LETTERS

Variability of Rainfall Affecting Runoff from a Semiarid Rangeland Watershed[1]

H. B. OSBORN AND R. B. HICKOK

Southwest Watershed Research Center
Tucson, Arizona

Abstract. On the 58-square-mile Walnut Gulch watershed in southeastern Arizona, summer precipitation is characterized by intense thunderstorms of limited areal extent; winter precipitation, usually rain, is characterized by low-intensity storms of wide areal extent. For 11 years of record from 30 recording gages, about 70% of the annual precipitation of 11.22 inches occurred in the summer months June through September. Summer precipitation exceeded winter precipitation in each of the 11 years of record. Average annual precipitation varied from 7.1 to 14.2 inches for the period of record. During the same period, point precipitation varied from slightly under 5 inches to slightly over 20 inches. The lowest annual point precipitation was about 50 to 60% of the highest. Significantly more summer rainfall was recorded on the highest elevations than on the lowest, which indicated an effect of elevation on precipitation. However, the most summer rainfall, for the 11-year period of record, was recorded near the center of the watershed, which indicated possible topographic influences other than watershed elevation. Annual runoff from Walnut Gulch varied from 0.02 inch (1 acre-foot per square mile) to 1 inch (53 acre-feet per square mile). For the same period on a 1-square-mile subwatershed, annual runoff varied from 0.02 inch (1 acre-foot per square mile) to about 6 inches (320 acre-feet per square miles). (Key words: Hydrology; precipitation; runoff)

INTRODUCTION

The Southwest Watershed Research Center of the U. S. Department of Agriculture, Agricultural Research Service, is studying water yields from semiarid rangelands in Arizona and New Mexico. The principal research areas are the 58-square-mile Walnut Gulch watershed in southeastern Arizona and the 67-square-mile Alamogordo Creek watershed in eastern New Mexico. Also, precipitation and runoff records are obtained from several small watersheds (up to one square mile in area) west of Albuquerque and near Capitan, New Mexico, and near Safford, Arizona (Figure 1).

Since 1960, several papers based on data and observations from these studies have been published (see Bibliography). The extreme variability of thunderstorm rainfall has been discussed in many of these papers, but the discussion has been mostly qualitative because of the short period of record. Other papers in the past 24 years also have discussed the variability of rainfall in the Southwest, mostly from a qualitative standpoint. This was primarily because precipitation stations in the Southwest were so widely scattered. Now, however, with 11 years of record from an intensive network of recording rain gages on the Walnut Gulch watershed, we can present a more quantitative picture of rainfall variability, which will apply to much of the semiarid rangeland in Arizona and New Mexico.

DESCRIPTION OF EXPERIMENTAL WATERSHED

Walnut Gulch, Tombstone, Arizona, is an ephemeral tributary of the north-flowing San Pedro River, which in turn is a tributary of the west-flowing Gila River. Its watershed ranges in elevation from just under 4000 to about 6000 feet. The main channel is incised, generally cutting through deep alluvial fill. The lower two-thirds of the watershed is covered primarily with low shrubs, and the upper one-third is dominantly grassland.

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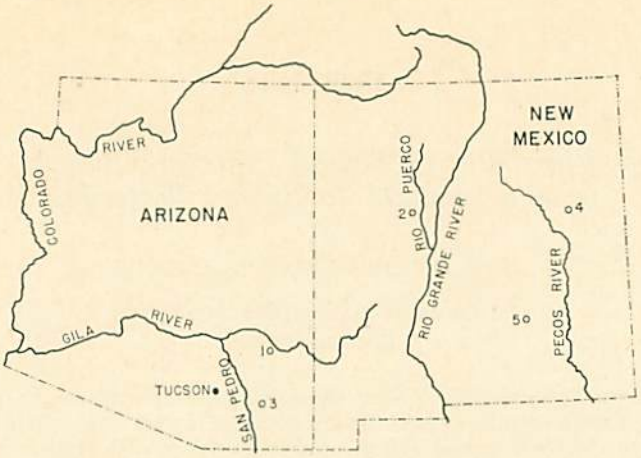

1. SAFFORD, ARIZONA
2. ALBUQUERQUE, NEW MEXICO
3. WALNUT GULCH nr TOMBSTONE, ARIZONA
4. ALAMOGORDO CREEK nr SANTA ROSA, NEW MEXICO
5. FORT STANTON, NEW MEXICO

Fig. 1. Locations of experimental watersheds.

Runoff from 10 of the larger subwatersheds (3 square miles and larger), and from the entire watershed (58 square miles), is measured with prerated, critical-depth flumes, which were designed and constructed especially to measure the flashy, sediment-laden flows. The runoff measuring flumes range in capacity from 6000 to 26,000 cubic feet per second. The first was constructed in the winter of 1957–1958, and the latest was finished in the winter of 1966–1967.

The present recording rain gage network covering the watershed includes 92 stations. However, while the gage network was being developed, the recording rain gages were rather unevenly distributed over the watershed. Therefore, except where indicated, data from 30 rain gages, which were fairly evenly distributed, were chosen for this analysis of the temporal and spatial variability of the rainfall for the period 1955–1965 (Figure 2).

VARIABILITY OF SEASONAL RAINFALL

The ratio of average winter-to-summer precipitation over the entire watershed, for the 11-year study, 1955–1965, varied from 0.17 in 1955 to 0.74 in 1957 (Table 1). The ratio at individual gages has varied from about 0.1 to more than 0.8.

The heaviest period of winter rainfall occurred in early December 1965, when about 3.5 inches of rain were recorded in 10 days. This amounted to about 75% of the winter rainfall in 1965–1966 and almost 30% of the annual rainfall. However, no runoff was recorded during this period from watersheds larger than 20 acres.

The heaviest period of summer rainfall occurred in the summer of 1955. The summer rainfall, almost all of which fell in July and August, averaged about 12 inches on the watershed and constituted about 85% of the 1955 annual precipitation. The lowest summer rainfall, less than 5 inches, occurred in 1960 and amounted to about 65% of the annual rainfall. The winter rainfall for both the highest and lowest years of summer rainfall was about the same, just over 2 inches.

VARIABILITY OF ANNUAL RAINFALL

Average annual rainfall over the watershed varied from lows of 7.1 and 7.5 inches in 1960 and 1956, respectively, to highs of 14.2 and 13.8 inches in 1955 and 1958, respectively. The most

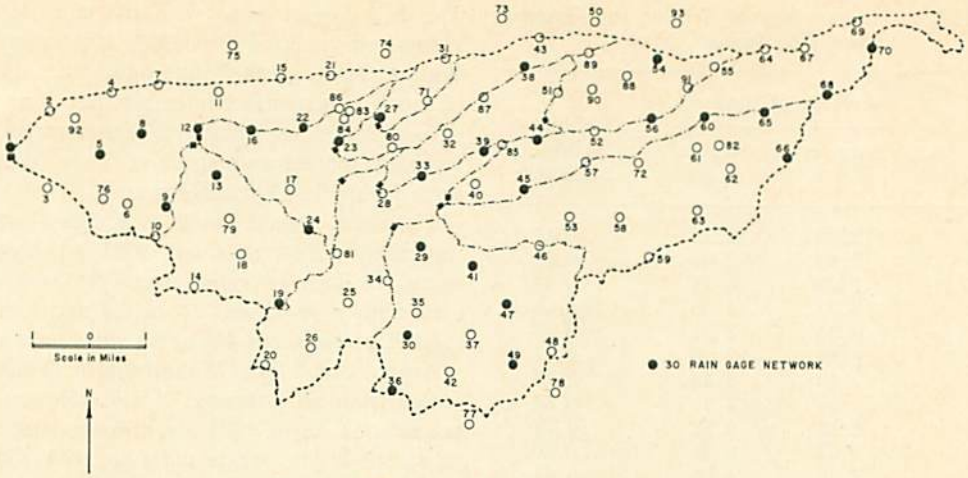

Fig. 2. Walnut Gulch rain gage network.

rainfall, 19.1 inches in 1955 and 20.6 inches in 1958, was recorded at Rain Gage 33. Nearly as much rainfall was recorded at Rain Gage 28, approximately one mile from Rain Gage 33, although this gage was not included in the analysis.

The lowest point rainfall on the watershed in the wet years was 11.6 inches in 1955 at Rain Gage 54 and 9.8 inches in 1958 at Rain Gage 65. In 1955, the lowest point rainfall was about 60% of the highest; in 1958, the lowest was less than 50% of the highest. For eleven years of record, the average low annual point rainfall on the watershed was 55% of the high, or 8.2 inches to 14.8 inches.

MEAN ANNUAL AND MEAN SEASONAL PRECIPITATION

Watershed averages. The mean annual rainfall for the Walnut Gulch watershed for 11 years of record (1955 through 1965) was 11.22 inches. Of this amount, 7.77 inches, or 70%, occurred in the summer (June through September). Furthermore, 6.32 inches occurred in July and August, which was about 55% of the annual total. The maximum summer monthly rainfall occurred in July; the maximum winter monthly rainfall occurred in December.

The median rainfall was 11.30 inches, as compared with the mean of 11.22. Therefore, there was a preponderance of values above the mean. A more usual skewed distribution would show a median below the mean.

Areal variations. There was considerable variation in mean annual and mean seasonal precipitation over the watershed. Both mean winter and mean summer precipitation were highest at Rain Gage 33, whereas both mean winter and mean summer precipitation were lowest at Rain Gage 1 (Figures 3 and 4). The mean summer rainfall was 6.64 and 9.90 inches, and the mean winter rainfall was 2.77 and 4.01 inches at Rain Gages 1 and 33, respectively. Rain Gage 33 was in almost the exact center of the watershed, whereas Rain Gage 1 was at the outlet. Considerably higher rainfall was recorded at Rain Gages 65, 66, 68, and 70 on the upper end of the watershed than at Rain Gage 1 at the outlet. Rain Gages 65, 66, 68, and 70 are above 5000 feet elevation, and Rain Gage 1 is at 4000 feet, which indicates a possible orographic effect due to elevation alone. However, the fact that Rain Gage 33, at 4500 feet elevation, has recorded significantly greater rainfall than any of the rain gages on the upper end of the watershed indicates that there may be orographic effects other than that of watershed elevation.

On the other hand, it is possible that the mean values of precipitation are biased by the heavy rains in July 1955 and August 1957 and 1958. Most of the heavy rains during these months were centered on or near Rain Gage 33. Other years of record indicate a more random distribution of precipitation along with a possible elevation effect, as indicated previously.

RAINFALL-RUNOFF RELATIONS

In general, runoff is more variable than precipitation. The stream channels are normally

TABLE 1. Comparison of Winter and Summer Rainfall on Walnut Gulch

Year	Average of 30 Gages		Ratio of Winter to Summer
	Summer, inches	Winter, inches	
1955	12.06	2.10	0.17
1956	5.42	2.07	0.38
1957	7.02	5.21	0.74
1958	8.72	5.05	0.58
1959	9.80	3.21	0.33
1960	4.83	2.26	0.47
1961	7.40	3.49	0.47
1962	6.26	3.39	0.54
1963	8.15	2.58	0.32
1964	9.62	2.84	0.30
1965	7.25	*4.65	0.64
Mean	7.77	3.45	0.44

* 3.5 inches of this total were recorded in a 10-day period in December.

dry, with runoff generally restricted to a few afternoons and evenings during the summer season. Flows last from minutes to hours, rather than days, and almost never continue past sunrise of the following day. There is no ground water contribution to surface flows on Walnut Gulch. This is true of almost all small, semiarid rangeland watersheds (100 square miles or less) in the Southwest.

The dominant factor in runoff variability on small watersheds is the variability of rainfall. The July-August rains were the more intense events and produced about 90% of the runoff on Walnut Gulch. A small, but significant, amount of runoff occurred in September, but June runoff was almost negligible. No winter runoff was recorded for subwatersheds of more than 20 acres during the 11 years of record.

The mean annual runoff at Flume 1, at the watershed outlet, is about 1000 acre-feet, or about 0.3 inch of runoff from the watershed area. This is less than 3% of the mean annual rainfall, and is about 4% of the summer rainfall.

Annual runoff from Walnut Gulch (Flume 1) varied from an estimated 1 inch (53 acre-feet per square mile) in 1955 to a measured 0.02 inch (1 acre-foot per square mile) in 1965. During the same period, annual point rainfall varied from 20 inches to 5 inches over the watershed.

Runoff also varies with the varying capabilities of the normally dry alluvium channels to abstract water from surface flows. Runoff per unit area decreases with increasing watershed size, primarily because of the increasing channel losses (Table 2). Therefore, rainfall variability has a greater effect on runoff from smaller than from larger watersheds.

For example, about 8 inches of runoff have been measured from subwatershed 4 (580 acres) for the period of record (1955–1965). Six inches of this was measured in 1955; one exceptional event recorded a peak of 1250 cubic feet per second. In other words, from 1956 through 1965 there was an average runoff of 0.2 inch per year,

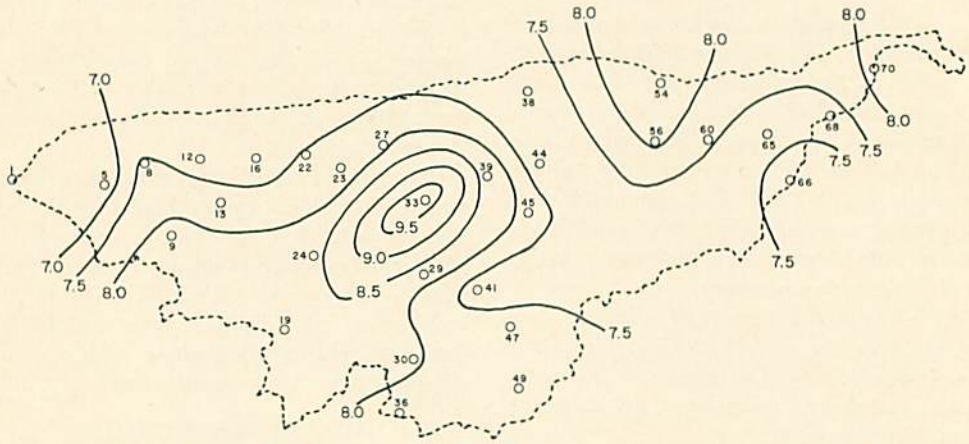

Fig. 3. Walnut Gulch mean summer precipitation (30 recording rain gages, June-September 1955–1965).

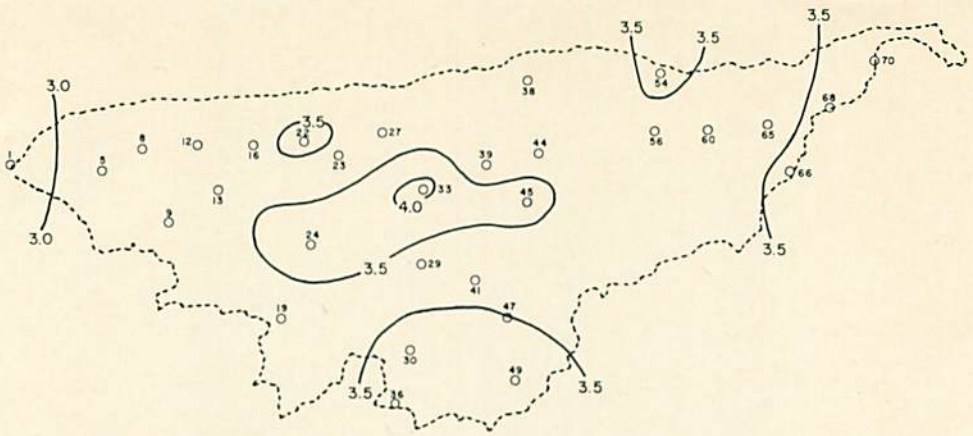

Fig. 4. Walnut Gulch mean winter precipitation (30 recording rain gages, October-April 1955–1965).

TABLE 2. Runoff–Walnut Gulch Subwatersheds (1955–1965)

Subwatershed number	1	2	6	5	8	3	11	4
Subwatershed area, square miles	57.7	43.9	36.7	8.61	6.0	3.47	3.2	0.88
Average annual runoff, inches	0.30	0.37	0.37*	0.36	0.44*	0.52	1.36*	0.77
Peak discharge, inches/hour	0.54	0.60	0.31	0.40	1.10	1.26	2.44	2.01

* Five years of record, or less.

but when the 1955 runoff is added, the eleven-year mean is about 0.8 inch. Records from other subwatersheds indicate that the exceptional event in 1955 on subwatershed 4 was, roughly, on the order of a '10-year storm' for a 1-square-mile watershed. Several storms with similar intensities and volumes have been recorded on other parts of the Walnut Gulch watershed, but not on a gaged 1-square-mile subwatershed.

Annual runoff on subwatershed 4 has varied from over 6 inches (320 acre-feet per square mile) in 1955 to about 0.02 inch (1 acre-foot per square mile) in 1960. In comparison, the lowest measured annual point rainfall was about 8 inches (not in 1960) and the highest about 17 inches (in 1955).

BIBLIOGRAPHY

Fletcher, J. E., Some characteristics of precipitation associated with runoff from Walnut Gulch Watershed, Arizona, Paper presented at the 42nd Annual Meeting of the American Geophysical Union, Washington, D. C., April 1961.

Keppel, R. V., A record storm event on the Alamogordo Creek Watershed in eastern New Mexico, *J. Geophys. Res., 68*(16), 4877–4880, August 15, 1963.

Kincaid, D. R., H. B. Osborn, and J. L. Gardner, Use of unit-source watersheds for hydrologic investigations in the semiarid Southwest, *Water Resources Res., 2*(3), 381–392, 1966.

Osborn, H. B., and W. N. Reynolds, Convective storm patterns in the southwestern United States, *Intern. Assoc. Sci. Hydrol. Bull., 8*(3), 71–83, September 1963.

Osborn, H. B., Effect of storm duration on runoff from rangeland watersheds in the semiarid southwestern United States, *Intern. Assoc. Sci. Hydrol. Bull., 9*(4), 40–47, December 1964.

Osborn, H. B., and R. V. Keppel, Dense rain gage networks as a supplement to regional networks in semiarid regions, *I.A.S.H. Symp. Design of Hydrological Networks, Publ. No. 68,* 675–687, 1965.

Renard, K. C., and H. B. Osborn, Rainfall intensity comparisons from adjacent 6-hour and 24-hour recording rain gages, *Water Resources Res., 2*(1), 145–146, 1966.

Schreiber, H. A., and D. R. Kincaid, Regression models for predicting on-site runoff, *Water Resources Res., 3*(2), 389–395, 1967.

Workman, E. J., The problem of weather modification, *Science, 138,* 3538, Oct. 19, 1962.

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