

Proceedings of the Workshop on
ESTIMATING EROSION and SEDIMENT YIELD
on RANGELANDS
Tucson, Arizona
March 7-9, 1981



U.S. Department of Agriculture
Agricultural Research Service

Agricultural Reviews and Manuals • ARM-W-26/June 1982

THE USLE RAINFALL FACTOR FOR SOUTHWESTERN U.S. RANGELANDS

J. R. Simanton and K. G. Renard^{1/}

INTRODUCTION

Mass thunderstorms, occurring primarily during the summer months of rough September, dominate the rainfall/runoff/erosion relationships in the rangeland areas of the Southwest (for high mountain ranges, snow-significant). To estimate the erosion associated with such areas, the Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is being used to estimate the climatic variability and the potential erosion due to raindrop

The air-mass thunderstorms in the region are typically highly variable in time and space, of limited areal extent, and of short duration. About 11 in. of the annual 12 in. of precipitation occurs during this summer thunderstorm season in southeastern Arizona and central New Mexico respectively.

The Southwest Rangeland Watershed Research Center of USDA's Science and Conservation Administration has conducted research on several experimental watersheds in Arizona and New Mexico which has included the use of numerous recording gauges (Fig. 1). Data from these locations are used in this paper to estimate the rainfall erosion index (product of the kinetic energy and 30-min intensity) to illustrate the extreme temporal and spatial variability of the USLE rainfall erosion index (EI). Finally, a method is proposed for estimating the average annual rainfall erosion index (R) when data are not available but when the 2-yr frequency 6-hr duration precipitation can be esti-

Temporal Variability

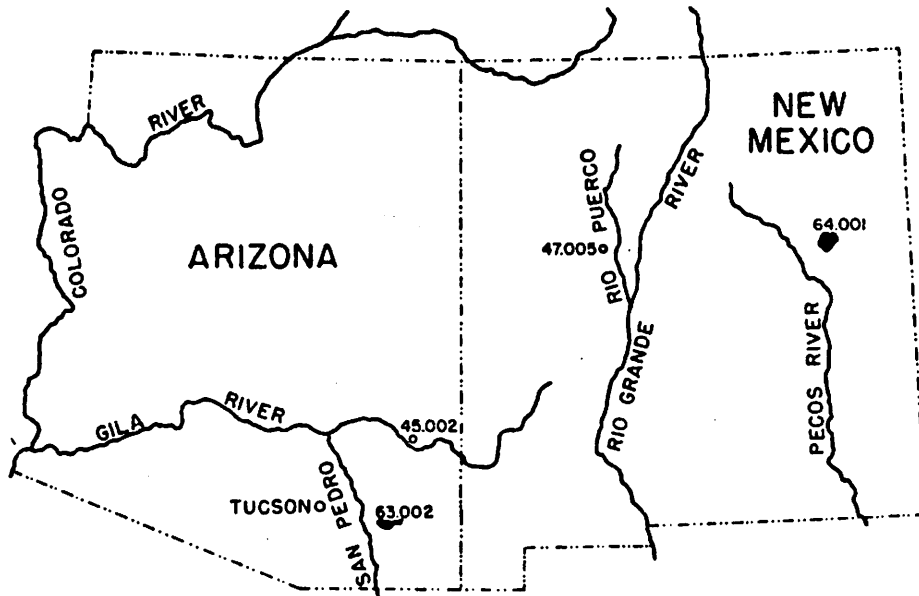
The extreme temporal variability of EI on the four areas studied is found daily, seasonally, and within a single storm (Renard and Simanton, 1975, Simanton et al., 1980). Total annual EI for one long-term rainfall record from

four different watershed locations is plotted versus probability in Figure 2. The steepness of the fitted lines indicates extreme annual variability in annual EI variability is even more dramatic when compared to the precipitation variability (Fig.3). For example, the coefficient of variability (CV) for rainfall is 0.27, whereas that for EI is 0.67.

The average annual rainfall erosion index (R), the coefficient of variability and percent of annual EI contributed by summer storms at each of the

Hydrologist and Hydraulic Engineer, USDA-SEA-AR, Southwest Rangeland Watershed Research Center, 442 East Seventh Street, Tucson, AZ 85705.

gages shown in Fig. 2 are listed in Table 1. Seasonal EI variability is more pronounced when summer EI values are plotted versus probability (Fig. 3). The CV for only the summer storms' EI on Walnut Gulch is 0.74, whereas the is 0.67 for the annual rainfall EI. Summer thunderstorms are most important rangeland erosion studies.



LOCATION OF EXPERIMENTAL WATERSHEDS

- SAFFORD, ARIZONA (LOCATION 45)
- ALBUQUERQUE, NEW MEXICO (LOCATION 47)
- WALNUT GULCH nr TOMBSTONE, ARIZONA (LOCATION 63)
- ALAMOGORDO CREEK nr SANTA ROSA, NEW MEXICO (LOCATION 64)

- NOTE -
LAST THREE DIGITS DENOTE RAINGAGE NUMBER

Figure 1.--Location map of the four experimental watersheds.

A single storm can contribute a large portion of the annual rainfall variability. For example, the largest storm within a year was observed to account for 76, 74, 66, and 85% of the annual EI for the Walnut Gulch (WG), Safford (Saff), Alamogordo Creek (AC), and Albuquerque (Albq) locations, respectively (Fig. 5). The bar graphs of Fig. 5 not only illustrate the largest storm contribution to the annual EI for each of the watershed locations but also exemplify the annual EI variability. We found, in a study conducted on small watersheds on WG, the largest storm contributed, on the average over a 7-yr period, 58% to annual soil loss. The average contribution of the largest storm to the annual EI for this same period was 41%. Also, as another example of the importance of a large storm, the maximum storm EI's at Safford in 1943, 1944, and 1961 were larger than the annual EI's for the remaining 22 yr of record. Similar results were found at the other locations. Although the USLE is not intended to estimate soil loss on a per-storm basis, this largest storm may be the most significant factor in annual soil loss.

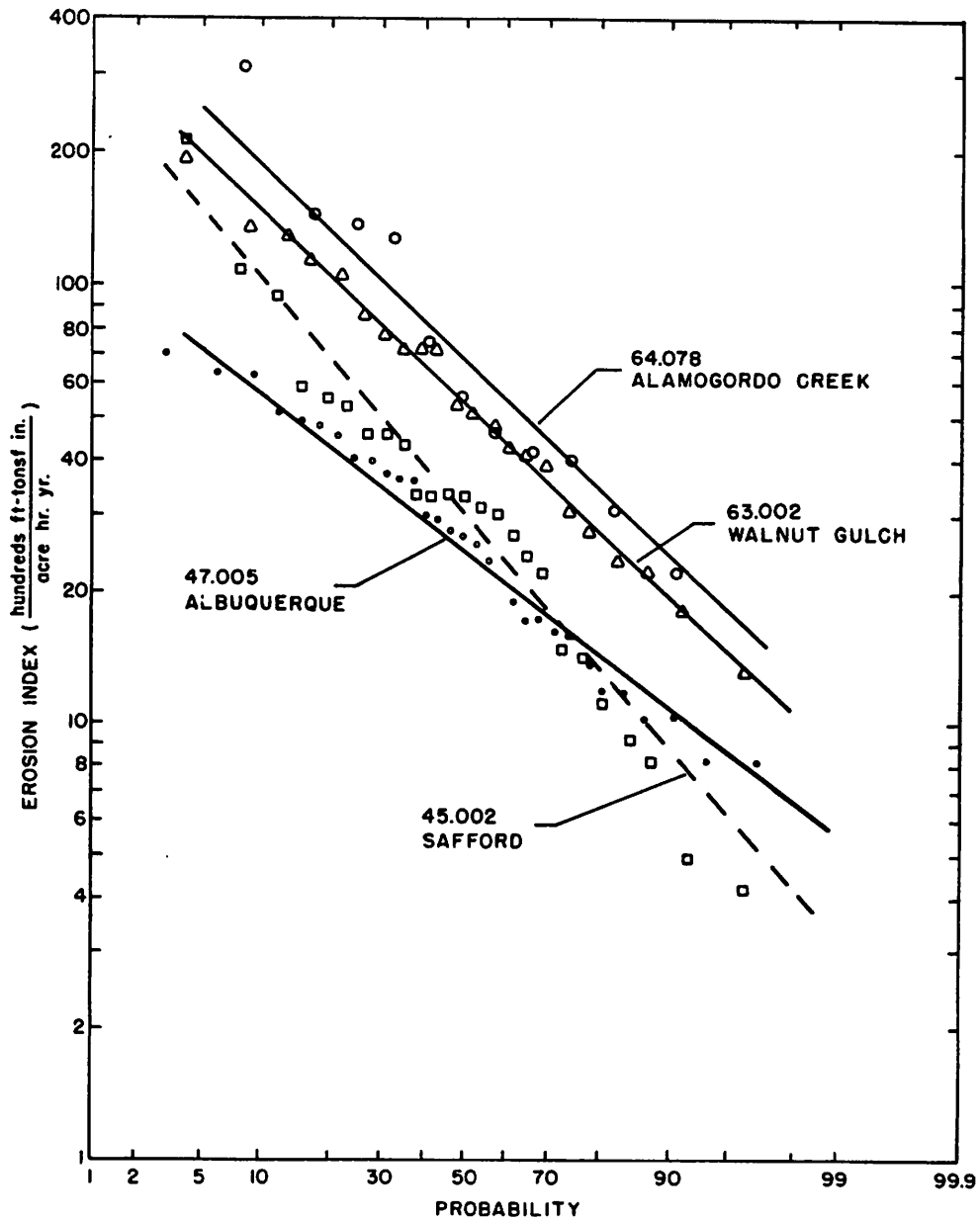


Figure 2.--Log-normal probability of erosion index for long-term annual rainfall records from each of the studied watersheds.

Table 1.—Average annual R factor, coefficient of variability, and percent summer contribution of four Southwestern U.S. watersheds.

Location	Average annual R	Coefficient of variability	Summer EI Contribution (% of annual)
WG	64	0.67	91
Safford	42	1.04	85
AC	81	0.83	93
Albq.	30	0.58	90

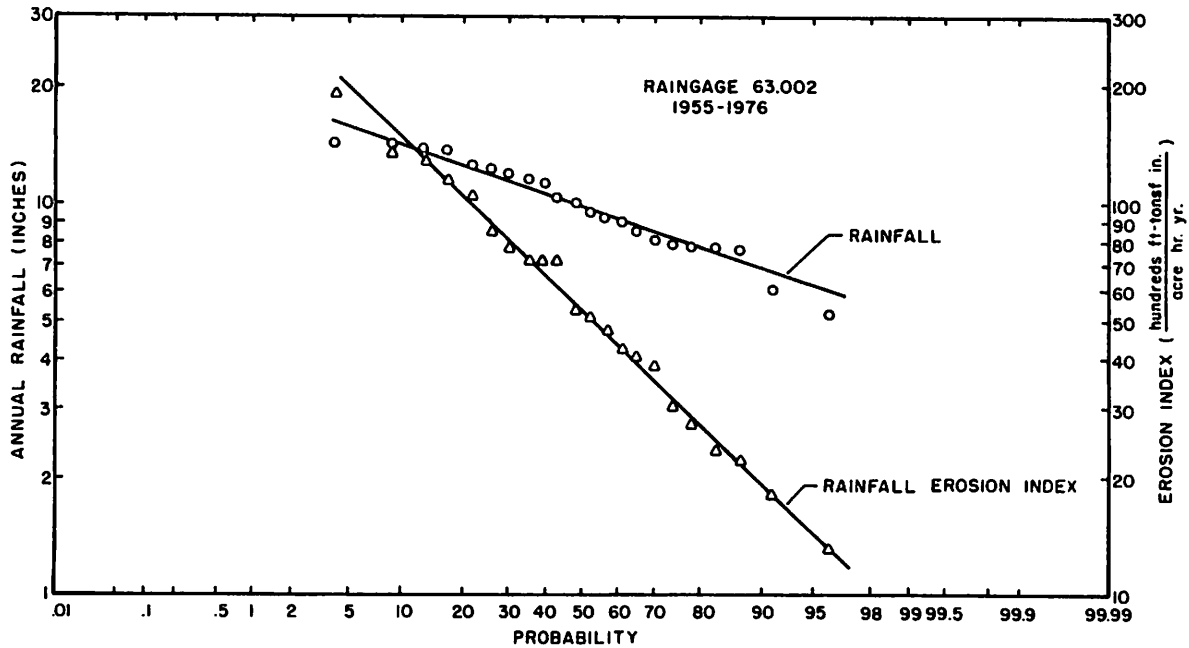


Figure 3.--Log-normal probability of rainfall and erosion index for one raingage on the Walnut Gulch experimental watershed.

Three storms were selected from the summer thunderstorm data from the WC and AC watersheds to illustrate the temporal EI variability within a single storm. The storm data are plotted in dimensionless form in Fig. 6. Because EI computation is based on maximum 30-min rainfall intensity, most of the EI units are derived from a relatively short, high-intensity portion of the storm. Thus, in thunderstorm dominated precipitation areas, such as the rangelands of Arizona and New Mexico, records from recording rain gages with depths for short time intervals must be used to compute storm EI. Standard rain gage data or hourly precipitation values may greatly underestimate EI. However, these are the type of data most widely available in the southwestern United States. Of the 280 reporting weather stations in Arizona, only 12% use recording gages, and data from these are generally available for only hourly depths. If these recording gages were evenly spaced throughout the state, each gage would represent the rainfall pattern of 3500 mi². Osborn et al. (1972) reported that to describe the rainfall patterns of the 58-mi² Walnut Gulch Watershed, 1000 gages would be needed to have a correlation of 0.9 between adjacent gages.

Total rainfall and EI from one raingage at each of the four watersheds were correlated to determine the feasibility of using a total rainfall term instead of energy-related rainfall factor in the USLE (Table 2). The results of this analysis are not encouraging. Wischmeier and Smith (1958) reported the correlation coefficient increased from 0.68 to 0.82 when they used EI rather than total rainfall for correlation with erosion data on a Shelby soil.

Table 2.—Correlation of total-rainfall and erosion index.

Location	r	n
WG (63.002)	0.79	19
Safford (45.002)	0.75	25
AC (64.078)	0.64	11
Albq. (47.005)	0.61	30

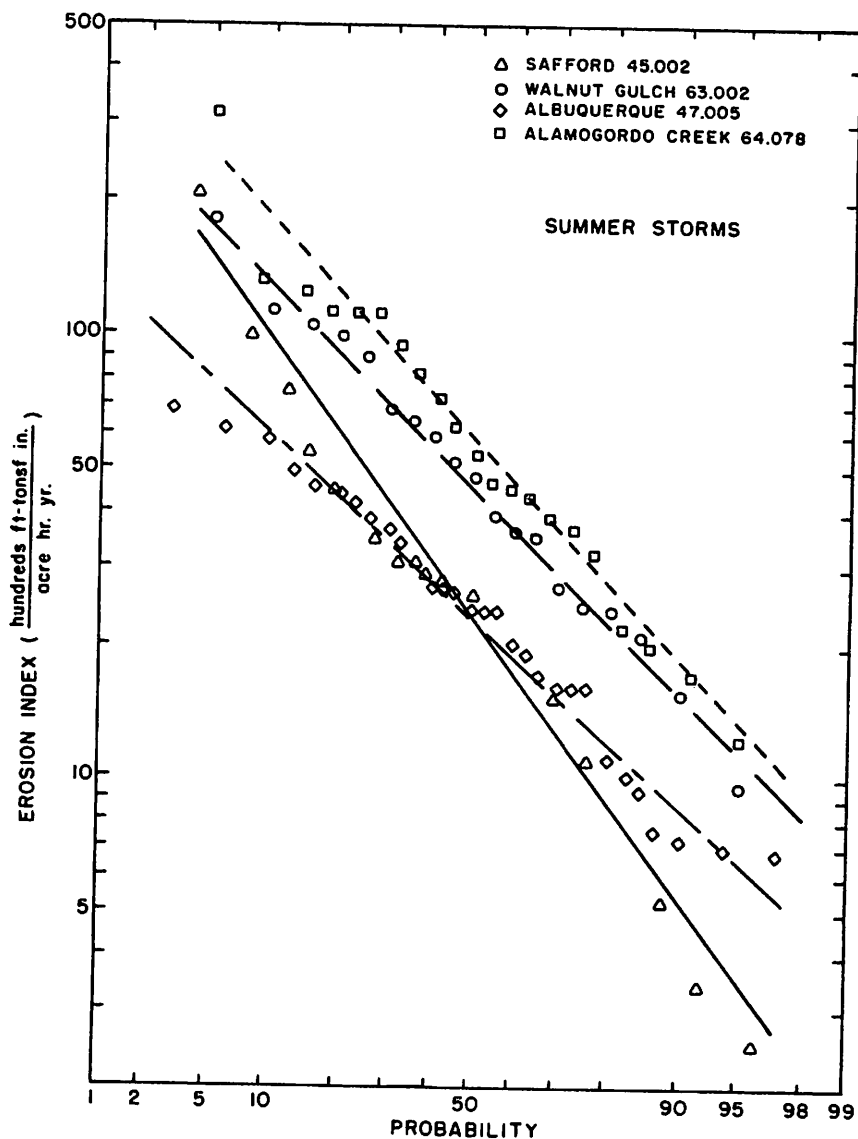


Figure 4.--Log-normal probability of erosion index for long-term summer rainfall records from each of the studied watersheds.

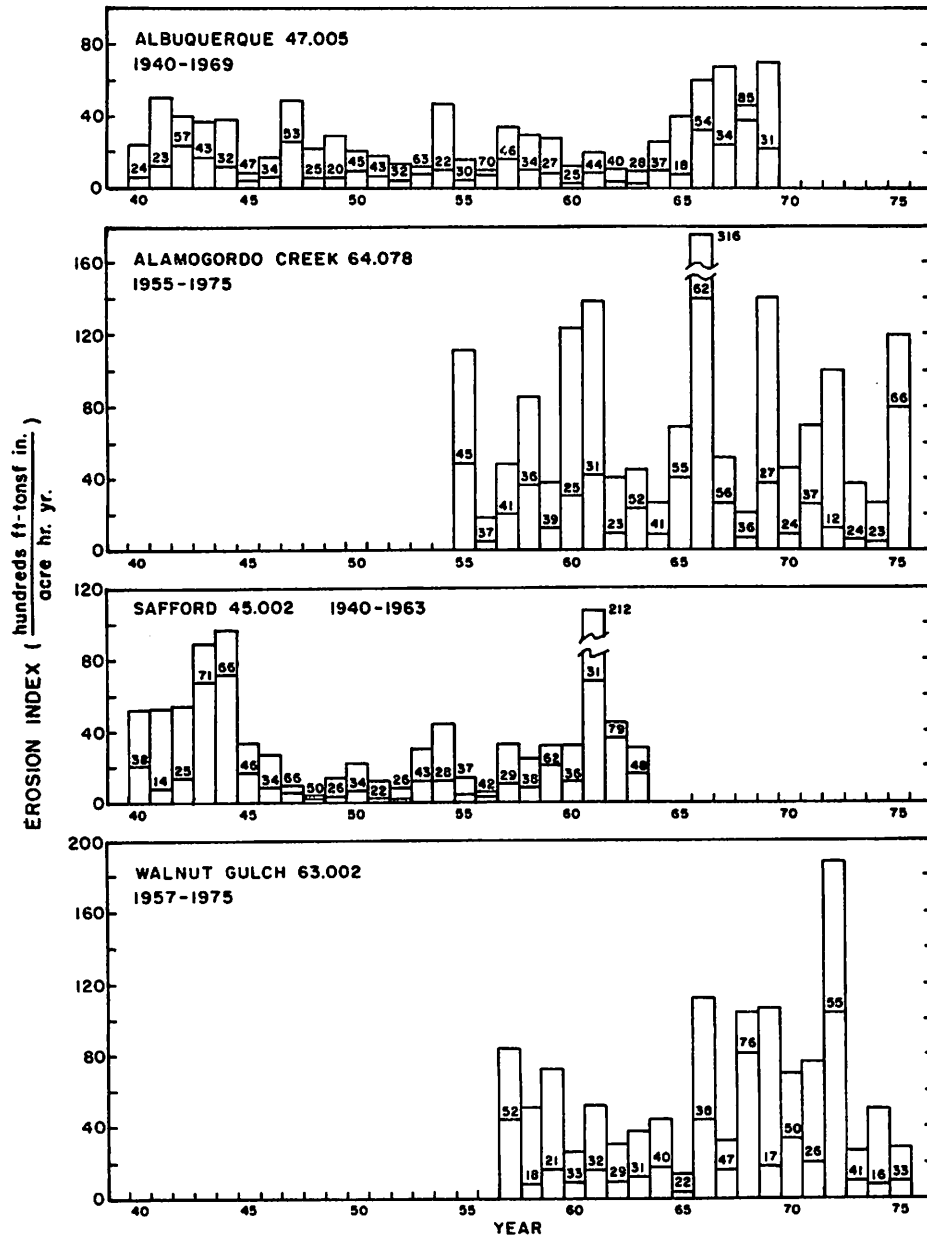


Figure 5.--Annual erosion index, largest storm-erosion index, and percent contribution of the largest storm to the annual erosion index (values in bars represent percent of annual contributed by largest storm).

Spatial Variability

Spatial variability of EI associated with thunderstorm rainfall is illustrated using isoerodent maps for individual storms and years. The raingage networks of the WG and AC watersheds were used to produce the

shown in Figures 7, 8, 9, and 10. The July 22, 1964 storm on WG lasted less than an hour with almost 1.8 in of rain falling in 20 min at the storm center. The storm EI decreases from 100 near the storm center to about 30 in a radius of about 2 mi. Results are similar for most thunderstorms at this location.

The isoerodent map for the June 16, 1966 storm on the AC watershed illustrates single storm EI for one of the largest events recorded at this location. The storm lasted slightly over 2 hr and produced almost 3 in of rainfall in 30 min at the storm center. The EI varied widely with almost 260 units at the storm center to only 10 units 4 mi away.

Such spatial variability from individual storms leads to the expectation of extreme annual variability. Figures 9 and 10 illustrate the annual variability for WG and AC for the same years used to illustrate individual storm variability (1964 and 1966). In general, highs and lows of both precipitation and EI agreed for both areas, although EI unit per unit of rainfall differed. At the lowest annual rainfall depth on WG there were 3 EI units per in of

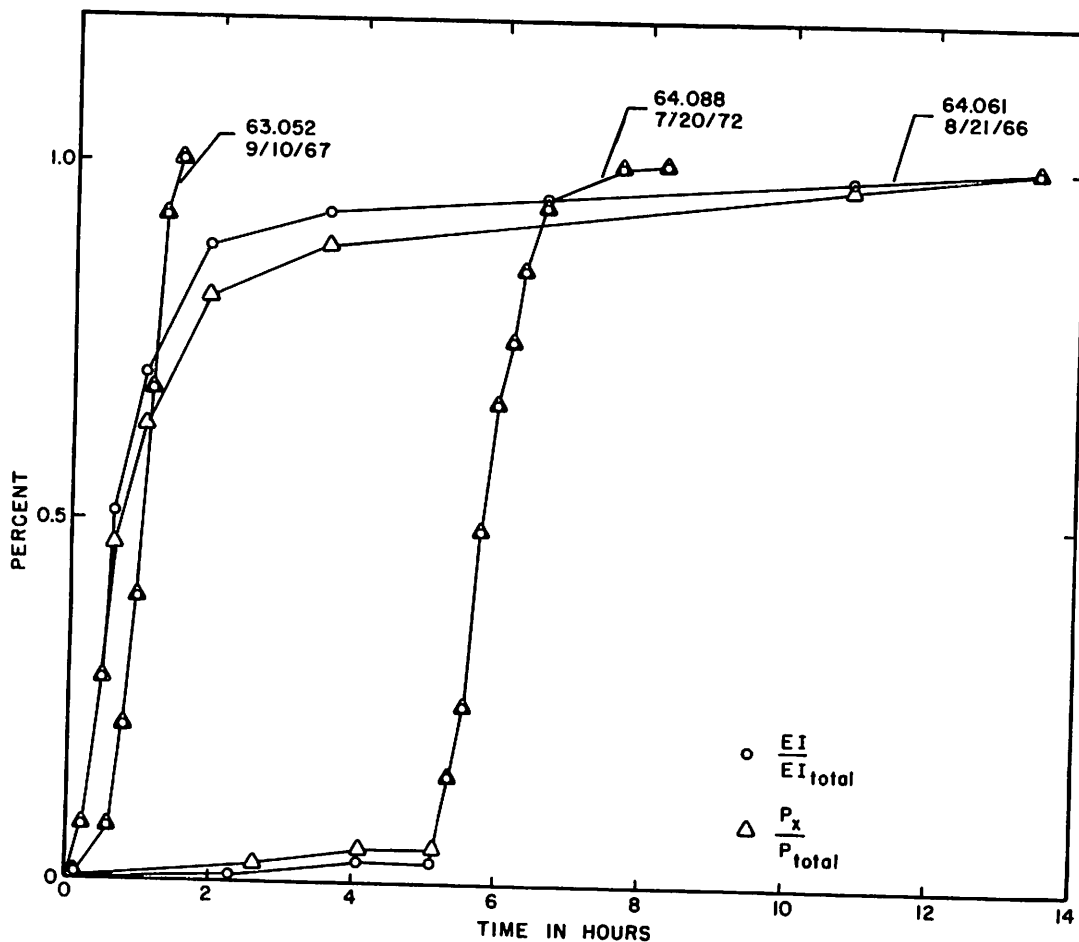


Figure 6.--Comparison of dimensionless precipitation and rainfall-erosion index for three select storms on Walnut Gulch (63.052) and Alamogordo Creek (64.008 and 64.061) (From Renard and Simanton, 1975).

precipitation, whereas AC had 6 EI units per in of precipitation. For the imum annual rainfall depth there were 15 EI units per in rainfall on WG an on AC. This points out that the record from a single gage yields a value that point only and the results should not be extrapolated more than about a mile to estimate the erosion from a storm or for an individual year. For sion studies being conducted on small watersheds in the Southwest, it is recommended that a recording raingage be located within 0.3 mi (Osborn et 1979).

Frequency Analysis

Analysis of southeastern Arizona rainfall data has shown that a log-normal distribution generally fits the data quite well (Reich and Renard 1981). The same has been observed for the rainfall EI. The 2-yr EI (50% probability

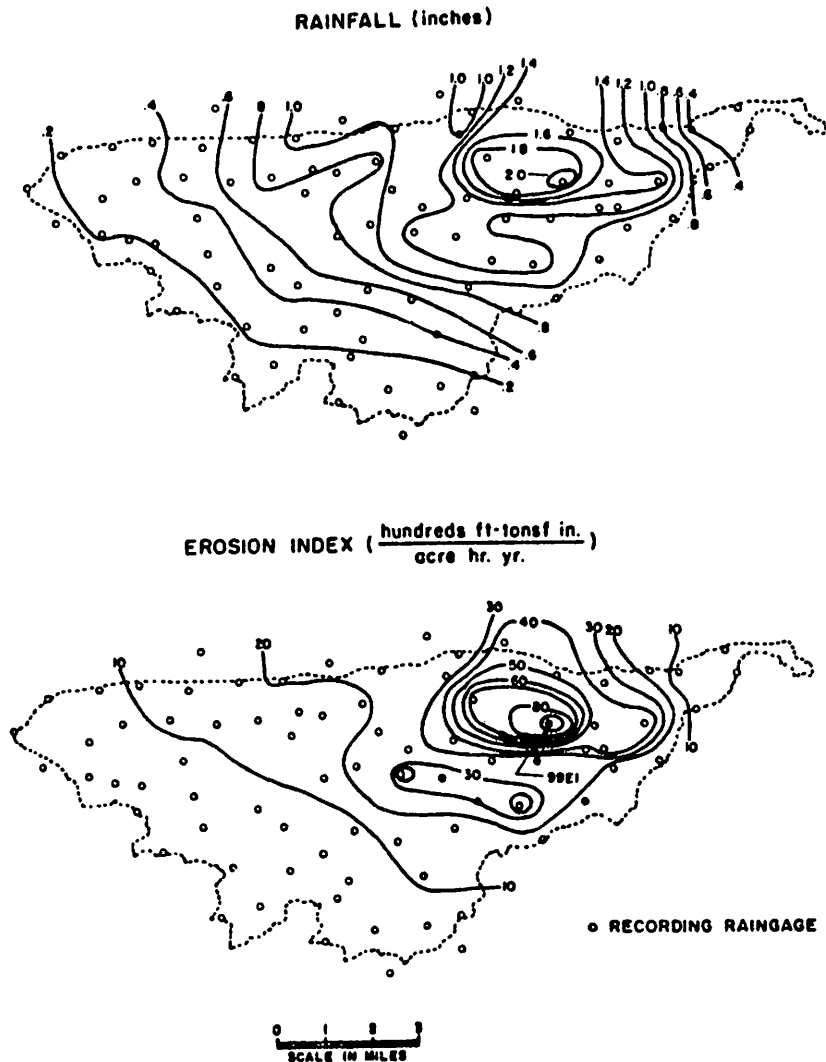


Figure 7.--Isohyetal and isoerodent maps for the July 22, 1964 storm on the Walnut Gulch experimental watershed.

four watersheds are listed in Table 3. Included in this table are estimated 2 yr EI values using various prediction equations and NOAA Atlas II (Miller et al. 1973) estimates of 2-yr 6-hr rainfall. Figure 11 shows, graphically, the predicted EI of the three equations given the 2-yr 6-hr rainfall.

Table 3.—Actual and predicted average annual EI values using NOAA Atlas II rainfall values and three EI prediction equations.

Location	NOAA 2-yr-6-hr Rainfall (in)	Actual 2-yr EI*	Predicted EI <u>1/</u>	Predicted EI <u>2/</u>	Predicted EI <u>3/</u>
<u>WG</u>					
(.002)	1.4	54	57	57	47
(.022)	1.5	58	66	66	53
(.042)	1.5	56	66	66	53
(.060)	1.6	64	76	76	58
<u>Safford</u>					
(.002)	1.2	30	40	41	37
(.005)	1.3	38	48	48	42
(.009)	1.3	39	48	48	42
(.014)	1.4	48	57	57	47
<u>AC</u>					
(.026)	1.8	68	98	98	71
(.037)	1.8	70	98	98	71
(.067)	1.9	76	111	110	77
(.078)	1.8	68	98	98	71
<u>Albuq.</u>					
(.005)	1.0	25	27	27	27

*EI = $\frac{\text{hundreds ft. tonsf in}}{\text{acre hr yr}}$ from 50% probability from Figure 2 and similar figures.

$\frac{1}{EI} = 27(P_6)^{2.2}$ $P_6 = 2 \text{ yr-6 hr rainfall in inches (Ateshian 1974)}$.

$\frac{2}{EI} = 27.38(P_6)^{2.17}$ (Wischmeier 1974).

$\frac{3}{EI} = 27.23(P_6)^{1.62}$ from log-log fit of 2-yr 6-hr rainfall and actual 2-yr EI.

The predicted EI values of the first two equations are in considerable error. However, the predicted EI values, using the regionally developed equation, are very close to the actual EI values. The third equation ($EI = 27.23(P_6)^{1.62}$) was developed using NOAA Atlas II 2-yr 6-hr rainfall values and actual EI values for four widely-spaced raingages on each of the WG, AC, and Safford watersheds and one recording raingage on the Albuquerque watershed. This regionally developed equation is essentially an equation that represents a thunderstorm-dominated rainfall input and, perhaps, could be extended to other areas where thunderstorms dominate the rainfall input.

SUMMARY

Estimating the rainfall erosivity factor for rangelands of the southwestern United States is very difficult because of the thunderstorm dominated hydrology. The EI values vary tremendously, both in time and space, and, on an annual basis, can be dominated by just one storm. Rainfall records from a single recording raingage can be used to estimate the EI only for the area within 0.3 mi radius of that point. Because EI computation is based on maximum 30-min rainfall intensity, most of the EI units are derived from the relatively short, high-intensity portion of the thunderstorm. Thus, in thunderstorm dominated rainfall areas such as Arizona and New Mexico, recording raingages with depths

for short time intervals are needed to compute storm EI. An EI predict equation that is based on widely available precipitation frequencies was developed for the thunderstorm-dominated regions of Arizona and New Mexico. This equation might also be used in other regions where thunderstorm rainfall dominates the hydrologic and erosion processes.

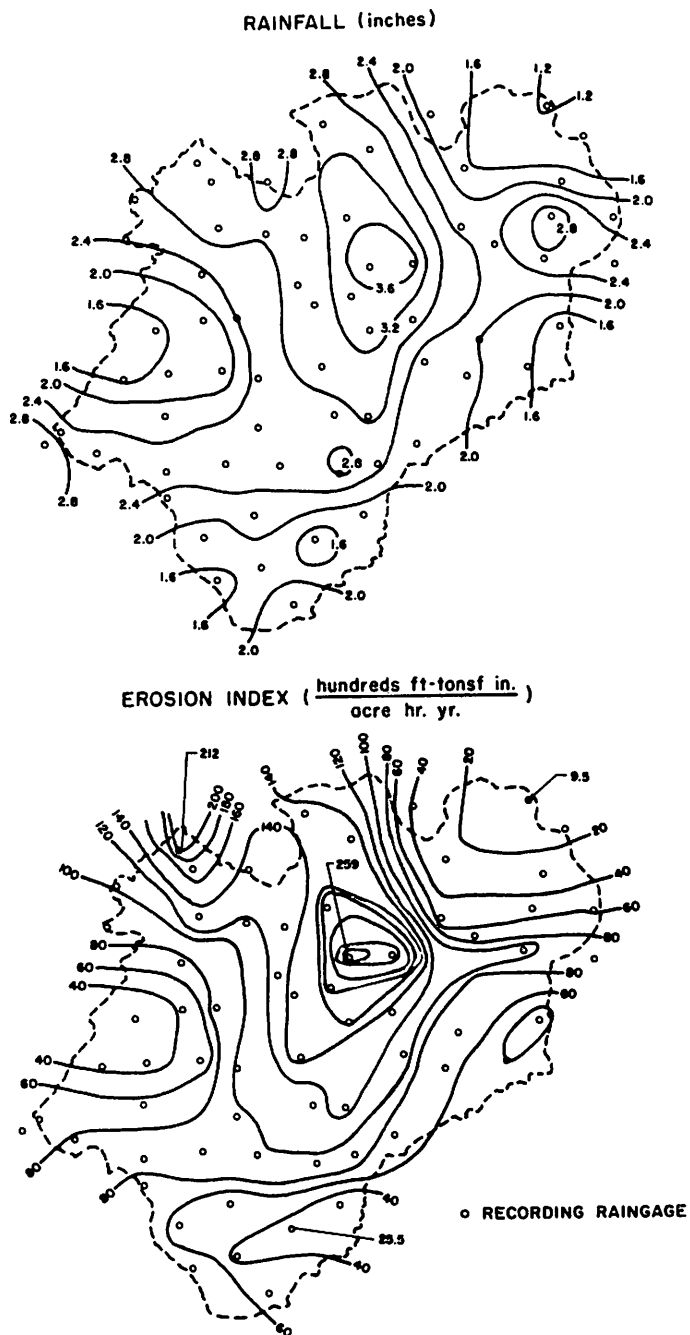


Figure 8.--Isohyetal and iserodent maps for the July 16, 1966 storm on the Alamogordo Creek experimental watershed.

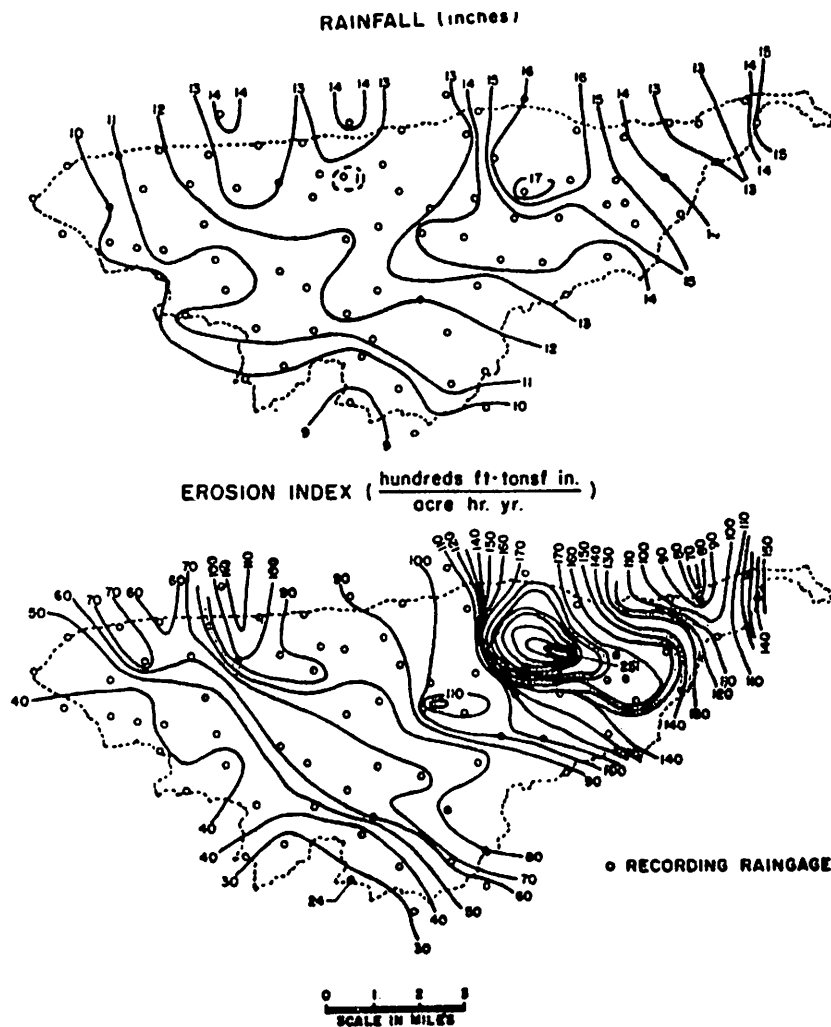


Figure 9.--Isohyetal and isoerodent maps for the 1964 annual totals on the Walnut Gulch experimental watershed.

REFERENCES

- hian, J. K. H.
74. Estimation of rainfall erosion index. J. Irrig. and Drain. Div., ASCE 100(IR3):293-307.
- er, J. F., Frederick, R. H., and Tracey, R. J.
73. Precipitation frequency atlas of the western United States. IV: New Mexico, and VIII: AZ. NOAA Atlas 2, National Weather Service. NOAA, Silver Spring, MD.
- rn, H. B., Lane, L. J., and Hundley, J. F.
72. Optimum gaging of thunderstorm rainfall in southeastern Arizona. Water Res. Research, AGU 8(1):259-265.
- rn, H. B., Renard, K. G., and Simanton, J. R.
79. Dense networks to measure convective rainfall in the southwestern United States. Water Resources Research 15(6):1701-1711.

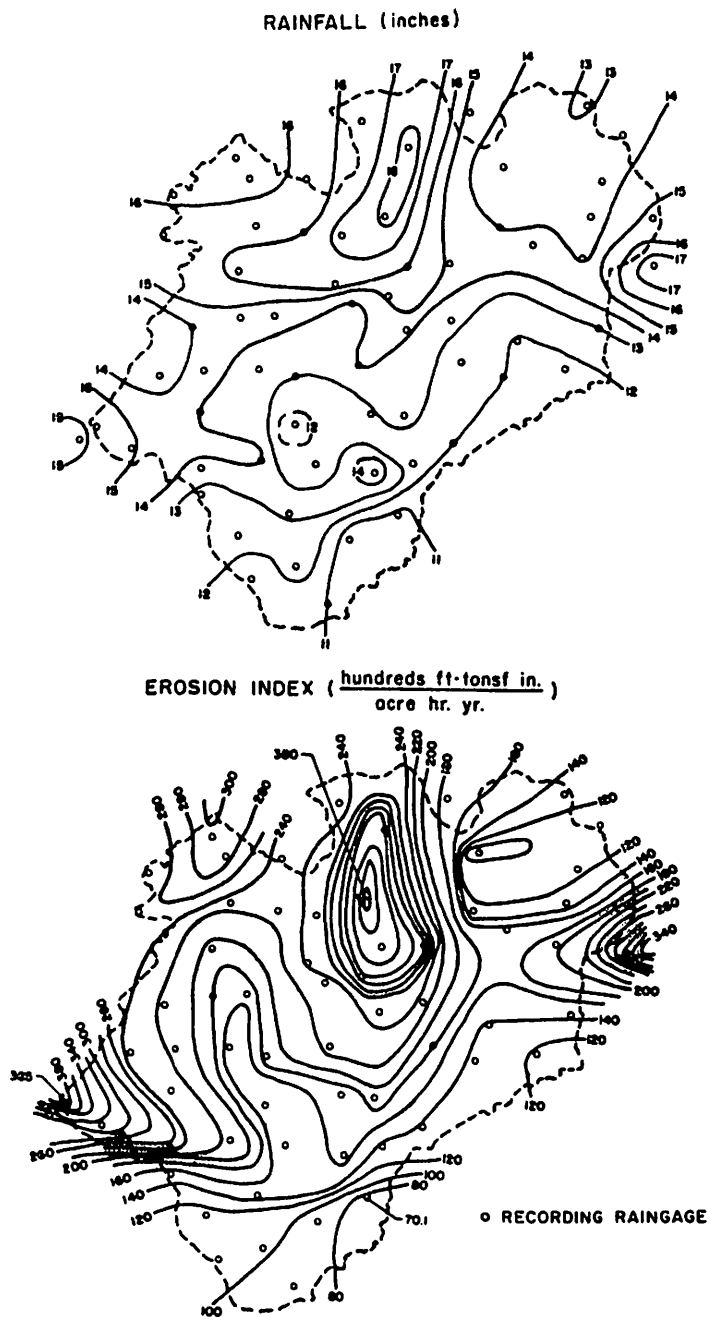


Figure 10.--Isohyetal and isoerodent maps for the 1966 annual totals on the Alamogordo Creek experimental watershed.

Reich, B. M., and Renard, K. G.

1981. Application of advances in flood frequency analysis. *Water Resour. Bulletin, Am. Water Res. Assoc.* 17(1):67-74.

Renard, K. G., and Simanton, J. R.

1975. Thunderstorm precipitation effects on the rainfall-erosion index in the universal soil loss equation. *Proc. Ariz. Sec., Am. Water Resour. Assoc., Hydrol. Sec., Ariz. Acad. Sci.* 5:47-54.

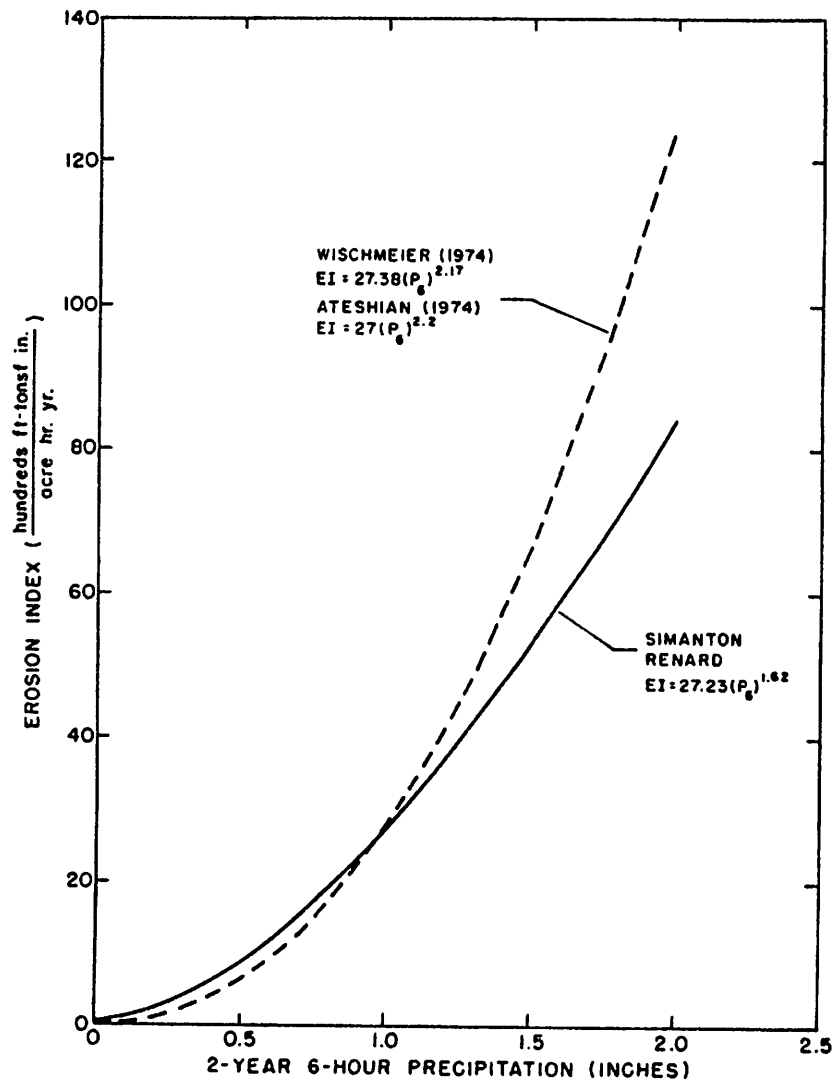


Figure 11.--Erosion index prediction from three equations using the 2-yr 6-hr rainfall.

Simanton, J. R., Osborn, H. B., and Renard, K. G.

1980. Application of the USLE to southwestern rangelands. Proc. Ariz. Sec. Am. Water Resource Assoc. Hydrol. Sec., Ariz. Acad. Sci. 10:213-220.

Wischmeier, W. H.

1974. New developments in estimating water erosion. Proc. 29th Annual Meeting, Soil Cons. Soc. Am., Ankeny, IA. p. 179-186.

Wischmeier, W. H., and Smith, D. D.

1958. Rainfall energy and its relationship to soil loss. Am. Geo. Union Trans. 39:285-291.

Wischmeier, W. H., and Smith, D. D.

1978. Predicting rainfall erosion losses.--A guide to conservation planning. U.S. Dept. of Agric., Agric. Handbook No. 537.