Extract of publication no. 68 of the I.A.S.H.
Symposium Design of Hydrological Networks, pp. 675-687 1966

DENSE RAIN GAGE NETWORKS AS A SUPPLEMENT TO REGIONAL NETWORKS IN SEMIARID REGIONS (1)

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Abstrakt

Because of their small size, widely scattered distribution, and short duration, convective thunderstorms typical of the southwestern United States and many other semiarid regions can best be described by data gathered from dense recording rain gage networks on sufficiently large areas. Data are presented from two such networks — one of 60 recording gages located on a 67-square-mile area in eastern New Mexico, and one of 80 recording gages on 58-square-miles in southeastern Arizona — showing depth-area and intensity-duration characteristics for convective thunderstorms. Comparisons are made between the frequency relationship computed from the long-time record at a point and that from a few years of dense network records based on the station-year concept. A storm on the eastern New Mexico area with exceptionally high intensities for durations up to 30 minutes is discussed.

INTRODUCTION

Most of the winter precipitation in the intermountain and plains areas of the southwestern United States occurs as low-intensity rain or snow along slow-moving cold fronts. Summer rains, on the other hand, occur as short-duration, high-intensity thunderstorms resulting from purely convective buildup or from convective cells developed along weak, fast-moving cold fronts. In summer, under favorable atmospheric conditions, moist air flows into the region from the Gulf of Mexico. This flow of moist air may continue for several days or even weeks, depending upon the relative positions of a high-pressure ridge over the central and southeastern United States and a corresponding low-pressure area over northern Mexico.

Although heavy rains may be measured at one or several points in the region during a period of moist air flow, such records may not define the storm precipitation for the region; that is, scattered rains occur, related to distinct cloud cells, and isohyetal maps based on these point measurements and extended over large areas of the Southwest, would be meaningless. A multicellular thunderstorm may draw energy from as much as 1,000 square miles of land surface (Workman, 1962), whereas the resulting runoff-producing precipitation may cover only a hundredth of this area.

In Arizona, the United States Weather Bureau maintains about 50 recording rain-gage stations, most of which were established in comparatively recent years, and about 350 standard nonrecording gages scattered unevenly over the state. Even with this total of approximately 400 measuring stations, it is apparent that the runoff-producing portions of a great many thunderstorms are never measured. Detailed studies of watershed areas of 100 square miles or less, therefore, require more intensive networks of gages than are normally available.

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From 1934 to 1943, the Research Division of the Soil Conservation Service carried on watershed studies at the Navajo Experiment Station in northwestern New Mexico. Here, from April through October, they maintained a network of 270 rain gages — of which 62 were recording — on an area of approximately 100 square miles (Hubbell, *et. al.*, 1941). Four recording gages, at altitudes ranging from 6,200 to 8,000 feet, were maintained throughout the year. Altitude on the experimental area ranged from approximately 6,200 feet to 8,800 feet. During this relatively short period of record, precipitation data showed that most of the summer rains were of small areal extent, and amount and intensities varied widely over relatively short distances. Winter precipitation — which produced no runoff except that from spring snow melt — was, on the contrary, more evenly distributed.

Methods and procedures

Experience gained at the Navajo Experiment Station furnished the primary basis for establishing the intense rain gage networks on the present experimental watersheds of the Southwest Watershed Research Station of the Agricultural Research Service, where runoff-producing precipitation is of primary interest. From the data furnished by these networks, convective storms have been studied in four areas of Arizona and New Mexico (fig. 1). These areas are the 67-square-mile Upper Alamogordo

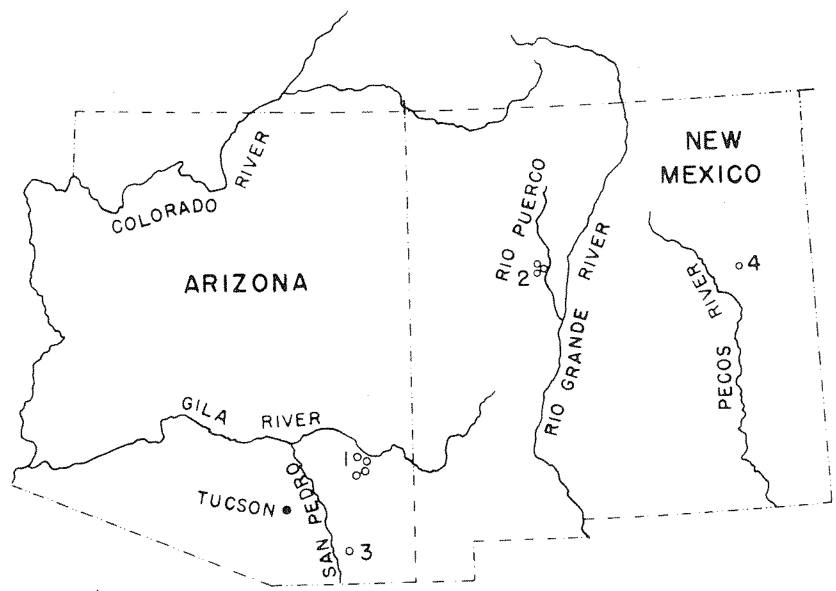

Fig. 1 — Locations of experimental watersheds:
1. Safford, Arizona
2. Albuquerque, New Mexico
3. Walnut gulch nr. Tombstone, Arizona
4. Alamogordo creek nr. Santa Rosa, New Mexico

Creek Watershed in east-central New Mexico, near Santa Rosa; the 58-square-mile Walnut Gulch Watershed at Tombstone in southeastern Arizona; four small watersheds of about one square mile each near Safford, Arizona; and three small watersheds

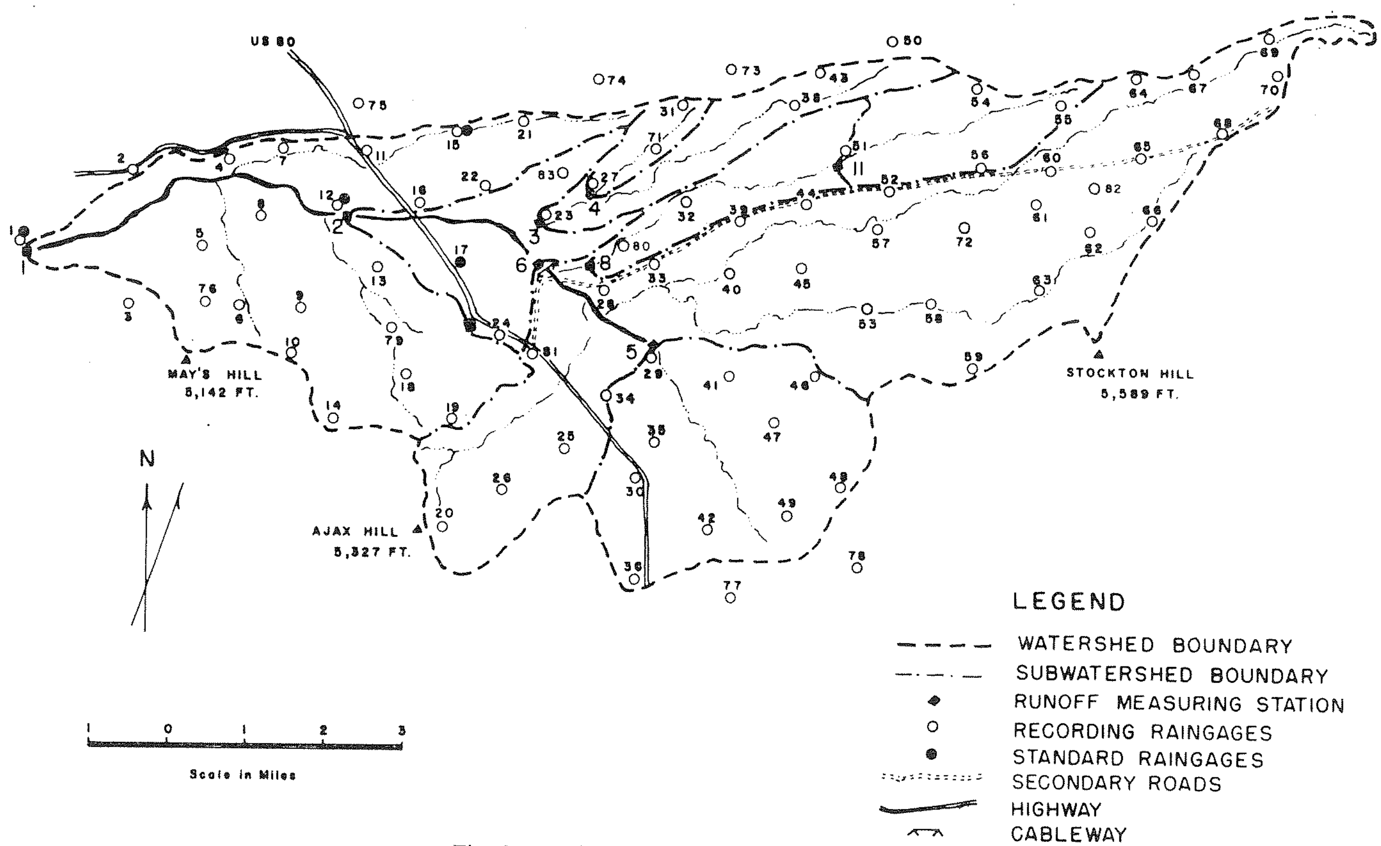

Fig. 2 — Walnut gulch experimental watershed

on the Montano Grant in the valley of the Rio Puerco west of Albuquerque, New Mexico. Records from the larger watersheds, which were instrumented in 1954 and 1955, afford data for intensive study of convective storms; those from the smaller areas, which have been under study since 1939, furnish information for study of somewhat longer periods. Also, attempts are planned to correlate information from the intense networks with that from nearby long-term United States Weather Bureau gages.

There are 76 recording rain gages on the Walnut Gulch watershed and 6 more just outside the watershed boundary (fig. 2). Originally, about 60 gages were installed Thus, each gage represented an area of approximately 1 square mile. Later, with intensified study on subwatersheds of less than a square mile, others were added. Six gages were installed just off of the perimeter of the watershed to aid in isohyetal mapping of summer storms. The present network, therefore, has resulted from the original planning, based primarily upon the Navajo Experiment Station observations, and our own experience during the early years on this specific area. The data and observations accumulated from 1954 to the present indicate that we now have close to an optimum rain-gage network for intensive studies of water yield from semiarid Southwestern rangelands.

On the Upper Alamogordo Creek watershed are 60 recording rain gages, of which 4 are just outside the perimeter of the watershed (fig. 11). This density of somewhat less than one gage to the square mile will probably be increased as work on the water shed is intensified.

Results and discussion

Walnut Gulch Watershed

Precipitation records of the 1964 summer season on the Walnut Gulch area are used to illustrate magnitude, extent, and variability of the convective rains of the region and to show, also, why we feel that our present network of gages furnishes us an adequate sampling of the storms that strike the watershed. Several runoff-producing storms are used to indicate the great variation in total storm precipitation

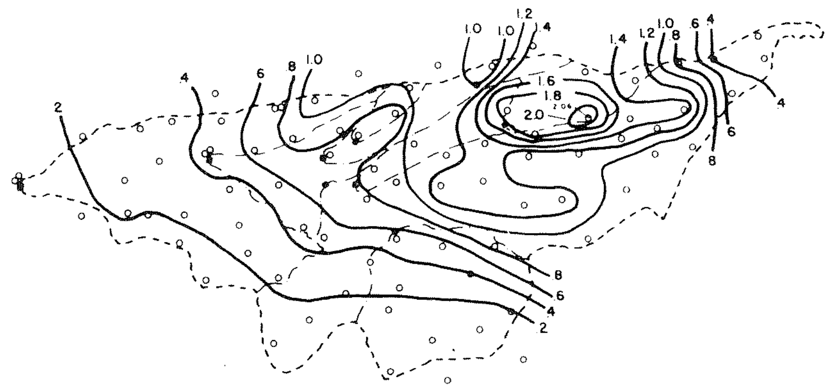

Fig. 3 — Walnut gulch watershed. — Precipitation (inches). Storm of July 22, 1964 (6: 30 P. M.)

on the area (figs. 3-5). Usually no runoff results from rainfall totaling less than 0.4 inch. If we trace the 0.4-inch isohyet, therefore, the limited area of runoff-producing precipitation in each storm is easily demonstrated.

Adequacy of recording rain gages for measuring point rainfall, as well as for representing the area assigned to them, has been questioned. To examine these questions, we have used records from several gages on the Walnut Gulch area that were separated by various distances. Records from the 1964 convective season have been

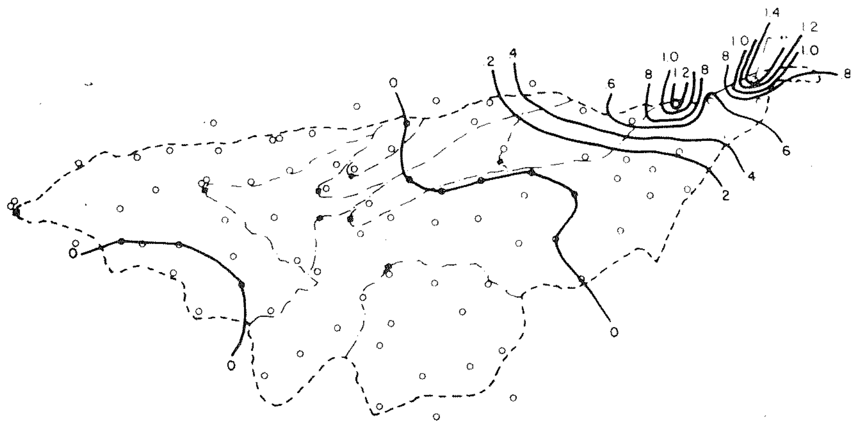

Fig. 4 — Walnut gulch watershed. — Precipitation (inches). Storm of July 30, 1964 (12: 00 Noon)

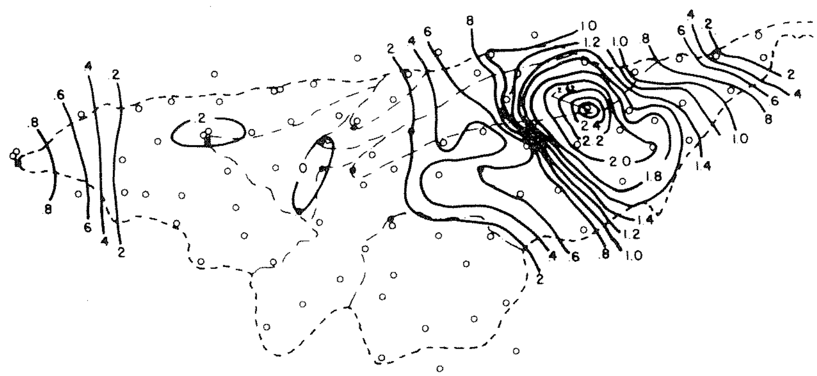

Fig. 5 — Walnut gulch watershed. — Precipitation (inches). Storm of Sept. 11, 1964 (5: 00 P. M.).

used for this evaluation (Tables 1, 2, and 3) because of their excellent quality and because the rainfall of 1964 was above average. Conclusions drawn from these records are substantiated by comparison with earlier records from the area.

Since 1960, amounts and intensities of precipitation have been measured by paired recording rain gages side-by-side at two locations on the watershed. The time scale of one gage of each pair was 6 hours per revolution; that of the other, 24 hours. Although both amounts and 10-minute intensities recorded by the two members of each pair may differ somewhat (Table 1), the differences are probably due to internal

TABLE 1

Total Depth and Maximum 10-Minute Depth for Runoff-Producing Storms for two Pairs of Adjacent(*) Recording Rain Gages in 1964

Date	Total Depth		Maximum 10-minute Depth	
	6-hour drive	24-hour drive	6-hour drive	24-hour drive
		Rain Gage 2		
7/12	0.60	0.53	0.16	0.14
7/18	.81	.75	.31	.28
8/1	.44	.43	.20	.23
9/9-10	1.04	1.03	.57	.57
9/11	.60	.57	.43	.40
		Rain Gage 61		
7/12	0.65	0.71	0.19	0.17
7/22	1.38	1.36	.65	.68
7/31	.67	.71	.17	.20
8/2	.64	.64	.40	.34
8/8	.40	.50	.18	.24
9/8	.79	.86	.21	.26
9/9-10	1.78	1.77	.43	.54
9/11	2.09	2.03	.76	.58

(*) Separation approximately 2 feet

TABLE 2

Total Depth and Maximum 10-Minute Depth for Runoff-Producing Storms at Nearby (*) Recording Rain Gages in 1964

Date	Total Depth		Maximum 10-Minute Depth	
	RG 83	RG 84	RG 83	RG 84
7/13	0.51	0.39	0.21	0.20
7/22	.86	.91	.44	.41
7/31	.46	.51	.20	.23
8/8	.58	.55	.31	.34
9/16	.75	.80	.53	.42
8/27	.37	.43	.14	.18
9/8	.86	.90	.40	.41
9/9-10	.97	.86	.41	.38

(*) Separation approximately 900 feet

TABLE 3

Total Depth and Maximum 10-Minute Depth for Runoff-Producing Storms for Three Rain Gages on Walnut Gulch Watershed Number 4 (*) in 1964

Date	Total Depth			Maximum 10-Minute Depth		
	RG 27	RG 71	RG 31	RG 27	RG 71	RG 31
7/13	0.28	1.23	0.93	0.12	0.53	0.45
7/22	.64	.72	1.07	.39	.40	.80
7/31	.40	.33	.24	.19	.15	.21
8/8	.68	.39	.18	.28	.22	.15
8/16	.81	.43	.24	.41	.36	.20
7/27	.35	.46	.53	.12	.23	.30
9/8	.69	.60	1.06	.33	.25	.63
9/9-10	1.00	.87	1.10	.44	.42	.42

(*) Area approximately 550 acres

functioning of the gages rather than to differences in total storm cach. These data suggest that, at least for the heavier storms, recording gages furnish good estimates of point rainfall. Other studies indicate that, for intervals of less than 10 minutes, records of intensity from 6-hour gages are, in general, more reliable than those from 24-hour gages (Renard and Osborn, 1965).

Comparison of the catch of rain gages 83 and 84, situated about 900 feet apart on the 19.3-acre Lucky Hills subwatershed shows some differences in the totals and in the 10-minute intensities (Table 2). Other records from these two gages have shown greater differences for a few intense storms, but for most rains the catch of either gage has been representative for the subwatershed. The two gages are maintained in such close proximity to ensure a record for the added advantage of recording the occasional storm in which the "sharp edge" of an individual convective cell strikes this small subwatershed. Such a "sharp edge" of an individual thunderstorm cell occurs along the receding edge of the multicellular thunderstorm. The cell spreads out slightly in one direction, but is cut off in the other. This phenomenon causes marked differences in precipitation within a distance of a few hundred feet. During such a storm that occurred on this subwatershed in 1963, rain gage 83 caught approximately 0.80 inch, whereas rain gage 84 recorded only 0.40 inch.

Adjacent to the Lucky Hills area is Watershed Number 4 — which covers 550 acres and is about two miles long and one-half mile wide — within which are three recording rain gages. At the outlet is rain gage 27, which is less than half a mile from gages 83 and 84. Rain gage 71 is situated one mile from gage 27, and rain gage 31.is at the upper end of the watershed, one mile from gage 71. Among these three gages, precipitation may vary considerably (Table 3), and it is evident that no one of the three would satisfactorily record the highly variable storms that occur over a two-mile-long watershed. The differences, however, are such that the data from all three gages may be used with assurance to developed isohyetal maps for the area. Whether the data may be simply averaged or should be area-weighted to elucidate precipitation-runoff relationships, however, is still uncertain.

Although we realize that records from individual gages do not accurately represent rainfall over a square mile of area, the foregoing observations, together with many others, afford us confidence in developing isohyetal maps for storm events on the

Fig. 6 — Walnut gulch watershed. — Summer Precipitation (inches). July-Sept., 1963
1963 Average = 7.80 inches

58-square-mile Walnut Gulch watershed. Furthermore, we believe a dense network of gages of this sort furnishes reliable data for interpreting storm precipitation over any comparable area in the semiarid zones of the southwestern United States.

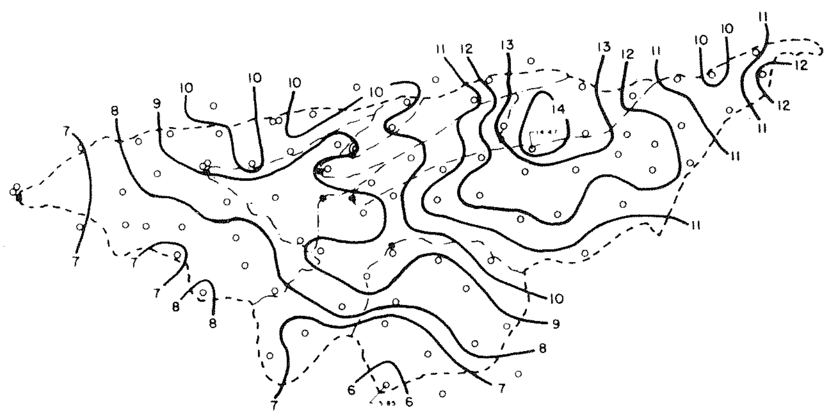

Fig. 7 — Walnut gulch watershed. — Summer Precipitation (inches) July-Sept., 1964
1964 Average = 9.80 inches

Summer precipitation on the Walnut Gulch watershed varies widely, both in areal distribution and in years (figs. 6-10). Maximum precipitation for July through September, 1963, was 10.7 inches; minimum was 4 inches. Corresponding values for 1964 were 14.5 inches and 5.80 inches, with the maximum occurring in the part of the watershed that received the minimum in 1963. Wide areal variations appear also in the monthly isohyetal maps for July, August, and September, 1964. Such areal and yearly variations are characteristic for the Southwest.

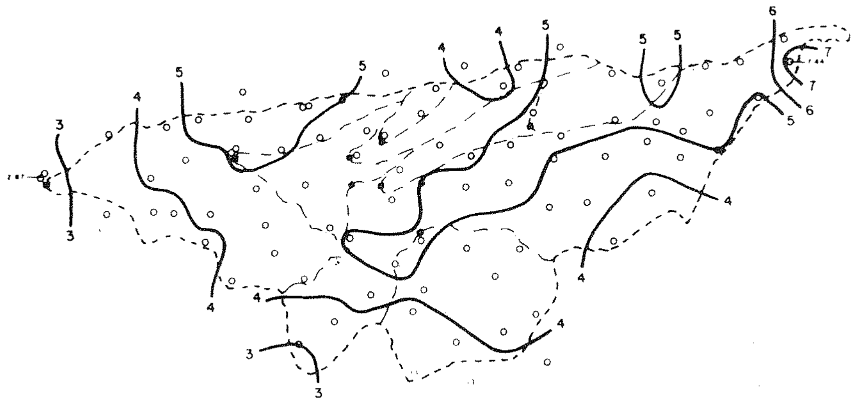

Fig. 8 — Walnut gulch watershed. — Precipitation (inches). July, 1964.

Upper Alamogordo Creek Watershed

During the period of record on the Alamogordo Creek Experimental Watershed, which began in 1955, two exceptionally intense thunderstorms have been recorded. The first of these, which occurred on June 5, 1960, resulted from a weak cold front

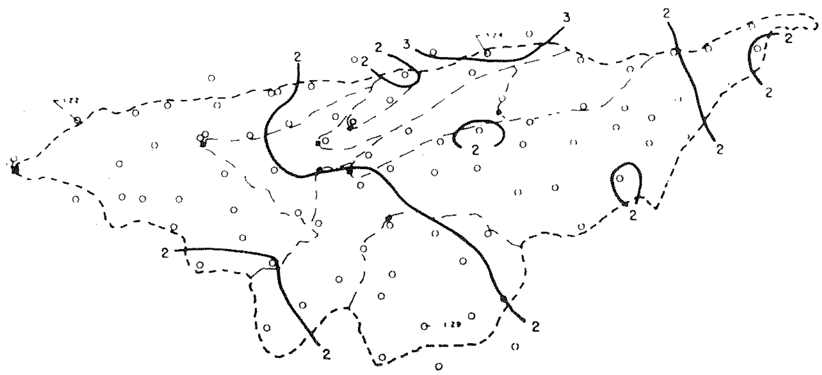

Fig. 9 — Walnut gulch watershed. — Precipitation (inches). August, 1964.

moving through the area coupled with strong afternoon convective heating (Keppel, 1963). The storm apparently centered over the study area: five gages in the interior of the watershed recorded more than 4 inches of rain in less than two hours (fig. 12). One of the five recorded 3.09 inches in 15 minutes. Peak and volume of runoff recorded at the stream gaging station at the lower end of the study area far exceeded any other observed during the period of record. The second storm occurred in the early morning

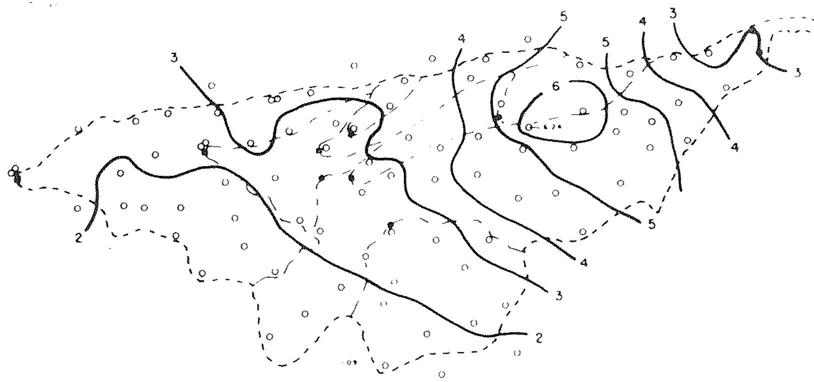

Fig. 10 — Walnut gulch watershed. — Precipitation (inches). Sept., 1964.

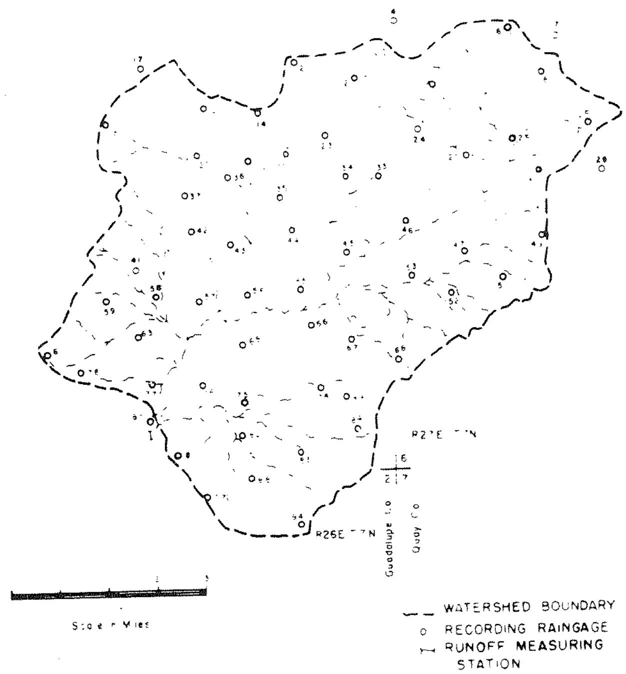

Fig. 11 — Alamogordo creek, New Mexico experimental watershed

of July 13, 1961 (fig. 13). Again, one gage recorded 3.09 inches in 15 minutes, although it was a different gage from any of the five mentioned above for the 1960 storm. Since a considerable amount of the precipitation of this storm fell as large hailstones

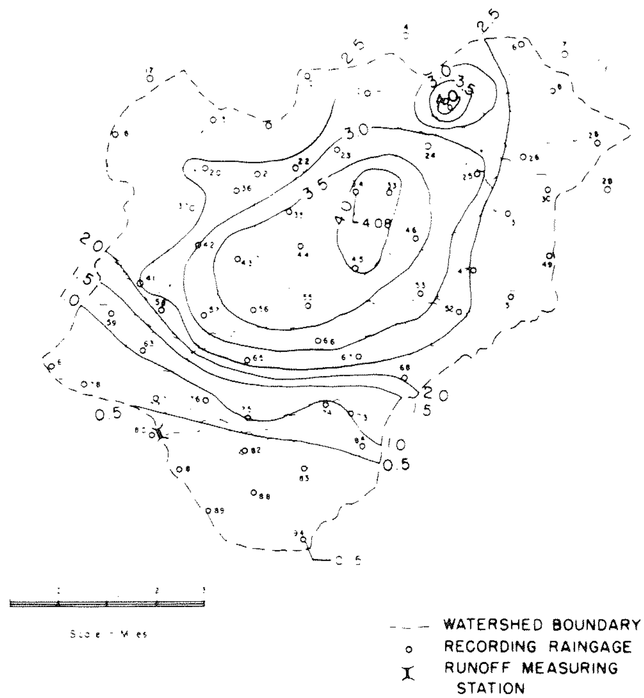

Fig. 12 — Alamogordo creek watershed. — Precipitation (inches). Storm of June 5, 1960

(fig. 14), which lay on the ground for as long as 24 hours, peak and volume of runoff amount to only half of that caused by the 1960 storm (Osborn and Reynolds, 1963).

At the time of these two events, relatively small amounts of precipitation were recorded at surrounding Weather Bureau stations (0.75 inch or less), which emphasizes the value of intense rain-gage networks for studying and evaluating magnitude and areal extent of runoff-producing storms in the semiarid areas of the Southwest.

SUMMARY

In Arizona and New Mexico, the network of U.S. Weather Bureau recording and non-recording rain gages is not sufficiently dense to measure the runoff-producing portion of a great many summer thunderstorms. Since the runoff-producing storms are of great importance in studies of water yields of semiarid watershed, the Agricultural Research Service has established experimental watersheds with dense networks of recording rain gages to define these summer thunderstorms. Past and present experience has indicated that a density of one rain gage per square mile of watershed is adequate in the southwestern United States for all but very small watersheds of a few square miles or less. Data are now being collected on the magnitude, areal extent, and frequency of these high-intensity, small-area summer thunderstorms.

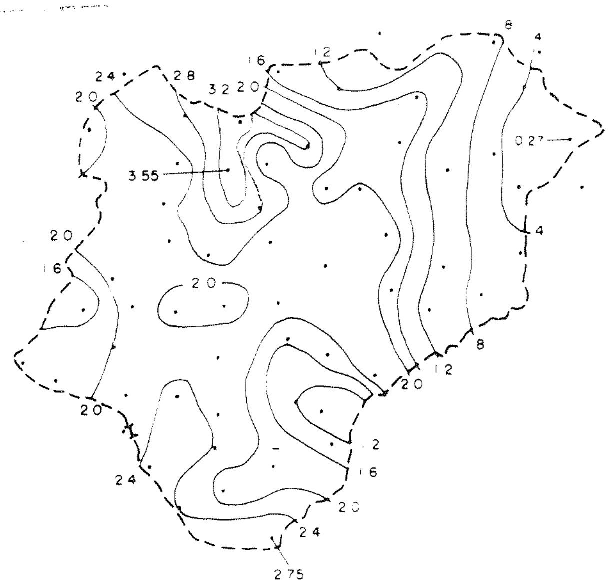

Fig. 13 — Alamogordo creek watershed. — Precipitation (inches). Storm of July 13, 1961.

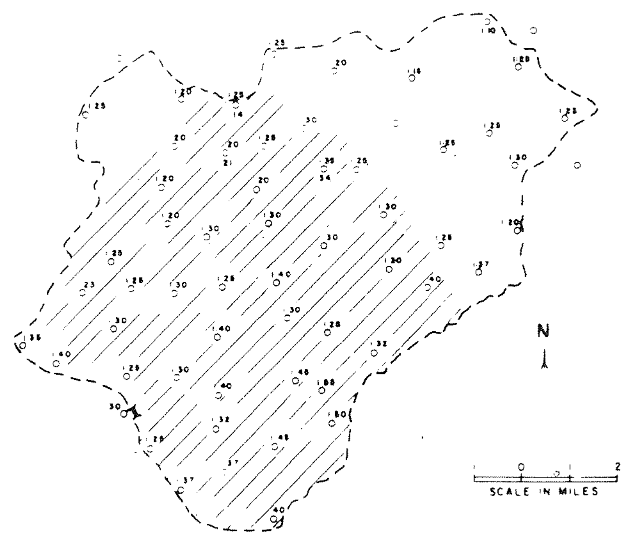

Fig. 14 — Starting times (A.M.) for first recorded precipitation. Storm of July 13, 1961. Alamogordo creek experimental watershed. — Total watershed area = 67 Sq.miles Area covered by giant hail = 35 Sq. miles.

REFERENCES

HUBBELL, D.S., GARDNER, J.L. and SHERMAN, G.L., 1941. Progress Report of the Navajo Soil and Water Experiment Station, Mexican Springs, New Mexico, 1934-1939. SCS-ESR-9. (Processed).

KEPPEL, R.V., 1963. A Record Storm Event on the Alamogordo Creek Watershed in Eastern New Mexico. *J. Geophys. Res.*, **68** (16): 4877-4880. August 15.

OSBORN, H.B. and REYNOLDS, W.N., 1963. Convective Storm Patterns in the Southwestern United States. *Internatl. Assoc. Sci. Hydrol. B.*, **8** (3): 71-83. September.

RENARD, K.G. and OSBORN, H.B., Rainfall Intensity Comparisons from Adjacent 6-Hour and 24-Hour Recording Rain Gages. (In manuscript).

WORKMAN, E.J. 1962. The Problem of Weather Modification. *Science*, **138** (3538): 407-412, Oct. 19.