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APPLICABILITY OF THE UNIVERSAL SOIL LOSS EQUATION TO SEMIARID RANGELAND CONDITIONS IN THE SOUTHWEST

by

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INTRODUCTION

Sediment is the primary pollutant in the streams and lakes of the United States, especially in the western states where, although perennial streams are not as prevalent, the erosion rates are higher than most other places. Langbein and Schumm (1958) showed that the highest sediment yields per unit area are often encountered in the mixed brush-grass areas of the Southwest. Here, limiting moisture results in sparse vegetation cover to break up the erosive forces of both the precipitation and the runoff, as it moves over the land surface.

To design a prediction equation, parameters applicable to the area in which the equation is used are necessary. An erosion prediction method that has recently received wide attention in the United States is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965) for cultivated agricultural areas of the eastern United States. The USLE is given as:

$$A = RKLSCP$$

where:
- A = estimated soil loss (tons/acre/year)
- R = rainfall factor
- K = soil-erodibility factor
- L = slope length factor
- S = slope gradient factor
- C = cropping-management factor
- P = erosion control practice factor

Numerical values of the seven factors have been determined from research conducted east of the Rocky Mountains for plots both with natural and artificial rain. Limited data for the area west of the Rocky Mountains restricts the usefulness of the USLE in that area. Sedimentation and hydrologic data collected on the Walnut Gulch Experimental Watershed in Southeastern Arizona were used to estimate numerical values for the six factors for semiarid rangeland conditions.

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USING THE USLE

The first step in analyzing the applicability of the USLE to semiarid rangeland watersheds was to determine values for each parameter used in the equation, and the amount of variability associated with these values.

RAINFALL FACTOR (R)

The R factor is the average number of erosion-index (EI) units in a year's rainfall or the EI units in an individual storm, if the equation is used to predict individual storm erosion. The EI units in foot-tons/acre, are determined by multiplying the total kinetic energy of the storm times its maximum 30-minute intensity (Wischmeier and Smith, 1958). Each storm's EI value is accumulated to obtain a yearly EI value or R factor. Iso-erodent maps, lines of equal R factors, are available for portions of the United States east of the 140th meridian (Wischmeier and Smith, 1958). To use the term elsewhere requires computing the EI value from precipitation data from recording raingages.

Figure 1 shows the average monthly distribution of EI values for a 16 year record at raingage 22 on Walnut Gulch. The peak in July and August is directly related to the summer rainy season, characterized by convective thunderstorms. The highly variable nature of this type of precipitation has been well documented. (Osborn and Laursen, 1972; Osborn and Lane, 1972; Osborn, Lane, and Hundley, 1972; Smith and Schreiber, 1973).

The probability of a given annual EI value in southeastern Arizona can differ appreciably within a small geographic area. A log normal probability distribution of EI values for two gages located only 7 miles apart is shown in Figure 2 to illustrate this variability.

The EI value variability in any year is also closely related to the occurrence of one or more large storms in a given year, so that 20 to 50% of the annual total EI value is associated with one unusual storm. Figure 3 illustrates this relationship. The cross-hatched portion of each bar graph shows the percentage of the annual EI value associated with the largest storm of that year. Figure 3 also illustrates the variability of the annual EI value for the 16 year record at this gage. From this figure, we can see the problem associated with using a long-term average EI value for the erosion estimate in any year.

SOIL ERODIBILITY FACTOR (K)

The K factor, a soil erodibility index, is experimentally determined from "unit" plot data. A unit plot is 72.6 feet long, with a uniform 9% slope, in continuous fallow, and tilled up and down the slope (Wischmeier and Smith, 1965). For a given soil, it is the erosion rate per unit of erosion index from "unit" plots on that soil. Values of K have been determined for many eastern soils but not for many western soils.

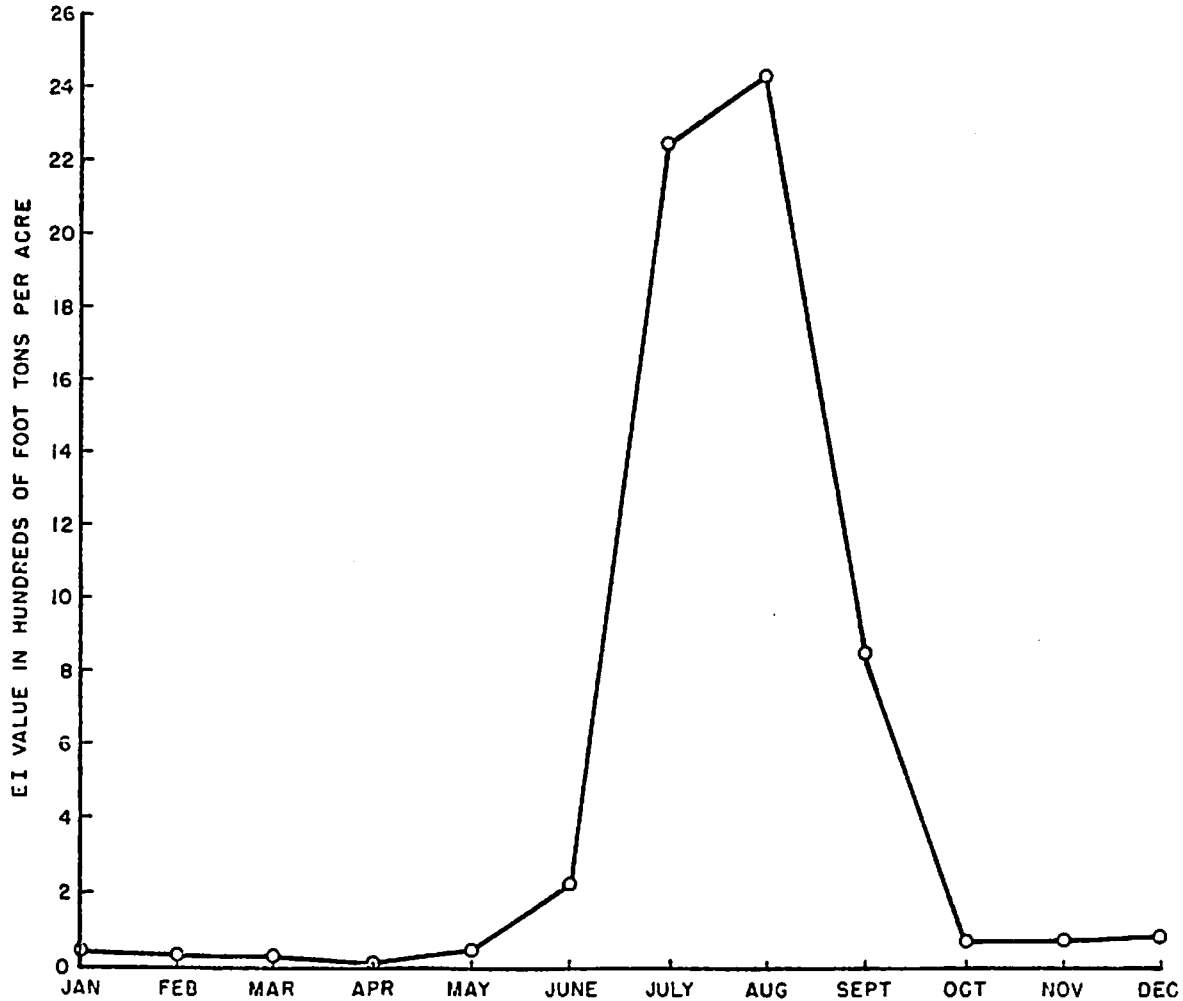

FIGURE 1. Seasonal Distribution of EI Values for a 16 Year Average (1954-1969) at Walnut Gulch Raingage 63.022.

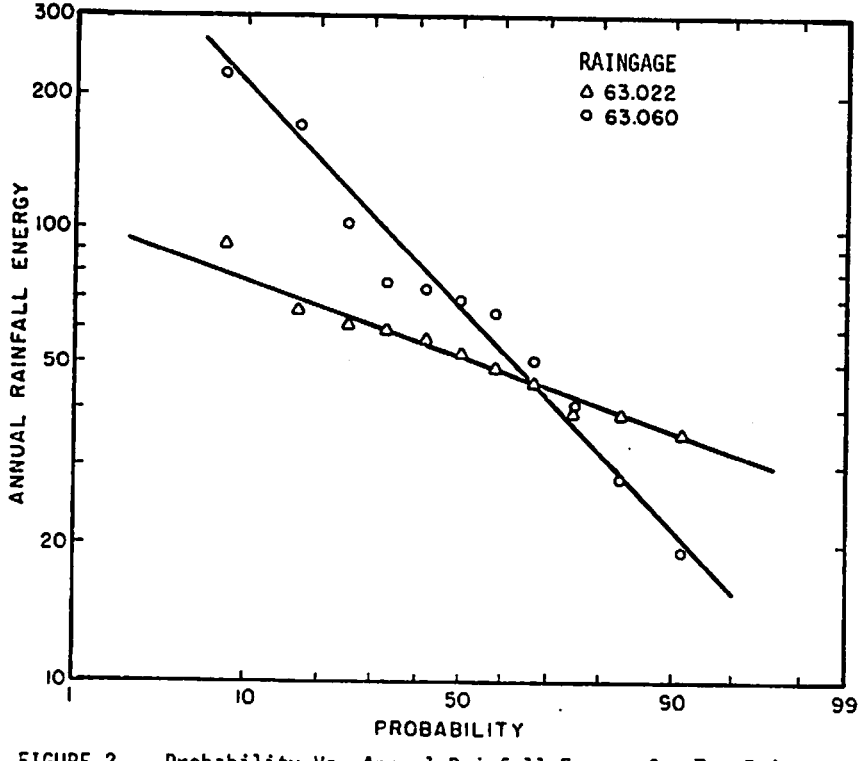

FIGURE 2. Probability Vs. Annual Rainfall Energy for Two Raingages on Walnut Gulch with Records from 1959 Thru 1969.

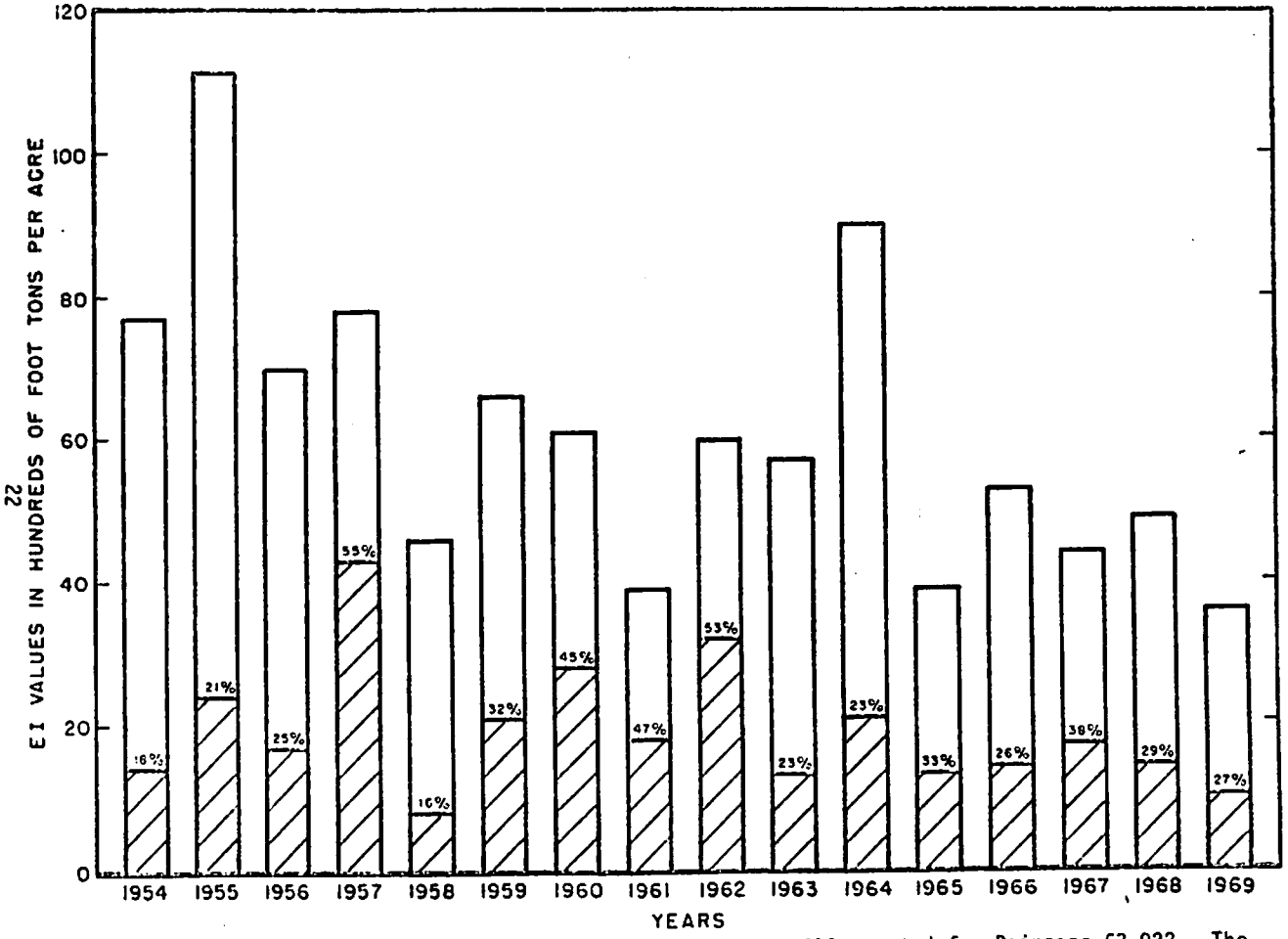

FIGURE 3. Largest Storm EI Contribution to Yearly Total EI is Illustrated for Raingage 63.022. The Percentage Shown on Each Bar is the Amount of the Annual Total Associated with the Largest Storm.

Wischmeier et al. (1971) presented a soil erodibility nomograph (Figure 4) which assists in determining K values for any soil. To use the nomograph, the percent silt and very fine sand (0.05-0.10 mm), percent sand (0.10-2.0 mm), percent organic matter, soil structure, and permeability must be known. These parameters can be readily obtained for most soils with standard laboratory analyses. For the Walnut Gulch Watershed soils, the K value determined from the nomograph is 0.10.

Many western soils are quite poorly developed and may have erodibility characteristics quite different from that experienced in other parts of the country. For example, many western soils contain large amounts of carbonates (caliche) which may provide additional soil particle cohesion. Western soils are often dominated by very coarse material which may also limit erodibility. Investigations seem warranted to evaluate the effects of these coarse materials, such as sand, gravel, and cobbles, on the erodibility factor.

CROPPING-MANAGEMENT FACTOR (C)

The C factor is a ratio of soil loss from land cropped under specific conditions to the corresponding soil loss from tilled, continuous fallow land. The term was developed primarily to handle conditions connected with crops and rotations of agronomic agriculture. On rangeland areas, guidelines for determining a value of C are not generally available. The term also varied seasonally, reflecting crop growth stage. (Wischmeier and Smith, 1965). Such a seasonal variability should not be necessary for rangeland conditions, unless the brush encountered loses its foliage during the winter. Of greater consequence is the relative density of plant cover. On the brush-grass areas in Southeastern Arizona, the vegetative cover is generally less than 10% basal area and approximately 30% crown cover.

Wischmeier, working with range scientists of the USDA Soil Conservation Service (SCS), has proposed some C values for permanent pasture, rangeland, and idle land. A portion of this information from the Soil Conservation Service Technical Release No. 51 is reproduced in Table 1. Interestingly, the percent ground cover has a very dramatic effect on the C factor as would be expected. For example, on the first line of the table, if the ground cover is composed of a grass or grass-like plant, the erosion would be expected to be 150 times greater for bare soil that for one with nearly 100% ground cover.

The western rangeland areas are often dominated by erosion pavements, consisting of gravel-size material that are residual from geologic erosion which has removed the finer materials from soil profiles. The erosion pavement role in the C factor can be very significant. Often, it may have an effect similar to vegetation in reducing erosion. This erosion pavement can withstand the energy of the falling raindrop and the erosive force of flowing water. The effects of erosion pavement on soil erosion seemingly is a very fruitful area for future research. The erosion pavement was included as ground cover in the watersheds discussed subsequently.

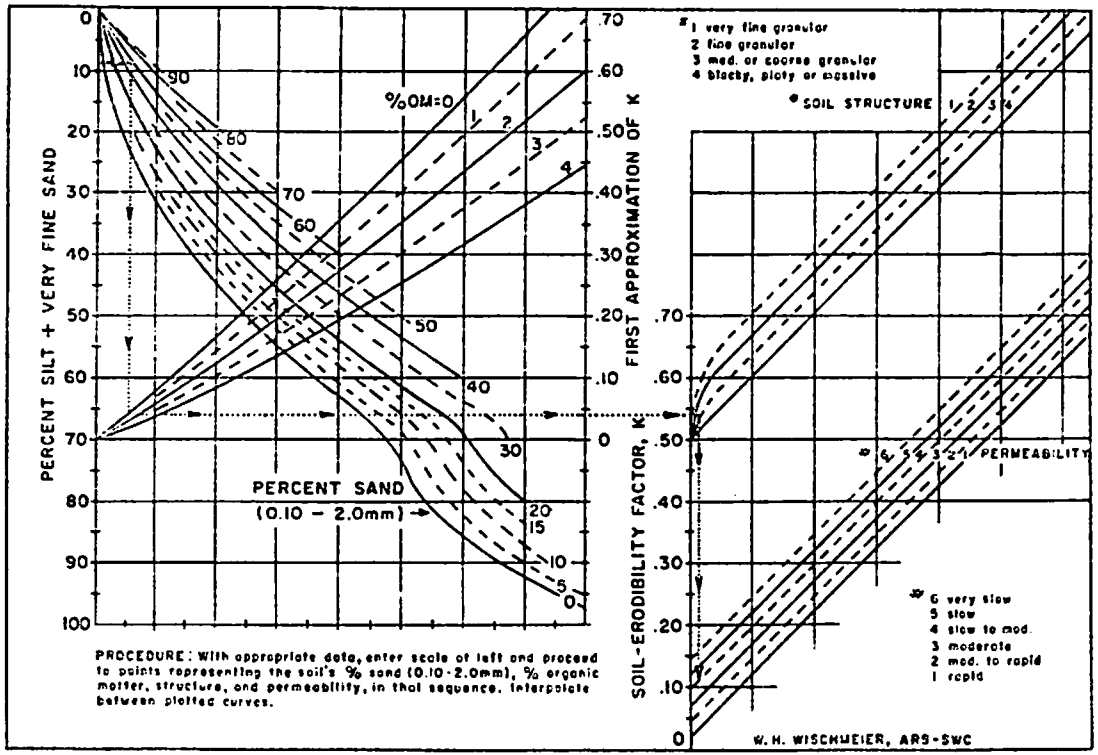

FIGURE 4. Soil Erodibility Nomograph. The Dotted Line Illustrates the Sequence for Determining a K Value Using Values for a Rillito-Nickel soil (8% Silt and Fine Sand; 1% OM; 55% Sand; Medium Granular Soil Structure; and Moderate Permeability).

TABLE 1.

"C" VALUES FOR PERMANENT PASTURE, RANGELAND, AND IDLE LAND[1]
FROM SCS T.R. 51

VEGETAL CANOPY			COVER CONTACTS SURFACE					
TYPE AND HEIGHT OF RAISED CANOPY [2]	CANOPY COVER % [3]	TYPE [4]	PERCENT GROUND COVER					
			0	20	40	60	80	95-100
COLUMN NO.	2	3	4	5	6	7	8	9
NO APPRECIABLE CANOPY		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
CANOPY OF TALL WEEDS OR SHORT BRUSH (0.5m. FALL HEIGHT)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
APPRECIABLE BRUSH OR BUSHES (2m. FALL HEIGHT)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011

1/ All values assume: (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists.

2/ Average fall height of waterdrops from canopy to soil surface.

3/ Portion of total-area surface that would be hidden from view by canopy in a vertical projection.

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

W: Cover at surface is mostly broadleaf herbaceous plants (LIKE WEEDS).

EROSION-CONTROL PRACTICE FACTOR (P)

The P factor is the soil loss ratio of the supporting practice to the soil loss with up-and-down hill culture. This ratio should obviously be less than one, if the erosion-control practice is effective. Since there are generally no cultivational practices involved on rangelands, the P ratio should be 1.0. However, since rangeland rejuvenation is becoming increasingly common, P values may be needed to reflect rangeland treatment practices, such as pitting, subsoiling to break up caliche layers, and root plowing for brush removal. In most rangeland erosion predictions, the C and P terms can be combined.

SLOPE LENGTH (L) AND GRADIENT (S) FACTORS

In practice, slope length and gradient are often considered as one term. This factor is the ratio of soil loss per unit area on a field slope to the soil loss from the basic "unit"plot (9% slope and 72.6 feet long). The ratio for specific length/gradient combinations may be obtained from the slope-effect chart shown in Figure 5.

MODIFICATION OF THE UNIVERSAL SOIL LOSS EQUATION FOR APPLICATION TO SMALL WATERSHEDS

The next step in analyzing the applicability of the USLE to semiarid rangeland conditions was to compare predicted soil losses from small subwatersheds of Walnut Gulch to the measured soil losses.

DESCRIPTION OF THE STUDY AREA

The 58-square-mile Walnut Gulch Watershed, located near Tombstone, Arizona, is operated by the Agricultural Research Service of the United States Department of Agriculture.

Precipitation, based on the 73 year record from the Tombstone gage, averages 14.5 inches per year with approximately 75% occurring during the summer "monsoon" season of June, July, August, and September. During this period, precipitation is dominated by short duration, convective thunderstorms with intensities varying to 4.5 inches per hour for durations less than 1 hour.

Vegetation on the watershed consists of both grass and shrubs. Grass species include sideoats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilas*), black grama (*Bouteloua eriopoda*), and tobosagrass (*Hilaria mutica*). Shrub species include creosotebush (*Larrea divaricata*), tarbush (*Flourensia cernua*), whitethorn (*Acacia constricta*), and sandpaper bush (*Mortonia scabrella*).

The USLE is intended for estimating erosion or soil loss per unit area from field size areas. However, for very small watersheds, the equation has been found to predict sediment yield fairly accurately where the sediment delivery ratio can be assumed to equal unity. An illustration of these estimates for 4 small watersheds follows. Two of the watersheds are contiguous (8.3 and 11.0 acre) (Figure 6),

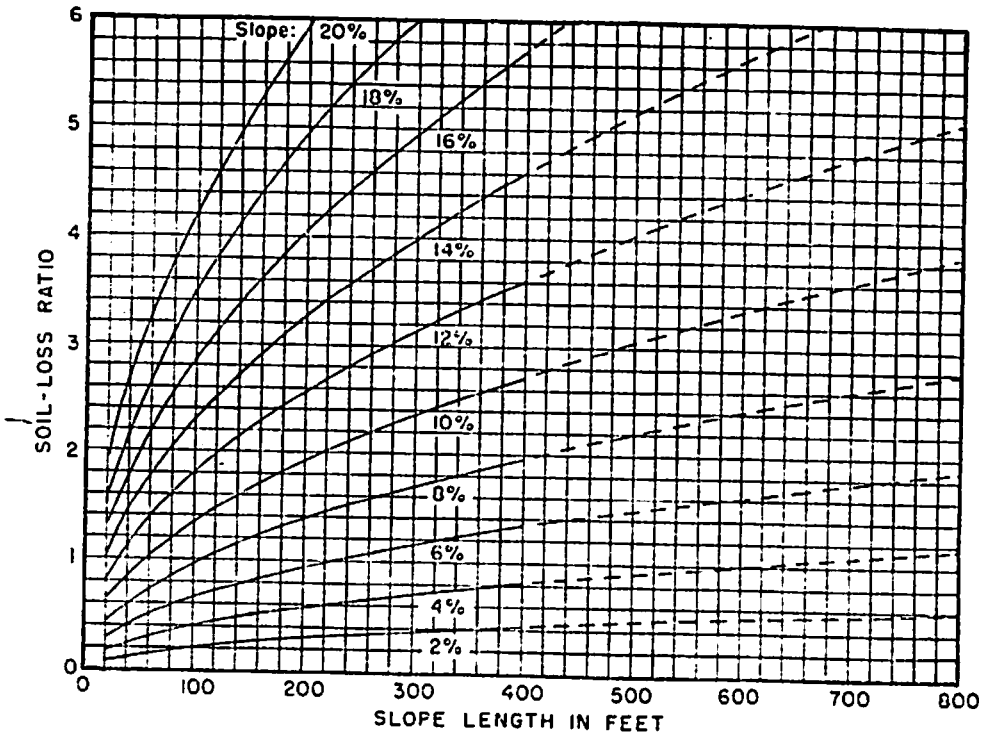

FIGURE 5. Slope-Effect Chart From Wischmeier and Smith (1965).

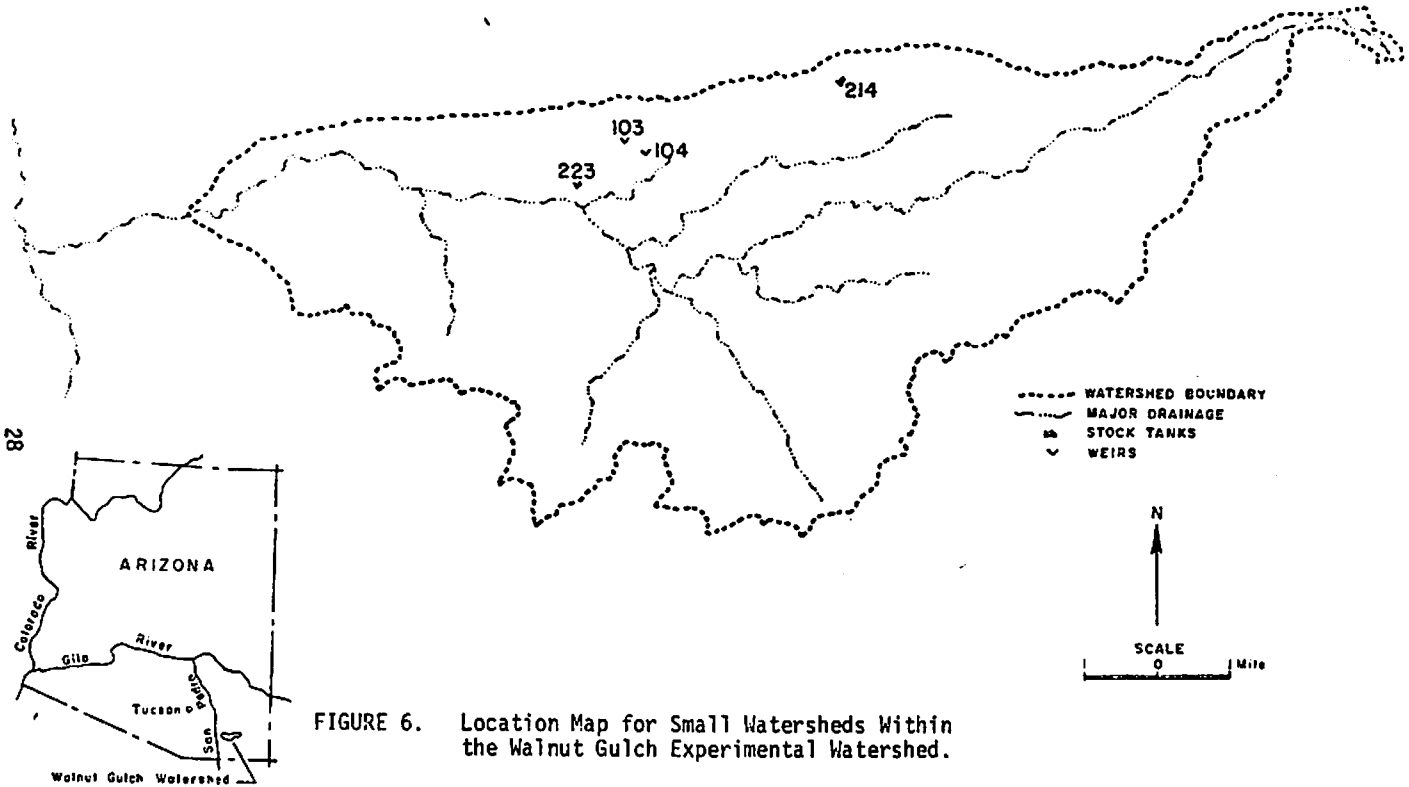

FIGURE 6. Location Map for Small Watersheds Within the Walnut Gulch Experimental Watershed.

and one of the 2 is a subdrainage of a larger 108-acre watershed. These drainages have similar soils, a similar topographic factor, and the same brush dominated vegetative cover. EI values differed slightly, as indicated by recording raingages located adjacent to the watersheds. The intense thunderstorm on July 27, 1973, was used to estimate the soil erodibility term K.

TABLE 2.

Measured Parameters of Four Walnut Gulch Watersheds Used

Watershed Number	Area Acres	R	K	LS	C	P	E_C	Measured (tons/acre)
63.103	8.3	39.2	.10	1.2	.038	1	3.86	.69
63.104	11.0	43.4	.10	1.2	.038	1	1	.20
63.214	372.0	82.3	.10	1.3	.038	1	1	.52
63.223	108.0	62.7	.10	1.4	.038	1	3.86	1.64

The stream channels differ appreciably between the two small watersheds (Table 2). The 11.0-acre watershed (63.104) has a channel that traverses fairly erosion resistant caliche-conglomerate outcrops which limits channel erosion and control the gradient. The smaller (8.3-acre) watershed (63.103) has a channel with an almost limitless supply of fine sand and silt. Thus, the sediment yield from this watershed contains not only watershed overland flow erosion, but also erosion from the channel bed and banks.

DETERMINATION OF FACTORS FOR USE IN THE USLE

The USLE was solved to obtain the soil-erodibility (K) factor (a value of 0.10 was obtained which verifies the value obtained from the nomograph) for the watershed without the erodible channel. This K factor value was then used with the USLE to compare the predicted sediment yield (or erosion) from the watershed with the eroding channel. An additional term was included in the USLE to include the concept or role of the channel's influence on sediment yield. Thus, the modified erosion equation postulated was:

$$A = (RKLSCP)E_C$$

where the new term E_C reflects channel erosion.

The channel erosion term, E_C, is analogous in many respects to the sediment delivery ratio used for watersheds when the onsite erosion is used to estimate sediment yield at the outlet. In most of these

watersheds, however, the sediment delivery ratio is less than unity (Roehl, 1963), and decreases as the watershed size increases. Although research is presently incomplete, channel erosion may be a very significant factor in the sediment yield from watersheds in semiarid areas such as Southeastern Arizona.

APPLICATION OF THE USLE TO LARGER WATERSHEDS

The utility of this modified equation was tested with data from the two larger watersheds with 108 and 372 acre drainage areas (Table 2). Stock ponds at the watersheds outlet are used to measure runoff and sediment from the watersheds. The 108-acre watershed (63.223) contains the 8.3-acre subwatershed mentioned previously and has similar but proportionally larger channels. For this area, the annual sediment yield (erosion from land surface and channels) was estimated by determining the loss in storage volume of a stock watering pond. The R term was the average of yearly EI values for the same time period as the sediment accumulation.

The predicted value using the modified erosion prediction equation and the data of Table 2, was 1.29 tons/acre/year as compared with an average 1.64 tons/acre/year for four years of data.

The 372-acre watershed (63.214) in another portion of the Walnut Gulch Watershed has a non-erodible channel very similar to that of the 11.0-acre watershed. The R factor was determined by using the average EI values for the same 7 years of sediment accumulation. Assuming the channel erosion factor E_C is equal to unity, the predicted sediment yield or erosion was 0.39 tons/acre/year as compared with the measured value of 0.52 tons/acre/year.

DISCUSSION OF RESULTS

Although the coincidence of agreement between predicted and actual sediment yield is encouraging for the limited data presently available, additional work is needed before the USLE can be applied to other areas in the Southwest. The inclusion of an additional term to reflect channel erosion appears warranted, because sometimes the erosion from the land surface may be less than that measured at the watershed outlet, i.e., the sediment delivery ratio is less than 1. At other times, erosion from the channel bed and banks may produce quantities of sediment comparable or larger than the sediment produced from the land surface erosion, and the sediment delivery ratio would be larger than 1.0. Additional experiments are needed before criteria for selecting this term are developed.

Soils, such as those of Walnut Gulch, developed under semiarid environments are undoubtedly quite different from those developed under a humid environment. It is very difficult to extrapolate K values of soils from one region to soils of another region because of the many different soil properties involved such as the gravels and cobbles prevalent in many western soils. Thus, additional research seems warranted to determine the soil erodibility for Western soils.

Slope length and gradient are difficult factors to measure and apply to anything other than an individual hillslope. Wischmeier and Smith (1965) define slope length as the distance from the point of overland flow origin to either of the following, whichever is limiting for the major part of the area under consideration: (1) the point where the slope decreases to the extent that deposition begins, (2) the point where runoff enters a well defined channel that may be part of a drainage network, or (3) a constructed channel, such as a terrace of diversion. Because of the complex network of channels on semiarid rangeland watersheds with channels extending to apparent watershed divides, these criteria are difficult to define.

The rainfall factor is perhaps the most difficult factor of the USLE to evaluate for the semiarid rangeland. Precipitation variability in basin and range topography is extreme, and data are generally not available to quantify the term. Much work will be required to develop the criteria to evaluate this term in the USLE.

Guidelines for using the cover term C have been proposed for sparse vegetation conditions, but many of the values need further testing. The erosion pavement which is prevalent in most rangeland areas of the Southwest may be as important for controlling erosion as vegetative terms. Experiments are needed to evaluate this premise.

REFERENCES CITED

Langbein, W.B., and S.A. Schumm, "Yield of Sediment in Relation to Mean Annual Precipitation". Am. Geophys. Union Trans. 39:1076-1084, (1958).

Osborn, H.B., and L.J. Lane, "Depth-Area Relationships for Thunderstorm Rainfall in Southeastern Arizona". Trans. ASAE, 15(4):670-673, (1972).

Osborn, H.B., L.J. Lane, and J.F. Hundley, "Optimum Gaging of Thunderstorm Rainfall in Southeastern Arizona". Water Resources Research, 8(1):259-265, (1972).

Osborn, H.B., and E.M. Laursen, "Thunderstorm Runoff in Southeastern Arizona". Proc. ASCE 98(HY7):1129-1145, July, (1972).

Roehl, J.W., "Sediment Source Areas, Delivery Ratios, and Influencing Morphological Factors". International Association Science Hydrology, Pub. No. 59, pp. 202-213, (1963).

Smith, R.E., and H.A. Schreiber, "Point Processes of Seasonal Thunderstorm Rainfall Events". Water Resources Research 9(4): 871-884, (1973).

Soil Conservation Service, USDA, "Procedure for Computing Sheet and Rill Erosion on Project Areas". Tech. Release No. 51, Geology, September, (1972).

Wischmeier, W.H., C.B. Johnson, and B.V. Cross, "A Soil Erodibility Nomograph for Farmland and Construction Sites". Journal of Soil and Water Conservation, 26(5):189-192, Sept.-Oct., (1971).

Wischmeier, W.H., and D.D. Smith, "Rainfall Energy and its Relationship to Soil Loss". Trans. American Geophys. Union., 39(2):285-291, April, (1958).

Wischmeier, W.H., and D.D. Smith, "Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains". Agr. Handbook 282, U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C., (1965).