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# THUNDERSTORM PRECIPITATION EFFECTS ON THE RAINFALL-EROSION INDEX OF THE UNIVERSAL SOIL LOSS EQUATION

by

Kenneth G. Renard and J. Roger Simanton

The Universal Soil Loss Equation (USLE) is widely used for estimating annual and individual storm erosion from field-sized watersheds. The equation, which was developed from thousands of plot years of data and from rainfall simulation runs, accounts for most soil, vegetation, climate and cultural practices that affect erosion. Wide field testing has demonstrated that this is an excellent method for estimating erosion on small areas (Renard, Simanton, and Osborn, 1974).

Predictive equations are based on indices of measureable factors. Consequently, the prediction is no better than the measured indices. The Universal Soil Loss Equation is given in equation 1 as:

$$A = RKLSCP \qquad (1)$$

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.

Of the six variables of the USLE, the rainfall factor is perhaps the most difficult to describe in terms of distribution and probability in basin and range topography that has orographic influences. An additional complication is the unpredictability of the air-mass thunderstorm, which is characterized by high intensity, short duration, and limited areal extent. Such storms produce most of the runoff (except for snowmelt on the highest mountain areas) in the semiarid southwest. Since thunderstorm precipitation varies widely in space and time, a method to estimate the average annual erosion it causes is difficult to develop.

Wischmeier and Smith (1965) presented an iso-erodent map of the United States for areas east of the 104th meridian. For locations west of the 104th meridian, erosion index (EI) values must be computed from rainfall data or estimated with some predictive scheme. Ateshian (1974) attempted to define the rainfall pattern and the resulting EI of the entire United States with two distribution graphs. He then developed prediction equations for annual EI based on the 2-year frequency, 6-hour rainfall depth. Renard (1975) and Renard and Simanton (1975) showed that rainfall patterns of two watersheds in the southwest do not fit the curves presented by Ateshian and that prediction equations generally underestimate actual EI values. These studies and others have shown that rainfall variability is a major factor in the hydrology of the semiarid southwest.

Experimental watersheds of the Southwest Watershed Research Center are used to illustrate the rainfall EI variability in Arizona and New Mexico (Figure 1). The EI in all instances was computed using the procedure described by Wischmeier and Smith (1958) for precipitation data digitized from charts collected from continuous recording rain gages. Breakpoint depth readings are made using an analog-to-digital converter at intensity changes reflected in the cumulative trace. By using this procedure, the intensity at gage locations can be estimated fairly accurately for time intervals of 2 minutes and longer (Renard and Osborn, 1966; Sutter, et al., 1972).

## SPATIAL VARIABILITY

Spatial variability in rainfall from air-mass thunderstorms has been extensively documented (e.g., Osborn and Renard, 1969). The isohyetal map for a storm on July 22, 1964, on the Walnut Gulch Experimental Watershed shows the high intensity portion of this storm, which lasted less than an hour, with almost 1.8 inches of rain falling in 20 minutes at the storm center. As would be expected, the EI for this storm is also quite varied (Figure 2), decreasing from 100 units near the storm center to about 30 units in a radius of about 2 miles. Results are similar for most storms at this location.

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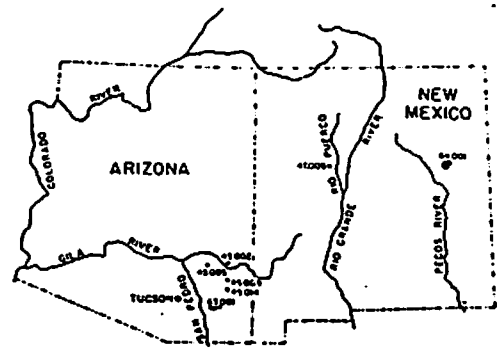
The authors are Research Hydraulic Engineer and Hydrologic Technician, respectively, United States Department of Agriculture, Agricultural Research Service, Western Region, Southwest Watershed Research Center, 442 East Seventh Street, Tucson, Arizona 85705.

FIGURE 1. Locations of rain gages referred to in this report.




LOCATION OF EXPERIMENTAL WATERSHEDS

SAFFORD, ARIZONA (LOCATION 43)
ALBUQUERQUE, NEW MEXICO (LOCATION 47)
WALNUT GULCH or TOMBSTONE, ARIZONA (LOCATION 63)
ALAMOGORDO CREEK or SANTA ROSA, NEW MEXICO (LOCATION 64)

-NOTE-
LAST THREE DIGITS DENOTES RAINGAGE NUMBER

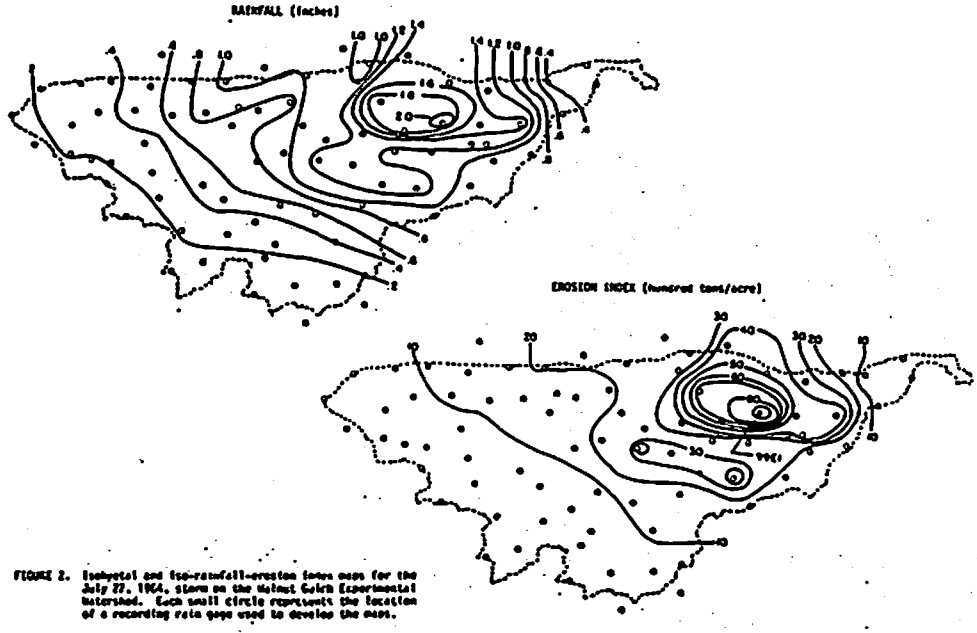



FIGURE 2. Isohyetal and iso-rainfall-erosion index maps for the July 27, 1964, storm on the Walnut Gulch Experimental Watershed. Each small circle represents the location of a recording rain gage used to develop the maps.

The isohyetal and iso-erodent index maps for the June 16, 1966, storm on the Alamogordo Creek Experimental Watershed are presented (Figure 3) to illustrate single-storm EI and precipitation variability. This storm, one of the largest measured by this precipitation network (Renard, et al., 1970), lasted slightly over 2 hours and produced almost 3 inches in 30 minutes at the storm center. As expected, the EI for this storm varied widely, from almost 260 units at the storm center to only 9.5 units in the northeast section of the 67-square-mile area. This storm occurred over most of the watershed, whereas most storms wet only a portion of the area.

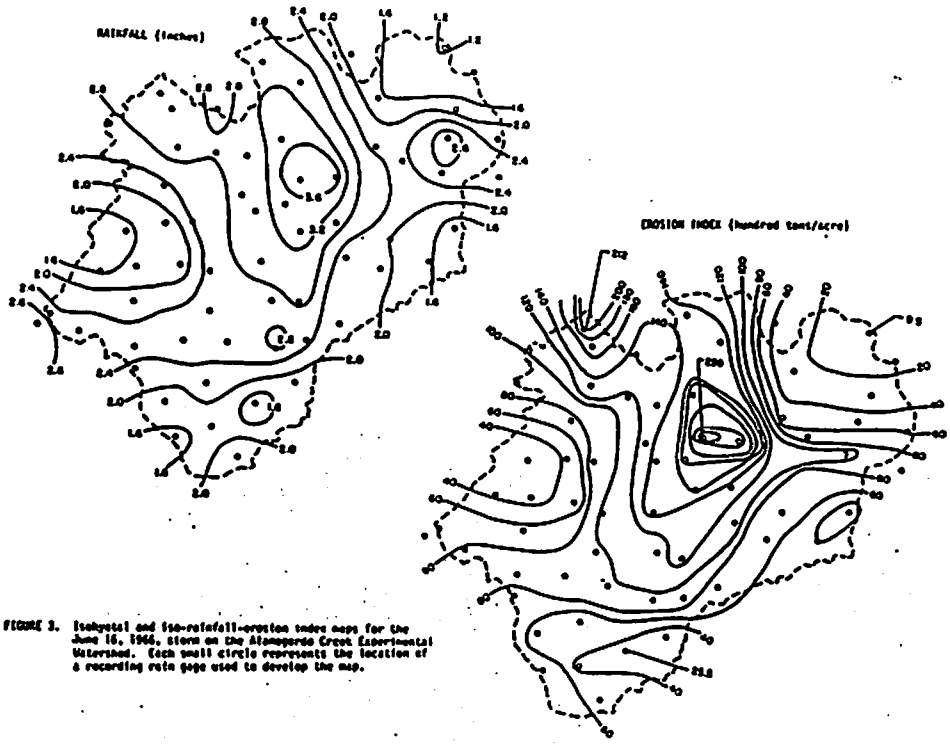



FIGURE 3. Isohyetal and iso-rainfall-erosion index maps for the June 16, 1966, storm on the Alamogordo Creek Experimental Watershed. Each small circle represents the location of a recording rain gage used to develop the map.

Such spatial variability from individual storms leads to the obvious expectation of appreciable annual variability in both precipitation and EI. Figures 4 and 5 illustrate the annual variability for Walnut Gulch and Alamogordo Creek, respectively, for the same years that were used to illustrate the individual storm varabilities. In general, highs and lows of both precipitation and EI agreed for both areas, although EI units per unit of rainfall differed. At the lowest rainfall depth on Walnut Gulch , there were 2.7 units of EI per inch of annual rainfall, whereas at the maximum rainfall depth, there were 14.8 units of EI per inch of annual rainfall. In other years at Walnut Gulch, the annual maximum precipitation depth has been almost twice the minimum depth, with no apparent pattern to the position of highs and lows on the watershed. For the lowest rainfall depth on Alamogordo Creek, there were 6.4 units of EI per inch of annual rainfall, whereas at the maximum rainfall depth, there were 21.1 units of EI per inch of annual rainfall.

Thus, we must conclude that the record from a single gage yields an EI value for that point only and the results should not be extended to more than about a mile to estimate the erosion from a storm or for an individual year.

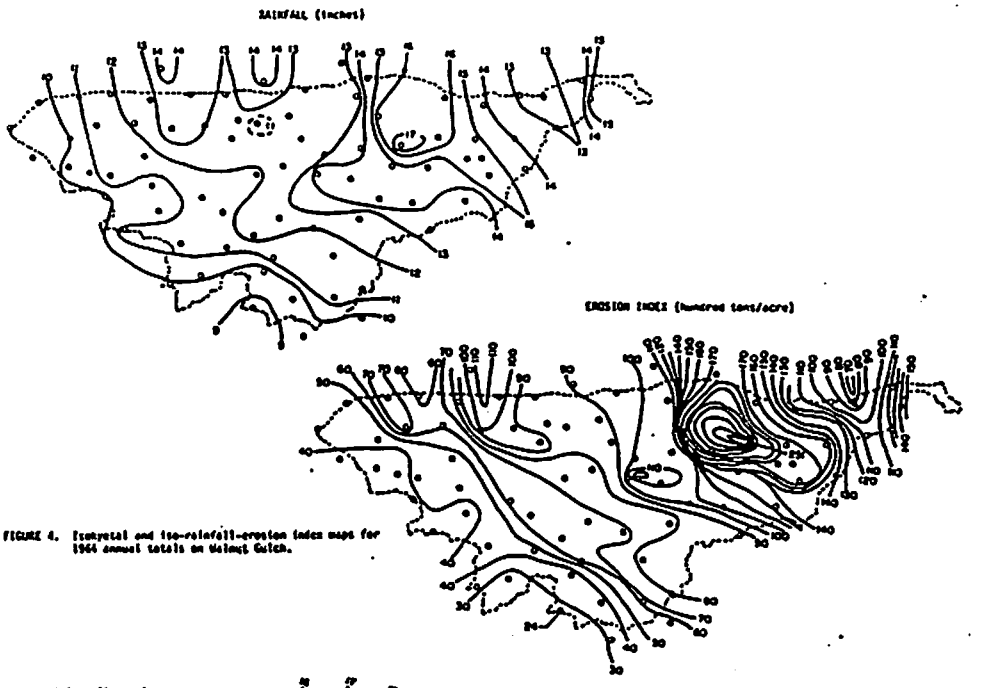



FIGURE 4. Isohyetal and iso-rainfall-erosion index maps for 1966 annual totals on Walnut Gulch.

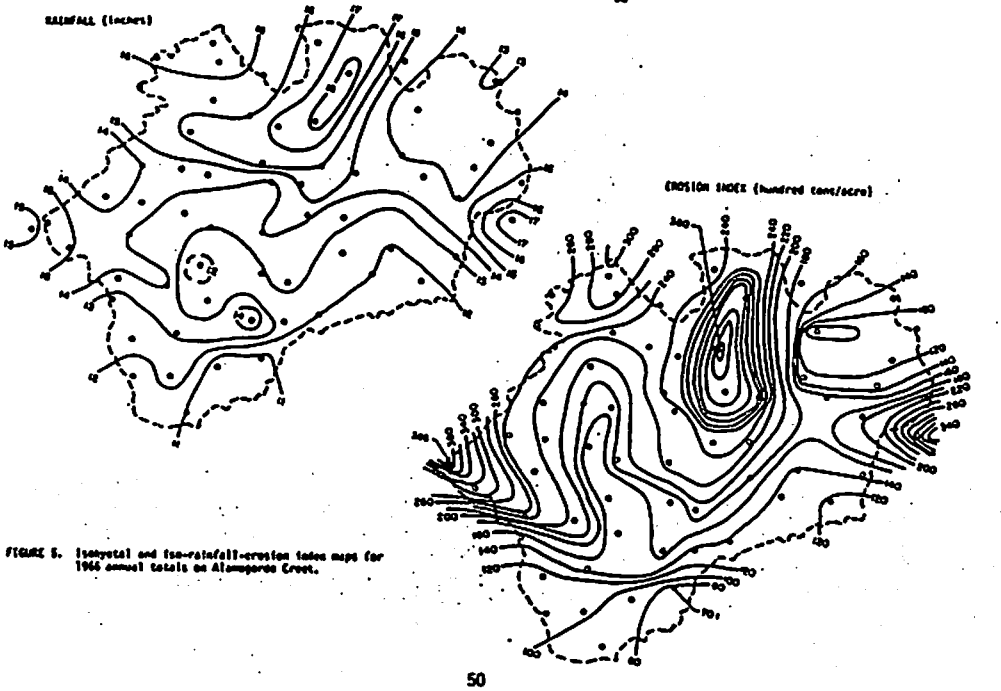



FIGURE 5. Isohyetal and iso-rainfall-erosion index maps for 1966 annual totals on Alamogordo Creek.

## TEMPORAL VARIABILITY

Because EI computation is based on maximum 30-minute rainfall intensity, most of the EI units are derived from a relatively short, high-intensity portion of the storm (Figure 6). The September 10, 1967, storm produced 3.45 inches of rainfall in only 86 minutes, and most of this fell in one hour. The dimensionless EI and rainfall points essentially coincided for this storm and for the July 20, 1972, storm. The first 5 hours and the last hour of the latter storm probably produced very little rainfall exceeding the infiltration rate and, therefore, most of the EI units did not result from these low intensities. The August 21, 1966, storm produced 5.46 inches of rainfall, lasted for 13.5 hours, and resulted from a thunderstorm superimposed on a slow-moving cold front. Of the 266 EI units resulting from this storm, almost 80% were produced during the first 2 hours, the period of highest intensity.

Thus, in thunderstorm dominated precipitation areas, such as Arizona and New Mexico, one must use recording rain gages with depths for short time intervals to compute the EI for the Universal Soil Loss Equation. Standard rain gages or hourly precipitation values may greatly underestimate the EI.

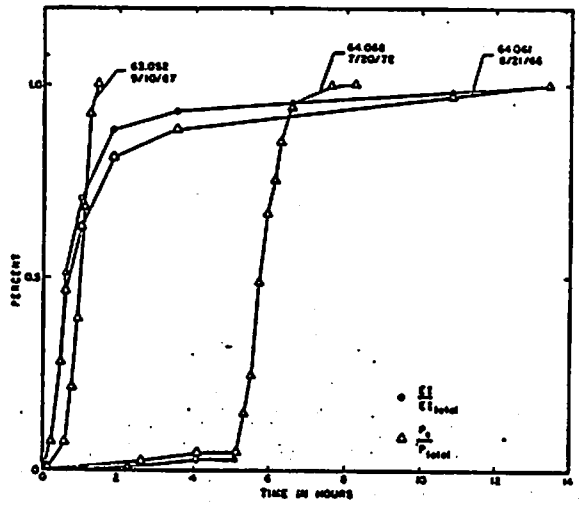



FIGURE 6. Comparison of dimensionless precipitation and rainfall-erosion index for three select storms on Walnut Gulch (63.052) and Alamogordo Creek (64.066 & 64.061). (From Renard and Simanton, 1975)

## PROBABILITY OF ANNUAL EI

Rain gage records from four experimental watersheds maintained by the Southwest Watershed Research Center were selected and EI computed for the entire rain gage record. The resulting data were ranked, plotted, and a least-squares straight line calculated to fit the data (Figures 7 and 8).

The two frequencies for the Walnut Gulch gages differ markedly even though the gages are only about 7 miles apart. In addition to appreciable differences in the mean EI (54 vs. 68), the standard deviations (or slope of the line) differ markedly. Less difference might be expected with longer records, even though the precipitation data indicate that thunderstorms occur randomly and that any difference in annual rainfall associated with elevation is mostly a winter phenomenon (Osborn, et al., 1972).

The Safford gages, 2, 5, 9, and 14, are on four small watersheds that are, respectively, 11 miles east, 5.8 miles west, 15.8 and 28.2 miles south of Safford. These four gages have similar 50% probability values for EI ranging from 26 to 37. That gage 2 had the lowest value probably reflects the slightly lower annual rainfall for that location.

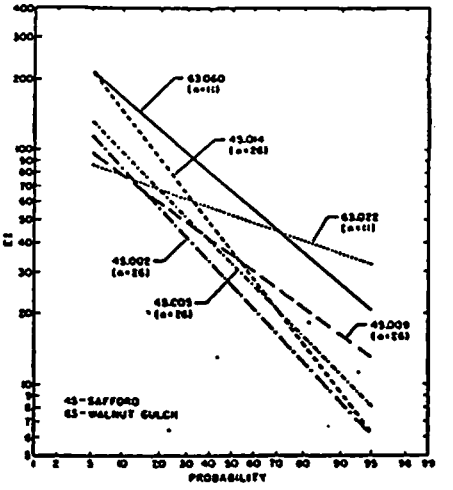



FIGURE 7. Log-normal probability distribution of the annual rainfall-erosion index for select rain gages on the Walnut Gulch and Safford Watersheds in Arizona. n refers to the record length used to compute the line.

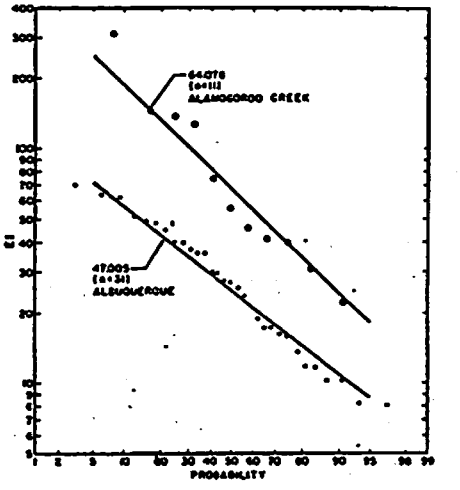



FIGURE 8. Log-normal probability distribution of the annual erosion index for a rain gage on the Albuquerque and Alamogordo Creek Watersheds. n indicates the number of years used to compute the line and each point represents the actual annual erosion index.

In New Mexico, the gage on the Albuquerque Watershed is 22 miles west of the city. Its EI, as do those from the other locations, closely fits a log-normal probability distribution. Such unusual storms (Figure 3) as have occurred on the Alamogordo Creek area have never been measured at Albuquerque. This accounts for the relatively low annual 25 EI units at the 50% probability.

The 50% probability EI value for gage 78 on Alamogordo Creek is 68. Although only one gage for Alamogordo Creek is shown, variation among gages on this 67-square-mile watershed matched that found on the Walnut Gulch Watershed.

## CONTRIBUTION OF THE LARGEST STORM TO THE ANNUAL EI

Unusual storms are very important in the amount of erosion they produce (Piest, 1963). Osborn and Renard (1969) observed that on semiarid watersheds, "individual exceptional storms produce as much surface runoff as several years of normal runoff." The single largest storm's contribution to the annual EI was investigated and reported (Figure 9) for one gage each on the Albuquerque and Safford Watersheds.

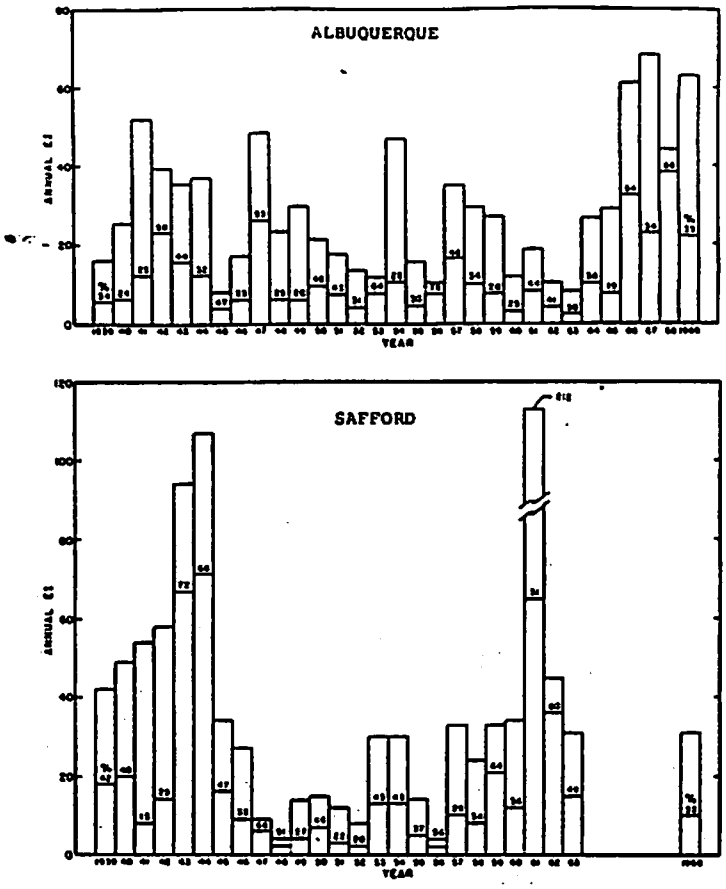



FIGURE 9. Annual rainfall-erosion index and the maximum storm within the year for Albuquerque and Safford watersheds. Number in each bar are the percent of the annual EI contributed by the maximum storm's EI.

The bar graphs show annual total EI, largest annual storm EI, and the percentage of the annual EIthat the largest storm contributed. As an illustration of the importance of a large storm, maximum storm EI's at Safford in 1943, 1944, and 1961, are larger than the annual EI in the other 23 years of the record. The variability in annual EI is not as wide at Albuquerque, although the largest storm in 1968 produced a higher EI than the annual value for all but six of the 31 years of record. Although no conclusion can be drawn from this analysis, it does illustrate that a single large storm is very important in estimating average annual erosion.

## DAILY PRECIPITATION AS AN INDICATION OF EI

The generally greater availability of precipitation data from standard and recording gages reporting daily or hourly totals suggests the importance of developing a method to estimate EI from these data. About 12% of the 280 reporting weather stations in Arizona (Climatological Data Arizona, 1973) use recording gages, but the data are generally available only for hourly depths. If the 33 recording stations were evenly spaced throughout the state, each gage would be representative of the rainfall pattern of 3500 square miles. Osborn, Lane, and Hundley (1972) reported that

to describe the rainfall patterns of the 58-square-mile Walnut Gulch Watershed with a correlation of 0.9 between adjacent gages, one would need 1000 gages.

The problem of reliably estimating EI in Arizona is obvious. Total precipitation and EI from all watershed locations previously mentioned were correlated to determine the feasibility of using a total precipitation factor as a rainfall variable in the USLE. It must be recognized that the EI computation involved indirect use of the rainfall depth, so complete independence is not present. The correlation coefficients obtained from this analysis are shown in Table 1.

Results of this analysis are not particularly encouraging when the use of intensity to compute EI is recognized. Wischmeier and Smith (1958) reported $R^2$ increased from 0.68 to 0.82 when they used EI rather than total precipitation for erosion data on a Shelby soil.

Table 1 indicates an improvement in the correlation when individual storm EI for Alamogordo Creek was used instead of the annual total. However, annual EI for Walnut Gulch was better correlated than individual storm EI. This difference is probably attributed to the differences in rainfall characteristics (Figure 6). Additional work may improve the predictions.

TABLE 1.

Correlation of Total-Precipitation and Erosion Index

| | GAGE NUMBER | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 45.002* | 45.005* | 45.009* | 45.014* | 47.005* | 63.002** | 63.002* | 64.078** | 64.078* |
| r | 0.75 | 0.64 | 0.84 | 0.47 | 0.61 | 0.61 | 0.91 | 0.76 | 0.64 |
| n | 26 | 26 | 26 | 26 | 31 | 682 | 11 | 850 | 11 |

* Analysis made using annual totals of EI and rainfall
** Analysis made using individual storm EI and rainfall

## CONCLUSIONS

1. Records from a single precipitation gage in climatic areas dominated by thunderstorms can be used to estimate the EI only for the point in question on individual storms or for a specific annual value. Extrapolating the results for more than about a mile leads to serious error in estimating the erosion by use of the USLE.
2. Short time intervals must be used to obtain an adequate estimate of the EI when using the USLE.
3. The variability of the annual EI can be approximated with a log-normal distribution. Gages 2 to 5 miles apart may differ appreciably in both the mean and standard deviation of the EI.
4. Although EI is correlated with annual precipitation, it is better correlated with individual storms for the Alamogordo Creek area but not on Walnut Gulch.
5. Investigations are needed to facilitate estimating the average annual EI from precipitation data as reported in state climatological summaries for states west of the 104th meridian.
6. Additional work is needed to facilitate estimating the EI value from the precipitation data available in most areas of the southwest where thunderstorms dominate the rainfall pattern.

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