SOME REGIONAL DIFFERENCES IN RUNOFF-PRODUCING THUNDERSTORM RAINFALL IN THE SOUTHWEST [1/]

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INTRODUCTION

Regional differences in rainfall amounts and intensities in the Southwest have been noted by numerous investigators. However, quantitative descriptions of these differences, usually as depth-duration frequencies, generally have ignored differences in the storm system that generated the rainfall and have lumped essentially different storm populations together. Sellers (1960) suggested that rainfall in Arizona could be subdivided into roughly three categories--frontal winter rainfall, air-mass thunderstorm rainfall, and frontal-convective rainfall. Frontal-convective storms include those that result from tropical storms off Baja California and occasionally, as described by Sellers (1960), come "rampaging through southern Arizona."

In this paper, estimates by Leopold (1944) and Hershfield (1961) of rainfall depth-duration frequencies for Arizona and New Mexico are compared with more recent rainfall records from U.S. Weather Bureau rain gages in southern Arizona and New Mexico and Agricultural Research Service rain gages on the Walnut Gulch Experimental Watershed in southeastern Arizona and the Alamogordo

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Creek watershed in eastern New Mexico. Some regional differences in thunderstorm rainfall depths and intensities are indicated, and possible reasons for these differences are advanced. Stations along the "rim" in central Arizona were not included in this analysis, since the orographic effects on rainfall are much greater along the "rim" than across most of southern Arizona. The "rim" should be analyzed separately and then compared with records at other stations.

RAINFALL DEPTH-DURATION FREQUENCY

Leopold (1944) made the first in-depth study of characteristics of heavy rainfall in New Mexico and Arizona. He referred to earlier work by Yarnell (1935), but pointed out that Yarnell had only 5 long-term stations with which to make his analysis. Leopold admitted that he was handicapped by a scarcity of data, particularly at higher elevations, but he did have several more years of record at the long-term stations and many more short-term records to analyze.

Leopold's analysis was restricted to 24-hour rainfall, since almost all of the available data were from standard rain gages. He determinedd the 100-year, 24-hour rainfall for a large number of stations in Arizona and New Mexico but did not try to group or compare stations topographically or climatically.

Hershfield (1961), on the other hand, determined rainfall depths for return intervals from 2 to 100 years and durations from 30 minutes to 24 hours for the United States. These values were produced in U.S. Weather Bureau Technical Paper 40 as a rainfall atlas of the United States. Depth-duration frequencies for individual stations were averaged or "smoothed" to develop design curves. These curves are still used widely throughout the United States.

Three long-term stations in Arizona (Casa Grande, Tucson, and Tombstone) and the long-term station at Santa Rosa, New Mexico were chosen specifically to illustrate some similarities and differences in point rainfall in the Southwest, and because the Tombstone and Santa Rosa stations are the closest long-term stations to the Walnut Gulch and Alamogordo Creek watersheds, respectively (Fig. 1).

Selected 100-year frequencies for these four stations, as determined from Technical Paper 40, are shown in Table 1. These data suggest that short-duration rainfall (2 hours and less) is greater in southeastern Arizona (Tucson and Tombstone) than in the remainder of southern Arizona or eastern New Mexico, or that the more intense short-duration rainfall is more likely to occur in southeastern Arizona than in the remainder of southern Arizona or eastern New Mexico.

On the other hand, the expected 100-year, 24-hour rainfall depth is 0.5 inch higher in south-central Arizona than in southwestern or southeastern Arizona or eastern New Mexico. Leopold, with much less available information, estimated 24-hour, 100-year rainfall depths of 3.6, 3.3, and 3.5 inches for Tucson, Tombstone, and Santa Rosa, respectively, but 6.0 inches for Casa Grande. The 100-year, 24-hour rainfall depths for other stations near Casa Grande were less than 3.0 inches in all cases.

The explanation of the much higher estimate for Casa Grande may be largely chance, as will be shown later in this paper.

WALNUT GULCH RAINFALL

The Agricultural Research Service has operated the 58-square-mile Walnut Gulch Experimental Watershed in southeastern Arizona since 1954. Of the 95

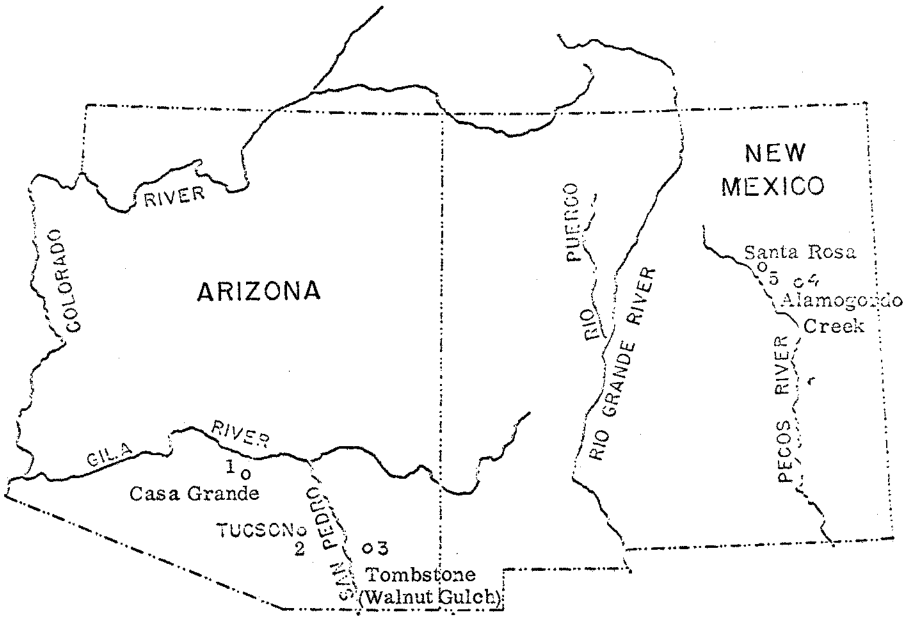

Fig. 1. Location of selected rain gage stations in southern Arizona and eastern New Mexico.

TABLE 1. One-hundred-year storm depths for four durations at selected stations in Arizona and New Mexico (from U.S. Weather Bureau Technical Paper 40)

Duration	Casa Grande	Tucson	Tombstone	Santa Rosa
30 minutes	2.25	2.5	2.5	2.25
1 hour	2.75	3.0	3.0	2.75
2 hours	3.0	3.5	3.5	3.0
24 hours	5.5	5.0	5.0	5.0

recording rain gages on or immediately adjacent to Walnut Gulch, about 80 are evenly scattered over the watershed.

The maximum one-hour point rainfall recorded on Walnut Gulch was 3.45 inches on September 10, 1967. The maximum 30-minute rainfall for the same storm at the same point was 2.52 inches. Between 2.5 and 2.65 inches of rainfall in 30 minutes was recorded at three points almost simultaneously on August 17, 1957. Also, just over 2.5 inches of rainfall in 30 minutes was recorded at two rain gages on Walnut Gulch on October 4, 1954. These are the only known occurrences of rainfall exceeding 2.5 inches in 30 minutes on Walnut Gulch in 15 years of record.

A thorough search of U.S. Weather Bureau data for southern Arizona did not uncover a record of more than 2.5 inches in one hour other than on Walnut Gulch. If each U.S. Weather Bureau recording rain gage is assumed to be an independent sampling point, there are about 1000 gage-years of record in southern Arizona. If all recording gages on Walnut Gulch are independent points, there are also about 1000 gage-years of record from Walnut Gulch; if they are all dependent points, there are 15 years of record. Studies by Osborn, Lane, and Hundley (1969) and Osborn and Renard (1970) suggest that the true value is closer to 1000 gage-years than to 15 gage-years.

The U.S. Weather Bureau record for southern Arizona includes several stations with 30 or more years of record and about 30 stations with 20 to 30 years of record. One might expect to find greater recorded intensities in the U.S. Weather Bureau record since it covers a longer period, a wider range of topographic and climatic locations, and the stations are almost certainly independent sampling points, at least for sampling air-mass thunderstorm rainfall. Yet, three separate events on Walnut Gulch greatly exceeded anything recorded at USWB recording rain gages in southern Arizona. This suggests that something other than chance is responsible for the difference between the 1000-gage-year USWB record and the Walnut Gulch record.

Two possible explanations are that (1) southeastern Arizona experiences more intense air-mass thunderstorm rainfall than does south-central and southwestern Arizona, and (2) the gages on Walnut Gulch represent enough independent points, at least for sampling "record" rains, that the dense network on Walnut Gulch is, in some way, a more efficient "measure" of maximum point rainfall than is the 1000-gage-year USWB record.

For the first hypothesis, summer rainfall as recorded at USWB stations generally decreases from east to west across southern Arizona. In general, the elevation of the recording rain gage stations also decreases from east to west across southern Arizona. The decrease in elevation may be the primary reason for decreasing rainfall. For example, Walnut Gulch gages (4000-6000 feet) record about 60 percent more summer rainfall than Tucson (2600 feet). The three long-term (over 30 years) USWB recording stations in southern Arizona are Tucson (2600 feet), Phoenix (1100 feet), and Yuma (near sea level), and there is considerably less summer rainfall at Phoenix than at Tucson and much less at Yuma than at Phoenix. Also, Walnut Gulch is closer to the primary source of summer moisture, the Gulf of Mexico.

It is difficult to establish that the record for Walnut Gulch is a more efficient "measure" of maximum point rainfall than the 1000-gage-year record for southern Arizona. At present, it seems that some element of chance combined with more intense summer rainfall on Walnut Gulch is the probable answer.

However, one might say that the network of rain gages on Walnut Gulch represents a 58-square-mile "rain gage" located in a region that receives more intense summer rainfall than do USWB recording rain gage stations in south-central and southwestern Arizona.

Walnut Gulch records suggest that on a 58-square-mile watershed in southeastern Arizona air-mass thunderstorm rainfall of 2.5 inches or more in 30 minutes might be expected about once in five years. Rainfall of 2.75 inches or greater in 30 minutes has never been recorded on Walnut Gulch or at any USWB recording rain gage in southern Arizona. (No storms with short-duration rainfall as high as those recorded on Walnut Gulch have been measured at USWB recording rain gages in northern Arizona.)

ALAMOGORDO CREEK RAINFALL

The Agricultural Research Service has operated the 67-square-mile Alamogordo Creek watershed in eastern New Mexico since 1955. At present, there are 65 recording rain gages on the watershed. The maximum known 30-minute rainfall recorded on a rain gage in the Southwest was 3.5 inches on Alamogordo. Keppel (1963) reported that this record rainfall resulted from combined convective heating and a weak cold front moving rapidly across the watershed on the afternoon of June 5, 1960. The combination of available moisture, convective heating, and frontal activity appeared ideal for producing an extreme thunderstorm rain.

On Alamogordo Creek, there were three frontal-convective storms in 15 years in which over 3.0 inches of rainfall was recorded in 30 minutes at one or more points on the watershed. This suggests a recurrence interval for such an event of about five years. No storms in which 3.0 inches or more was measured have been recorded at USWB recording rain gages in New Mexico. There are fewer recording rain gages in New Mexico than in Arizona, and the network of rain gages on Alamogordo Creek is less dense than the one on Walnut Gulch. Therefore, the occurrence of three "greater-than-3.0-inch" storms on Alamogordo Creek and none greater than 2.75 inches on Walnut Gulch would appear to be for some reason other than chance.

ANALYSIS OF STANDARD RAIN GAGE RECORDS IN SOUTHERN ARIZONA

A different picture of air-mass thunderstorm rainfall is suggested from analysis of U.S. Weather Bureau standard rain gage records in southern Arizona. Fogel (1968) and others have suggested that 24-hour records from standard gages in southern Arizona in July and August generally represent short-duration thunderstorm rainfall which occurred in the afternoon or evening of the day before the standard 8:00 a.m. reading was taken.

If the U.S. Weather Bureau network of standard gages is assumed to be made up of independent sampling points, there are about 2900 gage-years of record--700, 1400, and 800 gage-years in southeastern, south-central, and southwestern Arizona, respectively. All storms of more than 3.0 inches for air-mass thunderstorm days, as determined from standard rain gage records, are shown in Tables 2, 3, and 4. Those records suggest that expected point 100-year air-mass thunderstorm rainfall is about 3.0 inches throughout southern Arizona. Also, on four occasions significantly greater storm depths have been recorded in south-central Arizona than in either southeastern or southwestern Arizona, suggesting that the likelihood of such an extreme rainfall (about 4.5 inches) may be greater in south-central Arizona than in southeastern and southwestern Arizona.

TABLE 2. Standard gage 24-hour point rainfall depths of over 3 inches for air-mass thunderstorm days in southeastern Arizona (700 gage-years of record)

Station	Depth	Date
Flying H Ranch	3.53	Aug. 20, 1955
Bisbee	3.37	Aug. 8, 1970
Granville	3.32	July 25, 1964
Cochise Stronghold	3.22	July 18, 1941
Fort Grant	3.20	Aug. 20, 1955
Rucker Canyon	3.01	July 20, 1938

TABLE 3. Standard gage 24-hour point rainfall depths of over 3.0 inches for air-mass thunderstorm days in south-central Arizona (1400 gage-years of record)

Station	Depth	Date
Superstition Mountains	4.93	Aug. 19, 1954
Casa Grande	4.50	July 26, 1936
Ruby	4.43	July 22, 1941
Cortaro	4.41	July 14, 1953
Sahuarito	3.90	July 21, 1970
Tempe Citrus Station	3.87	Sept. 15, 1967
Pisinemo	3.80	Aug. 7, 1955
Sasabe	3.50	Aug. 15, 1960
Stewart Mountain	3.48	July 17, 1967
Tumacacori	3.47	Aug. 5, 1958
Kitt Peak	3.46	July 30, 1964
Casa Grande	3.42	Aug. 12, 1964
Willow Springs Ranch	3.15	July 21, 1954

TABLE 4. Standard gage 24-hour point rainfall of over 3.0 inches for air-mass thunderstorm days in southwestern Arizona (800 gage-years of record)

Station	Depth	Date
Santa Margarita	4.10	Aug. 22, 1935
Yuma	4.01	Aug. 16, 1909
Kofa Mountains	4.00	July 28, 1958
Covered Wells	3.82	July 29, 1958
Alamo	3.60	Aug. 2, 1964
Ajo	3.25	Aug. 10, 1960

The information presented in these tables points out the importance of increasing sample size in developing such records. For example, in Table 2, the earliest recorded storm over 3 inches is that in 1938 in Rucker Canyon. All of the other observations are since 1941. A similar situation exists in Table 3, but it is even more noticeable, for only the 1936 storm predates 1940, and there are only two storms before 1953 in the maximum thirteen. There were approximately 600 gage years of record prior to 1940, 600 gage years from 1940 to 1950, 750 gage years from 1950 to 1960, and 950 gage years from 1960 to 1970. Only about 20 percent of the record predates 1940, and 60 percent of the available record is for the 20 years between 1950 and 1970.

The reason for higher 100-year, 24-hour estimates for Casa Grande by both Leopold and Hershfield is indicated in Table 3. An exceptional rainfall at Casa Grande in 1936 heavily biased Leopold's frequency analysis for this station and probably biased Hershfield's estimates for the region around the station as well. The maximum recorded rainfalls from air-mass thunderstorms in south-central Arizona actually approach the 100-year, 24-hour estimates of rainfall depth for that region given in U.S. Weather Bureau Technical Paper 40.

CONCLUSIONS

Conclusions from analysis of thunderstorm rainfall in Arizona and New Mexico are somewhat conflicting. Recording rain gage records suggest that air-mass thunderstorms produce a greater number of more intense short-duration (about one hour and less) rains in southeastern Arizona than in south-central or south-western Arizona. Furthermore, possibly because of more frontal activity and less distance from the principal source of summer moisture, the Gulf of Mexico, the thunderstorms in eastern New Mexico can be more intense than those in southeastern Arizona.

On the other hand, records from standard rain gages in southern Arizona suggest that rainfall from individual air-mass thunderstorms may be greater in south-central Arizona than in southeastern or southwestern Arizona. However, a frequency analysis of air-mass thunderstorms, based on standard gages, indicates that the 100-year point rainfall is about 3 inches in all three regions.

Finally, with more data becoming available from stations in the more inaccessible regions in Arizona and New Mexico (such as along the Mogollon Rim), in-depth studies may soon be possible that would include more exact separation of thunderstorm types and a better definition of rainfall according to station location. In any case, thunderstorm rainfall models, to be useful, must take into account regional differences evident in recording rain gage data from Arizona and New Mexico.

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