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# TIME DISTRIBUTION OF PRECIPITATION IN 4- TO 10-DAY STORMS--ARKANSAS-CANADIAN RIVER BASINS

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# TIME DISTRIBUTION OF PRECIPITATION IN 4- TO 10-DAY STORMS--ARKANSAS-CANADIAN RIVER BASINS

Ralph H. Frederick[1]

## ABSTRACT

Precipitation-frequency values for periods up to 10 days have been available for a number of years. This report suggests a time distribution for precipitation-frequency values for the 4- through 10-day durations over the Arkansas-Canadian River Basins. The suggested distributions were developed from single station data and are considered valid for basins up to 100 square miles and possibly a little larger.

The basic data period is 1941-70, and a sample of 1,712 storm periods for each duration was examined. Intrastorm comparisons of observation-day data and precipitation "bursts" led to the conclusion that 4- to 10-day storms over the Arkansas-Canadian River Basins are basically two-burst storms. The bursts tend to come at the beginning and ending of the storm period, and the larger burst is equal to the 1-day precipitation-frequency value for the same return period used for the total storm.

## INTRODUCTION

Weather Bureau Technical Paper No. 49, "Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States," [Miller 1964] presents maps of precipitation-frequency values. It makes no suggestion as to the time distribution of the precipitation within the various N-day periods. The distribution of precipitation within these time intervals is frequently important and can become more critical for the longer periods. It is unrealistic to expect the distribution of precipitation over a period of from one to several days to be linear. Precipitation can, of course, continue for several days at a relatively steady rate, but it is more usual for the large annual events of N-day precipitation to consist of interspersed periods of light or no precipitation and heavier bursts. This is, of course, even more evident in regions and seasons in which convective precipitation occurs. Under these conditions, a linear distribution of the precipitation in design studies might result in poorly designed hydrologic structures. An initial study of this distribution was done for the Ohio River Basin [Miller and Frederick 1972]. The present study covers the Arkansas River Basin above Keystone Dam, OK, and the Canadian River Basin above Union City, OK. These basins consist primarily of flat to moderately hilly terrain with a gradual upslope toward the northwest. The Rocky Mountains lie along the western boundary of the basins and are about the

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only important terrain feature over the basins. Except for the front face of the Rocky Mountains, orography has a minor influence on the amount and distribution of precipitation in this area.

The results presented here were derived from point precipitation data. Since a high percentage of the 4- to 10-day storms are summer situations with a high degree of convective activity, application of the results beyond 100 square miles may result in unacceptable errors.

## DATA SAMPLE

Tabulations of the annual maximum N-day precipitation for N = 1 to N = 10 were made for each station shown in figure 1. Stations were chosen on the basis of having a complete record (with minimal breaks) during the selected period and providing the required geographic distribution. These stations are listed in table 1 together with the period of record used and the magnitude and date of beginning of the largest 4-, 6-, 8-, and 10-day precipitation amounts for each station. In some cases, station names and locations changed during the data period. The names and elevations listed are for 1970 or the last year of record used.

An annual maximum N-day storm period is defined as the N consecutive days in a year during which the greatest amount of precipitation fell for the specified number of days. Where an N-day maximum event began at the end of December and extended into January, the event was assigned to the year having the larger amount of precipitation. The storm period was first defined as beginning with a day with measurable precipitation. Each of the remaining days could, but need not, have had measurable precipitation. For example, the 6-day storm for a given year was found by comparing all 6-day periods that began with a day of precipitation and selecting the one with the greatest 6-day total precipitation. The first day must have measurable precipitation, but each of the following five might or might not.

Because the N-day storm was defined in this way, there was a tendency for more precipitation to occur on the first day than on any of the succeeding days of the N-day period. To examine the extent of bias, the N-day storms were defined in two ways: 1) measurable precipitation on the first day; 2) measurable precipitation on the last day. A comparison of average daily precipitation in "first-day" and "last-day" storms for the 8- and 10-day durations showed small differences, except on the first and last day. When the average percent of total precipitation occurring on the first day of a "first-day" storm was compared with the average percent occurring on the last day of a "last-day" storm, and the second day with the N-1 day, and so on, only small differences were found (fig. 2). As shown in figure 2, the curves are nearly mirror images of each other. In each of the methods of selection used, the majority of the large bursts still came near the beginning and end of the storm period, as will be shown later. All results were highly influenced by the fact that about half the storms studies had precipitation on both the first and last days of the period.

Precipitation during the N-day storm for the eastern portion of the study area averaged considerably greater than in the western sections.

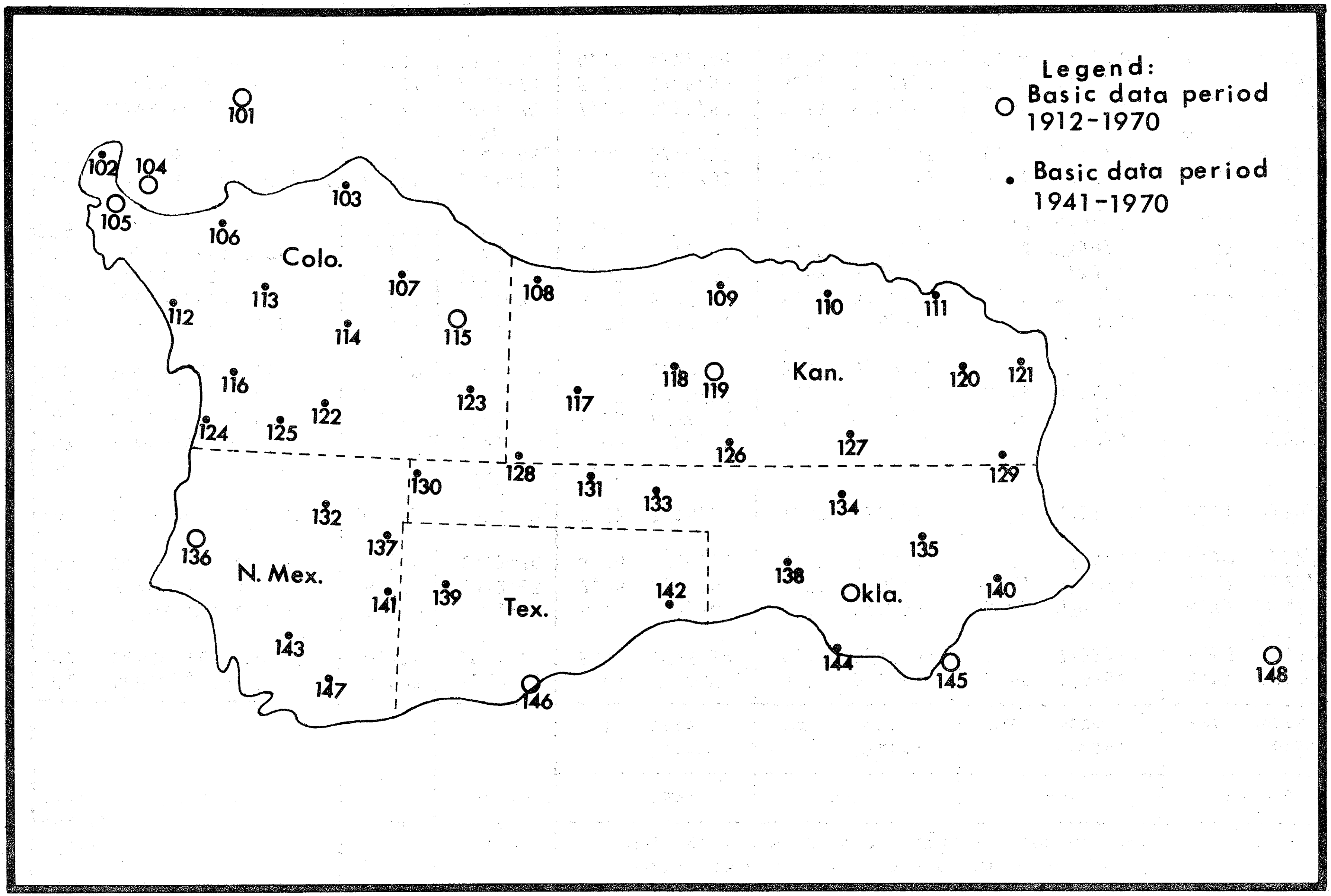

Figure 1.--Station location map showing generalized outline of Arkansas and Canadian Basins.

Table 1.--Arkansas-Canadian River Basins--station index

| Ident. no. on fig. 1 | Station | Elev. (ft.) | Period of Record | Magnitude and date of beginning of largest 4-, 6-, 8-, and 10-day precipitation at each station. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 4-Day | | 6-Day | | 8-Day | | 10-Day | |
| | | | | Amt. | Begin. Date | Amt. | Begin. Date | Amt. | Begin. Date | Amt. | Begin. Date |
| 101 | Denver, CO | 5,221 | 1912-70 | 4.66 | 5/5/69 | 4.71 | 5/3/69 | 5.55 | 5/8/57 | 6.27 | 5/8/57 |
| 102 | Leadville, CO | 10,158 | 1931-70 | 6.15 | 7/26/37 | 6.23 | 7/25/37 | 6.47 | 7/22/37 | 6.53 | 7/17/34<br>7/25/37 |
| 103 | Limon 10SSW, CO | 5,560 | 1941-70 | 5.13 | 8/5/54 | 5.45 | 8/5/54 | 5.73 | 8/5/54 | 6.37 | 8/5/54 |
| 104 | Hartsel, CO | 8,866 | 1912-65 | 2.95 | 8/2/36 | 4.07 | 7/31/36 | 4.31 | 7/30/36 | 5.19 | 7/27/36 |
| 105 | Buena Vista, CO | 7,954 | 1912-70 | 4.20 | 7/29/32 | 4.30 | 7/29/32 | 4.30 | 7/29/32 | 4.30 | 7/29/32 |
| 106 | Lake Moraine, CO | 10,265 | 1939-57, 1959-68, 1970 | 7.87 | 5/18/55 | 7.97 | 5/18/55 | 8.49 | 4/17/42 | 8.78 | 5/10/55 |
| 107 | Haswell, CO | 4,535 | 1941-70 | 5.05 | 5/26/44 | 5.05 | 5/26/44 | 5.40 | 9/22/41 | 5.40 | 9/22/41 |
| 108 | Tribune 1W, KS | 3,612 | 1941-70 | 5.05 | 6/18/51 | 5.43 | 6/18/51 | 5.96 | 6/21/51 | 6.24 | 6/21/51 |
| 109 | Ness City, KS | 2,260 | 1941-70 | 6.97 | 9/18/59 | 7.36 | 9/18/59 | 8.19 | 9/18/59 | 8.19 | 9/18/59 |
| 110 | Great Bend, KS | 1,850 | 1941-70 | 6.20 | 8/22/69 | 6.23 | 8/20/69 | 6.47 | 7/25/50 | 9.48 | 8/24/69 |
| 111 | McPherson 2S, KS | 1,495 | 1941-70 | 6.70 | 7/10/51 | 7.04 | 7/8/51 | 7.05 | 5/28/62 | 7.99 | 5/25/62 |
| 112 | Westcliffe, CO | 7,860 | 1941-70 | 6.13 | 8/1/66 | 6.37 | 8/1/66 | 6.76 | 7/29/66 | 6.89 | 7/27/66 |
| 113 | Pueblo, CO | 4,639 | 1941-70 | 3.83 | 10/7/57 | 4.59 | 4/18/42 | 5.32 | 4/17/42 | 5.33 | 4/16/42 |
| 114 | Rocky Ford 2ESE, CO | 4,178 | 1941-70 | 4.05 | 7/22/66 | 4.42 | 7/19/66 | 4.42 | 7/19/66 | 4.53 | 7/15/66 |
| 115 | Lamar, CO | 3,617 | 1912-70 | 7.43 | 6/3/49 | 7.48 | 6/3/49 | 7.48 | 6/3/49 | 7.58 | 5/28/49 |
| 116 | Walsenburg P PL, CO | 6,221 | 1941-70 | 6.50 | 5/17/55 | 7.03 | 5/18/55 | 7.31 | 5/17/55 | 7.41 | 5/17/55 |
| 117 | Ulysses, KS | 3,050 | 1940-68, 1970 | 8.82 | 5/16/55 | 8.99 | 5/16/55 | 9.17 | 5/16/55 | 9.43 | 5/16/55 |
| 118 | Cimarron, KS | 2,625 | 1941-70 | 7.10 | 5/18/55 | 7.65 | 5/16/55 | 7.65 | 5/16/55 | 8.60 | 5/16/55 |
| 119 | Dodge City, KS | 2,582 | 1912-70 | 5.57 | 5/16/55 | 5.71 | 7/28/27 | 6.94 | 5/14/51 | 7.23 | 5/13/51 |
| 120 | Wichita, KS | 1,321 | 1941-70 | 6.82 | 4/22/44 | 8.65 | 9/23/45 | 9.46 | 9/21/45 | 10.10 | 9/21/45 |

Table 1.--Arkansas-Canadian River Basins--station index - continued

| Ident. no. on fig. 1 | Station | Elev. (ft.) | Period of Record | Magnitude and date of beginning of largest 4-, 6-, 8-, and 10-day precipitation at each station. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 4-Day | | 6-Day | | 8-Day | | 10-Day | |
| | | | | Amt. | Begin. Date | Amt. | Begin. Date | Amt. | Begin. Date | Amt. | Begin. Date |
| 121 | El Dorado, KS | 1,282 | 1941-70 | 8.01 | 9/3/42 | 8.98 | 9/3/42 | 11.04 | 8/31/65 | 11.04 | 8/31/65 |
| 122 | Doherty Ranch, CO | 5,130 | 1941-70 | 4.44 | 6/3/49 | 5.10 | 6/4/49 | 5.68 | 6/3/49 | 5.75 | 6/3/49 |
| 123 | Two Buttes 1NW, CO | 4,075 | 1934-44,<br>1948-65,<br>1967 | 10.54 | 6/16/65 | 11.17 | 6/14/65 | 11.17 | 6/14/65 | 11.61 | 6/16/65 |
| 124 | North Lake, CO | 8,800 | 1936-40<br>1943-49,<br>1952,<br>1954-70 | 5.43 | 5/17/55 | 5.76 | 5/18/55 | 6.04 | 5/17/55 | 6.04 | 5/17/55 |
| 125 | Trinidad, CO | 6,030 | 1935-40,<br>1942-48,<br>1954-70 | 6.24 | 5/17/55 | 6.89 | 5/18/55 | 6.92 | 5/17/55 | 7.17 | 5/10/55 |
| 126 | Ashland, KS | 1,970 | 1941-70 | 6.17 | 8/27/68 | 7.45 | 5/14/51 | 7.45 | 5/14/51 | 8.69 | 5/14/51 |
| 127 | Medicine Lodge, KS | 1,450 | 1941-70 | 8.42 | 5/15/51 | 8.42 | 5/15/51 | 8.88 | 5/15/51 | 8.88 | 5/15/51 |
| 128 | Elkhart, KS | 3,585 | 1940-50,<br>1952-70 | 6.52 | 6/8/42 | 6.64 | 6/8/42 | 6.64 | 6/8/42 | 7.60 | 8/23/69 |
| 129 | Arkansas City, KS | 1,118 | 1941-70 | 7.41 | 7/4/58 | 8.71 | 9/25/45 | 9.66 | 9/24/45 | 11.03 | 9/22/45 |
| 130 | Kenton, OK | 4,350 | 1940-67,<br>1969-70 | 8.56 | 9/21/41 | 8.56 | 9/21/41 | 8.81 | 9/21/41 | 9.80 | 9/21/41 |
| 131 | Hooker 1N, OK | 3,015 | 1940-46<br>1948-70 | 7.65 | 10/4/46 | 7.65 | 10/4/46 | 7.65 | 10/4/46 | 8.75 | 9/29/46 |
| 132 | Des Moines, NM | 6,632 | 1938-46,<br>1948,<br>1951-70 | 6.07 | 5/17/55 | 6.11 | 5/17/55 | 6.11 | 5/17/55 | 6.85 | 9/21/41 |
| 133 | Beaver 1SW, OK | 2,500 | 1941-70 | 8.22 | 5/14/51 | 8.26 | 5/12/51 | 8.26 | 5/12/51 | 9.23 | 5/14/51 |
| 134 | Alva, OK | 1,374 | 1941-70 | 5.79 | 9/23/59 | 6.32 | 5/13/57 | 7.28 | 5/10/57 | 9.31 | 6/21/51 |
| 135 | Enid, OK | 1,245 | 1941-70 | 8.41 | 5/13/57 | 9.68 | 7/4/60 | 9.68 | 7/4/60 | 10.31 | 5/16/57 |

Table 1.--Arkansas-Canadian River Basins--station index - continued

| Ident. no. on fig. 1 | Station | Elev. (ft.) | Period of Record | Magnitude and date of beginning of largest 4-, 6-, 8-, and 10-day precipitation at each station. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 4-Day | | 6-Day | | 8-Day | | 10-Day | |
| | | | | Amt. | Begin. Date | Amt. | Begin. Date | Amt. | Begin. Date | Amt. | Begin. Date |
| 136 | Aurora, NM | 8,130 | 1912-49,<br>1951,<br>1953-57,<br>1959 | 5.62 | 6/9/13 | 6.76 | 6/7/13 | 6.85 | 6/6/13 | 6.99 | 6/7/13 |
| 137 | Clayton, NM | 4,970 | 1941-70 | 6.86 | 9/20/41 | 6.88 | 9/19/41 | 6.88 | 9/19/41 | 8.67 | 9/20/41 |
| 138 | Mutual, OK | 1,865 | 1940-62,<br>1964-70 | 6.70 | 9/17/65 | 7.56 | 10/22/41 | 7.56 | 10/22/41 | 9.67 | 10/14/41 |
| 139 | Dalhart FAA AP, TX | 3,989 | 1941-70 | 8.48 | 7/25/62 | 8.48 | 7/25/62 | 8.48 | 7/25/62 | 8.52 | 7/18/62 |
| 140 | Stillwater 2W, OK | 895 | 1941-70 | 10.95 | 10/2/59 | 11.79 | 9/30/59 | 11.79 | 9/30/59 | 17.57 | 9/24/59 |
| 141 | Amistad 1SSW, NM | 4,500 | 1941-70 | 6.01 | 4/30/41 | 6.63 | 4/27/41 | 7.93 | 4/26/41 | 8.03 | 4/24/41 |
| 142 | Canadian, 1ENE, TX | 2,335 | 1940-51,<br>1953-70 | 9.10 | 5/15/51 | 9.25 | 5/15/51 | 9.95 | 5/15/51 | 9.95 | 5/15/51 |
| 143 | Bell Ranch, NM | 4,500 | 1941-70 | 4.49 | 10/15/60 | 8.20 | 9/18/41 | 9.32 | 9/22/41 | 9.90 | 9/21/41 |
| 144 | Weatherford, OK | 1,660 | 1941-70 | 11.91 | 6/21/48 | 11.95 | 6/21/48 | 12.99 | 6/21/48 | 12.99 | 6/21/48 |
| 145 | Oklahoma City, OK | 1,285 | 1912-70 | 8.39 | 5/31/32 | 10.29 | 9/26/27 | 11.78 | 5/28/32 | 12.36 | 5/28/32 |
| 146 | Amarillo, TX | 3,607 | 1912-70 | 8.38 | 5/15/51 | 9.01 | 6/5/60 | 9.18 | 6/5/60 | 9.24 | 6/3/60 |
| 147 | Tucumcari 3NE, NM | 4,096 | 1941-70 | 6.40 | 7/5/60 | 8.02 | 7/4/60 | 8.02 | 7/4/60 | 8.36 | 7/4/60 |
| 148 | Ft. Smith, AR | 447 | 1912-70 | 12.08 | 6/9/45 | 12.66 | 6/8/45 | 12.78 | 6/6/45 | 14.41 | 6/8/45 |

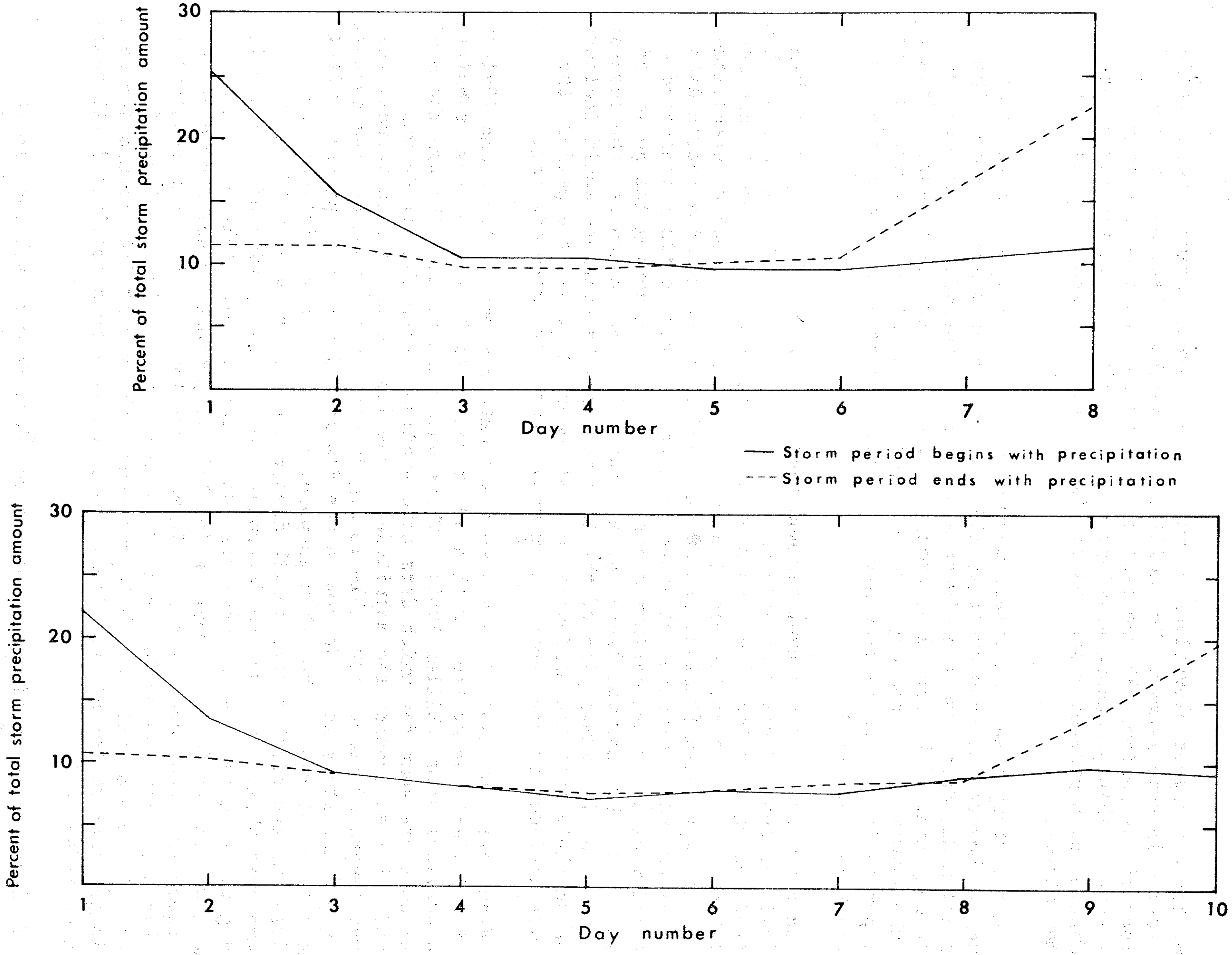

Figure 2.--Average percent of total 8- and 10-day precipitation amount that occurred on each day.

Except for the higher elevations of the Rockies, normal annual precipitation also varies in this manner. To facilitate comparisons between stations and portions of the region, all the data were first converted into percent of storm total. This procedure eliminated the likelihood that the larger storms would have had a greater impact on the final time distributions than the smaller storms.

In the study area, the annual maximum N-day totals were a mixture of 1) summer showers and thunderstorms and 2) a few large winter storms. The observation-day data from the winter storms often represent a complete, or nearly complete, 24-hr period of precipitation. On the other hand, rainfall from the summer situations may have occurred during only a small part of the 24-hr period in the observation day. The data analysis made no distinction between these two cases.

In a few cases, the annual maximum event occurred during a period when original sources indicated an accumulated value (that is, the value published occurred during a period of 48 hours or more; separate 24-hr amounts are not available). In those instances, standard methods of distributing precipitation values were used [Paulhus and Kohler 1952]. If parts of a year's data were missing and examination of storm data from nearby stations indicated a probability of an annual maximum event having occurred during the period of missing data, the year was listed as missing. In some instances, the reverse was also true; if examination of the data from nearby stations would indicate it was unlikely that the maximum value had occurred within the period, the year was included in the series, even though some data were missing.

Examination of table 1 shows two basic data periods; 1912-70 and 1941-70. Data for 1912-61 for stations with a 59-yr record (1912-70) had been tabulated for a previous study [Miller 1964]. These data were updated through the most recent complete year for which data were available when this study was started. For estimating the magnitude of the long return-period values, the maximum length of record available is highly desirable. However, the purpose of the present study is to determine the distribution of precipitation within various time intervals. For this purpose, the intrastorm relations are required and the total record length does not necessarily have to be the maximum available. In order to determine the shortest period of record which would give valid results, several periods of record were analyzed. It was found that results for the 30-yr period 1941-70 produced results consistent with those from the longer record. It was therefore decided that tabulations for this study for the period 1941-70 would be compatible with those for the period 1912-70 and little or no improvement would result from tabulating data for longer periods for all stations. This resulted in a total of 1,712 cases for each N-day period.

To investigate possible regional bias, data from 12 stations in the northwestern corner of the study area were contrasted with data from 12 stations in the southeastern portion of the network. This grouping could be expected to illustrate any regional differences present. Such differences, if any, should be greatest between the geographical extremes of the basin. A study of the percent of storm total which fell on each day of the storm was made using data from the two groupings. The 20 percent of storms with the greatest precipitation total (hereafter called top 20 percent) and the 20 percent of storms with the smallest total precipitation (hereafter called low 20 percent) at each station were examined. Analyses showed small differences in average daily percentages between the storms at the northwestern and southeastern stations, or between the largest and smallest storms. For example, figure 3 shows the comparison of the accumulated percent of days with X percent or less of total storm precipitation versus percent of total storm precipitation. All days are treated as elements of a single population, disregarding their chronological order. For example, about 30 to 50 percent of all days in the 8-day storms had no precipitation, and about 80 percent of all days had 24 percent or less of the total storm precipitation. The smaller storms tended to have more days with no precipitation but fewer days with small percentages (< 10 percent) of storm total. Analysis of the average percent of total storm precipitation which fell on the day of maximum precipitation showed the northwestern stations to average very slightly higher than did stations in the southeastern group. Likewise, storms with total precipitation less than the amount to be equaled or exceeded once every 2 years had a little higher average percent on the maximum day than did storms with precipitation amounts indicative of longer return periods. Differences were generally 5 percent or less. These differences are slight and are equivalent to the variation determined from the charts in U.S. Weather Bureau Technical Paper Nos. 40 and 49 [Hershfield 1961, Miller 1964]; for example, the ratio of the 2-yr 24-hr to 2-yr 10-day values as read from the charts in these publications is slightly higher than is the 100-yr 24-hr to 100-yr 10-day ratio.

In addition to the tabulations of the N-day event each year, tabulations were made of the maximum 1-, 2-, 3-, . . . (N-1)-day event that occurred within each N-day maximum. These M-day values (the maximum 1-, 2-, 3-, . . . (N-1)-day events within the maximum N-day period) were not necessarily the maximum amount for that duration for the particular year. They were, in some cases, the second, third, or lower value for that year. These tabulations were used to aid in determining the magnitude of the bursts within each N-day storm.

## METEOROLOGICAL DESCRIPTION OF STORMS

Although precipitation in the study area can come from a variety of storm types, the most common situation to cause annual maximum 4- to 10-day events is a summer (or warm season) storm with convective activity from both air mass storms and storms caused by frontal or low pressure activity. One of the more persistent cases of this occurred in July 1950, when 31 of the 44 stations having data for that year had their maximum annual value beginning sometime in July. Five of these 31 values were ranked as one of the three largest 10-day storms for the station concerned. On the other hand, one value for July 1950 ranked 25th in a sample of 30. The chronological distribution of these maximum annual events within the month was widespread as shown in table 2. For instance, Lake Moraine, CO (106), had its maximum 10-day amount from July 3 through July 12, and 16 days after July 12 also reported measurable precipitation. At the other extreme, Amistad, NM (141), had its maximum 10-day amount for 1950 beginning on July 30 and extending well into August. Climatological Data [National Climatic Center 1950] for

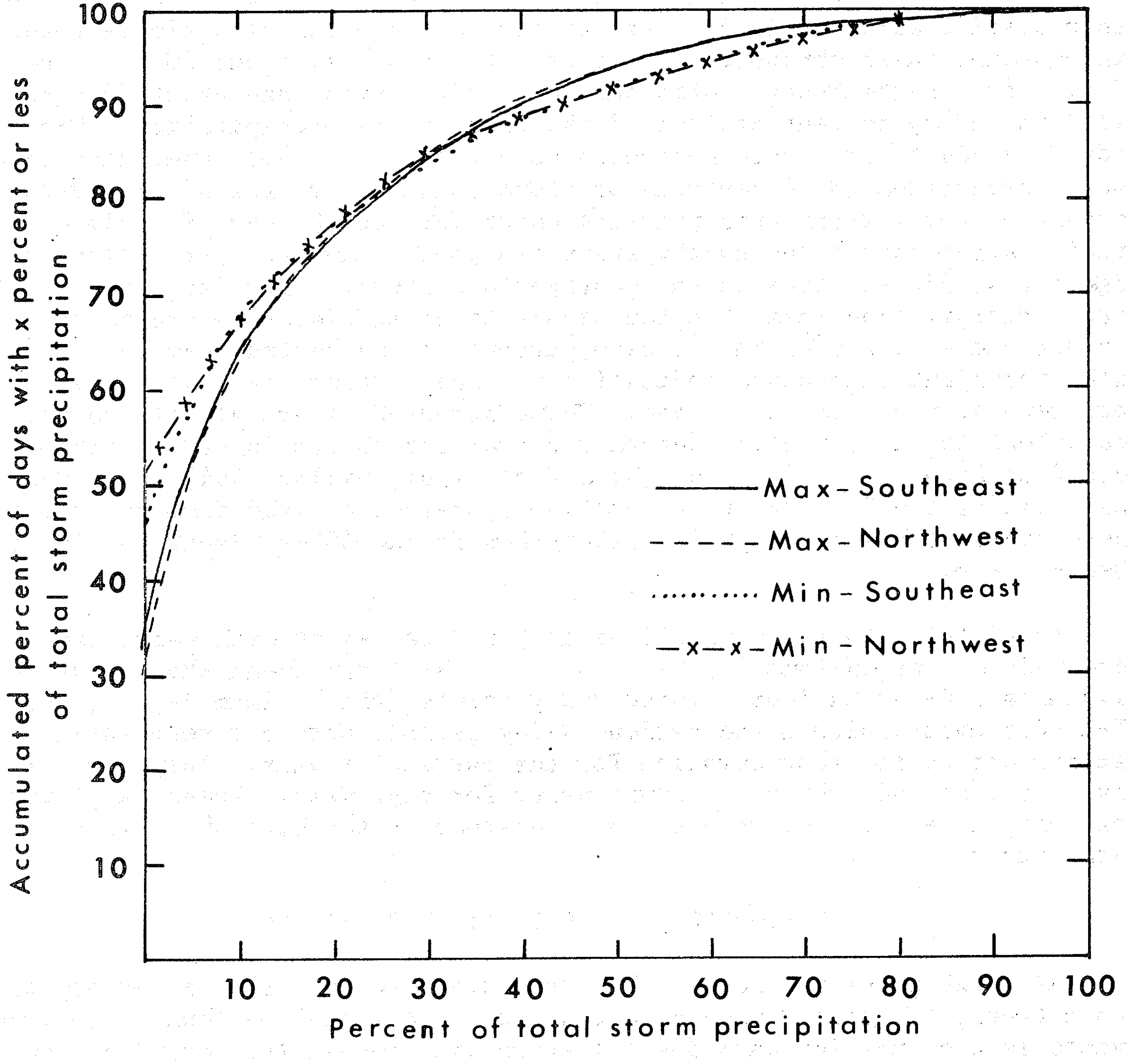

Figure 3.--Accumulated percent of storm precipitation for 8-day storms.

| Station no. | July 1950 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | August 1950 |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 103 |  | X | X | X |  |  |  |  |  |  | X | X | X |  | X | X | X |  |  |  |  | X |  | [X | X |  | X | X | X | X |  | Ⓧ | ] |  |  |  | X |  |  |
| 106 |  |  | [Ⓧ | X | X | X | X | X | X | X | X | X] | X | X |  | X | X | X | X | X | X | X | X | X | X | X | X | X |  |  | X | X |  | X |  |  | X |  |  |
| 107 |  |  | X |  |  |  |  | X | X | X |  |  |  |  |  |  |  |  |  | X | [X |  |  |  | Ⓧ |  |  | X |  | X] |  |  |  |  |  |  | X | X |  |
| 109 |  | X | X |  | X |  |  |  |  |  |  | X | X |  |  |  |  |  |  |  |  | [X |  |  | Ⓧ |  | X | X |  | X | X] |  |  |  |  |  |  | X |  |
| 110 |  | X |  |  | X |  |  | X |  | X |  |  | X |  |  |  |  | X | X |  |  |  |  |  | [X |  | X | X |  | Ⓧ | X | X |  | ] | X | X |  | X |  |
| 112 |  |  |  | X | X | X | X |  | X | X |  | [X | X | X |  |  | X |  |  |  | Ⓧ] |  |  | X |  |  | X |  |  |  | X | X |  |  |  | X | X |  |  |
| 113 |  |  | X |  | X |  |  | X | X |  | X |  | X |  |  | X | X | X | [Ⓧ | X |  | X | X | X | X | X | X | X] |  |  |  | X |  |  |  |  |  |  |  |
| 115 |  | X |  |  |  |  |  | X |  | X |  |  |  |  |  |  | [Ⓧ | X | X | X |  |  |  | X |  | ] | X |  |  |  | X |  |  | X |  | X | X |  |  |
| 116 |  |  | X |  | X | X |  |  |  | X |  |  | X |  |  |  | X |  |  | [X | X |  | Ⓧ | X | X | X | X |  | ] | X |  | X |  |  |  |  |  |  |  |
| 117 | X | X | X |  | X |  |  |  | X |  |  | X |  |  |  |  |  | X | [X |  | X |  |  | X | X |  | Ⓧ | X] |  |  | X | X |  |  |  |  |  | X |  |
| 119 | X | X | X | X |  |  |  |  |  |  | X | X |  |  |  |  | X | X |  |  |  |  | [X | X | X | X |  | X |  | Ⓧ | X | X] |  |  |  |  | X | X |  |
| 120 | X |  | X |  |  |  | X |  | X | X | X | X |  |  |  | X | X | X | X |  |  |  |  | X | X |  |  | X |  | [X | Ⓧ | X |  |  | X | X |  | X | ] |
| 121 |  | X | X |  |  | X |  |  | X | X |  |  | X |  |  | X | X | X | X |  |  |  |  | X | X | X |  |  | [X | X | Ⓧ |  | X |  | X | X |  | X] |  |
| 122 |  |  |  | X |  | X |  |  |  |  |  |  | X |  |  |  |  | X |  | [X | X | X | X |  |  | X |  |  | Ⓧ] |  | X |  |  |  |  | X | X |  | X |
| 126 |  | X | X |  | X |  |  | X |  | X |  | X | X |  |  |  |  | X | X |  | X | X |  |  | [Ⓧ |  | X | X | X | X | X | X |  | ] |  |  |  | X |  |
| 128 |  |  | X |  | X |  |  |  | X |  |  | [Ⓧ | X |  |  |  |  | X | X |  | X] |  |  | X |  |  | X | X |  |  | X | X |  |  |  |  |  |  |  |
| 129 |  | X |  |  |  | X | X | X | X | [Ⓧ |  |  | X |  |  | X | X | X | X] |  |  |  |  |  | X | X |  |  | X | X | X | X | X |  | X | X |  | X |  |
| 130 | X |  |  | X | X | X |  |  | X | X |  | X |  |  |  |  |  | X |  | X |  |  |  | [X | X |  | X | X | X | X | Ⓧ |  | X] |  |  |  |  |  | X |
| 131 | X |  | X |  | X |  |  |  | [X |  |  | X |  |  |  |  |  | Ⓧ] |  |  | X |  |  |  |  |  | X | X |  |  | X | X |  |  |  |  |  |  | X |
| 133 |  | X | X |  | X |  |  |  | X |  |  | X | X |  |  |  |  | [Ⓧ | X |  | X | X |  |  | X | X | X] | X | X | X |  | X |  |  |  |  |  | X |  |
| 134 |  | X | X |  |  |  |  | X | X |  |  |  | X |  |  |  | X | X | X |  | X | X |  |  | [Ⓧ | X | X | X | X | X | X | X |  | ] |  |  |  | X |  |
| 135 |  | X |  |  |  |  |  |  | X |  |  |  | X |  |  |  |  | X | X | X | X | X | X |  | [X | X |  |  | Ⓧ | X | X | X | X | ] |  |  |  | X |  |
| 137 |  | X |  | X | X |  |  | X |  | X | [X | X |  |  |  |  | X | X | X | Ⓧ] |  |  |  |  |  | X | X |  | X |  | X |  | X |  |  |  |  | X | X |
| 139 | X |  | X | X | X | X |  |  |  |  | [X | X |  |  |  |  |  | Ⓧ |  | X] |  |  |  |  |  |  | X | X | X | X | X |  |  |  |  |  |  |  | X |
| 140 |  |  |  |  | X |  |  | X |  | X | X |  | [X |  |  |  |  | X | X | Ⓧ | X | X] |  |  | X | X |  |  | X | X | X | X | X |  | X |  |  |  |  |
| 141 |  |  | X |  | X | X |  |  |  |  | X | X |  |  |  |  |  | X | X | X |  |  |  |  |  |  | X |  | X | [X | X | Ⓧ | X |  |  |  |  |  | X] |
| 142 |  |  | X | X | X |  | X |  |  | X |  |  |  |  |  |  |  | [X | X | X | Ⓧ |  |  |  |  |  | X] |  |  |  | X | X |  |  |  |  |  |  |  |
| 143 |  |  |  |  |  |  | [Ⓧ |  | X | X | X | X | X |  | X | X] | X | X |  | X | X | X |  |  |  |  |  |  | X | X | X | X | X |  | X |  |  |  |  |
| 144 |  |  |  | X | X |  |  |  | X |  | X | X |  | X |  |  | [X | X | X | Ⓧ | X |  |  |  | X | ] |  |  | X | X |  | X |  |  |  |  |  | X |  |
| 147 |  | X | X |  | X | X |  |  |  |  |  | X |  | X |  |  | X |  | X | X | [Ⓧ | X |  |  | X |  |  | X | X | X] | X |  |  |  |  |  |  |  |  |
| 148 |  |  | X | X | X |  |  |  | X | X | X |  |  |  | [X | X | X | X |  | X | X | Ⓧ |  | ] | X |  |  |  | X | X | X | X |  |  | X | X |  |  |  |

X = day of precipitation; ▭ = maximum annual 10-day precipitation;
Ⓧ = maximum day within maximum annual 10-day precipitation

Table 2.--Distribution of days with measurable precipitation in July and early August 1950 for stations having maximum annual 10-day storms during that period

July 1950 for the states within the Arkansas-Canadian Basins area all mention that this was the wettest July of record.

The mid-May period of 1955 produced the maximum 4-, 6-, 8-, and 10-day storms of record at several stations. Large 4-day totals were 8.82 inches at Ulysses, KS (117), 7.87 inches at Lake Moraine, CO (106), and 7.10 inches at Cimmaron, KS (118). Corresponding 10-day amounts were 9.43, 8.78, and 8.60. The moisture from this storm was brought from the Pacific by the circulation around an upper-level Low centered in the northwestern states. Surface cold frontal disturbances brought heavy rains and thunderstorms during the period May 17-19. Numerous 24-hr amounts were in excess of 3.00 inches. The period of heavy precipitation centered around May 17-19 was at some stations coupled with other storm periods as early as May 10 and at others with periods as late as May 26 to obtain maximum 10-day amounts.

During the later half of April 1942, 24 stations had the maximum 10-day storm for that year and at 10 of these stations the storm was one of the three largest 10-day storms in the sample. The 24 stations were widely distributed through the basins. The first and maximum burst of precipitation came from April 17 through 20. The weather maps for that period show a small Low in the Oklahoma panhandle on the early morning of April 16. This Low faded out. By the morning of the 18th, there was another Low in central Colorado which moved to the Texas panhandle 24 hours later. During this period, Ulysses, KS (117), reported 3.48 inches of precipitation on the observation for April 18, while Lake Moraine, CO (106), and Westcliffe, CO (112), each reported around 5.00 inches for the 2-day period April 18-19. The second burst of precipitation on April 23-24 resulted from the approach and development of a Low which was centered in extreme northeast New Mexico on the weather map for April 24. Amounts of precipitation were generally lighter in this burst, with a few stations receiving only around 0.50 inch. Des Moines, NM (132), and Lake Moraine, CO (106), had around 2.25 inches. This example illustrates the type of situation in which early season storms can bring maximum N-day precipitation amounts. Lows of the Colorado type can form and remain in the vicinity for a period of time and are followed several days later by another storm of the same type.

## SEASONALITY OF STORMS

Examination of a table (table 3) showing the months during which the annual maximum 4- to 10-day storms occurred suggests that any seasonal distribution be made on other than the traditional (winter equals December, January, and February, and summer equals June, July, and August) calendar basis. In the Arkansas and Canadian Basins, the winter months have relatively few occurrences (2 percent or less per month) of annual maximum N-day storms. April has four times as many occurrences as does March, while May averages about two and one-quarter times as many as April. It thus appears that March is a logical month with which to end the winter season. The months following May continue to have large numbers of 4- to 10-day annual maximum storms; and, so, May appears to be the logical month with which to begin the summer season. This leaves April as the transition season between the cold and warm seasons. The ending of the warm period is less clear cut. August has just under one and one-half times as many storms as September, but September has over one and one-half times as many storms as October. For this reason, September can be included in the warm season sample, although this is somewhat arbitrary. Since October has over two and three-quarters times the number of storms that occurred in November, October is classified as the transitional month, with November as the beginning of the winter season. Table 3 shows the percent of storms by months and by seasons when they are defined as above.

Table 3 shows the increasing preference for a summer (as defined above) maximum as the length of the period increases. This summer preference is also greater when one looks at the largest storms. For instance, if one takes the 10 percent of the storms with the greatest volume at each station, at the 10-day duration, 85.9 percent of such storms occur during the May through September period. Conversely, of the smallest 10-percent storms, only 73.6 percent are summer storms.

Table 3.--Percent of N-day storms by month and season

| | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4-day | 0.5 | 0.6 | 1.8 | 7.9 | 18.8 | 14.2 | 19.0 | 15.6 | 10.5 | 7.5 | 2.3 | 1.3 |
| 6-day | 0.7 | 0.5 | 1.9 | 8.6 | 18.1 | 14.8 | 20.9 | 14.9 | 10.0 | 6.4 | 2.3 | 0.9 |
| 8-day | 0.5 | 0.8 | 1.9 | 8.6 | 19.0 | 15.5 | 21.1 | 14.2 | 9.5 | 6.0 | 2.2 | 0.7 |
| 10-day | 0.5 | 0.6 | 2.0 | 7.9 | 19.6 | 15.2 | 22.4 | 14.2 | 9.8 | 5.3 | 2.0 | 0.5 |

| | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| 4-day | 6.5 | 7.9 | 78.1 | 7.5 |
| 6-day | 6.3 | 8.6 | 78.7 | 6.4 |
| 8-day | 6.1 | 8.6 | 79.3 | 6.0 |
| 10-day | 5.6 | 7.9 | 81.2 | 5.3 |

This suggested seasonal distribution shows only minor variations when the data sample of 12 stations in the northwest and 12 stations in the southeast portion of the network are compared. Some of the percentages change, but the basic pattern remains the same.

Storm systems that affect the Arkansas and Canadian Basins during the winter season tend to move rapidly. Since there is a long trajectory over mountainous terrain before moisture from the Pacific can reach the study basin, the major intrusions of moisture would be more likely to come from the Gulf of Mexico. The distance from this moisture source is less than from the Pacific. The terrain is much less variable, and, in general, presents only a gradual upslope from the gulf to the Arkansas and Canadian Basins. Sustained moisture flow from the Gulf of Mexico is less likely in winter than in summer because of the transitory nature of winter systems. During the summer period, when weather systems move more sluggishly (especially at southern latitudes) or even stagnate, a flow of humid air from the Gulf of Mexico can persist for long periods. During such times, air mass thunderstorms or thunderstorms triggered by minor weather disturbances can cause large amounts of precipitation. Such situations are the cause of a great many of the annual maximum N-day storms.

Since the 10-day duration is the duration of greatest seasonality, (greatest percent in summer, least in other three seasons), 10-day storms were examined to detect differences between seasons. Graphs were made of the accumulated frequency of occurrence of the percent of precipitation on the maximum day and another showing accumulated frequency of percent of precipitation on all days. From the small samples for winter, spring, and fall that were available, differences in the seasonal curves appeared minor and un-systematic. The conclusion was, therefore, that there are no seasonal differences in the distribution of precipitation in this sample.

On the other hand, when curves of the accumulated percent of occurrence of percent on maximum days are plotted for top 20-percent and low 20-percent storms, there is a distinct difference. Since the low 20 percent represents smaller return periods than are generally of interest, a similar curve for storms ranked in the 40- to 60-percent class intervals was plotted. The curves for storms in the top 20 percent and storms in the 40- to 60-percent class interval showed no essential differences.

Another analysis was made of the average percent of storm total on the maximum day for storms in the top 20 percent, the 40- to 60-percent class interval, and low 20 percent. Table 4 shows the results of this analysis. Differences between the average percent that fell on the maximum day for the 40- to 60-percent class interval and the similar average for the low 20 percent of storms are several times those found between average values from the top 20 percent and the storms in the 40- to 60-percent class interval.

Table 4.--Average on maximum 1 day in N-day by rank

| | Top 20-percent class interval $\bar{X}_{(20)}$ | 40- to 60-percent class interval $\bar{X}_{(60)}$ | Low 20-percent class interval $\bar{X}_{(100)}$ | $\frac{\bar{X}_{(100)} - \bar{X}_{(60)}}{\bar{X}_{(60)} - \bar{X}_{(20)}}$ |
|---|---|---|---|---|
| 4-day | 61.835 | 64.636 | 71.399 | 2.4145 |
| 6-day | 56.063 | 58.498 | 62.710 | 1.7298 |
| 8-day | 51.731 | 52.470 | 58.072 | 7.5805 |
| 10-day | 47.164 | 48.750 | 53.739 | 3.1456 |

## INDEPENDENCE OF DATA

The same synoptic situation often produces the annual maximum N-day precipitation amount at several locations over the Arkansas-Canadian Basins. The 30-yr sample (1941-70) of 10-day storms was examined to determine how often a single storm produced the annual maximum event at several stations.

The May 1955 storm (previously discussed under Meteorological Description of Storms) caused the annual maximum 10-day precipitation for that year at 29 of the 48 stations in the network. At six of the stations, it was the largest 10-day storm in the 30-yr sample. These 29 stations were not grouped geographically but extended from Lake Moraine, CO (106), in the northwest to Stillwater 2NNW, OK (140), in the southeast. A mid-September storm in 1955 brought the largest 10-day total precipitation for that year to 10 stations, with March, June, July, August, and October having the annual maximum 10-day at at least one of the network stations.

Mention has been made of July 1950 (Meteorological Description of Storms), when 31 of the 46 stations (two stations had records missing for that year) had their annual maximum 10-day events in that month. These, however, could not be ascribed to the same storm, since the beginning data for the 10-day storm periods varied from July 3 (at Lake Moraine, CO (106)) to July 30 (at Amistad, NM (141) and Wichita, KS (120)). While several stations received their maximum rains during the same or overlapping 10-day periods, the time variation is so widespread that no one set of synoptic circumstances could be said to cause more than a relatively few of the occurrences during this month.

The year 1960 is an example of a year without an outstanding 10-day period of precipitation. Thirteen stations had the greatest 10-day amount in October that year. The mid-month period saw several troughs and Lows pass through or near the Arkansas-Canadian Basins. July 1960 also had several periods of precipitation that gave the annual maximum 10-day amount to some stations. Beginning days of the 10-day periods in July start as early as July 3; and one station, El Dorado, KS (121), began its 10-day period on July 31. Also in 1960, annual maximum 10-day amounts came in January, February, and April through October.

The conclusion is drawn that a single storm can cause the maximum N-day precipitation at several stations in the Arkansas-Canadian Basins. However, since most of the storms occur during the warm season and are not brought about by general, regularly moving Lows, the storms can be considered independent. As a general rule, there will be a period of storminess and frequent thunderstorms that will bring the annual maximum 10-day precipitation to about 20 to 25 of the 49 stations in the network. The annual maximum 10-day storms at the remainder of the stations will come at other times, with some being isolated cases and others in which groups of 5 to 10 stations will have the annual maximum storm from the same set of circumstances.

In the data sample, no single weather situation caused more than a couple percent of the total cases. Even when the same situation resulted in annual maximum N-day events at several stations, the data for the individual stations were still partly independent. There are at least two reasons for this: 1) each station had a unique location relative to the storm path; 2) the storm is changing with time as it moves. The data sample is considered to be sufficiently independent for this study and to be representative of the storms that occur over the Arkansas-Canadian Basins.

## OCCURRENCE OF PRECIPITATION ON ALL DAYS

Annual maximum precipitation amounts for periods of 4 days duration or longer generally come from a series of storms. The precipitation is usually in separate periods, interspersed with intervals of little or no precipitation. As the duration of the storm increases, the percentage of storms with precipitation on each day decreases. Table 5 shows the percent of annual maximum N-day storms that had precipitation on some portion of L-observation days (not necessarily consecutive) included within the storm period for all storms and for the top 50 percent of storms at each station.[1]

Table 5.--Percent of N-day storms having L days with measurable precipitation

| Duration (days) | L days | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | | | | | **All storms** | | | | | |
| 4 | 4.6 | 21.1 | 39.0 | 35.3 | | | | | | |
| 6 | 1.6 | 10.7 | 21.0 | 31.8 | 23.9 | 11.0 | | | | |
| 8 | 0.8 | 5.2 | 14.1 | 23.1 | 24.4 | 19.4 | 9.9 | 3.1 | | |
| 10 | 0.4 | 2.4 | 8.5 | 15.8 | 22.5 | 22.8 | 14.4 | 8.3 | 3.7 | 1.2 |
| | | | | | **Top 50 percent of storms** | | | | | |
| 4 | 3.1 | 15.3 | 37.7 | 43.9 | | | | | | |
| 6 | 1.2 | 7.0 | 17.2 | 32.8 | 28.5 | 13.3 | | | | |
| 8 | 0.5 | 2.7 | 10.0 | 22.1 | 25.4 | 22.5 | 12.2 | 4.2 | | |
| 10 | 0.4 | 0.8 | 5.2 | 13.0 | 21.5 | 24.4 | 16.8 | 10.5 | 5.4 | 2.0 |

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[1] Top 50 percent was defined as the 50 percent of storms with the greatest precipitation total at each station. The total number of storms in this sample was 851 (instead of 1712 ÷ 2 = 856). A station with an odd number of years of record had one less value in the top 50 percent than in the lower 50 percent. For instance, each 59-yr record had 29 values in the top 50 percent and 30 values in the low 50 percent.

Table 6 shows the distribution of percent of storm total that fell on each storm day. For instance, of the over 17,000 days included in the study of 10-day storms, 44.5 percent had no measurable precipitation, while 25.8 percent had some precipitation, but less than 10 percent of the storm total. For the top 50 percent of storms, comparable figures are 40.6 percent and 28.7 percent. The table shows that at all durations storms with precipitation amounts greater than would be expected every other year have fewer non-precipitation days and fewer days with a relatively large percent of the storm total.

Figure 4 illustrates the accumulated percentage frequency of consecutive days with no precipitation in N-day storms for all storms and for top 50 percent. Examination of table 5 and figure 4 shows the difference between the larger storms and the lesser storms. Since the top 50 percent of storms would be expected to represent return periods greater than 2 years, the data for this portion of the storms are considered applicable at that return period or greater. Additional examination showed that a contrast between the top 50 percent and the top 20 percent continued the trend that the longer the return period the greater number of days on which precipitation was observed.

## NUMBER OF BURSTS

Precipitation is characterized by variations in both time and space and rarely falls at a uniform rate. The present studies are concerned with the variation of precipitation with time for durations of 96 to 240 hours. The basic data were tabulated using observation-day intervals. No attempt was made to determine whether, on adjoining days, precipitation fell as one or more "bursts" or periods of precipitation, i.e., whether the precipitation was nearly continuous or whether the two adjoining observation days of precipitation were actually two or more rain periods separated by periods of several hours with little or no precipitation. Thus far, the word "burst" has been used to mean a period of heavier precipitation of undefined limits. In the remainder of this paper, "burst" is defined as a period of significant precipitation separated from other periods of significant precipitation by an interval of little or no precipitation. The maximum burst is defined as the sum of the percent of the total precipitation that occurred on the maximum day of the N-day period plus the percent that fell on all contiguous days, provided each such day had at least 7.5 percent of the storm total. The second burst is defined as the sum of the percent of the total precipitation that occurred on the maximum day of the N-day period that was not included in the maximum "burst" plus the percent that fell on all contiguous days, provided each such day had at least 7.5 percent of the storm total. Similarly, a third, fourth, or possibly a fifth burst could be defined.

If the assumption is made that there is a 50-percent chance of significant precipitation on any day of a storm period, the various possible combinations of days with and without significant precipitation can be determined. If the storms studied were randomly distributed within the storm sample, there would be an equal number of the various possible combinations of storms with significant precipitation on all days, on 1 day,

Table 6.--Daily distribution by class intervals of percent of storm total on each day of N-day storms

| Duration | Class interval (percent) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.000 | 0.001<br>9.999 | 10.000<br>19.999 | 20.000<br>29.999 | 30.000<br>39.999 | 40.000<br>49.999 | 50.000<br>59.999 | 60.000<br>69.999 | 70.000<br>79.999 | 80.000<br>89.999 | 90.000<br>99.999 | 100.000 |
| | **All storms** | | | | | | | | | | | |
| 4-Day | 23.8 | 20.7 | 11.5 | 10.0 | 8.1 | 6.3 | 5.3 | 4.2 | 3.5 | 2.8 | 2.6 | 1.2 |
| 6-Day | 33.6 | 23.6 | 11.9 | 8.8 | 6.7 | 5.0 | 3.4 | 2.7 | 1.8 | 1.3 | 0.9 | 0.3 |
| 8-Day | 40.2 | 25.1 | 11.2 | 7.7 | 5.5 | 3.6 | 2.7 | 1.8 | 1.1 | 0.6 | 0.4 | 0.1 |
| 10-Day | 44.5 | 25.8 | 10.8 | 7.2 | 4.6 | 2.7 | 1.8 | 1.4 | 0.6 | 0.4 | 0.2 | < 0.1 |
| | **Top 50 percent of storms** | | | | | | | | | | | |
| 4-Day | 19.4 | 22.1 | 12.7 | 11.5 | 8.8 | 7.0 | 5.6 | 4.1 | 3.2 | 2.6 | 2.2 | 0.8 |
| 6-Day | 30.0 | 25.5 | 12.9 | 9.6 | 7.1 | 5.3 | 3.4 | 2.5 | 1.6 | 1.2 | 0.7 | 0.2 |
| 8-Day | 36.4 | 27.8 | 12.0 | 8.3 | 5.6 | 3.8 | 2.7 | 1.6 | 0.9 | 0.5 | 0.3 | 0.1 |
| 10-Day | 40.6 | 28.7 | 11.8 | 7.5 | 4.7 | 2.8 | 1.7 | 1.2 | 0.5 | 0.3 | 0.2 | < 0.1 |

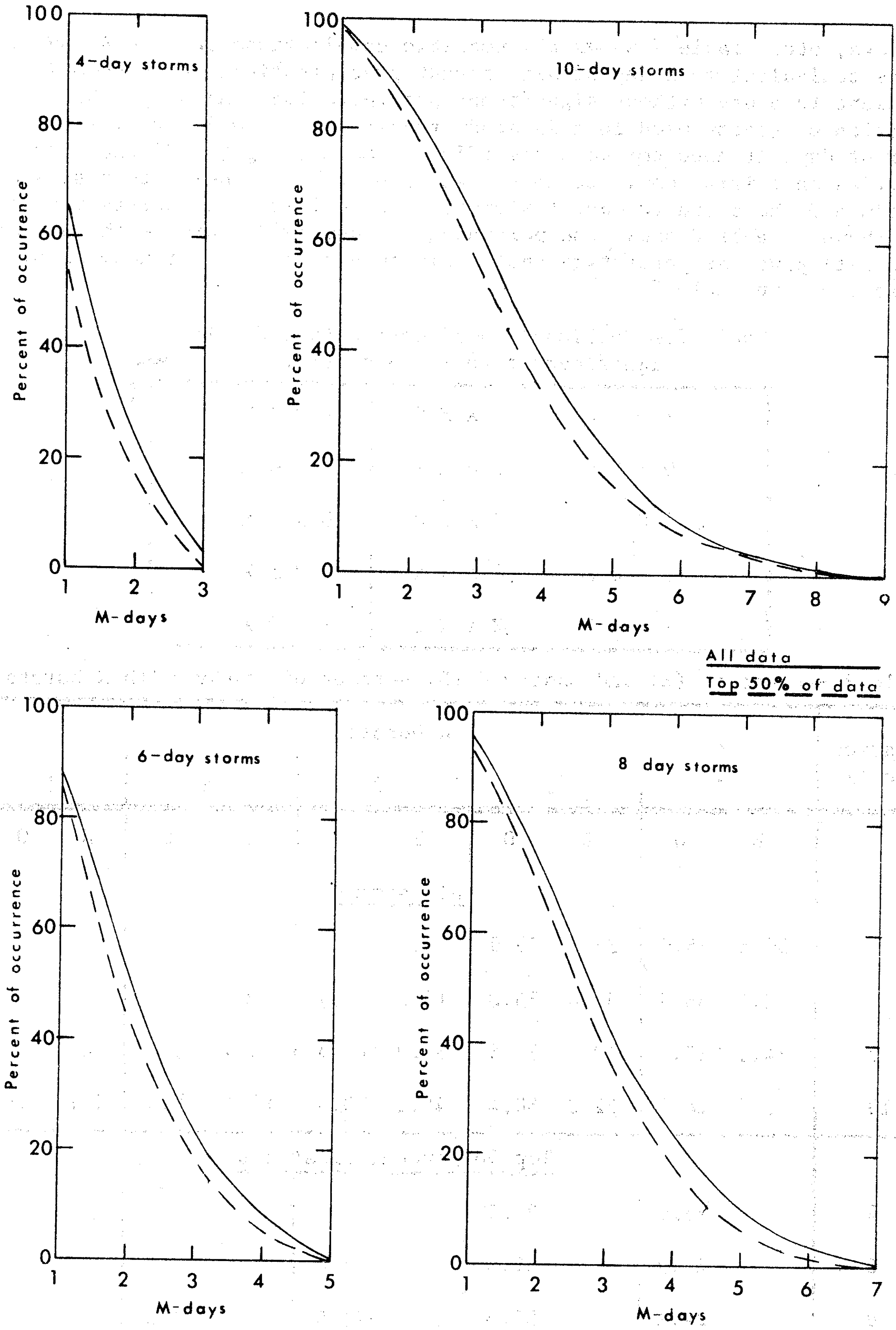

Figure 4.--Percent of occurrences of M consecutive days of zero precipitation in 4-, 6-, 8-, and 10-day storms.

on 2 days, etc. Table 7 shows all possible combinations for the 4-day storms. An X is equivalent to a day of significant precipitation, and a zero is equivalent to a day without significant precipitation. Although the definition of storms used in this study requires measurable precipitation on the first day, it need not be a significant amount; e.g., 0.01 inch would qualify as an initial day. Columns 1 and 2 of table 7 show one-burst storms, and column 3 shows the two-burst storms. The definition of bursts is that given above. Table 8 shows the percentage of observed storms with one through five bursts plus the percentage that would be expected in a random sample, such as shown in table 7.

Table 7.--Combinations of days with and without significant rain in 4-day storms

| | | |
|---|---|---|
| X 0 0 0 | 0 X X 0 | X 0 X 0 |
| 0 X 0 0 | 0 0 X X | X 0 0 X |
| 0 0 X 0 | X X X 0 | 0 X 0 X |
| 0 0 0 X | 0 X X X | X 0 X X |
| X X 0 0 | X X X X | X X 0 X |

Table 8.--Expected (E) and observed (0) percent of storms with K bursts

| Duration (days) | K bursts | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | |
| | E | 0 | E | 0 | E | 0 | E | 0 | E | 0 |
| | | | | | All storms | | | | | |
| 4 | 66.6 | 65.0 | 33.3 | 35.0 | 0 | | | | | |
| 6 | 33.3 | 36.5 | 55.6 | 55.8 | 11.1 | 7.7 | 0 | | | |
| 8 | 14.1 | 22.4 | 49.4 | 55.5 | 32.9 | 20.5 | 3.5 | 1.6 | 0 | |
| 10 | 5.4 | 14.3 | 32.3 | 50.4 | 45.2 | 30.0 | 16.1 | 5.3 | 1.1 | 0 |
| | | | | | Top 50 percent of storms | | | | | |
| 4 | | 66.0 | | 34.0 | | | | | | |
| 6 | | 29.9 | | 62.3 | | 7.8 | | | | |
| 8 | | 24.1 | | 53.4 | | 21.0 | | 1.5 | | |
| 10 | | 14.7 | | 49.9 | | 29.9 | | 5.5 | | |

In each case, the two-burst storm shows a greater than expected value and (except for 4-day storms) is the most frequently observed event. Even at the 4-day duration, the two-burst event occurs over one-third of the time. Three or more burst events are observed less often than expected but at the 8- and 10-day durations comprise a significant portion of the sample. The 10-day storms were analyzed using varying burst cutoff values from 2.5 percent to 12.5 percent. In all cases, the data showed a multi-burst (two-or three-burst) storm to be most common. The same tendency exists when the storms are stratified into large (highest 20 percent) and small (lowest 20 percent) 10-day storms. If the burst cutoff value of 7.5 percent were lowered, the number of storms with three or more bursts would increase. For example, if the threshold limit were reduced to 5 percent, the percentage of 10-day storms with three bursts would increase to 34.9 percent, while the percentage of one-burst storms would increase to 11.1 percent.

In the section on Occurrence of Precipitation on All Days, a difference was noted between the top and bottom 50 percent of the storms. In the burst analysis, no such systematic difference was found. This is because in the burst analysis the burst can consist of more than 1 day, and successive days with precipitation are additive in many cases when viewed from the burst concept.

## PROBABILITY OF X PERCENT OF THE N-DAY STORM IN VARIOUS INTERVALS

Each of the storms was analyzed to determine the maximum percentage of the storm total that fell within various periods. The maximum 1-day within N-days is self-explanatory. The maximum 2-, 4-, 6-, and 8-day amounts were for consecutive day periods, but it was not mandatory that each day have measurable precipitation. This section defines the probability that the maximum M-day period within the N-day storm will contain a specified percentage of the total storm precipitation.

The curves presented in figures 5 through 8 are derived from data contained in the largest 50 percent of the storms at each station. As previously mentioned, smaller storms (generally below the level of the 2-yr return period) tend to contain more zeroes and fewer days with measurable precipitation. The curves presented using the top 50 percent are not significantly different from curves made using only the top 20 percent of storms and are considered representative for storms in the Arkansas-Canadian Basins at and above the 2-yr return period.

Figure 5 shows percent of the 4-day total falling on the maximum 1-day and 2-day periods within the 4-day storm and the probability of exceeding this percent. The average maximum 1-day amount would be about 60 percent of the storm total. Over 90 percent of the 4-day storm total will fall within 2 consecutive days with a probability of about 0.38. These curves do not indicate on which day or days of the 4-day period the precipitation fell. Even though the first day must contain precipitation, it might not be within the maximum 2-day period.

Figure 6 illustrates the probability of receiving x percent of the 6-day precipitation during the maximum M-days. The average maximum 1-day

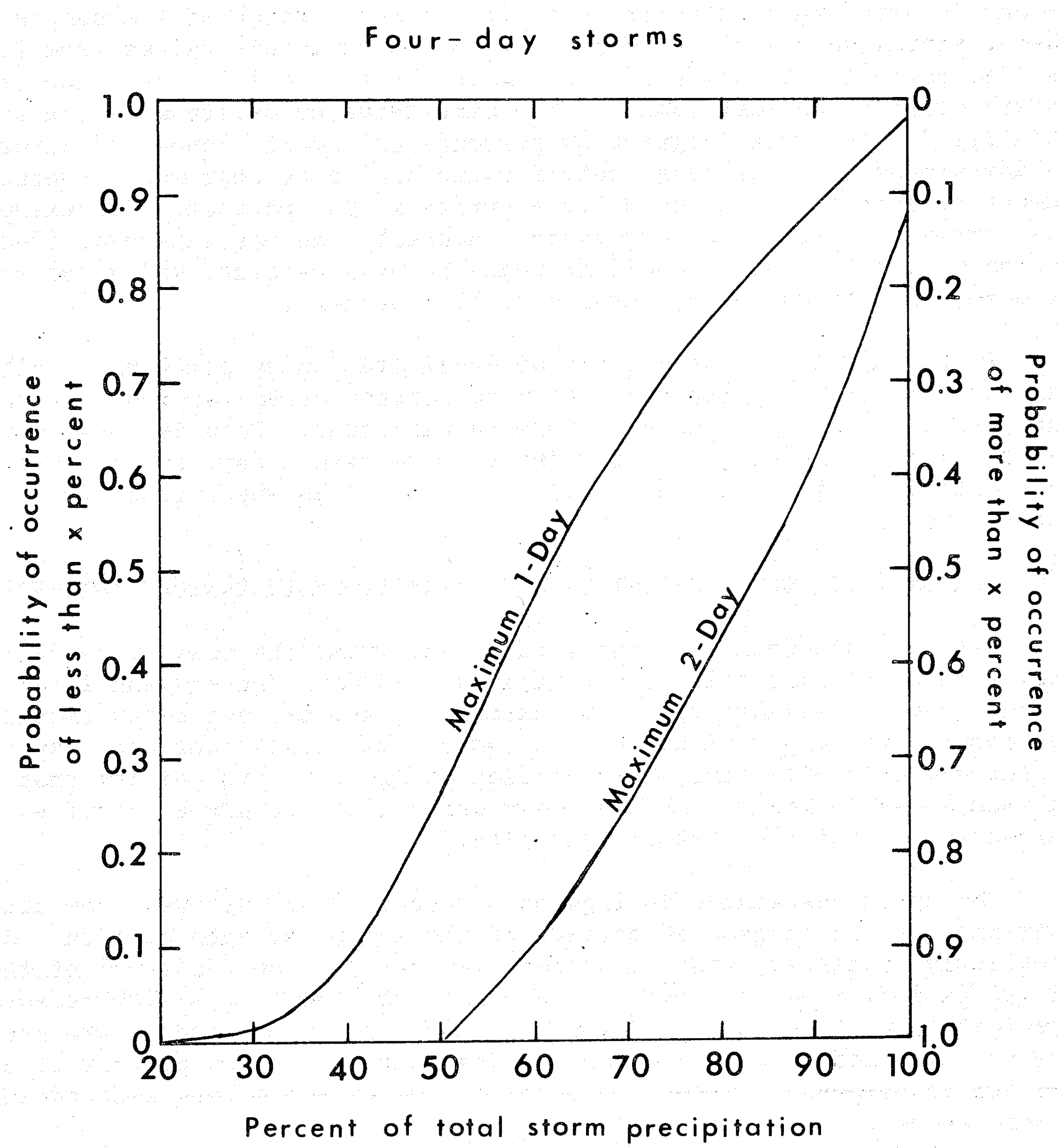

Figure 5.--Percent of precipitation observed on maximum M days in 4-day storm.

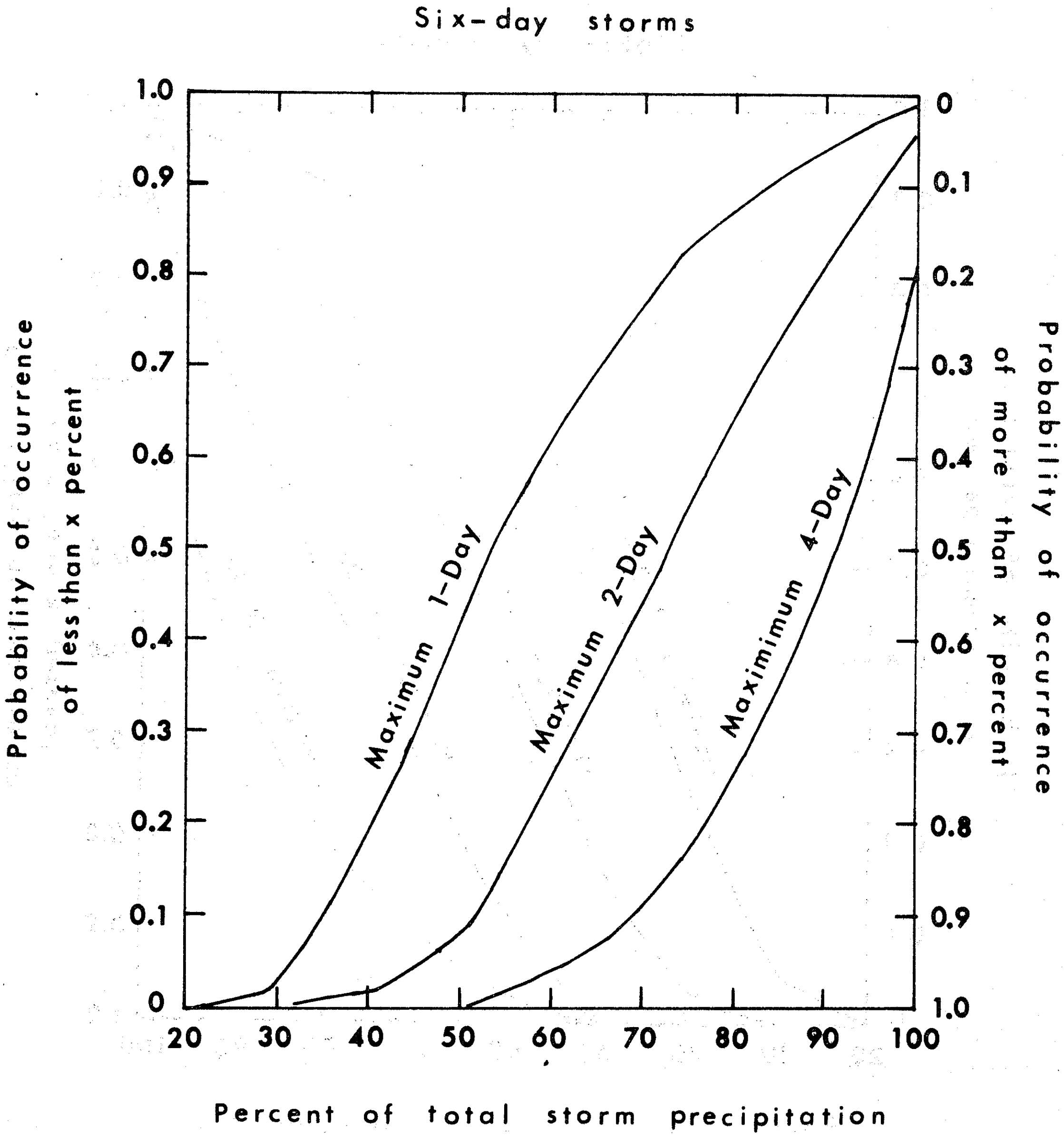

Figure 6.--Percent of precipitation observed on maximum M-days within 6-day storm.

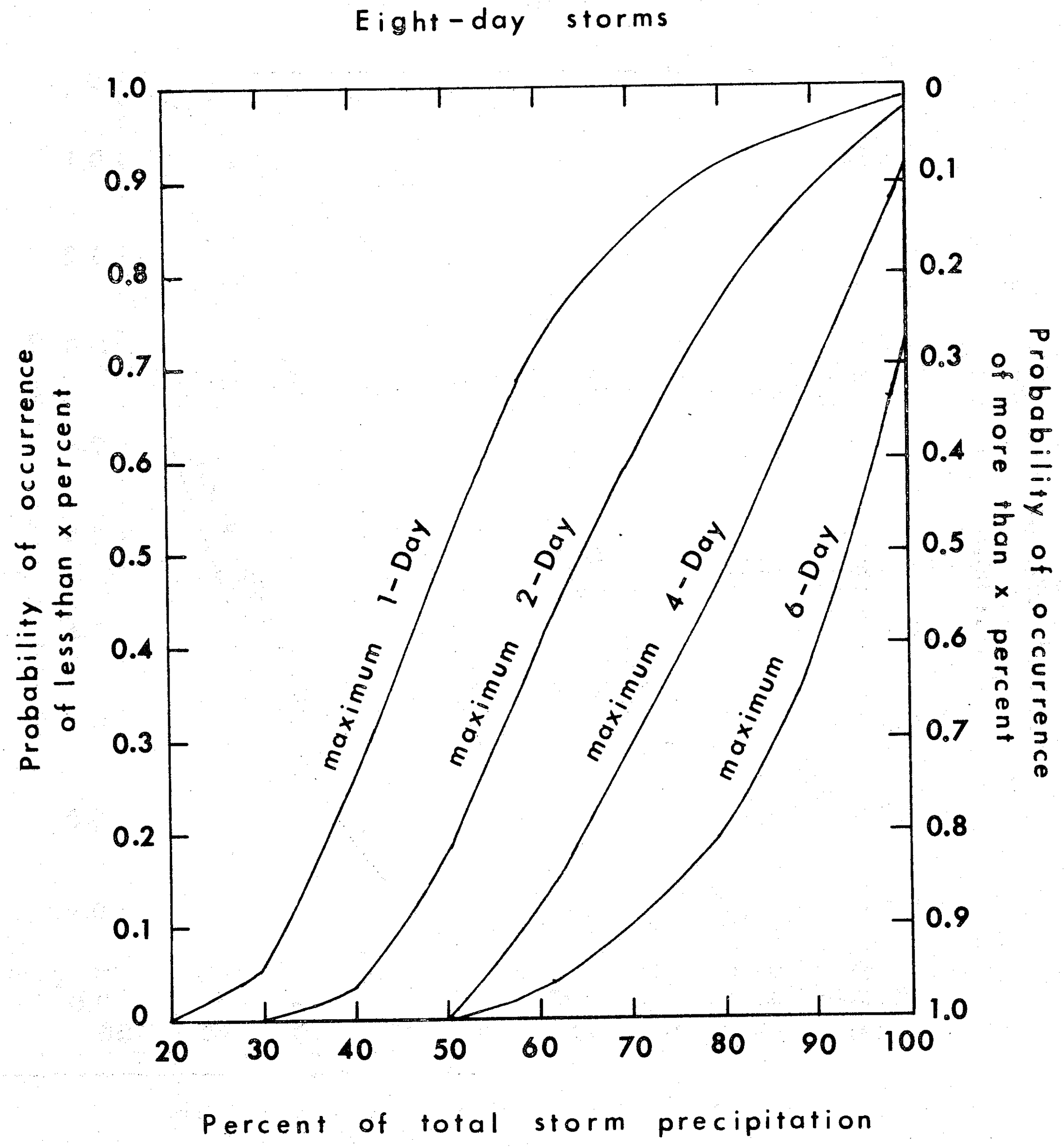

Figure 7.--Percent of precipitation observed on maximum M-days within 8-day storm.

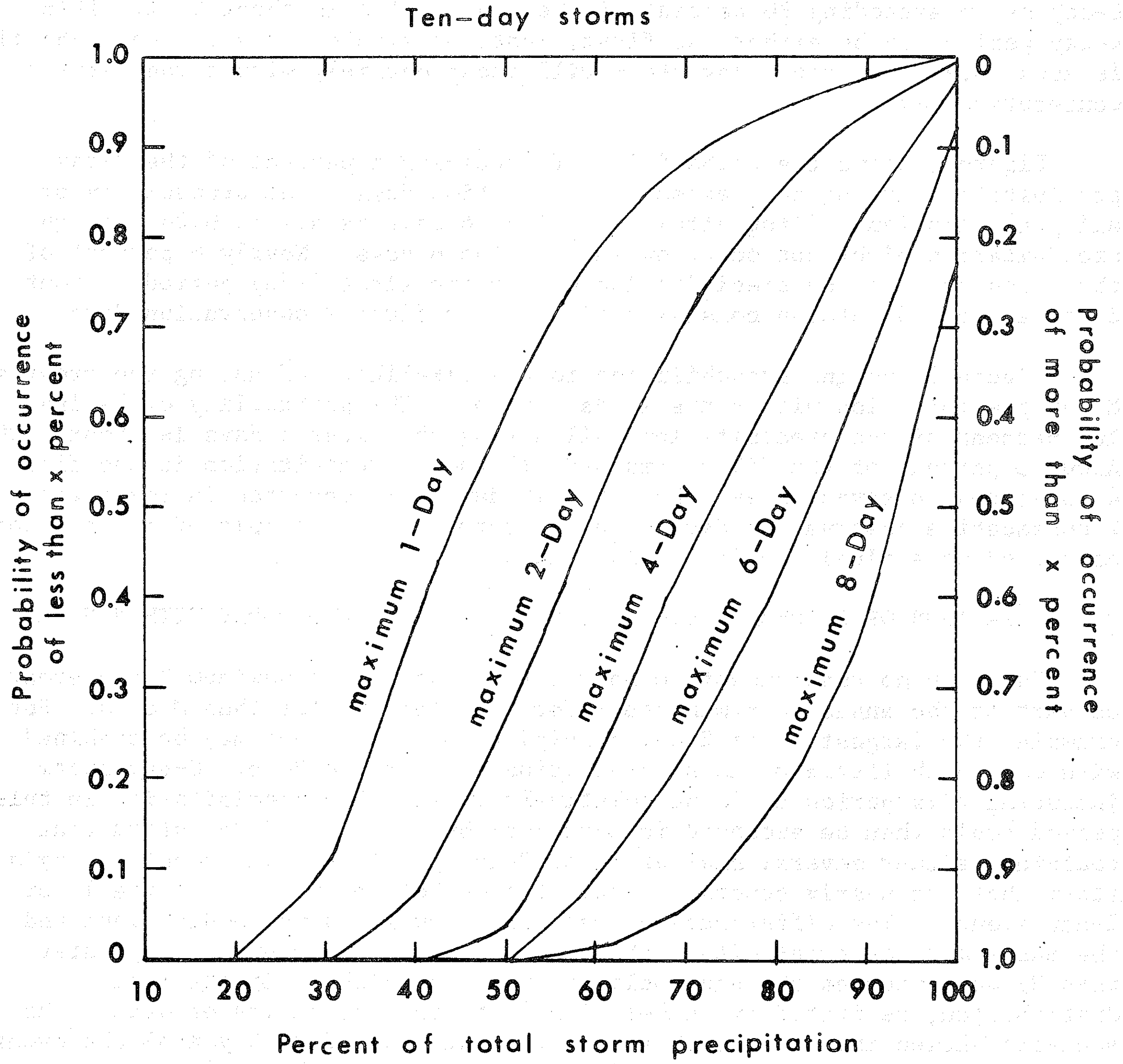

Figure 8.--Percent of precipitation observed on maximum M-days within 10-day storm.

precipitation would be slightly over 50 percent of the 6-day total amount. About 5 percent of the 6-day storms fell within 2 consecutive observation days; some of these may have occurred in less than a 24-hr period. As shown on figure 6, the probability of the maximum 4 observation days within the 6-day storm exceeding 70 percent of the 6-day total is about 0.91. This 4-day period may be either the first, last, or middle 4 days. The probability is about 0.20 that the 6-day storm will occur entirely within the first 4 consecutive days.

Figure 7 shows the probability of receiving x percent of the 8-day precipitation during the maximum M observation days. The probability of all precipitation falling within the first 6 days is almost 0.26, though precipitation might not occur on each of the 6 days. Nearly 8 percent of the cases had all the precipitation during the first 4-day period. About 2 percent of 851 storms consisted of only the first 2 observation days.

Figure 8 assigns probabilities to the likelihood of having the greatest M-day precipitation within the 10-day period. The probability of having 100 percent of the precipitation fall during the first 6 days is about 0.80. About 3 percent of the 851 storms had all their precipitation in the first 4 days; and in seven cases, the total 10-day storm occurred in the first 2 consecutive observation days. Three storms in this sample of 10-day storms consisted of a single day's precipitation.

## COMPARISON OF EXTREME VALUE ANALYSIS FOR M-DAY AND M-DAY WITHIN N-DAY

There is no requirement in nature that the annual maximum M-day event be part of the annual maximum storm for a period greater than M days. For example, the largest 1- or 2-day precipitation for a year may be combined with days with little or no precipitation so that the 8- or 10-day storm including this period could be relatively small. The precipitation in this period could then be exceeded in that year by an 8- or 10-day storm that contained either several smaller 1- or 2-day precipitation amounts or by a storm that had nearly constant precipitation but no unusually large 1- or 2-day events. The differences between the annual maximum M-day event and the maximum M-day event within the annual maximum N-day event (N greater than M) were studies through application of the Fisher-Tippett Type I distribution, as fitted by Gumbel [1958], to the two series of data. The analysis showed that at the shorter return periods (2 to 5 years) the event computed from the series of annual maximum values is about 10 to 15 percent larger than the event computed from the maximum M-day value within the annual maximum N-day storm (fig. 9).

Examination of the three largest 7-day storms for each station (a sample of 144 storms) shows that over 80 percent of such storms also include the annual maximum 1-day precipitation for that year. Comparison of the three largest 1-day storms for each station with the three largest 7-day storms for each station shows that over 45 percent of the time they came from the same storm. The largest 1-day precipitation amount at each of the 48 stations was examined. Seventeen of these 48 events were included within the largest 7-day amount at that station. In 10 cases, the maximum 1-day amount was included in the second or third highest 7-day amount.

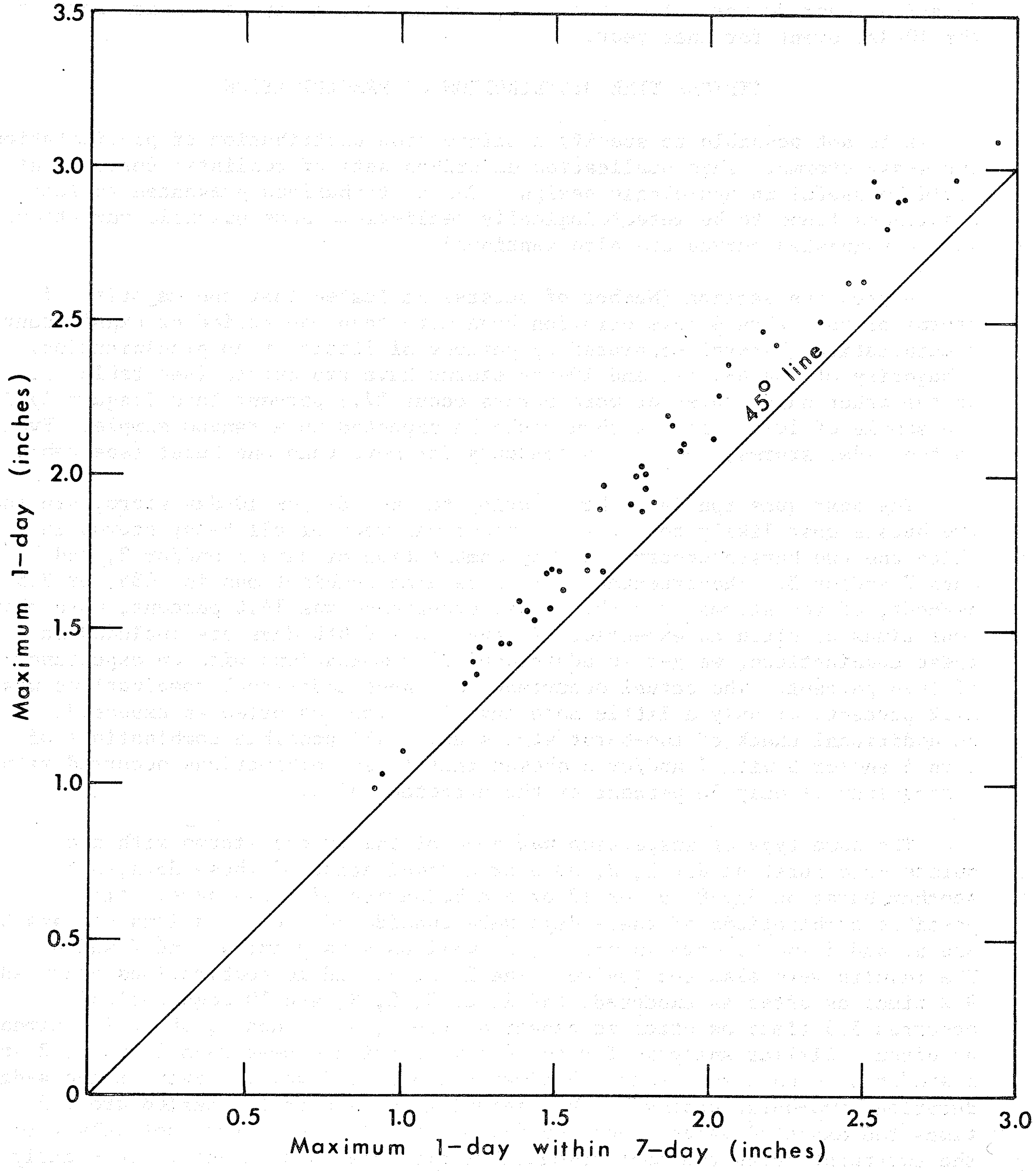

Figure 9.--Two-yr return period comparison of maximum 1 day vs. maximum 1 day within 7 days precipitation.

The three largest 1-day values at each station were selected (a sample of 144). As shown in figure 10, nearly 90 percent of the time, the 1-day event was included in the maximum annual 4-day storm. Even at the 10-day duration, over 80 percent of the time, the largest 1-day storms are part of the 10-day event for that year.

## TYPICAL TIME DISTRIBUTION OF PRECIPITATION

It is not possible to specify a unique time distribution of precipitation for N-day storms. This publication describes sets of realistic curves that would be useful in hydrologic design. The distributions presented reflect conditions found to be meteorologically realistic. Some possible variations on the suggested curves are also mentioned.

A previous section (Number of Bursts) indicated that the majority of storms of more than 4 days duration have more than one period of significant precipitation (bursts) separated by periods of little or no precipitation. A majority of the 6-, 8-, and 10-day storms have two bursts (see table 7). On the other hand, three or more bursts occur 27.1 percent less frequently in the sample of 10-day storms than would be expected in a random sample. Even in the 4-day storms, there is a tendency for more than one burst (see table 7).

The next question is: When, during the 6-, 8-, or 10-day storm, are the two bursts most likely to occur? A count was made of all 8-day storms in which the two bursts occurred on any combination of days 1 and/or 2, and days 7 and/or 8. The expectancy of these nine combinations is .035, or 3.5 percent, of the storms, and the actual occurrence was 14.6 percent, more than four times as often as expected. If the 3rd and 6th days are included in these combinations, we get an additional 27 combinations with an expectancy of 10.6 percent. The actual occurrence of these additional combinations was 14.2 percent, or only a little more than 1.3 times as often as expected. An additional check of two-burst storms using all possible combinations of days 4 and/or 5 with 7 and/or 8 showed that these combinations occurred with a frequency of only 58 percent of the expected value.

The same type of inspection was made of the 10-day storms with two bursts--one burst on day 1, 2, or 3 or a combination of those days, with another burst on day 8, 9, or 10 or a combination of those days. All possible combinations of these days were considered. Combinations of days 5 and 6, and 8 and 9, were inspected, as well as days 3 and 4, and 7 and 8. The results were also conclusive. The 1, 2, 9, and 10 combinations occurred 9.2 times as often as expected; the 1, 2, 3, 8, 9, and 10 combinations occurred 5.5 times as often as expected; the 3, 4, 7, and 8, about 1.5 times as often. Similar analysis for the 6-day duration showed days 1 and/or 2 and 5 and/or 6 to have more than 1.5 times the expected value. Even at the 4-day duration, two-burst storms at the beginning and end of the period are 1.5 times the expected value. For the 6-, 8-, and 10-day storms, not only were the two-burst types the most common, but also one burst tends to come early in the storm period and the other burst late.

This problem can also be examined by consideration of the time of occurrence of the maximum 1- and 2-day amounts within the storm sample.

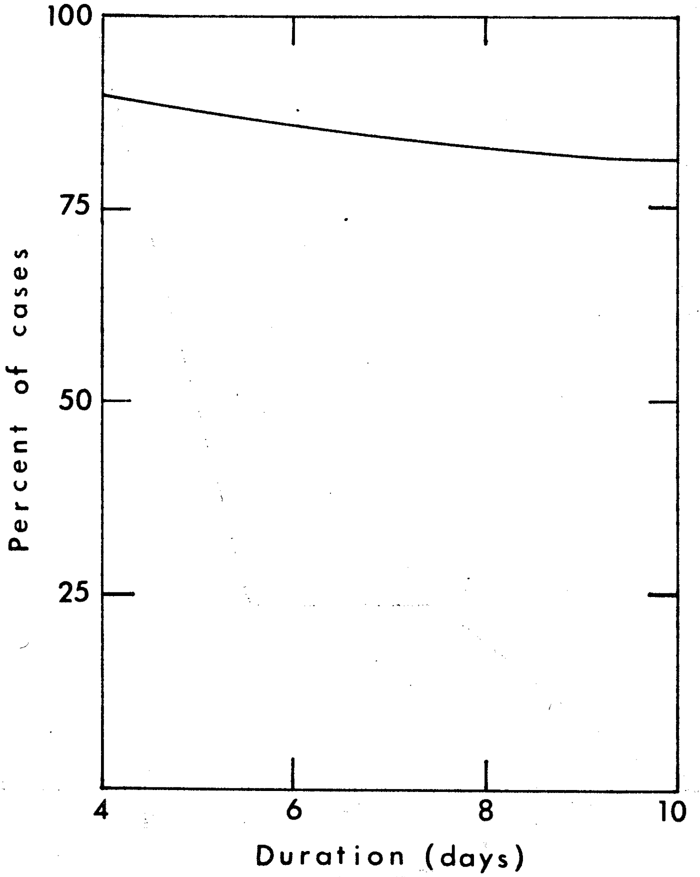

Figure 10.--Percent of time that one of the three largest 1-day storms at each station is included within maximum annual N-day storm.

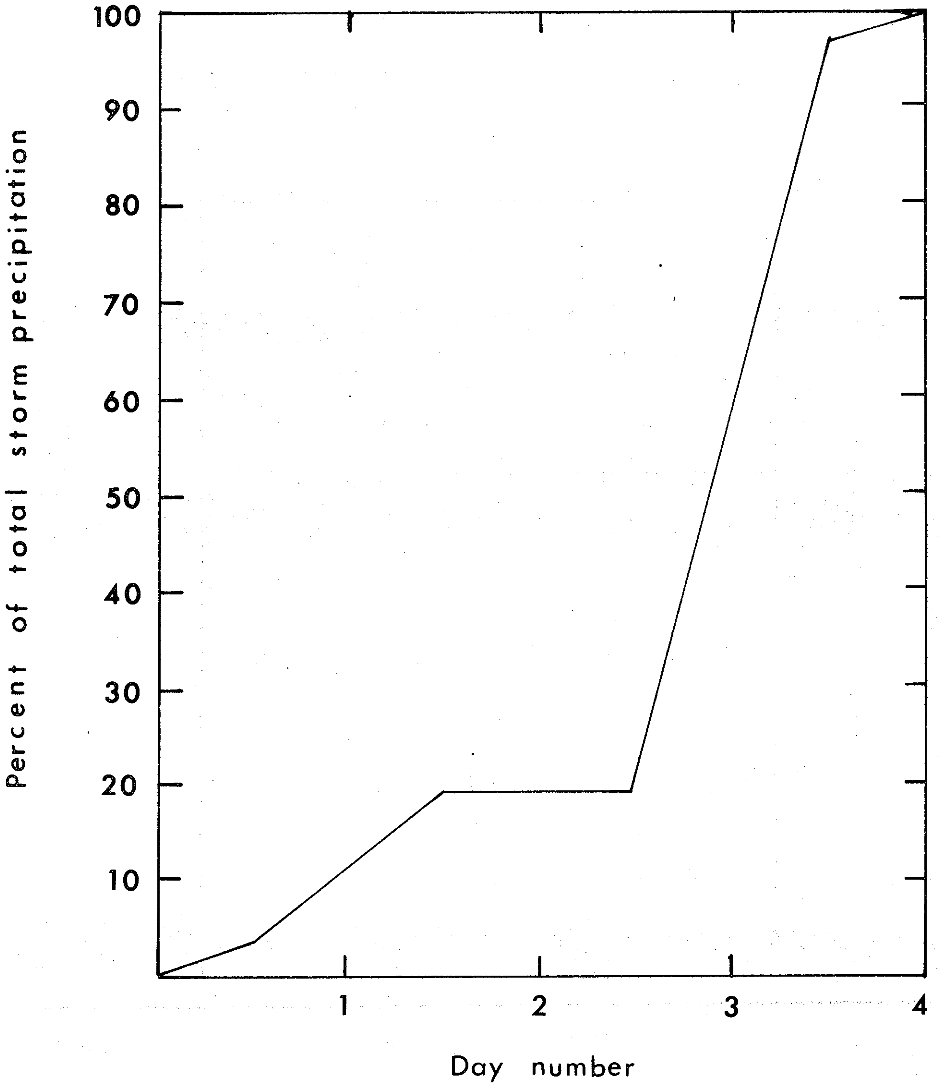

Figure 11.--Typical 4-day storm distribution.

Almost three-fourths of the 6-day storms studied had the maximum 1-day amount on either the first or last 2 days of the period. About 61 percent of the storms studied had the maximum 1-day of the 8-day storm on one of the first 2 or last 2 days. Also, of the seven possible 2-day combinations during the 8-day period (1-2, 2-3, . . . 7-8), the 2-day combinations 1-2, 2-3, 6-7, and 7-8 contained over 70 percent of the maximum 2-day precipitation values. Of the five possible 4-day combinations within 8 days, the middle period consisting of days 3 through 6 had the maximum 4-day amount in only 8 percent of the cases. Examination of the distribution of the greatest M-day amount of precipitation within the 10-day storms once again shows that the greatest probability of the heaviest precipitation occurs at either the beginning or ending of the 10-day period. Over 50 percent of the greatest 1-day amounts within the 10-day period occur on one of the first 2 days or last 2 days. This contrasts with well under a third of the maximum 1-day precipitation coming on one of the middle 4 days. Over 40 percent of the greatest 2-day (observation days) precipitation amount within the 10-day storm is on either the first 2 days or the last 2 days.

Analysis of the time distribution of the maximum burst in 10-day storms shows that slightly over 34 percent of such bursts occur when either day 1 or 2 is the day of maximum precipitation. The day of maximum precipitation falls on either day 9 or 10 only 18.6 percent of the time versus an expected value of 20 percent. However, this is greater than any other 2-day combination except days 1 and 2. This preference for the maximum burst to occur at the beginning of the storm period results partially from the definition of the storm period, which requires it to begin with a day of measurable precipitation. Had the reverse definition been adopted (that the storm period had to end with a day of measurable precipitation), the percentages would have been: about 20 percent of the maximum bursts occur when day 1 or 2 is the maximum day and 32.5 percent occur when day 9 or 10 is the maximum day. The analysis also shows the magnitude of the maximum burst to average slightly less than 65 percent of the total storm volume. This is in general agreement with the ratio of the 100-yr 24-hr precipitation to the 100-yr 10-day amounts taken from Technical Paper Nos. 40 and 49 [U.S. Weather Bureau 1961, 1964]. The magnitude of the second burst in the 10-day storms is slightly over 25 percent. Similar percentages for the 8-day storms are about 70 percent for the maximum burst and near 27 percent of the second burst.

The discussion of the preceding paragraphs indicates that the typical curve will contain two bursts and that the bursts will be near the beginning and end of the precipitation period. Figure 10 illustrates the logic of including the X-yr 1-day with the X-yr N-day storm when working with relatively long return periods. It is also logical to assume that the (N-1)-day storm would have the same return period as the N-day storm; and for durations over 6 days, the (N-2)-day amounts would have the return period assigned to the N-day storm. The magnitude of the maximum and second bursts included within each typical curve is approximately equal (within 5 percent) to the average magnitude indicated by the sample of 1,712 storms.

The suggested time distribution for a 4-day storm in the Arkansas-Canadian River Basins is shown in figure 11. This curve, as well as those for the longer durations, shows the maximum burst occurring as the second of the two periods of heavier precipitation. With about equal probability, the maximum burst could occur as the first of the two bursts. A period of light precipitation is shown before the first burst and another after the larger burst. These periods of light precipitation are suggested by the data, which show that large bursts of precipitation tend to begin and/or end with periods of less intense precipitation. Similar curves are shown in figures 12, 13, and 14 for the 6-, 8-, and 10-day periods of precipitation, respectively. Detailed specifications for drawing the suggested curves are given in the appendix.

The data sample used in these investigations did not indicate the necessity for independent curves either for different geographic portions of the Arkansas-Canadian River Basins or for different seasons. Number of bursts and time of occurrence within the storm were independent of geography (as noted earlier, samples for fall, winter, and spring were quite small). The same can be said for the inclusion of the values for the same return period for 24-hr, N-1, and, for the longer durations, N-2 day events within the N-day storm. The small differences found in the percent of the maximum single day within the N-day storm (see section on Data Sample) are approximately the same as the ratios between values for various durations for the same return period that can be developed from the charts of Technical Paper Nos. 40 and 49 [Hershfield 1961 and Miller 1964]. The methods detailed in the appendix provide for these variations by using values from these charts as basic input data.

Other assumptions could be made about the amount of precipitation that occurs in the maximum or second highest burst. The precipitation could be concentrated on 1 day in a single large burst or it could be spread almost evenly over the entire period.

An example of a 6-, 8-, and 10-day annual maximum without large 1-day values was found in early August 1963. At Lake Moraine, CO (106), the largest single day of the 6-day storm had less than 22 percent of the total storm precipitation and more than 11 percent on the day with least precipitation. For the 8-day storm, the largest day was just over 17 percent and the smallest, 5 percent. The greatest single day of the 10-day period had less than 17 percent, but there was 1 day of no precipitation, and the day of least precipitation had just under 5 percent. Among 30 storms, this storm ranked no. 21 at 6-day duration, 19 at 8-day, and 15 at 10-day. The annual maximum 4-day for 1963 was not from this period. This case of persistent precipitation resulted from a continued flow of moisture from the Gulf of Mexico to Colorado. As is typical of summer conditions, few organized surface systems moved through the area, but showers and thunderstorms occurred almost daily.

Another example of 10-day annual maximum with relatively constant rains was in the last third of September 1945, when 15 of 46 (two stations missing that year) had their annual maximum 10-day. Stillwater, OK (140), had 2 inches or more of rain on 4 of the 10 days beginning September 21. However, with a total of 12.97 for the 10 days, no single day had as much as 22 percent of the storm total, and only 2 days had more than 20 percent. September 22 and 23 had less than 4 percent between them, while no precipitation is observed on September 24. Once again, a persistent inflow from the gulf provided the

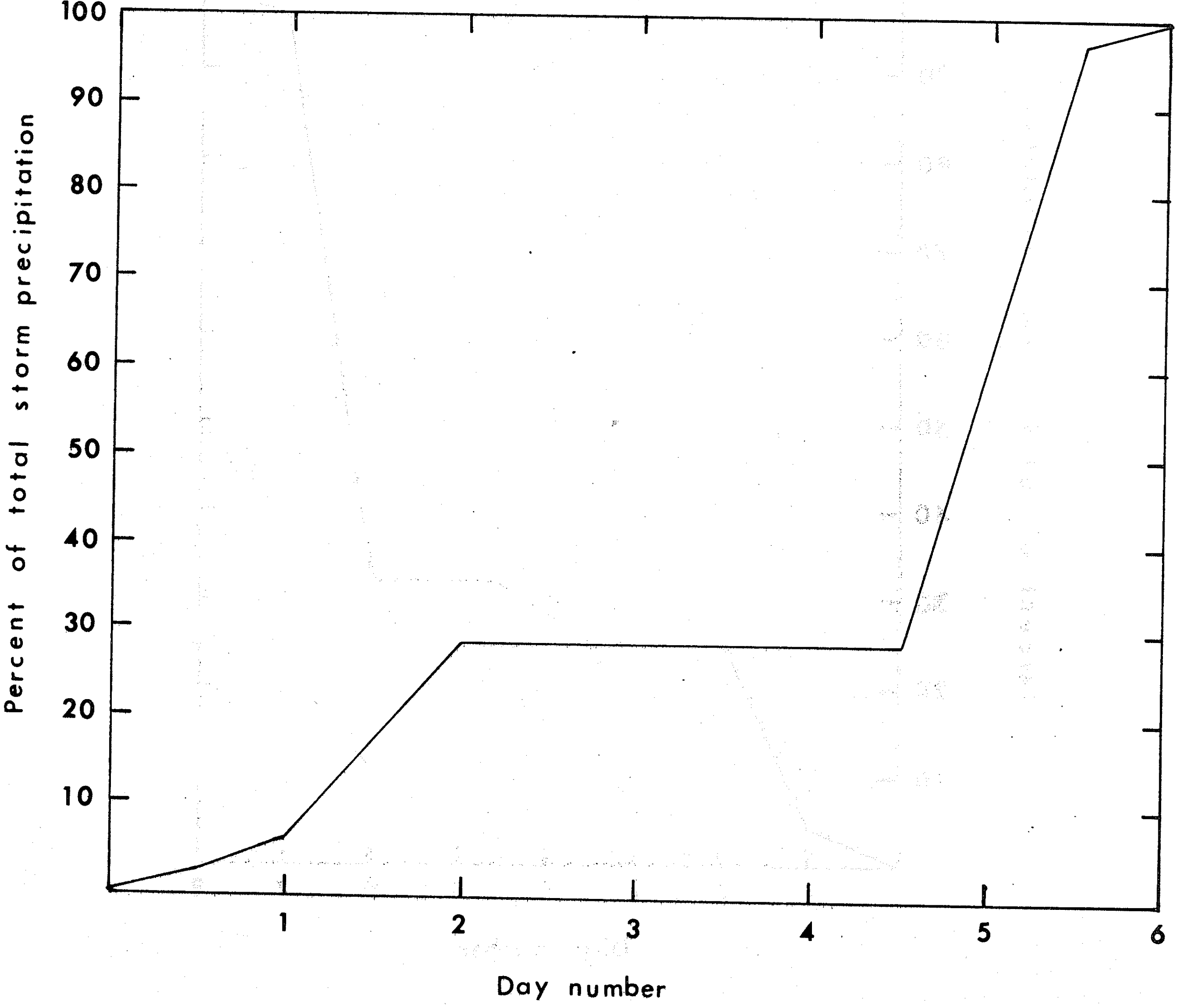

Figure 12.--Typical 6-day storm distribution.

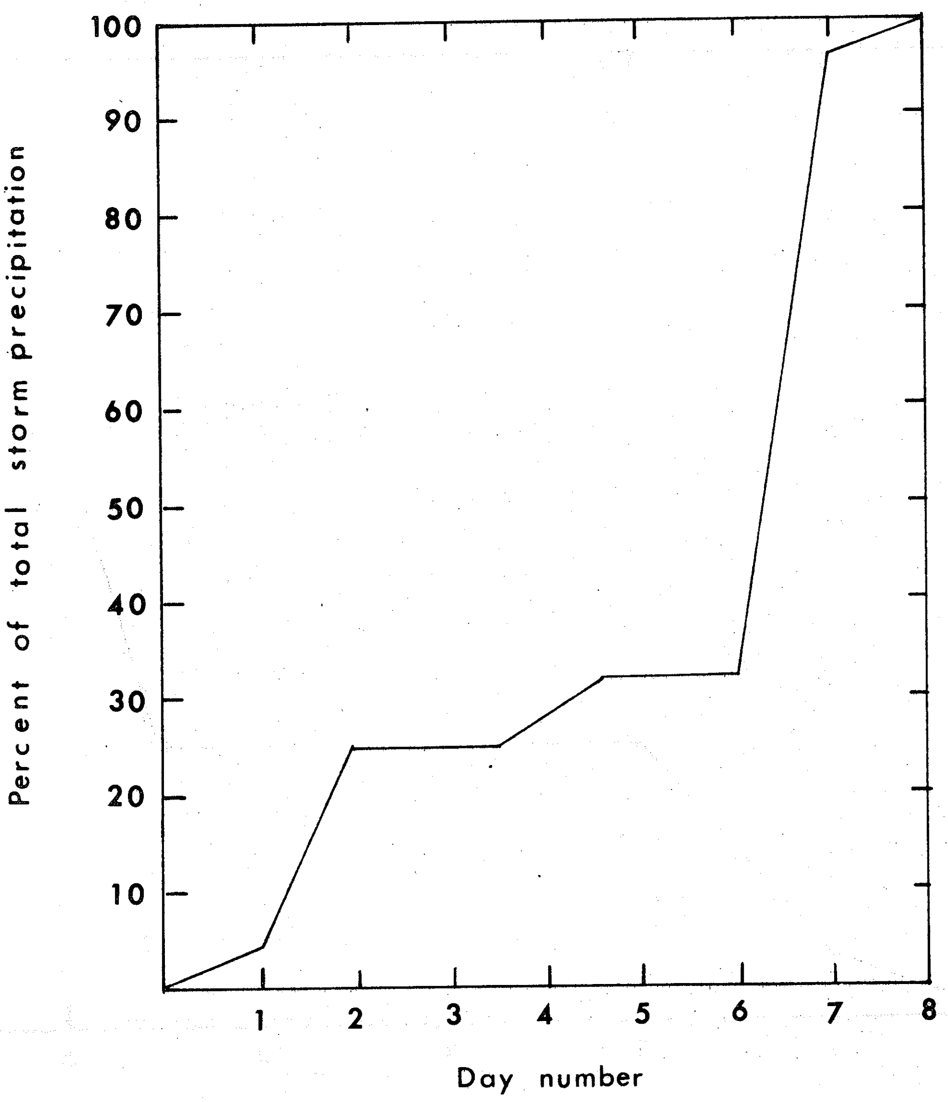

Figure 13.--Typical 8-day storm distribution.

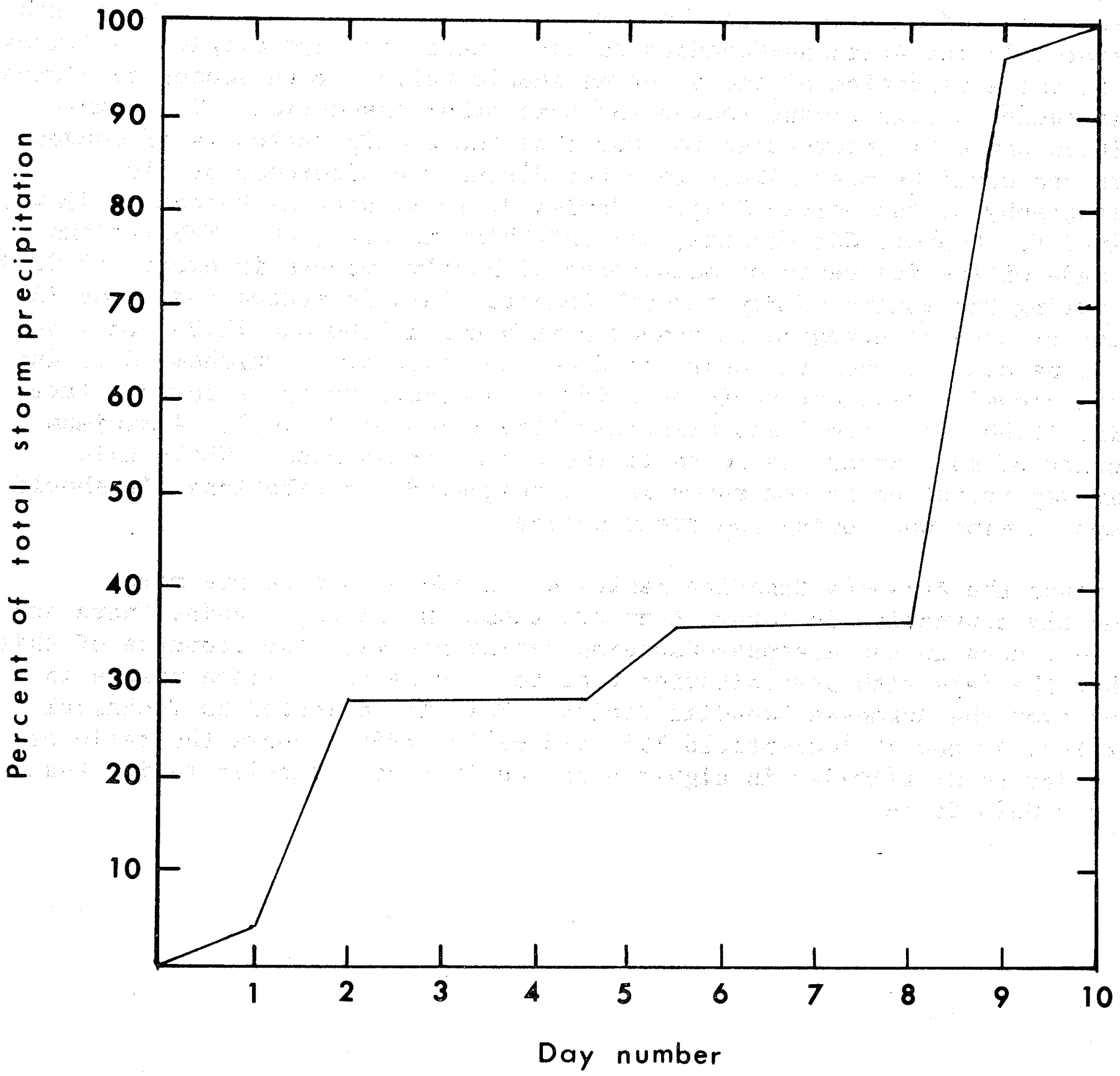

Figure 14.--Typical 10-day storm distribution.

source of moisture for numerous periods of precipitation caused by the passage and repassage of a cold front.

Differences in a typical time distribution for the Arkansas-Canadian Basins are relatively minor compared with results found in the Ohio Basin. However, the Arkansas-Canadian River Basins have a much higher percent of maximum annual N-day storms in the warm season than does the Ohio River Basin. Therefore, in the Arkansas-Canadian region, antecedent hydrologic conditions used in the application of these curves should reflect warm season conditions, unless there is significant reason for some other assumption. The summer condition would be interpreted to mean that the precipitation is of convective nature and would be most likely to occur during the afternoon or night. Climatography of the United States, Series 82 [U.S. Weather Bureau 1963], was examined for Denver, CO; Wichita, KS; and Oklahoma City, OK. Tabulations were made of the frequency of occurrence of hourly amounts in excess of 0.10 inch during the months of May through August. This indicated that over 70 percent of such occurrences at Denver were between 1:00 and 11:00 p.m., and only 15 percent between the hours of 2:00 and 11:00 a.m. Oklahoma City and Wichita showed a distinct preference for such events to occur between late evening (8:00-10:00 p.m.) and breakfast time (7:00-8:00 a.m.). A minimum frequency of such events is found in the hours around noon. While this within-day variation is not shown in the suggested distributions, it should be kept in mind when using the distribution.

Since the Arkansas-Canadian Basins 4- to 10-day storms are more frequently convective in nature than are those in the Ohio Basin, there are more zero days in the Arkansas-Canadian Basins storms. The converse of this is that the days with precipitation tend to have larger average values in storms over the Arkansas-Canadian Basins. This is reflected in Technical Paper Nos. 40 and 49 [Hershfield 1961 and Miller 1964], where the ratio of N-yr/1-day to N-yr/10-day is higher over the Arkansas-Canadian region than over the Ohio Basin.

# ACKNOWLEDGMENTS

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# REFERENCES

Gumbel, E. J., "Statistics of Extremes," Columbia University Press, 1958, 375 pp.

Hershfield, David M., "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years," U.S. Weather Bureau Technical Paper No. 40, 1961, 115 pp.

Miller, John F., "Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States," Weather Bureau Technical Paper No. 49, 1964, 29 pp.

Miller, J. F., and R. H. Frederick, "Time Distribution of Precipitation in 4- to 10-Day Storms--Ohio River Basin," NOAA Technical Memorandum NWS HYDRO-13, 1972, 44 pp.

Paulhus, J. L. H., and M. A. Kohler, "Interpolation of Missing Precipitation Records," Monthly Weather Review, Vol. 80, No. 8, Aug. 1952, pp. 129-133.

Swenson, Bennett, "The Ohio and Mississippi River Floods of January-February 1937," Monthly Weather Review, Supplement No. 37, 1938, 55 pp.

U.S. Weather Bureau, Climatological Data by Sections, National Climatic Center, Asheville, N.C., July 1950.

U.S. Weather Bureau, "Decennial Census of United States Climate--Summary of Hourly Observations," Climatography of the United States No. 82, by State, 1963.

# APPENDIX

## TIME DISTRIBUTION OF 4- TO 10-DAY STORMS--ARKANSAS-CANADIAN RIVER BASINS

In the section on Typical Time Distribution of Precipitation, curves for 4- to 10-day storms were proposed for use in hydrologic design. This appendix quantifies these curves and extends them to the intermediate durations of 5, 7, and 9 days. Each distribution shows two precipitation bursts during the storm period; for storms of 8 or more days duration, a smaller third burst is used. The largest burst is toward the end of the storm period, the second largest near the beginning. These positions could be reversed if that is determined to be the more critical situation hydrologically. The curves use the same return period for the 24-hr (N-1)-day, and, at the longer durations, the (N-2)-day precipitation as for the N-day storm. In the instructions, the following terminology is used:

1. N-day means the precipitation value for N = 1 to 10 days for the selected return period. This value is from the charts found in Weather Bureau Technical Paper Nos. 40 and 49 [Hershfield 1961 and Miller 1964] and figure 3 from Technical Paper No. 49. It is suggested that the analyst read the 24-hr, 2-day, 4-day, 7-day, and 10-day values from the charts; plot the values on figure 3, Technical Paper No. 49; and draw a straight line of best fit. The values for 1 to 10 days should then be read from the line of best fit. Values read from the maps should be discarded.

   If values for a basin larger than a few acres are required, the procedure is to obtain average point values for the basin location from the charts of Technical Paper Nos. 40 and 49, plot the values on figure 3 of Technical Paper No. 49, and draw a straight line of best fit. The values for 1 to 10 days should then be read from the straight line of best fit and adjusted by the appropriate areal reduction factors.

2. Day N means the day number within the N-day storm. Day N can be fractional.

3. U.A. stands for "uncommitted amount." In each distribution, the N-day, (N-1)-day, and the 24-hr values are distributed first. At the longer durations, the (N-2)-day is also distributed. The precipitation amount remaining after the distribution of the specified durations is labeled U.A. in the instruction for its distribution.

Distribution of 4-day storm:

Read: 24-hr__________ 3-day__________ 4-day__________

Steps:

1. Plot 4-day value at day 4 __________
2. Compute: (4-day - 3-day)/2 __________
3. Plot Item 2 at day 1/2 __________
4. Plot (day 4 - Item 2) at day 3 1/2 __________
5. Subtract (day 3 1/2 - 24-hr) and plot at day 2 1/2 and at day 1 1/2 __________
6. Starting at origin, connect plotted points with straight lines.

Distribution of 5-day storm:

Read: 24-hr__________ 4-day__________ 5-day__________

Steps:

1. Plot 5-day value at day 5 __________
2. Compute: (5-day - 4-day)/2 __________
3. Plot Item 2 at day 1/2 __________
4. Plot (day 5 - Item 2) at day 4 1/2 __________
5. Subtract (day 4 1/2 - 24-hr) and plot at day 3 1/2 and at day 1 1/2 __________
6. Starting at origin, connect plotted points with straight lines.

Distribution of 6-day storm:

Read: 24-hr__________ 5-day__________ 6-day__________

Steps: 1. Plot 6-day value at day 6 __________

2. Compute: (6-day - 5-day)/2 __________

3. Plot Item 2 at day 1/2 __________

4. Subtract (day 6 - Item 2) and plot at day 5 1/2 __________

5. Subtract (day 5 1/2 - 24-hr) and plot at day 4 1/2 and at day 2 __________

6. Subtract (day 4 1/2 - day 1/2) = uncommitted amount (U.A.) __________

7. Add (day 1/2 + 1/8 U.A.) and plot at day 1 __________

8. Starting at origin, connect plotted points with straight lines.

Distribution of 7-day storm:

Read: 24-hr__________ 5-day__________ 6-day__________ 7-day__________

Steps: 1. Plot 7-day value at day 7 __________

2. Plot 6-day value at day 6 __________

3. Subtract (6-day - 5-day) and plot at day 1 __________

4. Subtract (day 6 - 24-hr) and plot at day 5 __________

5. Subtract (day 5 - day 1) = U.A. __________

6. Add (day 1 + .75 U.A.) and plot at day 2 and at day 3 1/2 __________

7. Starting at origin, connect plotted points with straight lines.

Distribution of 8-day storm:

Read: 24-hr__________ 6-day__________ 7-day__________ 8-day__________

Steps: 1. Plot 8-day value at day 8 __________

2. Plot 7-day value at day 7 __________

3. Subtract (7-day - 6-day) and plot at day 1 __________

4. Subtract (7-day - 24-hr) and plot at day 6 and at day 4 1/2 __________

5. Subtract (day 6 - day 1) = U.A. __________

6. Add (day 1 + .75 U.A.) and plot at day 2 and at day 3 1/2 __________

7. Starting at origin, connect plotted points with straight lines.

Distribution of 9-day storm:

Read: 24-hr__________ 7-day__________ 8-day__________ 9-day__________

Steps: 1. Plot 9-day value at day 9 __________

2. Plot 8-day value at day 8 __________

3. Subtract (8-day - 7-day) and plot at day 1 __________

4. Subtract (day 8 - 24-hr) and plot at day 7 and at day 4 1/2 __________

5. Subtract (day 7 - day 1) = U.A. __________

6. Add (day 1 + .75 U.A.) and plot at day 2 and at day 3 1/2 __________

7. Starting at origin, connect plotted points with straight lines.

Distribution of 10-day storm:

Read: 24-hr__________ 8-day__________ 9-day__________ 10-day __________

Steps: 1. Plot 10-day value at day 10 __________

2. Plot 9-day value at day 9 __________

3. Subtract (9-day - 8-day) and plot at day 1 __________

4. Subtract (day 9 - 24-hr) and plot at day 8 and at day 5 1/2 __________

5. Subtract (day 8 - day 1) = U.A. __________

6. Add (day 1 + .75 U.A.) and plot at day 2 and at day 4 1/2 __________

7. Starting at origin, connect plotted points with straight lines.

## 100-Yr 6-Day--Intersection of Colorado-Kansas-Oklahoma Border

Distribution of 6-day storm:

Read: 24-hr 5.73 5-day 8.03 6-day 8.45

Steps:

1. Plot 6-day value at day 6 — 8.45 ○
2. Compute: (6-day - 5-day)/2 (8.45 - 8.03)/2 — 0.21
3. Plot Item 2 at day 1/2 — 0.21 △
4. Subtract (day 6 - Item 2) and plot at day 5 1/2 (8.45 - 0.21) — 8.24 ◐
5. Subtract (day 5 1/2 - 24-hr) and plot at day 4 1/2 and at day 2 (8.24 - 5.73) — 2.51 ~○~
6. Subtract (day 4 1/2 - day 1/2) = uncommitted amount (U.A.) (2.51 - .21) — 2.30
7. Add (day 1/2 + 1/8 U.A.) and plot at day 1 (0.21 + 0.29) — 0.50 ◆
8. Starting at origin, connect plotted points with straight lines.

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Note: Symbols refer to plotted positions in figure A1.

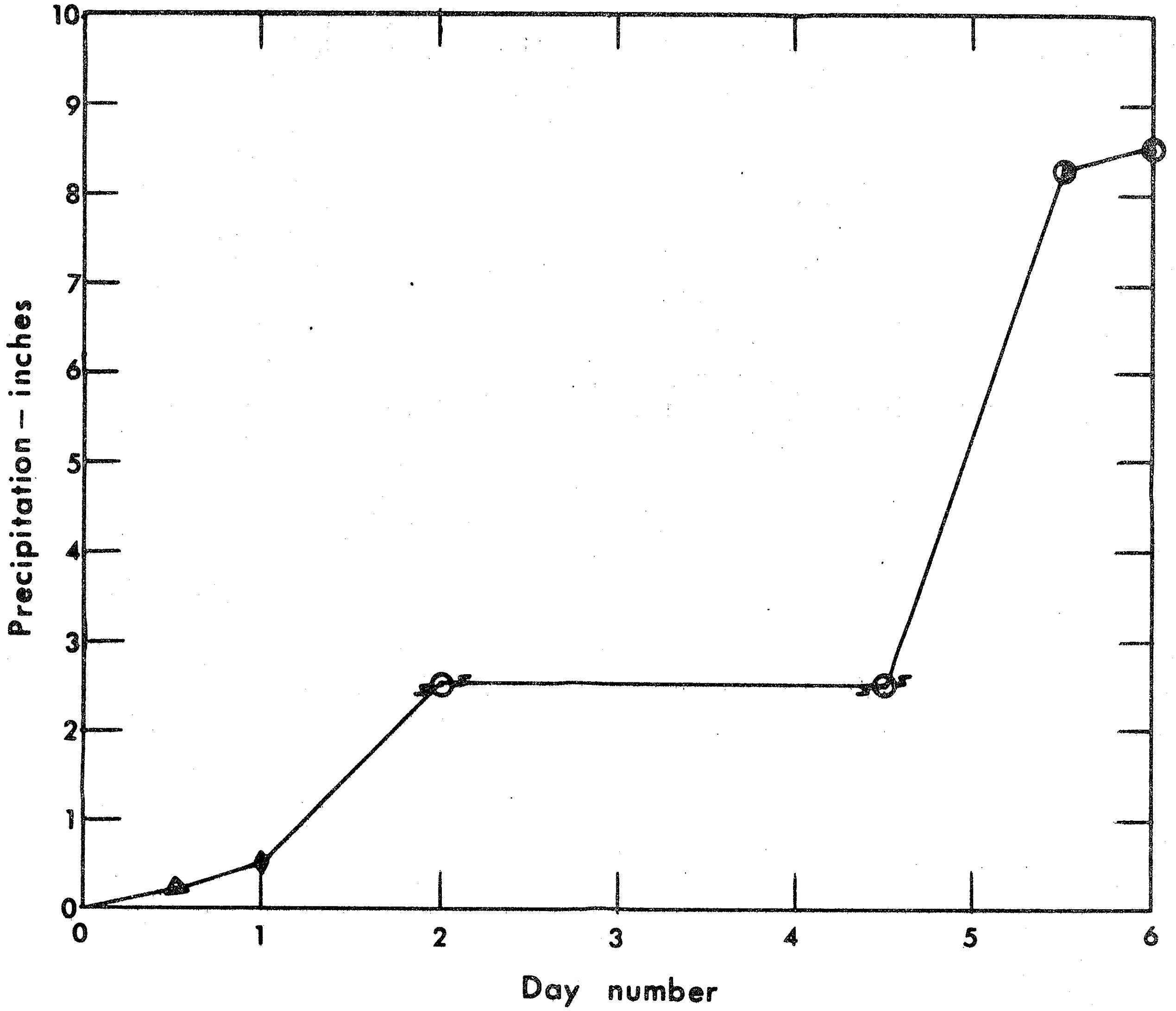

Figure A1.--Sample distribution of 100-yr 6-day values read from TP 40 and TP 49 at intersection of Colorado-Kansas-Oklahoma border.