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Frequency Distributions of Heavy Precipitation in Illinois: Updated Bulletin 70

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ILLINOIS
Illinois State Water Survey
PRAIRIE RESEARCH INSTITUTE

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Introduction

This study was designed to update the Illinois State Water Survey (ISWS) Bulletin 70, evaluating rainfall frequency relations in Illinois using current precipitation datasets. The study primarily used the National Oceanic and Atmospheric Administration (NOAA) daily precipitation data from 1948 to 2017 to perform regional frequency analysis (RFA) using the L-moments approach. Additional information on precipitation relationships for less than 24 hours were obtained from NOAA hourly precipitation data from 1948 to 2014 and Cook County Precipitation Network (CCPN) data from 1989 to 2016. Precipitation frequency relations were developed for storm durations from 1 to 240 hours and for recurrence intervals from 2 to 500 years. The results are presented for the same 10 geographic sections as in Bulletin 70 (Figure 1) to maintain the continuity of hydrologic studies and compatibility with regulations.

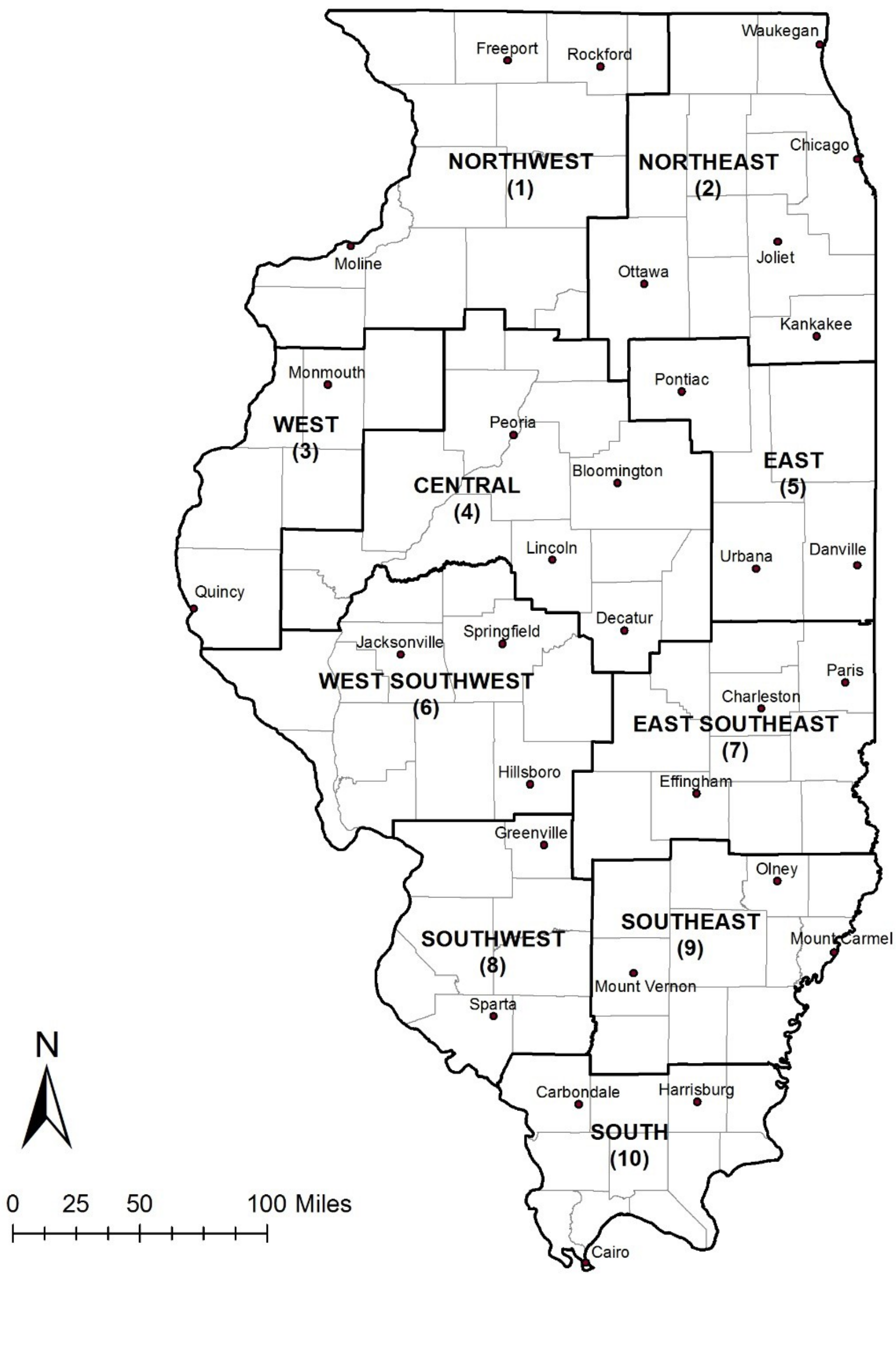

Figure 1 Climatic sections used in developing Illinois frequency estimates

Previous Studies

Several previous studies have examined precipitation frequencies related to Illinois, including Yarnell (1935), ISWS Bulletin 46 (Huff and Neil, 1959), and the U.S. Weather Bureau Technical Paper 40 (Hershfield, 1961).

The two studies currently applicable to Illinois are the ISWS Bulletin 70 (Huff and Angel, 1989) and NOAA Atlas 14 (Bonnin et al., 2006). ISWS Bulletin 70 is the current state standard for expected extreme rainfall events. The Illinois Department of Natural Resources (IDNR), Office of Water Resources (OWR) requires the use of Bulletin 70 for flood studies requiring state permits. Many Illinois county and community stormwater ordinances require that designs are based on Bulletin 70 as well. Bulletin 70 was based on analyses of precipitation data from 1901 to 1983, and the distributions were adjusted for the observed increases in the number of heavy precipitation events in Illinois.

In 2006, the NOAA National Weather Service (NWS) published NOAA Atlas 14 (Bonnin et al., 2006) for several states, including Illinois. The period of record for the data included in these analyses extends to 2000, providing 17 years of additional data over that available for Bulletin 70. However, the resulting frequency analysis yielded unexpected results of lowered precipitation estimates, especially at longer return periods.

Figure 2 shows a comparison of precipitation totals for an event of 24 hours in duration and a 1 percent annual chance probability (100-year storm). Positive (blue) numbers signify that the Atlas 14 study's total precipitation values are higher than the Bulletin 70 values, and negative (brown) numbers indicate that the Atlas 14 study's total precipitation values are lower than the Bulletin 70 values. Despite the additional 20 years of data that should have reflected the continued trend toward heavier events, the Atlas 14 study produced smaller values at many locations. Similar differences were found at other storm durations and probabilities. These results have hampered its acceptance in Illinois for design purposes.

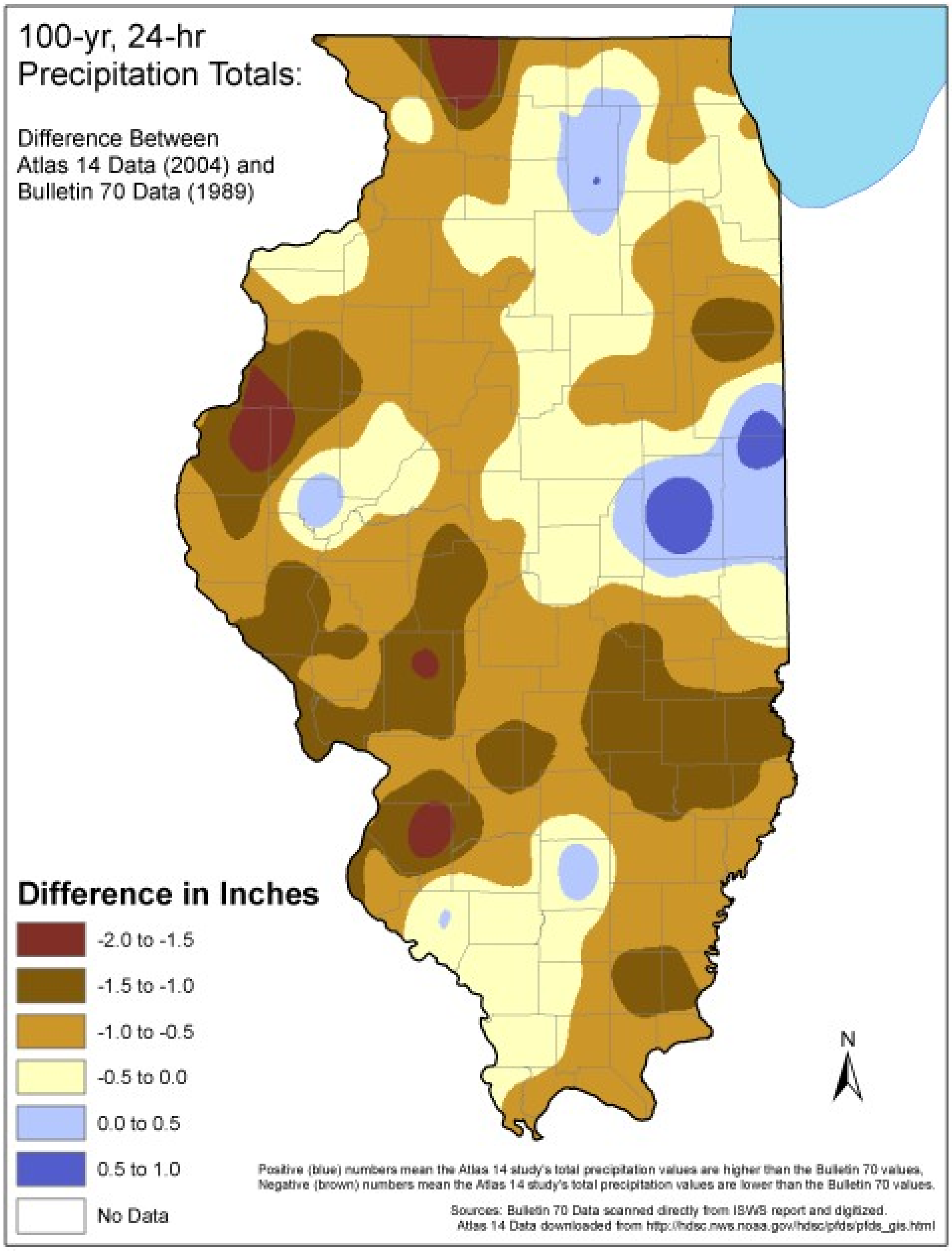

Figure 2 Differences in precipitation totals between Bulletin 70 and NOAA Atlas 14 for the 100-year, 24-hour storm

Climate Change and Its Impact on Heavy Precipitation in Illinois

Observed state increases in precipitation in general and heavy precipitation in particular have been a concern for several decades. As noted previously, a climate change adjustment was made in Bulletin 70 to address the trends already observed in the 1980s. In 2015, the IDNR, in cooperation with the Illinois State Water Survey, produced a report for the Urban Flooding Awareness Act outlining the impacts of increased precipitation in Illinois (Winters et al., 2015). Over a 10-year period, the IDNR documented $2.3 billion dollars in costs in urban areas. Some $1.6 billion in damages resulted from five severe storms. More than 90 percent of these damages occurred outside the mapped 1 percent annual chance floodplain.

Historical records for the statewide average annual precipitation for Illinois from 1895 to 2017 are shown in Figure 3. Based on a linear trend, Illinois precipitation has increased from 36 to 40 inches, or 11 percent over the past century. Illinois has become more likely to experience exceptionally wet years in recent decades. The year 1993 was the wettest on record with 51.18 inches of precipitation. The next two wettest years were 2009 with 50.96 inches and 2008 with 50.18 inches. All of these years were noted for widespread flooding across Illinois.

Temperatures in Illinois have warmed by about 1.2 degrees Fahrenheit over the past century. Warmer air can increase evaporation into the atmosphere by almost 4 percent with each degree increase in air temperature, meaning that on average, storms have more water available for precipitation. A longer warm season would increase the opportunity for thunderstorms. Additional work suggests that the increasingly intensive agricultural practices of the Midwest (more acreage and more plants per acre) have elevated summer humidity levels as well (Alter et al., 2017).

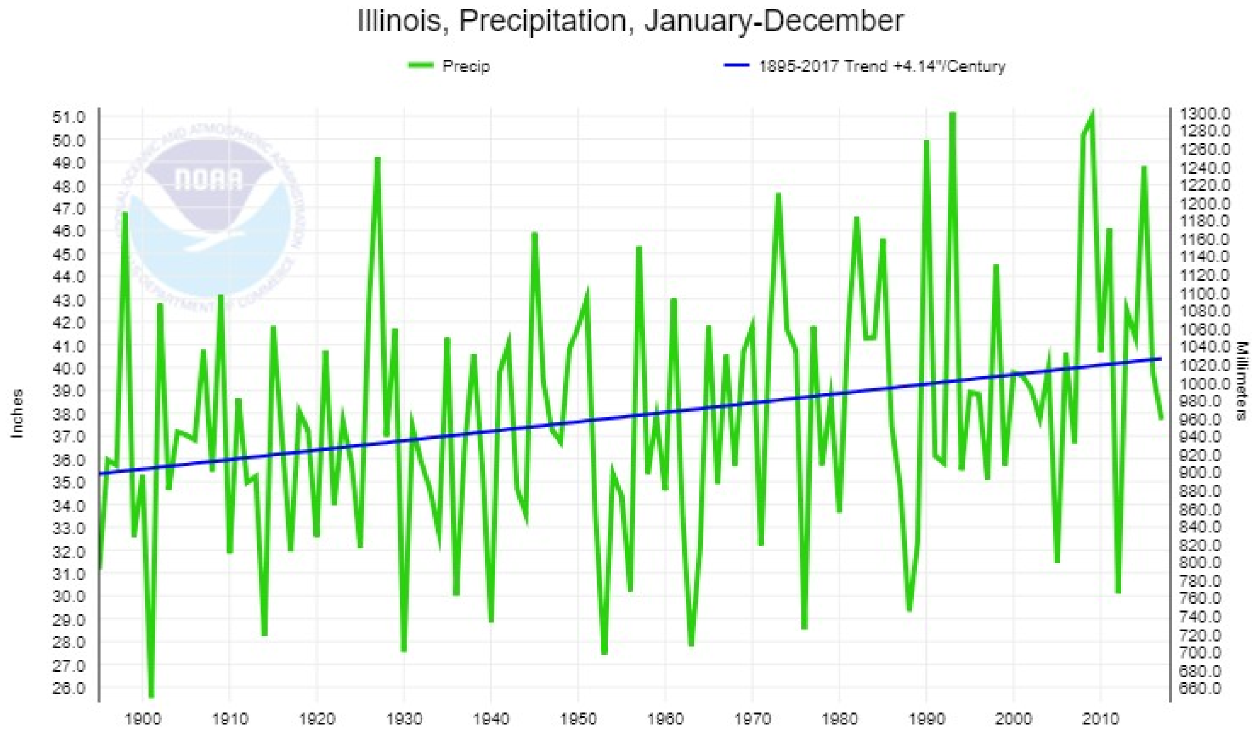

Figure 3 Statewide average annual precipitation for Illinois from 1895 to 2017. The green line shows the year-to-year variability. The blue line is a linear trend showing an increase of 4.14 inches over the past century. Source: NOAA NCEI, 2018.

Not only have the amounts of annual and seasonal precipitation increased, but so too have the numbers of extreme precipitation events (Frankson et al., 2017). Figure 4 shows the observed annual number of days with precipitation greater than 2 inches per station for 1900–2014 on average over 5-year periods. These values are averaged over 43 available long-term stations in Illinois. The average number of annual events has been above the long-term average for most 5-year periods since the 1960s. During the most recent 5-year period (2010–2014), Illinois experienced a record number of events in which stations averaged more than two 2-inch events annually. The dark horizontal line in Figure 4 is the 1900–2014 average of approximately 1.6 days per year. This pattern of heavier precipitation events has continued since the 2014 cutoff in the figure.

Conventional analyses of the frequency of extreme precipitation assumed a stationary time series (e.g., NOAA Atlas 14). This assumption meant that the longest period of record was always desired for the analysis. However, considerable evidence shows that the assumption of stationarity cannot be met (DeGaetano, 2009; Groisman et al., 2012). A concern of the current study was that an upward trend in precipitation could result in an underestimation of the current frequency of heavy precipitation by sampling earlier, drier years in the record.

For this study, the problem was minimized by using only the more recent records. As a result, the period of record selected for this report extended from 1948 to 2017. A recent study (DeGaetano and Castellano, 2018) supported this notion, showing that using 70 years of data or less can minimize the impacts from trends in precipitation. The selection of this period had the added benefit of yielding significantly more stations available for the study. In general, the number of stations increased significantly in Illinois after World War II, greatly improving the spatial coverage across the state.

The following sections of the report provide more details on the data sources and quality control, describe the methodology, and provide the results for the 10 geographic sections in tables, graphs, and maps. Additional research results on precipitation relationships will be shared in a second report to be published in 2019. That report will revisit the distribution of precipitation within the storm, also known as the Huff curves, along with the relationship between point and areal precipitation patterns out to 400 square miles.

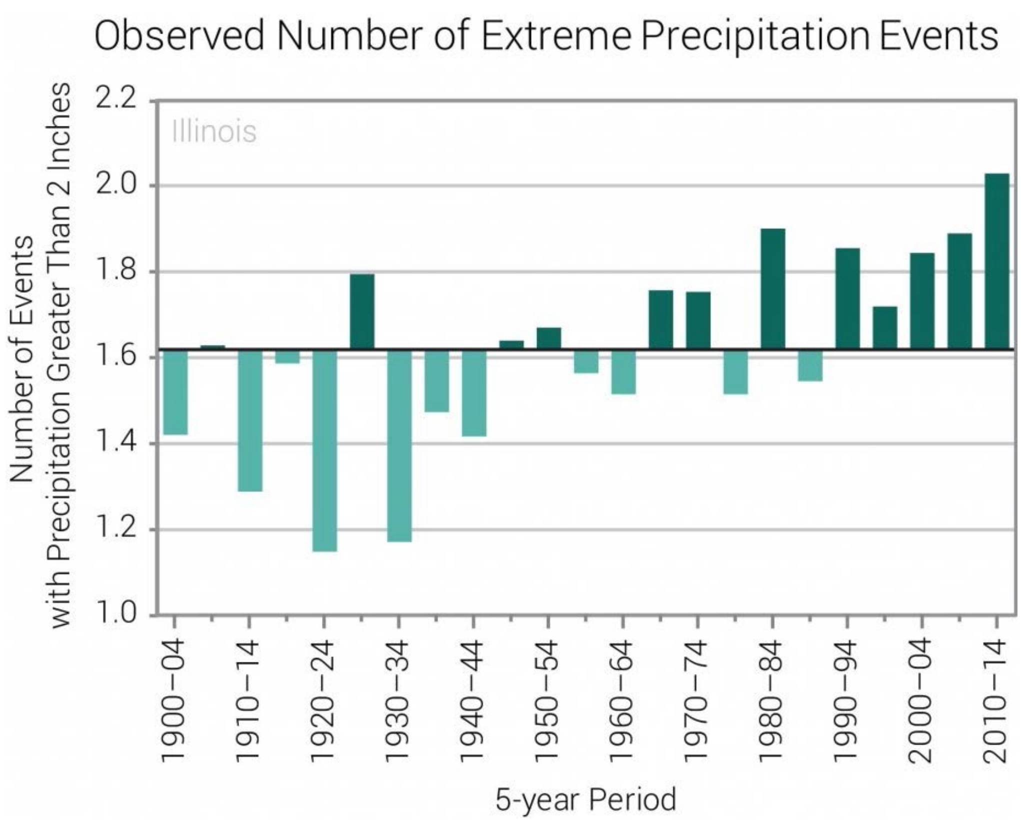

Figure 4 The observed annual number of days with precipitation greater than 2 inches for 1900–2014 on average over 5-year periods (Source: Frankson et al., 2017)

Precipitation Data Used in the Study

Three precipitation data sources were used in this study. As in Bulletin 70, the primary data source was the Global Historical Climatology Network Daily (GHCN-Daily), available through the NOAA National Center for Environmental Information (NCEI). This network of daily quality-controlled cooperative observers with the National Weather Service (NWS) is the longest serving network with the widest coverage across the state. The NWS provides equipment, training, and forms for observers, as well as the first level of quality assurance as the observations are reported. A more detailed description of this data source can be found at https://www.ncdc.noaa.gov/ghcn-daily-description. Data were downloaded using the CRAN R package 'rnoaa'. A total of 761 stations was downloaded from Illinois and from adjacent counties of neighboring states (Missouri, Iowa, Wisconsin, Indiana, and Kentucky) for consideration in this study. From this pool of stations, several criteria were applied to achieve the final list of stations.

As noted in the Introduction, the period since 1948 was notably wetter than earlier time periods and had more heavy precipitation events. To minimize the potential for underestimating the frequency of heavy precipitation events from sampling the earlier, drier period, only the data from the 1948–2017 period were considered in this study. From this pool of stations, only the stations with 30 years of data during the 1948–2017 period were selected. A minimum of 30 years was needed to develop reliable statistics for a station. In addition, data from each of those years had to be 90 percent complete. This was a common requirement in many climatological studies to strike a balance between the negative effects of missing data versus rejecting years with nearly complete records. A total of 176 stations met the criteria of the study. The map of daily stations used in this report is shown in Figure 5.

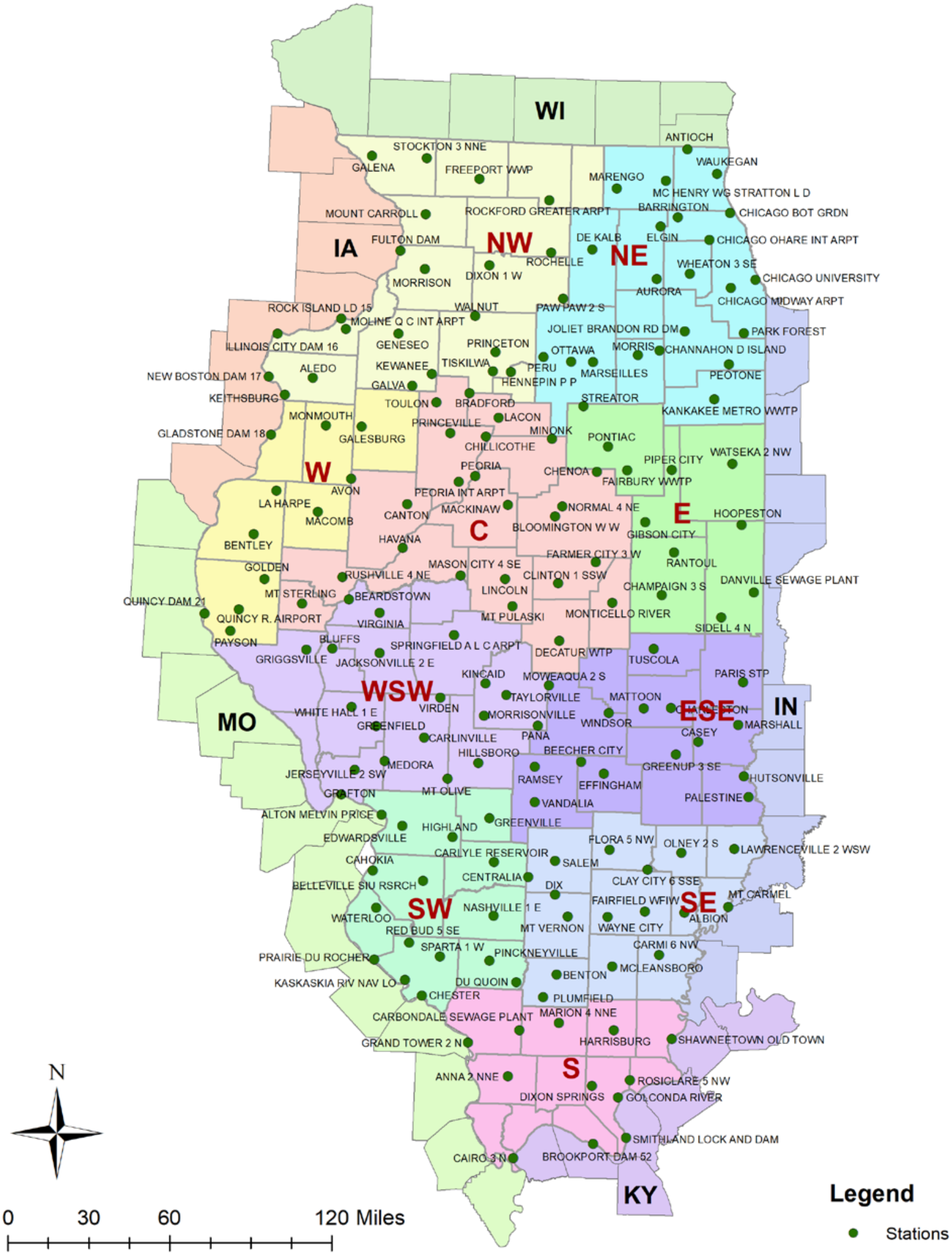

Figure 5 Daily precipitation stations used in this study

The second data source was the hourly precipitation dataset from NOAA. These data have been collected from automated gages since 1948. Unfortunately, the gages required a higher level of maintenance, which resulted in a much higher rate of missing data than that from the daily data network. As a result, the data were of limited use in this study. Their primary use for this report was to confirm earlier relationships developed between 24-hour and less than 24-hour amounts used in Bulletin 70 and NOAA Atlas 14. These relationships are documented later in this report. A total of 73 stations were examined in this study. A map of those stations with hourly data is shown in Figure 6.

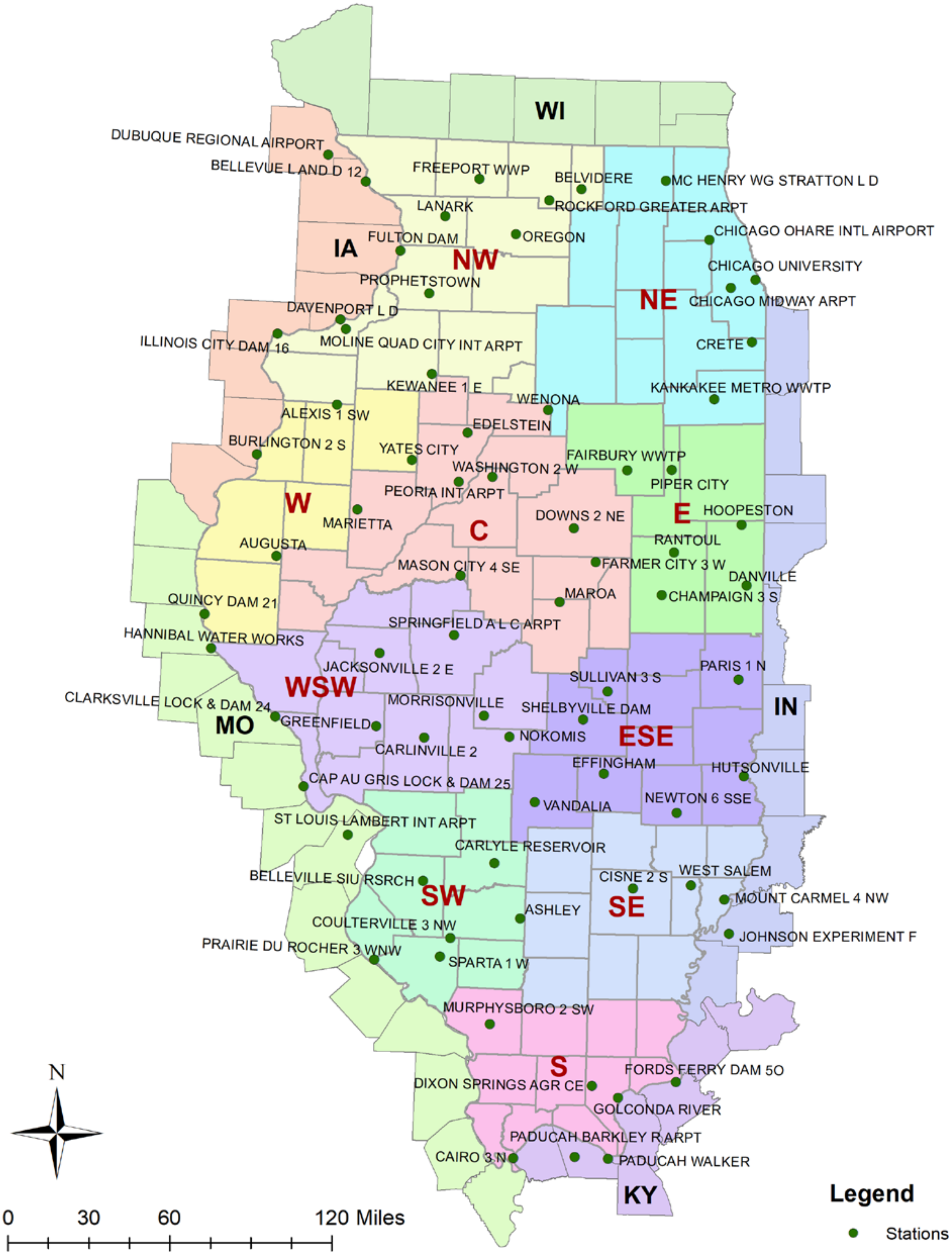

Figure 6 Hourly precipitation stations used in this study

The final data source for this study was the Cook County Precipitation Network (CCPN). This network is a collaborative study between ISWS and the US Army Corps of Engineers to produce consistent and accurate data for the Chicagoland region. The 25 recording gages have an average grid spacing of 5 to 7 miles (Bauer, 2018). A map of the stations is shown in Figure 7. As with the NOAA hourly data, the CCPN hourly data were used for this report to confirm earlier relationships developed between 24-hour and less than 24-hour amounts.

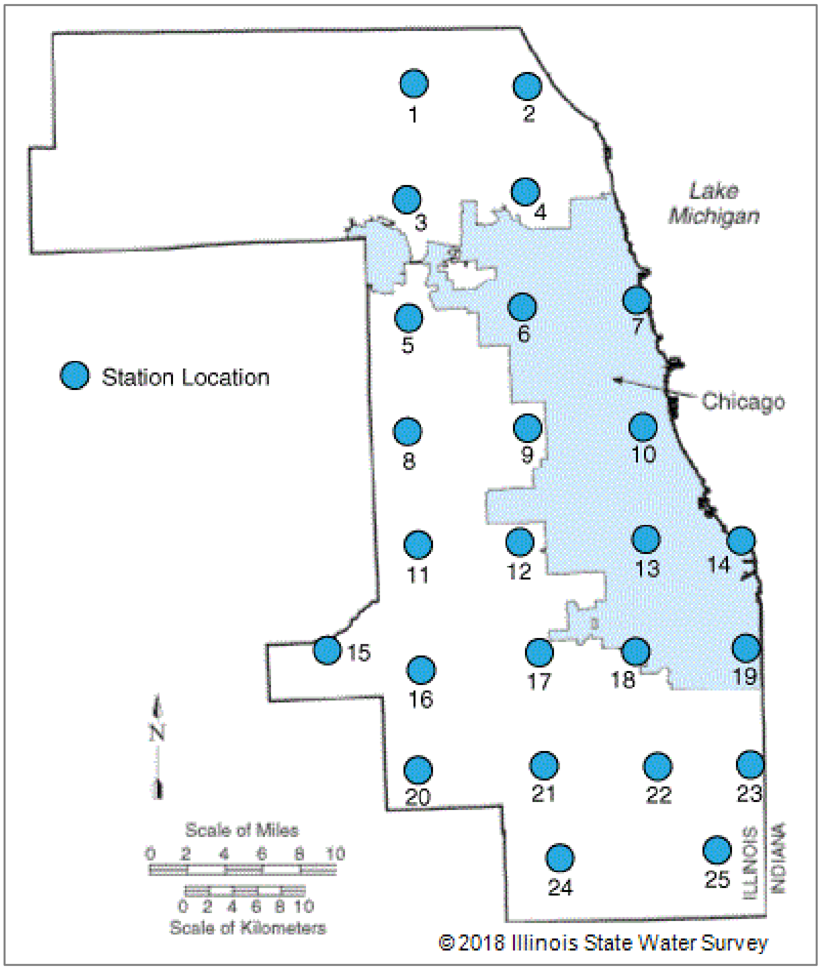

Figure 7 Precipitation stations in the Cook County Precipitation Network (CCPN)

Methodology Description

For each region (section), the annual maximum series (AMS) data observed at each station were used as inputs to produce regional (sectional) statistical frequency estimates for storm durations from 1 hour to 240 hours and for recurrence intervals from 2 to 500 years. For each duration of 24 hours or more, the frequency analysis was based on the L-moments method and Langbein's formula for debiasing. Due to significant uncertainty in hourly data, the frequency analysis for durations shorter than 24 hours was replaced by the application of newly calculated x-hour:24-hour ratios. This approach was similar to that of the original Bulletin 70. To maintain consistency with the format of the original Bulletin 70, the site estimates were averaged for each section, adjusted for temporal trends, and presented in the final tables appearing later in this text.

Annual Maximum and Partial Duration Series

Frequency estimates at a station can be calculated based on either an annual maximum series (AMS) or a partial duration series (PDS). The AMS-based method involves selecting the largest precipitation amount from each year on record for each duration of interest. In the PDS-based method, a given number of rainfall totals are selected that are larger than a predefined threshold for all durations independently of the year of occurrence. With this method, multiple events can occur in the same calendar year. Selected events need to be screened for independence, i.e., to determine if two precipitation peaks can be considered coming from the same event before inclusion in the final dataset. The PDS method uses the available precipitation information more completely than the AMS-based method does. As a result, the AMS method estimates are biased, particularly for smaller recurrence intervals. On the other hand, no method has been widely accepted for threshold selection and accounting for dependence between the events in the PDS-based approach, making the method somewhat subjective. To reconcile the strengths and weaknesses of the two methods, many precipitation frequency studies (Perica et al., 2011) used the AMS approach and then corrected for the bias using the Langbein's equation (Langbein, 1949). Similarly, in this study, the Langbein's equation (Eq. 1) was used to convert frequencies associated with AMS data to the ones with PDS data, thus providing unbiased frequency estimates.

$$T_{AMS} = \frac{1}{(1 - \exp(-\frac{1}{T_{PDS)}})} \qquad (1)$$

where T_{AMS} and T_{PDS} are the recurrence intervals (return periods) associated with AMS and PDS data, respectively. After conversion, the AMS-based frequencies of 2.54, 5.52, 10.51, 25, 50, and 100 years correspond to the PDS-based 2, 5, 10, 25, 50, and 100-year frequencies, respectively. For example, the unbiased estimate of a 2-year recurrence interval rainfall can be calculated using the AMS approach for a recurrence interval of 2.54 years.

Constrained vs. Unconstrained Daily Precipitation

Daily rainfall data include all precipitation that was recorded on a given calendar day between the fixed monitoring times, such as between 7 a.m. on a certain day and 7 a.m. on the following day. This amount may be smaller than the maximum rainfall in a given 24-hour period. Instances will occur in which the maximum 24-hour rainfall will span more than a single calendar day. Adjustment factors to account for this difference have been determined through a comparative analysis of Hershfield (1961), Huff and Neil (1959), Huff and Angel (1989), Markus et al. (2007), and Perica et al. (2011). The conversion factors are shown in Table 1. To avoid confusion between the constrained and unconstrained precipitation, all results in this report are presented in hours (e.g., 24-hour or 240-hour precipitation).

Table 1 Conversion from Constrained to Unconstrained Precipitation Adopted in this Study

From	1 day	2 days	3 days	5 days	10 days
To	24 hours	48 hours	72 hours	120 hours	240 hours
Conversion factor	1.13	1.04	1.02	1.01	1.00

Sub-Daily Precipitation Frequency Conversions

As for Bulletin 70, sub-daily precipitation frequencies were obtained for this study based on x-hour to 24-hour type conversions. The direct regional frequency analysis of sub-daily data produced significantly variable and uncertain results because of numerous factors, such as the number/spatial coverage of hourly stations, their shorter record lengths, missing/incomplete data, and questionable quality of the data at some of these stations.

To determine the conversion factors, an extensive study of the average ratios of x-hour to 24-hour rainfall was performed using the hourly data. The ratios obtained in this study by running a regional frequency analysis (RFA) for 1948 to 2017 were compared with ISWS Bulletin 70 and NOAA Atlas 14, and the differences among the ratios were not found to be significant (Table 2). The adopted conversion factors were identical to those in Bulletin 70.

Table 2 X-hr:24-hr Ratios

Storm Duration (hours)	RFA 1948-2017	Bulletin 70	Atlas 14	Adopted
1	0.42	0.47	0.47	0.47
2	0.56	0.58	0.57	0.58
3	0.64	0.64	0.63	0.64
6	0.76	0.75	0.75	0.75
12	0.87	0.87	0.86	0.87
18	0.94	0.94	N/A	0.94

Stationary Regional Frequency Analysis

Although the observed precipitation datasets were nonstationary, the authors first performed the stationary frequency analysis based on the L-moments (Hosking, 2000; Hosking and Wallis, 1997), and then adjusted the results to account for trends. The method accounting for trends was adopted from the original Bulletin 70 and described in the Nonstationary Temporal Trend Analysis section. The L-moments methodology first computed the point rainfall depths for each duration and recurrence interval at each raingage. For consistency with Bulletin 70, these depths were then averaged for each section and expressed as sectional frequencies (see the Results section). Past research results (Vogel and Fennessey, 1993) indicate that regional frequency analysis based on the L-moments is more robust and better identifies the parent distribution compared to other more traditional estimation techniques, particularly for regional studies. This methodology was also adopted by NOAA (Bonnin et al., 2006; Perica et al., 2011) and applied in previous studies in Illinois (Markus et al., 2007; Hejazi and Markus, 2009). The L-moments method uses the discordancy measure (Hosking and Wallis, 1997) to identify statistically unusual (discordant) sites in a region and the heterogeneity measure to assess if the region is homogeneous. Next, for each region, the method finds the best-fit statistical distribution among the following distributions (Hosking, 2000): Exponential, Gamma, Gumbel, Normal, Generalized Pareto, Generalized Extreme Value, Generalized Logistic, Generalized Normal, Pearson 3, and Wakeby. To construct 90 percent confidence limits, 500 synthetic datasets that have the same statistical features as the adopted distribution were generated using a Monte Carlo simulation technique (Hosking and Wallis, 1997). In this method, each synthetic dataset produces a quantile. The upper confidence limit separates the upper 5 percent and the lower 95 percent, and similarly, the lower confidence limit separates the lower 5 from the top 95 percent of all generated quantiles.

Nonstationary Temporal Trend Analysis

Traditional hydroclimatologic studies typically relied on long-term precipitation records, which have been used to estimate the probability of heavy precipitation events that will occur in the future. The underlying assumption was that the precipitation data were stationary, or in other words, that future variability will be similar to the past variability. However, numerous studies have indicated that the frequency and intensity of precipitation in Illinois have been increasing in the past several decades and will continue to increase in the future (Winters et al., 2015). Therefore, because of climate change, precipitation stationarity cannot be assumed. To account for nonstationarity, the approach used in the original Bulletin 70 was adopted. The Bulletin 70 approach divides the whole period, in this case 1948–2017, into two equal periods, 1948–1982 and 1983–2017, and then estimates frequency quantiles (e.g. 24-hour 100-year storm) for the first half (RFA_1), the second half (RFA_2), and the whole period (RFA_0). The nonstationary adjustment factor NAF is defined as

$$NAF = \frac{RFA_2}{RFA_1} \qquad (2)$$

The frequency quantile RFA, which accounts for the trend in peaks, is given by

$$RFA = NAF \cdot RFA_0 = RFA_0 \frac{RFA_2}{RFA_1} \qquad (3)$$

The trend adjustment factors used in this study are shown in Table 3. A companion report, to be published in 2019, will provide more in-depth information through nonstationarity analysis and comparisons with other approaches that have been designed to determine frequency as a function of time (e.g., Salas et al., 2018; Serago and Vogel, 2018; Cheng et al., 2014).

Table 3 Temporal Trend Adjustment Factors for 10 Sections

	Climatic section	24 hrs	48 hrs	72 hrs	120 hrs	240 hrs		Average
1	Northwest	1.07	1.07	1.03	1.05	1.12		1.07
2	Northeast	1.06	1.12	1.13	1.18	1.21		1.14
3	West	1.00	0.96	0.91	0.92	1.02		0.96
4	Central	1.02	0.94	0.94	0.97	1.08		0.99
5	East	0.99	0.94	0.92	0.96	1.02		0.97
6	West Southwest	0.99	0.97	0.98	1.02	1.10		1.01
7	East Southeast	1.05	0.97	1.02	1.01	1.12		1.03
8	Southwest	1.11	1.09	1.10	1.13	1.26		1.14
9	Southeast	1.07	1.09	1.04	1.03	1.09		1.06
10	South	0.96	1.02	1.06	1.03	0.99		1.01

Results

Frequency Estimates

To determine the precipitation frequency, the previously described regional frequency analysis was applied to the AMS data. The results were then converted to the PDS domain based on the relationship defined in Eq. 1 and adjusted for the trend (Eq. 3). These results, however, still had occasional minor inconsistencies caused by several factors, such as variable data length for different durations, which resulted in irregular frequency curves. To produce the final curves, these irregularities had to be smoothed out, which was done based on the authors' professional judgment and knowledge of specific regions and gages.

The results for all sections are shown in the following tables. Table 4 displays the key for the codes used in Table 5, where the results are presented numerically. The results are shown graphically in Figures 8–12.

Table 4 Storm and Sectional Codes for Table 5

Storm Code		*Sectional Code*	
1	240 hours	1	Northwest
2	120 hours	2	Northeast
3	72 hours	3	West
4	48 hours	4	Central
5	24 hours	5	East
6	18 hours	6	West Southwest
7	12 hours	7	East Southeast
8	6 hours	8	Southwest
9	3 hours	9	Southeast
10	2 hours	10	South
11	1 hour		

Table 5 Rainfall Frequencies

		Rainfall (inches) for given recurrence interval						
Storm code	*Section code*	*2-year*	*5-year*	*10-year*	*25-year*	*50-year*	*100-year*	*500-year*
1	1	5.48	6.86	7.98	9.55	10.84	12.14	15.65
1	2	5.60	7.09	8.25	9.90	11.26	12.65	16.00
1	3	5.62	7.00	8.10	9.60	10.65	11.64	13.99
1	4	5.46	6.87	8.04	9.53	10.55	11.50	13.65
1	5	5.50	6.84	7.90	9.35	10.45	11.55	13.96
1	6	6.00	7.38	8.47	9.95	10.99	11.95	14.08
1	7	6.57	7.86	8.90	10.20	11.20	12.06	13.95
1	8	6.75	8.18	9.30	10.80	11.95	13.10	15.95
1	9	7.06	8.30	9.22	10.37	11.21	11.96	13.75
1	10	6.36	7.65	8.76	10.40	11.66	12.96	16.20
2	1	4.35	5.51	6.46	7.88	8.96	10.20	13.33
2	2	4.42	5.63	6.68	8.16	9.39	10.66	13.81
2	3	4.51	5.66	6.62	7.94	8.93	9.83	11.99
2	4	4.27	5.42	6.42	7.75	8.72	9.60	11.54
2	5	4.34	5.43	6.41	7.73	8.79	9.80	11.93
2	6	4.49	5.60	6.49	7.77	8.69	9.57	11.53
2	7	5.00	6.11	7.01	8.23	9.11	9.95	11.71
2	8	5.31	6.51	7.47	8.79	9.81	10.84	13.45
2	9	5.73	6.78	7.60	8.64	9.47	10.20	11.97
2	10	5.18	6.30	7.29	8.69	9.78	10.91	13.84
3	1	3.90	4.95	5.87	7.21	8.30	9.45	12.30
3	2	3.97	5.08	6.05	7.49	8.64	9.85	12.81
3	3	4.11	5.18	6.08	7.34	8.31	9.18	11.27
3	4	3.88	4.96	5.90	7.17	8.09	8.98	10.81
3	5	3.88	4.90	5.78	7.04	8.01	8.93	11.00
3	6	4.00	5.00	5.83	7.01	7.91	8.73	10.61
3	7	4.35	5.37	6.19	7.34	8.19	8.97	10.57
3	8	4.74	5.82	6.71	7.96	8.89	9.86	12.32
3	9	5.13	6.09	6.86	7.87	8.63	9.34	10.93
3	10	4.54	5.61	6.50	7.78	8.79	9.86	12.55

Table 5 (continued)

		Rainfall (inches) for given recurrence interval						
Storm code	*Section code*	*2-year*	*5-year*	*10-year*	*25-year*	*50-year*	*100-year*	*500-year*
4	1	3.61	4.59	5.43	6.72	7.73	8.83	11.53
4	2	3.66	4.71	5.62	6.99	8.13	9.28	12.10
4	3	3.76	4.76	5.62	6.81	7.72	8.60	10.58
4	4	3.59	4.61	5.47	6.65	7.55	8.40	10.21
4	5	3.54	4.49	5.32	6.48	7.38	8.27	10.26
4	6	3.66	4.61	5.38	6.48	7.33	8.11	9.93
4	7	3.92	4.85	5.61	6.67	7.46	8.21	9.76
4	8	4.28	5.29	6.10	7.25	8.15	9.08	11.40
4	9	4.64	5.54	6.27	7.24	7.94	8.58	10.06
4	10	4.06	5.02	5.86	7.04	8.01	9.02	11.56
5	1	3.34	4.22	5.03	6.20	7.20	8.25	10.84
5	2	3.34	4.30	5.15	6.45	7.50	8.57	11.24
5	3	3.48	4.45	5.24	6.38	7.25	8.06	9.91
5	4	3.32	4.30	5.10	6.20	7.05	7.85	9.53
5	5	3.12	3.97	4.71	5.78	6.62	7.43	9.32
5	6	3.23	4.07	4.76	5.79	6.56	7.31	9.04
5	7	3.49	4.33	5.00	5.98	6.71	7.40	8.84
5	8	3.69	4.56	5.27	6.30	7.14	7.96	10.06
5	9	4.07	4.89	5.55	6.42	7.06	7.68	8.99
5	10	3.63	4.52	5.28	6.38	7.29	8.23	10.57
6	1	3.14	3.97	4.73	5.83	6.77	7.75	10.19
6	2	3.14	4.04	4.84	6.06	7.05	8.06	10.57
6	3	3.27	4.18	4.93	6.00	6.82	7.58	9.32
6	4	3.12	4.04	4.79	5.83	6.63	7.38	8.96
6	5	2.93	3.73	4.43	5.43	6.22	6.98	8.76
6	6	3.04	3.83	4.47	5.44	6.17	6.87	8.50
6	7	3.28	4.07	4.70	5.62	6.31	6.96	8.31
6	8	3.47	4.29	4.95	5.92	6.71	7.48	9.45
6	9	3.83	4.60	5.22	6.03	6.64	7.22	8.45
6	10	3.41	4.25	4.96	6.00	6.85	7.73	9.93

Table 5 (continued)

		Rainfall (inches) for given recurrence interval						
Storm code	*Section code*	*2-year*	*5-year*	*10-year*	*25-year*	*50-year*	*100-year*	*500-year*
7	1	2.91	3.67	4.38	5.40	6.26	7.18	9.43
7	2	2.91	3.74	4.48	5.61	6.53	7.46	9.78
7	3	3.03	3.87	4.56	5.55	6.31	7.01	8.62
7	4	2.89	3.74	4.44	5.39	6.13	6.83	8.29
7	5	2.71	3.45	4.10	5.03	5.76	6.46	8.11
7	6	2.81	3.54	4.14	5.04	5.71	6.36	7.86
7	7	3.04	3.77	4.35	5.20	5.84	6.44	7.69
7	8	3.21	3.97	4.58	5.48	6.21	6.93	8.75
7	9	3.54	4.25	4.83	5.59	6.14	6.69	7.82
7	10	3.16	3.93	4.59	5.55	6.34	7.16	9.19
8	1	2.51	3.17	3.77	4.65	5.40	6.19	8.13
8	2	2.51	3.23	3.86	4.84	5.63	6.43	8.43
8	3	2.61	3.34	3.93	4.79	5.44	6.05	7.43
8	4	2.49	3.23	3.83	4.65	5.29	5.89	7.15
8	5	2.34	2.98	3.53	4.34	4.97	5.57	6.99
8	6	2.42	3.05	3.57	4.34	4.92	5.48	6.78
8	7	2.62	3.25	3.75	4.49	5.03	5.55	6.63
8	8	2.77	3.42	3.95	4.73	5.36	5.97	7.54
8	9	3.05	3.67	4.16	4.82	5.30	5.76	6.74
8	10	2.72	3.39	3.96	4.79	5.47	6.17	7.92
9	1	2.14	2.70	3.22	3.97	4.61	5.28	6.94
9	2	2.14	2.75	3.30	4.13	4.80	5.49	7.20
9	3	2.23	2.85	3.35	4.08	4.64	5.16	6.34
9	4	2.12	2.75	3.26	3.97	4.51	5.02	6.10
9	5	2.00	2.54	3.01	3.70	4.24	4.76	5.97
9	6	2.07	2.60	3.05	3.71	4.20	4.68	5.79
9	7	2.23	2.77	3.20	3.83	4.29	4.74	5.66
9	8	2.36	2.92	3.37	4.03	4.57	5.09	6.44
9	9	2.60	3.13	3.55	4.11	4.52	4.92	5.75
9	10	2.32	2.89	3.38	4.09	4.66	5.26	6.76

Table 5 (continued)

		Rainfall (inches) for given recurrence interval						
Storm code	*Section code*	*2-year*	*5-year*	*10-year*	*25-year*	*50-year*	*100-year*	*500-year*
10	1	1.94	2.45	2.92	3.60	4.17	4.78	6.29
10	2	1.94	2.49	2.99	3.74	4.35	4.97	6.52
10	3	2.02	2.58	3.04	3.70	4.21	4.67	5.75
10	4	1.93	2.49	2.96	3.60	4.09	4.55	5.53
10	5	1.81	2.30	2.73	3.35	3.84	4.31	5.41
10	6	1.87	2.36	2.76	3.36	3.80	4.24	5.24
10	7	2.02	2.51	2.90	3.47	3.89	4.29	5.13
10	8	2.14	2.64	3.06	3.65	4.14	4.62	5.83
10	9	2.36	2.84	3.22	3.72	4.09	4.46	5.21
10	10	2.10	2.62	3.06	3.70	4.23	4.77	6.13
11	1	1.57	1.98	2.36	2.92	3.38	3.88	5.09
11	2	1.57	2.02	2.42	3.03	3.53	4.03	5.28
11	3	1.64	2.09	2.46	3.00	3.41	3.79	4.66
11	4	1.56	2.02	2.40	2.91	3.31	3.69	4.48
11	5	1.47	1.87	2.21	2.72	3.11	3.49	4.38
11	6	1.52	1.91	2.24	2.72	3.08	3.44	4.25
11	7	1.64	2.04	2.35	2.81	3.15	3.48	4.15
11	8	1.73	2.14	2.48	2.96	3.36	3.74	4.73
11	9	1.91	2.30	2.61	3.02	3.32	3.61	4.23
11	10	1.71	2.12	2.48	3.00	3.43	3.87	4.97

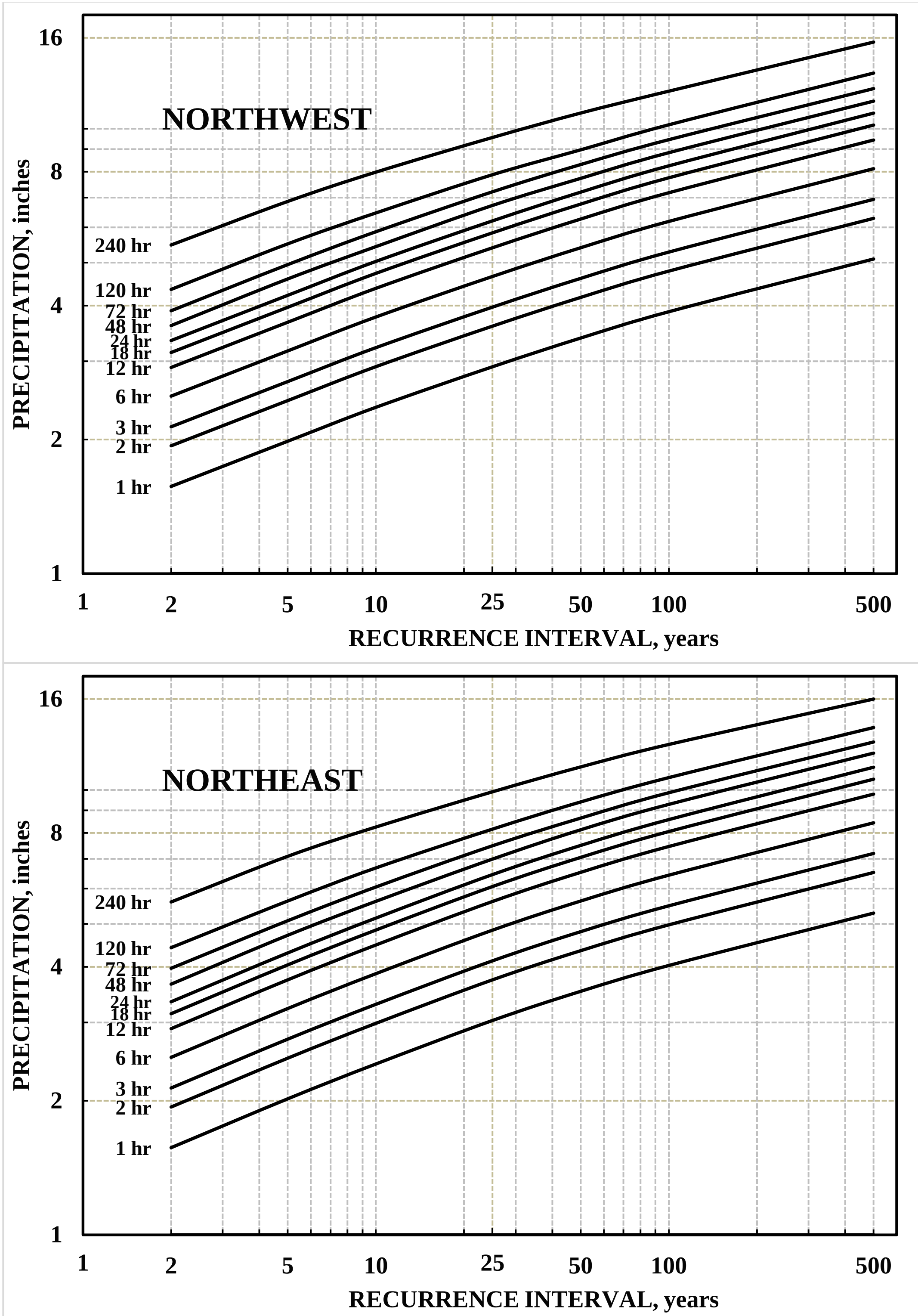

Figure 8 Frequency distributions of precipitation for Illinois climatic sections Northwest and Northeast for storm periods of 1 hour to 240 hours days and recurrence intervals of 2 to 100 years.

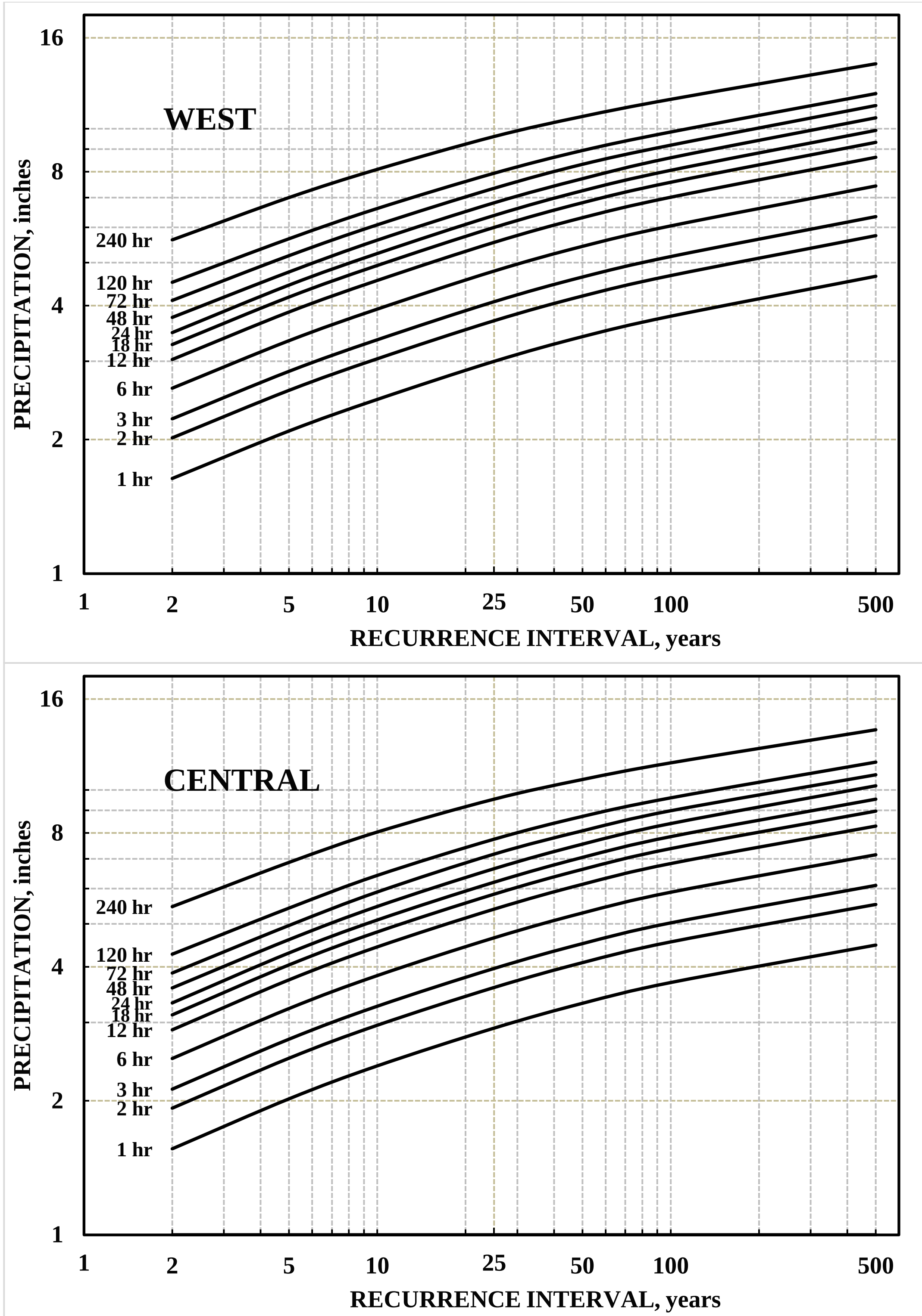

Figure 9 Frequency distributions of precipitation for Illinois climatic sections west and central for storm periods of 1 hour to 240 hours and recurrence intervals of 2 to 100 years

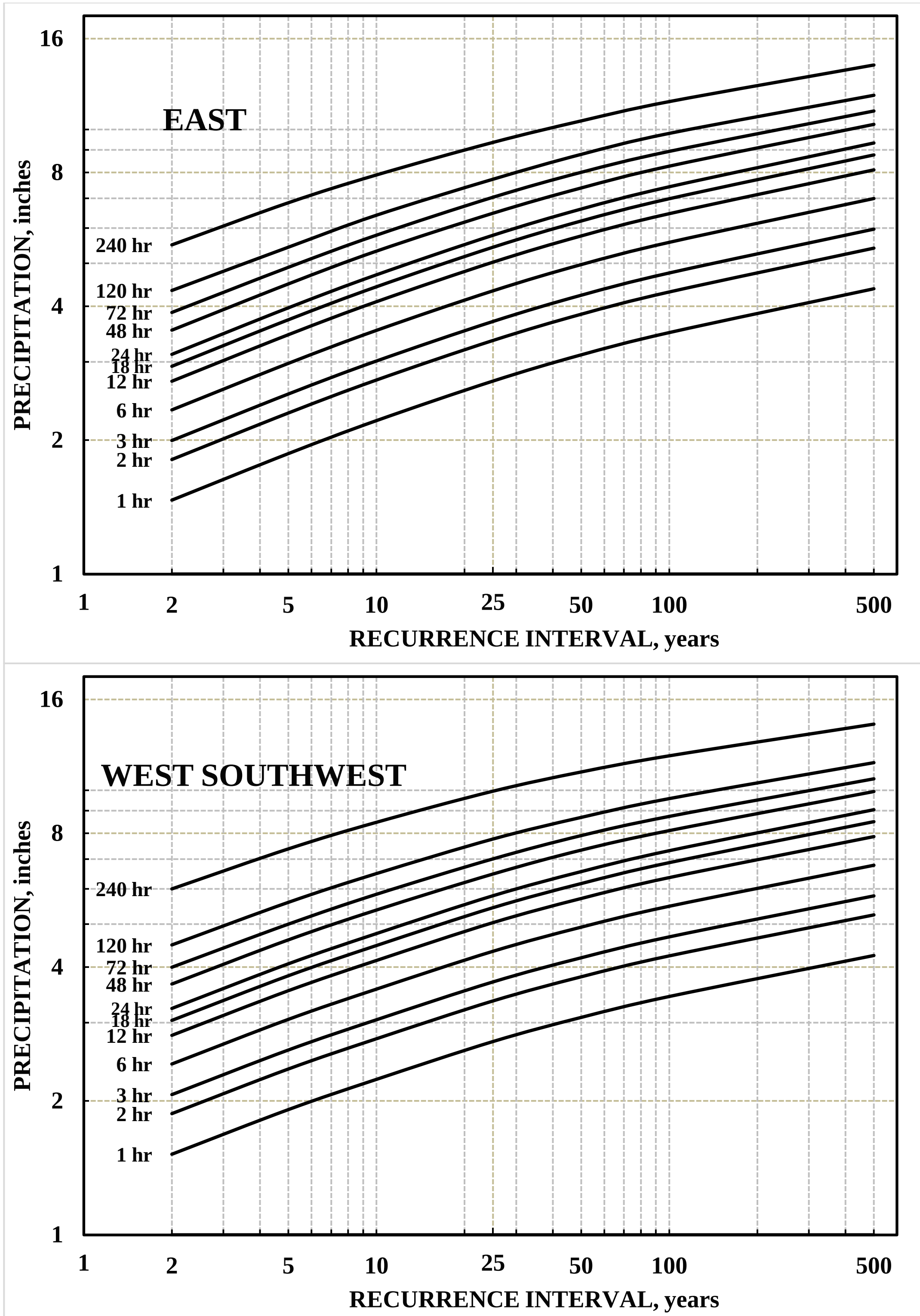

Figure 10 Frequency distributions of precipitation for Illinois climatic sections east and west southwest for storm periods of 1 hour to 240 hours and recurrence intervals of 2 to 100 years

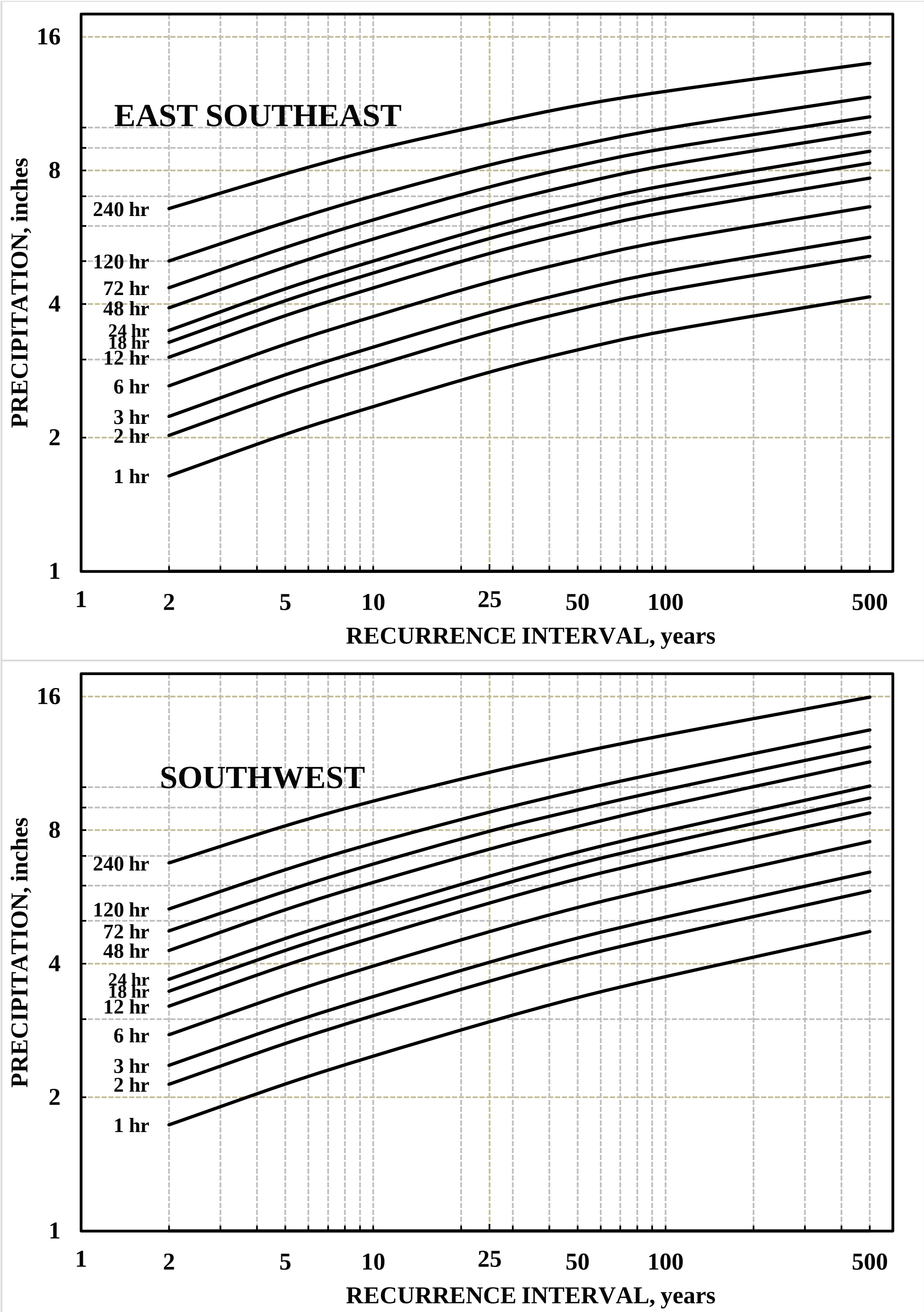

Figure 11 Frequency distributions of precipitation for Illinois climatic sections east southeast and southwest for storm periods of 1 hour to 240 hours and recurrence intervals of 2 to 100 years

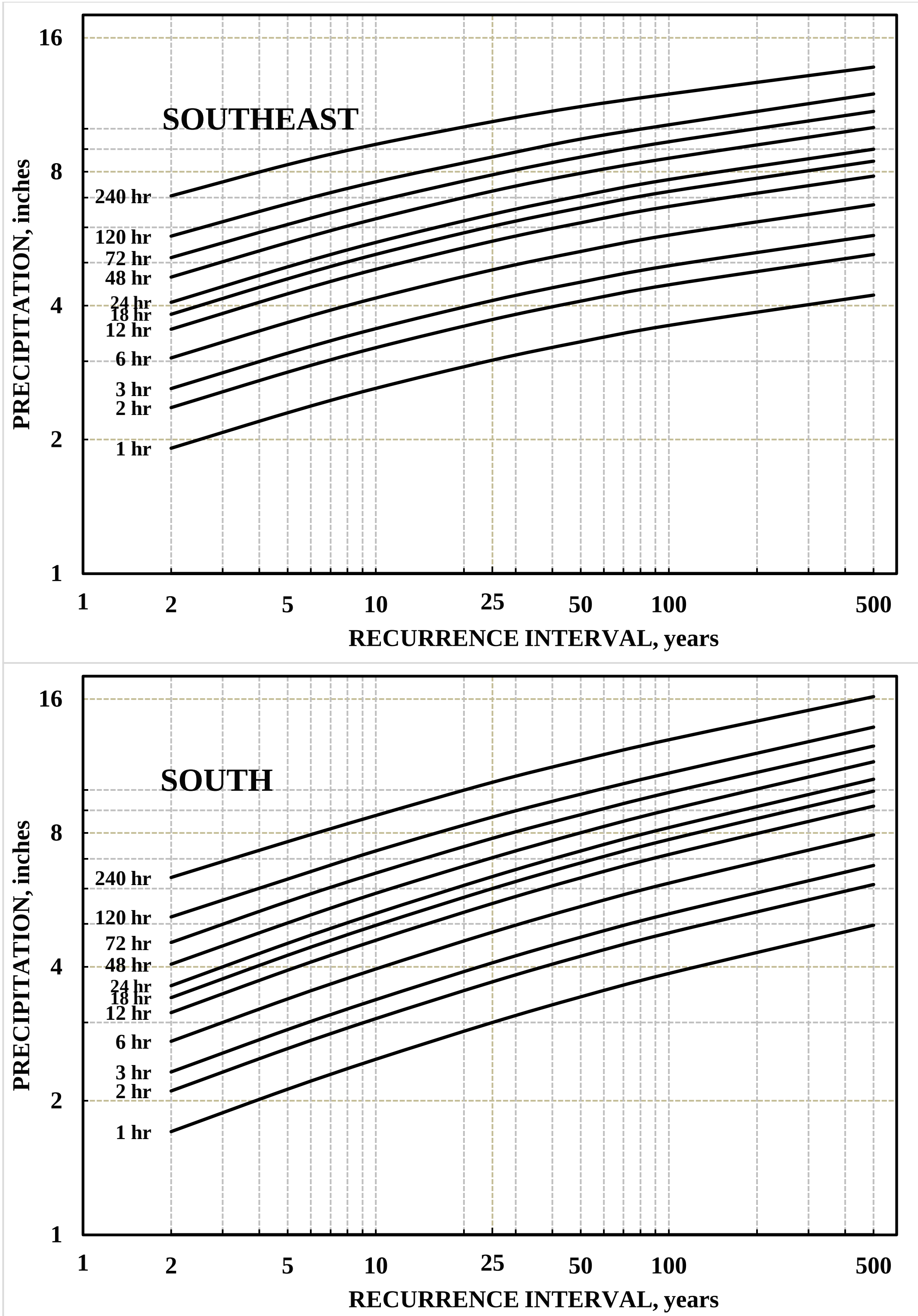

Figure 12 Frequency distributions of precipitation for Illinois climatic sections southeast and south for storm periods of 1 hour to 240 hours and recurrence intervals of 2 to 100 years

Confidence Limits

Confidence limits were calculated based on the methodology described in the previous Frequency Estimates section. Confidence limits are provided for section codes 1–10 and for storm codes 1–11 (Table 4), and are shown in Table 6.

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
1	1	**5.48** (5.04 - 5.95)	**6.86** (6.30 - 7.48)	**7.98** (7.30 - 8.73)	**9.55** (8.67 - 10.53)	**10.84** (9.76 - 12.06)	**12.14** (10.82 - 13.63)	**15.65** (13.53 - 18.10)
1	2	**5.60** (5.14 - 6.09)	**7.09** (6.48 - 7.75)	**8.25** (7.49 - 9.08)	**9.90** (8.89 - 11.04)	**11.26** (10.01 - 12.72)	**12.65** (11.08 - 14.51)	**16.00** (13.40 - 19.13)
1	3	**5.62** (5.21 - 6.11)	**7.00** (6.47 - 7.62)	**8.10** (7.44 - 8.86)	**9.6** (8.73 - 10.58)	**10.65** (9.59 - 11.84)	**11.64** (10.34 - 13.05)	**13.99** (11.96 - 16.14)
1	4	**5.46** (5.07 - 5.90)	**6.87** (6.36 - 7.43)	**8.04** (7.43 - 8.71)	**9.53** (8.75 - 10.38)	**10.55** (9.62 - 11.56)	**11.5** (10.40 - 12.70)	**13.65** (12.02 - 15.40)
1	5	**5.50** (5.14 - 5.89)	**6.84** (6.38 - 7.34)	**7.9** (7.34 - 8.50)	**9.35** (8.64 - 10.12)	**10.45** (9.60 - 11.40)	**11.55** (10.52 - 12.71)	**13.96** (12.39 - 15.72)
1	6	**6.00** (5.55 - 6.51)	**7.38** (6.82 - 8.02)	**8.47** (7.81 - 9.21)	**9.95** (9.11 - 10.88)	**10.99** (9.97 - 12.09)	**11.95** (10.74 - 13.26)	**14.08** (12.31 - 15.96)
1	7	**6.57** (6.03 - 7.14)	**7.86** (7.22 - 8.55)	**8.90** (8.16 - 9.72)	**10.20** (9.29 - 11.27)	**11.20** (10.09 - 12.49)	**12.06** (10.71 - 13.62)	**13.95** (11.94 - 16.28)
1	8	**6.75** (6.10 - 7.44)	**8.18** (7.35 - 9.06)	**9.30** (8.26 - 10.40)	**10.80** (9.38 - 12.30)	**11.95** (10.16 - 13.87)	**13.10** (10.84 - 15.56)	**15.95** (12.28 - 20.09)
1	9	**7.06** (6.45 - 7.73)	**8.30** (7.54 - 9.12)	**9.22** (8.32 - 10.19)	**10.37** (9.21 - 11.62)	**11.21** (9.75 - 12.71)	**11.96** (10.18 - 13.74)	**13.75** (11.06 - 16.40)
1	10	**6.36** (5.81 - 6.92)	**7.65** (6.94 - 8.38)	**8.76** (7.87 - 9.67)	**10.40** (9.19 - 11.69)	**11.66** (10.07 - 13.35)	**12.96** (10.92 - 15.16)	**16.20** (12.63 - 20.04)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
2	1	**4.35** (3.96 - 4.77)	**5.51** (5.00 - 6.07)	**6.46** (5.84 - 7.16)	**7.88** (7.07 - 8.80)	**8.96** (7.99 - 10.12)	**10.20** (9.01 - 11.67)	**13.33** (11.44 - 15.78)
2	2	**4.42** (4.02 - 4.83)	**5.63** (5.09 - 6.18)	**6.68** (6.01 - 7.38)	**8.16** (7.26 - 9.12)	**9.39** (8.25 - 10.63)	**10.66** (9.22 - 12.22)	**13.81** (11.44 - 16.42)
2	3	**4.51** (4.14 - 4.92)	**5.66** (5.18 - 6.19)	**6.62** (6.03 - 7.29)	**7.94** (7.16 - 8.86)	**8.93** (7.97 - 10.12)	**9.83** (8.66 - 11.33)	**11.99** (10.11 - 14.43)
2	4	**4.27** (3.92 - 4.66)	**5.42** (4.97 - 5.92)	**6.42** (5.87 - 7.02)	**7.75** (7.03 - 8.53)	**8.72** (7.84 - 9.67)	**9.6** (8.54 - 10.73)	**11.54** (10.02 - 13.21)
2	5	**4.34** (4.00 - 4.71)	**5.43** (5.00 - 5.90)	**6.41** (5.89 - 6.99)	**7.73** (7.06 - 8.49)	**8.79** (7.98 - 9.75)	**9.8** (8.81 - 11.01)	**11.93** (10.42 - 13.87)
2	6	**4.49** (4.13 - 4.90)	**5.60** (5.14 - 6.12)	**6.49** (5.95 - 7.13)	**7.77** (7.06 - 8.59)	**8.69** (7.84 - 9.69)	**9.57** (8.54 - 10.78)	**11.53** (9.93 - 13.35)
2	7	**5.00** (4.60 - 5.45)	**6.11** (5.60 - 6.68)	**7.01** (6.41 - 7.70)	**8.23** (7.45 - 9.11)	**9.11** (8.16 - 10.19)	**9.95** (8.80 - 11.27)	**11.71** (9.95 - 13.69)
2	8	**5.31** (4.83 - 5.86)	**6.51** (5.90 - 7.23)	**7.47** (6.74 - 8.37)	**8.79** (7.82 - 9.97)	**9.81** (8.62 - 11.29)	**10.84** (9.36 - 12.68)	**13.45** (11.00 - 16.39)
2	9	**5.73** (5.19 - 6.31)	**6.78** (6.12 - 7.50)	**7.60** (6.81 - 8.49)	**8.64** (7.63 - 9.84)	**9.47** (8.23 - 10.99)	**10.20** (8.67 - 12.09)	**11.97** (9.50 - 14.95)
2	10	**5.18** (4.71 - 5.71)	**6.30** (5.71 - 6.99)	**7.29** (6.56 - 8.18)	**8.69** (7.68 - 9.94)	**9.78** (8.47 - 11.41)	**10.91** (9.22 - 13.02)	**13.84** (10.96 - 17.59)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
3	1	**3.9** (3.52 - 4.28)	**4.95** (4.47 - 5.46)	**5.87** (5.28 - 6.52)	**7.21** (6.46 - 8.12)	**8.30** (7.39 - 9.46)	**9.45** (8.33 - 10.91)	**12.30** (10.56 - 14.76)
3	2	**3.97** (3.60 - 4.36)	**5.08** (4.59 - 5.60)	**6.05** (5.44 - 6.71)	**7.49** (6.69 - 8.39)	**8.64** (7.66 - 9.78)	**9.85** (8.63 - 11.29)	**12.81** (10.82 - 15.18)
3	3	**4.11** (3.77 - 4.50)	**5.18** (4.74 - 5.71)	**6.08** (5.53 - 6.76)	**7.34** (6.61 - 8.27)	**8.31** (7.39 - 9.50)	**9.18** (8.05 - 10.70)	**11.27** (9.42 - 13.83)
3	4	**3.88** (3.55 - 4.25)	**4.96** (4.53 - 5.45)	**5.90** (5.37 - 6.51)	**7.17** (6.48 - 7.98)	**8.09** (7.25 - 9.09)	**8.98** (7.97 - 10.21)	**10.81** (9.30 - 12.69)
3	5	**3.88** (3.57 - 4.19)	**4.9** (4.50 - 5.32)	**5.78** (5.30 - 6.32)	**7.04** (6.42 - 7.77)	**8.01** (7.24 - 8.94)	**8.93** (7.98 - 10.10)	**11** (9.56 - 12.94)
3	6	**4.00** (3.65 - 4.38)	**5.00** (4.55 - 5.49)	**5.83** (5.28 - 6.44)	**7.01** (6.28 - 7.81)	**7.91** (7.01 - 8.91)	**8.73** (7.64 - 9.96)	**10.61** (8.93 - 12.54)
3	7	**4.35** (3.99 - 4.74)	**5.37** (4.91 - 5.87)	**6.19** (5.65 - 6.80)	**7.34** (6.65 - 8.14)	**8.19** (7.34 - 9.16)	**8.97** (7.94 - 10.13)	**10.57** (9.02 - 12.32)
3	8	**4.74** (4.31 - 5.23)	**5.82** (5.27 - 6.45)	**6.71** (6.04 - 7.48)	**7.96** (7.07 - 8.94)	**8.89** (7.78 - 10.10)	**9.86** (8.47 - 11.35)	**12.32** (10.09 - 14.72)
3	9	**5.13** (4.66 - 5.65)	**6.09** (5.51 - 6.74)	**6.86** (6.17 - 7.65)	**7.87** (6.95 - 8.89)	**8.63** (7.49 - 9.87)	**9.34** (7.95 - 10.87)	**10.93** (8.80 - 13.29)
3	10	**4.54** (4.09 - 5.01)	**5.61** (5.04 - 6.23)	**6.50** (5.80 - 7.27)	**7.78** (6.86 - 8.83)	**8.79** (7.62 - 10.16)	**9.86** (8.38 - 11.63)	**12.55** (10.05 - 15.65)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
4	1	**3.61** (3.26 - 3.97)	**4.59** (4.14 - 5.09)	**5.43** (4.89 - 6.06)	**6.72** (6.01 - 7.59)	**7.73** (6.87 - 8.84)	**8.83** (7.78 - 10.25)	**11.53** (9.84 - 13.98)
4	2	**3.66** (3.31 - 4.02)	**4.71** (4.26 - 5.20)	**5.62** (5.06 - 6.24)	**6.99** (6.25 - 7.87)	**8.13** (7.21 - 9.26)	**9.28** (8.15 - 10.73)	**12.10** (10.33 - 14.56)
4	3	**3.76** (3.46 - 4.10)	**4.76** (4.36 - 5.19)	**5.62** (5.13 - 6.15)	**6.81** (6.17 - 7.52)	**7.72** (6.92 - 8.62)	**8.6** (7.63 - 9.73)	**10.58** (9.06 - 12.40)
4	4	**3.59** (3.26 - 3.94)	**4.61** (4.18 - 5.07)	**5.47** (4.96 - 6.04)	**6.65** (5.99 - 7.41)	**7.55** (6.77 - 8.48)	**8.40** (7.47 - 9.53)	**10.21** (8.86 - 11.92)
4	5	**3.54** (3.25 - 3.83)	**4.49** (4.12 - 4.89)	**5.32** (4.87 - 5.82)	**6.48** (5.90 - 7.14)	**7.38** (6.67 - 8.22)	**8.27** (7.41 - 9.32)	**10.26** (8.94 - 12.01)
4	6	**3.66** (3.35 - 4.01)	**4.61** (4.19 - 5.06)	**5.38** (4.88 - 5.94)	**6.48** (5.84 - 7.22)	**7.33** (6.55 - 8.24)	**8.11** (7.18 - 9.21)	**9.93** (8.53 - 11.62)
4	7	**3.92** (3.57 - 4.27)	**4.85** (4.41 - 5.30)	**5.61** (5.09 - 6.16)	**6.67** (6.02 - 7.39)	**7.46** (6.68 - 8.35)	**8.21** (7.28 - 9.28)	**9.76** (8.39 - 11.36)
4	8	**4.28** (3.88 - 4.73)	**5.29** (4.77 - 5.86)	**6.1** (5.46 - 6.81)	**7.25** (6.43 - 8.20)	**8.15** (7.14 - 9.34)	**9.08** (7.85 - 10.56)	**11.4** (9.42 - 13.79)
4	9	**4.64** (4.22 - 5.12)	**5.54** (5.02 - 6.15)	**6.27** (5.63 - 7.01)	**7.24** (6.42 - 8.22)	**7.94** (6.92 - 9.16)	**8.58** (7.34 - 10.07)	**10.06** (8.13 - 12.37)
4	10	**4.06** (3.66 - 4.45)	**5.02** (4.51 - 5.53)	**5.86** (5.22 - 6.50)	**7.04** (6.22 - 7.95)	**8.01** (6.98 - 9.20)	**9.02** (7.72 - 10.56)	**11.56** (9.38 - 14.33)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
5	1	**3.34** (3.00 - 3.69)	**4.22** (3.79 - 4.68)	**5.03** (4.50 - 5.61)	**6.20** (5.51 - 6.99)	**7.20** (6.34 - 8.21)	**8.25** (7.20 - 9.54)	**10.84** (9.16 - 13.00)
5	2	**3.34** (3.00 - 3.69)	**4.30** (3.85 - 4.77)	**5.15** (4.60 - 5.73)	**6.45** (5.71 - 7.26)	**7.50** (6.59 - 8.55)	**8.57** (7.46 - 9.93)	**11.24** (9.48 - 13.63)
5	3	**3.48** (3.19 - 3.79)	**4.45** (4.07 - 4.86)	**5.24** (4.79 - 5.74)	**6.38** (5.81 - 7.05)	**7.25** (6.56 - 8.09)	**8.06** (7.23 - 9.07)	**9.91** (8.61 - 11.47)
5	4	**3.32** (3.01 - 3.65)	**4.30** (3.89 - 4.74)	**5.10** (4.61 - 5.64)	**6.20** (5.58 - 6.91)	**7.05** (6.31 - 7.93)	**7.85** (6.99 - 8.92)	**9.53** (8.31 - 11.16)
5	5	**3.12** (2.86 - 3.38)	**3.97** (3.64 - 4.31)	**4.71** (4.30 - 5.15)	**5.78** (5.25 - 6.38)	**6.62** (5.97 - 7.39)	**7.43** (6.63 - 8.41)	**9.32** (8.08 - 10.96)
5	6	**3.23** (2.95 - 3.54)	**4.07** (3.71 - 4.47)	**4.76** (4.32 - 5.26)	**5.79** (5.21 - 6.45)	**6.56** (5.85 - 7.37)	**7.31** (6.45 - 8.30)	**9.04** (7.73 - 10.59)
5	7	**3.49** (3.18 - 3.80)	**4.33** (3.93 - 4.74)	**5.00** (4.53 - 5.50)	**5.98** (5.39 - 6.64)	**6.71** (6.00 - 7.54)	**7.40** (6.54 - 8.42)	**8.84** (7.58 - 10.44)
5	8	**3.69** (3.36 - 4.04)	**4.56** (4.15 - 5.01)	**5.27** (4.78 - 5.82)	**6.3** (5.67 - 7.03)	**7.14** (6.37 - 8.03)	**7.96** (7.03 - 9.05)	**10.06** (8.60 - 11.78)
5	9	**4.07** (3.71 - 4.44)	**4.89** (4.45 - 5.35)	**5.55** (5.03 - 6.10)	**6.42** (5.79 - 7.12)	**7.06** (6.32 - 7.91)	**7.68** (6.80 - 8.70)	**8.99** (7.73 - 10.51)
5	10	**3.63** (3.29 - 4.00)	**4.52** (4.08 - 5.01)	**5.28** (4.73 - 5.88)	**6.38** (5.66 - 7.21)	**7.29** (6.36 - 8.36)	**8.23** (7.07 - 9.59)	**10.57** (8.67 - 13.03)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
6	1	**3.14** (2.82 - 3.47)	**3.97** (3.56 - 4.40)	**4.73** (4.23 - 5.28)	**5.83** (5.18 - 6.57)	**6.77** (5.96 - 7.71)	**7.75** (6.77 - 8.96)	**10.19** (8.61 - 12.22)
6	2	**3.14** (2.82 - 3.47)	**4.04** (3.62 - 4.48)	**4.84** (4.32 - 5.39)	**6.06** (5.37 - 6.82)	**7.05** (6.19 - 8.03)	**8.06** (7.01 - 9.33)	**10.57** (8.91 - 12.81)
6	3	**3.27** (3.00 - 3.57)	**4.18** (3.83 - 4.57)	**4.93** (4.50 - 5.40)	**6.00** (5.46 - 6.62)	**6.82** (6.16 - 7.60)	**7.58** (6.80 - 8.53)	**9.32** (8.09 - 10.78)
6	4	**3.12** (2.83 - 3.43)	**4.04** (3.66 - 4.46)	**4.79** (4.34 - 5.31)	**5.83** (5.24 - 6.50)	**6.63** (5.93 - 7.46)	**7.38** (6.57 - 8.39)	**8.96** (7.81 - 10.49)
6	5	**2.93** (2.69 - 3.18)	**3.73** (3.42 - 4.06)	**4.43** (4.04 - 4.84)	**5.43** (4.94 - 6.00)	**6.22** (5.61 - 6.94)	**6.98** (6.23 - 7.90)	**8.76** (7.59 - 10.30)
6	6	**3.04** (2.77 - 3.32)	**3.83** (3.48 - 4.20)	**4.47** (4.06 - 4.94)	**5.44** (4.90 - 6.06)	**6.17** (5.50 - 6.93)	**6.87** (6.06 - 7.81)	**8.50** (7.26 - 9.95)
6	7	**3.28** (2.99 - 3.57)	**4.07** (3.70 - 4.45)	**4.70** (4.26 - 5.17)	**5.62** (5.07 - 6.25)	**6.31** (5.64 - 7.09)	**6.96** (6.15 - 7.91)	**8.31** (7.13 - 9.81)
6	8	**3.47** (3.16 - 3.80)	**4.29** (3.90 - 4.71)	**4.95** (4.49 - 5.47)	**5.92** (5.33 - 6.60)	**6.71** (5.99 - 7.55)	**7.48** (6.61 - 8.51)	**9.45** (8.08 - 11.07)
6	9	**3.83** (3.49 - 4.17)	**4.6** (4.19 - 5.03)	**5.22** (4.73 - 5.74)	**6.03** (5.44 - 6.70)	**6.64** (5.94 - 7.43)	**7.22** (6.39 - 8.18)	**8.45** (7.26 - 9.88)
6	10	**3.41** (3.10 - 3.76)	**4.25** (3.83 - 4.71)	**4.96** (4.45 - 5.53)	**6** (5.32 - 6.78)	**6.85** (5.98 - 7.86)	**7.73** (6.64 - 9.02)	**9.93** (8.15 - 12.25)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
7	1	**2.91** (2.61 - 3.21)	**3.67** (3.29 - 4.07)	**4.38** (3.92 - 4.88)	**5.40** (4.80 - 6.08)	**6.26** (5.52 - 7.14)	**7.18** (6.26 - 8.30)	**9.43** (7.97 - 11.31)
7	2	**2.91** (2.61 - 3.21)	**3.74** (3.35 - 4.15)	**4.48** (4.00 - 4.99)	**5.61** (4.97 - 6.32)	**6.53** (5.73 - 7.44)	**7.46** (6.49 - 8.64)	**9.78** (8.25 - 11.86)
7	3	**3.03** (2.78 - 3.30)	**3.87** (3.54 - 4.23)	**4.56** (4.17 - 5.00)	**5.55** (5.05 - 6.13)	**6.31** (5.70 - 7.03)	**7.01** (6.29 - 7.89)	**8.62** (7.49 - 9.98)
7	4	**2.89** (2.62 - 3.18)	**3.74** (3.39 - 4.13)	**4.44** (4.01 - 4.91)	**5.39** (4.85 - 6.01)	**6.13** (5.49 - 6.90)	**6.83** (6.08 - 7.76)	**8.29** (7.23 - 9.71)
7	5	**2.71** (2.49 - 2.94)	**3.45** (3.16 - 3.75)	**4.10** (3.74 - 4.48)	**5.03** (4.57 - 5.55)	**5.76** (5.19 - 6.43)	**6.46** (5.77 - 7.32)	**8.11** (7.03 - 9.53)
7	6	**2.81** (2.56 - 3.08)	**3.54** (3.23 - 3.89)	**4.14** (3.76 - 4.57)	**5.04** (4.53 - 5.61)	**5.71** (5.09 - 6.41)	**6.36** (5.61 - 7.23)	**7.86** (6.72 - 9.21)
7	7	**3.04** (2.76 - 3.31)	**3.77** (3.42 - 4.12)	**4.35** (3.94 - 4.79)	**5.2** (4.69 - 5.78)	**5.84** (5.22 - 6.56)	**6.44** (5.69 - 7.32)	**7.69** (6.60 - 9.08)
7	8	**3.21** (2.93 - 3.51)	**3.97** (3.61 - 4.36)	**4.58** (4.16 - 5.06)	**5.48** (4.93 - 6.11)	**6.21** (5.54 - 6.99)	**6.93** (6.11 - 7.88)	**8.75** (7.48 - 10.25)
7	9	**3.54** (3.23 - 3.86)	**4.25** (3.87 - 4.66)	**4.83** (4.38 - 5.31)	**5.59** (5.03 - 6.20)	**6.14** (5.50 - 6.88)	**6.69** (5.91 - 7.57)	**7.82** (6.72 - 9.14)
7	10	**3.16** (2.86 - 3.48)	**3.93** (3.55 - 4.36)	**4.59** (4.12 - 5.12)	**5.55** (4.92 - 6.27)	**6.34** (5.54 - 7.27)	**7.16** (6.15 - 8.35)	**9.19** (7.55 - 11.34)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
8	1	**2.51** (2.25 - 2.77)	**3.17** (2.84 - 3.51)	**3.77** (3.38 - 4.21)	**4.65** (4.14 - 5.24)	**5.4** (4.76 - 6.15)	**6.19** (5.40 - 7.15)	**8.13** (6.87 - 9.75)
8	2	**2.51** (2.25 - 2.77)	**3.23** (2.89 - 3.57)	**3.86** (3.45 - 4.30)	**4.84** (4.28 - 5.45)	**5.63** (4.94 - 6.41)	**6.43** (5.60 - 7.44)	**8.43** (7.11 - 10.22)
8	3	**2.61** (2.39 - 2.85)	**3.34** (3.06 - 3.65)	**3.93** (3.59 - 4.31)	**4.79** (4.36 - 5.29)	**5.44** (4.92 - 6.06)	**6.05** (5.42 - 6.81)	**7.43** (6.46 - 8.60)
8	4	**2.49** (2.26 - 2.74)	**3.23** (2.92 - 3.56)	**3.83** (3.46 - 4.23)	**4.65** (4.18 - 5.18)	**5.29** (4.74 - 5.95)	**5.89** (5.24 - 6.69)	**7.15** (6.23 - 8.37)
8	5	**2.34** (2.15 - 2.54)	**2.98** (2.73 - 3.24)	**3.53** (3.23 - 3.86)	**4.34** (3.94 - 4.78)	**4.97** (4.47 - 5.54)	**5.57** (4.97 - 6.31)	**6.99** (6.06 - 8.22)
8	6	**2.42** (2.21 - 2.65)	**3.05** (2.78 - 3.35)	**3.57** (3.24 - 3.94)	**4.34** (3.91 - 4.83)	**4.92** (4.39 - 5.53)	**5.48** (4.84 - 6.23)	**6.78** (5.80 - 7.94)
8	7	**2.62** (2.38 - 2.85)	**3.25** (2.95 - 3.55)	**3.75** (3.40 - 4.13)	**4.49** (4.04 - 4.98)	**5.03** (4.50 - 5.66)	**5.55** (4.91 - 6.31)	**6.63** (5.69 - 7.83)
8	8	**2.77** (2.52 - 3.03)	**3.42** (3.11 - 3.76)	**3.95** (3.59 - 4.37)	**4.73** (4.25 - 5.27)	**5.36** (4.78 - 6.02)	**5.97** (5.27 - 6.79)	**7.54** (6.45 - 8.83)
8	9	**3.05** (2.78 - 3.33)	**3.67** (3.34 - 4.02)	**4.16** (3.78 - 4.58)	**4.82** (4.34 - 5.34)	**5.3** (4.74 - 5.93)	**5.76** (5.10 - 6.53)	**6.74** (5.79 - 7.88)
8	10	**2.72** (2.47 - 3.00)	**3.39** (3.06 - 3.76)	**3.96** (3.55 - 4.41)	**4.79** (4.24 - 5.41)	**5.47** (4.77 - 6.27)	**6.17** (5.30 - 7.20)	**7.92** (6.51 - 9.77)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
9	1	**2.14** (1.92 - 2.36)	**2.7** (2.42 - 3.00)	**3.22** (2.88 - 3.59)	**3.97** (3.53 - 4.48)	**4.61** (4.06 - 5.25)	**5.28** (4.61 - 6.10)	**6.94** (5.86 - 8.32)
9	2	**2.14** (1.92 - 2.36)	**2.75** (2.46 - 3.05)	**3.30** (2.94 - 3.67)	**4.13** (3.66 - 4.65)	**4.80** (4.22 - 5.47)	**5.49** (4.78 - 6.35)	**7.20** (6.07 - 8.72)
9	3	**2.23** (2.04 - 2.43)	**2.85** (2.61 - 3.11)	**3.35** (3.07 - 3.68)	**4.08** (3.72 - 4.51)	**4.64** (4.20 - 5.17)	**5.16** (4.63 - 5.81)	**6.34** (5.51 - 7.34)
9	4	**2.12** (1.93 - 2.34)	**2.75** (2.49 - 3.04)	**3.26** (2.95 - 3.61)	**3.97** (3.57 - 4.42)	**4.51** (4.04 - 5.08)	**5.02** (4.47 - 5.71)	**6.1** (5.32 - 7.14)
9	5	**2.00** (1.83 - 2.16)	**2.54** (2.33 - 2.76)	**3.01** (2.75 - 3.29)	**3.70** (3.36 - 4.08)	**4.24** (3.82 - 4.73)	**4.76** (4.24 - 5.38)	**5.97** (5.17 - 7.01)
9	6	**2.07** (1.89 - 2.26)	**2.60** (2.37 - 2.86)	**3.05** (2.76 - 3.36)	**3.71** (3.33 - 4.12)	**4.20** (3.74 - 4.72)	**4.68** (4.13 - 5.32)	**5.79** (4.95 - 6.78)
9	7	**2.23** (2.03 - 2.43)	**2.77** (2.52 - 3.03)	**3.20** (2.90 - 3.52)	**3.83** (3.45 - 4.25)	**4.29** (3.84 - 4.83)	**4.74** (4.19 - 5.39)	**5.66** (4.85 - 6.68)
9	8	**2.36** (2.15 - 2.58)	**2.92** (2.65 - 3.21)	**3.37** (3.06 - 3.73)	**4.03** (3.63 - 4.50)	**4.57** (4.08 - 5.14)	**5.09** (4.50 - 5.79)	**6.44** (5.50 - 7.54)
9	9	**2.60** (2.38 - 2.84)	**3.13** (2.85 - 3.43)	**3.55** (3.22 - 3.91)	**4.11** (3.70 - 4.56)	**4.52** (4.04 - 5.06)	**4.92** (4.35 - 5.57)	**5.75** (4.95 - 6.73)
9	10	**2.32** (2.11 - 2.56)	**2.89** (2.61 - 3.21)	**3.38** (3.03 - 3.77)	**4.09** (3.62 - 4.62)	**4.66** (4.07 - 5.35)	**5.26** (4.52 - 6.14)	**6.76** (5.55 - 8.34)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
10	1	**1.94** (1.74 - 2.14)	**2.45** (2.20 - 2.72)	**2.92** (2.61 - 3.26)	**3.60** (3.20 - 4.06)	**4.17** (3.68 - 4.76)	**4.78** (4.17 - 5.53)	**6.29** (5.31 - 7.54)
10	2	**1.94** (1.74 - 2.14)	**2.49** (2.23 - 2.76)	**2.99** (2.67 - 3.32)	**3.74** (3.31 - 4.21)	**4.35** (3.82 - 4.96)	**4.97** (4.33 - 5.76)	**6.52** (5.50 - 7.90)
10	3	**2.02** (1.85 - 2.20)	**2.58** (2.36 - 2.82)	**3.04** (2.78 - 3.33)	**3.70** (3.37 - 4.09)	**4.21** (3.80 - 4.69)	**4.67** (4.19 - 5.26)	**5.75** (4.99 - 6.65)
10	4	**1.93** (1.74 - 2.12)	**2.49** (2.26 - 2.75)	**2.96** (2.68 - 3.27)	**3.60** (3.24 - 4.01)	**4.09** (3.66 - 4.60)	**4.55** (4.05 - 5.17)	**5.53** (4.82 - 6.47)
10	5	**1.81** (1.66 - 1.96)	**2.30** (2.11 - 2.50)	**2.73** (2.50 - 2.99)	**3.35** (3.05 - 3.70)	**3.84** (3.46 - 4.29)	**4.31** (3.85 - 4.88)	**5.41** (4.69 - 6.35)
10	6	**1.87** (1.71 - 2.05)	**2.36** (2.15 - 2.59)	**2.76** (2.50 - 3.05)	**3.36** (3.02 - 3.74)	**3.80** (3.39 - 4.28)	**4.24** (3.74 - 4.82)	**5.24** (4.48 - 6.14)
10	7	**2.02** (1.84 - 2.21)	**2.51** (2.28 - 2.75)	**2.90** (2.63 - 3.19)	**3.47** (3.13 - 3.85)	**3.89** (3.48 - 4.37)	**4.29** (3.79 - 4.88)	**5.13** (4.40 - 6.05)
10	8	**2.14** (1.95 - 2.34)	**2.64** (2.41 - 2.91)	**3.06** (2.77 - 3.38)	**3.65** (3.29 - 4.08)	**4.14** (3.69 - 4.66)	**4.62** (4.08 - 5.25)	**5.83** (4.99 - 6.83)
10	9	**2.36** (2.15 - 2.58)	**2.84** (2.58 - 3.11)	**3.22** (2.92 - 3.54)	**3.72** (3.36 - 4.13)	**4.09** (3.66 - 4.59)	**4.46** (3.94 - 5.05)	**5.21** (4.48 - 6.10)
10	10	**2.1** (1.91 - 2.32)	**2.62** (2.37 - 2.91)	**3.06** (2.74 - 3.41)	**3.7** (3.28 - 4.18)	**4.23** (3.69 - 4.85)	**4.77** (4.10 - 5.56)	**6.13** (5.03 - 7.56)

Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
11	1	**1.57** (1.41 - 1.74)	**1.98** (1.78 - 2.20)	**2.36** (2.12 - 2.64)	**2.92** (2.59 - 3.29)	**3.38** (2.98 - 3.86)	**3.88** (3.38 - 4.48)	**5.09** (4.30 - 6.11)
11	2	**1.57** (1.41 - 1.73)	**2.02** (1.81 - 2.24)	**2.42** (2.16 - 2.69)	**3.03** (2.69 - 3.41)	**3.53** (3.10 - 4.02)	**4.03** (3.51 - 4.67)	**5.28** (4.46 - 6.40)
11	3	**1.64** (1.50 - 1.78)	**2.09** (1.91 - 2.29)	**2.46** (2.25 - 2.70)	**3.00** (2.73 - 3.31)	**3.41** (3.08 - 3.80)	**3.79** (3.40 - 4.26)	**4.66** (4.05 - 5.39)
11	4	**1.56** (1.41 - 1.72)	**2.02** (1.83 - 2.23)	**2.4** (2.17 - 2.65)	**2.91** (2.62 - 3.25)	**3.31** (2.97 - 3.73)	**3.69** (3.28 - 4.19)	**4.48** (3.91 - 5.24)
11	5	**1.47** (1.35 - 1.59)	**1.87** (1.71 - 2.03)	**2.21** (2.02 - 2.42)	**2.72** (2.47 - 3.00)	**3.11** (2.80 - 3.47)	**3.49** (3.12 - 3.95)	**4.38** (3.80 - 5.15)
11	6	**1.52** (1.38 - 1.66)	**1.91** (1.74 - 2.10)	**2.24** (2.03 - 2.47)	**2.72** (2.45 - 3.03)	**3.08** (2.75 - 3.46)	**3.44** (3.03 - 3.90)	**4.25** (3.63 - 4.98)
11	7	**1.64** (1.49 - 1.79)	**2.04** (1.85 - 2.23)	**2.35** (2.13 - 2.59)	**2.81** (2.53 - 3.12)	**3.15** (2.82 - 3.54)	**3.48** (3.07 - 3.96)	**4.15** (3.56 - 4.91)
11	8	**1.73** (1.58 - 1.90)	**2.14** (1.95 - 2.36)	**2.48** (2.25 - 2.74)	**2.96** (2.66 - 3.30)	**3.36** (2.99 - 3.77)	**3.74** (3.30 - 4.26)	**4.73** (4.04 - 5.54)
11	9	**1.91** (1.75 - 2.09)	**2.3** (2.09 - 2.52)	**2.61** (2.37 - 2.87)	**3.02** (2.72 - 3.35)	**3.32** (2.97 - 3.72)	**3.61** (3.19 - 4.09)	**4.23** (3.63 - 4.94)
11	10	**1.71** (1.55 - 1.88)	**2.12** (1.92 - 2.35)	**2.48** (2.22 - 2.77)	**3.00** (2.66 - 3.39)	**3.43** (2.99 - 3.93)	**3.87** (3.32 - 4.51)	**4.97** (4.08 - 6.13)

Comparisons with Existing Sources

The frequency analysis in this study was compared with Bulletin 70 (Huff and Angel, 1989) and NOAA Atlas 14 (Bonnin et al., 2006). Study results were formatted similar to those of Bulletin 70, and the comparisons were made for each section, as shown in Figures 13–23. Similar comparisons with Atlas 14 were not possible, however, because Atlas 14 did not provide values for the sections defined in Bulletin 70. Instead, the frequency estimates for each county (represented by its centroid) in a section were averaged and compared with the results for the same section in this study, meaning that some additional uncertainty was introduced. Nonetheless, this comparison still provides usable information on general trends. The comparisons between the new frequency analyses (updated Bulletin 70) and Atlas 14 are presented in Figures 24–33.

Bulletin 70, NOAA Atlas 14, and this study have numerous differences, such as the selection of gages, periods of record, data processing, methods used for frequency analysis, and methods for trend adjustment. Despite these differences, comparisons made with the existing studies (spanning 30 years) still provide a general idea about the changes in precipitation frequency with time.

Final Remarks

This study used updated data through 2017 and techniques (L-Moments) to provide an update to the original Bulletin 70, published in 1989. Compared with the original Bulletin 70 (Huff and Angel, 1989), the results of this study generally show increasing precipitation amounts at selected frequencies for most of the sections with some relatively smaller decreases in the southern and western sections of Illinois. The present study shows consistent increases compared with NOAA Atlas 14 (Bonnin et al., 2006) and better reflects the current risk of heavier precipitation events.

The changing climate of heavy precipitation observed in Illinois and the Midwest presents a significant challenge for storm water management. The observed increases noted in this report, along with the expectation of continued increases over the 21st Century (Easterling et al. 2017), will necessitate more frequent assessments of precipitation frequency, as suggested by Winters et al. (2015). To help plan for future climate change, this analysis, representing the present time, should be accompanied with frequency analysis of climate model-generated data for future time horizons (Markus et al., 2017, 2018).

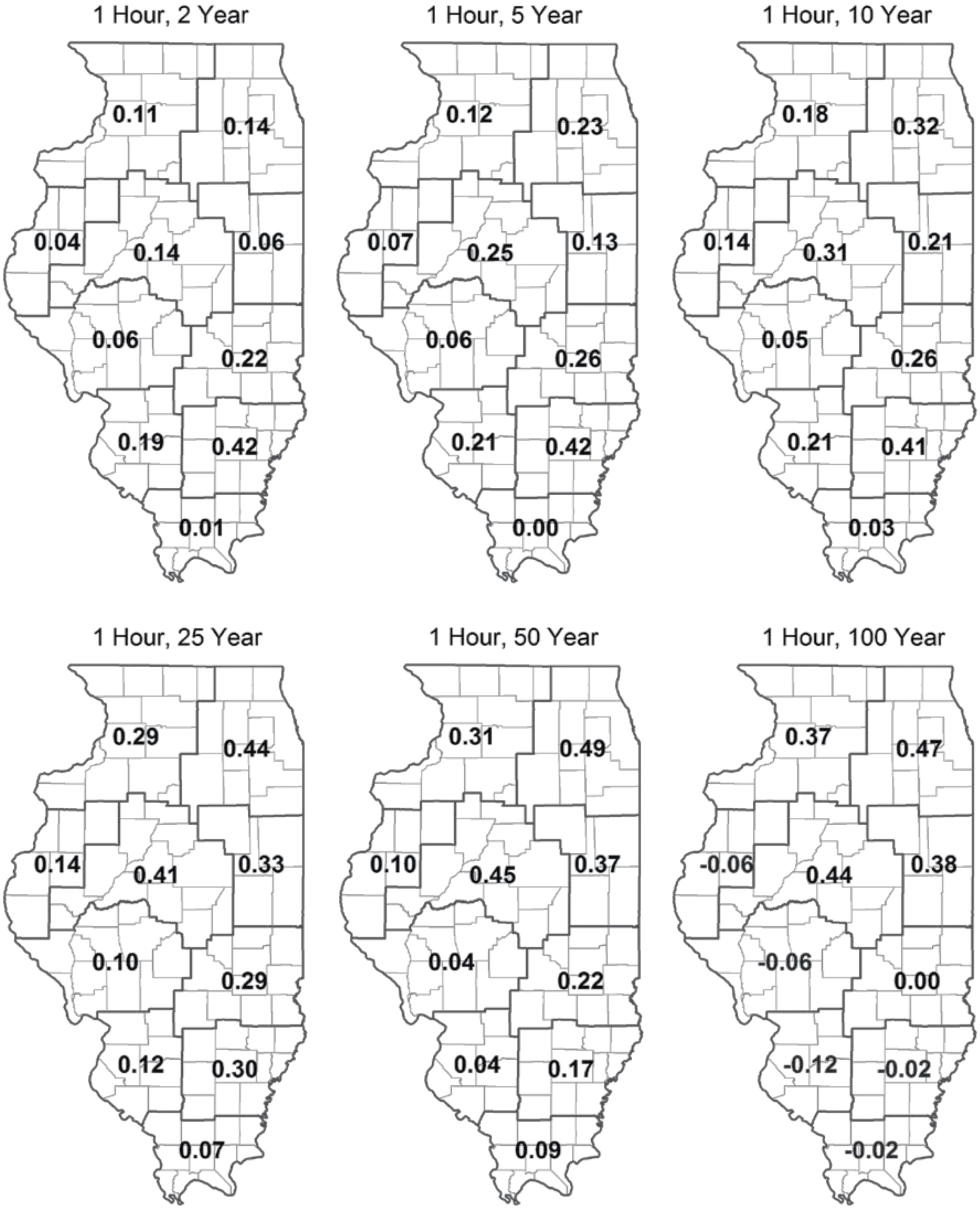

Figure 13 Differences in inches between this study and Bulletin 70 for a 1-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

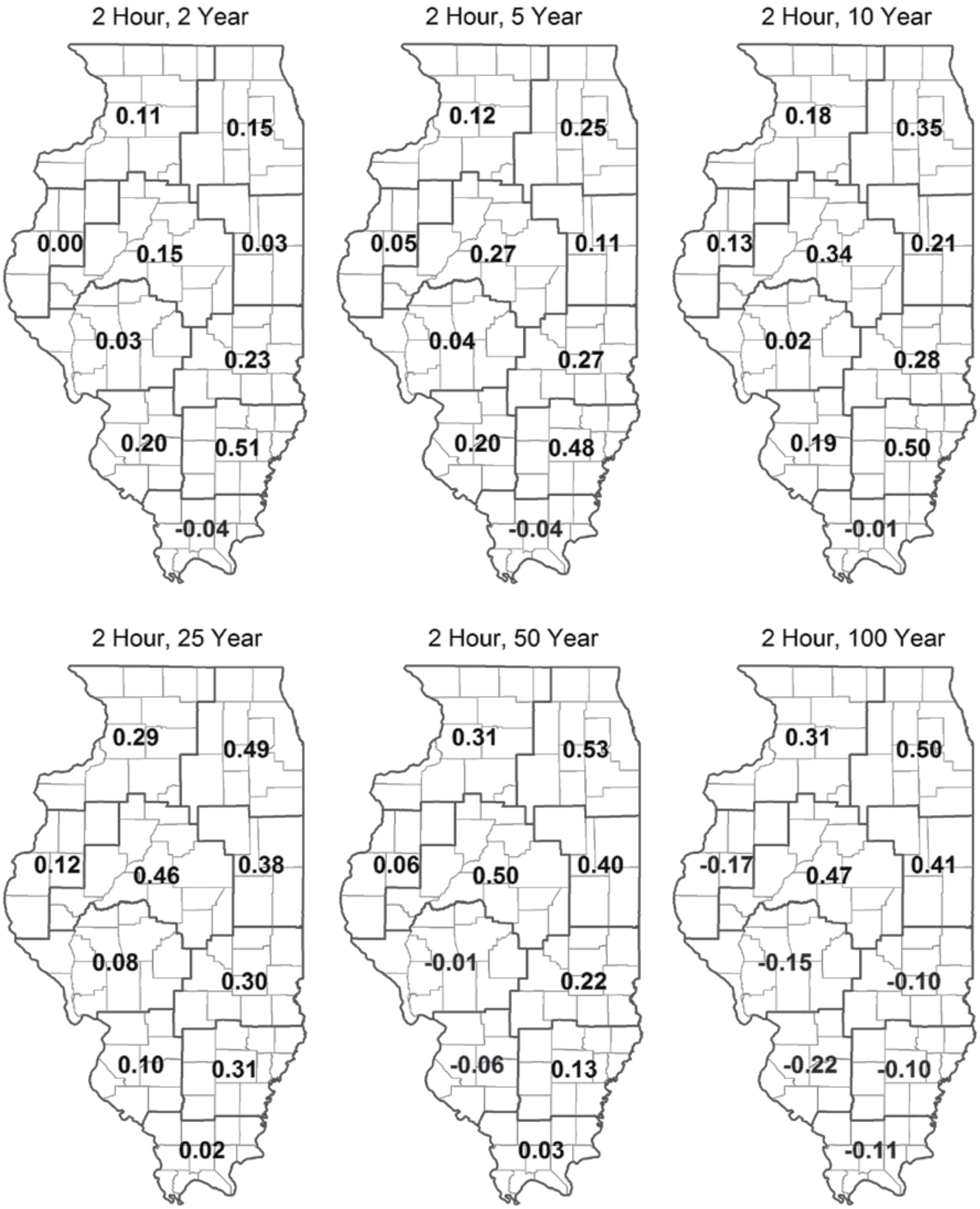

Figure 14 Differences in inches between this study and Bulletin 70 for a 2-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

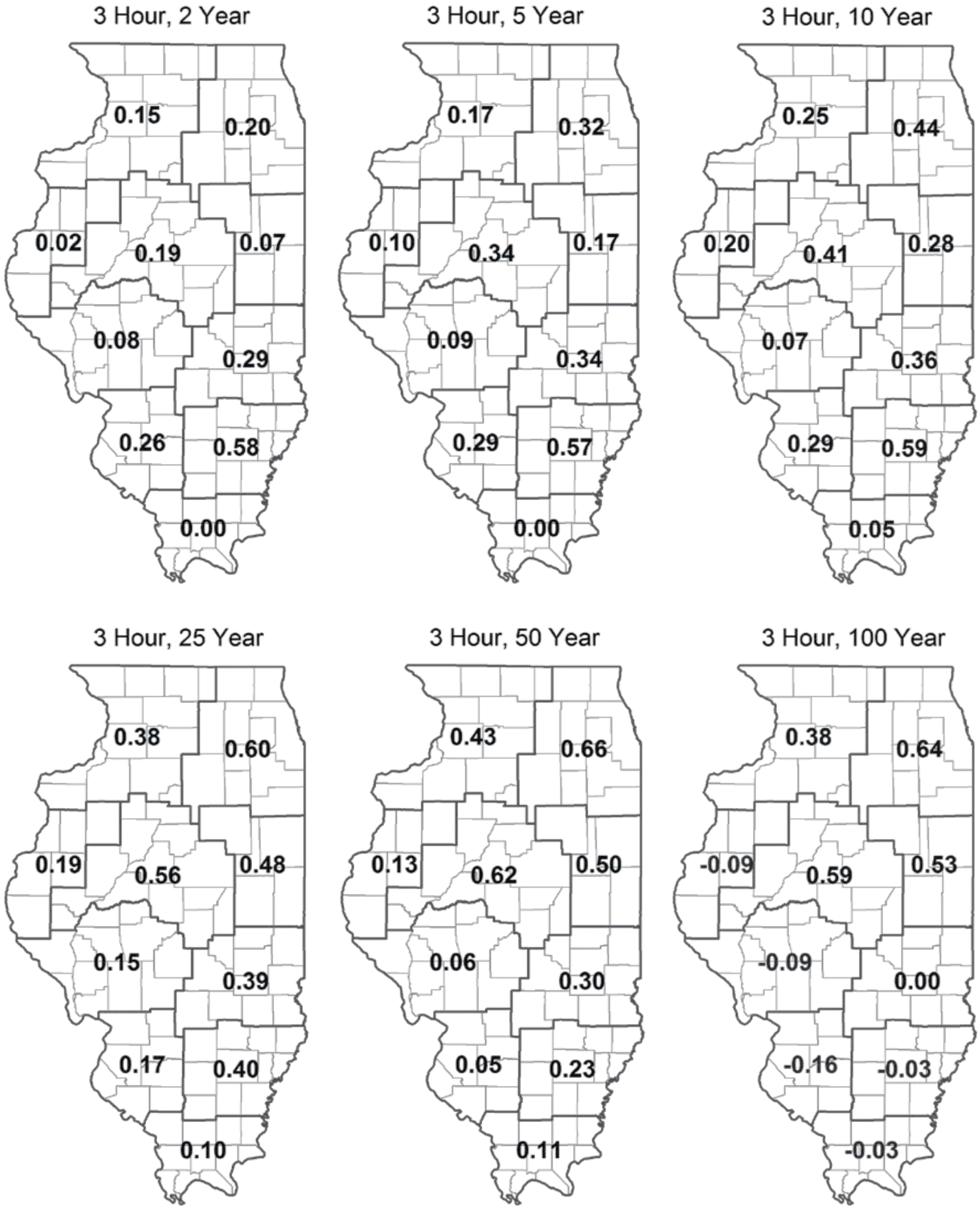

Figure 15 Differences in inches between this study and Bulletin 70 for a 3-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

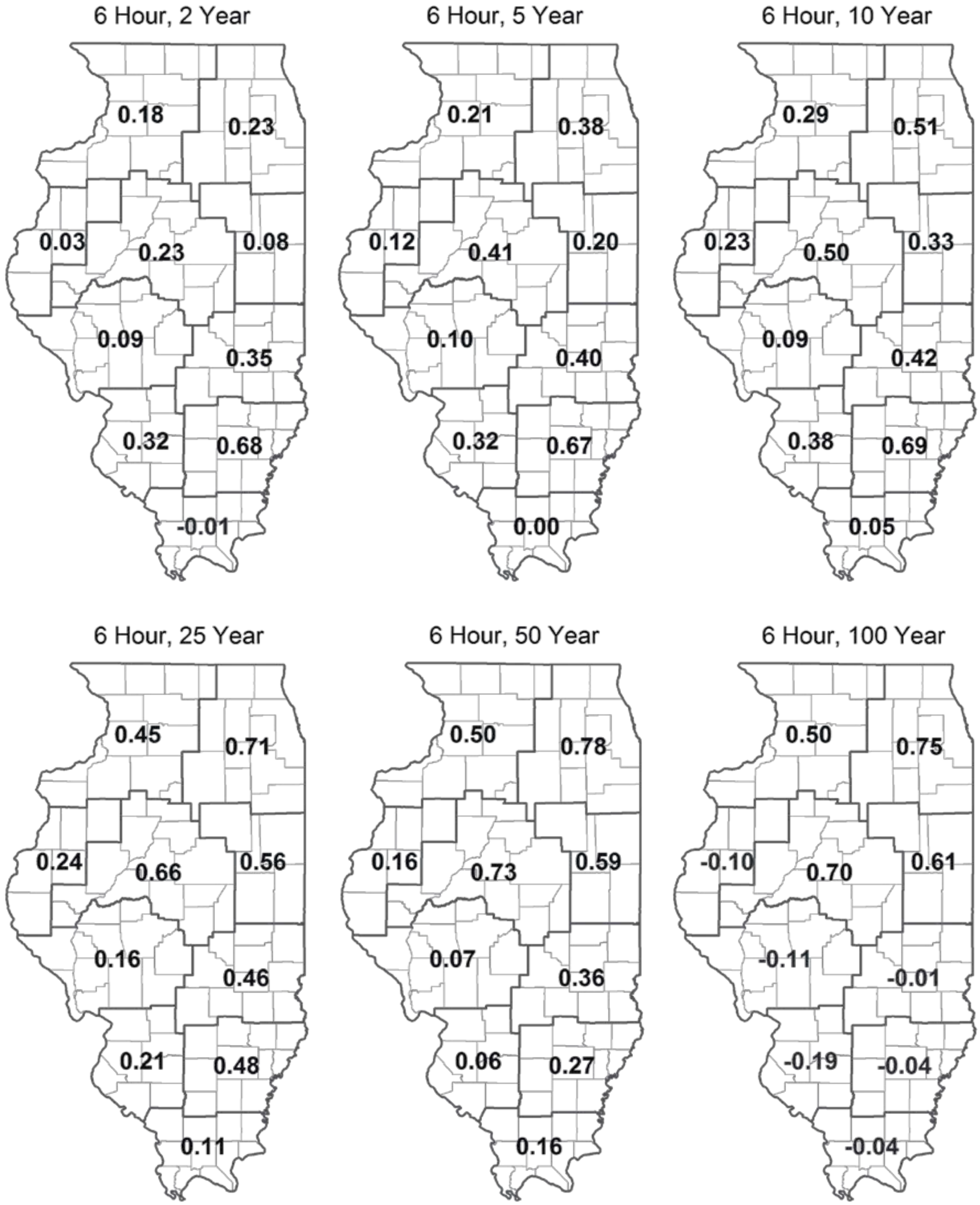

Figure 16 Differences in inches between this study and Bulletin 70 for a 6-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

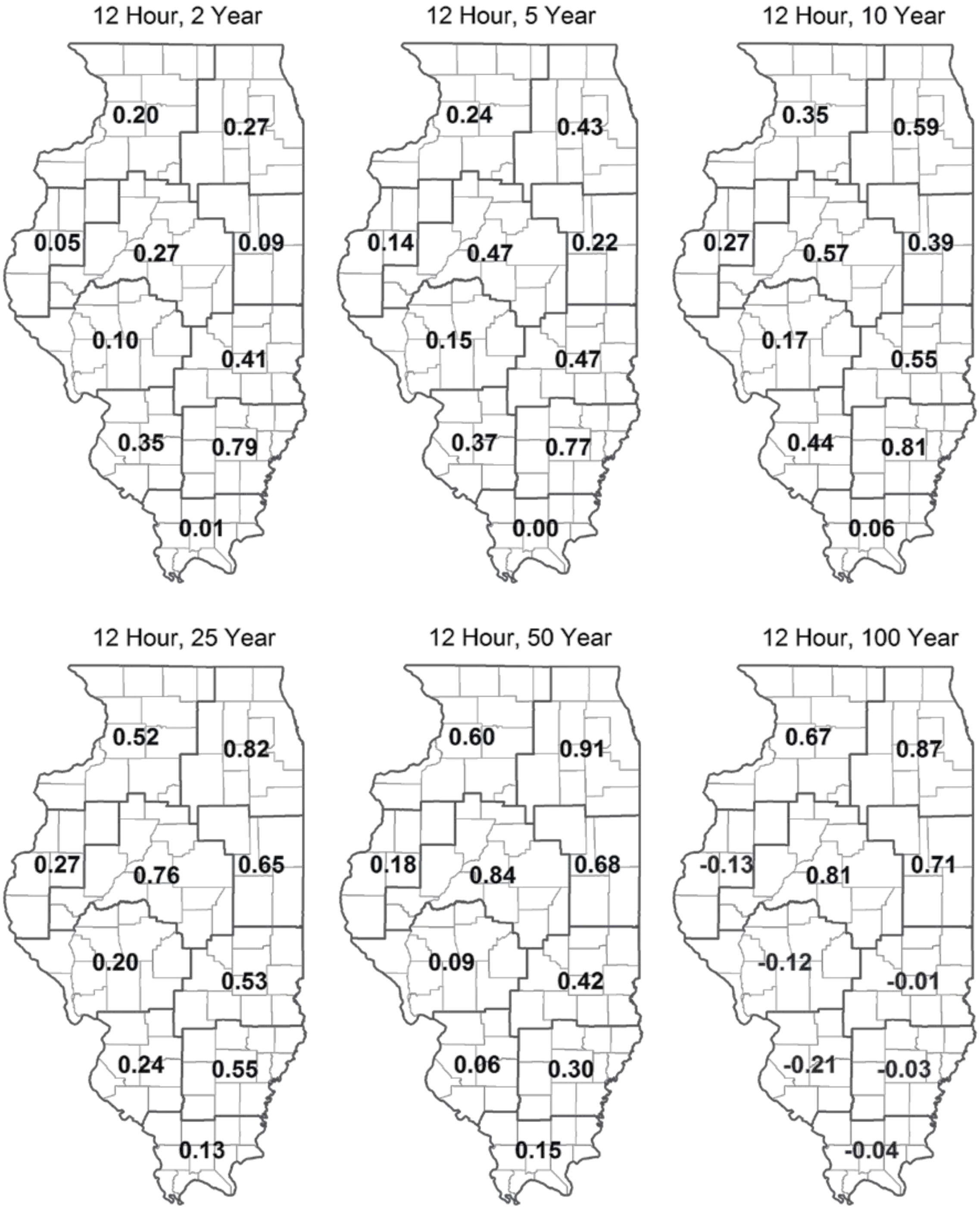

Figure 17 Differences in inches between this study and Bulletin 70 for a 12-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

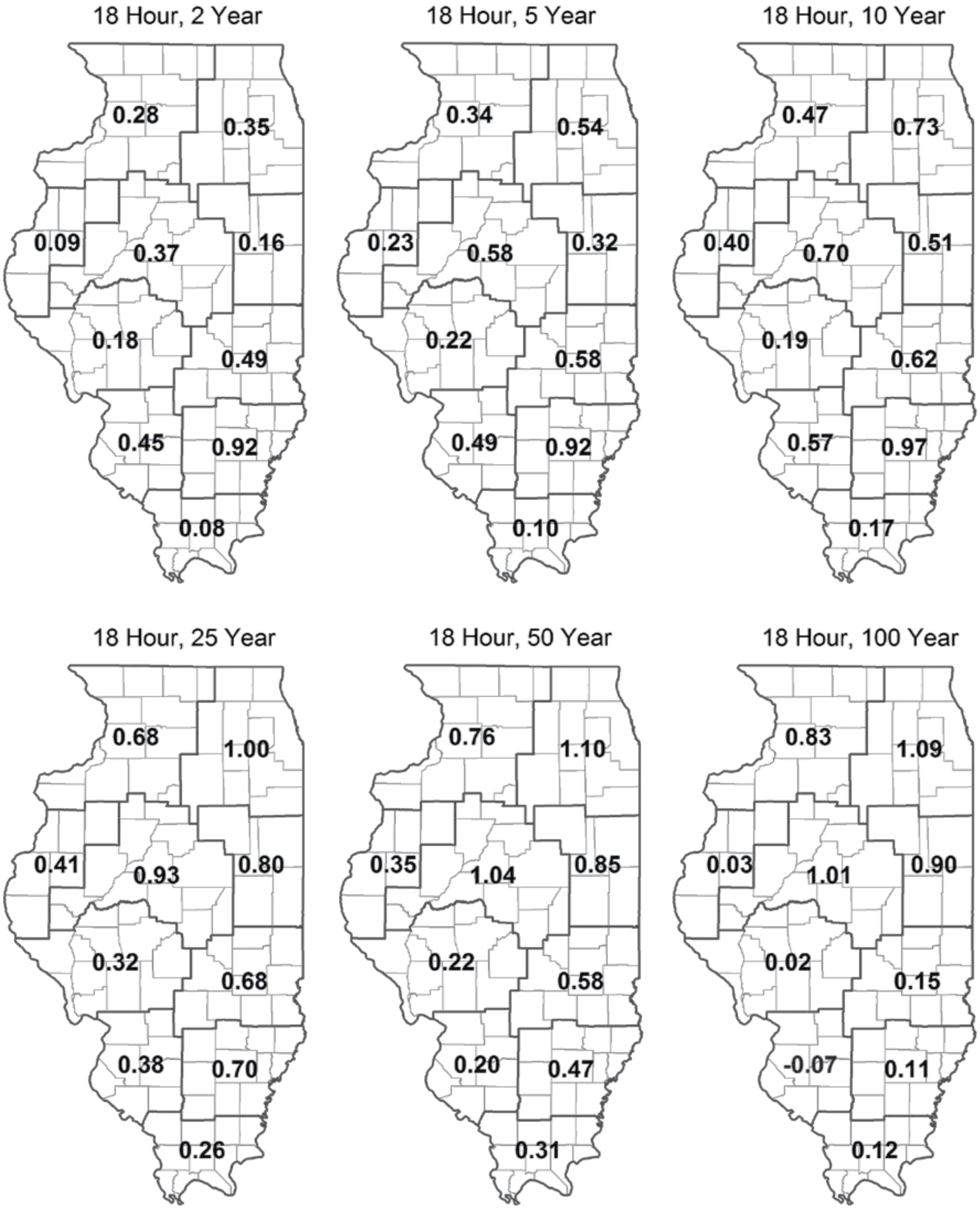

Figure 18 Differences in inches between this study and Bulletin 70 for an 18-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

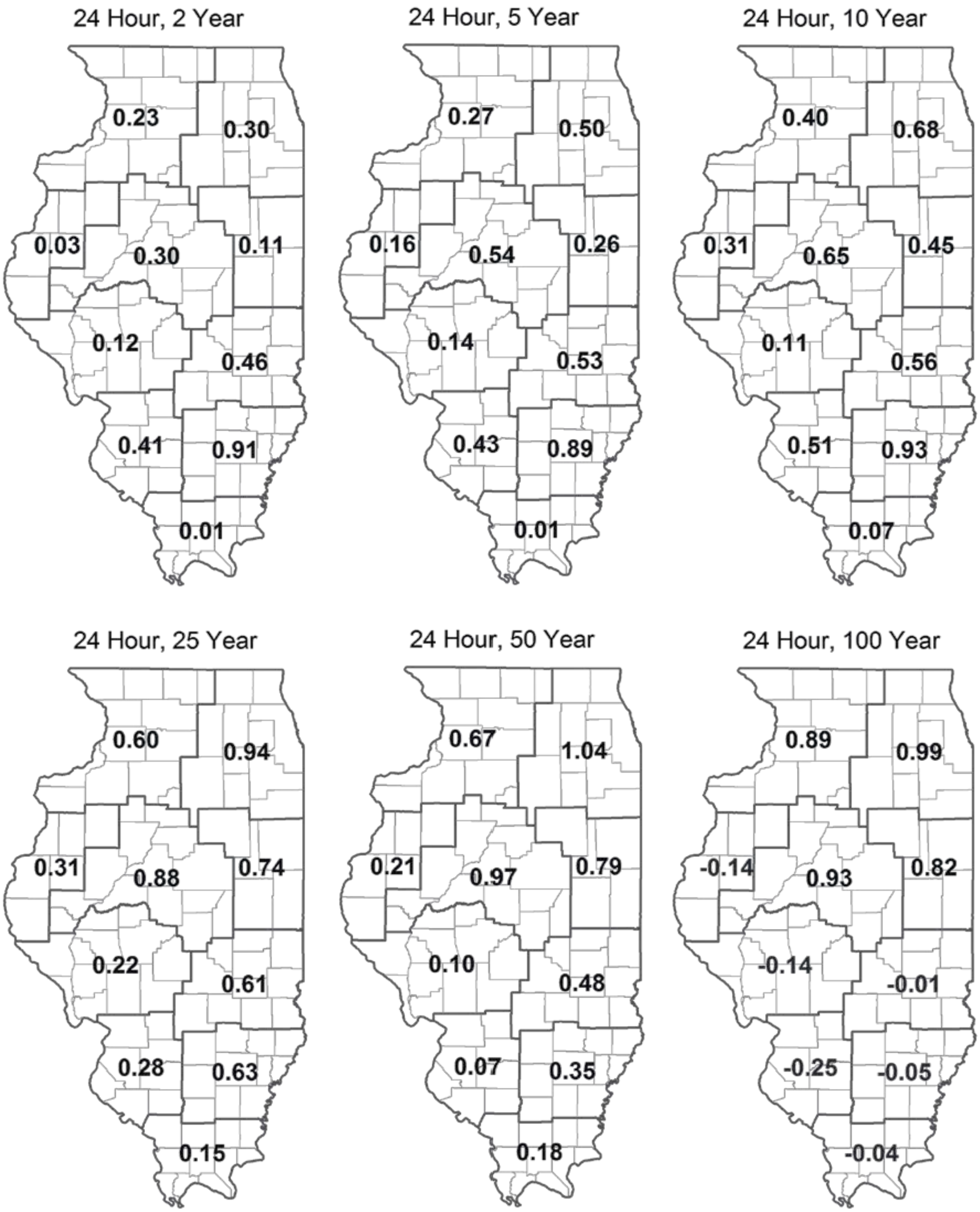

Figure 19 Differences in inches between this study and Bulletin 70 for a 24-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

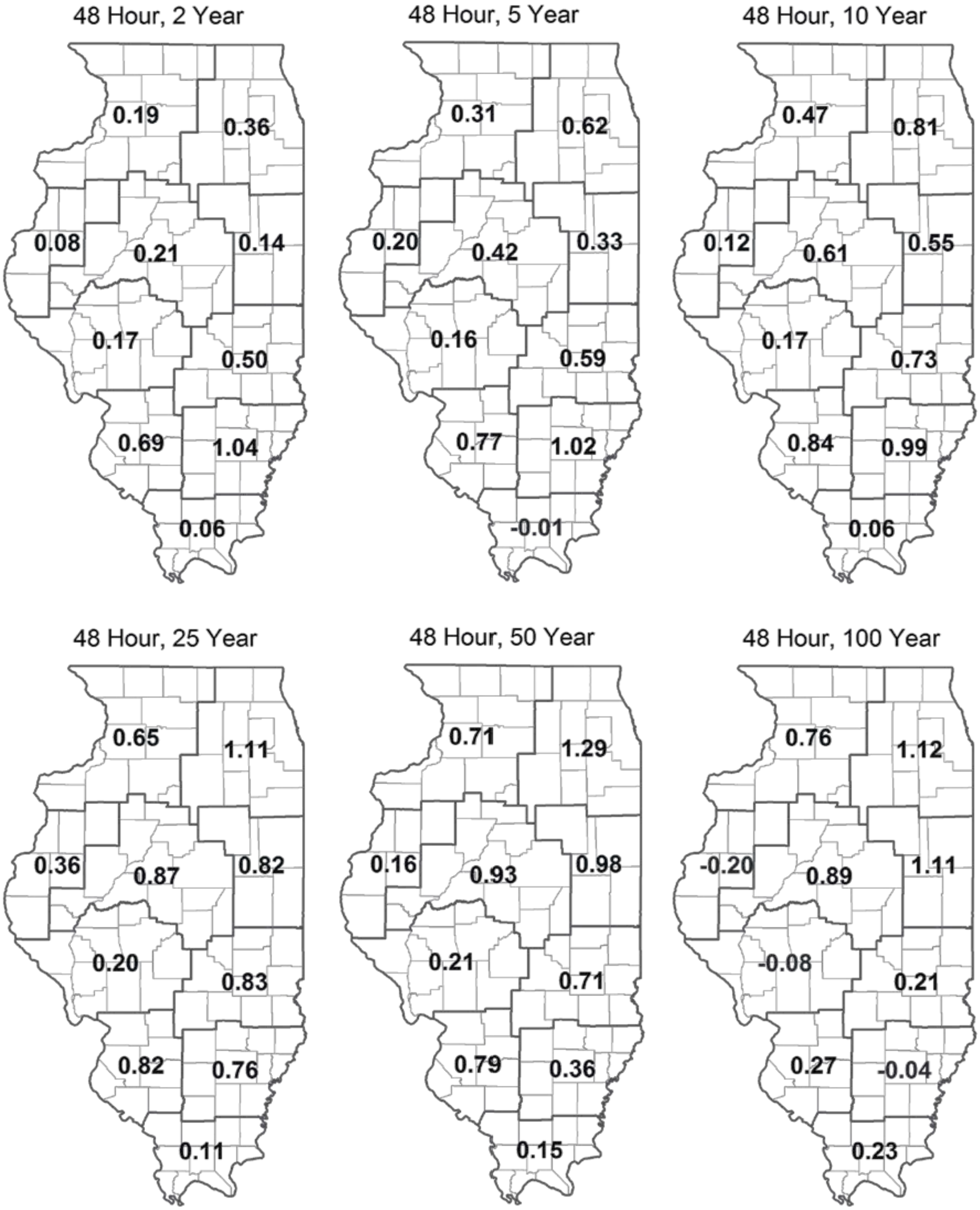

Figure 20 Differences in inches between this study and Bulletin 70 for a 48-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

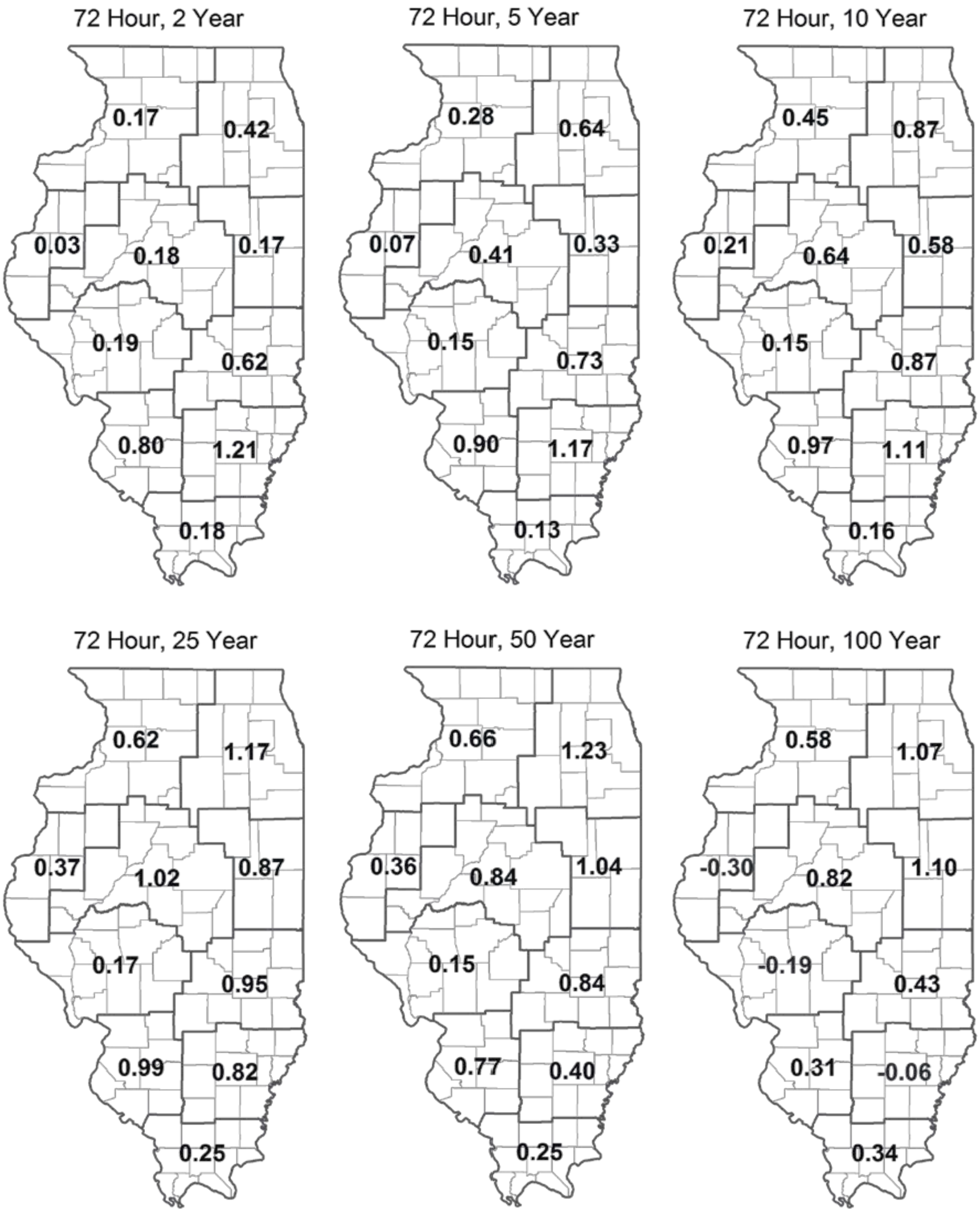

Figure 21 Differences in inches between this study and Bulletin 70 for a 72-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

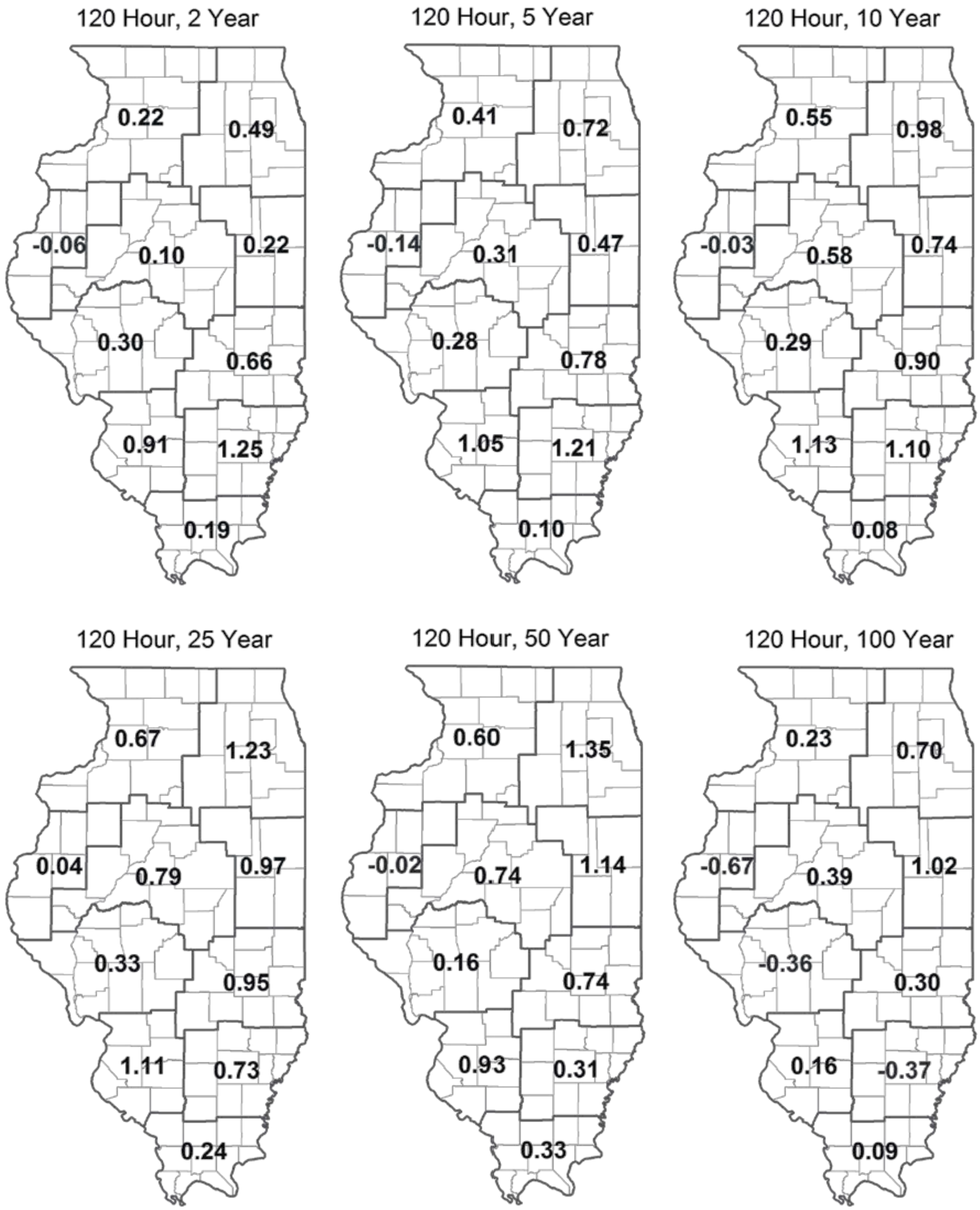

Figure 22 Differences in inches between this study and Bulletin 70 for a 120-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

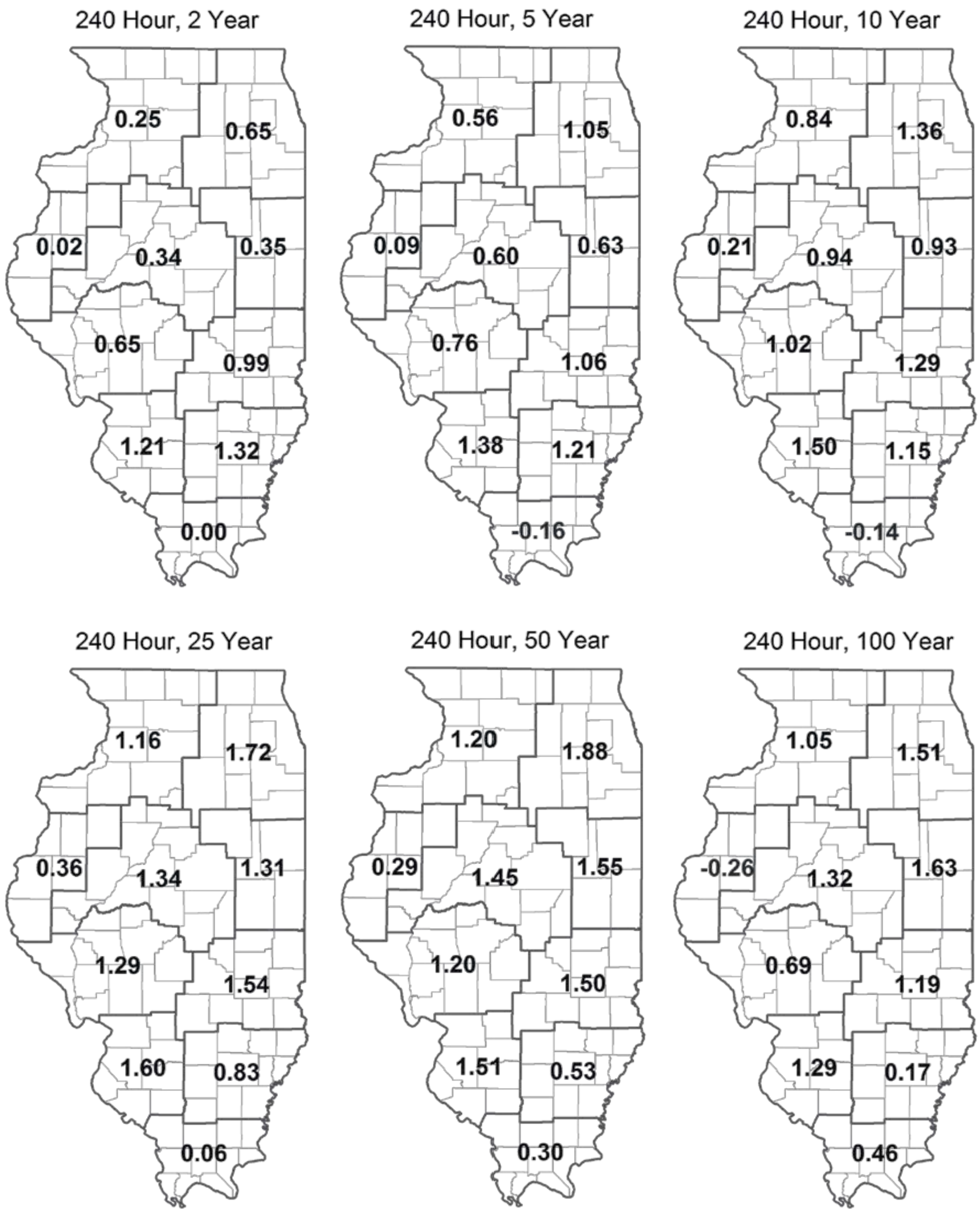

Figure 23 Differences in inches between this study and Bulletin 70 for a 240-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Bulletin 70.

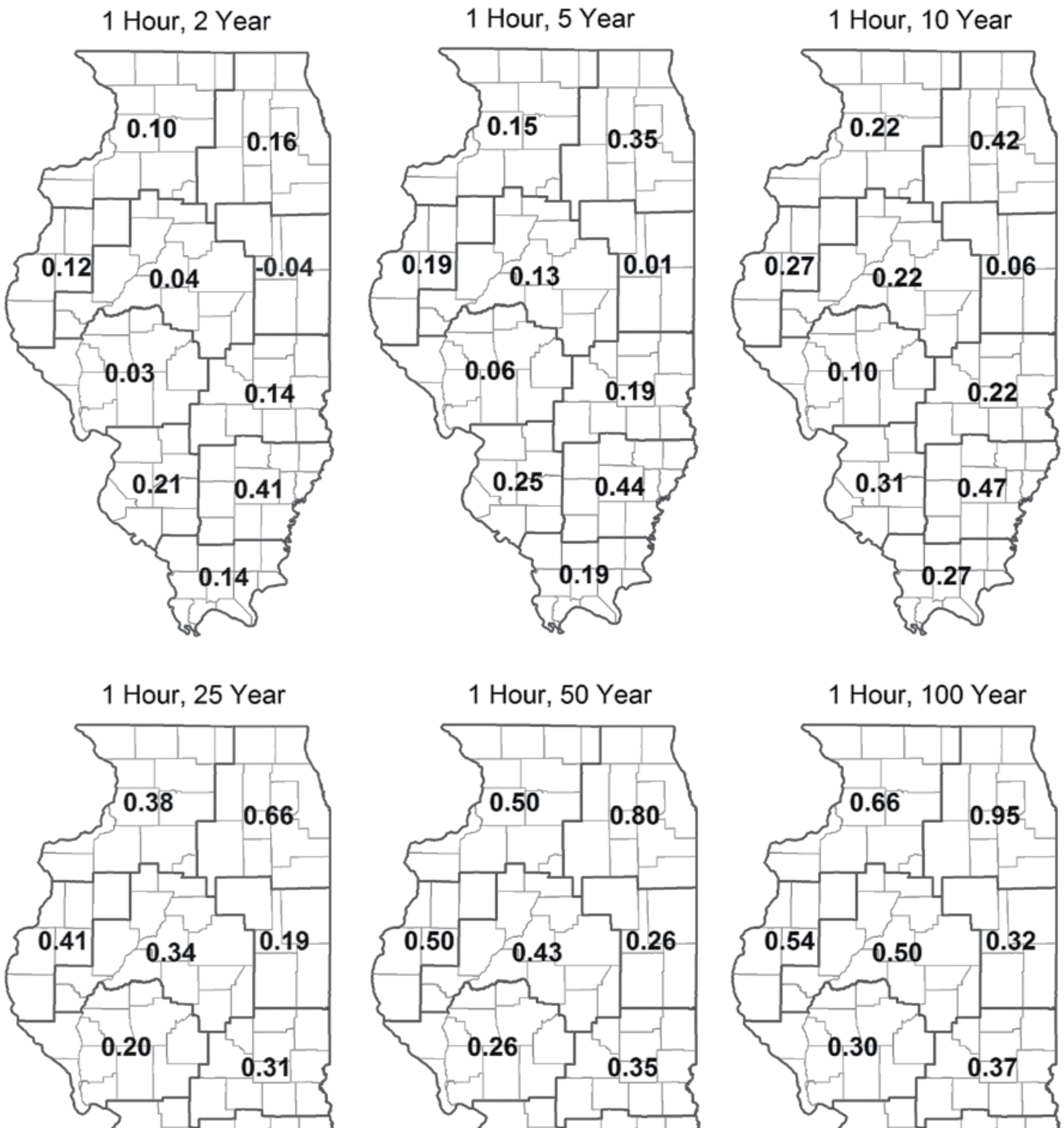

Figure 24 Differences in inches between this study and NOAA Atlas 14 for a 1-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

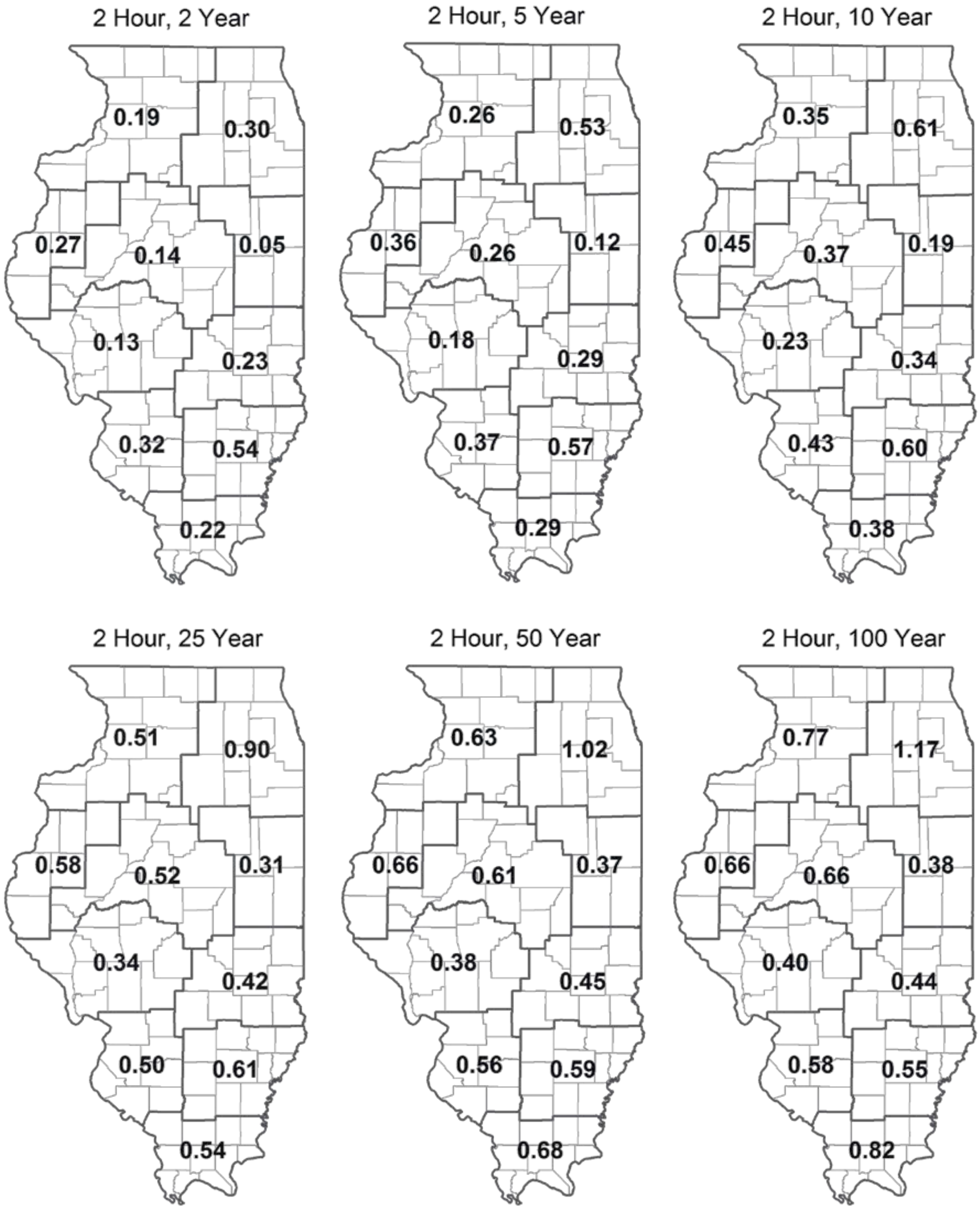

Figure 25 Differences in inches between this study and NOAA Atlas 14 for a 2-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

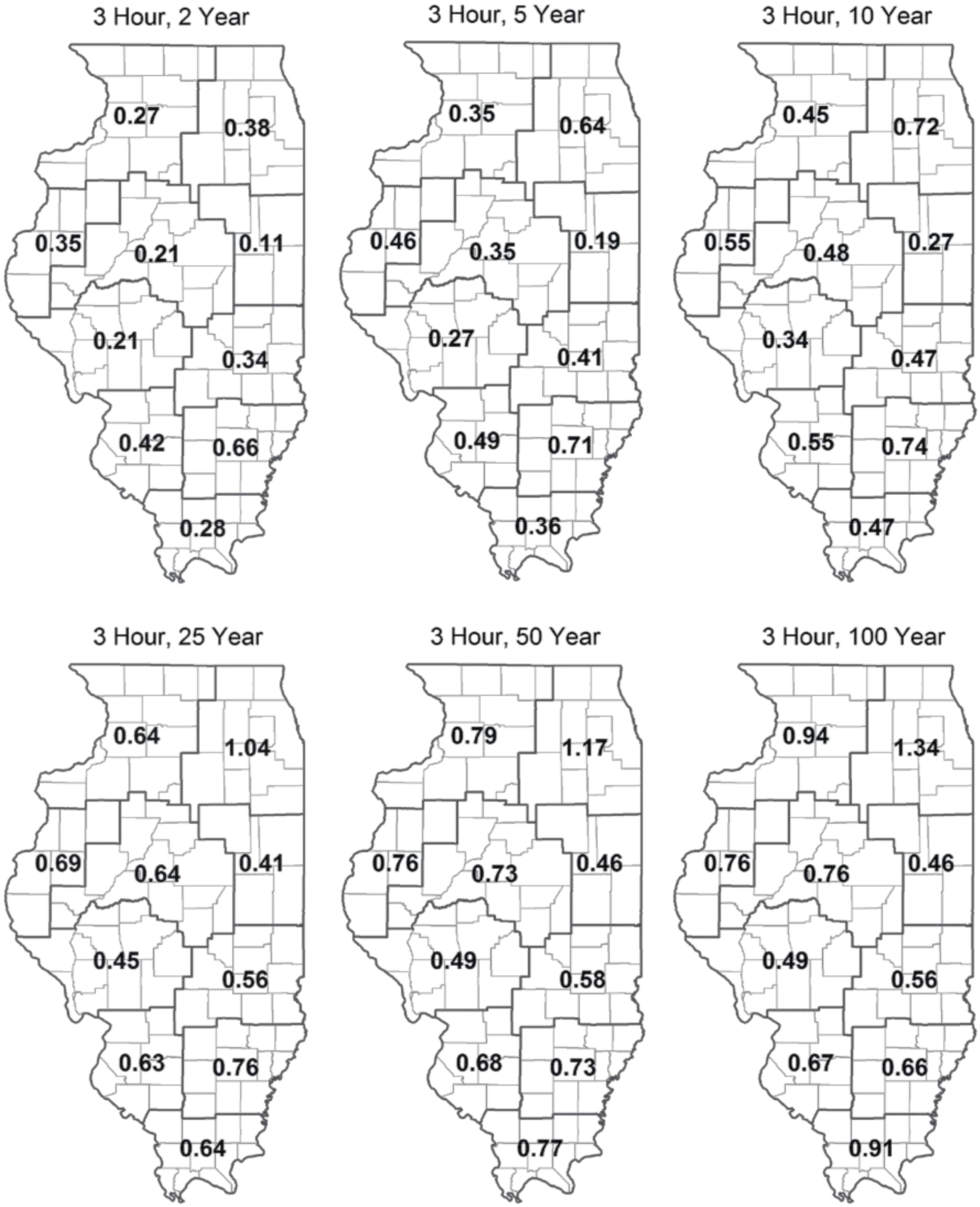

Figure 26 Differences in inches between this study and NOAA Atlas 14 for a 3-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

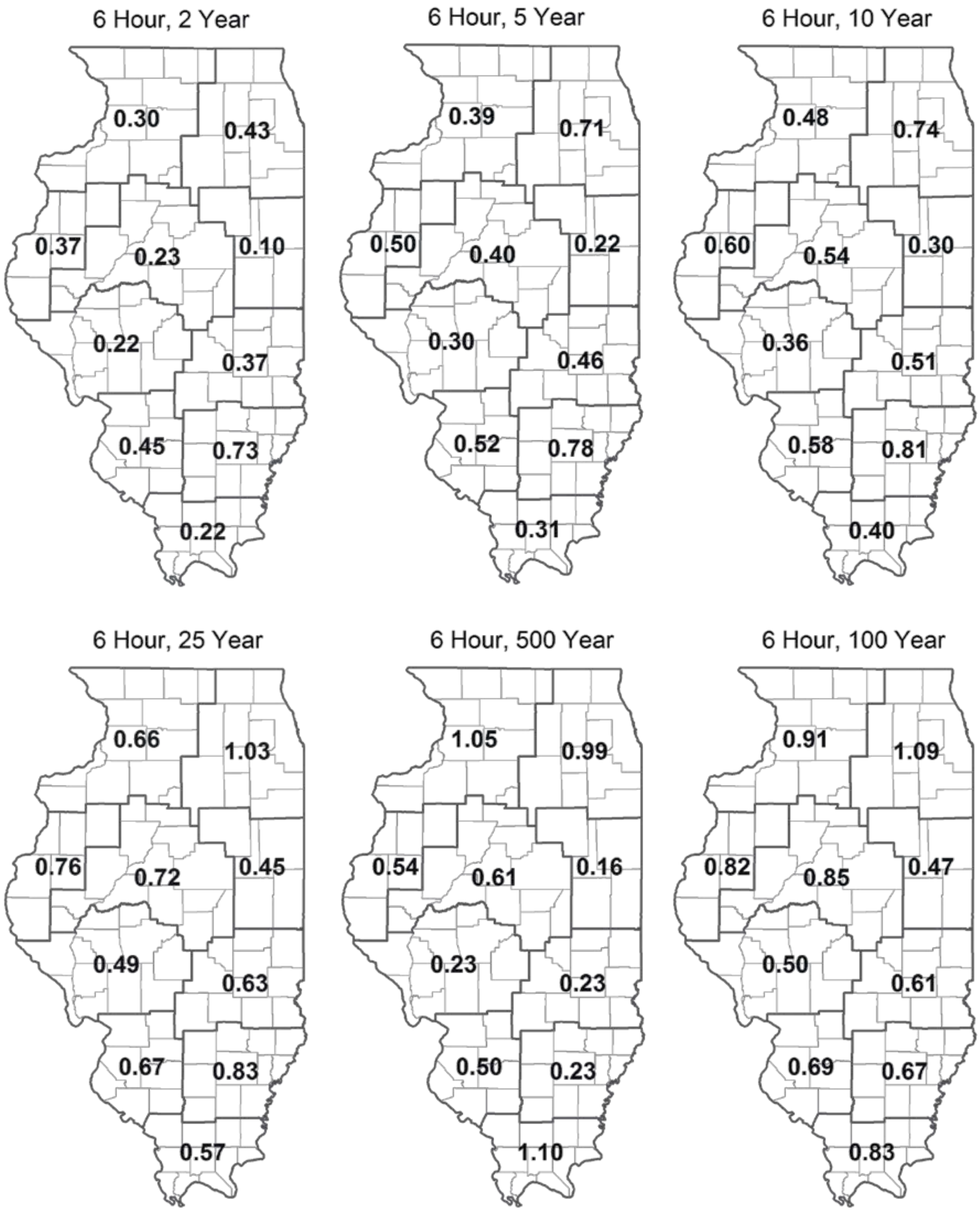

Figure 27 Differences in inches between this study and NOAA Atlas 14 for a 6-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

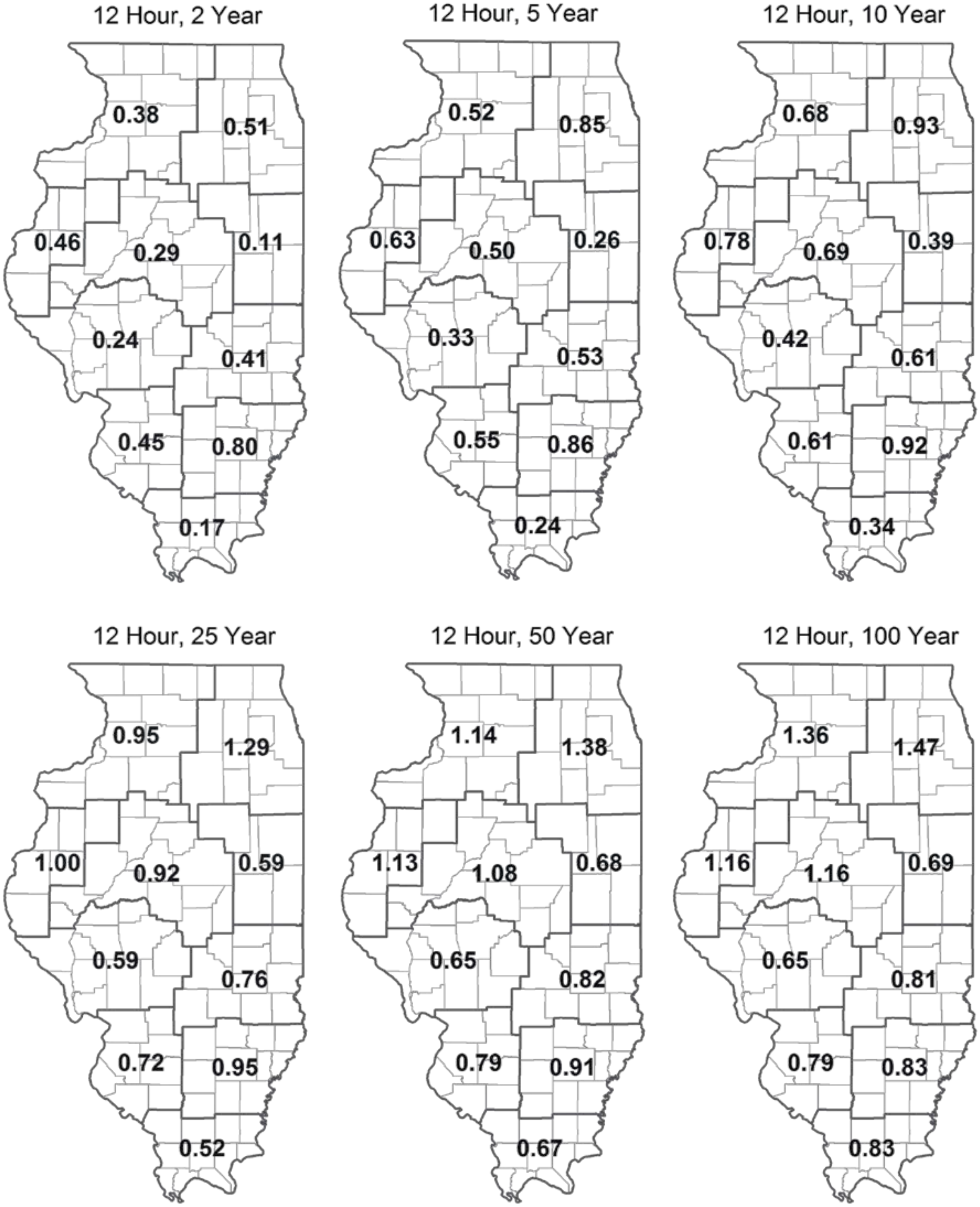

Figure 28 Differences in inches between this study and NOAA Atlas 14 for a 12-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

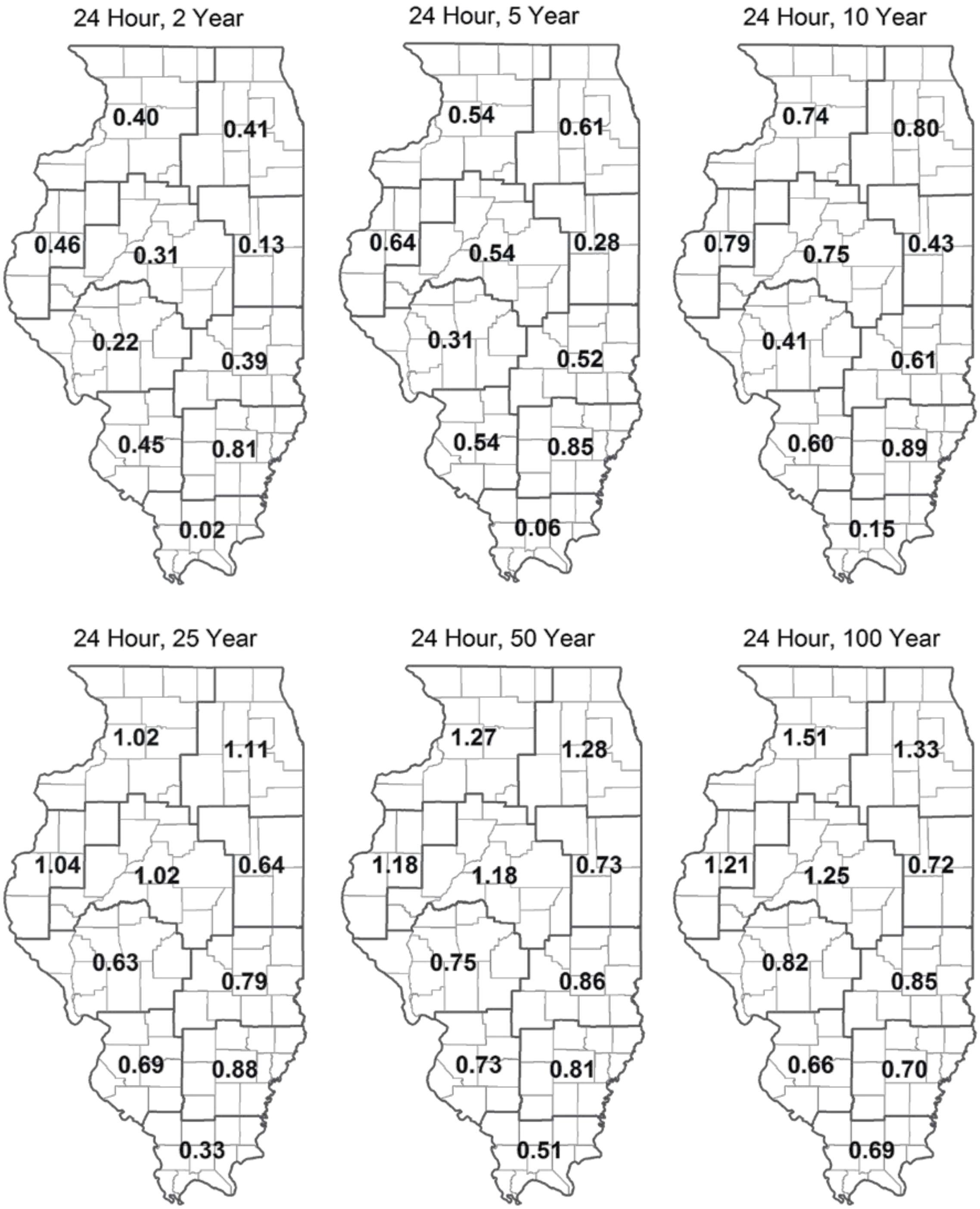

Figure 29 Differences in inches between this study and NOAA Atlas 14 for a 24-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

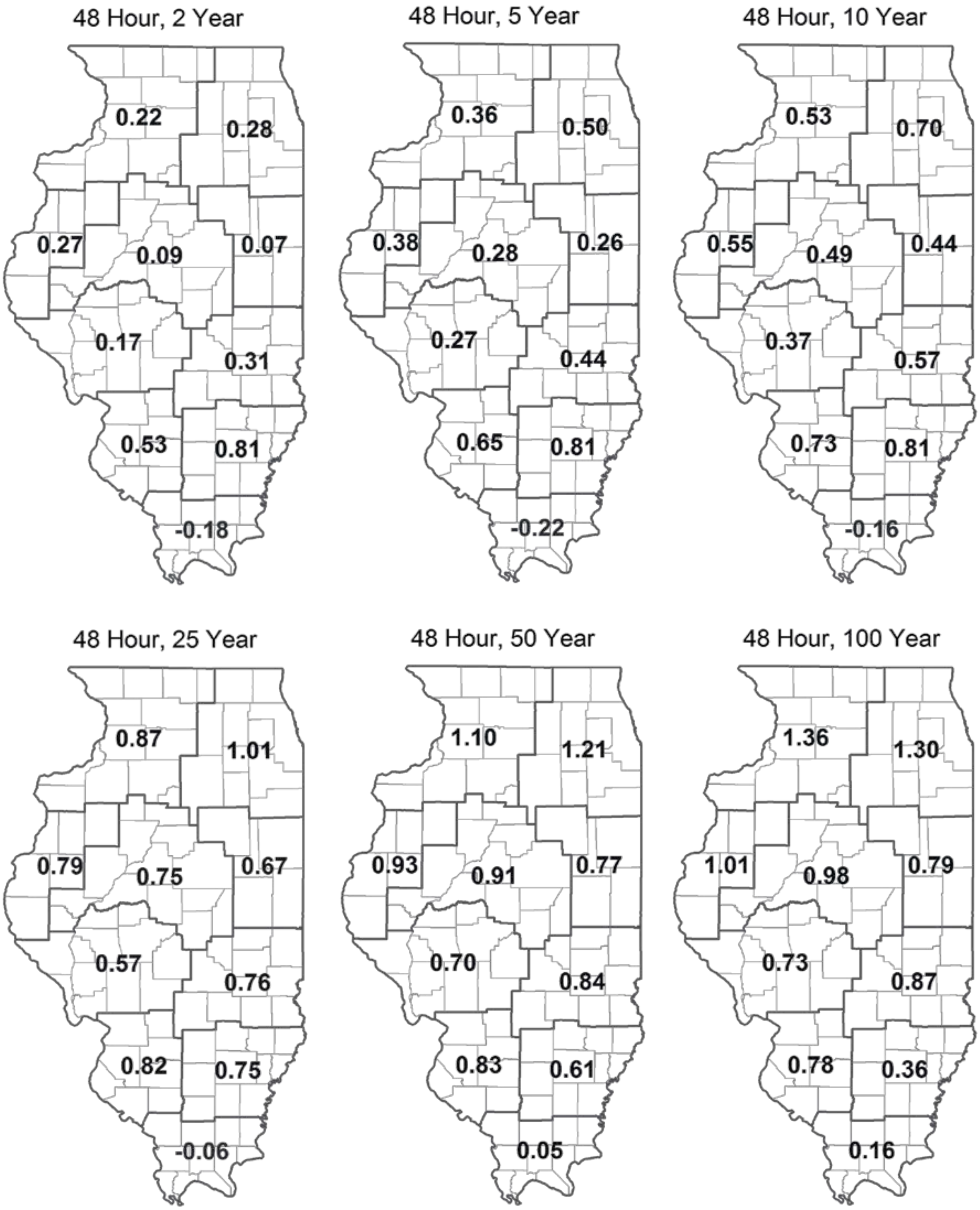

Figure 30 Differences in inches between this study and NOAA Atlas 14 for a 48-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

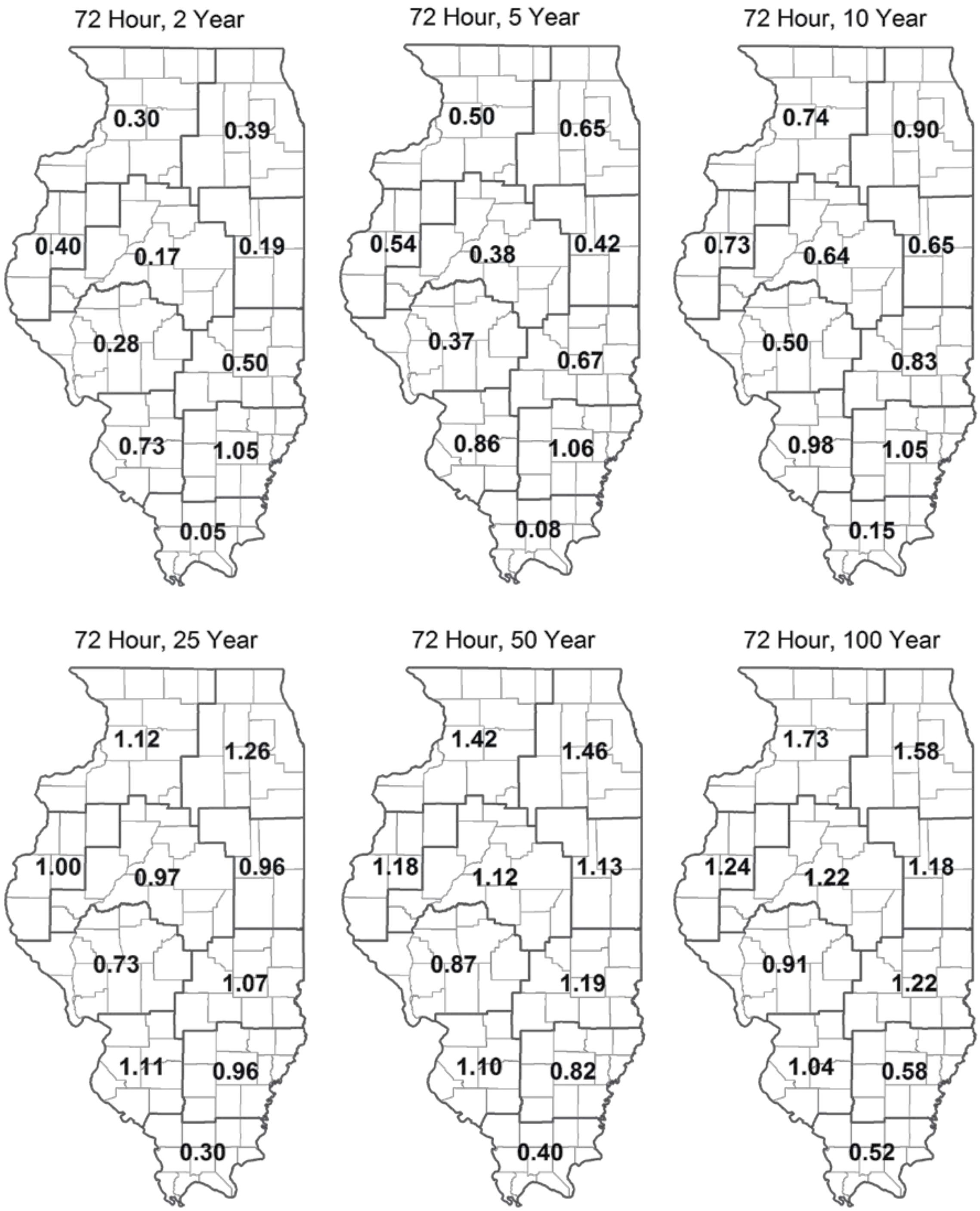

Figure 31 Differences in inches between this study and NOAA Atlas 14 for a 72-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

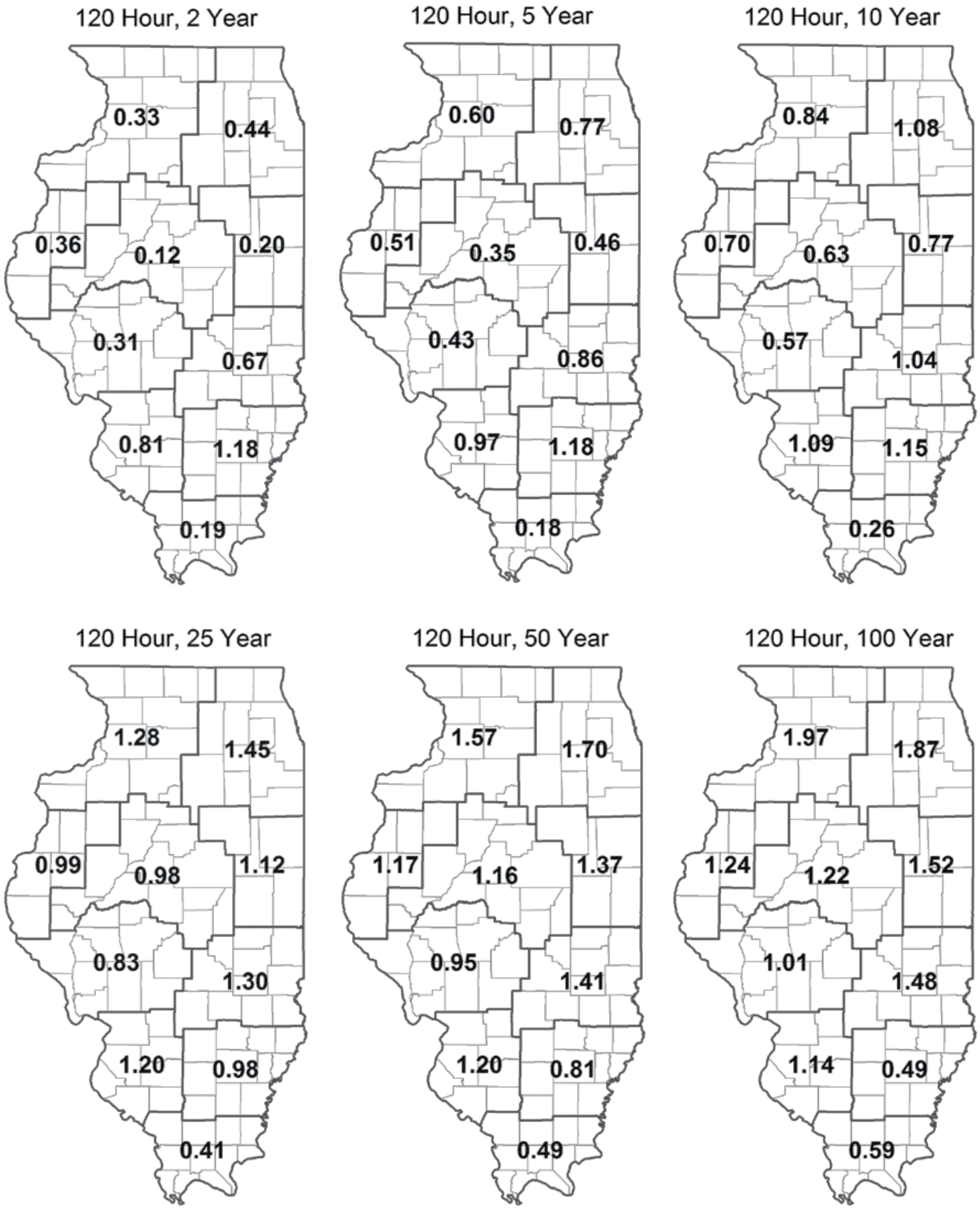

Figure 32 Differences in inches between this study and NOAA Atlas 14 for a 120-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

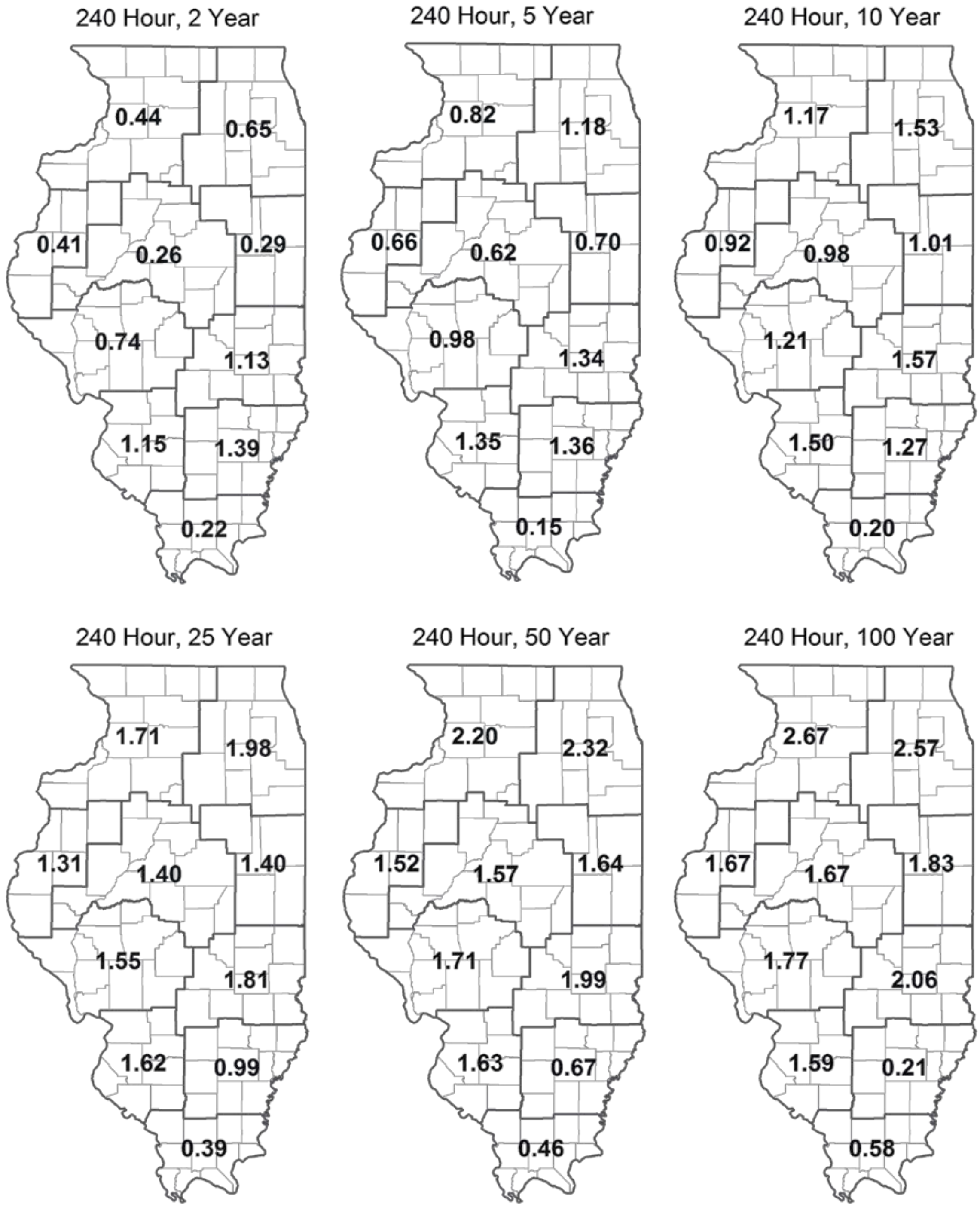

Figure 33 Differences in inches between this study and NOAA Atlas 14 for a 240-hour duration and 2-, 5-, 10-, 25-, 50-, and 100-year frequencies for 10 sections in Illinois. Positive numbers denote an increase and negative numbers show a decrease compared with Atlas 14.

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