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SOIL EROSION AND SEDIMENT CONTROL ON THE RECLAIMED COAL MINE LANDS OF SEMI-ARID SOUTHWEST

by

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ABSTRACT

Extensive disturbances are expected during the remainder of this century due to strip mining in the semi-arid West. Reclamation and revegetation of these disturbed areas is a slow process, primarily due to dry and harsh climatic conditions. Erosion and sediment losses are high. Monitoring of the soil erosion process is a crucial step in planning for a long lasting and stable rehabilitation of these disturbed areas. Erosion plots have been laid out to collect data for the Universal Soil Loss Equation for estimating soil loss from recontoured coal mine spoils. Effectiveness of different cultural and mechanical treatments for erosion control is also being evaluated. Since large-scale coal mining operation has just begun on the Black Mesa, preliminary data could be very effective and useful in Watershed Management planning.

INTRODUCTION

Energy demands are rising at a rapid rate in the United States and energy supplies are rapidly dwindling. As the cost of oil and natural gas continues to rise, coal will be looked to more and more as a major source of energy. The Southwest has approximately 62,000 square miles of coal deposits, about 3000 of which lie in Arizona. Most of this land is on the Black Mesa in the northeast corner of the state. Of the nearly 2.1 million acres comprising the Black Mesa, 14,000 have coal deposits underneath. These deposits are being stripped at the rate of 400 acres per year, a process greatly altering the soil profile and surrounding landscape. To reclaim the overburden strip material successfully, runoff and erosion rates must be accurately predicted. Three erosion plots were laid out on the Mesa for validating the Universal Soil Loss Equation (USLE).

Before the USLE can be used in the West, some factors must be modified to accommodate new environmental settings. The USLE is intended for estimating soil loss on large cultivated fields, and problems could arise when applying the equation to small watersheds. This is a subject which should be studied in more detail.

DESCRIPTION OF STUDY AREA

Black Mesa comprises 2.1 million acres of highlands gently sloping up from the Little Colorado River to an elevation of 8100 feet at its northern rim. The entire area is located on the Navajo and Hopi Indian reservations in northeastern Arizona. The climate is dry and harsh. Precipitation averages twelve inches per year, but is highly variable with long dry spells. Most of the summer precipitation is from convection storms, but with some coming as snowfall in winter. Temperatures range from about 27°F in January to about 80°F in July.

Vegetation on natural sites consists mainly of sagebrush and grasses, with pinyon and juniper at higher elevations. The reclaimed sites have no vegetation or at most, a sparse cover of Russian Thistle (Salsola kali).

Soils on the natural sites are poorly developed and severly eroded. They are generally shallow with an abundance of rock outcrops and are low in plant nutrients and organic matter. Overgrazing and the harsh environment have left the soil surface unprotected and vulnerable to erosional processes.

In an erosion study on the Mesa three 100-ft. plots were laid out on three different watersheds with slopes of 5, 8, and 17 percent. Each of the plots was on a uniform slope. A total of 240 nails were placed in each plot with four centimeters remaining above the soil surface. Three rows, each consisting of 80 nails, were placed in each plot 30, 60, and 90 feet from the top of the slope. Placing of the anils in each row was in four blocks with 1 foot spacing between the nails. Each block was 5 ft. wide and 4 ft. long.

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UNIVERSAL SOIL LOSS EQUATION

The Universal Soil Loss Equation was developed for use in areas east of the Rocky Mountains for considering problems specific to eastern United States. The equation is A = RKLSCP where A = soil loss in tons per acre, R = rainfall factor, K = soil erodibility factor, L = slope length factor, S = slope gradiant factor, C = cropping factor, and P = erosion control factor. The equation is adapted to Arizona by the U.S. Soil Conservation Service (1976).

Rainfall factor (R).

The R factor is the average number of erosion index (EI) units in a year's rainfall. EI values are found by multiplying the total kinetic energy in a storm by its maximum 30 minute intensity and dividing by 100. Kinetic energy for each storm can be calculated with the formula y = 916 +331 log (X) where y is the kinetic energy in foot tons per acre and x is rainfall intensity inches per hour (Wischmeier and Smith 1958). R values have been computed for eastern United States, but have not been for most areas west of the Rocky Mountains. The procedure outlined in Technical Note #32 of the WTSC-Portland (1975) can be used as a guide in computing this factor for the states of Washington, Oregon, California, Montana, Idaho, Wyoming, Colorado, and Arizona.

The states are divided into moisture and temperature zones and the procedure applied to each area. This paper will deal only with northeastern Arizona, which is designated as ustic in moisture regime and mesic or frigid for temperature zone. The term ustic is applied to areas where moisture is limited, but present at times when conditions are suitable for plant growth. Mesic implies annual soil temperatures of 47-59 degrees Farenheit; frigid indicates areas where annual soil temperature is less than 47 degrees. If there is no 0 horizon mean summer soil temperature is greater than 59 degrees, and if there is an 0 horizon mean summer soil temperature is 47 degrees or more.

R factors for Arizona have been calculated from the two year-six hour isopluvial map prepared by the National Weather Service. Values for the R factor can be determined from Figure 1, which was developed by the U.S. Soil Conservation Service.

Using rain gauge data from the Black Mesa for 1976, an R factor of 21 was obtained. This is lower than the 35 obtained from the Soil Conservation Service Planning Note No. 11 (Figure 1). These values are the average of a value which fluctuates with annual rainfall. The below average value obtained for 1976 reflects the low rainfall for that year and will be used for the soil loss estimates in this paper.

Soil erodibility factor (K).

This factor is a function of the physical and chemical properties of the soil. The K factor can be determined experimentally from a "unit plot" 72.6 feet long with a uniform 9% slope which is tilled up and down slope and is continuously fallow. For a given soil K is the erosion ratio per unit of erosion index from "unit" plots on that soil (Wischmeier and Smith 1965).

The overburden material consists mainly of sandstone and shale with smaller amounts of clay. All the reclaimed area has been recontoured to a slope of 20% or less and all precipitation falling on the site is contained within the area. The recontoured area has fine texture and a structure which can be defined as massive. It varies from 30 to 80 feet in depth, and infiltration rates are low because of crusting and puddling caused by its lack of structure and fine particles filling in the spaces between larger particles. This direct result of rain impact will be greatly reduced when vegetation becomes established, but until this is achieved infiltration rate will be quite low.

Wischmeier, Johnson, and Cross (1971) developed a nomograph to determine K using the following soil characteristics: percent silt and very fine sand, percent sand, percent organic matter, soil structure, and permeability. The last two are divided into 4 and 6 classes respectively (Figure 2).

The particle size distribution in the recontoured overburden material is 40% sand, 36% silt and very fine sand, and has no organic matter. It has a massive soil structure (Class 2), and slow infiltration rate (Class 5). Using the nomograph (Figure 2), a value of 35 was obtained for K.

Slope length (L) and gradient (S) factors.

Rate of soil loss is greatly affected by slope length and gradient. There two parameters have been studied separately in research, but can be combined as one topographic factor (LS) for field application. This factor is the ratio of soil loss per unit area on a field to the corresponding loss from the "unit plot" defined under the K factor. Values for LS can usually be taken directly from the chart (Figure 3). If there are several slopes on one field, use the value of slope with the greatest erodability. For convex and concave hills, use the steepest slope occurring on the hill.

The study site consits of three slopes with uniform conditions except for slope gradient. Site A has a 5% slope, B an 8%, and C a 17%. All are 100 feet long. The LS factors for the plots are: A = .53, B = 1.0, and C = 3.1.

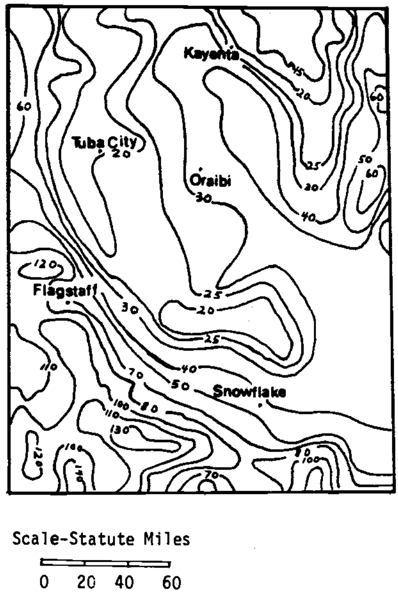
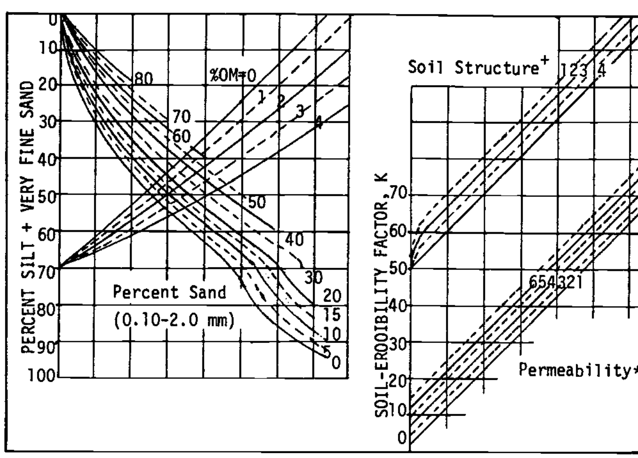


Figure 1. Average annual values of R in northeastern Arizona. After-USDA, Soil Conservation Service, Phoenix, Arizona, March 1976. (Values on this map include R s where snowmelt is a factor).



+1 very fine granular
2 fine granular
3 med. or coarse granular
4 blocky, platy or massive

*1 rapid
2 mod. to rapid
3 moderate
4 slow to mod.
5 slow
6 very slow

Figure 2. Soil Erodibility Nomograph. After-W. H. Wischmeier(1971).

Table 1. "C" Values for Permanent Pasture, Rangeland, and Idle Land[1/]

Vegetal Canopy			Cover That Contacts the Surface					
Type and Height of Raised Canopy[2/]	Canopy Cover[3/] %	Type[4/]	Percent Ground Cover					
			0	20	40	60	80	95-100
Column No.:	2	3	4	5	6	7	8	9
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds	25	G	.36	.17	.09	.038	.012	.003
or short brush		W	.36	.20	.13	.082	.041	.011
(0.5 m fall ht.)	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.067	.038	.011
Appreciable brush	25	G	.40	.18	.09	.040	.013	.003
or brushes		W	.40	.22	.14	.085	.042	.011
(2 m fall ht.)	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
(4 m fall ht.)	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

1/ All values shown assume: (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists. Idle land refers to land with undisturbed profiles for at least a period of three consecutive years.

2/ Average fall height of waterdrops from canopy to soil surface: m = meters.

3/ Portion of total-area surface that would be hidden from view by canopy in a vertical projection, (a bird's-eye view).

4/ G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep.

W: Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface, and/or undecayed residue.

Plant cover factor (C).

This factor, often called the cropping factor, was defined for agricultural land as the ratio of soil loss from land under specified cropping conditions to loss from tilled, continuously fallow land, all other factors being equal. In extending the C factor to other land uses, two interrelated parameters come into play: (1) vegetative cover on the soil surface and (2) canopy cover (7). C factors have been developed for pastures, range and idle land; woodland; and for cropland and hayland. Table A shows computed C values for pasture, rangeland, and idle land.

Reclaimed land on Black Mesa has no appreciable canopy cover for most of the year. Vegetation grows for about three months in summer consisting of Russian Thistle, with a cover density of about 20%. The plant cover is present when most of the major rains occur which provides some protection from erosion. A plant cover factor of .24 was taken from Table A.

Erosion control factor (P).

If some erosion control has been implemented in an area, it must be taken into account to accurately predict soil erosion. The P factor is the ratio of soil loss with control practices in effect to soil loss on land with straight row cropping up and down slope. P values have been compiled for contouring, contour strip cropping, control irrigated furrows, and terracing (for prediction of contribution to off-field sediment load). If no erosion control is implemented, this factor is equal to 1. Values for slopes of 2 to 24% are listed below.

Land	P Values			
Slope (%)	Contouring	Contour Stripcropping	Contour Irrigated	Terracing
2.0 - 7	0.50	0.25	0.25	0.10
8.0 - 12	0.60	0.30	0.30	0.12
13.0 - 18	0.80	0.40	0.40	0.16
19.0 - 24	0.90	0.45	0.45	0.18

There have been no erosion control practices applied to the study sites on the Black Mesa. After the overburden material was dumped, the only mechanical manipulation was regrading piles to reduce their slope, which has been considered in the slope gradient factor. When tractors (D-9 cats) regraded the slopes they moved only up and down slope so that their tread marks ran perpendicular to the slope direction. This will help reduce erosion while the tracks last, but they are erased after the first major rain. The P factor for the study sites is equal to one.

RESULTS AND CONCLUSIONS

The erosion plots on the Black Mesa had an average of 0.17, 0.49 and 0.57 centimeters of erosion on the 5%, 8%, and 17% slopes respectively. Expressed in tons per acre these figures are 0.04, 0.13, and 0.15.

These values represent nine months of data from July 1976 to March 1977, and can only be considered as preliminary. However, erosion during the rainy season from July to September. The rain from March 1976 to July 1976 amounted to less than one inch and there was no runoff. The same period in 1977 should have a similar rainfall and runoff pattern.

The erosion predicted for the three plots by the USLE is .935, 1.764, and 5.47 tons per acre for the 5%, 8%, and 17% slopes. These values are all much higher than those measured on the study plots.

More data should be collected from the erosion plots for long time averages to compare with the USLE. Runoff sediment plots are presently being installed on the Black Mesa which will provide additional data for comparison studies to the erosion plots and to the Universal Soil Loss Equation estimates.

The major reason for the difference between estimated and actual soil loss may be explained by the soil factor (K) and rainfall factor (R) of the USLE. More extensive studies should be carried out on these factors as they apply to disturbed soils. Modification may be necessary in these factors to apply the USLE to reclaimed strip mined land in the southwest.

While no definite conclusions can be drawn from this preliminary report, it indicates where problems will be encountered and shows the direction that future studies should be directed for accurate estimated of erosion with the Universal Soil Loss Equation.

SLOPE-EFFECT CHART (Topographic Factor, LS)

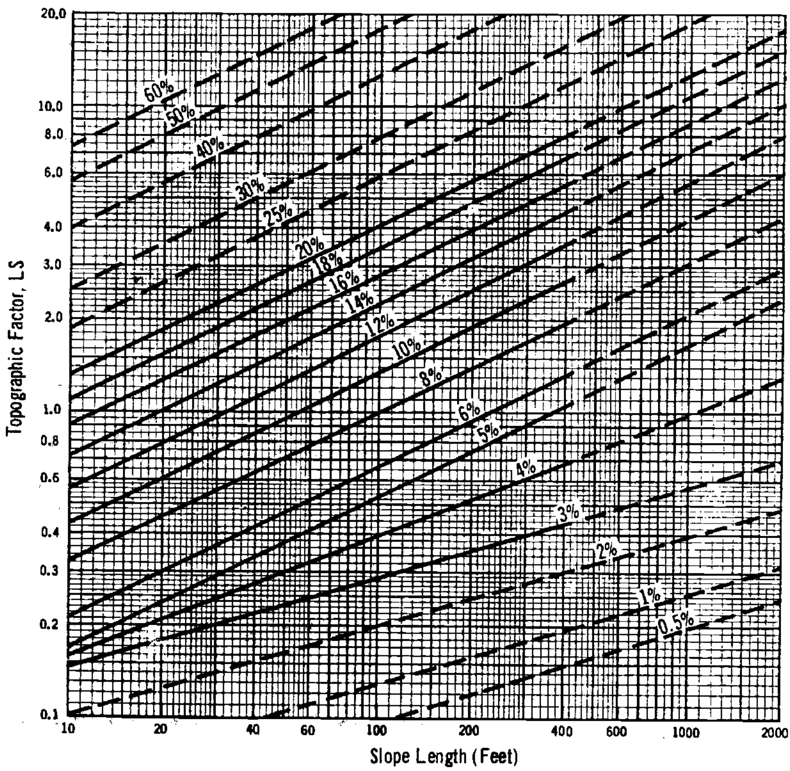


Figure 3. After U.S. Department of Agriculture, Technical Release No. 51 (1975). The curves were derived by the formula:

$$LS = \left(\frac{\lambda}{72.6}\right)^m \left(\frac{430x^2 + 30x + 0.43}{6.57415}\right)$$

where λ = field slope length in feet and $m = 0.5$ if $s = 5\%$ or greater, 0.4 if $s = 4\%$, and 0.3 if $s = 3\%$ or less; and $x = \sin\theta$. θ is the angle of slope in degrees.

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