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RUNOFF ESTIMATES FOR THUNDERSTORM RAINFALL ON SMALL RANGELAND WATERSHEDS

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ABSTRACT

Almost all runoff from small rangeland watersheds in the Southwest is the result of intense thunderstorm rainfall, and the variability of this rainfall is an important runoff-influencing factor in such areas where high intensity rainfall dominates watershed hydrology. Thunderstorm runoff estimates for small rangeland watersheds can be made using a multitude of estimating techniques ranging from simple table and graph procedures to utilizing high-speed computers, and even the most sophisticated models greatly simplify the rainfall input. In this paper, the combined effects of rainfall quantity and intensity, and the rainfall energy factor, EI, in the Universal Soil Loss Equation (USLE), were analyzed, and simple procedures for estimating semiarid rangeland runoff volumes were developed. Equally good correlations with runoff volumes were found for EI, and for total storm rainfall times maximum rainfall intensities for 5, 10, and 30 minutes and the square of the maximum 60-minute rainfall.

INTRODUCTION

Almost all runoff from very small (less than 1 mi^2) rangeland watersheds in the Southwest is the result of intense thunderstorm rainfall. Thunderstorm runoff estimates for small rangeland watersheds can be made using various estimating techniques ranging from simple table and graph procedures to utilizing high-speed computers. Most of these models greatly simplify the actual rainfall input to the system. For example, the curve number method, developed by the Soil Conservation Service (Kent, 1973), incorporates rainfall volume, along with certain watershed characteristics such as soil cover and antecedent moisture conditions, to estimate runoff volumes. The method does not allow for varying rainfall intensity, although the effect of intensity is known to be imporatant (Simanton et al., 1973; Hawkins, 1978). Linear regression is another rather simple procedure for runoff estimation. Schreiber and Kincaid (1967) and Osborn and Lane (1969) applied multiple linear regression analyses to semiarid rangeland watershed hydrologic data and found that 70% of the variance in predicted runoff was attributed to differences in rainfall amounts. They also found that, because of the interrelation between rainfall quantity and intensity, there was no significant improvement in the prediction when both parameters were included in a stepwise linear regression.

In this paper, the combined effects of rainfall amounts and intensities, and their relationships to runoff, are analyzed, and simple procedures for estimating semiarid rangeland runoff volumes are discussed.

Study Area Description

Data used in this study were collected from the Walnut Gulch Experimental Watershed located in southeastern Arizona (Fig. 1). There are 95 recording raingages and numerous instrumented subwatersheds within the 58-mi^2 experimental watershed. The semiarid climate of the area is characterized by a bimodal precipitation pattern, with approximately 70% of the 12-inch average annual rainfall occurring during the summer months of July, August, and September. Almost all watershed runoff occurs during this summer rainy season, and is a result of short-lived, high-intensity airmass thunderstorms. The sub-watersheds studied (63.101, 63.104, 63.105, 63.201, and 63.214), ranging in size from 0.45 acre to 372 acres, have similar physical characteristics, and are typical of the many thousands of acres of semiarid rangeland with mixed grass and brush cover in southeastern Arizona, southwestern New Mexico, and northern Sonora, Mexico. Creosote bush (*Larrea divaricata*), white-thorn (*Acacia constricta*), and tarbush (*Flourensia cernua*) are the principle species making up the 40% canopy cover of the brush-dominated vegetation. The soils are a well-drained, gravelly loam formed in calcareous old alluvium. The soil surface has minimal vegetative basal cover, with up to 60% gravelly erosion pavement. Watershed side slopes range from 3 to 15%, with about a 9% average. Grazing has been eliminated on the smaller watersheds (63.101, 63.104, and 63.105) since 1963, but cattle have been continuously grazing the larger watersheds (63.201 and 63.214) at the rate of about 5 animals per section per year. Rainfall data were tabulated from 24-hour recording raingages located on, or very near (within 1,000 ft of), the studied watersheds. Runoff was measured with small flumes or broad-crested weirs equipped with water-level recorders.

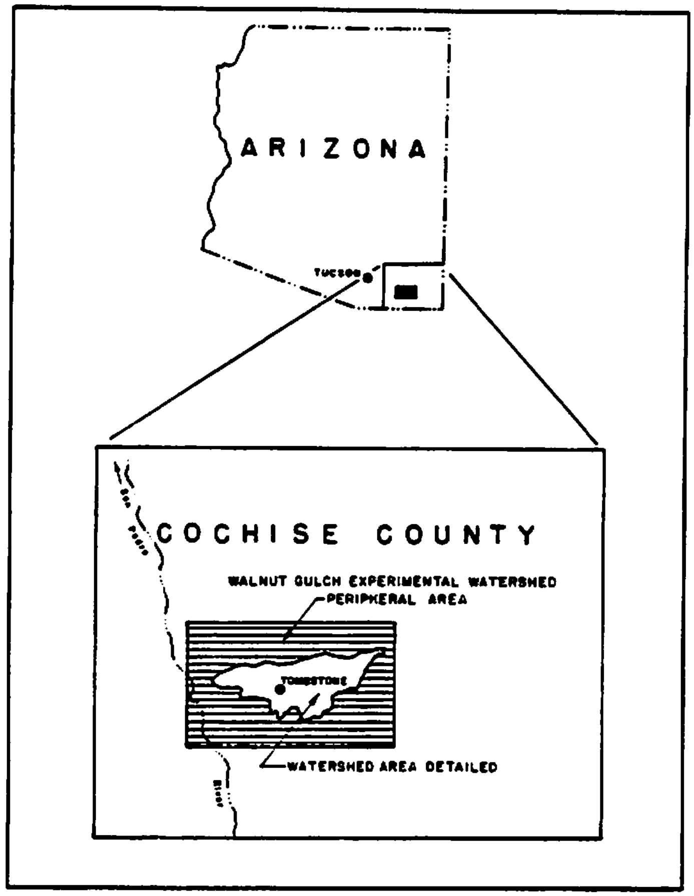

Figure 1. Location of Walnut Gulch Experimental Watershed.

RESULTS

In the initial analysis, a basic rainfall-runoff linear regression relationship

$$y = ax + b, \tag{1}$$

where x = rainfall factor, EI, in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), and y = runoff, Q (inches), was developed using runoff events from the smallest watershed (63.105, 0.45 acre). The smallest watershed was used because it best represented a homogeneous plot with no channel abstractions. The EI factor for each runoff-producing storm was computed from recording raingage data and an equation expressing the relationship between energy and rainfall intensity. The EI units are usually expressed in hundreds of ft-ton/ac-in. hr. The EI factor is the product of the total storm energy per acre (E) and the maximum 30-min intensity (I). In some years, over half of the annual EI (or R) has been the result of one storm (Renard et al., 1974). The probability distribution of total summer EI values and summer rainfall amounts for a raingage near 63.105 are shown in figure 2. For the period of study (1965-1975), summer precipitation varied from 5 inches to a little over 10 inches, while EI varied from about 30 to about 200. The range of EI values is a direct measure of the varying rainfall intensities, and is a much better indicator of potential runoff and erosion than is total summer rainfall. The correlation between EI and runoff, for 63.105 and the rainfall-runoff equations (with and without the record event), are shown in figure 3. The regression equations were:

$$y = 0.018x + 0.015 \tag{2}$$

and

$$y = 0.020x + 0.005 \tag{3}$$

When the regression equations, developed from the data without the very large event, were used to estimate runoff from the large event, there was only an 18% difference between the actual and estimated volume. This suggests that the sample size was adequate. Either equation would be acceptable for prediction, although Eq. (2) is preferred.

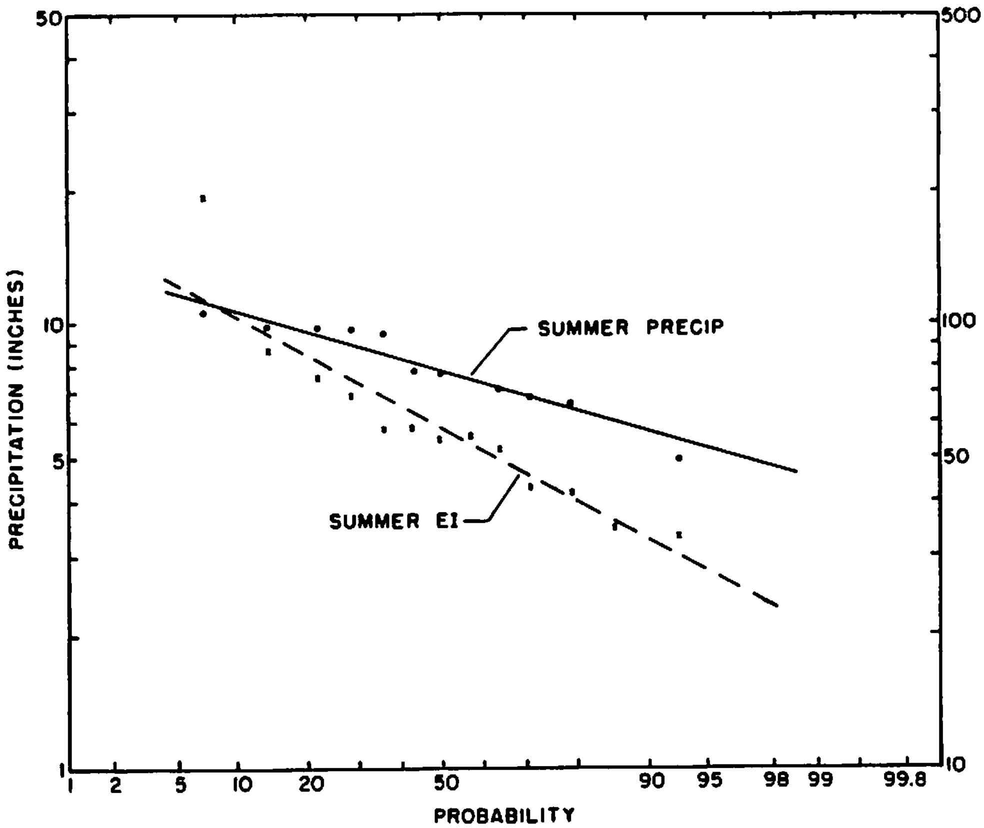

Figure 2. Occurrence probabilities for summer rainfall and summer erosion index (EI) (Raingage 83, 1963-1975).

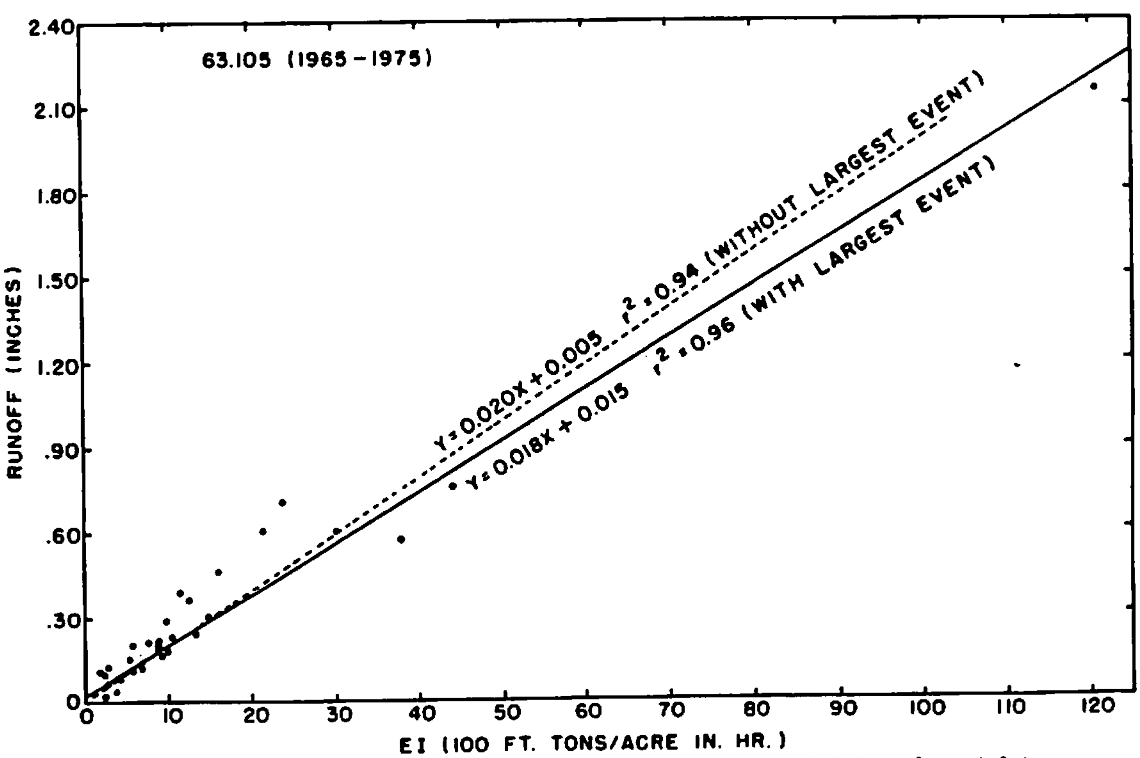

Figure 3. Correlation of EI with runoff for subwatershed 63.105, Walnut Gulch.

The regression equations were developed using EI values from runoff-producing rainfall only. Before the equation could be applied to larger watersheds, it had to be modified to reflect the influence of drainage area. Antecedent storm conditions are usually dry, and the sand-bottomed ephemeral stream channels associated with semiarid rangelands absorb a significant volume of runoff (Keppel and Renard, 1962). Larger watersheds generally have wider channels which abstract an increasingly larger volume of runoff. Furthermore, runoff-producing rainfall is limited in areal extent. Therefore, average annual runoff decreases with increasing watershed size. Based on analyses by Renard (1977) for larger watersheds and data from very small watersheds, the relationship of runoff volume to area was determined as:

$$Q = 1.06\ A^{-.135} \tag{4}$$

where Q = runoff volume (in.), and
A = area (acres).

Runoff estimates for the larger watersheds, based on Eq. (2), were reduced using Eq. (4) and the ratios of watershed area for the larger watersheds to 63.105.

Watershed Runoff Estimates:

Storm runoff estimates for the four larger watersheds are shown in table 1. Runoff was badly underestimated for the two largest watersheds, which may suggest less channel abstraction than anticipated or an inadequate sample of runoff-producing events, or both. Also, one must remember that Eq. (4) represents the average for Walnut Gulch subwatersheds.

Table 1. Statistics for regression of actual vs estimated storm runoff estimates from area-modified basic equation developed on 63.105.

Watershed	Area (ac)	n	Slope	Intcp	Std error of est	r^2
63.105	.45	--	--	--	--	--
63.101	3.2	54	0.975	0.000	0.038	0.94
63.104	11.2	50	0.972	0.008	0.034	0.93
63.201	110.	32	0.690	0.006	0.021	0.92
63.214	372	25	0.656	0.023	0.014	0.82

Other Precipitation Parameters:

Other precipitation parameters were correlated to the runoff from the smallest watershed to determine if a simpler, more widely-available precipitation parameter (other than EI) could be used in watershed runoff estimation. Thirteen rainfall factors (Table 2) were correlated to each other, to runoff volume, and to peak runoff rate from watershed 63.105. The rainfall factors and their correlation matrix are given in table 2. Of the six parameters that were highly correlated ($r > 0.95$) to runoff, the $(P_{60})^2$ (the square of the maximum 60-min rainfall) parameter appears to be the simplest single rainfall parameter to use in estimating rangeland storm runoff volume. Because most of the runoff-producing rainfall is associated with short duration (1 hr or less) thunderstorm events, and because there is usually only one event a day, the 60-min rainfall can be estimated, with some confidence, from the daily total reported in NOAA monthly climatological reports. In figure 4, actual runoff is compared to estimated runoff with linear regression equations using various precipitation parameters, including $(P_{60}{}^2)$.

The analysis included only runoff-producing storms, and a single very large event (EI > 120) was included in the data. Therefore, a modified linear regression technique (Diskin, 1970) was used to estimate runoff from all summer rainfall ($(P_{60})^2$) and runoff data, and both the Diskin method and the regression/reduction method were made on the data exclusive of the largest event. The analyses indicated no significant difference between using the Diskin method and the basic equation.

Peak Runoff Rate:

Runoff peaks and volumes are highly correlated on small watersheds dominated by thunderstorm rainfall (Table 2; Osborn and Lane, 1969; Renard et al., 1974). Therefore, the correlation coefficients (Table 2) also indicated that the peak run-off rate was correlated to P_{60}, EI, and $(P_{60})^2$, though not as well as was runoff volume. Of the linear regression equations associating P_{60}, EI, and $(P_{60})^2$ with peak runoff, the P_{60} gave the best estimate (fig. 5).

Return Frequency Runoff Estimates:

Widely available precipitation frequency information is found in the NOAA Precipitation Atlas for the western United States (Miller et al., 1973). These 1-hr amounts $(P_{60})^2$ were then used to estimate runoff for various return periods. The ratio of estimated runoff to rainfall were plotted versus return

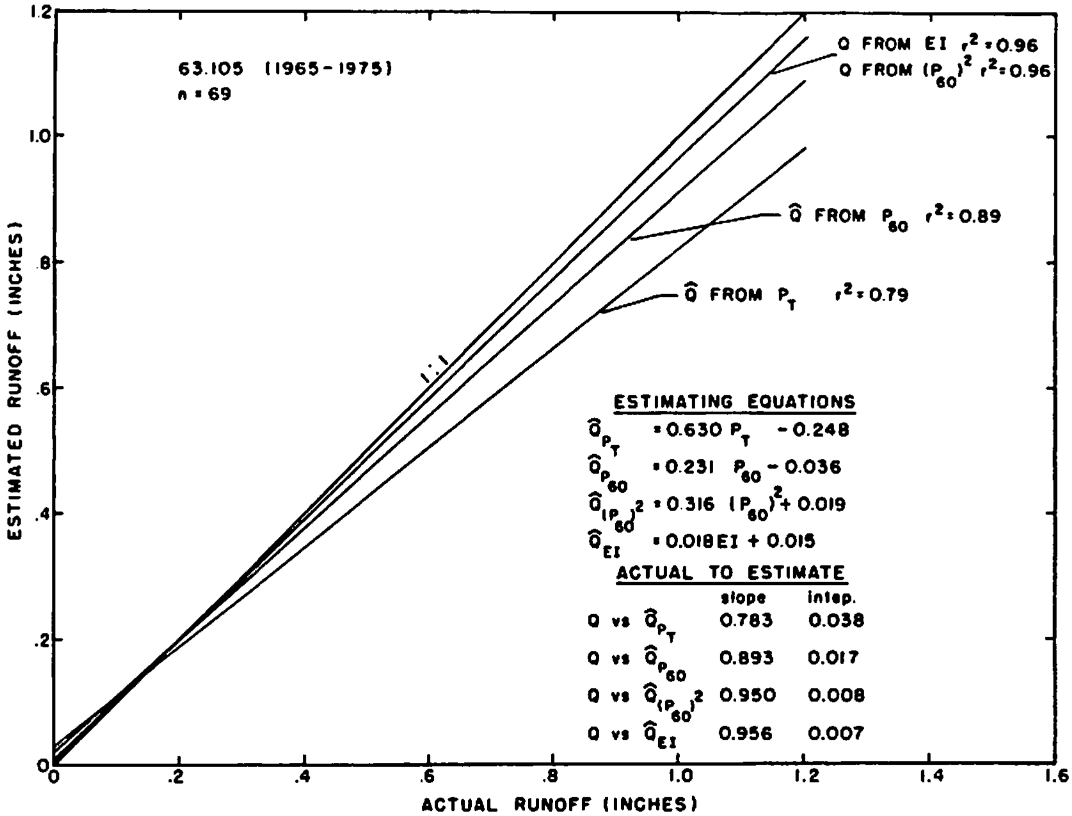

Figure 4. Comparison of actual and estimated runoff with four single-parameter regression equations.

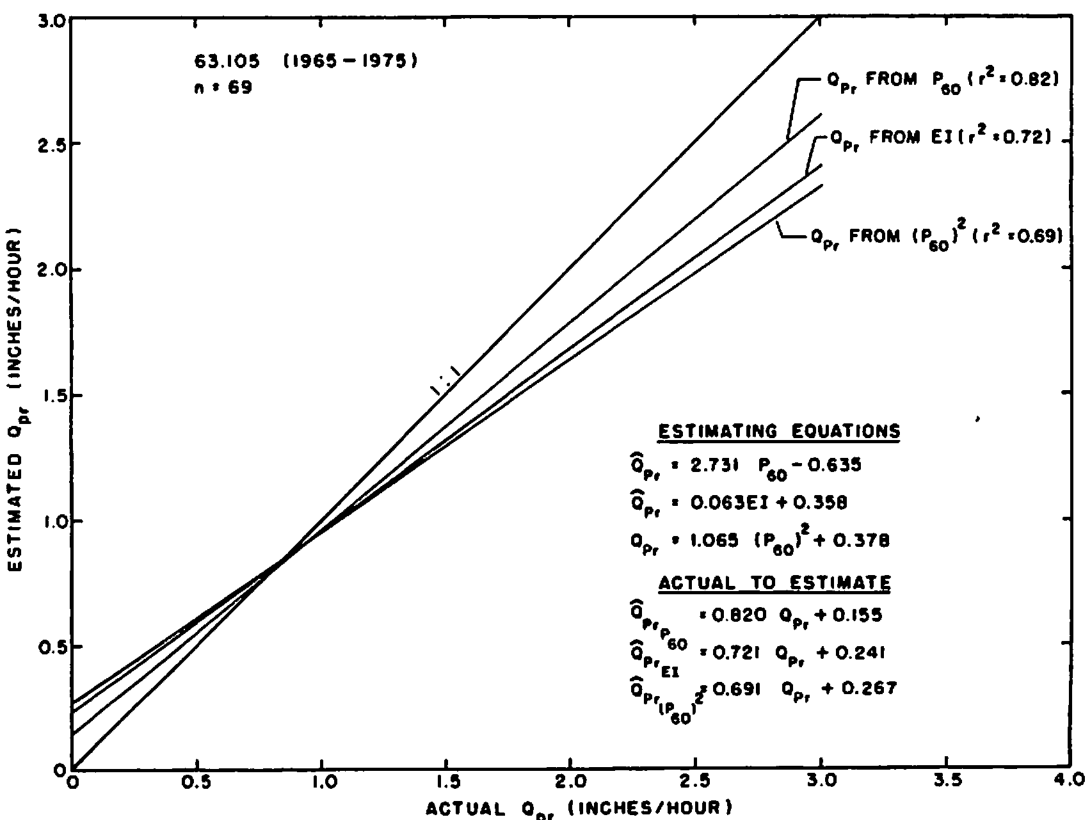

Figure 5. Comparison of actual and predicted peak discharges with three single-parameter regression equations.

period and compared to the plot of the return period versus the ratio of actual runoff to rainfall for 63.105 (fig. 6). The return period of the actual runoff and rainfall was calculated using 22 years of data and the Gumbel method for estimating frequency functions of extreme values (Gumbel, 1958). Estimates based on NOAA Atlas 2 were significantly lower than those based on actual data.

Table 2. Correlation coefficients of 13 precipiation parameters and two runoff parameters (only runoff-producing rainfall used in analysis. N = 69) (All values are significant at the 1% level).

	P_T	P_{60}	P_{30}	P_{15}	P_{10}	P_5	EI	E_{max}	P_{Tx30}	P_{Tx15}	P_{Tx10}	P_{Tx5}	$(P_{60})^2$	Q	Q_{pr}
P_T		.94	.92	.83	.77	.70	.87	.66	.89	.92	.92	.91	.89	.87	.82
P_{60}			.98	.90	.85	.78	.92	.71	.93	.96	.96	.95	.92	.93	.87
P_{30}				.95	.90	.84	.90	.73	.91	.95	.95	.95	.89	.91	.88
P_{15}					.99	.94	.78	.80	.79	.87	.88	.88	.76	.82	.89
P_{10}						.97	.73	.80	.73	.83	.84	.85	.70	.78	.87
P_5							.68	.75	.68	.77	.79	.81	.65	.72	.83
EI								.56	1.00	.98	.98	.97	1.00	.97	.81
E_{max}									.57	.65	.67	.66	.55	.63	.73
P_{Tx30}										.99	.98	.97	1.00	.97	.82
P_{Tx15}											1.00	.99	.98	.98	.88
P_{Tx10}												1.00	.97	.97	.89
P_{Tx5}													.96	.97	.89
$(P_{60})^2$														.97	.80
Q															.91

P_T = Total storm amount (in).
P_{60} = Max 60-min storm depth (in).
P_{30} = Max 30-min intensity (in/hr).
P_{15} = Max 15-min intensity (in/hr).
P_{10} = Max 10-min intensity (in/hr)
P_5 = Max 5-min intensity (in/hr).
EI = USLE rainfall factor (ft tons/ac in hr).
E_{max} = Max energy within storm (ft tons/ac).
P_{Tx30} = Total storm amount x max 30-min intensity (in^2/hr).
P_{Tx15} = Total storm amount x max 15-min intensity (in^2/hr).
P_{Tx10} = Total storm amount x max 10-min intensity (in^2/hr).
P_{Tx5} = Total storm amount x max 5-min intensity (in^2/hr).
$(P_{60})^2$ = Square of max 60-min storm depth (in^2).
Q = Runoff volume (in).
Q_{pr} = Runoff peak rate (in/hr).

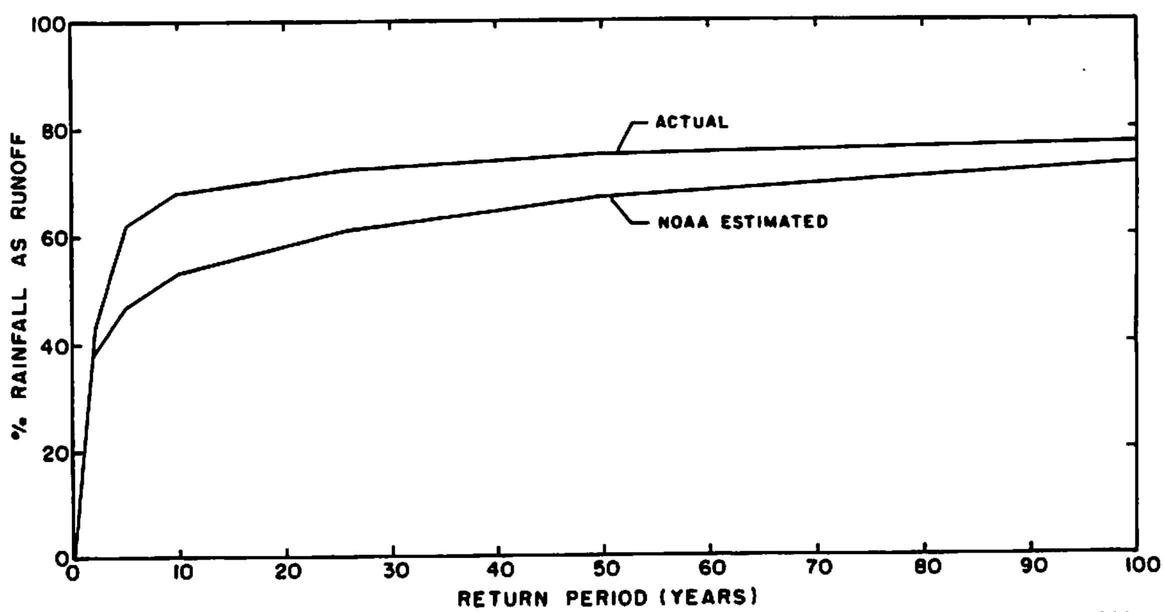

Figure 6. Return periods of ratios of Gumbel fitted precipitation and runoff and of NOAA precipitation and equation estimated runoff for 63.105, Walnut Gulch.

CONCLUSION

Linear regression techniques can be used to estimate runoff volumes from small rangeland watersheds. In the semiarid Southwest, where thunderstorms dominate the runoff-producing rainfall, there are two contributing factors: rainfall quantity and intensity. These factors are reflected in the EI term of the USLE. This term, when regressed with storm runoff volumes from a small rangeland watershed, produced a linear equation that could be used to estimate watershed storm runoff volumes. However, because of the inverse relationship found in semiarid rangelands between watershed drainage area and runoff volumes, an additional step to regression is needed in the method before it can be applied to larger watersheds. Runoff estimates for various-sized watersheds indicated the procedure could be useful if the estimated watersheds were in the same climatic regime and had similar, but not necessarily identical, vegetation cover. These conditions are found in large parts of southeastern Arizona, southern New Mexico, western Texas, and northern Mexico.

In comparing different estimating parameters, we found that $(P_{60})^2$ gave a good estimate of runoff volume, and that P_{60} gave good estimates of runoff peak rate. The P_{60} parameter can be estimated for different return frequencies from the NOAA Precipitation Atlas. Data from this atlas can be used with the runoff-estimating equations to give runoff estimates for various return frequencies. The estimated runoff volumes for the shorter return frequencies were lower than actual volumes. These differences can be attributed to the low NOAA precipitation estimates (Reich and Osborn, 1982).

REFERENCES

Diskin, M. H. 1970. Definition and uses of the linear regression model. Water Resources Research, AGU 6(6):1668-1673.

Gumbel, E. J. 1958. Statistics of extremes. Columbus University Press, 395 p.

Hawkins, R. H. 1978. Effects of rainfall intensity on runoff curve numbers. Hydrology and Water Resources in Arizona and the Southwest. American Water Resources Assoc., Ariz. Section--Arizona Acad. of Sci., Hydrology Sec., Proc. 1978 meetings, Flagstaff, Arizona 8:53-64.

Kent, K. M. 1973. A method for estimating volume and rate of runoff in small watersheds. USDA, SCS-TP-149, April, 1953. 53 p.

Keppel, R. V., and Renard, K. G. 1962. Transmission Losses in Ephemeral Stream Beds. J. Hydr. Div., Proc. ASCE 88(HY3):59-68.

Miller, J. F., Frederick, R. H., and Tracey, R. J. 1973. Precipitation Frequency Atlas of the Western United States, Vol. 8--Arizona. NOAA National Weather Service, Silver Springs, Maryland. 41 p.

Osborn, H. B., and Lane, L. J. 1969. Rainfall-runoff relationships for very small semiarid rangeland watersheds. Water Resources Research, AGU 5(2): 419-425.

Reich, B. M., and Osborn, H. B. 1982. Improving point rainfall prediction with experimental watershed data. In: Statistical Analysis of Rainfall and Runoff. Water Resources Publication, Littleton, Colorado 41-54.

Renard, K. G. 1977. Past, present and future water resources research in arid and semiarid areas of the southwestern United States. Australian Institution of Engineers, 1977 Hydrology Symposium, p. 1-29.

Renard, K. G., Simanton, J. R., and Osborn, H. B. 1974. Applicability of the universal soil loss equation to semiarid rangeland conditions in the Southwest. Hydrology and Water Resources in the Southwest, Water Resources Research Center, University of Arizona, Tucson 4:18-31.

Schreiber, H. A., and Kincaid, D. R. 1967. Regression models for predicting on-site runoff from short-duration convective storms. Water Resources Research, AGU 3(2):389-395.

Simanton, J. R., Renard, K. G., and Sutter, N. G. 1973. Procedures for identifying parameters affecting storm runoff volumes in a semiarid environment. USDA-ARS W-1, 12 p.

Wischmeier, W. H., and Smith, D. D. 1978. Predicting rainfall erosion--a guide to conservation planning. USDA Agriclture Handbook No. 537.