in spring and summer, when the majority of the excessive rainstorms occur, particularly those producing 25-year to 100-year events.

Results of the St. Louis studies show that in Illinois, only St. Clair and Madison Counties (shaded area, figure 7) are significantly affected by the urban anomaly. The effect should be most pronounced in Madison County northeast and east of the city. Of the stations used in this study of Illinois frequency distributions, only Mascoutah-Belleville would incorporate any significant urban effect on the natural rainfall distribution. St. Louis (Lambert Field) in figure 7 is usually upwind of the major urban area. It would rarely, if ever, be affected by heavy rainstorms, which almost always move across the area from the southwest or northwest quadrants (from south-southwest through west to north-northwest).

Evidence of the presence of urban rain modification was indicated in some of the isohyetal patterns derived in conjunction with the present study (figures 10 through 17). Except during the 1971-1975 field research in the St. Louis area, there has been no raingage network of sufficient density, such as the Chicago network, to identify and define the intensity and areal extent of the St. Louis anomaly.

However, the results of the METROMEX project at St. Louis (Changnon et al., 1977) and other Water Survey studies of heavy rainstorm climatology (Huff and Changnon, 1972; Huff and Vogel, 1976) suggest that the frequency values for Madison County should be increased by 15% over the southwest section values in table 13 to adjust for the St. Louis urban effect. The values will then be in agreement with the findings in the earlier studies of inadvertent weather modification in the St. Louis region. No adjustment is needed for St. Clair County because the Mascoutah-Belleville data appear to have adequately accounted for the urban anomaly in that region.

5. VARIABILITY WITHIN CLIMATIC SECTIONS

Variation between Point and Section Frequency Distributions

Frequency relations for climatic sections and individual stations within each section are presented in Section 3. The sectional relations provide estimates of the mean rainfall to be expected for various recurrence intervals and rain periods in areas that have similar precipitation climate with respect to heavy rainfall occurrences. However, natural variability will produce variations for any given recurrence interval and storm period. This variability will be substantial even when long periods of record, such as the 83 years used in the present Illinois study, are integrated into the development of frequency relations. Therefore, a measure of this variability is presented in this section for those who have need for such information.

The method employed involved comparing the variations in rainfall amounts between the frequency distributions derived for individual stations within a given climatic section and those indicated by the sectional mean distributions. The variability obtained by this method results primarily from random sampling variations due to the spatial distribution of heavy rainstorms in a particular climatic section during the sampling period. Variability due to other causes, such as observational and processing errors, has been minimized by using the individual frequency distributions to measure the dispersion about the sectional mean frequency distributions, rather than the raw data observations.

The effects of "outliers" and "inliers," which are nonrepresentative of the expected rainfall for a given recurrence interval and storm duration, are also minimized but not completely eliminated by the method employed. "Outliers" and "inliers" are rainfall amounts that either exceed or are less, respectively, than any value expected to occur normally within the length of record undergoing analysis, such as the 83 years used in the present study. For example, the 200-year storm event must occur in some year, and at some of the observational points this could have been within the 83-year sample. These abnormal values are important in some hydrologic design considerations, and results of their analysis are discussed later in this section.

The analytical approach employed by Huff and Neill (1959) was used. This method consists of computing the standard deviations about the sectional curves at selected recurrence intervals for the storm period undergoing analysis. From these computations, confidence bands can be drawn to provide an estimate of the variability likely to occur between the mean distributions and points selected at random within the given climatic section. Station (point) deviations about each sectional curve were expressed as a percent of the sectional mean in assessing the dispersion. The dispersion calculations were made for recurrence intervals of 1, 2, 5, 10, 25, 50, and 100 years for storm periods of 1 to 10 days.

Initial analyses of the percentage deviations of station frequency values about the mean curves for each of the ten climatic sections indicated that several sections could be combined to obtain a more reliable measure of the intrasectional variability. That is, the magnitudes of the percentage deviations were quite similar. The number of stations (and thus the number of point frequency curves) varied from three to nine among the ten climatic sections. This is an insufficient number to obtain either a reliable estimate of the standard deviation or a coefficient of variation on a sectional basis.

Further study led to the conclusion that the state could be divided into two regions of comparable relative variability: the northern region, consisting of the northwest, northeast, west, central, and east climatic sections; and the southern region, consisting of the west southwest, east southeast, southwest, southeast, and south sections (figure 7). The northern half of Illinois has a shorter convective season and fewer heavy storms than the southern half, and hence greater variability would be expected in the north.

Assessment of the distribution of percentage deviations also indicated that rain periods could be readily combined into two groups to increase the sample size in the dispersion calculations. Storm periods of 24, 48, and 72 hours were placed in one group. The dispersion characteristics of this group also serve as an approximation of rain periods of 1 to 24 hours because the shorter durations are strongly related to the 24-hour rainfall values. The second storm group includes intermittent rain periods of 5 to 10 days, which produce some of the serious flooding problems in Illinois, as discussed in the introduction to this report.

Results of the dispersion study are shown in table 20. The coefficient of variation (%) is shown for each data grouping. As expected, the variability about the sectional mean curve increases with increasing recurrence interval. The relative variability at the 100-year frequency for storms ≤72 hours is approximately twice that at the 2-year recurrence interval. The variability in the southern part of the state tends to be less than in the northern part. This is believed to be related to the longer convective rainfall season in the south. There is not much difference between the variability in the two groups of rain periods. In the north, slightly smaller percentages

Table 20. Dispersion of Point Rainfall Frequency Distributions about Sectional Mean Distributions for Various Recurrence Intervals and Rain Periods

Recurrence interval (years)	*Coefficient of variation (%) for given recurrence*	
	*North**	*South**
	Storm periods of 1 - 72 hours	
1	3.3	2.0
2	3.8	2.2
5	4.5	2.4
10	5.1	2.7
25	5.8	3.1
50	6.5	3.6
100	7.4	4.7
	Storm periods of 5 - 10 days	
1	3.4	2.8
2	3.8	2.8
5	4.4	3.0
10	4.8	3.2
25	5.3	3.4
50	5.7	3.9
100	6.2	4.8

**North = NW, NE, W, C, and E sections; South = WSW, ESE, SW, SE, and S sections* are indicated for the 5- to 10-day rain periods. In the south, percentages are somewhat higher for the 5- to 10-day storms for the shorter recurrence intervals but merge for the 25-year and longer recurrences.

Use of the percentages in table 20 to compute the dispersion of point rainfall values about any sectional mean frequency distribution is illustrated in the following example. Assume one wishes to determine the maximum positive and negative departures that will include 95% of the occurrences for a 24-hour storm having a recurrence interval of 50 years in the northwest section. Reference to the mean frequency distribution for 24-hour storms in the northwest (table 13) shows a value of 6.53 inches.

Table 20 shows a coefficient of variation of 6.5% in the northern region of the state for a storm period of 24 hours and a recurrence interval of 50 years. Multiply 6.5% by 2 to obtain the value encompassing 95% of the dispersion about the 50-year recurrence value. Then multiply this value (13%) by 6.53 inches to obtain the rainfall amount to be added to and subtracted from the 6.53 inches to obtain the rainfall values that should incorporate 95% of the future point rainfall frequency distributions within the northwestern section for 24-hour storm periods.

Table 21 provides a measure of maximum and minimum rainfall values for recurrence intervals of 1 to 100 years for 24-hour storm periods within the northwest section at the 95% and 99% probability levels (two and three standard deviations about the sectional mean curve). This table was derived from the sectional relationships (table 13) and table 20, by following the procedure described above. Curves for the northwest sectional mean and for two standard deviations about the mean are shown in figure 22 through use of the information provided in table 21. A similar set of curves for the southern climatic section is also shown in figure 22 to illustrate differences between northern and southern Illinois. As indicated earlier, the intrasectional variability is less in the southern part of the state, and this is evident from the dispersion curves for the northwestern and southern sections. The sectional frequency distributions and table 20 can be used to derive tables and curves, such as those presented here, for any climatic section and any storm period of use in analyzing the intrasectional variability resulting from temporal variability in the natural precipitation distribution.

Nonrepresentative Extreme Rainfalls

As indicated earlier, during a given sampling period involving a large number of observation stations, a few stations will experience extreme rainfall amounts that are not representative either of average conditions for the points at which they occurred, or of average frequency relations in the climatic section in which they are recorded. These extremes are labeled "outliers," the amounts that greatly exceed the amounts expected to occur at a given location for a given rain duration and recurrence interval. Likewise, "inliers" are maximum amounts well below the normal expectancy for the given point or climatic section during the sampling period (83 years in the present Illinois study). The Urbana example discussed in Section 3 illustrates this.

The probability of outlier storms is of interest to the hydrologic community because they are likely to produce runoff conditions that exceed the flood control capabilities of hydrologic systems designed on the basis of a normal time distribution of heavy rainstorms. Such storms can result in severe overflows and, in extreme cases, can damage or destroy containment structures. From the standpoint of floodwater control, inliers are of little concern to the design hydrologist.

Table 21. Variability about the Sectional Mean Curve for 24-Hour Storm Periods in the Northwest Section

Recurrence interval (years)	*Sectional mean (in.)*	*Rainfall (in.) for given standard deviation*			
		+2	*+3*	*-2*	*-3*
1	2.57	2.74	2.82	2.40	2.32
2	3.11	3.35	3.47	2.87	2.75
5	3.95	4.31	4.48	3.59	3.42
10	4.63	5.10	5.34	4.16	3.92
25	5.60	6.25	6.57	4.95	4.63
50	6.53	7.38	7.80	5.68	5.26
100	7.36	8.45	8.99	6.27	5.73

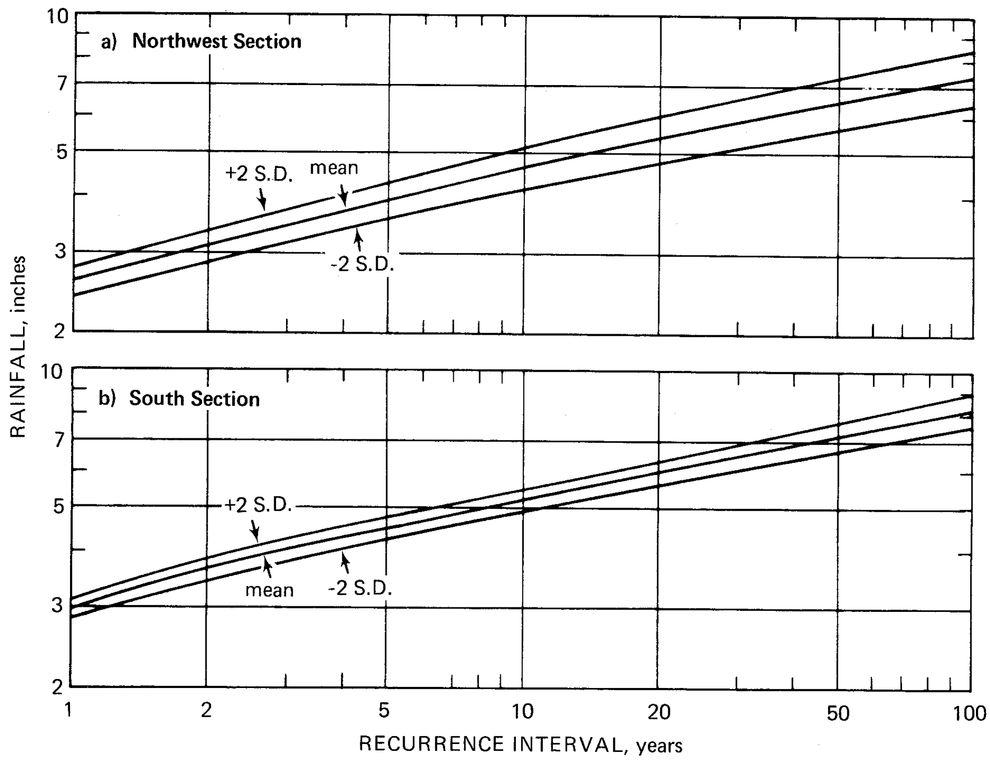

Figure 22. Examples of dispersion about sectional mean curves

In the present study, investigations of extreme rainfall events were confined to outlier storms. However, there is no standard definition of what constitutes an outlier storm. Our approach was to include those rainfall amounts that exceeded three standard deviations about the 100-year frequency value for each climatic section. The standard deviation was calculated in the same manner described earlier in evaluating the dispersion of point frequency relations about sectional mean curves. Analyses were performed for rain periods ranging from 24 hours to 10 days. Results for the 24-hour analysis may be used as a first approximation for rain periods that have durations less than 24 hours. Ranked rainfall amounts for each sampling station were compared with the three-standard-deviation rainfall at the 100-year frequency level for the appropriate climatic section.

The results are summarized briefly in tables 22 through 26. In these tables, the stations at which outlier storms were recorded are shown for each rainfall period. For each station, information is provided regarding the climatic section in which each qualifying rainfall occurred, the station rainfall amount, the difference between this amount and the value of +3 standard deviations in the given section, and the starting date of the storm.

Table 22 shows that most of the nine extreme values for 24-hour rain periods occurred in the northern half of the state. Of the nine qualifiers, seven were summer storms. Other analyses performed in the present study show that the heaviest storms tend to occur in summer, and that they occur most frequently in northern and central Illinois in June-August. In the lower part of table 22, information is provided for nine severe rainstorms during 1951-1961 for which detailed field surveys and analyses were carried out by the Water Survey, or which were centered on dense raingage networks of the Survey. These storms are generally larger with respect to maximum rainfall than those observed at the fixed sampling points of the National Weather Service climatic network. The climatic network is not sufficiently dense to detect the maximum point rainfall

Table 22. Observed Occurrences of 24-Hour Rainfall Amounts Exceeding Three Standard Deviations at the 100-Year Recurrence Interval during 1901-1983

Climatic analysis of daily data, 1901-1983

NWS stations	*Climatic section*	*Maximum rainfall (inches)*	*Difference from +3 standard deviations (in.)*	*Starting date*
Aurora	NE	10.56	1.30	10/10/54
Ottawa	NE	9.90	0.64	7/14/58
Galva	NW	9.50	0.51	8/20/24
Rockford	NW	9.50	0.51	7/19/52
La Harpe	W	10.25	0.23	6/10/05
Paris	ESE	10.20	1.41	6/27/57
Flora	SE	11.20	2.03	3/7/31
Mascoutah	SW	10.61	1.25	8/16/46
Belleville	SW	11.30	1.95	6/14/57

Network and field-surveyed storms, 1951-1961

Approximate location	*Climatic section*	*Maximum rainfall (inches)*	*Starting date*
Near Pontiac	C	13.0	7/9/51
NE of Rockford	NW	12.5	7/19/52
Near Waterman	NE	11.7	10/10/54
W of Rantoul	C	10.9	5/26/56
Near E. St. Louis	SW	16.5	6/14/57
SW of Paris	ESE	12.4	6/27/57
Near Kankakee	NE	11.3	7/12/57
Near Marion	S	10.7	8/16/59
Near Clinton	C	11.0	5/7/61

in most severe storms. For example, in table 22, the Aurora storm that began on October 10, 1954, and the field-surveyed storm labeled "near Waterman" occurred in the same storm system. At Waterman, the 24-hour total was 11.7 inches, compared with 10.56 inches at Aurora. Likewise, the storm northeast of Rockford on July 19, 1952 (lower part of table 22) had a maximum of 12.5 inches at its center compared to 9.5 inches at the Rockford NWS station (upper part of table 22). The median rainfall for the nine field-surveyed storms in the 11-year period 1951-1961 was 11.7 inches, compared with 10.2 inches for the nine heaviest storms recorded in the 61-station NWS network.

Obviously, there had to be many more storms of the field-surveyed type in the 83-year sample, but there is no way of accurately determining their number or locations. The 1951-1960 decade was one in which an abnormal number of heavy storms occurred, based on the 61-station sample. For example, five of the nine heaviest 24-hour storms observed in the 61-station NWS network occurred in this decade (table 22). Thus, the 1951-1961 group of network or field-surveyed storms yielding 10 inches or more of rainfall at their center probably is not typical of the frequency of such storms over an extended period of time, such as 50 or 75 years.

Other Water Survey studies indicate that 10-inch storms have an average recurrence interval of 1.5 to 2.0 years in Illinois (Huff, 1978); that is, one will occur somewhere in the state on the average of once every 18 to 24 months. However, they tend to occur in clusters rather than in any systematic fashion. This is illustrated in figure 23, which shows that four of the outlier type of storms (maximum amount ≥ 10 inches) occurred in 1956-1957. A fifth storm (May 1957) had more than 9 inches at the center. Two of these storms (those of June 14-15, 1957, and July 12-13, 1957) lasted less than 12 hours. All were field-surveyed by the Water Survey.

Table 23 provides information on 48-hour storm periods. There were ten qualifying 48-hour storms,

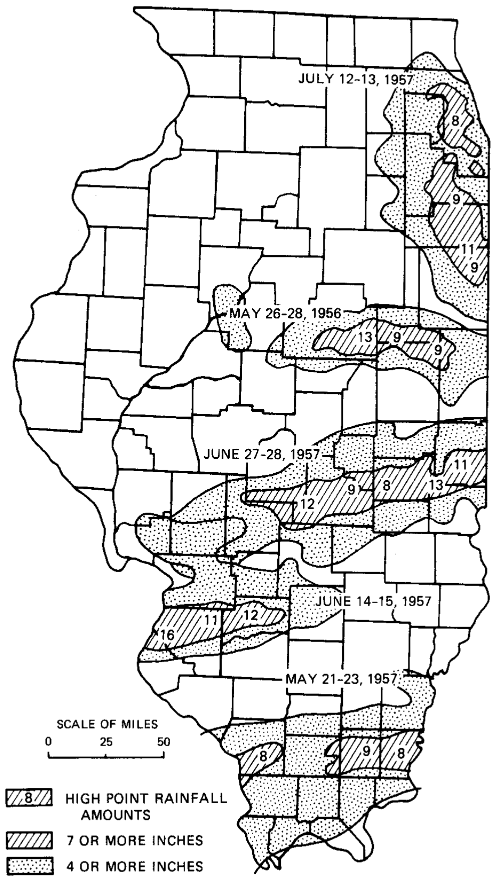

Figure 23. Major rainstorms in Illinois during 1956-1957

with amounts ranging from 10.92 inches to 13.68 inches. These storms were dispersed more evenly throughout the state than the 24-hour storms. The median departure from three standard deviations was 1.36 inches, compared with 1.25 inches for the 24-hour storms. Thus, the 48-hour extremes tended to have greater deviations from the sectional mean than those for 24-hour rainfall. Their occurrence was most frequent in summer.

The number of extreme events for 72-hour storms (table 24) was 11, and they occurred most frequently in the southern part of the state (the opposite of the situation for 24-hour storms). Storms of this length usually occur in conjunction with major storm systems involving passage of low centers and/or warm and cold fronts, especially in the transition seasons. In contrast, the 24-hour storms are most commonly associated with one or more squall lines or areas, last only a few hours, and in the case of the more extreme weather events, such as those discussed here, occur most commonly at night.

Table 25 shows the statistics for 5-day extreme events. There were only seven qualifying rainfalls in this category, and three of these occurrred during one of the greatest storms in Illinois history, which occurred on August 16-18, 1946, in southwest Illinois and eastern Missouri. Only four extreme events occurred in the 10-day category (table 26), and two of these were also part of the August 1946 storm.

Independence of Extreme Rain Events

Tables 22 through 26 illustrate how extreme rain events for different rain periods are likely to occur

Table 23. Observed Occurrences of 48-Hour Rainfall Amounts Exceeding Three Standard Deviations at the 100-Year Recurrence Interval during 1901-1983

NWS stations	*Climatic section*	*Maximum rainfall (inches)*	*Difference from +3 standard deviations (in.)*	*Starting date*
Aurora	NE	11.34	1.37	10/10/54
Belleville	SW	12.06	2.01	6/14/57
Flora	SE	12.14	2.30	3/7/31
Harrisburg	S	10.92	0.79	10/10/05
Mascoutah	SW	13.68	3.65	8/16/46
Mt. Vernon	SE	10.64	0.70	8/16/46
New Burnside	S	10.93	0.90	10/6/10
Paris	ESE	11.04	1.27	6/27/57
Rockford	NW	11.33	1.36	7/19/52
St. Louis	SW	11.94	1.89	8/16/46

Table 24. Observed Occurrences of 72-Hour Rainfall Amounts Exceeding Three Standard Deviations at the 100-Year Recurrence Interval during 1901-1983

NWS stations	*Climatic section*	*Maximum rainfall (inches)*	*Difference from +3 standard deviations (in.)*	*Starting date*
Anna	S	10.91	0.05	10/6/10
Aurora	NE	11.34	0.61	10/10/54
Belleville	SW	12.20	1.30	6/14/57
Flora	SE	12.20	1.47	3/7/31
Harrisburg	S	12.88	2.02	10/6/10
Mascoutah	SW	15.24	4.34	8/16/46
Mt. Vernon	SE	11.83	1.10	8/16/46
New Burnside	S	12.21	1.35	10/6/10
Paris	ESE	11.04	1.30	6/27/57
Rockford	NW	11.33	0.60	7/19/52
St. Louis	SW	14.63	3.73	8/16/46

Table 25. Observed Occurrences of 5-Day Rainfall Amounts Exceeding Three Standard Deviations at the 100-Year Recurrence Interval during 1901-1983

NWS stations	*Climatic section*	*Maximum rainfall (inches)*	*Difference from +3 standard deviations (in.)*	*Starting date*
Aurora	NE	11.62	0.19	10/10/54
Belleville	SW	12.81	0.59	7/14/57
Flora	SE	12.87	0.76	5/9/61
Harrisburg	S	12.88	0.50	10/6/10
Mascoutah	SW	15.30	3.08	8/16/46
Mt. Vernon	SE	12.56	0.50	8/16/46
St. Louis	SW	14.97	2.25	8/16/46

Table 26. Observed Occurrences of 10-Day Rainfall Amounts Exceeding Three Standard Deviations at the 100-Year Recurrence Interval during 1901-1983

NWS stations	*Climatic section*	*Maximum rainfall (inches)*	*Difference from +3 standard deviations (in.)*	*Starting date*
Aurora	NE	14.20	2.17	10/10/54
Belleville	SW	14.68	1.17	6/14/57
Mascoutah	SW	15.68	2.17	8/16/46
St. Louis	SW	15.39	1.88	8/16/46

within a single storm system. This is very evident for the storm of August 16-18, 1946, which accounted for the largest outliers for rain periods of 48 hours to 10 days. Outliers for rain periods of 24 to 72 hours occurred in the storm systems of October 10-11, 1954, at Aurora and June 27-28, 1957, at Paris. However, the 72-hour amounts in these two storms occurred within less than 48 hours and generally in less than 24 hours. The 48-hour amounts were so large that they also qualified as 72-hour totals. Of the nine field-surveyed storms listed in table 22, five had durations of less than 12 hours.

This presents a problem that warrants consideration. Statistically, when a single storm event is included in the sample for several storm durations, the samples are not independent. Furthermore, it is questionable whether a storm event lasting a certain number of hours should be included in the sample for longer durations, such as the Aurora and Paris examples mentioned above. A study of this factor and how it affects heavy rainfall frequency distributions is feasible and should be considered.

The results in tables 22 through 26 indicate that approximately 15% of the state (9 of 61 stations) received 24-hour rainfalls that meet our definition of an outlier or extreme rain event. This increased to 16% with 48-hour storms (10 of 61 stations) and to 18% (11 of 61 stations) for 72-hour storm periods. Extreme events appear to be less likely for 5- to 10-day periods, as indicated by the occurrence frequencies of 11% (7 of 61 stations) for 5-day periods and 7% (4 of 61 stations) for 10-day storm periods.

6. SEASONAL DISTRIBUTIONS OF HEAVY RAINFALL EVENTS

In the design of some hydrologic systems or structures, it is pertinent to know not only the frequency distributions of maximum storm rainfall amounts for various storm durations, but also the seasonal distribution characteristics of the heavy rainstorms. For example, a storm of intensity equivalent to a 5-year recurrence interval occurring in spring when the soil is near saturation may have different consequences than the same 5-year storm occurring in a drier summer month. Winter storms, generally producing less precipitation than summer storms, can be devastating if they occur over frozen ground. With or without snow cover, they can cause rapid flooding.

Consequently, it was decided to investigate the seasonal frequency distributions of heavy rainfall events, in addition to the standard type of frequency distribution derived from combining all storm data without regard to month or season. For this investigation, it was decided to study the four traditional seasons: winter (December-February), spring (March-May), summer (June-August), and fall (September-November).

Method of Analysis

In developing the frequency distributions of heavy rainfall events by season from the 1901-1983 sample, relations were determined for rain periods varying from 30 minutes to 10 days and for recurrence intervals of 1 year to 100 years. Frequency relations were computed for individual stations and for each of the ten climatic sections (figure 7), as was done for the total sample analysis in Section 3.

One problem faced in the seasonal analyses was the likelihood of substantially larger sampling errors (sampling variability) because of the division of the annual (total) sample into four seasons. Another concern was the derivation of accurate climatic trend factors for the smaller, more variable seasonal samples. An effort was made to minimize these problems by relating the seasonal frequency relations to those derived from the annual data in Section 3.

In doing this, seasonal frequency relations were developed from the raw data for each of the ten climatic sections. For each recurrence interval and rain period, the ratio of the seasonal to the annual rainfall value was calculated. These seasonal ratios were then used in conjunction with the annual frequency curves to obtain adjusted seasonal curves. The sectional ratios were also applied to the annual curves for each station within each section to obtain station (point) seasonal curves for the 61 Illinois stations. Spot-checking of the adjusted (annual-related) curves with those obtained directly from the seasonal data showed relatively small differences overall, but the adjusted curves provided a more logical and consistent pattern between the various recurrence intervals, rain periods, and climatic sections.

Table 27 illustrates the relations between summer and annual frequency distributions for 24-hour storm periods and recurrence intervals of 1 to 100 years in each of the ten climatic sections. The ratio