


Contract Report 2000-07

**Continued Operation of a Raingage Network for  
Collection, Reduction, and Analysis of Precipitation Data  
for Lake Michigan Diversion Accounting:  
Water Year 1999**

by  
**Nancy E. Westcott**

**Prepared for the  
U.S. Army Corps of Engineers, Chicago District  
and U.S. Geological Survey**

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Illinois State Water Survey  
Atmospheric Environment Section  
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

CONTINUED OPERATION OF A RAINGAGE NETWORK  
FOR COLLECTION, REDUCTION, AND ANALYSIS OF PRECIPITATION DATA  
FOR LAKE MICHIGAN DIVERSION ACCOUNTING:  
WATER YEAR 1999

FINAL REPORT

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and  
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Nancy E. Westcott  
Principal Investigator

Atmospheric Environment Section  
Illinois State Water Survey  
2204 Griffith Drive  
Champaign, Illinois 61820-7495

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## ABSTRACT

A dense raingage network has operated in Cook County since the fall of 1989, to provide accurate precipitation for use in simulating runoff for purposes of Lake Michigan diversion accounting. This report describes the network design, the operations and maintenance procedures, the data reduction methodology, and an analysis of precipitation occurring during Water Year 1999 (October 1998 through September 1999). The data analyses include 1) monthly and Water Year 1999 amounts at all sites, 2) Water Year 1999 amounts in comparison to patterns from network Water Years 1990-1998, and 3) the ten-year network precipitation average for Water Years 1990-1999. Also included are: raingage site description, instructions for raingage technicians, documentation of raingage maintenance, and documentation of high storm totals.

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Nancy E. Westcott, Meteorologist

## 1. INTRODUCTION

The volume of water diverted from Lake Michigan into the state of Illinois is monitored to ensure that the diversion does not exceed a long-term average of 3,200 cubic feet per second (cfs) as imposed by a 1967 U.S. Supreme Court Order, which was updated in 1980. This diversion has a long history, dating back to the mid-1800s with the completion of the Illinois and Michigan Canal. Over the years, it has been affected by such events as the reversal of the flow of the Chicago River and completion of the Chicago Sanitary and Ship Canal in 1901, and has weathered various legal proceedings that attempted to ensure that the diversion could be monitored and did not exceed certain limits. One of the key components of the monitoring procedure, administered by the U.S. Army Corps of Engineers (COE), Chicago District, is the accurate representation of the precipitation that falls over portions of the Cook County, Illinois region.

The primary components of Illinois' diversion from Lake Michigan are as follows: 1) water is pumped directly from Lake Michigan as the source of potable water supply and discharged into the river and canal system in the greater Chicago area as treated sewage; 2) storm runoff is discharged from the diverted watershed area of Lake Michigan, draining to the river and canal system; and 3) water enters the river and canal system directly from Lake Michigan.

The storm runoff from the Lake Michigan watershed basin enters the combined and separate sewer systems and watercourses. The combined sewers mix sanitary system flow with runoff, and this water then goes to the treatment plants or, during major flood events, becomes surcharged into the water courses. When large storm events are predicted (and greater than normal storm runoff is anticipated), the canal system is drawn down prior to the event to prevent flooding. If the event fails to materialize, canal system levels are restored using a direct diversion from Lake Michigan through three facilities located along the shoreline: the Chicago River Controlling Works, O'Brien Lock and Dam, and the Wilmette Controlling Works.

The method for computing the diversion involves the direct measurement of diversion flow at Romeoville, Illinois, as measured by an acoustic velocity meter. Flow at Romeoville consists of both diversion and nondiversion flows (deductions). The theory behind diversion accounting is to use the flow at Romeoville and deduct from it flows not attributable to diversion. Diversion flows that bypass Romeoville are added to the resultant flow, yielding a net computed diversion of water from Lake Michigan. The

deductions to the Romeoville record include runoff from 217 square miles of the Des Plaines River watershed that is discharged into the canal, the ground-water supply whose effluent is discharged into the canal, water used by federal facilities, and the Indiana water supply that is discharged into the canal via the Calumet River system and the Calumet Sag Channel.

The diversion is approximated by adding the Lake Michigan water supply pumpage, direct diversions from Lake Michigan, and runoff from 673 square miles of diverted Lake Michigan watershed. This approximation is performed to cross-check the computed diversion.

In both of these procedures, it is necessary to estimate runoff from the Des Plaines River and the Lake Michigan watersheds. Hydrologic simulations of runoff perform two functions. One is to model runoff. The second is to aid in determining the runoff, ground-water, and sanitary proportions of treatment plant discharge. Inputs into the simulation model consist of land-use and climatological data. Of the latter, the most significant is precipitation data.

Accurate precipitation data, thus, are essential to properly simulate the runoff process. Runoff can constitute a significant portion of the diversion. For example, from Water Year 1986 through Water Year 1989 (a water year extends from October 1 through September 30 of the following calendar year), runoff from the Des Plaines River watershed constituted a 142 cfs (4 percent) deduction from the Romeoville measurement record in the diversion computations. In the cross-check approximations, the Lake Michigan watershed runoff constituted a 729 cfs (23 percent) share of the total diversion.

However, the precipitation data available for use by the accounting procedure prior to Water Year 1990 (particularly Water Years 1984-1989) displayed patterns inconsistent with known, long-term Chicago-area patterns (e.g., Changnon, 1961, 1968; Huff and Changnon, 1973; Vogel, 1988, 1989; Peppler, 1990, 1991a, 1993a). These patterns also diverge from the known urban effects found within the precipitation patterns for the Cook County region for heavier rainfall distributions from 1949-1974 (Huff and Vogel, 1976), particularly toward the south, and within patterns observed during the operation of a dense raingage network and radar system in the Chicago area during the late 1970s (Changnon, 1980, 1984).

The recent unusual patterns were caused by abnormally low precipitation totals at a select number of the 13 sites used by the accounting procedure (Figure 1). Inspection of these sites (Vogel, 1988), which are irregularly distributed over the region, revealed that the low precipitation totals were caused by 1) inadequate raingage exposure (e.g., gages situated on rooftops or too near natural or artificial, flow-restricting obstructions) and 2) different observing, data reduction, and quality control

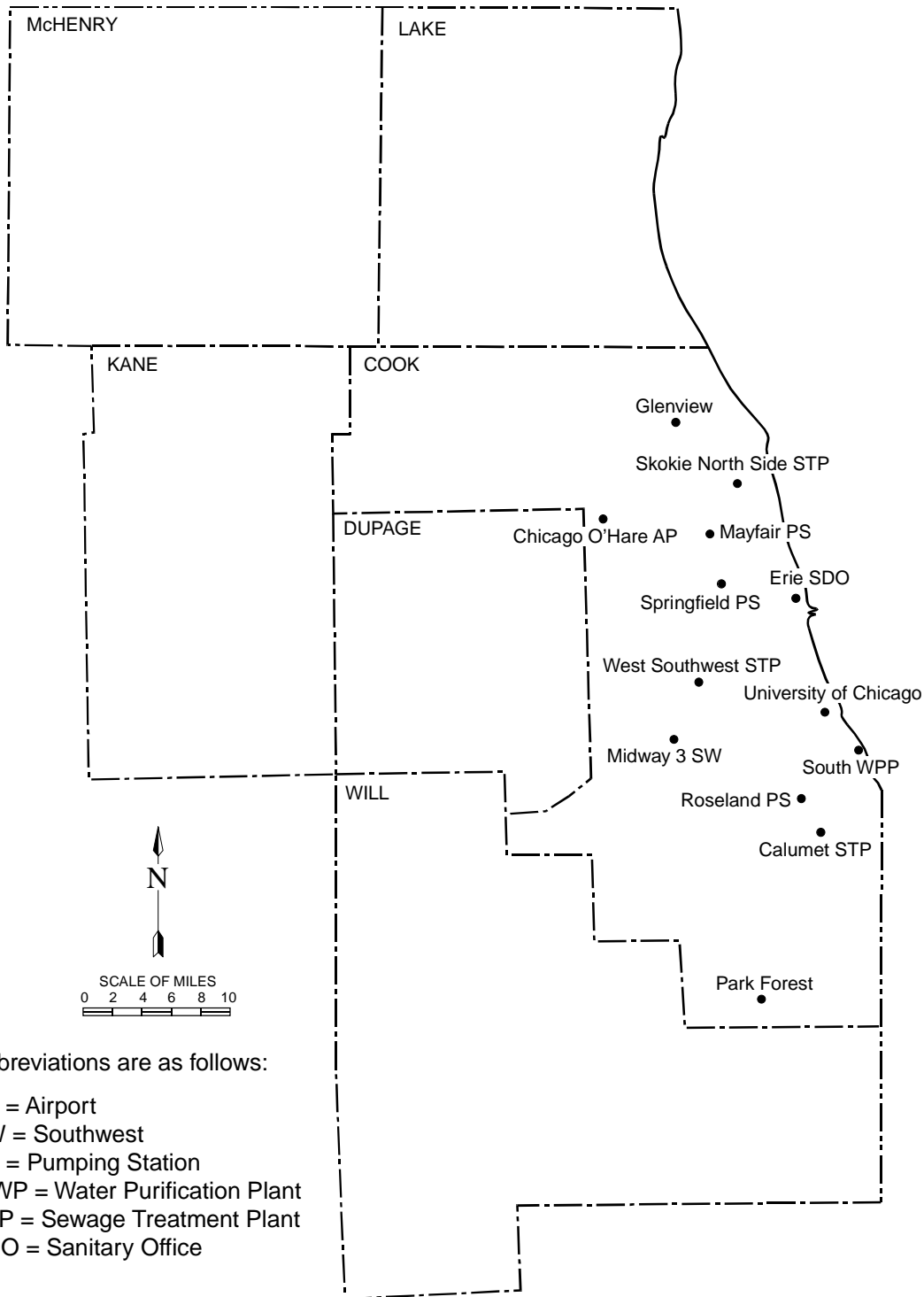


Figure 1. Raingage locations used for diversion accounting purposes prior to Water Year 1990. These include National Weather Service gages located at Chicago O’Hare AP, Midway 3 SW, University of Chicago, and Park Forest; City of Chicago gages located at Mayfair PS, Springfield PS, South WWP, and Roseland PS; and Metropolitan Water Reclamation District of Greater Chicago gages located at Glenview, Skokie North Side STP, Erie SDO, West Southwest STP, and Calumet STP.

practices used by the individual groups responsible for raingage operation and data collection (National Weather Service - NWS, Metropolitan Water Reclamation District of Greater Chicago - MWRDGC, and City of Chicago - CC). Vogel (1988) established that the unusual precipitation patterns began occurring in the late 1960s when some changes were made in data collection and reduction.

Vogel (1988) devised a procedure to adjust the questionable values, thus making the data suitable for use in the accounting procedure. This procedure, however, is tedious to implement, and the adjusted precipitation values may not completely capture the actual precipitation regime, although the data produced are much improved over the original values. This procedure also illuminated difficulties experienced when trying to merge data observations from different observing agencies and equipment into one data set. Vogel (1988) gave the following recommendation at the end of his report on the reduction and adjustment of the Water Year 1984 data and on field evaluations of the NWS, MWRDGC, and CC sites:

"With these types of differences it will always be hard to maintain a consistent set of high-quality precipitation observations for the Chicago urban region. A precipitation network which must produce a set of high-quality observations should have a consistent set of gages; should be managed by one group with fixed quality control procedures, exposure criteria, and a set operating procedure. Management by one group would allow for consistent 1) observations, 2) quality control, and 3) spatial and temporal precipitation patterns.

"To achieve this, it is recommended that a raingage network be established to monitor the precipitation over northeast Illinois relevant to the diversion of Lake Michigan waters. This network should consist of 10 to 15 weighing-bucket-recording raingages. The raingages should be reasonably spaced across the affected area. The network should be managed by one group to ensure that the best possible exposures are obtained initially, and that these exposures are inspected at least annually. The data from such a network should all be quality-controlled in a consistent manner.

"Weighing-bucket raingages with daily charts would be capable of obtaining hourly or smaller time increments if daily charts are used. To reduce costs and to increase security, it is recommended that these raingages be located on private property, and that the observers be given a modest annual stipend. The charts from the observers should be mailed to a central location for data processing, quality control, and extraction of hourly precipitation totals. Raingages should be evenly spaced, as much as possible, and sites would be found after consulting with the agencies involved" (pp. 41-42).



Using Vogel's recommendation as a model, the State Water Survey (SWS) and the COE jointly decided in late 1988 to devise, install, and operate a new raingage network, funded by the COE. The purpose of the new network was to produce consistent, accurate data for the diversion accounting, which would require little or no adjustment. The implementation and operation of such a network would have to be justified on the grounds of both long-term cost savings and greater accuracy.

This report describes the maintenance and operation of the network, along with the data reduction and analysis techniques employed, and brief data analyses for Water Year 1999, the tenth year of network operation.

## 2. NETWORK DESIGN

The SWS has operated dense raingage networks in the past (e.g., Huff, 1970, 1979), which tested gridded raingage spacing of 6 feet to 6 miles. Adequate sampling of convective-type precipitation (spring and summer) was found to require nearly twice as many gages as required by more widespread, continuous precipitation (fall and winter). With that in mind, and opting for an optimum grid spacing, an initial attempt at creating a grid resulted in an array of 40 raingages located in the Cook County region within the Lake Michigan and Des Plaines River watersheds of the MWRDGC North, Central, South, and Lemont basins. Due to cost considerations, however, some spring/summer catchment ability was sacrificed, and a 25-site grid was devised using a 5- to 7-mile grid spacing between gages. Also due to cost considerations, raingages were not installed outside the watershed boundaries to better define isohyetal patterns at those boundaries. These 25 raingages, more than the 10 to 15 gages Vogel had originally envisioned, have provided adequate coverage for precipitation catchment during Water Years 1990-1999, the first ten years of network operation (Peppler, 1991b, 1991c, 1993b, 1994, 1995; Westcott, 1996, 1997, 1998, 1999), and are consistent with the "best current engineering practice" as specified in the 1967 and 1980 Supreme Court decrees.

Topographic maps of the Cook County region were used to approximate the location of each of the 25 sites and fine-tune their placement to best position the sites with respect to residential areas, industrial facilities, or municipal grounds. Since terrain effects are fairly minimal in northeastern Illinois, gridding was possible. Gridding also allows the use of simple arithmetic averaging to compute areal depths instead of other labor-intensive methods such as the Thiessen polygonal method.

Once candidate locations were found, several preliminary field trips were made to the Cook County region, and letters were written by the SWS in summer 1989 seeking permission to use the selected locations as raingage sites. Due to the urbanization of the region, site selection was sometimes a frustrating venture, as it was difficult in many instances to identify good catchment areas free of barriers for ground-level placement. When selecting sites, highest priority was given to those at ground level in relatively open, secure areas, since obstructions and local wind eddies

produced by flow barriers present the largest sources of error in collecting precipitation data. Placing the collector at ground level mitigates wind effects on catchment and represents the ideal exposure (Legates and Willmott, 1990), but it is not practical in wintertime when snow is measured. Thus, as has been standard SWS practice, each raingage was to be placed on stakes with its base approximately 8 inches above ground level and the top of its orifice at about 4 feet. When asked for permission to site a raingage on their property, most individuals, businesses, and municipalities were extremely receptive. As of September 30, 1999, only nine sites have been relocated to a different property since the network began collecting data in October 1989.

In late September and early October 1989, the entire 25-gage network was installed (Figure 2). Each universal weighing-bucket raingage used throughout the network was fitted with a battery-powered electric chart drive for more consistent and reliable operation. The SWS provided all raingages from its inventory. Appendix I contains complete site descriptions for each network location, accurate as of September 30, 1999.

The weighing-bucket recording raingages used are as reliable as any others available (see Jones, 1969, for a complete description of tests of different raingages). All raingages are subject to catchment errors due to winds, wetting losses, evaporation, splashing into or out of the gage, and blowing snow (Legates and Willmott, 1990). Koschmieder (1934) noted that as wind speed increases, gage catch decreases. Legates and Willmott (1990) found that raingage errors "tend to be proportional to total precipitation and amount to nearly 11 percent of the catch." To prevent loss due to blowing snow during the winter, the Nipher shield and the shield used by Lindroth (1991) are helpful, but were not considered for the new network due to cost and vandalism considerations. In October 1997, an Alter shield was installed at site #13, located at a very windy lakefront location.

### 3. NETWORK OPERATION AND MAINTENANCE

Each raingage in the network was fitted with a 24-hour chart drive and chart cylinder gears that rotate the chart cylinder once every 24 hours. The 24-hour chart allows resolution down to 15-minute periods. Because a chart can measure up to 12 inches of precipitation, each gage is fitted with a galvanized bucket capable of holding 12 inches of precipitation in calibration with the 8-inch orifice opening used on the raingage collector. An upward pen traverse on a chart measures the first 6 inches the bucket catches, and a reversed, downward pen traverse measures inches 7-12. The latter traverse, though often unnecessary, is vital whenever more than 6 inches of precipitation occurs between chart periods, or during winter when the antifreeze-charged buckets are allowed to accumulate precipitation without dumping for long periods of time.

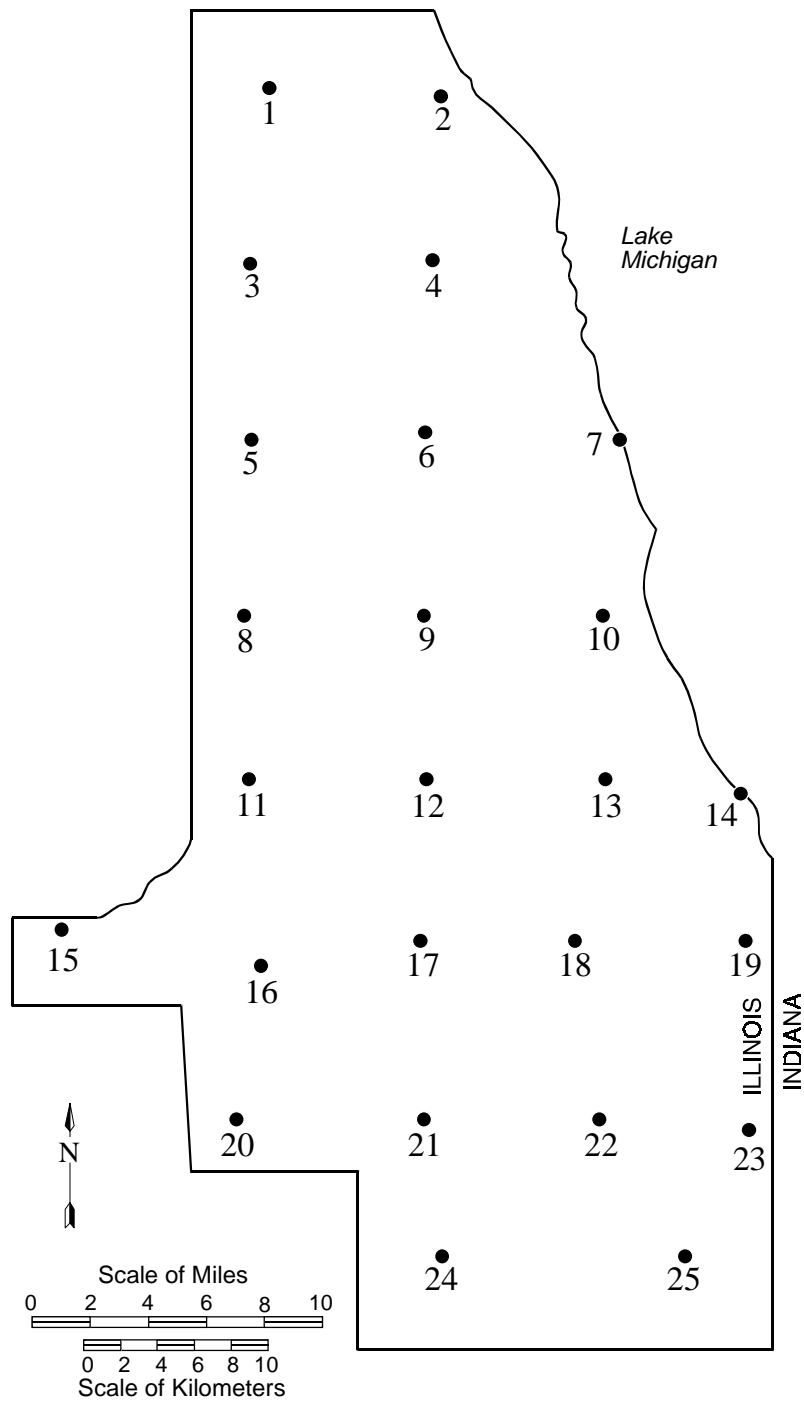


Figure 2. The 25-site rain gauge network used during Water Years 1990 to 1999.

A single team of observers living in Cook County, services each gage every 6-8 days, which means that 6-8 traces are drawn on each chart. Servicing includes removing and replacing the current chart, checking the pen point, dumping the bucket from April-October (the warm season of the year), and noting any problems, including chart-drive malfunction, gage imbalance or instability, vandalism, unauthorized movement of the gage, etc. During the warm season, evaporation shields are fitted into the collection orifice above the bucket to mitigate evaporation. During the cool season (November-March), these shields are removed and a 1-quart charge of antifreeze is added to each bucket. This allows frozen precipitation to melt in the bucket as it is caught, allowing the weighing mechanism to give a proper reading. Appendix II contains a complete set of servicing instructions provided to the raingage observers.

Each week a complete set of 25 charts collected by the observers is mailed to the SWS, along with notations about problems. The following section, describing data reduction, explains what happens to the data collected on the charts.

Approximately once every four months, or when necessary, the SWS raingage service leader visits the network to perform routine maintenance and repairs for which the observers do not possess adequate expertise. These activities include a site assessment of observer-noted problems and the determination of solutions. Because most problems pertain to the chart drives, the solution is often to replace the drive or its batteries. If replaced, a chart drive is cleaned and readied for reuse at the SWS. Two spare chart drives allow for flexibility here. Other typical problems (mentioned above) can be solved on these trips as well. Appendix III provides a complete maintenance history, including site relocations, for the raingage network, and more fully describes the kinds of maintenance and repairs conducted. This information is accurate through September 30, 1999.

#### 4. DATA REDUCTION

Each set of charts that arrives at the SWS is edited to identify the various traces on the charts and to number sequentially by date those showing precipitation. This is perhaps the most important step in the reduction procedure. A running inventory of "on" and "off" chart times is also maintained to ensure that the on-times on the newly received charts match the off-times on the last set of charts analyzed. Occasionally, the observers make inadvertent errors in the on-time/off-time designations, particularly when time zones change in October and April (charts are always kept on Central Standard Time). The on- and off-times are marked on the charts, with the on-time revolution designated as "1", and the last revolution designated as appropriate. Then, the various precipitation periods (storms) are identified and numbered based on their sequence in relation to the first and last revolutions. This editing procedure also acts as a trouble-shooting exercise to identify chart-drive problems (running slow, fast, or not at all). Raingage instability can also be identified from a shaky pen trace. Skipping or unusually heavy traces indicate problems with the pen tip. Calibration problems can be noted if a trace reverses before the 6-inch line is reached. Finally, the editing stage

permits the identification of missing periods of data on the charts, and these are appropriately marked. After all charts have been edited, they are ready to be digitized with a Summagraphics Microgrid II digitizer.

All values are fed into a 486/33 Mhz personal computer. Each chart is processed separately. The four corners of a chart are digitized to set the grid, then on- and off-times are entered and their locations digitized. The number of revolutions on each chart is noted. Each trace indicating precipitation is digitized by "clicking-on" each breakpoint along the respective trace. Once a chart is digitized, computer output gives details on the precipitation that was measured on the chart, in storm amount format, with appropriate beginning and ending times. Also included is an analysis of whether the chart drive is running slow or fast, which helps assess whether a chart drive requires servicing. Errors made during the editing stage can also be caught during digitization. If a chart drive stops during a collection period, the beginning and ending points of the missing period are digitized and appropriately stored in the computer.

Once a calendar month of data is logged into the computer, a C-language computer program, written at the SWS, calculates hourly precipitation values at all 25 sites for each hour of the month in question. These calculations are based on a linear interpolation between digitized breakpoints on the traces. The newly computed hourly values are compared to the digitized storm values during program execution to ensure consistent precipitation amounts. A printout of the entire monthly data array contains data for all 25 stations for all hours of the month. Monthly totals appear at the bottom of the printout. Missing values are denoted as 99.99.

This data array is then used to check for time and space consistency, to divide the data into storm periods, and to fill in missing values with interpolated information. A storm is defined as a precipitation period separated from preceding and succeeding precipitation periods by approximately 6 hours at all stations in the network. This definition has been used by Huff (1967) for an area of similar dimensions in central Illinois, by Vogel (1986) to define extreme storm events in the Chicago area, and by Vogel (1988, 1989), Peppler (1990, 1991a-c, 1993a,b, 1994, 1995), and Westcott (1996, 1997, 1998, 1999) to define storms for Water Years 1984-1999. For each storm, values are summed and plotted on maps using all available data and stations, and isohyetal patterns are drawn. During Water Year 1999, 114 such storms were defined.

After a generalized precipitation pattern is obtained for each storm, interpolated storm totals are manually estimated from the pattern for each site having missing information during that storm. Wind information, if available (usually the resultant direction and speed at Chicago O'Hare Airport), and known urban effects in the Chicago area (Huff and Vogel, 1976; Changnon, 1980, 1984) may be taken into account when drawing isolines and interpolating values. A computer program using an objective analysis program is then executed to objectively determine new values for hours designated as missing. The objective routine is also used to re-create values at data sites for which questionable values were identified during the storm analysis stage.

After execution of the program, the new values are compared to the manually estimated ones, and any unrealistic objective values are adjusted. Once everything has been verified, a final computer file of hourly precipitation values for the month being analyzed is archived.

## 5. DATA ANALYSIS

The Water Year 1999 data set was used to produce various analyses, including: 1) monthly and water year amounts at all sites (Table 1), 2) water year amounts (Figure 3) and comparisons to patterns from network Water Years 1990-1998 (Figure 4), 3) monthly amounts (Figures 5) as documentation of the data collected, and 4) an analysis of the ten-year network precipitation average for Water Years 1990-1999 (Figure 6).

Table 1 and Figure 3 show Water Year 1999 precipitation amounts. Isopleths in Figure 3 (and Figures 4-6) are labeled in inches, while values in Table 1 are given to the nearest hundredth of an inch. Considering the total annual network precipitation amount, Water Year 1999 was an average year. The Water Year 1999 network average of 36.33 inches was within about 1 percent of the 1961-1990 Chicago O'Hare Airport annual precipitation normal of 35.82 inches. The network average precipitation for Water Years 1990-1998 was 40.00, 39.19, 36.56, 51.78, 29.23, 34.68, 36.88, 34.09, and 36.12 inches, respectively. The nine-year (1990-1998) network average precipitation was 37.85 inches. There were 114 precipitation events in Water Year 1999, and eight of these events included at least one site where the storm total exceeded the one-year recurrence interval (Appendix IV). On average, seven such heavy rainstorms occurred in Water Years 1990-1999.

The largest precipitation amounts during Water Year 1999 occurred in three areas oriented northwest to southeast: one across southwest Chicago (sites #15 and #20), one across north-central Chicago, (sites #3, #5, #6, #9, and #10), and one centered at site #2. (see Figure 2 and Appendix I for site information). The lightest amounts occurred at the southeastern sites #14, #19, #23, #24, and site #25. The heaviest precipitation in the network during Water Year 1999 (40.49 inches) fell at site #10 in downtown Chicago, while the lightest fell at site #23 (30.40 inches) in the southeastern part of the network.

Figure 4 provides maps of precipitation amounts for network Water Years 1990-1998. The general pattern for Water Year 1999 is unlike many previous years in that the heaviest precipitation is distributed over the northern half of the network as well as the far southwestern portion of the network. The "urban high" of the near lake, central Chicago area noted in other network water years and in other Chicago-area research (e.g., Huff and Vogel, 1976) was one of three peak precipitation regions in 1999. The pattern of low values in the southeastern region is somewhat similar to that found for Water Year 1992.

As in the case of the other network water year patterns, the spatial pattern for Water Year 1999 does not contain the wildly varying anomalies found in an analysis using sites operated by the MWRDGC, the NWS, and the CC raingages for Water Years 1984-1989. Precipitation data from those sites were the input for diversion accounting before construction of the present network (see Peppler, 1993b for those patterns). While there is a 9.5-inch gradient in the annual amount between sites #10 and #14, these values are supported by surrounding sites. Additionally, gradients of 15 to 20 inches were common in the 1984-1989 analysis.

**Table 1. Monthly and Water Year Precipitation Amounts for Water Year 1999 (inches)**

<i>Site</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Total</i>
1	5.63	2.07	0.12	3.58	1.42	1.20	7.94	2.43	4.32	1.43	4.08	3.49	37.71
2	4.68	2.23	0.94	4.37	1.73	1.55	8.21	3.64	4.30	1.43	3.38	3.51	39.97
3	5.13	2.07	0.97	4.07	1.51	1.34	7.11	3.95	4.90	2.25	2.38	3.39	39.07
4	4.76	2.06	0.86	3.81	1.09	1.57	7.26	3.62	4.15	1.95	2.51	2.95	36.59
5	4.46	1.91	1.11	4.56	1.28	1.72	7.51	3.82	4.73	3.47	2.22	3.01	39.80
6	4.72	2.01	1.06	5.04	1.05	1.54	6.82	3.86	4.54	2.71	2.98	3.05	39.38
7	3.63	1.91	1.20	4.61	1.04	1.14	6.30	3.34	6.05	2.79	3.04	2.47	37.52
8	5.03	1.93	1.14	4.22	0.83	1.12	5.82	4.98	3.95	2.64	2.65	2.97	37.28
9	3.97	2.24	1.43	4.51	1.15	1.41	7.18	3.57	4.84	3.02	3.28	3.27	39.87
10	4.37	2.14	1.55	4.73	1.34	2.05	4.90	4.60	6.93	2.35	3.48	2.15	40.59
11	3.99	1.89	1.47	3.60	1.18	1.49	5.91	4.17	4.07	1.82	2.69	3.18	35.46
12	3.38	1.84	1.28	3.96	1.26	1.31	5.80	4.25	6.20	3.71	2.38	2.28	37.65
13	3.44	1.69	1.59	3.96	1.07	1.61	5.53	3.88	4.41	1.68	3.33	1.82	34.01
14	3.01	1.40	1.06	3.97	1.00	1.04	5.10	3.77	4.07	2.29	2.64	1.64	30.99
15	3.92	1.72	1.37	3.38	1.34	1.39	7.14	5.42	4.37	3.36	2.26	3.80	39.47
16	3.75	1.78	1.39	3.71	0.95	1.69	6.24	4.21	5.25	3.10	1.92	2.06	36.05
17	3.37	1.69	1.53	3.48	1.24	1.62	6.23	3.73	6.59	1.70	2.03	1.65	34.86
18	3.76	1.78	1.33	3.88	1.24	1.16	5.79	4.11	5.36	2.24	2.25	1.83	34.73
19	2.60	1.27	1.19	4.12	0.90	1.70	5.68	3.62	4.75	3.12	2.24	2.09	33.28
20	3.43	1.60	1.23	3.79	0.99	1.48	6.73	4.88	6.74	2.70	3.48	1.50	38.55
21	3.17	1.64	1.21	3.75	0.84	1.77	6.11	4.25	4.60	2.36	3.91	1.67	35.28
22	2.86	1.41	1.30	4.05	1.19	1.66	7.10	4.90	5.65	1.96	2.58	1.72	36.38
23	2.65	1.25	1.36	3.22	0.48	1.46	4.94	3.67	4.67	2.43	2.47	1.80	30.40
24	2.25	1.06	1.19	4.05	0.75	1.49	6.79	4.28	4.51	1.14	2.80	1.50	31.81
25	2.78	1.44	1.55	3.12	1.03	1.19	4.96	4.90	3.89	1.98	3.17	1.56	31.57
<i>Avg</i>	3.79	1.76	1.22	3.98	1.12	1.47	6.36	4.07	4.95	2.39	2.81	2.41	36.33

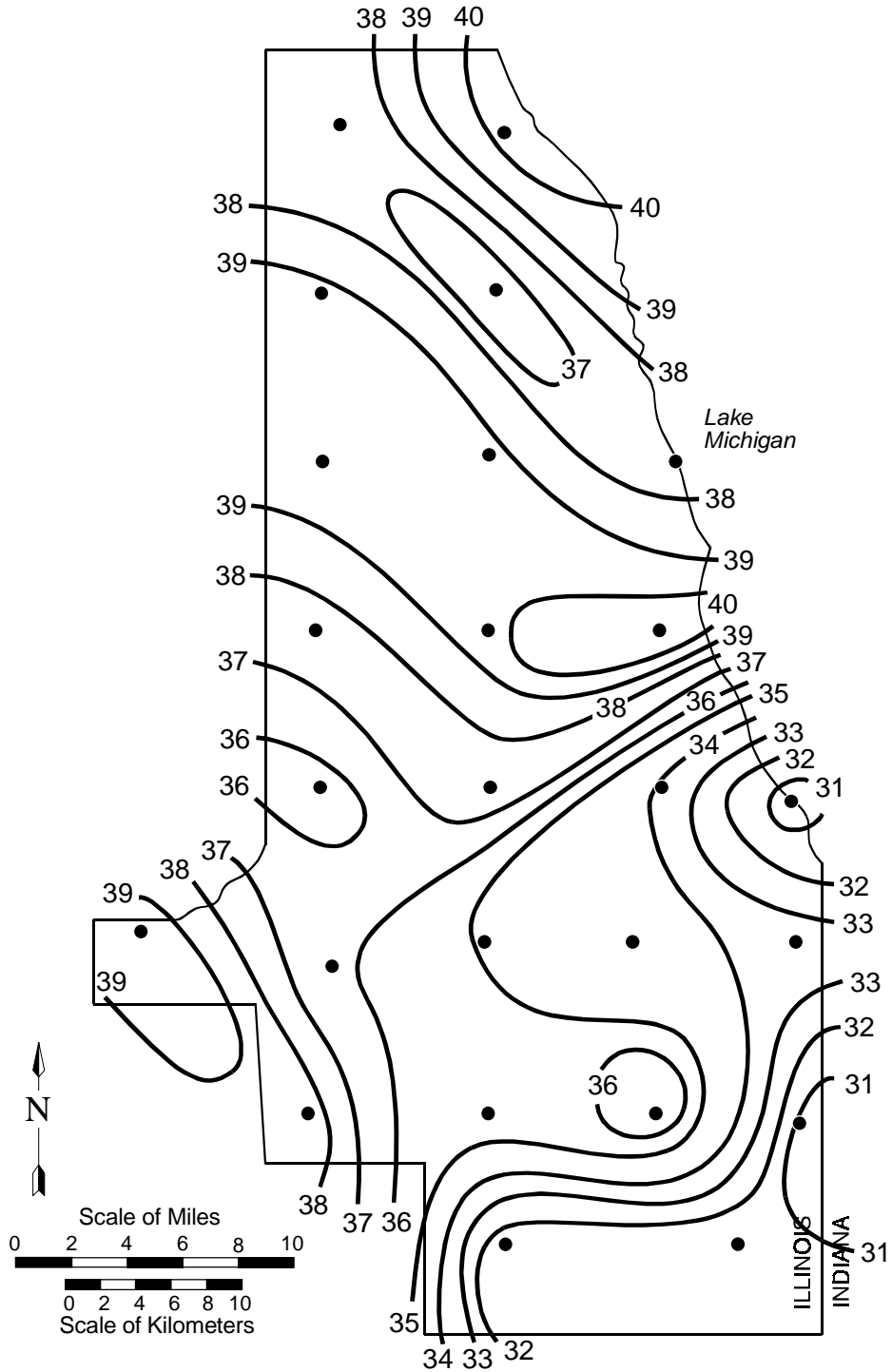


Figure 3. Precipitation pattern (inches) for Water Year 1999.



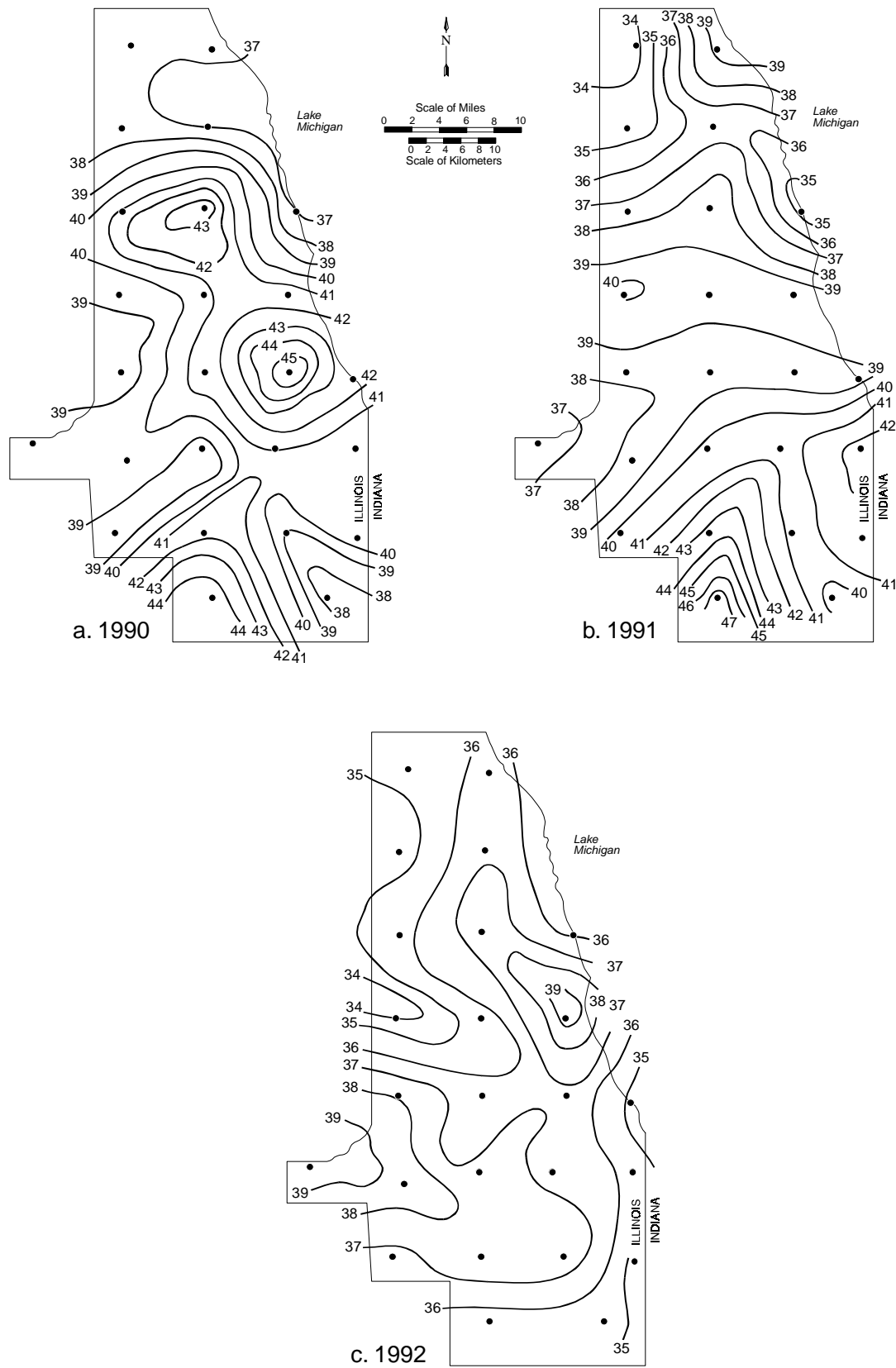


Figure 4. Precipitation pattern (inches) for Water Years 1990 - 1998.

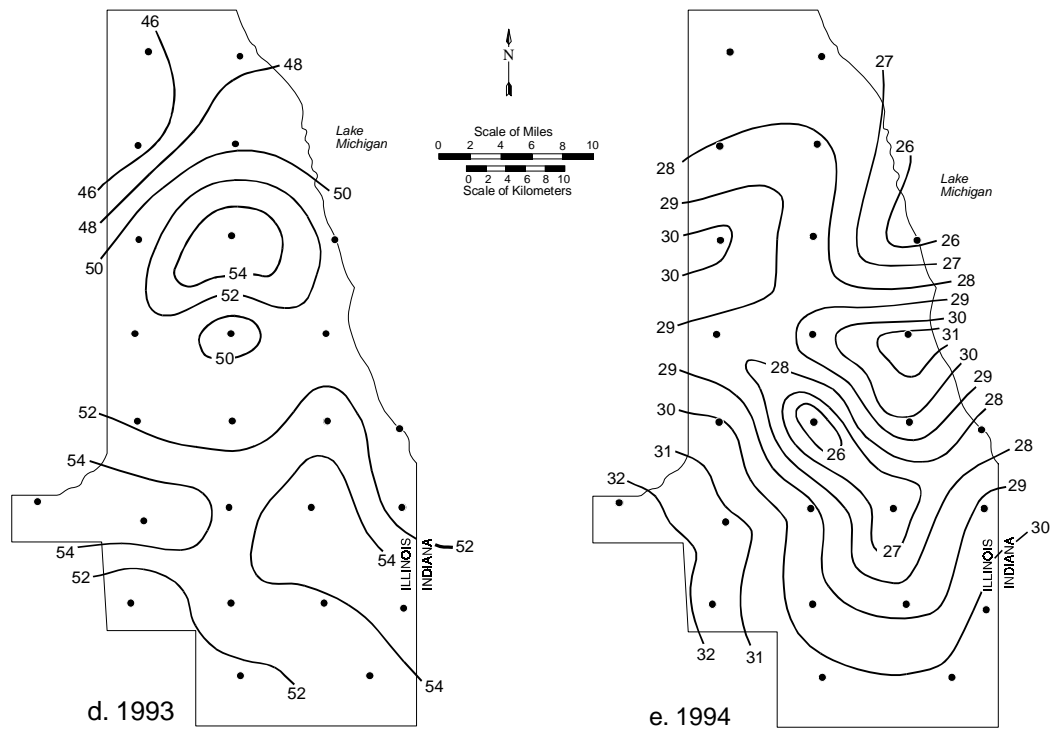


Figure 4. Continued.

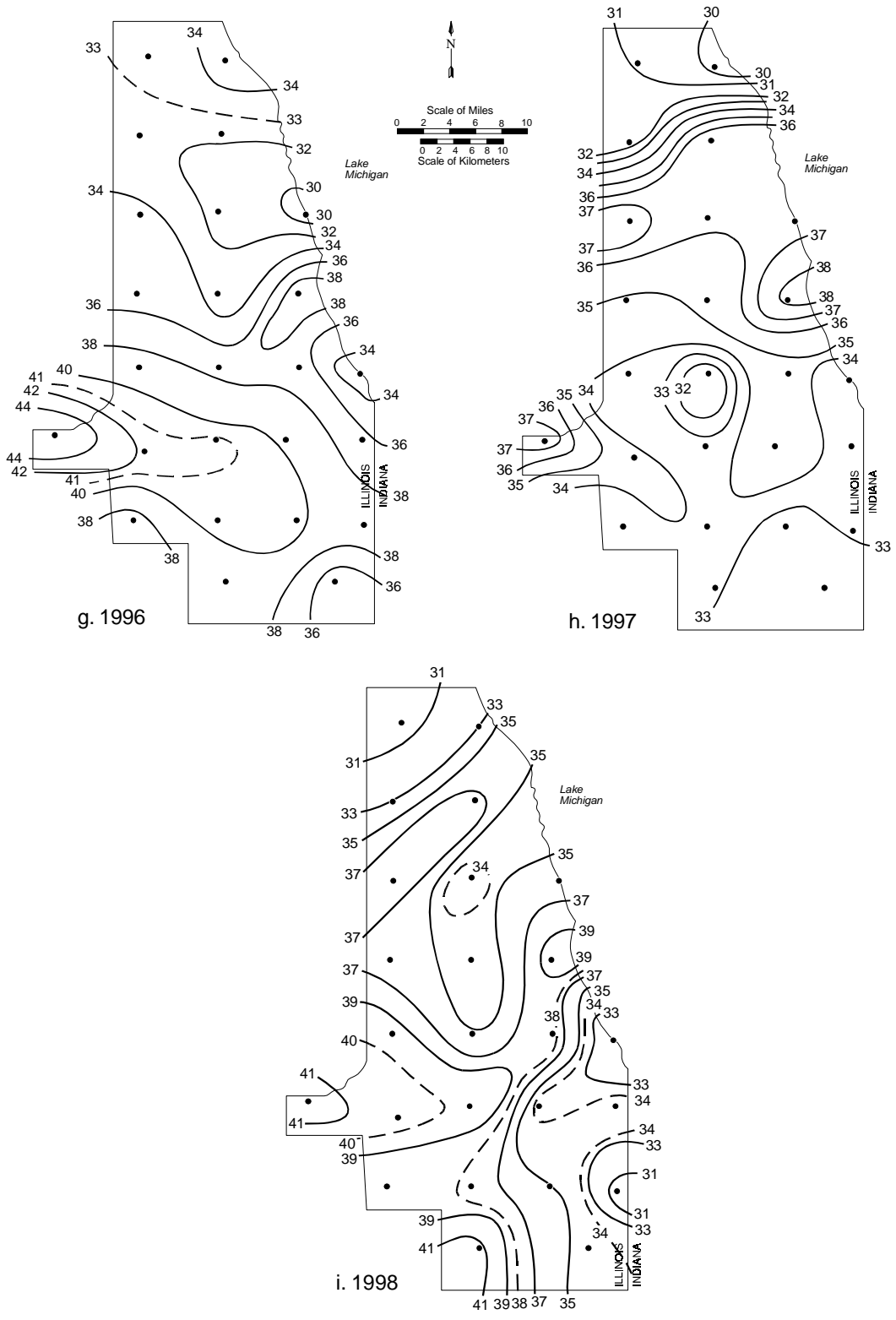


Figure 4. Concluded.

Monthly analyses during Water Year 1999 are shown in Figure 5a-l (see also Table 1). The rainiest month of the water year was April when the network average precipitation exceeded 6.25 inches, about 192 percent of the nine-year April network average of 3.31 inches. The heaviest precipitation was observed in the northern part of the network. Other months when network precipitation equaled or exceeded 3.50 inches include October, January, May, and June. The January average was about 175 percent of the nine-year January network average of 2.77 inches. In October, May, and June, the network average precipitation was within 17 percent of the nine-year monthly network average. Heavy precipitation amounts were in the northwestern portion of the network (October), in the north-central region (January), in the northern third and southwest regions (April), in the west-central region (May), and in a band extending from the southwest region northeastward toward the urban center and the lake shore (June).

Ten precipitation events occurred in April, with 15, 15 and 14 events in May, June and August, respectively. In all but four months (November, December, March and September), at least nine precipitation events occurred. There were fewer precipitation events during Water Year 1999 than in previous years with near-normal precipitation. Water Year 1996 had an annual network average of 36.8 inches of precipitation and 128 precipitation events. Water Year 1998 had an annual network average of 36.1 inches of precipitation, and 138 events. Water Year 1999 had an annual network average of 36.3 inches of precipitation, but only 114 precipitation events. Thirteen of these 114 events resulted in a network average of greater than one inch. Events with network average precipitation of more than 1.0 inch were observed four times in April, twice in January and June, and once each in October, November, December, August and September.

Precipitation amounts smaller than 75 percent of the nine-year average occurred during six months in Water Year 1999. In November, December, February and March, 50, 73, 54 and 55 percent of the nine-year (1990-1998) network monthly average precipitation, respectively, was observed, and for two summer months of the Water Year 1999 (July and August), 67 and 65 percent of the nine-year monthly average rainfall was observed, respectively. Less than 2.0 inches of precipitation fell during the cold season months of November, December, February and March. Precipitation amounts and the spatial gradient in precipitation amount generally were small in magnitude during those months.

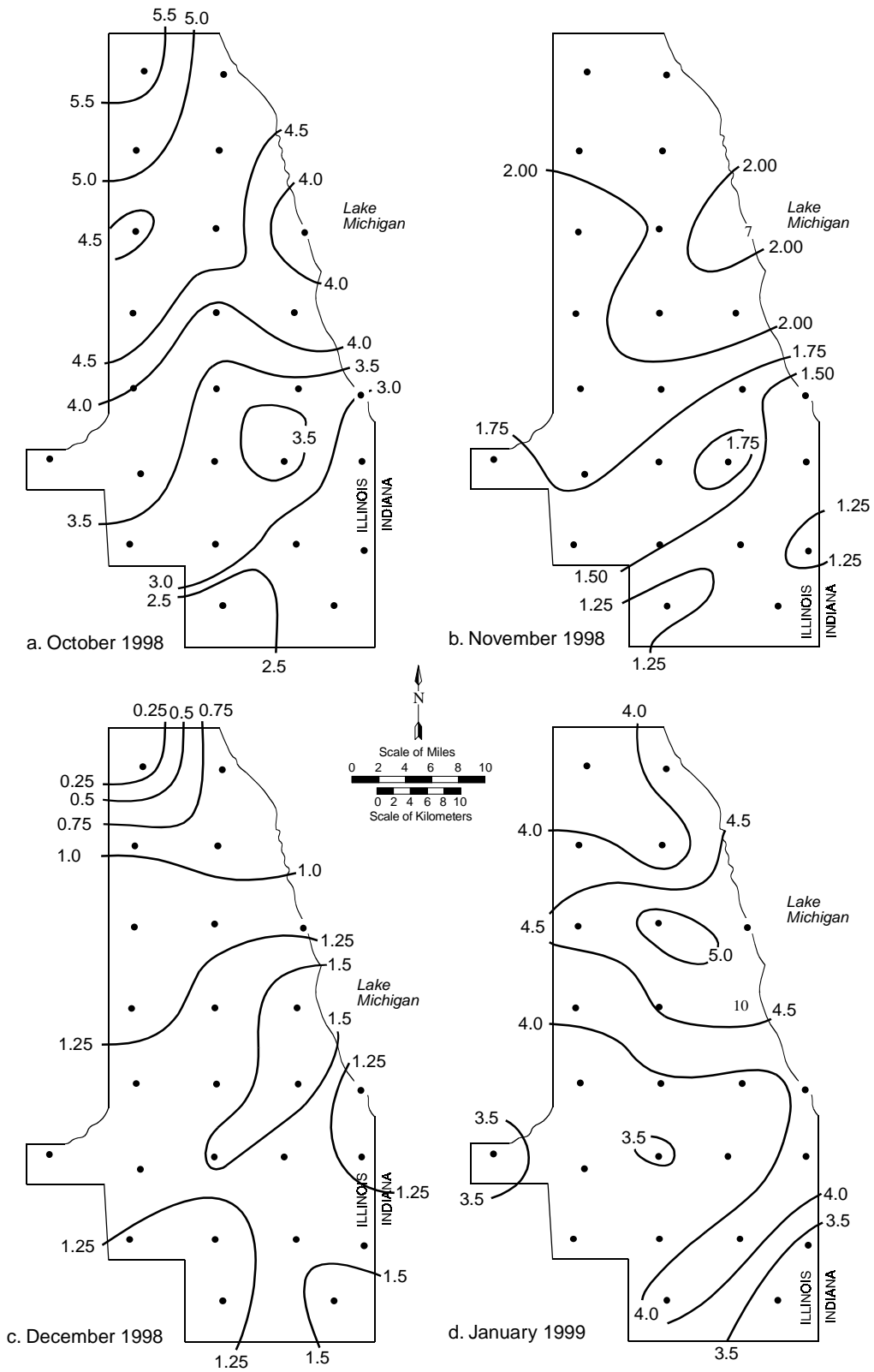


Figure 5. Precipitation pattern (inches) for October 1998 - September 1999.

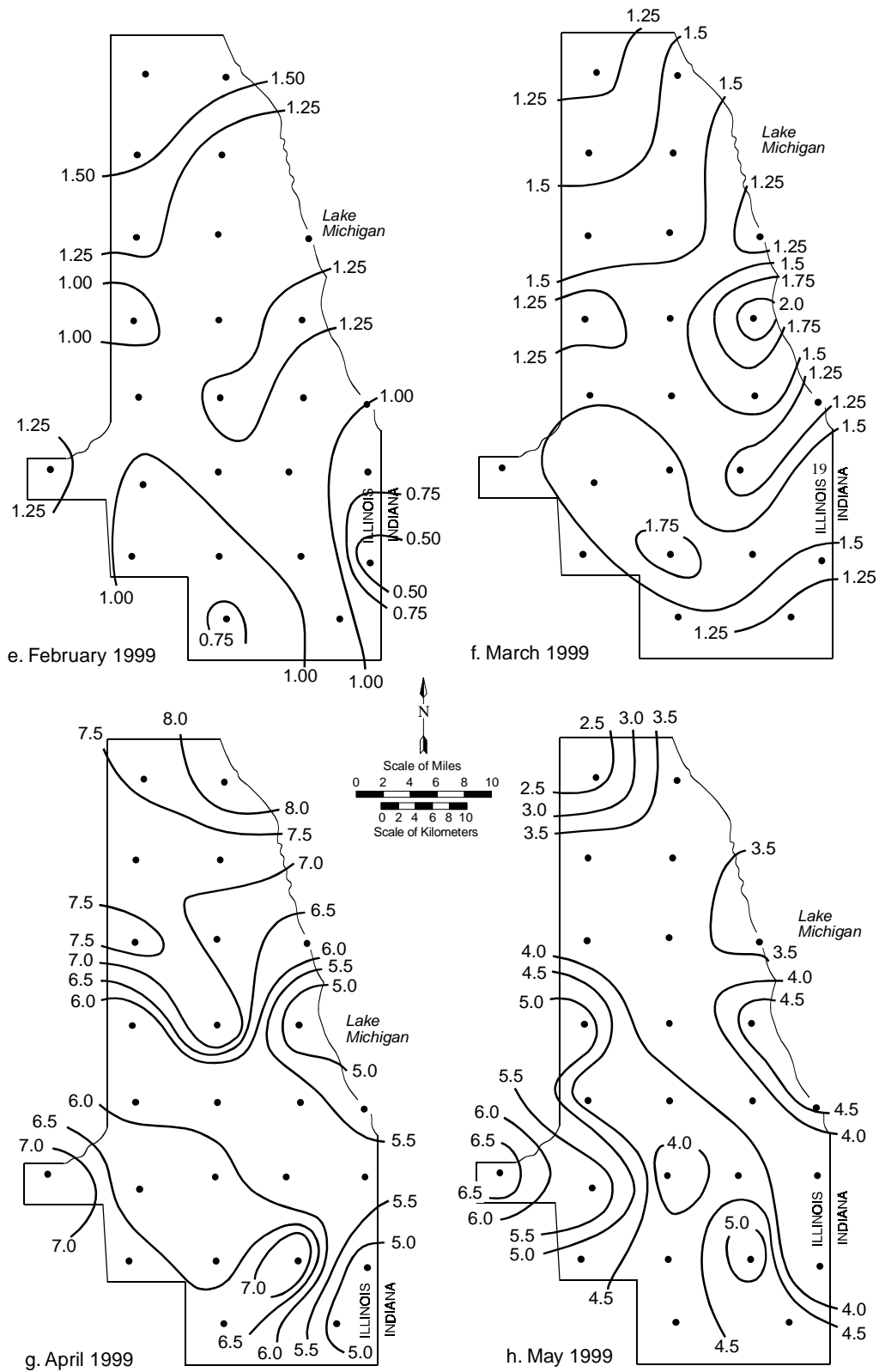


Figure 5. Continued.

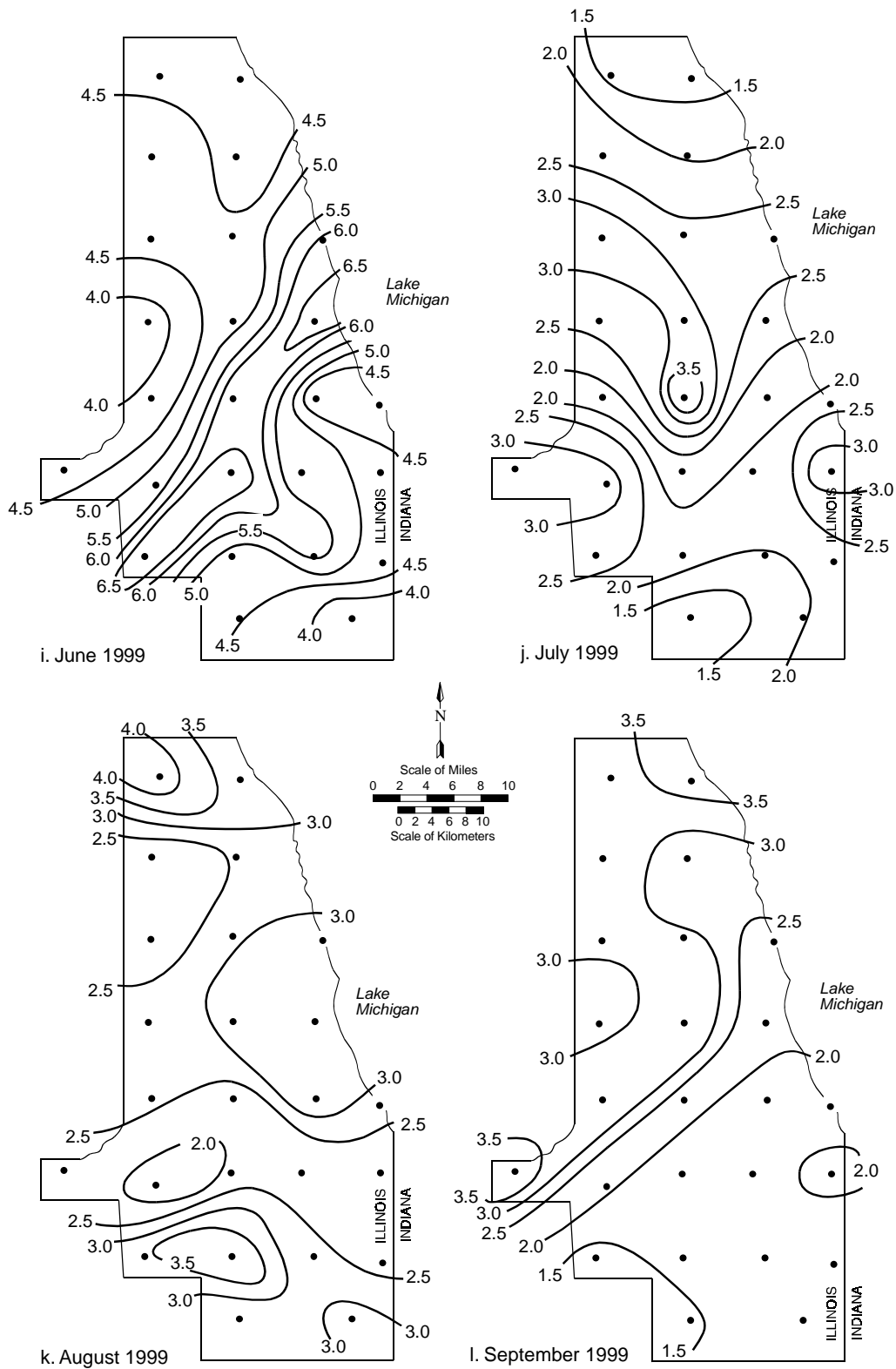


Figure 5. Concluded.

The ten-year (1990-1999) average precipitation pattern (Figure 6) reveals an area of higher values across south-central Chicago (sites #15, #16, #17, # 20, #21, and #24), reaching northward to sites #13 and #10. Lower values occurred at the northern sites #1, #2, #3, and #7, and at the lake site #14. The ten-year network-wide average is 37.49 inches.

Storm durations of one hour to three days were considered, and recurrence intervals were determined according to the standards set for northeastern Illinois (Huff and Angel, 1989). Of the 114 precipitation events identified during Water Year 1999, eight had at least one gage for which the amount surpassed the one-year recurrence interval for the given storm duration. Within these eight storms only 14 gages exceeded the one-year recurrence interval, and only four gages exceeded the two-year recurrence interval. No gages exceeded the other recurrence intervals. Only one of the previous nine years (1994) had fewer gages with heavy precipitation. This is the only year with no gages exceeding the 5-year or greater recurrence interval.

Of the eight 1999 Water Year heavy precipitation events, one event included all four gages exceeding the two-year recurrence intervals and 7 of the 14 gages exceeding the one-year recurrence interval (16-18 October 1998, Storm #7). The remaining seven events included only one gage exceeding the one-year recurrence interval. Appendix IV contains specific information concerning the eight Water Year 1999 precipitation events with gages that exceeded the one-year recurrence interval.



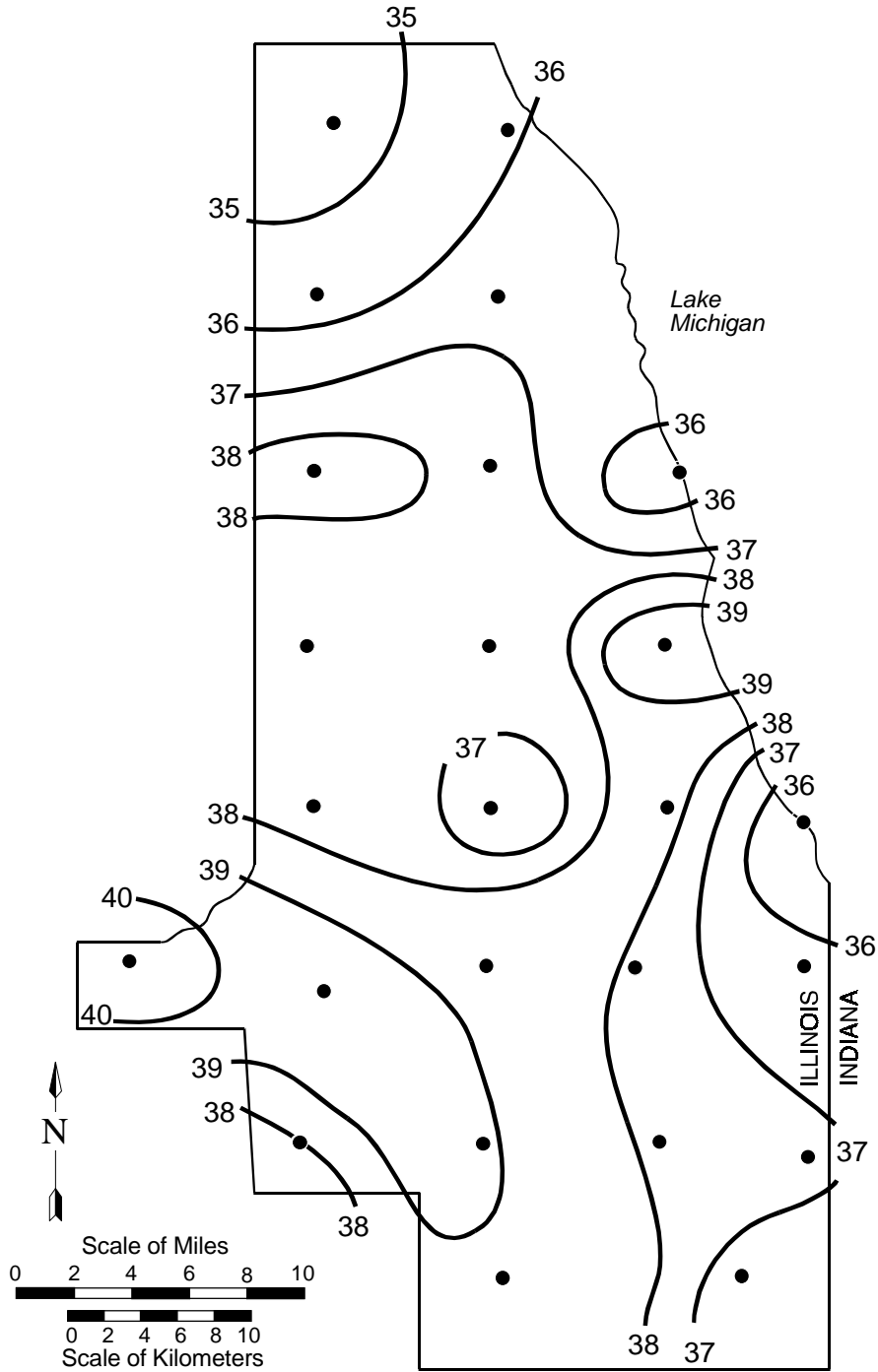


Figure 6. Ten-year average precipitation pattern (inches) from Water Years 1990-1999.

## 6. SUMMARY

The Cook County raingage network has now collected precipitation data during ten water years, 1990-1999. The siting of the raingages, the areal coverage of the network, and the careful quality control of the data allow the U.S. Army Corps of Engineers, Chicago District, to more accurately estimate the storm runoff portion of the diversion of water from Lake Michigan into Illinois. Because of the relatively dense spacing of the deployed raingages, the network also provides high-quality data for research on the precipitation variability of the Cook County region.

## 7. ACKNOWLEDGMENTS

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## APPENDIX II: INSTRUCTIONS FOR RAINGAGE TECHNICIANS

1. Supplies required for proper servicing of the instruments in the Cook County raingage network:
  - a. A supply of 24-hour rotation raingage charts (Belfort number 5-4047-B)
  - b. A supply of spare felt-tipped pen points
  - c. A roll of paper towels or similar absorbent material
  - d. A ball-point pen or pencil
  - e. Grass clippers and/or sickle
  - f. A clipboard
  - g. A spare 12-quart bucket
2. Make sure you have the correct time in the Central Standard Time zone:

Please coordinate your watch with the broadcast tone from radio station WMAQ or WGN, etc., on the hour, before starting a day's servicing schedule, and recheck if possible when out in the field. Try to be within 15 seconds of the correct time.

3. Order of servicing upon arrival at a site (try to complete within 5-10 minutes of arrival):
  - 1) Cut the grass around the raingage if necessary or applicable. Do this to the specifications of the landowner or below the level of the raingage door, whichever is shorter.
  - 2) Open the sliding door on the side of the instrument case by pushing out on the hinge lock and pulling up on the door handle, depress the bucket platform upright casting to ink the OFF time on the chart (a vertical line). Note the time on your watch, and move the pen point and arm away from the chart by pushing out on the pen bracket. Lift up on the drum cylinder to disengage it from the electric chart drive, and remove it from the instrument case. Write the OFF date and time on the chart. Carefully remove the chart from the drum to avoid smearing the fresh ink at the end of the trace.
  - 3) Write this OFF time as the ON time on a new chart, and apply it to the drum cylinder, making sure the crease at the right end of the chart is sharp and the chart is tight on the cylinder. This helps prevent skipping when the pen point travels over the drum clip, as well as preventing false indications of a precipitation event. Make a small mark with your pen or pencil on the chart near the zero-inch line to indicate the ON time. Try to match the chart reading with the ON time as closely as possible. Reinstall the chart cylinder onto the electric chart drive, making sure the chart cylinder and drive gears mesh.

4) Quickly remove the collector from the top of the gage by rotating the collector clockwise to disengage the tongue-and-groove assembly, set it down, and then carefully lift the bucket off of the weighing platform (if there is water in it) and dump the water on the ground. Reposition the bucket on the platform and reinstall the collector by setting it on top of the raingage case and turning counterclockwise until the tongue-and-groove assembly meshes. During wintertime operation when a charge of antifreeze is in the bucket, leave the antifreeze until the chart reading passes the 6-inch mark. At that point, dump the bucket contents into a large plastic bucket and dispose of properly. **DO NOT POUR SOLUTION ONTO THE GROUND!** If wintertime conditions prevail, recharge the empty bucket with a quart of antifreeze. At any time of the year, once the collector is repositioned, check the gage to make sure the collector orifice top edge is level. With a level positioned on the collector orifice, depress the stakes with your shoe or boot on the side(s) reading high, lightly or firmly depending on how much out of level the gage is and how soft the ground is.

5) Move the pen arm and point over near the chart cylinder and rotate the cylinder counterclockwise until the pen point coincides with the pencil mark on the chart denoting the ON time. Let the pen point rest on the chart there, and depress the platform casting again to make a vertical pen line at the ON time. This also assures that the pen point is writing correctly. If not, check the tip of the pen point to see why it is not drawing. Replace if necessary. It helps if the word "ON" is written on the chart near the ON line for later chart editing purposes. Re-zero the pen point if necessary by turning the fine adjustment screw. It isn't a bad idea to "zero" the pen near the 0.25-inch mark instead to prevent evaporation from taking the pen point below the zero line.

6) Wipe the inside base of the gage to keep it relatively clean. Check the just-removed chart for any irregularities and note them on the upper right corner. As you are doing this, keep an eye on the new chart to make sure the drum is rotating and the pen is writing. When you are sure everything is operating correctly, carefully close the gage door and push the hinge lock in to secure it. Make sure you have removed all supplies and tools from the site before moving on to the next one.

#### 4. Completed raingage charts and site repairs:

When a complete set of 25 charts has been collected for a week, place them in numerical order, put them in one of the postage-paid envelopes provided, and mail them to the State Water Survey, noting the name of the project director on the envelope. If any serious problems were encountered during servicing, please call the project director "collect" to relay the information. Situations worthy of immediate attention include chart-drive stoppages, unauthorized movement of the raingage, vandalism, and theft. Repairs will then be scheduled as soon as possible. Make minor repairs (e.g., pen point stuck under drum

cylinder, debris in the collection bucket, etc.). Major repairs will require the attention of the State Water Survey.

5. Change in site status:

If you become aware that there has been or will be a change of status of one of the sites in the network, or one of the landowners requests movement of the raingage, please alert the State Water Survey immediately so that the project director can contact the landowner to work out a new arrangement. It is important to try to keep the sites as permanent as possible during the course of this project.

6. Public relations:

As a representative of the State of Illinois, it is imperative that you make your contacts with the landowners and others as cordial as possible and respect their property. They are providing an important service by agreeing to have the instrumentation on their property, so please keep their good will. Refer any questions from them concerning the project and your job that you are unable to answer to the project director.



## APPENDIX IV: DOCUMENTATION OF HIGH STORM TOTALS

This appendix documents individual station storm totals (within the 114 storms) that exceeded an annual event (one-year recurrence interval) during Water Year 1999. Within the storm period, if several precipitation periods were present at an individual gage and were separated by six hours or more, only the heaviest precipitation period was considered. Storm durations of one hour to three days were evaluated. The precipitation amounts for one-year to 100-year recurrence intervals, and the aforementioned storm durations for northeastern Illinois are given below (Huff and Angel, 1989).

<i>Storm Duration</i>	<i>Precipitation Amounts (inches)</i>						
	<i>1-yr</i>	<i>2-yr</i>	<i>5-yr</i>	<i>10-yr</i>	<i>25-yr</i>	<i>50-yr</i>	<i>100-yr</i>
1 hour	1.18	1.43	1.79	2.10	2.59	3.04	3.56
2 hours	1.48	1.79	2.24	2.64	3.25	3.82	4.47
3 hours	1.60	1.94	2.43	2.86	3.53	4.14	4.85
6 hours	1.88	2.28	2.85	3.35	4.13	4.85	5.68
12 hours	2.18	2.64	3.31	3.89	4.79	5.62	6.59
18 hours	2.30	2.79	3.50	4.11	5.06	5.95	6.97
24 hours	2.51	3.04	3.80	4.47	5.51	6.46	7.58
48 hours	2.70	3.30	4.09	4.81	5.88	6.84	8.16
72 hours	2.93	3.55	4.44	5.18	6.32	7.41	8.78

The values listed in the following table exceed the numbers above for the given storm duration. An "e" indicates a partial or full estimate for a particular site and storm. The last column indicates whether a particular gage within the given storm exceeded a precipitation value greater than an annual event (2-year to 100-year recurrence intervals considered).

STORM TOTALS

<i>Storm #</i>	<i>Date</i>	<i>Site #</i>	<i>Duration (hour)</i>	<i>Amount (inch)</i>	<i>Storm Recurrence Frequency</i>
7	10 / 16-18 / 98	1	28	3.55	2-year
		2	27	2.94	
		3	30	3.25e	2-year
		4	31	2.77	
		5	25	2.71	
		6	30	3.11	2-year
		8	30	3.13	2-year
		47	4 / 8-9 / 99	2	9
53	4 / 21-23 / 99	1	32	2.95	
69	5 / 31 / 99	25	10	2.21	
75	6 / 11 / 99	10	4	1.75	
77	6 / 12--13 / 99	6	13	2.37	
92	7 / 21 / 99	5	3	1.61	
114	9 / 27-29 / 99	15	33	2.81	