7161 March, 1970 HY 3

65

Journal of the
HYDRAULICS DIVISION
Proceedings of the American Society of Civil Engineers

FLOOD PEAKS FROM SMALL SOUTHWEST RANGE WATERSHED[a]

By Kenneth G. Renard,[1] M. ASCE, John C. Drissel,[2] and
Herbert B. Osborn,[3] M. ASCE

INTRODUCTION

The Soil and Water Conservation Research Division of the Agricultural Research Service has been collecting precipitation and runoff data from the Alamogordo Creek watershed in northeastern New Mexico since 1955 (Fig. 1). During this period, five exceptional runoff-producing storms have occurred on the watershed. Three of these were intense short-lived thunderstorms, and the other two were frontal events of several days duration. The three thunderstorms occurred on June 5, 1960, July 13, 1961, and June 16, 1966; the two frontal storms occurred from July 4 through July 10, 1960 and August 21 through August 24, 1966. The storms in 1960 and 1961 were reported in earlier publications (5,6).[4]

In this paper the three storms that produced the largest runoff peaks on record, June 5, 1960, June 16, 1966, and August 21-24, 1966, are described and compared. Although the storms of July 4-10, 1960 and July 13, 1961 in-

---

Note.—Discussion open until August 1, 1970. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 96, No. HY3, March, 1970. Manuscript was submitted for review for possible publication on May 12, 1969.

[a] Presented at February 3-7, 1969, ASCE National Meeting on Water Resources Engineering, held at New Orleans, Louisiana.

[1] Research Hydraulic, Engr., Southwest Watershed Research Center, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, Tucson, Ariz.

[2] Research Agricultural Engr., Southwest Watershed Research Center, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, Tucson, Ariz.

[3] Research Hydraulic Engr., Southwest Watershed Research Center, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, Tucson, Ariz.

[4] Numerals in parentheses refer to corresponding items in the Appendix.—References.

cluded either exceptional precipitation intensities or volumes, they produced much lower runoff peaks and are mentioned only briefly.

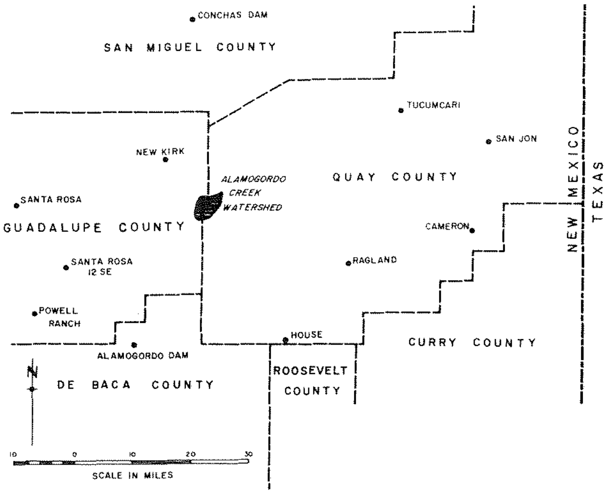

FIG. 1.—LOCATION MAP SHOWING WEATHER BUREAU STATIONS IN VICINITY OF ALAMOGORDO CREEK WATERSHED

Frequency analyses were performed and are discussed in the paper for the annual peak discharges and the associated storm runoff volume.

STUDY AREA

The Alamogordo Creek watershed (Fig. 1) is located on the western edge of the Llano Estacado about 35 miles east of Santa Rosa, New Mexico. The 67-sq mile watershed under study is located in the headwaters of Alamogordo Creek, a tributary of the Pecos River at the uppermost end of Alamogordo Reservoir. The ground cover in the watershed in dominated by a species of grass known as blue grama. Primarily the watershed consists of a flat, recessed basin surrounded by a steep escarpment which rises approximately 500 ft above the valley floor. Channel gradients are generally about 0.5% with incised channels in the lower portions of the area and broad swales in the central part of the basin where the drainage system is poorly defined. Precipitation is measured by a network of 64 weighing-type recording rain gages. Runoff from the watershed is measured at the outlet by a laboratory-rated flume-weir which was constructed in 1955.

UNUSUAL PRECIPITATION EVENTS AND RESULTING RUNOFF

Precipitation in northeastern New Mexico is produced either by convective heating in the summer, or by frontal activity in the winter, or by a combination of both in the late spring, summer, and early fall. In the winter, light rain and snow occur when fronts move across the region. The winter storm events which amount to about 30% of the annual 13-in. average precipitation (3) produce only limited runoff. Most rainfall events in the summer result from purely convective buildup when moist air moves into the region from the Gulf of Mexico. These storms normally occur in the late afternoon and early evening. The most intense rains, those that produce the highest peak runoffs, result from a combination of weak, fast-moving cold fronts and strong convective heating. If a stronger, slow-moving, which sometimes almost appears stationary, cold front moves across the area in the summer, rain may occur almost continuously for days. Thunderstorms within these longer events occasionally produce high peak discharges in addition to the normal high runoff volumes.

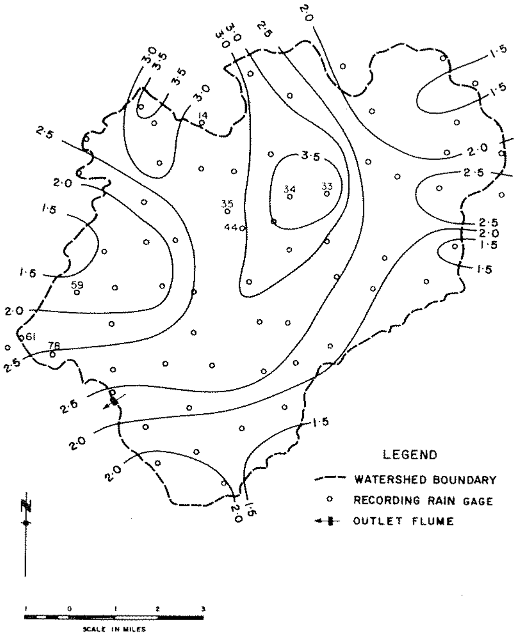

FIG. 2.—ISOHYETAL MAP FOR STORM OF JUNE 16, 1966

The highest runoff peak discharge in the 14 yr of record on the Alamogordo Creek watershed was produced during a frontal-convective storm on the afternoon of June 5, 1960(5). A weak, fast-moving cold front, combined with strong afternoon convective heating, produced over 4 in. of rainfall at the storm center near the center of the watershed. At one rain gage, rainfall exceeded 3 in. in 15 min. A peak discharge of 7,460 cfs was measured at the outlet from the 67-sq mile watershed. All runoff-producing rainfall fell in less than one hr. No hail was experienced during the storm.

The second largest peak, 6,480 cfs, was recorded on the evening of June 16, 1966. Again, the storm was centered on the watershed and was produced by the combination of a cold front and afternoon convective heating. No hail was observed during this event. The isohyetal map for this storm event is shown in Fig. 2. The storm total ranged from 3.98 in. at the storm center to slightly under 1.50 in. in the northeast corner of the study area.

The third highest peak was recorded during the storm of August 21-24, 1966. A thunderstorm occurring during the frontal storm and lasting about 2 hr produced an intense rain on the southwestern rim of the watershed, near Rain Gage 61. Although rain was general over the watershed, the intense rain did not cover it completely and the peak discharge was only about 4,000 cfs.

The storm early on the morning of July 13, 1961 produced higher intensities than those on June 16, 1966, but a large part of the precipitation was in the form of giant hail (6). The runoff peak was only about 2,500 cfs for this event and resulted mainly from melting hail. Because of high watershed losses, the runoff volume, as well as the peak discharge, on July 13, 1961 was much less than from the other two purely convective thunderstorm events in 1960 and 1966.

The storm from July 4, through July 10, 1960 produced the most rainfall for any one storm event during the period of record. Individual thunderstorm cells within this storm did not produce exceptionally heavy rains, and therefore the runoff peaks, there were several, were all less than 2,000 cfs.

Hydrographs of storm runoff at the outlet of Alamogordo Creek have frequently had long durations at or near the peak discharge. This phenomenon is believed to be caused by a resistant geologic formation in the watershed which has limited the channel formation. Channels above this rock outcrop are broad and shallow and limit the outflow from these channels over the outcrop described as being like weir flow from a reservoir (7). Durations at or near the peak discharge, were found to be related to the peak discharge in previous work.

FREQUENCY OF INTENSE RAINFALL

The frequency of intense rainfall at a point or on a watershed is of particular interest to hydrologists and others interested in predicting runoff peak

TABLE 1.—RAINFALL IN VICINITY OF THE ALAMOGORDO CREEK WATERSHED

Station (1)	Rainfall, in inches, June 16-17, 1966 (2)	Rainfall, in inches, August 21-24, 1966 (3)
Santa Rosa	0.82	3.90
Santa Rosa 12SE	2.14	5.18
Powell Ranch	3.20	3.55
Alamogordo Dam	0.81	2.50
House	2.25	1.64
Ragland	1.00	1.70
Cameron	2.50	1.51
San Jon	0.32	1.27
Tucumcari	0.27	1.16
Conchas Dam	0.32	1.42
Newkirk	2.60	2.09
Average	1.48	2.36

rates in the Southwest. Exceptional runoff-producing storms may be centered on different parts of a relatively small watershed, 50 sq miles or so, much more often than at one point on the watershed. Therefore, peak rates of runoff developed from precipitation records for the entire watershed and not from just one point, even if this point is centrally located, are preferable.

TABLE 2.—MAXIMUM POINT RAINFALL IN INCHES FOR THREE MAJOR STORMS

Gage number	Duration, in minutes							
	5	10	15	20	30	60	120	360
(*a*) June 5, 1960 Storm								
14	0.16	0.26	0.37	0.40	0.54	0.71	0.76	1.56
33	1.23	2.10	2.61	2.92	3.25	3.70	3.82	3.98
34	2.02[a]	2.54[a]	2.91[a]	3.22[a]	3.54[a]	3.88[a]	3.96[a]	4.07[a]
35	0.80	1.32	1.75	2.02	2.40	2.81	2.93	3.01
44	0.97	1.68	2.17	2.58	2.93	3.45	3.61	3.67
59	0.24	0.40	0.60	0.76	1.04	1.43	1.52	1.56
61	0.15	0.20	0.34	0.39	0.41	0.56	0.66	0.69
78	0.12	0.24	0.29	0.30	0.32	0.49	0.56	0.60
(*b*) June 16, 1966 Storm								
14	0.48	0.86	1.11	1.31	1.92	2.13	2.43	2.77
33	0.56	1.10	1.63	2.08	2.80	3.14	3.33	3.62
34	0.77	1.36	1.83[a]	2.21[a]	2.96[a]	3.49[a]	3.79[a]	3.98[a]
35	0.77	1.40[a]	1.60	1.70	2.19	2.54	2.64	2.90
44	0.89[a]	1.32	1.54	1.74	2.31	2.54	2.63	2.99
59	0.39	0.59	0.91	0.97	1.07	1.18	1.24	1.52
61	0.56	0.93	1.22	1.30	1.47	1.63	1.67	2.41
78	0.53	0.86	1.20	1.45	1.60	1.82	1.90	2.53
(*c*) August 21, 1966 Storm								
14	0.30	0.43	0.53	0.60	0.74	0.99	1.44	2.26
33	0.14	0.24	0.33	0.40	0.51	0.71	0.89	1.08
34	0.09	0.17	0.23	0.28	0.35	0.51	0.68	0.80
35	0.11	0.16	0.23	0.28	0.31	0.36	0.76	1.62
44	0.10	0.16	0.23	0.27	0.36	0.64	1.02	1.60
59	0.48	0.79	1.03	1.34	1.84	2.66	3.32	3.67
61	0.73[a]	1.22[a]	1.64[a]	1.98[a]	2.43[a]	3.58[a]	4.55[a]	5.02[a]
78	0.42	0.76	1.12	1.48	1.92	3.16	4.08	4.55

[a] Maximum point rainfall.

Rainfall values at U.S. Weather Bureau stations in the vicinity of the Alamogordo Creek watershed for both 1966 storms are given in Table 1 for comparison with the amounts measured on the experimental watershed. These precipitation stations and their proximity to the Alamogordo Creek watershed are shown in Fig. 1. Areal distribution for the August 21-24 storm was very general in the vicinity of the watershed, while the June 16-17 storm areal distribution was not extensive. In fact, the Weather Bureau records indicate that there were probably multicellular storms throughout the eastern section of New Mexico for this date in June.

Maximum point rainfall values for periods of 5, 10, 15, 20, 30, 60, 120, and 360 min for the storms of June 5, 1960 and June 16, 1966 and August 21-24, 1966 are shown in Table 2. The storms on June 5, 1960 and June 16, 1966 were centered on the watershed. The heaviest rainfall for periods of 15 min and more for both storms was recorded at Rain Gage 34 near the center of the watershed. The 6-hr, 50-yr maximum point rainfall, determined by the U.S. Weather Bureau, was exceeded at Rain Gage 34 in 2 hr during both events within a 7-yr period (Tables 2 and 3). The 1-hr value at Rain Gage 34 for both storms exceeded the 100-yr expectancy, 2.8 in. (Table 3). Of course, this is partially happenstance, but the use of 6-hr periods for calculating maximum point rainfall for this region for small watersheds is probably questionable. The 6-hr values are probably about what the 2-hr values should be, based on our experiences. The 6-hr values actually represent a compromise between a population represented by the longer lasting, lower intensity frontal storms and one represented by the intense thunderstorms. The longer duration storms produce the flood peaks from the large watersheds, drainage areas > 100 sq mi; but thunderstorms produce the flood peaks from smaller watersheds. If values from the two populations are determined separately and plotted as separate lines on the same graph, they might be expected to cross near the 6-hr values used by the Weather Bureau.

TABLE 3.—MAXIMUM POINT RAINFALL[a]

Number of years (1)	1 hr, in inches (2)	6 hr, in inches (3)	24 hr, in inches (4)
2	1.10	1.87	
5	1.50	2.40	
10	1.80	2.80	3.40
25	2.20	3.30	
50	2.40	3.70	
100	2.80	4.20	

[a] From Special Studies Branch, Office of Hydrology, Weather Bureau, Environmental Science Services Admin., U.S. Department of Commerce.

At Rain Gage 61, the maximum 6-hr rainfall was 5.02 in. for the August 21 storm, which plots as a 1,000-yr event for the region according to U.S. Weather Bureau values. This gage is on the edge of the watershed, so the peak rate of runoff at the outlet of the experimental area was much lower than on June 5, 1960 and June 16, 1966. Even during this event, almost all of the runoff-producing precipitation at Rain Gage 61 fell in about 2 hr, with the 2-hr total being 91% of the 6-hr total.

RUNOFF FREQUENCY

Economic analysis of most water resource development projects requires that a frequency analysis of the data be performed. Flood studies using probability methods were first suggested by Fuller in 1914 (4). However, owing to the shortage of long-period records on American streams at that time, the use of probability methods was limited until later, and even now, many problems arise in such analyses.

The methods of frequency analysis for flood flows have developed along divergent lines; and, hence, the results often differ markedly. As stated by Benson (1): "The present state of the art is such that no general agreement has been reached as to preferable techniques, and no standards have been established for design purposes, as has been done in other branches of engineering."

The 14-yr annual peak discharge-time series for the Alamogordo Creek watershed was analyzed and fitted to a normal, log-normal, Gumbel, log-Gumbel, and a 2-parameter gamma distribution. Although the record is short, the analysis was felt to be justified because of the lack of long-term records for such small watersheds. The volume of runoff associated with the annual peak discharge was also analyzed and fitted to the same theoretical distributions. The correlation coefficient between the peak discharge and the runoff volume was 0.94, which is highly significant.

TABLE 4.—TIME-SERIES STATISTICS ALAMOGORDO CREEK EXPERIMENTAL WATERSHED[a]

Time series statistics (1)	Q maximum, in cubic feet per second (2)	$\not{V}$ maximum, in acre-feet (3)
$\bar{x}$, mean	1,909	678
$\hat{s}$, unbiased standard deviation	2,259	1,015
$\hat{c}_v$, coefficient of variation	1.18	1.50
c_s, coefficient of skew	2.15	3.12
k, kurtosis	7.20	13.25
c_s/c_v	1.82	2.08

[a] 67-sq mile drainage area.

TABLE 5.—TIME-SERIES STATISTICS

Time series of logarithms (1)	Q maximum, in cubic feet per second (2)	$\not{V}$ maximum, in acre-feet (3)
$\bar{x}$, mean of logarithms	1,027	319
$\hat{s}$, unbiased standard deviation	3.65	3.44
$\hat{c}_v$, coefficient of variation	0.187	0.223
c_s, coefficient of skew	-0.917	0.211
k, kurtosis	6.36	3.76
c_s/c_v	-4.90	0.95

The statistical parameters of this time series (Table 4) were determined by the method of moments. As might be expected for such a short record, the unbiased standard deviation is quite large and exceeds the value of the mean. The large positive value of the coefficient of skew indicates a nonsymmetrical distribution with a long tail on the right side of the frequency distribution graph. The large value of kurtosis, a normal distribution has kurtosis of 3.0, indicates the frequency distribution is very peaked and not normally distributed.

For the logarithmic models, logarithms were taken of the data, and the statistical parameters were recomputed. The distributions of the logarithms of the data were much nearer to a normal distribution (Table 5), with the skew being nearly zero, slightly negative on the peak discharges; and the kurtosis indicating a much less peaked frequency distribution than was encountered in the untransformed data.

TABLE 6.—PEAK DISCHARGE AND RUNOFF VOLUMES FOR SELECTED FREQUENCIES FROM VARIOUS FREQUENCY PLOTS

Recurrence interval T_r, in years (1)	Probability ($X \le x$), as a percentage (2)	Arithmetic (3)	Semilog (4)	Normal (5)	Log normal (6)	Gumbel (7)	Log Gumbel (8)	Gamma (9)
(*a*) Peak Discharge in cubic feet per second								
1.02	2	10	25	—	70	—	140	100
1.05	5	20	100	—	125	—	185	206
1.11	10	130	200	—	200	—	240	343
1.25	20	400	400	50	350	50	360	650
2	50	1,220	900	1,920	1,030	1,500	830	1,480
5	80	2,800	4,300	3,820	3,100	3,530	2,600	3,000
10	90	6,800	6,100	4,800	5,400	4,850	5,500	4,030
20	95	10,100	8,000	5,620	8,700	6,100	11,500	5,070
50	98	—	10,500	6,650	14,500	7,800	30,000	6,500
(*b*) Runoff Volume in acre-feet								
1.02	2	5	—	—	—	—	40	100
1.05	5	10	—	—	40	—	54	139
1.11	10	60	50	—	63	—	70	200
1.25	20	130	100	—	110	—	105	300
2	50	390	400	690	320	500	205	580
5	80	810	1,400	1,520	900	1,400	800	1,000
10	90	2,600	2,100	1,960	1,550	2,000	1,750	1,285
20	95	4,600	2,800	2,320	2,450	2,570	3,600	1,550
50	98	—	3,700	2,730	4,500	3,310	10,000	1,920

Frequency graphs were prepared for the theoretical distributions of the normal, Gumbel, gamma, log-normal, and log-Gumbel distributions. These graphs shown in Fig. 3 through 7 also show the plotted data with the probabilities of individual observations determined, using the Weibull plotting position:

$$P_r\ (X \ge x) = \frac{m}{n+1} \qquad (1)$$

in which m = rank in descending order from largest; n = number of years; and P_r = probability.

For comparative purposes, values of the peak discharge and runoff volume for various selected probabilities are shown in Table 6, the values were determined from various frequency graphs. In addition to the values from the graphs of Figs. 3 to 7, the values for simple arithmetic and semilogarithmic distributions were developed, and theoretical lines were fitted by eye to the observed data. According to Dalrymple (2), this Cartesian plotting method is justified as a mathematical fit because no mathematical distribution is completely applicable. However, the extreme curvilinearity of the line prohibits any extrapolation, which is one of the arguments in favor of the transformations which assume straight lines. Since most extrapolations beyond the period of record at the station are questionable anyway, the curvilinear relationship may be a blessing in disguise. The same reasoning can be developed for the semilogarithmic method. Neither of these graphs is presented because of their questionable curvilinear nature.

A wide range in the value of the expected peak discharge is to be expected from the information presented in Table 6. The range is indicative of the broad confidence limits that might be expected for such techniques, were the mathematics developed for computing the confidence limits. These wide variabilities are also indicated by examining the sample statistics in which the standard deviation of the peak discharge is greater than the sample mean for the untransformed data. The short length of record might further explain some of the wide differences encountered in the table. Because of the short record, the skew of the frequency distribution may be greater than that which will be evidenced from longer records.

TABLE 7.—SAMPLE STATISTICS FOR PARTIAL DURATION AND ANNUAL TIME SERIES OF PEAK DISCHARGES[a]

Statistics (1)	Annual Series (2)	PARTIAL DURATION Peaks > 1 cfs (3)	PARTIAL DURATION Peaks > 100 cfs (4)
	Sample Size		
	14	81	41
Mean	1,909	570	1,086
Standard deviation	2,259	1,246	1,586

[a] Peak discharges, in cubic feet per second.

The problem of testing the goodness of fit of the model and the observed probability density function is an area where considerable research needs to be performed. In the field of water resources, nearly every investigator uses different criteria for evaluating simulated data. Many of the methods involve more or less standard statistical tests (i.e., Student's t, X^2, F-level, etc.) with idiosyncracies incorporated to emphasize the fit in certain portions of the range being tested. Thus, for example, in the instance of flood frequencies, a greater weighting at the high frequencies would seem to be essential in testing the fit between the observed data and the predicted probability.

The writers felt that a X^2 test might be used to test the null hypothesis for differences between the model and the empirical probability density function. Thus, the time series of annual peak discharge and the associated runoff volume was arbitrarily divided into seven increments, and the frequency of occur-

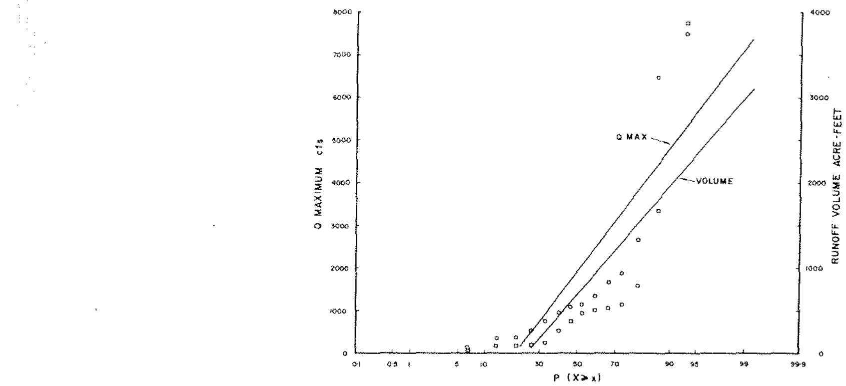

FIG. 3.—NORMAL FREQUENCY DISTRIBUTION OF FLOOD PEAKS AND VOLUMES

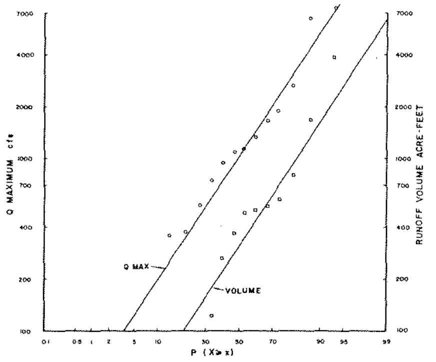

FIG. 4.—LOG-NORMAL FREQUENCY DISTRIBUTION OF FLOOD PEAKS AND VOLUMES

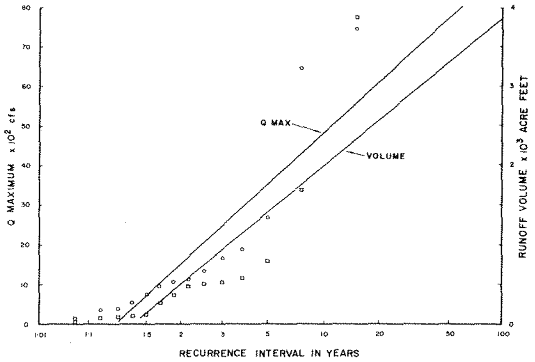

FIG. 5.—GUMBEL FREQUENCY DISTRIBUTION OF FLOOD PEAKS AND VOLUMES

rence for each increment was compared with the theoretical frequency using the chi-square test. Using this test, the gamma and the log-normal models agreed significantly with the null hypothesis that the theoretical and observed frequency distributions were similar. It was felt, however, that this lack of fit with the other models might be associated with the short records. Using seven increments for only 14 yr of record gave several increments with zero frequency and thereby increased the chi-square value. This might be overcome with a longer record or by using fewer increments; a longer record would be desirable. Using fewer increments would not be desirable for describing with certainty the probability density function and the cumulative probability curve.

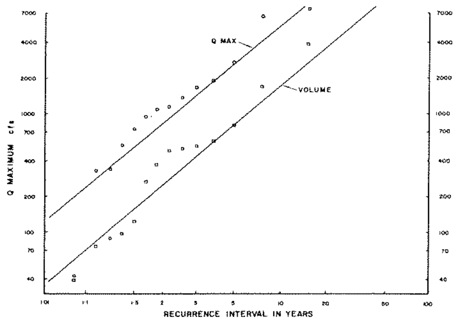

FIG. 6.—LOG-GUMBEL FREQUENCY DISTRIBUTION OF FLOOD PEAKS AND VOLUMES

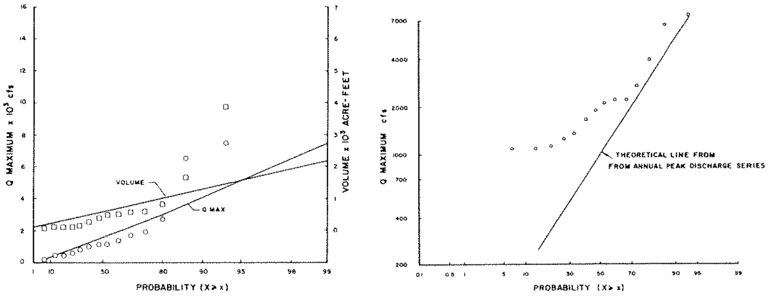

FIG. 7.—GAMMA FREQUENCY DISTRIBUTION OF FLOOD PEAKS AND VOLUMES

FIG. 8.—LOG NORMAL FREQUENCY DISTRIBUTION OF FLOOD PEAKS, USING THE PARTIAL DURATION SERIES

Because the five largest precipitation events occurred in three different years, not all of these events would be included in the frequency runoff distributions based on an annual series. A partial duration series on the other extreme would include all events above some arbitrarily selected base discharge. Table 7 shows that the standard deviation and mean are much larger using the annual series.

To demonstrate the differences that might be encountered, the frequency distribution graph based on the annual series is compared with the observed distributions of individual storms using a partial duration series. Fig. 8 shows this difference to be quite large in the lower probabilities. With increased length of record, these lines might be expected to come closer together.

SUMMARY

Several exceptional runoff-producing storms have been recorded on the Alamogordo Creek Experimental Watershed in northeastern New Mexico. Rains of 3.5 in. or more in one hr have been recorded on four occasions during the period of record, 1955-1968. Exceptional runoff-producing events may be centered on different parts of a relatively small watershed much more often than at one point on the watershed. Thus, the frequency expectancy of, a 3.5-in., 1-hr rain on a finite size area, is much lower than would be the corresponding frequency for an individual point.

Point rainfall estimates from the U.S. Weather Bureau can be misleading if applied to predicting runoff peaks from small watersheds in northeastern New Mexico. Maximum point rainfall values for durations of less than 6 hr are quite low according to the data presented. The 100-yr, 1-hr point rainfall of 2.8 in. was exceeded twice in 7-yr at the same gage on the watershed, and the 50-yr, 6-hr maximum point rainfall was exceeded in just 2-hr in the same storm. In another storm, Rain Gage 61 received 5.02 in. in 6 hr which would be classified as the 1,000-yr, 6-hr event for the region. These records seem to indicate that the current U.S. Weather Bureau maximum point rainfall values for 6-hr periods are too low and probably represent no more than the 2-hr values.

The annual series of peak discharge and the associated runoff volume was approximated fairly well by a log-normal or by a gamma distribution. The 20-yr flood was determined to be 8,700 cfs and 7,330 cfs, respectively, while the 50-yr flood was 14,500 cfs and 9,000 cfs, respectively (Table 6). The variability among the estimated discharges for the higher probabilities is to be expected for short records having wide variations in the annual peak discharge such as those discussed in this paper.

The expected peak discharge for a given frequency from a partial duration series is considerably higher than that from an annual series based on short periods of record.

ACKNOWLEDGMENTS

This paper is a contribution of the Southwest Watershed Research Center, Soil and Water Conservation Research Division, Agricultural Research Service, in cooperation with New Mexico Agricultural Experiment Station, Las Cruces, New Mexico.

APPENDIX.—REFERENCES

1. Benson, M. A., "Uniform Flood-Frequency Estimating Methods for Federal Agencies," *Water*

Resources Research, Vol. 4, No. 5, 1968, pp. 891–908.

2. Dalrymple, T., "Flood-Frequency Analysis," *Manual of Hydrology,* U.S. Geological Survey Water Supply Paper 1543-A, Part 3, Flood-Flow Techniques, 1960, 80 pp.
3. Drissel, J. C., and Osborn, H. B., "Variability in Rainfall producing Runoff from a Semiarid Rangeland Watershed, Alamogordo Creek, New Mexico," *Journal of Hydrology,* Vol. 6, 1968, pp. 194–201.
4. Fuller, W. E., "Flood Flows," *Transactions,* ASCE, Vol. 77, 1914, pp. 564–617.
5. Keppel, R. V., "A Record Storm Event on the Alamogordo Creek Watershed in Eastern New Mexico," *Journal of Geophysical Research,* Vol. 68, No. 16, 1963, pp. 4877–4880.
6. Osborn, H. B., and Reynolds, W. N., "Convective Storm Patterns in the Southwestern United States," *Internatl. Assoc. Scientific Hydrology Bulletin,* Vol. 8, No. 3, 1963, pp. 71–83.
7. Renard, K. G., and Keppel, R. V., "Hydrographs of Ephemeral Streams in the Southwest," *Journal of the Hydraulics Division,* ASCE, Vol. 92, HY2, Proc. Paper 4710, March, 1966, pp. 33–52.

7161 FLOOD PEAKS FROM SMALL WATERSHED

KEY WORDS: ephemeral streams; flash floods; floods; frequency analysis; hydraulics; runoff; thunderstorms

ABSTRACT: Runoff on the 67-sq-mile Alamogordo Creek Experimental Watershed in northeastern New Mexico is generated from storm precipitation with greatly differing characteristics. The largest peak discharges occurred from a combination of convective heating and weak summer cold fronts. Thunderstorms within frontal systems have produced large peak discharges and runoff volumes, whereas the long-duration summer frontal storms have produced appreciable volumes of runoff, but much lower peak discharges. For a storm duration of less than six hours, the point precipitation frequencies appear to be higher than those published by the U.S. Weather Bureau. The data show the importance of watershed rainfall values as compared to single point values. The five largest runoff events during the 14 yr record are compared and discussed in relation to precipitation differences. By extrapolation of the available data, using a log-normal frequency distribution, the 20-yr flood was estimated to be 8,700 cfs.

REFERENCE: Renard, Kenneth G., Drissel, John C., and Osborn, Herbert B., "Flood Peaks from Small Southwest Range Watershed," Journal of Hydraulics Division, ASCE, Vol. 96, No. HY3, Proc. Paper 7161, March, 1970, pp. 773-785.