing counterparts.

The older reclaimed hillslope yielded sediment at an average rate within the range of the natural hillslopes, while the newly reclaimed hillslope yielded sediment at a much higher average rate. However, toward the end of the period of record, the rate of sediment yield from this surface appears to be similar to that of the other reclaimed surface and the two natural surfaces. If so, then it seems that reclamation practice and subsequent natural adjustments are capable of recreating a semblance of geomorphic stability in about five years at this study area.

Likewise, the average sediment concentration for the older reclaimed hillslope is within the range for the natural hillslopes, while that for the newly reclaimed hillslope is substantially higher. And again, toward the end of the period of record, the sediment concentration from this surface appears to be similar to that of the other reclaimed surface and the two natural surfaces. This, too, likely reflects the development of vegetation cover at this site through time.

The sediment derived from the natural hillslopes contains roughly the same proportion of sand, silt and clay, while that from the reclaimed hillslopes contains mostly clay. The percentages of silt and clay in the sediment always exceeds the percentages in the soils and surface materials from which they were derived. This suggests that hydrologic processes are selective with regard to the soil separates entrained and transported. At this locale, it seems that the clay fraction is more readily eroded than other authors have suggested. This may be due to the high sand content resulting in minimal aggregation.

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