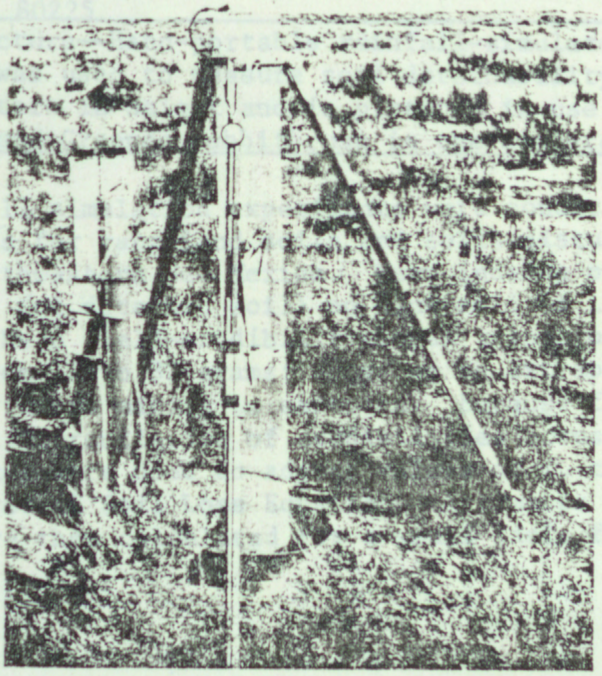
ERODIBILITY OF SELECTED SOILS AND ESTIMATES OF SEDIMENT YIELD IN THE SAN JUAN BASIN, NEW MEXICO



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES INVESTIGATIONS 81-44

NTIS NO. PB82 195744

Paper copy : $7.50
Microfiche : $4.00

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. 81-44	2.	3. Recipient's Accession No.

4. Title and Subtitle

ERODIBILITY OF SELECTED SOILS AND ESTIMATES OF SEDIMENT YIELDS IN THE SAN JUAN BASIN, NEW MEXICO

5. Report Date
Approved 7/15/81

6.

7. Author(s)
Rebecca M. Summer (Simons and Li Associates Fort Collins, Colo. 80526)

8. Performing Organization Rept. No.
WRI 81-44

9. Performing Organization Name and Address

U.S. Geological Survey, Water Resources Division
Box 25046 MS420
Denver Federal Center
Lakewood, Colorado 80225

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

U.S. Geological Survey, Water Resources Division
Box 25046 MS 420
Denver Federal Center
Lakewood, Colorado 80225

13. Type of Report & Period Covered
Interim

14.

15. Supplementary Notes Cover picture--Hand-portable rainfall-simulator infiltrometer developed by McQueen (1963), which was used to measure soil detachability in this study. The infiltrometer is about 2 meters in height and is pictured in use on a mesa covered with big sagebrush, snakeweed, and Greenes rabbitbrush in the Kimbeto study area.

16. Abstract (Limit: 200 words)

Onsite rainfall simulation experiments were conducted to derive field-erodibility indexes for rangeland soils and soils disturbed by mining in coal fields of northwestern New Mexico. Mean indexes on rangeland soils range from 0 grams (of detached soil) on dune soil to 121 grams on wash-transport zones. Mean field-erodibility-index values of soils disturbed by mining range from 16 to 32 grams; they can be extrapolated to nearby coal fields where future mining is expected. Because field-erodibility-index data allow differentiation of erodibilities across a variable landscape, these indexes were used to adjust values of K, the erodibility factor of the Universal Soil Loss Equation. Estimates of soil loss and sediment yield were then calculated for a small basin following mining.

17. Document Analysis a. Descriptors

Soil erosion, impact (rainfall), land reclamation, small watersheds (basin)

b. Identifiers/Open-Ended Terms

Field-erodibility index, Universal Soil Loss Equation, rainfall simulator, New Mexico

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	Unclassified	33
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ERODIBILITY OF SELECTED SOILS AND ESTIMATES OF SEDIMENT YIELDS IN THE SAN JUAN BASIN, NEW MEXICO

U.S. GEOLOGICAL SURVEY

Water Resources Investigations 81-44

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ERODIBILITY OF SELECTED SOILS AND ESTIMATES OF SEDIMENT YIELDS IN THE SAN JUAN BASIN, NEW MEXICO

By Rebecca M. Summer

U.S. GEOLOGICAL SURVEY

Water Resources Investigations 81-44

Denver, Colorado

1981

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to

U.S. Geological Survey
Water Resources Division
Mail Stop 420, Box 25046
Denver Federal Center
Denver, Colorado 80225

For sale by

National Technical Information
Service
U.S. Department of Commerce
Springfield, VA 22161

CONTENTS

ILLUSTRATIONS

TABLES

ERODIBILITY OF SELECTED SOILS AND ESTIMATES OF SEDIMENT YIELDS IN THE SAN JUAN BASIN, NEW MEXICO

by

Rebecca M. Summer

ABSTRACT

Onsite rainfall-simulation experiments were conducted to derive field-erodibility indexes for rangeland soils and soils disturbed by mining in coal fields of northwestern New Mexico. Mean indexes on rangeland soils range from 0 grams (of detached soil) on dune soil to 121 grams on wash-transport zones. Mean field-erodibility-index values of soils disturbed by mining range from 16 to 32 grams; they can be extrapolated to nearby coal fields where future mining is expected. Because field-erodibility-index data allow differentiation of erodibilities across a variable landscape, these indexes were used to adjust values of K, the erodibility factor of the Universal Soil Loss Equation. Estimates of soil loss and sediment yield were then calculated for a small basin following mining.

INTRODUCTION

Soil erodibility is an inherent physical property indicating the susceptibility of soil to detachment by raindrop splash. The purpose of this study was to collect soil-erodibility data to predict sediment yield from coal-mining lands in northwestern New Mexico. Erodibility was determined by measuring onsite soil detachment and dispersion, and deriving relative erodibilities of selected soils in three control basins. A portable rainfall simulator was used in determining erodibility indexes for a variety of rangeland soils underlain by economic coal deposits and for soils disturbed by mining. These indexes were used as base data to estimate soil loss and sediment yield from a basin where coal mining is planned. This study was done in support of a project to calibrate and improve a precipitation-runoff-sediment yield model for the Ah-shi-sle-pah Wash basin (fig. 1).

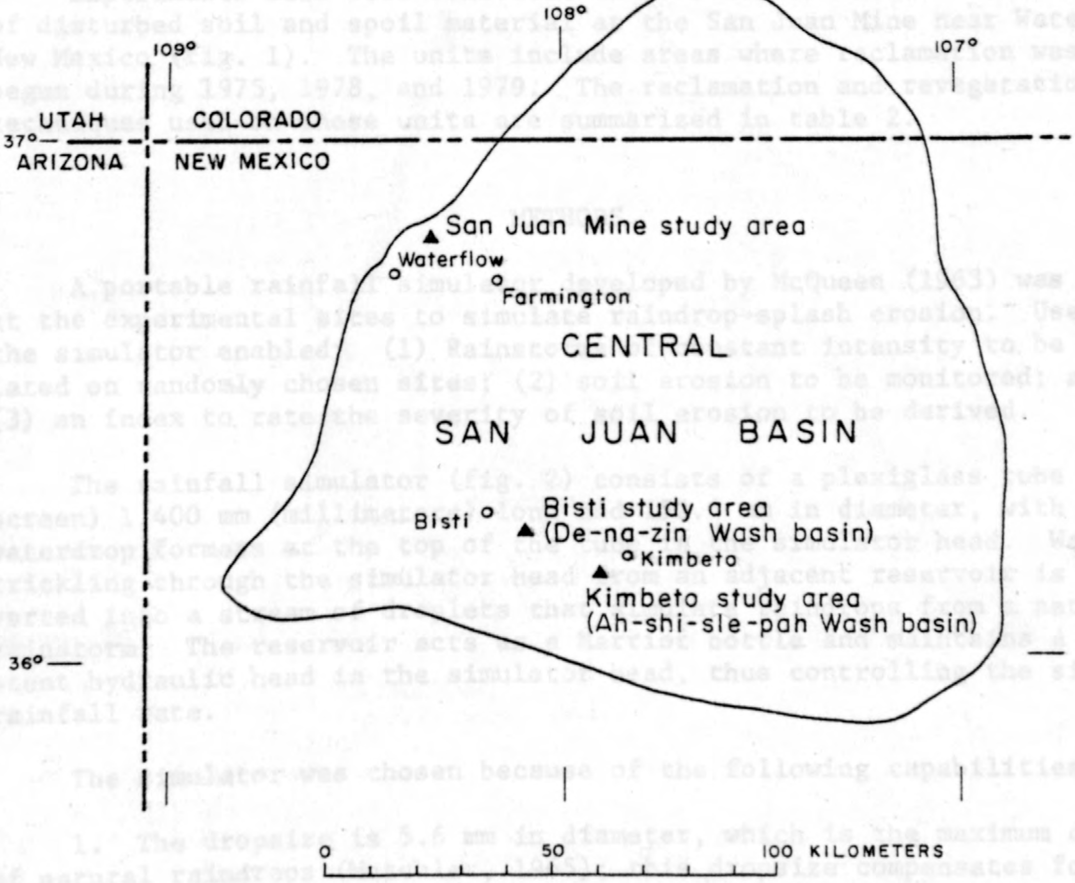


Figure 1.--Location of study areas.

STUDY AREAS

Soil-erodibility data were collected for rangeland soils at two locations in the San Juan Basin: At the Kimbeto study area (near the Kimbeto Settlement) in the 20.4-km^2 (square kilometer) Ah-shi-sle-pah Wash basin, approximately 65 km (kilometers) southeast of Farmington, New Mexico, and at the Bisti study area in De-na-zin Wash basin, approximately 55 km south of Farmington (fig. 1). These areas are underlain by commercial coal deposits found in the Fruitland Formation of Late Cretaceous age, which consist of interbedded coal, mudstone, sandstone, and shale. Experimental sites were located on different soil-landscape units composed of various soil types and their associated vegetation and landforms (table 1). The sites were selected at random within a few meters of a site on each unit where soil sampling had been done for a previous study (R. F. Miller, U.S. Geological Survey, oral commun., 1979). Soil types were differentiated on the basis of soil properties, particularly horizon development, texture, and structure.

Experiments also were conducted at reclamation units on a mixture of disturbed soil and spoil material at the San Juan Mine near Waterflow, New Mexico (fig. 1). The units include areas where reclamation was begun during 1975, 1978, and 1979. The reclamation and revegetation techniques used on these units are summarized in table 2.

METHODS

A portable rainfall simulator developed by McQueen (1963) was used at the experimental sites to simulate raindrop-splash erosion. Use of the simulator enabled: (1) Rainstorms of constant intensity to be simulated on randomly chosen sites; (2) soil erosion to be monitored; and (3) an index to rate the severity of soil erosion to be derived.

The rainfall simulator (fig. 2) consists of a plexiglass tube (wind screen) 1,400 mm (millimeters) long and 152.4 mm in diameter, with wire waterdrop formers at the top of the tube in the simulator head. Water trickling through the simulator head from an adjacent reservoir is converted into a stream of droplets that simulate raindrops from a natural rainstorm. The reservoir acts as a Marriot bottle and maintains a constant hydraulic head in the simulator head, thus controlling the simulated rainfall rate.

The simulator was chosen because of the following capabilities:

1. The dropsize is 5.6 mm in diameter, which is the maximum diameter of natural raindrops (Mutchler, 1965); this dropsize compensates for the shorter fall height of the waterdrops compared to raindrops by increasing the energy of impact at the surface.
2. The simulator can be adjusted to reproduce different peak intensities of natural rainstorms.

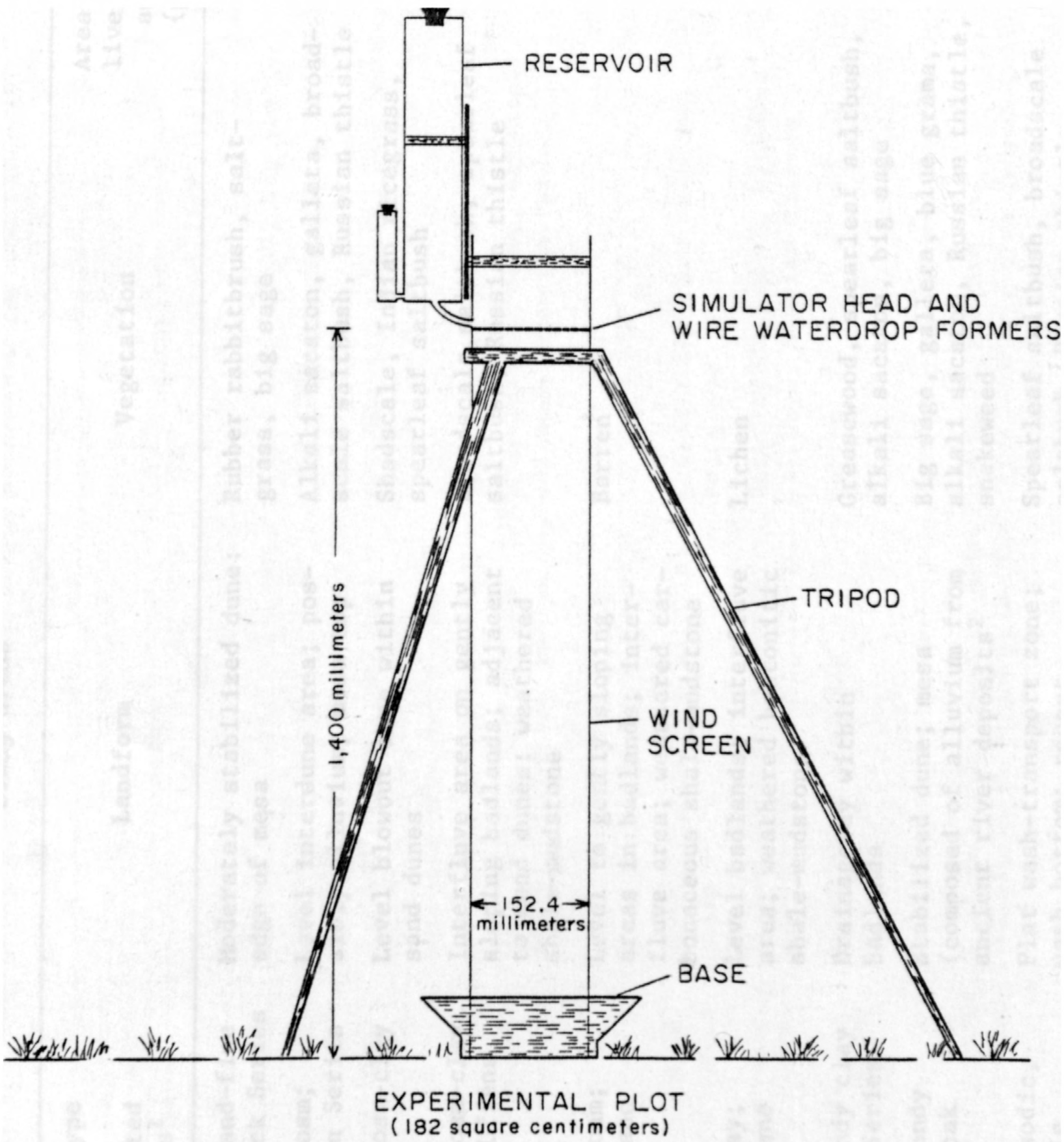


Figure 2.--Portable rainfall simulator used during study.

Table 1.--*Description of soil-landscape units at Kimbeto (K) and Bisti (B) study areas*

Soil-landscape unit	Soil type and suggested series[1]	Landform	Vegetation	Area covered by live vegetation and mulch (percent)
K-1	Loamy fine sand-fine sand; Shiprock Series	Moderately stabilized dune: edge of mesa	Rubber rabbitbrush, salt-grass, big sage	42
K-2	Fine sandy loam; sodic; Avalon Series	Level interdune area; possibly alluvium; mesa top	Alkali sacaton, galleta, broad-scale saltbush, Russian thistle	35
K-3	Silty clay loam-clay Uffen Series	Level blowout zone within sand dunes	Shadscale, Indian ricegrass, spearleaf saltbush	18
K-4	Silty clay loam-clay; sodic; Muff-Uffens Series	Interfluve area on gently sloping badlands; adjacent to sand dunes; weathered shale-mudstone	Broadscale saltbush, spearleaf saltbush, Russian thistle	8
K-5	Silty clay loam; sodic; Huerfano Series	Level to gently sloping areas in badlands; interfluve area; weathered carbonaceous shale-mudstone	Barren	0
K-6	Clay loam-clay; sodic; Huerfano Series	Level badlands; interfluve area; weathered bentonitic shale-mudstone	Lichen	17
K-7	Clay loam-sandy clay loam; Uffen Series	Drainageway within badlands	Greasewood, spearleaf saltbush, alkali sacaton, big sage	25
K-8	Loamy fine-sandy loam sand; Doak Series	Stabilized dune; mesa (composed of alluvium from ancient river deposits[2]	Big sage, galleta, blue grama, alkali sacaton, Russian thistle, snakeweed	30
K-9	Sandy loam, sodic, Turley-Stumble Series	Flat wash-transport zone; wash bottom; recent alluvium	Spearleaf saltbush, broadscale saltbush, Russian thistle	9

Table 1.--*Description of soil-landscape units at Kimbeto (K) and Bisti (B) study areas*--Continued

Soil-landscape unit	Soil type and suggested series[1]	Landform	Vegetation	Area covered by live vegetation and mulch (percent)
K-10	Fine sand; Sheppard Series	Moderately stabilized dune; elongate ridge adjacent to channel	Rubber rabbitbush, big sage, saltgrass	18
K-11	Silt loam-clay loam; sodic; Avalon Series	Shallow wash bottom; possibly alluvial-eolian deposits from dunes and badland outcrops	Greasewood, galleta, blue grama, alkali sacaton	37
K-12	Loamy sand-sandy clay loam; sodic; Turley-Stumble Series	Shallow wash bottom; possibly alluvium and eolian deposits from shale outcrops; in situ-weathered shale and mudstone	Spearleaf saltbush, broadleaf saltbush, Russian thistle	14
B-1	Fine sand-loamy fine sand; Sheppard Series	Stabilized dune on alluvial plain	Rubber rabbitbush, big sage saltgrass	29
B-2	Clay loam; sodiac; Stumble-Turley Series	Flat wash-transport zone; wash bottom; recent alluvium	Spearleaf saltbush, broadleaf saltbush, Russian thistle	3
B-3	Weathered shale; incipient soil; silty clay loam; badlands	Steep shaly slopes of badlands	Barren	

[1]Suggested series name assigned to each unit based on data from M. H. Mustard and R. F. Miller (U.S. Geological Survey, written commun., 1979), L. M. Shown (U.S. Geological Survey, oral commun., 1978, 1979), and U.S. Soil Conservation Service (1977a).

[2]U.S. Geological Survey (1976).

Table 2.--*Description of reclamation units studied at San Juan Mine*

Reclamation unit	Year reclamation began	Soil type	Landform and degree of slope	Reclamation techniques	Vegetation cover (percent)
C	1979	Silt loam-sandy loam	Level to gently sloping fields (0-5°)	300 millimeters of topsoil; mulched (prairie grass); no irrigation; nitrogen and potassium fertilizer.	0
D	1978	Silt loam-sandy loam	Level to gently sloping fields (0-10°)	200 millimeters of topsoil; mulched; seeded with grasses and forbs; irrigated with 360 millimeters of water during first year; nitrogen and potassium fertilizer.	77
E	1975	Silt loam-loam	Level to gently sloping fields (0-10°)	150 millimeters of topsoil; mulched; seeded with shrubs (fourwing saltbush sage), grasses and forbs; irrigated with 360 millimeters of water during first year; irrigated with 100 millimeters of water during second year; nitrogen and potassium fertilizer.	58

3. Measurements are as accurate and consistent as those obtained from other infiltrometer systems, such as those used by the U.S. Soil Conservation Service and the U.S. Forest Service. McQueen (1963) compared the accuracy of the simulator with the "Rocky Mountain Type F infiltrometer" (Dortignac, 1951) on experimental sites in the montane zone of the Rocky Mountains in Colorado. No significant differences in infiltration rates were measured by these instruments at 16 sites.

4. The simulator is portable and requires only one or two people for operation.

5. There is relatively small water requirement of 6 to 8 liters per experiment.

6. Installation is simple and rapid.

7. The simulator is stable and can be operated under adverse conditions, such as windy, rainy weather or on steep slopes.

Three or four replicate simulation experiments at different sites were conducted on most units at a standard application rate of 140 mm/h (millimeters per hour) for 1 hour (see table 3). This rate simulates the energy equivalent of a natural rainstorm having a peak intensity of 21 mm/h (Laws, 1941; Laws and Parson, 1943), which occurs on the average of once every 5 years in the study area (Miller and others, 1973). If infiltration rates of various soils were not exceeded, intensities were increased incrementally to as much as 500 mm/h. Additional information about instrumentation and the relationship between simulated versus natural rainfall are discussed by Summer (1980).

Sediment detached by raindrop splash was collected, ovendried, and weighed, yielding an erodibility index based on the mass of detached soil per unit area per unit time [(g/182 cm^2)/h] (grams per 182 square centimeters per hour) at the given rainfall rate. This field-erodibility index (FEI) defines erodibility in terms of detachability, which is an attribute of soil consistency that is a measure of the soil's degree of cohesion and adhesion (Templin, 1947).

EXPERIMENTAL RESULTS

Erodibility of rangeland soils

Mean values of FEI determined on each soil-landscape unit at the Kimbeto and Bisti study areas are listed in table 3. Comparisons of the FEI values (fig. 3) indicate a continuum of erodibilities occurring across the landscape. The range of indexes was arbitrarily divided into three erodibility groups: Least, moderate, and most, to compare distribution and relative differences between soils.

Least erodible group

No runoff or detachment occurred on active sand dunes at sites on soil-landscape units K-10 and B-1 (figs. 3 and 4) under an intensity of

Table 3.--*Results of rainfall-simulation experiments at Kimbeto (K) and Bisti (B) study areas*

Soil-landscape unit	Number of experimental sites	Simulated intensity (millimeters per hour)	Mean erodibility index ±1 standard deviation (grams per 182 square centimeters per hour)
K-1	3	[1]160-170	30 ± 11
K-1	3	140	8 ± 3
K-2	4	140	16 ± 7
K-3	3	140	54 ± 14
K-4	4	140	45 ± 11
K-5	3	140	20 ± 9
K-6	3	140	11 ± 4
K-7	4	140	31 ± 11
K-8	4	140	21 ± 6
K-9	3	140	50 ± 18
K-10	3	140	0
K-10	1	[2]180	0
K-10	1	[2]200-260	0
K-10	1	[2]500	0 (prewet)[3]
K-11	4	140	29 ± 4
K-12	3	140	121 ± 24
B-1	3	140	0
B-1	1	[2]140-400	49 (prewet)[3,4]
B-2	4	140	69 ± 26
B-3	2	140	23 ± 4

[1]Greater rates were experimented with before deciding upon the standard rate of 140 millimeters per hour.

[2]Greater intensity applied to site if FEI = 0 when intensity of 140 millimeters per hour was used.

[3]Site was wetted with several liters of water before experiment because FEI = 0 when intensity of 140 millimeters per hour was applied on natural (unwetted) site.

[4]Simulator operation was only 20 minutes.

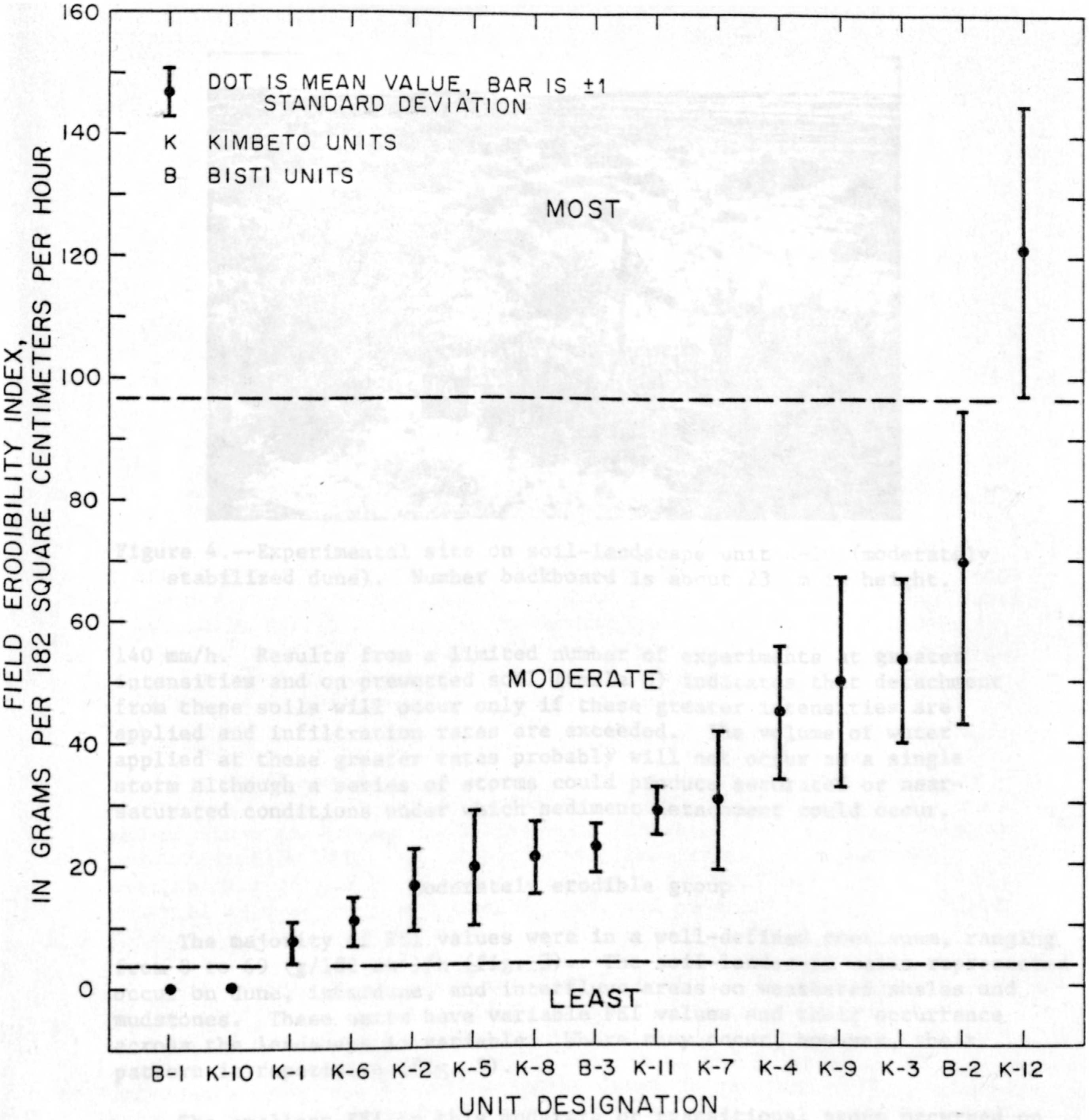


Figure 3.--Comparisons of mean field-erodibility-index values on undisturbed soils (based on 50 sites).

Figure 4.--Experimental site on soil-landscape unit K-10 (moderately stabilized dune). Number backboard is about 23 cm in height.

140 mm/h. Results from a limited number of experiments at greater intensities and on prewetted soil (table 3) indicates that detachment from these soils will occur only if these greater intensities are applied and infiltration rates are exceeded. The volume of water applied at these greater rates probably will not occur as a single storm although a series of storms could produce saturated or near-saturated conditions under which sediment detachment could occur.

Moderately erodible group

The majority of FEI values were in a well-defined continuum, ranging from 8 to 69 (g/182 cm^2)/h (fig. 3). The soil-landscape units represented occur on dune, interdune, and interfluve areas on weathered shales and mudstones. These units have variable FEI values and their occurrence across the landscape is variable. Where they occur, however, their pattern is repetitive (fig. 5).

The smallest FEI in this moderate or transitional group occurred on partly stabilized dunes (unit K-1), while slightly larger indexes occurred on finer-textured soil on gently to steeply sloping interfluve landforms (units K-6, K-2, K-5, and B-3), and on stabilized dunes (unit K-8) (fig. 6). Sandy material, such as that on unit K-1, is susceptible to detachment because of lack of cohesion, but relatively large infiltration rates and lack of ponding result in less particle detachment.

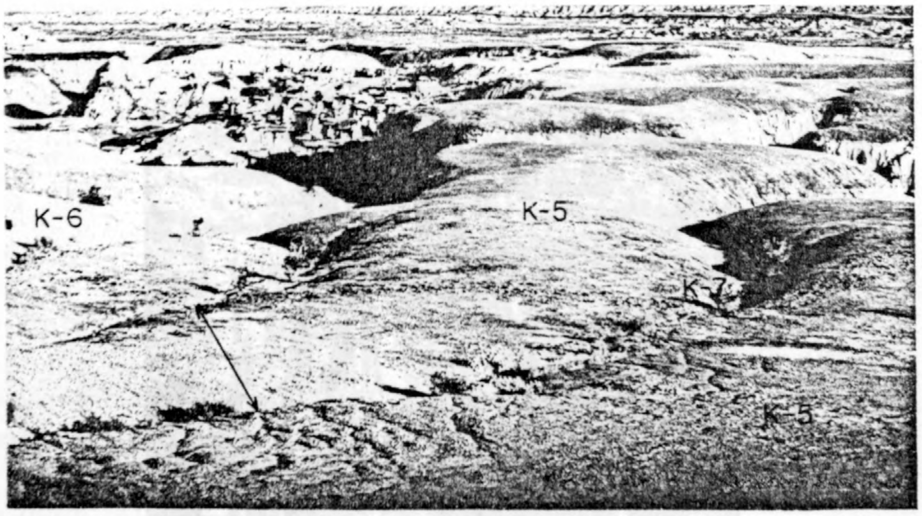


Figure 5.--Typical spatial distribution of badland soil-landscape units in the Kimbeto study area. Unit K-5 is weathered carbonaceous shale, which is barren. Unit K-6 is bentonitic shale with some lichen cover. Unit K-7 is a sparsely vegetated drainageway. The arrow in the lower left part of the photograph indicates about 2 meters distance on the ground.

The remaining soils in the moderate group having relatively large FEI values occur primarily on wash-transport zones; these are alluvial plains where the predominant transport mechanism is overland flow with some streamflow (fig. 7). Experimental results indicate that the availability of poorly aggregated alluvium and fine, silty eolian material derived from surrounding dunes are probably reasons for these relatively large erodibilities.

Differences between similar soil types found in the moderate group may be attributed to the relationships of total salinity to sodium content of the topsoil and to expanding clay. As the sodium component increases, surface sealing and ponding occur, and detachment may either increase or decrease depending on the depth of ponding at the surface. Mutchler and Hansen (1970) indicate that the energy of raindrop impact dissipates when water depth exceeds one-third the diameter of the raindrop. Expanding clay may affect detachability by causing surface cracks to close and induce ponding.

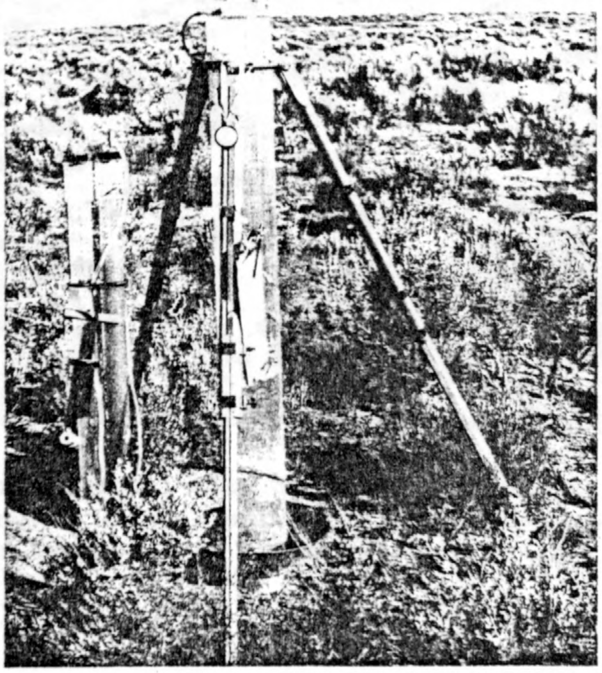


Figure 6.--Rainfall experiment using the portable rainfall simulator on soil-landscape unit K-8.

Most erodible group

The greatest detachability of rangeland soil is characteristic of soil-landscape unit K-12. Because this landform (fig. 8) is not a presently active wash-transport zone compared to unit K-9 (fig. 7), it is probable that sediment is not flushed out of the system as frequently; consequently, more deposition occurs and accumulated sediment is available for splash detachment. The large amount of detachment, as much as 145 (g/182 cm^2)/h, appears to be a function of the amount of available surface material, the apparent noncohesiveness of that material, and ponding in the cracks. Onsite observations indicate that large cracks in the soil remain open at the surface; water ponds; and sediment is splashed into the ponded water where it is temporarily suspended.

<u>Erodibility of soils disturbed by mining</u>

Rainfall-simulation experiments were conducted on three reclamation units at the San Juan Mine (fig. 9); results are summarized in table 4.

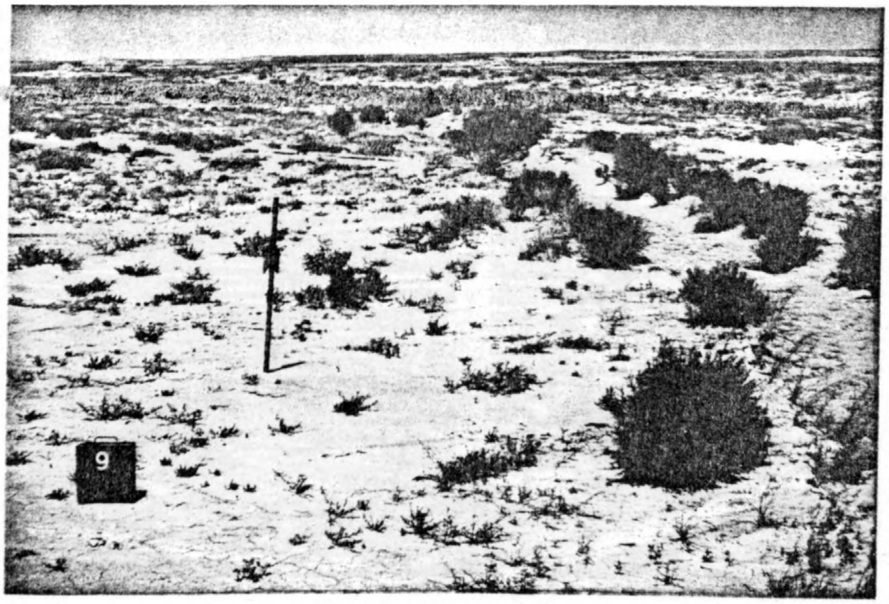


Figure 7.--An experimental site on soil-landscape unit K-9 (wash-transport zone). Line of shrubs on right-hand side defines channel bank. Number backboard is about 23 cm in height.

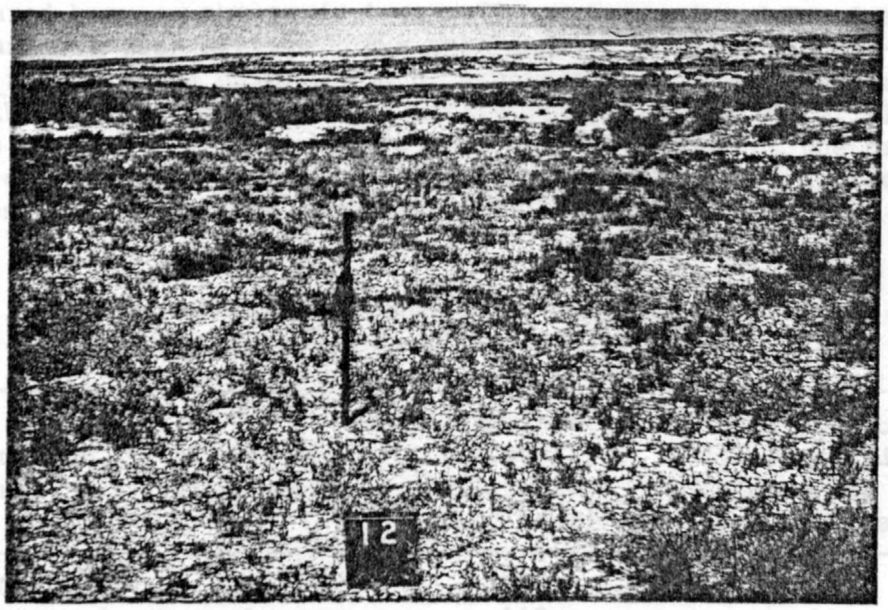


Figure 8.--An experimental site on soil-landscape unit K-12 (shallow wash bottom). Number backboard is about 23 cm in height.

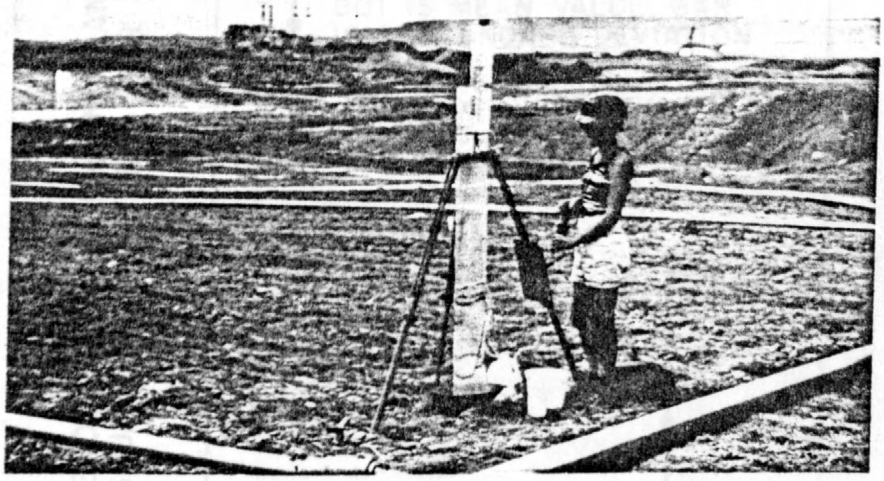


Figure 9.--Rainfall experiment using the portable rainfall simulator on reclamation unit C at the San Juan Mine (reclamation began during 1979).

As figure 10 illustrates, virtually no difference in FEI values was measured between the sandy loam soils on units C and D, although D was reclaimed 1 year earlier. The mean index for sites on unit E was twice that for sites on units C and D, probably reflecting the greater erodibility of finer-textured (silty loam and loam) material. Soils at sites on unit E also may erode more easily because of the presence of dark carbonaceous material that forms less stable aggregates than non-carbonaceous materials at sites on units C and D.

Table 4.--*Results of rainfall-simulation experiments on soils disturbed by mining at the San Juan Mine*

Reclamation unit	Number of experiments	Simulated intensity (millimeters per hour)	Mean erodibility index ±1 standard deviation (grams per 182 square centimeters per hour)
C	3	140	16 ± 5
D	3	140	19 ± 7
E	3	140	32 ± 12

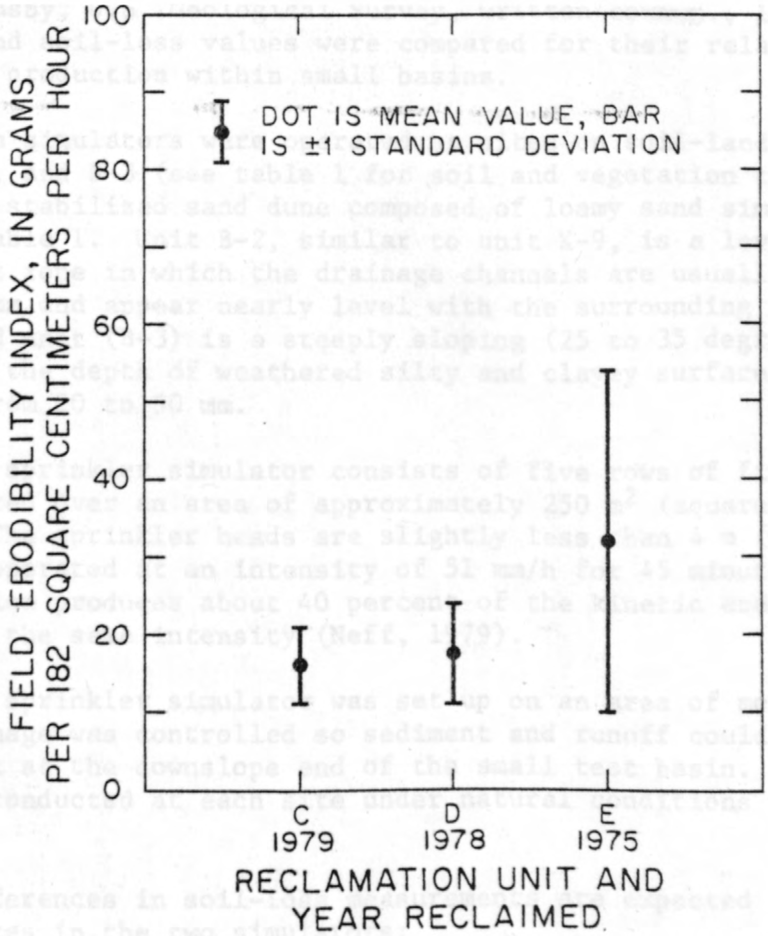


Figure 10.--Comparisons of mean field-erodibility-index values for soils disturbed by mining (based on nine experimental sites).

If similar reclamation procedures are practiced, the range of indexes at the mine reflects projected erodibilities following surface mining at the Kimbeto and Bisti areas. Comparisons between figures 4 and 10 indicate that the relative magnitude of detached sediment that can be expected on reclaimed mined land will be comparable with smaller values of FEI in the moderate erodibility group of rangeland soils; for example, units K-2 and K-8.

Portable rainfall simulator compared to a sprinkler simulator

Volumes of eroded soil generated using the portable rainfall simulator were compared with volumes generated by a larger-scale sprinkler simulator for relative magnitudes of soil loss. Simulated rainfalls were reproduced at the same experimental sites using both simulators

(G. C. Lusby, U.S. Geological Survey, written commun., 1976). FEI values and soil-loss values were compared for their relationship to sediment production within small basins.

Both simulators were operated at sites on soil-landscape units B-1, B-2, and B-3 (see table 1 for soil and vegetation types). Unit B-1 is a stabilized sand dune composed of loamy sand similar to unit K-1 in table 1. Unit B-2, similar to unit K-9, is a level wash-transport zone in which the drainage channels are usually incised less than 60 mm and appear nearly level with the surrounding alluvial plain. The third unit (B-3) is a steeply sloping (25 to 35 degrees) shaly outcrop; the depth of weathered silty and clayey surface material ranges from 20 to 50 mm.

The sprinkler simulator consists of five rows of five sprinklers distributed over an area of approximately 250 m^2 (square meters) (Neff, 1979). The sprinkler heads are slightly less than 4 m (meters) high and are operated at an intensity of 51 mm/h for 45 minutes. This combination produces about 40 percent of the kinetic energy of a natural storm of the same intensity (Neff, 1979).

The sprinkler simulator was set up on an area of more than 200 m^2 and drainage was controlled so sediment and runoff could be collected at one point at the downslope end of the small test basin. One simulation run was conducted at each site under natural conditions with no pre-wetting.

Differences in soil-loss measurements are expected from inherent differences in the two simulators:

1. Differences in plot sizes and application rates (see table 5) make comparison of the simulators difficult.
2. The sprinkler simulator causes detachment and transport of sediment by sheet and rill erosion as well as splash erosion, and it incorporates the combined effects of vegetation, topography, and soil through a test basin. Soil loss measured is a net result of the amount of material eroded minus that which has been stored or deposited before reaching the outlet point.
3. The portable rainfall simulator causes only soil detachment and reflects inherent soil properties on a site-specific basis. Soil loss measured is the amount of available detachable soil at a point within the test basin.

Comparative results of the experiments confirm these expected differences:

1. Both simulators failed to produce runoff and sediment during simulations at sites on unit B-1; infiltration rates were not exceeded; the sandy soil was not at or near saturation; runoff was not generated.
2. Approximately 70 g/182 cm^2 of soil was removed during experiments using the portable rainfall simulator on the wash-transport zone (B-2),

Table 5.--*Soil-loss measurements on the Bisti study area resulting from use of the portable rainfall simulator and a sprinkler simulator*

[g = grams; cm^2 = square centimeters; g/m^2 = grams per square meter]

Soil-landscape unit	Portable rainfall simulator (140 millimeters per hour for 1 hour; 12-experiment average)		Sprinkler simulator[1] (51 millimeters per hour for 45 minutes; 3-experiment average)		
				Equivalent area	
B-1, moderately stabilized dune	0 g/182 cm^2	0 g/m^2	0 g/291 m^2	0 g/182 cm^2	0 g/m^2
B-2, wash-transport zone	69 g/182 cm^2	3,791 g/m^2	4,286 g/277 m^2	0.28 g/182 cm^2	15.47 g/m^2
B-3, shaly outcrop	23 g/182 cm^2	1,264 g/m^2	260,814 g/231 m^2	20.55 g/182 cm^2	1,129 g/m^2

[1] G. C. Lusby, U.S. Geological Survey, written commun. (1976).

compared to approximately 0.3 g/182 cm^2 from an equivalent area during the experiments using the sprinkler simulator. These two orders of magnitude difference between the measurements may be due, in part, to storage and deposition within the nearly level wash-transport zone, even though a large mass of detachable sediment is available for transport.

3. Differences in the intensity and duration of the simulated rainfalls probably contribute to the dissimilar results in table 5. If the simulated rainfalls are compared only in terms of kinetic energy, they are about equivalent and comparable with the energy of a natural rainfall rate of approximately 20 mm/h. However, raindrop-impact frequency is another important variable of both rainfall intensity and kinetic energy in erosion studies. Differences between the impact frequency of the two simulators are apparent; however, further study is required to evaluate raindrop-impact frequency to soil detachment and transport (Walker and others, 1978).

4. The two measurements from the wash-transport zone indicate a sediment-delivery ratio for the sprinkler-simulator test basin [the ratio of sediment delivered at a downstream point in the basin to the gross erosion from the area upstream from that point (Wischmeier and Smith, 1978)]. This ratio (about 0.004) is only a preliminary estimate for alluvial plains in this area.

5. Soil-loss measurements on the shaly interfluve area were approximately the same, about 20 g/182 cm^2, for each of the simulators. These steep, relatively impermeable slopes probably do not provide much storage, so the available detached sediment is quickly and efficiently transported out of the test basin.

ESTIMATES OF SOIL LOSS AND SEDIMENT YIELD

Data from the rainfall-simulation experiments are of value in providing more quantitative information for predicting potentially erodible soils, soil loss, and sediment yield in a study area. Relative erodibilities, defined as FEI values, can be used as criteria to estimate sediment-production components of watershed models. Accordingly, FEI values were used to estimate sediment-production components and sediment yield from the Ah-shi-sle-pah Wash basin (fig. 1), most of which is characterized by badland topography.

The model used in this study to estimate soil loss is the Universal Soil Loss Equation (USLE) (Wischmeier and others, 1958). This equation was originally developed to estimate soil losses from sheet and rill erosion on nonirrigated farms in the Midwest. Over the years, the equation has been applied to range and forested lands to predict long-term (22-year rainfall cycle) average soil losses with varying degrees of success, depending on the amount of quantitative data available to estimate the factor values (Wischmeier, 1977). The equation is:

$$A = R\ K\ L\ S\ C\ P \qquad (1)$$

where

A = average annual soil loss from sheet and rill erosion,
R = rainfall-energy-intensity term,
K = soil-erodibility term,
L = slope-length term (ratio of slope length to reference length of 22.13 meters),
S = slope-gradient term (ratio of slope gradient to reference gradient of 9 percent),
C = cover (vegetation or mulch) term, and
P = cultural-practices term (value of 1.0 used if there are no cultural practices, as was the case in this study).

In the following discussion, estimated K values for soils in Ah-shi-sle-pah Wash basin are defined and correlated with FEI developed in this study for the Kimbeto soil-landscape units. Corrected or adjusted K values then are used to determine the expected amount of detachable sediment available from each soil-landscape unit. Soil loss (as defined in equation 1) from each unit then is calculated, based on corrected K values, in conjunction with data from L. M. Shown, U.S. Geological Survey, written commun., (1979). Finally, sediment yield for the basin is estimated, using the USLE with estimates of the average sediment-delivery ratio and channel erosion in the basin.

K values

Standardized values of the erodibility factor, K, and FEI values determined for the Kimbeto sites were compared and correlated. K and FEI values were then calibrated to improve estimates of K values for specific soils in the study area, and to evaluate FEI values in terms of standard values of erodibility assigned to soils throughout the United States.

The K factor is defined in equation 1 as the rate of erosion per unit R, when all other factors are at unity (Wischmeier and Smith, 1965). The K factor represents all the physical and chemical properties of soils that affect their erodibility (Wischmeier and Mannering, 1969). K values can be defined by field measurements on benchmark soils made during a long time (minimum of 5 years), or by indirect calculations using relationships defined by the erodibility nomograph of Wischmeier and others (1971). This nomograph provides an estimate of K for the medium-textured agricultural soils as a function of texture, permeability, structure, and organic matter.

Estimates of the erodibility factor derived from Wischmeier's nomograph, K_e, were assigned to soils in the study area because no benchmark soils have been established. All estimates of K_e were then converted to metric values by multiplying values from the nomograph by 1.292 (Arnoldus, 1977). Two values of K_e were calculated for certain soils. K_e-, the estimated K value for soil series, was derived by the U.S. Soil Conservation Service using Wischmeier's nomograph (1971); and the other value, K_e*, the estimated K value for soil-landscape units based on soil properties determined at each particular site and entered into the nomograph (Wischmeier and others, 1971), was assigned by the author after measuring or estimating pertinent soil properties (texture, structure, permeability, and organic matter) at some of the rainfall-experiment sites. Only five of the soils, which had a range of FEI values, were assigned a K_e* value (see table 6) because it was believed that this provided an adequate basis for comparing and calibrating FEI and K values. Corrected estimates of K_e (K_{ce}) were then defined by assigning values of K using the K_e* values as references, and in accordance with the erodibilities defined by the FEI values. Judgment was used in assigning K_{ce} values that reflected the measured differences in FEI values among soil types. Consequently, the range of K_{ce} values is notably larger than either K_e* or K_e- so that the variability in erodibility, as evidenced by onsite observations and measurements, is represented.

Table 6.--*Comparisons of field-erodibility indexes and K values for soil-landscape units at the Kimbeto study area*

[FEI: Field-erodibility index based on a rainfall simulation rate of 140 millimeters per hour using the portable rainfall simulator; K_e-: Estimated K value for soil series derived by the U.S. Soil Conservation Service using the erodibility nomograph (Wischmeier and others, 1971) and converted to metric value (Arnoldus, 1977); K_e*: Estimated K value for soil-landscape units based on soil properties that were measured at experimental sites, entered into the nomograph (Wischmeier and others, 1971) and converted to metric value; K_{ce}: Corrected estimates of K values (metric) for each unit based on K_e-, K_e*, and relative rankings indicated by FEI values.]

Soil landscape unit	Soil series (estimated)	FEI	K_e-	K_e*	K_{ce}
K-10	Sheppard	0	0.13	---	0.01
K-1	Shiprock	8	.31	0.03-0.04	.03
K-6	Huerfano--badlands	11	.31	---	.05
K-2	Avalon	16	.50	---	.12
K-5	Huerfano--badlands	20	.31	---	.17
K-8	Doak	21	.48	.13	.18
K-11	Avalon	29	.50	---	.28
K-7	Uffens	31	.31	---	.31
K-4	Muff-Uffens	45	.26-.31	---	.49
K-9	Turley-Stumble	50	.36	.44	.56
K-3	Huerfano--blowout zone	54	.31-.41	.32	.61
K-12	Turley-Stumble	121	.36	.32	1.03+

Results of the experiment, determinations of K_e- and K_e* values, and comparison with FEI rankings are given in table 6. The soil-landscape units are arranged in order from the smallest to the largest FEI values. Considering the soils with assigned K_e* values, the range of FEI values, from 8 to 121, is similar in magnitude change to the range of K_e* values from 0.03 to 0.44, but unlike the limited range of K_e- values, from 0.31 to 0.48, probably because K_e- represents a general estimate describing a range of surface soils in a soil series (table 6), whereas K_e* is based on soil properties at the specific site where the FEI value was determined. Therefore, differences in the ranges of K_e- and K_e* and similarity in the ranges of FEI and K_e* will be expected.

Considering the erodibility rankings for the five soils, K_e* and FEI values rank the first three soils in the same order. Neither K_e-, K_e*, or FEI values indicate the same order of erodibility for all five soils. K_e- appears to be a general rating (as previously indicated), and masks distinct differences in erodibility determined during rainfall simulations at the experimental sites. As a result, these ratings are grouped and values overlap, depending on the similarity of the soil-series classification. K_e also is based on a function represented by the nomograph describing an average annual erodibility for many recurring storms of various amounts, intensities, and frequencies; while FEI represents a relative erodibility on a standard storm basis. The effect of this factor is illustrated by a reversal of order in values of FEI and K_e* for units K-12 and K-9 (table 6).

Another factor affecting the order of erodibility values is that specific characteristics of these soils are considered to cause a great degree of variability in the values of both K_e and FEI across the landscape. Soils that are characteristically sodium affected (table 1) contain swelling clays, have large surface cracks, and impart a great degree of variability to infiltration rates, internal cohesion, and detachability. When K_e values from the nomograph are determined for those soils, such as units K-2, K-4, K-9, and K-12, the reliability of K_e is reduced because the function defining the nomograph is derived from medium-textured, nonsodium-affected, agricultural soils in the Midwest. Other studies of soils with properties similar to those in the study area also have shown that K_e values calculated from the nomograph are not always reliable (Singer and others, 1977; Tanji and others, 1978; Young and Mutchler, 1977).

In addition to this direct comparison of erodibility values, the results of the calibration procedure using FEI and K_e values are shown in the K_{ce} column of table 6. Values of FEI were used as guidelines to modify K_e because data from the portable rainfall simulator differentiates relative erodibilities of the soils studied. K_{ce} values were first assigned to the five soils having K_e* values; then, the remaining soils were assigned a K_{ce} value proportional to the corresponding FEI value. These corrected values constitute the best available estimates based on site-specific data; they are used as the K component in the following analysis of sediment production in Ah-shi-sle-pah Wash basin.

The comparison discussed does not prove that either K_e or FEI values are the correct values of erodibility for the soils studied; it is a comparison of the methods used to derive erodibilities, and it indicates how FEI values for a group of soils relate to K values, which are a standard soil-conservation parameter. The comparison indicates that FEI values give a more distinct differentiation of a soil's relative erodibility on a given storm basis, while K_e values give more general rankings and tend to merge soil types across the landscape, averaging out the wide variety of storms occurring during several years. Both results illustrate that estimation of K is important in evaluations of sediment production.

Soil loss

The USLE has been widely used to estimate soil loss across different soils in drainage basins where surface mining has occurred or will occur in the future (U.S. Soil Conservation Service, 1977b; L. M. Shown, U.S. Geological Survey, written commun., 1979; Wischmeier and Smith, 1978). This equation appears to be the best method for predicting postmining values of erosion loss in drainage basins like those in the study area. Soil loss, as defined in equation 1, has been estimated for Ah-shi-sle-pah Wash basin (fig. 1) as follows:

1. The basin, 21.1 km^2 was first divided into potentially mineable and nonmineable areas on the basis of the depth to underlying coal deposits. The downstream one-half of the basin is underlain by mineable coal, defined as coal beds covered by less than 61 m of overburden (U.S. Bureau of Land Management, written commun., 1978). The nonmineable area is defined as the area that is not underlain by presently economically mineable coal deposits.
2. Values of soil loss, A, were calculated for the mineable area after reclamation based on data from a similar area, the San Juan Mine, which is currently (1979) being reclaimed (fig. 1). Conditions and characteristics of the reclaimed sites at the San Juan Mine are reasonably representative of the expected landscape if Ah-shi-sle-pah Wash basin is mined and reclaimed. Silty-loam and sandy-loam topsoils are used in reclamation at the San Juan Mine; these soil types also are in the Ah-shi-sle-pah Wash basin and are probable choices for topsoil material following mining. Therefore, in the following discussion, data from reclamation units C, D, and E are extrapolated to potential reclamation units in the Ah-shi-sle-pah Wash basin, defined as units C*, D*, and E*.

Estimates of K_{ce} for the potential reclamation units are listed in table 7. These estimates were obtained by the same calibration technique used in table 6. Specifically, FEI values for the soils disturbed by mining (table 4) were correlated with the proportional relationship between FEI and K_{ce} in table 6. For example, the mean FEI for unit C is 16, which is equal to that of unit K-2; therefore, the K_{ce} of unit C (and of unit C*) is 0.12 (table 7).

Table 7.--*Estimated postmining soil loss from sheet and rill erosion on mineable area in Ah-shi-sle-pah Wash basin based on data from reclamation units at the San Juan Mine*

[R = rainfall-energy intensity; K_{ce} = corrected soil erodibility; L = slope length; S = slope gradient; LS = topographic factor; C = cover term; A = soil loss; A_w = area-weighted soil loss; Mg/hm^2 = megagrams per square hectometer; m^3/km^2 = cubic meters per square kilometer]

Potential reclamation unit (based on table 2)	R[1]	K_{ce}	L (meters)	S (percent)	LS	Ground cover (percent)	C	A (Mg/hm^2)	A[2] (m^3/km^2)	A_w[3] (Mg/hm^2)	A_w[4] (Mg/hm^2)
C*	35	0.12	152	10	3.7	10 (mulch)	0.78	12.1	938.0	6.5	3.4
	35	.12	152	2	.33	10 (mulch)	.78	1.1	85.3		
D*	35	.16	152	10	3.7	77	.017	.4	31.0	.2	
	35	.16	152	2	.33	77	.017	.03	2.3		
E*	35	.37	152	10	3.7	58	.23	11.0	932.2	5.7	
	35	.37	152	2	.33	58	.23	1.0	84.7		

[1]Rainfall data from Miller and others (1973).

[2]Calculations using specific weights of 1.29 megagrams per cubic meter for sandy soils, and 1.18 megagrams per cubic meter for loamy soils.

[3]A_w = Weighted average of A, assuming one-half of the area is reclaimed to a 10-percent slope and one-half to a 2-percent slope.

[4]A_w = weighted average of A, assuming the area is reclaimed according to characteristics of units C and D.

R, L, S, and C values (equation 1) are listed in table 7 for potential reclamation units in Ah-shi-sle-pah Wash basin (units C*, D*, and E*). Estimates of L and S are based on probable combinations of lengths and slopes of the regraded landscape following mining; values of the cover factor C are based on measurements at the reclamation units at the San Juan Mine.

Weighted values of soil loss (A_w) were calculated for the potential reclamation units. Values of A_w for units C* and D* decrease from 6.5 to 0.2 Mg/hm^2 (megagram per square hectometer) as a function of the cover factor. The weighted average value, 3.4 Mg/hm^2, is used as a component to compute sediment yield because sandy-loam topsoil is superior material for reclaiming mined land in this region (L. M. Shown, U.S. Geological Survey, written commun., 1979). The A_w of unit E*, which is a finer-textured soil, is estimated to be 5.7 Mg/hm^2. This value was not used to determine sediment yield although it is possible that there may not always be enough sandy topsoil available during an ongoing operation to reclaim a recently mined section of land; then a finer-textured material would probably be used as a topsoil and the expected A (soil loss) would be that of unit E*.

Estimates of soil loss also were calculated for the nonmineable area in the basin as well as premining conditions for the total basin. Components of USLE were determined for each of the soil-landscape units: Values of K are the improved estimates, K_{ce}, from table 6; L and S were onsite estimates; and C was measured onsite. A weighted soil loss was determined by estimating the percentage area represented by each unit on aerial photographs and then computing a weighted average soil loss (A_w). Results are given in table 8.

Areas represented by unit K-4 would have the greatest soil loss, 27.6 Mg/hm^2. These units represent landforms on sloping, dissected areas in the badlands. Values of A are smallest on active dunes on the bottomlands, as represented by unit K-10, and on a flat wash-transport area, as represented by unit K-11, immediately adjacent to the dunes. Average soil loss from the total basin would be 7.6 Mg/hm^2 under premining conditions. The largest value of A_w, 8.7 Mg/hm^2, is estimated for the mineable area before mining occurs, and comparisons with A_w values in table 7 indicate that soil loss may noticeable decrease following mining and reclamation.

Sediment yield

Sediment yield is the mass of eroded sediment per unit area actually transported out of a basin. The technique used to estimate sediment yield from Ah-shi-sle-pah Wash basin was to apply a sediment-delivery factor to the amount of gross erosion, as discussed by Wischmeier and Smith (1978). This method uses the USLE with sediment-delivery ratios and channel-erosion estimates:

$$S_y = E(DR)/W_s \qquad (2)$$

Table 8.--*Estimated soil loss from sheet and rill erosion in Ah-shi-sle-pah Wash basin under existing rangeland conditions*

[R = rainfall-energy intensity; K_{ce} = corrected soil erodibility; L = slope length; S = slope gradient; LS = topographic factor; C = cover term; A = soil loss; A_w = area-weighted soil loss; Mg/hm^2 = megagrams per square hectometer; m^3/km^2 = cubic meters per square kilometer]

Soil landscape unit[1]	R^2	K_{ce}	L (meters)	S (percent)	LS	Ground cover (percent)	C	A = (R K L S C) (Mg/hm^2)	A = (R K L S C) (m^3/km^2)	A_w[3] (Mg/hm^2)
K-1	35	0.03	4.6	36	4.4	42	0.29	1.3	100.8	
K-4	35	.49	6.1	27	3.1	8	.52	27.6	2,339.0	
K-5	35	.17	6.1	27	3.1	0	1.0	18.4	1,426.4	
K-6	35	.05	6.1	27	3.1	17	.29	1.6	124.0	
K-7	35	.31	7.6	18	1.7	25	.21	3.9	330.5	
K-9	35	.56	152.4	1	.21	9	.48	2.0	169.5	
K-10	35	.01	6.1	31	3.8	18	.33	.4	31.0	
K-11	35	.28	61.0	1	.16	37	.15	.2	16.9	
K-12	35	1.03+	91.4	1	.18	14	.35	2.3	194.9	
										[4]6.3
										[5]8.7
										[6]7.6

[1]Description of units are given in table 1.

[2]Rainfall data from Miller and others (1973).

[3]A_w = average A in megagrams per cubic hectometer weighted by area represented by each unit.

[4]Nonmineable area.

[5]Mineable area (premining).

[6]Total area (premining).

where

S_y = sediment yield,

E = gross erosion (total soil loss from slopes and channel erosion),

DR = sediment-delivery ratio, and

W_s = area of the watershed upstream from the point for which S_y is computed.

S_y values shown in table 9 were calculated by entering values of A_w from table 7 and 8 into equation 2. Channel erosion was estimated by measuring the length of streams in the basin and approximating average erosion from the banks and channel bottom (L. M. Shown, U.S. Geological Survey, oral commun., 1979). The sediment-delivery ratios were estimated by L. M. Shown, U.S. Geological Survey, oral commun., (1979) based on an evaluation of the sediment-transport efficiency of channels, as related to probable flow conditions, channel type, and cover; and on expected amounts of deposition at places where upland-slope gradients change abruptly, and deposition on alluvial plains.

Using these estimates of sediment-production components, the resulting value of S_y is 12,449 megagrams for the total basin in the presently unmined state or an equivalent of 599 Mg/km^2. This value is almost twice the amount estimated by L. M. Shown, (U.S. Geological Survey, written commun., 1979) for an adjacent basin, Tsosie Swale. The basin slope of Tsosie Swale has a smaller mean gradient than Ah-shi-sle-pah Wash basin where badland topography is prevalent; therefore, less erosion and runoff are expected on Tsosie Swale and all soils in Tsosie Swale are sandy; thus, K and A_w are expected to be smaller than Ah-shi-sle-pah Wash basin.

A separate estimate of sediment yield from Ah-shi-sle-pah Wash basin was made by L. M. Shown (U.S. Geological Survey, written commun., 1979) using a numerical method developed by the Pacific Southwest Interagency Committee (1968) and modified by Frickel and others (1975). That estimate of 1,316 Mg/km^2 for the basin in an unmined state is more than twice the amount calculated in this study (599 Mg/km^2). These estimates need to be compared with sediment amounts measured during several years by sampling at a gaging station to verify the accuracy. Such sediment measurements were begun by the U.S. Geological Survey on Ah-shi-sle-pah Wash basin during 1977.

The S_y estimated for postmining conditions in Ah-shi-sle-pah Wash basin is 7,613 megagrams (5,325 + 2,288) for the total basin (table 9) or an equivalent of 366 Mg/km^2. This value is about 60 percent of the value estimated for premining conditions, which indicates that S_y may decrease following mining because some of the slopes of the steep bad-lands would be modified, reclaimed, and revegetated.

Table 9.--*Estimates of premining and postmining sediment yield from Ah-shi-sle-pah Wash basin*

[A_w = area-weighted soil loss; C_e = channel erosion; DR = sediment-delivery ratio; S_y = sediment yield; W_s = area in basin; Mg/hm^2 = megagrams per square hectometer; Mg/km^2 = megagrams per square kilometer; km^2 = square kilometers; Mg = megagrams]

Part of basin	A_w[1]		C_e	DR	S_y	W_s[2]	S_y
	(Mg/km^2)	(Mg/km^2)	(Mg/km^2)		(Mg/km^2)	(km^2)	(Mg)
Nonmineable area (Areas represented by units K-1 to K-12)	6.3	627	105	0.7	512	10.4	5,325
Mineable area before mining (Areas represented by units K-1 to K-12)	8.7	874	105	.7	685	10.4	7,124
Mineable area after mining (Areas represented by units C* and D*[3])	3.4	336	105	.5	220	10.4	2,288

[1]Average area-weighted soil loss from sheet and rill erosion.

[2]Total basin area was 21.2 square kilometers, but only 20.8 square kilometers were included in the calculations.

[3]See table 7.

APPLICATION TO WATERSHED MANAGEMENT

Results of this study can be applied to the development of watershed models on rangeland. Runoff-sedimentation models provide a means of evaluating hydrologic and sediment components of an area and predicting their temporal and spatial variation. These models have been developed for use on agricultural lands (Falletti, 1977); Simons and others (1975) have developed one model for subalpine forested land; and several models discussed by Van Haveren and Leavesley (1979) and Smith (1977) describe basin models for natural rangelands. Falletti (1977) emphasized the importance of defining a sediment-production component for watersheds on wildlands (rangeland and wilderness); he noted that values for sediment production are not available.

Determinations of detachment rates during this study may prove valuable in modifying and improving watershed models for use on coal fields like those in northwestern New Mexico. Estimates of spatial variability or erodibility would also improve the capability of the model to predict changes in sediment production laterally across different soil types. Spatial variability can be included within the context of a watershed model by employing the Monte Carlo simulation method, which was used by Smith and Hebbert (1979) to simulate variability in infiltration rates.

CONCLUSIONS

Onsite studies have been conducted on certain coal fields of northwestern New Mexico to assess soil erodibility. Erodibility was determined at experimental sites by conducting rainfall-simulation experiments on undistrubed surface soils and soils disturbed by mining. A rainfall simulator developed by McQueen (1963) was used to simulate rainfall, during which relative erodibilities based on grams of detached soil per rainfall experiment, were defined. This approach allowed assessment of the relation between the field-erodibility index and associated landforms and vegetation. In addition, the data were used to predict approximate soil loss and sediment yield from the study areas.

Results of 66 rainfall-simulation experiments at the Kimbeto and Bisti study areas and the San Juan Mine are summarized as follows:

1. Tests on the undisturbed, unmined landscapes at the Kimbeto and Bisti study areas show that the smallest FEI value is for loamy sandy soil on active dunes (FEI = 0). These soils are not susceptible to detachment, relative to other units, and probably will not contribute a large amount of sediment to runoff following surface mining.
2. Soil-landscape units on gently to steeply sloping interfluve areas have a continuum of mean FEI values ranging from 8 to 69. These soils are moderately susceptible to erosion compared to other landscape units. Because erodibilities are variable and the spatial distribution of the units also is variable, prediction of the amount of soil erosion is difficult.

3. The greatest susceptibility to erosion occurs in a wash-transport area (mean FEI = 121). An accumulation of fine alluvial and eolian material (silts, clays) on the surface appears to be easily detached by splash impact, and this area is expected to be a major source of sediment in these basins.

4. A limited amount of data on soils disturbed by mining indicates that mean erodibility indexes are variable and range from 16 to 32. The FEI values on the reclamation sites compare with smaller values in the moderate erodibility group of undistrubed soils. These results provide a guideline for reclamation management and the relative erodibilities can be extrapolated to nearby basins, such as Ah-shi-sle-pah Wash and De-na-zin Wash basins.

Comparisons between the portable rainfall simulator and a sprinkler system were made to consider sediment-loss measurements in very small watersheds. Results indicate that the portable rainfall simulator measures soil detachability, while the sprinkler simulator also measures transport capacity of surface flow by measuring sediment transported out of a very small catchment. For example, indexes from the two techniques were comparable when soil detached from shaly slopes of badlands was transported out of the area without subsequent deposition. On the other hand, indexes measured on a wash-transport zone were not comparable, apparently because deposition occurred on the nearly level landscape. Measurements from both simulators indicate a local sediment-delivery ratio about equal to 0.004 for a test basin in the wash-transport zone; more study is needed to verify this ratio.

Soil-erodibility data were used to calculate soil loss and sediment yield within Ah-shi-sle-pah Wash basin. These values represent approximations of expected sediment production preceding and following surface mining of economical coalbeds. Results indicate soil loss from the non-mineable landscape is 6.3 Mg/hm^2, compared to 3.4 Mg/hm^2 on the mineable area, if it is mined and reclaimed using sandy-loam topsoil. Sediment yield from the entire basin in a premining state is estimated to be 599 Mg/km^2, which is about one-half the amount estimated by L. M. Shown (U.S. Geological Survey, written commun., 1979) using modified techniques established by the Pacific Southwest Inter-Agency Committee. Sediment yield from the basin under postmining conditions is estimated to be 366 Mg/km^2, assuming one-half the basin is surface-mined and reclaimed.

Besides providing quantitative data for estimating sediment yield, the erodibility indexes developed during this study can be used to define soil-loss components in basin models. Until sediment-production measurements from unmined and mined watersheds are collected during several years, FEI values constitute the best estimates of soil-detachment available for the coal fields.

Results of this study are based on point-site data and the error associated with extrapolation to sediment-yield values for watersheds that may be mined and reclaimed is unknown. More research is required to functionally relate site data to areal erosion within a basin, and to evaluate the methods in this study as predictive tools. Nevertheless, the relative rankings of a soils susceptibility to detachment are maintained, and FEI values appear to allow more realistic estimates of the K factor than those estimated by the U.S. Soil Conservation Service for the basins studied. This information provides useful guidelines for reclaiming erodible soils and managing mine soils following surface-mining operations.

REFERENCES CITED

Arnoldus, H. M. J., 1977, Predicting soil losses due to sheet and rill erosion, *in* Guidelines for watershed management: Food and Agriculture Organization Conservation Guide, Rome, p. 99-124.

Dortignac, E. J., 1951, Design and operation of Rocky Mountain infiltrometer: U.S. Forest Service, Rocky Mountain Experiment Station, Paper No. 5.

Falletti, D., 1977, Sediment prediction in wildland environments: A review, *in* Foster, G. R., ed., Soil Erosion: Prediction and Control: U.S. Soil Conservation Service, Special Publication 21, p. 183-192.

Frickel, D. G., Shown, L. M., and Patton, P. C., 1975, An evaluation of hillslope and channel erosion related to oil-shale development in the Piceance basin, northwestern Colorado: Colorado Department of Natural Resources, Colorado Water Resources Circular 30, 37 p.

Laws, J. O., 1941, Measurements of the fall-velocities of waterdrops and raindrops: Transactions, Geophysical Union 22, p. 709-721.

Laws, J. O., and Parsons, B. A., 1943, The relation of raindrop size to intensity: Transactions, American Geophysical Union 24, p. 452-459.

McQueen, I. S., 1963, Development of a hand portable rainfall simulator infiltrometer: U.S. Geological Survey Circular 482, 16 p.

Miller, J. F., Frederick, R. H., and Tracey, R. J., 1973, Precipitation-frequency atlas of the western United States: U.S. Department of Commerce, National Weather Service, NOAA Atlas 2, New Mexico, v. IV, 43 p.

Mutchler, C. K., 1965, Waterdrop formation from capillary tubes: U.S. Department of Agriculture, Science and Education Administration, no. 4-107, p. 3-12.

Mutchler, C. K., and Hansen, L. M., 1970, Splash of a waterdrop at terminal velocity: Science, v. 25, p. 1311-1312.

Neff, E. L., 1979, Rainfall simulation activities--Sidney, Montana, *in* Proceedings of the Rainfall Simulator Workshop, Tucson, Arizona, March 8-9, 1979, U.S. Department of Agriculture, Science and Education Administration, ARM-W-10, p. 160-161.

Pacific Southwest Inter-Agency Committee, 1968, Report on factors affecting sediment yield in the Pacific Southwest area: Water Management Subcommittee, Sedimentation Task Force, 10 p.

Simons, D. B., Li, R. M., and Stevens, M. A., 1975, Development of models for predicting sediment yield from small watersheds: Colorado State University, Fort Collins, Colorado, Report No. CR74-75, DBS-RML-MAS 24, 127 p.

Singer, M. J., Huntington, G. L., and Sketchley, H. R., 1977, Erosion prediction on California rangelands: Research development and needs, *in* Foster, G. R., ed., Soil Erosion: Prediction and Control: U.S. Soil Conservation Service, Special Publication 21, p. 143-151.

Smith, R. E., 1977, Field test of a distributed watershed erosion/sedimentation model, *in* Foster, G. R., ed., Soil Erosion: Prediction and Control: U.S. Soil Conservation Service, Special Publication 21, p. 201-209.

Smith, R. E., and Hebbert, R. H. B., 1979, A Monte Carlo analysis of the hydrologic effects of spatial variability of infiltration: Water Resources Research 15, p. 419-429.

Summer, R., 1980, Alpine soil erodibility on Trail Ridge, Rocky Mountain National Park, Colorado [Ph.D. dissertation]: University of Colorado, Boulder, Colorado, 187 p.

Tanji, K. K., Singer, M. J., Henderson, D. W., Whittig, L. D., and Bigger, J. W., 1978, Nonpoint sediment production in the Colusa Basin drainage area: University of California, Davis, California, Water Science Engineering Paper 4016.

Templin, E. H., 1947, Report of the committee on terminology relating to soil consistance: Soil Science Society of America, Proceedings No. 12, p. 524-525.

U.S. Geological Survey, 1976, Moisture relations in soils associated with the vegetation, *in* Resource and potential reclamation evaluation--Bisti West study site, New Mexico: Bureau of Land Management EMRIA Report No. 5, 108 p.

U.S. Soil Conservation Service, 1977a, Soil Survey of San Juan County, New Mexico, Albuquerque, New Mexico [preliminary draft].

______ 1977b, Preliminary guidance for estimating erosion on areas disturbed by surface mining activities in the interior western United States (unpublished report to U.S. Environmental Protection Agency, Region VIII), 57 p.

Van Hareren, B. P., and Leavesley, G. H., 1979, Hydrologic modeling of coal lands: Report on status of modeling effort of the EMRIA program: U.S. Department of the Interior, Bureau of Land Management and Geological Survey, May 1979, 13 p.

Walker, P. H., Kinnell, P. I. A., and Green, P., 1978, Transport of a noncohesive sandy mixture in rainfall and runoff experiments: Soil Science Society of America Journal 42, p. 793-801.

Wischmeier, W. H., 1977, Use and misuse of the Universal Soil Loss Equation, *in* Foster, G. R., ed., Soil Erosion: Prediction and Control: U.S. Soil Conservation Service, Special Publication 21, p. 371-378.

Wischmeier, W. H., Johnson, C. B., and Cross, B. C., 1971, A soil erodibility nomograph for farmland and construction sites: Journal of Soil Water Conservation 26, p. 189-193.

Wischmeier, W. H., and Mannering, J. V., 1969, Relation of soil properties to its erodibility: Journal of Soil Science 33, p. 131-137.

Wischmeier, W. H., Smith, D. D., 1965, Predicting rainfall erosion losses from cropland east of the Rocky Mountains: U.S. Department of Agriculture Handbook 282, 47 p.

Wischmeier, W. H., and Smith, D. D., 1978, Predicting rainfall erosion losses--A guide to conservation planning: U.S. Department of Agriculture, Science and Education Administration, Agriculture Handbook 537, December 1978, 58 p.

Wischmeier, W. H., Smith, D. D., and Uhland, R. E., 1958, Evaluation of factors in the soil loss equation: U.S. Department of Agriculture, Agricultural Engineering 39, p. 458-462.

Young, R. A., and Mutchler, C. K., 1977, Erodibility of some Minnesota soils: Journal of Soil Water Conservation, p. 180-182.