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A method for establishing base-line soil loss rates on surface mine sites

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A METHOD FOR ESTABLISHING BASE-LINE SOIL LOSS RATES ON SURFACE MINE SITES

by

Paul Flack

A Thesis submitted to the Faculty of the
SCHOOL OF RENEWABLE NATURAL RESOURCES
for the Degree of
MASTER OF SCIENCE
WITH A MAJOR IN WATERSHED MANAGEMENT
in the Graduate College
THE UNIVERSITY OF ARIZONA

1989

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ABSTRACT

Surface mining operations require a comparison of post-mining erosion rates with pre-mining soil loss to ascertain if remedial measures are needed. In this study the Universal Soil Loss Equation (USLE) was modified to reflect conditions of western rangelands to develop a procedure for estimating pre-mining soil loss rates. The modification used back-calculation for the C-Factor and an adjusted R-Factor based on storm size. Soil loss simulation based on stochastic precipitation patterns is appropriate to the site - the La Plata mine area in northern New Mexico - and increases the flexibility of the USLE as a soil loss predictor for western rangelands.

CHAPTER 1

INTRODUCTION

Sediment is recognized as one of the major pollutants resulting from surface coal mining operations in the western United States. Measuring and controlling sediment loss from mine sites is a major problem coal companies encounter when complying with the policies of regulatory agencies. For example, the administration of the San Juan Mine in northwest New Mexico would like to avoid constructing sediment ponds, although this procedure is used by some western mining companies. Sediment basins may not be necessary if it can be shown that soil loss from a mine site after mining, regrading, and revegetation is no greater than the soil loss from the same area before mining. This requires baseline data, but the establishment of baseline erosion rates in the semi-arid western rangelands is difficult because of low and infrequent rainfall. Many years would be required to collect sufficient empirical information to be convincing, however, the Universal Soil Loss Equation (USLE), generally accepted as an estimator of soil loss by many government agencies, can provide a short cut. Unfortunately, the USLE has not been fully adapted for western rangelands, where special considerations are required because rangeland conditions differ greatly in the West from those used to derive the USLE.

Some researchers (Foster, 1981a; Laflen, 1981) have noted special problems with adapting the USLE to western states. Others (Simanton and renard, 1982) have proposed variations to modify the equation for semi-arid conditions. Nevertheless, the USLE remains the tool most often used to estimate soil loss. The USLE estimates the average soil loss over a period of time and does not take into account variations that occur from year to year.

A method is needed that allows estimates of soil loss that might be expected from year to year under variable rainfall conditions. Such a procedure would enable mining companies to evaluate the success of reclamation efforts and regulatory agencies would have a better means of evaluating a mining company's compliance or non-compliance with state and federal laws. If it can be shown that post-mining soil losses fall within the range of pre-mining losses, then compliance will have been attained.

In this study a method was developed for evaluating expected soil loss rates from unmined sites using the USLE and stochastic methods to simulate the probabilities for pre-mining soil loss.

CHAPTER 2

OBJECTIVES

The primary objective of the study was to develop the probabilities of pre-mining soil loss rates for four selected sites at the San Juan Coal Company's La Plata mine site near Farmington, New Mexico. Secondary objectives were: (1) to assess the effectiveness of fabric dams as a data collection tool; and (2) to calibrate the USLE for the four study sites selected.

CHAPTER 3

DESCRIPTION OF THE STUDY AREA

The La Plata Mine is approximately 18 miles north of Farmington, New Mexico. The lease area consists of 3,191 acres of rolling to sharply dissected surfaces. Approximately 2,310 acres of the lease area are to be mined (Figure 1).

The mine lease lies along the northwest flank of the San Juan Basin. The structure of the basin confines the beds to a northeast-southwest strike and an average southeastward dip of approximately 11 degrees. The stratigraphic section in the La Plata area reflects the Late Cretaceous transition from shallow marine depositional environment to a terrestrial fluvial depositional environment. The three formations encompassing this depositional environmental change are (in ascending order) the Lewis Shale, the Pictured Cliffs Sandstone, and the Fruitland Formation.

Environment

The climate of the La Plata lease area is semi-arid, characterized by low humidity, infrequent precipitation, and large annual and diurnal temperature variations. Elevation ranges from 5,900 to 6,200 feet. The seasonal distribution of precipitation is divided between a wet season from July through October and a drier season from November through June. The higher midsummer precipitation is attributed to convective thunderstorms caused by an influx of moist air from the Gulf of Mexico. These storms are normally intense and of short duration. The La Plata area averages about 11 to 12 inches of precipitation per year. Snowfall is erratic.

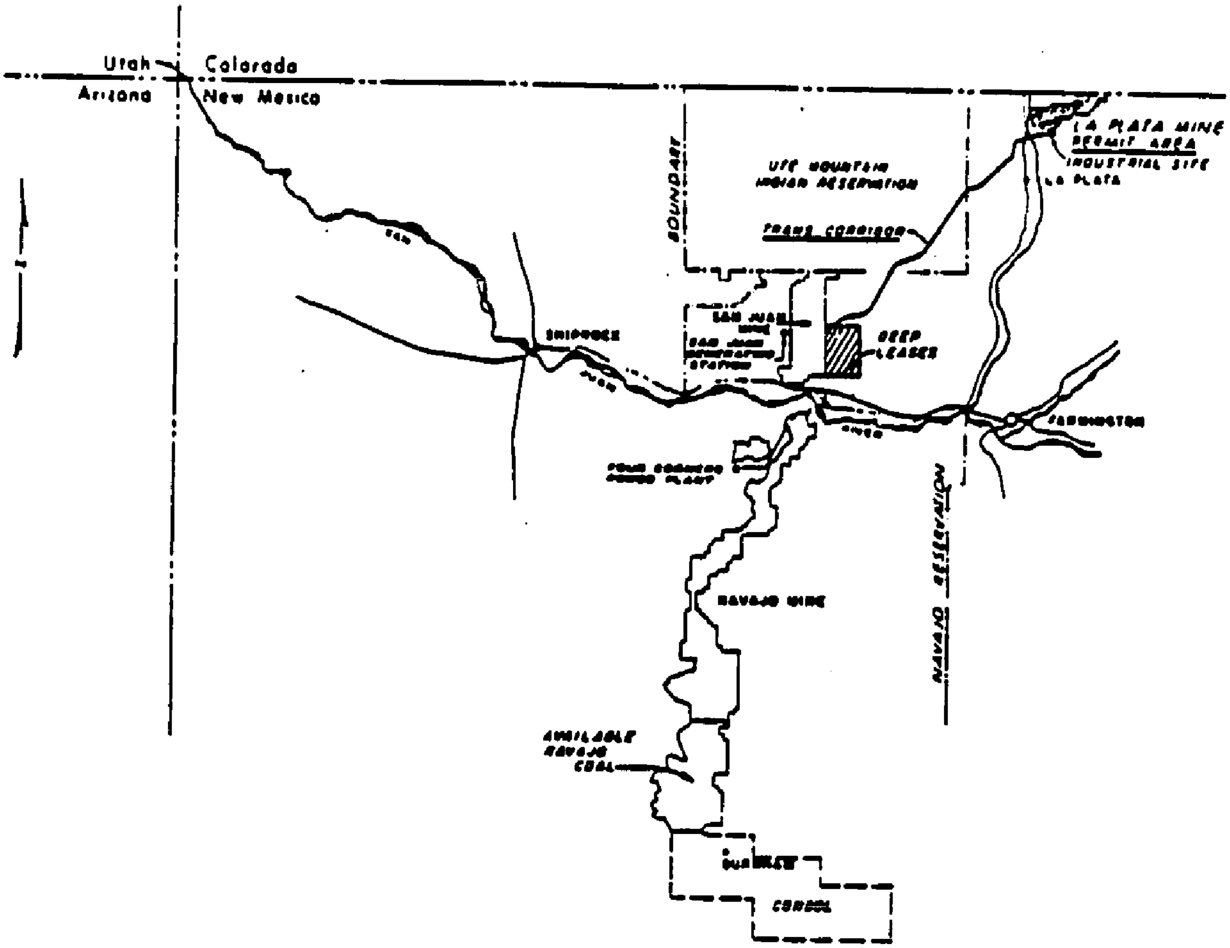

Figure 1. Location Map of La Plata Mine, Farmington, New Mexico.

Summer daytime temperatures usually average in the low 90s (Fahrenheit), with August being the warmest month. The growing season averages 140 days, beginning in mid-May and ending in late September.

Vegetation

Vegetation on the La Plata mine site is characterized by stands of pinyon (Pinus edulis) and one-seed juniper (Juniperus monosperma)intermingled with sagebrush (Artemesia tridentata) and greasewood (Sarcobatus vermiculatus). The pinyon-juniper generally is found on the rolling hills common to the area. Sagebrush stands are found on flat to gently sloping landscapes. Greasewood is mixed with sagebrush along the major drainages.

Soils

The soils of the area are deep, well-drained to extremely well-drained, and are found on ancient river terraces. These soils formed in moderately fine textured alluvial material of mixed origin and in calcareous, gravelly alluvium of mixed origin. Interspersed throughout the area are soils formed from both weathered shale and sandstone.

The soil series for each of the study sites are (USDA, 1978):

WATERSHED #1	BUCKLE
WATERSHED #2	TRAVESSILLA
WATERSHED #3	DISTURBED SPOIL
WATERSHED #4	DISTURBED SPOIL.

CHAPTER 4

METHODS AND PROCEDURES

Determination of the probable rate of soil loss for the La Plata lease area before mining required the adaptation of the Universal Soil Loss Equation (USLE) to western rangelands and the specific conditions found on the lease area. This required: (1) measuring actual soil loss on representative plots within the lease area; (2) modifying the energy factor of the USLE to better represent the erosive power of Southwest storm events; (3) adjusting the cover factor of the USLE to the specific conditions found on the plots and calibrating the equation; (4) developing a stochastic model of storm size and annual frequency of occurrence; (5) simulating a long-term sequence of annual rainfall, and (6) applying the modified USLE to the simulation to estimate probabilities of soil loss. The data collection period began May 26, 1984 and terminated September 14, 1986. Because of the start-up of mining operations in late 1985 and 1986, four of the original eight study plots were destroyed. Only data from the remaining four plots was used in the statistical analysis.

Fabric Dams

In this study, fabric dams were used to assist in the calibration of the USLE. The dams were selected because they have been reported to provided effective and inexpensive measures of soil erosion under a variety of conditions (Dissmeyer, 1982).

Eight small study plots (approximately one acre each), representing a broad range of soil-cover complexes, were selected in 1984 on the La Plata mine site. On each plot, one semi-permeable fabric dam was constructed for the purpose of trapping eroded soil. Each dam was located at the drainage outlet of a plot. Sediment pins were arranged linearly on a 2 foot x 10 foot grid behind each dam. The grid consisted of two rows of eight pins each. The first row of pins was flush against the face of the dam. The second row was placed 2 feet upstream from the first row. The pins were constructed of 1.5 foot sections of 0.5 inch rebar driven approximately six inches into the ground (Figure 2). A single washer (0.75 inch in diameter) was placed over each pin to indicate the surface elevation at the time of installation. An initial measurement from the surface washer to the top of the pin was recorded. After a rainstorm event, overland flow carrying sediment was temporarily detained behind the dam. As water seeped through the dam, suspended sediment was deposited behind the dam. Measurements made from the surface washer to the new ground surface determined the soil loss. Using grid area, number of pins, and average depth of sediment, the volume of soil trapped was computed, using the following equation:

$$EV = A \times P \times D \qquad (1)$$

where:

EV = erosion volume (cubic feet per plot).

A = grid area in square feet

P = number of grid points with sediment deposits ÷ total number of grid points.

D = average depth of sediment for grid points with deposits (feet)

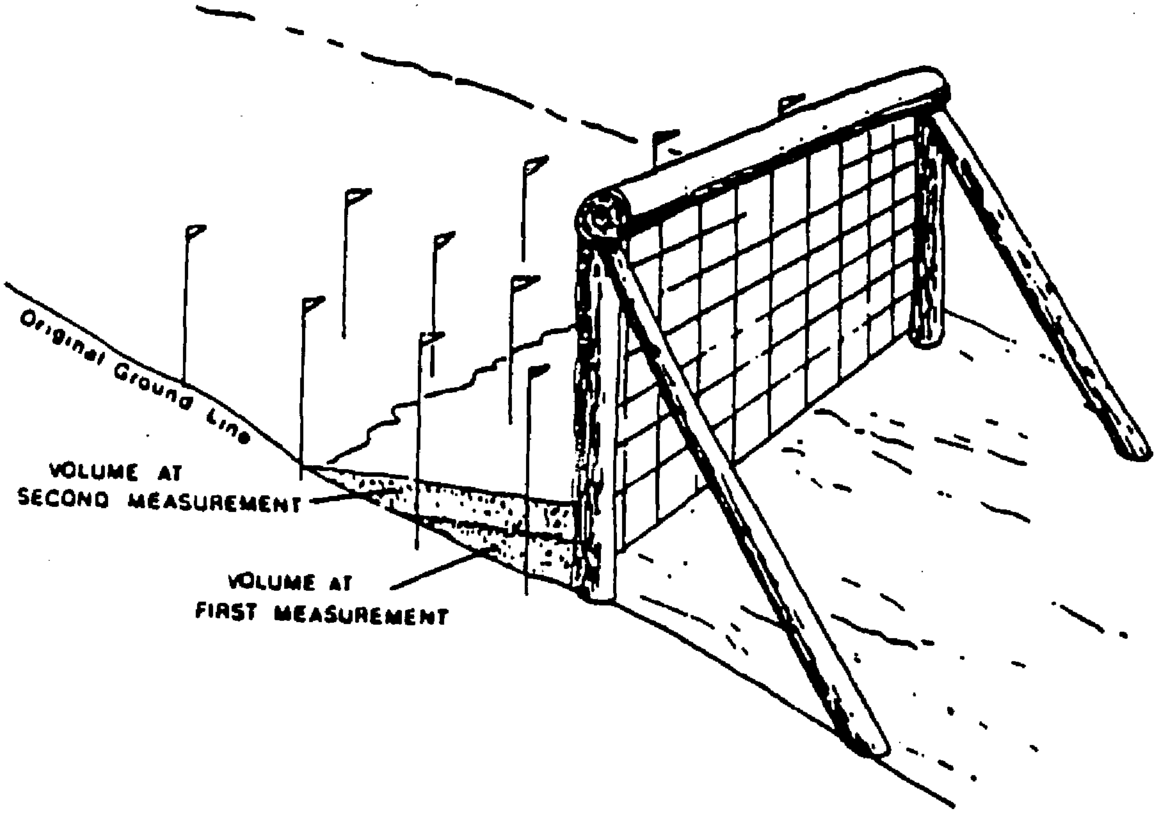

Figure 2. Fabric Dam Set-Up.

Erosion volume per acre equals EV divided by plot area drained in acres. Conversion of volume to weight was made by measuring the bulk density of the sediment at each plot. Three core samples were taken from each plot and the bulk density of each sample was measured. The average of the three measurements was used in the later calculations.

Universal Soil Loss Equation

The USLE is an empirical formula for predicting soil loss due to sheet and rill erosion. The equation was developed from 10,000 plot-years of runoff and soil loss data, collected on experimental agricultural plots in the Eastern and Midwestern United States. The equation relates soil loss to six major multiplicative factors. The USLE, as given by Wischmeier (1976), is:

$$A = R \times K \times LS \times C \times P \qquad (2)$$

where:

A = the computed soil loss per unit area, expressed in units selected for K and for a period selected for R.

R = rainfall and runoff factor, expressed by the number of erosion index units, also identified as the sum of EI products for individual storms in a season.

K = the soil erodibility factor, defined as the loss rate per erosion index unit for a specific soil, as measured on a unit plot 72.6 feet long with a uniform 9% slope and continuously in clean tilled fallow.

LS = the slope length and slope gradient factors, respectively. The slope length factor (L) is the ratio of soil loss from a field of a given length to a test plot, 72.6 feet long under identical conditions. The slope gradient factor (S) is the ratio of soil loss for the field slope gradient to that from a 9% slope, under otherwise identical conditions.

C = the cover and management factor, which is the ratio of soil loss from an area with specified cover and management to that from an identical area in continuous tilled fallow.

P = the support practice factor is the ratio of soil loss with a given support practice to a standard of straight row farming up and down slope.

Only the R and K factors have units in the equation; the rest of the factors are dimensionless ratios.

Although 40 years of research and application have gone into the development of the USLE for use on cropland, the equation has proven inadequate for western rangeland conditions. Two modifications of the R-factor and C-factor were made in the La Plata study. The modifications were introduced to improve the USLE as a predictor of soil loss for the conditions on the study sites.

Determination of the R-Factor

The research data of Wischmeier (1959) indicated that when factors other than rainfall are held constant, storm soil losses are directly proportional to a rainstorm parameter, identified as the erosion index EI. By definition, the value of the EI for a given rainstorm equals the product of total storm energy (E) times the maximum 30 minute rainfall intensity (I), where E is expressed in hundreds of foot-tons per acre and I is in inches per hour. If size and terminal velocity of rain during a storm event are known, the kinetic energy of the storm can be calculated. However, the measurement of these parameters is not practical, and they are assumed to be directly related to rain intensity (Wischmeier and Smith, 1978):

$$E = 916 + 331 \log I \qquad (3)$$

where:

E = kinetic energy (foot-tons/acre-inch).

I = rainfall intensity (inches/hour).

The energy term indicates raindrop detachment, while the maximum intensity component indicates the prolonged peak rates of runoff. Technically, EI indicates how particle detachment is combined with transport capacity. The relation of soil loss to EI is linear, and individual storm values are directly additive.

Studies made by the Agricultural Research Service at Walnut Gulch near Tombstone, Arizona indicated that only the larger thunderstorms produce soil loss (Simanton and Renard, 1982). These storms usually exceeded 0.30 inches and occurred only in the summer. Best results were obtained at Walnut Gulch when the EI values for all storms exceeding 0.30 inches were summed over yearly periods to obtain an average annual R value.

Air-mass thunderstorms, occurring primarily during the summer months of May through October dominate the rainfall/runoff/erosion relation at La Plata. The air-mass thunderstorms in the region are highly variable in both time and space, of limited areal extent, and of short duration. A single storm can contribute a large portion of the annual rainfall erosivity. Although the USLE is not intended to estimate soil loss on a per storm event basis in this region, the largest storm during the summer may be the most significant factor in the annual soil loss (Simanton and Renard, 1982).

Because of the inadvertent loss of the recording gages at the study site during the study period, rainfall intensity data were available for only six storms. Therefore, use of the Wischmeier-Smith kinetic energy relationship was not feasible. For this study, a method was developed to estimate the annual R value without the use of nearby rainfall intensity data. In addition, it was necessary to have an R value that reflected the variability in rainfall from year to year. It was assumed that there was a direct relationship between the size of storm and the EI value of the storm. Because rainfall amounts and distributions are similar at Walnut Gulch and La Plata, it was decided to use Walnut Gulch data. Two assumptions were made: (1) the EI value for a given storm is the same at La Plata as it is at Walnut Gulch, and (2) only storms equal to or exceeding 0.30 inches contribute to the erosion process at La Plata. Smaller rainfall events and snowmelt were excluded from the analysis.

It was found that a second order equation was adequate to describe the relation between EI and storm amounts for the Walnut Gulch data. See Figure 3.

$$EI = 0.697 - 1.527P + 13.72P^2 \qquad (4)$$

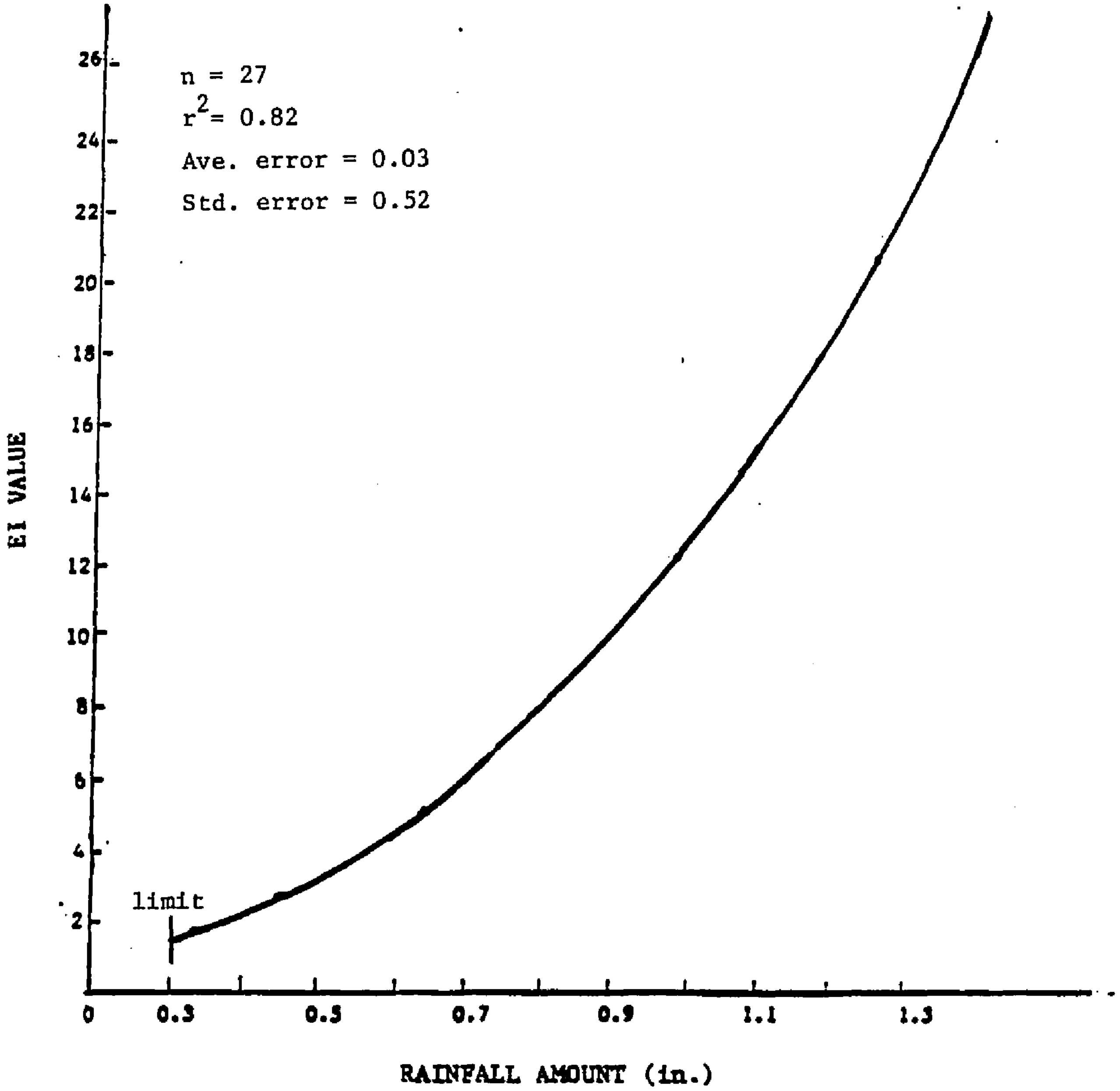

Figure 3. EI Versus Rainfall Amount.

where:

P - precipitation of storm events greater than 0.30 inches

EI - erosion index.

Determination of the C-Factor

The cover-management factor (C) is a sensitive factor in the USLE. There is uncertainty as to the proper value of C for rangelands. Published C-factors (Wischmeier and Smith, 1978) frequently used for rangelands were derived from the basic relations among canopy, ground cover, soil consolidation, plants, and the erosion process. Data for these relations have been obtained mainly from studies for cropland conditions and have never been validated for rangelands. Foster (1981b) identified several problems with the use of existing values of the C-factor on western rangelands. Some of the problems are:

1. Erosion pavement--in much of the Southwest selective erosion by wind and water has left a gravelly surface cover. The overall effect of the pavement and how to measure the effect are not yet fully understood.
2. Percent cover--because of the spatial distribution of rangelands vegetation, percent cover may not always be a good indicator of vegetational effects on the erosion process.
3. Freezing and thawing--freezing and thawing occurs often on western rangelands, but the effect on soil cover is not fully understood. The question remains whether or not freezing and thawing should be considered as part of the C-factor or part of the K-factor.

4. Infrequent storms--questions remain as to whether or not infrequent and highly variable storms require C-factors that are more accurate with respect to specific conditions at the time and location of the storm than are required in the eastern United States.

To avoid many of the problems associated with C-factor evaluation, the procedure used in this study was to calibrate the USLE with actual measurements of soil loss made at each site using the R-factor determined from the measured precipitation. The equation is

$$C = A/[R \times K \times LS \times P] \tag{5}$$

where:

A - actual soil loss measurement for each watershed
R - calculated R-factor using the actual storm amounts producing the soil losses which were measured.
K, LS, P - as defined previously.

This technique treats the C-factor as a calibrating parameter in the soil loss equation. It was assumed that once determined, the C-factor remains constant from year to year.

Determination of the K-Factor

Some soils erode more easily than others even when all other factors are held constant. This difference, caused by the soil itself, is referred to as the soil erodibility. The relative erodibility of different soils is difficult to judge from field observations. Soils with a low K value can exhibit high erosion rates when the soil occurs on long or steep slopes. Conversely, a soil with a high K value may show little evidence of erosion when it occurs on short and/or gentle slopes or with good vegetative management. Direct measurement of the erodibility factor is both costly and time consuming. For these reasons, a soil erodibility nomograph, developed by Wischmeier et al. (1971, was used to determine the K values for each research plot. The nomograph is not reproduced here.

Use of the nomograph requires estimates of four soil parameters as they relate to soil erodibility. First, three soil samples from each watershed were taken and mechanical analysis was performed to find the proportions of sand, silt, and clay. Next, the percent organic matter in the soil was determined (USDA, 1978). Due to the sparse vegetation at La Plata, organic matter content was less than 1% for all sediments. Third, the soil structure was analyzed from each soil type. The soil structure reflects average relations between structure type and size. By convention, structure data used are those of the topsoil only. Lastly, the soil permeability was needed to complete the requirements of the nomograph. This value refers to the soil profile as a whole, but the controlling soil layer is usually below the surface layer. Soil permeability measurements as given in the San Juan County Soil Survey (USDA, 1978) were used from the Buckle and Travessilla series. Permeability from the disturbed spoil plots was measured at the field laboratory using falling head permeameters.

Determination of the LS-Factor

Both the length (L) and the steepness of the land slope (S) affect the rate of soil loss. The two factors have been evaluated separately in research and are represented in the USLE by L and S, respectively. For field application, however, the convention is to consider the two as a single factor, LS. The LS ratio from specified combinations of field slope length and uniform gradient are available from USDA's slope-effect chart (USDA, 1978), not reproduced here.

In this study, study plots were chosen with a uniform slope gradient. Slope was read in percent using an Abney level and slope length was paced in the field. In the past, there has been a tendency to overestimate slope length on rangelands (Blackburn, 1980). The slope length is defined as the distance from the point of origin of overland flow to the point where either the slope decreases enough that soil deposition occurs, or the runoff water enters a well defined channel. For rangelands field application, however, this definition proves ambiguous and difficult to apply. Often, depositional areas are not obvious. In addition, whether or not the rills and small ravines characteristic of rangelands morphology constitute a well defined channel is not always clear. Since explicit, workable guidelines were not available for determination of maximum slope length, the precepts as given by Dissmeyer (1982) were followed to standardize the measurement from all plots. Results are shown in Table 1.

Table 1. Measured L and S Factors and LS Index

Plot No.	Length (L) (ft.)	Slope (S) %	LS Index
1	62	2	.16
2	18	4	.19
3	24	8	.48
4	28	3	.18

Determination of the P-Factor

The P-Factor is used for soil erosion control practice on cropland and does not apply at La Plata, and P was taken equal to 1.0.

The Precipitation Model

The objective of the precipitation model was to generate synthetic data reflecting the expected number and size of precipitation events. The approach was to develop a stochastic event-based model using a combination of theoretical probability distributions and a random number generator. Two empirical frequency distributions were developed, one distribution for the number of storms per year and another from size of storms. Historical precipitation records, collected near Farmington, New Mexico, were analyzed to obtain the distributions. The empirical data were fitted to theoretical distributions. The Kolmogrov-Smirnov (K-S) test was used to indicate the goodness of fit between the frequency distribution of actual and theoretical data at the 0.05 significance level. Once the distribution that produced the best fit was selected, random numbers were used in the distribution to simulate the number and size of storms for each year over a 100-year simulation period.

Several basic assumptions were made in designing the model. First, it was assumed that the rainfall/runoff/erosion relations at the La Plata site are the result of convective-type thunderstorms. Second, the time step of the model was one day, therefore, all precipitation which occurred on one day was assumed to be one event.

Third, the precipitation model presumed that storm events occurred independently of each other. Lastly, a storm event was defined to be a storm which produced a minimum of 0.30 inches because this was the minimum amount of rainfall required to activate the erosion processes.

Initial Data Analysis

The purpose of the data analysis was to prepare the rainfall data for "curve-fitting" with the theoretical probability distributions. Daily precipitation records were available from the years

1969-1986 from the New Mexico State University Agricultural Experiment Station, located four miles southwest of Farmington, New Mexico. The first step in the analysis was to select the storms which equaled or exceeded 0.30 inches from the data set. Secondly, the mean and variance were computed from these storms. These parameters were used in the selection of the probability distribution. The rainstorm events were placed into one of 10 frequency intervals and empirical probability and cumulative density functions were computed. At this point, selection of a theoretical probability distribution was possible.

Selection of a Theoretical Distribution

The process of selecting a theoretical distribution from simulation purposes involved the aid of the computer program &Tnl. This program, originally written by Jones (1981), was used to determine the probability density function (PDF) and cumulative density function (CDF) from each of the distributions under consideration.

The output from &Tnl includes: (1) three theoretical cumulative and probability density distributions--gamma, exponential, and geometric--generated from the method of moments parameter estimates, and (2) the arithmetic difference, from each frequency interval, between the empirical cumulative density distribution and each theoretical density distribution (Manuel, 1986).

The arithmetic difference was used to evaluate the closeness of fit. This procedure is called the K-S test. The values needed to evaluate the significance of the calculated differences are available in most statistical tests (Manuel, 1986). The occurrence of a single difference greater than the assigned K-S value was the criterion from rejecting a particular theoretical distribution. If more than one theoretical distribution passed the K-S test, one theoretical distribution was selected subjectively for best fit.

The cumulative probability function for any random variable is uniformly distributed over the interval 0 to 1, and random variables are generated from this probability distribution (Haan, 1982). These variables are generated by: (1) generating a uniform random number, (2) setting the random number equal to the CDF value of the random variable distribution, and (3) solving the distribution equation for the random variable.

Erosion Loss Simulation

Simulation of pre-mining rates at La Plata incorporated three major processes. The first process involved simulating the regional rainfall pattern (magnitude and number of storms) using the precipitation model. The second process involved using the generated precipitation to calculate a yearly R-factor. Lastly, the R-factor was used in the USLE with the remaining parameters to estimate the actual soil loss. The model was operated in the following sequence:

1. A random number is generated and entered into the distribution function (gamma) representing the yearly number of storms equal to or greater than 0.30 inches, yielding the number of storms (>0.30 inches) per year.
2. Another random number is generated and entered into the precipitation per event distribution function (exponential).
3. The generated precipitation amount is entered in the EI regression algorithm to obtain the EI for each storm event.

4. The EI values are summed from the number of storms specified in (1), giving an annual R value.

5. The R value is inserted into the USLE equation and a yearly soil loss rate is computed.

The sequence was repeated 100 times to yield a 100-year simulation of soil loss rates at the La Plata mine site, based on actual rainfall and soil loss measurements (Figure 4).

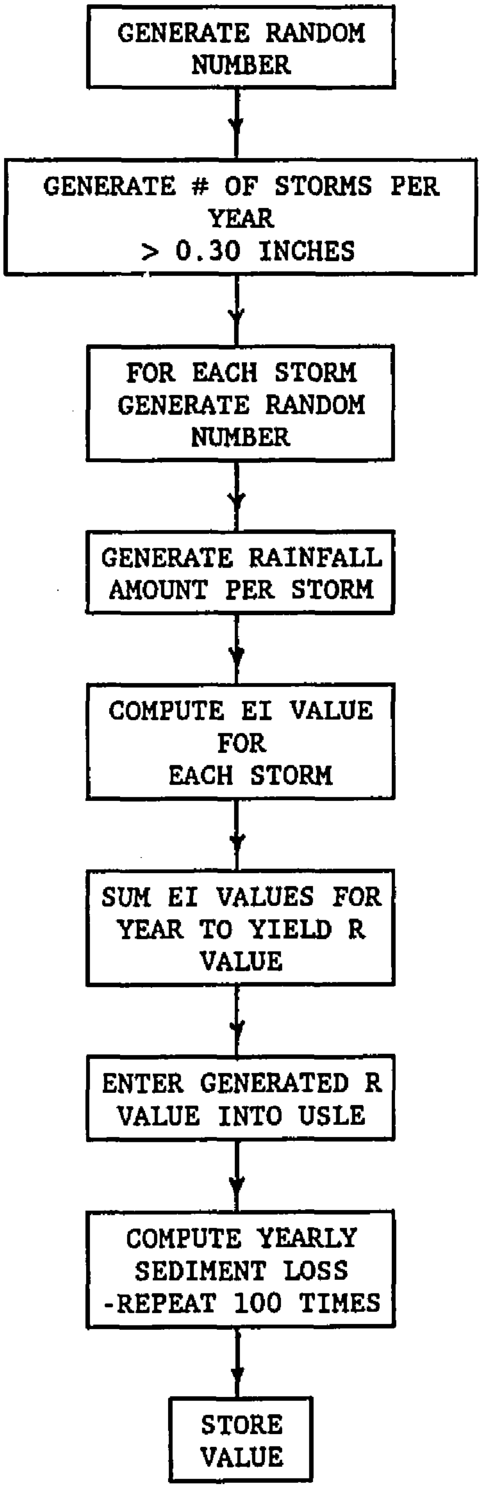

Figure 4. Erosion Loss Simulation Flow Chart

CHAPTER 5

RESULTS AND DISCUSSION

This study combines several approaches to predict soil loss on Southwest rangelands. The accuracy and feasibility of these methods are individually analyzed in this Chapter.

Fabric Dams

Fabric dams have been used extensively in the Southeast United States (Dissmeyer, 1982), however, only recently have they been used on western rangelands. The dams were used in this research because they were inexpensive to install and, in conjunction with the sediment pins, provided a relatively simple means of data collection. Eight dams were originally placed throughout the mine site, but due to changes in the mining plan, four of the dams were rendered useless before the study was completed.

During the study, it was not certain whether the fabric dams completely trapped all the sediment eroding from the plots. Three of the four dams incurred tears in the fabric which possibly affected data results. There was evidence of undercutting on dam #1 and side cutting on dams #2, #3, and #5. The fabric dam setup yielded erosion rates much lower than previously reported on western rangeland (Simanton and Renard, 1982).

The performance of the erosion pins was suspect. As mentioned previously, the pins often were pushed over by large flow events, making accurate readings difficult. For example, approximately 40% of the pins needed to be reset after the October 14, 1985 storm event. Conversely, measuring the small amount of deposition from small storms proved difficult -- a major disadvantage of using erosion pins in the Southwest. For the smaller flow events sediment loss would have been more accurately measured by weighing the sediment trapped rather than using depth units.

Perhaps the biggest problem with the fabric dams used at La Plata was not knowing the precise area contributing to the erosion process. Small rills would develop on the plots and guide runoff around the dams. This partially explains the low erosion rates recorded at the sites. For future studies, it is recommended that research plots be bordered with an edging to be sure that the dams trap all the sediment.

Finally, extrapolating the data from the plots to the entire mine site would require constructing a fabric dam on each soil type and the number of dams needed could be prohibitively large. Data from fabric dam plots are only valid for the area for which the data was taken and should be extrapolated with care to the entire watershed.

Overall, the performance of the fabric dam/erosion pin methodology was not encouraging. While fabric dams offered an economically appealing way of measuring soil loss at La Plata, their effectiveness in trapping all the soil from the plots was marginal. It is recommended that other methods be examined for western rangeland conditions. Average rates of erosion and other factors for the research plots are given in Table 2.

Table 2. Average Factors to Compute Erosion Rates

Equation (1) Factors						
Soil Type	"A" (ft²)	"P"	"D" (ft)	"EV" (ft³)	Bulk Density (g/cm³)	Erosion Rates ton/acre/year)
Buckle	20	.40	.07	.56	1.3	0.04
Travessilla	20	.38	.06	.44	1.4	.01
Disturbed Spoil	20	.51	.09	.96	1.5	.12
Disturbed Spoil	20	.54	.09	1.03	1.4	.43

R-Factor Evaluation

Analysis of the six storms over the two-year study period yielded an average R value of 30 index units per year at La Plata. Despite the fact that two years is too short a period to generate reliable long term estimates of R, these preliminary results are encouraging when compared to other R value estimates. The published USDA isoerodent maps (USDA, 1978), based on actual rainfall recordings, give the Four Corners area an R value of 20. The use of the two-year, six-hour regression analysis (Simanton and Renard, 1982) yielded a value of 27 (the two-year six hour event at La Plata as given in the NOAA atlas [1960] is estimated to be 1.02 inches). Based on these comparisons, the EI-storm size regression analysis provided reasonable estimates of the R values.

The assumption that snowmelt is insignificant in terms of contributing to the R value at La Plata was made for three reasons: (1) low amounts of snowfall are recorded at La Plata; (2) water equivalent of snowfall is low; (3) well drained soils exist at the site and snowmelt runoff is small. Data collection during periods of snowmelt and freezing and thawing was impossible, because of limited access into the research area. It is unlikely that it snows often enough or in great enough quantities to have melt water contribute significantly to the erosion process at La Plata. Nevertheless, further research to verify this conclusion is warranted.

Because of similar rainfall patterns, it was assumed that intensity data collected at Walnut Gulch, Arizona was applicable at La Plata (Farmington). Comparisons of rainfall intensity data between the two sites showed that intensity values were somewhat higher at Walnut Gulch than at Farmington. Of the 132 storms recorded at Walnut Gulch, 82 had higher intensities than the average 30-minute intensity at Farmington. However, the shortage of intensity values for the study site made it impractical to predict the long term differences in EI values between the two areas. With the addition of future rainfall data, further refinements of the regression equation can be made to better represent the research site. The main advantage of using the regression equation is that storm amount, and not intensity, is used to compute the EI. This is beneficial in the West, where a paucity of recording stations creates a large information gap with regard to rainfall intensity.

C-Factor Evaluation

The C-factor is the most difficult USLE parameter to estimate, especially for rangeland conditions. If only rangeland vegetation is considered, ground cover is low, and C is high. However, in the Southwest, the vegetation often is clumped in a random pattern on the watershed and can act as an effective barrier to the erosion process.

In addition, seven of the eight watersheds at La Plata had erosion pavement. Assessing the effects of the pavement was difficult. On one hand, the pavement protected the soil from direct raindrop impact and surface runoff erosion (Simanton and Renard, 1982), however, the pavement may also have concentrated runoff and increased the erosion potential.

From initial data, a threshold precipitation intensity appears to exist, dictating which process dominates the effect of the surface pavement. Below the threshold, the surface pavement protects the soil surface from erosion. Precipitation events at or above the threshold amount cause runoff volumes and velocities which can erode the surface pavement and the surrounding unprotected soil surface. With only two years of data, any estimate of the threshold precipitation amount for this study would be subject to great uncertainty, therefore, no conclusive predictions were made. Preliminary data indicate that the surface pavement maintained a high degree of integrity even at relatively high rainfall intensities, thereby effectively hindering the erosion process.

Erosion pavement has been traditionally considered as part of the C-factor (its use in the K-factor is discussed later) and is expressed as a percent cover of the total area, however, detailed guidelines as to measurement and effect of erosion pavement is lacking. Estimates of the pavement's effects are often more qualitative than quantitative.

At La Plata, it was assumed that estimates of the vegetation cover and erosion pavement effects would be the most subjective, and subject to greater error than the other USLE factors. Therefore, the C value was chosen to be the calibrating factor between the predicted and actual soil loss. Calibration involved solving the USLE for C and using measured soil loss rates as the A value. The C estimates at La Plata using this technique were comparable with results obtained in other studies conducted on western rangeland (Simanton and Renard, 1982). Back-calculation of the C-factor was made using the R value determined from the EI-storm size regression.

The C value obtained through back-calculation differed by as much as an order of magnitude from the conventional published C values (USDA, 1978). See Table 3. This leads to the conclusion that the conventional values are not valid for western rangeland conditions. Indeed, use of the published C values in the USLE greatly over-predicted soil loss at La Plata. Research from the Walnut Gulch Experimental Watershed (Simanton and Renard, 1982) also has shown smaller C values than previously reported for rangelands. The difference can be primarily attributed to the need to include the erosion pavement in the published C values. Erosion pavement is common to western rangeland and should be considered as an integral part of the erosion process in the Southwest. Including the pavement as part of the overall percent cover significantly decreases the C value.

Table 3. C-Value Comparison

Plot No.	R = 30 Calibrated C	R = 20 Calibrated C	USDA "C" Value
Travessilla	0.01	0.02	0.45
Buckle	0.03	0.05	0.45
Buckle	0.03	0.04	0.45
Spoil	0.03	0.04	0.45

The need for long time periods to obtain both an average R and C value has been cited by many researchers (e.g., Smith and Wischmeier, 1957). A data analysis by Dissmeyer and Foster (1984) suggested a minimum of 10 years of data for determining a satisfactory R value. Simanton and Renard (1982) advise at least four years of data collection to determine a satisfactory C and K value. Further investigations are needed in the area of C-factor evaluation on rangeland and guidelines need to be established for measuring the effect of erosion pavement.

K-Factor Evaluation

The soil erodibility nomograph provides a simple means of combining soil parameters to estimate erodibility. At the mine site, K estimates ranged from 0.17 for the disturbed spoil sites to 0.37 for the Buckle soils. Travessilla soils had an intermediate value of 0.20. Even though more data are needed before these values can be considered conclusive, the nomograph values were not significantly different from previously reported values (USDA, 1978). See Table 4.

Research by Simanton, et al. (1980) has shown that if erosion pavement is considered as part of the C-factor, the use of the soil erodibility nomograph is suitable for estimation of K values for most rangeland conditions. Most researchers consider erosion pavement and large rock fragments as an integral part of the C value and use the nomograph to evaluate the K-factor. As mentioned previously, this may introduce error into the overall USLE calculation because of the qualitative aspect of erosion pavement measurements. By contrast, the erosion pavement could be considered as part of the K-factor. If this is done, the estimation of this parameter is made more difficult, because the soil erodibility nomograph fails to address rock fragments larger than 2.0 mm. Clearly, there is a need for explicit guidelines to quantify the effects of erosion pavement. Specific guideline should better define both the C- and K-factors for rangeland conditions.

Table 4. Soil Characteristics and K-Factors

Plot No.	Soil Texture	Structure	% Organic Matter	Permeability	K-Factor
1	Sandy-silt loam	Medium granular	<1	Slow to moderate	.47
2	Sandy loam	Moderate coarse	<1	Moderate	.32
3	Sandy-clay loam	Moderate crumb	<1	Moderate to rapid	.57
4	Sandy-clay loam	Moderate crumb	<1	Moderate	.50

At the La Plata site, erosion pavement was not measured directly, either as part of the K or C values, but rather its effects were "lumped" into the back-calculated C value. By doing this, the problem of evaluating the effects of erosion pavement was avoided and enabled the K value to be estimated using the erodibility nomograph.

The accuracy of the K-factor is of particular concern in comparing pre-mined soils to post-mined soils. In many cases, the K value has been assumed to be constant for both conditions, but soils that have been moved, mixed, or otherwise disturbed, may, and indeed do, undergo a change in erodibility. This is primarily due to changes in soil structure. For this reason, the K value for the pre-mined soil may not be the same as for the post-mined soil. Moreover, estimating K values for post-mined soils often is difficult because conditions continuously change with time until stable conditions are established. In such cases, the nomograph proves to be a relatively simple and economic method for evaluating the changes in the K value for post-mined soils until a steady-state is reached.

Precipitation Model

The two parameter gamma distribution was found to fit the actual distribution of number of storm events per year equal to or greater than 0.30 in. at Farmington (Figure 5; Table 5). The PDF (summed later) for the gamma distribution is:

$$f(x) = \frac{\lambda^n x^{n-1} e^{-\lambda x}}{k(n)} \tag{7}$$

In this distribution, x is the number of storms per year greater than 0.30 in., n is the shape parameter, lambda (λ) is the scale parameter, and k(n) is the gamma function. A gamma generator, originally written by Long (1984), was used to determine the gamma function.

Table 5. K-S Test for Gamma Distribution

Theoretical CDF	Actual CDF	Difference
0.003	0.111	0.108
0.074	0.388	0.382
0.289	0.611	0.322
0.566	0.770	0.212
0.790	0.880	0.098
0.929	0.990	0.070

The exponential distribution was found to fit the distribution of precipitation per event (Figure 6; Table 6). The PDF for the exponential distribution is:

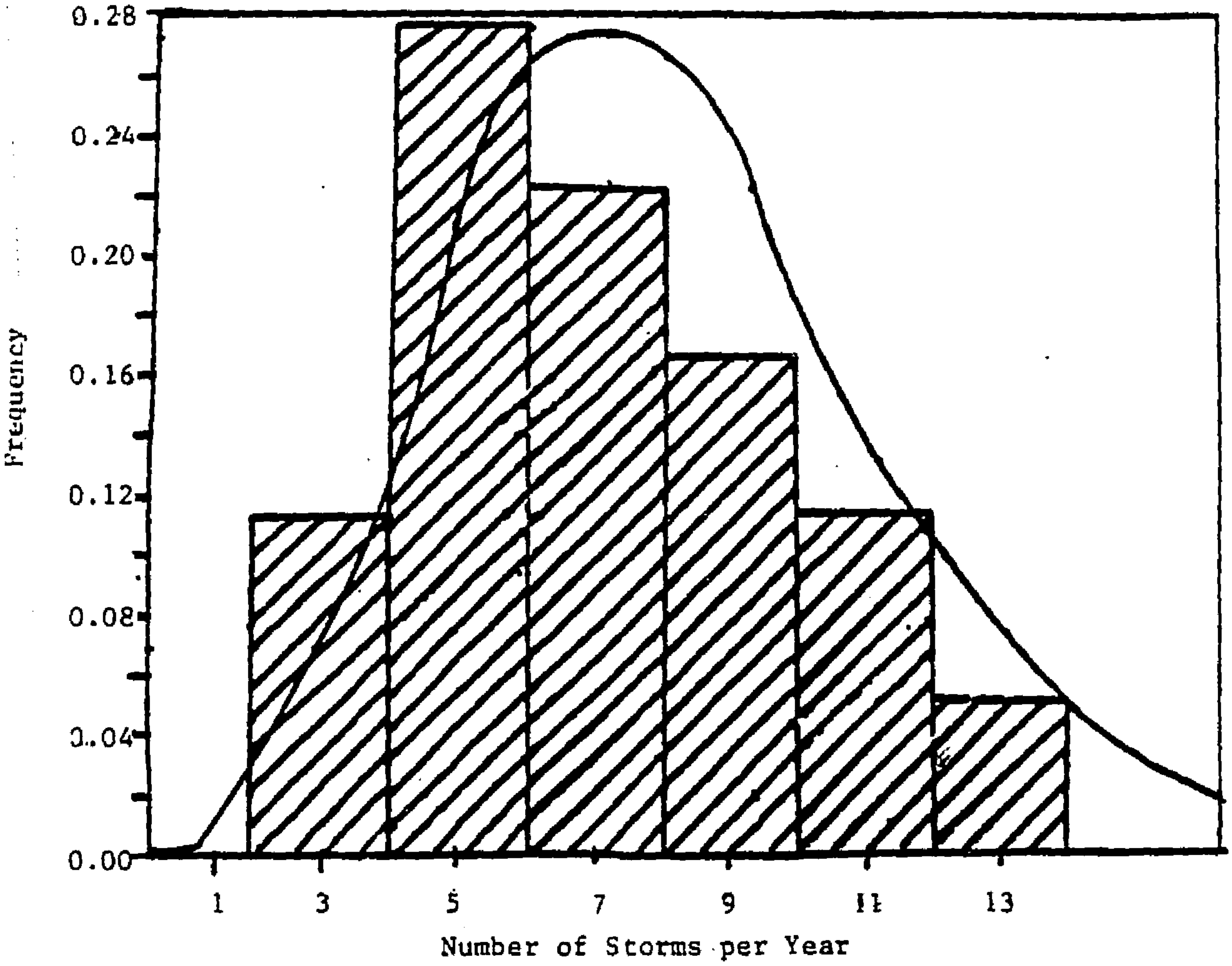

Figure 5. Number of Storms per Year Versus Frequency

$$f(x) = \lambda e^{-\lambda x} \tag{7}$$

where

$$\lambda = \frac{1}{\bar{x}}$$

and $\bar{x} = mean$

In this distribution, x is the precipitation per event and the mean is the actual distribution mean. Note that all parameters are estimated by the methods of moments (Benjamin and Cornell, 1970). See Table 7.

Table 6. K-S Test for Exponential Distribution

Theoretical PDF	Actual PDF	Difference
0.3934	0.3606	0.3280
0.6321	0.5901	0.0419
0.7768	0.7868	0.0101
0.8646	0.8524	0.0122
0.9179	0.9016	0.0162
0.9502	0.9508	0.0006
0.9698	0.9601	0.0138
0.9816	0.9836	0.0090
0.9888	0.9991	0.0110
0.9932	0.9999	0.0063

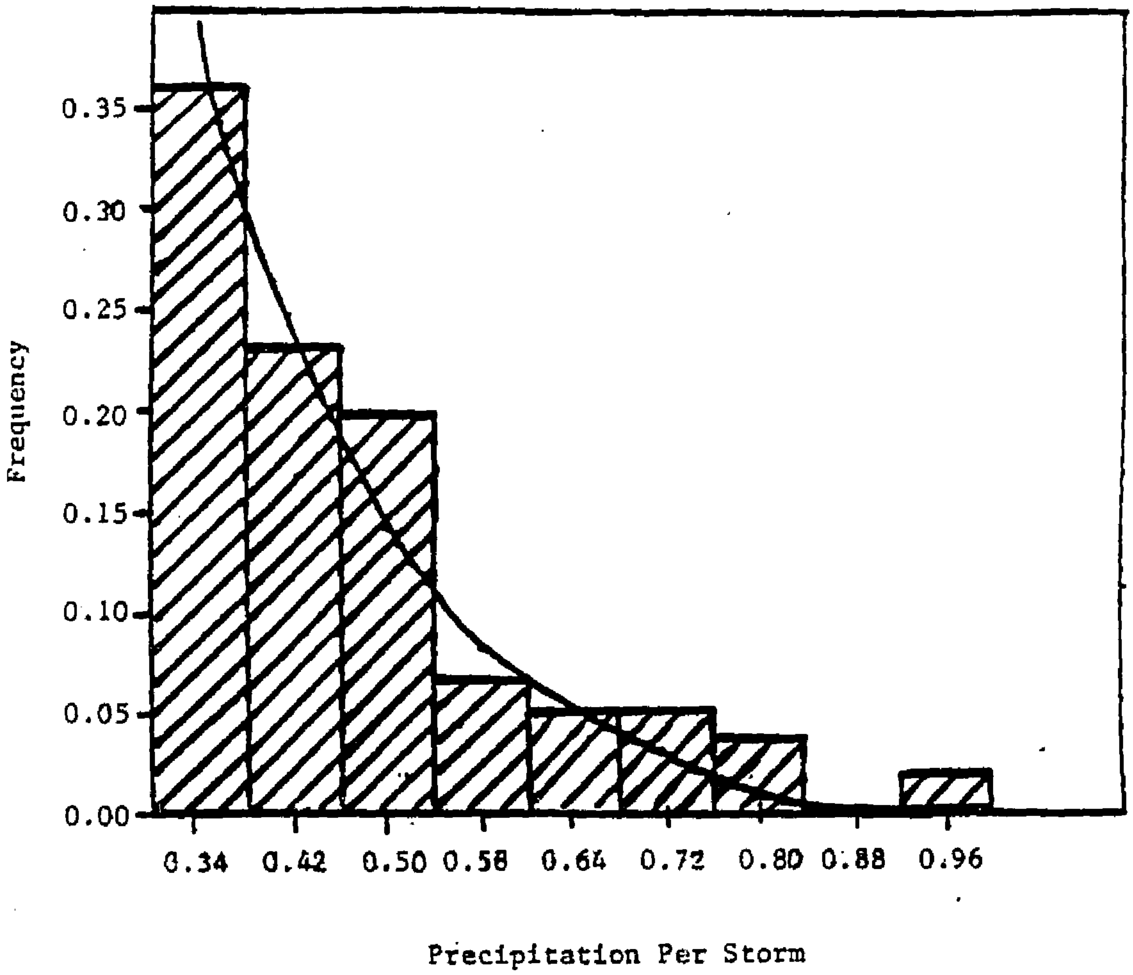

Figure 6. Precipitation per Storm Event Versus Frequency

Table 7. Distribution Parameters and Values

Distribution	Parameter	Value
Gamma (no. of storm events/yr)	Mean	8.20
	Variance	3.28
	Lambda	2.50
	n	6.25
Exponential (precipitation/ storm event)	Mean	0.16
	Variance	0.03
	Lambda	6.25

Erosion Loss Simulation

The erosion loss model generated reasonable results for the conditions at the La Plata mine site. The plots with Travessilla soil showed the least amount of erosion and the disturbed spoil plots produced the greatest amount of sediment. Approximate straight line fitted probabilities for a given soil's loss rate are shown in s 7, 8, and 9. Table 8 summarizes these results. Several factors can account for variations in loss rates among the soil types.

First, Travessilla soils are well drained, have a small percentage of silt, and occurred on fairly gentle slopes. The additive effects of these characteristics are the most likely explanation for the low soil loss rates. Second, the relatively high erosion rates on the disturbed spoil plots can be attributed to the lack of soil structure, low permeability rates, lack of cover, and the steepest slopes of all the plots. The Buckle soils generally showed intermediate USLE values when compared to the other two soil

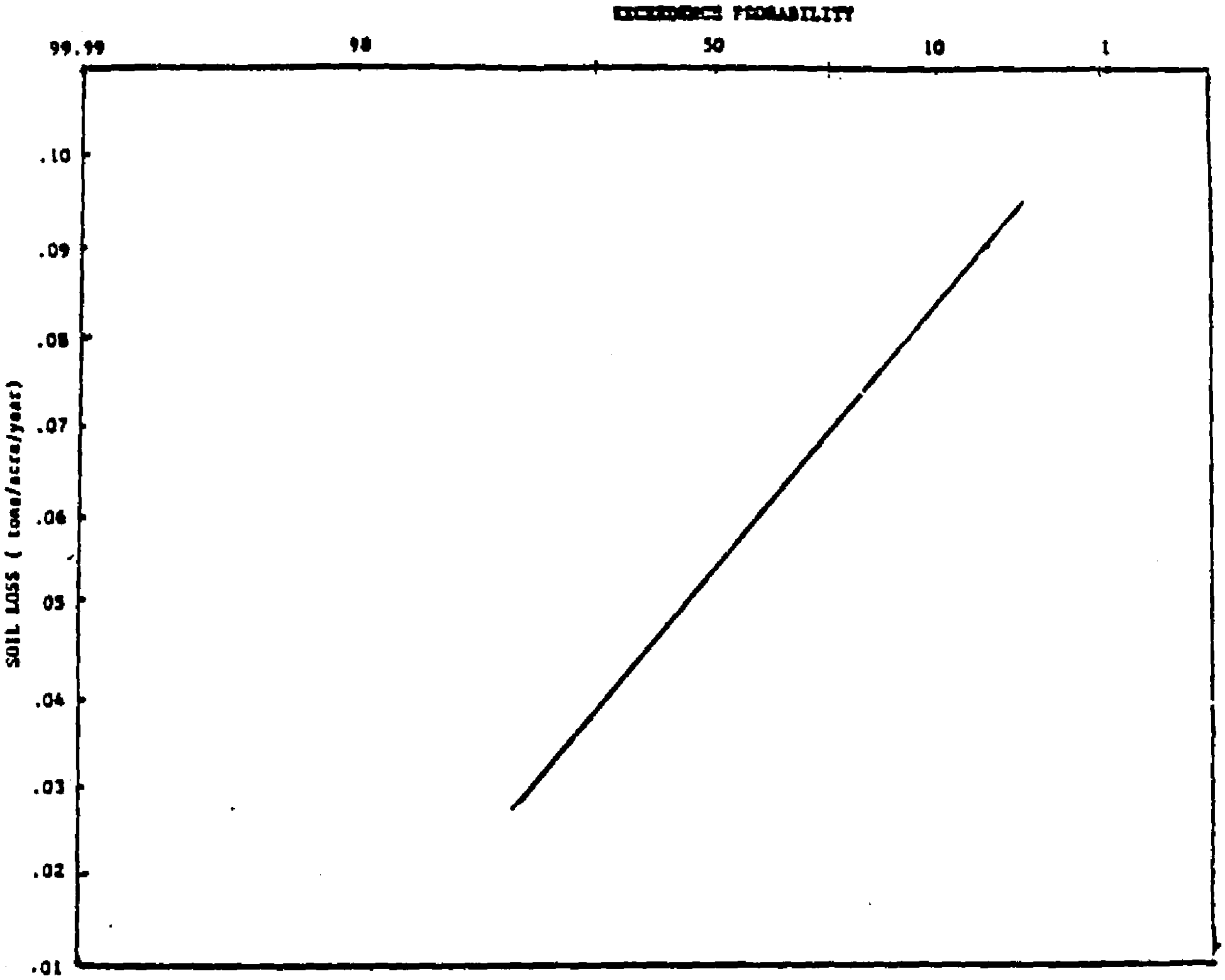

Figure 7. Exceedence Probability Versus Soil Loss for Travessilla Soil.

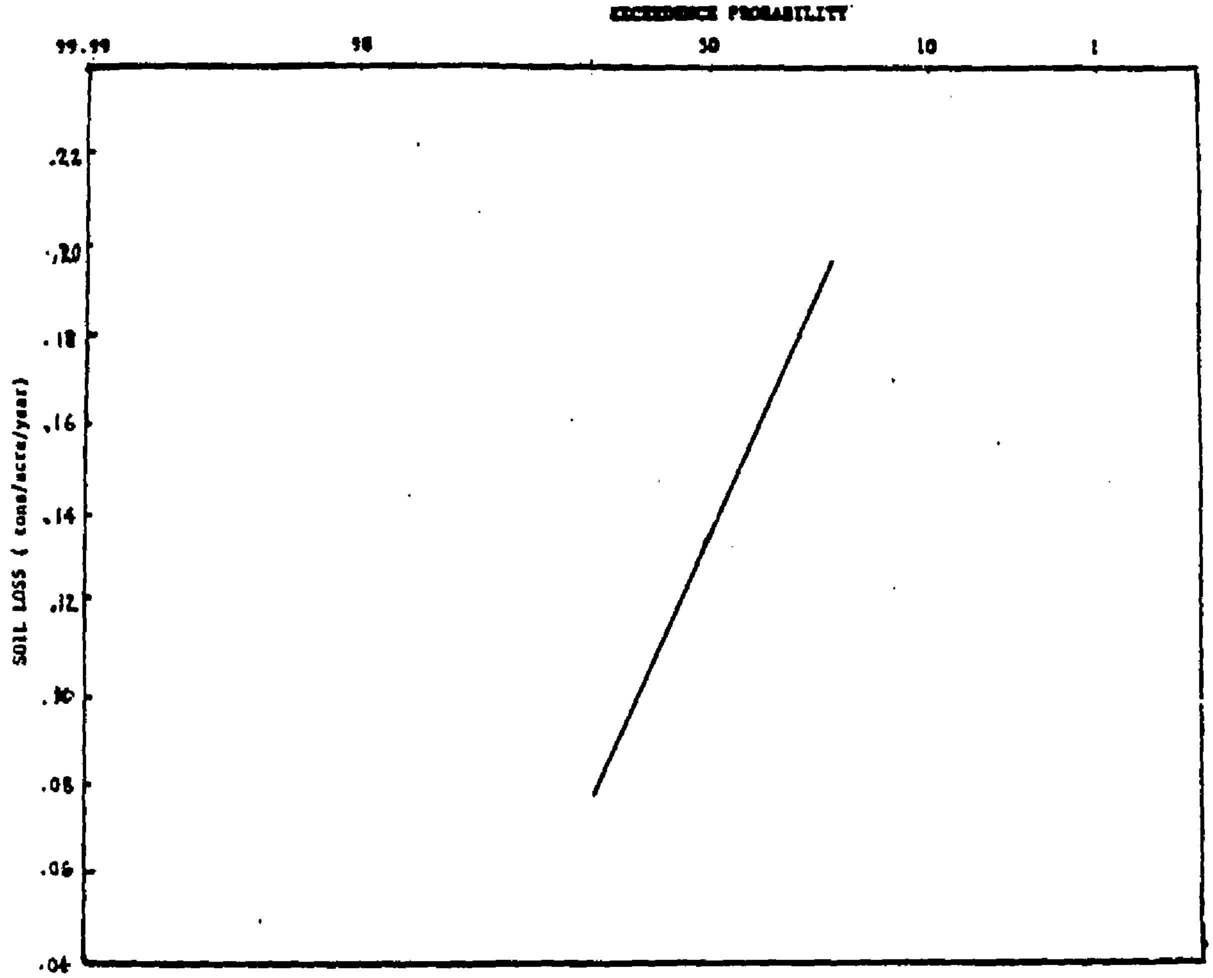

Figure 8. Exceedence Probability Versus Soil Loss for Buckle Soil.

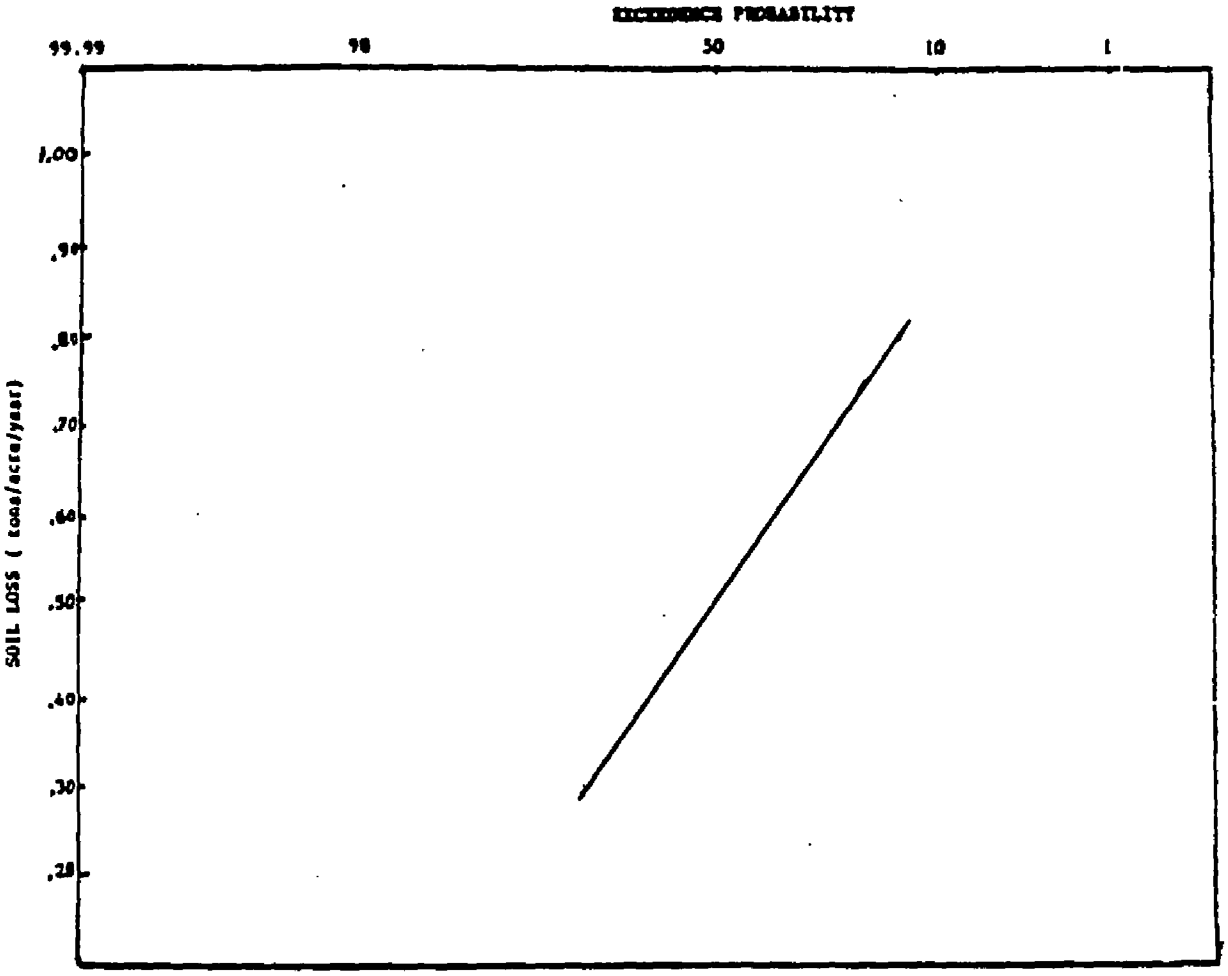

Figure 9. Exceedence Probability Versus Soil Loss for Disturbed Spoil.

groups, therefore, it is not surprising to obtain intermediate soil loss rates for the Buckle plots.

There are several areas for improving the erosion model. The fact that the erosion simulation neglects the effects of antecedent moisture conditions is an obvious shortcoming. Antecedent moisture affects the permeability rate, water holding capacity, and soil erodibility of the soil. Because of the lack of field data to quantify the effects of antecedent moisture, the model does not integrate antecedent moisture into the erosion process. Another drawback of the simulation is that rainfall data used in designing the model was not taken directly at the mine site, but rather at the University of New Mexico weather station, located at Farmington, approximately 25 miles south of the mine. Differences in storm magnitude would be expected because of the 1500 foot elevation difference between the weather station and the mine site. Because of the lack of rainfall data at the research site, the only intent of the model was to present a methodology for erosion loss predictions. With the addition of rainfall data from the mine site itself, refinement of the distributions used in the precipitation generation could be expected.

Table 8. Erosion Loss Simulation Results

	Probability of Exceedance Tons/Acre/Year		
Soil Type	< 25%	< 50%	< 75%
Travessilla	0.040	0.55	0.070
Buckle	0.08	0.14	0.19
Spoil	0.32	0.52	0.70

The erosion model increases the flexibility of the USLE in handling the stochastic nature of rainfall in the Southwest. The contribution of large storms can be taken into account and this improves the estimation of R values for rangeland conditions. Because the C-factor is based on the generated yearly R-factor, improvements in the R estimation also improves the C-factor. As more data pertaining to R, C, and K are collected, adjustments can easily be made in the program.

CHAPTER 6

CONCLUSIONS

The main objective of the study at La Plata was to develop pre-mining soil loss rates which could be compared with post-mining erosion rates. This information would make it possible to assess the effectiveness of future reclamation practices.

Assessing pre-mining erosion rates required that the Universal Soil Loss Equation be calibrated for the research site. Calibration was achieved by back-calculating the C-factor in the USLE, using actual soil loss measurements and an adjusted R-factor. The R-factor was computed using a multiple regression equation between EI and storm size for Walnut Gulch, Arizona. The results obtained were dependent on only two years of on-site soil loss data, and this is too short a time to conclusively estimate the USLE C-factors. Further tests will be needed to refine the calibration procedure.

From this study, the following conclusions can be made:

1. The USLE, as presented in original form by Wischmeier and Smith (1978), did not adequately predict soil loss at the La Plata mine site, but must be modified for western rangeland conditions.
2. R-factor evaluation can be performed adequately using a multiple regression relation between EI and storm size. With additional data, refinements of the relation can be made.

3. Back-calculating the C-factor is a satisfactory method for predicting C values. This technique effectively calibrates the USLE for rangeland conditions. Early observations indicate that existing published C-values are inadequate for western rangeland conditions.

4. The soil loss computer simulation increases the flexibility of the USLE method. It accounts for the stochastic precipitation patterns appropriate to the La Plata mine area. This increased flexibility improves the USLE as a soil loss predictor for western rangeland.

5. The simulated soil loss appears to be a feasible means of evaluating pre-mined soil loss rates to be compared to post-mine rates.

6. The ability of the fabric dams to trap all the eroding sediment is questionable, therefore, there is a definite need to improve the dams and to examine other methods for collecting sediment data.

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