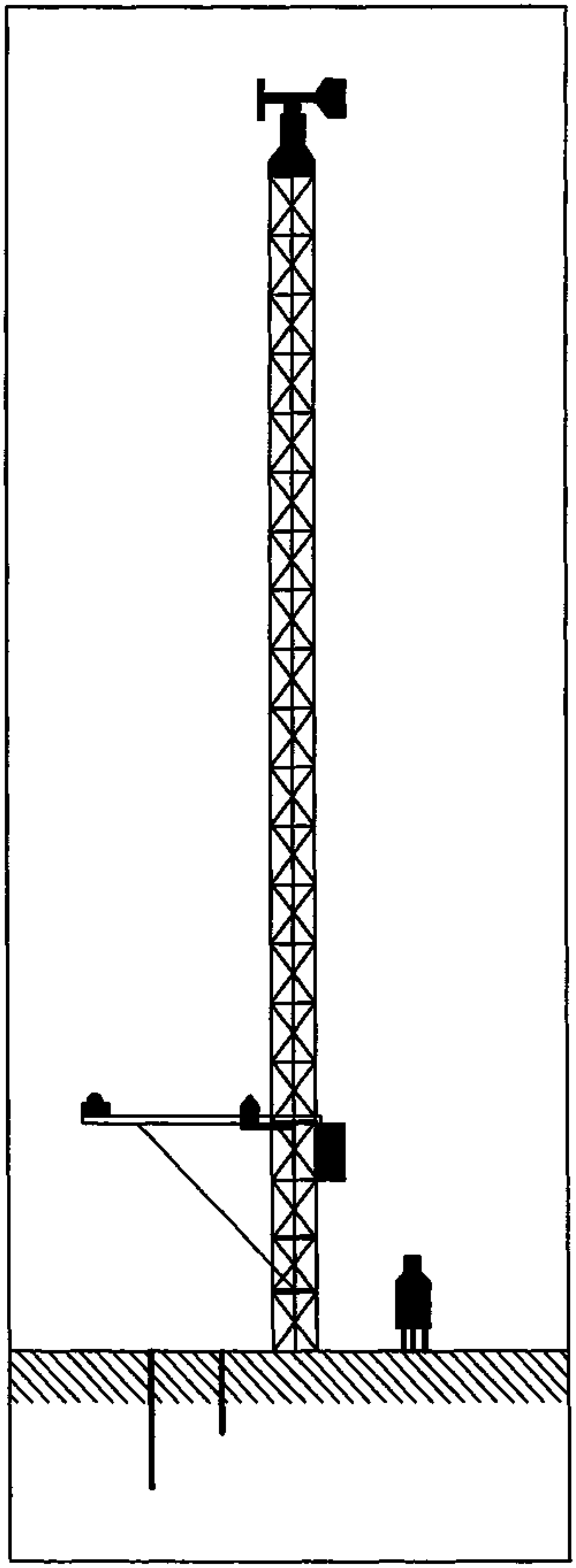

1994
Annual Report

The Illinois Water and Atmospheric Resources Monitoring (WARM) Network

Randy Peppier, Director
WARM Network Program

Illinois State Water Survey
Champaign, Illinois

May 1995
Miscellaneous Publication 165
(WARM Network Publication 3)

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A Division of the Illinois Department of
Energy and Natural Resources

The Illinois State Water Survey was founded in 1895. It is the primary agency in Illinois concerned with water and atmospheric resources. Research and service programs encompass the assessment and evaluation of ground, surface, and atmospheric water resources as to quantity, quality, and use. Scientific research anticipates and reacts to practical problems in the state of Illinois. Much of the Survey's work is facilitated by an extensive database collected and developed over the course of a century.

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ANNUAL REPORT

THE ILLINOIS WATER AND ATMOSPHERIC RESOURCES MONITORING (WARM) NETWORK

WARM Network Program
Randy Peppier, Director

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May 1995

Cover illustration depicts a typical Illinois Climate Network weather station.

This report printed on recycled and recyclable papers.

TABLE OF CONTENTS

- INTRODUCTION . . . 1
- WARM NETWORK DESCRIPTION . . . 1
  - Shallow Ground-Water Observation Wells . . . 1
  - Instream Suspended Sediment Sampling . . . 4
  - Automated Climate Monitoring/Illinois Climate Network . . . 7
  - Soil Moisture Measurements . . . 10
  - Surface Water Data Compilation . . . 14
  - Other Routinely Collected Data . . . 14
  - WARM Network Organization . . . 16
- USES AND BENEFITS . . . 20
  - Governmental Agencies . . . 20
  - Agriculture . . . 20
  - Engineering . . . 21
  - Meteorology/Hydrology . . . 21
  - Education . . . 21
  - Public Information . . . 21
- PRODUCTS . . . 22
- THE FUTURE OF THE WARM NETWORK . . . 22
- AN ANALYSIS OF THE WET 1993 SUMMER IN ILLINOIS . . . 23
  - Introduction . . . 23
  - Climate Background . . . 23
  - Analysis of Illinois Conditions . . . 24
    - Pre-November 1992 . . . 24
    - November 1992 . . . 26
    - December 1992-May 1993 . . . 26
    - June 1993-September 1993 . . . 27
    - Post-September 1993 (through December 1994) . . . 35
  - Two Non-Mississippi River Flood Cases . . . 35
    - Cook County . . . 35
    - Mason/Tazewell Counties . . . 37
  - Impacts . . . 37
- SUMMARY . . . 40
- ACKNOWLEDGEMENTS . . . 40
- REFERENCES . . . 41
- APPENDIX A . . . 43
- APPENDIX B . . . 57

INTRODUCTION

The Illinois State Water Survey (ISWS), a division of the Illinois Department of Energy and Natural Resources, is headquartered in Champaign on the campus of the University of Illinois. It is the primary agency in Illinois concerned with the measurement and evaluation of water resources. Its research and service programs encompass ground, surface, and atmospheric water resources.

A cornerstone in helping the Water Survey achieve its mission is a statewide network of data-gathering sites called the Water and Atmospheric Resources Monitoring Network, or WARM Network for short. The WARM Network continuously collects and compiles data to allow comprehensive assessments of Illinois' water and atmospheric resources and dissemination of timely information on these resources to users in Illinois and across the United States.

The ISWS began network data collection at ground-water sites in the 1950s, while automated climate data-gathering stations came into use in the late 1980s. Evolution of the network continues, as increased automation of data collection and near real-time retrieval and dissemination of data are either proposed or currently being implemented. The WARM Network was originally organized as the Illinois Benchmark Network (IBN) in 1983, combining the pre-existing suspended sediment, climate (then nonautomated), soil moisture, and ground-water networks. In 1992, the IBN was reorganized and expanded as the WARM Network.

This report is the first in an annual series that describes the WARM Network and presents significant analyses of data collected by the network. Analyses in this report include documentation of the Great Flood of 1993 from an Illinois perspective and monthly averages of various climate and soil moisture variables, which will be an annual feature (see Appendices A and B).

WARM NETWORK DESCRIPTION

Data measurement and compilation systems operating within the WARM Network framework in 1994 include (see also Peppier, 1995a):

- 18 shallow ground-water observation wells
- 15 instream suspended sediment sampling sites
- 19 automated climate monitoring stations
- 18 soil moisture measurement sites
- Compilation of surface water data

Shallow Ground-Water Observation Wells

The ISWS established its network of shallow ground-water observation wells (Figure 1, Table 1) in the early 1960s, though measurements at a few of the network sites had begun during the 1950s. These wells provide information on changes in statewide water table levels and are located in rural areas remote from domestic or municipal pumping sites so that only natural fluctuations in shallow ground-water levels are measured. Data are collected continuously on charts using Leupold & Stevens Continuous Recorders. The charts are manually retrieved by Water Survey field technicians at the end of each calendar month, and values from the charts are

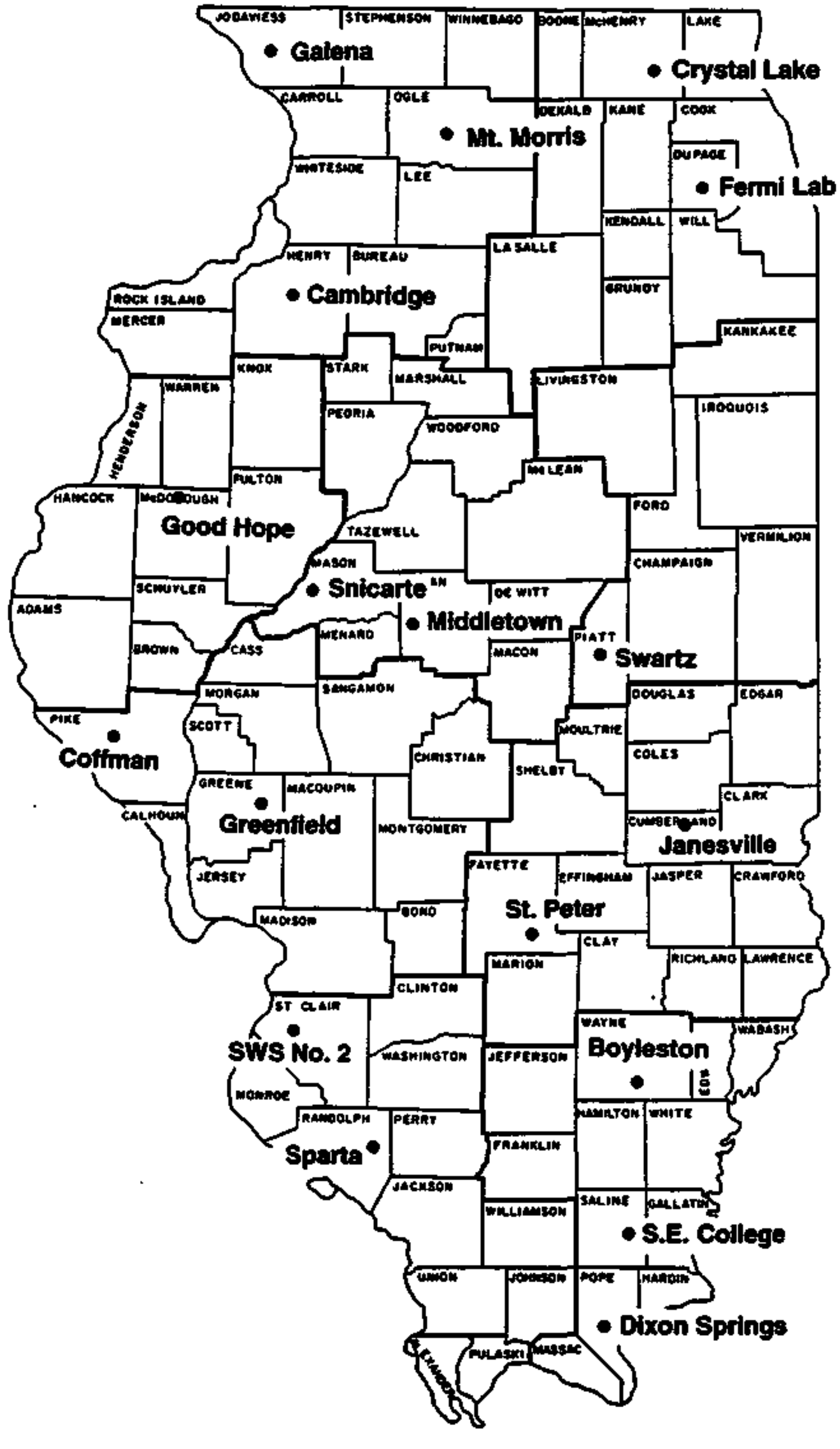


Figure 1. WARM Network shallow ground-water observation wells

Table 1. WARM Network Shallow Ground-Water Observation Wells

Site name	*Crop reporting district*	*Earliest data*
Galena	Northwest	9/63
Mt. Morris	Northwest	12/60
Cambridge	Northwest	10/61
Crystal Lake	Northeast	9/50
Fermi Lab	Northeast	4/84
Good Hope	West	6/80
Snicarte	Central	3/58
Middletown	Central	11/57
Swartz	East	6/54
Coffman	West-Southwest	3/56
Greenfield	West-Southwest	5/65
Janesville	East-Southeast	4/69
St. Peter	East-Southeast	5/65
SWS#2	Southwest	1/52
Sparta	Southwest	11/60
Boyleston	Southeast	3/84
S.E. College	Southeast	8/84
Dixon Springs	Southeast	1/55

entered into a relational database. Well maintenance is performed annually at the sites, though field staff do perform small repairs if needed during their monthly visits.

Sites were selected to allow placement of at least one well in each physiographic region of the state, while ensuring a reasonable spatial distribution. Wells were placed near existing weather station operations at sites that allowed reasonable access for field staff but limited opportunities for vandalism. Most importantly, wells were placed in remote areas so as to measure only natural changes in water table levels.

Shallow ground-water wells are designed to intercept water-bearing stringers and lenses of silt, sand, or gravel, which are only a few inches thick and are contained in the unconsolidated materials above bedrock. The water levels in these wells fluctuate seasonally and in response to variations in precipitation. While each monitoring well may differ in type—from the hand-dug 60-inch diameter brick-lined well to the modern machine-installed 2-inch diameter PVC well—the data collected from all the shallow ground-water wells allow scientists to assess both short- and long-term trends in water table levels under natural conditions. These measurements improve our understanding of the effects of phenomena such as droughts and floods, and particularly their lingering impacts. Data are reported monthly in the form of a newsletter (described later). Over the years, ISWS staff have made this information readily available to many users, including the media, government agencies, consulting engineers, well-drilling contractors, scientists, and the general public.

Instream Suspended Sediment Sampling

Instream suspended sediment sampling (Figure 2, Table 2) began at most network locations in 1981. Fifteen sites are located at road bridges along various Illinois streams where U.S. Geological Survey (USGS) streamgaging stations are housed. The water samples taken from these sites are analyzed primarily to measure the concentration of suspended sediments in the streams and to calibrate the instantaneous sediment load in tons per day. Computations of the sediment load are facilitated by discharge rating tables provided for each site by the USGS.

Observers who live near the streamgaging sites collect water samples at midstream each week. ISWS field staff pick up these samples approximately every 18 weeks and deliver them to the Survey's Sediment Laboratory for suspended sediment concentration analysis. Every six weeks the field staff also collect a calibration cross section of samples across the width of the stream, including the location at which the local observer samples are taken. The calibration cross sections are collected as quality control to verify that the weekly observer samples accurately represent the instream suspended sediment loads. Every other set of calibration samples is analyzed for particle size. A complete data set contains, for each sampling site, the date, sample time, streamgage height, water temperature, concentration of suspended sediment sample, instantaneous water discharge, and instantaneous sediment load.

Instruments used to sample suspended sediments include a depth-integrating suspended sediment sampler attached to a cable and reel assembly. A California-style sediment box attached midstream at each bridge site permanently houses the sampling equipment for the local observers, while portable depth-integrating sampling equipment is transported to each site by ISWS field staff for calibration sampling.

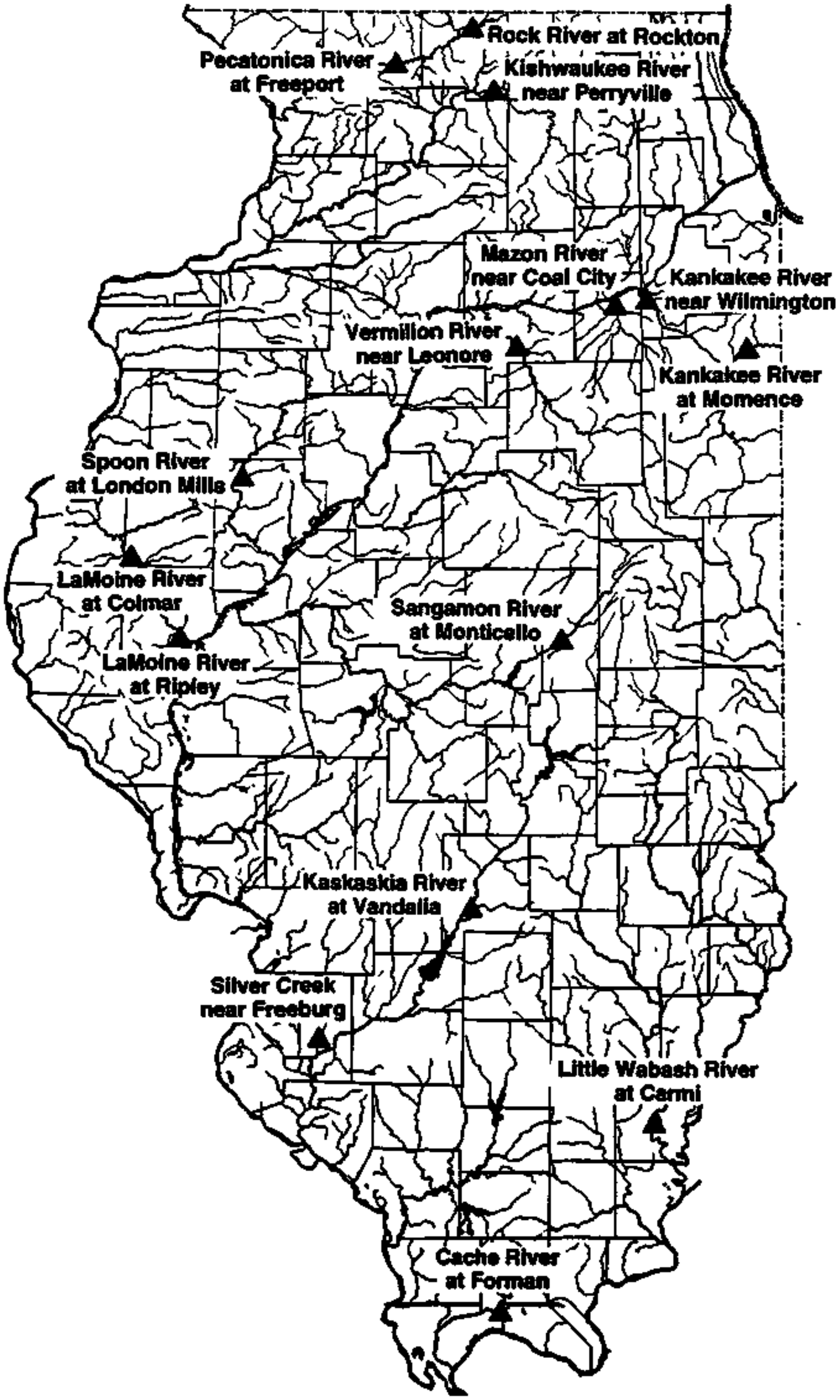


Figure 2. WARM Network instream suspended sediment sampling sites

Table 2. WARM Network Instream Suspended Sediment Sampling Sites

Site name	*County*	*Earliest data*
Pecatonica River at Freeport	Stephenson	1981
Rock River at Rockton	Winnebago	1981
Kishwaukee River near Perryville	Winnebago	1983
Mazon River near Coal City	Grundy	1981
Kankakee River near Wilmington	Will	1983
Spoon River at London Mills	Fulton	1981
La Moine River at Colmar	McDonough	1981
La Moine River at Ripley	Brown	1983
Vermilion River near Leonore	La Salle	1981
Kankakee River at Momence	Kankakee	1982
Sangamon River at Monticello	Piatt	1981
Kaskaskia River at Vandalia	Fayette	1981
Silver Creek near Freeburg	St. Clair	1981
Little Wabash River at Carmi	White	1981
Cache River at Forman	Johnson	1981

Suspended sediments flowing in streams are often deposited in lakes, many of which in Illinois are used for municipal drinking water supplies and/or recreational purposes. Many Illinois lakes were formed by damming of a stream or river. As soon as a dam is constructed and the water stored, the lake begins to fill with sediment. Rivers and streams transport sediment both in suspension and along the bed because of the energy contained within the flowing water. With the creation of a lake, the flow area increases tremendously, decreasing the flow velocity of the water. With the decrease in velocity, the sediment particles are deposited within the lake. Typically, fine-grained particles stay in suspension longer and are deposited in the deeper parts of lakes while heavy, coarse particles—such as sands, gravels, and pebbles—settle immediately in shallower areas near the inflow to the lake. In time, the upper parts of a lake fill with sediment, creating marshy, muddy flats with willow, brush, and vegetation and ultimately decreasing the lake's storage capacity.

While soil erosion and sedimentation are natural processes that have occurred for millions of years, they have been greatly accelerated in the last century by human activities such as agricultural practices and changes in land use (e.g., conversion of woodland and prairie to farmland and the clearing of land for construction). Sedimentation in Illinois lakes is regarded as a major water resource problem for the state. Sedimentation surveys conducted by ISWS staff have indicated that Illinois lakes are losing their capacities at the rate of 0.2 to 4.0 percent a year. Lakes that lose two percent of their capacity a year will lose half their original capacity in only 25 years.

Common problems caused by lake sedimentation include loss of water supply for municipalities; increases in water treatment costs; susceptibility to droughts because of decreased capacity; promotion of noxious weed growth; closing of public beaches because of high turbidity, nitrate levels, and bacterial levels; fish kills; and creation of mud flats. The magnitude of these problems, with respect to both the physical and chemical aspects of sediments, is still under study, and answers to questions about sedimentation can only come from continued collection of high quality stream data. It is essential for state planners to know which lakes are most susceptible to excessive sedimentation in order to properly manage water resources for the future. A 1985 Governor's proclamation helps ensure the necessary data collection and analysis are done.

Automated Climate Monitoring/Illinois Climate Network

Automated climate monitoring (Figure 3, Table 3) began in 1988-1989 and includes fully instrumented weather stations located mainly at Illinois community colleges and at University of Illinois and Southern Illinois University agricultural experimental farms/research centers. This group of stations is better known as the Illinois Climate Network (ICN), Illinois' most comprehensive source for near real-time weather data. In fact, some ICN data variables, such as solar radiation and soil temperature, are available nowhere else.

The ICN first began collecting data in late 1980, but was not completely automated until 1988-1989. The original intent of the network was to collect high quality solar radiation and wind data for evaluating the economic potential of solar and wind energy in Illinois, a project funded by the Illinois Department of Energy and Natural Resources. Complete details about the early days of the ICN are contained in Hendrie (1983). Recognizing the potential of the ICN for monitoring and detecting climate change, the Illinois Global Climate Change Task Force decreed

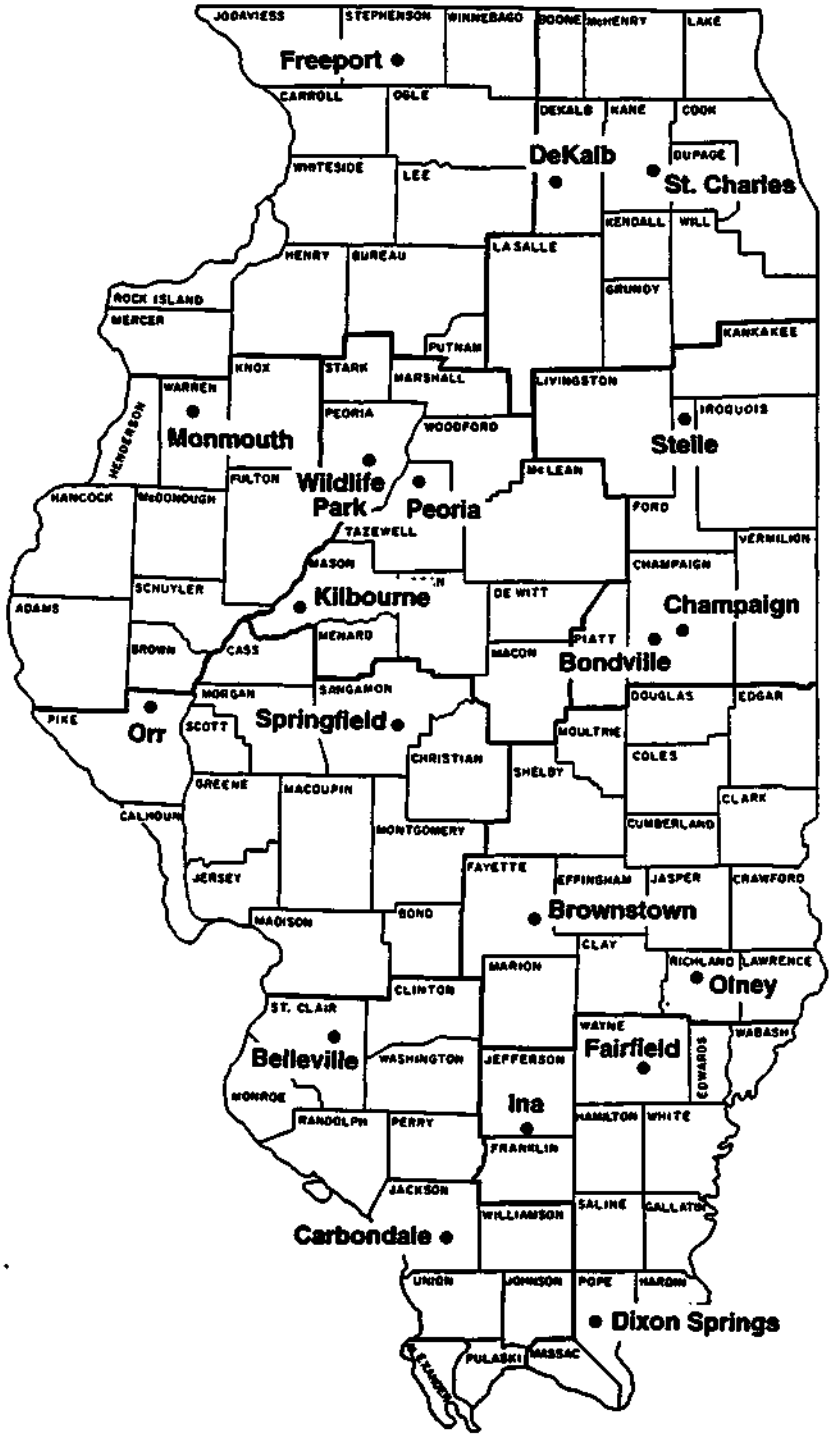


Figure 3. WARM Network Illinois Climate Network station locations

Table 3. WARM Network Illinois Climate Network Sites

Site name	*Crop reporting district*	*Earliest data*
Freeport	Northwest	7/1/89
De Kalb	Northeast	1/1/89
St. Charles	Northeast	1/1/88
Monmouth	West	6/21/89
Wildlife Park	Central	1/1/89
Peoria	Central	1/1/89
Kilbourne	Central	1/1/89
Stelle	East	1/1/89
Bondville	East	8/20/90
Champaign	East	2/16/89
Orr	West-Southwest	7/1/89
Springfield	West-Southwest	1/1/89
Brownstown	East-Southeast	8/25/89
Olney	East-Southeast	10/24/89
Belleville	Southwest	11/16/89
Carbondale	Southwest	12/14/89
Ina	Southeast	4/18/90
Fairfield	Southeast	9/14/91
Dixon Springs	Southeast	2/9/90

in early 1995 that "the Illinois State Water Survey is to maintain the Illinois Climate Network in perpetuity" (personal communication).

Variables currently measured at ICN sites include barometric pressure, wind speed and direction, solar radiation, air temperature, relative humidity, soil temperatures at depths of 4 and 8 inches, and precipitation. Estimates of quantities such as dewpoint, evapotranspiration, and degree days (various base temperatures) are made from the measured data. The weather instruments housed at the ICN sites were selected to withstand harsh environments and to provide a high degree of accuracy and reliability. Field instruments are inspected on a regular basis, and instrument readings are periodically verified with traceable standards to ensure that data are of the highest quality possible.

Figure 4 gives a typical tower arrangement/site layout. A propvane anemometer atop each 10-meter tower monitors both wind speed and direction. A temperature/relative humidity probe is housed in a shelter 2 meters above ground level on the tower. Also at that level on an arm extending from the tower is a pyranometer, which measures incoming solar radiation, and contained within a shelter at about the 2-meter level is a pressure transducer for measuring barometric pressure. The datalogger enclosure, which also contains a multiplexer and all communications equipment, is attached to the tower at approximately eye-level. Soil temperature thermocouples are buried at depths of 4 and 8 inches at sufficient distances from the tower. Finally, a weighing-bucket raingage, which measures both liquid and frozen precipitation, is located near the tower but outside of its rain shadow.

Most sites are connected to local power and telephone lines, though some sites in southern and central Illinois use solar panels to provide power, and a cellular phone is installed at Dixon Springs. All sites are well grounded with a new system in 1994 to minimize the effects of lightning storms in the vicinity of ICN sites and direct lightning strikes. See Hollinger et al. (1994) for more detail and specifications on ICN site instrumentation.

Weather instruments are read every 10 seconds by on-site automated dataloggers which store the data, compute and store hourly means and/or totals, and derive daily maximum and minimum values. These hourly and maximum/minimum values are transmitted to the ISWS each day just after midnight using modems and standard telephone lines. The raw data retrieved are then subjected to extensive computerized and manual quality control procedures to produce verified hourly and daily data and summaries. Finally, the data are added to a permanent database archive. Timely quality control allows for quick resolution of instrument and communication problems, minimizes missing data, and provides users with the most reliable data set available. Reinke et al. (1995) contains detailed information concerning ICN data quality control.

Complete site characterizations for the ICN, including a thorough analysis of obstructions to the winds measured at the sites, are described in Hollinger et al. (1994). This information is vital for those interested in using ICN data for research purposes, for constructing wind climatologies, or for those looking to wind as an alternative energy source.

Soil Moisture Measurements

Soil moisture measurements (Figure 5, Table 4) have been taken routinely since the early 1980s at various Illinois community colleges and university agricultural experimental farms/

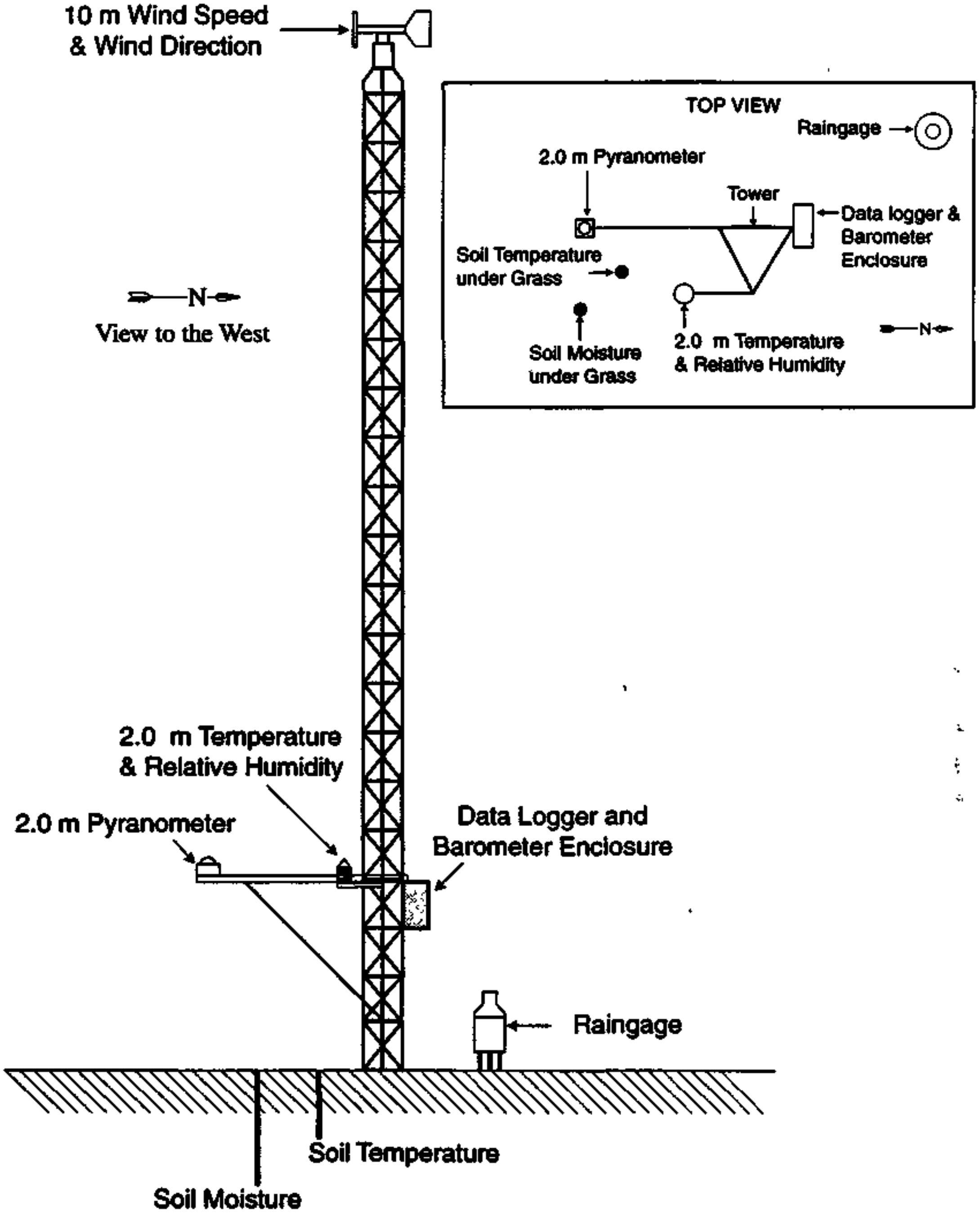


Figure 4. Typical Illinois Climate Network weather station layout

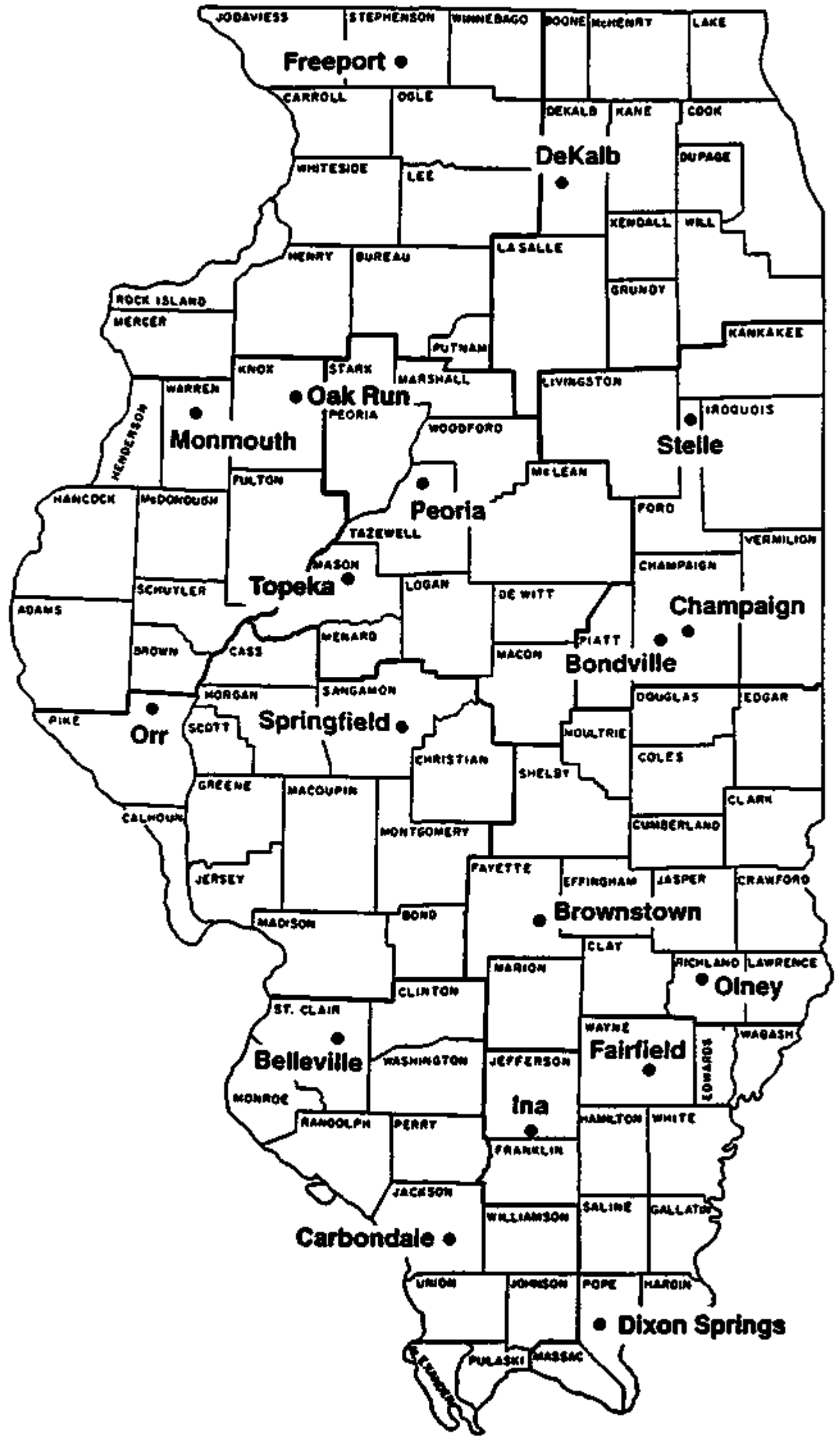


Figure 5. WARM Network soil moisture measurement sites

Table 4. WARM Network Soil Moisture Measurement Sites

Site name	*Crop reporting district*	*Earliest data*
Freeport	Northwest	4/15/82
De Kalb	Northeast	5/21/81
Monmouth	West	6/19/81
Oak Run	West	6/1/81
Peoria	Central	10/25/82
Topeka	Central	6/1/81
Stelle	East	3/31/86
Bondville	East	2/19/81
Champaign	East	6/26/86
Orr	West-Southwest	5/6/81
Springfield	West-Southwest	7/22/82
Brownstown	East-Southeast	4/30/81
Olney	East-Southeast	7/23/82
Belleville	Southwest	5/13/82
Carbondale	Southwest	11/24/82
Ina	Southeast	8/5/82
Fairfield	Southeast	9/26/91
Dixon Springs	Southeast	4/29/81

research centers. All but two of the soil moisture measurement sites are co-located at ICN stations. Data are manually collected twice per month during the growing season (March through September) and once per month otherwise, using neutron surface and depth probes. After the soil moisture data have been reduced, soil moisture reports (described later) are issued.

The neutron depth probes and surface moisture gages used to collect information emit neutrons at a high velocity. Hydrogen ions contained in the soil water slow the movement of the neutrons and deflect some of them back to the probe and gage, where they are counted by detectors. The amount of water in the soil is then determined according to the number of neutrons that return to the probe and gage.

The amount of water in the soil is an important factor for the growth of crops and the management of many farming operations such as plowing, planting, harvesting, and application of fertilizers, herbicides, and pesticides. For farmers and others in agribusiness, soil moisture conditions play an integral role in the decision-making process. During times of extremes weather regular monitoring allows the agricultural community to pinpoint areas with unusual soil moisture conditions and to subsequently evaluate and forecast the severity of stresses on crops. Soil moisture data are also of use in evaluating the potential for the onset of flood or drought conditions. Comparison of current conditions to longer-term averages helps place current conditions into context with past events. Soil types at each site have been documented, and sites were chosen initially to be representative of conditions both at and near the respective sites.

Surface Water Data Compilation

Surface water data from a streamgaging network operated by the USGS are compiled by ISWS staff to meet many needs. Data from streamgaging stations equipped with telemetry (Figure 6) are used for WARM Network reporting purposes and are obtained through the cooperation of the National Weather Service. In addition to monitoring high and low river stages, staff calculate provisional mean monthly flows for 13 stations to augment the mean flows for four index stations reported by the USGS.

WARM Network staff also compile data on statewide lake and reservoir water levels by conducting monthly phone surveys of lake and reservoir operators (Figure 6). Reservoir water elevation data are used to construct a historical record of reservoir operation and response.

Streamgage and water elevation data are of particular importance during times of extreme conditions. During wet periods, comparisons between current conditions and the historical record are particularly useful since they help pinpoint areas that are or will be at risk of flooding. Measurements collected during dry periods help alert local officials to possible water shortages in their communities.

Other Routinely Collected Data

ISWS staff routinely collect data for projects not formally considered part of the WARM Network. Among these are the Illinois Observation Well Network with more than 100 observation wells drilled into aquifers to monitor pumpage (described in the section on *Shallow*

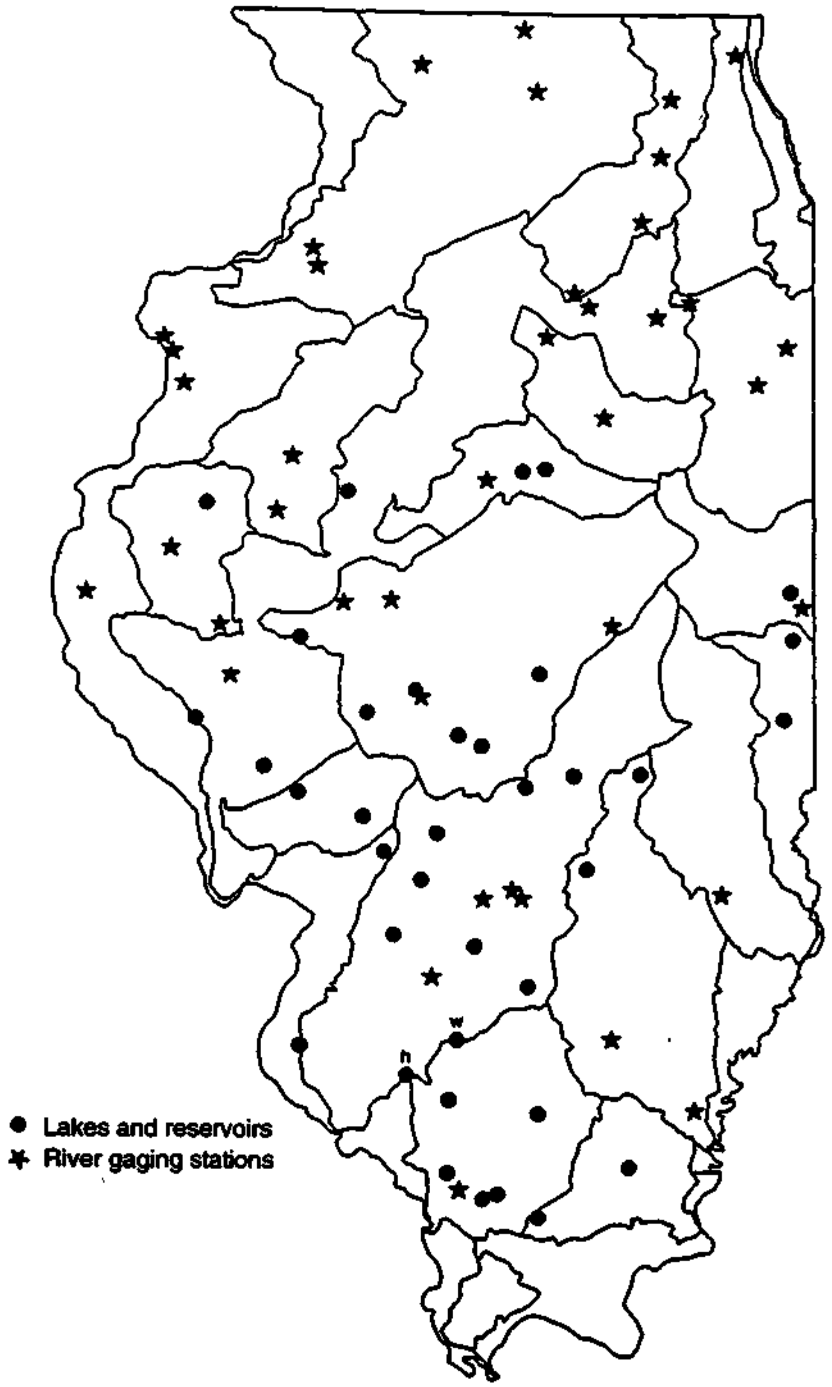


Figure 6. U.S. Geological Survey river gaging stations and Illinois lakes and reservoirs

Ground-Water Observation Wells and in Figure 7), the Cook County Precipitation Network (CCPN) with 25 sites (Figure 8), the Imperial Valley Water Authority (IVWA) Precipitation Network of Mason and Tazewell Counties with 25 sites (Figure 8), the National Atmospheric Deposition Program (NADP) with 5 Illinois sites (Figure 9), and atmospheric dry deposition monitoring at Bondville, Illinois, performed by both the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (USEPA).

Illinois Observation Well Network wells, in contrast to WARM Network shallow ground-water wells, are drilled into aquifers located near pumping centers (Figure 7). These wells monitor the response of local and/or regional aquifers to pumpage for municipal and industrial water use.

For the CCPN (Figure 8), staff use weighing-bucket raingages to measure precipitation, both liquid and frozen, for the U.S. Army Corps of Engineers' Lake Michigan Diversion Accounting project. Under a U.S. Supreme Court Order, the Corps is responsible for the accounting of all water diverted from Lake Michigan into Illinois. One portion of the diversion is storm runoff, which is estimated in part using precipitation data. Thus, precipitation data on the Lake Michigan and Des Plaines River watersheds within Cook County are collected continuously. The CCPN began operation in October 1989 and is expected to continue indefinitely, with funding now secure through March 2000.

The IVWA Network (Figure 8), which uses the same type of equipment as the CCPN, is operated to provide data about precipitation variability and aquifer recharge in the very sandy, highly irrigated areas of Mason and Tazewell Counties in west-central Illinois. It began in September 1992 and is scheduled to operate through at least August 1995. Data from both the CCPN and the IVWA Network are used in the analysis of the wet summer of 1993, which is presented later in this report.

The five NADP sites operating in Illinois (Figure 9) are part of a nationwide network of more than 100 observation platforms that measure wet deposition for the purpose of learning more about precipitation chemistry, including the presence of chemicals such as sulfate, nitrate, chloride, ammonium, phosphate, calcium, magnesium, sodium, and potassium. Dry deposition monitoring conducted at Bondville is done routinely to monitor air concentrations of sulfate, sulfur dioxide, and nitrates.

WARM Network Organization

The WARM Network Director is headquartered at the main ISWS offices in Champaign, along with most database operations and the field technician responsible for statewide maintenance of the automated ICN. The technician also collects soil moisture data for the central third of the state, along with shallow well and suspended sediment data for east-central Illinois. During 1994, staff at the Peoria office of the ISWS collected shallow well and suspended sediment data for west-central Illinois. In southern Illinois, a scientist at the Southern Illinois University office of the ISWS in Carbondale collects soil moisture, shallow well, and suspended sediment data, while a field technician headquartered in Batavia collected similar data for northern Illinois. The suspended sediment database is maintained at Carbondale and duplicated in Champaign, while all other databases are maintained at Champaign.

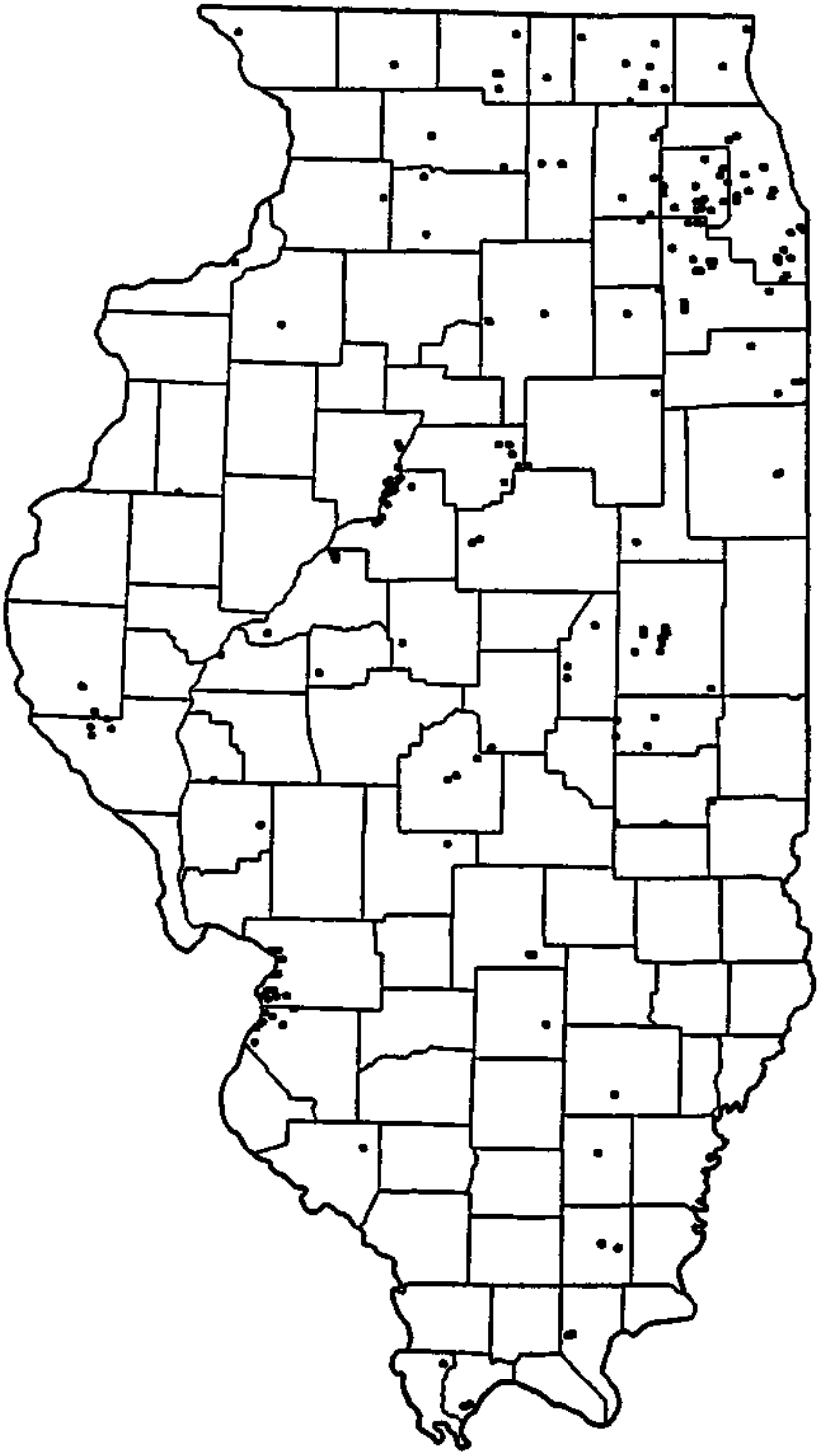


Figure 7. Illinois State Water Survey deep ground-water observation wells as of 1993

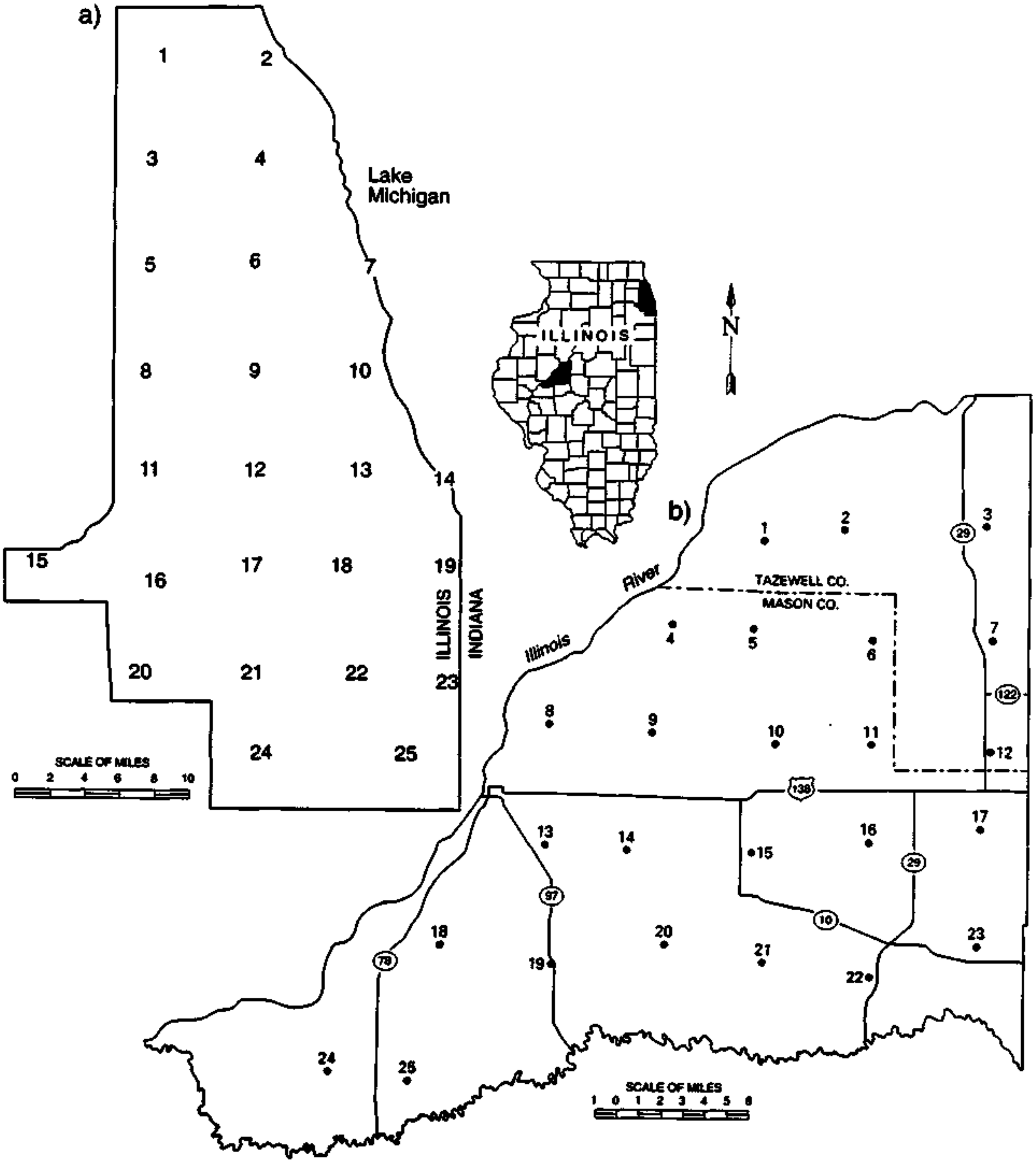


Figure 8. U. S. Army Corps of Engineers Cook County Precipitation Network (a) and Imperial Valley Water Authority Precipitation Network (b)

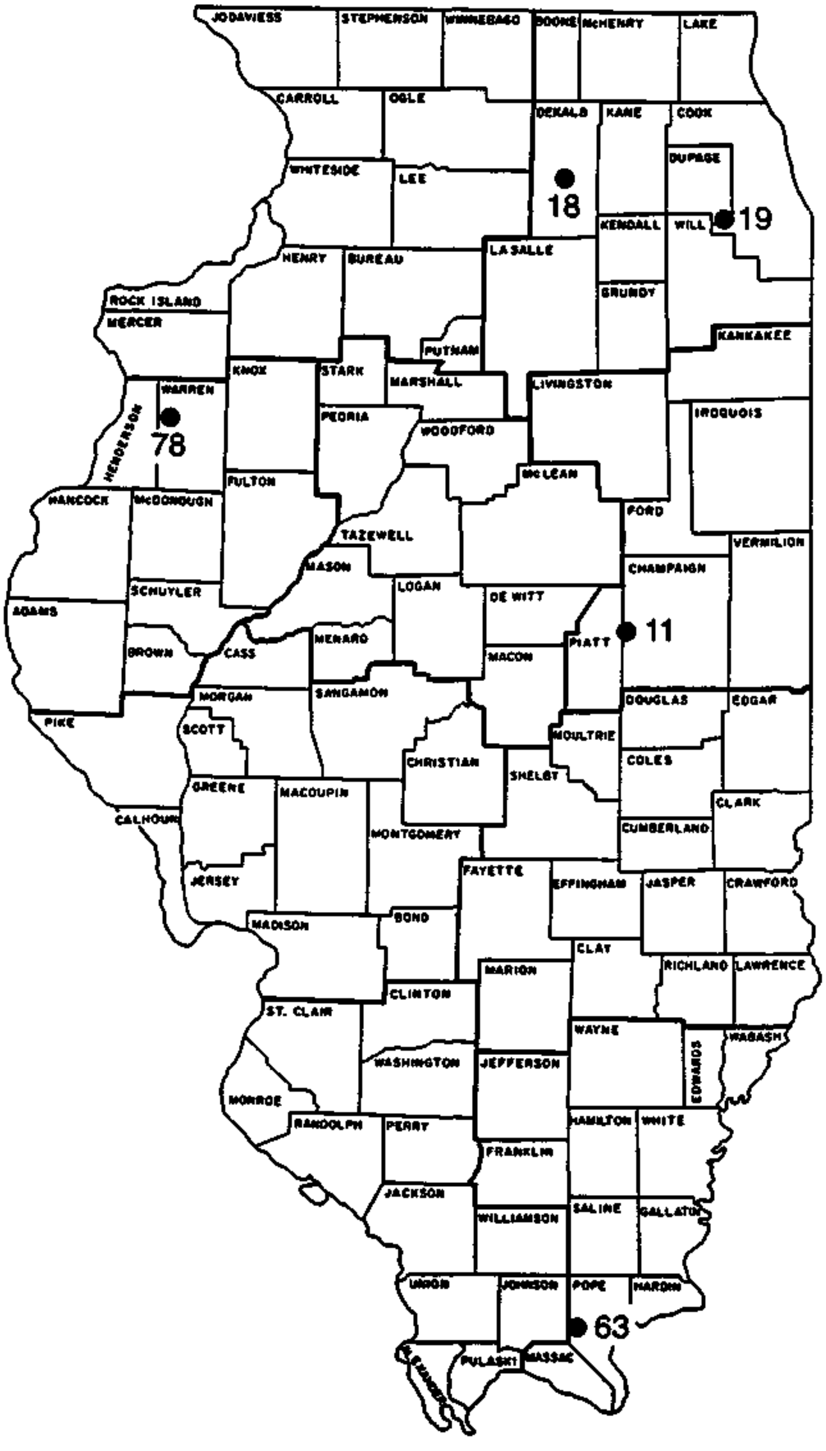


Figure 9. National Atmospheric Deposition Program instrument locations in Illinois

Monthly meetings of all staff involved in the ICN portion of the WARM Network are conducted in Champaign to ensure smooth operation. Meetings between all WARM Network staff and a steering committee are held almost annually to update all appropriate staff on network operations during the past year.

The worth of the network is estimated to be in excess of $400,000, including instrumentation, vehicles, and personnel. Field staff log more than 70,000 miles per year for data collection and site repairs.

USES AND BENEFITS

Governmental Agencies

WARM Network data have been particularly valuable to Illinois governmental planners during times of extreme conditions. Water Survey staff routinely brief the Governor's Drought and Hood Response Task Forces on current climate, soil moisture, surface water, and ground-water conditions, and give analyses and opinions. Planning done on the basis of these data during and after the severe drought of 1988 has helped mitigate the effects of subsequent dry periods (e.g., spring 1992), particularly with respect to public water supplies and agriculture. Network data were also used for the planning done during the past year in the aftermath of the Great Flood of 1993. In these cases, WARM Network data benefit all citizens of Illinois.

Agriculture

The agricultural community has traditionally been the largest user of WARM Network data, particularly the ICN and soil moisture data. ICN data benefit agricultural producers in terms of irrigation scheduling, chemical applications, pest management, and other management decisions, particularly during the growing season. Many decision makers in Illinois agriculture and agribusiness/industry rely on this statewide network for timely climate information. For instance, the Illinois Department of Agriculture uses ICN wind data to help document pesticide drift complaints. Seed companies and the Illinois Cooperative Extension Service (CES) use various data for monitoring crop development and assessing potential vulnerability to pest damage. The CES, the University of Illinois School of Agriculture, the ISWS, and some agricultural publications (e.g., FarmWeek) use ICN data for various newsletters and outdoor field day demonstrations. University agronomists and graduate students use the data to develop and improve crop simulation models, support field projects, and monitor the effects of weather and climate on agriculture. WARM Network staff also use these data for teleconference weather briefings and for the preparation of scientific articles.

As mentioned previously, soil moisture data are useful to agricultural producers and others in agribusiness who must make decisions on farming operations such as when to plow, plant, harvest, and apply herbicides, pesticides, and fertilizers. Soil moisture data allow for routine identification of areas where plant stresses might be severe.

Engineering

Private businesses, researchers, and the state government have used ICN data to investigate the scientific and economic potential of harnessing the wind and solar radiation as alternative energy resources in Illinois. WARM Network staff have themselves begun investigating the potential for using wind and solar energy in the flood-stricken town of Valmeyer in southwestern Illinois, which is being relocated to a higher elevation east of its original site. Present ICN sites were evaluated in 1993 using both collected wind data and a survey of surrounding wind obstructions (natural and man-made) to assess the effects of the obstructions on the wind fields around the sites (Hollinger et al., 1994). Consulting engineers and well-drilling contractors have used ground-water data for various projects around the state.

Meteorology/Hydrology

ICN and soil moisture data have been used to help support national field programs such as the 1992 NOAA STORM-FEST program, which studied winter storms. These data have also been used by the staffs of national research centers looking into such questions as the variability of the earth's hydrological cycle and global climate change. Climate, soil moisture, surface water, and ground-water data have all been used, along with other information, by Water Survey researchers monitoring and studying the state's water resources and climate change (e.g., Lamb et al., 1992; Bhowmik et al., 1994; Peppier, 1995b).

Education

WARM Network staff have recently begun participating in educational outreach activities, mainly using ICN data. These activities include site tours, workshops, classroom exercises (Schmalbeck and Peppier, 1994), and, in the near future, computerized data access with accompanying related curricular activities (Reinke and Peppier, 1995). The latter effort, a joint initiative planned with the University of Illinois College of Education, involves the development of a computerized, floppy disk-based atlas of ICN climatologies, which will be accompanied by curriculum suitable for use in the middle-school grades. Computerized access to data for educational and other uses will soon include placement of WARM Network data and analyses on the World Wide Web (WWW), so that anyone in the world who has the capability to connect to the Internet can access the information.

Public Information

All WARM Network data are made available to the electronic and print media, with requests for information and interviews increasing during extreme events such as the 1988 drought and the 1993 flood. These data, particularly WARM Network ground-water and climate information, are also requested and used by many private citizens in Illinois.

PRODUCTS

Presently, WARM Network data and information are distributed in several ways. The most visible method at present is in the form of two newsletters. The *Illinois Water and Climate Summary,* a monthly publication with a circulation of nearly 200, describes and analyzes Illinois' water and atmospheric resources on a monthly basis. It provides an overview of current conditions in relation to long-term averages, and describes in depth current weather/climate, soil moisture, surface water, and ground-water conditions. The *Soil Moisture Summary* is distributed to more than 50 subscribers twice monthly during the growing season (March to September) and once monthly otherwise (October to February). Using maps and tables, it describes current statewide soil moisture conditions, compares them to the previous measurement period and to longer-term averages (in the form of percentages of normal), and discusses short-term expectations given National Weather Service climatic outlooks. In addition, during October through March, projections are made of anticipated soil moisture conditions at the beginning of the next growing season. Both publications are distributed free of charge.

Other data products include one-page soil moisture data summaries, which are available after each measurement period for each site in the network; monthly climate data summaries for each ICN site; well records; and customized products for particular data sites, variables, and analyses. Finally, brochures describing the WARM Network in general, and the ICN and soil moisture components of the network in particular, are available free of charge from the Water Survey. All are available upon request by contacting the author.

THE FUTURE OF THE WARM NETWORK

To allow the WARM Network to remain as viable and comprehensive as possible, funds are continually sought to maintain and enhance network operations. Ongoing and planned enhancements include modernization of portions of the network (especially soil moisture and ground-water), with emphasis on the automation of the data-gathering process, and the maintenance of a modern, digital database that is easily accessible to all who need the data. Expansion of the network in terms of the number of stations is also being pursued.

During late 1992, development of a new automated soil moisture profiler began. The profiler will allow for real-time monitoring of this important parameter within the current ICN site framework to a depth of 2 meters. In 1994, an improved soil temperature profiler was completed, which allows for measurement of soil temperatures along one profile to a depth of 1 meter. Both instruments are described in Belding et al. (1995). Cellular technology was installed in summer 1994 for data retrieval at the extreme southern Illinois site of Dixon Springs. This technology eliminates the need for installing phone lines in remote areas. Solar panels, which preclude the necessity for installing power lines in remote locations, have also been used at some ICN sites. Automated shallow ground-water wells were installed in late 1993 at ICN sites in Champaign and Bondville to assess the feasibility of automating this portion of the WARM Network. Similar wells are scheduled to be constructed in early 1995 at Freeport, DeKalb, and St. Charles. Finally, as mentioned previously in this report, WARM Network staff are currently working to make data and analyses worldwide via the WWW and the Internet.

Plans for 1995 and beyond include the development of a near real-time (hourly) data retrieval system, to be followed by a more formalized on-line dissemination system available to users with a computer and either a modem or an Internet connection. Finally, construction of automated shallow ground-water wells at all ICN sites and the possible construction of automated deep ground-water wells are also being pursued.

These ongoing and planned improvements to the WARM Network will help make it one of only a handful of such modernized ***water resources*** data-gathering networks in the United States.

AN ANALYSIS OF THE WET 1993 SUMMER IN ILLINOIS

Introduction

Because the WARM Network measures most components of the water cycle, its data have been of primary interest to governmental and agricultural concerns in Illinois, especially during extreme conditions such as droughts and floods. The data became a primary tool for researchers and state government during the severe drought of 1988 not only for monitoring the drought but also for assessing impacts and developing policy to lessen the blow of future dry periods (e.g., Lamb et al., 1992). In 1993, these data were again used heavily during the summer' and early fall to monitor and describe conditions and help assess damage from the Great Flood on the Mississippi River (e.g., Bhowmik et al., 1994; Kunkel et al., 1994; Peppier, 1995b). Not only was Mississippi River flooding severe in Illinois, but many other rivers across the state overflowed their banks. Some areas experienced flash flooding due to overabundant precipitation, while Mason County experienced persistent flooding due to a rise of the water table above the land surface. This section of the report presents data from the WARM Network and other data collected by the ISWS to briefly describe the wet summer of 1993 from an Illinois perspective.

Climate Background

Illinois is situated in a northern temperate zone in which weather systems move predominantly from west to east. These systems bring warm, moist air into the region from sources such as the Gulf of Mexico, as well as cool, dry air from regions such as Canada, and the clashing of these air masses can create conditions favorable for precipitation. Persistent, widespread precipitation-producing weather patterns can cause flooding.

Flooding occurs somewhere in Illinois nearly every year, though major events such as the Great Flood of 1993 are much less frequent. Examples of events causing flooding include weather systems that produce prolonged, concentrated liquid precipitation; intense melting of large snowpacks; ice jams on streams; and wintertime weather systems that produce heavy liquid precipitation over snow-covered or frozen ground. Five significant floods in Illinois' history previous to 1993 occurred in 1937,1943,1961,1982, and 1987 (USGS, 1992). Conversely, dry or drought periods in Illinois occurred during 1930-1936,1952-1957,1962-1967 (USGS, 1992), and recently in 1988-1989.

The general meteorological and precipitation conditions during 1993 that are described here are from Bhowmik et al. (1994) and Kunkel et al. (1994). Overabundant rainfall over the eastern Great Plains and the western Midwest from May to August 1993 was primarily a function of the persistence of abnormal patterns in the large-scale weather features over the region (Bhowmik et al., 1994). The polar jet stream, which normally flows across southern Canada during the warm season, was displaced much farther south than is "typical" during the summer, bringing frequent low-pressure systems across the Great Plains and Midwest. Meanwhile, the so-called Bermuda High in the Atlantic Ocean, which is normally well off the southeastern coast of the United States, was located much farther west than normal, near the eastern coast of the United States.

This relatively close proximity of the two large systems allowed for greater than normal interaction between them, causing greater import of moisture from the Gulf of Mexico, and subsequently enhanced precipitation. The pattern began to manifest itself near the end of May 1993 and persisted through the end of July 1993. While this pattern was similar to the patterns that have occurred with past heavy rain events, it was much more persistent (Kunkel et al., 1994).

Some incredible rainfall events occurred in the Great Plains/Midwest during the May-September period, including more than 30 inches falling during July alone in Worth County, Missouri. The unprecedented persistent heavy rain patterns that contributed to the flooding in the Upper Mississippi River basin were the largest of this century for the two-, three-, four-, and twelve-month periods encompassing the summer of 1993. Totals for these periods are estimated to have a probability of occurrence of less than 0.005 yr^{-1} ; that is, events such as this should happen only once every 200 or more years (Kunkel et al., 1994). The number of reporting stations receiving weekly totals in excess of 100 mm (about 4 inches) was the largest in at least 45 years. Other conditions that contributed to the flood included above normal soil moisture levels at the beginning of June 1993, large areas of moderate to heavy rains, occurrence of rain areas oriented along the main stems of major rivers, a large number of localized extreme daily rainfall amounts, and below normal evaporation (Kunkel et al.,1994).

Analysis of Illinois Conditions

WARM Network analyses that follow are divided into time periods according to the statewide precipitation regime that occurred, because excessive precipitation was the biggest contributor to the observed flooding conditions. Figure 10 shows statewide departures from normal of several parameters discussed throughout this section. Precipitation departure data here are from National Weather Service first-order and cooperative stations in Illinois. These are used instead of ICN precipitation data because of their long length of record and greater spatial density.

Pre-November 1992

With the exception of July (well above normal) and September (slightly above normal), every month in 1992 before November experienced below normal precipitation (Figure 10). Precipitation was well below normal during May and June, prompting a brief early growing season drought, which was mitigated by heavy July rains. Mean streamflows were near normal during this period, while ground-water levels generally declined. Reservoirs were mostly below

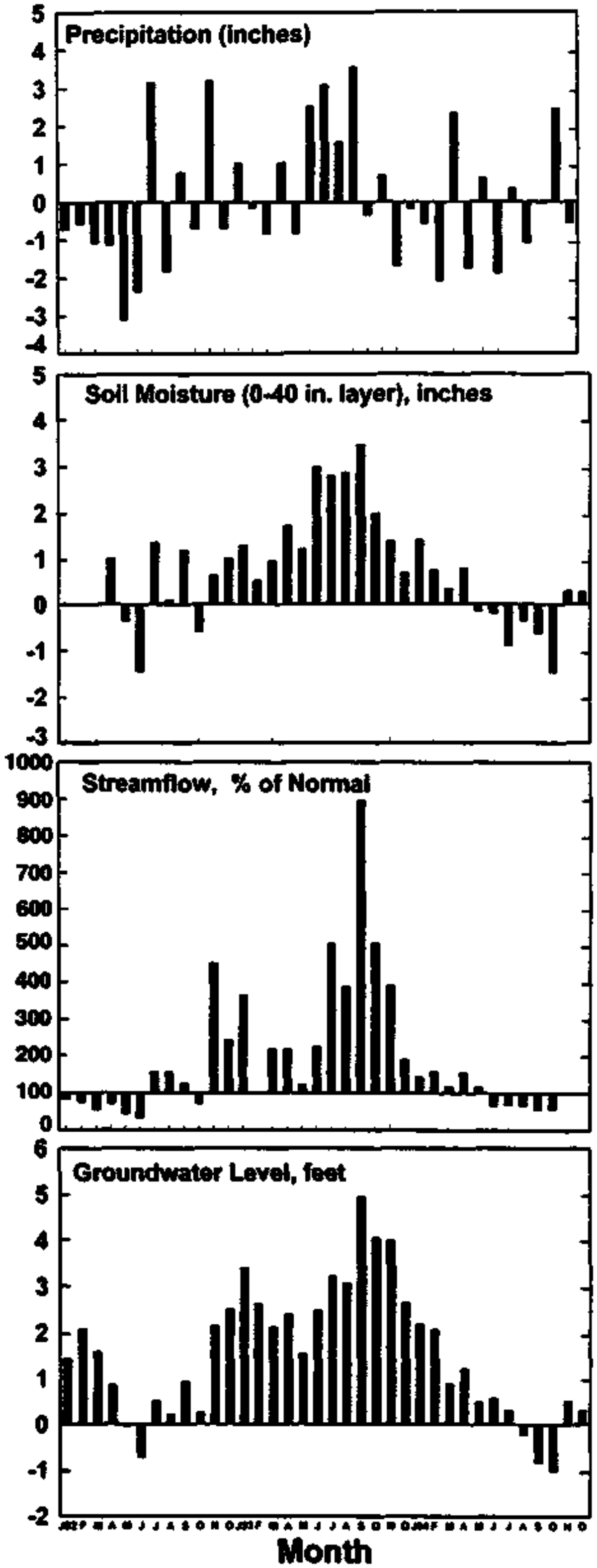


Figure 10. 1992-1994 statewide departures from normal of precipitation, soil moisture water equivalent (0-to-40-inch layer), mean streamflow, and shallow ground-water levels

normal pool or target operating levels, particularly by October. Soil moisture in the 0-to-40-inch layer bounced above and below normal, likely in response to the precipitation. By July 1, soil moisture was less than 25 percent of normal statewide in the 0-to-6-inch layer, and was near that value across the western half of the state in the 6-to-20-inch layer. However, the large precipitation events in July prevented an agricultural drought. Streamflows in July and August began to reflect the heavier July precipitation, and ground-water levels in September reflected the surplus. Nothing during this period particularly foreshadowed events to come.

November 1992

Statewide precipitation in November 1992 was nearly double that of the 1961-1990 average, as many areas received more than 8 inches (Figure 10). The month ranked as one of the five wettest Novembers on record in Illinois, dating back to 1895. Statewide streamflows and river stages increased substantially during the month; streamflows were more than 400 percent of normal, and nine stations recorded peak stages above flood stage, with flooding occurring in central and southern Illinois. Ground-water departures above normal also increased dramatically during the month, particularly in western Illinois, registering 2 feet above normal statewide. Soil moisture in the 0-to-40-inch layer also rose above normal by the end of November, with the greatest increases in the south. Projections at that time for the following April indicated that soil moisture would be recharged to field capacity by the beginning of the growing season. Thus, the heavy precipitation of November did much to reverse a general downward trend in Illinois water resources observed during most of 1992.

December 1992 - May 1993

This period marked a return to relatively normal precipitation, with slightly above normal precipitation in January and April and slightly below normal precipitation during the other four months (Figure 10). However, beginning with November 1992, this period marked the onset of great departures above normal of streamflow, ground-water levels, and soil moisture, and a gradual increase in reservoir levels.

Indeed, streamflows were at least 200 percent of normal every month during this period except February and May. Streamflows became particularly high in northern Illinois along the Rock River basin, in part due to heavy precipitation and snowmelt that occurred in Wisconsin. Rivers in this basin were above flood stage by May. Flows in January were among the highest three ever recorded for the month at most sites, as each site was in the much above normal range. Reservoirs reached or exceeded normal pool at most locations by February.

Ground-water levels were at least 2 feet above normal every month during the period except May, with particularly high levels in northern and western sections of the state. The Coffman well in west-southwestern Illinois was as much as 9.6 feet above normal, and the Mt. Morris well in northern Illinois was as much as 10.1 feet above normal. Soil moisture in the 0-to-40-inch layer was at least a half inch above normal every month during the period and was almost 2 inches above normal in April. By March it became apparent that conditions were so moist that April field work would be hampered in some areas, particularly in the north.

Thus, beginning in November 1992 and continuing through May 1993, great increases occurred in all water resources in Illinois, which helped compound the problems that arose later in the summer.

June 1993 - September 1993

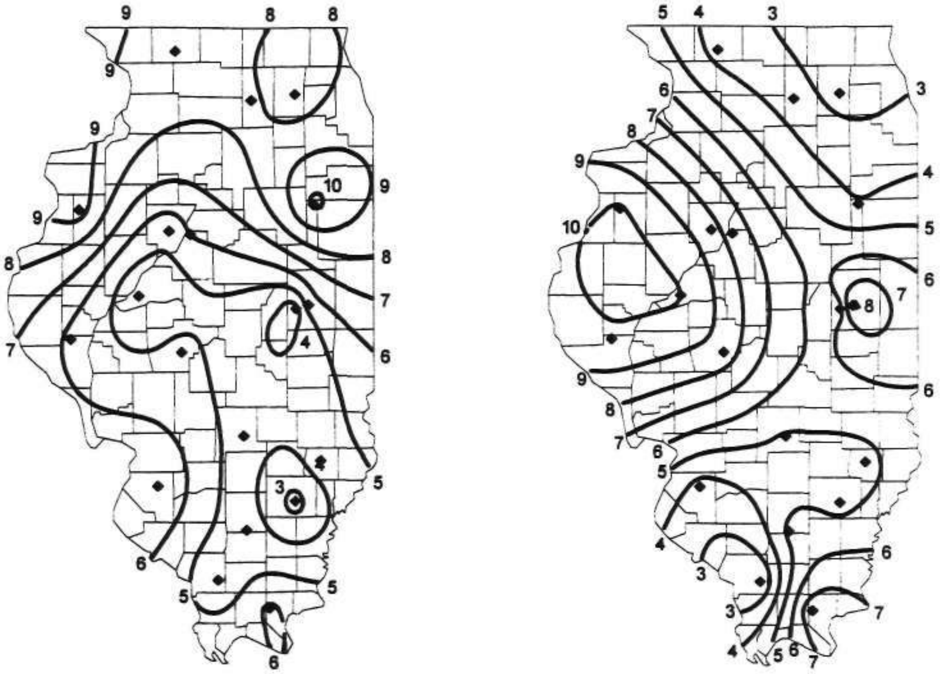
Precipitation during this period was extremely high, more than 1.75 inches above normal statewide during each of the four months (Figure 10). Precipitation in July and September was a whopping 3 inches above normal statewide. Some northeastern Illinois locations received more than 16 inches of rain in June, while west-central Illinois recorded more than 12 inches in July, east-central Illinois received more than 10 inches in August, and west-southwestern Illinois recorded more than 10 inches in September. Figure 11 shows ICN monthly precipitation patterns in inches for this period.

Streamflows, ground-water levels, and soil moisture content all approached or exceeded record levels during this period over many areas of the state. Statewide, streamflows were more than 200 percent of normal in June; they increased to 400 to 500 percent of normal in July and August, and were an incredible 913 percent of normal in September. In June the highest streamflows were in the north. By the end of July, record flows and stages were recorded at many locations, not only along the Mississippi River, but also along the Rock River basin in the north and the lower Illinois River basin (mainly due to Mississippi River backwater) in the west-southwest. Sixteen of 27 sites reporting had peak stages above flood stage during the month, and by September, 13 sites still exceeded flood stage. Also by September, record stages and flows were being recorded at stations in central and southern Illinois.

Figure 12 gives a historical perspective of how peak stages during 1993 compared to peaks during other significant flood years at streamgaging sites along the Mississippi River from Clinton, Iowa, to Thebes, Illinois. Figure 13 shows daily stages from January 1 through August 31,1993, at three stations along the Mississippi River: Keithsburg and Thebes, Illinois, and St. Louis, Missouri. Figure 14 displays long-term, median, and 1993 discharges at six streamgaging locations along streams within the interior of Illinois. Finally, Figure 15 shows a plot of instantaneous suspended sediment loads in tons/day relative to streamflow conditions, from the Pecatonica River at Freeport in extreme northwestern Illinois. The figure plots weekly sample values for the station's entire period of record. Though other high load periods have occurred since 1981, an upward trend in sediment load appears to have occurred at this site during the high flow/high precipitation periods of 1993, with data through October.

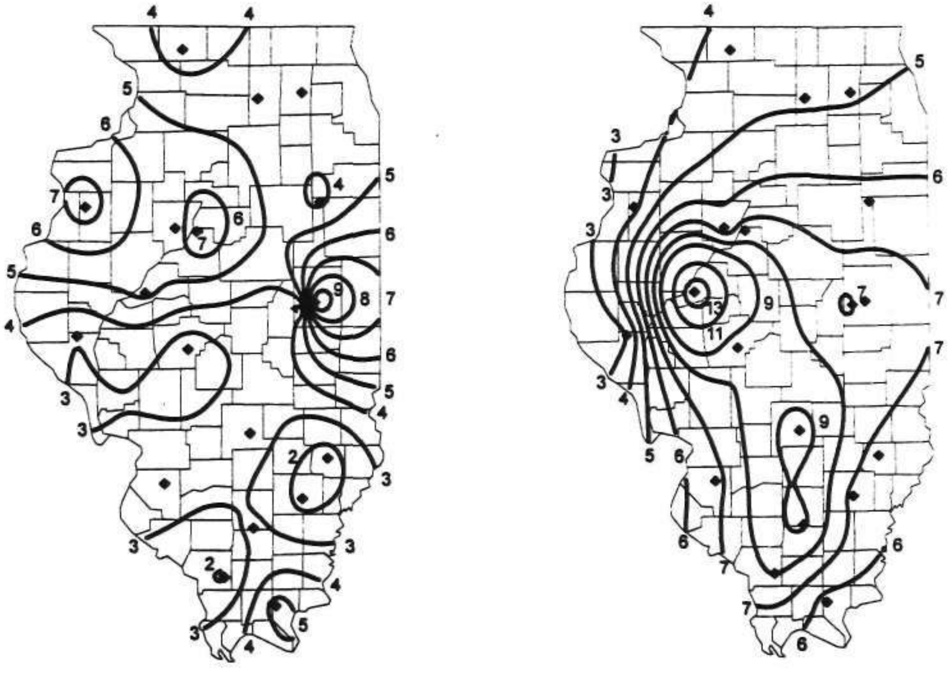
Statewide, reservoir levels were at or above normal pool in June and remained so through September. The state's two major flood-control reservoirs, Lake Shelbyville in south-central Illinois and Carlyle Lake in the southwest, where levels are controlled, were well above target operating levels. (Lake Shelbyville had been so for the previous 11 months.) Figure 16 shows 1993 surface water elevations at Lake Shelbyville, Carlyle Lake, and Rend Lake, with comparisons to averages and either target operating levels or normal pool.

Ground-water levels also exceeded record levels at several wells during this period. Interestingly, some of these wells had gone dry during the drought of 1988 (e.g., Snicarte in west-central Illinois—see Figure 17 for depth-to-water levels at this well). Statewide, levels were 2 feet or more above average during the period, and nearly 5 feet above average in September. In June the Coffman well in west-southwestern Illinois was 9.8 feet above average, and in August the Cambridge well in northwestern Illinois was 7.5 feet above average. In September ground-water levels were so high in Mason County in west-central Illinois (where Snicarte is located) that widespread ground-water flooding began, some of which still existed at the end of 1994.



a) June

b) July



c) August

d) September

Figure 11. June-September 1993 Illinois Climate Network precipitation (inches)

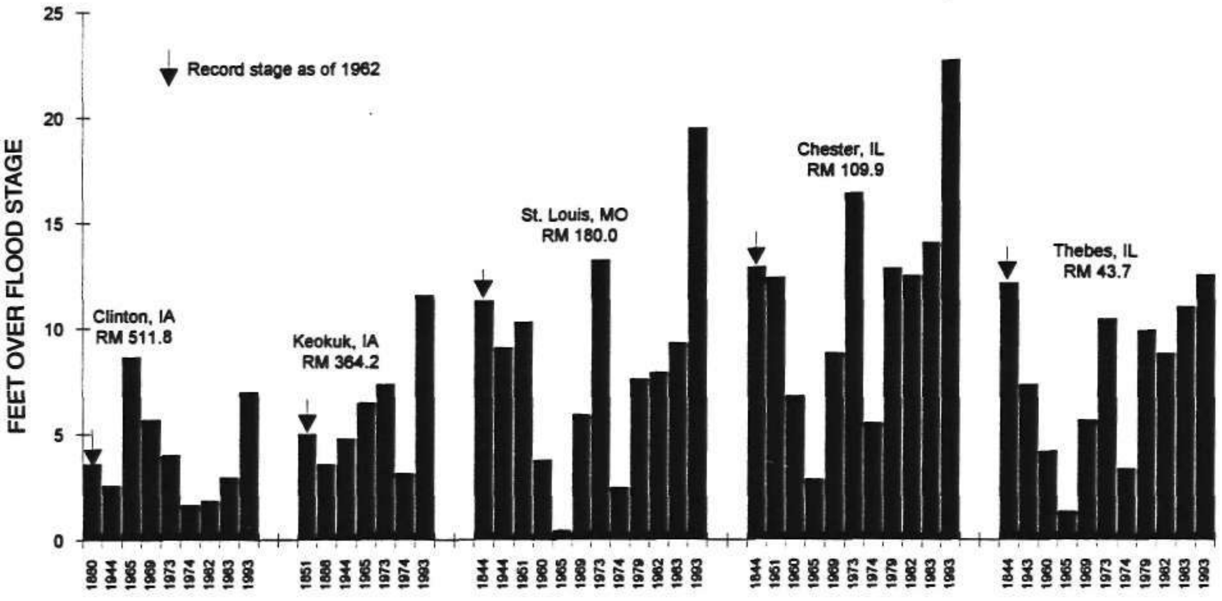


Figure 12. Partial historical record of peak stages over flood stage on the Mississippi River (RM is river mileage north from the confluence of the Mississippi and Ohio Rivers)

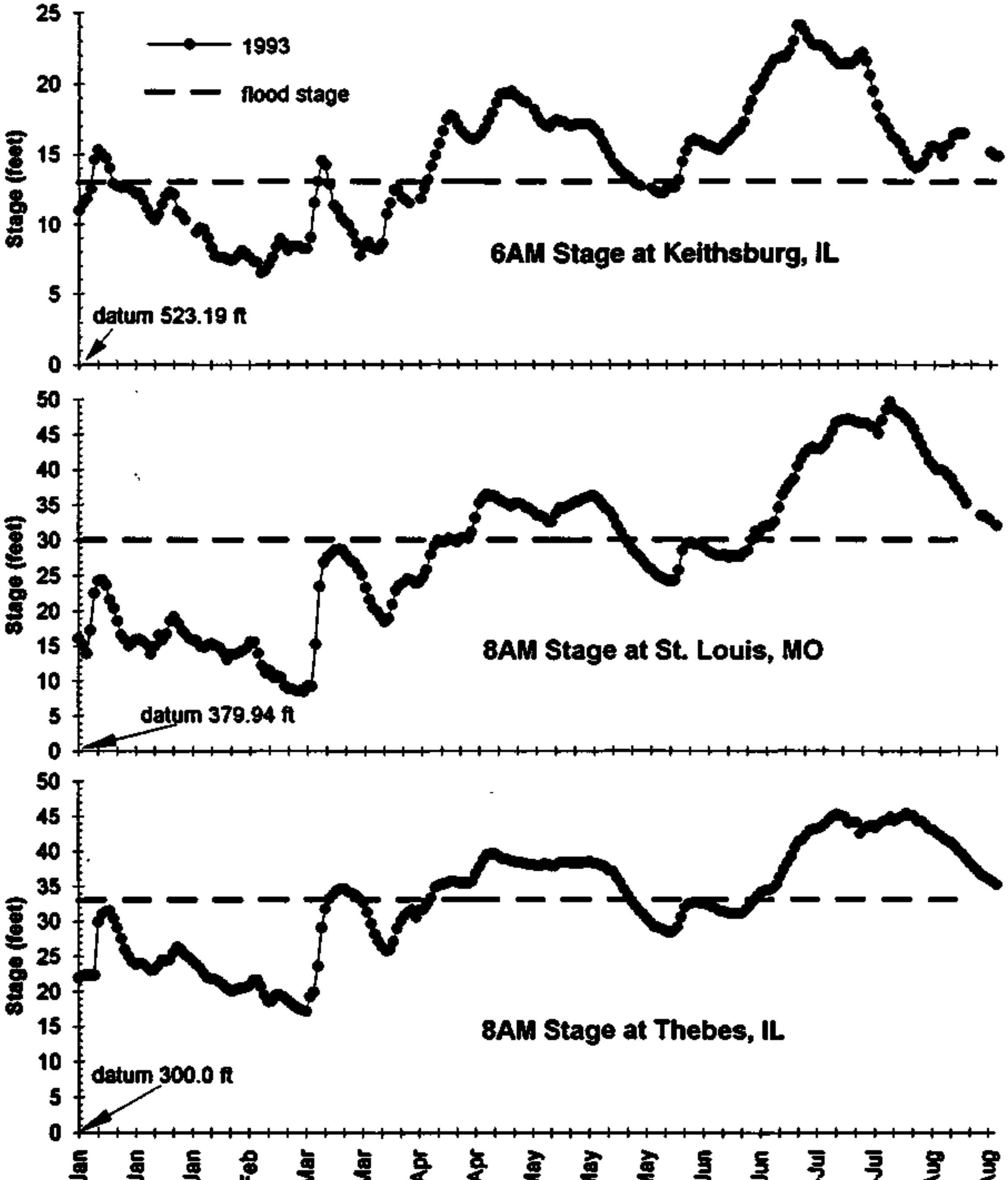


Figure 13. Daily stages (feet) from January 1 through August 31,1993, at three stations along the Mississippi River

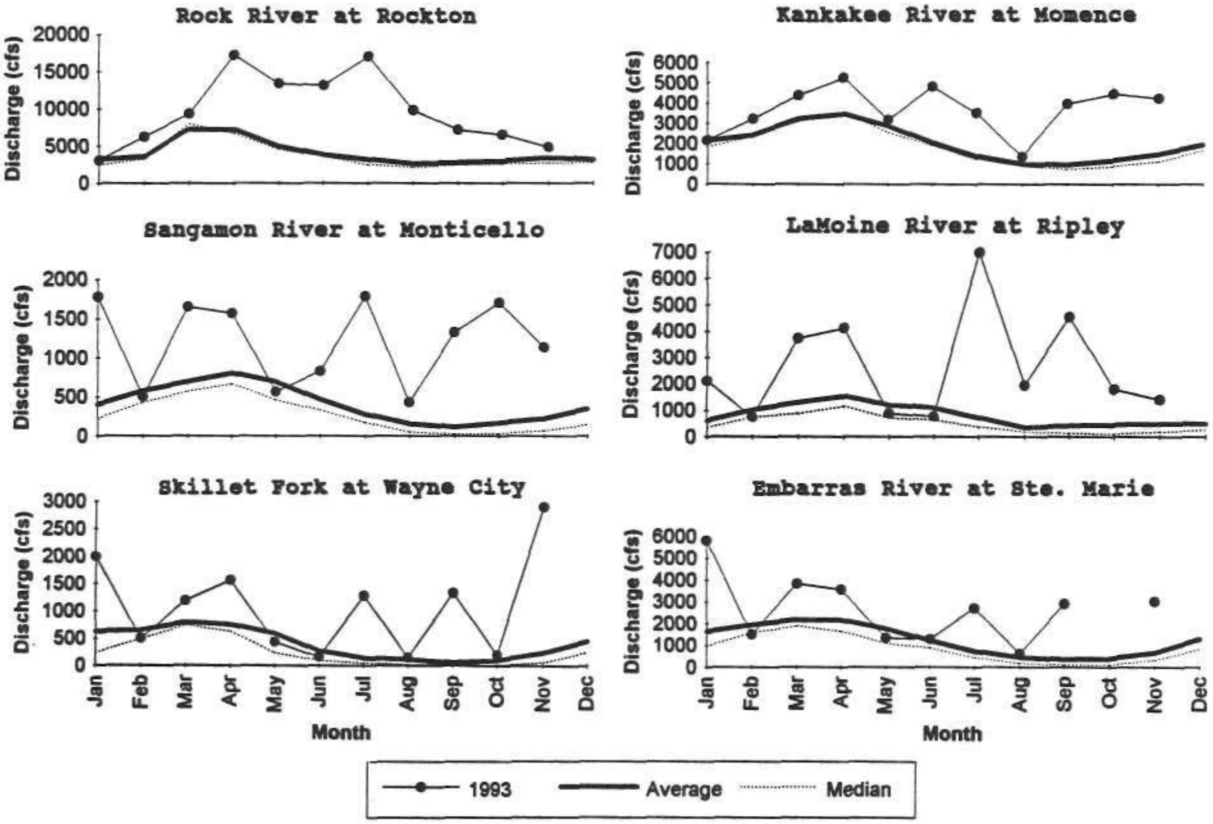


Figure 14. Long-term average, median, and monthly discharges in cubic feet per second (cfs) along six interior Illinois streams

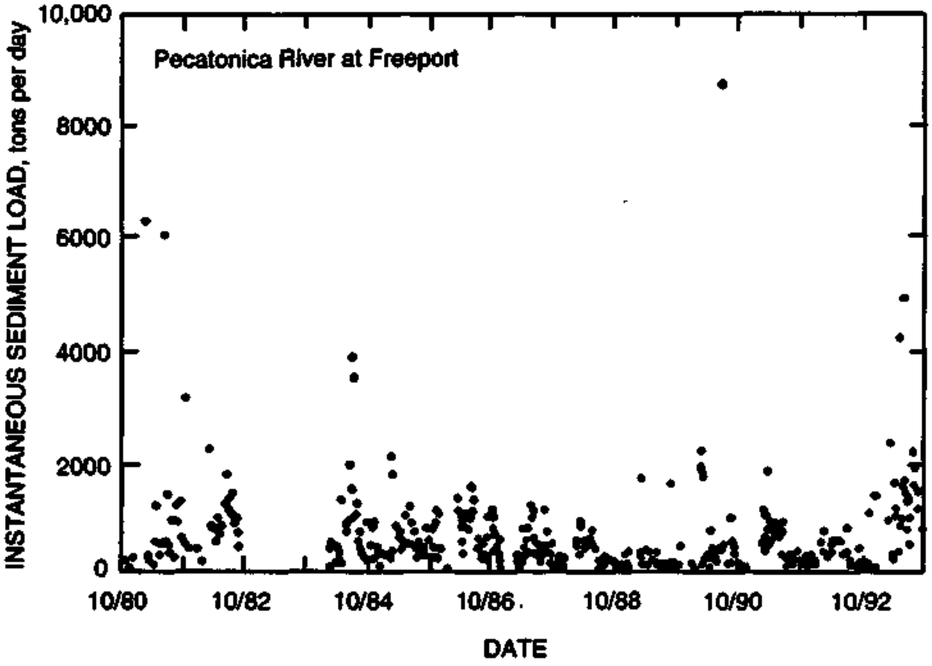


Figure 15. Instantaneous suspended sediment loads from weekly samples for the Pecatonica River at Freeport

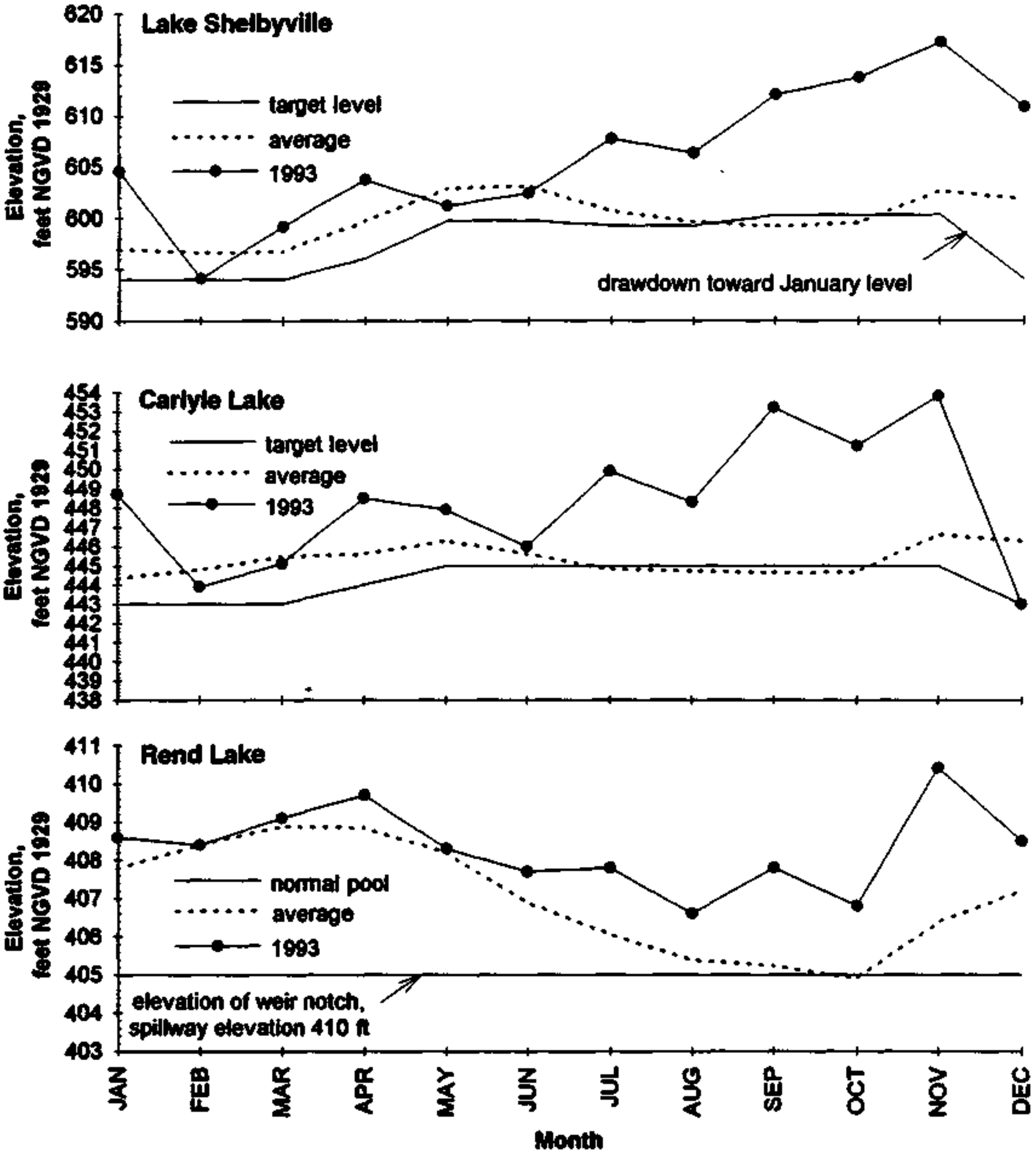


Figure 16. Average (1983-1993) and 1993 month-end water surface elevations (feet, National Geodetic Vertical Datum 1929) for three major reservoirs in Illinois

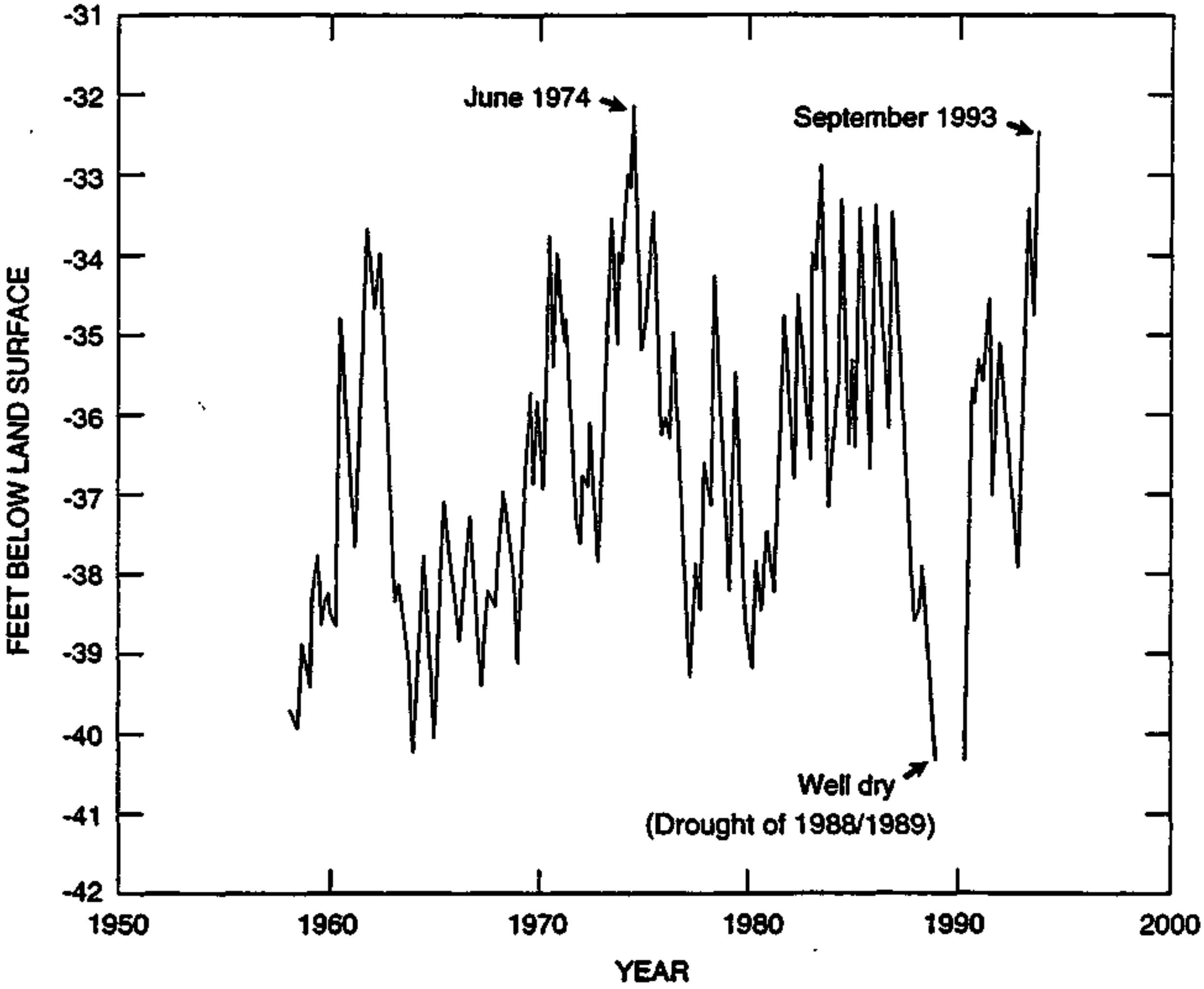


Figure 17. Period of record ground-water levels at the Snicarte shallow observation well in the Havana Lowlands region of Mason County near the Illinois River (from Bhowmik et al., 1994)

Soil moisture during this four-month period also reached maximum levels statewide. In the 0-to-40-inch layer, soil moisture was about 3 inches above normal, with the largest departure above normal, 3.48 inches, occurring in September. By September soil moisture exceeded normal in all measured soil layers down to 72 inches across the state, and it exceeded 300 percent of normal in at least one location in all layers. Consequently, harvesting was hampered in many areas of the state in late September and beyond. Figure 18 shows the percentage of normal soil moisture for the 0-to-6-, 6-to-20-, 20-to-40-, and 40-to-72-inch soil layers at the end of September/early October 1993.

Post-September 1993 (through December 1994)

After September the precipitation regime changed drastically, as precipitation was below to well below normal throughout the period except in November 1993 and April, June, and November 1994 (Figure 10). While April and November 1994 precipitation exceeded 200 percent of normal, this did little to change the downward trends in the other water resource parameters documented here until November 1994. Precipitation in December 1993 and March, May, and July 1994 was significantly below normal, and the spring and summer dryness eventually caused much agricultural concern in southwestern through east-central Illinois—amazing considering the events of the previous year.

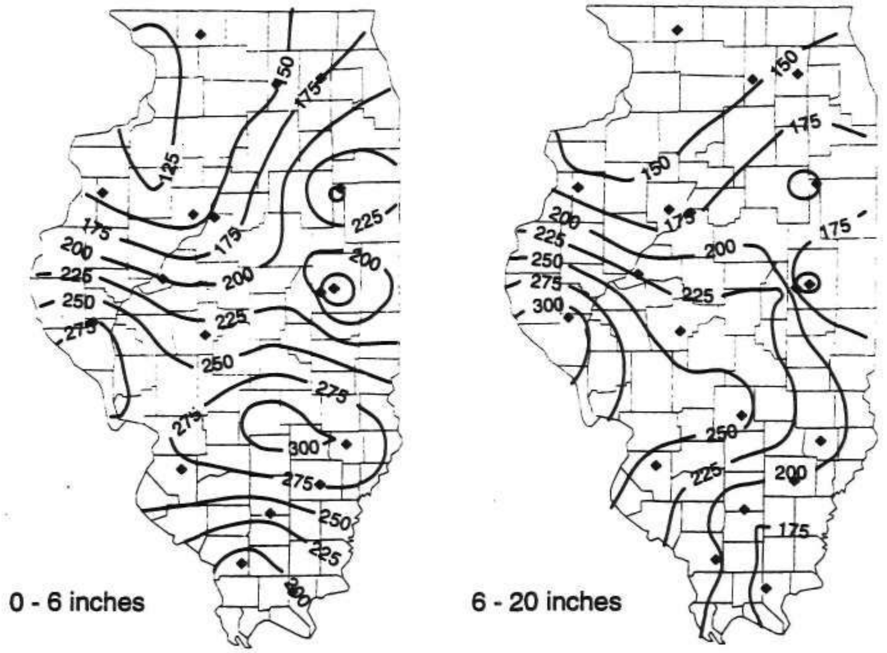
Streamflows, ground-water levels, and soil moisture had all peaked during September 1993 and generally began declining until November 1994. Streamflows, which had been more than 900 percent of normal statewide during September, finally dropped below normal by June, particularly so in central and southern Illinois. By July 1994 no streams exceeded flood stage. Reservoir levels declined gradually over the period, except during April, and by September only 3 of 45 reporting reservoirs exceeded normal pool. Ground-water levels dropped below normal in August 1994. (Some departures below normal emerged in eastern and southern Illinois by July.) Soil moisture in the 0-to-40-inch layer dropped below normal in May and remained below normal through September. Large shortfalls occurred in shallow layers in northern Illinois by May, in central Illinois by June, and in the rest of the state by July. Some parts of west-southwestern Illinois registered less than 30 percent of normal in shallow soil layers at the end of July. Just ten months earlier, these areas had soil moisture contents nearly 300 percent of normal.

Two Non-Mississippi River Flood Cases

Cook County

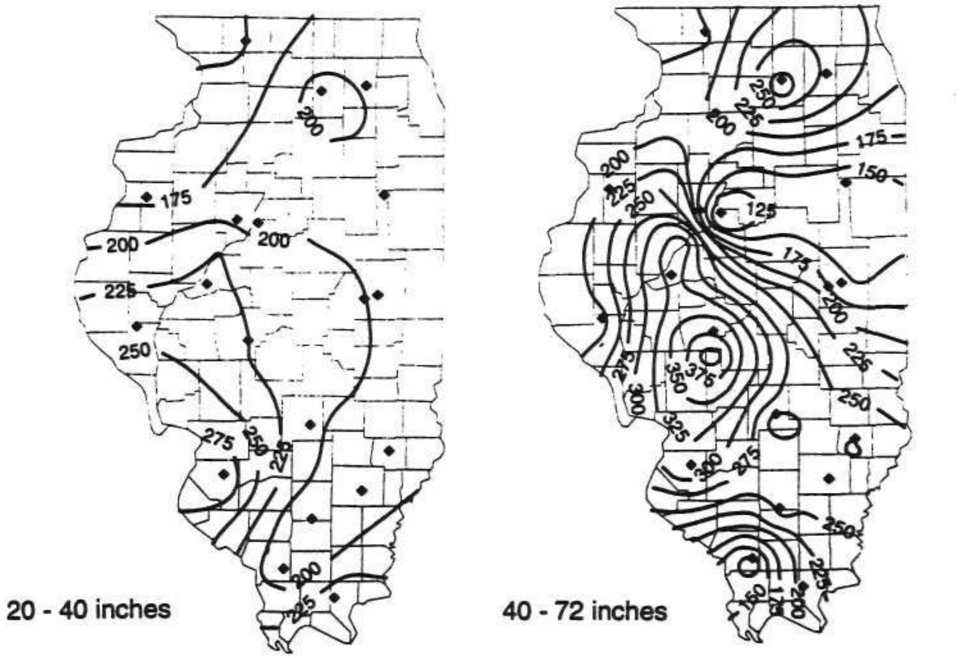
On June 7-8,1993, a series of precipitation-laden thunderstorms passed through the Cook County/Chicago region. Though this area was relatively immune from the widespread, lingering flooding experienced in other parts of the state, the precipitation that fell during this period caused flash flooding in many areas, including several interstate highways, and widespread basement flooding.

The ISWS has been collecting precipitation data in Cook County since October 1989 with a dense network of 25 raingages. This data network is funded by the U.S. Army Corps of Engineers and the USGS. The U.S. Army Corps of Engineers uses the data to help account for all water that is diverted from Lake Michigan into Illinois (stormwater runoff is considered part



0 - 6 inches

6 - 20 inches



20 - 40 inches

40 - 72 inches

Figure 18. End of September/early October 1993 percent of normal soil moisture in four soil layers, based on 1985-1992 means

of the diversion). Figure 19 shows June 1993 precipitation. Values ranged from just under 8 inches in the northwestern portion of the network near Des Plaines to more than 16 inches in the southeastern part of Chicago some 14 miles south of downtown. The 16 inches recorded in southeastern Chicago represented 46 percent of the long-term annual average of the National Weather Service's Chicago O'Hare Airport station.

During the June 7-8 period alone, nearly 7 inches of rain was recorded in southeastern Chicago, and more than 5 to 6 inches was received across a broad area of the south-central portion of the network. The recurrence interval for such precipitation events ranges from 10 to more than 50 years. Some heavy events also occurred in August and September 1993, but not of the magnitude recorded in June nor of the severity measured during the summer in downstate Illinois.

Mason/Tazewell Counties

As mentioned previously, widespread ground-water flooding occurred in Mason County in west-central Illinois, south of Peoria along the eastern banks of the Illinois River. Widespread flooding (some of which still existed at the end of 1994) began during late summer 1993 due to a rise of the water table above the land surface in response to above normal precipitation. The area is characterized by sandy soils, which require irrigation to produce satisfactory yields of corn and soybeans.

The ISWS began collecting precipitation data in this region in August 1992 with a dense network of 25 raingages to provide information about rainfall variability and ground-water recharge to the area's local water authority. Figure 20 shows the distribution of precipitation that fell from June through September 1993. Precipitation across the area during this period alone nearly matched or exceeded the long-term annual averages (about 35 inches) of nearby National Weather Service cooperative stations in Havana and Mason City. Values ranged from 29 inches in the far southeast to more than 38 inches in the south-central portion of the network. Values in excess of 36 inches were common over most of the southwestern third of the network and in the northeast. The ground-water flooding, shown within the hatched area of Figure 20, closely matched the heavy precipitation in the southwestern portion of the network. Flooding also occurred in southwestern Tazewell County (northeastern portion of the network) due to the heavy precipitation there, resulting in an overflow of the Mackinaw River.

Impacts

Almost everyone in Illinois was affected in some way by the wet conditions throughout the state during 1993 and 1994. Flooded, chronically wet fields ruined crops or greatly reduced yields in affected areas. Commerce was impeded not only along river courses but also along highways and railroads that became impassable for extended periods of time. The extensive flooding of homes, farmlands, and businesses by river and ground-water overflows led to the outright abandonment of some towns (e.g., Valmeyer, Illinois) and the temporary disruption of business/industrial activities.

In Illinois alone, six deaths were attributed to the flood (Bhowmik et al., 1994). More than 16,000 individuals were displaced from their homes, and more than 6,000 structures were

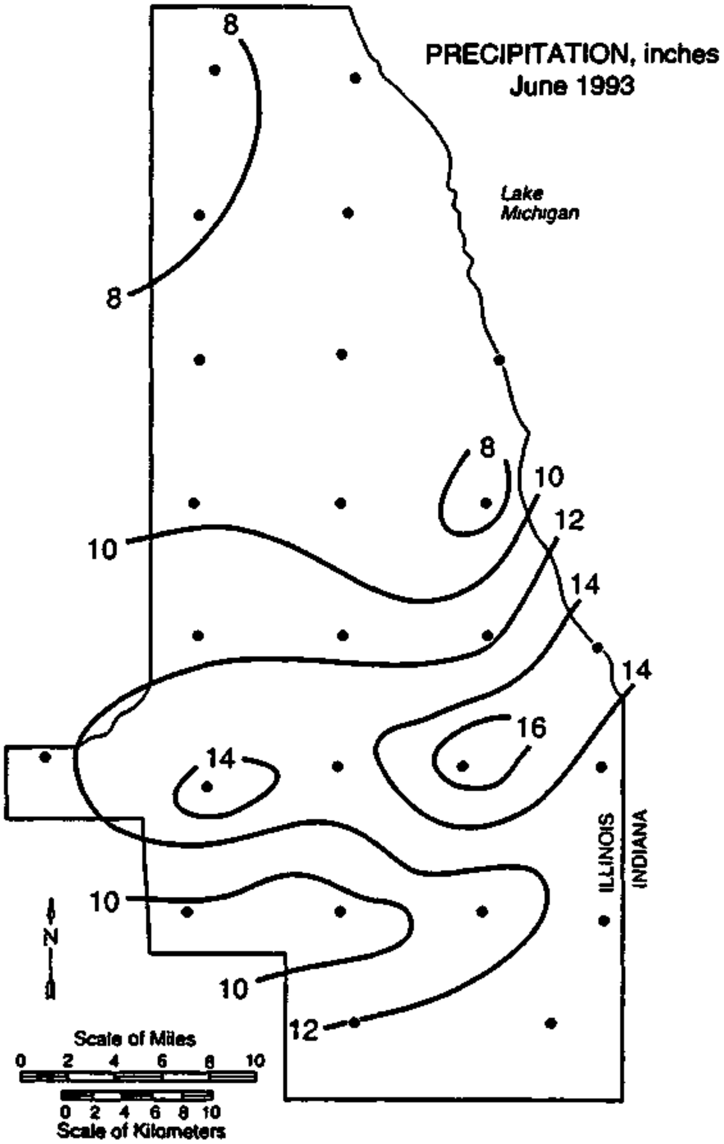


Figure 19. June 1993 Cook County Network precipitation

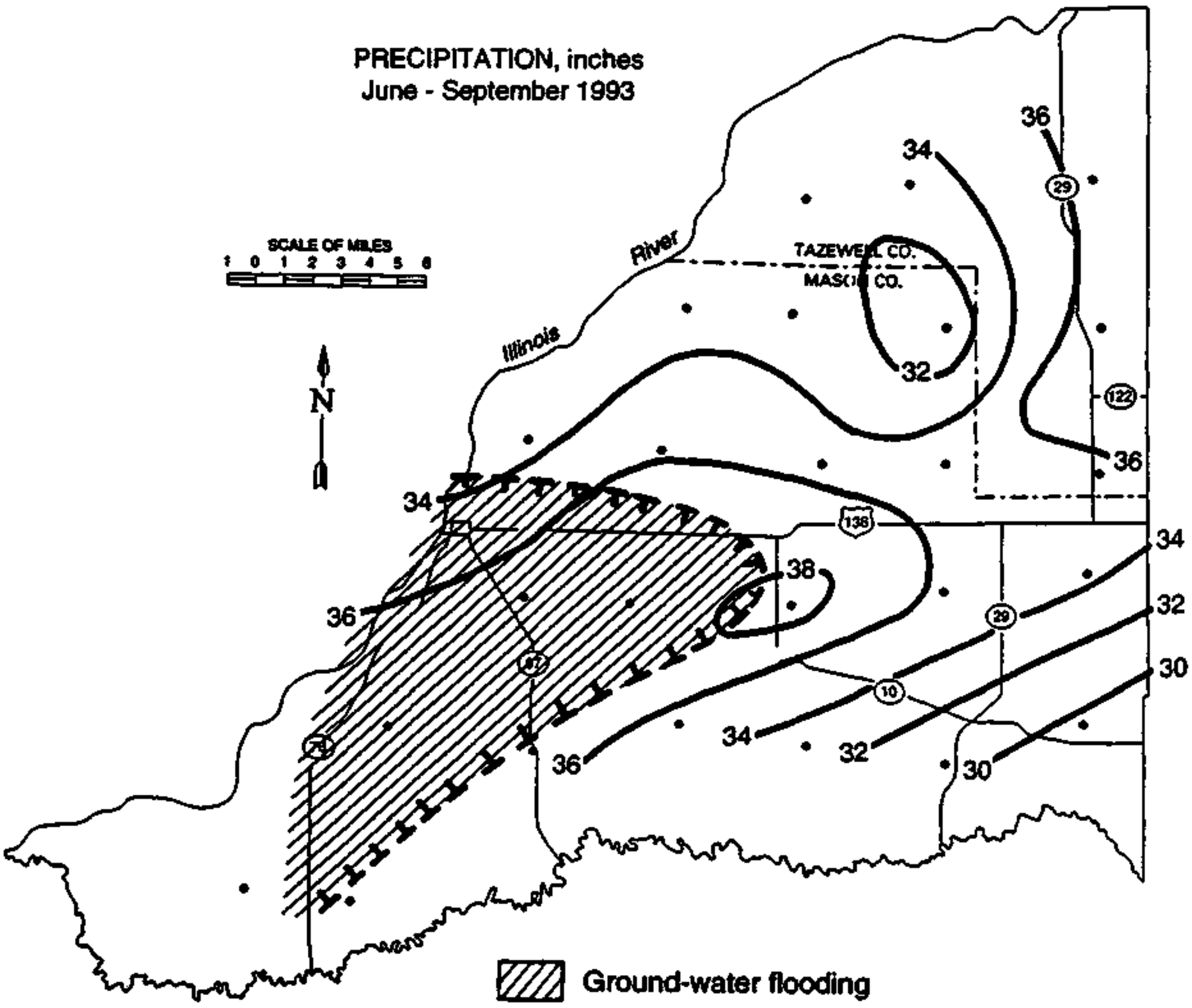


Figure 20. June-September 1993 Imperial Valley Water Authority Network precipitation

either lost or severely damaged by floods. More than 10,000 jobs were affected, and 18 communities were severely flooded, with 17 either losing essential supplies or suffering damaged municipal systems. Seventeen public water supplies were rendered inoperative for days or weeks or operated under "boil orders." Three of these systems were deemed permanently inoperable.

As of July 15,1993, flooding had claimed 312,000 acres of corn and 276,000 acres of soybeans, and total agricultural acreage losses approached 900,000 acres, about three to four percent of the state's planted acreage. Monetary losses as of August 1,1993, were estimated to be around $930 million.

Environmental impacts included excessive erosion and contamination of surface and ground-water supplies by bacterial organisms (from overflowed wastewater treatment plants and failed septic systems), natural sediments, and agricultural chemicals. Some wells were completely submerged by floodwaters. Flooding did have some beneficial impacts on the aquatic habitats and fisheries of affected areas, but pests such as mosquitoes and zebra mussels were also aided by the flooding.

SUMMARY

Data collected or assembled by the WARM Network allowed ISWS staff and Illinois and federal governmental agencies to monitor conditions during the wet summer of 1993, assess preceding conditions, and track the eventual decline of water resources after September 1993. Modernization and expansion of the network, particularly with respect to automation of current manual measurements and the development of more real-time data retrieval and dissemination systems, will allow for even better tracking of unusual events and quicker responses to them.

For more information about the WARM Network and its various components, or to obtain publications or data, please contact the author at 217/244-1798 (phone), 217/333-6540 (fax), or via e-mail at rpeppler@uiuc.edu.

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REFERENCES

Belding, M. J., S. E. Hollinger, and R. A. Peppier, 1995: Development of new soil temperature and soil moisture profilers for the Illinois Climate Network. Preprints, 11th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology of the American Meteorological Society, Dallas, Texas, January 15-20,1995, pp. 363-364.

Bhowmik, N. G., Scientific Editor, and A. G. Buck, S. A. Changnon, R. H. Dalton, A. Durgunoglu, M. Demissie, A. R. Juhl, H. V. Knapp, K. E. Kunkel, S. A. McConkey, R. W. Scott, K. P. Singh, T-W Soong, R: E. Sparks, A. P. Visocky, D. R. Vonnahme, W. M. Wendland, 1994: *The 1993 Flood on the Mississippi River in Illinois.* Illinois State Water Survey Miscellaneous Publication 151,149p.

Hendrie, L. K., 1983: *Illinois Solar Weather Program.* Illinois State Water Survey Contract Report 304,78p.

Hollinger, S. E., B. C. Reinke, and R. A. Peppier, 1994: *Illinois Climate Network: Site Descriptions, Instrumentation, and Data Management.* Illinois State Water Survey Circular 178,63p.

Kunkel, K. E., S. A. Changnon, and J. R. Angel, 1994: Climatic aspects of the 1993 Upper Mississippi River basin flood. *Bulletin of the American Meteorological Society,* 75:811-822.

Lamb, P. J., Scientific Editor, and J. R. Angel, G. M. Bender, A. Durgunoglu, S. E. Hollinger, D. M. A. Jones, H. V. Knapp, K. E. Kunkel, S. A. McConkey, D. H. Portis, G. S. Ramamurthy, R. W. Scott, R. G. Semonin, K. P. Singh, H. A. Wehrmann, W. M. Wendland, 1992: *The 1988-1989 Drought in Illinois: Causes, Dimensions, and Impacts.* Illinois State Water Survey Research Report 121,154p.

Peppier, R. A., 1995a: The Illinois WARM Network—an overview. 11th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology of the American Meteorological Society, Dallas, Texas, January 15-20,1994, pp. 357-362.

Peppier, R. A., 1995b: An analysis of the wet 1993 summer in Illinois as observed by the Illinois WARM Network. Preprints, Ninth Conference on Applied Climatology of the American Meteorological Society, Dallas, Texas, January 15-20,1995, pp. 243-248.

Reinke, B. C, and R. A. Peppier, 1995: Illinois Climate Network educational outreach activities. Preprints, Fourth Symposium on Education of the American Meteorological Society, Dallas, Texas, January 15-20,1995, pp. 80-81.

Reinke, B. C, M. Schoen-Petersen, and S. E. Hollinger, 1995: Automated quality control and archival of hourly and daily weather data collected by the Illinois Climate Network. Preprints, 11th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology of the American Meteorological Society, Dallas, Texas, January 15-20,1995, pp. 353-356.

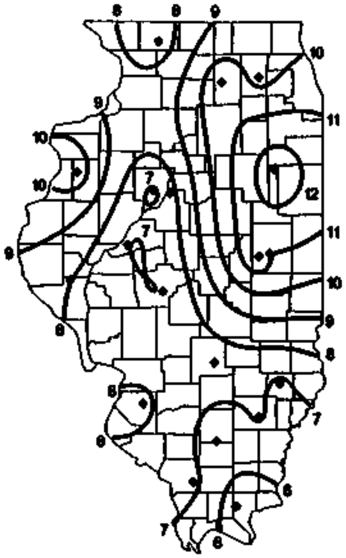
Schmalbeck, L. M., and R. A. Peppier, 1994: First steps toward the Illinois School Children's Atmospheric Network (ISCAN)—a role for scientists in science education. *Bulletin of the American Meteorological Society,* 75:631-635.

U.S. Geological Survey, 1992: *National Water Summary 1988-1989—Floods and Droughts: ILLINOIS.* From U.S. Geological Survey Water Supply Paper 2375, pp. 263-269.

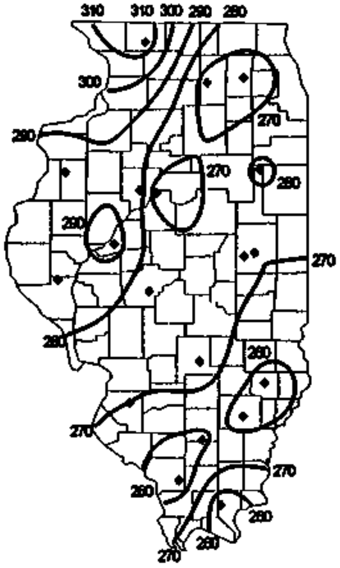
APPENDIX A

This appendix contains monthly averages of selected variables collected by the WARM Network for each calendar month of 1994. These include wind speed (miles per hour, or mph), wind direction (degrees from 0 to 359), total number of hours having wind speeds above 8 mph (important for wind energy considerations), air temperature (degrees Fahrenheit), total solar radiation (amount of sunshine or solar radiation received, in mega-Joules per meter squared), total potential evapotranspiration (the amount of water that can be evaporated and transpired from a well-watered grassy surface), and 4- and 8-inch soil temperatures (degrees Fahrenheit).

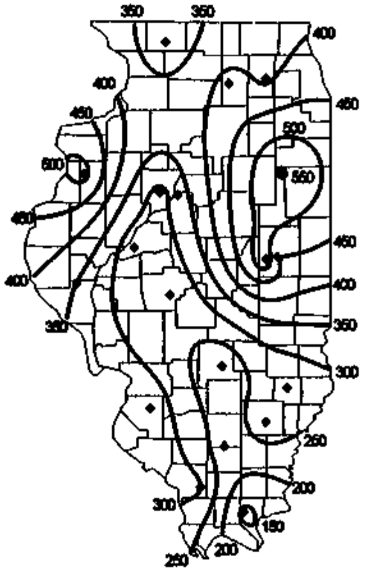
Average Wind Speed (mph)



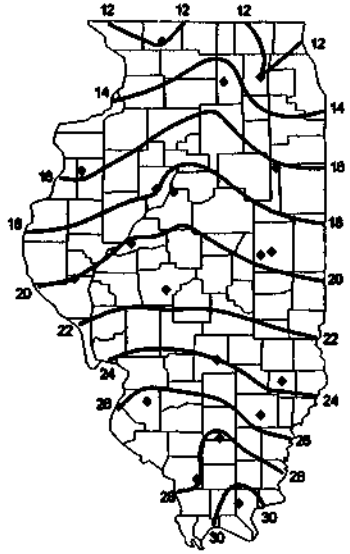
Average Wind Direction (deg)



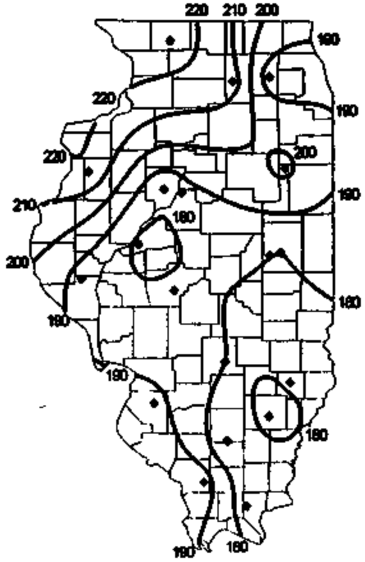
Total Hours Wind Speed above 8 mph



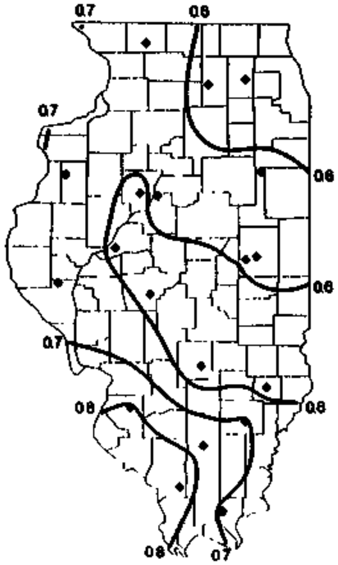
Average Temperature (deg F)



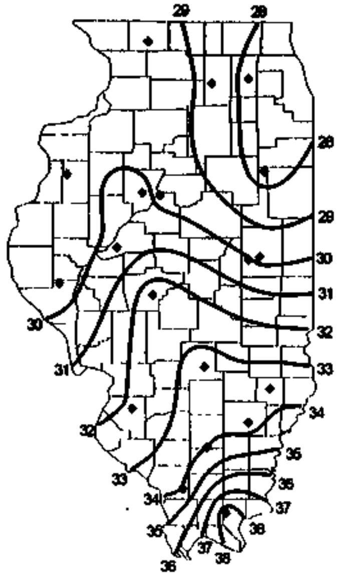
Total Solar Radiation (MJ / m^2)



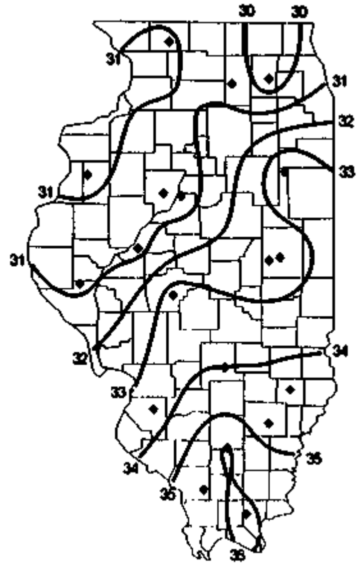
Total Potential Evapotranspiration (in)



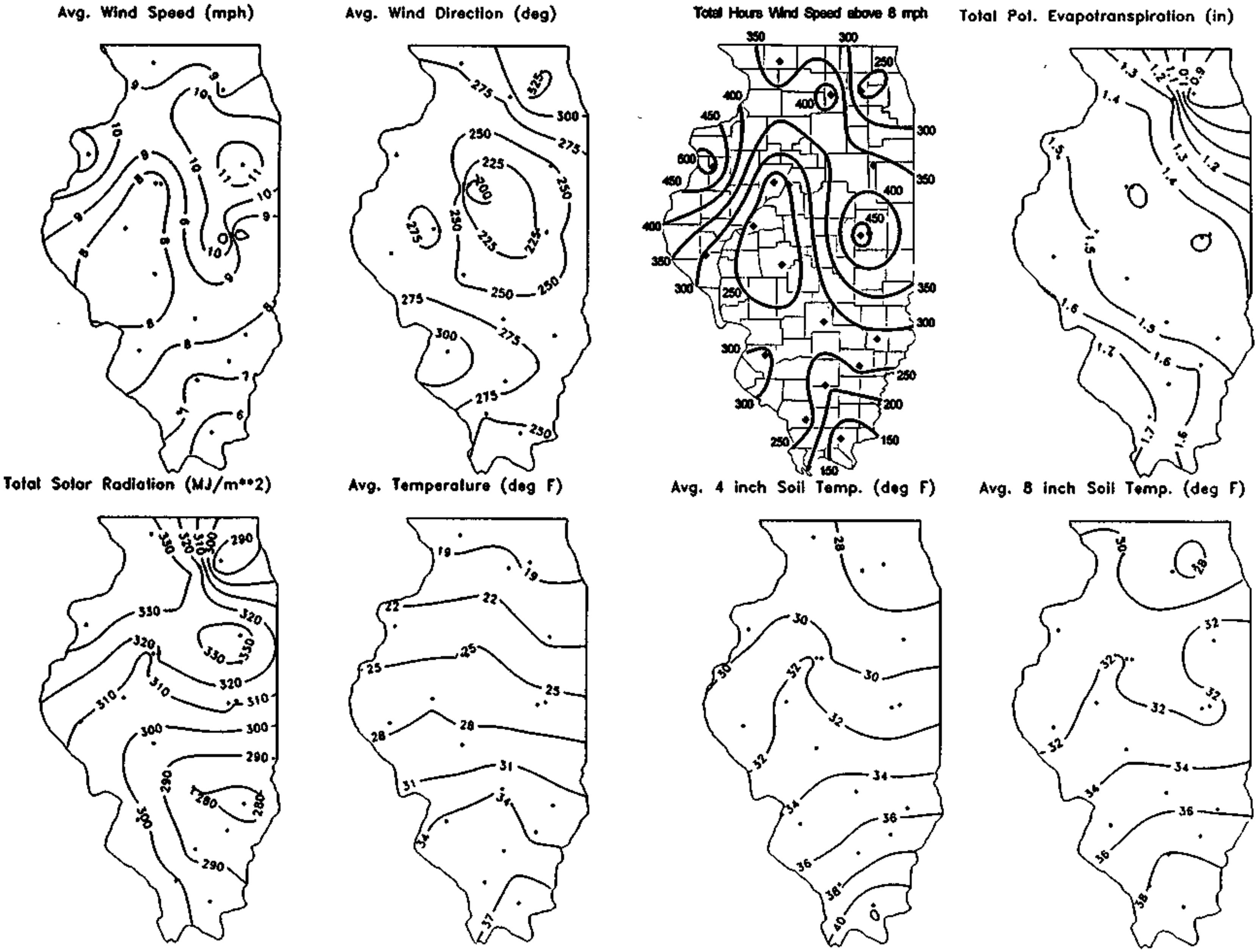
Average 4 Inch Soil Temperature (deg F)



Average 8 Inch Soil Temperature (deg F)



January 1994



Avg. Wind Speed (mph)

Avg. Wind Direction (deg)

Total Hours Wind Speed above 8 mph

Total Pot. Evapotranspiration (in)

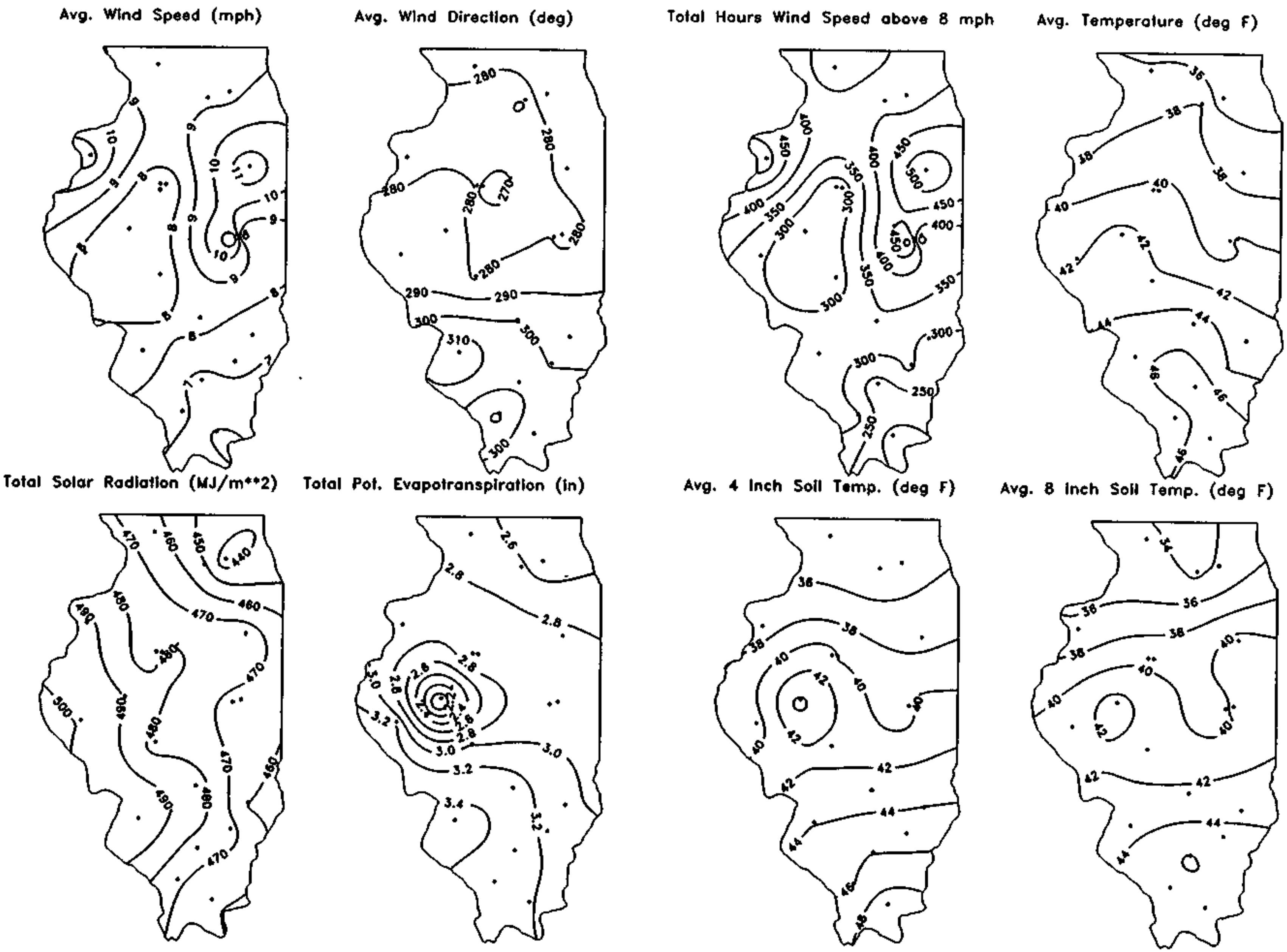
Total Solar Radiation (MJ/m**2)

Avg. Temperature (deg F)

Avg. 4 inch Soil Temp. (deg F)

Avg. 8 inch Soil Temp. (deg F)

February 1994



Avg. Wind Speed (mph)

Avg. Wind Direction (deg)

Total Hours Wind Speed above 8 mph

Avg. Temperature (deg F)

Total Solar Radiation (MJ/m**2)

Total Pot. Evapotranspiration (in)

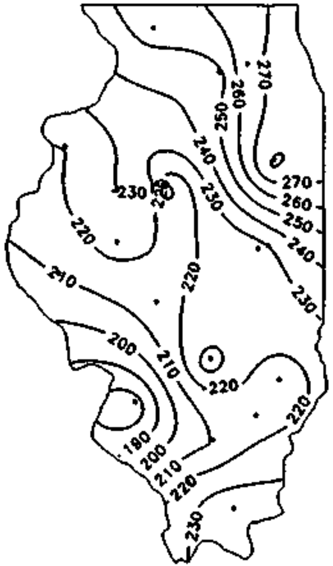
Avg. 4 Inch Soil Temp. (deg F)

Avg. 8 Inch Soil Temp. (deg F)

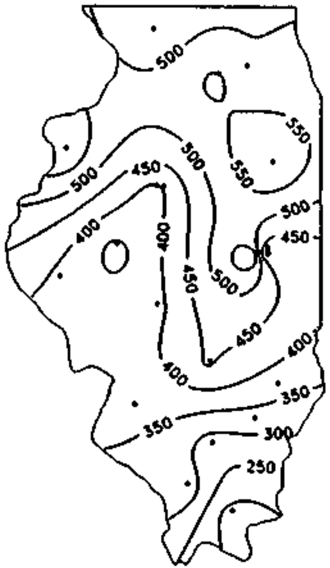
March 1994

Avg. Wind Speed (mph)

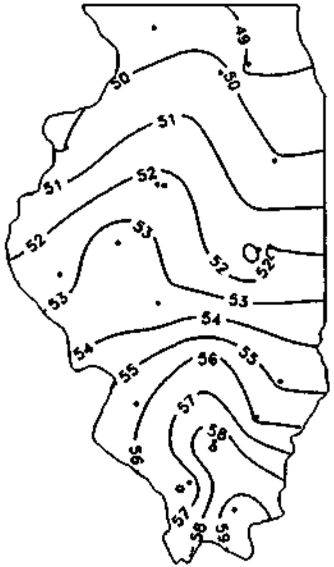
Avg. Wind Direction (deg)



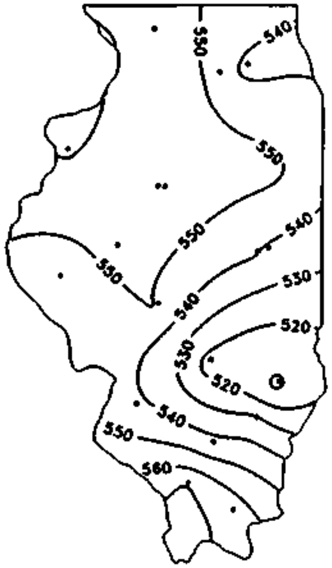
Total Hours Wind Speed above 8 mph



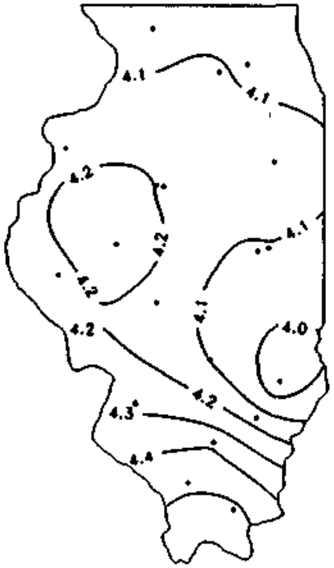
Avg. Temperature (deg F)



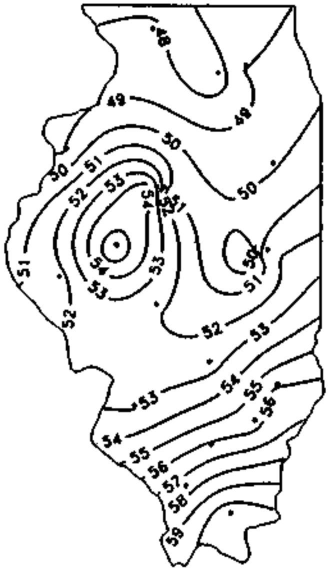
Total Solar Radiation (MJ/m**2)



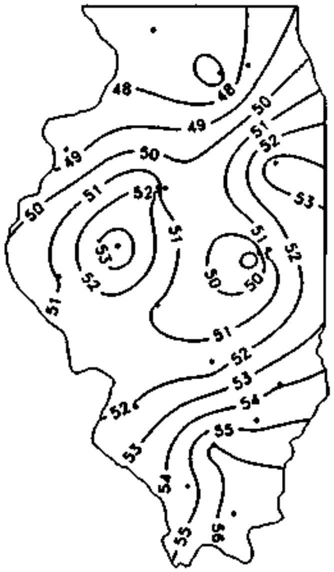
Total Pot. Evapotranspiration (in)



Avg. 4 Inch Soil Temp. (deg F)



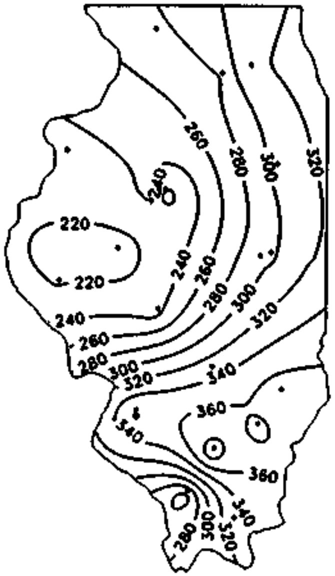
Avg. 8 Inch Soil Temp. (deg F)



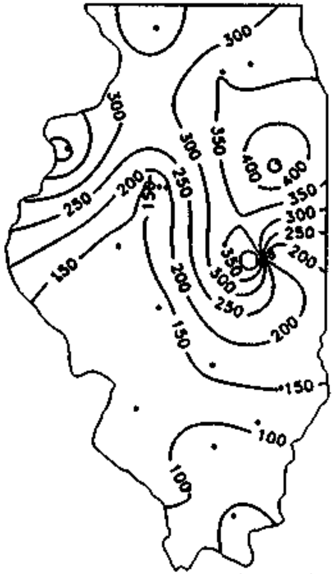
April 1994

Avg. Wind Speed (mph)

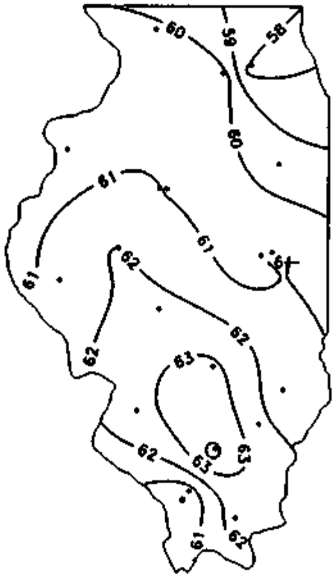
Avg. Wind Direction (deg)



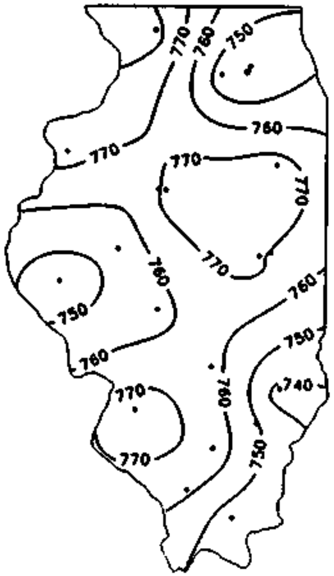
Total Hours Wind Speed above 8 mph



Avg. Temperature (deg F)

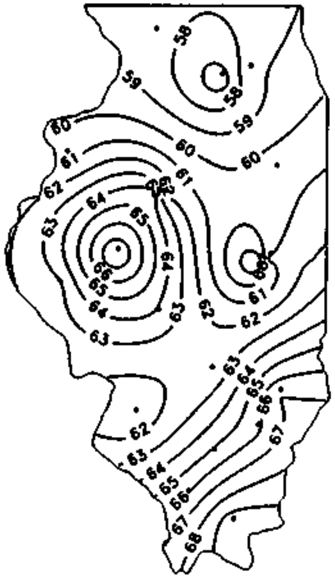


Total Solar Radiation (MJ/m**2)



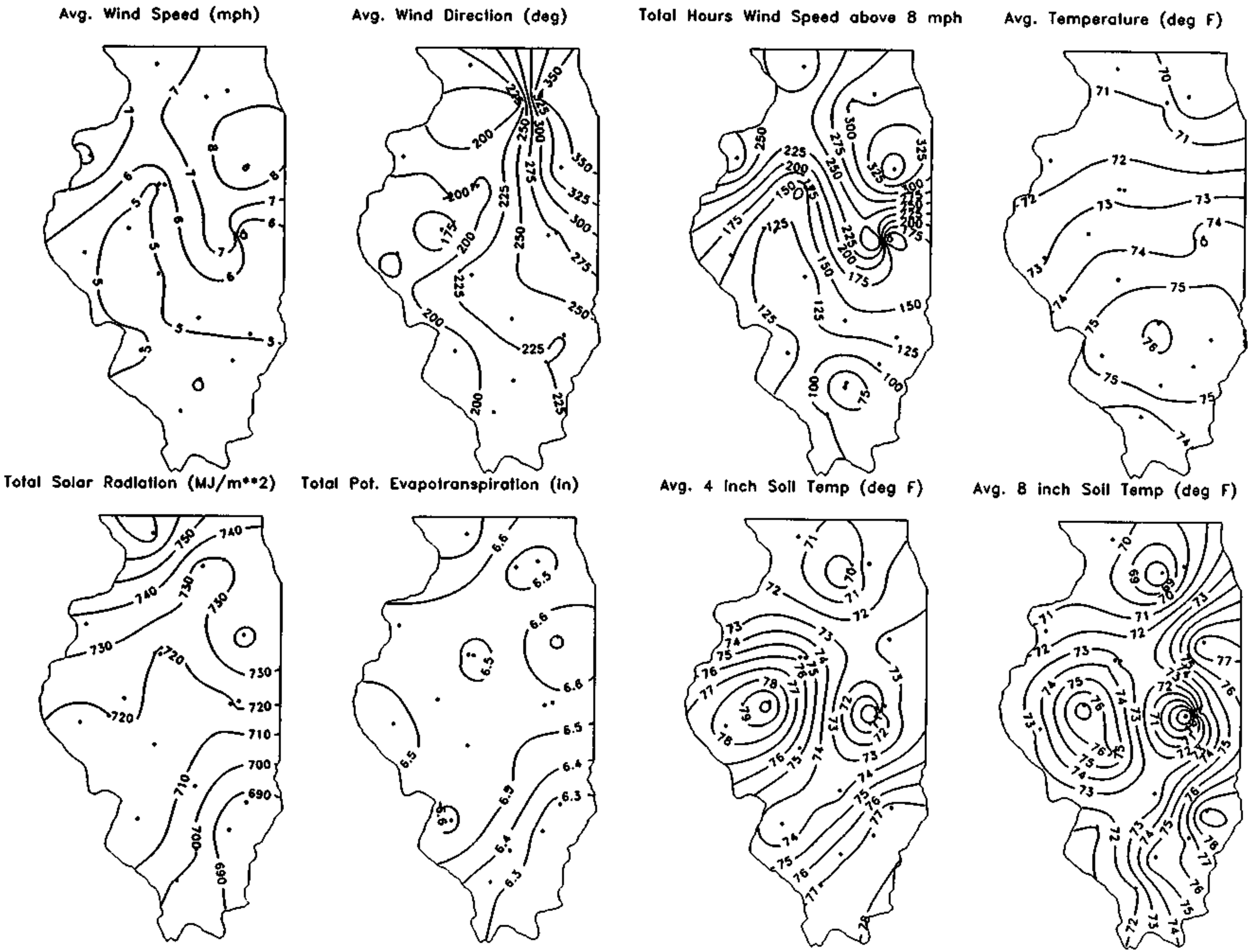
Total Pot. Evapotranspiration (in)

Avg. 4 inch Soil Temp. (deg F)



Avg. 8 inch Soil Temp. (deg F)

May 1994



Avg. Wind Speed (mph)

Avg. Wind Direction (deg)

Total Hours Wind Speed above 8 mph

Avg. Temperature (deg F)

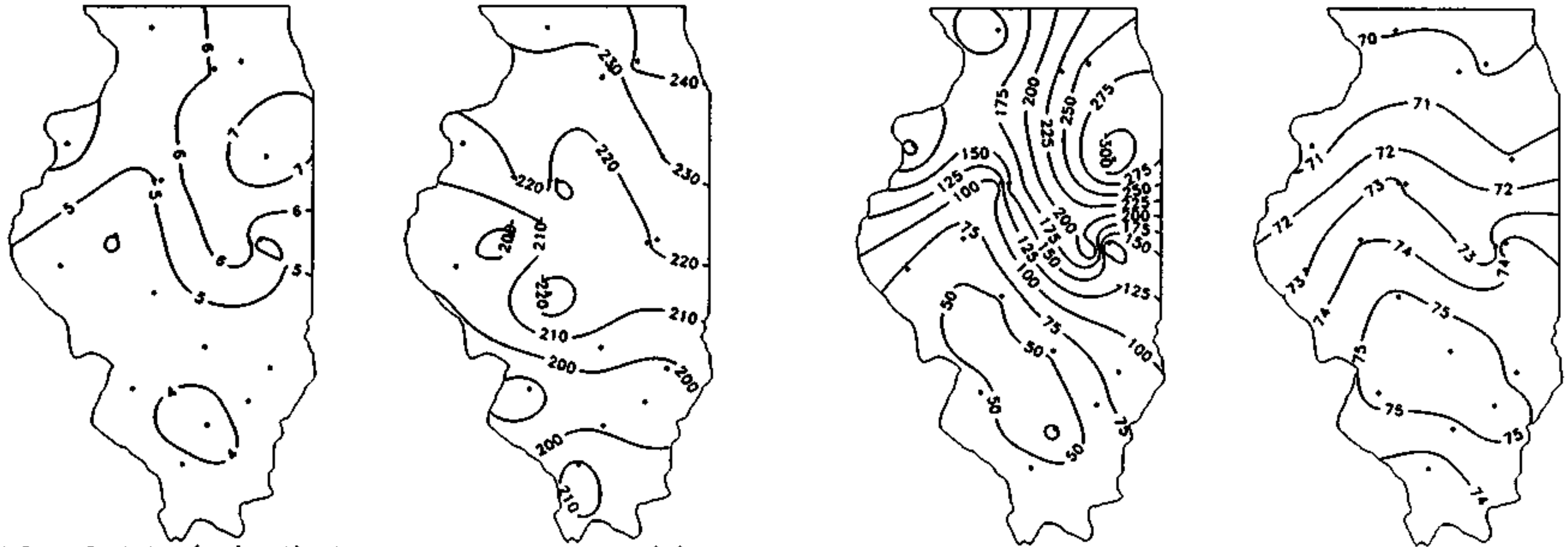
Total Solar Radiation (MJ/m**2)

Total Pot. Evapotranspiration (in)

Avg. 4 inch Soil Temp (deg F)

Avg. 8 inch Soil Temp (deg F)

June 1994

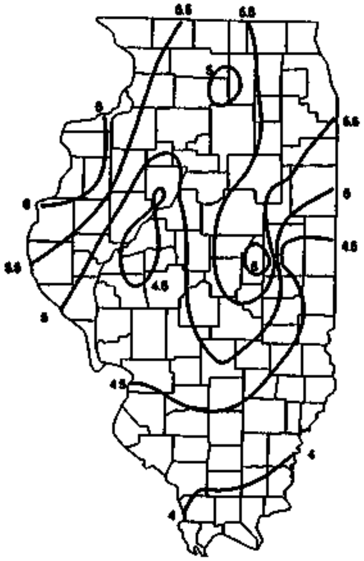


Avg. Wind Speed (mph) Avg. Wind Direction (deg) Total Hours Wind Speed above 8 mph Avg. Temperature (deg F)

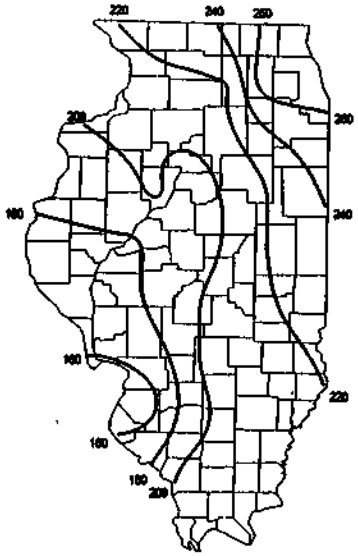
Total Solar Radiation (MJ/m**2) Total Pot. Evapotranspiration (in) Avg. 4 Inch Soil Temp (deg F) Avg. 8 Inch Soil Temp (deg F)

July 1994

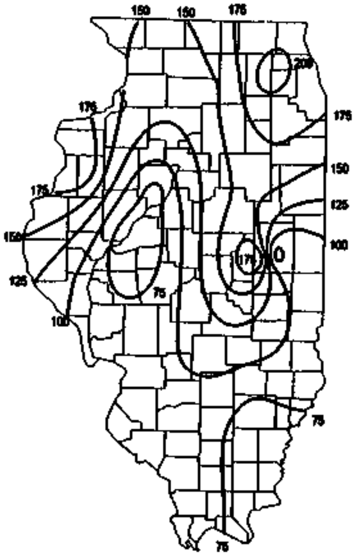
Avg. Wind Speed (mph)



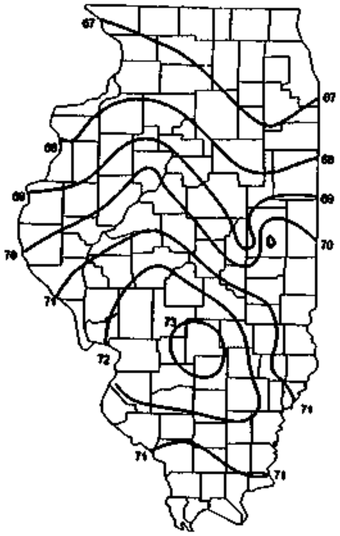
Avg. Wind Direction (deg)



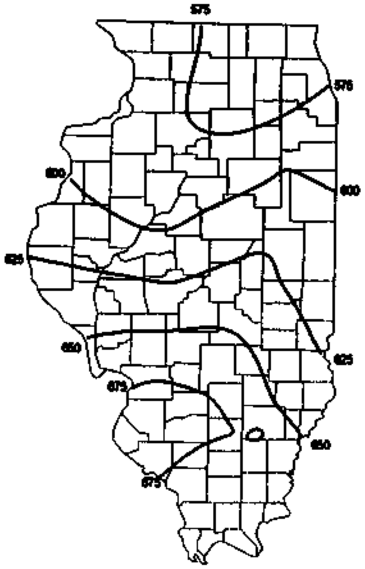
Total Hours Wind Speed above 6 mph



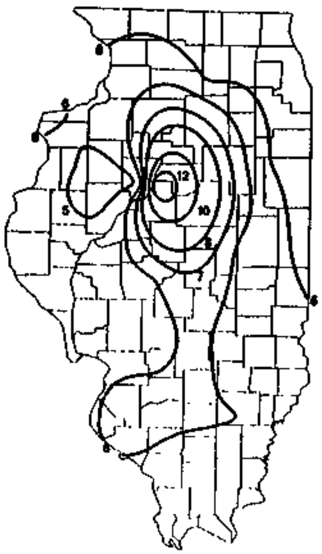
Avg. Temperature (deg F)



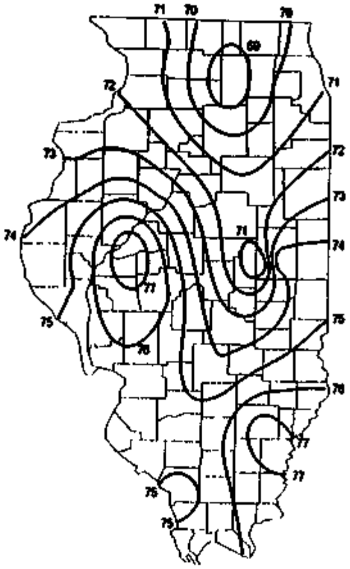
Total Solar Radiation (MJ / m^2)



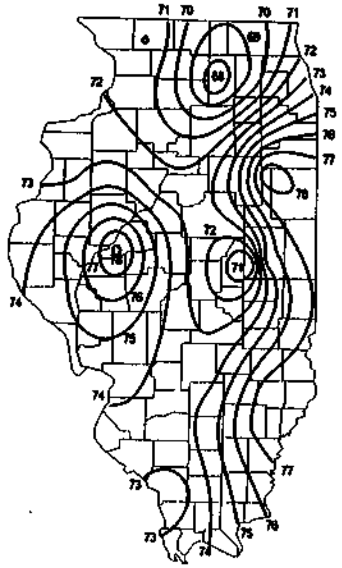
Total Pot. Evapotranspiration (in)



Avg. 4 inch Soil Temp (deg F)



Avg. 8 inch Soil Temp (deg F)



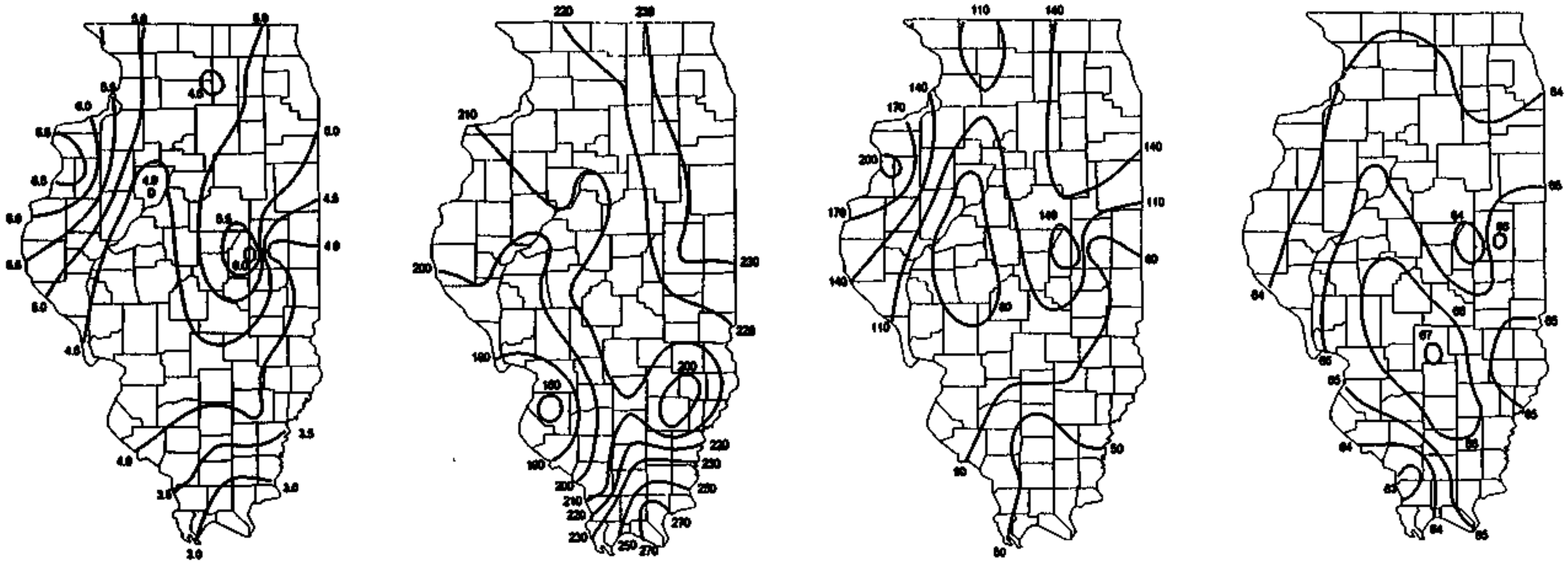
August 1994

Avg. Wind Speed (mph)

Avg. Wind Direction (deg)

Total Hours Wind Speed above 8 mph

Avg. Temperature (deg F)

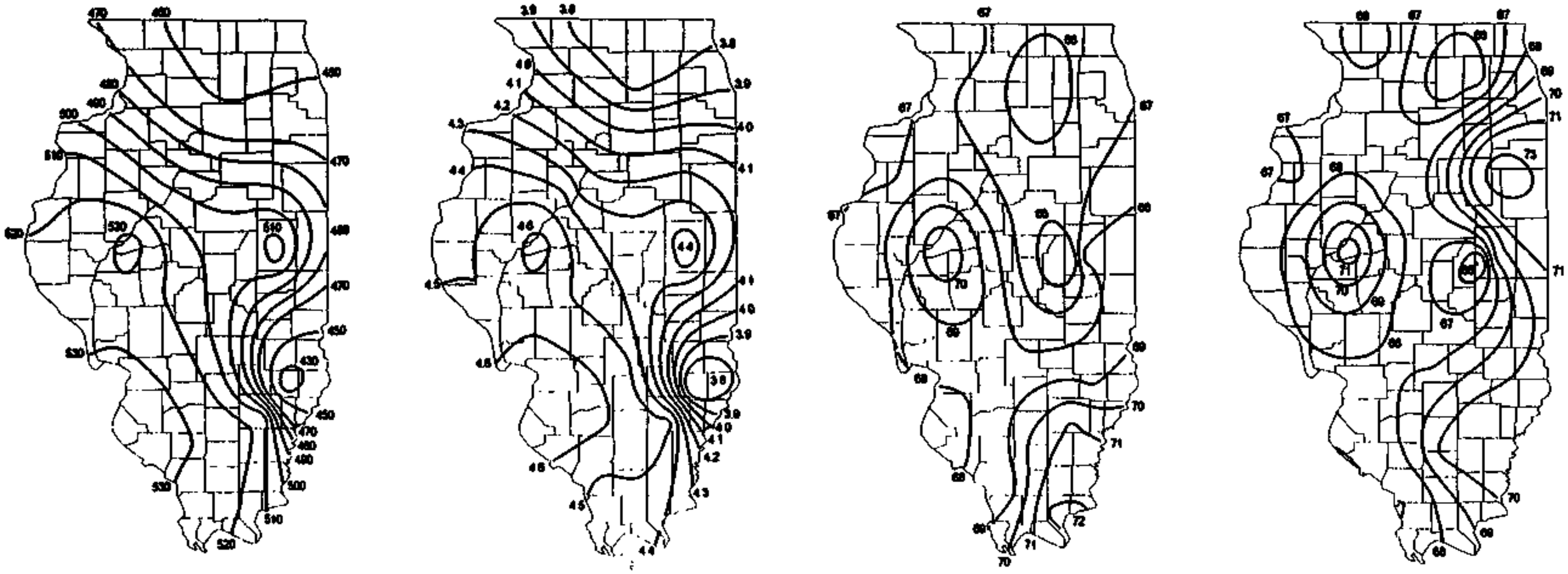


Total Solar Radiation (MJ / m^2)

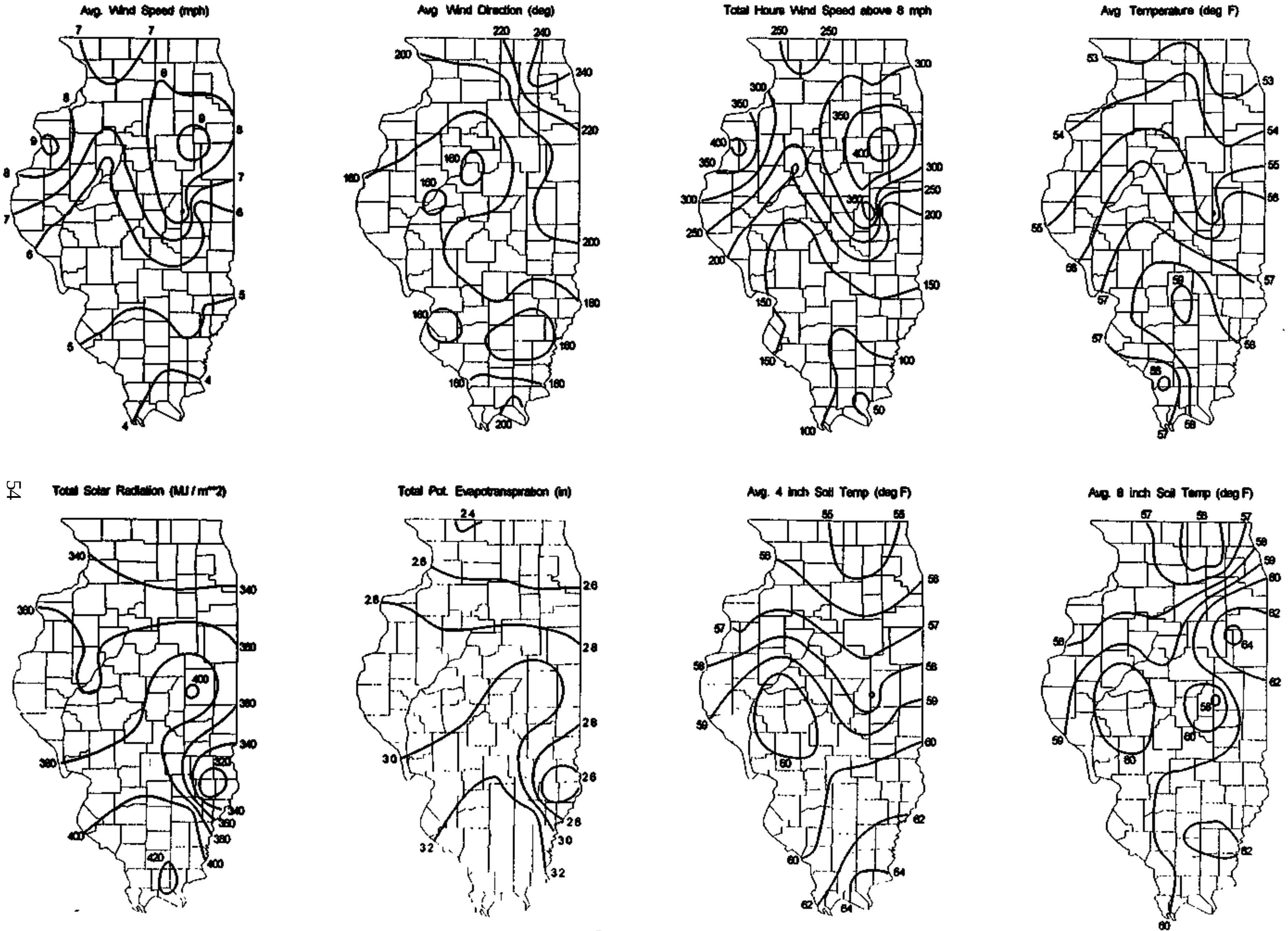
Total Pot. Evapotranspiration (in)

Avg. 4 inch Soil Temp (deg F)

Avg. 8 inch Soil Temp (deg F)



September 1994



Avg. Wind Speed (mph)

Avg Wind Direction (deg)

Total Hours Wind Speed above 8 mph

Avg Temperature (deg F)

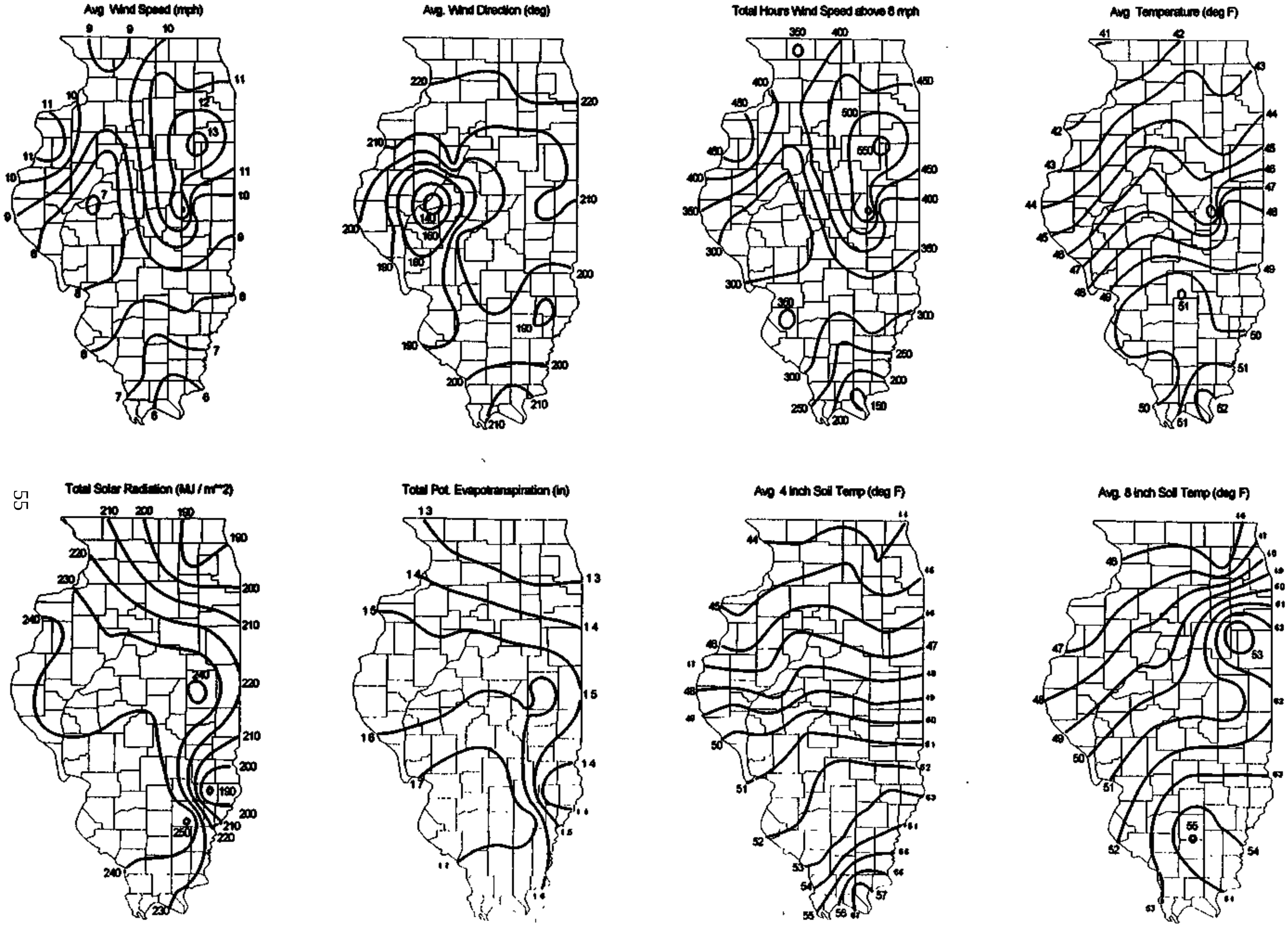
Total Solar Radiation (MJ / m**2)

Total Pot. Evapotranspiration (in)

Avg. 4 inch Soil Temp (deg F)

Avg. 8 inch Soil Temp (deg F)

October 1994


Avg Wind Speed (mph)

Avg. Wind Direction (deg)

Total Hours Wind Speed above 8 mph

Avg Temperature (deg F)

Total Solar Radiation (MJ / m**2)

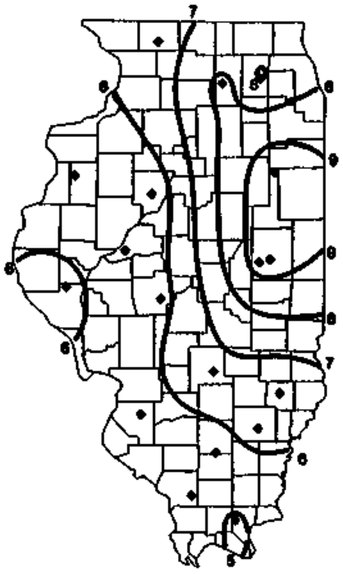
Total Pot. Evapotranspiration (in)

Avg 4 inch Soil Temp (deg F)

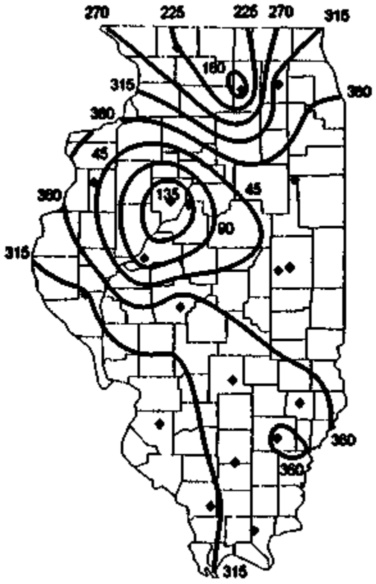
Avg. 8 inch Soil Temp (deg F)

November 1994

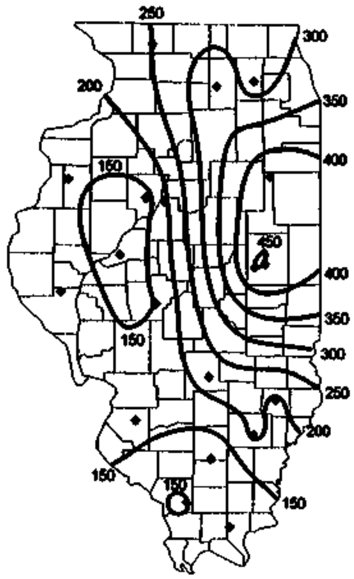
Avg. Wind Speed (mph)



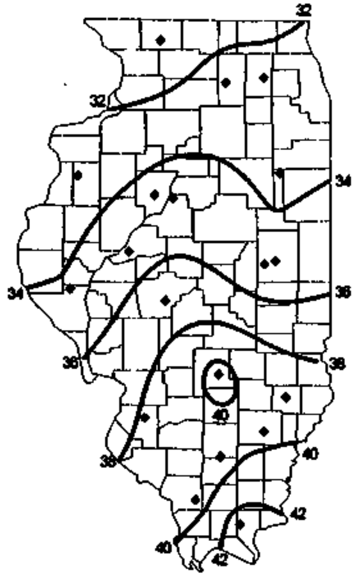
Avg. Wind Direction (deg)



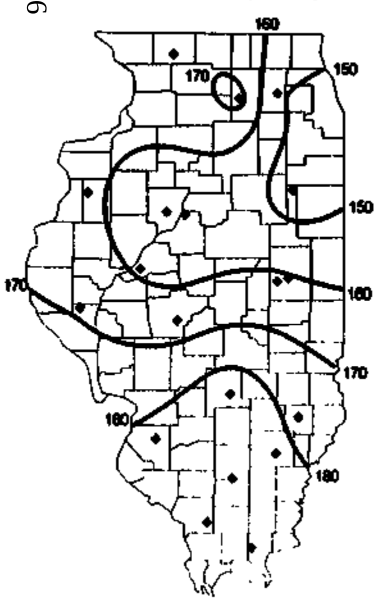
Total Hours Wind Speed above 8 mph



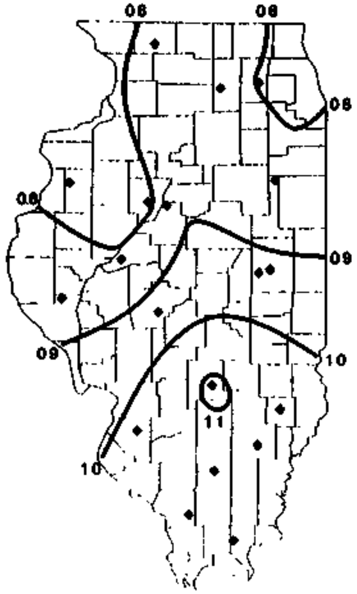
Avg. Temperature (deg F)



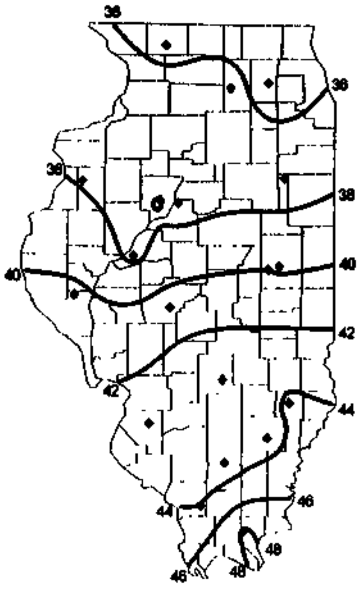
Total Solar Radiation (MJ / m**2)



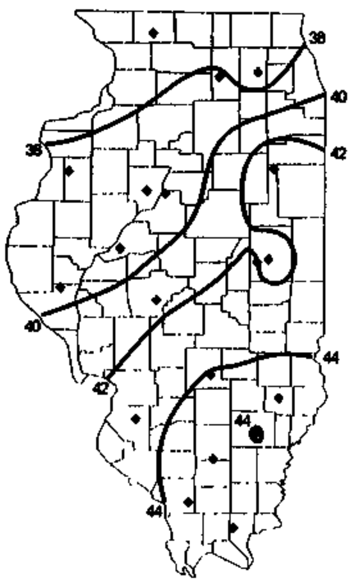
Total Pot. Evapotranspiration (in)



Avg 4 inch Soil Temp (deg F)



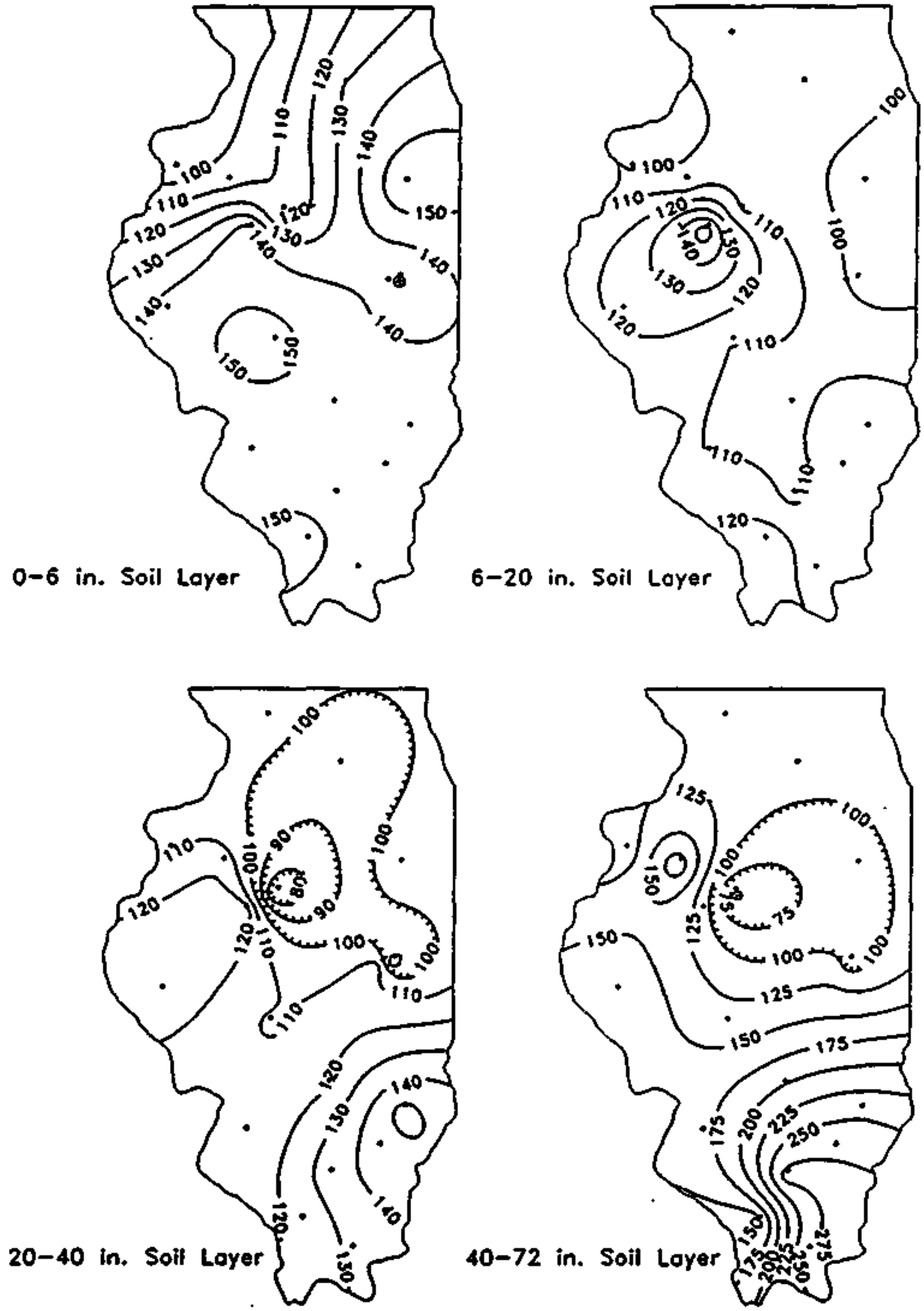
Avg. 8 inch Soil Temp (deg F)



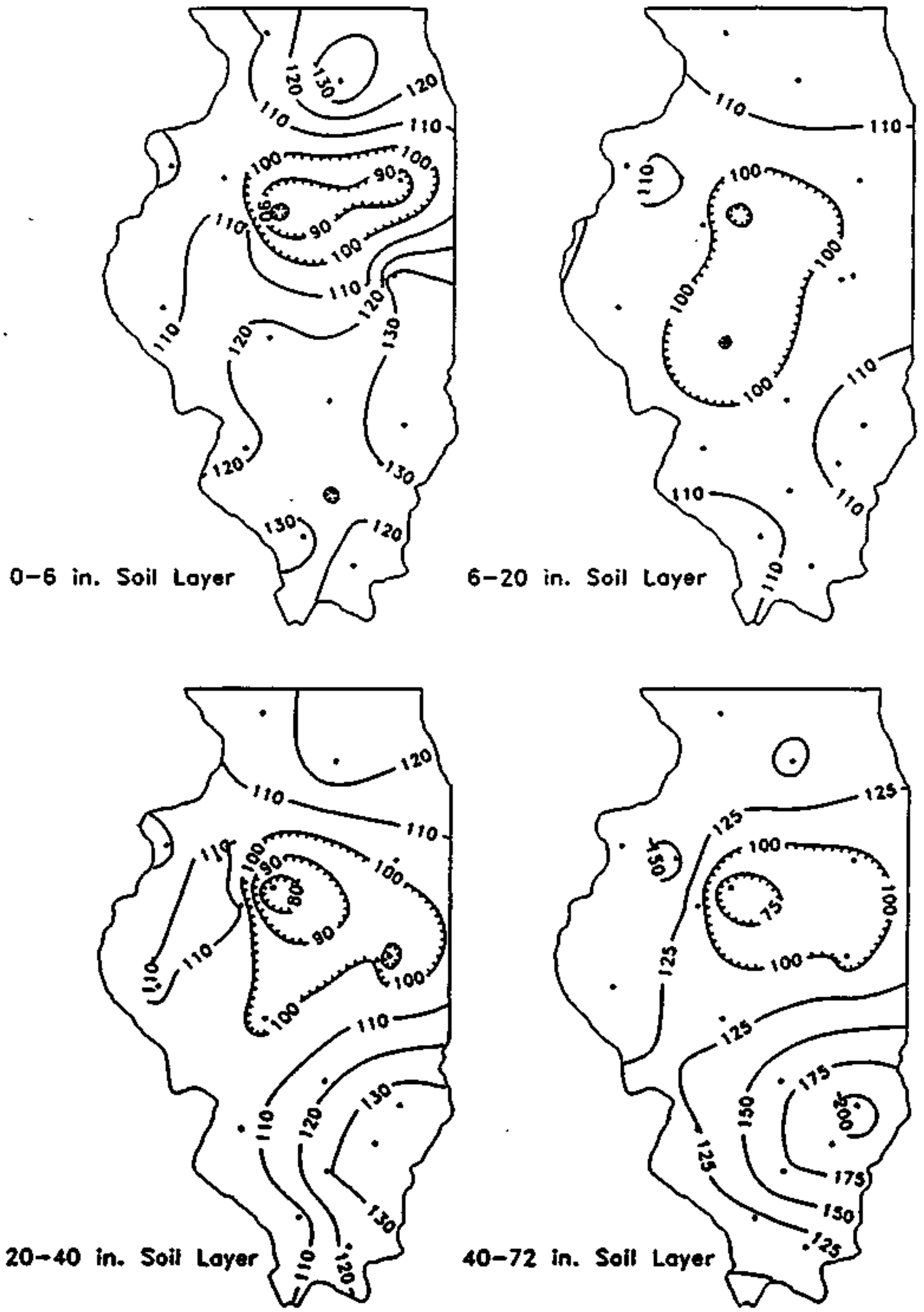
December 1994

APPENDIX B

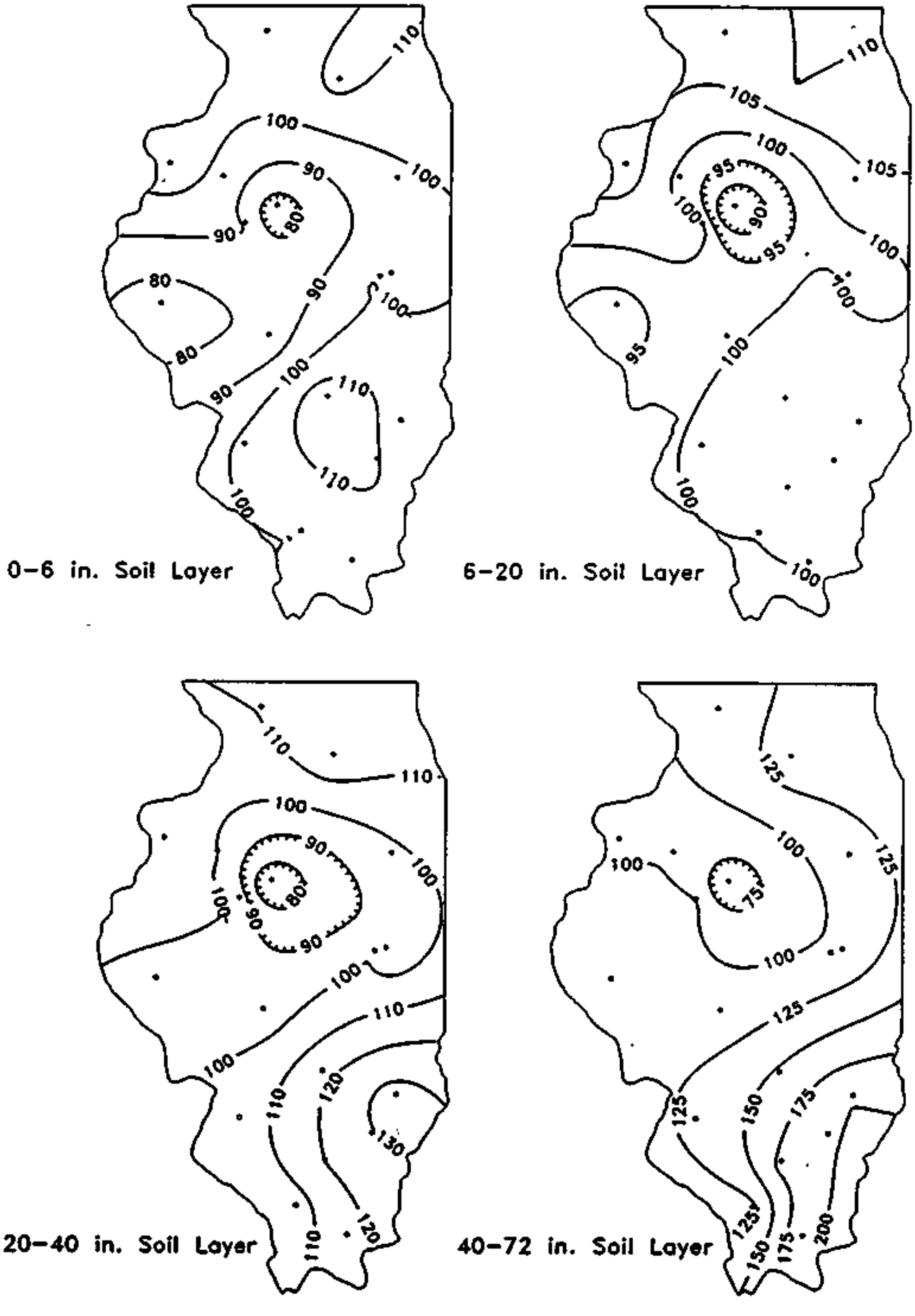
This appendix contains 1994 end-of-month percentages of normal soil moisture in four composite soil layers: 0 to 6 inches, 6 to 20 inches, 20 to 40 inches, and 40 to 72 inches from the surface. Soil moisture normals are based on 1985-1992 averages.



February 1,1994, percent of 1985-1992 average



March 1,1994, percent of 1985-1992 average



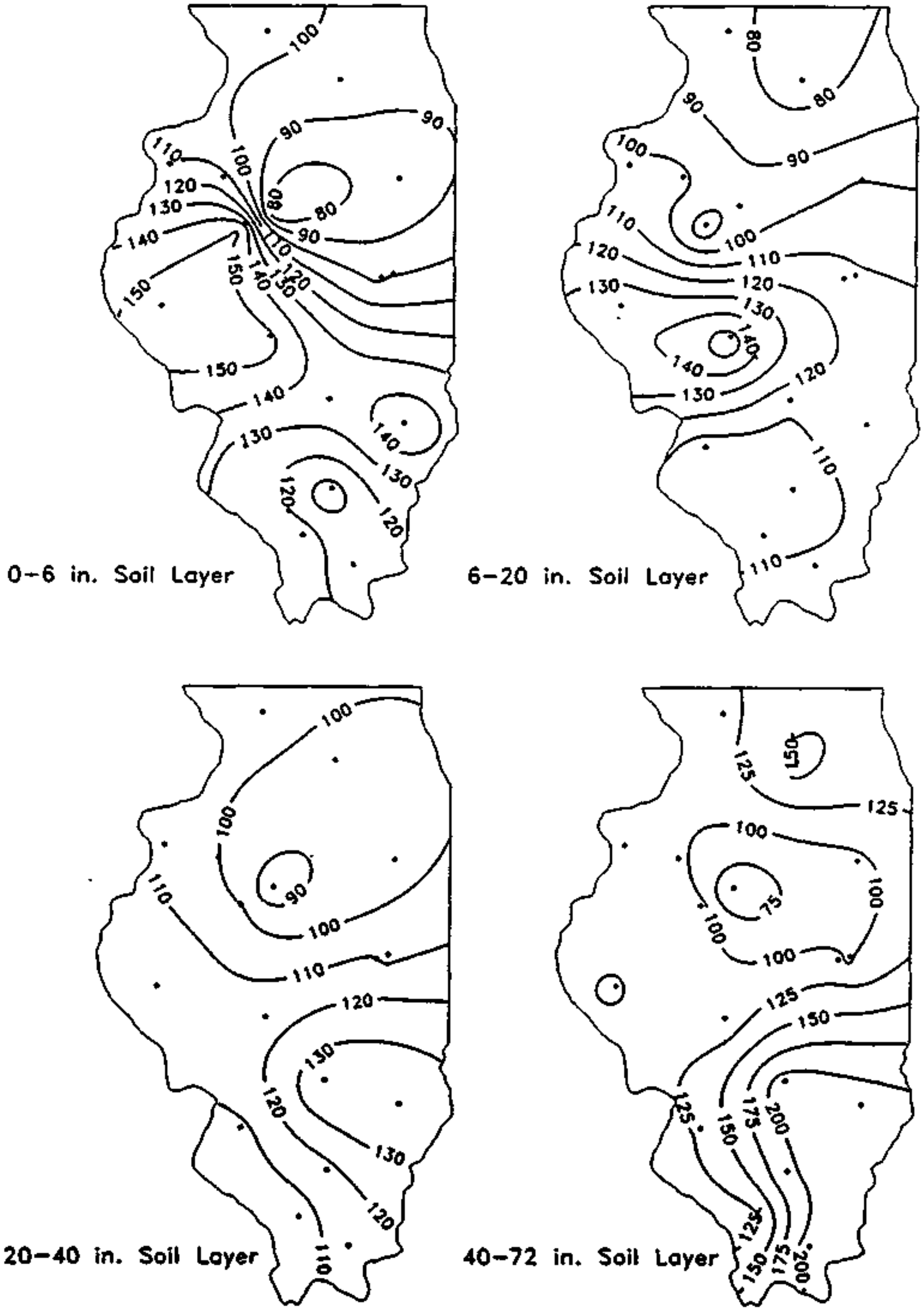
0–6 in. Soil Layer

6–20 in. Soil Layer

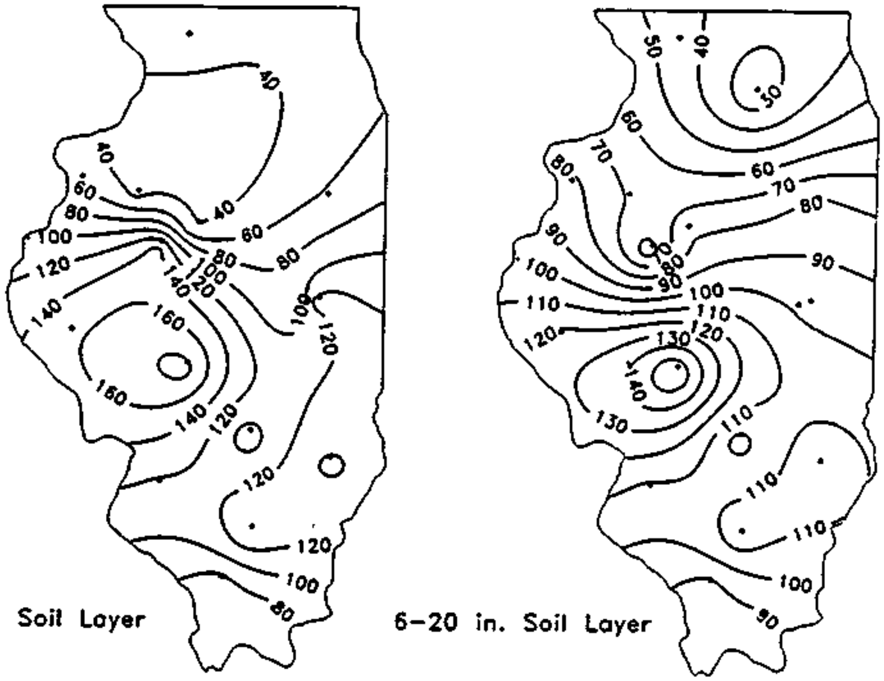
20–40 in. Soil Layer

40–72 in. Soil Layer

April 1,1994, percent of 1985-1992 average

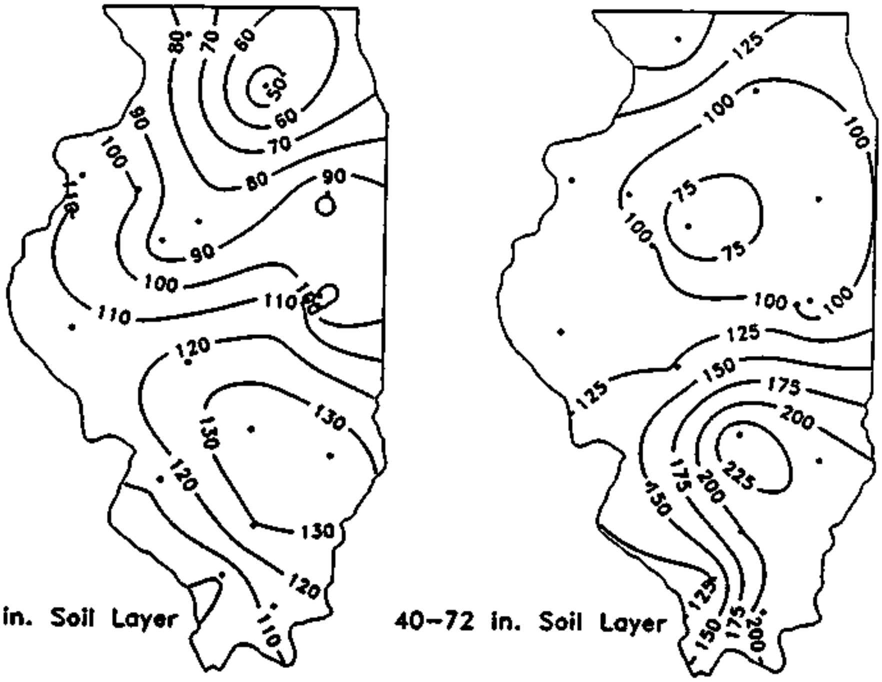


May 1,1994, percent of 1985-1992 average



0-6 in. Soil Layer

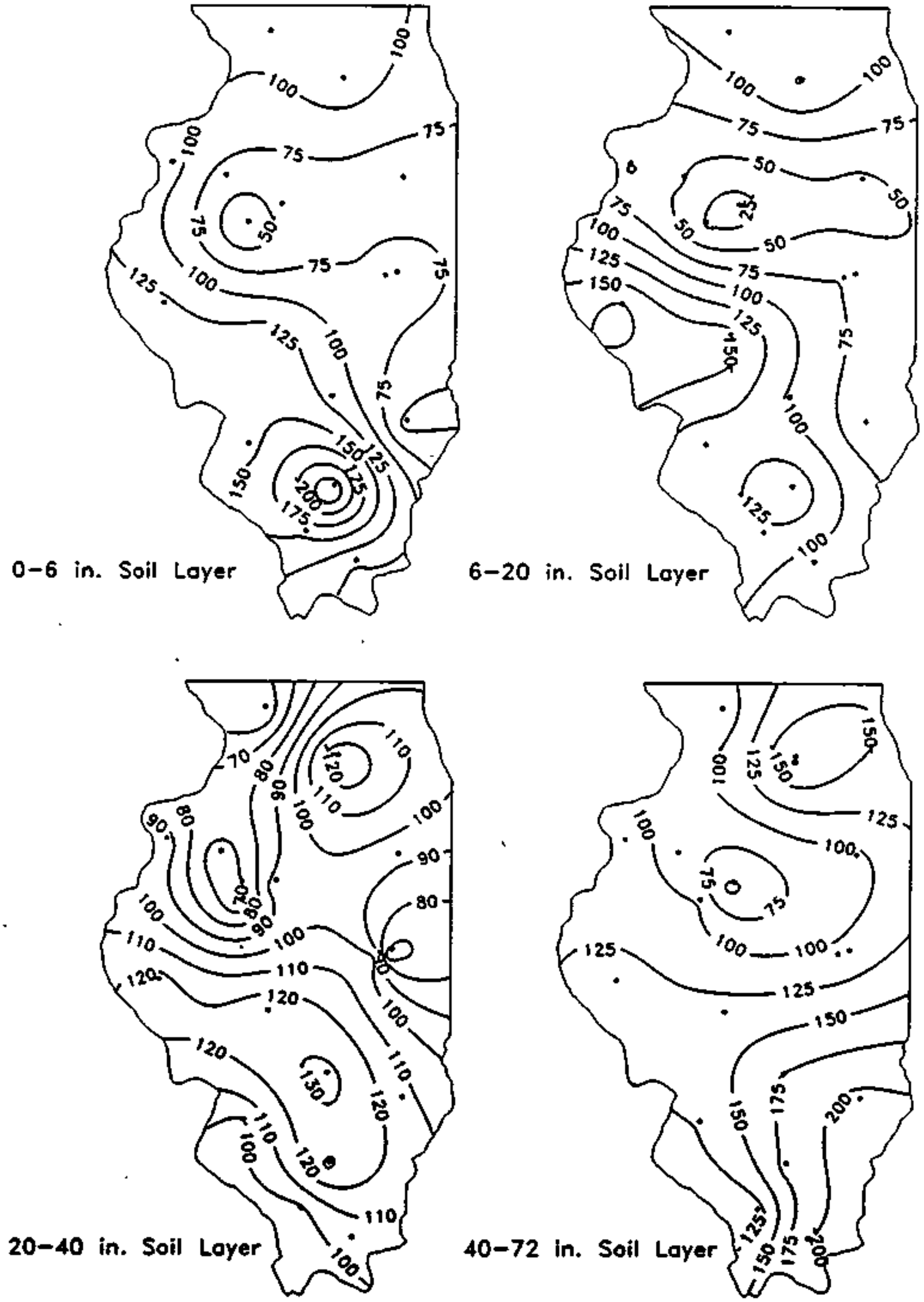
6-20 in. Soil Layer



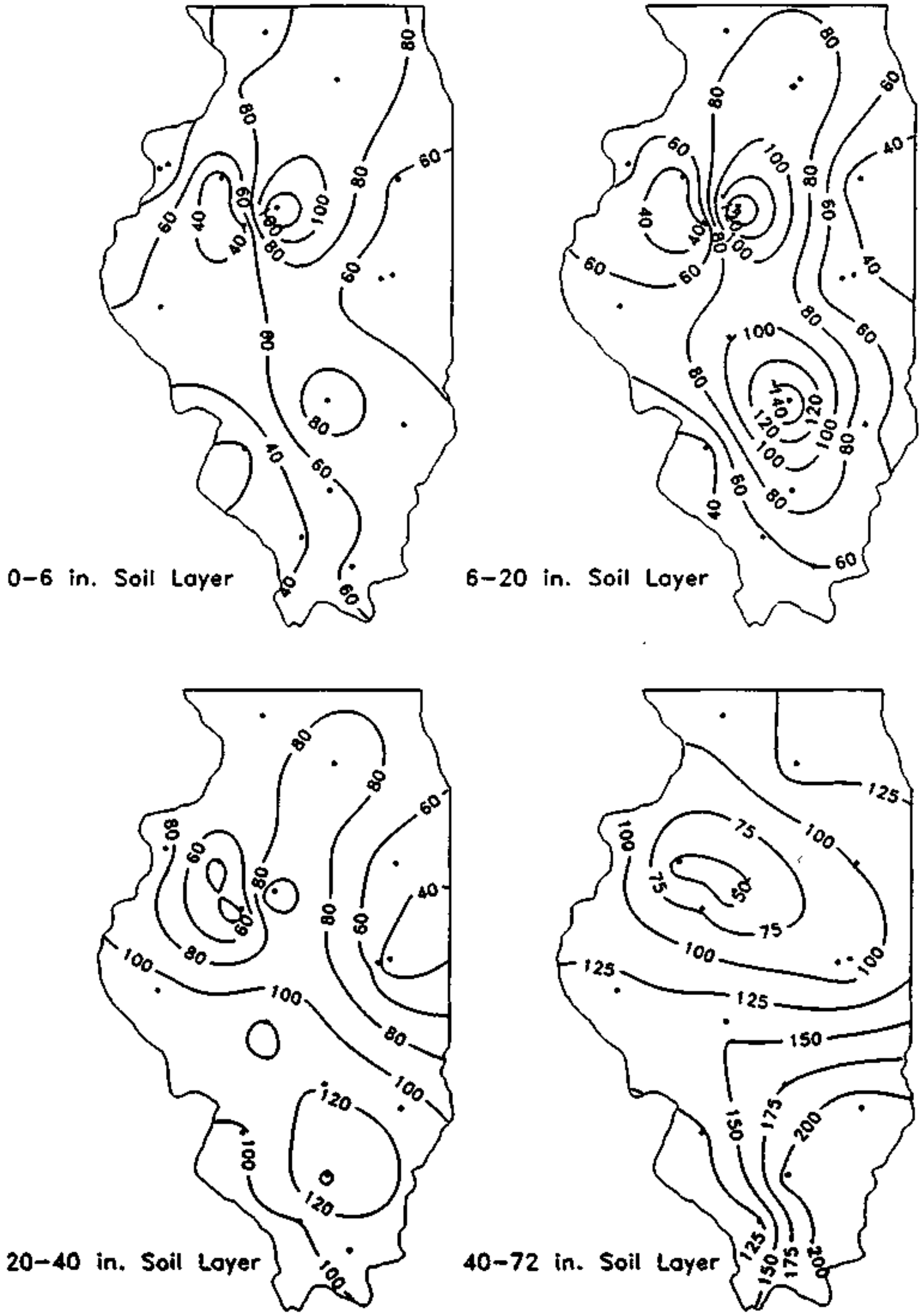
20-40 in. Soil Layer

40-72 in. Soil Layer

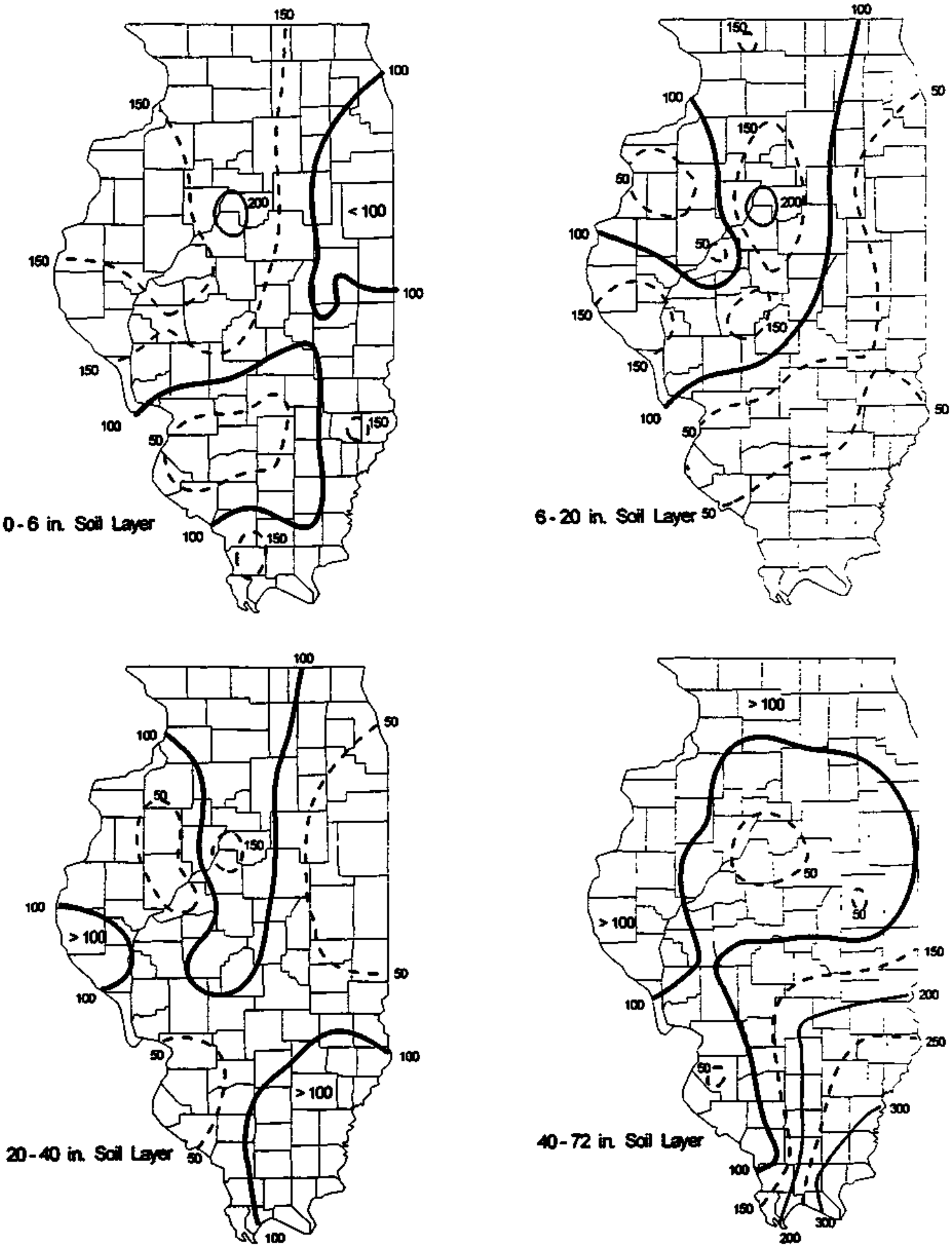
June 1,1994, percent of 1985-1992 average



July 1,1994, percent of 1985-1992 average



August 1,1994, percent of 1985-1992 average



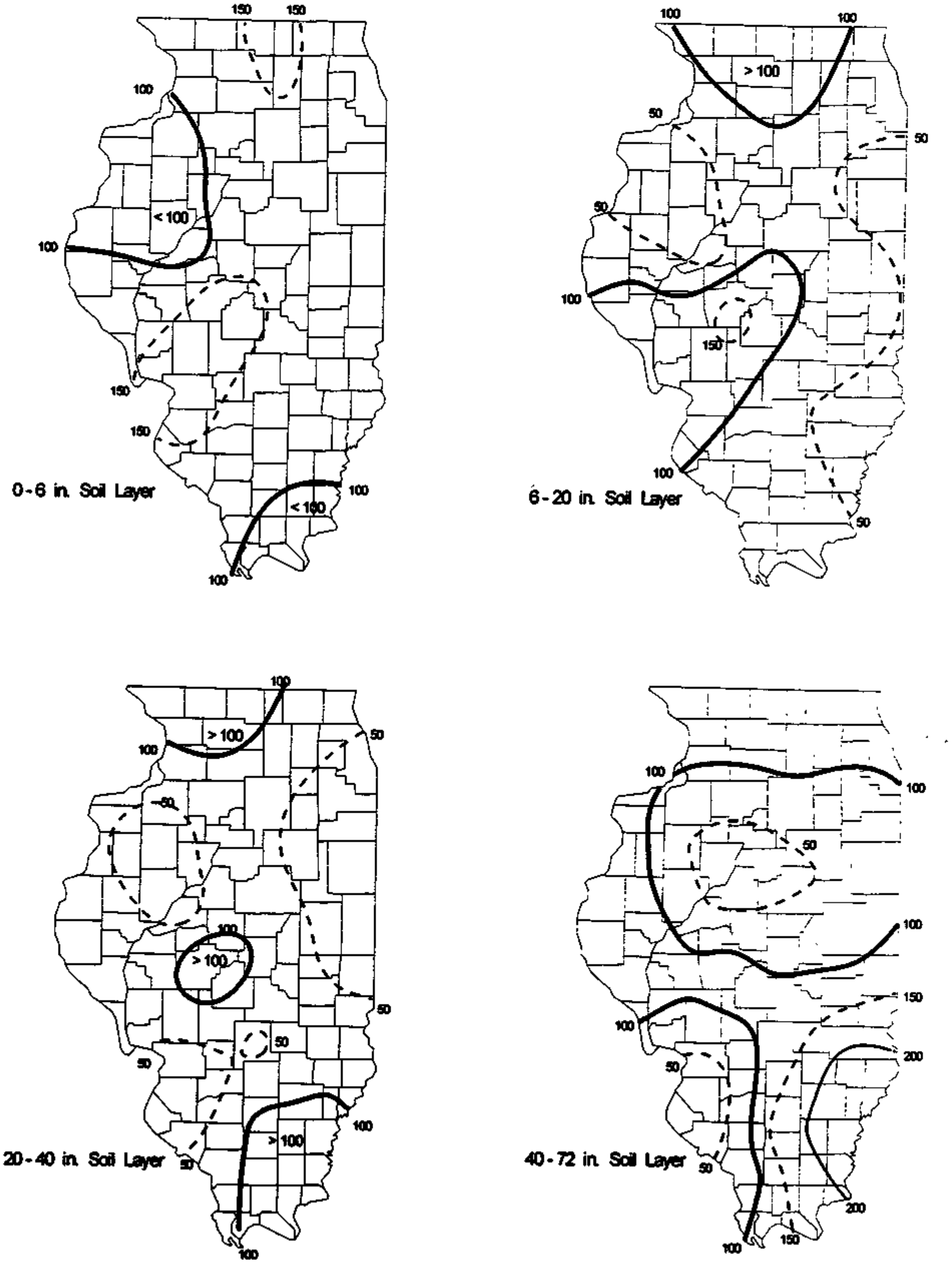
0 - 6 in. Soil Layer

6 - 20 in. Soil Layer

20 - 40 in. Soil Layer

40 - 72 in. Soil Layer

September 1,1994, percent of 1985-1992 average



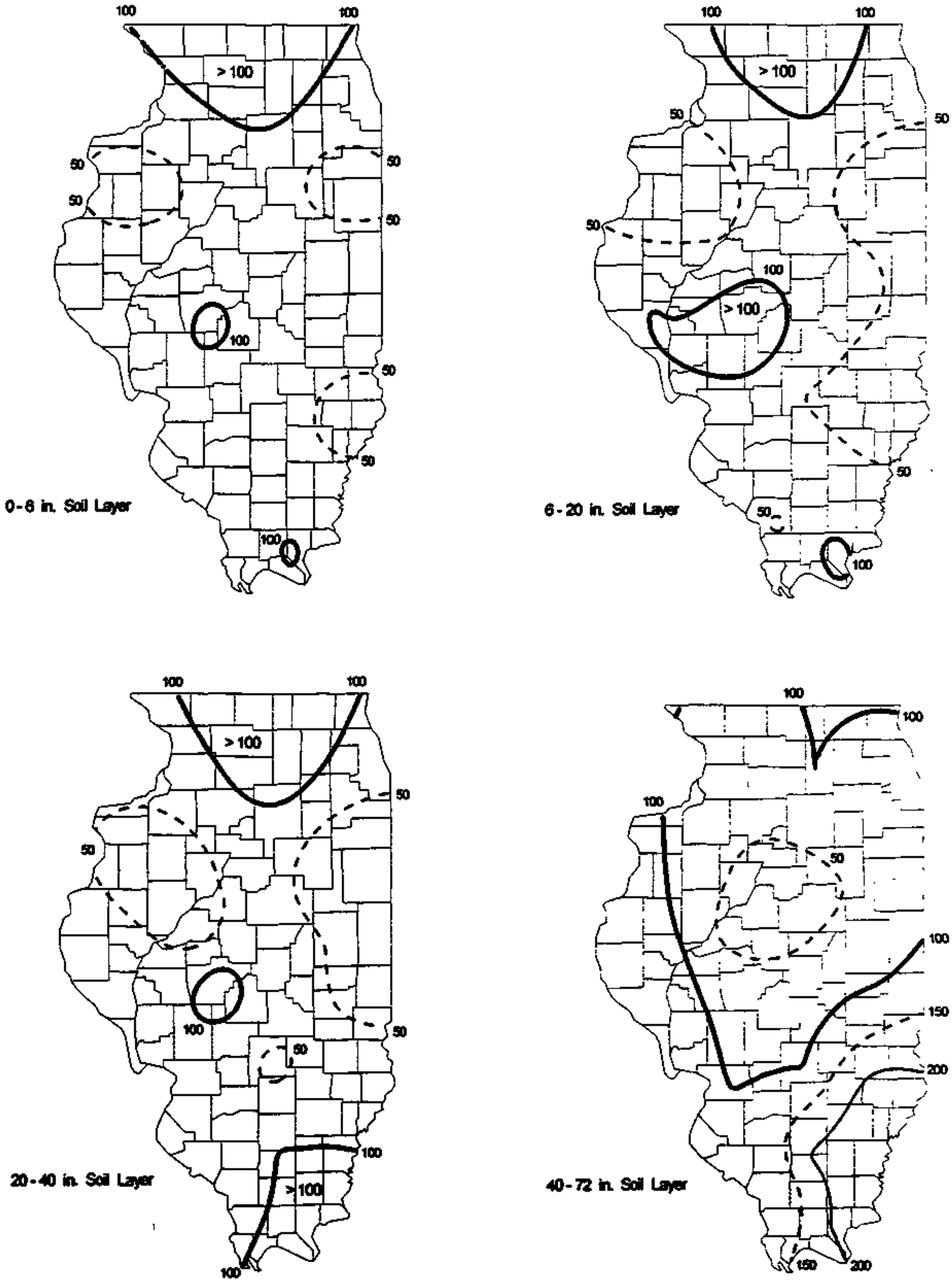
0 - 6 in. Soil Layer

6 - 20 in. Soil Layer

20 - 40 in. Soil Layer

40 - 72 in. Soil Layer

October 1,1994, percent of 1985-1992 average

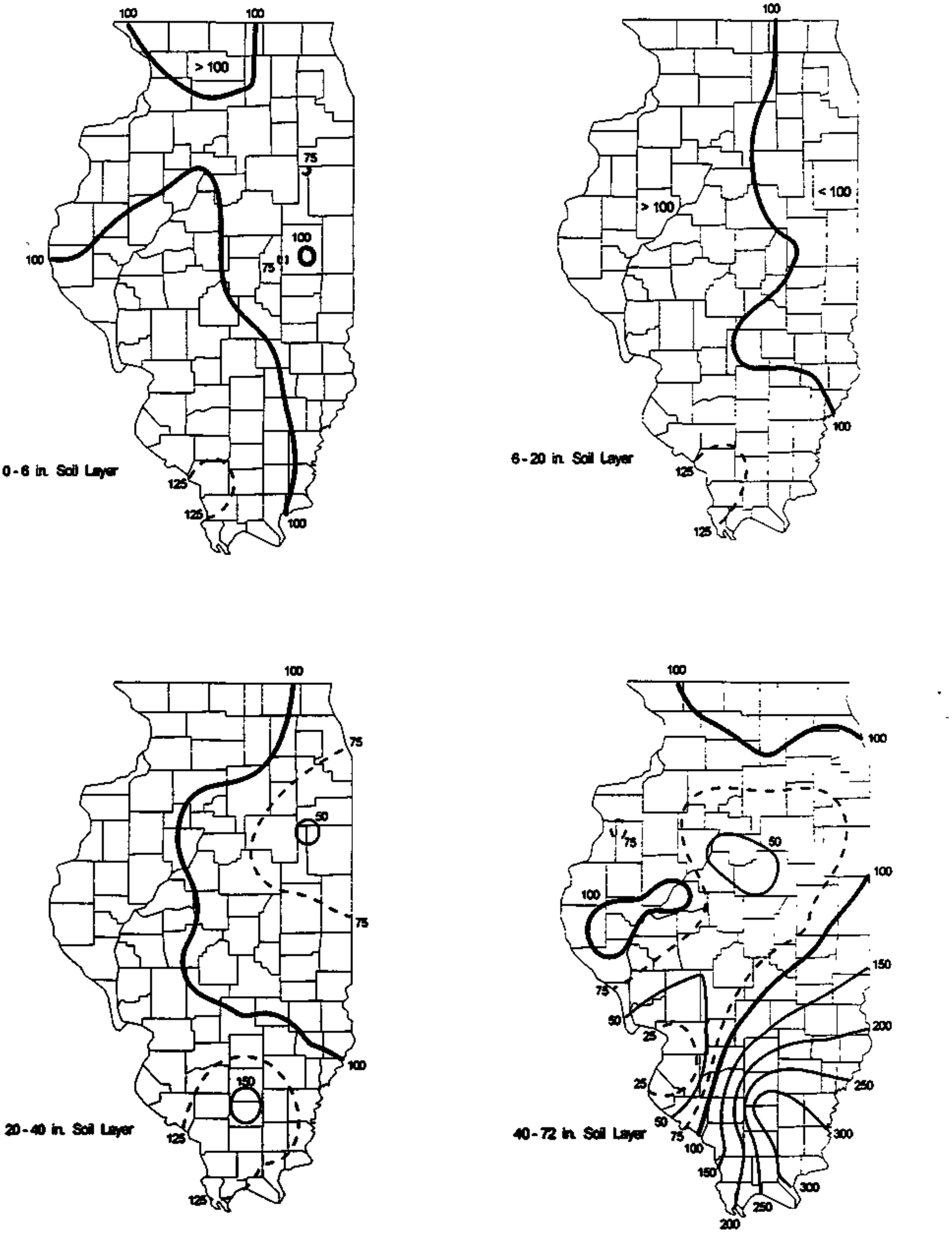

0 - 6 in. Soil Layer

6 - 20 in. Soil Layer

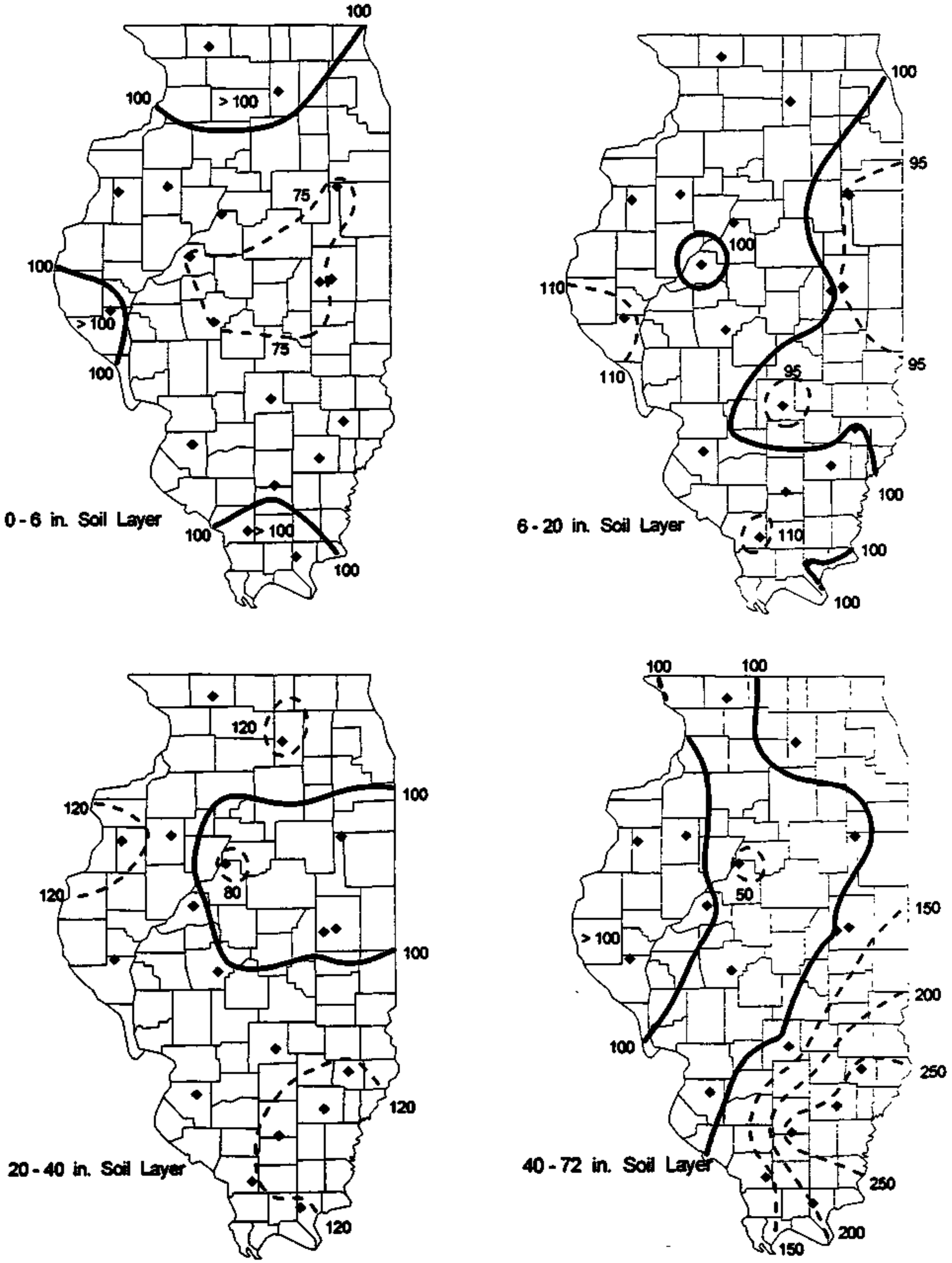
20 - 40 in. Soil Layer

40 - 72 in. Soil Layer

November 1,1994, percent of 1985-1992 average



December 1,1994, percent of 1985-1992 average



January 1,1995, percent of 1985-1992 average