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TIME DISTRIBUTION OF PRECIPITATION IN 4- TO 10-DAY STORMS--OHIO RIVER BASIN

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John F. Miller[1] and Ralph H. Frederick[2]

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 Ohio River Basin. 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 1937-1966 and a sample of 1,484 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 Ohio River Basin 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," was published in 1964 [Miller, 1964]. Although this paper 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.

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The purpose of this study is to examine the distribution of precipitation within N-day storms over a relatively limited region. The area selected for this initial study was the entire Ohio River Basin. This basin is a region of varied topography and is influenced by many different storm types. The topography, though varied, does not provide as strong an orographic influence on the amount and distribution of precipitation as does the topography over much of the western United States. The storms were studied with a view toward classifying the time distribution of N-day precipitation-frequency values in a manner that is logical and as typical of the majority of the storms as possible. The distribution of precipitation within the largest N-day storm each year can vary from the case where all, or nearly all, of the precipitation occurred on 1 day to those cases with nearly equal amounts on each day. There are, however, some time distributions which are meteorologically realistic and which more nearly describe a typical storm than do others.

The results presented here were derived from point precipitation data and are most applicable to areas up to 100 square miles. The results should have an acceptable degree of accuracy for areas up to 400 square miles.

Since the study was confined to a limited geographic area, the question of its applicability to other geographic regions is unresolved. Additional studies on other basins in varying climatic regimes would be required to establish the validity of the time distributions presented for those regions.

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.

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.

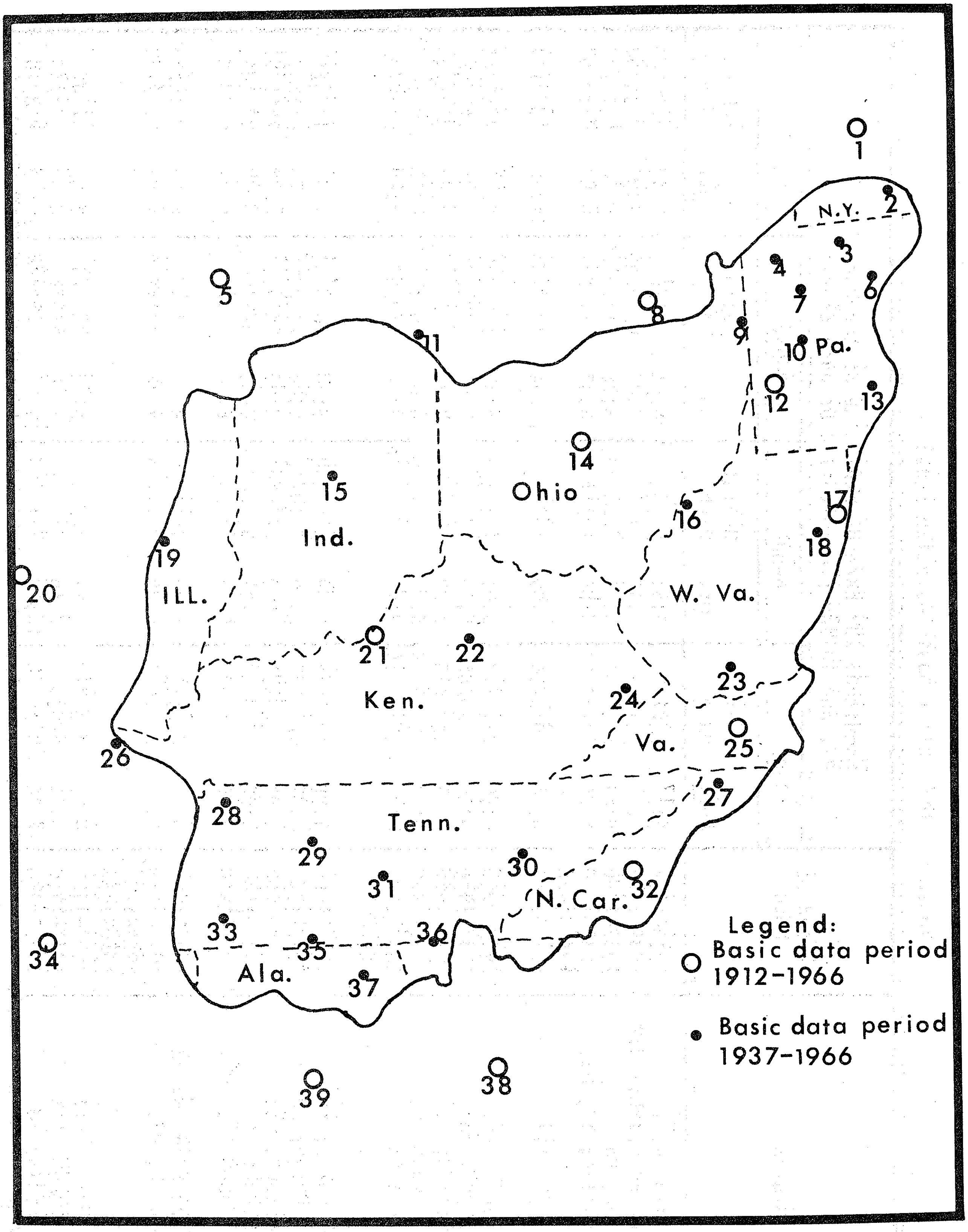

Figure 1. Station location map showing generalized outline of Ohio River Basin and basic record length for each station.

Table 1. Ohio River Basin--**station index**

Ident. no. on fig. 1	Station	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
1	Buffalo, N.Y.	1912-1966	4.17	8/7/63	5.81	6/18/28	6.61	8/7/63	7.45	7/29/63
2	Allegany St.Pk., N.Y.	1937-1966	4.54	7/17/42	6.47	9/17/58	7.05	9/16/58	7.05	9/16/58
3	Warren, Pa.	1937-1966	5.61	8/28/59	5.61	8/28/59	6.16	11/20/50	6.54	6/10/37
4	Meadville, 1S, Pa.	1937-1939, 1941-1966	5.29	10/13/54	6.06	10/11/54	6.35	6/14/37	6.83	9/30/59
5	Chicago, Ill.	1912-1966	6.75	10/9/54	7.09	10/5/54	11.04	10/3/54	11.58	10/3/54
6	Ridgeway, Pa.	1937-1966	4.99	7/17/42	5.01	7/17/42	5.37	7/17/42	6.99	7/11/42
7	Franklin, Pa.	1937-1966	5.10	5/26/46	5.29	1/21/37	6.68	5/26/46	7.51	7/7/58
8	Cleveland, O.	1912-1966	6.97	3/23/13	7.22	3/23/13	7.26	3/21/13	7.40	3/23/13
9	Youngstown, O.	1937-1966	5.59	10/12/54	6.03	10/10/54	6.08	10/10/54	6.08	10/10/54
10	Butler, Pa.	1937-1957, 1959-1964, 1966	4.83	10/13/54	5.02	10/13/54	5.29	4/2/57	5.40	9/30/59
11	Fort Wayne, Ind.	1937-1966	4.86	10/4/55	5.99	8/27/50	6.50	10/3/54	7.61	10/3/54
12	Pittsburgh, Pa.	1912-1966	4.37	4/11/48	5.06	7/10/19	5.06	7/10/19	5.80	8/4/55
13	Johnstown, Pa.	1937-1966	4.92	7/29/61	5.99	7/29/61	5.99	7/29/61	6.30	7/25/61
14	Columbus, O.	1912-1966	6.96	3/23/13	7.57	3/4/64	8.25	3/4/64	8.50	3/4/64
15	Indianapolis, Ind.	1937-1966	5.40	7/1/38	5.69	3/4/64	6.36	3/4/64	9.32	6/23/38
16	Parkersburg, W. Va.	1937-1966	5.22	4/11/48	5.22	4/11/48	6.43	8/14/47	6.58	7/14/58
17	Davis, W. Va.	1912-1918, 1922-1937, 1940-1966	5.74	10/1/29	6.80	3/17/36	7.26	8/11/55	7.86	3/17/36
18	Elkins, W. Va.	1937-1966	4.82	6/6/47	4.97	6/3/47	5.49	8/11/41	5.61	3/10/63
19	Effingham, Ill.	1937-1966	6.91	5/5/61	7.16	5/5/61	7.16	5/5/61	8.39	6/7/45
20	St. Louis, Mo.	1912-1966	14.90	8/13/46	14.97	8/12/46	14.97	8/12/46	15.39	8/8/46

Table 1. Ohio River Basin--station index - Continued

Ident. no. on fig. 1	Station	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
21	Louisville, Ky.	1912-1966	8.61	1/21/37	12.31	3/4/64	12.71	3/2/64	12.89	3/2/64
22	Lexington, Ky.	1937-1966	7.80	6/21/60	7.99	3/4/64	9.20	6/21/60	9.76	6/22/60
23	Flat Top, W. Va.	1938-1966	4.73	1/28/57	6.33	7/19/38	7.08	2/27/55	7.67	2/26/55
24	Pikeville, Ky.	1937-1942, 1944-1966	5.61	6/19/42	5.66	8/12/58	6.74	9/27/64	7.46	2/26/55
25	Wytheville, Va.	1912-1966	6.21	7/17/64	6.94	7/17/64	7.63	5/15/42	7.68	5/14/42
26	Cairo, Ill.	1937-1966	7.96	3/7/64	11.44	3/4/64	11.70	3/2/64	11.77	3/2/64
27	Jefferson, N.C.	1937-1966	12.52	8/11/40	13.04	8/10/40	13.31	8/11/40	13.65	8/10/40
28	Dover, 1W, Tenn.	1937-1966	11.21	1/21/37	15.10	1/17/37	19.48	1/17/37	20.37	1/15/37
29	Nashville, Tenn.	1937-1966	6.43	1/5/46	8.09	1/17/37	9.16	1/17/37	9.63	1/14/37
30	Knoxville, Tenn.	1937-1966	6.49	7/8/39	9.39	1/27/57	9.63	1/27/57	10.51	1/27/57
31	McMinnville, Tenn.	1937-1966	7.63	2/11/48	9.97	1/27/57	10.09	1/25/57	10.98	1/23/57
32	Asheville, N.C.	1912-1966	8.51	10/24/18	10.14	10/24/18	10.55	10/24/18	10.70	10/20/18
33	Waynesboro, Tenn.	1938-1966	9.17	2/12/48	9.57	2/10/48	9.98	2/7/48	10.90	2/5/48
34	Memphis, Tenn.	1912-1966	10.64	11/20/34	10.64	11/20/34	12.76	1/17/37	12.76	1/17/37
35	Coldwater, Tenn.	1937-1966	8.34	1/2/49	8.76	1/27/57	9.73	1/15/54	10.45	1/14/54
36	Chattanooga, Tenn.	1937-1966	8.05	9/13/57	8.40	9/11/57	10.76	12/10/61	12.25	12/9/61
37	Scottsboro, Ala.	1937-1966	6.90	12/27/42	8.28	11/13/57	9.12	12/11/61	10.89	12/9/61
38	Atlanta, Ga.	1912-1966	11.75	12/7/19	11.83	12/7/19	12.33	12/7/19	12.34	12/5/19
39	Birmingham, Ala.	1912-1966	13.58	2/19/61	14.53	7/5/16	15.31	2/18/61	15.46	2/17/61

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 10-day storms were defined in three ways: 1) measurable precipitation on the first day; 2) measurable precipitation on the last day; and 3) if there were not measurable precipitation on both the first and last day of the 10-day period, the zero day or days needed to complete the 10-day period were allowed to occur at the beginning or ending of the period, at random. A comparison of average daily precipitation in "first-day" and "last-day" storms 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 ninth day, and so on, only small differences were found (fig. 2). The result is that the curves of figure 2 are nearly mirror images of each other. The distribution of average daily precipitation amounts from the storms when the zero days were placed at random showed only minor differences from the two previous distributions in that, as expected, the differences tended to be divided equally between the beginning and ending days of the period. In each of the three methods of selection used, the majority of the large bursts still came near the beginning and end of the storm period. All results were highly influenced by the fact that nearly two-thirds of the storms studied had precipitation on both the first and last day of the period.

Precipitation during the N-day storm for the southern portion of the study area averaged considerably greater than in the northern sections. 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 a large storm would have had a greater impact on the final time distributions than a small storm.

In the study area the annual maximum N-day totals were a mixture of 1) summer showers and thunderstorms and 2) large winter storms. The observation-day data from the winter storms often represent a complete, or nearly complete, 24-hour period of precipitation. On the other hand, rainfall from the summer situations may have occurred during only a small part of the 24-hour period which comprises 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 published sources indicated an accumulated value (i.e., the value published occurred during a period of 48 hours or more, and separate 24-hour 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

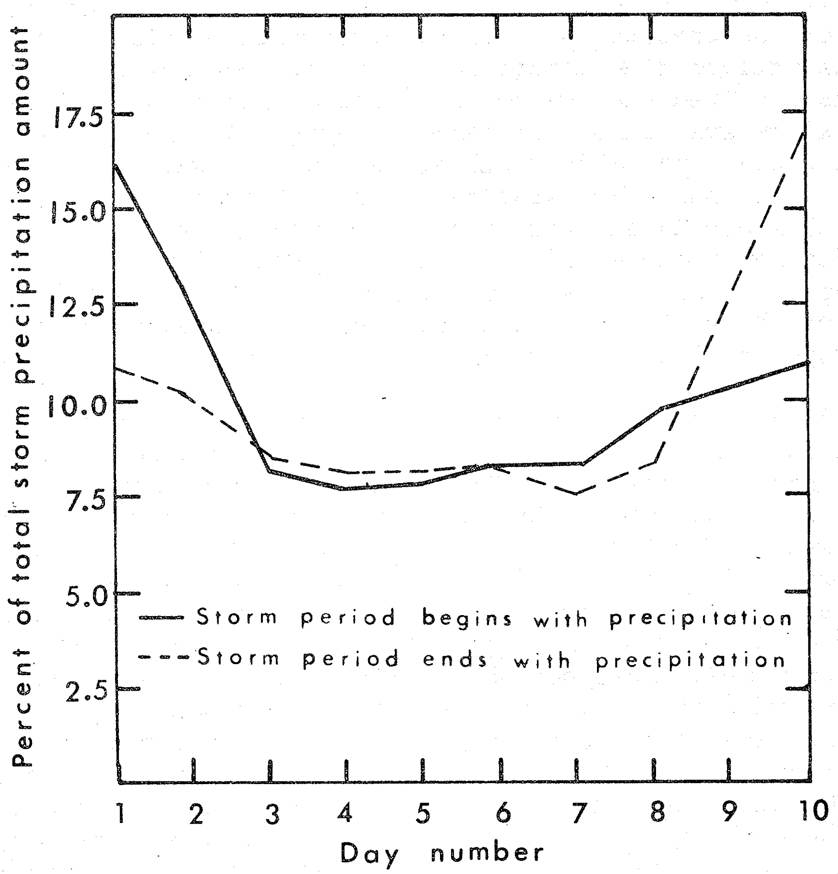

Figure 2.--Average percent of total 10-day storm precipitation amount that occurred on each day.

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; 1912-1966 and 1937-1966. Data for 1912-1961 for stations with a 55-year record (1912-1966) 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. The 55-year record was also extended back in time for as long as possible. 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 analysed. It was found that results for the 30-year period 1937-1966 produced results consistent with those from the longer record. It was, therefore, decided that tabulations for this study for the period 1937-1966 would be compatible with those for the period 1912-1966 and little or no improvement would result from tabulating data for longer periods for all stations. This resulted in a total of 1,484 cases for each N-day period.

Figure 1 shows the densest grouping of stations in the northeastern and southwestern portions of the study area. This selection of stations was intentional, and was done to provide data for comparisons of regional differences within the study area. 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 dense groupings. The highest and lowest 20 percent of storms selected on the basis of total storm precipitation at each station within these two groups were examined. Analyses showed little difference in average daily percentages between the storms at the northeastern and southwestern stations, or between the largest and smallest storms, e.g., 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 25 to 35 percent of all days in the 8-day storms had no precipitation, and about 80 percent of all days had 26 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 northern stations to average slightly higher than did stations in the southern group. Likewise, storms with a return period of less than two years had a little higher average percent on the maximum day than did storms with longer return periods. Differences were generally five percent or less. These differences are slight and are equivalent to the variation determined from the charts in Hershfield [1961] and Miller [1964]; e.g., the ratio of the 2-year 24-hour to 2-year 10-day values as read from the charts in these publications is slightly higher than is the 100-year 24-hour to 100-year 10-day ratio. There was a difference in the seasonal distribution of these storms, which will be discussed in the section on Seasonality of Storms.

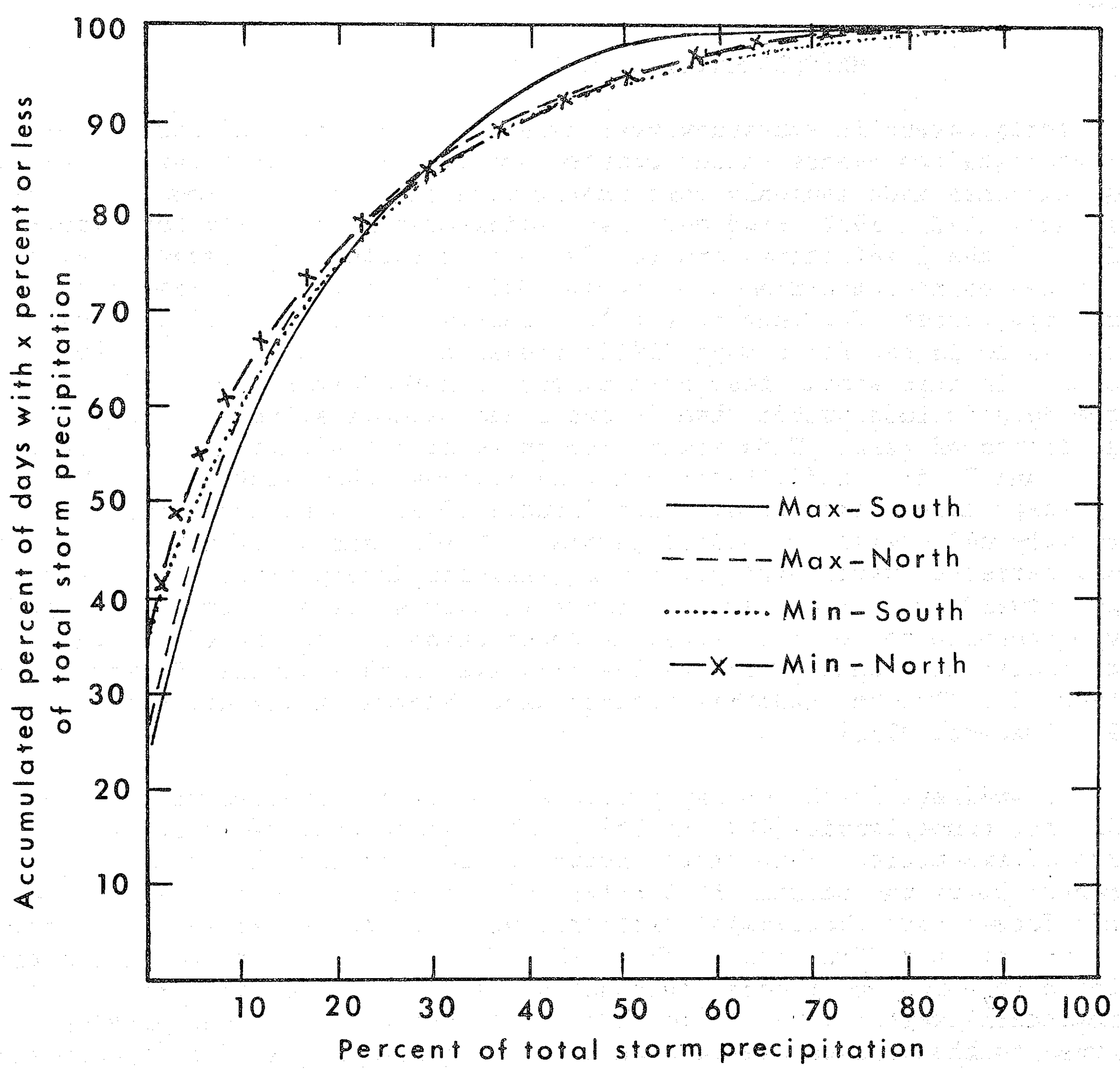

Figure 3.--Accumulated percent of storm precipitation for 8-day storms.

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 which 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 the determination of the magnitude of the bursts within each N-day storm.

METEOROLOGICAL DESCRIPTIONS OF STORMS

Precipitation in the study area comes from a variety of storm types. The precipitation events which comprise the annual series of maximum 4- to 10-day amounts most commonly come from moving extratropical Lows. The storm of January 13-25, 1937, produced heavy rains over much of the Ohio River Basin. Of the 1,484 storms studied for each duration, the largest 6-, 8-, and 10-day events came from this storm. Of all the stations examined for this study, Dover, 1W, Tennessee (28)*, received the most rain from this storm, 15.10 inches for 6 days, 19.48 inches for 8 days and 20.37 inches for 10 days. In this storm, four of the days included within the 6-day, and five of the days included within the 8- and 10-day storms at Dover 1W had over three inches of rain. This storm also produced the maximum or near maximum 6-, 8-, and 10-day precipitation amounts at many other stations in the Basin. The precipitation lasted from about January 13 to 25 and contained three relatively well-defined rainfall periods. These rainfall "bursts" resulted from a series of waves moving along a quasi-stationary front from Texas northeastward across the Basin. Such a weather situation frequently brings heavy precipitation to this area. A description of this storm written shortly after it occurred can be found in the Monthly Weather Review, Supplement No. 37, "The Ohio and Mississippi River Floods of January and February 1937" [Swenson, 1938].

The smallest of the 10-day precipitation totals studied was 5.40 inches at Butler, Pennsylvania (10), in 1959. This storm resulted from a combination of two events. The first period of precipitation began on September 30 as the remains of Hurricane Gracie moved across the study area. Gracie formed over the tropical Atlantic Ocean on September 20, 1959, crossed the coast of South Carolina on the 29th, and took on extratropical characteristics on the 30th as it moved through western North Carolina and southwestern Virginia. The storm then continued northward and slowly recurved to the northeast across western Pennsylvania. It finally crossed the New Hampshire coast on the evening of October 1. The second burst of precipitation at Butler resulted from a Low that formed over Texas on the afternoon of October 4th and moved to the vicinity of the Great Lakes by late evening on October 7. As this Low remained nearly stationary over the Great Lakes and slowly filled, another Low which had formed over the Northern Plains on the 6th moved eastward and merged with it. The precipitation at Butler ended as the combined Lows moved eastward.

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* Numbers in parenthesis following station names refer to identification numbers in table 1 and figure 1.

About 4 percent of the 10-day storm periods had 85 percent or more of their total precipitation on two adjoining days within the period. In some instances, this represented precipitation that actually occurred within a 24-hour interval. Two of these cases, the storm period for St. Louis, Missouri (20), starting on July 5, 1942, and the storm for Cairo, Illinois (26), starting on August 5, 1952, illustrate this type of storm. In each case the primary burst of precipitation resulted from showers and thunderstorms associated with a cold front. A narrow band of precipitation was associated with each frontal system. The geographical precipitation distribution was spotty with nearby stations receiving lesser amounts of rainfall. In both cases, some precipitation amounting to less than 5 percent of the storm total occurred several days removed from the primary burst. This small amount came from air mass showers.

SEASONALITY OF STORMS

To examine the seasonality of storms, the data sample was divided into northern and southern halves along a line about 38 degrees north. Four seasons were defined: winter - December, January and February; summer - June, July and August; with the intervening months spring and fall. Table 2 shows the percent of 10-day storms for each season, by sections. Additionally, the seasonal distribution is shown for the highest and lowest 20 percent of the storms for each station within each section. Examination of this table shows that within each portion of the Basin the different seasons contribute a different percentage of the total number of storms. Differences between them are not large. Each season contributes a significant percentage of the total sample. In the southern portion of the Ohio River Basin, 32.6 percent of all storms occur in winter. Of the largest storms (highest 20 percent) 42.6 percent occur in winter. Of the lowest 20 percent, 23.6 percent occur in winter. At the northern stations the greatest percentage of all storms occur during the summer (43.2%). This tendency is present in both the highest 20 percent sample (51.3%) and the lowest 20 percent sample (37.7%).

While an explanation of all the seasonal variation shown in table 2 is not within the purview of this paper, the meteorological reasons for a larger percentage of storms in the southern portion during the winter and the northern portion during the summer can be discussed. During the winter season, weather disturbances generally follow a more southerly path than during the summer season. The southern portion of the Ohio River Basin is in the path of many storms and it is not unusual for a weather disturbance to remain in this vicinity for several days. Since this area is also within range of the abundant moisture supply of the Gulf of Mexico, a winter storm or a series of such storms can bring large amounts of precipitation over a period of several days. Frequently, such storms pass eastward or northeastward too rapidly, or too far away, to bring large precipitation amounts to the northern portions of the Ohio River Basin. Also, northern portions of the basin are further removed from the Gulf of Mexico.

Table 2. Seasonal distribution, in percent, of 10-day annual maximum storms.

	WINTER (Dec-Jan-Feb)	SPRING (Mar-Apr-May)	SUMMER (Jun-Jul-Aug)	FALL (Sep-Oct-Nov)
	Southern Portion of Ohio River Basin			
All Storms	32.6	24.5	27.6	15.2
Highest 20% of each Station's Storms	42.6	15.6	25.5	16.3
Lowest 20% of each Station's Storms	23.6	33.3	22.2	20.8
	Northern Portion of Ohio River Basin			
All Storms	11.7	26.1	43.2	19.0
Highest 20% of each Station's Storms	8.6	18.4	51.3	21.7
Lowest 20% of each Station's Storms	14.3	28.6	37.7	19.5

Frequently, during the summer months of the year, the circulation around the Bermuda High extends westward over the Eastern United States for periods of several days. This transports large amounts of moisture northward and northeastward over the entire Ohio River Basin. When this circulation finally breaks down and weather disturbances move across the Basin, heavy showers and thunderstorms frequently result. Convective showers and thunderstorms in the warm, humid air in advance of, and directly associated with, the frontal systems frequently cause the annual maximum N-day precipitation in the northern Ohio River Basin. While such conditions may also cause large N-day precipitation amounts over the southern Basin, they are often not the annual maximum event. There are two reasons for this: 1) the frontal systems are likely to be weaker and more diffuse than they are farther north, and 2) a winter storm in the southern portion is more likely to produce a larger total precipitation amount than the summer weather disturbances.

The seasonal preferences discussed and shown in table 2 are not large and large storms can and do occur at any time of the year over any section of the Basin. For this reason, seasonal curves were not considered necessary. Further justification for preparing only one set of distribution curves will be discussed under the section headed Number of Bursts.

INDEPENDENCE OF DATA

The same synoptic situation often causes the annual maximum N-day precipitation amounts at several locations in the Ohio River Basin. The 30-year sample (1937-1966) of 10-day storms was examined to determine how often a single storm produced the annual maximum event at several stations.

The January 1937 storm (previously discussed under Meteorological Descriptions of Storms) caused the annual maximum 10-day precipitation for that year at 16 of the 37 stations in the network (two stations had missing records). These 16 stations were not grouped geographically, but extended from Memphis, Tennessee (34), to Johnstown, Pennsylvania (13). Five of the remaining stations had their annual maximum 10-day storm for 1937 in mid-June, and four at the end of December 1936 and early January 1937. Storms scattered from April through October produced the annual maximum 10-day precipitation at the remaining stations with no more than two stations having their maxima in the same storm.

During a 17-day period, October 3 through 19, 1954, 17 of the 39 stations, all in the northern half of the Ohio River Basin, received their annual maximum 10-day storm. During this period, a series of cold fronts brought scattered large rainfall amounts to some stations in the northwestern part of the study area. For example, Chicago, Illinois (5), had 3.95 inches on the 3d, 2.27 on the 9th, and 3.94 on the 10th; Columbus, Ohio (14), had 1.59 inches on October 3d; Ft. Wayne, Indiana (11), had 1.75 inches on the 3d and 2.09 on the 5th; and Franklin, Pennsylvania (7), had 4.00 inches on October 11. A second period of heavy rains began at mid-month as another cold front and tropical storm, Hazel, combined to bring 2.00- to 4.00-inch rains to several stations from Indiana eastward to West Virginia.

During this 17-day period, Chicago, Columbus, and Ft. Wayne experienced their maximum 10-day values from the 3d through the 12th, with well over 80 percent of the precipitation through October 10. Two stations, Buffalo, New York (1), and Cleveland, Ohio (8), had their maximum 10-day amounts during this same month from the 10th through the 19th, with over 90 percent coming after October 12. These examples indicate the scattered nature of the precipitation in time and space.

Also during 1954, 13 stations in the southern portion of the Ohio River Basin had their maximum 10-day storm beginning on January 14. Heavy rains from the 14th through the 16th were caused by a Low moving slowly northeastward. This was followed by a strong Canadian High on the 17th through the 19th. Storminess resumed on the 20th as a cold front approached and low pressure impulses moved northeastward along the front as it passed through the southern portion of the study area.

Although the maximum 10-day storms in 1954 were distributed as discussed above, this does not mean that the southern stations did not receive precipitation during the October period nor that the northern half of the Basin had fair weather during the January period. The January storm gave mostly light amounts in Pennsylvania; Johnstown (13), for example, reported only 1.03 inch during the 10-day period beginning January 14. Hazel (October) brought some moderate to heavy precipitation amounts to the southeastern portion of the study area, but they did not exceed the large rains of January.

In 1949, no one weather situation caused the annual maximum 10-day precipitation at a large group of stations. Six stations had their maximum 10-day storm beginning during the period May 18-20, six began between January 16 through 22, and five reported the maximum beginning in the period July 9 through 12. In all, 1949 had 13 separate weather situations which resulted in the maximum 10-day storm at one or more of the study stations.

The conclusion is drawn that a single storm can cause the maximum N-day precipitation at several stations over the Ohio River Basin. These stations can be grouped geographically but it is also possible for them to be widely distributed throughout the Basin. As a general rule, however, a year will have about seven to ten stations with the maximum 10-day storm from the same weather situation, and several other storm situations will cause a maximum storm at one or more stations.

In the data sample, no single weather situation caused more than about one 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; and 2) the storm is changing with time as it moves. The data sample is therefore considered to be independent for this study and to be representative of the storms which occur over the Ohio River Basin.

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 3 shows the percent of annual maximum N-day storms which had precipitation on some portion of L-observation days (not necessarily consecutive) included within the storm period.

Of the nearly 15,000 days included in the study of 10-day storms, over 35 percent were days with no measurable precipitation. An additional 33 percent of the days had some precipitation but less than 10 percent of the storm total. At the other extreme, less than 3 percent had over 50 percent of the storm total in a single observation day. There were seven (less than 0.5 percent) cases with greater than 90 percent of the 10-day precipitation on 1 day.

Table 3. 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
4	0.7	14.7	39.2	45.4						
6	0.1	3.6	16.7	32.4	30.1	17.1				
8	0.1	0.9	6.0	16.8	27.9	26.9	15.3	6.1		
10	0.0	0.5	1.7	8.3	17.3	25.1	21.5	15.3	8.0	2.3

Of the 1,484 10-day storms studied, 1,450 had one or more non-precipitation days; 1,127 had at least one period of 2 consecutive days with no measurable precipitation; and 631 had at least one period of 3 consecutive days with no precipitation. Figure 4 illustrates the percentage frequency of consecutive days with no precipitation in 10-day storms.

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 of little or no precipitation. Thus far the word "burst" has been used to mean a period of relatively 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.

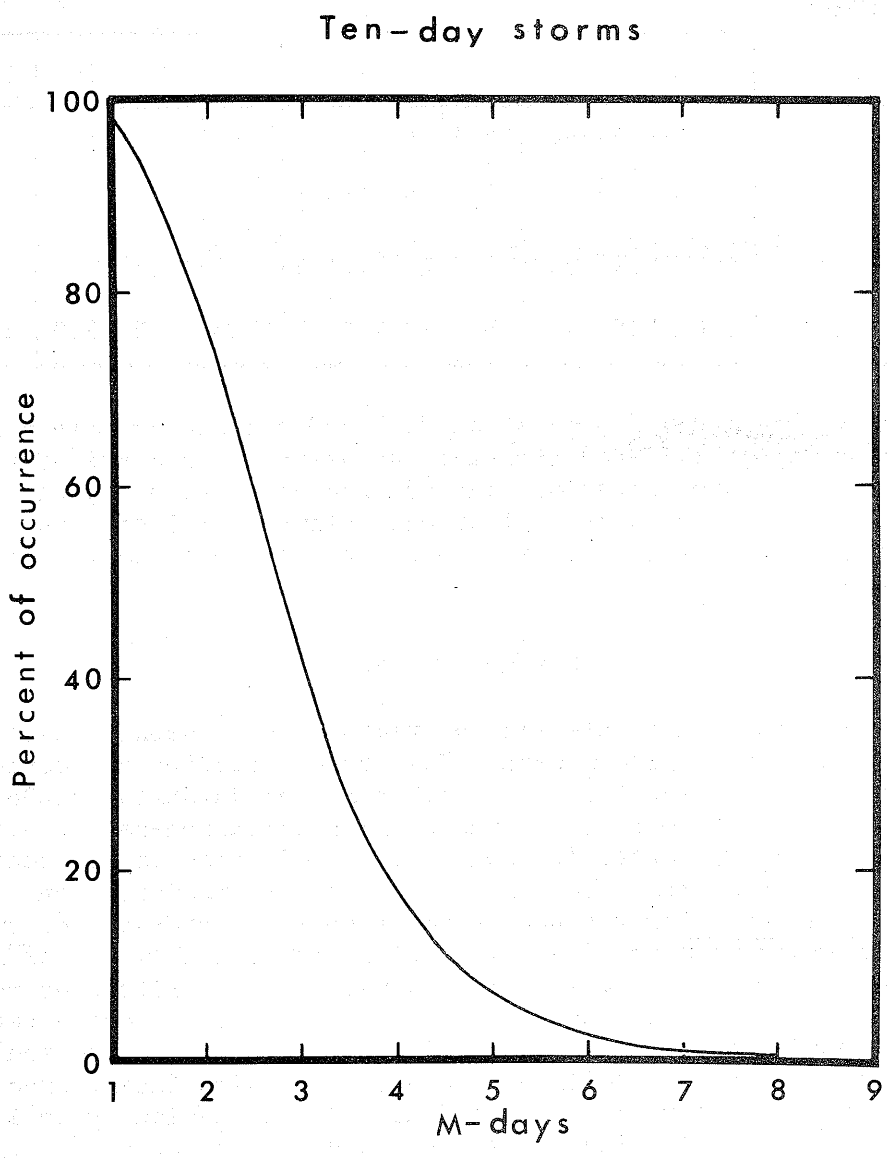

Figure 4.--Percent of occurrences of M consecutive days of zero precipitation in 10-day storms.

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 one day, on two days, etc. Table 4 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.

Table 4. 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

Columns 1 and 2 of table 4 show one-burst storms and column 3 shows the two-burst storms. The definition of bursts is that given above. Table 5 shows the percentage of observed storms with 1 through 5 bursts plus the percent that would be expected in a random sample, such as shown in table 4.

Table 5. Expected (E) and observed (O) percent of storms with K bursts.

Duration (Days)	Percent of Storms with K bursts									
	1		2		3		4		5	
	E	O	E	O	E	O	E	O	E	O
4	66.6	64.0	33.3	36.0	0					
6	33.3	28.0	55.6	63.9	11.1	8.1	0			
8	14.1	14.4	49.4	56.8	32.9	27.6	3.5	1.1	0	
10	5.4	8.4	32.3	44.7	45.2	40.4	16.1	6.4	1.1	0

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 duration comprise a significant portion of the sample. The 10-day storms were analysed using varying burst cut-off values from 2.5 percent to 12.5 percent. In all cases, the data showed a multi-burst (2 or 3) storm to be most common. The same tendency exists when the storms are stratified into large (highest 20%) and small (lowest 20%) 10-day storms. If the burst cut-off value of 7.5 percent were lowered, the three or more burst storms 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 43.5 percent, while the percentage of one-burst storms would decrease to 4.9 percent.

In the discussion of "Seasonality of Storms" it was indicated that the southern portion of the Ohio River Basin had a tendency for the annual maximum 10-day storms to occur during the winter season, while in the northern portion summer storms were more frequent. The number of bursts in 10-day storms were analysed by portion of the basin and by season. Table 6 shows the percentage of 10-day storms with K bursts for the northern portion during the summer season and the southern portion during the winter season.

Table 6. Percent of 10-day storms with K bursts

Portion of basin and season	Percentage of storms with K bursts			
	1	2	3	4
North - summer (N = 331)	7.3	42.9	44.7	5.1
South - winter (N = 233)	10.3	45.9	39.5	4.3

The differences shown in table 6 are not considered significant, especially in view of the relatively small sample size. This table is additional evidence to support the conclusion that seasonal curves are not necessary in this study.

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

Each of the storms was analysed to determine the maximum percentage of the storm total which 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. Although the section on Data Sample mentions small differences in percent of total storm precipitation on the maximum day between northern and southern stations and between storms of different magnitudes, such differences are small. Separate cumulative probability curves were developed by region and are not considered by storm magnitude and no consistent pattern was present. Differences between the curves were mostly less than 10 percent. This analysis was restricted to observation-day intervals.

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 days with a probability of about 0.33. These curves do not indicate on which day or days of the 4-day period the precipitation fell.

Figure 6 illustrates the probability of receiving x percent of the 6-day precipitation during the maximum M-days. The average maximum 1-day precipitation would be slightly under 50 percent of the 6-day total amount. In two cases the largest annual 6-day event consisted of precipitation on only one observation day. In one case (at Coldwater, Tennessee (35), on August 29-September 3, 1960) this was the smallest 6-day event in the station sample. The other case (at Allegany State Park, New York (2), September 3-8, 1961) was in the lower half of the data sample for this station. Both cases were convective. About 1 percent of the 6-day storms fell within two consecutive observation days; some of these may have occurred in less than a 24-hour 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 0.84. Nine-tenths of the time the maximum 4-day amount will be over 62 percent of the storm total. This 4-day period may be either the first, last, or middle four days. The probability is about 0.13 that the 6-day storm will occur entirely within the first four 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 the precipitation falling during the first six days is about 0.14. Two percent of the cases had all the precipitation during the first 4-day period, while seven (less than 0.5 percent) of 1,484 storms consisted of only the first two observation days. At Allegany State Park, New York, the maximum 8-day amount in 1961 occurred on September 3d when 3.65 inches of rain fell. In rank this was the 19th of the thirty 8-day storms studied from Allegany State Park. These figures indicate the wide variability possible when studying N-day storms.

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 six days is about 0.03. Eight (slightly over 0.5 percent) of the 1,484 storms had all their precipitation in the first 4 days and in one case the total 10-day storm occurred in the first two consecutive observation days. No storm in this sample of 10-day storms consisted of a single day's precipitation.

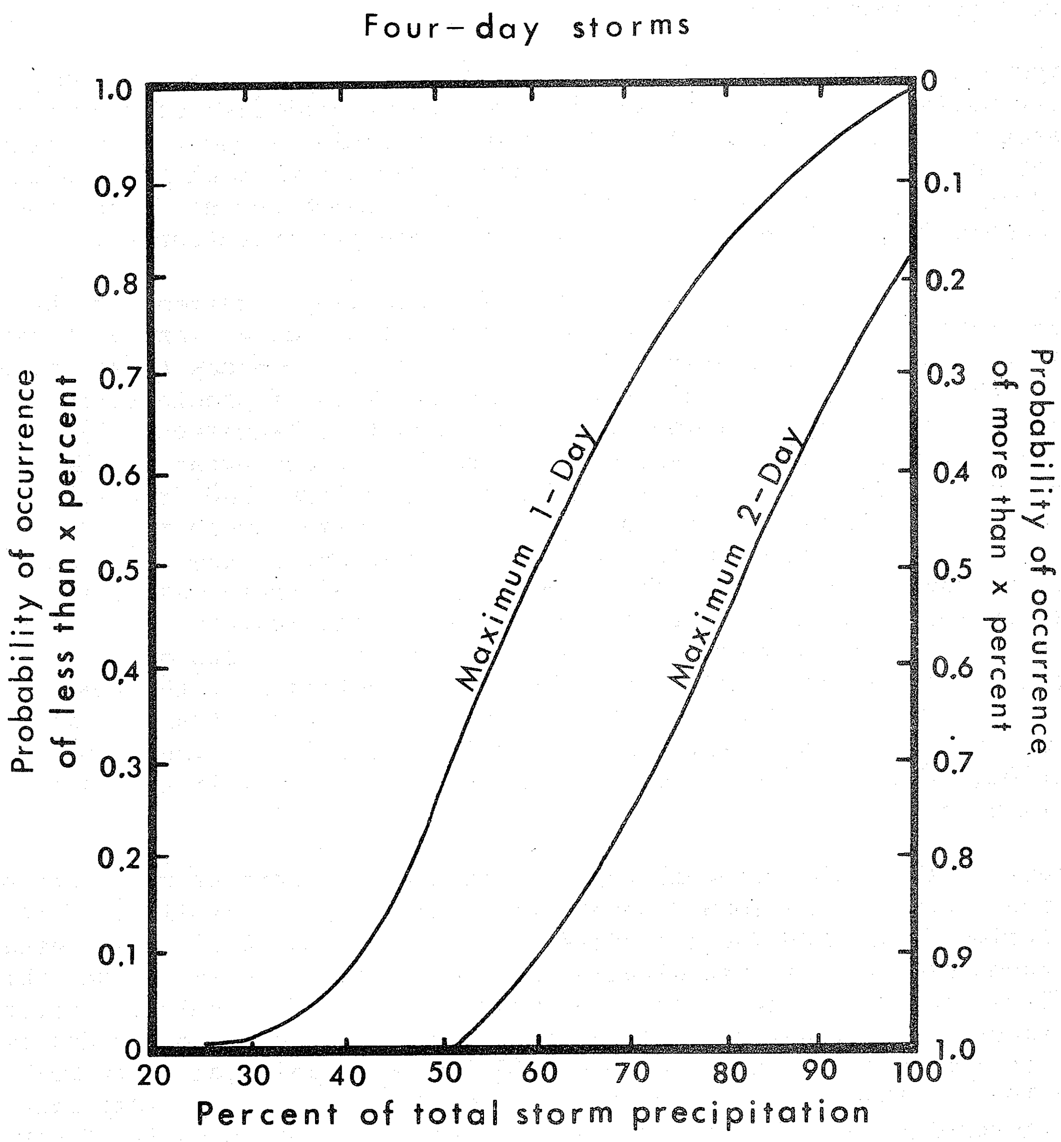

Figure 5. Percent of precipitation observed on maximum M-days in 4-day storm.

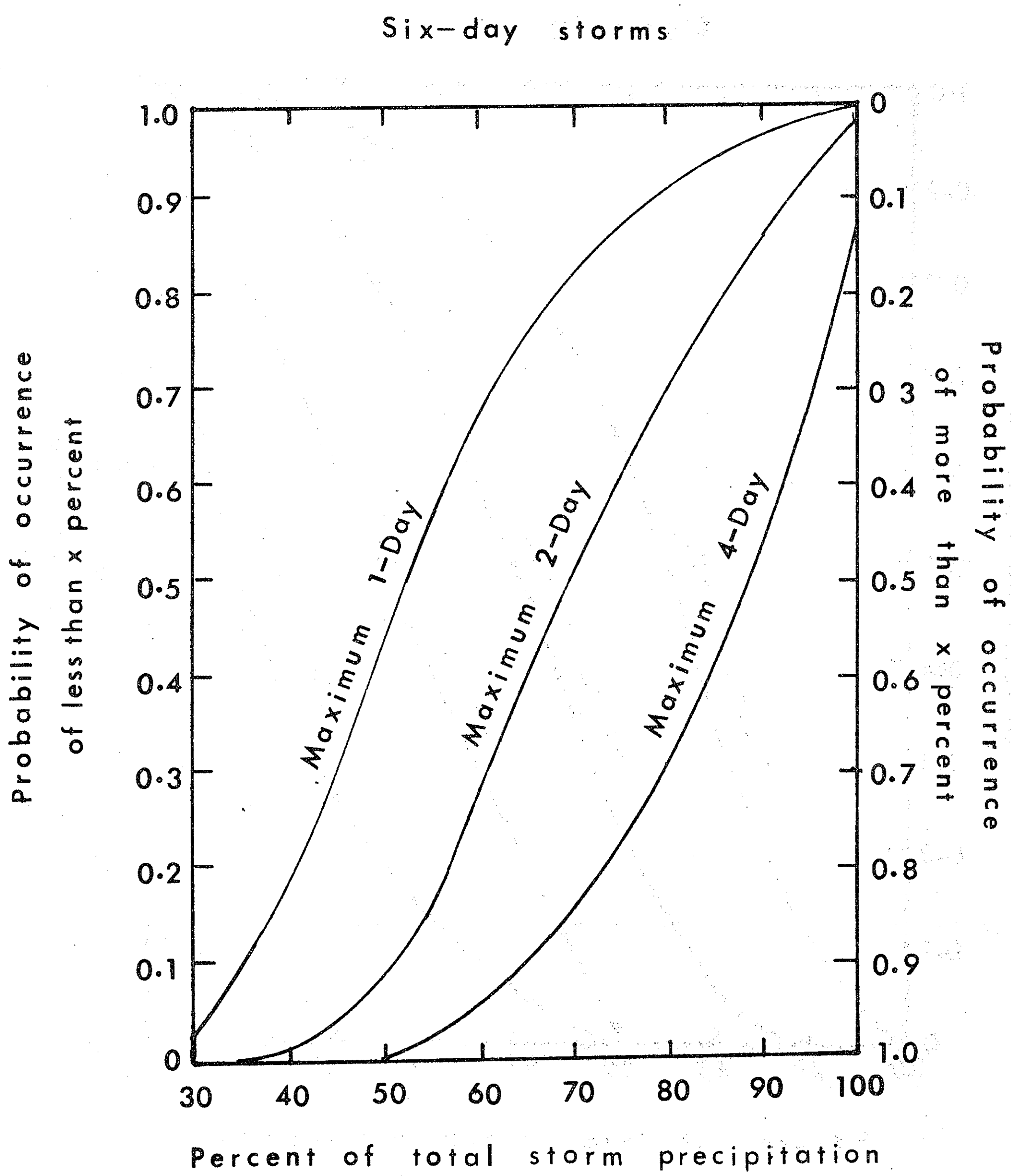

Figure 6. Percent of precipitation observed on maximum M-days within 6-day storm.

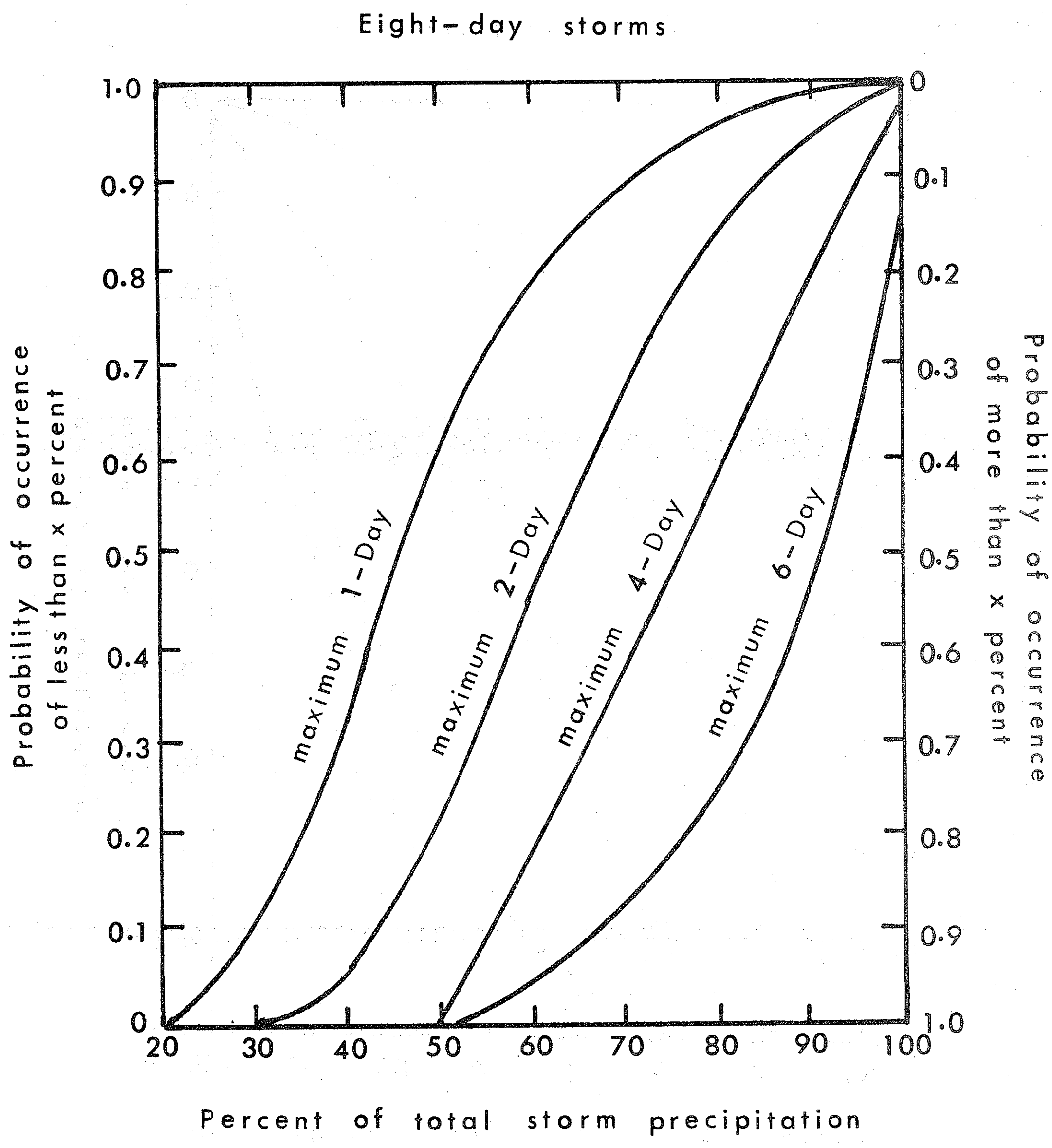

Figure 7. Percent of precipitation observed on maximum M-days within 8-day storm.

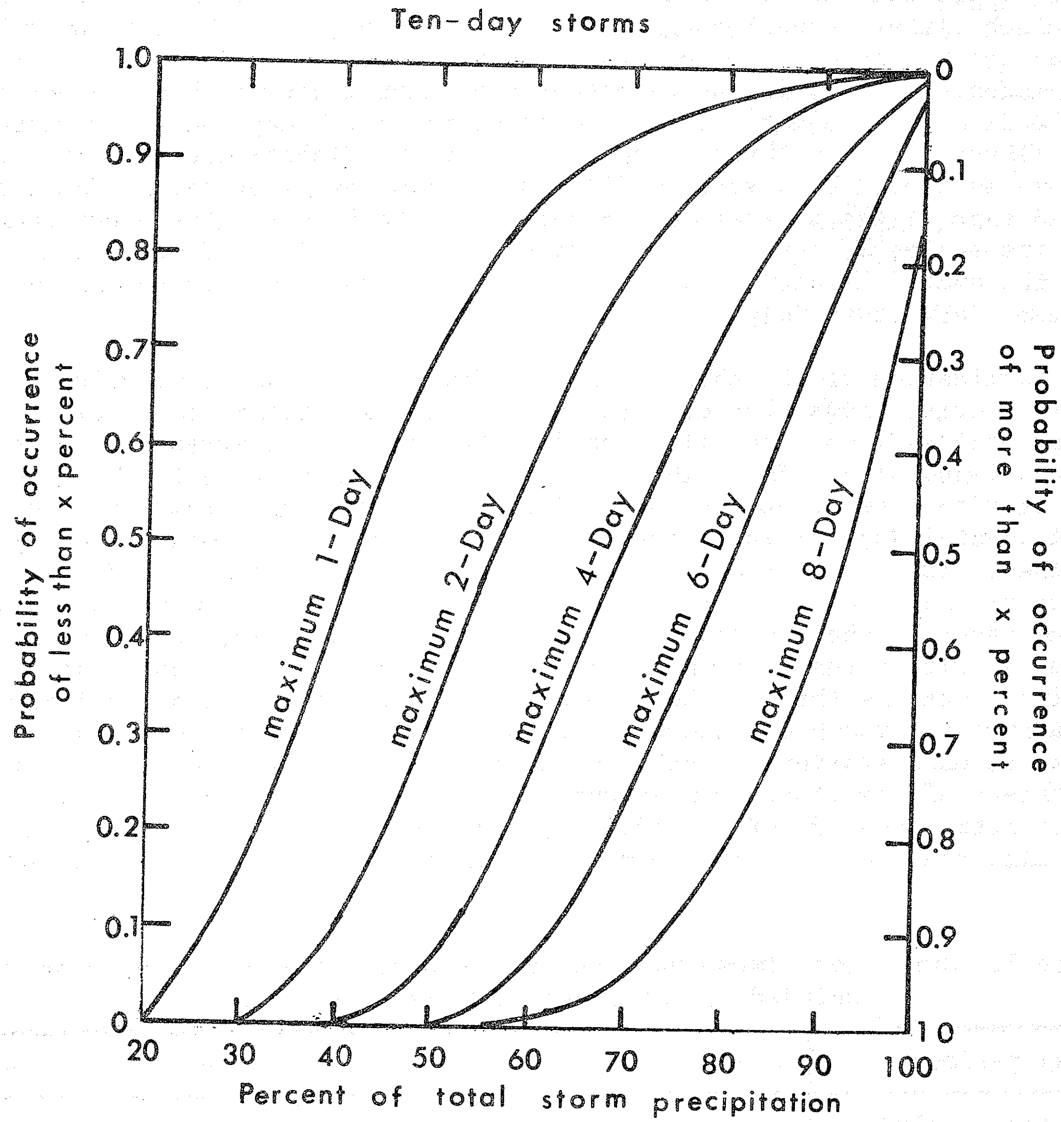

Figure 8. Percent of precipitation observed on maximum M-days within 10-day storm.

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 period which 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 studied 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 117 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 one-third of the time they came from the same storm. The largest 1-day precipitation amount at each of the 39 stations was examined. Twelve of these 39 events were included within the largest 7-day amount at that station. In one case, the maximum 1-day amount was included in the second highest 7-day event; and in four instances, the greatest 1-day storm was within the third highest 7-day amount. Table 7 shows the number of times that the three highest 1-day storms at each station are included in the annual maximum N-day storm for that year. One of the three largest 1-day storms at each station is included within the annual maximum event well over 80 percent of the time, even at durations as long as 10 days. Thus, at the longer return periods of 50 and 100 years, it is likely that the N-day storm will also contain an M-day storm with a relatively long return period.

Table 7. Number of times that one of the three largest 1-day storms is included in the annual maximum N-day storm

N-day period	4	5	6	7	8	9	10
No. that include max. 1-day event	105	106	107	105	101	99	98

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, which would be useful in hydrologic design. The distributions

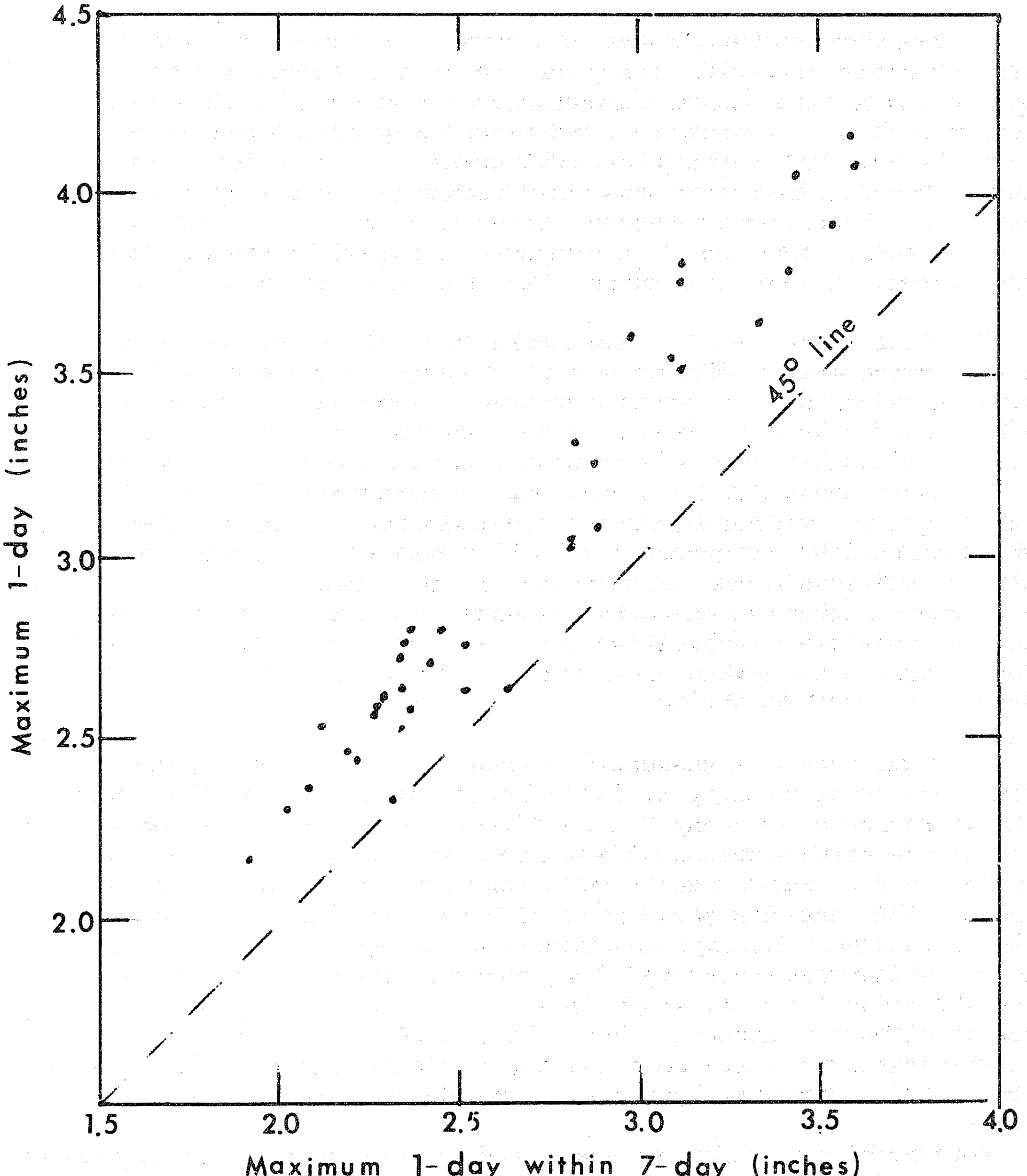

Figure 9. 2-year return period comparison of maximum 1-day vs. maximum 1 day within 7 days precipitation.

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-day durations have more than one period of significant precipitation (bursts) separated by periods of little or no precipitation. A majority of the 6- and 8-day storms have two bursts (see table 5). While only about 45 percent of the 10-day storms have two bursts, this is 12+ percent greater than would occur randomly. On the other hand, three or more bursts occur 15.6 percent less frequently in the storm sample 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 4).

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 12.6 percent, about 3.5 times as often as expected. If the third and sixth 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 17.7 percent, or only a little over 1.5 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 75 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 3 and 4, and 7 and 8. The results were also conclusive. The 1, 2, 9, and 10 combinations occurred 6.7 times as often as expected: the 1, 2, 3, 8, 9, and 10 combinations occurred 3.4 times as often as expected: the 3, 4, 7, and 8, about 1.5 times; and the 5, 6, 8, and 9 occurred only 0.6 times as often as expected. For the 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. 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 58 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 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 less than 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 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 28 percent of such bursts occur when either day 1 or 2 is the day of maximum precipitation. Also, 22.5 percent of the time, the day of maximum precipitation falls on either day 9 or 10. This preference for the maximum burst to occur at the beginning of the storm period partially results 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: slightly over 20 percent of the maximum bursts occur when day 1 or 2 is the maximum day and 31.5 percent occur when day 8 or 9 is the maximum day. The analysis also shows the magnitude of the maximum burst to average slightly less than 60 percent of the total storm volume. This is in good agreement with the ratio of the 100-year 24-hour precipitation to the 100-year 10-day amounts taken from Hershfield [1961] and Miller [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 slightly over 60 percent for the maximum burst and slightly over 25 percent for 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. Table 6 illustrates the logic of including the X-year 1-day within the X-year 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 3 percent) to the average magnitude indicated by the sample of 1,484 storms. Although the data suggest that the precipitation should not be continuous, the curves show some precipitation on each day.

The suggested time distribution for a 4-day storm in the Ohio River Basin is shown in figure 10. 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. There is a period of light precipitation shown before the first burst and another shown after the larger burst. This period of light precipitation is suggested

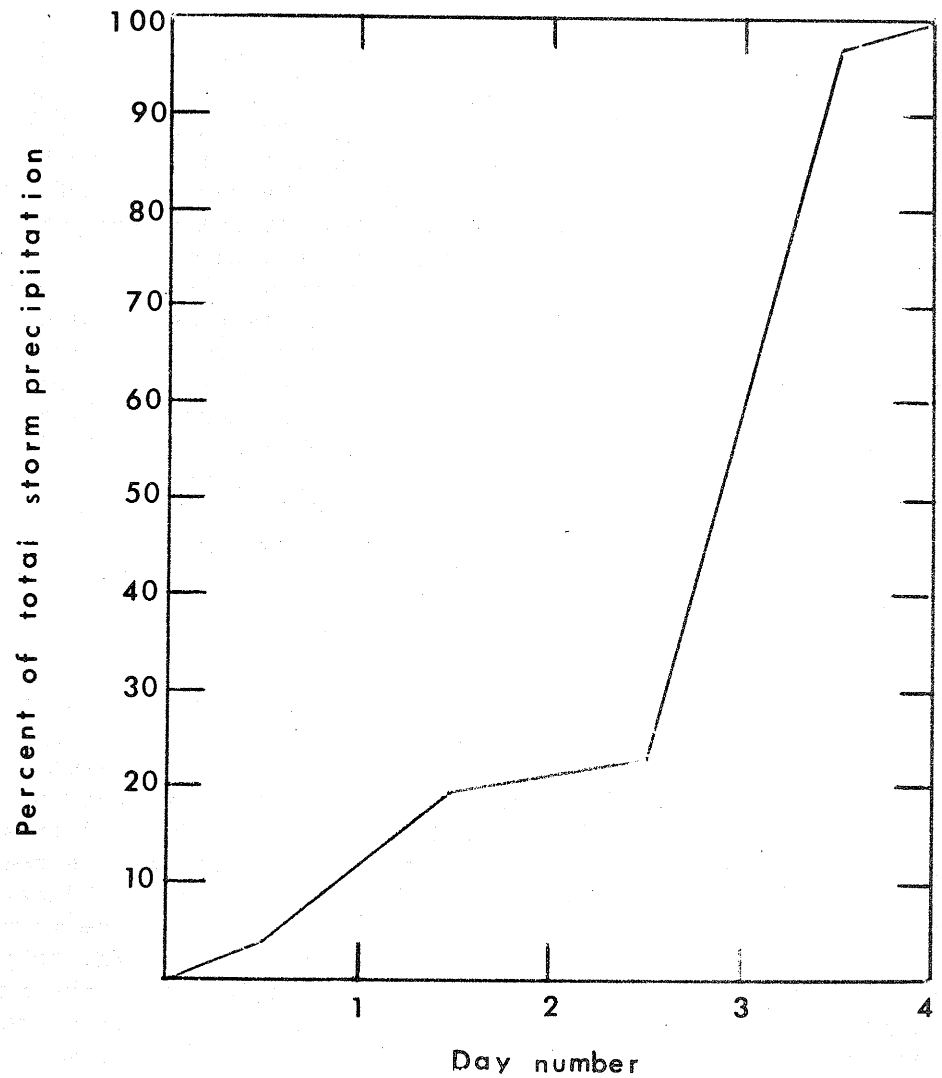

Figure 10. Typical 4-day storm distribution.

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 11, 12, and 13 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 Ohio River Basin or for different seasons. Number of bursts and time of occurrence within the storm were independent of geography, magnitude and season. The same can be said for the inclusion of the values for the same return period for 24-hour, 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 by 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. Examples of each type of distribution could be cited. The maximum 6-day period of precipitation (table 1) at Memphis, Tennessee (34), for the period of record from 1912-1966 was the 10.64 inches that fell in November 1934. Comparison of this storm with the values presented by Miller [1964] indicates a return period of approximately 30 years for the 6-day amount. The maximum observation-day amount, 10.32 inches, was 97 percent of the storm total. This value would have a recurrence interval in excess of 1,000 years when evaluated using the amounts for the various return periods presented by Hershfield [1961].

The other extreme could be represented by the maximum value observed (table 1) for the 8-day duration at Nashville, Tennessee (29). There was some precipitation for 19 consecutive days at Nashville in January 1937, and it rained 24 days during the month. The maximum day during this 8-day storm period had less than 25 percent of the storm total, and the minimum day, 2 percent of the total amount. Four of the 8 days had more than 10 percent of the storm total. At Davis, West Virginia (17), the 1937 8-day storm showed measurable precipitation on each of the days, with no single day having as much as 20 percent of the storm total.

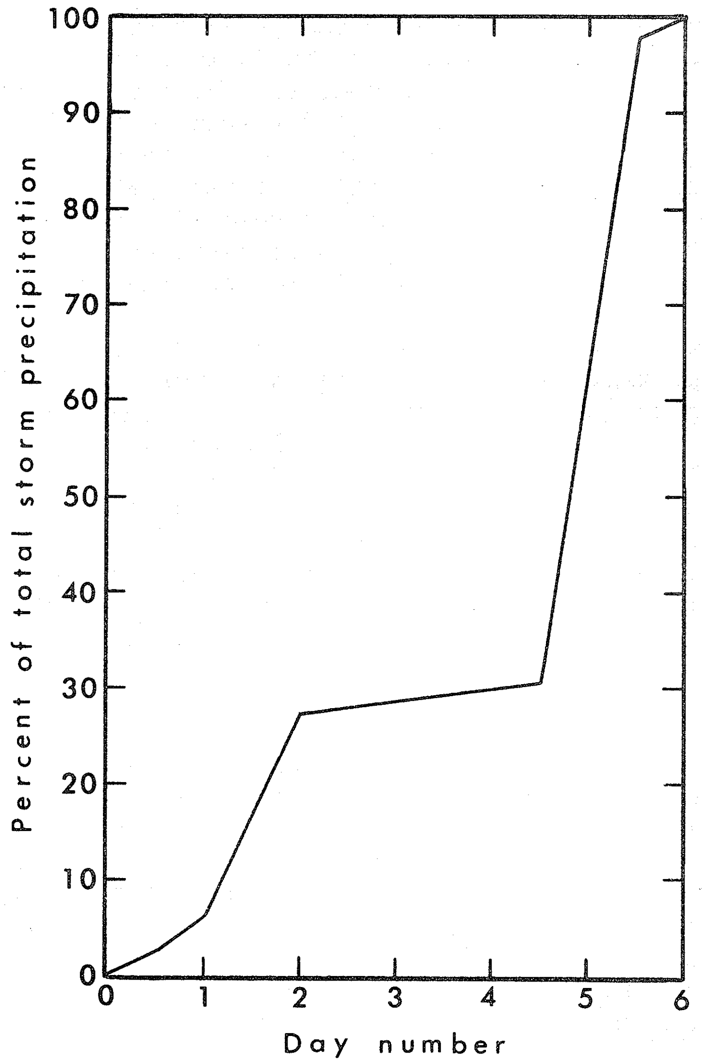

Figure 11. Typical 6-day storm distribution.

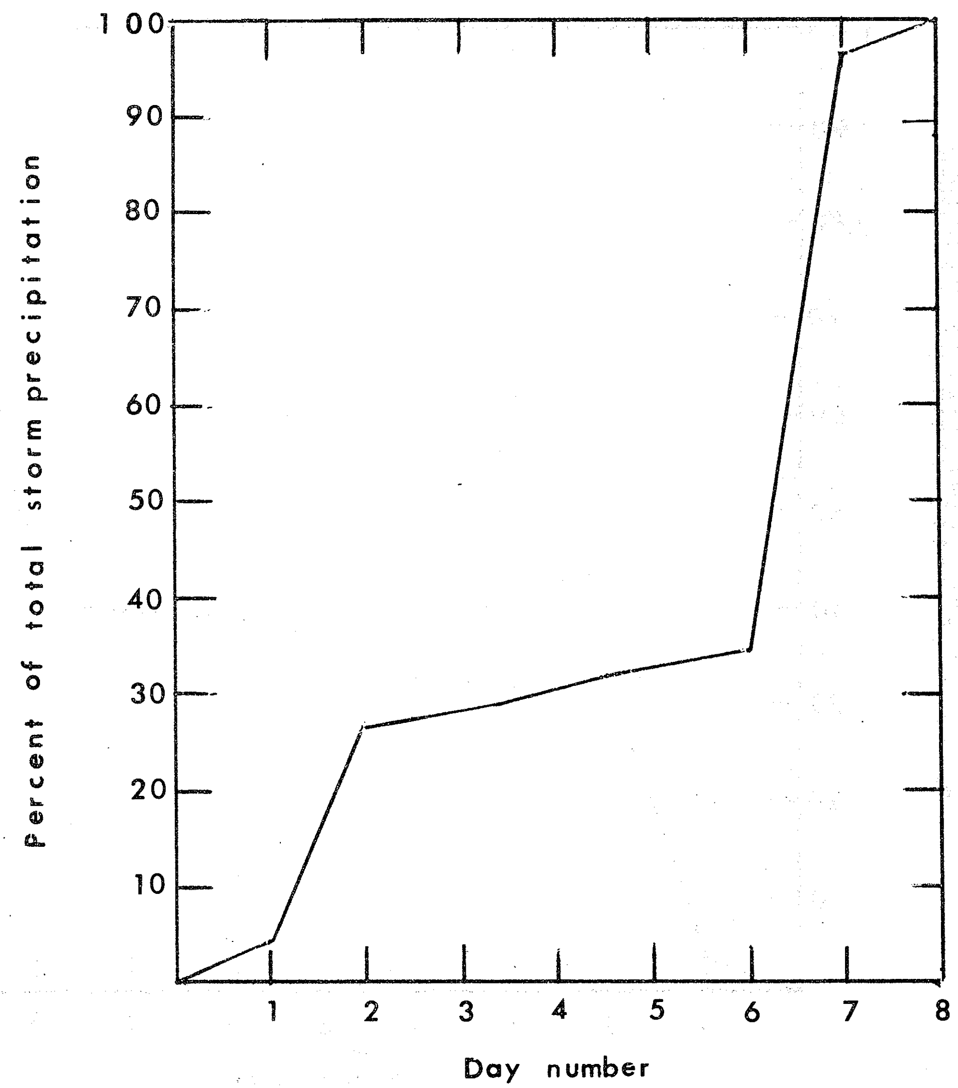

Figure 12. Typical 8-day storm distribution.

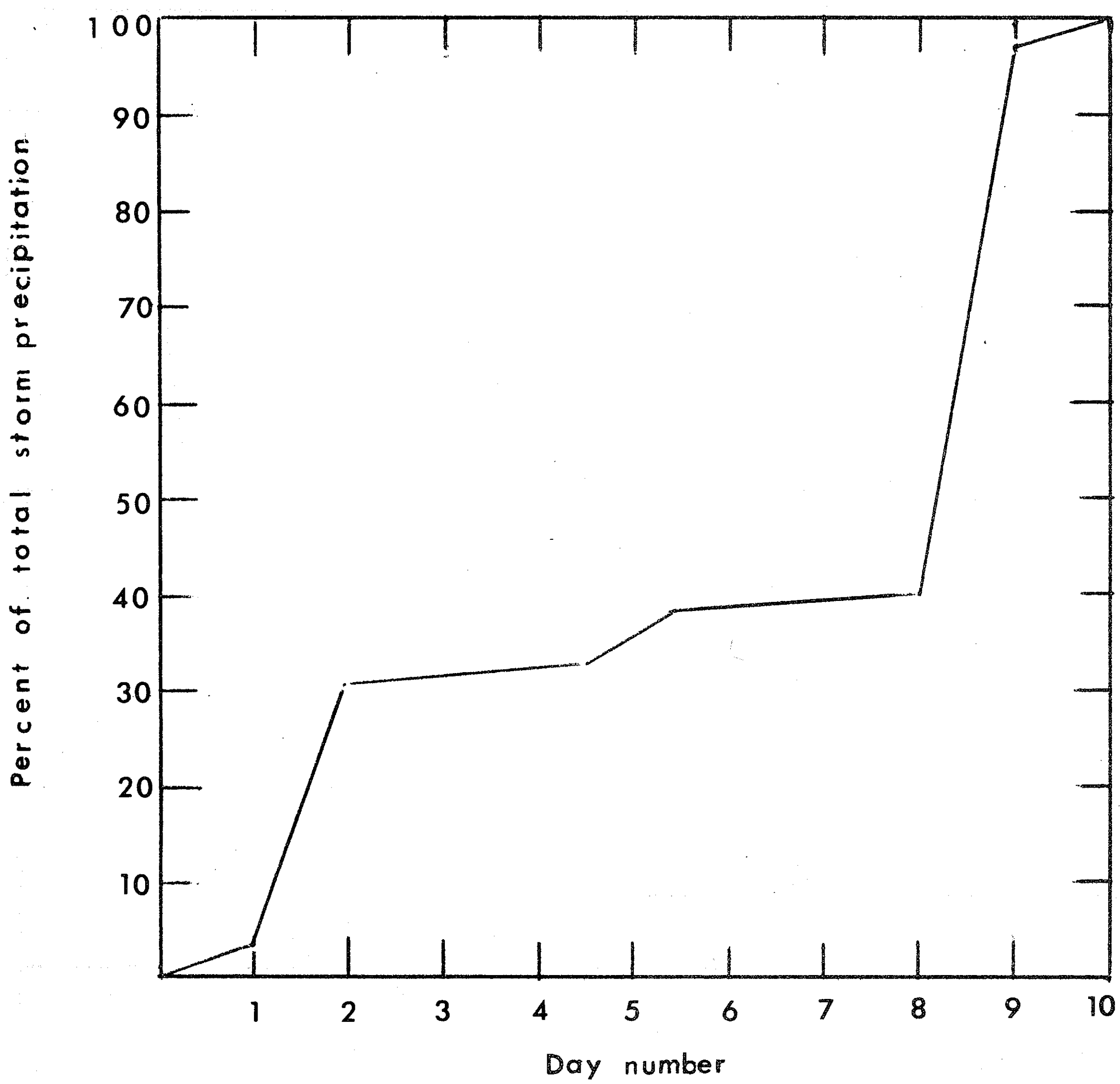

Figure 13. Typical 10-day storm distribution.

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APPENDIX

Time Distribution of 4- to 10-Day Storms--Ohio River Basin

In the section, 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 eight or more days duration a smaller third burst is used. The largest burst is toward the end of the storm period; the second near the beginning. These positions could be reversed if that is determined to be hydrologically the more critical situation. The curves use the same return period for the 24-hour, (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 Papers No. 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-hour, 2-day, 4-day, 7-day, and 10-day values from the appropriate 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 Papers No. 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-hour 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-hour__________ 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-hour) and plot at day 2 1/2 __________
6. Subtract (day 2 1/2 - day 1/2) - uncommitted amount __________
7. Subtract (day 2 1/2 - 1/6 U.A.) and plot at day 1 1/2 __________
8. Starting at origin, connect plotted points with straight lines.

Distribution of 5-Day Storm:

Read: 24-hour__________ 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-hour) and plot at day 3 1/2 __________
6. Subtract (day 3 1/2 - day 1/2) - uncommitted amount __________
7. Subtract (day 3 1/2 - 1/5 U.A.) and plot at day 1 1/2 __________
8. Starting at origin, connect plotted points with straight lines.

Distribution of 6-Day Storm:

Read: 24-hour__________ 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-hour) and plot at day 4 1/2 __________
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. Subtract (day 4 1/2 - 1/8 U.A.) and plot at day 2 __________
9. Starting at origin, connect plotted points with straight lines.

Distribution of 7-Day Storm:

Read: 24-hour__________ 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) - plot at day 1 __________
4. Subtract (day 6 - 24-hour) - plot at day 5 __________
5. Subtract (day 5 - day 1) - U.A. __________
6. Add (day 1 + .75 U.A.) - plot at day 2 __________
7. Subtract (day 5 - .25 U.A.) - Should equal day 2 __________
8. Starting at origin, connect plotted points with straight lines.

Distribution of 8-Day Storm:

Read: 24-hour__________ 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) - plot at day 1 __________
4. Subtract (7-day - 24-hour) - plot at day 6 __________
5. Subtract (day 6 - day 1) U.A. __________
6. Subtract (day 6 - .09 U.A.) - plot at day 4 1/2 __________
7. Add (day 1 + .75 U.A.) - plot at day 2 __________
8. Add (day 2 + .09 U.A.) - plot at day 3 1/2 __________
9. Starting at origin, connect plotted points with straight lines.

Distribution of 9-Day Storm:

Read: 24-hour__________ 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) - plot at day 1 __________
4. Subtract (day 8 - 24-hour) - plot at day 7 __________
5. Subtract (day 7 - day 1) - U.A. __________
6. Subtract (day 7 - .07 U.A.) - plot at day 5 __________
7. Add (day 1 + .75 U.A.) - plot at day 2 __________
8. Add (day 2 + .07 U.A.) - plot at day 4 __________
9. Starting at origin, connect plotted points with straight lines.

Distribution of 10-Day Storm:

Read: 24-hour__________ 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) - plot at day 1 __________
4. Subtract (day 9 - 24-hour) - plot at day 8 __________
5. Subtract (day 8 - day 1) - U.A. __________
6. Subtract (day 8 - .05 U.A.) - plot at day 5 1/2 __________
7. Add (day 1 + .75 U.A.) - plot at day 2 __________
8. Add (day 2 + .05 U.A.) - plot at day 4 1/2 __________
9. From origin, connect day 1, day 2, day 4 1/2, day 5 1/2, day 8, day 9, day 10. __________

Distribution of 6-Day Storm:

Read: 24-hour 5.2 5-day 7.4 6-day 7.7

Steps:

1. Plot 6-day value at day 6 — 7.7 ○
2. Compute: (6-day - 5-day)/2 $\frac{7.7 - 7.4}{2} = .15$ — .15
3. Plot Item 2 at day 1/2 — .15 △
4. Subtract (day 6 - Item 2) and plot at day 5 1/2 $7.7 - 0.15 = 7.55$ — 7.55 X
5. Subtract (day 5 1/2 - 24-hour) and plot at day 4 1/2 $7.55 - 5.2 = 2.35$ — 2.35
6. Subtract (day 4 1/2 - day 1/2) - uncommitted amount (U.A.) $2.35 - .15 = 2.20$ — 2.20
7. Add (day 1/2 + 1/8 U.A.) and plot at day 1 $.15 + \frac{2.20}{8} = .425$ — .425 ♦
8. Subtract (day 4 1/2 - 1/8 U.A.) and plot at day 2 $2.35 - .275 = 2.075$ — 2.075
9. Starting at origin, connect plotted points with straight lines.

(Symbols refer to plotted positions on figure A1)

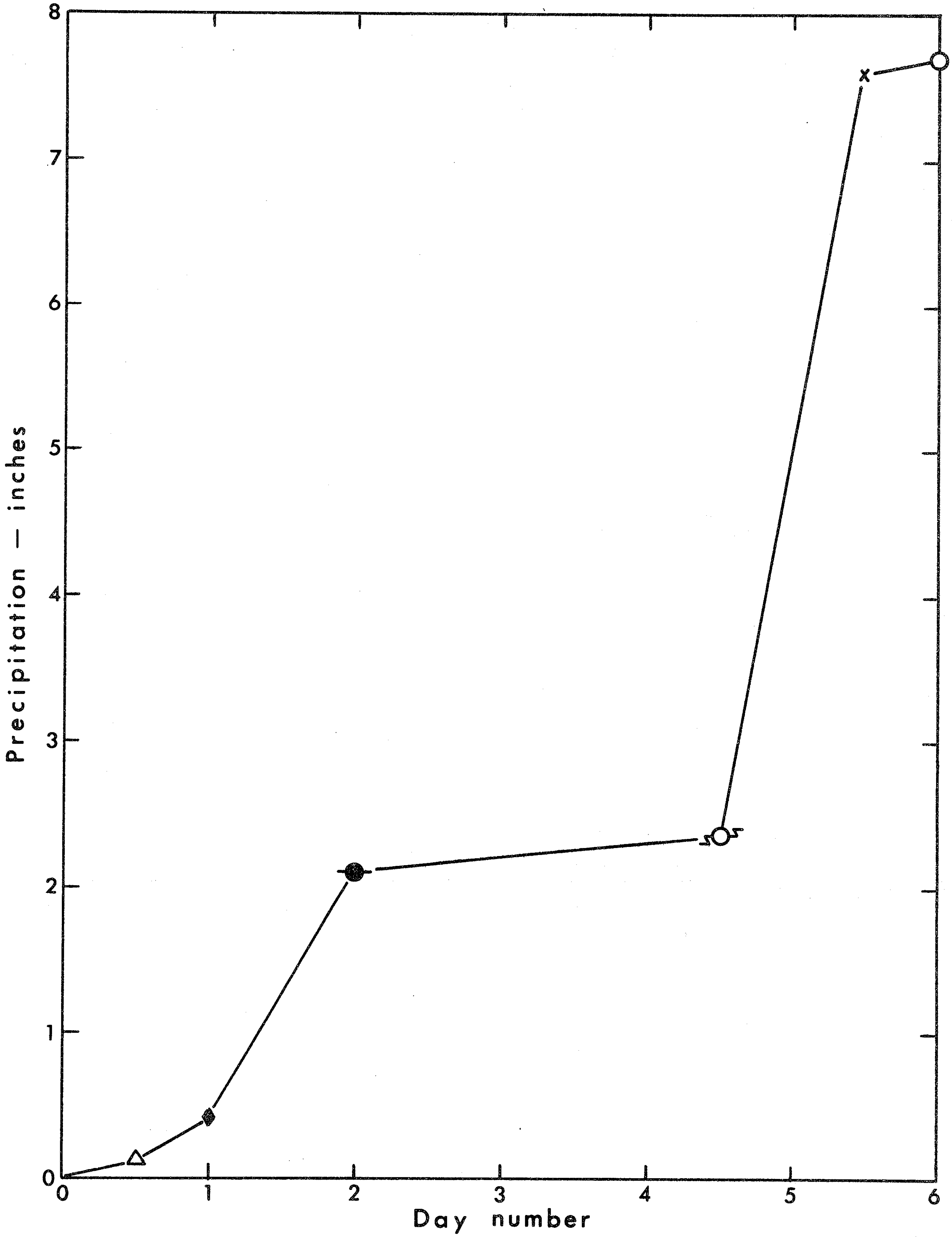

Figure A1. Sample distribution of 100-year 6-day values read from TP-40 and TP-49 at southwestern tip of Pennsylvania border.