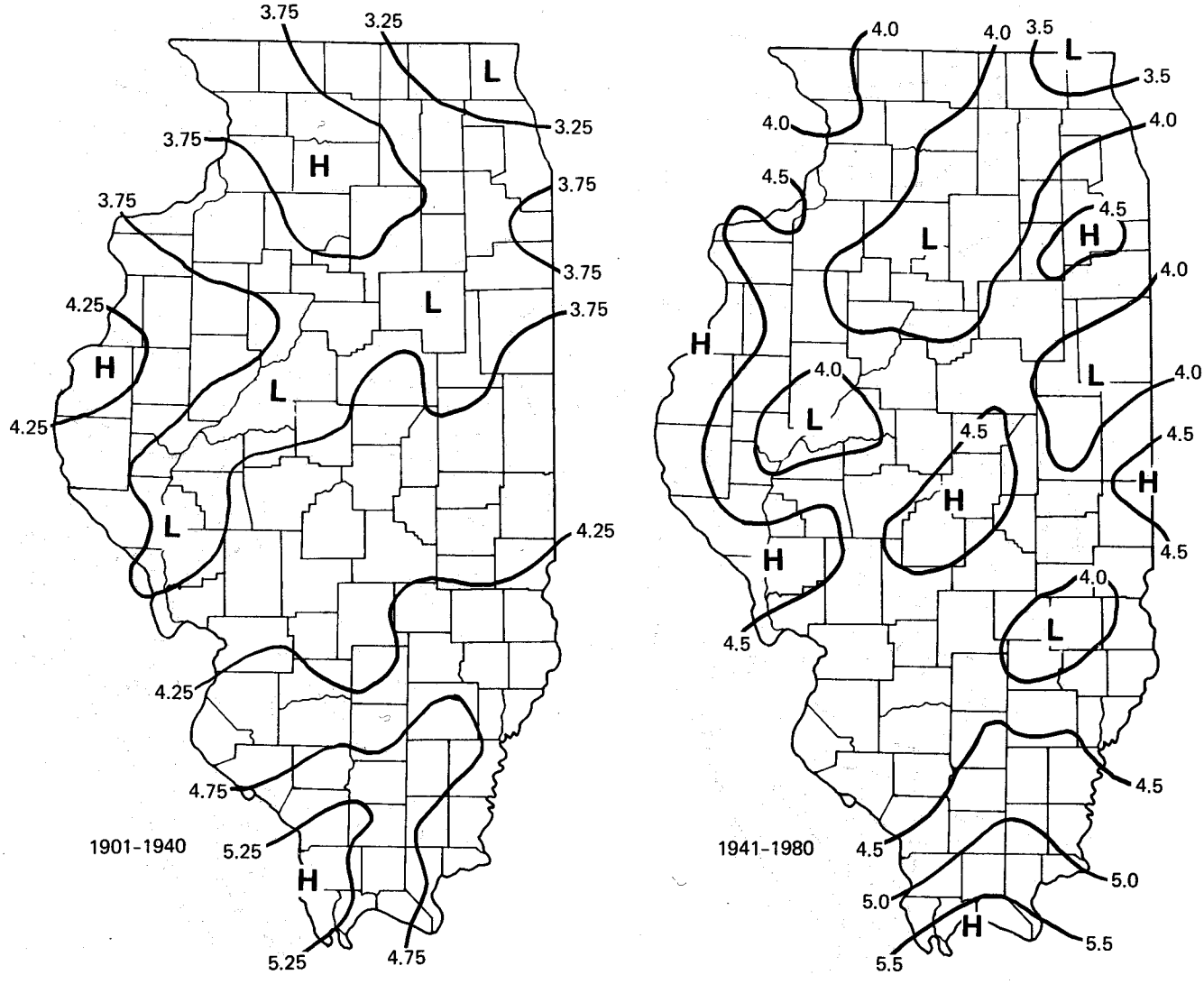

Figure 6. Isohyetal patterns of 5-year, 48-hour rainfall (inches) based on 1901-1940 and 1941-1980 data

2. COMPARISON OF INDEPENDENT 10- AND 20-YEAR PERIODS

In the previous section, results of a study of two 40-year periods (1901-1940 and 1941-1980) were presented. The results indicated that the frequency/intensity regime of heavy storms was considerably different in the two periods. For given recurrence intervals (2 years, 5 years, etc.) and rainfall durations (1 hour, 12 hours, 24 hours, etc.), the 1941-1980 data indicated heavier rainfall amounts. Thus the data indicated a climatic change or trend in the frequency distributions of heavy rainstorms. In this section, the existence of a climatic trend is explored further through comparison of data for four 20-year and eight 10-year independent periods in the 80-year sampling period at the 61 Illinois precipitation-reporting stations.

Trend Analyses of 20-Year Periods

Computations were made of the 80-year trends (1901-1980) in 1-day to 10-day rainfall amounts, based on frequency distributions derived for each of

four independent 20-year periods (1901-1920, 1921-1940, 1941-1960, 1961-1980). For determination of the frequency distributions, the state was divided into ten sections having approximately equivalent precipitation climate with respect to the temporal and spatial distributions of heavy rainstorms (see figure 7). These sections vary somewhat from the nine National Weather Service climatic sections (figure 3), which were used in the 40-year comparisons described in Section 2 (see Section 3 for further details on the selection of the ten climatic sections).

Sectional frequency distributions were obtained by combining all station data for each of the ten climatic sections. These sectional values were then used in the climatic trend evaluation. Time trends were computed for recurrence intervals of 1, 2, 3, and 5 years in each section for 1-, 2-, 3-, 5-, and 10-day storm periods. Rainfall frequency values for recurrence intervals of 10 years or longer were not used because of the relatively short sampling periods (10 to 20 years) employed in the time-trend study.

The results are briefly summarized in table 5, with 1-day rainfall used as an example. Percentage changes for the 80-year period, obtained from linear trend curves, are shown for each climatic section and for selected recurrence intervals. The linear trend for each recurrence interval was obtained by fitting a curve to the values obtained from the frequency distributions determined for each of the four 20-year periods.

In general, table 5 shows an upward trend in the intensity of rainfall from 1901 to 1980 for the given recurrence intervals in the northwestern, northeastern, western, central, eastern, and west southwestern sections (all but the four southernmost Illinois sections). The trend toward heavier rainfall with increasing time was greatest in the northeastern section and relatively small in the western section. The upward trend in heavy rainfall intensities encompasses most of the northern and central parts of the state. For southern Illinois, table 5 indicates a decreasing trend in the intensity of heavy storm events (east southeastern, southwestern, southeastern, and southern sections).

The percentage increase or decrease in rainfall becomes larger with increasing recurrence interval in the northwestern, northeastern, west southwestern, southwestern, southeastern, and southern sections. For comparative purposes, climatic fluctuations have been defined as events persisting from approximately 10 to 100 years. Based on this definition, a climatic fluctuation has been present in these six sections, and this fluctuation has been more pronounced for the more severe rainstorms; that is, the percentage change has been greater with the more extreme events (storms with longer recurrence intervals).

However, this variation with length of recurrence interval is not indicated in the other four sections (west, central, east, and east southeast). These sections are primarily in the central part of the state, and they separate the areas in northern Illinois that have relatively large upward trends in rainfall intensity from the southern Illinois regions that have downward trends.

The time-trend analysis illustrated in table 5 supports the findings from the comparison of the early and late 40-year periods (Section 1). Both the 40-year and 20-year comparison studies indicate an upward trend in the intensity of rainfall for given

Table 5. Percentage Changes in 1-Day Rainfall from 1901 to 1980, Based on Trend Analysis Applied to Frequency Distributions from Four Independent 20-Year Samples

Recurrence interval (years)	*Percentage change for given section from 1901 to 1980*									
	NW	*NE*	*W*	*C*	*E*	*WSW*	*ESE*	*SW*	*SE*	*S*
1	+12	+16	+5	+8	+10	+11	-4	-4	+5	+3
2	+9	+19	+6	+9	+13	+13	-4	-12	-10	-1
3	+11	+22	+5	+10	+11	+15	-2	-17	-13	-1
5	+16	+29	-1	+9	+10	+15	+1	-22	-14	-3
Average	+12	+21	+4	+9	+11	+13	-2	-14	-8	-1

recurrence intervals during the 80-year sampling period in the northern and central portions of the state, and decreasing intensity in the southern part.

The variance explained by the 20-year trend curves was calculated to help evaluate the strength of the trends. The results are summarized in table 6. For each climatic section, the variance explained in the frequency distributions of 2-year and 5-year rainfall amounts for 1-day storm periods is shown in the left portion of the table. The median variance explained for 1-, 2-, 3-, 5-, and 10-day amounts is shown in the right portion.

In general, table 6 indicates a relatively strong trend (high variance) in both the 1-day rainfalls and the 1- to 10-day medians in the northwestern, northeastern, central, and eastern sections for the 2-year and 5-year recurrence-interval values. Weak trends (low variance) are indicated for one or both of the recurrence intervals for the other sections. The section medians indicate relatively strong trends, in general, for the 2-year values, but somewhat weaker trends for the 5-year recurrences, particularly for 1-day rainfalls.

The natural temporal variability is very large among severe weather events such as heavy rainstorms. Therefore a relatively large number of samples is needed to establish firm long-term averages, trends, and other statistical measures of the parameter distribution (heavy rainstorms in our case). A 20-year sample includes ten independent 2-year samples, but only four independent 5-year samples. Thus it is likely that the stronger 2-year trend in table 6 is related to more adequate sampling of the natural variability.

Table 7 illustrates how the 24-hour, 5-year rainfall amounts derived from the four 20-year sampling periods varied from those obtained from the 83-year sample (1901-1983) used as a basis for developing the Illinois frequency distributions. For each 20-year sample, the differences between the 83-year and 20-year values were calculated for each of the 61 Illinois stations. The differences were then expressed as the percentage of stations falling into selected difference categories.

Thus, table 7 shows that the differences in the 24-hour, 5-year rainfall amounts for 1901-1920 from the amounts for 1901-1983 equaled or exceeded +10% at 23% of the stations, and were +1 to +9% at 23% of the observation points. There was no difference between the two frequency curves at 8% of the stations. Differences were from -1 to -9% at 19% of the stations, and they were equal to or below -10% at 27% of the stations. Thus a total of 46% of the stations showed positive differences, and another 46% fell into the negative class.

The values in table 7 indicate an increasing percentage of positive deviations with increasing time and, conversely, a decreasing percentage of negative differences with increasing time. For example, the percentage of positive deviations increased from 46%

Table 6. Variance between 1-Day to 10-Day Rainfalls Explained by Sectional Time-Trend Curves Derived from Four Frequency Distributions Based on Consecutive 20-Year Samples

	Variance explained (r^2) for given recurrence interval (yrs)			
	1-day rainfall		*Median for 1- to 10-day rainfall*	
Section	*2 yrs*	*5 yrs*	*2 yrs*	*5 yrs*
NW	0.89	0.95	0.87	0.85
NE	0.80	0.84	0.95	0.84
W	0.39	0.27	0.39	0.90
C	0.99	0.91	0.91	0.81
E	0.91	0.61	0.92	0.80
WSW	0.50	0.14	0.67	0.02
ESE	0.74	0.17	0.47	0.17
SW	0.38	0.64	0.38	0.22
SE	0.92	0.46	0.74	0.46
S	0.98	0.16	0.34	0.37
Median	0.85	0.54	0.71	0.63

Table 7. Percentages of Precipitation-Reporting Stations Showing Specified Percentage Differences in 24-Hour, 5-Year Rainfall Amounts for the 20-Year Sampling Periods from Amounts for the 83-Year Period (1901-1983)

	Percentage of stations having specified percentage difference						
20-year period	*≥+10*	*+1 to +9*	*No diff.*	*-1 to -9*	*≤-10*	*≥+1*	*≤-1*
1901-1920	23	23	8	19	27	46	46
1921-1940	13	20	8	41	18	33	59
1941-1960	31	28	10	21	10	59	31
1961-1980	24	36	11	19	10	60	29

to 60% from the 1901-1920 curves to the 1961-1980 curves. Likewise, the negative deviations decreased from 46% to 29% from 1901-1920 to 1961-1980.

The lowest percentage (33%) of positive deviations was obtained from the 1921-1940 curves, which included data from the great drought of the 1930s. During this same sampling period, the percentage of stations with negative deviations from the 1901-1983 values reached a maximum of 59%.

In general, table 7 supports the results of the areal analyses of 20-year sampling periods discussed previously and of the 40-year comparisons presented in Section 1. That is, there has been a general trend toward an increase in the intensity of heavy rainfall events over a major portion of Illinois since the beginning of this century.

Trend Analyses of 10-Year Periods

The same analysis procedures used in the 20-year trend analysis were followed for the 10-year analyses. However, results indicated that the sampling periods were too short and the natural variability too large to provide reliable information concerning possible climatic trends in the frequency distributions of heavy rainfalls.

During an average year, for example, Illinois has a total of 112 days with measurable rainfall precipitation, or 1,120 samples in a 10-year period. However, in the frequency distribution of maximum storm rainfall for 24-hour periods, the 1-year and longer recurrence-interval values are largely defined by the ten largest events in a 10-year sampling period. This is less than 1% of the samples available for studying climatic changes or trends in daily rainfall. Thus, unless a trend is very pronounced, it will not be readily discernible in the standard type of heavy rainfall frequency analysis.

Table 8 shows the variance explained by the 10-year trend curves. It is similar to table 6, which shows the variance explained by the 20-year curves. The variance explained by the trend curves derived from the eight 10-year periods during 1901-1980 was relatively small for nearly all sections, and it was much smaller than that indicated by the 20-year trends.

Summary

The analyses of the 20-year sampling periods discussed in this section helped to verify results from the 40-year comparisons. However, because of sampling inadequacies, the 10-year samples were of little assistance in evaluating the presence of long-term climatic trends in the frequency distributions of heavy rainfall.

To repeat, the presence of a climatic fluctuation, exhibiting trends upward in the north and downward in the south, was most evident in the comparison of frequency distributions derived from the 40-year samples. These findings received considerable additional support from the 20-year trend analyses. The evidence was inconclusive in the 10-year samples because of the sampling problem. Because the 40-year comparisons are the most reliable source of information on climatic trends available, the results from that portion of our study have been used in applying a climatic trend adjustment to the Illinois frequency distributions derived from 1901-1983 data (see Section 3).

Table 8. Variance between 1-Day to 10-Day Rainfalls Explained by Sectional Time Trend Curves Derived from Eight Frequency Distributions Based on Consecutive 10-Year Samples

	Variance explained (r^2) for given recurrence interval (yrs)			
	1-day rainfall		*Median for 1- to 10-day rainfall*	
Section	*2 yrs*	*5 yrs*	*2 yrs*	*5 yrs*
NW	0.30	0.65	0.46	0.55
NE	0.41	0.31	0.43	0.47
W	0.05	0.15	0.04	0.08
C	0.47	0.50	0.45	0.47
E	0.20	0.40	0.24	0.33
WSW	0.10	0.42	0.03	0.10
ESE	0.01	0.20	0.04	0.11
SW	0.22	0.19	0.14	0.25
SE	0.29	0.54	0.29	0.17
S	0.01	0.04	0.01	0.02
Median	0.21	0.35	0.19	0.21

3. FREQUENCY DISTRIBUTIONS OF HEAVY RAINFALL EVENTS

Data Used

The data used in developing the frequency relations consisted of both daily and hourly precipitation records from Illinois and from nearby stations in surrounding states. The daily data, mostly from nonrecording raingages, spanned the 83-year period from 1901 through 1983. They included data from the 61 precipitation-reporting stations discussed previously (figure 7), whose records had been carefully edited in previous Water Survey studies and were considered of acceptable accuracy for the frequency study. Records for most stations were complete for the 83-year period, but several did not begin until 1902 to 1908, one (Kankakee) did not start until 1917, and another (New Burnside) was terminated in 1957. These stations were used to ensure adequate coverage in certain areas.

The daily data were supplemented by hourly data for 34 recording-gage stations in Illinois and 21 stations in surrounding states for the 36-year period, 1948-1983 (figure 8). These data were used primarily in developing frequency distributions for rain periods of less than 24-hour durations. The recording stations are not as uniformly distributed as the daily reporting stations, and the quality of the data obtained from some of them was questionable. The 61-station, 83-year sample from the daily reporting stations was the primary database used in developing the Illinois frequency relations, because of both the length and quality of these records. The need to provide estimates of 50-year to 100-year recurrences dictated the use of records as long as possible.

Analytical Approach

Frequency relations were developed for rain periods varying from 5 minutes to 10 days and for recurrence intervals ranging from 2 months to 100 years. These durations and recurrence intervals should encompass the various needs of hydrologists and other users of rainfall frequency information for heavy storm occurrences. Initially, frequency distributions were determined for each of the 61 stations, and they are presented in the appendices of this report.

However, as pointed out by Huff and Neill (1959), the most reliable estimate of rainfall frequency relations can be obtained by combining all data within an area of relatively homogeneous precipitation climate with respect to the occurrence of heavy rainstorms. The analyses then yield areal mean relationships applicable to all locations within a specific climatic section of the state. These areal mean relationships moderate effects from the natural variability factor (random variations) somewhat and are less affected by measurement or computational errors in specific station data.