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CONVECTIVE STORM PATTERNS IN THE SOUTHWESTERN UNITED STATES (1)

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ıs les régions inter-montagneuses et dans celles des hautes plaines du Sud-Quest la précipitation nnière, la majeure partie des pluies ayant lieu en été. La plus grande partie de la précipitation e a lieu sous forme de pluie à basse intensité ou de neige le long de fronts froids à vitesse de nent lente; la précipitation estivale se présente lors d'orages électriques de courte durée mais le intensité d'un amassement purement convectif ou de noyaux convectifs qui se développent l'un front froid à vitesse de déplacement rapide. Presque tout l'écoulement est le résultat des onvectifs estivaux.

nt donné que la précipitation produisant l'écoulement est d'un intérêt primordial pour le Centre erches des Services de Précipitation du Sud-Uuest, Service des Recherches d'Agriculture, à État d'Arizona, les orages convectifs ont fait lo'bjet d'une analyse particulièrement détaillée ieuse. Les durée, intensité, étendue aérienne, mouvement, nature et fréquence pour des volumes tensités variables desdits orages convectifs sont analysés à l'aide de données recueillies par des denses, destinés à mesurer la précipitation pluviale et se trouvent répartis dans quatre centres dans les États d'Arizona et du Nouveau-Mexique. Les centres principaux se trouvent dans ɔn de cinquante-sept milles carrés à Tombstone, État d'Arizona, appelé Walnut Gulch Experi-Watershed et dans une autre région de soixante-cinq milles carées, près de Santa Rosa, État du ı-Mexique, appelé Alamogordo Creek Watershed. Trois orages d'intensité exceptionnelle mais e différente, ayant eu lieu respectivement en 1960 et 1961 dans la région d'Alamogordo Creek ed et en 1961 dans la région de Walnut Gulch Experimental Watershed, ont été analysés et s d'une façon détaillée.

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he Southwestern intermountain and high plains areas, precipitation is seasonal, with the major he rainfall occurring in the summer. Most winter precipitation occurs as low-intensity rain or ng slow-moving cold fronts. Most summer precipitation occurs as short-duration, high-intensity storms from purely convective buildup or from convective cells developing along a weak fast-cold front. Almost all runoff occurs from the summer convective storms.

e runoff-producing precipitation is of primary interest at the Southwest Watershed Research Agricultural Research Service, Tucson, Arizona, the convective storms have been most tho-analyzed. Duration, intensity, areal extent, movement, character, and return frequencies for volumes and intensities of these convective storms are analyzed from records from dense net-recording rain gages in four study areas in Arizona and New Mexico. The primary study areas 8-square-mile Walnut Gulch Experimental Watershed at Tombstone, Arizona, and the 67-square-mogordo Creek Watershed near Santa Rosa, New Mexico. Three "record" storms of differing r occurring in 1960 and 1961 on Alamogordo Creek Watershed and one "record" storm in the Wlanut Gulch Watershed are analyzed and compared in detail.

the intermountain and high plains areas of the Southwestern United States, precipitation nal, with the greater part falling in summer. Most winter precipitation occurs as low-y rain or snow along slow-moving cold fronts. Summer rains generally occur as short-n, high-intensity thunderstorms from purely convective buildup, or from convective veloping along weak, fast-moving cold fronts. Almost all runoff is produced by summer ive storms.

noff-producing precipitation is of primary interest in studies by the USDA, Agricultural h Service, Southwest Watershed Research Center. On the basis of records from dense

Contribution of the Soil and Water Conservation Research Division, Agricultural Research USDA, in cooperation with the State Agricultural Experimental Stations, Arizona and New

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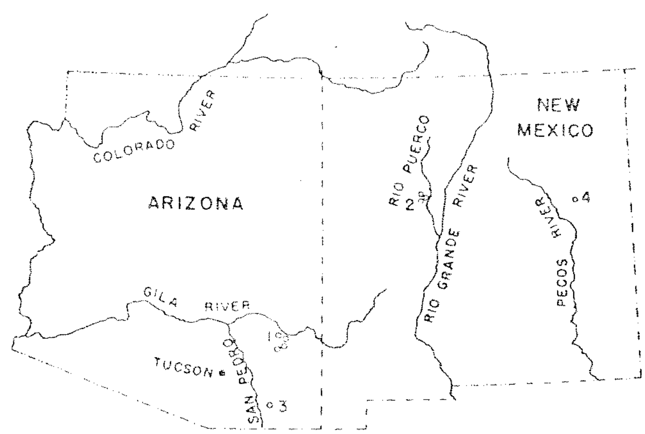
etworks of recording rain gages, convective storms have been studied in four areas in Arizona nd New Mexico (fig. 1). These areas are the 67-square-mile Alamogordo Creek watershed near anta Rosa, New Mexico; the 58-square-mile Walnut Gulch watershed at Tombstone, Arizona; our small watersheds of about 1 square mile each near Safford, Arizona; and three ranging in ize from 40 to 183 acres on the Montaño Grant west of Albuquerque, New Mexico. Records rom the larger areas, instrumented in 1954 and 1955, permit intensive study of convective torms; those from the smaller areas, which have been under study since 1939, allow long-term onsideration of such events.

ALAMOGORDO CREEK EXPERIMENTAL WATERSHED

The Alamogordo Creek Experimental Watershed is located on the western edge of the Llano Estacado about 35 miles east of Santa Rosa, New Mexico. As part of the watershed esearch program, a network of 57 rain gages has been in continuous operation since 1955. The watershed consists primarily of a flat, recessed basin almost entirely surrounded by a steep scarpment. Most of the rain gages are located on the floor of the basin, but a few are scattered long the rim. There is a difference of 300-500 feet between the elevation of the basin floor and he surrounding plateau.

Record Storm Events of 1960

In 1960, two exceptional storm events were recorded on the Alamogordo Creek watershed. The first was a high-intensity thunderstorm on the afternoon of June 5; the second was a series of connected rains through a six-day period, July 3 through July 8, with the heaviest rain falling on the morning of July 6. The June storm has been analyzed in detail by R.V. Keppel. (3) A brief summary is included here for comparison of this event with others reported. An analysis of the July storm is presented in detail.



1. Safford, Arizona.
2. Albuquerque, New Mexico.
3. Walnut gulch nr. Tombstone, Arizona.
4. Alamogordo Creek nr Santa Rosa, New Mexico.

Fig. 1 — Locations of experimental watersheds.

(3) R.V. Keppel, A Record Storm Event on the Alamogordo Creek Watershed in Eastern New Mexico — June 5, 1960. Presented at American Geophysical Union National Meeting, April 18, 1961. (Pending publication).

'orm of June 5, 1960

n occluded front moved across northeastern New Mexico and northwestern Texas on ·. Weather Bureau stations recorded up to 0.75 inch of rain as this front passed. Since was sufficient moist air aloft from the Gulf of Mexico, with normal strong convective g in the afternoon, conditions were particularly good for thunderstorm activity. The ng storm was localized, with its center over the experimental watershed (fig. 2a). Rainfall from 0.15 inch to 4.09 inches, with five gages recording 4.00 inches of rain or more. ge 34, seventy-five percent (3.09 inches) of the total precipitation of 4.09 inches fell in utes; and 96 percent fell in the first hour (fig. 3). Intensities and depth-area relationships s storm are compared with similar values from other storms on this and other experi- l watersheds and with Weather Bureau records (table 1, figs. 9 and 10). These comparisons scussed later.

orm of July 3-8, 1960

The synoptic situation at least partially responsible for these unprecendented rains l a moderately cold high pressure cell moving slowly down the eastern slope of the central Mountain range and thence eastward over the central plains. To the south a weak low re center was located in northern Mexico. These systems moved very slowly and the ng air circulation produced a flow of warm, moist air from the Gulf of Mexico north- rd for several days. As the moist air was lifted by the higher terrain and by the overrunn- the colder air to the west and north widespread rains and considerable instability re- " (4)

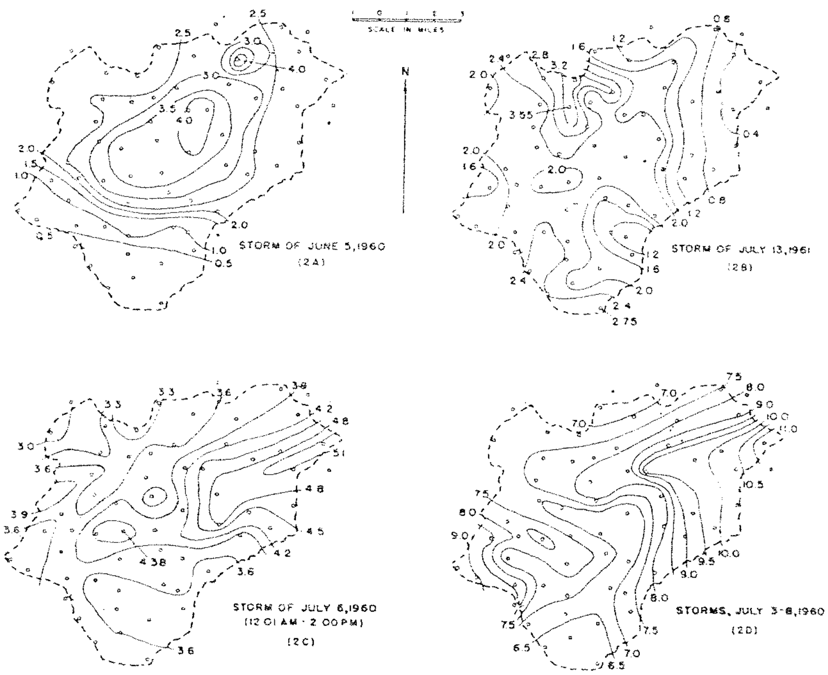


Fig. 2.

.F. Von Escher, *Climatological Data*, New Mexico, July 1960, Volume 64, No. 7, U.S. r Bureau.

TABLE 1

omparison of maximum point rainfall intensities of six storms, on four New Mexico and Arizona atersheds, with values of the 100-year event expected at nearest first order Weather Bureau stations. (5)

Location	Rainfall Intensity (Inches/Hour) Time Interval in Minutes				
	5	10	15	30	60
.lamogordo Creek, New Mex.					
Rain gage 34, June 5, 1960	24.4	15.0	12.5	7.2	3.9
Rain gage 21, June 5, 1960)	(7.4)	(7.0)	(6.0)	(4.0)	(2.3)
.lamogordo Creek, New Mex.					
Rain gage 21, July 13, 1961	18.1	14.3	12.4	6.8	3.5
Rain gage 34, July 13, 1961)	(5.9)	(5.1)	(4.0)	(2.6)	(1.7)
.lamogordo Creek, New Mex.					
Rain gage 28, July 6, 1960 (1 : 00 a.m. — 2 : 00 p.m.)	1.5	1.5	1.5	1.5	1.0
1ontaño, New Mexico					
Rain gage 1, August 24, 1957	6.7	6.2	5.4	3.2	1.8
afford, Arizona					
Rain gage 5, August 2, 1939	8.2	7.0	6.6	4.9	3.1
Valnut Gulch, Arizona					
Rain gage 9, August 22, 1961	10.6	8.0	7.0	4.6	2.4
:oswell, New Mexico, 100-year expectancy	8.6	6.4	5.0	3.9	2.5
.marillo, Texas 100-year expectancy	9.6	8.0	6.0	5.1	3.3
anta Fe, New Mexico 100-year expectancy	6.5	4.9	3.9	2.5	1.6
.lbuquerque, New Mex. 100-year expectancy	5.8	4.9	4.1	2.9	1.8
'hoenix, Arizona 100-year expectancy	6.5	5.0	4.1	2.9	1.9

Note : Use average of Roswell and Amarillo values as best estimate for Alamogordo Creek Watershed.

In effect, these atmospheric conditions produced a stationary front. The pattern described ıy the New Mexico State climatologist is unusual only with respect to the very slow movement ıf the cold front. Normally, weak cold fronts move rather rapidly through this region, adding o the magnitude of afternoon and evening thunderstorms such as the one on June 5, 1960, but ıroducing only small amounts of general frontal precipitation. Thunderstorms were recorded ın the experimental watershed on the afternoons of July 3 and July 4, as the front moved into he area. Thereafter, precipitation fell as general frontal rains. This heavy frontal precipitation s uncommon in the Southwest during the summer "convective" season.

Average total precipitation for the six-day period, as reported by U.S. Weather Bureau ;ages in the region, was 8.5 inches; the average for the experimental watershed was almost dentical. The amount recorded within the experimental watershed, however,varied from 6.1 nches at the southern periphery to 11.2 inches on the northern rim (fig. 2d), thus demonstrating

(5) Technical Paper No. 25, U.S. Weather Bureau.

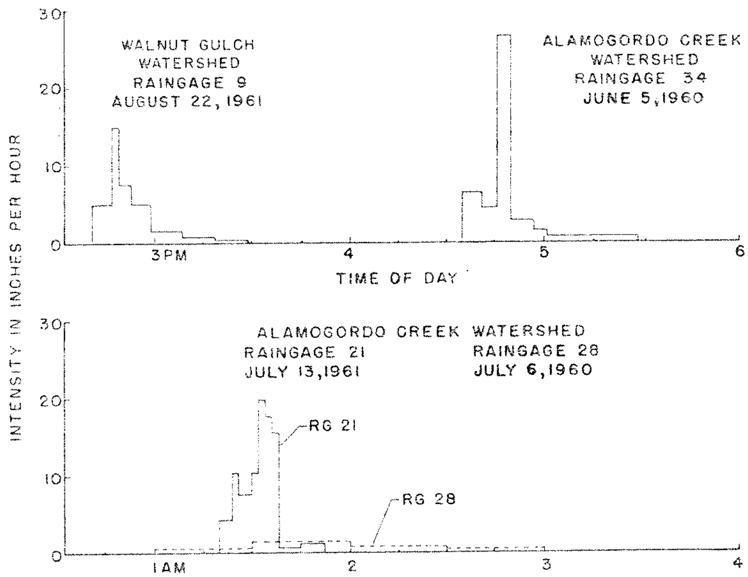


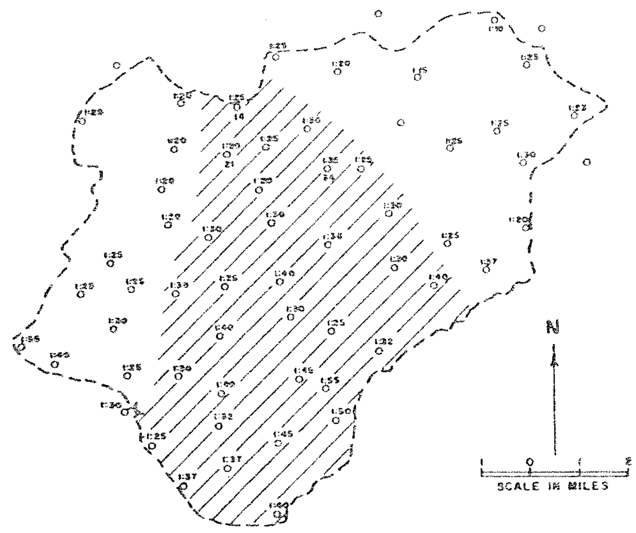
Fig. 3 — Histograms of selected storms.

this region, even with a frontal-type storm, considerable local variation may be expected this storm, no local or regional orographic effects due to differences in elevation were ible. Heaviest rainfall on the watershed was recorded on the east and central parts; was on the northwest rim (fig. 2d). Regionally, Weather Bureau records indicate that ts of rainfall increased from northwest to southeast; whereas, elevation decreases in ection. Large-scale isohyetal maps such as those developed for this region by the Weather , furnish excellent guides to average rainfall over extensive areas. They are of questionable however, for determining rainfall at a point or on watersheds of a few hundred square r smaller.

eaviest rain during the storm series fell on July 6 between 12 : 01 a.m. and 2 : 00 p.m. . Owing to different beginning times over the watershed, most of the rain at any one gage ing a 12-hour interval, and their total catches may thus be considered as representing r amounts. Technical Paper No. 25, U.S. Weather Bureau, gives 4.32 inches for the r 100-year return period in this area. Several gages in the central and the eastern sections vatershed recorded amounts equaling or exceeding this value. Data from weather stations out northeastern New Mexico show that new records were set during this storm period rvals of 12 hours and longer.

Storm Event of 1961

e first runoff of 1961 resulted from a convective storm falling in the early hours of July 13 ak cold front moved across the watershed. A short, highly intense burst of rain followed eavy fall of giant hail produced a maximum of 3.55 inches of precipitation at gage 21 b, 3, and 4). At this gage, 3.09 inches of precipitation fell in 15 minutes. This maximum ute amount equaled the prior record amount, measured 2 miles to the southeast on June 5, he record extends from 1955 to the present.



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

LEGEND

GIANT HAIL

WATERSHED BOUNDARY

RECORDING RAINGAGES

RUNOFF MEASURING STATION

Fig. 4.

The hail storm moved in a southerly direction, covering approximately 35 square miles f the watershed (fig. 4). Over a 35-square-mile area, hail was several inches deep; over a 10-juare-mile area, considerably deeper; and ten hours after the storm, drifts up to 2 feet deep npeded travel in a four-wheel-drive vehicle. Some hailstones as large as hens eggs were obser-ed on the ground as late as noon of the 13 th. So intense was the hail storm in this area that any juniper trees, wild sunflowers, and elm tress were completely stripped of foliage.

The variation in depth of precipitation over the watershed for 2-, 5-, 10-, 15-, and 30-minute eriods (fig. 7) was developed from isohyetal maps of maximum intensities for these periods. Four of these maps are shown in fig. 6). Over much of the watershed, amounts of precipitation ceeded one inch. The storm was comprised of four or more convective cells, which overlapped oth in time and space (fig. 5.) Although as much as 2.75 inches was recorded on the south lge of the watershed (fig. 2b), the centers of the two cells producing the greatest amount and tensity of precipitation, including hail, occured over the north central part. It was here that e highest intensities occurred — over 16 inches per hour for 5 minutes, over 12 inches per our for 10 and 15 minutes (fig. 6). Intensities near the southern edge of the watershed, where e other two cells seem to have centered, were considerably lower.

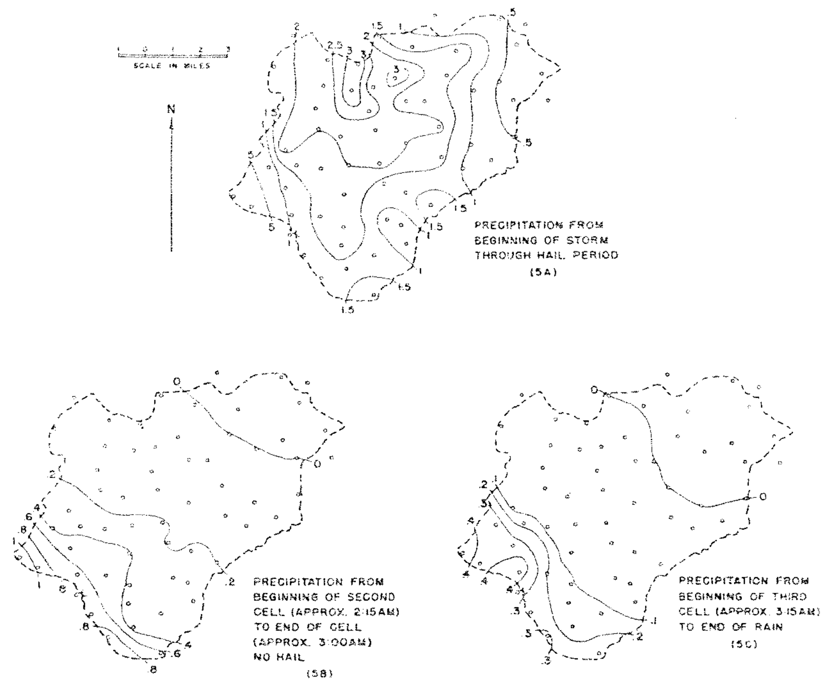
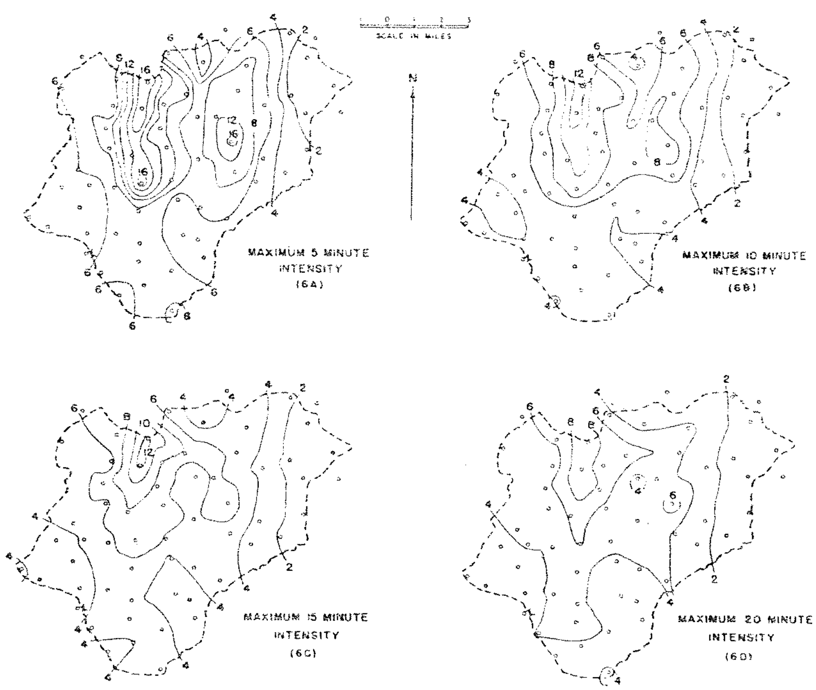

SCALE IN MILES
N
PRECIPITATION FROM BEGINNING OF STORM THROUGH HAIL PERIOD (5A)
PRECIPITATION FROM BEGINNING OF SECOND CELL (APPROX. 2:15AM) TO END OF CELL (APPROX. 3:00AM) NO HAIL (5B)
PRECIPITATION FROM BEGINNING OF THIRD CELL (APPROX. 3:15AM) TO END OF RAIN (5C)

Fig. 5.


SCALE IN MILES
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MAXIMUM 5 MINUTE INTENSITY (6A)
MAXIMUM 10 MINUTE INTENSITY (6B)
MAXIMUM 15 MINUTE INTENSITY (6C)
MAXIMUM 20 MINUTE INTENSITY (6D)

Fig. 6.

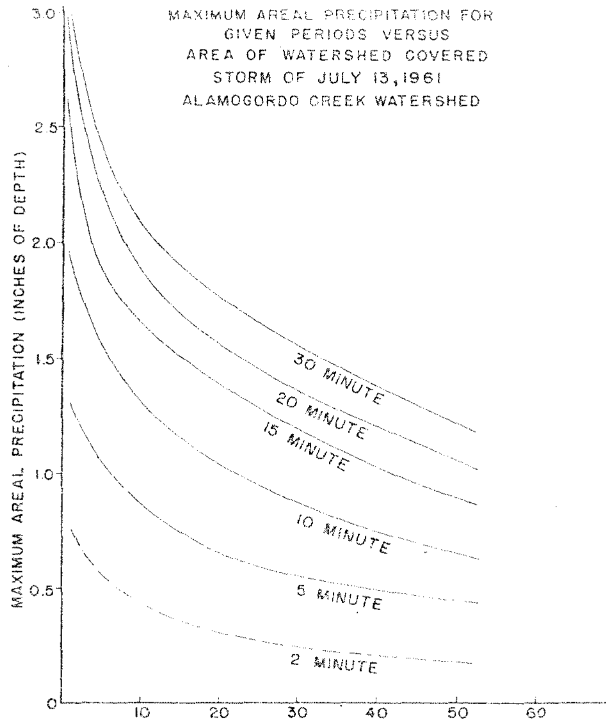


Fig. 7 — Watershed area covered (square miles).

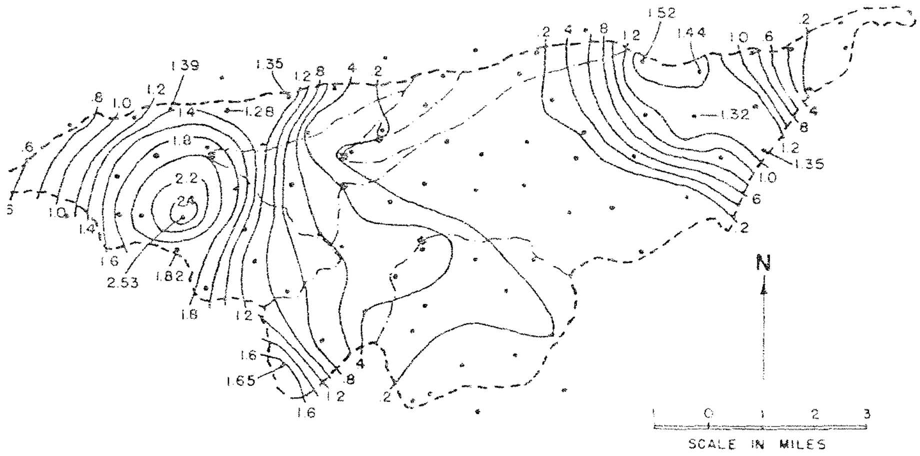
WALNUT GULCH EXPERIMENTAL WATERSHED

This 58-square-mile watershed, with a vegetational cover of desert grasses and desert shrubs, ies in the San Pedro valley of southeastern Arizona. It is representative of semiarid rangeland in his part of Arizona and an adjacent area in New Mexico. Precipitation is measured by a network of 70 recording rain gages.

Typical of this area and of the Southwest, generally, are multicellular, convective thunder-torms of high intensity, short duration, and limited extent. Such a storm occurred on the vatershed on the afternoon of August 22, 1961. Heaviest precipitation — 2.53 inches — , which included a considerable amount of small hail, was recorded near the western end of the watershed (fig. 8). About 70 percent of this total fell during the first 15 minutes; 90 percent, within the first 30 minutes (fig. 3). Previous records of point rainfall on the watershed have qualed or slightly exceeded the maximum for 15 minutes recorded during this storm. Com-arison of depth-area values of this storm with those of the convective storms of June 5, 1960 nd of July 13, 1961 at Alamogordo Creek shows that they are much lower.

On the basis of precipitation data collected on the Walnut Gulch Experimental Watershed etween 1955 and 1959, Fletcher (6) showed that 65 to 70 percent of the annual precipitation — nd all of that producing runoff — falls during the summer. Major runoff results from multi-ellular convective storms, some of which have has as many as six recognizable cells within the

(6) Joel E. FLETCHER, Some Characteristics of Precipitation Associated with Runoff from Walnut ulch Watershed, Arizona, Paper presented at the AGU meeting, April, 1961, Wahington, D.C. (Pend-g publication).



WALNUT GULCH WATERSHED

ISOHYETAL MAP

STORM OF AUGUST 22, 1961

(DEPTH IN INCHES)

Fig. 8

are-mile watershed. Assuming that convective cells have random areal distribution and ıacing of the gages on the watershed furnished an adequate sample of this distribution, eloped estimates of point duration-intensity frequencies. Fletcher's estimates for 100-year ·requencies agree closely with the 5- to 20-minute intensity values recorded at rain gage 9 the storm of August 22, 1961 (table 1).

.D AND MONTAÑO GRANT WATERSHEDS

ıe four watersheds in the vicinity of safford, Arizona, are dispersed in an elliptical area ut 150 square miles. Precipitation is recorded by nine 12-hour recording rain gages. In ;t, the Montaño Grant watersheds all lie within a one-square-mile area, and precipitation ;ured by five 12-hour recording gages.

:cords from the two groups, extending from 1939 to the present, furnish uninterrupted y data for this period. Highest intensities recorded on the two sets of watersheds are :omparable; but, for durations up to 15 minutes, they are somewhat lower than those d at Walnut Gulch, and much lower than those at Alamogordo Creek (table 1). The ıigher intensities at Alamogordo Creek are probably due to differences in origin of con- storms in that locality; but the differences between intensities observed on the small ıeds near Safford and Albuquerque and those observed on Walnut Gulch may be at .rtially attributable to more adequate sampling by the greater number of gages on the vatershed.

the Safford watersheds, 105 convective storms with amounts of 0.75 inch or more en recorded in the 22 years of study. The most intense of these, recorded by two gages, mile apart, on one of the watersheds in 1939, had an intensity of over 8 inches per hour minutes, over 7 inches per hour for ten minutes, and over 6 inches per hour for 20 minutes (table 2). This probably equaled or possibly exceeded the 100-year point return frequency for the region (table 1). This storm illustrated the limited areal extent of such extreme events. Runoff overtopped and partially destroyed the stream-gaging structure on this watershed, whereas none of the other three of the group recorded any runoff.

TABLE 2

Number of times intensities were exceeded for given periods for storms greater than 0.75 inch on the four Safford watersheds (*).

Maximum Intensity	Time Intervals (Minutes)					
	5	10	15	20	30	60
Inches/Hour						
8.0	1					
7.0	4	1				
6.0	6	3	1	1		
5.0	15	6	3	1		
4.0	35	19	9	4	1	
3.0	70	46	23	15	8	1
2.0	95	90	77	61	25	3
1.0	105	105	105	103	102	44

(*) Twenty-two years of record; total of nine 12-hour recording rain gages on four watersheds.

Analysis of the 105 convective storms recorded indicates that, for the average storm, about half of the precipitation fell during a 10-minute period, and two-thirds fell during a 20-minute period.

TABLE 3

Number of times intensities were exceeded for given periods for storms greater than 0.65 inch on the Montaño watersheds. (*)

Maximum Intensity	Time Intervals (Minutes)					
	5	10	15	20	30	60
Inches/Hour						
8.0						
7.0						
6.0	1	1				
5.0	1	1	1			
4.0	4	2	1	1		
3.0	14	6	2	1	1	
2.0	28	17	12	4	2	
1.0	38	38	38	37	25	3

(*) Twenty-two years of record; total of five 12-hour recording rain gages.

'n the Montaño watersheds, 38 convective storms with amounts of 0.65 inch or more have ecorded in the 22 years of study. The most intense of these, which was recorded on all ges, had an intensity of over 6 inches per hour for 10 minutes, over 5 incher per hour for nutes, and over 4 inches per hour for 20 minutes (table 3). Intensities recorded for periods gh 60 minutes during this event far exceeded recorded intensities for any other event on watersheds. Since the gages record precipitation on less than 1 square mile, however, quency of an event of this magnitude is uncertain.

SSION AND CONCLUSIONS

'omparison of records from the Alamogordo Creek watershed leads to the conclusion ne convective storms recorded have been randomly distributed, with no observable oro-ic influences. Likewise, although thunderheads first appear along the rim as warm air up the escarpment from the basin, local topography has produced no discernible oro-ic effect on frontal precipitation on the area. Although regional topography has some nce on frontal precipitation, such influence appears to be overridden by other controlling s.

Iost convective storms in the region represented by these study areas are of short duration, olume, and limited areal extent. Although on-site runoff often occurs, comparatively few s produce channel flow. Runoff-producing storms, defined as those that result in channel re of relatively high intensity. Such storms cause most of the floodwater damage, surface n, arroyo formation, and sediment deposition. They also contribute occasionally to into reservoir storage for downstream use. Because of the importance of such ephemeral 1 flows in the intermountain and high plains areas of the Southwest, knowledge of fre-y of storms that produce them is important. That estimates of point rainfall frequencies adequate for predicting recurrence of such flows is suggested by the fact that, at both ogordo Creek and Walnut Gulch, the 100-year frequency of both amount and intensity mated from Weather Bureau records at Amarillo, Roswell, and Tombstone, was equaled eeded at some gage on the watershed during the second year of record. This has been ed several times since. If the 8-year record at Alamogordo Creek is represenitive, it is ted that the "100-year" frequency based on the official records at Amarillo and Roswell e equaled or exceeded at some point on this 67-square-mile area on the average of once two years, and that storms of the magnitude of those of June 5, 1960 and July 13, 1961 e equaled at a frequency of once in every four years.

'ur records at Walnut Gulch furnish further evidence of the inadequacy of rainfall fre-y estimates based on single, widely dispersed gages for predicting runoff-producing events. g none of the storms that produced major runoff events was the highest intensity recorded long-term Weather Bureau gage at Tombstone. During many of these events, little or ecipitation was recorded by this gage, which is located approximately one mile from the channel. All gages on the watershed are within 10 miles of the Tombstone gage.

Inder favorable atmospheric conditions heavy convective storms may occur at scattered ons over relatively wide areas. On August 22, 1961, heavy convective rains were recorded lnut Gulch and were reported at several other points in southeastern Arizona. A near l event deluged Tucson, 65 miles from Walnut Gulch, causing heavy damage and drowning persons inside the city limit. However, because each individual thunderstorm draws its from a considerable area, possibly 1,000 square miles or more, (7) only a few Weather u stations in southeastern Arizona recorded heavy precipitation on this date. The majority tions recorded light precipitation.

'omparison of records of convective storms in New Mexico and Arizona reveals that, eral, amounts and intensities recorded during individual storms increase to the eastward), 10, and table 1).

) E. J. WORKMAN, The Problem of Weather Modification. *Sience*, Vol. 138, No. 3538, Oct. 19, 1962.

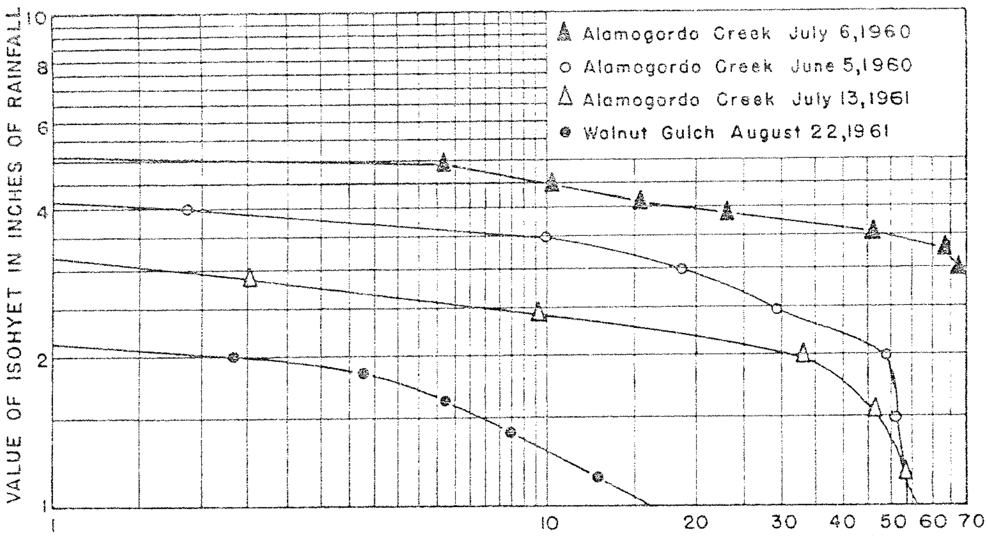


Fig. 9 — Area in square miles enclosed by isohyet, Maximum depth-area for selected storms

Quantity and duration of intense precipitation appears to be based primarily on the availability of moisture. Moist air moves into the Southwest in the summer from the Gulf of Mexico along a high pressure system centered, generally, over the central United States. The location of this high and the corresponding location and extent of a thermal low to the south (normally located over northern Mexico) regulates the amount of moisture and the path of flow into the Southwest. Shifts in the high will shut off an area or open it up to the flow of moist air from the Gulf.

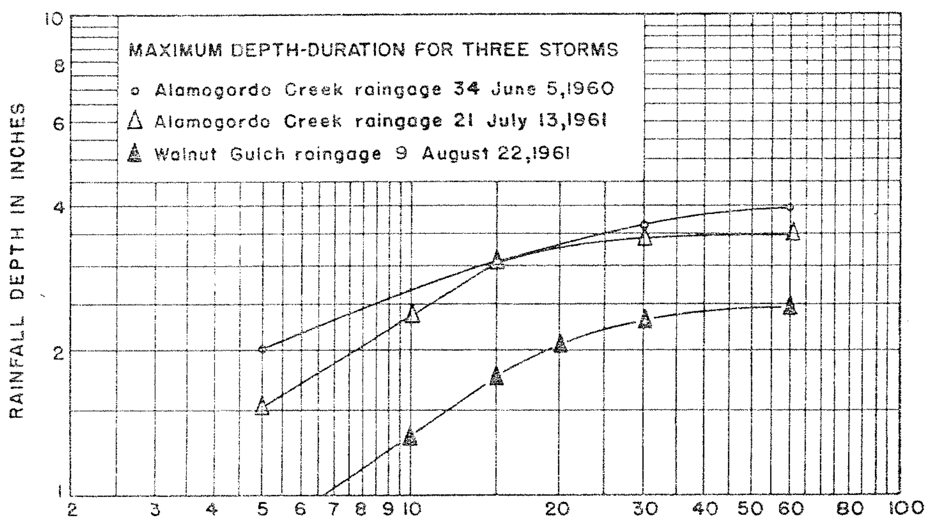


Fig. 10 — Time in minutes.

he duration of intense precipitation is further influenced by topography. Both the Safford /alnut Gulch watersheds are surrounded by mountain ranges. Each peak and high hill to develop its own thunderhead. The result is that limited energy is available for any one ɜrstorm. Eastern New Mexico, on the other hand, is generally flat plateau land where storms can build up to greater magnitude.

lso, the frontal systems in eastern New Mexico, while generally weak, give an added lift vective storms. Giant hail seems to develop more readily along these fronts. Here again, ɔuntainous terrain around Walnut Gulch and Safford limits the lateral movement which essential to the development of giant hail. Giant hail was reported on one occasion in st on the Walnut Gulch watershed, but such an occurrence in southeastern Arizona is nusual.

ıRY

Convective storms are of comparatively great importance throughout the Southwestern l States. Their occurrence and nature vary considerably over the region. For example, e of more available moisture, differing topographic features, and stronger frontal systems, es and intensities of rain are greater in northeastern New Mexico than in western New ɔ and southeastern Arizona.

Intense networks of rain gages on four Agricultural Research Service experimental heds in Arizona and New Mexico provide good records for intensive studies of the nature vective storms in the intermountain and high plains areas of these states.

Point frequencies based on records from a few scattered gages are shown by the studies nadequate for the prediction of expected areal distributions, volumes, and intensities of :tive rainfall necessary for hydrologic planning of work on small watersheds.

Suitable predictions for convective rainfall parameters for specific localities may be ped from records from intense recording rain gage networks, operated over a relatively few