Table 15, Increases/Decreases in New 24-Hour Maximum Rainfall Values in Illinois from Those in U.S. Weather Bureau Technical Paper 40 (Hershfield, 1961)

	Differences (in inches and percentages) for given recurrence intervals											
	2 yrs		*5 yrs*		*10 yrs*		*25 yrs*		*50 yrs*		*100 yrs*	
	in.	*%*	*in.*	*%*	*in.*	*%*	*in.*	*%*	*in.*	*%*	*in.*	*%*
Chicago	0.1	3	0.3	8	0.5	11	0.9	16	1.3	20	1.9	25
Moline	0.0	0	0.0	0	0.1	0	0.4	7	0.7	11	1.1	15
Peoria	-0.1	3	-0.2	6	0.0	0	0.1	2	0.3	5	0.5	7
Springfield	0.1	3	-0.2	6	0.1	2	0.3	5	0.6	9	0.9	12
Quincy	0.2	6	0.1	2	0.2	4	0.6	10	0.8	11	1.3	16
Urbana	0.0	0	-0.2	7	-0.1	2	-0.1	2	0.2	3	0.4	6
St. Louis	0.3	9	-0.3	8	-0.1	2	0.4	7	0.8	11	1.3	16
Cairo	0.0	Q	0.1	2	0.1	2	0.4	6	0.6	11	1.3	16
Mean		3		5		3		7		10		14
Median‘		3		6		2		6		11		15

4. URBAN EFFECTS ON FREQUENCY DISTRIBUTIONS

In view of the results of the substantial past Water Survey research on the effects of urban environments on the incidence and magnitudes of heavy rainstorms, it was considered necessary to assess and incorporate (if feasible) urban effects on the frequency distributions of heavy rainfall in Illinois. Two major-urban areas are of sufficient size to cause local effects: the Chicago urban area, and a region lying east and northeast of the St. Louis metropolitan area. Other urban areas within or adjacent to the state are not considered large enough to affect the heavy rainfall distributions significantly.

Several earlier studies revealed evidence of local shifts of heavy rain events in the Chicago area. Detweiller and Changnon (1976) found an upward trend in the Chicago (and St. Louis) maximum annual daily rain values; Changnon (1980a) found that increased urban flooding in Chicago was related to local increases in heavy rain events; and Changnon (1980b) showed how storms were enhanced in urban areas. Huff and Changnon (1973) demonstrated that both Chicago and St. Louis have experienced sizable local increases in summer thunderstorms and rain days.

Huff and Changnon (1987) revealed that urban-related increases in heavy rains occurred in the St. Louis area during 1971-1975, when intensive field studies (METROMEXProject, Changnon et al., 1977) were carried out in that region. Thus, considerable evidence exists, in both cities and their environs, of localized increases in heavy rain events on the order of 10 to 25% in both incidence and magnitude.

The Chicago Effect

Huff and Vogel (1976) made a detailed study of the heavy rainfall distribution within the Chicago urban area and the surrounding six-county area, using an urban network of 16 recording raingages on an area of approximately 430 square miles during the 1949-1974 period (figure 18). These gages were operated by the Metropolitan Sanitary District of Greater Chicago, the city of Chicago, and the National Weather Service. Frequency distributions of point rainfall were derived for storm rainfall periods of 5 minutes to 72 hours and for recurrence intervals of 6 months to 50 years.

Results of this study indicated a central urban high in the isohyetal patterns for a given storm duration and recurrence interval. This high appeared to consist of two centers, one over the north central portion of the urban area and the other over the extreme southern part. The pattern is illustrated in figure 19 for 12-hour to 72-hour storm periods and a recurrence interval of 5 years.

However, even more pronounced highs in the heavy rainfall distributions were indicated 1) in the Aurora region, about 23 miles west of the western boundary of the urban area; and 2) at Joliet, about 13 miles

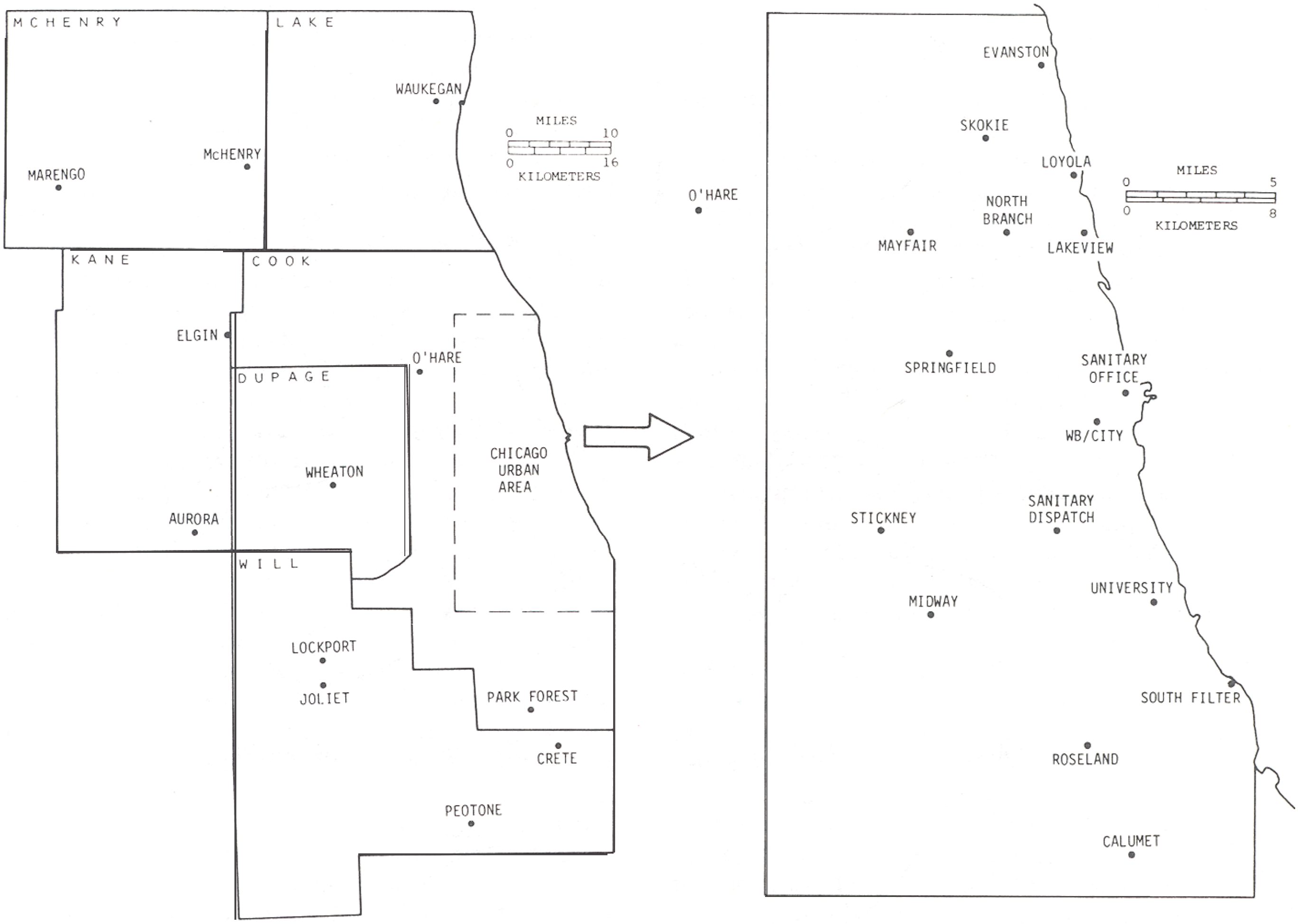


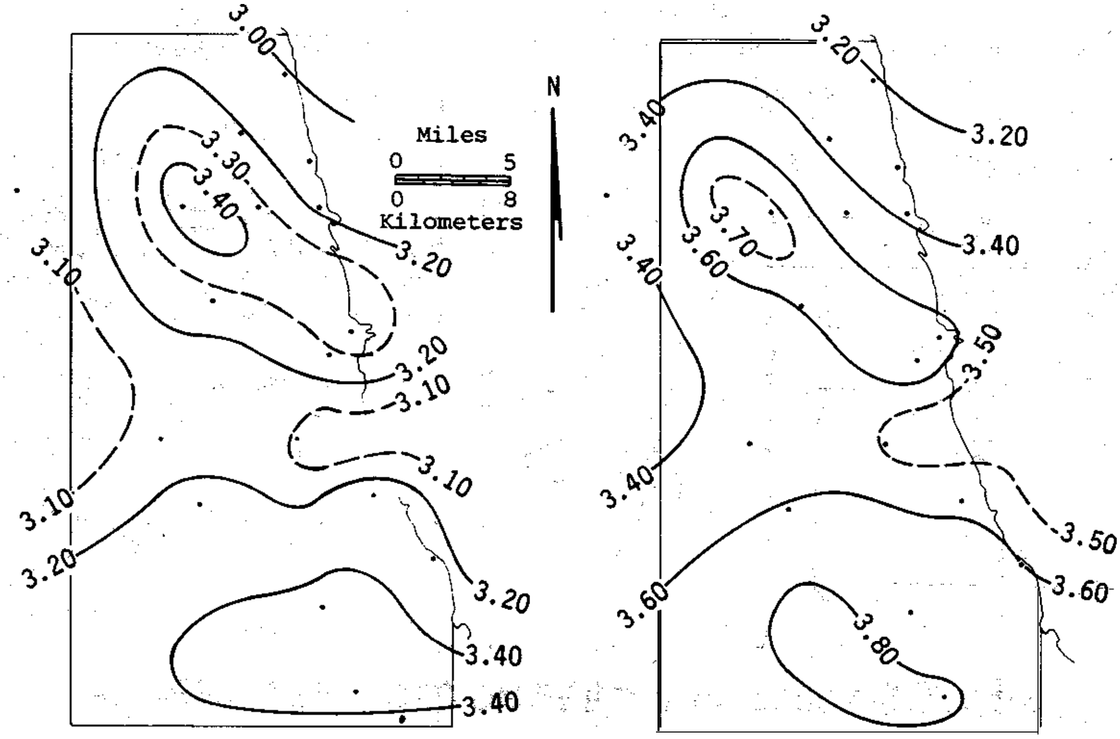
Figure 18. Location maps for northeast Illinois study

southwest of the central city. These areas are usually upwind of the city in heavy rainstorms, and therefore are not usually influenced significantly by the urban environment. The 1949.1974 data indicated a low in the climatic pattern of heavy rainstorms in the Waukegan area north of the city.

Results of the 1949.1974 and the present 1901.1983 study suggest that the south urban high is quite likely related to a natural local climatic feature that produces an area of increased rainfall extending from Aurora to Joliet and south-southeast to Kankakee. The north central high (figure 19) appears to be urban-related; that is, produced by rainfall enhancement by the urban environment (Changnon, 1980b). The Waukegan low in the extreme northeast part of the urban area may be related to the stabilizing influence of Lake Michigan on convective rainfall, which results in fewer raincells and lower rain rates than experienced over the adjacent rural areas (Changnon, 1984b).

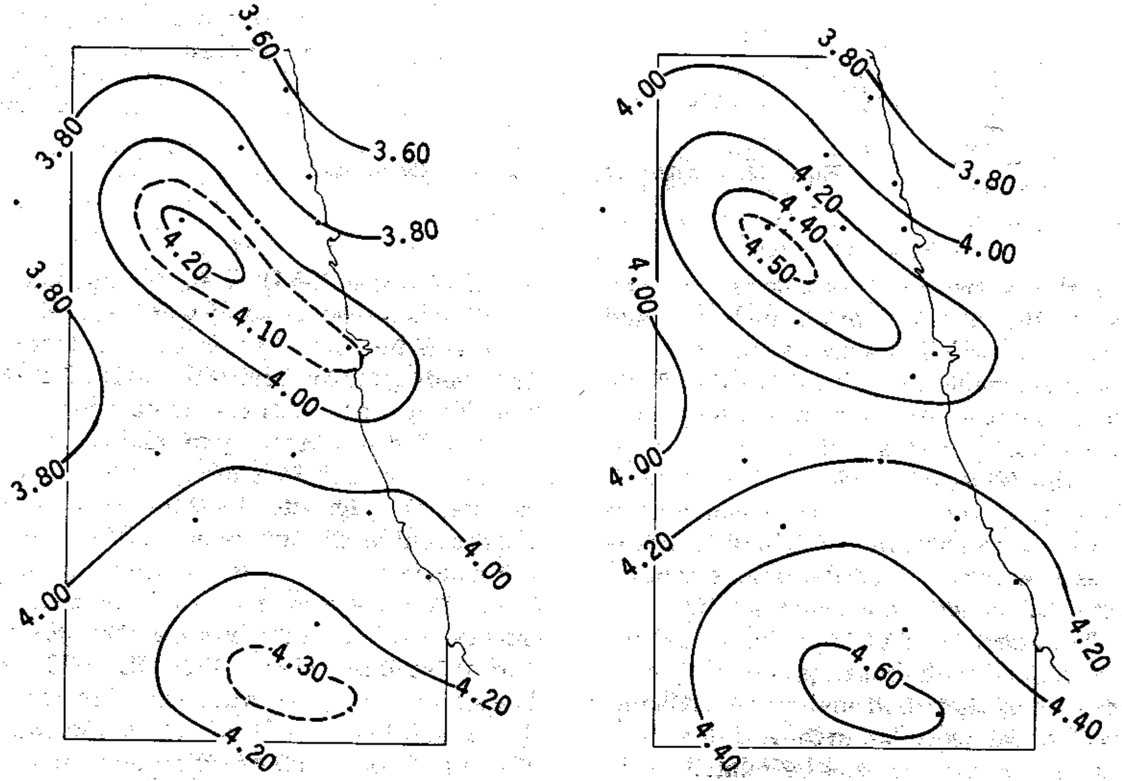
The results of the Huff-Vogel study and the present Illinois frequency study were evaluated to determine whether there is a need to adjust the 1949.1974 findings to conform with the 1901-1983 results. The Chicago raingage network data have apparently deteriorated substantially in quality since 1974, according to recent data analyses and inspection of existing raingage sites by Water Survey scientists. Consequently, the urban network data since 1974 could not be used in assessing the adjustment needs.

An adjustment was achieved by comparing frequency relations obtained from the 1949.1974 data with those obtained from the 1901-1983 data for the long-term stations at Waukegan, Marengo, Aurora, Joliet, and the main urban station of the National Weather Service. This station has been located at Midway Airport since 1943, but previously was at the NWS downtown office (1901-1926) and at the University of Chicago (1927-1942) (at the locations and “University” in figure 18).



12-HOUR. 5-YEAR RAINFALL

5-YEAR RAINFALL



48-HOUR, 5-YEAR RAINFALL

72-HOUR, 5-YEAR RAINFALL

Figure 19. Isohyetal patterns (inches) in the Chicago urban area (from Huff and Vogel, 1976)

In assessing the need to adjust the 1949-1974 results, ratios of 1901-1983/1949-1974 rainfall were calculated for selected recurrence intervals and rain periods. The results for 24-hour rain periods are illustrated in table 16, in which the 1901-1983/1949-1974 rainfall ratios are shown for various recurrence intervals for the five stations used in the assessment analysis. Relatively small differences are indicated, on the average, for Chicago, Waukegan, and Marengo. However, the ratios for Aurora and Joliet (to the west and southwest) indicate a substantial increase in the intensity of rainfall for the given recurrence intervals. Similar findings were obtained for the other storm periods tested.

The magnitudes of the ratios indicated that it was necessary to adjust the frequency relations for the Chicago urban area and the six surrounding counties to reflect findings from the longer sampling period (1901-1983), and to include the climatic fluctuation adjustment incorporated into the 1901-1983 analyses (Section 3). The first step was to construct ratio maps for the urban and six-county areas, using the five-station analytical results. This allowed adjustment of the 1949-1974 rainfall amounts at the various urban stations and other stations (e.g., Wheaton and Elgin) not included in the 1901-1983 data sample. This was initially done for a 24-hour storm period and recurrence intervals of 1 to 100 years. Isohyetal maps were then drawn for the urban area and for the surrounding six-county area.

The maps for the urban area for 24-hour rain periods are shown in figure 20. The spatial patterns shown by these maps and those constructed from the 1949-1974 data are essentially the same. For example, in both these maps and those in figure 19, two urban highs are shown, one over the north central and the other over the southern part of the city. Both figures show a low in the northeastern part of the city that apparently continues southward offshore east of the urban area. Both figures show a secondary low extending west of the city.

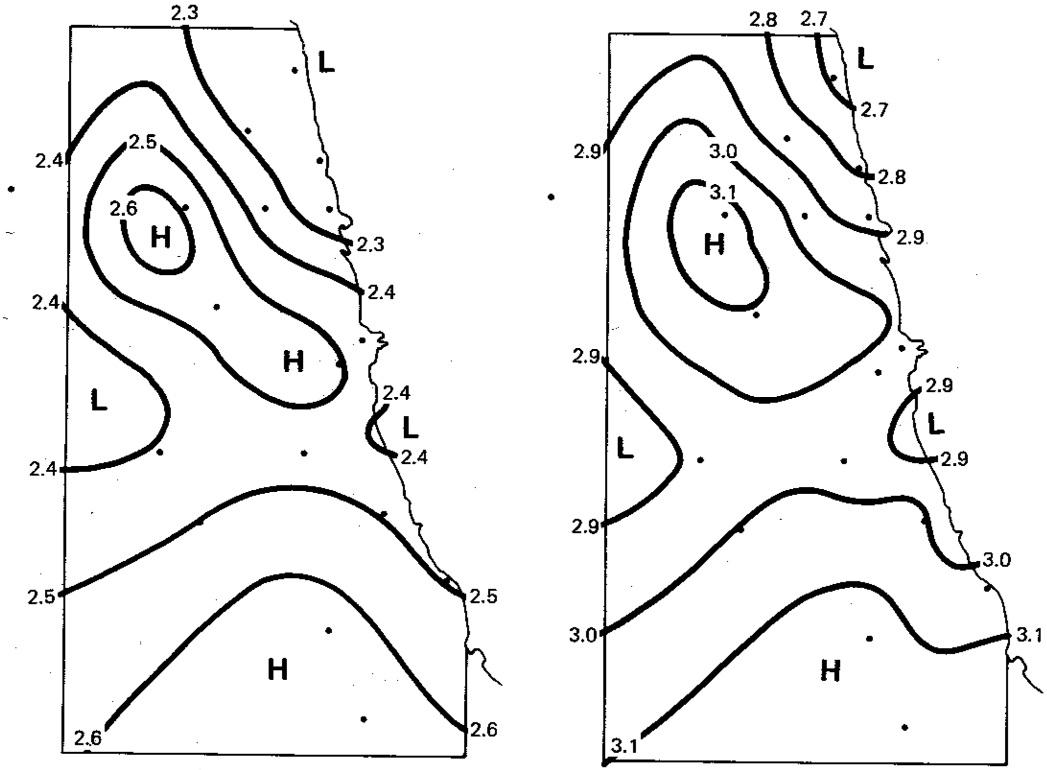
Figure 21 shows the adjusted isohyetal patterns of 24-hour rainfall for the six-county area outside of the urban area. Reference to the results of Huff and Vogel (1976) showed that the six-county maps derived from the two sampling periods were also very similar with respect to isohyetal patterns. The six-county maps show a pronounced low in the Waukegan area and a strong high in the southwestern and southern part of the region from Aurora to Joliet and eastward. From figures 20 and 21, it is apparent that the southern urban high is an extension of the Aurora-Joliet-Kankakee high discussed previously.

Although the isohyetal patterns derived from the two sets of data are very similar, the rainfall values derived from the 1901-1983 data are substantially larger in some regions for given recurrence intervals. This is illustrated in table 17, which was constructed from rainfall values interpolated from isohyetal maps for the two sampling periods. The smallest differences occurred at Waukegan and Marengo. Differences at the two urban stations (Midway and Mayfair) were larger, but not nearly as large as those for Aurora and Joliet.

It has been established from various Water Survey studies, including the 1949-1974 study and the present 1901-1983 study, that isohyetal patterns remain essentially the same for various storm periods and recurrence intervals. For example, note in figure 19 that the patterns are essentially the same for the 12-hour, 24-hour, 48-hour, and 72-hour isohyetal maps of 5-year rainfall. In view of this finding, it was decided to greatly reduce the work load (and, consequently, costs) by using the 24-hour isohyetal pat-

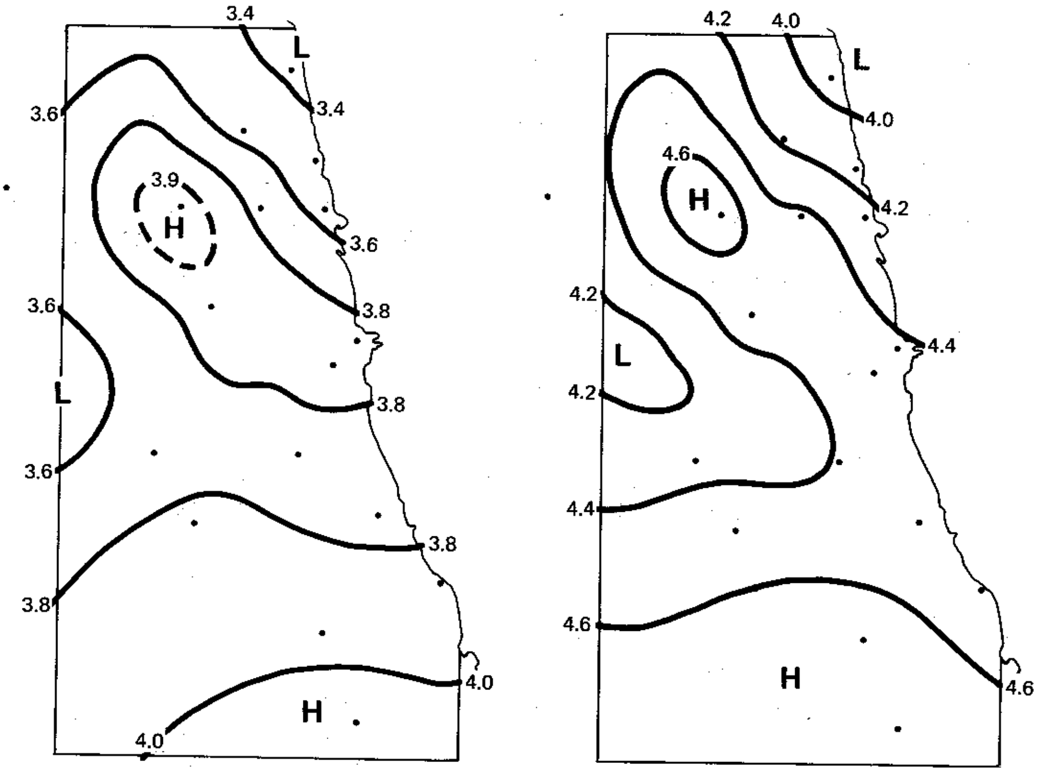
Table 16. 1901-1983/1949-1974 **Rainfall Ratios for Storm Periods of 24 Hours and Selected Recurrence Intervals**

Recurrence interval (years)	***Rainfall ratio for given station***				
	Chicago	***Waukegan***	***Marengo***	***Aurora***	***Joliet***
1	1.04	1.09	1.07	1.08	1.18
2	1.04	1.09	1.08	1.11	1.16
5	1.06	1.06	1.02	1.15	1.22
10	1.07	1.02	0.99	1.17	1.26
25	1.06	1.01	0.96	1.19	1.28
50	1.05	1.01	0.96	1.19	1.28
Average	1.05	1.05	1.02	1.15	1.23



1-year, 24-hour

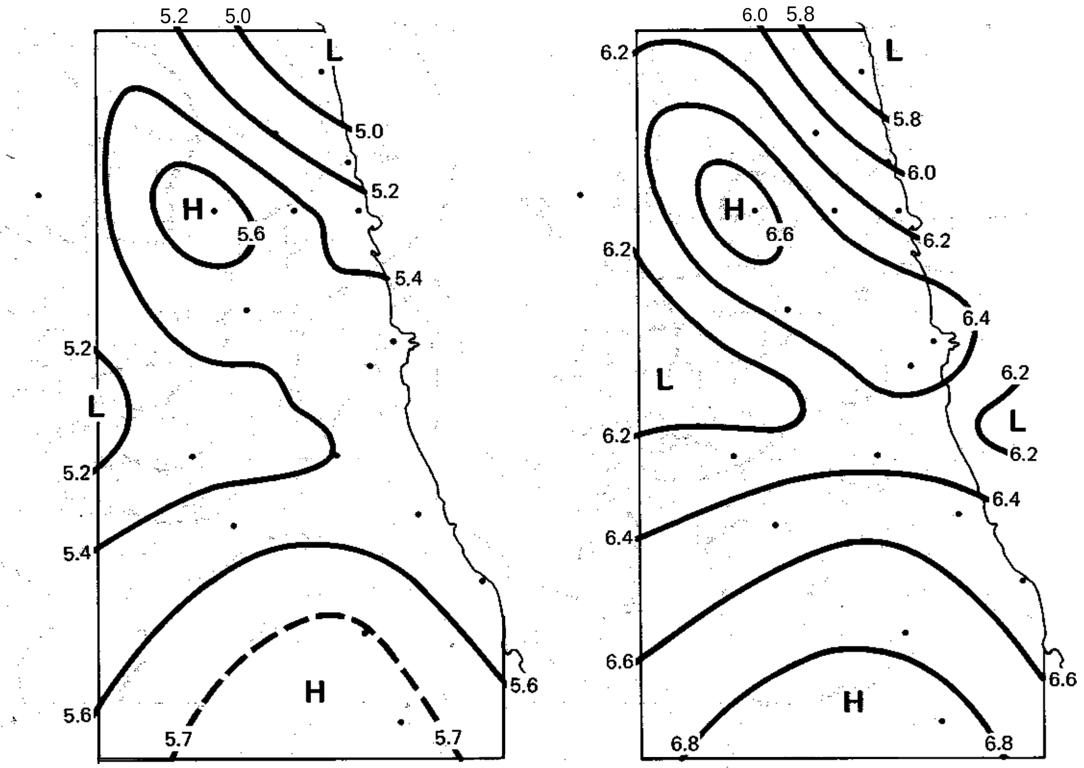
2-year, 24-hour



5-year, 24-hour

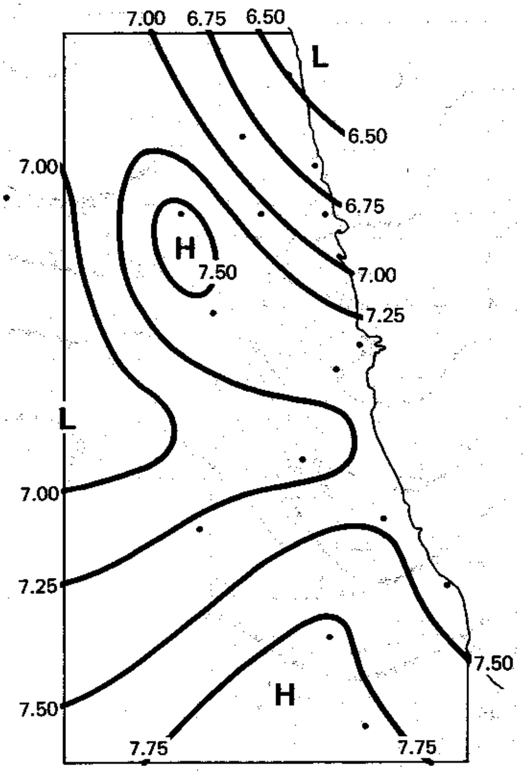
10-year, 24-hour

Figure 20. Frequency distribution of 24-hour maximum rainfall (inches), Chicago urban area (adjusted)



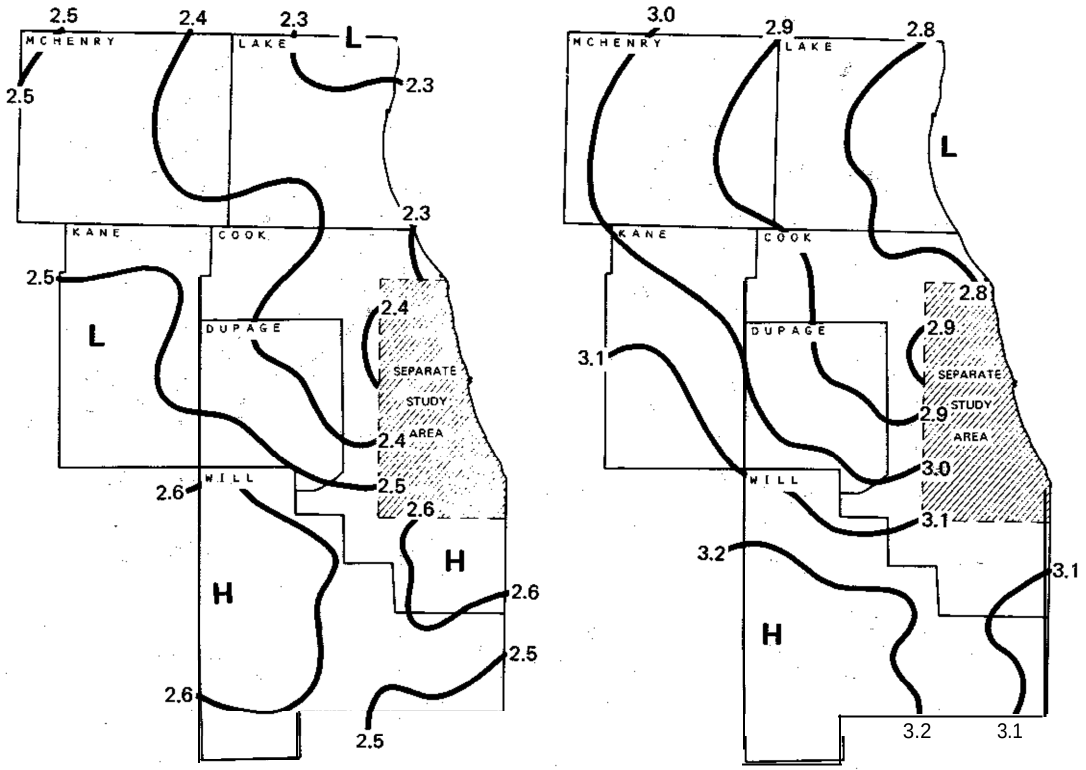
25-year, 24-hour

50-year, 24-hour



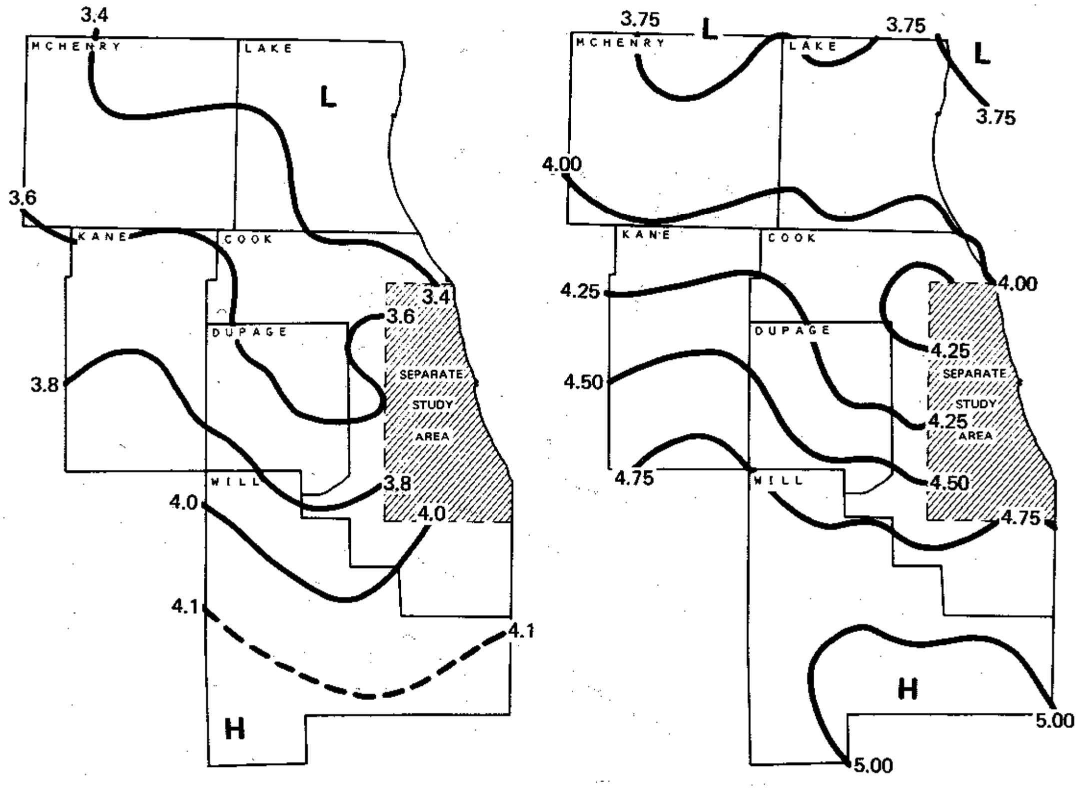
100-year, 24-hour

Figure 20. Concluded



1-year, 24-hour

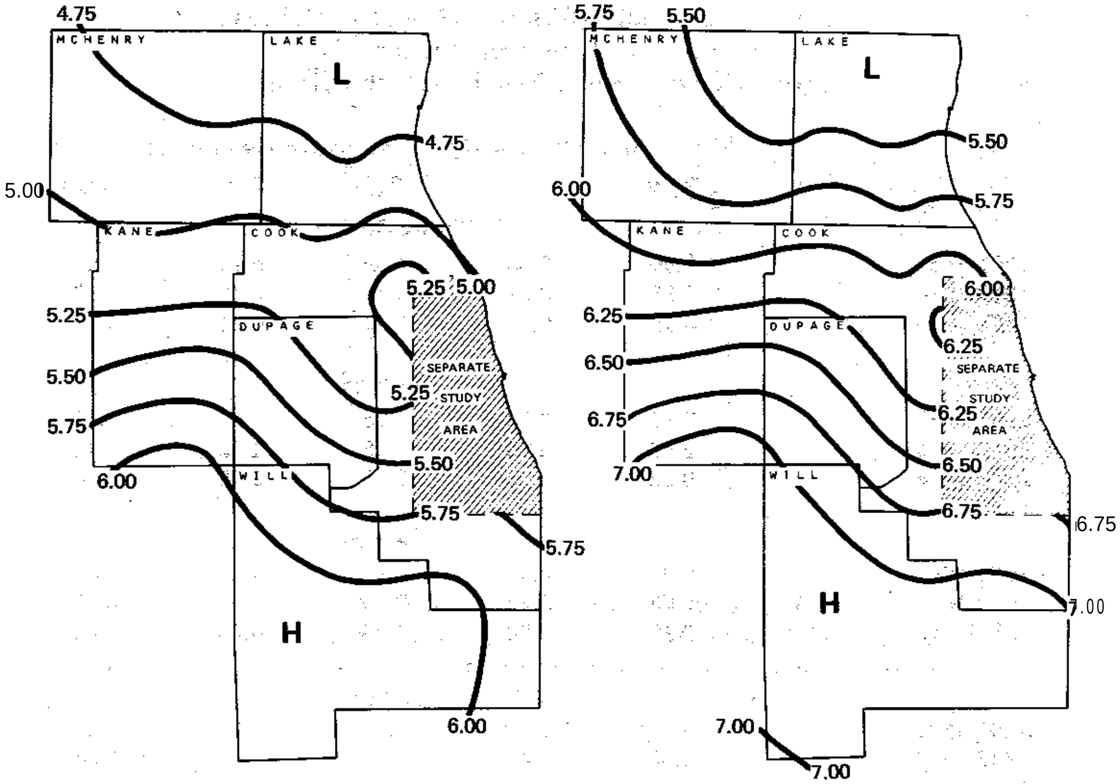
2-year, 24-hour



5-year, 24-hour

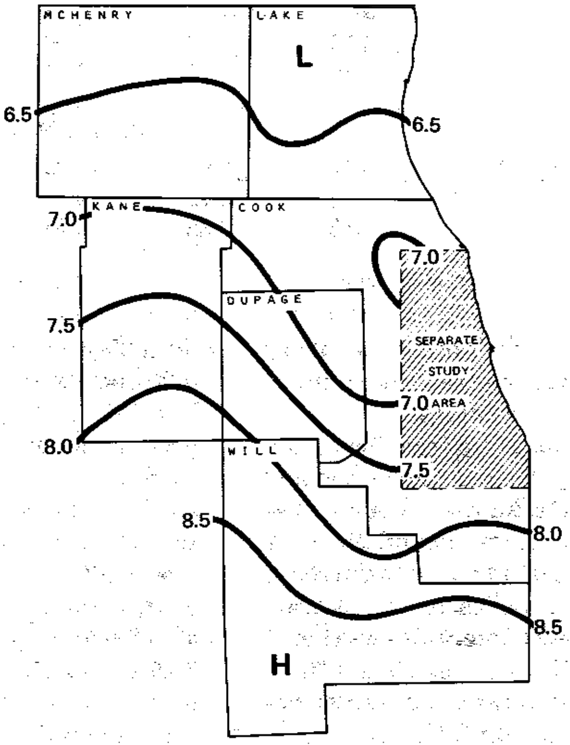
10-year, 24-hour

Figure 21. Frequency distribution of 24-hour maximum rainfall (inches), six-county (adjusted)



25-year, 24-hour

50-year, 24-hour



100-year, 24-hour

Figure 21. Concluded

Table 17. Differences between 24-Hour Storm Rainfall Amounts Derived from 1901-1983 and 1949-1974 Values for Selected Recurrence Intervals in Six-County Area of Northeastern Illinois

	Rainfall (inches) for given recurrence interval				
	2 yrs	5 yrs	*10 yrs*	25yrs	50yrs
			Chicago Midway		
1901-1983	**3.00**	**3.83**	**4.49**	**5.46,**	**6.47**
1949-1974	**2.88**	**3.62**	**4.18**	**5.15**	**6.17**
Difference	**0.12**	**0.21**	**0.31**	**0.31**	**0.30**
			Waukegan		
1901-1983	**2.82**	**3.38**	**3.75**	**4.60**	**5.45**
1949.1974	**2.60**	**3.20**	**3.65**	**4.55**	**5.41**
Difference	**0.22**	**0.18**	**0.10**	**0.05**	**0.04**
			Marengo		
1901-1983	**2.98**	**3.48**	**3.87**	**4.90**	**5.80**
1949-1974	**2.79**	**3.42**	**3.90**	**4.90**	**5.83**
Difference	**0.19**	**0.06**	**-0.03**	**0.00**	**-0.03**
			Aurora		
1901-1983	**3.10**	**3.90**	**4.76**	**6.00**	**7.10**
1949-1974	**2.80**	**3.45**	**3.96**	**4.92**	**5.85**
Difference	**0.30**	**0.45**	**0.80**	**1.08**	**1.25**
			Joliet		
1901-1983	**3.17**	**4.02**	**4.85**	**6.02**	**7.10**
1949.1974	**2.75**	**3.30**	**3.90**	**4.78**	**5.70**
Difference	**0.42**	**0.72**	**0.95**	**1.24**	**1.40**
			Chicago Mayfair		
1901-1983	**3.14**	**3.94**	**4.71**	**5.72~**	**6.72**
1949-1974	**3.02**	**3.72**	**4.40**	**5.40**	**6.40**
Difference	**.12**	**0.22**	**0.31**	**0.32**	**0.32**

terns as a base, and to express all other frequency relations for other storm periods and recurrence intervals as a function of the 24-hour values.

Tables 18 and 19 accomplish the transformation from figures 20 and **21** to any desired rain period and recurrence interval. Table 18 shows x-hour to 24-hour ratios for rain periods from 5 minutes to 72 hours. The ratios are applicable to all recurrence intervals. Table 19 provides ratios for calculating frequency values for recurrence intervals less than 1 year, which are not provided in figures 20 and **21.**

The following example illustrates the use of figures 20 and 21 in conjunction with tables 18 and 19. Assume a user wishes to calculate the maximum 6-hour rainfall expected to occur, on the average, once in 25 years at Aurora (figure 18). The 24-hour map for a 25-year recurrence (figure 21) shows a value of 6.00 inches at Aurora. Table 18 shows that the 6-hour/24-hour ratio is 0.75. Multiplying 6.00 by 0.75 gives a value of 4.50 inches for the 6-hour, 25-year storm.

Now, assume further that the user wishes to determine the 6-hour rainfall to be expected once in 6 months, on the average. Figure 21 shows that the 1-year, 24-hour storm value at Aurora is 2.55 inches. The 1-year value is obtained by multiplying 2.55 by 0.75, which gives 1.91 inches. Table 19 indicates that the 6-month value is 81% (0.81) of the 1-year amount. Then 1.91 multiplied by 0.81 yields 1.55 inches for the 6-hour, amount.

Next, assume that a user wishes to analyze an area for a rain period other than 24 hours. This can

Table 18. Average Ratios of X-Hour/24-HourRainfall for Illinois
(See table 11)

Rain period (hours)	Ratio, x-hr/24hr
0.08 (5 min.)	0.12
0.17 (10 min.)	0.21
0.25	0.27
0.50	0.37
1	0.47
2	0.58
3	0.64
6	0.75
12	0.87
18	0.94
24	1.00
48	1.08
72	1.16

Table 19. Ratios of Illinois Rainfall Amounts for Recurrence Intervals of Less than 1 Year to Rainfall Amounts for Recurrence Intervals of 1 Year, for Various Rainstorm Periods
(See table 12)

	Mean ratio, x-month to 12-month rainfall amount for given rainstorm period				
Storm period	2 months	3 months	4 months	6 months	9 months
<=24 hours	0.55	0.64	0.70	0.81	0.92
48 hours	0.53	0.62	0.69	0.80	0.92
72 hours	0.52	0.61	0.69	0.80	0.92

be done quite readily by replacing the 24-hour values for each isohyet with the computed value for any rain period of interest. For example, assume it is desired to determine the spatial amounts for the frequency distribution of 12-hour rainfall having a 5-year recurrence in DuPageCounty. Turning to the 5-year, 24-hour map in figure 21, multiply each isohyetal value by 0.87, the 12-hr/24-hr ratio in table 18. Then the 3.4-inch isohyet of figure 21 becomes 2.96 inches, and the 3.6-, 3.8-, and 4.0-inch isohyets convert to 3.13,3.31, and 3.48 inches, respectively.

Thus, figures 20 and 21 can be used in conjunction with tables 18 and 19 to calculate frequency distributions of storm rainfall for rain periods of 5 minutes to 72 hours and recurrence intervals ranging from 2 months to 100 years. This can be done for both the Chicago urban area and the six-county area of major interest in northeastern Illinois. The use of the ratio technique provides a consistent, accurate distribution, of, rainfall between storm periods and recurrence intervals.

The St. Louis Anomaly

Previous Water Survey studies (Huff and Changnon, 1972; Changnon et al., 1977; Changnon et al., 1985) have shown that inadvertent weather modification by the St. Louis urban environment substantially increases rainfall ,downwind of the city into Illinois, and that the urban enhancement tends to be largest in relatively heavy rainstorms. The anomaly is largely contained within a 25-mile radius, extending northeast, east, and southeast of central St. Louis into Illinois, and no significant effect has been identified beyond 50 miles. The effect is most pronounced 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 Neil1 (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 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