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EFFECT OF STORM DURATION ON RUNOFF FROM RANGELAND WATERSHEDS IN THE SEMIARID SOUTHWESTERN UNITED STATES

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ABSTRACT

Almost all runoff from the semiarid rangelands of the Southwestern United States results from intense convective storms of short duration. Depth-duration values for precipitation for this region that are developed through standard procedures may be misleading when used for runoff design. Various combinations of short bursts of rain can, and do, plot on average depth-duration curves, but such curves have little practical meaning for small watersheds (100 square miles or less). For design purposes for small watersheds, depths of precipitation for relatively short periods (15-30-60 minutes) for varying return periods and areas are needed. For runoff design for larger watersheds two probability estimates may be needed—the probability of storms of certain intensities and size falling on tributary watersheds of finite sizes, and the probability of storms developing over a multi-tributary system in such patterns as to produce important volumes and peaks of runoff.

RÉSUMÉ

Presque tout l'écoulement des régions semi-arides du sud-Ouest des États-Unis provient des averses convertives de courte durée. Les valeurs hauteurs-durées des précipitations de ces régions obtenues par les méthodes standard peuvent conduire à des erreurs quand on les utilise pour trouver la répartition de l'écoulement. Des combinaisons variées de courtes averses peuvent être mises sur des courbes hauteurs-durées, mais ces courbes ont peu de signification pour des bassins peu étendus (100 milles carrés ou moins). Pour l'établissement de projets pour les petits bassins versants, les hauteurs des précipitations pour des périodes relativement courtes (15-30-60 minutes), avec des périodes de retour et des surfaces variées sont nécessaires. Pour les valeurs d'écoulement se rapportant à des bassins plus étendus, deux estimations de probabilités peuvent être souhaitables — la probabilité d'averses d'intensités et d'étendues données, tombant sur des bassins tributaires d'étendues finies et la probabilité d'averses se développant sur un système à plusieurs tributaires dans une mesure suffisante pour produire d'importants volumes maxima d'écoulements.

Storm duration is an important variable in developing precipitation-runoff relationships. Depth-duration curves have been developed by many persons. The U.S. Weather Bureau has developed depth-duration curves for varying return periods for all regions of the United States. For example U.S. Weather Bureau Technical Paper 40 gives the following values for a location near Tombstone in southeastern Arizona, for a return period of 10 years: 2.5 inches in 6 hours, 2.0 inches in 2 hours, 1.7 inches in 1 hour, and 1.4 inches in 30 minutes. U.S. Weather Bureau Technical Paper 28 gives values for a return period of 2 years: 2.0 inches in 24 hours, 1.6 inches in 6 hours, and 1.1 inches in 1 hour. Depth-duration values from U.S. Weather Bureau Technical Papers 28 and 40 plot as straight lines on semilog paper (Fig. 1).

These rainfall estimates are commonly used as a basis for runoff design in the Southwestern United States. Unfortunately, this "straightline" approach is misleading when applied to other than major stream systems. Such depth-duration curves suggest that the longer the storm, the more the runoff. Generally speaking, however, for rangeland watersheds of about 100 square miles or less in the semiarid Southwest, the shorter the storm, the greater the runoff. Almost all runoff results from intense, shortlived, multicellular thunderstorms occurring over less than the

(*) In cooperation with the Arizona and New Mexico Agricultural Experiment Stations.

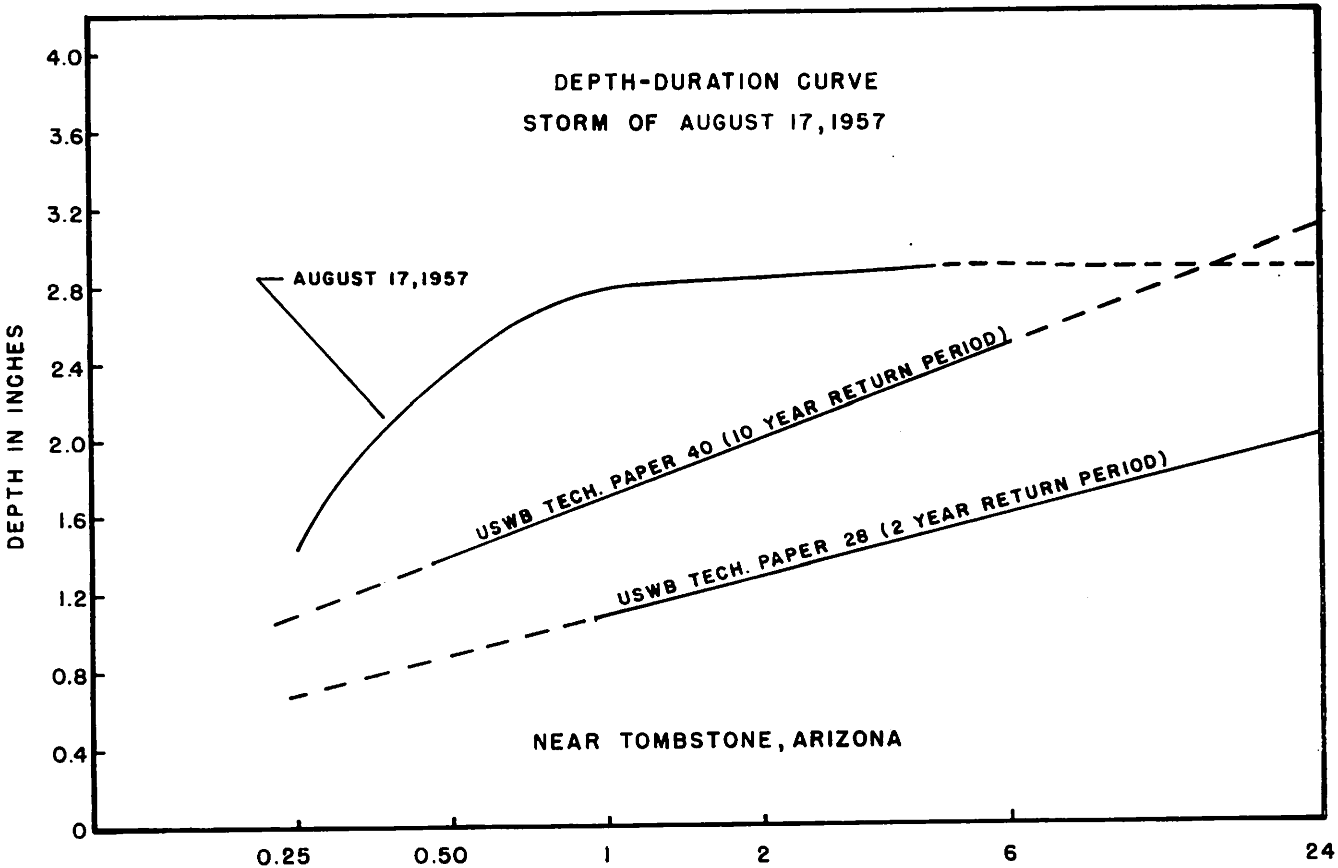

Fig. 1 — Duration in hours.

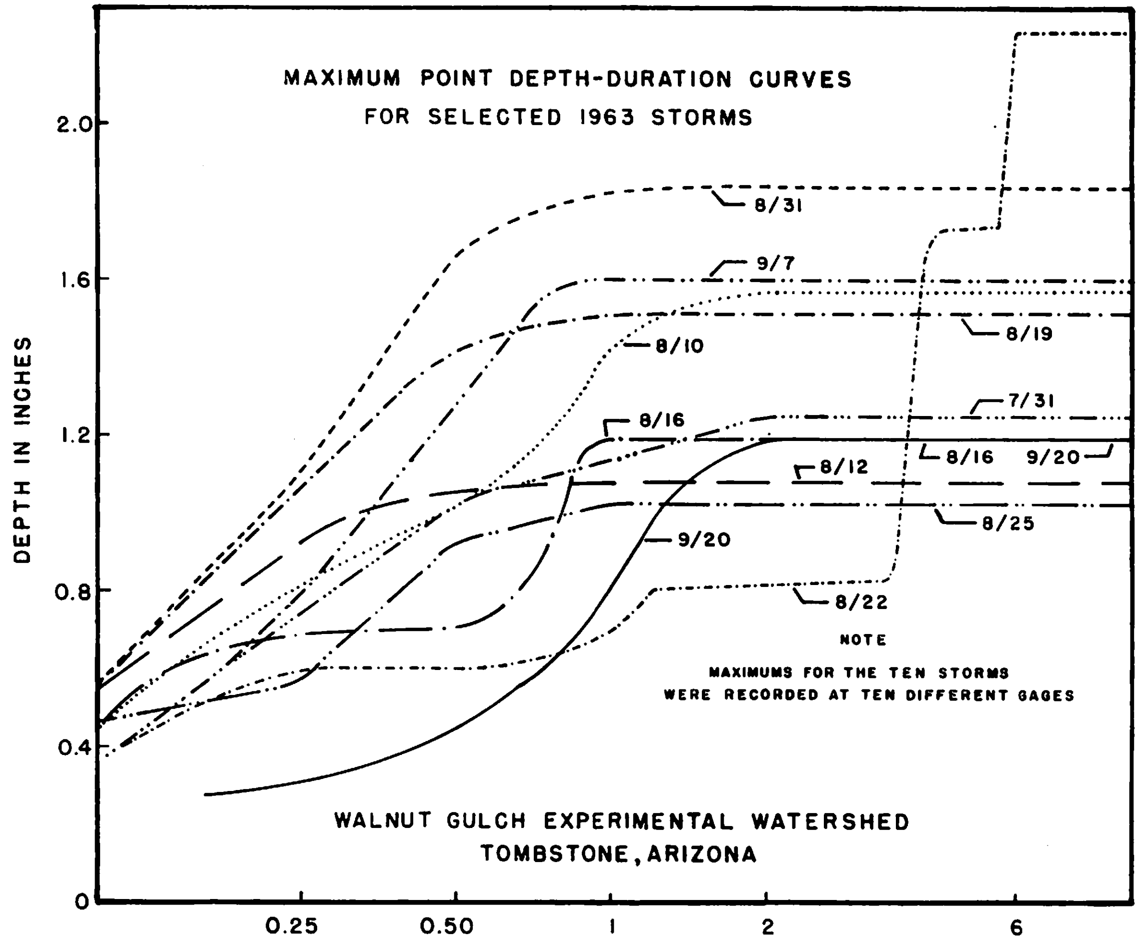

Fig. 2 — Duration in hours.

total watershed. Atmospheric moisture and energy available to generate such storms are limited, and if this moisture is discharged and the available energy utilized in a relatively short period (less than 1 hour), maximum volumes and peaks of runoff can occur. If the same moisture and energy are dissipated over a longer period, runoff peaks are reduced. Furthermore, runoff volumes are generally less with increased storm duration because of greater losses to evaporation, infiltration, and channel abstractions. Precipitation and runoff data from the Walnut Gulch Experimental Watershed (*) in southeastern Arizona are used to illustrate this point.

In nine years of record on the 58-square-mile Walnut Gulch watershed, no runoff has been

(*) An experimental watershed near Tombstone, Arizona, operated by the Southwest Watershed Research Project, Agricultural Research Service, Tucson, Arizona.

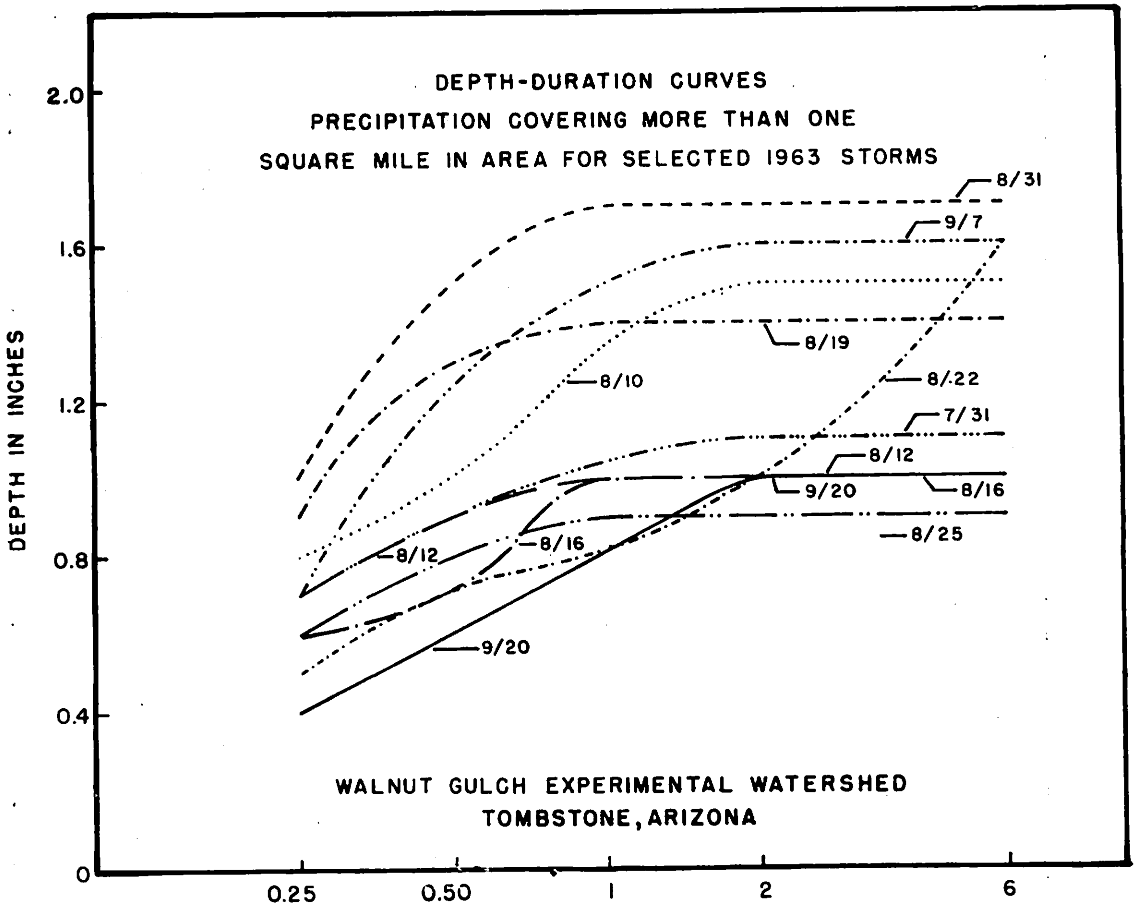

Fig. 3 — Duration in hours.

recorded from winter storms; all runoff has occurred from convective or frontal-convective, summer thunderstorms (*).

Depth for the maximum point rainfall is plotted against duration for the 11 largest runoff-producing storms in 1963 (Fig. 2). As would be expected, when area is added to the depth-duration relationship for the same storm (Fig. 3), smoother curves are produced than those representing point rainfall, but they are still quite similar.

When the storms are ranked in order of runoff produced, the largest volume and greatest peak, by far, were recorded from the storm on August 19 (Table 1). Considerably less runoff and lower peaks were recorded on August 25 and August 31; and these two storms, in turn, produced considerably more runoff than each of the remaining events.

(*) Joel E. Fletcher, Some Properties of Precipitation Associated with Runoff from Walnut Gulch Watershed, Arizona. Presented at AGU meeting, April 1961, Washington, D.C. (Pending Publication).

TABLE 1

1963 Storms over Walnut Gulch Watershed Ranked by Volume of Runoff Produced

Date	Area of Watershed Covered by 0.6 inch or more (sq. Miles)	Ranking by Area Covered
8/19	42	1
8/25	19	6
8/31	25	2
8/10	11	7
8/22	26	2
9/7	24	2
7/31	23	2
8/12	5	8

Of course, there are many variables that influenced the runoff, including watershed area covered, intensities, antecedent soil and channel moisture conditions, and direction of storm movement. The point illustrated by Figures 2 and 3 is that the runoff-producing rain for each of the largest 3 events fell in a relatively short period—2/3 in less than 15 minutes, 9/10 in less than 30 minutes, and all in less than one hour.

The longest runoff-producing storm of the season, and also the event that produced the greatest (daily) point rainfall (over 2 inches) occurred on the afternoon of August 22. Three distinct periods of intense rain were measured. Four distinct runoff peaks were recorded at the watershed outlet, but the largest was less than 1/3 of that recorded on August 19.

All of the largest runoff-producing events on Walnut Gulch in nine years of record were of the same general character as the events of August 19, 25, and 31, 1963—short-lived, high-intensity, multicellular events. The largest event on record occurred on August 17, 1957, when a peak discharge of approximately 18,000 cfs developed from a 42-square-mile subwatershed. High, but not exceptional, intensities were recorded over much of the watershed as the storm moved across the watershed and toward the outlet. Although all runoff-producing rain at individual gages (*) fell in less than 45 minutes (maximum was about 2.8 inches in 40 minutes, Fig. 1), approximately 75 minutes elapsed from the time the first heavy rain was recorded on the watershed to the time when the last heavy rain ended.

If rain occurring anywhere within an entire watershed (rather than point values) is considered in computing depth-duration values, all of the major runoff events will relate to slightly longer rainfall durations. For example, heavy precipitation for the largest runoff-producing event in 1963 (August 19) began at 8:55 a.m. on the upper part of the watershed and ended on the middle part of the watershed by 10:05 a.m. By clock time the depth-duration curve would be slightly lower for periods up to 70 minutes. In any case, 2-hour, and 6-hour point rainfall depths projected as exponentials of the one-hour depth would be meaningless.

A depth-duration curve for the storms of July 19 and 20, 1955 (Fig. 4) illustrates the difference between a semi-logarithmic straight line estimate of the depth-duration relationship and the actual events. These two storms represent the largest point, 24-hour precipitation values in the nine years of record on Walnut Gulch. However, the second rain occurred about 15 hours after the first, and all flow from the first storm had ceased several hours before the second storm occurred. The peak flow for the period resulted from about 2.4 inches of the rain, not the total 3.8 inches. Furthermore, the volume of runoff was considerably less from these two well-separated events than would be expected had the 24-hour rainfall of 3.8 inches occurred in one storm.

(*) Recording gage network, spaced approximately 1 gage per square mile.

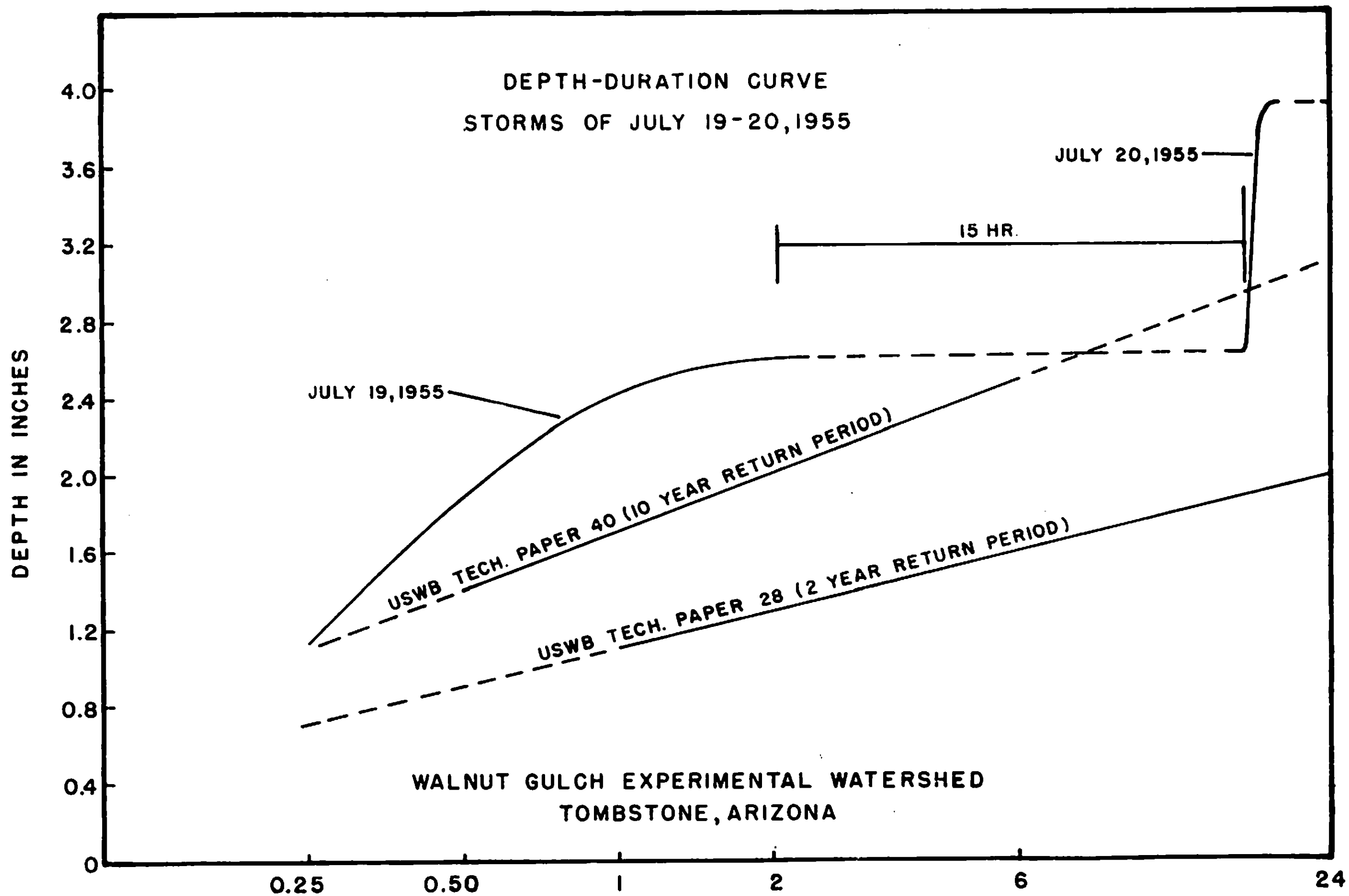

Fig. 4 — Duration in hours.

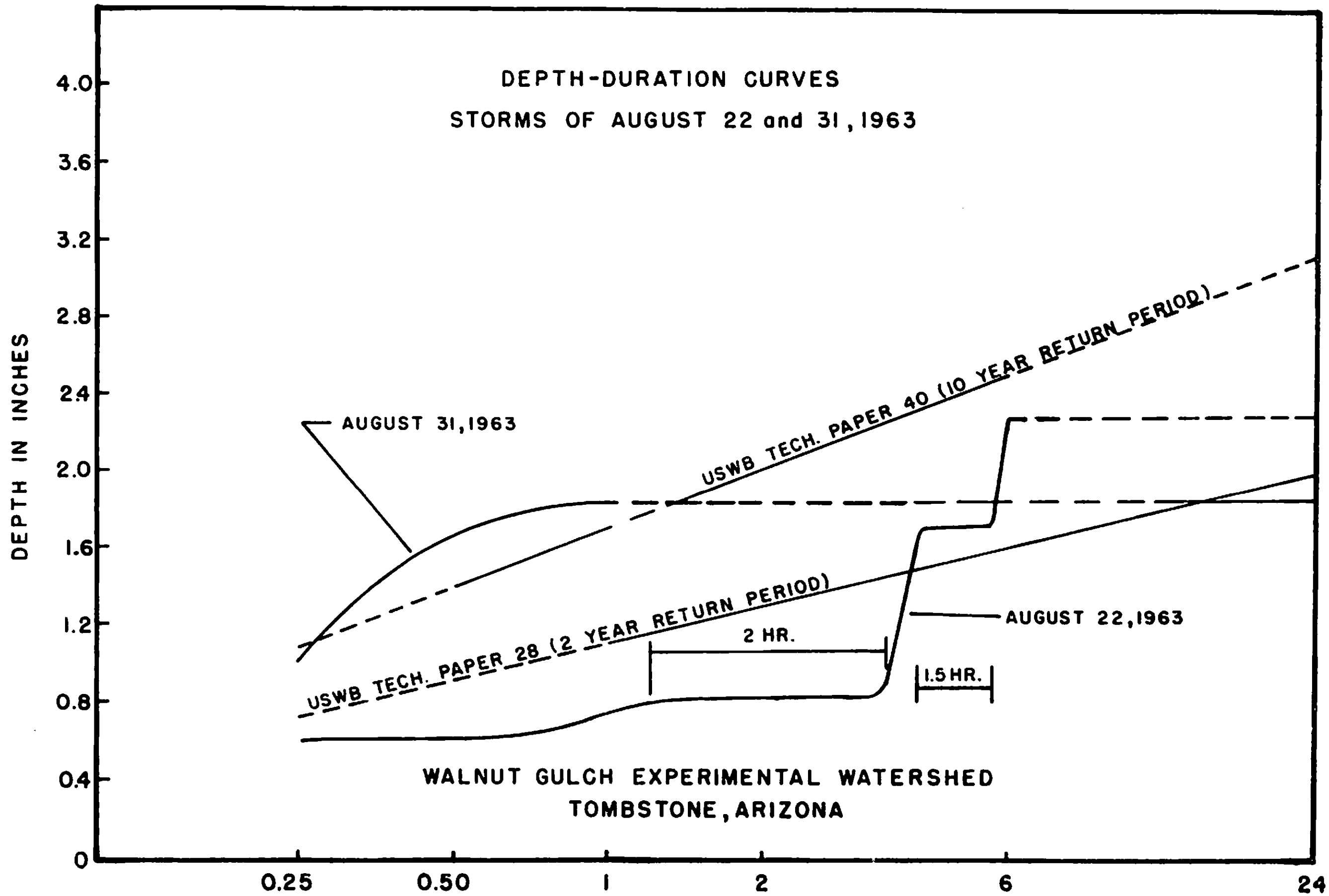

Fig. 5 — Duration in hours.

The depth-duration curves for the maximum point rainfall on August 22 and August 31, 1963 are plotted on Figure 5. The highest intensities of the year were recorded on August 31. The storm lasted for Approximately one hour, and no rain fell thereafter for two days. The depth-duration curve is higher than the U.S. Weather Bureau Technical Paper 40, 10-year values, up to 70 minutes, and then is flat for two days. The depths for 1, 2, 6, 12, 18, and 24 hours, and 2 days are the same—1.6 inches. The depth-duration curve for August 22, on the other hand, lies entirely below the 10-year return period curve from U.S. Weather Bureau Technical Paper 40. However, at 6 hours, the August 22 accumulated depth approached the 10-year estimate of Technical Paper 40.

From these examples and many others, it is apparent that the depth-duration curves for the Southwest for short durations, as developed on a national basis, are very rough and that more precise rainfall estimates are needed for runoff design. In this area runoff-producing storms consist of sharp bursts of rain covering only a few square miles. The distributions of these convective cells in time and space are vital in determining runoff, and average depth-duration curves drawn through these "bursts" are quite meaningless.

Conclusions derived from the intense networks at Walnut Gulch are supported also by data from several small watersheds under study near Albuquerque, New Mexico, and Safford, Arizona. One exceptional runoff-producing event has been recorded at each of these stations in 25 years of record, and these events were short-lived, high-intensity thunderstorms. All runoff-producing precipitation was recorded in less than one hour—3.1 inches at Safford and 1.8 inches at Albuquerque. Also records from another intense network of rain gages on the 67-square-mile Alamogordo Creek Experimental Watershed (*) in northeastern New Mexico indicate that the largest amounts of runoff are produced by similar short-lived storms. More than 3 inches of rain in a 4-inch storm were recorded in a 15-minute period on Alamogordo Creek. This storm on June 5, 1960, produced the record peak and volume of runoff from the watershed.

In northeastern New Mexico, primarily in the winter but occasionally in the summer, considerable runoff has been recorded from longer duration frontal storms. Actually, two sets of rainfall depth-duration curves should be developed for the Southwest—one for the short-lived, intense summer or convective storms, and the other for the winter or frontal storms. Thunderstorms cause by far the greatest peaks and most of the runoff, but an occasional winter storm will produce enough rain to cause limited runoff which may build up to important flows in major streams. Frontal events may determine the true depth-duration values for periods of six hours or longer. But, as is illustrated by the records at Walnut Gulch, two short-duration, intense storms separated by less than 24 hours can total as much as the occasional exceptional winter storm. In the summer storm, intensities may easily exceed 10 in/hr; in the winter storm, they seldom exceed 1 in/hr. The two types of storms cannot be validly combined in one depth-duration curve.

In summary, depth-duration values, such as those developed in U.S. Weather Bureau Technical Paper 40 may be misleading when used for runoff design for the semiarid rangeland regions of the Southwestern United States. In these regions, almost all runoff results from intense convective storms of short duration. Various combinations of short burst of rain can, and do, plot on an average depth-duration curve, but such curves have little meaning. For design purposes for watersheds of about 100 square miles or less in the Southwest, depths for relatively short periods (15-30-60 minutes) for varying return periods and areas are needed, along with the probable size and separation of convective storm cells in both time and space. For runoff designs involving large watersheds, two probability estimates may be needed—the probability of storms of certain intensities and sizes falling on tributary watersheds of finite sizes, and the probability of storms developing over a multi-tributary system in such patterns as to produce important volumes and peaks of runoff.

(*) An experimental watershed near Santa Rosa, New Mexico, operated by the Southwest Watershed Research Project, Agricultural Research Service, Tucson Arizona.