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Timing and Duration of High Rainfall Rates in the Southwestern United States

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High-intensity rains of short duration and limited areal extent are important in the southwestern United States to engineers, hydrologists, meteorologists, and others concerned with the frequency, magnitude, duration, and distribution of thunderstorm rainfall. In this paper, data from two dense raingage networks, one in southeastern Arizona and the other in eastern New Mexico, were used to establish expected occurrences of high rainfall rates (50 mm/h and greater) and diurnal and seasonal variability in such occurrences. Expected occurrences and durations above various thresholds were determined for both point and area for each location.

INTRODUCTION

High-intensity rains of short duration and limited areal extent are considered common in the southwestern United States, but point and small area probabilities for specific regions are very low, even during the thunderstorm season. However, the magnitude, frequency, and areal extent of these intense rains can be important to professionals who must determine rain occurrence and the overall importance of these rains in both hydrologic and human resource systems. On one hand, flooding, water supply, forage survival, and erosion are all tied to thunderstorm rainfall. On the other hand, man's movement can be handicapped by unexpected high-intensity thunderstorm rainfall.

DATA

This analysis was based on data from 35 weighing-type recording raingages on the 150-km^2 Walnut Gulch experimental watershed in southeastern Arizona and the 170-km^2 Alamogordo Creek experimental watershed in eastern New Mexico (Figure 1). Point rainfall occurrences and intensities were determined for the 35 recording raingages in each network, including 'lines' of 12 and 10 gages at about 2-km intervals on Walnut Gulch and Alamogordo Creek, respectively (Figures 2 and 3). Storms were assumed random in time and space, so the Walnut Gulch line could be bent slightly to increase its length and gage encounters. Lines of gages, rather than clusters of gages, were used in the analyses because many of man's activities (aircraft landing and taking off) and developments (canal and roadway construction) are along continuous paths that approach straight lines. The chances of an aircraft encountering intense rainfall at some point along a landing path are greater than at any given point along the path. The chances of local flooding somewhere along a canal or roadway segment is greater than at any given point on the segment. Data were analyzed for a 10-yr period. Weighing recording raingages with 24-h clocks are not sensitive to instantaneous intensities, so intensities were determined with chart readers only for durations of 2 min and greater. For more detail on the raingage networks, see *Osborn et al.* [1979].

Analyses made for individual thunderstorm events were defined as those with rains exceeding specified intensities for 2 min or longer and separated by at least 1 hour without rainfall. The duration of continuous intense rainfall above selected thresholds was defined as the time between the first and last recorded intensity at or above the selected threshold at one or more gages on the line (Figure 4). The 35-gage networks were assumed to be reasonably representative of the area within the two watersheds. The lines of gages were assumed to be reasonably representative of smaller areas within the watersheds. However, raingages provide only a very small sample of thunderstorm rainfall. With gages at approximately 2-km intervals, there is a chance that both higher intensities and longer durations for intense rainfall will occur on the watershed and along the line. Therefore probabilities stated in the paper should be considered as lower limits to what may actually occur but should be

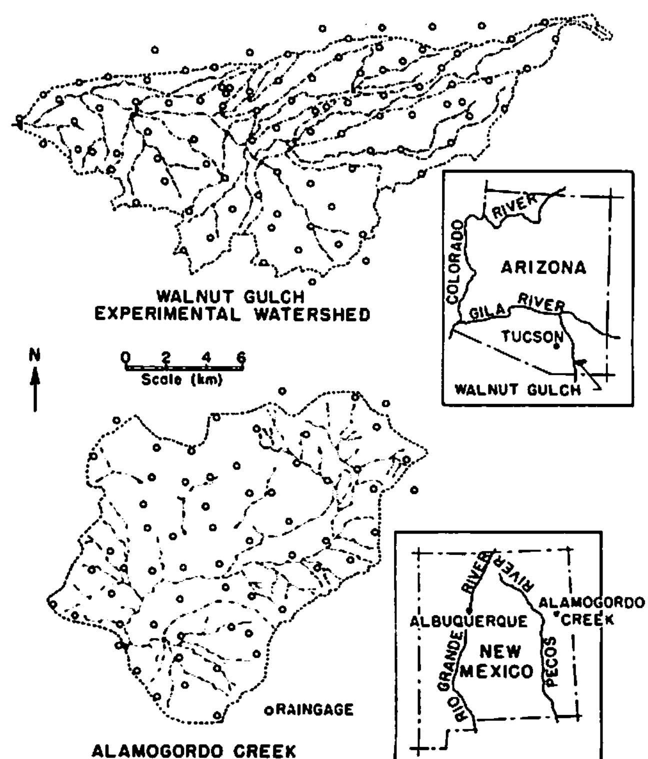

Fig. 1. Locations and raingage networks for USDA experimental watersheds in Arizona and New Mexico.

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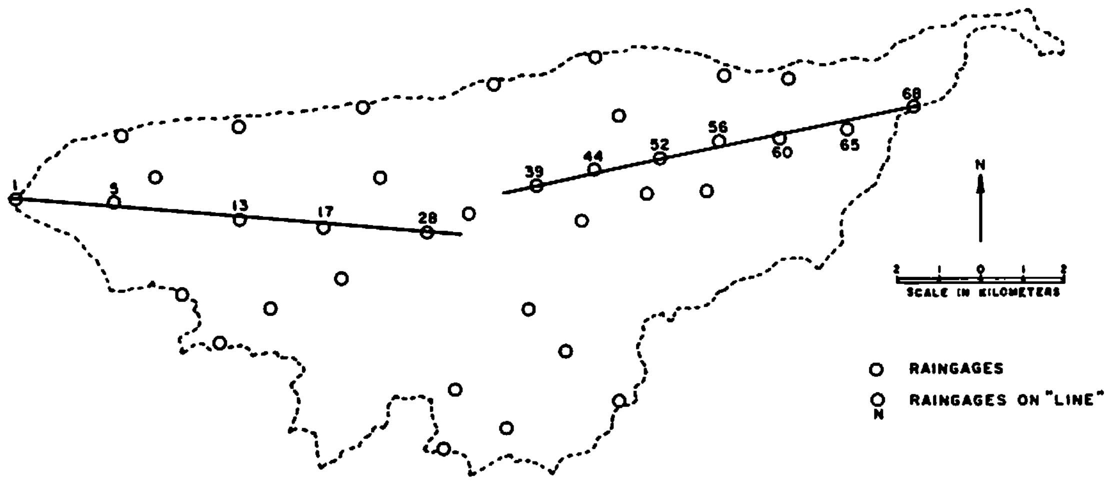

Fig. 2. Thirty-five-gage network including raingages along a line, Walnut Gulch.

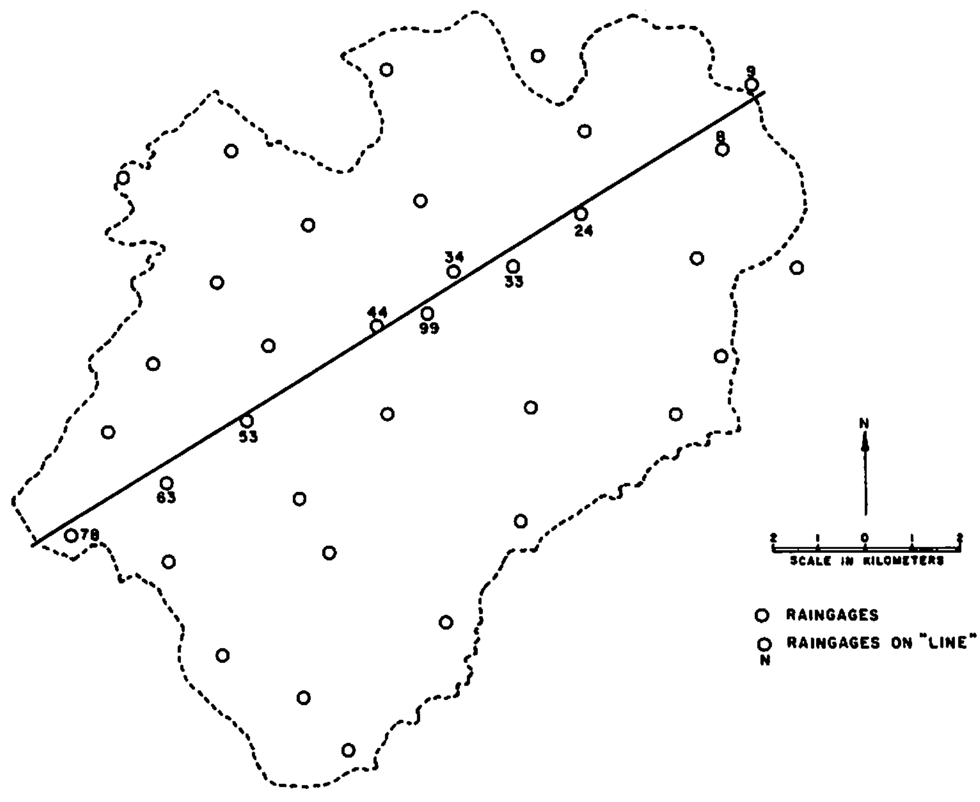

Fig. 3. Thirty-five-gage network including raingages along a line, Alamogordo Creek.

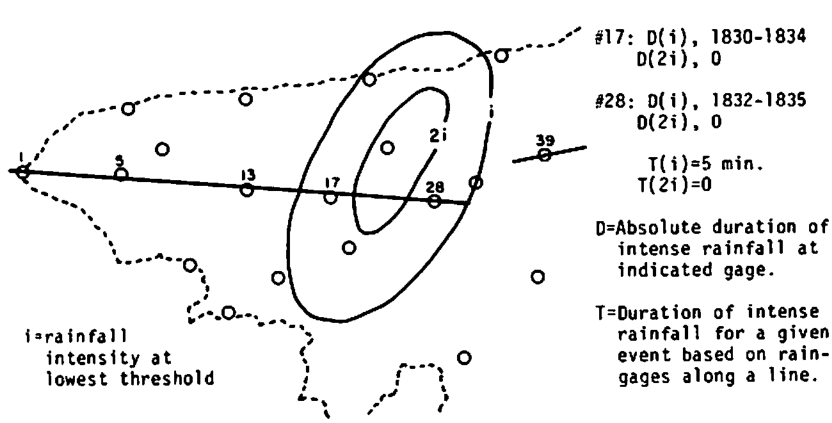

Fig. 4. Rainfall intensities for selected thresholds for a theoretical thunderstorm rain on Walnut Gulch.

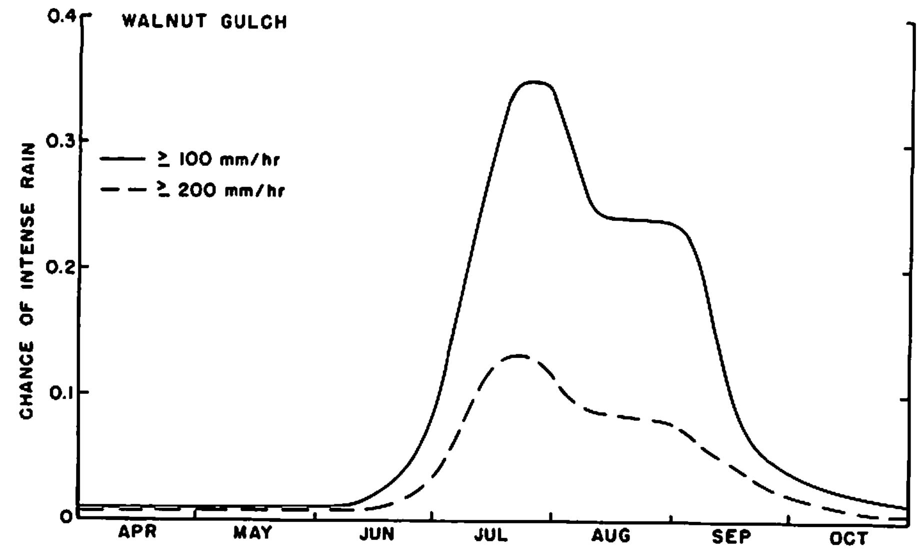

Fig. 5. Probability of intense rainfall on a line, Walnut Gulch.

adequate for most situations where probabilities along a line must be considered over probabilities at a point.

Climate

The sources of moisture for thunderstorms in the southwestern United States can be either the Gulf of Mexico or the Pacific Ocean [*Hales*, 1973; *Osborn et al.*, 1980]. The Gulf of Mexico is the source of most thunderstorm moisture in eastern New Mexico, while the Gulf and the Pacific are about equal sources of moisture for thunderstorms in southeastern Arizona. Almost all thunderstorms on Walnut Gulch are considered airmass events, with frontal activity having little direct effect on magnitude or areal extent [*Lane and Osborn*, 1973]. On the other hand, both airmass and frontal-convective thunderstorms are common on Alamogordo Creek. The largest runoff-producing events on Alamogordo Creek have been frontal-convective events associated with weak, fast-moving cold fronts. Apparently, frontal activity adds to the magnitude, duration, and areal extent of intense rainfall.

The thunderstorm season on Walnut Gulch is concentrated in July, August, and early September (about 80 days) (Figure 5), while on Alamogordo Creek it is longer, stretching from late May to early September (120 days) (Figure 6). The average annual precipitation is 290 mm on Walnut Gulch and 320 mm on Alamogordo Creek. Summer thunderstorm rains account for about 70% of the annual precipitation on Walnut Gulch and about 80% of the annual precipitation on Alamogordo Creek [*Renard*, 1970; *Osborn et al.*, 1979].

Rainfall Rates

For this study, frequencies were determined for high rainfall rates at points along lines, with high rainfall rates defined as intensities ≥ 50 mm/h for durations of 2 min or more. It was assumed that point samples were representative of rainfall on an area along the lines; similarly, the network of gages on Walnut Gulch are considered representative of rainfall over the entire watershed. Comparison of line and areal rainfall data on Walnut Gulch and Alamogordo Creek indicated that the line of gages was about 75% efficient in recording the high rainfall rates occurring within the entire watershed.

The chance of a high rainfall rate (100 mm/hr) along a line on a given day was greatest in late July on Walnut Gulch at about one chance in three (Figure 5), and there was about one chance in eight for a daily occurrence of 200 mm/hr or greater for the same period. There was about one chance in 12 for a high rainfall rate at a point and about one chance in 40 for an intensity ≥ 100 mm/hr.

The thunderstorm season also peaks in July on Alamogordo Creek, with the daily chance of a high rainfall rate about one in six (Figure 6). For 100 mm/hr or greater, the chance was about one in 12. Point probabilities on Alamogordo Creek were about one third of line probabilities as compared to about one fourth for Walnut Gulch.

The average and maximum number and durations of high intensity rains on Walnut Gulch and Alamogordo Creek are shown in Tables 1 and 2. Walnut Gulch had more intense rainfall events, but the events lasted longer and covered

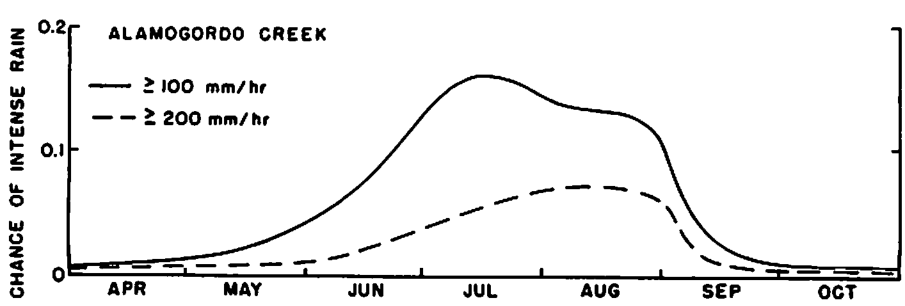

Fig. 6. Probability of intense rainfall on a line, Alamogordo Creek.

TABLE 1. Average and Maximum Seasonal Number and Duration of Events at a Point on Walnut Gulch and Alamogordo Creek

	Average											
	≥ 50		≥ 100		≥ 150		≥ 200		≥ 250		≥ 300	
	n	$\bar{t}$	n	$\bar{t}$	n	$\bar{t}$	n	$\bar{t}$	n	$\bar{t}$	n	$\bar{t}$
Walnut Gulch	4.6	7.0	0.94	4.3	0.29	3.0	0.06	2.4	0.02	2.0	0.006	2.0
Alamogordo Creek	4.3	7.4	1.00	4.8	0.31	3.9	0.10	3.0	0.04	2.4	0.015	2.3
	Maximum											
	≥ 50		≥ 100		≥ 150		≥ 200		≥ 250		≥ 300	
	n	Σt	n	Σt	n	Σt	n	Σt	n	Σt	n	Σt
Walnut Gulch	11	118	5	32	3	13	2	5	2	4	1	2
Alamogordo Creek	15	133	6	43	3	25	2	12	2	4	2	4

Measurements in mm/h. The n = number of events; $\bar{t}$ = average duration (in minutes) of intense rainfall per event; Σt = total duration (minutes) of intense rainfall.

more area on Alamogordo Creek, particularly for intensities ≥ 100 mm/hr. There was an average of four to five thunderstorms per season with intensities ≥ 50 mm/hr at a point on each watershed. There was an average of 20 and 12 thunderstorms with high rainfall rates per season along a line on Walnut Gulch and Alamogordo Creek, respectively (Tables 1 and 2). Both the average and maximum storm durations for intensities greater than 100 mm/hr were longer on Alamogordo Creek than on Walnut Gulch.

The maximum seasonal point and line frequency curves were about the same for the two watersheds (Figures 7 and 8). However, the range of values was much greater for Alamogordo Creek, suggesting greater uncertainty in expected seasonal daily occurrences. On Alamogordo Creek the minimum seasonal line frequency-intensity curve was about the same as the average point frequency curve. The seasonal number of point occurrences of high rainfall rates ranged from 0 to 11 on Walnut Gulch and 0 to 15 on Alamogordo Creek. A typical range over the watersheds for a single season for both watersheds was 3 to 10 for a 'wet' season and 0 to 5 for a 'dry' season. The range of seasonal occurrences along a line was 15 to 24 for Walnut Gulch and 5 to 22 for Alamogordo Creek. The range of average seasonal durations at a point was 21 to 52 min on Walnut Gulch and 9 to 65 min on Alamogordo Creek.

The greatest difference between the two watersheds was in storm durations for given intensities (Figures 9 and 10). Intense rainfall occurred less often on Alamogordo Creek, but when it did occur, it tended to last longer than on Walnut Gulch.

Diurnal variations in rainfall occurrences on Walnut Gulch and Alamogordo Creek were quite similar (Figure 11), and can be considered characteristic of much of the nonmountainous rangelands of the Southwest. About 80% of the storms with high rainfall rates occurred in a 10-h period between noon and 10 pm MST. There were a few more 'morning' storms on Alamogordo Creek and the 'afternoon' storms were concentrated a little later, but the differences were not significant for most uses. Walnut Gulch storms tended to end no later than midnight, while Alamogordo Creek storms sometimes lasted past midnight.

SUMMARY

Although high rainfall rates are common in the southwestern United States during the summer rainy season, the chance of occurrence at a specific time and place is very low. The importance of such events can be either general or specific and will depend on the interest of the involved party. Very intense rains have been recorded in both southeastern

TABLE 2. Average and Maximum Seasonal Number and Duration of Events Along a Line on Walnut Gulch and Alamogordo Creek

	Average											
	≥ 50		≥ 100		≥ 150		≥ 200		≥ 250		≥ 300	
	n	$\bar{t}$	n	$\bar{t}$	n	$\bar{t}$	n	$\bar{t}$	n	$\bar{t}$	n	$\bar{t}$
Walnut Gulch	19.6	14	6.4	6.6	2.8	4.4	0.5	3.6	0.4	2.2	.01	2.0
Alamogordo Creek	11.9	18	5.0	7.7	1.9	5.8	0.6	4.2	0.3	2.8	.01	2.0
	Maximum											
	≥ 50		≥ 100		≥ 150		≥ 200		≥ 250		≥ 300	
	n	Σt	n	Σt	n	Σt	n	Σt	n	Σt	n	Σt
Walnut Gulch	24	418	11	62	5	23	2	7	2	5	1	2
Alamogordo Creek	22	385	11	136	7	52	2	8	2	6	2	2

All measurements in mm/h. The n = number of events; $\bar{t}$ = average duration (min) of intense rainfall per event; Σt = total duration (min) of intense rainfall.

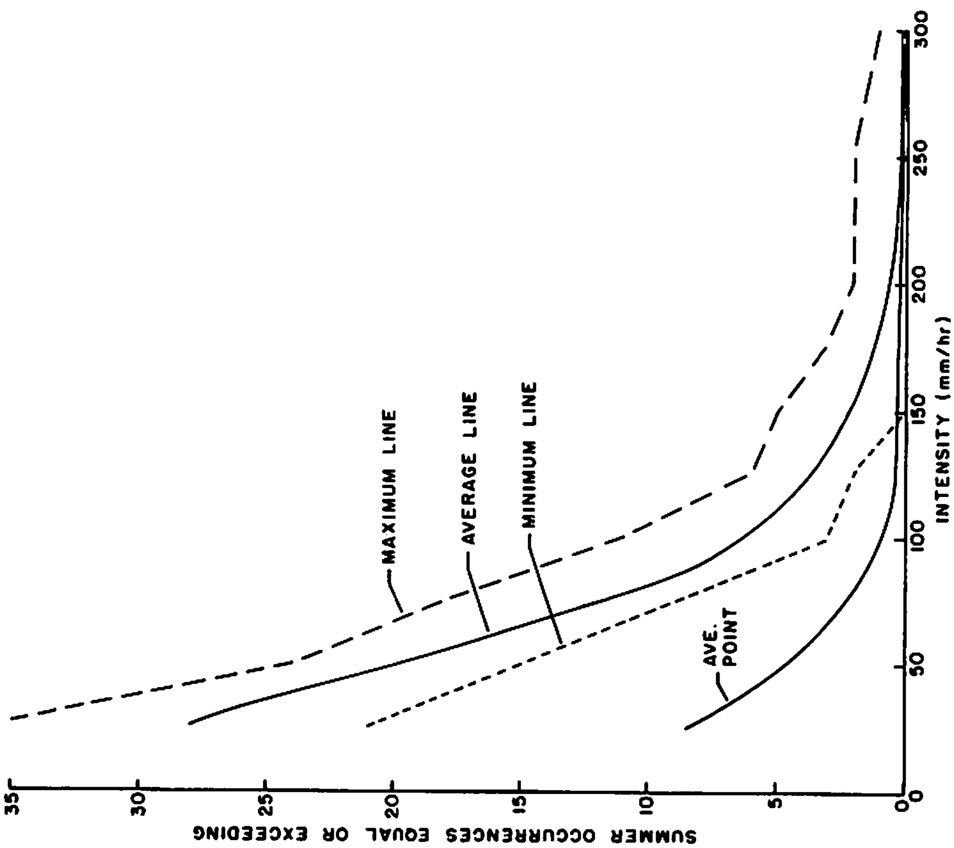

Fig. 7. Point and line frequency-intensity relationships, Walnut Gulch.

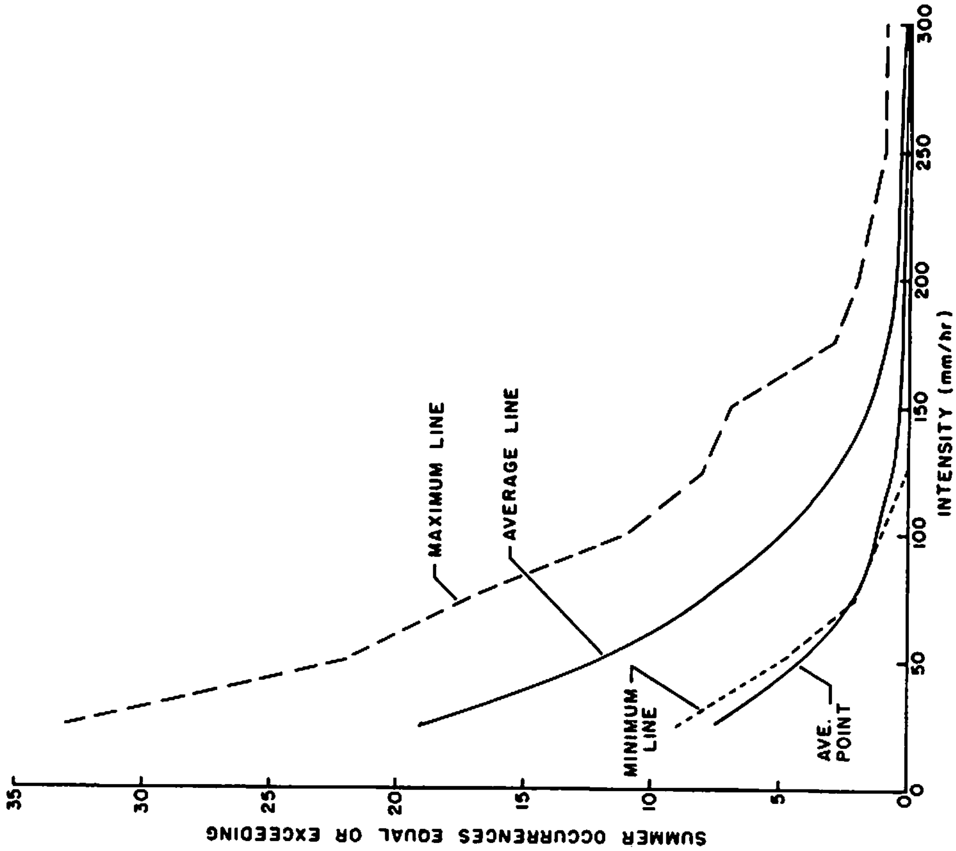

Fig. 8. Point and line frequency-intensity relationships, Alamogordo Creek.

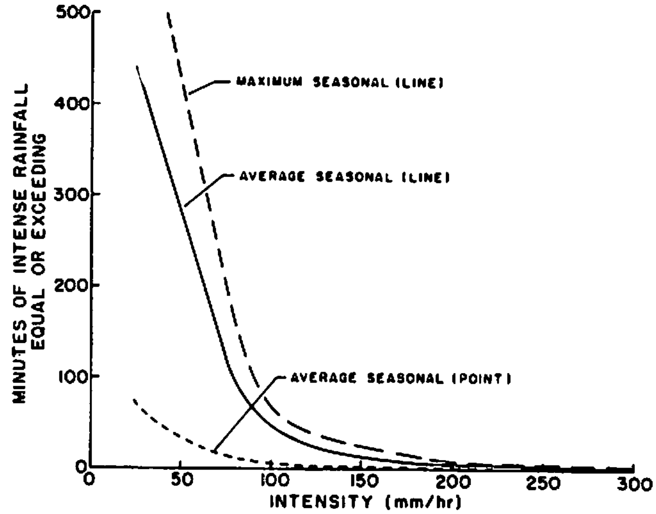

Fig. 9. Point and line frequency curves for durations of rainfall intensities, Walnut Gulch.

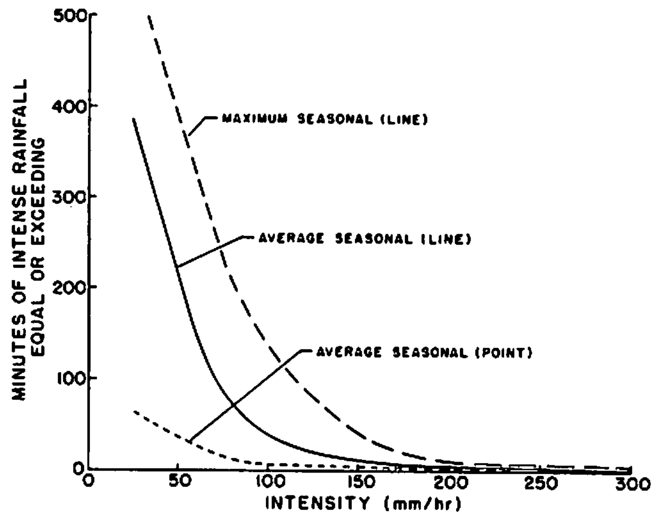

Fig. 10. Point and line frequency curves for durations of rainfall intensities, Alamogordo Creek.

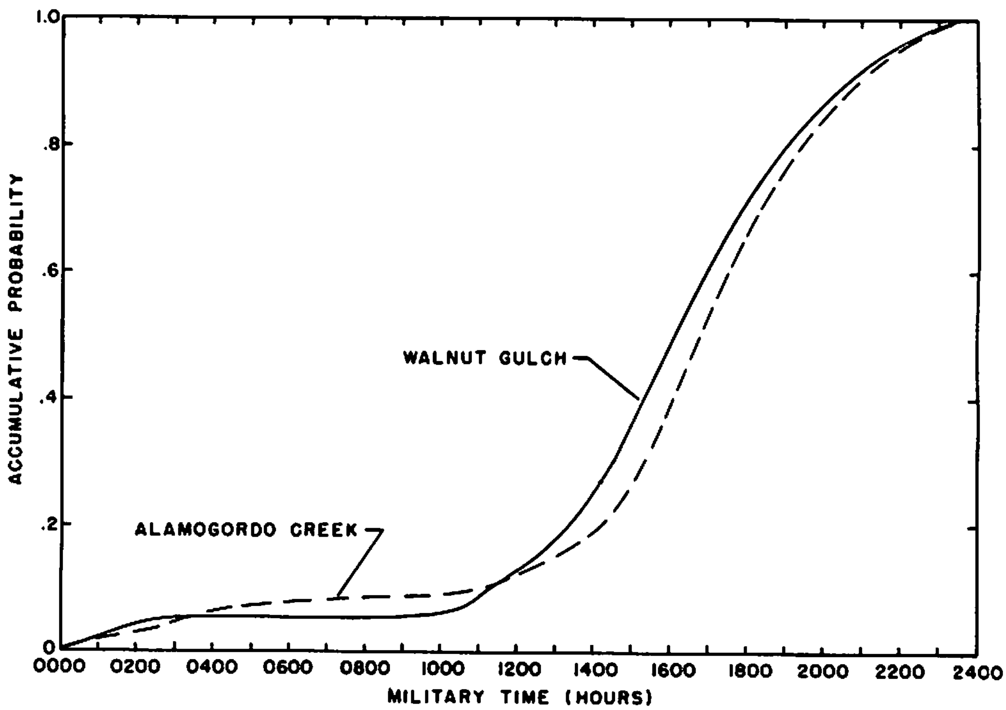

Fig. 11. Diurnal distributions of intense rainfall occurrences on Walnut Gulch and Alamogordo Creek.

Arizona and eastern New Mexico, with the major storms in New Mexico often covering larger areas and lasting longer. However, the storms are scattered over a longer season (120 days) in New Mexico, whereas they are generally concentrated in shorter periods (80 days) in Arizona.

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