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The 1988-1989 Drought in Illinois: Causes, Dimensions, and Impacts

Peter J. Lamb
Scientific Editor

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The 1988-1989 Drought in Illinois: Causes, Dimensions, and Impacts

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Title: The 1988-1989 Drought in Illinois: Causes, Dimensions, and Impacts.

Abstract: The 1988-1989 drought was one of the most disastrous droughts in the history of the state. Hydrologic, meteorological, and climatological aspects of the 1988-1989 drought in Illinois are addressed. The drought is evaluated in terms of precipitation, streamflow, lakes and reservoirs, and ground-water resources of the state. The meteorological conditions that produced the drought also are addressed. Impacts and problems resulting from the drought are discussed along with various actions taken to ameliorate the problems. Although the primary goal of the study was to quantify the drought, primarily in a physical sense, an important secondary goal was to assess the impacts and the actions employed in order to derive information needed in future planning and handling of Illinois droughts. The report thus ends with a set of recommendations for coping with future droughts.

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THE 1988-1989 DROUGHT IN ILLINOIS: CAUSES, DIMENSIONS, AND IMPACTS

PREFACE

Although Illinois generally enjoys abundant water resources, it also occasionally experiences moderate to severe drought conditions. If sufficiently prolonged and/or widespread, those drought conditions can severely impact agricultural and industrial production, public water supplies, transportation, recreation, and other socioeconomic activities. Such conditions were especially prevalent during the 1930s and early 1950s and have tended to recur in varying degrees since the mid 1970s (e.g.,1976-1977,1980-1981,1983,1988-1989, and 1991). In contrast, the period from the mid-1950s to the mid-1970s was remarkably drought-free in Illinois.

Investigation of the atmospheric and hydrologic aspects of drought has accordingly been an important activity of the Illinois State Water Survey. Furthermore, consistent with enabling legislation that directs the Water Survey to "publish the results of its investigations... [so] that the available water resources of the State may be better known," this work has been summarized in a number of definitive Water Survey reports. These have included both general treatments of drought-related phenomena (e.g., Huff and Changnon, 1963; Changnon et al., 1987) and investigations that have focused on specific drought periods (e.g., Hudson and Roberts, 1955; Changnon et al., 1982).

The present report was conceived as a sequel to the aforementioned document by Changnon et al. (1982), which focused specifically on "The 1980-1981 Drought in Illinois: Causes, Dimensions, and Impacts." Like its forerunner, this study describes the meteorological causes and climatological characteristics of the drought conditions, and assesses the diverse impacts of the drought on soil moisture, plant water use, surface heat exchanges, streamflows and lake levels, ground-water conditions, and agricultural production. However, unlike its forerunner, the present report commences with an outline of the administrative framework used by the State of Illinois to address drought-induced water problems. This infrastructure has largely evolved since the publication of Changnon et al. (1982) and indeed, it was partially shaped by recommendations contained in that report. It is particularly noteworthy that this administrative framework used the material summarized in Chapters 2 through 7 of the present report on a real-time basis during 1988-1989 to monitor and respond to the drought-related problems that emerged. Hopefully, the experience gained from these activities and reflected in this report will contribute to a further refinement and strengthening of Illinois' drought monitoring and response procedures and capabilities.

It is also appropriate to recognize the outstanding contributions made to this report by a long-term Water Survey scientist. The initiation of the Water Survey's drought monitoring activities began when Douglas M.A. Jones issued a statewide analysis of soil moisture conditions at the end of May 1988. This analysis revealed that "The lack of soil moisture is becoming serious throughout the state. Most areas of the state are about 5 inches below the level of soil moisture with which the growing season began. These values represent the layer from the surface to 20 inches from which the growing plants are extracting the most water. From the surface to the 6-inch depth all reporting stations are below the wilting point." This blunt recognition of a poor and rapidly deteriorating situation led to the immediate establishment of the procedure that the Water Survey used to monitor the drought conditions for the duration. It also revealed, just as rapidly, a substantial scientific opportunity that was borne in mind throughout the subsequent monitoring activities and which is embodied in the present report. Fittingly, Douglas Jones is a coauthor of one of the central chapters of the report. He retired from the Water Survey in July 1990, after 40 years of varied scientific activities, including some important innovations.

And finally, the scientific editor and authors express their thanks to a number of individuals for their efforts in preparing this report. Excellent technical editing was performed by Gail Taylor, with the assistance of Eva Kingston and Laurie Talkington. Tom Rice made an important contribution to Chapter 1. The figures were expertly prepared by John Brother, Linda Hascall, and David Cox. The word processing for various chapters was performed by Kathy Brown, Jean Dennison, Becky Howard, and Gloria Levitt.

PETER J. LAMB

CONTENTS

1. INTRODUCTION

by

Richard G. Semonin

The drought of 1988-1989 in Illinois was one of the most disastrous in the history of the state. This report describes the meteorological conditions responsible for the lack of precipitation and discusses the impacts of the drought on the water and agricultural resources of Illinois. The report was prepared in fulfillment of the Illinois State Water Survey's responsibilities under the Illinois Water Plan Task Force to diagnose and thereby promote a better understanding of the meteorological causes and hydrological and other effects of the extremely dry conditions throughout Illinois.

We therefore begin this report by outlining the administrative framework that the state of Illinois uses to address drought-induced water problems. The material summarized in the succeeding chapters of this report was used on a real-time basis during 1988-1989 by this administrative framework to help it monitor and respond to the water-related problems that emerged.

1.1. Background

The Illinois Water Plan Task Force was appointed by Governor James R. Thompson in 1980 to guide policy decisions regarding the adequacy of programs to deal with increasing numbers of water issues. The Task Force is presently composed of members from the Illinois Water Resources Center, the Office of the Governor, and the Departments of Transportation, Agriculture, Conservation, Commerce and Community Affairs, Mines and Minerals, Public Health, and Energy and Natural Resources. The Illinois Environmental Protection Agency, Emergency Services and Disaster Agency, Bureau of the Budget, and Capital Development Board also are represented.

The Task Force focuses on significant water issues not being sufficiently addressed by current programs, as well as on emerging issues that can be anticipated to lead to future problems or conflicts. In consideration of public and advisory group views and its own maturing judgment, the Task Force has agreed to address the following ten issues:

1. Erosion and Sediment Control
2. Integration of Water Quality and Quantity Management
3. Water Conservation
4. Flood Damage Mitigation
5. Competition for Water
6. Aquatic and Riparian Habitat
7. Water-Based Recreation
8. Atmospheric Changes and Management
9. Drought Contingency Planning
10. Illinois Water Use Law

The Water Plan Task Force issued Special Report Number 3 (1983) dealing with the drought contingency planning issue. Several ongoing programs useful to the state's drought contingency programming activities were already in place within several agencies. Recognition of these programs led to the formation of a Drought Response Task Force (DRTF) that included representatives of these agencies.

1.2. Drought Response Task Force

The DRTF is co-chaired by the Director of the Water Resources Division of the Illinois Department of Transportation (DOT/DWR) and the Head of the Public Water Supply Division of the Illinois Environmental Protection Agency (EPA/PWSD). When conditions show continual declines in the available water resources, the DRTF is convened either by the Governor or by the DRTF Co-Chairs. Representatives from the following state agencies were included on the DRTF, and each has made a contribution to this chapter:

Richard Byrd, Illinois Department of Commerce and Community Affairs (DCCA)

James R. Brim, Illinois Department of Agriculture (Natural Resources Division) (DOA/DNR)

David L. Smith, Illinois Emergency Services and Disaster Agency (ESDA)

Illinois Office of the Governor (OG)

Richard G. Semonin, Illinois Department of Energy and Natural Resources (Water Survey Division) (ENR/SWS)

Greg Tichacek, Illinois Department of Conservation (Office of Resource Management) (DOC/ORM)

Gary Clark and Donald R. Vonnahme, Illinois Department of Transportation (Division of Water Resources (DOT/DWR)

Roger Selburg, Illinois Environmental Protection Agency (Public Water Supply Division (EPA/PWSD)

Each DRTF agency has technical expertise and capabilities in specific areas of drought management. Their capabilities include in-depth knowledge regarding statewide rainfall distribution on a daily basis, alternate water supply sources for both emergency and long-range uses, installation of emergency pumping and piping equipment, emergency declaration authority, water sanitation and quality considerations, graduated water conservation practices, aquatic habitat impact assessment, and methods of financing alternate water supplies.

Throughout the year, ENR/SWS issues a monthly summary of water and weather conditions for the entire state to each of the DRTF agencies. This information is used to detect the onset of a drought. The summary includes information on lake and stream stages, ground-water levels, soil moisture, and pertinent weather variables such as precipitation and temperature.

The OG and the Co-Chairs assess the monthly water and weather information and determine when to convene the DRTF. Each of the agencies maintains staff in the field, and the DRTF frequently is made aware of real or potential impacts from precipitation deficiencies through staff contact with the public and local units of government. When convened, the DRTF sets a schedule for regular weekly briefings. These briefings usually are provided in conference telephone calls, but when necessary to resolve particular issues, they are provided in face-to-face meetings. The Water Plan Task Force was sensitized to the evolving 1988 drought as early as May, and the DRTF was convened at that time. It held weekly briefings until May 1990, when the drought was officially declared ended in Illinois.

1.3. Pertinent Illinois Law

The DRTF does not possess any regulatory power unto itself, but those agencies that have statutory authority also carry that responsibility to the Task Force deliberations. The implementation of agency power is discussed where appropriate in the following accounts of activities during the 1988-1989 drought.

Under the Illinois Emergency Services and Disaster Agency Act of 1988, the Governor is given broad powers to respond as necessary to emergencies. These powers include the right to suspend statutes, rules, or regulations as needed, and the power to take real estate in accordance with certain provisions. These powers last for 30 days and follow an emergency declaration by the Governor, which may be renewed.

The application of these powers is usually triggered by a request from a local unit of government. Local units of government generally make these requests when their local resources or authorities are insufficient to respond to an emergency.

The DRTF and its member agencies closely monitor the activities of all units of local government and are prepared to advise on the appropriateness of a request for a disaster declaration. In general, any emergency declaration sought through ESDA should be initiated or clearly supported by a local unit of government and concurred in by a lead state agency if the request demands actions outside ESDA's capabilities or expertise.

The basic issue before the DRTF in 1988 and 1989 was whether the state should use its powers to mandate that local communities and/or public water supplies implement appropriate drought responses such as water conservation.

A number of factors must be understood concerning this issue:

1) The DRTF and its agencies have the capabilities to monitor all "potential water-short" systems and generally have ample opportunity to encourage an appropriate voluntary response by the local unit of government.

2) Any measures that could conceivably be mandated by the state could also be undertaken by the appropriate local unit of government under its own powers.

3) A unit of local government cannot be mandated to undertake an activity when that unit of local government does not have clear statutory powers to implement the mandate.

4) The "State Mandates Act" requires that the state may have to fully fund the resulting expenses incurred by a local unit of government as a result of an activity mandated by the state.

The 1983 Water Plan Task Force report on drought contingency planning strongly encourages the use of "voluntary measures" as the most appropriate response by local units of government. The general information and arguments needed to encourage an appropriate voluntary response by a local unit of government are the same as the information and arguments that would be needed to obtain a higher level of response or mandate from an agency or the Governor's office. If these arguments are not persuasive on the local level, they would probably not be persuasive at a higher level.

In general, the agencies represented on the DRTF must put significant effort into encouraging local communities and public water supply systems to voluntarily undertake the measures necessary to extend the viability of their water supply systems. The DRTF will not issue a mandate that a community or public water supply implement water conservation measures if the community or public water supply chooses not to do so.

1.4. Task Force Activities during the 1988-1989 Illinois Drought

During 1988-1989, DOT/DWR established the agenda for weekly conference calls. These calls usually began with a discussion of past rainfall, the accumulating deficit, and the outlook for precipitation in the short and long term. EPA/PWSD then reported on public water supplies that were under stress, DOA/DNR described the status of crops and livestock, and ESDA and DCCA described their emergency equipment and funding application requests. DOC/ORM reported on the status of 160 state-owned and public lakes, as well as on observed impacts on fish, forestry, and wildlife. The OG representative provided guidance regarding policy issues and maintained an awareness of the entire evolving drought picture to brief the Governor and seek executive power if deemed necessary.

All participating agencies with statutory authority reacted to accelerate requests through their respective systems regarding permits, variances, and other forms of assistance.

DOT/DWR Activities

DOT/DWR has a major role on the DRTF. Its director co-chairs the DRTF, and the agency serves as the focal point for information from all participating agencies. During the 1988-1989 drought, DOT/DWR acted directly to resolve emerging water use conflicts.

For example, with support from other agencies, DOT/DWR met with irrigators to seek voluntary restrictions on their water use where such high-capacity wells were presumed to impact nearby domestic wells. The meeting was very successful and achieved nearly 100 percent cooperation among the irrigation well operators.

DOT/DWR was also involved in developing the state's position regarding the diversion of additional Lake Michigan water through the Illinois River system to assist commercial barge traffic below St. Louis.

A public utility requested permission from DOT/DWR to alter the dike structure around a cooling water lake for the purpose of importing additional water from a nearby abandoned strip-mine lake. The additional water was needed to make up losses due to excessive evaporation and the inability to withdraw adequate water from the primary nearby river source.

EPA/PWSD Activities

The Public Water Supply Division of the EPA maintained liaison with water treatment plant operators throughout the state and retained records of available resources and consumption. The division also worked directly with several communities to assist in resolving water quality issues as new sources were sought. This information was communicated during the weekly meetings, and other agencies responded as appropriate.

EPA/PWSD carefully monitored 35 public water supplies placed on a weekly watch list on the basis of historical supply performance. Of these 35, 16 had repeatedly experienced water shortages in less severe droughts than the drought of 1988-1989.

Some emergency permitting was granted for the use of water supplies not previously considered for public use. For example, one small community requested permission to use water from an interstate highway borrow pit by connecting it to the existing water treatment plant and distribution system.

The EPA assisted the U.S. Army Corps of Engineers in ensuring that water quality standards were met in rehabilitation of an abandoned well and in development of the supply system for a small community in eastern Illinois. The agency also worked closely with suppliers tapping into new surface waters and various quarries to ensure maintenance of high-quality water for the public.

DCCA Activities

Pamphlets on water conservation were prepared by DCCA, and more than 500 were distributed to municipalities for local copying and distribution. Additional drought-related material was also prepared, printed, and distributed. DCCA coordinated communications efforts between the DRTF and local units of government.

Community Development Assistance Program funds are administered by DCCA for the improvement of public facilities. Only one small community applied for funds to redrill wells and reset pumps in an area of high irrigation pumpage. It was somewhat surprising that more applications for improvement of water systems were not requested during this very severe drought.

Two workshops were held in the state to obtain feedback from municipalities on their problems. These workshops were attended by 150 people, who indicated that they found them useful. Some communities adopted DCCA's sample ordinance for water conservation. A mass mailing was prepared and distributed to community leaders offering assistance in the form of future workshops on local drought management by DRTF members. The mailing included model ordinances for communities to consider to provide local government the authority to better deal with water emergencies.

Materials are still being distributed on request. However, demand has slowed since the end of the drought.

DOA/DNR Activities

DOA/DNR publishes a weekly crop report that describes the status of soil moisture and the condition of crops during the growing season. These reports provided a near real-time assessment of the impact of rainfall on agriculture in Illinois throughout the 1988-1989 growing seasons.

Livestock producers were a major concern of the DRTF, and a number of alternatives were considered to ensure the availability of water for their operations. Three reservoirs operated by the U.S. Army Corps of Engineers were made available for water hauling upon application. ESDA provided a pump and personnel at one of the lakes, but fortunately the water emergency was not extremely severe for livestock, and only a single permit was issued. In other areas of the state not so close to lakes, the EPA compiled a list of locations where treatment plant effluent was of sufficiently high quality that it could temporarily be used for livestock watering. Some concern was expressed regarding the use of this water by the growers, but, as it turned out, other alternatives and ordinary on-farm supplies were adequate during the drought.

DOA/DNR established a "Hay Hotline" to bring together sellers and buyers. The sellers outnumbered the buyers by almost 2 to 1. The Hotline received numerous calls seeking information in addition to those regarding buying or selling of hay. The number of sales actually made is not known, but the service was very well received by the agricultural community.

ESDA Activities

A minimal length of piping and at least two pumps are maintained by ESDA for use in Illinois where needed to tap into alternate water supplies during emergencies. These minimal resources were strained by requests, but fortunately, as a short-term problem was solved in one community, they became available for use in other ones. ESDA worked with the Illinois National Guard to provide water "buffalos" to those communities without a nearby water source. The drought of 1988-1989 demonstrated that these facilities should be increased in anticipation of needs during the next water emergency.

Emergency funds are available to assist recovery from natural disasters, although no applications for such funds were received despite the extreme water shortages around the state.

DOC/ORM Activities

DOC/ORM provided indicators of drought severity by continuously monitoring the terrestrial and aquatic natural systems throughout the state. Many migratory birds departed typical habitats in search of suitable feeding areas. Some left the state entirely, and others became concentrated in smaller, more suitable areas, subjecting them to predation. The prairie grass seed crop was totally lost in 1988, posing future habitat problems for some terrestrial species.

Numerous fish kills were reported, especially in small ponds, as a result of extremely high water temperatures, lowered water levels, and diebacks of algal blooms. The severe drought impact on crops necessitated pesticide spraying to control spider mites on soybeans, which secondarily caused some small-pond fish kills. On some major lakes and streams, decreased concentrations of dissolved oxygen were directly responsible for fish kills.

In addition to monitoring the drought impacts on these natural resources, DOC/ORM maintains a number of lakes for recreation in Illinois. Those lakes that had sufficient storage as water supplies were made available in stressed areas as necessary.

OG Activities

The Office of the Governor staff representative kept the Governor informed about the status of the drought. The staff representative also provided advice as to the proper time to intervene in water conflict issues according to the powers vested in that office.

ENR/SWS Activities

In addition to its role in providing data on weather and on water resource depletion to the DRTF member agencies, ENR/SWS was responsible for evaluating alleged interference between high-capacity wells and nearby wells. This responsibility was statutorily given as part of the Illinois Water Use Act of 1983 as amended in 1987. Present law permits a well owner to file a complaint against another with the county Soil and Water Conservation District (SWCD). The complaint, including a description of the nature of the perceived impact, is then forwarded to ENR/SWS for evaluation in the field, and a written report is prepared for the SWCD. If a well constructed in accordance with state standards is found to be impacted by a high-capacity well, DOA/DNR then has the authority to order a decrease in pumpage from the offending well.

More than 150 complaints were filed during the 1988-1989 drought; however, no wells were confirmed as impacted by nearby irrigation practices. The complaints were initiated by individuals who experience water source interruptions, but investigation showed most that of the impacted wells did not conform to the standards established by the state for domestic wells in areas of high ground-water use.

The surface water and ground-water engineers in ENR/SWS responded to an enormous number of requests for assistance. Many of these requests were for advice on new potential resources and for evaluations of quantity from newly developed resources. The ENR/SWS database of nearly 100 years was invaluable for responding to the needs of individuals and local government units.

Finally, ENR/SWS has the responsibility to prepare scientific reports describing the conditions leading up to and during a drought for the purpose of improving anticipatory capabilities in the state. This report was prepared in partial fulfillment of this requirement. Knowledge of the atmospheric conditions that portend a serious drought would allow the state agencies, including the Governor's office, to mobilize their support for individual citizens and municipalities and to better meet the water-short emergencies that follow.

1.5. Summary and Discussion

The primary accomplishment of the DRTF in 1988-1989 was its relative success in advising local government units on their water problems and offering them possible solutions. The solutions were normally within the ability of local governments to provide. With each drought, the number of troubled communities decreases because some communities have previous1y adopted long-range solutions. At the same time, in each successive drought additional communities develop problems as a result of aging facilities, sediment accumulation and other deterioration of impoundments, or local development in an already stressed water resource area.

The DRTF worked through the method of persuasion and was very successful in this most recent serious drought period. Most communities recognize their growing water resource problems and are willing to listen to advice. Surprisingly, no individual or local unit of government expected the state to solve their problem.

In retrospect, one or two things are readily apparent and worthy of discussion. The first issue relates to the degree of authority that state government can or should possess to mandate measures taken by individuals and local units of government regarding water resources during a drought. Second, differing levels of water shortage may make it desirable to define different levels of response from state government.

Illinois is a rich water resource state, with both surface water impoundments and productive ground-water aquifers. The water problem most frequently encountered historically has been too much water during periods of flooding. The issue of water use conflict is of recent origin and has not been addressed satisfactorily in Illinois law. The previously described Water Use Act (as amended) applies only to restrictions on ground-water withdrawals under defined emergency conditions in four of the 102 counties in the state. Should this law be re-examined, strengthened, and adopted for the entire state? Nearly 50 percent of the water resources used in Illinois are derived from the Lake Michigan diversion and supply the heavily populated northeastern counties of Illinois. However, the remaining 50 percent is largely ground water and supplies rural, agricultural areas, where competition for water resources is experienced most frequently. These issues were highlighted by the 1988-1989 drought and will become key issues for the DRTF in the future.

Another question relates to when a drought is a drought. In the absence of accurate forecasts of water deficits, most droughts are initially "felt" as opposed to quantitatively measured. At what level of impact should the state activate a warning system that water resources are in jeopardy? A legitimate concern is that the state can overreact to a perceived problem only to have the problem disappear with the next catch of precipitation. The desirable level of involvement must be considered by the DRTF and the Water Plan Task Force. This report may help to establish the criteria necessary to trigger the state into action and to minimize the impact of future droughts.

2. ATMOSPHERIC CIRCULATION AND SYNOPTIC METEOROLOGY

by

Robert W. Scott

A climatic aberration of the dimensions of the 1988-1989 drought is the product of a substantial departure from normal of the large-scale behavior of the atmosphere. This chapter outlines the large-scale atmospheric circulation and resulting synoptic meteorological conditions that occurred in the central United States during 1988-1989. It is intended to provide the meteorological background that is necessary for the remainder of this report to be fully appreciated.

2.1. Typical Precipitation Patterns in Illinois

The climate of Illinois is categorized as temperate continental. In the warm months from April through October, frequent incursions of maritime tropical air from the Gulf of Mexico move over the state. During the remainder of the year, the dominant air mass is maritime polar air of Pacific origin, which is modified considerably by the North American continent by the time it reaches Illinois. Occasionally, polar continental air from Canada spreads over the state during the winter, causing temperatures to plunge well below normal. However, these outbreaks are usually of very short duration.

Precipitation frequency is relatively homogeneous throughout the year, with slightly shorter periods between rainfall events in the spring. Quantitatively, however, event amounts are largely determined by the direction of the synoptic-scale airflow, with the heaviest precipitation limited to periods of southerly flow from the Gulf of Mexico moisture source.

With sufficient moisture, most precipitation events in Illinois are produced by the passage of frontal systems across the Midwest (Huff, 1981). Fronts are guided by the location of the polar-front jet stream (PFJS), an upper level (~13 kilometers or km) current of strong winds beneath which large-scale cyclonic weather systems tend to form and travel. The PFJS, in turn, is driven by differences in the heating of the atmosphere by continental and ocean surfaces.

During winter, frontal systems frequently move completely across the central and eastern United States and out over the adjacent waters of the Gulf of Mexico and the western Atlantic Ocean. On average, a front of some type (cold, warm, stationary, or occluded) overlies Illinois on 11 or 12 days a month (Morgan et al., 1975). Although precipitation from these individual systems is usually spread quite evenly over large areas, the actual amounts are lower than in other seasons because the Pacific Ocean typically is the source of the moisture. Air of this origin must pass over the intervening Rocky Mountains, which dries it considerably. Winter daily precipitation totals in excess of 0.10 inch occur on only four days a month in Illinois (Department of Commerce, 1985).

A few times during the period from December through March, a well-developed cyclonic system draws very moist air into the central United States from the Gulf of Mexico, leading to heavier precipitation in Illinois. Because of the generally stronger atmospheric dynamics and thermodynamics that develop over the Midwest when this situation exists, precipitation of a more convective nature is typical. This yields larger precipitation totals than occur under conditions when the Pacific Ocean is the moisture source (described above), but these totals can be quite variable from place to place. In general, however, the precipitation coverage is widespread. These conditions are often major producers of heavy wintertime snowstorms and early spring rains.

Later in the spring and throughout the summer, it is more rare for frontal passages to extend deep into the southern United States. Rather, they tend to “stall out” along the Ohio River valley, yielding higher frequencies of stationary fronts over Illinois.

Although the strong dynamics associated with these cyclonic systems are displaced northward into Canada, the close proximity of the frontal boundaries to Illinois considerably influences the precipitation across the state. This occurs as small perturbations in the mid-troposphere (5 to 8 km aloft) move eastward as “short waves” in association with the surface front, encountering a typically moist, tropical environmental air mass. These conditions, especially when coupled with increased summertime surface heating, can serve as triggering mechanisms to release the convective instabilities of the lower troposphere and generate systems of thunderstorms.

The opportunities for frontal-induced rainfall in spring and summer (April-August) are high, occurring on about 16 days a month (Morgan et al., 1975). Rainfall in excess of 0.1 inch occurs an average of six or seven days a month throughout this period, providing just over half of the state's annual average precipitation. Rainfall events are nearly always convective, yielding large local amounts but with totals that can vary considerably within very short distances. Rain days with totals in excess of 0.50 inch occur three times a month (DOC, 1985).

Precipitation in Illinois decreases again in the fall. Fewer fronts (about 13 a month) are located over the state (Morgan et al., 1975), and rain in excess of 0.10 inch occurs on only four or five days a month (DOC, 1985). Moisture flow from the south is significantly reduced from that of late spring and summer, and the strong dynamic frontal systems of winter and early spring have not yet redeveloped. Occasional heavy rain events do occur - the average precipitation is still between 2 and 3 inches per month-although these events are less common than in the late spring and summer.

2.2. Meteorological Patterns of Water Year 1987-1988

The above discussion described, in general terms, the typical temporal and quantitative patterns of Illinois precipitation during an "average" year. Year-to-year precipitation variations are dependent on the combined frequency of frontal passages from the northwest and moist air-mass intrusions from the south.

The meteorological drought experienced in Illinois and adjacent states during the spring and summer of 1988 was basically the result of a large-scale atmospheric circulation pattern that was established and maintained over the eastern United States during that period. This pattern greatly affected the synoptic meteorological conditions over the Midwest by decreasing the frequency of frontal passages and severely restricting the flow of moist southerly air into the area. While other factors may have exacerbated the situation and its effects on the inhabitants of Illinois, this was the primary cause of the drought from a meteorological standpoint.

In November-December 1987 Illinois precipitation was generally much higher than average statewide, while January-arch 1988 totals were relatively close to seasonal expectations. Precipitation opportunities were near average during those initial three months of 1988, with fronts occurring on about 29 days. This yielded precipitation totals that were somewhat less than average in the northern half of the state and greater than average in the southern half of the state, with the departures ranging from 0.6 to 1.5 inches in each region. Such departures are common in Illinois and generally constitute no reason for alarm. The state therefore entered the early spring of 1988 with a situation in which average spring-summer precipitation would probably have yielded adequate moisture for drought-sensitive activities.

Establishment of Drought Pattern

The first major change in the atmospheric circulation occurred in April 1988. On April 3, a trough of low pressure at 500 millibars (mb) moved onto the western coastline of North America and subsequently progressed eastward, pushing a cold front through Illinois on April 6. This synoptic situation marked the end of the typical seasonal pattern of frequent frontal passages and plentiful moisture availability over the state for several months. A synoptic pattern more conducive to adequate precipitation systems was not reestablished until mid-July.

The large-scale atmospheric circulation pattern that developed was most evident in the middle tropospheric pressure pattern over North America. This structure was characterized by three major features: a low-pressure trough located over New England and the Canadian Maritimes, a ridge of high pressure along the Rocky Mountains, and another deep trough just off the west coast of North America. Figure 2.1 shows this formation.

In general, this situation resulted in a high frequency of upper-level westerly-to-northwesterly winds over Illinois. Close to the surface, the weather conditions were dominated by high pressure either to the west of Illinois or along the northern Gulf coast. Neither of these high-pressure positions was favorable for the transport of warm, moist, low-level air into the Midwest from the Gulf of Mexico, which (as noted above) is important to the development of significant midwestern springtime rainfall. Instead, the near-surface winds were mostly from the southwest to northwest quadrant.

Although this pattern was somewhat fluid thoughout most of April and early May, it became more persistent as the spring season progressed, frequently showing a wave structure with a very large amplitude (figures 2.2-2.5). On occasion, the high-pressure ridge along the Rockies stretched from Mexico to the Arctic Circle (figure 2.6). While this situation is not extremely unusual for April, it is very rare for mid-June. This pattern blocked the movement of short waves from the eastern Pacific into the central Plains.

As a result, fronts were located over Illinois only eight times in April, six times in May, and six times in June - less than half the average frequency. Only three fronts occurred in the four weeks between May 25 and June 21, and none occurred between June 29 and July 10. Unfortunately, not only were fronts less frequent but, because the large-scale atmospheric circulation patterns were advecting air from the southwest to northwest, the fronts were typically accompanied by very little moisture when they crossed Illinois. The occurrence of suitable rainfall during these periods, especially early July, is crucial for Illinois agriculture.

In mid-June, to further worsen matters, the first in a series of surface high-pressure ridges set up over the central Plains, extending eastward into the mid-Mississippi valley (figure 2.7). This pushed the frontal track into southern Canada, at the same time permitting the early summer air over the central United States to warm excessively.

Because of the close proximity of the high-pressure center to Illinois and surrounding states, surface air basically circulated over a limited area and became much drier and hotter than is typical for the season. Record high temperatures were experienced across the state, with daytime maxima in excess of 100°F being common.

This excess surface heating enhanced the large-scale afternoon mixing between the surface air and that at higher elevations, producing strong surface wind speeds. Coupled with the extreme heat, this situation greatly enhanced the evapotranspiration from the surface and dried any remaining surface moisture. This subject is discussed more fully in chapter 4. The surface ridge remained in place for about a week in mid-June, disappeared for a week, and then returned to the same location for nearly two weeks in July.

Generally speaking, during spring and early summer 1988, only two major precipitation events brought widespread moderate rainfall to large areas of the state. These occurred on April 17 and again on May 23-24 , when a surface low-pressure center passing south of Illinois encountered an old weak front overlying the state.

In total, however, the weather patterns that affected Illinois from April to mid-July 1988 were not predisposed toward rainfall production. As the next chapter shows, most parts of the state received precipitation that was only one-third to one-half the monthly average for April, about one-half the usual total for May, and just 10 to 40 percent of the average for June.

Weakening of Drought Pattern

Ridging over the central United States continued into early July (figure 2.8). But by the middle of July, a break occurred in the long-lived upper tropospheric pressure pattern that had prevailed almost continuously since early April. This pattern was replaced by one that was more typical for mid-summer (figure 2.9). As a result, the persistent surface high pressure that had existed for so long over the center and southern United States moved eastward, and due to a more frequent southerly flow a deep layer of atmospheric moisture began moving northward into Illinois by the middle of the month.

At higher elevations, pressure troughs and ridges began a normal seasonal progression across the northern United States, steering fronts across the Midwest and generating localized areas of heavy rainfall. During the last three weeks of July, six fronts passed through the state, with the southern areas receiving the most substantial precipitation. This late July pattern continued into August, with two additional fronts traversing the state within the first nine days of the month. Parts of southern Illinois accordingly received above-average amounts of rainfall in July, but the weather continued to be extremely dry in central and northern Illinois.

Beginning about August 10, high pressure was again established aloft over the central Plains, as had occurred in June and July, and by August 16 similar conditions had become reestablished (figure 2.10). For the third time during the 1988 summer, Illinois temperatures became extremely hot for several days, with temperatures above 100°F reported statewide. This heat wave continued for just over a week, until the high pressure over the Plains was joined by a high-pressure area over central Canada that extended into the Arctic.

This large-amplitude pressure feature directed cooler air southward into the central United States, and a frontal passage across the state provided some moderate rainfall. But this occurred only in southern Illinois, where some Gulf moisture had returned.

Then, beginning on August 22, the upper air pattern broke down for good, initiating a nearly continuous string of surface low-pressure systems that moved eastward across southern Canada. Each of these systems extended slightly farther to the south than its predecessor. Upper-level winds over the Midwest turned back to the northwest, and a continuous replenishment of cool surface air from Canada occurred via several frontal passages across Illinois and the surrounding states.

However, few of these frontal passages were preceded by a flow of moist air from the Gulf of Mexico. As a result, only one of the frontal passages produced substantial (although localized) rainfall in northern Illinois. In total, August 1988 was thus generally dry throughout the state. This situation is described more fully in chapter 3.

The late-August pattern continued into the first two weeks of September, a time normally associated with drier weather. In that period, two cool dry fronts passed through the state, providing only spotty rainfall in most areas. On about September 11, a closed low-pressure circulation set up at high levels above the northern Rockies (figure 2.11). This pattern combined with high pressure over the southeastern states to bring air to Illinois from the southwest. Although this air was warmer than the air masses present earlier in the month, it was just as dry, and Gulf moisture continued to be unavailable to the state.

Fortunately for Illinois, however, a tropical cyclone moved through the western Gulf of Mexico in mid-September. Hurricane Gilbert came ashore just south of the Texas Gulf coast on September 16. This forced a large amount of Gulf moisture into the central United States, some of which crossed Illinois three days later. While this produced some localized heavy rains in the "several inch" range, most parts of the state received more moderate amounts. The remainder of September 1988 was dominated by nearly west-east flow aloft and little low-level moisture. Three weak and dry fronts moved through the state before the end of the month. The 1988 growing season thus ended in a dry mode, particularly in the southern half of the state.

Summary

A severe reduction in availability of Gulf moisture occurred almost continuously over Illinois from mid-spring to mid-summer 1988, and intermittently thereafter into the following fall. The surface airflow was generally from either the north-to-northwest out of Canada, which brought dry and cool air into the state, or from the southwest-to-west, which produced dry and very hot conditions.

The weather patterns that created the excessive heat also produced increased daytime wind speeds that worsened the surface conditions by substantially increasing evapotranspiration. Moisture availability became more seasonable during late July and early August, but because of the weakness of the frontal systems, the large rainfall amounts were rather localized and more widespread general rainfall did not occur. Moisture from Hurricane Gilbert passed across the state in mid-September, bringing the first statewide rainfalls to Illinois since spring, albeit moderate ones.

2.3. Meteorological Patterns of Water Year 1988-1989

As noted above, the midwestern conditions of Water Year 1987-1988 were dominated by a large-scale atmospheric circulation pattern that was established over the central and eastern United States in April 1988 and persisted until mid-July 1988, with very little variation in its large amplitude. The pattern produced very dry and hot conditions across Illinois and adjacent states. By mid-July, however, the pattern had broken down, and although it reemerged occasionally in succeeding months, it never lasted more than a few days. This change permitted more seasonable pressure patterns to occur over the Midwest, but because of a continued lack of Gulf of Mexico air as a moisture source, most areas still received insufficient moisture during the remainder of that water year.

In contrast, the rain events of Water Year 1988-1989 occurred on a more typical schedule. However, the severe lack of surface and soil moisture that developed in the spring of 1988 (see chapters 3 and 4) made even normal monthly rainfall totals a continuing concern in subsequent months. As a result, while the dry periods that occurred during 1988-1989 were not as lengthy or as severe as the drought in the spring and early summer of 1988, they were monitored much more closely than would have been the case had the state entered the year with normal moisture conditions.

Fall and Winter Patterns

October 1988 was dry in Illinois as a result of a semi-permanent upper-level, low-pressure center in the vicinity of James Bay (figure 2.12). This low-pressure center produced northwesterly surface flow across Illinois, which brought cool, dry conditions to the state. High pressure over the Rockies enhanced the airflow during the first two weeks of October. Although six frontal passages occurred during October, Gulf moisture generally did not advance north of the Ohio River; thus these events served only to reinforce the existing environment. Only the extreme eastern and southern parts of the state received beneficial rainfall during October, from one storm near the middle of the month.

A major shift in weather patterns occurred early in November 1988. A series of upper-level short waves moved across Illinois as a result of a trough of low pressure being located along the west coast of North America. Nearly west-east upper-level flow existed over central Canada and the northern United States to the east of the trough, so the short waves were slow to dampen. As many as eight systems passed over Illinois, providing the first excessive statewide rainfall in many months. Most areas received at least twice their normal monthly amount, as is documented in chapter 3.

Another major change in the atmospheric circulation over North America occurred toward the end of November 1988, and the pattern that was established (or a close variant of it) persisted for the next four months. This pattern was dominated by an upper-level, low-pressure trough that was initially located over eastern Quebec and then gradually retrograded to Hudson Bay (figure 2.13). It was accompanied by an active upper-level jet stream that moved back and forth across Illinois numerous times during December 1988-March 1989, producing a continuous oscillation between northwesterly and southwesterly flow over the state.

Frontal passages across the Midwest were frequent during this period, but the moisture influx from the Gulf of Mexico remained largely confined to the southeastern third of Illinois. That region received greater than normal rainfall during the December 1988 - April 1989 period, while the northwestern half of the state continued to be drier than normal.

Spring and Summer Patterns

A potentially disastrous change in this pattern was initiated in early April 1989, as an upper-level ridge of high pressure began to form and to become semi-fixed along the west coast of North America (figure 2.14). During the middle of this month, the ridge moved slowly eastward across North America. However, another ridge developed in the west in early May, which also remained fixed for several days before moving slowly eastward to the east coast by May 20. This recurring large-scale pattern constituted a threatening reminder of the spring 1988 situation, when a ridge was established over the center of the country and yielded the extremely severe meteorological drought condition described above.

Fortunately, the 1988 pattern did not recur. However, the large-scale atmospheric flow pattern that developed in the late spring and early summer of 1989 was still not conducive to abundant rainfall in Illinois. It was dominated by an upper-level, low-pressure trough that again formed over Hudson Bay and occasionally extended southward to the Great Lakes (figure 2.15).

This situation permitted frequent frontal passages across Illinois: an average of two or three occurred each week through the middle of June. However, because the lower tropospheric flow was typically from the west-southwest to the northwest significant moisture was excluded from Illinois and the adjacent states to its west. Illinois rainfall was above normal only in some scattered areas along the Indiana border and in the extreme southern part of the state.

The midwestern synoptic pattern from the middle of June into July continued to follow the developing theme for the 1989 summer: normal frontal activity that served as triggering mechanisms for convective rainfall, but insufficient low-level airflow from the Gulf to furnish the moisture needed to produce heavy widespread rainfall. A frontal boundary was frequently located near the Ohio River, which led to greater than normal precipitation in southern Indiana and Kentucky.

However, this frontal boundary also served to block moist surface conditions from reaching the state. As a result, much lighter and more scattered rainfall was typical. The 1989 early summer dryness was not in itself severe, but because it occurred in a year following a severe drought, added stress was placed on moisture-sensitive activities that needed excessive rainfall to begin to mitigate the impacts of the 1988 dryness.

In early July 1989, a mid-tropospheric ridge again began forming along the Rockies (figure 2.16) and was accompanied by anticyclonic surface conditions. The ridge did not “lock in” but typically would form and remain stationary for a few days and then slowly move eastward, allowing for a front to cross Illinois. Once again, however, this synoptic situation was not accompanied by the thick layer of low-level moisture from the Gulf, which is needed to fuel abundant rainfall. The above pattern took about six to eight days to cycle and yielded one major rainfall opportunity at the end of each period. Adequate rainfall amounts during these events were accordingly spotty. Thus the state remained relatively dry through mid-August, with the greatest rainfall once again falling in the extreme south.

The pattern began to change again in mid-August (figure 2.17), as a mid-tropospheric low-pressure system propagated along the U.S.-Canadian border and passed directly through the aforementioned ridge. This was followed by the passage of a series of mid-tropospheric cyclones along the same path. Simultaneously, an intensification occurred in the surface high pressure in the eastern Gulf of Mexico.

These changes led, for the first time in the 1989 summer, to the presence of a deep layer of Gulf moisture across Illinois in advance of the frontal passages. Rainfall amounts accordingly increased statewide, beginning in the third week of August and extending through mid-September. Nevertheless, August was still relatively dry, except for areas along the Wisconsin border, because of the lack of rainfall in the first two weeks of the month.

However, the changed circulation produced above-average September rainfall in all parts of Illinois except the extreme south, although the last two weeks of September were dry. While the series of mid-tropospheric cyclones persisted during those weeks, they moved further north into Canada. This in turn permitted the surface high pressure over the Gulf of Mexico to move northwestward and dominate conditions over the Midwest (figure 2.18), leading to a return to dry conditions.

Summary

In Water Year 1988-1989 no massive "block" to rainfall production occurred such as developed in the spring and early summer of 1988. The weather patterns experienced during that year were not considered to be abnormal. The frequency of frontal passages was sufficient to provide an adequate mechanism for precipitation initiation. However, an unusually high propensity for fronts to stagnate along the Ohio River valley and farther south in the Gulf states frequently prevented deep Gulf moisture from invading Illinois. Therefore when precipitation opportunities occurred, many areas of the state did not receive adequate precipitation amounts. As the next chapter documents, this situation led to a continuation of the 1988 drought conditions in Illinois during the 1989 growing season.

FIGURES

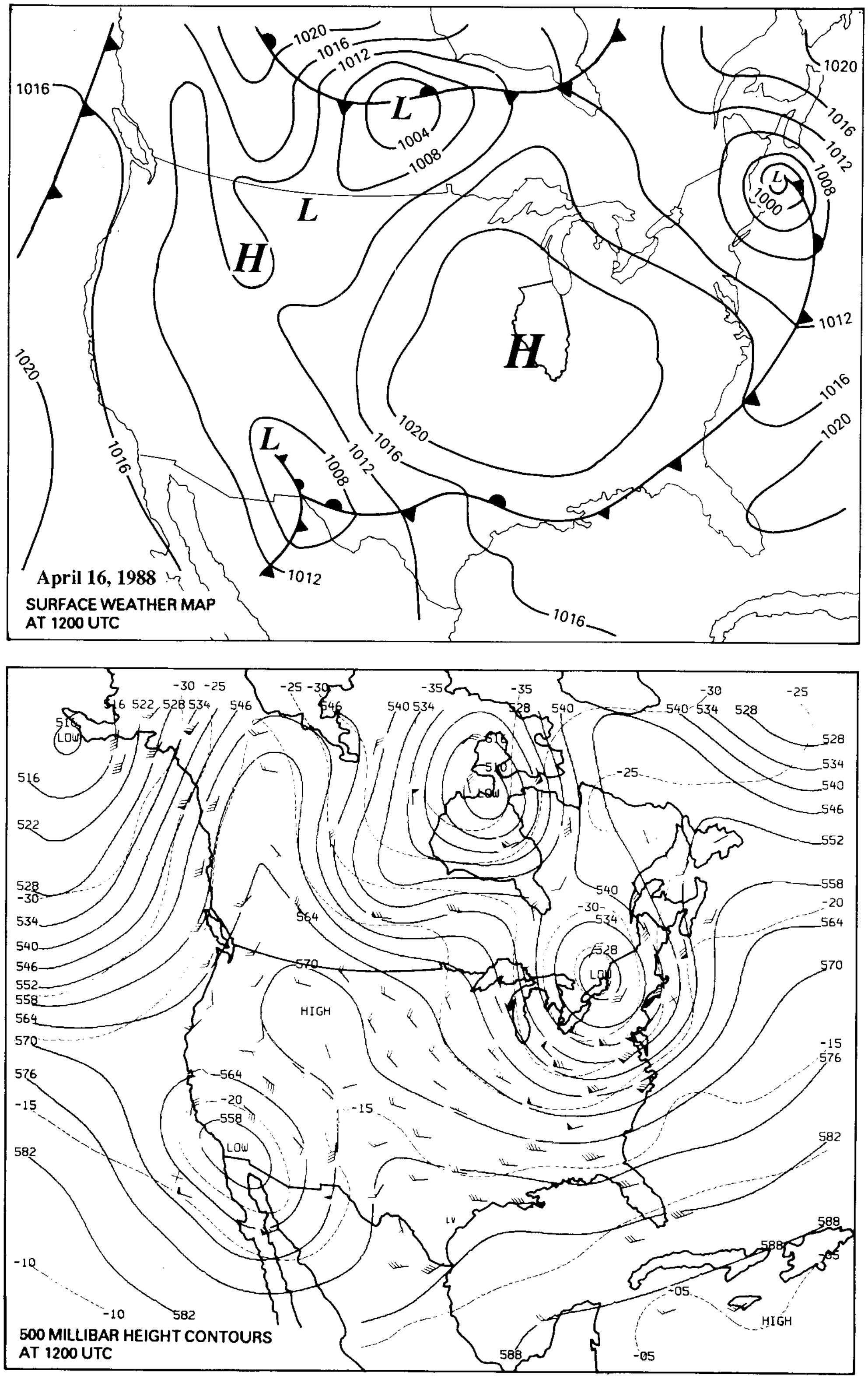

Figure 2.1. Surface and 500 Millibar Chart for April 16, 1988

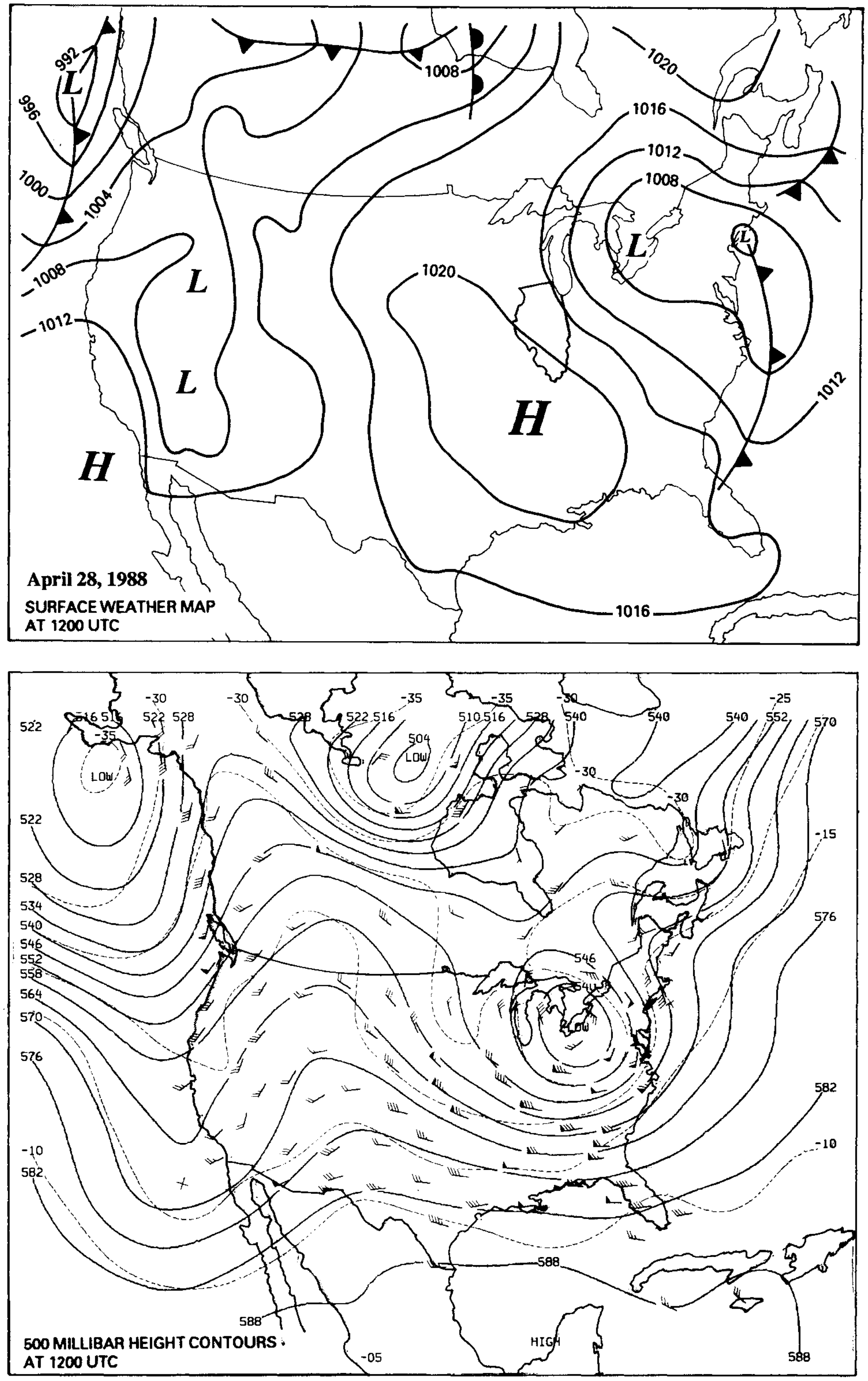

Figure 2.2. Surface and 500 Millibar Chart for April 28, 1988

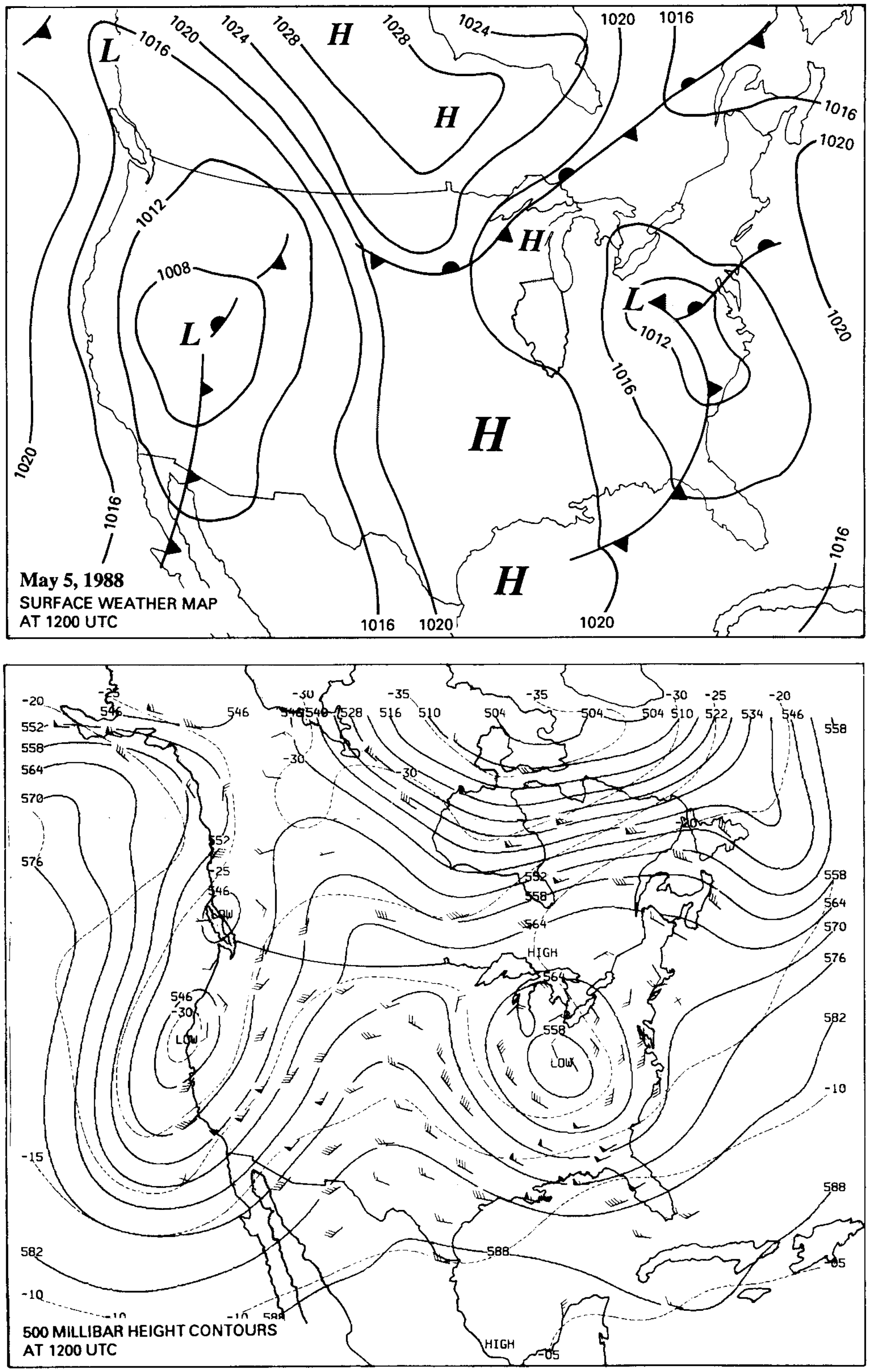

Figure 2.3. Surface and 500 Millibar Chart for May 5, 1988

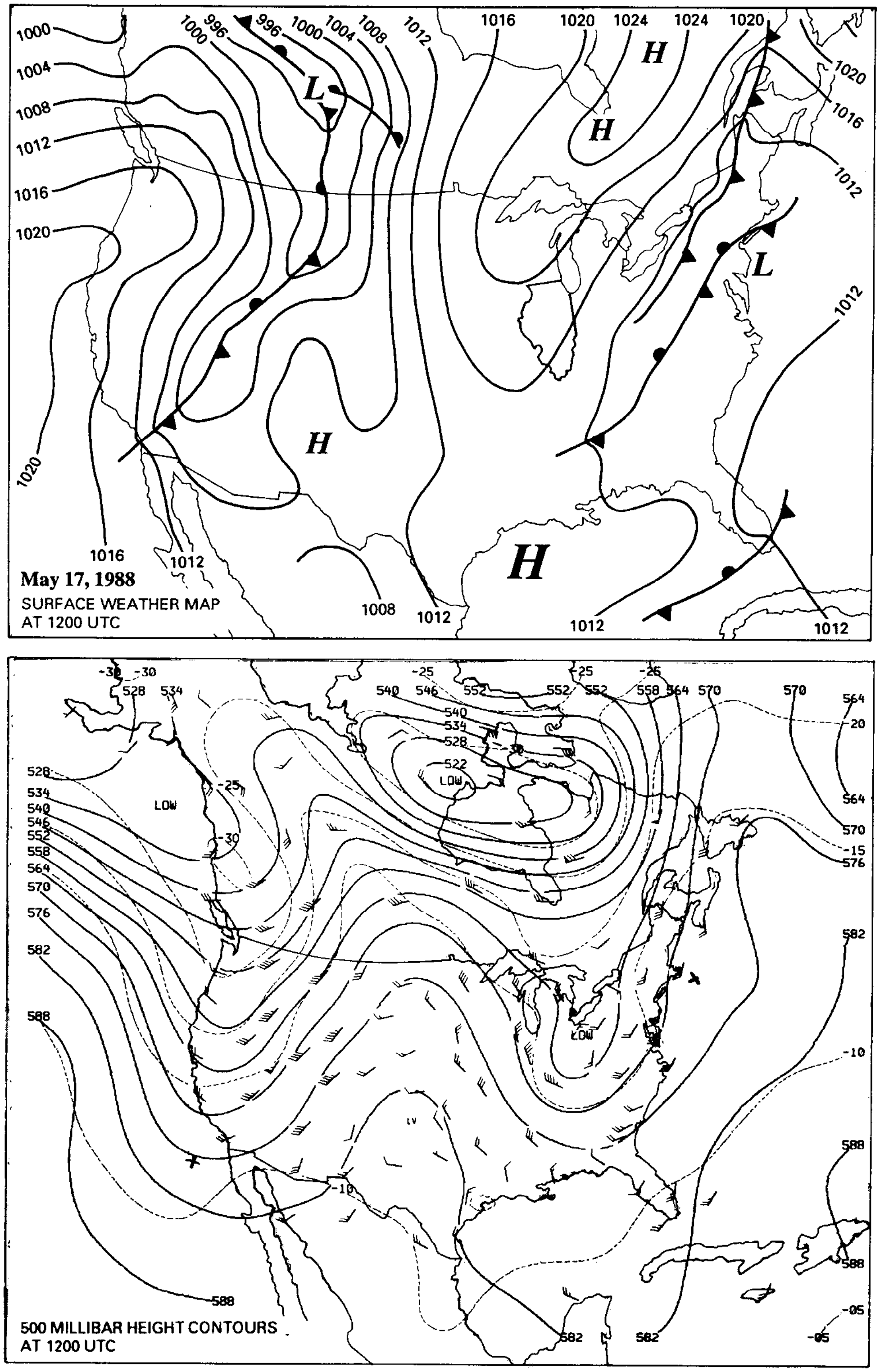

Figure 2.4. Surface and 500 Millibar Chart for May 17, 1988

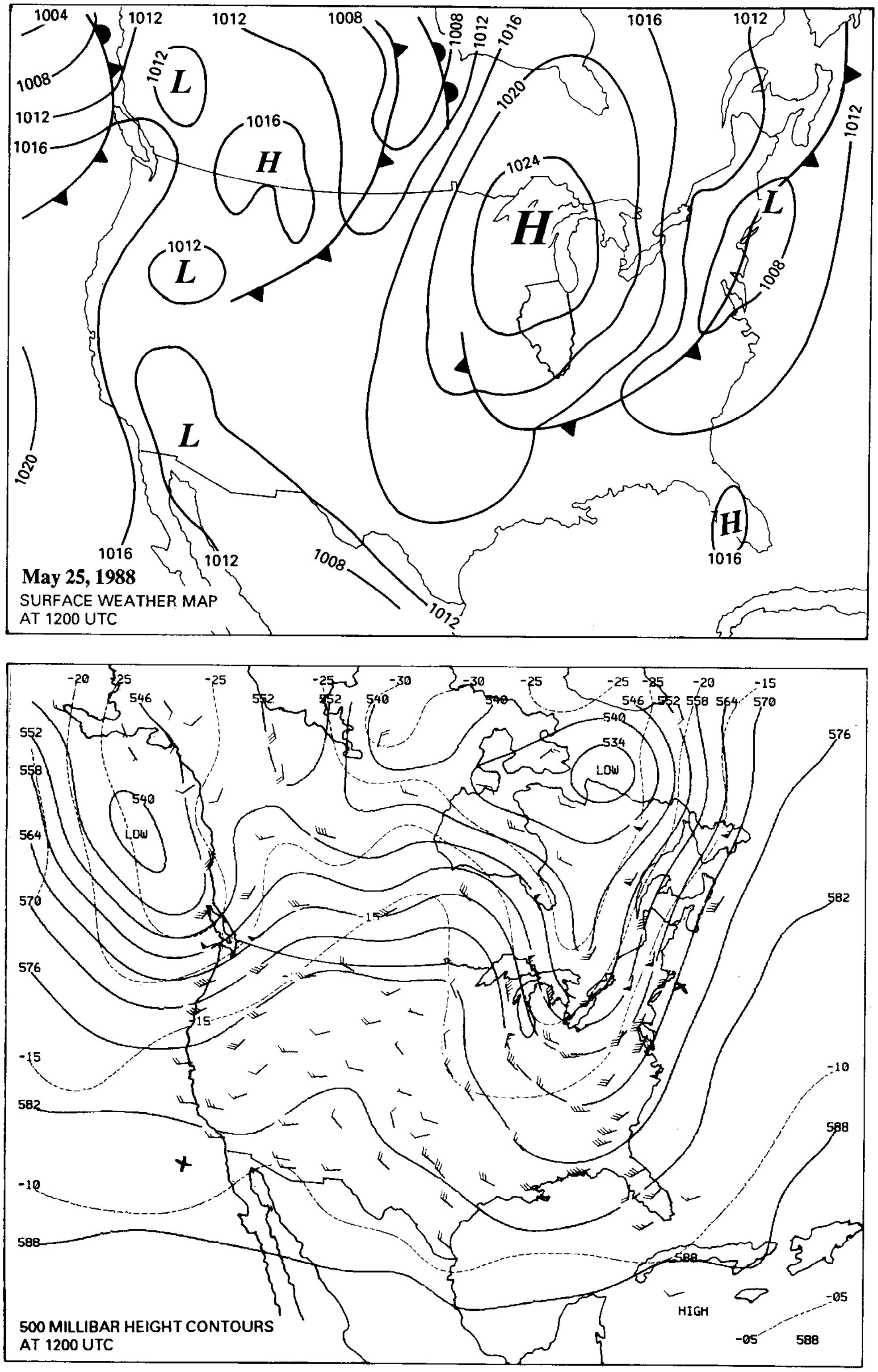

Figure 2.5. Surface and 500 Millibar Chart for May 25, 1988

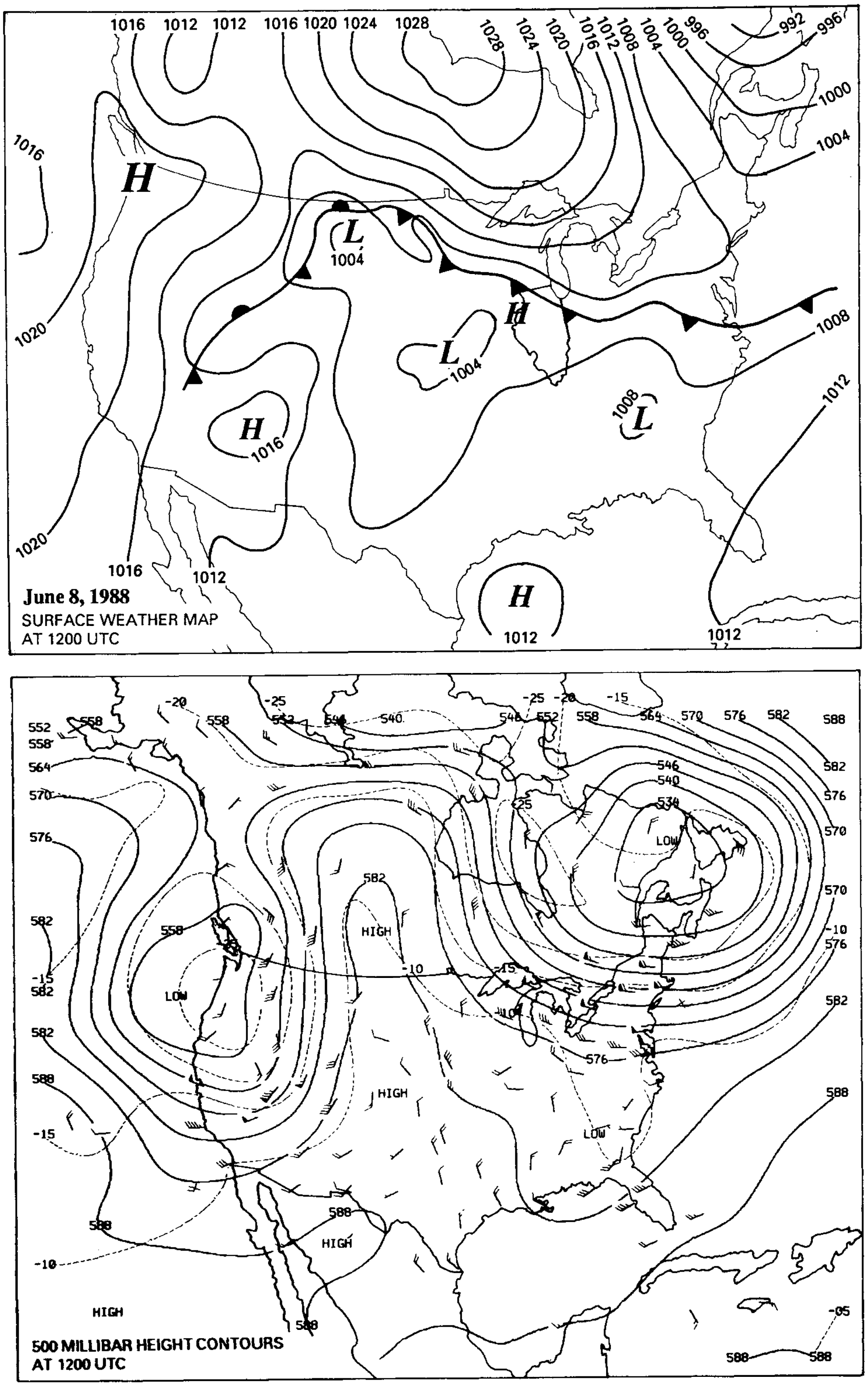

Figure 2.6. Surface and 500 Millibar Chart for June 8,1988

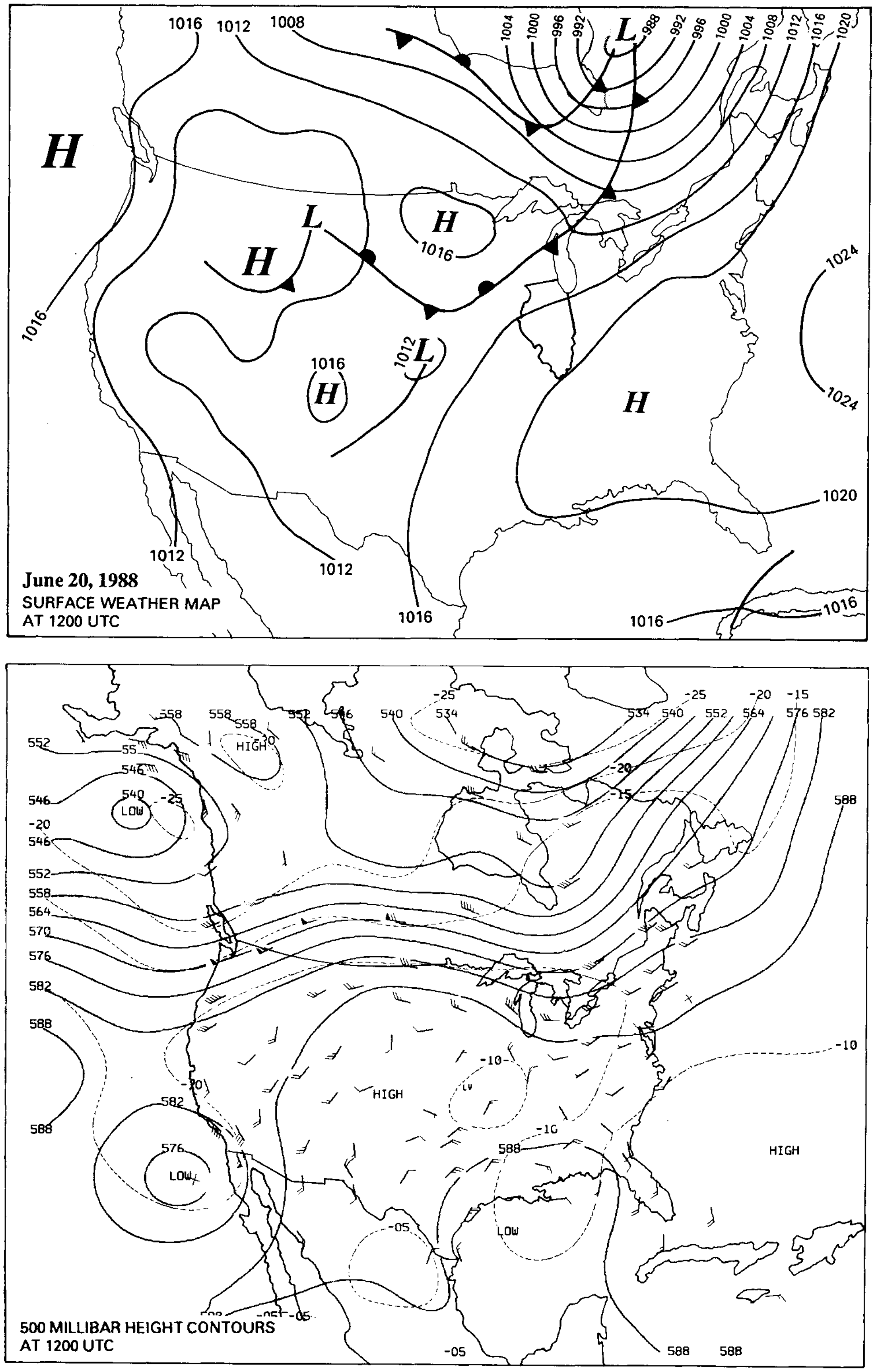

Figure 2.7. Surface and 500 Millibar Chart for June 20, 1988

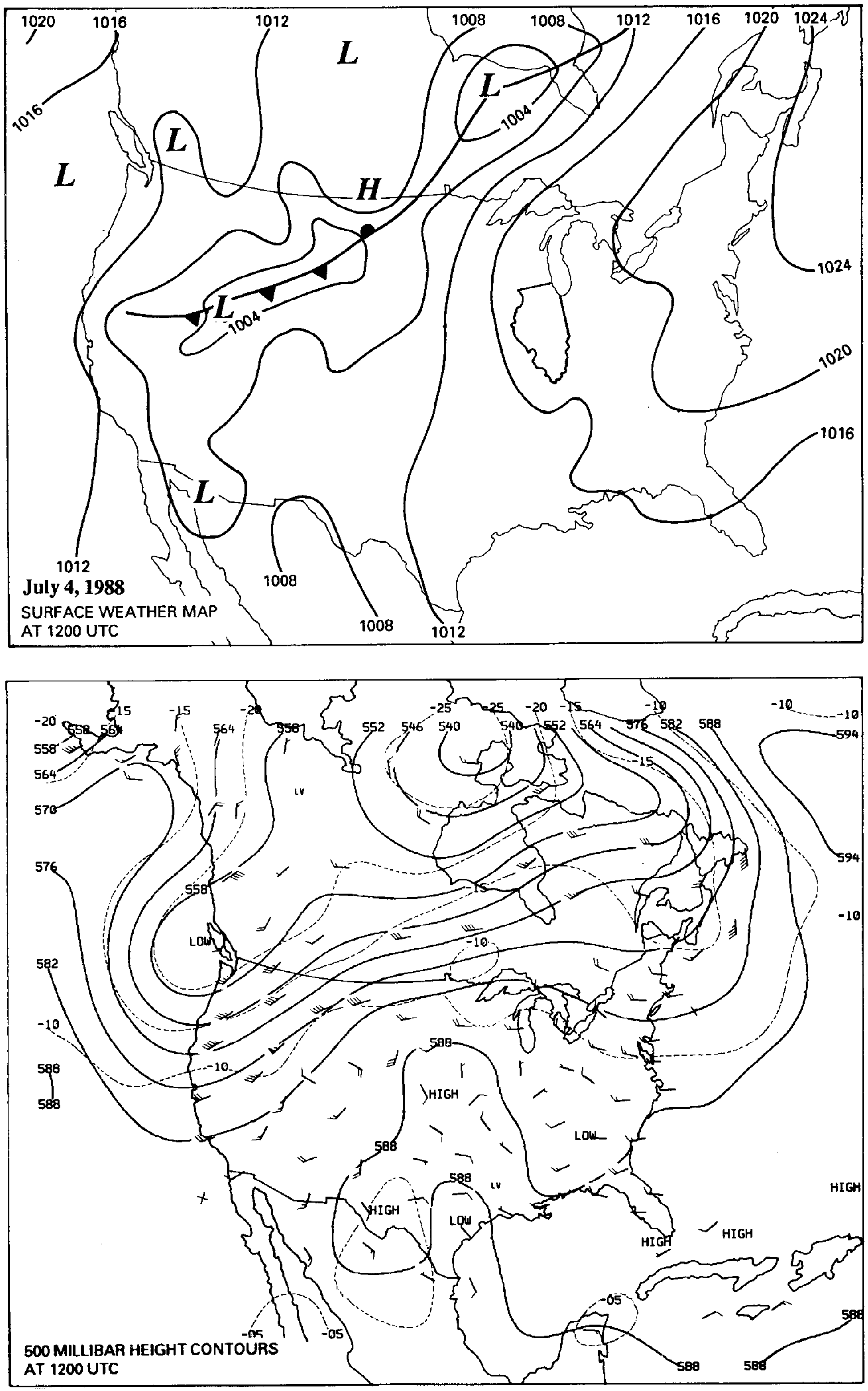

Figure 2.8. Surface and 500 Millibar Chart for July 4, 1988

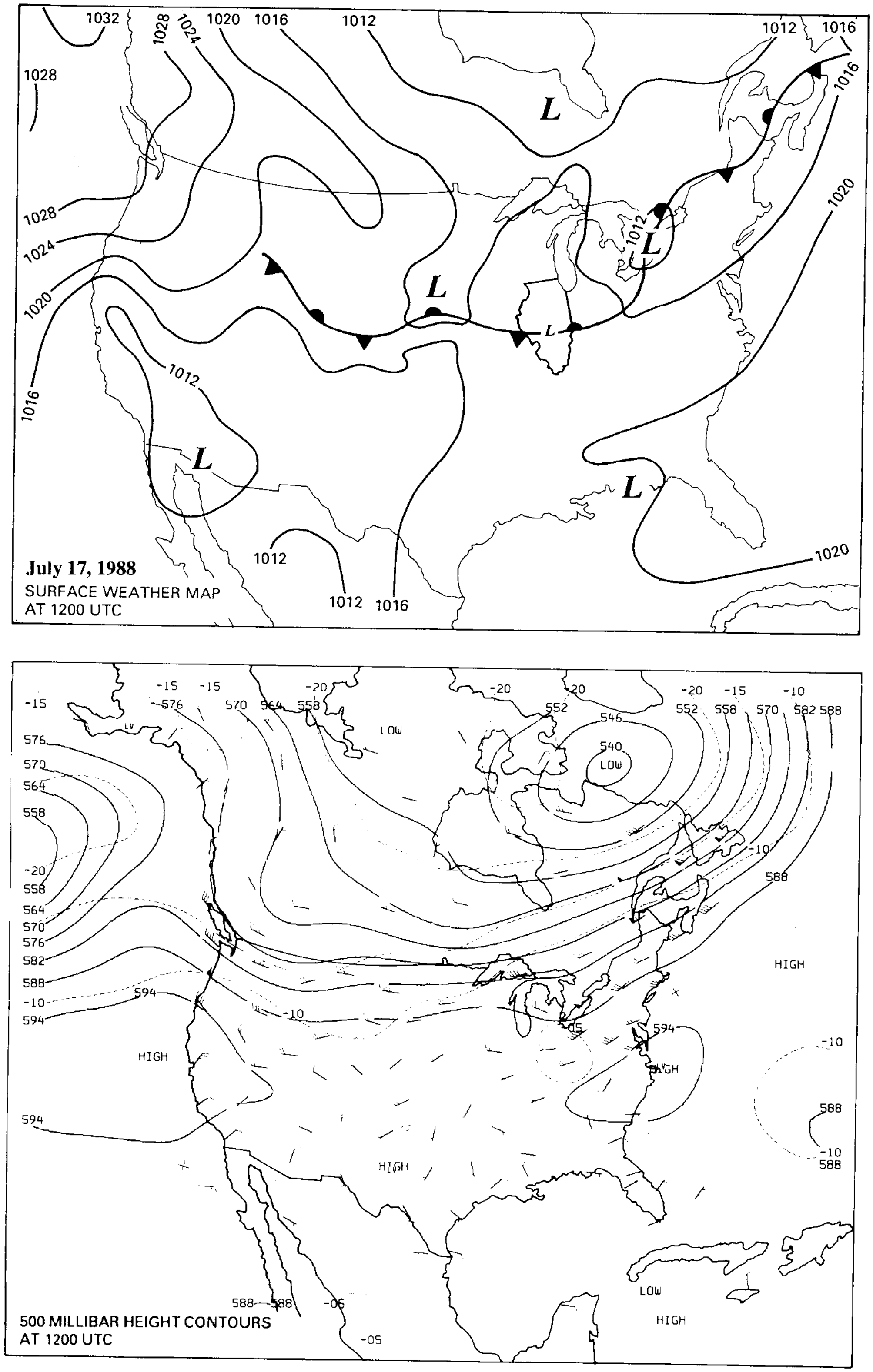

Figure 2.9. Surface and 500 Millibar Chart for July 17, 1988

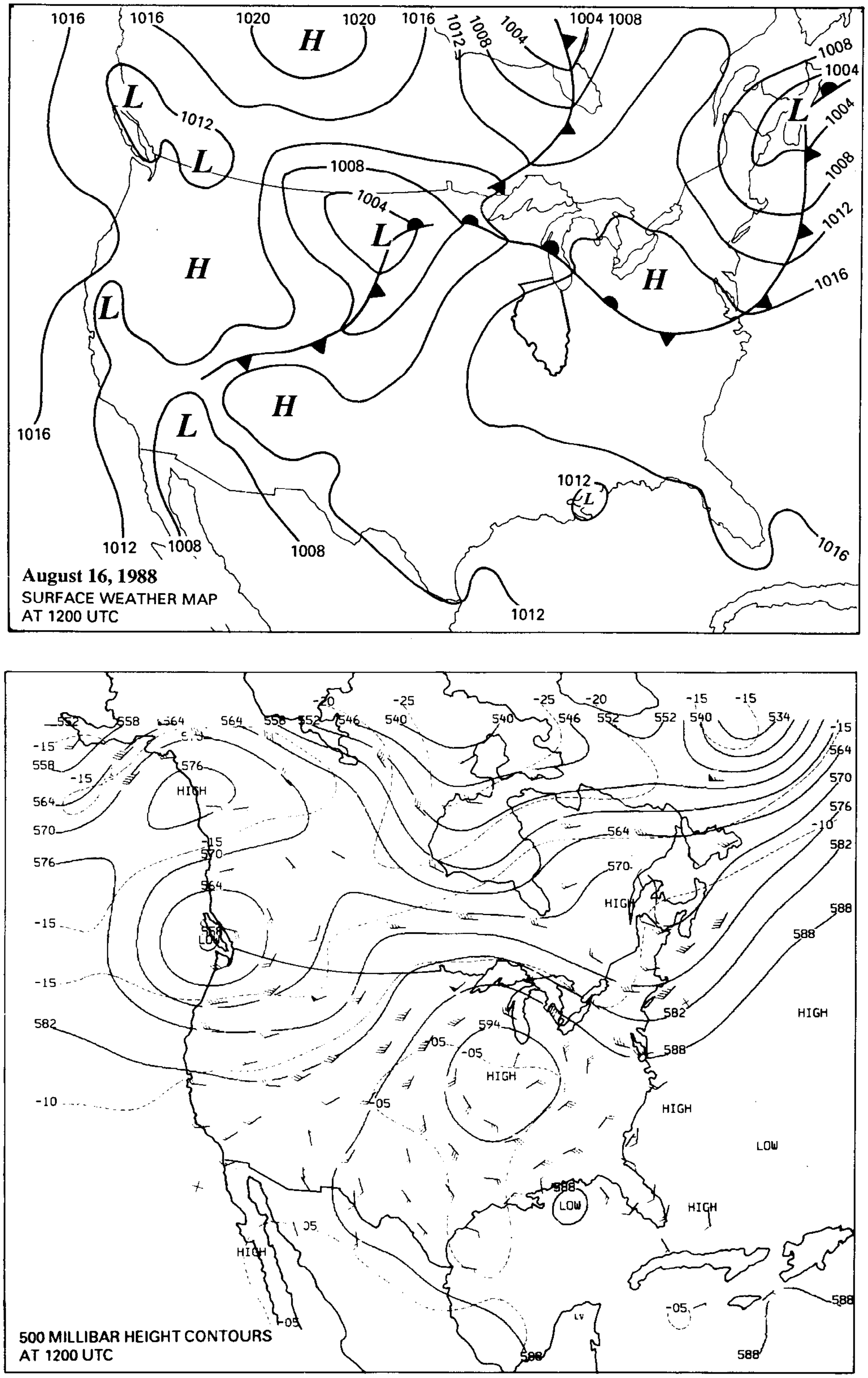

Figure 2.10. Surface and 500 Millibar Chart for Auaust 16, 1988

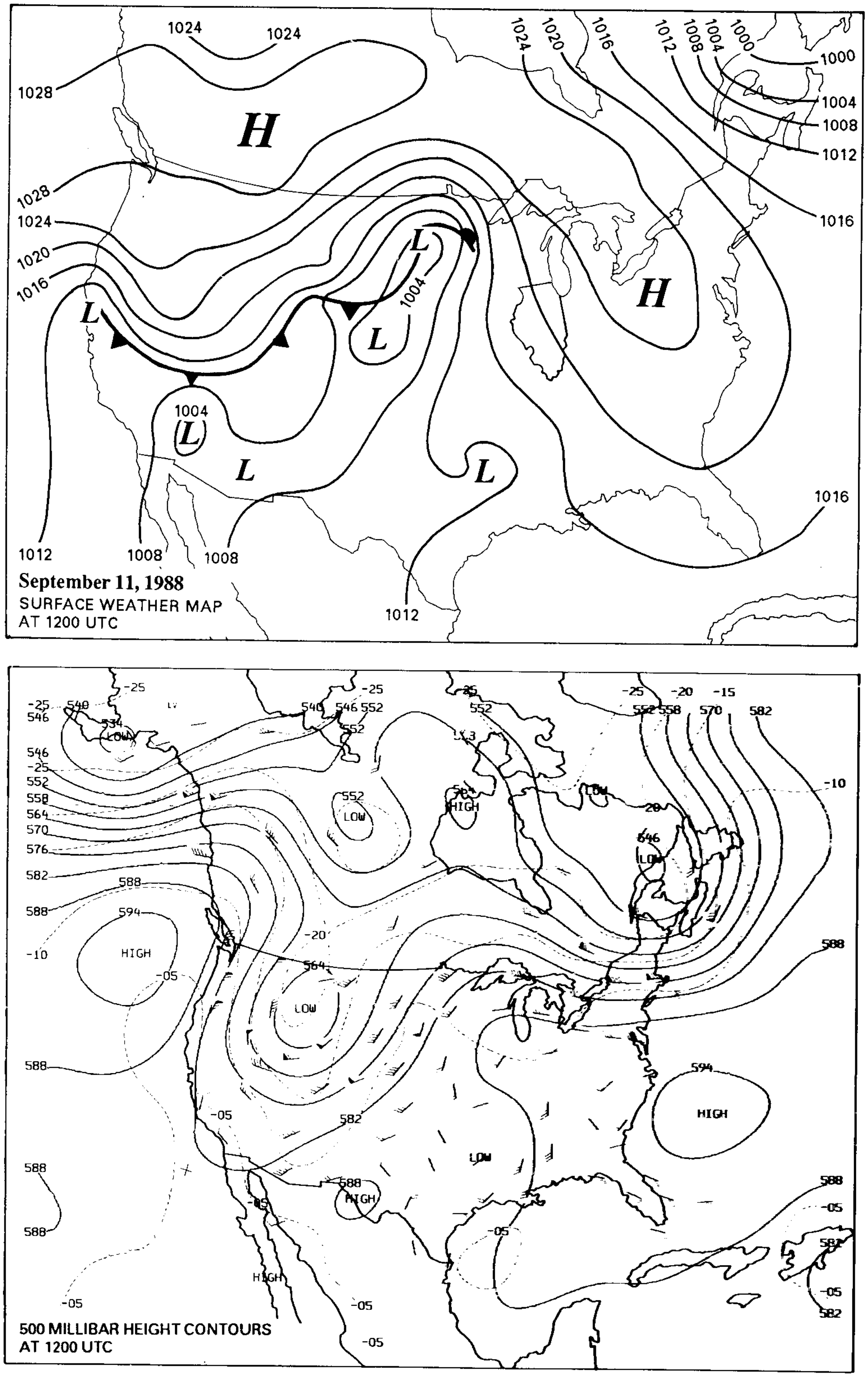

Figure 2.11. Surface and 500 Millibar Chart for September 11, 1988

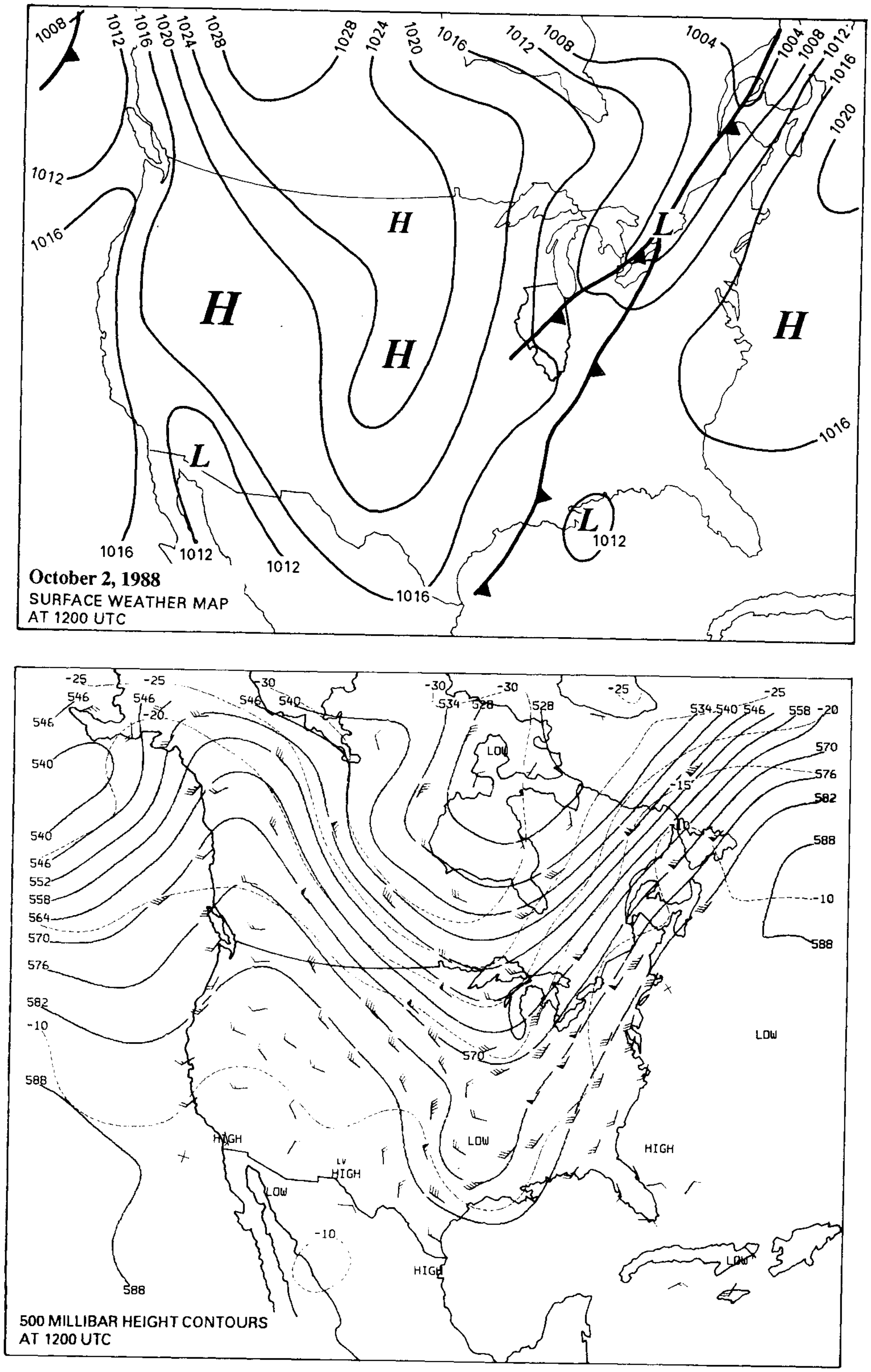

Figure 2.12. Surface and 500 Millibar Chart for October 2, 1988

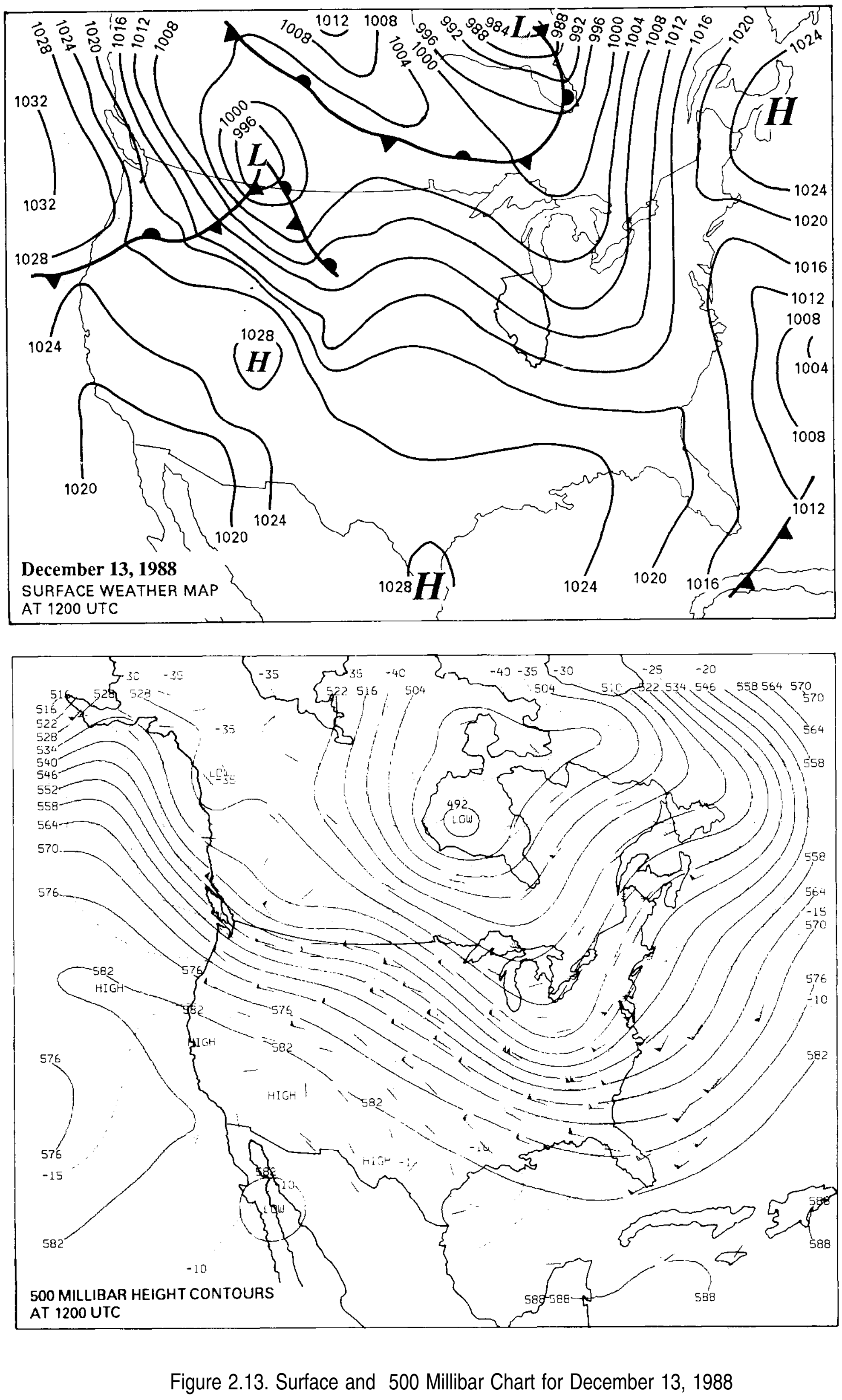

Figure 2.13. Surface and 500 Millibar Chart for December 13, 1988

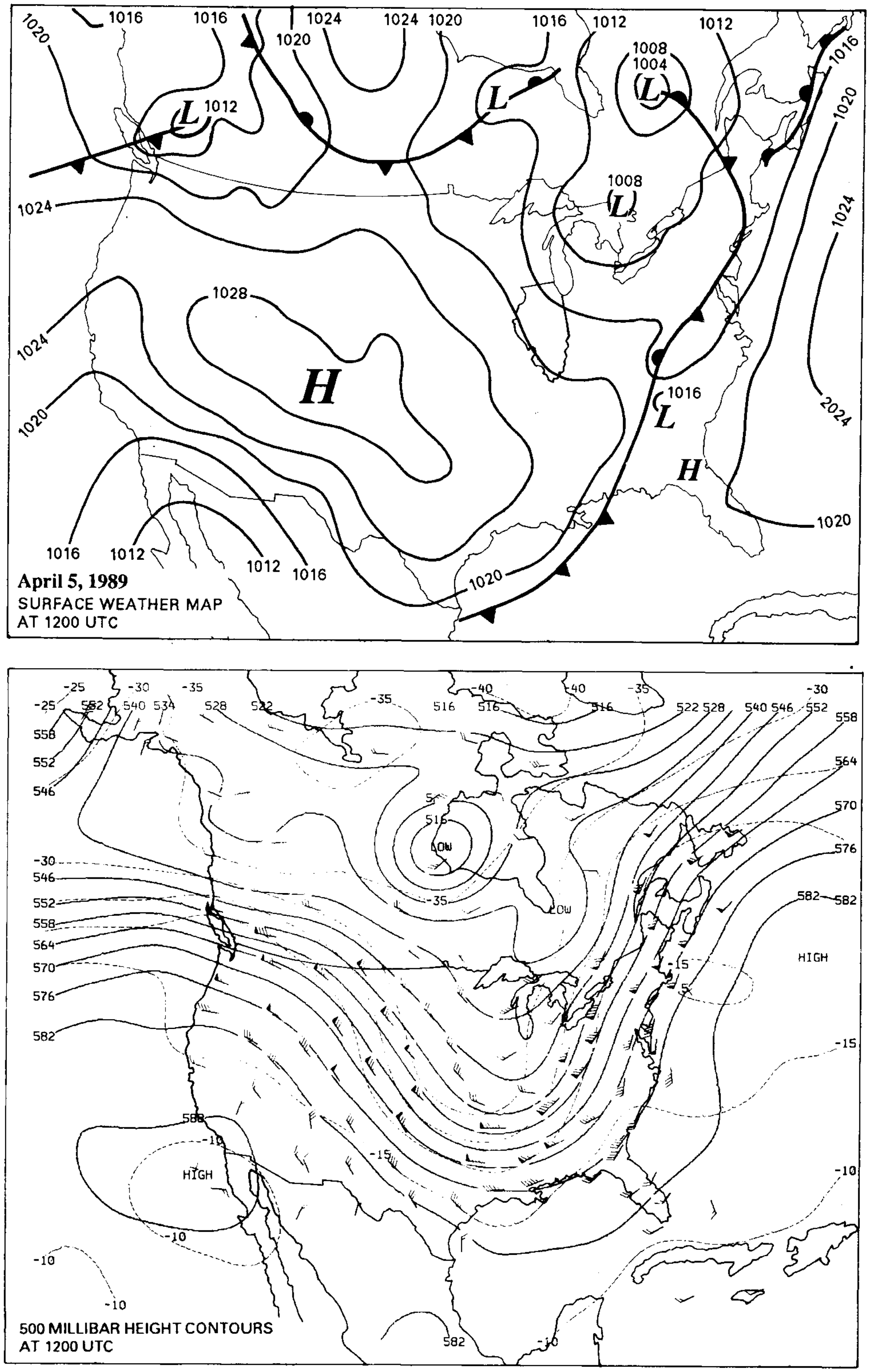

Figure 2.14. Surface and 500 Millibar Chart for April 5, 1989

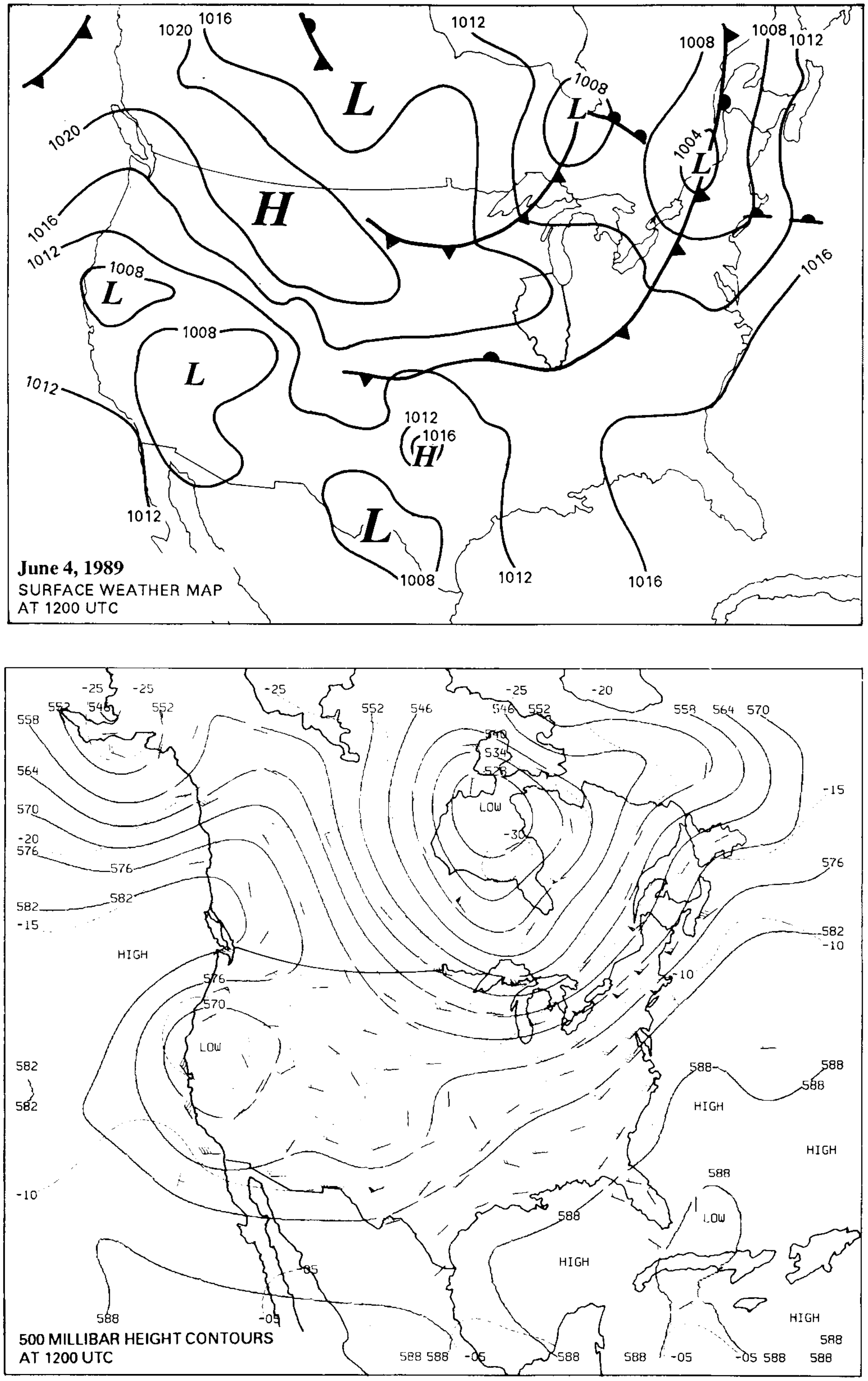

Figure 2.15. Surface and 500 Millibar Chart for June 4, 1989

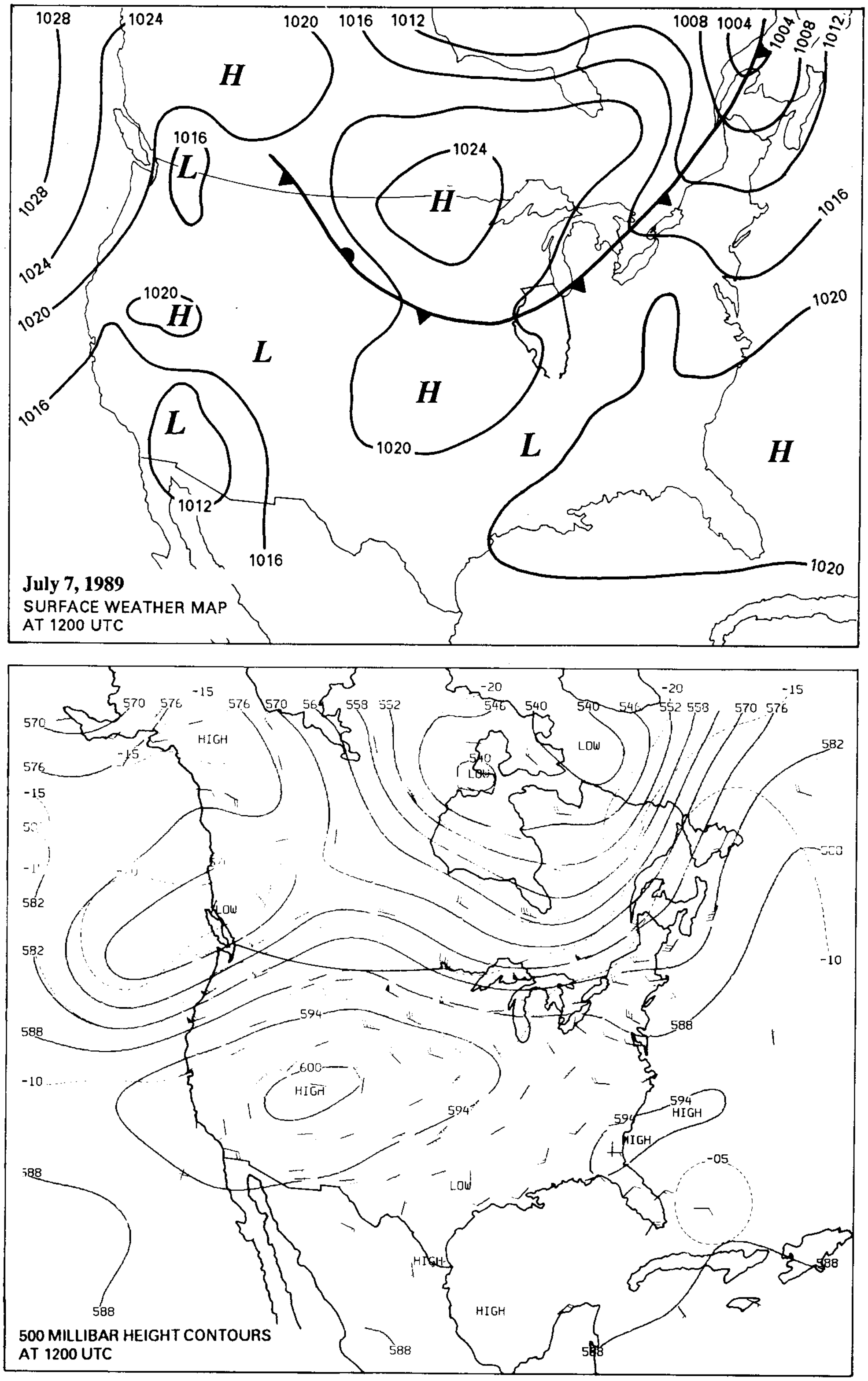

Figure 2.16. Surface and 500 Millibar Chart for July 7, 1989

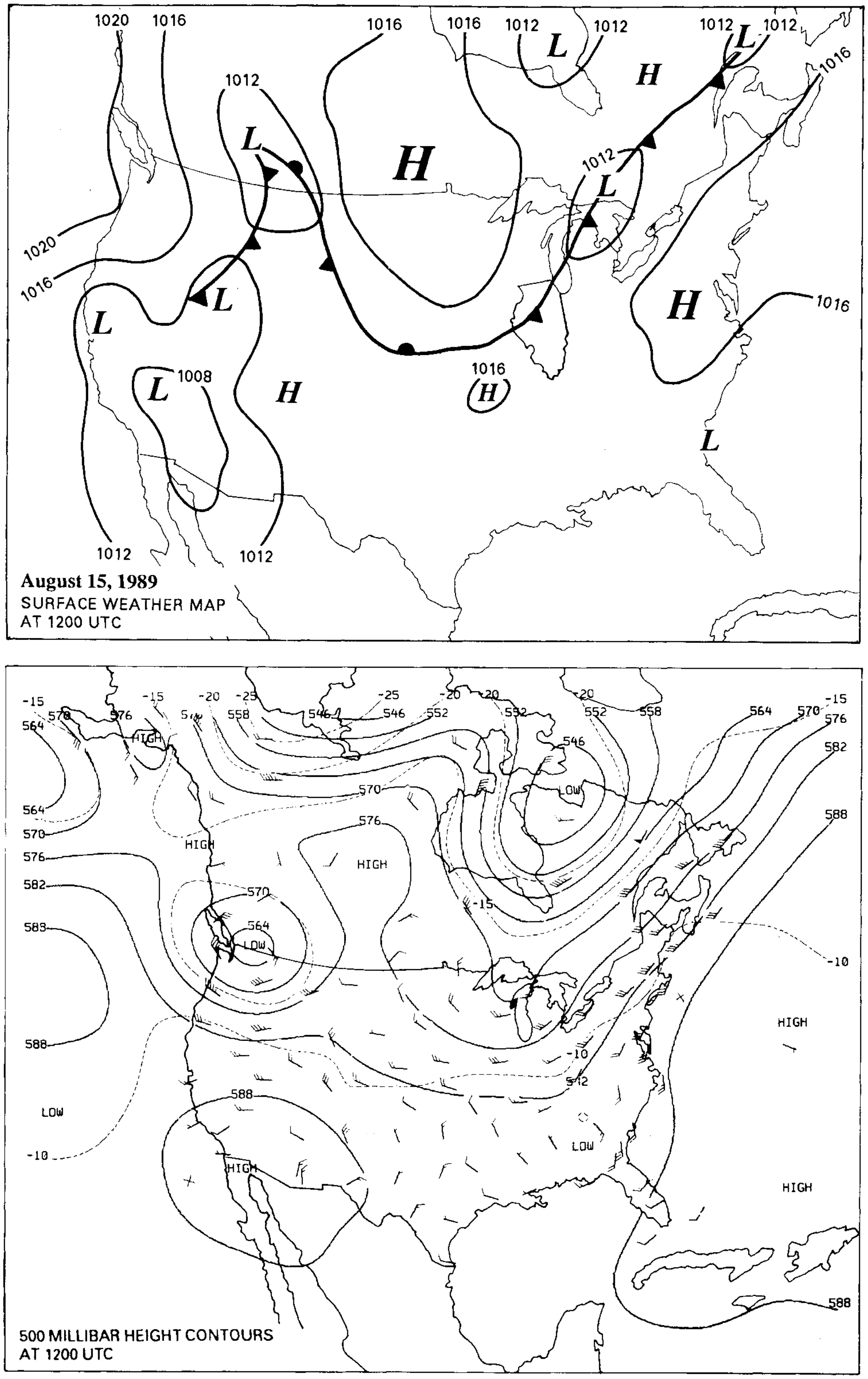

Figure 2.17. Surface and 500 Millibar Chart for August 15, 1989

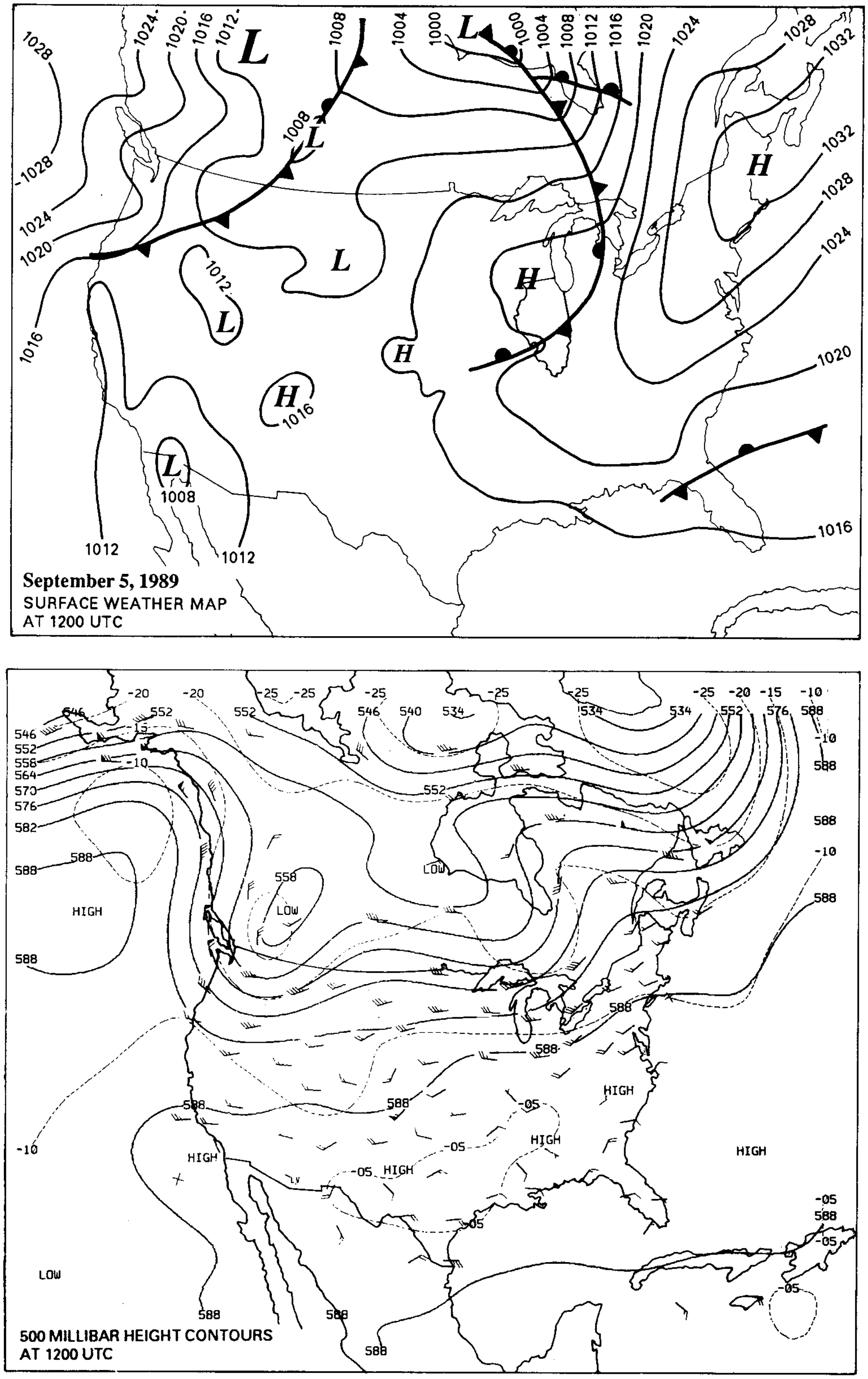

Figure 2.18. Surface and 500 Millibar Chart for September 5, 1989

3. SURFACE CLIMATE PATTERNS

by

Kenneth E. Kunkel, James R. Angel, and Wayne M. Wendland

This chapter documents how the large- and synoptic-scale atmospheric circulation patterns described in chapter 2 were manifest in anomalies of precipitation and surface temperature across the Midwest and throughout Illinois. It thus focuses on the meteorological aspects of the 1988-1989 drought and provides the background necessary for consideration of its agricultural and hydrological aspects in chapters 4-7.

3.1. A Midwestern Perspective

The 1988 meteorological drought affected not only Illinois, but all of the midwestern corn and soybean belt. Many of the impacts on Illinois, especially the high commodity prices from mid-1988 until mid-1989 and the low flows in the Mississippi and Ohio Rivers during mid-1988, were partially the result of drought conditions experienced in other parts of the Midwest. The extent and severity of the drought in the nine-state midwestern region (Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, and Wisconsin) are therefore documented in this section of the report.

Antecedent Conditions

To document the climatic state of the Midwest as it entered the 1988 drought, the Palmer Hydrological Drought Index (PHDI) for March 1988, obtained from the on-line database of the National Climatic Data Center (NCDC), is mapped by climate division in figure 3.1. Of the 75 climate divisions in the Midwest, only one division, in northwestern Minnesota, was suggested to be in a condition of extreme drought (-4 or less) at that time.

Five climate divisions—three in Minnesota, one in Kentucky, and one in southern Ohio—were experiencing severe drought (-3 to-3.99). The remaining 69 climate divisions were in various states of mild dryness or wetness. Most of the dry areas were at the headwaters of the Mississippi River and along the Ohio River valley, which suggests that the genesis of the mid-1988 low flows in these rivers already existed by March of that year.

1988 Midwestern Precipitation

Data from NCDC were used to calculate the percent of normal precipitation for each of the 75 midwestern climate divisions for each month from January 1988-September 1989. (The normal is the 1951-1980 average precipitation.) The median percent of normal for all 75 climate divisions is plotted by month in figure 3.2 to show the development and abatement of the meteorological drought.

In January and February 1988, the precipitation was only slightly below normal. By March 1988, however, the precipitation was only 77 percent of normal. It decreased dramatically through June 1988, which was the driest month of 1988-1989, with only 28 percent of normal precipitation. July 1988 was wetter but still had below-normal precipitation.

By July 1988, scattered heavy rains began to occur in the region, allowing some areas to recover while leaving others in a steady or deteriorating condition. In other words, by July 1988 there was greater spatial variability in the precipitation received across the Midwest. A return to near-normal precipitation after July 1988, along with the reduced evapotranspiration demands of the fall season, allowed parts of the Midwest to recover from their earlier precipitation shortfalls. During 1989, precipitation returned to normal for the Midwest as a whole.

The percent of normal precipitation received by each climate division was calculated for three important periods in 1988 (March-September, May-June, and June-August) and is presented in figures 3.3-3.5. The March-September period was selected because it gives a broad perspective on the entire growing season situation; May-June was the period of greatest precipitation deficiency; and June-August is the traditional summer season.

In March-September 1988 (figure 3.3), all but five climate divisions had below-normal precipitation. The Corn Belt (from Iowa to Ohio) received the lowest percentage of normal precipitation: values were typically below 75 percent, and in some parts of Illinois they were below 50 percent. Only the far north and far south of the midwestern region received near-normal precipitation.

During May-June 1988 (figure 3.4), a crucial period of crop germination and establishment, broad areas of severe precipitation deficiency occurred. No climate division received even near-normal rainfall during these two months. The lowest values (less than 25 percent) occurred in parts of Illinois, Indiana, Michigan, and Ohio. In June-August 1988 (figure 3.5), a more complex pattern occurred as a result of the return of scattered heavy rains in July and August. In general, the Corn Belt (especially Illinois) was still lacking in rainfall during this traditional summer season period, but some relief did occur in the far south and north and in western Iowa.

To provide a historical perspective on the 1988 midwestern drought, the climate division precipitation totals for the three periods discussed above were compared with the long-term record. Here, the long-term record was the 1895-1988 monthly climate division precipitation database developed at NCDC. For each of the three periods discussed above and for each climate division, the 94 years were ranked from driest to wettest, with a ranking of 1 representing the driest year.

For March-September 1988 (figure 3.6), 49 of the 75 climate divisions were below the 10th percentile (rankings of 9 or lower). The 10th percentile has been used in previous studies of drought (e.g., Gibbs and Maher, 1967) and represents a once-in-ten-year event. For 11 climate divisions, March-September 1988 was the driest March-September on record.

For the narrower MayJune 1988 period (figure 3.7), 73 of the 75 climate divisions were below the 10th percentile, and 41 of those divisions experienced the driest May-June on record. Figure 3.8 shows that for June-August 1988, 29 of the 75 climate divisions were below the 10th percentile, with six of those divisions experiencing their lowest precipitation on record. In general, figures 3.6-3.8 suggest that the 1988 spring-summer drought was one of the worst of this century in the Midwest. Furthermore, it is clear that the northern two-thirds of Illinois experienced some of the largest precipitation deficiencies in the entire Midwest.

1988 Midwestern Temperatures

Temperature played an important secondary role in the 1988 spring-summer midwestern drought. Figure 3.9 shows that temperatures started out on the low side in 1988, but by May they were consistently above normal. August temperatures departed the furthest from normal, placing additional stress on crops, livestock, and humans. It is interesting to note that the above-normal temperatures occurred after the precipitation deficiencies had begun (figure 3.2) and when soil moisture had become depleted (see chapter 4).

By September, temperatures had moderated slightly, and they fluctuated widely during the fall and the following winter (in October 1988, January 1989, and February 1989). However, the 1989 growing season produced no noteworthy temperature departures from normal, with most months having slightly below-normal temperatures.

The March-September 1988 temperature departures (not shown) exhibited a pronounced northwest-to-south gradient, with near-normal temperatures dominating the southern tier and increasingly higher-than-normal temperatures occurring toward Minnesota. Within the Corn Belt, Iowa experienced the greatest departures (>+4°F) for this period.

The May-June temperature departures (also not shown) resembled the March-September pattern, with some intensification of the positive anomalies in Iowa and Minnesota. During June-August 1988 (figure 3.10), temperatures were above normal in the Midwest except in southern Missouri, with the greatest departures occurring in the northern half of the region.

To provide a further historical perspective on the 1988 midwestern drought, the temperatures for each climate division were compared with the 1895-1988 historical database in the same manner as described for precipitation. The 94 years were ranked from hottest to coldest, with a rank of 1 indicating the hottest year.

The March-September 1988 rankings (not shown) revealed that this period was the hottest in 94 years for eight of the 75 climate divisions. These divisions were located in Minnesota and Wisconsin. For 43 of the 75 climate divisions, the March-September period was in the warmest 10 percent of March-September periods on record.

The May-June temperature rankings (also not shown) revealed that eight climate divisions had a rank of 1, and that for 31 divisions, the period fell in the warmest 10 percent on record. Temperatures were especially high in Iowa and the upper half of Michigan during that period. June-August was the hottest period during the 1988 drought. During those months, 19 climate divisions—primarily in Minnesota, Wisconsin, and Iowa—experienced their hottest year on record (figure 3.11). Furthermore, for 56 of the 75 climate divisions, that period was in the warmest 10 percent on record.

Hydrological Conditions at the End of the 1988 and 1989 Growing Seasons

The impact of the heat and dryness of the 1988 spring-summer drought on the climatic state of the Midwest is illustrated in figure 3.12 by the Palmer Hydrological Drought Index (PHDI) for September 1988. This figure is a counterpart to figure 3.1 for the preceding March and shows great changes from that time. By September 1988, large areas of the Midwest were in a condition of moderate, severe, or extreme drought. The only areas showing moist conditions by October 1988 were on the perimeter of the Midwest (for example, southern Missouri).

Figure 3.13 contains a counterpart PHDI map for one year later (September 1989). It shows that, despite the regionwide return to near-normal precipitation during late 1988 and 1989 (figure 3.2), hydrological drought conditions were still present by late 1989 in Minnesota, Iowa, northern Missouri, western Illinois, all of Wisconsin except its southeastern corner, and northern Michigan. However, a return to much moister conditions had occurred by this time in the extreme southeastern portion of the Midwest (southern Ohio and Indiana, and eastern Kentucky).

3.2. The Illinois Situation

This section documents the development of the 1988 meteorological drought conditions in Illinois, and the state's recovery from drought conditions during 1989. Attention is particularly focused on precipitation.

Illinois Precipitation

Mean annual precipitation in Illinois varies from about 860 millimeters, or mm (~34 inches) in the northern counties to about 1,200 mm (~46 inches) in the south. Extreme values recorded during the past century have varied from about 60 percent to as much as 160 percent of that mean.

Although the precipitation received in Illinois during 1988 was only 12 percent less than the 30-year average, the impact was substantial. This was the case because 1987 had already been somewhat drier than average, and because the precipitation of 1988 was unevenly distributed throughout the year and did not occur at the times it was most needed for agriculture.

Table 3.1 shows the statewide monthly average precipitation from October 1987 through September 1989, presented as a percentage of the 1951–1980 average for each calendar month. The large deficit from April–August 1988 had great impact because of the time of the year during which it occurred. Although the 30-year average (often called "normal") is not expected every year, deviations of the magnitude experienced during April–August 1988 are certainly beyond the ordinary. Interestingly, precipitation during the water year following the core of the 1988 drought (October 1988–September 1989) was still generally less than average, with only November 1988, February 1989, and September 1989 receiving more than the 1951–1980 average.

Figure 3.14 presents a time series of the statewide annual precipitation average from 1878–1989, thus providing a historical perspective on the 1988 drought. Although the stations on which figure 3.14 is based increased in number from about 40 in the late 1800s to about 170 in the early 1900s and thereafter, these stations were rather equally distributed across the state during the 112-year period, which suggests an adequate degree of homogeneity and representativeness.

No outstanding trend is apparent in the 112-year precipitation record for the state (figure 3.14). The annual values fluctuate but tend to remain within about a 10-inch range (33 to 43 inches). Figure 3.14 further shows that the annual Illinois statewide precipitation was less than that of 1988 in only four other years: 1901, 1930, 1953, and 1963. These extreme values were rather equally distributed throughout the time period, with a frequency of about once every 21 years. With a human life span being about 80 years, one should expect to experience about four years of near-equivalent precipitation deficiency in a lifetime.

Figure 3.15 shows the distribution of precipitation over Illinois in April–August 1988, presented as a percentage of the 1951–1980 mean. The driest areas were in the extreme western part of the state (from Moline to Quincy) and in central Illinois, extending from Kankakee through Decatur to Edwardsville. *The precipitation for those five months was less than 40 percent of the long-term average in these two areas.* The extreme southeastern corner of the state received only between 40 and 50 percent of the long-term average.

Three areas in the state were wetter than surrounding areas: 1) the extreme northeast, 2) a southwest-northeast-oriented region in the west-central part of the state, and 3) a similarly oriented area in southeastern Illinois that extended into southwestern Indiana. However, even these areas received only 50 to 80 percent of their average annual precipitation,

The percentage of Illinois that received 50 percent or less of its long-term average April–August precipitation in each year from 1901–1989 is documented in figure 3.16. (April–August was the most intense episode of the 1988 drought.) The spring–summer droughts that have affected the largest percentage of Illinois since 1901 are those of 1914 and 1936 (60 percent of the state), 1988 (54 percent), and 1930 (38 percent). By this criterion, the April–August drought of 1988 was the third worst on record in Illinois and impacted a larger area than the drought of 1930. The 1988 drought is suggested to have a recurrence frequency of approximately 40 years.

The severity of the 1988 drought can be ranked yet another way, as was shown in figures 3.7 and 3.8. For the May–June period (figure 3.7), we note that six of the nine climate divisions in Illinois experienced their driest weather in the 94 years of record. Only the west-central, southwest, and southeast districts were slightly more moist, with the 4th, 5th, and 3rd driest May–June, respectively, of the 94 years. Furthermore, the longer June–August period (figure 3.8) ranked as the driest of the 94 years for three Illinois districts. For four districts, the June–August period was between the 3rd and 7th driest, and the period ranked higher (15th and 23rd) only in the two southernmost districts.

Regardless of the method used to assess the severity of the 1988 drought, the intensity of that event dramatically influenced water availability, farm productivity, and income across Illinois. These impacts are dealt with in chapters 4–7. From a climatic standpoint, however, it is important to note that some 51 years had elapsed since the occurrence of a comparable growing-season drought in the state in 1936. Thus Illinois farmers who began their careers in the 1940s or later had no previous experience with a drought of the magnitude of that of 1988.

Illinois Temperatures

Temperatures in Illinois from late 1987 through late 1989 (figure 3.17) rather closely followed the trends for the entire midwestern region shown in figure 3.9. During the months immediately prior to the onset of the 1988 drought, Illinois temperatures varied over a rather wide range. For example, average temperatures for October 1987 were almost 7°F below the 1951–1980 mean, whereas those for November and December were up to 4°F above average. Early 1988 was characterized by a slightly cooler than average January and a cold February (4°F below average).

Temperatures during the spring-summer 1988 drought in Illinois were generally only 1° to 2°F warmer than average, except for August, which was 4.3°F above average. It was primarily because of the high August temperatures that the June–August 1988 period in the seven northernmost climate districts of Illinois fell within the seven warmest such periods since 1895. The intensity of the drought in Illinois was thus heightened by warmer than average temperatures, but it was firmly rooted in the substantially lower-than-average precipitation.

Monthly temperatures in Illinois during the 1988–1989 water year were within 2°F of average. The exceptions to this were October 1988 and February 1989 (about 7°F below average), January 1989 (almost 10°F above average), and May and September (about 4°F below average).

Entering and Emerging from Drought Conditions in Illinois

The substantial shortfall in statewide monthly precipitation during much of 1988 and, to a lesser extent, in 1987 and 1989 is clearly illustrated in figure 3.18. Because soil moisture, surface water, and ground water integrate precipitation over increasingly long periods of time (see chapters 4–6), the 12-month running mean statewide precipitation is presented in figure 3.18 as well as the contributing individual monthly values.

Note that the 12-month running mean time series decreased to less than zero (the mean) as early as November 1986. The drier-than-average first half of 1987 intensified this running mean deficit. The 12-month running mean returned to near zero by the end of 1987 and continued at that level until April 1988, when the substantially lower-than-average monthly precipitation again forced the 12-month running mean further into negative territory, The 12-month running means remained less than the 1951–1980 average through December 1990, when they returned to essentially zero.

The 12-month running mean precipitation had thus been below the mean for 50 consecutive months. Furthermore, this change occurred only after a year (1990) that was within the wettest 2 to 5 years of the 100 years or so of record in terms of annual precipitation over most of Illinois.

This rather slow recovery from the precipitation drought is further illustrated in figure 3.19, which shows the spatial variation in the accumulated precipitation deficit for three periods of increasing length beginning on April 1, 1988. That deficit tended to increase toward the west and northwest. However, despite the situation depicted in figure 3.19, chapters 4–6 show that the soil moisture and surface water conditions across the state had returned to their pre-drought levels by the end of 1989. Groundwater recovery did not occur until December 1990 (chapter 6).

FIGURES AND TABLE

MIDWEST CLIMATE CENTER

Palmer Drought Index
March, 1988

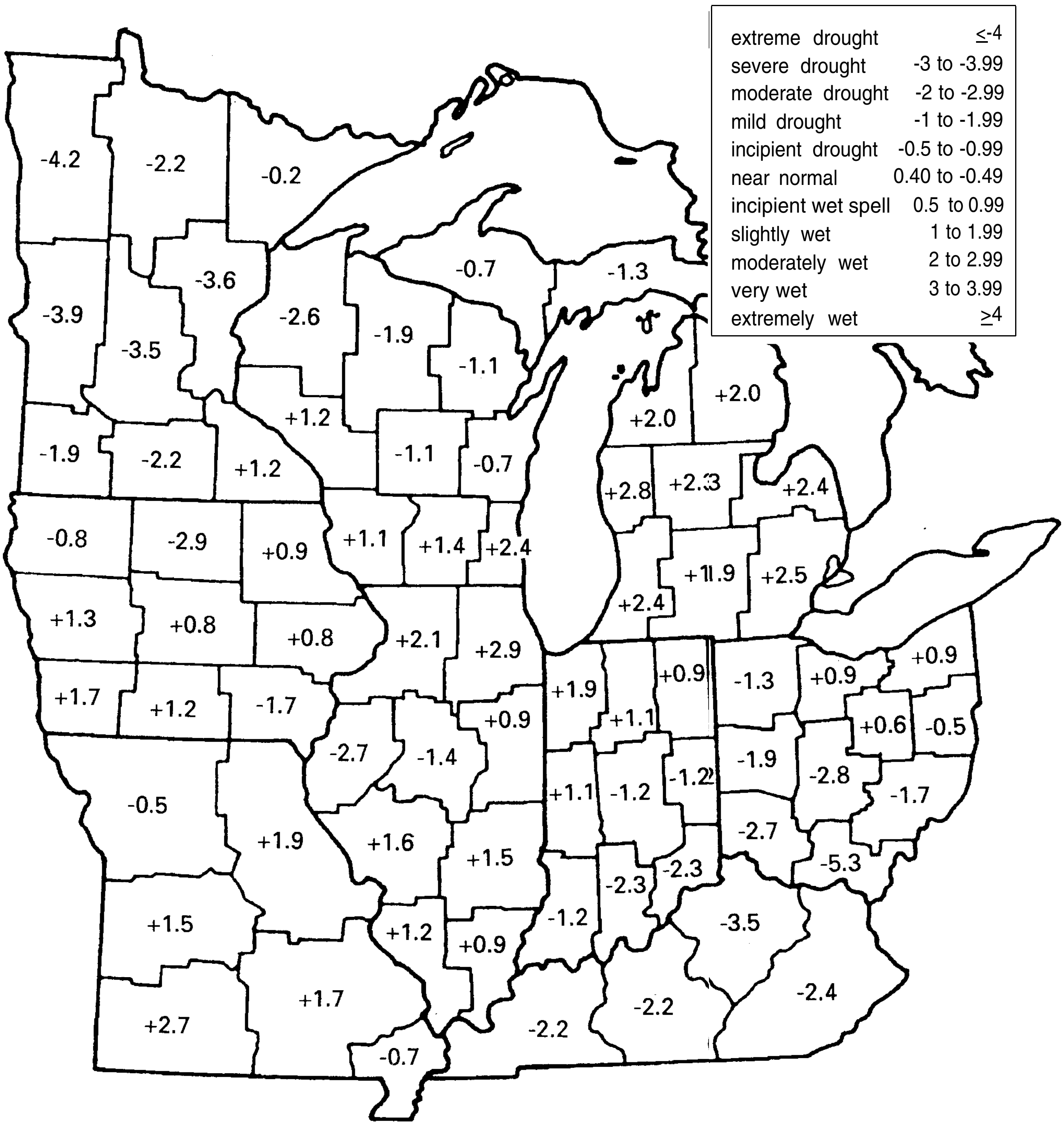

Figure 3.1. Palmer Hydrological Drought Index values for 75 midwestem climate divisions, March 1988

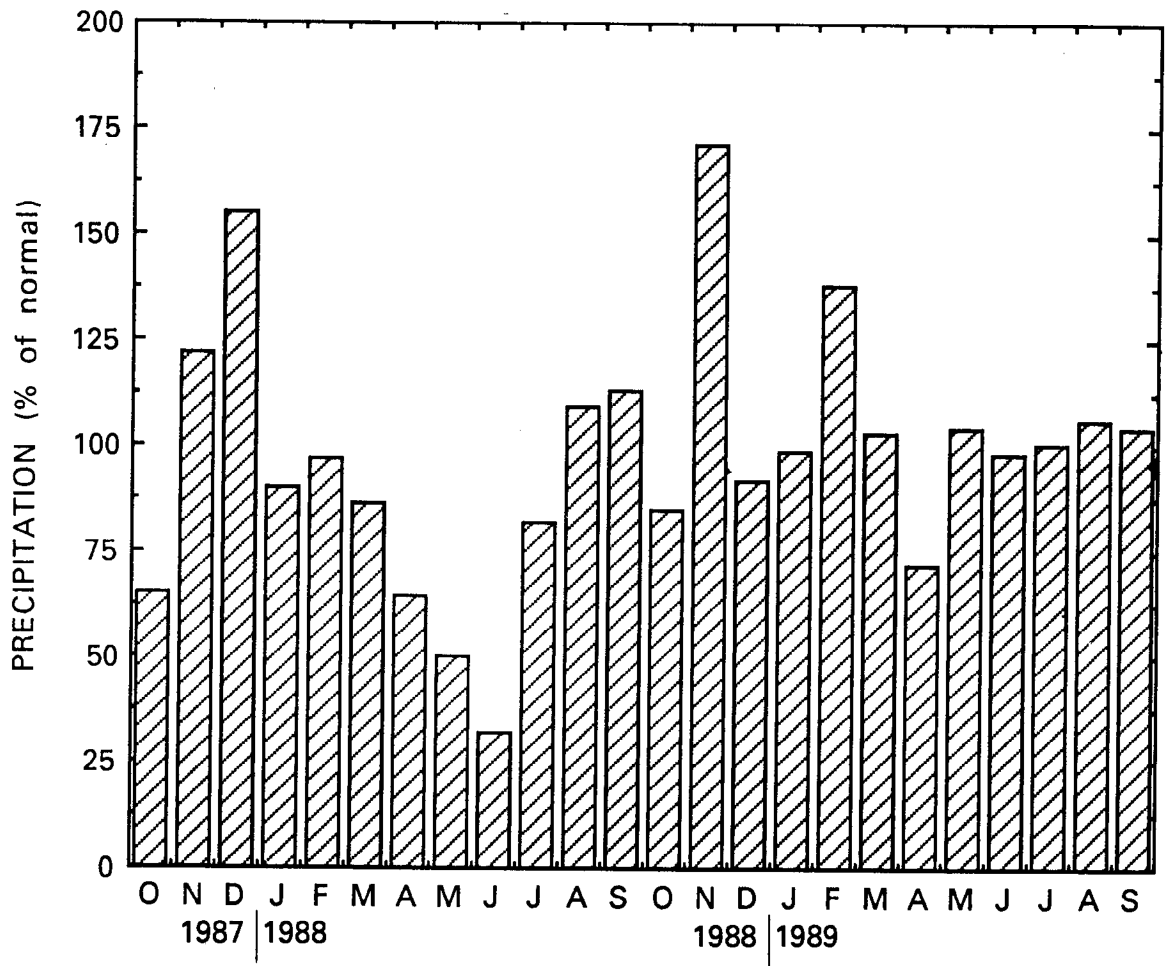

Figure 3.2. Monthly median percent of normal precipitation received
in each of 75 midwestern climate divisions, October 1987-September 1989:
normals used were 1951-1980 calendar monthly averages

MIDWEST CLIMATE CENTER

Precipitation March-September
Percent of Normal

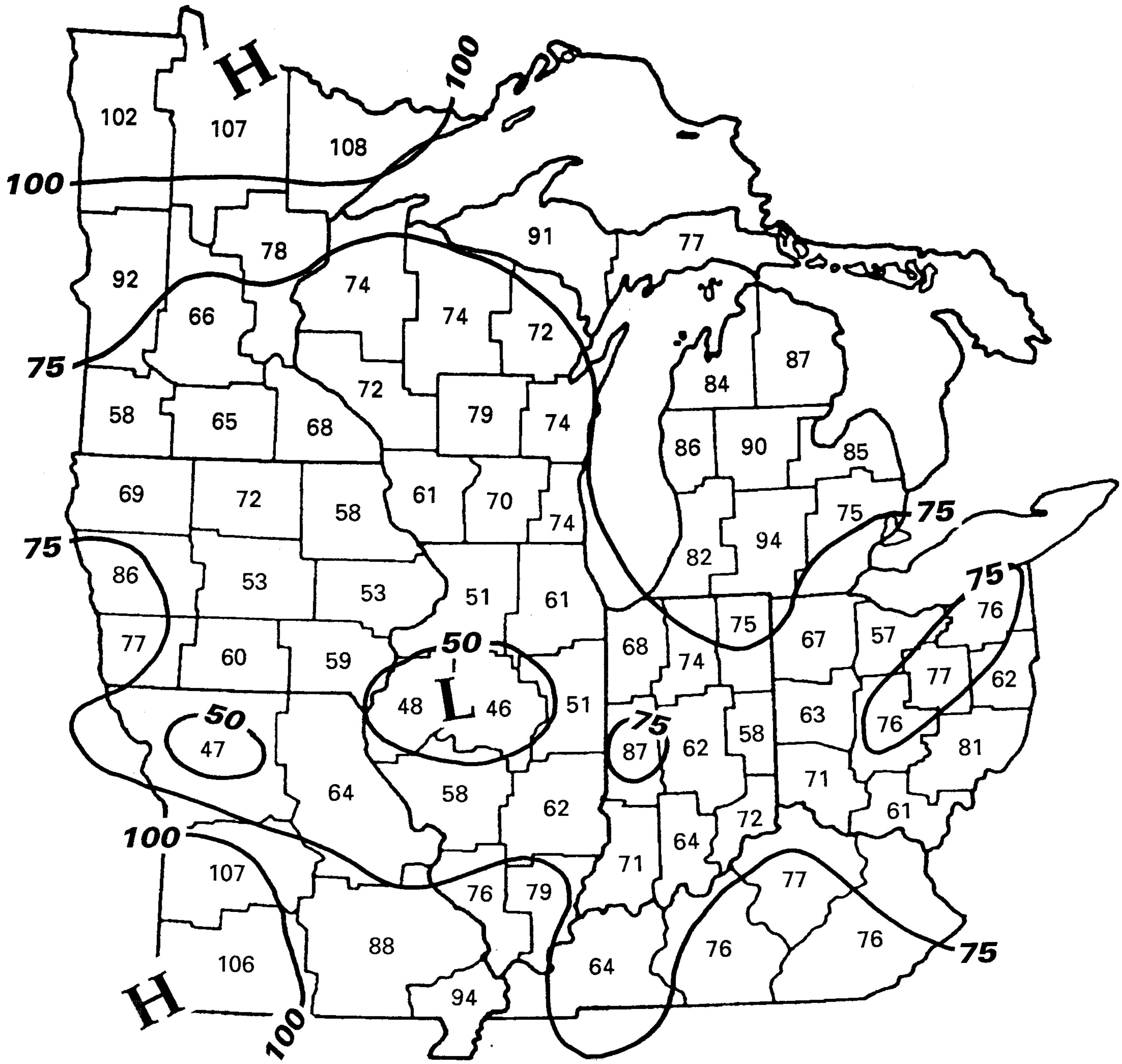

Figure 3.3. Percent of normal (1951-1980) precipitation
for 75 midwestern climate divisions, March-September 1988,
with 73 percent being average

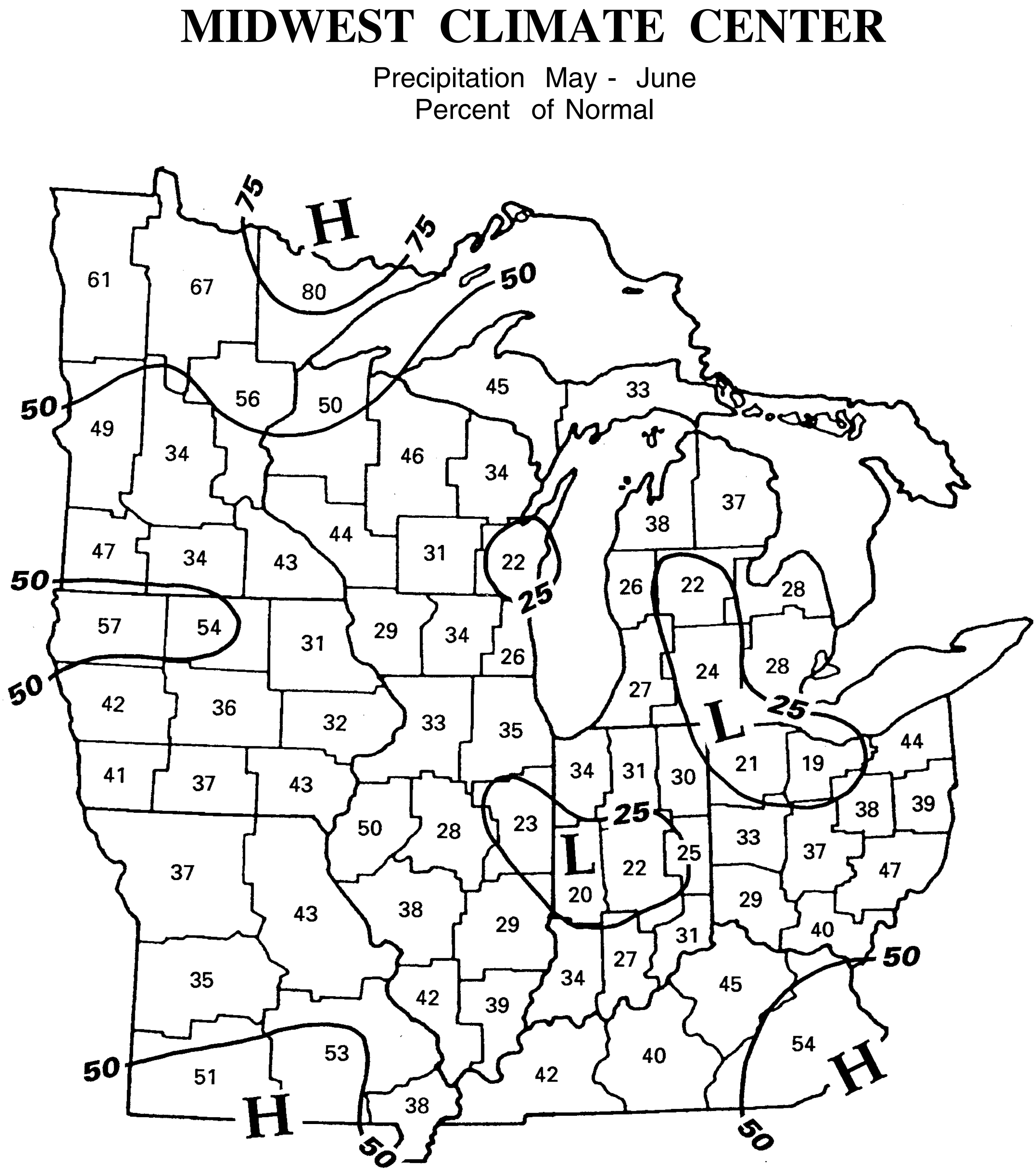

Figure 3.4. Percent of normal (1951-1980) precipitation for 75 midwestern climate divisions, May-June 1988, with 38 percent being average

MIDWEST CLIMATE CENTER

Precipitation June - August
Percent of Normal

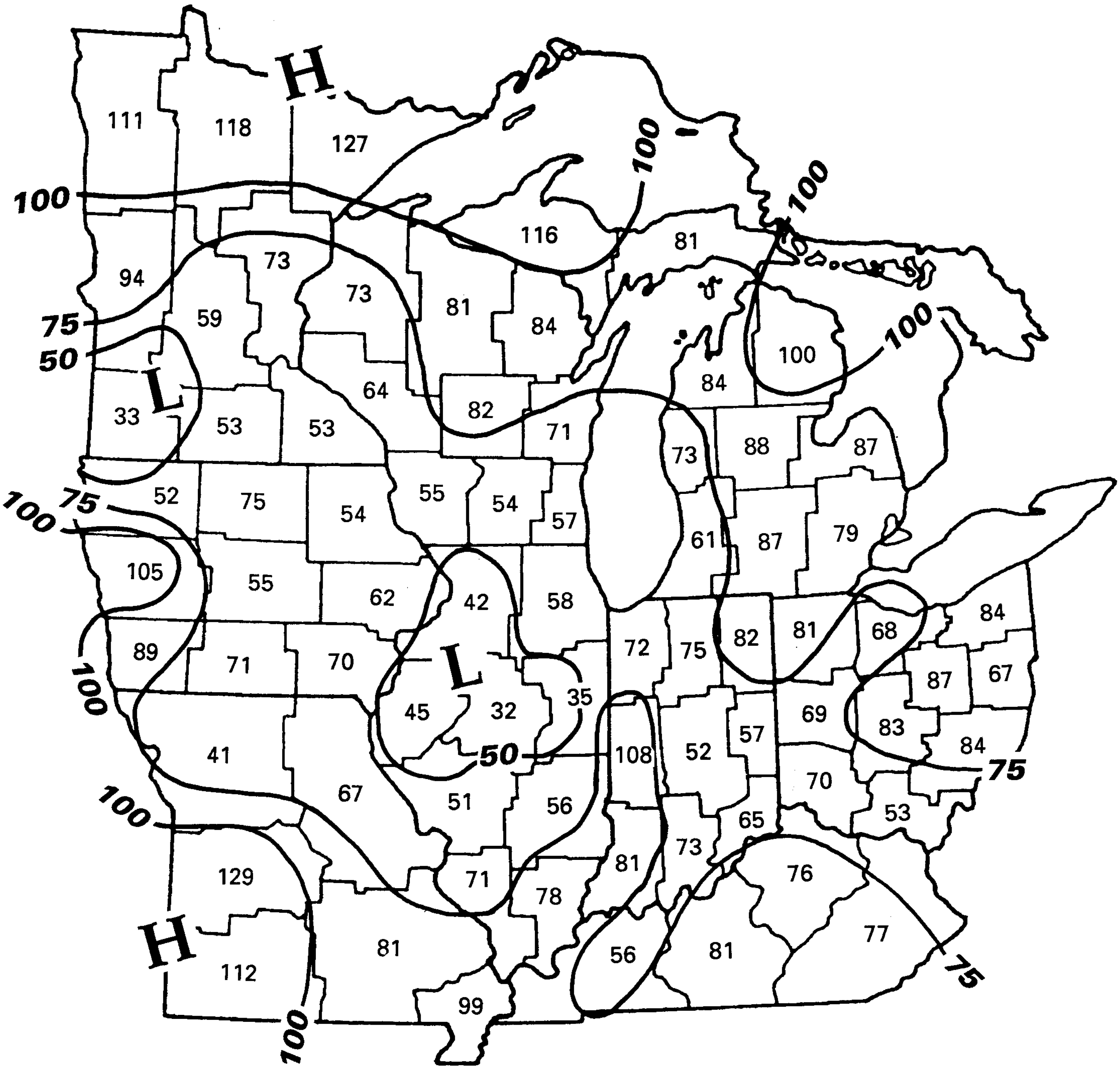

Figure 3.5. Percent of normal (1951-1980) precipitation for 75 midwestern climate divisions, June-August 1988, with 74 percent being average

MIDWEST CLIMATE CENTER

Rankings March - September
Precipitation

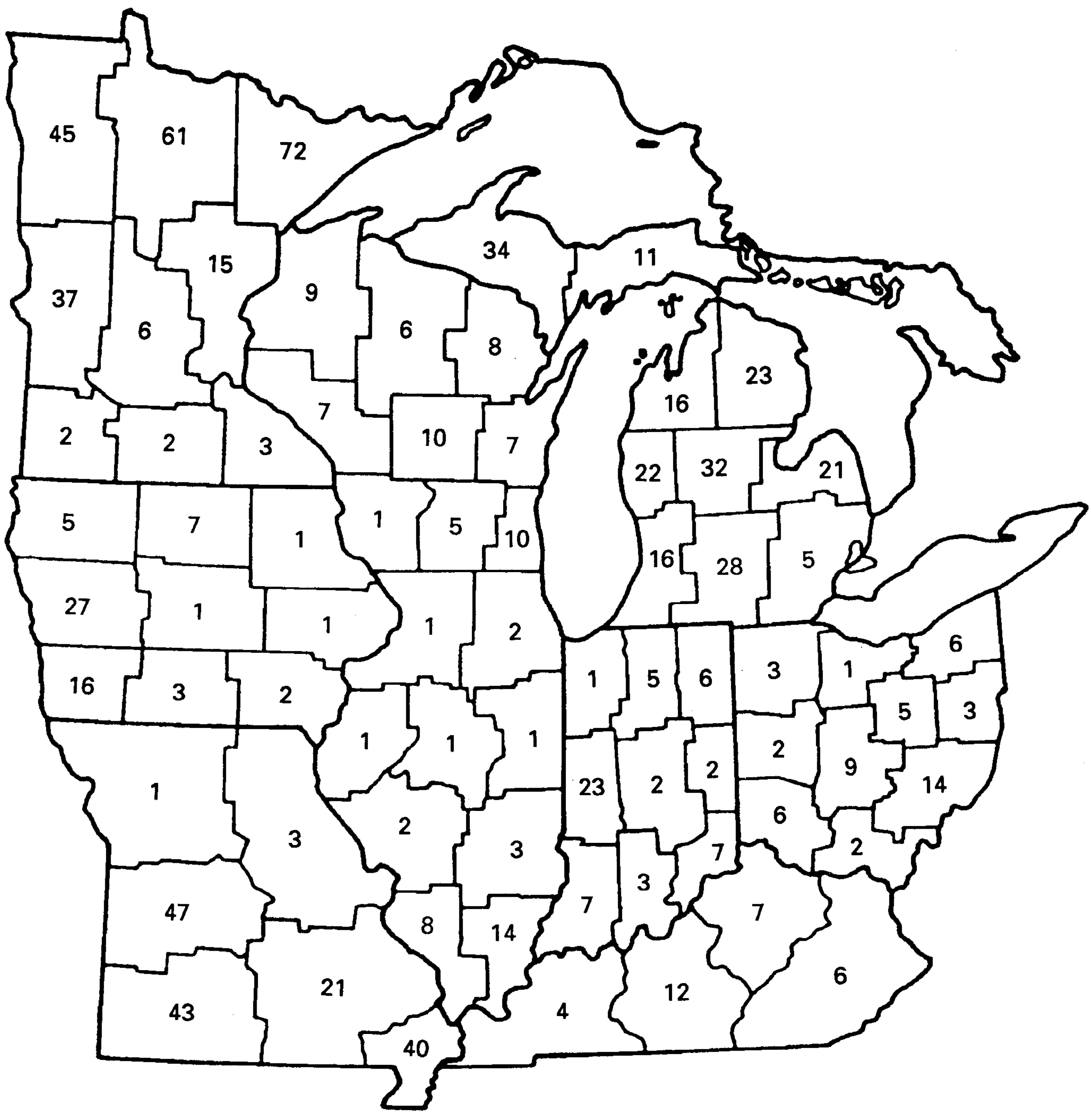

Figure 3.6. Ranking of March-September 1988 climate division precipitation totals
vs. long-term (1895- 1988) records for each division:
a ranking of 1 indicates that 1988 was the driest March-September on record

MIDWEST CLIMATE CENTER

Rankings May - June
Precipitation

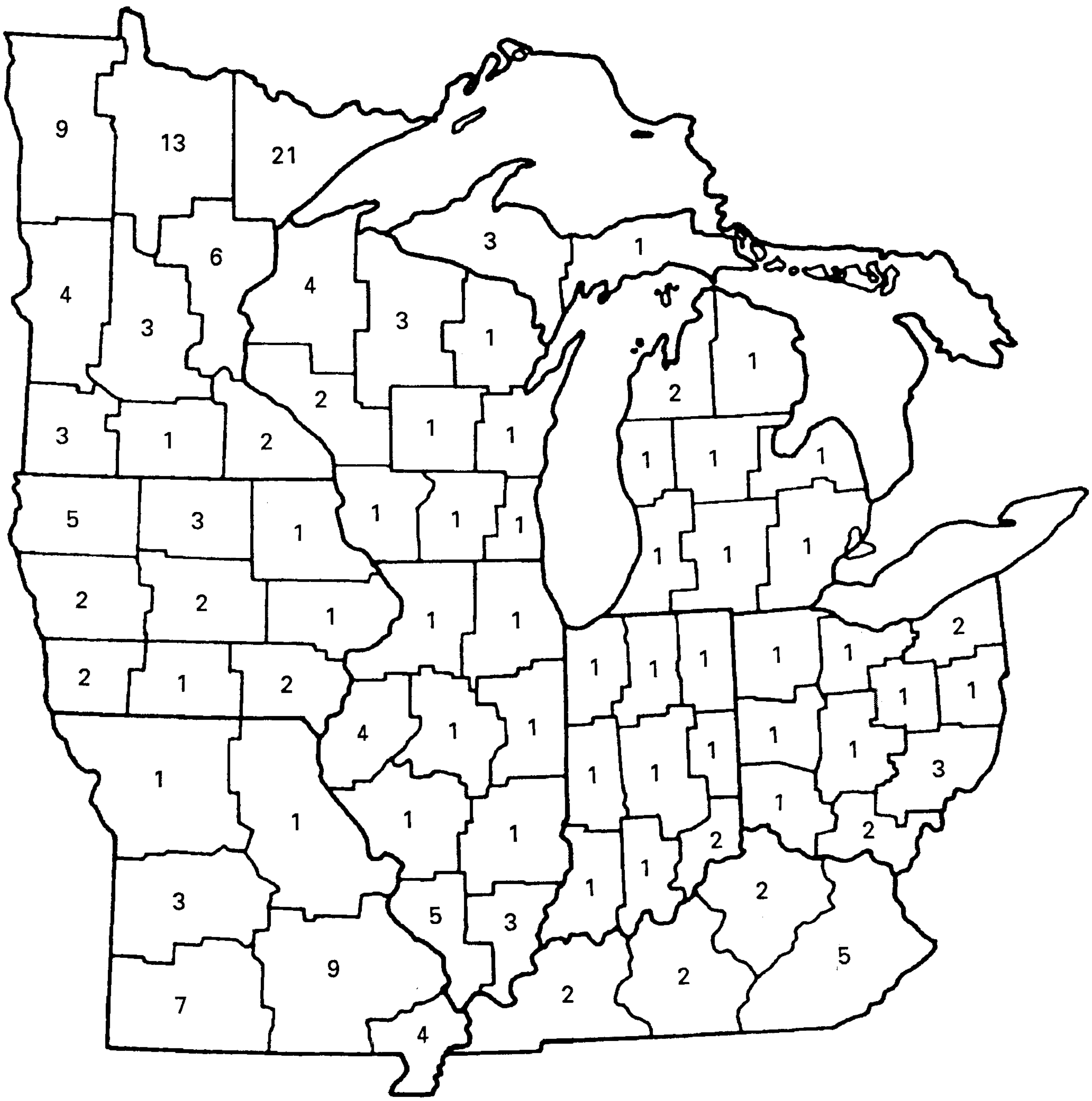

Figure 3.7. Ranking of May-June 1988 climate division precipitation totals vs. long-term (1895-1988) records for each division: a ranking of 1 indicates that 1988 was the driest May-June on record

MIDWEST CLIMATE CENTER

Rankings June -August
Precipitation

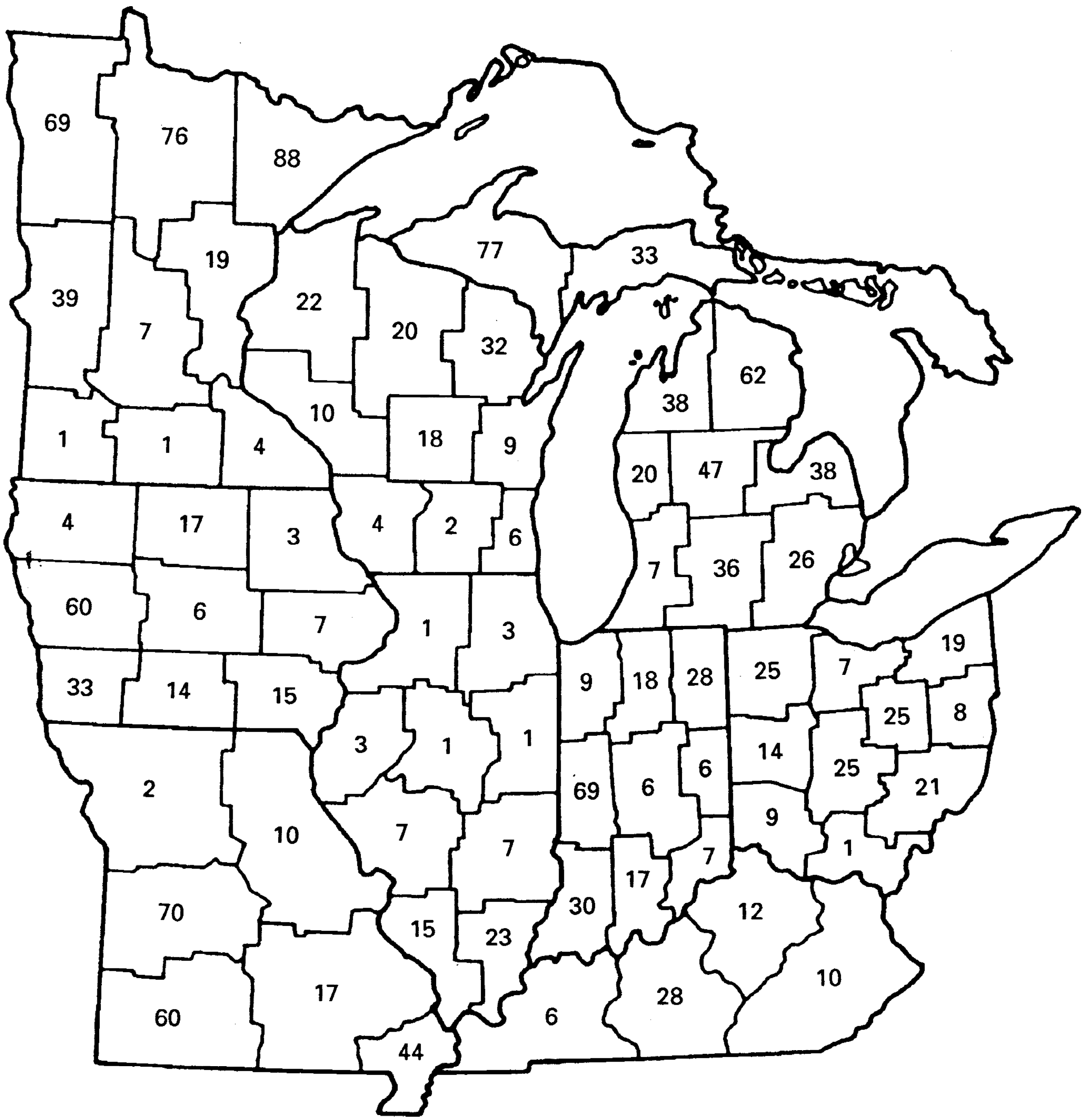

Figure 3.8. Ranking of June-August 1988 climate division precipitation totals vs. long-term (1895-1988) records for each division: a ranking of 1 indicates that 1988 was the driest June-August on record

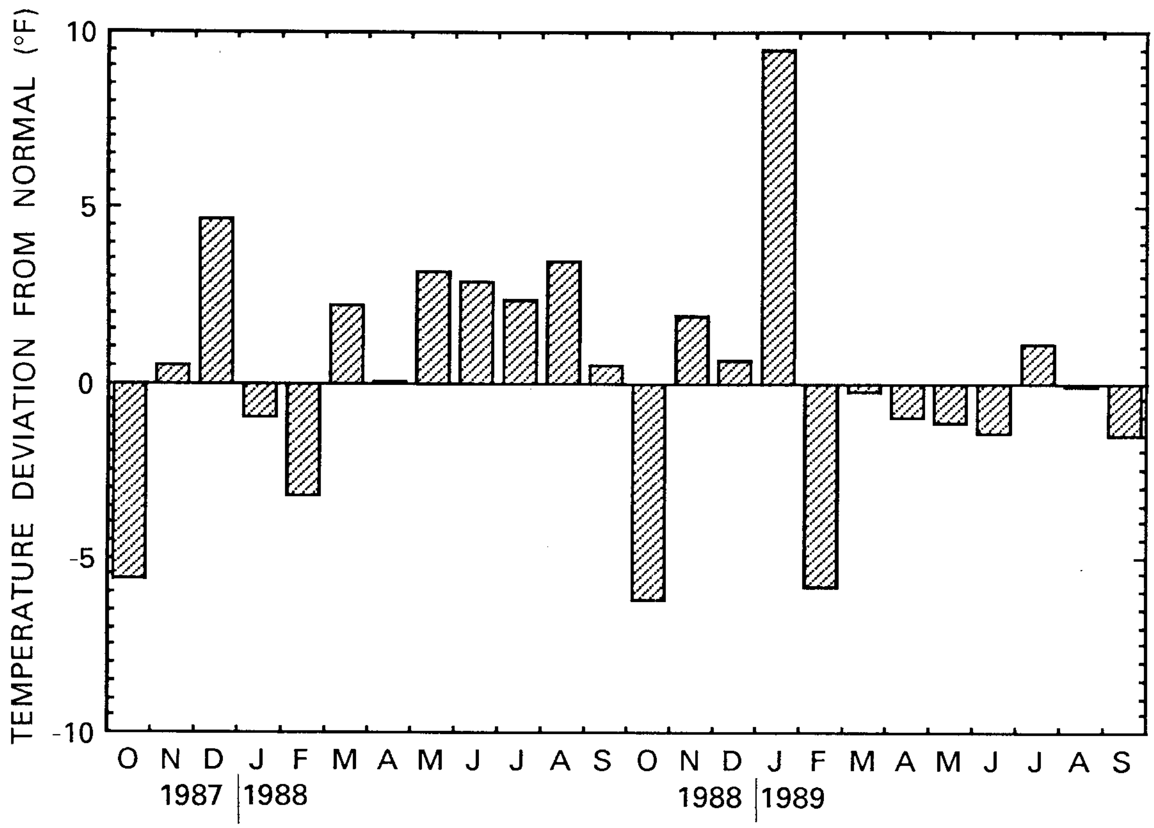

Figure 3.9. Average deviation from normal of monthly mean temperature (°F) for 75 midwestern climate divisions, October 1987-September 1989: normals used were 1951-1980 calendar monthly averages

MIDWEST CLIMATE CENTER

Temperature June - August
Departure from Normal

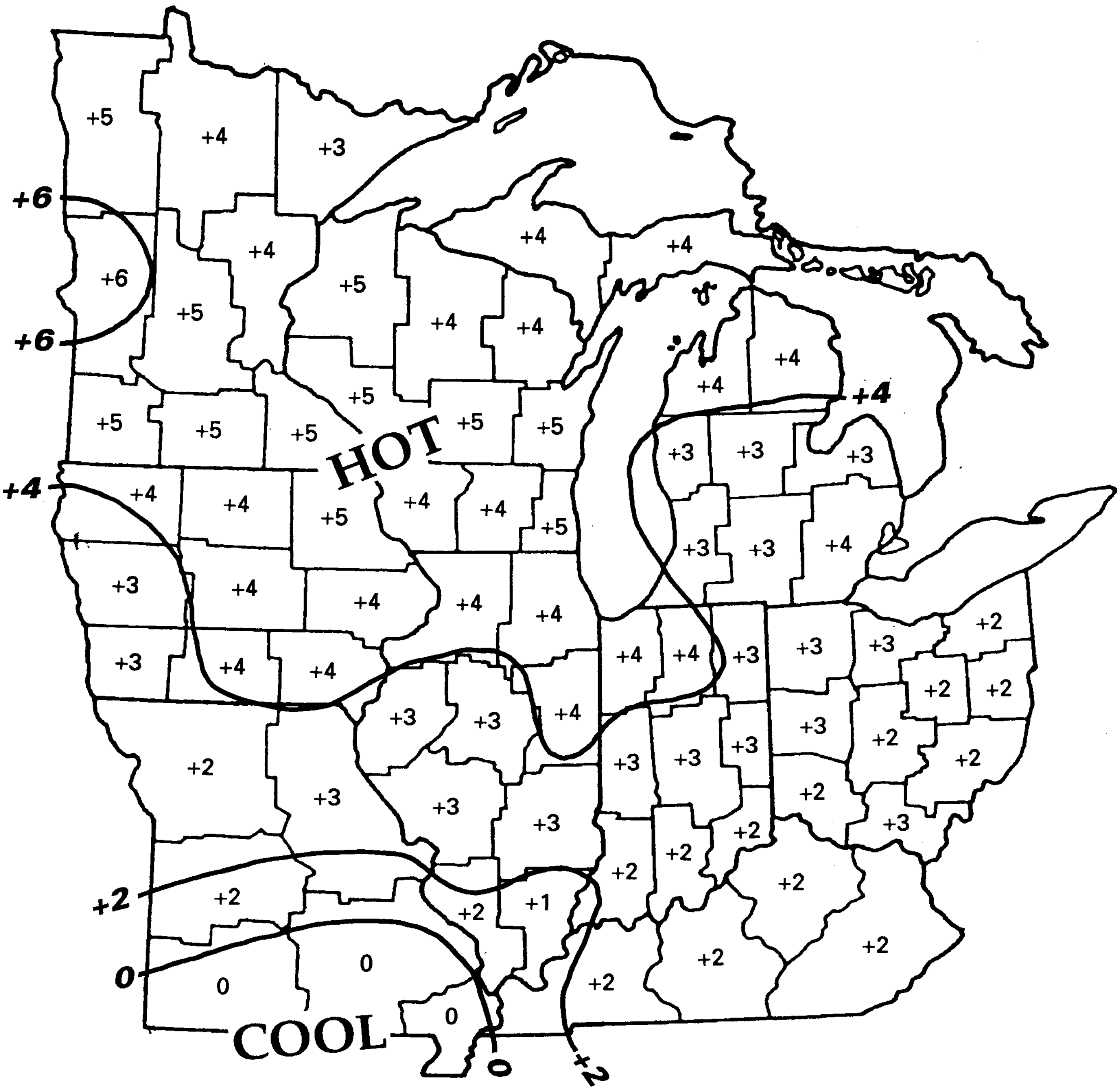

Figure 3.10. Mean temperature departure (°F) from 1951-1980 average
for 75 midwestern climate divisions, June-August 1988,
with +3.3°F average departure

MIDWEST CLIMATE CENTER

Rankings June - August
Temperature

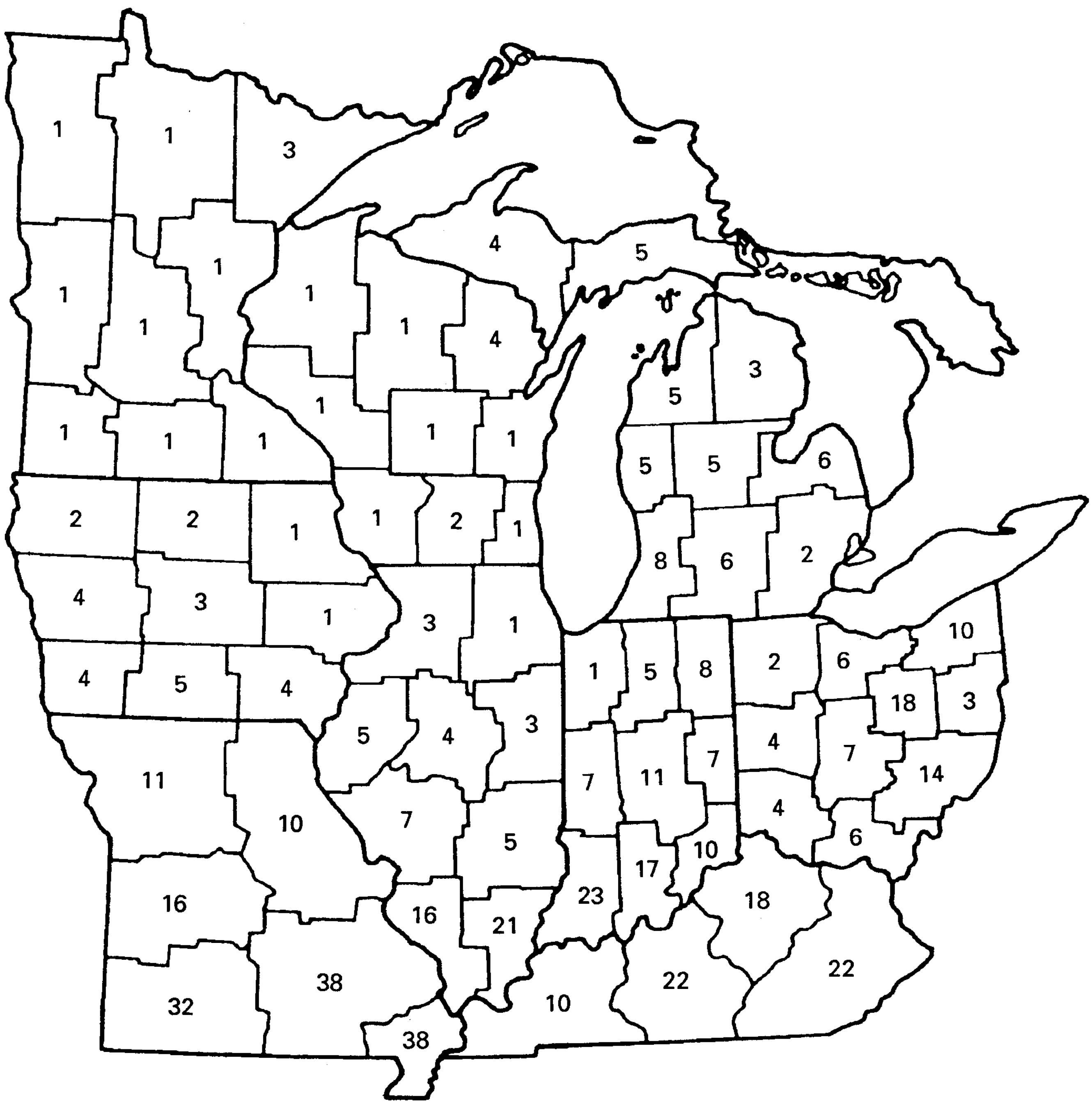

Figure 3.11. Ranking of June-August 1988 climate division mean temperatures
vs. long-term (1895-1988) records for each division:
a ranking of 1 indicates that 1988 was the hottest June-August on record

MIDWEST CLIMATE CENTER

Palmer Drought Index
September, 1988

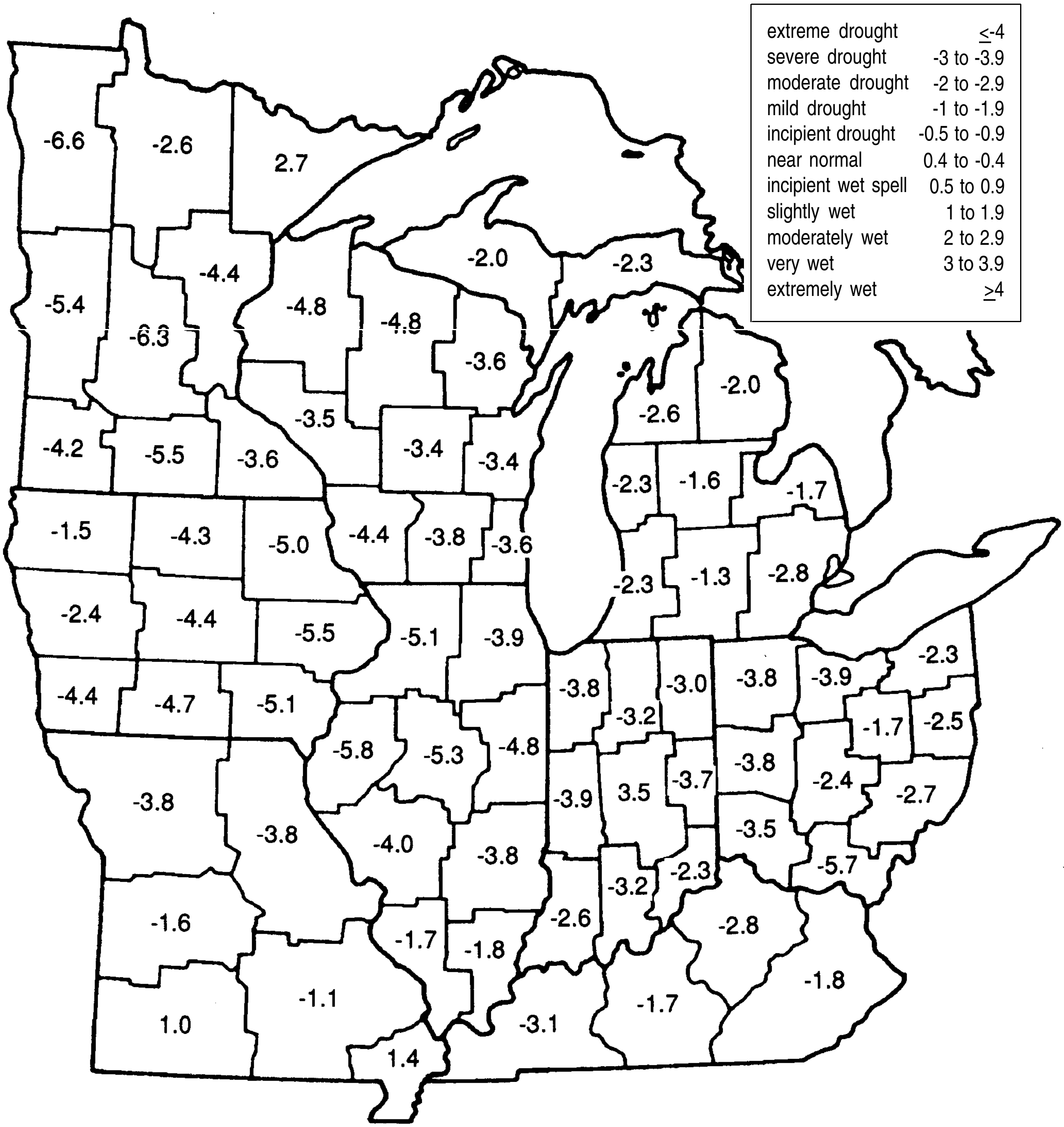

Figure 3.12. Palmer Hydrological Drought Index values for 75 midwestem climate divisions, September 1988

MIDWEST CLIMATE CENTER

Palmer Drought Index
September, 1989

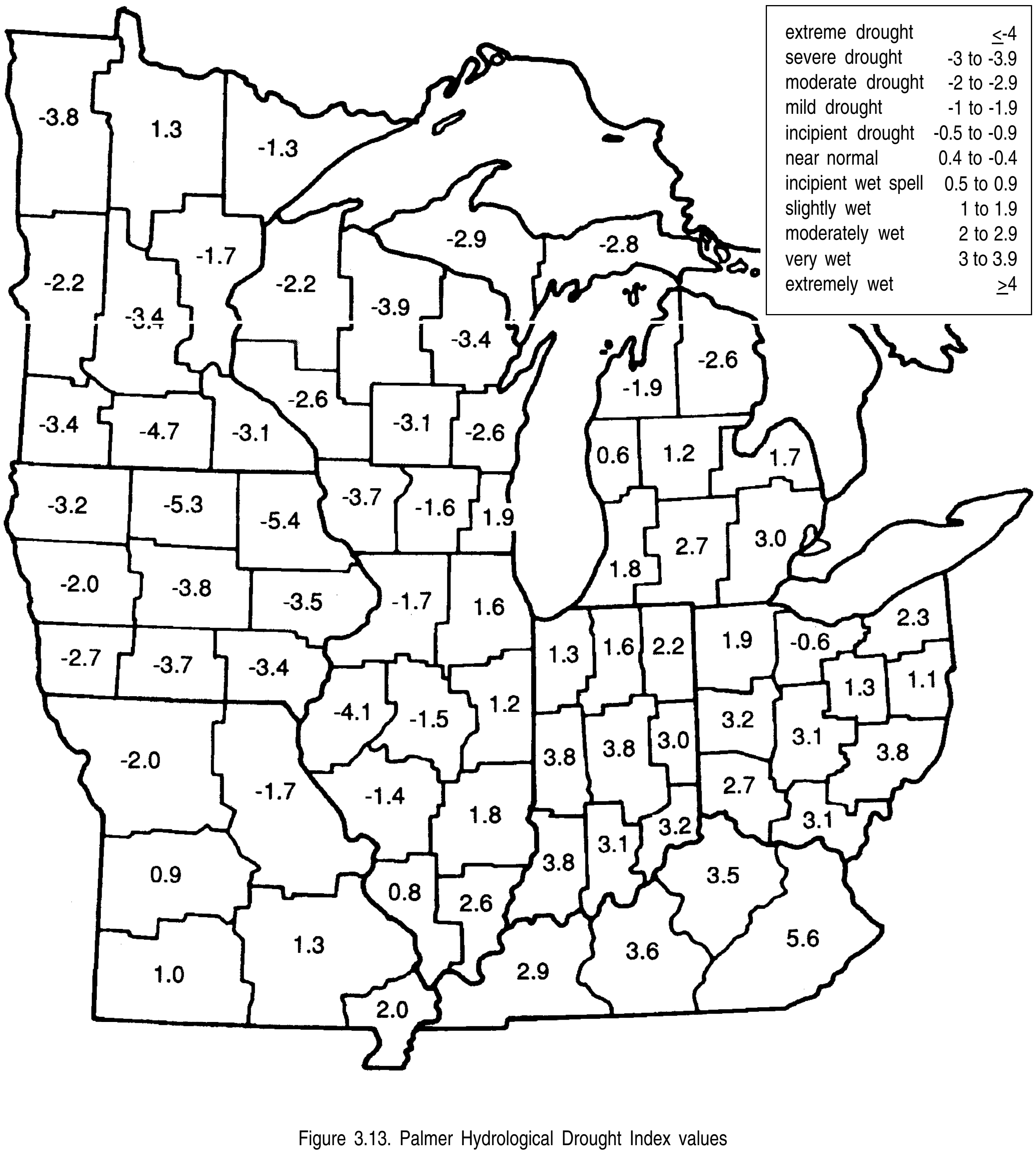

Figure 3.13. Palmer Hydrological Drought Index values for 75 midwestern climate divisions, September 1989

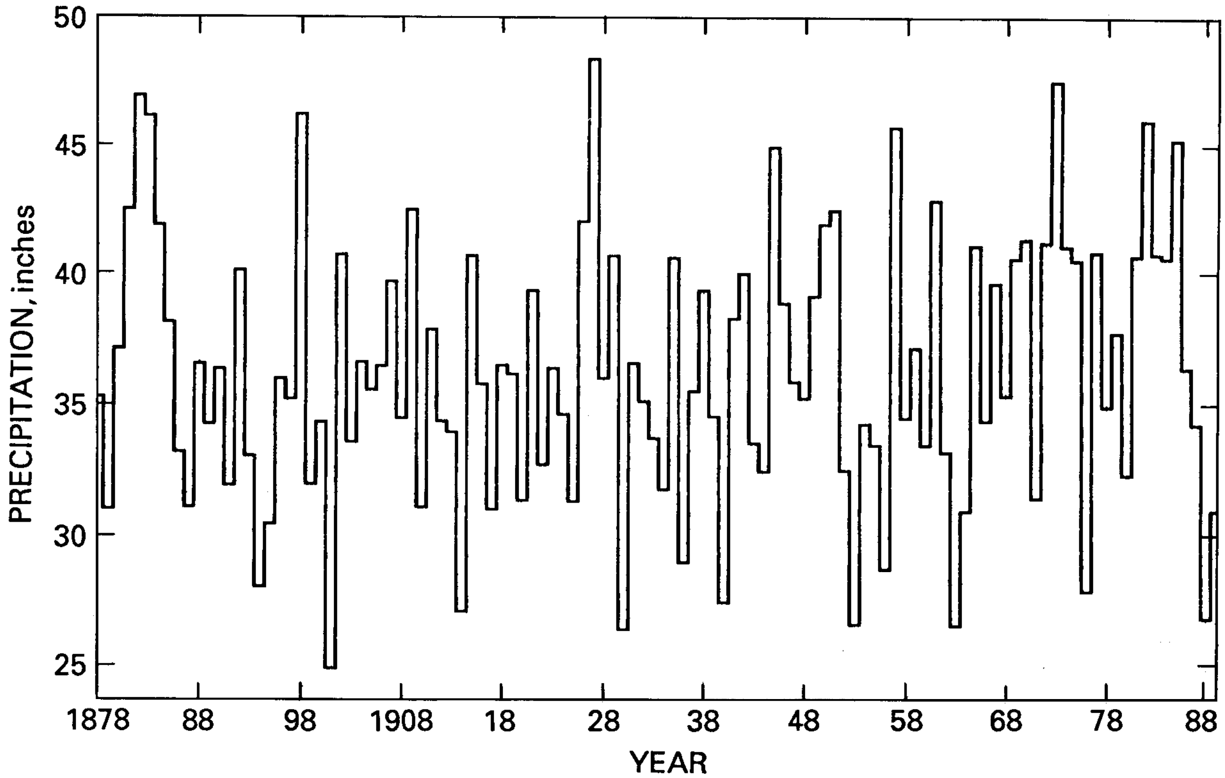

Figure 3.14. Illinois statewide annual mean precipitation (inches) based on available National Weather Cooperation Stations, 1878-1989. Statewide 113. year mean 37.60 inches. ±1 standard deviation indicated on figure. (Reprinted by permission of the American Water Resources Association and W.M. Wendland.)

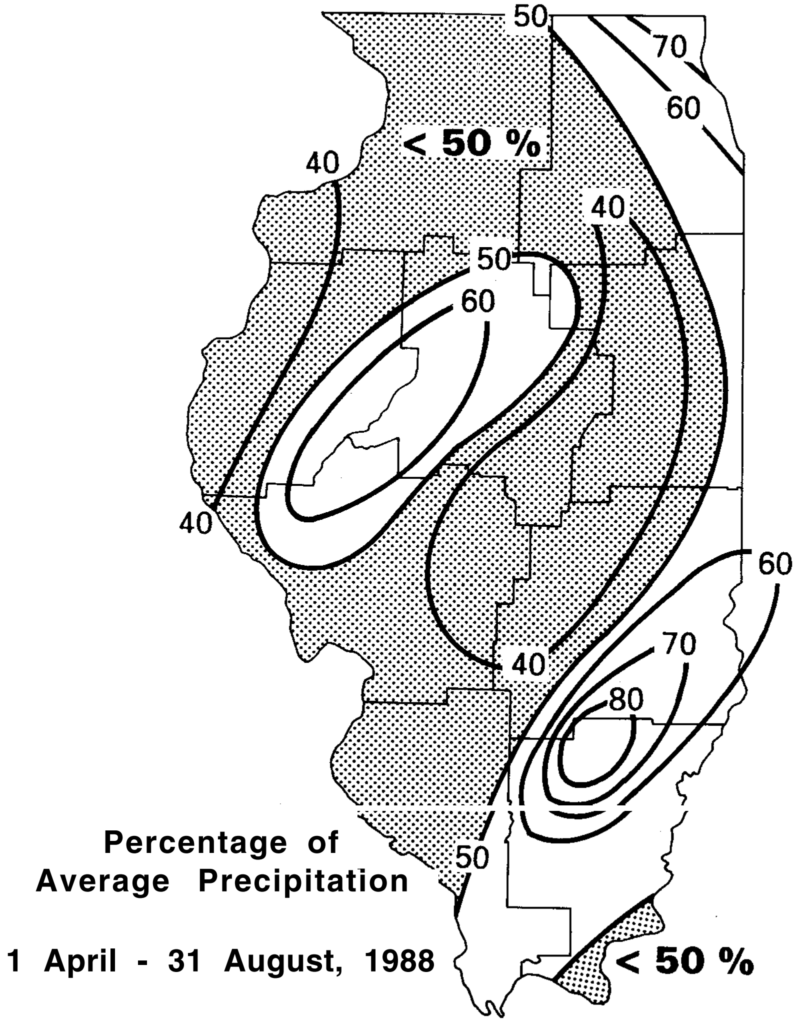

Figure 3.15. Precipitation from April 1-August 31, 1988, expressed as percent of 1951-1980 mean (Reprinted by permission of the American Water Resources Association and W.M. Wendland)

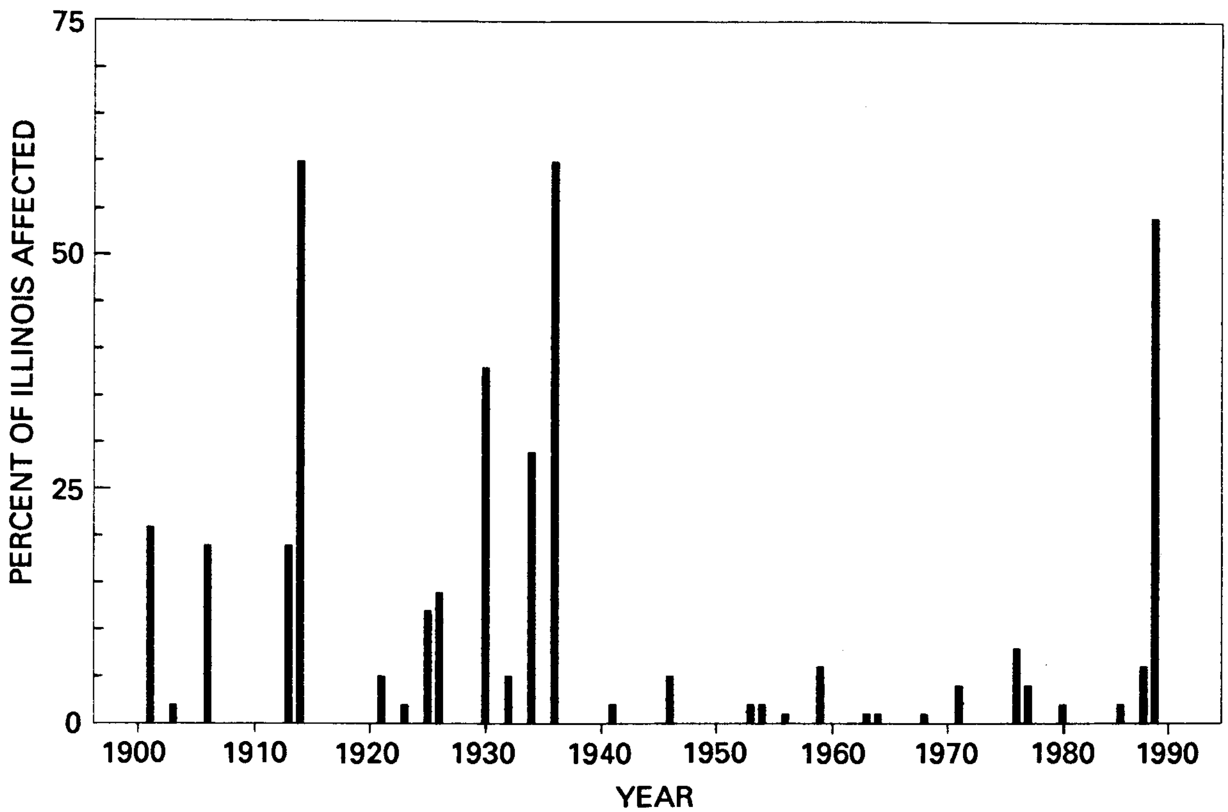

Figure 3.16. Percent of Illinois impacted by April-August droughts (defined as <50 percent of 1951-1980 average) from 1901-1989 (Reprinted by permission of the American Water Resources Association and W.M. Wendland)

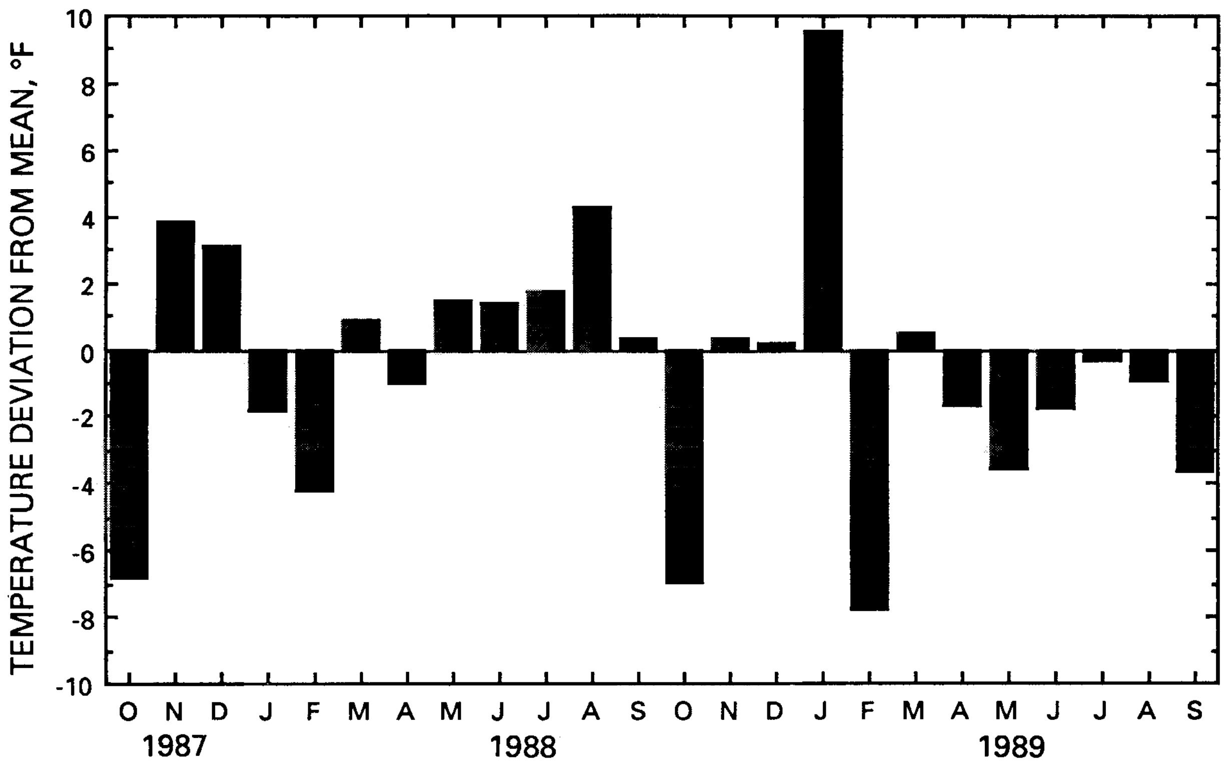

Figure 3.17. Temperatures in Illinois for 75 midwestern climate divisions from late 1987 through late 1989 (Adapted from 1990 *Water Resources Bulletin* 26(6):918; reprinted by permission of the American Water Resources Association and W.M. Wendland)

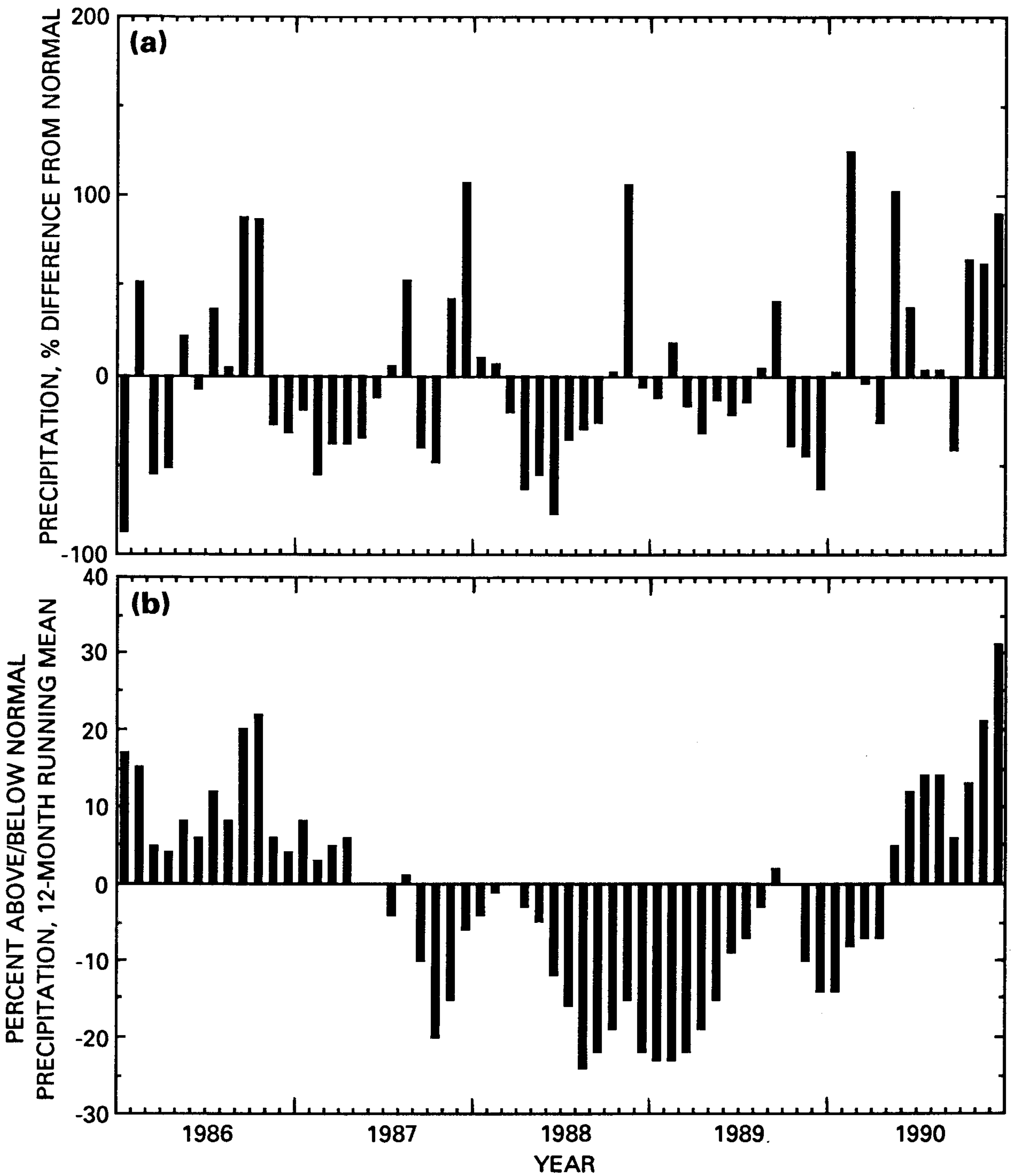

Figure 3.18. Statewide monthly precipitation, 1986–1990, showing (a) Percent difference from normal and (b) 12-month running mean time series, percent above and below normal (Adapted from 1990 *Water Resources Bulletin* 26(6)918; reprinted by permission of the American Water Resources Associatin and W.M. Wendland)

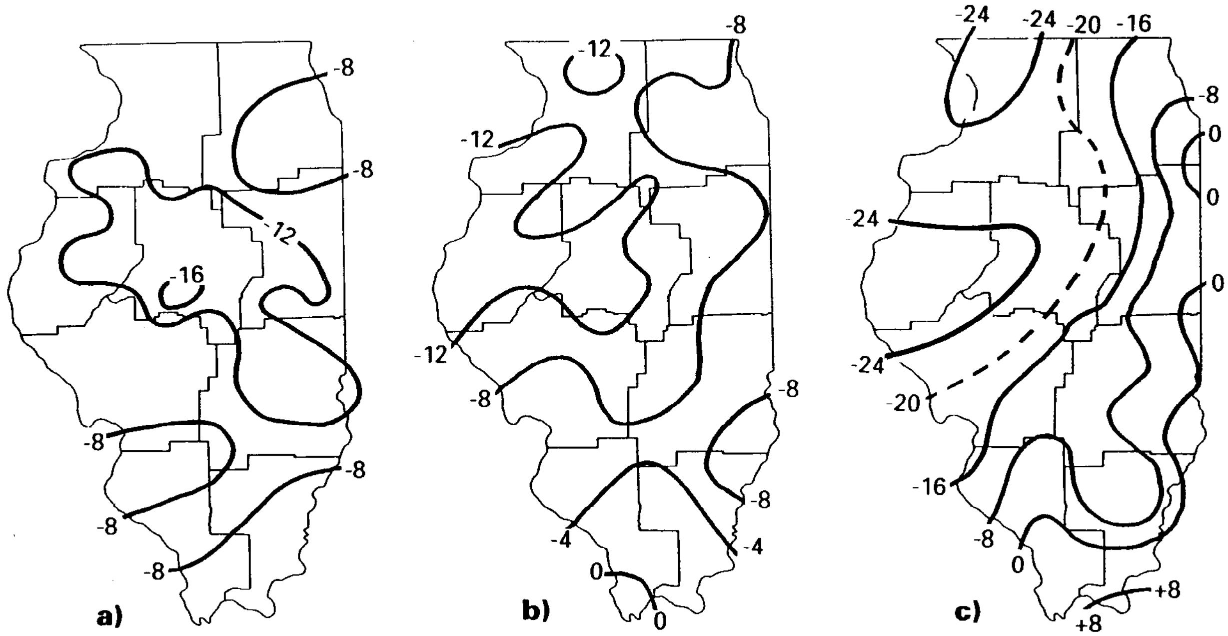

Figure 3.19. Precipitation deficit (inches) for (a) April 1-August 31, 1988; (b) April 1-December 31,1988; and (c) April 1-May 30, 1990 (Reprinted by permission of the American Water Resources Association and W.M. Wendland)

Table 3.1. Illinois Statewide Monthly Precipitation for Water Years 1988 and 1989, as a Percentage of the 1951-1980 Monthly Means

Water Year 1988 (1987-1988)	
October	48
November	142
December	211
January	144
February	109
March	95
April	46
May	44
June	23
July	54
August	57
September	86

Water Year 1989 (1988-1989)	
October	98
November	207
December	94
January	83
February	121
March	84
April	82
May	85
June	65
July	75
August	83
September	119

4. SOIL MOISTURE, PLANT WATER USE, AND SURFACE HEAT EXCHANGES

by
Steven E. Hollinger, Douglas M. A. Jones, Kenneth E. Kunkel, and Diane H, Portis

This chapter documents the effects of the precipitation and temperature anomalies described in the preceding chapter on the soil moisture conditions across Illinois. The impacts of the changes in soil moisture on plant water use and on the transfer of heat between the atmosphere and the vegetated land surface are also considered for a representative Illinois location. Since soil moisture status exerts a profound influence on surface water and ground-water conditions, the material presented here provides important background for the consideration of those other components of the hydrological cycle in chapters 5 and 6.

The research reported here was stimulated by the fact that one of the first visible signs of the 1988 drought was a pronounced drying of the soil during April and May. This drying was especially severe under grassed surfaces where soil water was being tapped for early spring crop growth. Fields being prepared for planting experienced significant drying of their surface layers, while the deeper soil layers tended to remain relatively moist.

The unique research opportunity offered by these developing environmental conditions was capitalized on fully because of some relatively new observational capabilities of the Water Survey. Those capabilities include the direct measurement of soil moisture and of the transfer of heat and water vapor between the earth's surface and the atmosphere. The latter measurements permit inferences regarding the extent to which drought is self-perpetuating.

4.1. Soil Moisture Monitoring

Commercial neutron probes designed to measure soil moisture content near the surface and to a depth of 2 meters (m) have been used to monitor the change of soil moisture at up to 17 sites across Illinois since 1981 (figure 4.1). During the 1988-1989 drought, all 17 stations were fully operational.

Measurements were made at all available sites twice each month during March-September and near the first day of the remaining months. In addition, the first station established (Bondville, near Champaign) has been sampled once per week since its record began in -February 1981. Thus the Bondville site, on a Flanagan soil, has a much more detailed soil moisture record than is available for the other sites across the state.

At each site, a neutron probe access tube is installed beneath a grassed surface. The access tubes extend to a depth of 2 m, and moisture readings are taken at each 20-centimeter (cm) depth from the soil surface. Additionally, a surface soil moisture reading is made by using a surface soil moisture neutron probe.

The neutron probe emits fast neutrons into the soil medium. When the neutrons collide with hydrogen atoms, they are slowed down, reflected back to the probe, and counted by a sensor in the probe. The number of slow neutrons counted is directly related to the number of hydrogen atoms in the soil. Because soil water is the largest and most variable source of hydrogen atoms in the soil, a direct correlation exists between the number of slow neutrons detected by the probe and the soil water content. Thus, as the soil dries out, fewer slow neutrons are sensed by the probe, indicating less water in the soil.

The neutron probe data from the 17 sites for the summers of 1987,1988, and 1989 were used to monitor the effects of the drought on the soil moisture conditions in the northern, central, and southern zones of the state. The northern zone was defined as the area north of Interstate 80, the southern zone the area south of Interstate 70, and the central zone the intervening area (figure 4.1). For each zone, the neutron counts were used to obtain averages of total water, total plant-available water, and percent of maximum plant-available water in the soil.

Plant-available water'is defined as the amount of water held in the soil that is available for use by plants. It can best be visualized by imagining the soil as a sponge. When water from heavy or frequent rains completely fill the soil pore space, the soil is said to be saturated. Not all of this water is available to the plant, however, because a part of it is pulled out of the pore space by the force of gravity.

After the soil has drained for approximately 24 hours, the soil is said to be at field capacity, and it holds the maximum amount of water that is available to the plant. When the soil has dried out to the extent that the plant can no longer pull water from the soil colloid fast enough to maintain its life, the soil is said to be at the permanent wilting point. Even though the plant cannot obtain any more water from the soil, some water remains in the soil. The maximum plant-available water is the quantity of water held between the field capacity and the permanent wilting point of the soil.

4.2. Soil Moisture Conditions, October 1986 – October 1989

Conditions throughout Illinois

Figures 4.2–4.4 show time series that indicate the total amount of water in four soil layers (0-15 cm, 15-50 cm, 50-100 cm, and 100-200 cm) in the northern, central, and southern zones of Illinois from October 1987 through September 1990. These figures readily show that soil moisture was lower during the 1988 spring–summer period than during the rest of the three water years documented.

These time series also clearly depict the general annual cycle of soil moisture for Illinois, particularly the October–March recharge period and the water deficit months of April through September. The horizontal lines on the 0-15-cm, 15.50-cm, and 50-100-cm time series indicate the amount of water held in each layer at the permanent wilting point. For the 50-100-cm layer in the southern zone and the 100-200-cm layer in all three zones, the amount of water held at the permanent wilting point is less than the lowest water amount shown and therefore is not indicated in the figures.

An important general feature related to figures 4.2–4.4 is that the northern and southern zones of the state experienced marginal soil moisture conditions during two of the three years shown, while the central zone had marginal soil moisture conditions in all three years. In the south, the dry years were 1987 and 1988, while the dry years in the north were 1988 and 1989. Therefore these data show a south-to-north migration of deficient soil moisture conditions during the three years. The following sections present the results for each of the three zones in greater detail.

Conditions in Northern Illinois

In the northern zone of Illinois, soil moisture reached its annual maxima on February 1, 1987; March 1, 1988; and March 1, 1989. The driest soil conditions occurred in May 1987, August 1988, and August 1989. Similar soil moisture deficiencies were experienced during August 1988 and August 1989, but the dry conditions persisted longer in 1988 than in 1989 (e.g., sub-wilting point values for the 0 -15-cm and 15-50-cm layers).

A further difference in soil moisture between 1988 and 1989 occurred in the 50-100-cm layer, where the recharge was greater in the 1987–1988 winter than during the 1988–1989 winter. The l00-200-cm soil moisture time series shows a continued drying throughout the three-year period, with only minor recharge occurring during the 1988–1989 winter.

Conditions in Central Illinois

In central Illinois, the soil was drier during the summer of 1987 (figure 4.3) than in the northern zone. During the summers of each of the three years, soil moisture in the 0-15-cm layer reached the wilting point at some time. The principal difference between the three years in this regard is the length of time that this condition persisted.

In 1987, the 0-15-cm wilting point was reached in mid-May and continued through mid-June, followed by a slow recharge throughout the rest of the summer. In 1988, the 0-15-cm wilting point was reached in mid-May and continued throughout the rest of the summer and through the end of October. Soil moisture in the 0-15-cm layer in central Illinois returned to a maximum in January 1989 and then decreased to a minimum in September 1989. The period of 1989 when soil moisture in the 0-15-cm layer was near the wilting point was relatively short (August through September).

The foregoing 1987–1989 temporal pattern was also characteristic of the 15-50-cm soil layer (figure 4.3). However, in 1989 soil moisture was more abundant in this deeper layer in central Illinois than farther north.

The soil moisture variability in the 50-l00-cm and 100-200-cm layers was higher in central Illinois than further north. Of particular interest is the moisture spike in central Illinois during September 1987 (figure 4.3). This occurred although the rainfall *totals* for that month were below normal across the zone. However, approximately 50millimeters (mm) of rain was received around September 15, just before and during the soil moisture measurement period.

The immediate return to drier soil moisture conditions after that time suggests that the soil layers below the 200-cm level were sufficiently dry for water to drain through them following these rains. The soil moisture spike thus appears to have resulted from the movement of water through the soil during the measurement period.

Conditions in Southern Illinois

The summers of 1987 and 1988 were both characterized by low soil moisture in southern Illinois (figure 4.4). Although soil moisture was slightly more abundant during the 1987 summer than during the 1988 summer, the dry period was longer in 1987 than 1988. Twice during the 1988 summer, soil moisture fell below the wilting point throughout the 0-50-cm soil layer. The first period was from late June until mid-July, and the second period ran from late August through October. The intervening soil moisture increase in this zone was due to rain during the last two weeks of July. During the winter of 1988–1989, the soil moisture in the southern zone was recharged by plentiful precipitation (649 mm); rains also kept the soil moisture conditions in a favorable state throughout most of the 1989 summer. By the time the soil had dried excessively in 1989, the crops were close to maturity.

4.3. Soil Moisture Deficit in Top 2 Meters

Table 4.1 shows the moisture deficits in the top 2 m of the soil in the northern, central, and southern zones of Illinois on April 1 and September 30 of 1987, 1988, and 1989. At most of the stations (figure 4.1), the deficits on these dates were concentrated in the top meter of the soil profile, with only minor moisture deficits occurring in the l-2 m soil layer.

On September 30 the central and southern portions of the state generally experienced greater soil moisture deficits than the northern zone. However, on April 1 these zones had smaller deficits than the northern zone as a result of having had more precipitation during the winter.

Both northern and central Illinois experienced their driest April 1 soil moisture conditions in 1989. Southern Illinois had its driest April 1 soil conditions in 1987. In general, the greatest September 30 soil moisture deficiencies in the state occurred in the southern zone, where a deficit of greater than 200 mm was recorded each year in the top 2 m. In 1988, the driest soils on September 30 were located in central Illinois. The wettest soil conditions at the end of summer occurred in 1989, when both central and southern Illinois were wetter than in September 1987 and 1988. Northern Illinois experienced its wettest September 30 soil conditions in 1987.

4.4. Comparison of Soil Moisture under Grassed and Cropped Surfaces

The soil moisture conditions documented in the preceding section occurred under grassed surfaces. However, the soil moisture in cultivated fields can be significantly different from the soil moisture under grass. In a cultivated field, when a crop is not actively growing, soil moisture loss occurs only through evaporation from the soil surface and is restricted to the top 10 cm of soil. It is likely that the steep soil moisture decline observed in the early spring of 1988 (figures 4.2–4.4) was delayed by approximately two to three weeks in fields where spring-planted crops were growing.

However, the resulting June–July soil moisture decrease would have been greater than the corresponding May–June decline under grass because of greater water requirements for cultivated crop growth and their rapid root development.Likewise, the recharge of soil moisture in the fall after the crop had stopped growing should have been earlier and quicker than the recharge under grass.

In an attempt to quantify this effect, a neutron access tube was installed in a cornfield approximately 50 m from the neutron access tube in the grassed area at Bondville (figure 4.1) in late June 1988. Measurements were made at the two sites through the end of October 1988. The soil moisture levels for the cultivated field with growing corn remained higher than for the sodded area except in the very deep layer (50-100 cm), from which corn roots removed more water than the grass roots. When the corn matured in late August, the soil moisture was recharged earlier in the cultivated field than under the sod. This was due to the continued growth of grass throughout September and October.

4.5. Lessons Learned and Plans for Future Soil Moisture Monitoring

As the previous section suggested, using soil moisture under grass to monitor the soil moisture available for crops requires some estimation of the available water in cropped fields. The major difficulty in this procedure involves the different water demands of the various crops compared to the water demands of natural grass, which uses soil water earlier in the spring and later in the fall than other crops.

Because of this problem, future monitoring of soil moisture will include the use of the Illinois Climate Network (ICN) to track the atmospheric moisture demand. From the data gathered by the ICN, potential evapotranspiration will be estimated and then converted to actual evapotranspiration for individual crops through the use of crop coefficients for estimation of soil water use by these crops.

Soil moisture conditions will be monitored for each crop type by using a water balance method that takes into account the addition of water by rainfall and the subtraction of soil water by evapotranspiration. This approach will also require the development of a method to estimate the efficiency of a precipitation event to recharge the soil moisture profile.

In addition to estimating the amount of soil water removed from the profile, we will attempt to identify the portion of the profile from which the extraction occurred. This will require simulation of the growth of the crop based on a planting date for each crop reporting district. These data will be obtained from the *Illinois Weekly Crop Report.* The crop and root development rates will be simulated on a weekly basis by using the ICN temperature data to compute growing degree day accumulations. Through simulation of the root depth and development, an evaluation can be made of where the plant is obtaining its water.

4.6. Influence of Drought Soil Moisture Conditions on Surface Heat Exchanges

Experimental Objectives

The depletion of soil moisture may have impacts beyond direct moisture stress on crops. During a summer with plentiful rainfall, much of the incoming solar energy is used for the evapotranspiration of water, resulting in a flux of latent heat from the surface to the atmosphere. A substantially smaller percentage of the incoming solar radiation is used to directly heat the air via a flux of sensible heat from the surface.

However, after soil moisture is depleted, a much larger percentage of the solar energy is used to directly heat the air and much less to evaporate water. As a result, the air near the earth's surface tends to be hotter and drier than usual. During the early part of a drought, the large-scale circulation patterns are generally responsible for dry, hot conditions, as was shown in chapter 2. However, once a drought is established and has desiccated the soil, the change in the partitioning of the sun's energy between evapotranspiration and direct heating near the earth's surface can exacerbate the dry, hot conditions through a self-reinforcing (or positive feedback) process.

A field experiment was set up in late June 1988 in a typical east-central Illinois cornfield with the objective of measuring how the persisting drought was changing the partitioning of energy at the surface. This work had two potential applications:

1) Since the transpiration process is responsible for most of the evapotranspiration of water, the resulting data would provide one measure of the physiological response of corn to the drought environment.

2) These data could also provide information on the extent to which the drought was self-perpetuating. Once altered and established, the energy exchange processes may serve to maintain the drought conditions.

A convenient measure of the way energy is partitioned at the earth's surface is the Bowen ratio (B), which is given by:

$$B = \frac{\text{sensible heat flux}}{\text{latent heat flux}}$$

Some of the results of this experiment will be presented in terms of this ratio.

Experimental Method

The field site used for this experiment was located near Champaign, Illinois, at 40°6'N, 88°14'W, at an elevation of 228 m. A National Weather Service cooperative observer climatological station (Urbana) is located about 600 m from the field site. The dimensions of the field are 400 m (east-west) by 320 m (north-south). The experimental equipment was located 190 m from the eastern edge and 190 m from the southern edge of the field.

Estimates of the sensible and latent heat fluxes were obtained by using the well-known eddy correlation technique (e.g., Oke, 1978, pp. 323-325): This technique uses direct measurements of the rapidly covarying fluctuations of wind, temperature, and water vapor by means of which heat and water vapor are transferred between the surface and the atmosphere. The necessary fluctuations were measured by using a sonic anemometer (for vertical wind fluctuations), a fine-wire thermocouple (for temperature), and a Krypton hygrometer (for water vapor), all of which were manufactured by Campbell Scientific, Inc. Several other meteorological variables were simultaneously measured.

The meteorological variables and the eddy correlation parameters are listed in table 4.2, along with the instruments used. The eddy correlation sensors, the pyranometer, and the wind sensor were interrogated by a Campbell Scientific 21X datalogger at frequencies of 5 hertz or Hz (eddy correlation sensors) and 0.1 Hz (other sensors), and the values obtained were averaged over ten-minute intervals. In addition, neutron probe measurements of soil moisture were made once a week at the location of the eddy correlation equipment.

The eddy correlation sensors were placed at a height of 2.4 m above ground level. The average height of the corn canopy varied from 1.0 m at the beginning of the experiment (June 30) to 1.4 m at the end (August 18). However, because the eddy correlation sensors could be damaged by rain, measurements were not made on days with a chance for rain. In addition, measurements were usually restricted to daytime hours. Data were obtained on a total of 17 days.

Results

Table 4.3 compares the monthly precipitation totals and average temperatures at the field site during January–August 1988 with their long-term average counterparts. During the important part of the 1988 growing season (April–August), the total precipitation of 211 mm was only 43 percent of the normal for that period. Temperatures during the period were 1.1°C above normal. Daily maximum temperatures exhibited larger departures, averaging 2.8°C above normal.

Figure 4.5 presents time series of the daily values of precipitation, maximum and minimum temperature, and water vapor pressure at the field site for the period June 15–August 25. During this 72-day period, there were only two days on which more than 10 mm of rain were received. Daily maximum temperatures reached or exceeded 35°C on 21 days. During the early part of this period, the atmospheric water vapor content was unseasonably low, but more seasonable values were experienced during the latter two-thirds of the period.

Figure 4.5 also shows the Bowen ratio (B) and a calculated variable called the potential Bowen ratio, which is the value of B that would occur if soil moisture were plentiful. This was calculated by following Thom (1976). Also shown in figure 4.5 are the weekly soil moisture measurements for three layers (0-15 cm, 15-50 cm, and 50-100 cm), which are expressed as a percentage of the plant-available soil moisture. At the beginning of the experiment, soil moisture was very low in the top layer, with no available water for plants. The plant-available soil moisture values rose in response to the July rains, but they fell again in August. In the lower two layers, soil moisture was also low and fell continually through the period.

During the first half of July, measured B values were much higher than the potential values, indicating higher sensible heat and lower latent heat fluxes than would be expected over a well-watered surface. The rain in late July lowered B to near the potential value. However, the dryness after July 25 resulted in a return to high B values in mid-August.

It is interesting to consider the impact of this change in the surface energy budget on the overlying atmosphere. The difference between the measured and the potential evapotranspiration (obtained from potential Bowen-ratio calculations) was integrated over the daytime period. During the first half of July and during mid-August, the calculated differences were approximately 2.5 mm/day or 75 mm/month. This value is equivalent to about 65 percent of the long-term average precipitation rate for July (see table 4.3) and about half of the potential evapotranspiration.

A similar calculation was made for the sensible heat flux, integrating the differences between measured and potential values over the daytime period. Again focusing on early July and mid-August, the calculated differences represent an excess heating rate of about 4 megajoules per square meter per day ($MJ/m^2/day$). Assuming that this energy is uniformly distributed over a mixing depth of 2 kilometers (km) (e.g., Kaimal et al., 1976), this represents a temperature increase of about 2°C per day in excess of normal heating.

A cursory examination of the atmospheric water budget during mid-summer points to the importance of evapotranspiration as a source of water vapor. Two studies (Rasmussen, 1968; Portis et al., 1991) using July upper air data provided vertical profiles of the monthly average convergence/divergence of water vapor. Rasmussen's (1968) study covered the entire United States east of the Rocky Mountains for 1961 and 1962, while the Portis et al. (1991) analysis was restricted to the heart of the U.S. Corn Belt (a 1,300 x 750 km box bounded by 81.0°W, 97.0°W, 36.5°N, and 44°N) for 1975,1976, and 1979.

The meteorological characteristics of these years are described by Peppler and Lamb (1989). They varied from rather wet to dry, although none was nearly as dry as 1988.

Rasmussen's (1968) analysis showed a net convergence of water vapor over the eastern United States for the 100-900-millibar (mb) layer, with divergence above 900 mb. The July results of Portis et al. (1991) (which were extracted for this study from the overall

May–August results presented by Portis et al.) were less conclusive, showing divergence throughout the profile in two years and lower level convergence in only one year.

However, a general monthly water budget can be written as

$$\frac{\partial w}{\partial t} = C_1 + ET - D_u - P \quad (4.1)$$

where

w = mean water vapor content in vertical column

t = time

C_1 = integral water vapor convergence at lower levels

ET = evapotranspiration

D_u = integral of water vapor divergence at upper levels

P = precipitation

Since changes in mean columnar water vapor content are small during mid-summer, lower level convergence and evapotranspiration must be approximately balanced by upper level divergence and precipitation. Table 4.4 summarizes the results of the two above investigations. An estimate of evapotranspiration, calculated as the residual of equation 4.1, is also given. The average value of the evapotranspiration estimates is very close to the mean free water surface evaporation of 140 mm reported for July at the Urbana site by Farnsworth et al. (1982). The results in table 4.4 suggest that evapotranspiration is the major source of mid-summer water vapor in the Midwest, with lower level convergence of water vapor (transported from the Gulf of Mexico) being much smaller. This suggests that interannual variations in mid-summer evapotranspiration caused by soil moisture anomalies may have the potential to significantly affect precipitation.

The severe dryness of the early part of the 1988 growing season was widespread in the Midwest (Kunkel and Angel, 1989). For instance, most areas in Michigan, Ohio, Indiana, Illinois, Wisconsin, Iowa, Missouri, and Minnesota received less than 50 percent of their long-term average precipitation during May and June. Thus wide areas experienced an unseasonably large depletion of soil moisture reserves prior to the July–August period of maximum moisture demand. Therefore the surface heat exchange impact results presented here are qualitatively representative of a very large area of the central United States.

Conclusions

It is generally difficult to separate the effects of global-scale atmospheric forcing and regional-scale surface layer forcing on atmospheric circulation patterns. However, the measured changes in the surface energy budget of a typical Illinois cornfield during the 1988 drought appear to be sufficiently large to have provided a significant contribution to the reduction of precipitation and the observed persistence of the 1988 drought. The evapotranspiration decrease was significant when considered in the context of the overall mid-summer atmospheric water budget and may have helped extend the period of deficient precipitation. The increase in sensible heating significantly increased near-surface air temperatures, probably helping to promote the atmospheric subsidence that suppressed the precipitation, as well as reducing the atmospheric water vapor available for conversion into precipitation.

FIGURES AND TABLES

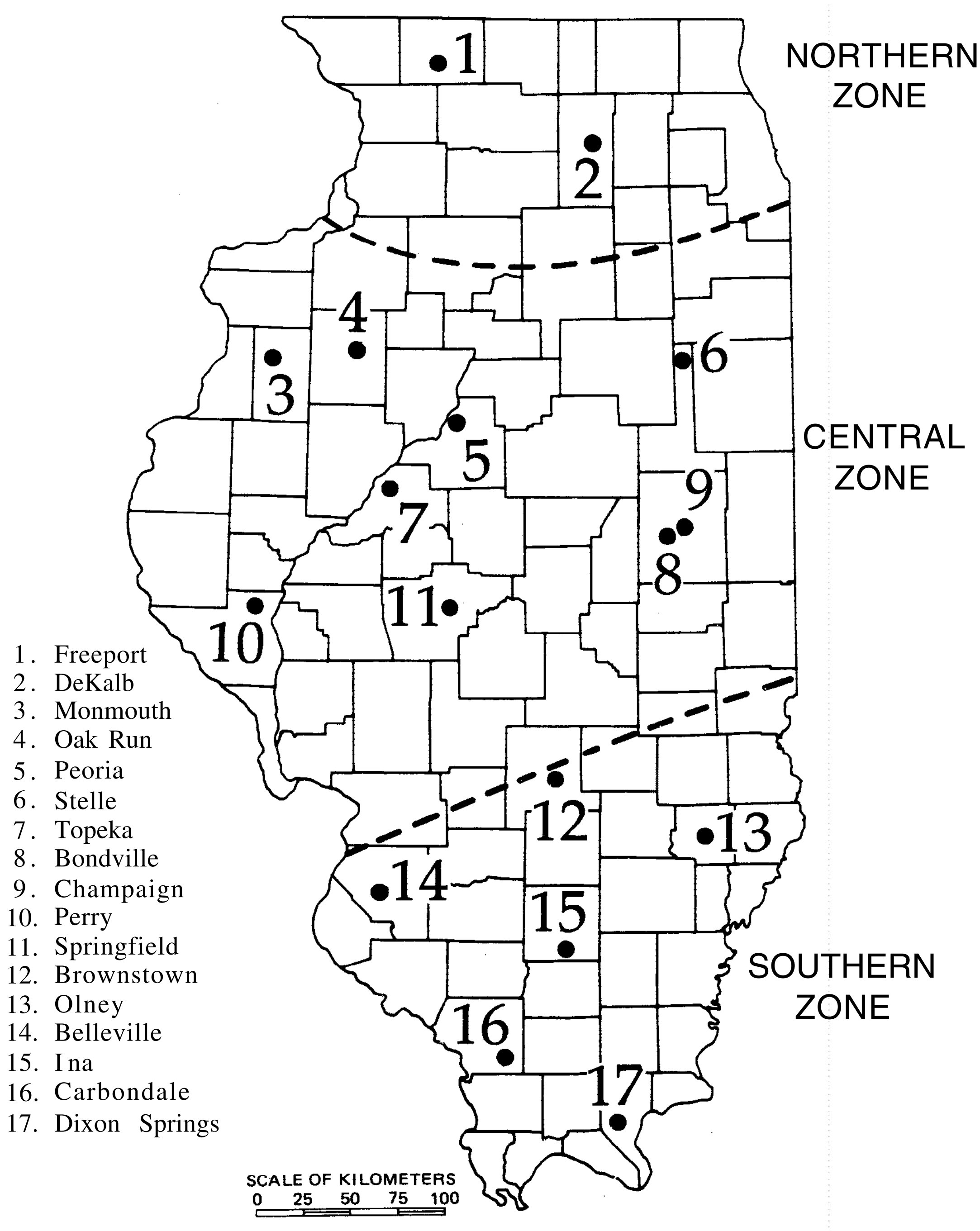

Figure 4.1. Location of soil moisture monitoring sites in Illinois

Northern

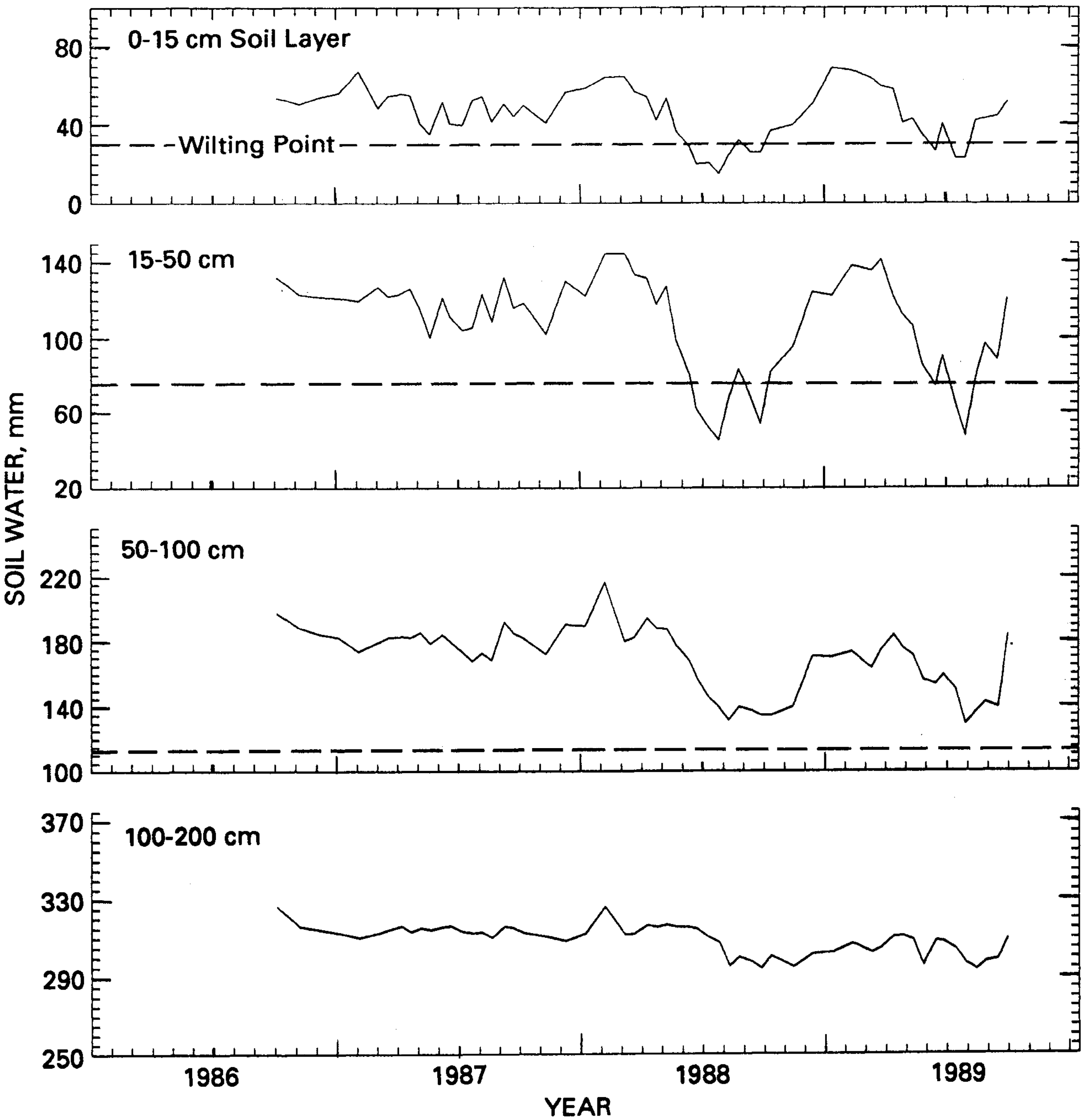

Figure 4.2. Total amount of soil water (millimeters) in indicated layers for northern zone of Illinois, October 1987-September 1989

Central

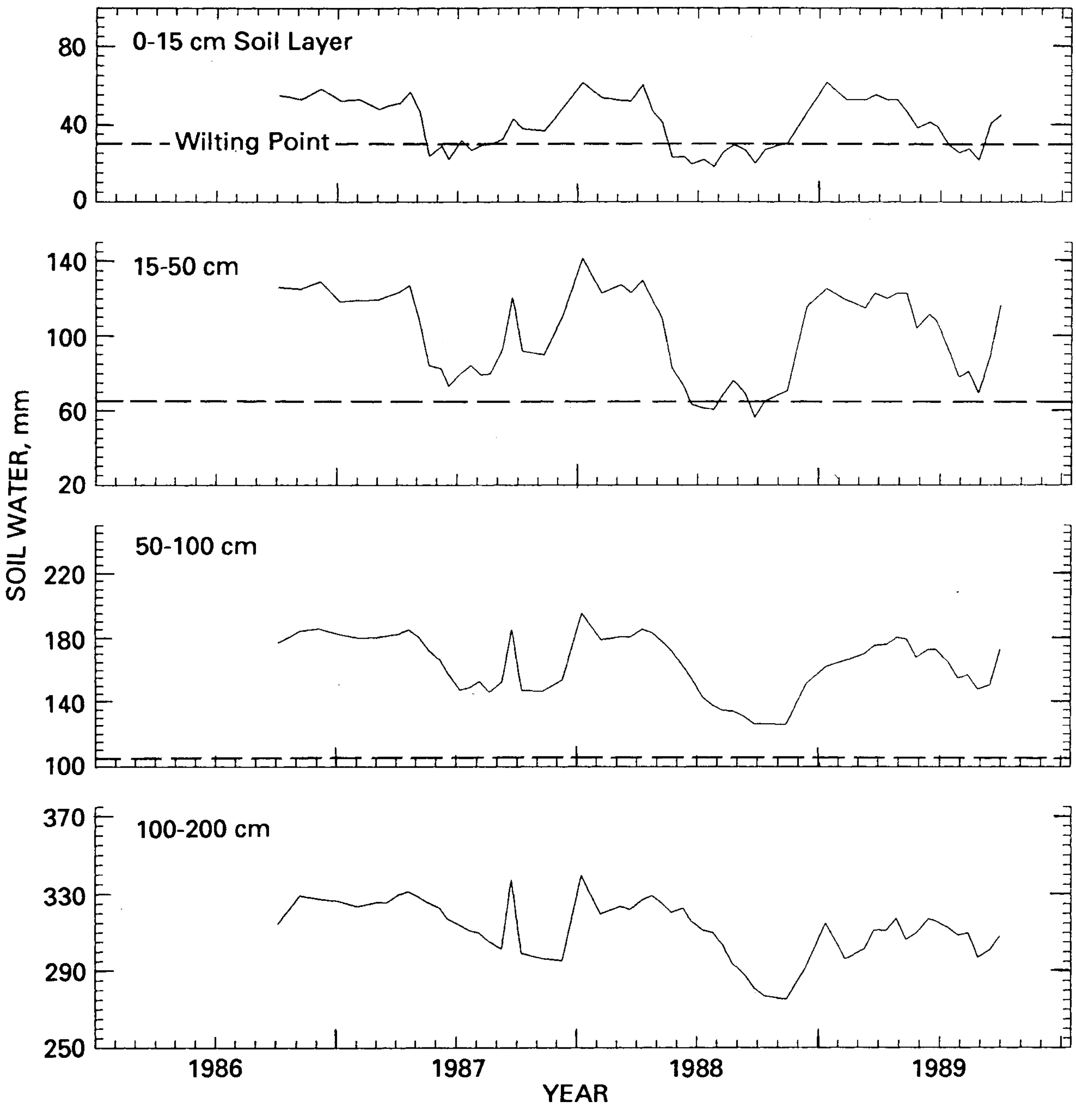

Figure 4.3. Total amount of soil water (millimeters) in indicated layers for central zone of Illinois, October 1987-September 1989

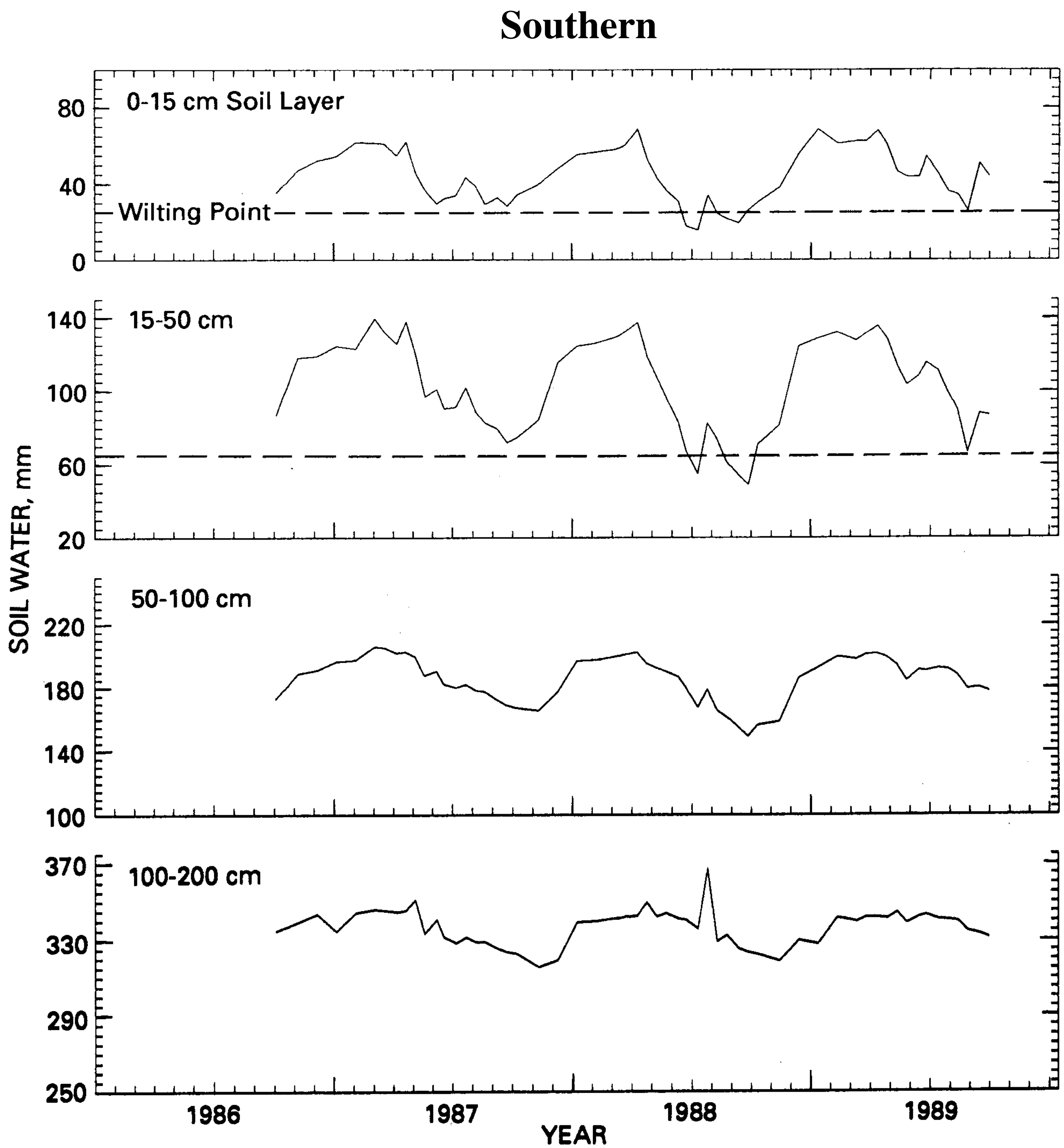

Figure 4.4. Total amount of soil water (millimeters) in indicated layers for southern zone of Illinois, October 1987-September 1989

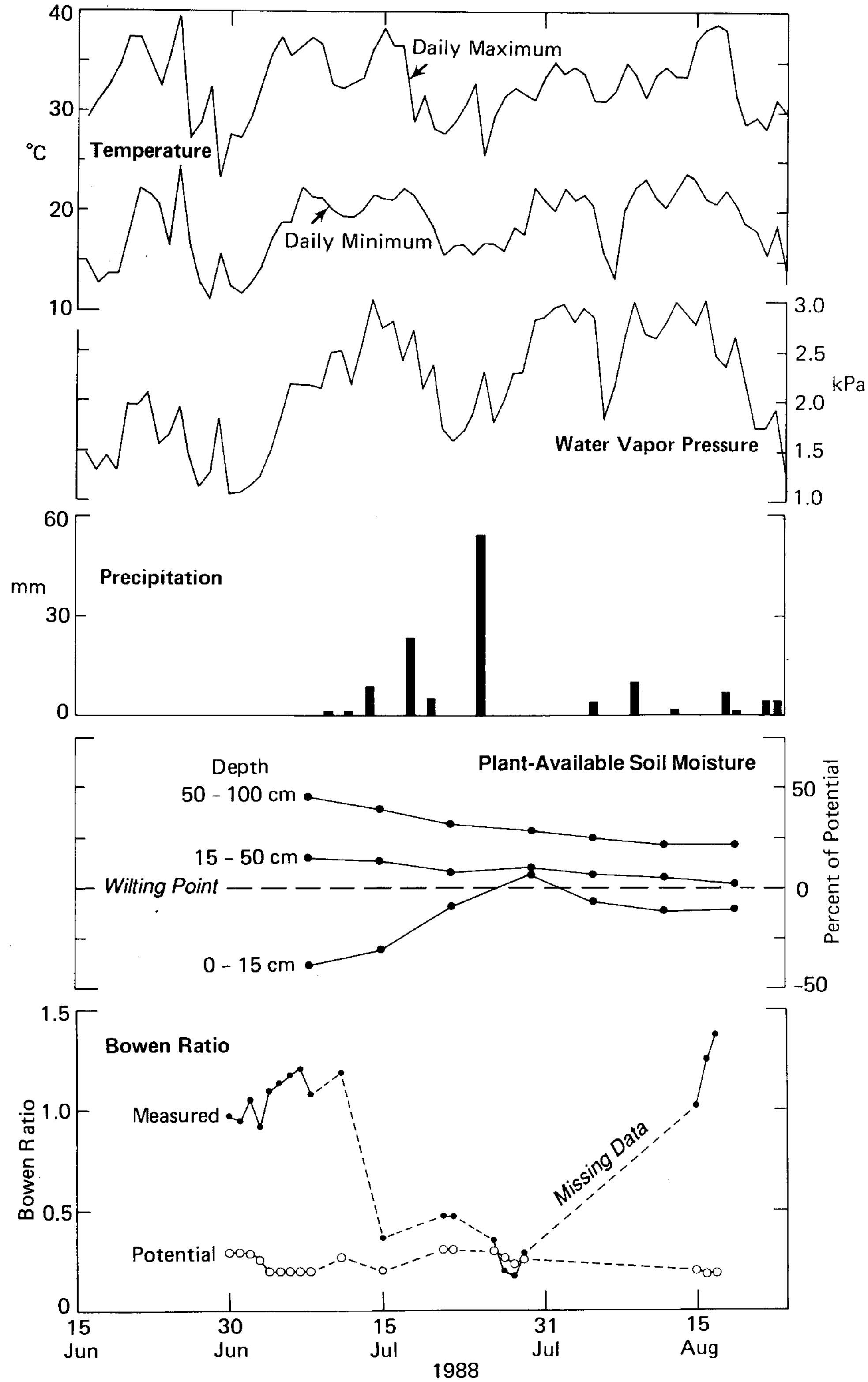

Figure 4.5. Daily values of maximum temperature, minimum temperature, precipitation, water vapor pressure, measured daytime Bowen ratio, and calculated daytime potential Bowen ratio, June 30-August 18,1988

Table 4.1. Soil Moisture Deficits (mm) in the Top 2 Meters of Soil on April 1 and September 30 for Different Zones of Illinois

	April 1			*September 30*		
	1987	*1988*	*1989*	*1987*	*1988*	*1989*
Northern	136.4	119.4	141.8	178.3	263.1	197.5
Central	79.8	65.2	108.2	190.2	273.4	166.4
Southern	118.4	90.6	98.6	229.4	264.6	204.3

Table 4.2. Measured Meteorological Variables and Instrumentation

Variable	*Height (m)*	*Instrument*	*Location*
Vertical wind	2.4	Sonic anemometer	Field site
Air temperature (fast response)	2.4	Thermocouple	Field site
Water vapor density (fast response)	2.4	Krypton hygrometer	Field site
Air temperature	1.5	Hygrothermograph	Climate station
Relative humidity	1.5	Hygrothermograph	Climate station
Wet-bulb temperature	1.5	Psychrometer	Climate station
Precipitation (daily)	–	Standard 10-inch raingage	Climate station
Incoming solar radiation	2.4	Epply PSP pyranometer	Field site
Wind speed and direction	2.4	Climatronics Mark IV wind sensor	Field site
Soil heat flux	5 cm, 10 cm depth	Micromet heat flux plates	Field site

Table 4.3. 1988 Monthly Total Precipitation and Mean Temperature Compared with the Climatological Averages

	1988 precipitation (mm)	*Average precipitation (mm)*	*1988 temperature (°C)*	*Average temperature (°C)*
January	55	50	-4.6	-4.1
February	33	48	-4.4	-1.5
March	64	84	4.2	3.9
April	38	98	10.8	11.3
May	39	91	18.6	17.1
June	8	100	23.0	22.2
July	93	111	25.6	24.0
August	33	93	25.0	22.9

Table 4.4. Water Vapor Budget Estimates (mm/month)

Month	*Study*	*C_l (layer)*	*D_u (layer)*	*P*	*ET*
July 1961, 1962	Rasmussen (1968)	l0 (100-90 kPa)	32 (90-25 kPa)	124	146
July 1975	Portis et al. (1991)	0	91 (100-30 kPa)	56	147
July 1976	Portis et al. (1991)	0	58 (100-30 kPa)	84	142
July 1979	Portis et al. (1991)	13 (92-78 kPa)	37 (100-92 kPa and 78.30 kPa)	129	153
Average		6	55	98	147

Note: C_l = integral of water vapor convergence at lower levels D_u = integral of water vapor divergence at upper levels; P = precipitation; ET = evapotranspiration; kPa = kilo Pascals (100 kPa = 1000 millibars).

5. STREAMFLOWS AND LAKE LEVELS

by

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The two preceding chapters documented the precipitation and temperature patterns characteristic of the 1988–1989 drought and their effects on soil moisture, plant water use, and surface heat exchanges. The focus now shifts to the hydrological effects of the drought, beginning in this chapter with the surface water conditions.

A hydrological drought is triggered by a meteorological drought, but streams and lakes experience a lag in responding to precipitation shortages. Streamflow is composed of direct runoff from precipitation, ground-water contribution in terms of baseflow, and return flows from municipal and industrial users. Each source has different spatial and temporal variations and lag times, including some persistence or carry-over effects caused by soil moisture and ground-cover conditions.

As shown in chapter 3, the meteorological drought of 1988 began in mid-February to early March. However, its effects on streamflow were not apparent until late April or May 1988 when the reduction in flows exceeded ordinary variations. Drought-related changes in lake levels were even slower to appear: reservoirs are usually drawn down by water supply withdrawals and evaporation losses during dry months or droughts, when withdrawals and losses are expected to exceed inflows.

Drought conditions such as those of 1988–1989 threaten the reliability of public water supplies that depend on surface water sources. Water volumes stored in reservoirs may become insufficient to meet water demands unless streamflows increase greatly. If drought conditions continue, some lakes may not recover sufficiently to meet demands in later months.

Furthermore, the flow in navigable rivers such as the Illinois and Mississippi may be lowered by drought conditions to the point that navigation, recreation, and water quality may be adversely impacted. With the large drainage areas of these rivers and the use of flow-regulation structures, drought impacts are felt a month or two later than would be the case for small to medium-sized tributaries.

5.1. Flow in Illinois Rivers and Streams

The variety of streamflow conditions throughout Illinois at the onset of the 1988–1989 drought, combined with regional hydrologic differences and variations in the beginning and intensity of the drought around the state, precluded any uniform response in terms of reduced streamflow. The first effects beyond ordinary fluctuations in flow were noticed in April 1988, and the first unusually low streamflows were observed in May 1988.

Monthly Ratios of Observed/Average Flow (%R)

Flows at 28 U.S. Geological Survey (USGS) streamgaging stations were assessed to provide a statewide picture of flow conditions during the drought. The locations of these stations are shown in figure 5.1, and they are listed in table 5.1 along with their drainage areas and the years for which daily flow records were available up to September 1989. The drainage areas range from 146 to 6,363 square miles (sq mi), and the lengths of flow records range from 19 to 75 years.

Observed monthly flows (Q) at these stations for the period March 1988 to September 1989 are given in table 5.2. Average monthly flows (Q_{av}) for the period of record are also given. The percent ratios of Q/Q_{av} are shown as %R; the smaller the %R, the greater the drought effect on the monthly flow for the gage under consideration. By May 1988, observed monthly flow was less than the long-term average monthly flow at all 28 stations.

Variations in %R from March 1988 to September 1989 are shown in figure 5.2 for eight of the streamgaging stations. They demonstrate the relative impacts (in terms of %R) of the drought from north to south and east to west in Illinois. Gage 3 (Elkhorn Creek near Penrose) represents the area north of the Rock River. This area has relatively high sustained flows, and even during the 1988–1989 drought it fared much better than the rest of the state. Gages 5, 8, 12, and 17 cover western and central Illinois, which had very low flows for many months during most of the March 1988–September 1989 period, and particularly in mid-1988.

In contrast, eastern and southern Illinois (the Embarras, Little Wabash, Big Muddy, and Cache River basins) were impacted during 1988 only. In 1989, the %R values for these catchments show large fluctuations, although the mean January–September 1989 flow was generally considerably higher than the long-term average for those months.

Minimum Monthly Flows

During the drought of 1988–1989, many observed monthly flows became the minimum monthly flows for that calendar month for the entire historical record, and in some of the remaining months the observed flows were within 50 percent of the lowest monthly flows of record. For each of the 28 selected USGS streamgaging stations, table 5.3 indicates the months when the observed monthly flows were the lowest on record and those when the flows were within 50 percent of the lowest on record. There were no record low flows or low flows within 50 percent of the record for gaging station 6 (Des Plaines River near Gurnee, with a major part of its drainage area in Wisconsin) or gaging station 28 (Cache River at Forman, with its drainage area in extreme southern Illinois).

The greatest spatial concentration of record low flows occurred in western and central Illinois. The LaMoine River at Colmar (station 15) had six months of record low flows and two months of low flows within 50 percent of the record low. The Spoon River at London Mills (station 11) had five months of record low flows and three months of low flows within 50 percent of the record low. The Vermilion River at Pontiac (station 8) had the lowest recorded flows for June through October 1988; the flow was zero from July through October. The Sangamon River at Monticello (station 12) had its lowest record flows from July through October 1988, when the %R values were only 1.43, 1.13, 0.42, and 0.78, respectively, which amounts to about 1 percent of the long-term average monthly flows. The stations with record low flows and low flows within 50 percent of the record low for the months January through December 1988 are shown in table 5.4.

7-Day, 10-Year Low Flows

Another way of assessing the effect of drought on reduced streamflow is to determine the lowest average flow observed over a consecutive 7-day period (Q7) and compare it with the 7-day, 10-year low flow (Q7,10) as described by Singh et al. (1988b, c) and Singh (1983). A 7-day, 10-year low flow is the lowest Q7 that may be expected to occur on the average of once in 10 years.

Q7 values during the 1988–1989 drought (with the month and year of occurrence) are given in table 5.5 for each of the 28 streamgaging stations, along with the Q7, 10 value for each station. At 19 stations (5,7-21, and 24-26), the Q7 was less than the Q7, 10. At five of these stations, Q7 was zero. These stations are located in an area bounded by Hamilton County (on the south), Kankakee County (north), St. Clair County (west), and Wabash County (east). This area constitutes about one-half of Illinois and does not include the northern or southern portions.

Some Illustrative Special Cases

The monthly flow in Bear Creek near Marcelline (drainage area 349 sq mi) in western Illinois (station 5) was less than 1 cubic foot per second (cfs) from July 1988 through February 1989, in contrast to the corresponding long-term average monthly flows, which range from 57 to 264 cfs. The Vermilion River at Pontiac (drainage area 579 sq mi) in the northern part of central Illinois (station 8) had zero flow for four months, July through October 1988; the long-term average monthly flows for these months range from 82 to 291 cfs. The river above Pontiac did not actually reach zero flow, but the water demand of the city of Pontiac, about 2 million gallons per day (mgd), exceeded the inflow to the stream. Consequently, water was pumped from some abandoned quarries to supplement the supply.

The Mackinaw River near Congerville (drainage area 767 sq mi) (station 10) had monthly flows from July through October 1988 of about 1.3 percent of the average monthly flows of 178 to 357 cfs. Because of tremendous drawdowns in Lake Bloomington and Evergreen Lake, which are used for Bloomington's water supply, an emergency permit was issued to the city, enabling it to pump water from the Mackinaw River to these lakes when river flow was above a certain specified low flow.

The flow in the Sangamon River at Monticello (drainage area 550 sq mi) (station 12) was only about 0.9 percent of the long-term average monthly flow from July through October 1988. The drastic reduction in the Sangamon River flow created a water supply crisis for the city of Decatur. Lake Decatur, the water supply source for Decatur, is on the Sangamon River, and the upstream drainage area is about 935 square miles. Decatur had to activate wells and a large abandoned quarry and also had to impose water-use restrictions.

Drastic reduction in the flow in the South Fork Sangamon River near Rochester (drainage area 867 sq mi) (station 13) occurred over a longer period: June 1988 to February 1989. Flows in the LaMoine River at Colmar (drainage area 655 sq mi) (station

15) and at Ripley (drainage area 1,293 sq mi) (station 16) were similarly impacted from July 1988 through February 1989. For the Skillet Fork at Wayne City (drainage area 464 sq mi) (station 26), such impacts occurred during June and from August through October 1988.

5.2. Illinois and Mississippi Rivers

An evaluation was made of the effect of the 1988–1989 drought on the monthly flows at three additional USGS gaging stations. These stations were 1) the Illinois River at Marseilles (drainage area 8,259 sq mi), 2) the Illinois River at Kingston Mines (drainage area 15,819 sq mi), and 3) the Mississippi River at St. Louis (drainage area 697,000 sq mi).

Information was developed at each of these stations on the long-term average monthly flow, monthly flows for the two water years with the lowest annual flows, observed monthly flows for the drought period March 1988 through September 1989, minimum monthly flow for the period of record, and water year with the minimum monthly flow. Full results are given in table 5.6. The flows at these gaging stations were not as severely impacted as those at the 28 stations previously discussed, mainly because 1) their large drainage areas were not completely affected by the drought, 2) flows were regulated by dams and locks, and 3) long travel times resulted in greater flow persistence.

Illinois River at Marseilles

The lowest annual flows on record at this station (5,808 and 5,583 cfs) occurred in Water Years 1940 and 1964, respectively. Annual flows for Water Years 1988 and 1989 were 8,212 and 8,744 cfs, respectively. Observed monthly flows in May, June, and July 1988 were lower than the corresponding minima observed up to 1987. Hence, flows in these drought months set new low-flow records.

Illinois River at Kingston Mines

The lowest annual flows at this station (6,957 and 6,820 cfs) occurred in Water Years 1940 and 1964, respectively. As just noted, these were also the lowest flow years for the Marseilles gage. Annual flows for Water Years 1988 and 1989 were 13,620 and 10,540 cfs, respectively. The May 1989 flow of 7,822 cfs was lower than the earlier record low of 8,090 cfs. Monthly low flows during May through September 1988 were from 15 to 40 percent higher than the record lows.

Mississippi River at St. Louis

The lowest annual flows at this station (67,700 and 79,109 cfs) occurred in Water Years 1934 and 1940, respectively. The monthly flow in June 1988 was about 10 percent higher than the record low for 1934–1989, and the monthly flow in July 1988 was only 0.2 percent higher than the record low. These low flows posed considerable problems for normal navigation.

5.3. Lakes and Reservoirs

More than 1.5 million people in central and southern Illinois typically receive water from surface supplies because of the paucity of suitable ground-water aquifers. The drought of 1988–1989 seriously affected storage in lakes and reservoirs. Reduced storage in water supply reservoirs caused many towns and cities to restrict water use, to augment supplies with water withdrawals from abandoned quarries, to reactivate some ground-water wells, or to import water from nearby water-affluent municipalities.

Figure 5.3 shows the locations of dams for 24 lakes and reservoirs whose levels are routinely monitored monthly by the Water Survey. Table 5.7 lists the names of these lakes; their counties, normal pool elevations, and upstream drainage areas; estimates of their 1990 storage at normal pool (Singh and Durgunoglu, 1990); average demand to be met during 1990 (Broeren and Singh, 1989); and 1990 population served (Singh et al., 1988a).

Departures from normal pool level from January 1988 through December 1989 for these 24 lakes and reservoirs are given in table 5.8. Values for a given month are positive if the lake level was higher than normal pool, and negative if the lake level was lower than normal pool.

As noted in chapter 3, section 3.2, the year 1987 was relatively dry through October. The resulting depressed levels in water supply lakes aroused considerable concern. Then, after a relatively wet November–December 1987 statewide, good water-level recoveries occurred, and surface water users started 1988 reassured as to the adequacy of their water supplies. Most of the lakes were full or nearly at normal pool levels in the first three to four months of 1988. Local wet conditions in March 1988 gave many small lakes an added boost just before the precipitation shortage began to attract attention (see table 3.1). This shortage was accompanied by above-normal temperatures that greatly reduced streamflows and increased evaporation from the lakes (figure 3.17).

Without the recovery of lake levels in late 1987 and early 1988, the spring and summer rainfall shortages and higher temperatures would have had a much more severe impact on the populations served by the surface water supply systems. The wise imposition of use restrictions in many communities by June 1988 helped to negate increased water use during the hot, dry months of the drought. The large reservoirs — Rend, Shelby, Carlyle, and Crab Orchard — never exhibited a great response to the rainfall shortage. Large declines in water surface elevation were generally confined to small to medium-sized reservoirs with large capacity/inflow ratios and relatively high water demands, such as Lake Bloomington, Evergreen Lake, and White Hall Reservoir. By the end of 1988, modest recovery was apparent at many lakes, but the water levels in these three reservoirs declined further.

5.4. Lake Level Forecasts

In June 1988, drought impacts on the reservoirs supplying water for the Bloomington Public Water Supply (PWS) and Decatur PWS were analyzed, and forecasts regarding their future levels and storage capabilities were made. Pertinent factors, such as precipitation, temperature, and the effect of precipitation on runoff, were also considered. The investigations performed for the Bloomington PWS are briefly described to illustrate the modeling and forecasting approaches that can be used in water supply management.

Bloomington Public Water Supply

The Bloomington PWS serves Bloomington, Hudson, Towanda, Hickory Highlands, Bloomington Township Water District, Lake Bloomington, Bloomington area subdivisions, and rural customers. In 1986, the estimated total population served was 51,260, and annual average daily water use was 8.4 mgd. The Bloomington PWS relies on surface water and uses two reservoirs: Lake Bloomington and Evergreen Lake.

By June 1988, very low precipitation amounts and high temperatures significantly reduced inflows to the reservoirs. In addition, evaporation considerably exceeded average values, thereby depleting reservoir reserves; and water demands were well above average levels, even with some constraints on use.

Water budget analyses were performed for Lake Bloomington and Evergreen Lake to quantitatively assess the depletion of their water reserves and to evaluate the fraction of average monthly runoff flowing into them during the period March through June 1988. Water use, evaporation, and inflow projections were developed and used to assess the potential declines in water levels and stored water in both reservoirs for particular drought forecasts.

End-of-month lake levels were obtained. For each reservoir, relations between design elevation and reservoir capacity, and between elevation and water surface area, were used to compute remaining storage and water surface areas corresponding to particular lake levels. Storage volumes were adjusted for capacity losses due to sedimentation. Pan evaporation data from the Urbana station were used to estimate lake evaporation.

Both temperature and evaporation were above normal from March through June 1988. Monthly average water use was obtained from the Bloomington water treatment plant superintendent. Reported water use was 8.63, 11.68, and 14.67 mgd for April, May, and June, respectively. No conservation measures had yet been imposed. A comparison of historical average flow values and the calculated 1988 values shows that 1988 flows were less than 20 percent of average flows. Long-term mean monthly flows for Money Creek at Towanda, upstream of Lake Bloomington (drainage area 49 sq mi), with the three driest years of record and 1988, are shown in table 5.9.

A water budget analysis was performed to project water reserves for the two-reservoir system for the period July through December 1988 on the basis of three different precipitation scenarios. Available stored water in the two reservoirs was estimated assuming July–December precipitation as 50 percent, 100 percent, and 150 percent of historical monthly average values. The fraction of precipitation that reaches a reservoir as runoff is affected by antecedent soil moisture and basin conditions. Depletion of soil moisture due to drought or very dry conditions results in more infiltration of precipitation and thus less runoff during a rain event than would occur during normal conditions.

Historical monthly average precipitation and streamflow data were used in developing estimates of monthly runoff associated with monthly average precipitation during very dry years. For each of the three precipitation scenarios, estimated R/P and R values were derived for P equal to 0.5 P, P, and 1.5 P, where R and P denote the historical average monthly runoff and precipitation, respectively. Inflow to each of the two water supply reservoirs was calculated from the R values shown in table 5.10 on the basis of their respective drainage areas.

For the Bloomington PWS, information on the combined available storage of the two reservoirs from one month to the next as well as future projections are important for planning and operation. Combined storage for the three scenarios is given in table 5.11 along with the PWS demands used to develop the projections, actual demands as obtained from the Bloomington PWS, and actual end-of-month combined storages calculated from actual end-of-month reservoir water levels observed at the two lakes.

It is clear from table 5.11 that combined storages with the scenario of 50 percent of average monthly precipitation and those computed from actual observations of lake levels for July, August, and September 1988 are similar. The observed precipitation over the three-month period was about 60 percent of average, but the daily maximum temperatures were about 5°F higher than average. This resulted in increased evaporation losses and increased soil moisture deficits, both of which significantly reduced runoff during the next three months. Increased evaporation loss and increased infiltration of water into the soil from July through September were practically offset by reduced pumpage of about 3 mgd.

During October through December 1988, the average daily pumpage was about 0.7 mgd less than the figure used in the forecasts. The carry-over effect of increased soil moisture deficiency and somewhat higher-than-average temperatures in November and December further reduced the combined storage in Lake Bloomington and Evergreen Lake.

5.5. Other Agency Reports

Beginning in July 1988, two other state agencies monitored and reported the conditions of selected lakes. The Division of Fisheries of the Illinois Department of Conservation (IDOC) issued weekly bulletins summarizing the status of 187 lakes in the 18 districts and five regions that it monitors across the state. Along with regularly reporting water levels in the lakes, IDOC listed the number and types of problems encountered every week by the district and the number of media contacts handled by the staff. The chief objective in reporting these problems was to account for fish mortality incidents.

For the five-month period July through November 1988, IDOC received reports or inquiries regarding about 200 instances of fish kills in public and private lakes, ponds, and streams. A variety of causes was identified or inferred, but those listed most often were low dissolved oxygen, thermal stress, and aerial drift of sprayed pesticides.

The Division of Public Water Supplies, Illinois Environmental Protection Agency (IEPA), also produced a weekly report detailing supply conditions for communities that had contacted IEPA for assistance or advice. Problems for both surface water and ground-water supplies were chronicled, along with community efforts to combat shortages by restricting use, recycling water, or drawing on auxiliary supplies. Towns supplied by surface water that were on IEPA's list from the beginning were Georgetown, Marion, Staunton, Shipman, and three towns that use the Little Wabash River as a source: Louisville, Flora, and Clay City. Others added later included Pontiac, Decatur, Springfield, and Blandinsville.

5.6. Lake Michigan

The drought of 1988–1989 was a major factor in lowering Lake Michigan to near-normal levels. When 1988 began, the lake level had been above average since 1977. Although it had briefly lowered to average levels in 1981, its subsequent rise was extremely dramatic. From October 1985 through January 1987, a period of 16 consecutive months, the lake set new records for average monthly levels. In January 1987, it was 2.75 feet above its long-term average level, and dire forecasts of shoreline erosion and damage to buildings by storm-driven waves were abundant.

However, the 1987 precipitation shortage over the Great Lakes basin allowed the lake level to fall 1.8 feet through the year; at the beginning of 1988 the lake was only about 0.9 foot above average level. In 1988 the effects of the midwestern drought were evident after a normal seasonal rise in the lake level for April. During May and June, instead of the usual rise of 0.5 foot, the lake fell about 0.2 foot. As July began, the lake dropped below its long-term average for the first time in nearly 11 years. The decline in lake level continued through September and then was halted by autumn precipitation in the basin. At the end of 1988, Lake Michigan was within 0.1 foot of its long-term average level, and in October 1989 the lake was about 0.4 foot below that level.

FIGURES AND TABLES

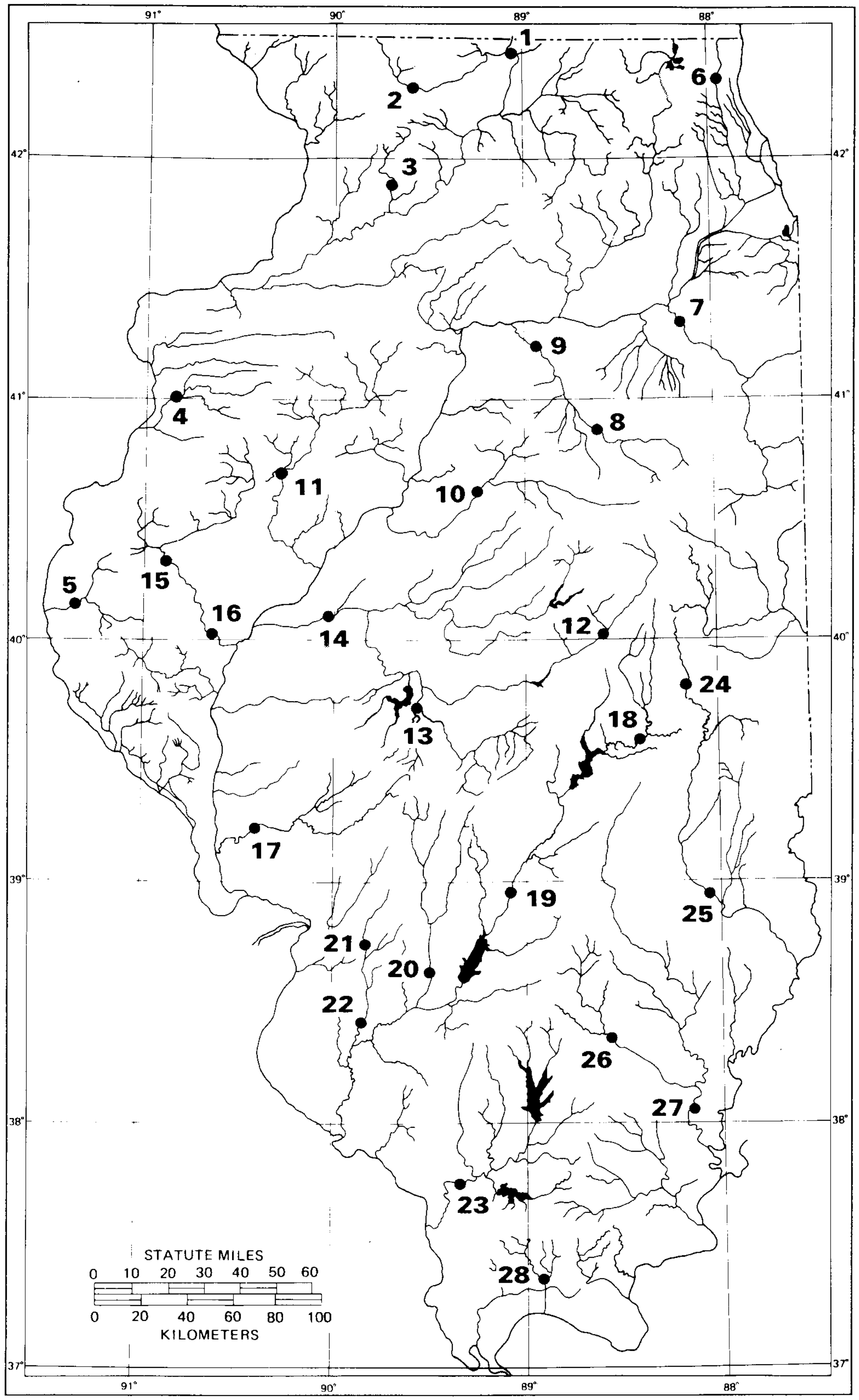

Figure 5.1. Location of 28 USGS streamgaging stations

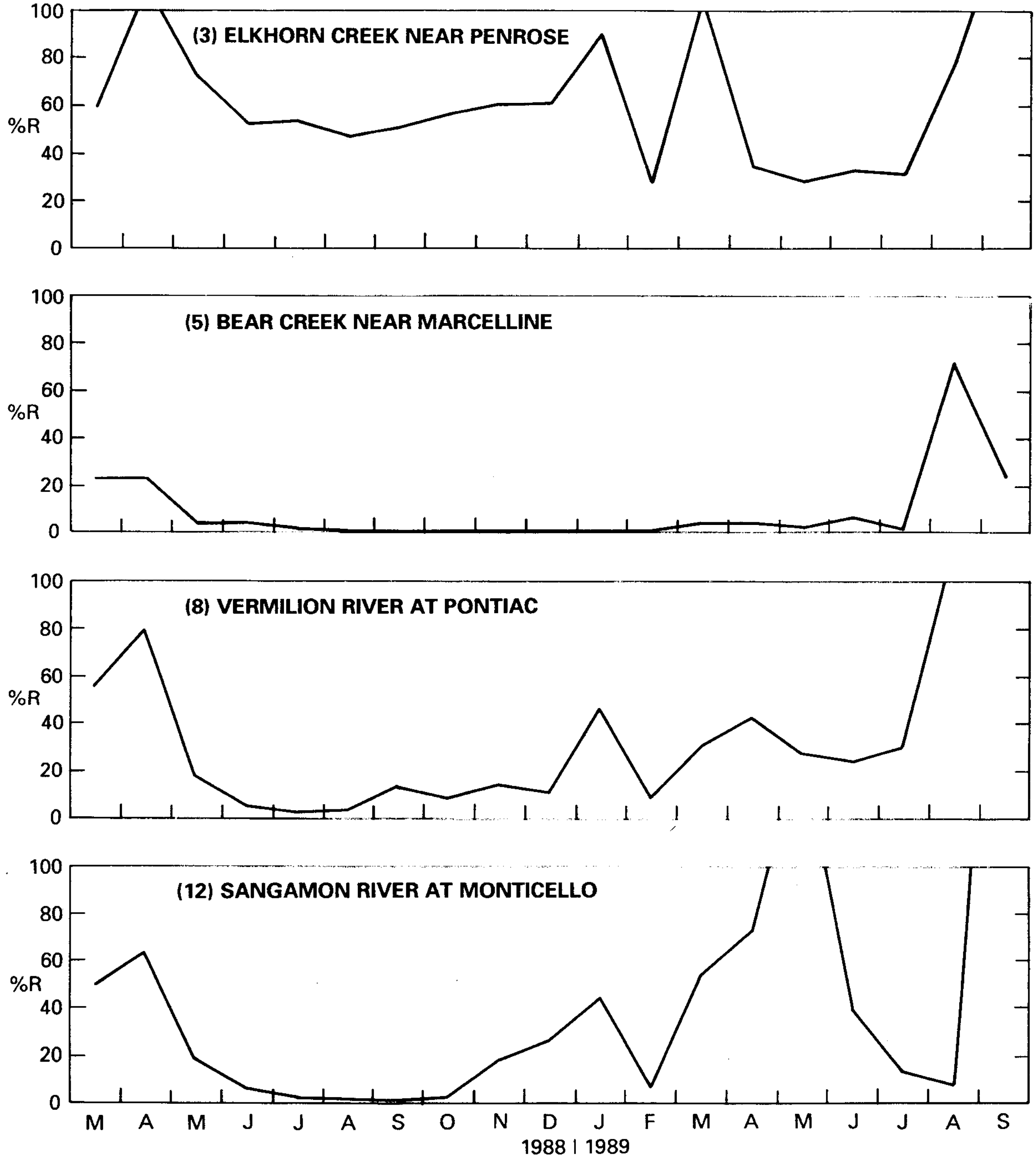

Figure 5.2. Monthly %R values, March 1988 to September 1989

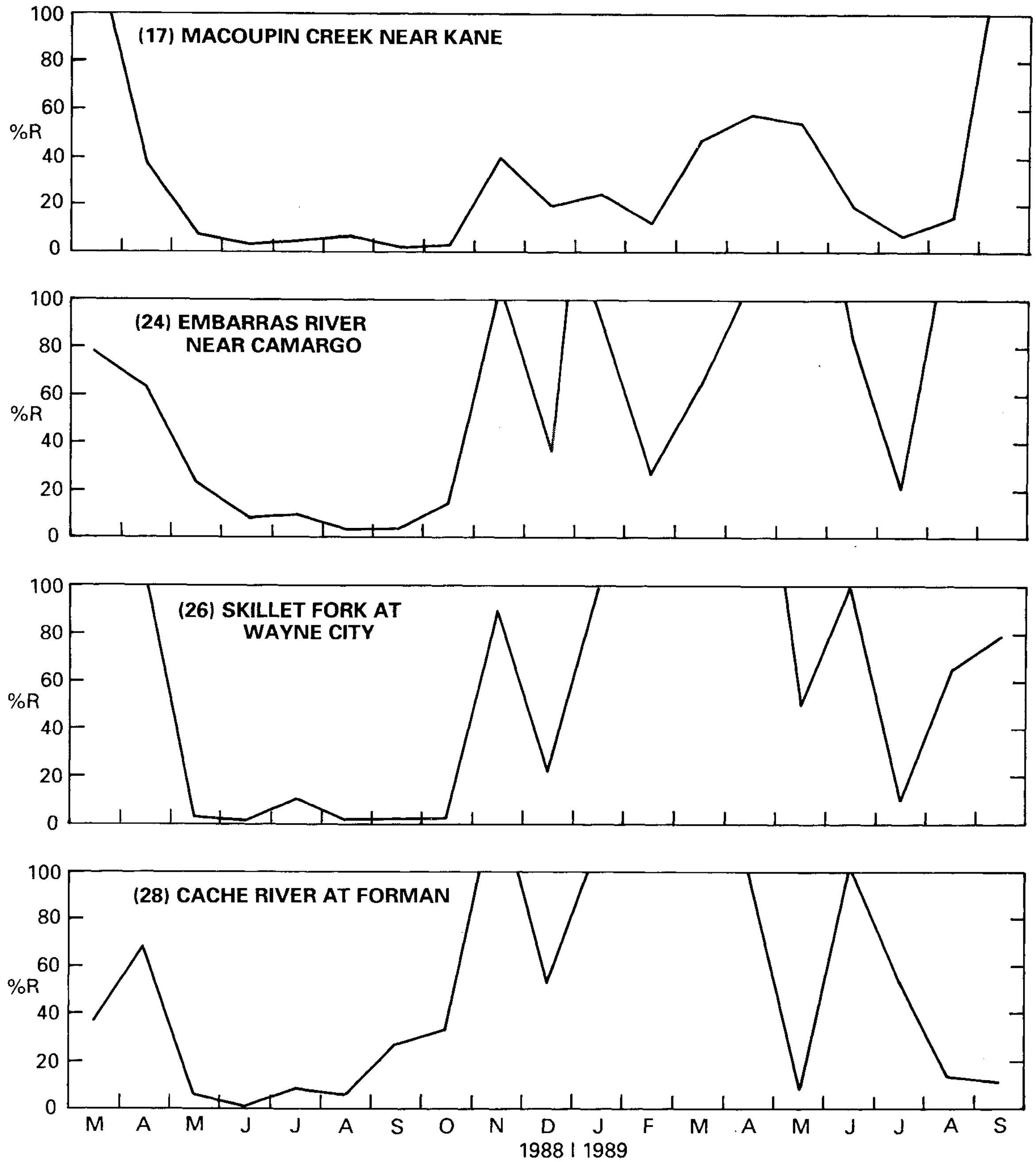

Figure 5.2. Concluded

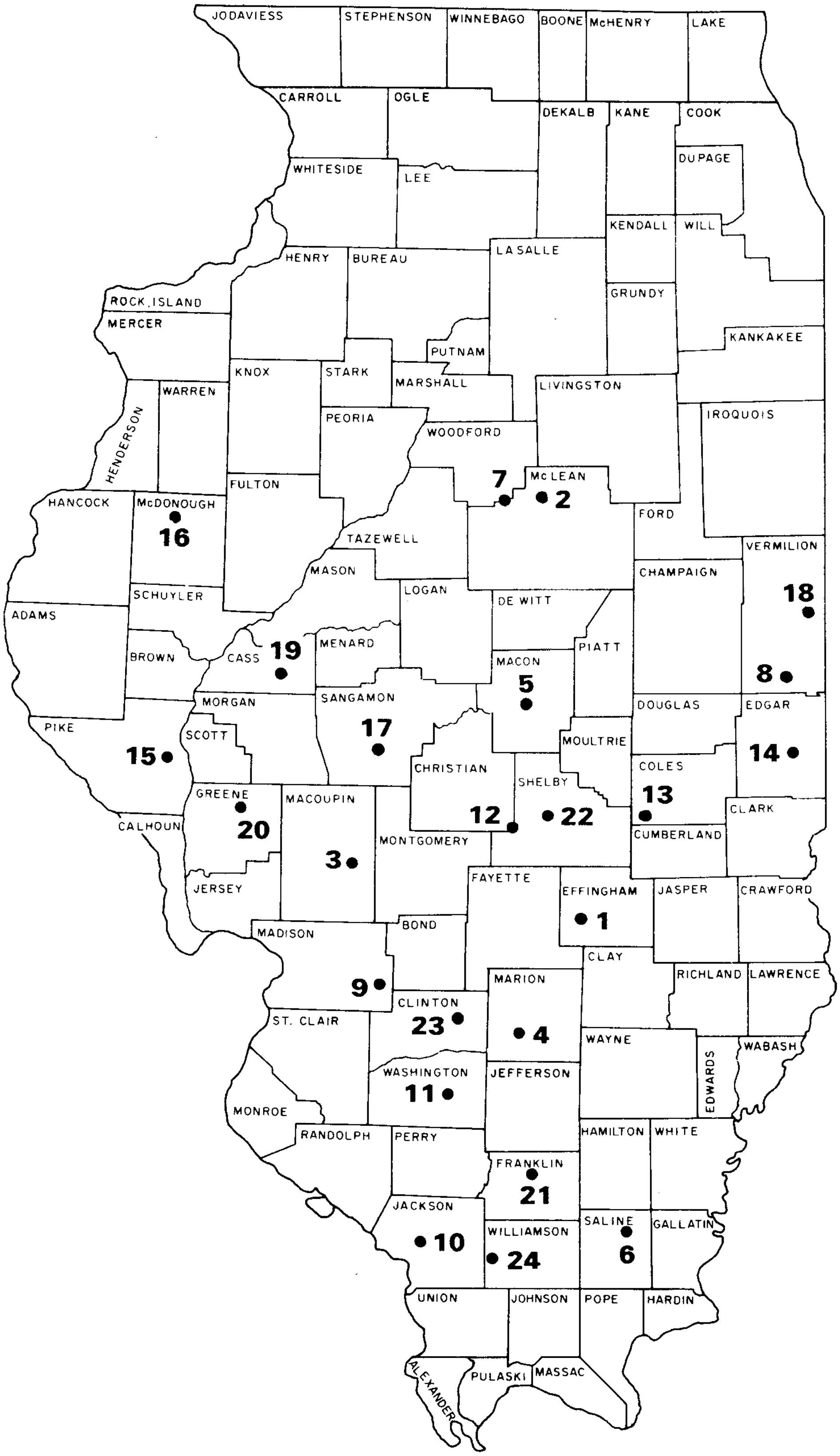

Figure 5.3. Location of dams for the 24 water supply lakes and major reservoirs monitored monthly by the Water Survey and described in table 5.7

Table 5.1. USGS Streamgaging Stations Used in Assessing Flow Conditions during the Drought

No.	*USGS no.*	*Stream and gaging station*	*Drainage area (sq mi)*	*Period of record*
1	05437500	Rock River at Rockton	6,363	10/39-9/89
2	05435500	Pecatonica River at Freeport	1,326	10/14-9/89
3	05444000	Elkhorn Creek near Penrose	146	10/39-9/89
4	05469000	Henderson Creek near Oquawka	432	10/34-9/89
5	05495500	Bear Creek near Marcelline	349	10/44-9/89
6	05528000	Des Plaines River near Gurnee	232	10/68-9/89
7	05527500	Kankakee River near Wilmington	5,150	10/15-9/89
8	05554500	Vernilion River at Pontiac	579	10/42-9/89
9	05555300	Vermilion River near Leonore	1,251	10/31-9/89
10	05567500	Mackinaw River near Congerville	767	10/44-9/89
11	05569500	Spoon River at London Mills	1,072	10/42-9/89
12	05572000	Sangamon River at Monticello	550	10/14-9/89
13	05576000	S.F. Sangamon River near Rochester	867	10/49-9/89
14	05583000	Sangamon River near Oakford	5,093	10/39-9/89
15	05584500	LaMoine River at Colmar	655	10/44-9/89
16	05585000	LaMoine River at Ripley	1,293	10/21-9/89
17	05587000	Macoupin Creek near Kane	868	10/40-9/89
18	05591200	Kaskaskia River at Cook Mills	473	10/70-9/89
19	05592500	Kaskaskia River at Vandalia	1,940	10/14-9/89
20	05594000	Shoal Creek near Breese	735	10/45-9/89
21	05594450	Silver Creek near Troy	154	10/66-9/89
22	05594800	Silver Creek near Freeburg	464	10/70-9/89
23	05599500	Big Muddy River at Murphysboro	2,169	10/30-9/89
24	03343400	Embarras River near Camargo	186	10/60-9/89
25	03345500	Embarras River at Ste. Marie	1,516	10/14-9/89
26	03380500	Skillet Fork at Wayne City	464	10/28-9/89
27	03381500	Little Wabash River at Carmi	3,102	10/39-9/89
28	03612000	Cache River at Forman	244	10/24-9/89

Table 5.2. Observed Monthly Average Flows (March 1988–September 1989), Long-Term Average Monthly Flows, and Minimum Monthly Flows at Selected Streamgaging Stations

March–December 1988

No.		*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1	Q	5,818	6,603	3,578	1,668	1,401	1,203	1,205	1,473	2,150	2,371
	Q_{av}	7,925	7,328	5,134	4,166	3,228	2,572	2,824	3,094	3,304	3,046
	%R	73.4	90.1	69.7	40.0	43.4	46.8	42.7	47.6	65.1	77.8
	Q_m	1,692	2,476	1,103	1,248	1,056	793	780	857	1,100	1,004
2	Q	1,324	1,276	884	601	503	390	398	455	513	483
	Q_{av}	1,796	1,184	947	931	785	667	739	684	735	666
	%R	73.7	108	93.3	64.6	64.1	58.5	53.9	66.5	69.8	72.5
	Q_m	356	396	232	266	211	233	218	228	258	201
3	Q	106	134	82.5	58.5	44.1	33.4	31.7	35.1	40.5	42.7
	Q_{av}	177	121	114	113	83	70	63	62	67	70
	%R	59.9	111	72.4	51.8	53.1	47.7	50.3	56.6	60.4	61.0
	Q_m	33.6	34.7	25.7	25.8	19.2	23.0	14.7	15.6	17.6	15.4
4	Q	134	295	92.3	40.9	14.2	15.5	18.0	16.5	23.8	20.4
	Q_{av}	448	497	428	413	281	129	132	160	172	169
	%R	29.9	57.3	21.6	9.90	5.05	12.0	13.6	10.3	13.8	11.8
	Q_m	47.4	33.4	53.1	31.3	6.60	9.60	5.60	7.10	9.90	8.40
5	Q	91.6	100	11.9	11.8	0.24	0.17	0.043	0.21	0.91	0.62
	Q_{av}	398	426	286	229	264	78	57	125	138	146
	%R	23.0	23.5	4.06	4.16	0.91	0.22	0.027	0.17	0.66	0.42
	Q_m	3.80	9.00	3.26	0.70	0.24	0.17	0.00	0.00	0.00	0.10
6	Q	299	528	111	48.5	63.5	67.3	41.7	36.9	96.5	66.8
	Q_{av}	452	417	239	169	115	90	108	102	114	154
	%R	65.2	127	46.4	28.7	55.2	74.8	38.6	36.2	84.6	43.4
	Q_m	61.8	79.9	31.3	23.1	19.00	4.80	5.10	5.50	7.20	12.7
7	Q	5,208	9,074	2,852	997	467	451	729	1,380	4,180	4,394
	Q_{av}	7,124	7,611	6,260	4,483	2,832	1,644	1,544	1,940	2,637	3,938
	%R	73.1	119	45.6	22.2	16.5	27.4	47.2	71.1	159	112
	Q_m	1,443	2,359	1,150	790	463	451	461	506	605	637
8	Q	394	680	119	27.0	0.00	0.00	0.00	0.00	58.4	75.8
	Q_{av}	707	852	689	538	291	120	82	120	200	332
	%R	55.7	79.8	17.3	5.02	0.00	0.00	0.00	0.00	29.2	22.8
	Q_m	23.7	109	71.1	27.0	0.00	0.00	0.00	0.00	1.50	4.60

Q = observed monthly average flow (cfs)
Q_{av} = average monthly flow for the period of record (cfs)
%R = (Q/Q_{av}) x 100%
Q_m = minimum monthly flow for the period of record (cfs)

Table 5.2. Continued

No.		*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
9	Q	740	1697	293	78.5	8.83	6.89	30.0	43.5	97.5	127
	Q_{av}	2,215	2,250	1,475	1,395	584	402	248	499	713	1,188
	%R	33.4	75.4	19.9	5.62	1.51	1.71	12.1	8.72	13.7	10.7
	Q_m	93.1	85.1	93.4	27.7	8.83	6.89	10.90	8.80	9.10	9.80
10	Q	293	669	144	49.6	6.09	1.22	1.84	2.57	18.3	33.3
	Q_{av}	905	1127	805	765	357	182	178	197	249	386
	%R	32.4	59.4	17.9	6.48	1.71	0.67	1.03	1.30	7.35	8.63
	Q_m	68.1	99.7	114	21.6	6.09	1.22	1.84	0.60	2.50	2.40
11	Q	576	1,281	325	119	30.2	11.1	10.4	18.9	50.6	38.6
	Q_{av}	166	1,355	1,119	1,066	626	277	331	319	362	424
	%R	49.4	94.5	29.0	11.2	4.82	6.90	3.14	5.92	14.0	9.10
	Q_m	132	71.2	94.3	80.8	30.2	11.1	10.4	15.1	23.0	14.3
12	Q	340	510	126	25.6	3.85	1.76	0.48	1.32	39.3	87.2
	Q_{av}	694	818	682	465	270	156	113	169	226	341
	%R	49.0	62.3	18.5	5.51	1.43	1.13	0.42	0.78	17.4	25.6
	Q_m	20.2	57.6	42.6	19.3	3.85	1.76	0.48	1.32	5.50	3.70
13	Q	1,123	625	78.9	3.20	4.78	2.79	1.43	1.06	61.2	8.90
	Q_{av}	1,067	1,067	785	781	431	285	107	170	251	599
	%R	105	58.6	10.1	0.41	1.11	0.98	1.36	0.62	24.4	1.49
	Q_m	13.1	79.0	17.9	3.20	1.70	1.00	1.10	1.06	0.70	0.20
14	Q	4,614	4,851	1,573	699	351	286	218	218	421	384
	Q_{av}	5,244	6,363	5,661	4,475	2,755	1,607	994	1,170	1,605	2,481
	%R	88.0	76.2	27.8	15.6	12.7	17.8	21.9	18.6	26.2	15.5
	Q_m	287	613	598	699	321	253	191	134	170	192
15	Q	109	254	55.3	21.1	3.89	2.82	1.75	0.67	4.95	4.53
	Q_{av}	758	848	603	647	407	162	274	303	262	268
	%R	14.4	30.0	9.17	3.26	0.96	1.74	0.64	0.22	1.89	1.69
	Q_m	30.5	22.9	20.8	21.1	3.89	2.82	1.75	0.67	4.50	3.00
16	Q	350	466	101	58.1	17.7	13.4	5.13	7.15	19.8	11.8
	Q_{av}	1,339	1,597	1,171	1,049	726	353	436	465	510	488
	%R	26.1	29.2	8.63	5.54	2.44	3.80	1.18	1.54	3.88	2.42
	Q_m	61.4	116	21.3	42.5	16.1	11.4	5.13	7.10	11.8	11.8

Q = observed monthly average flow (cfs)
Q_{av} = average monthly flow for the period of record (cfs)
%R = (Q/Q_{av}) x 100%
Q_m = minimum monthly flow for the period of record (cfs)

Table 5.2. Continued

No.		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
17	Q	1160	437	59.8	13.6	11.8	14.1	2.38	4.31	132	93.2
	Qav	895	1163	802	539	347	218	166	246	324	484
	%R	130	37.6	7.46	2.52	3.40	6.47	1.43	1.75	40.7	19.3
	Qm	3.80	23.1	2.90	13.6	11.8	6.90	2.38	2.60	4.50	1.80
18	Q	630	496	105	48.0	16.8	14.9	13.5	18.0	113	139
	Qav	854	732	591	444	306	210	88	153	288	666
	%R	73.8	67.8	17.8	10.8	5.49	7.10	15.3	11.8	39.2	20.9
	Qm	193	85.5	103	48.0	16.8	14.9	13.5	12.7	24.4	16.7
19	Q	2627	1456	170	61.9	48.7	60.7	39.1	46.2	372	410
	Qav	2602	2695	2089	1651	1007	577	397	620	775	1405
	%R	101	54.0	8.14	3.75	4.84	10.5	9.85	7.45	48.0	29.2
	Qm	34.7	157	94.1	61.9	42.7	25.1	18.9	14.9	15.5	18.2
20	Q	953	388	52.5	15.9	18.0	14.6	12.6	6.92	255	104
	Qav	1016	985	608	505	341	187	118	188	288	628
	%R	93.8	38.4	8.63	3.15	5.28	7.78	10.7	3.68	88.5	16.6
	Qm	11.9	56.0	12.3	15.9	2.50	7.40	2.30	1.20	4.60	8.00
21	Q	207	59.1	5.34	0.91	1.51	4.23	0.093	0.36	69.6	39.0
	Qav	254	241	91	97	68	17	14	28	83	214
	%R	81.5	24.5	5.87	0.94	2.22	24.9	0.66	1.29	83.9	18.2
	Qm	6.70	16.7	5.30	0.91	1.40	0.70	0.093	0.20	0.30	0.40
22	Q	647	259	36.7	12.4	45.9	19.0	11.4	6.70	229	88.8
	Qav	767	716	245	281	136	85	769	105	276	593
	%R	84.4	36.2	15.0	4.41	33.8	22.4	16.5	6.38	83.0	15.0
	Qm	34.5	45.3	25.4	12.4	12.9	10.7	4.30	2.50	2.20	6.90
23	Q	2838	4997	680	279	332	132	410	283	1887	870
	Qav	3862	3748	2899	1240	899	590	389	453	952	1673
	%R	73.5	133	23.5	22.5	36.9	22.4	105	62.5	198	52.0
	Qm	21.9	50.2	71.6	5.90	18.8	0.30	2.70	2.50	12.9	15.4
24	Q	209	185	52.0	14.3	9.59	1.61	0.99	6.66	100	80.6
	Qav	267	290	229	162	98	59	32	47	96	217
	%R	78.3	63.8	22.7	8.83	9.78	2.73	3.09	14.2	104	37.1
	Qm	76.8	35.6	36.5	14.3	9.59	0.10	0.00	0.00	0.00	1.10

Q = observed monthly average flow (cfs)
Qav = average monthly flow for the period of record (cfs)
%R = (Q/Qav) x 100%
Qm = minimum monthly flow for the period of record (cfs)

Table 5.2. Continued

No.		*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
25	Q	2260	1726	259	122	112	86.1	22.0	15.8	498	252
	Qav	2192	2166	1731	1233	730	432	329	4169	662	1294
	%R	103	79.7	15.0	9.89	15.3	19.9	6.69	3.80	75.2	19.5
	Qm	23.4	120	78.3	65.9	18.8	11.6	7.70	14.6	4.40	4.80
26	Q	940	772	12.1	1.48	15.2	1.36	1.13	1.30	217	98.6
	Qav	794	753	564	278	146	119	70	106	243	455
	%R	118	103	2.14	0.53	10.4	1.14	1.61	1.23	89.3	21.7
	Qm	2.00	11.6	9.00	1.48	1.10	0.10	0.00	0.00	0.10	0.30
27	Q	4249	5783	167	44.5	482	70.0	32.0	30.8	1473	457
	Qav	5542	5180	3770	2027	1292	782	367	511	1340	2782
	%R	76.7	112	4.43	2.20	37.3	8.95	8.72	6.03	110	16.4
	Qm	25.3	176	167	44.5	40.8	22.7	3.10	5.30	8.20	16.4
28	Q	227	397	20.4	2.45	9.32	4.90	17.3	19.5	260	179
	Qav	613	583	411	210	98	82	63	59	194	339
	%R	37.0	68.1	4.96	1.17	9.51	5.98	27.5	33.1	134	52.8
	Qm	12.2	40.7	10.4	1.40	1.70	0.00	0.40	0.00	0.70	0.60

January–September 1989

No.		*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Juk*	*Aug*	*Sep*
1	Q	2464	2420	5102	4509	2150	1901	1139	1634	2766
	Qav	3260	3981	7925	7328	5134	4166	3228	2572	2824
	%R	75.6	60.8	64.4	61.5	41.9	45.6	35.3	63.5	97.9
	Qm	800	1000	1692	2476	1103	1248	1056	793	780
2	Q	685	827	1394	53	383	311	274	292	424
	Qav	747	1114	1796	1184	947	931	785	667	739
	%R	91.7	74.2	77.6	45.4	40.4	33.4	34.9	43.8	57.4
	Qm	163	282	356	396	232	266	211	233	218
3	Q	86.9	42.5	185	42.7	32.7	37.6	26.0	56.0	103
	Qav	96	19	177	121	114	113	83	70	63
	%R	90.5	28.5	105	35.3	28.7	33.3	31.3	80.0	164
	Qm	14.6	22.3	33.6	34.7	25.7	25.8	19.2	23.0	14.7
4	Q	24.2	13.5	83.7	41.5	26.9	136	16.2	29.5	180
	Qav	241	366	448	497	428	413	281	129	132
	%R	10.0	3.69	18.7	8.35	6.29	32.9	5.77	22.9	136
	Qm	4.50	13.5	47.4	33.4	26.9	31.3	6.60	9.60	5.60

Q = observed monthly average flow (cfs)

Qav = average monthly flow for the period of record (cfs)

%R = (Q/Qav) x 100%

Qm = minimum monthly flow for the period of record (cfs)

Table 5.2. Continued

No.		*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
5	Q	0.94	0.66	13.3	14.7	3.26	16.6	2.89	56.2	38.6
	Qav	150	248	398	426	286	229	264	78	157
	%R	0.63	0.27	3.34	3.45	1.14	7.25	1.09	72.1	24.6
	Qm	0.30	0.66	3.80	9.00	3.26	0.70	0.24	0.17	0.00
6	Q	66.5	65.1	159	136	80.1	88.7	71.7	83.3	151
	Qav	142	187	452	417	239	169	115	90	108
	%R	46.8	34.8	35.2	32.6	33.5	52.5	62.3	92.6	144
	Qm	6.30	11.9	61.8	79.9	31.3	23.1	19.0	4.80	5.10
7	Q	6483	4291	5372	6554	4387	8271	3677	2090	9075
	Qav	4287	5411	7124	7611	6260	4483	2832	1644	1544
	%R	151	79.3	75.4	86.1	70.1	184	130	127	588
	Qm	580	709	1443	2359	1150	790	463	451	461
8	Q	157	39.9	216	361	194	127	86.3	138	1540
	Qav	342	466	707	852	689	538	291	120	82
	%R	45.9	8.56	30.6	42.4	28.2	23.6	29.7	115	187
	Qm	3.00	6.70	23.7	109	71.1	27.7	0.00	0.00	0.00
9	Q	279	111	509	517	291	245	140	47.1	3326
	Qav	813	1157	2215	2250	1475	1395	584	402	248
	%R	34.3	9.59	23.0	23.0	19.7	17.6	23.0	11.7	1341
	Qm	6.40	14.1	93.1	85.1	93.4	27.7	8.83	6.89	10.9
10	Q	74.8	26.9	123	190	197	111	25.1	4.25	132
	Qav	442	614	905	1127	805	765	357	182	178
	%R	16.9	4.38	13.6	16.9	24.5	14.5	7.03	2.34	74.2
	Qm	6.00	14.9	68.1	99.7	114	21.6	6.09	1.22	1.84
11	Q	63.7	35.4	193	144	94.3	200	31.7	11.1	927
	Qav	638	922	1166	1355	1119	1066	626	277	331
	%R	9.98	38.4	16.6	10.6	8.43	18.8	5.06	4.01	280
	Qm	11.3	35.4	132	71.2	94.3	80.8	30.2	11.1	10.4
12	Q	178	41.1	363	589	951	181	34.7	13.5	271
	Qav	403	577	694	818	682	465	270	156	113
	%R	44.2	7.12	52.3	72.0	139	38.9	12.9	8.65	240
	Qm	3.40	10.0	20.2	57.6	42.6	19.3	3.85	1.76	2.50

Q = observed monthly average flow (cfs)

Qav = average monthly flow for the period of record (cfs)

%R = (Q/Qav) x 100%

Qm = minimum monthly flow for the period of record (cfs)

Table 5.2. Continued

No.		*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
13	Q	10.7	4.48	183	750	700	372	13.0	6.34	51.2
	Qav	560	949	1067	1067	785	781	431	285	107
	%R	1.91	0.47	17.2	70.3	89.2	47.6	3.02	2.22	47.9
	Qm	4.80	4.48	13.1	79.0	17.9	3.20	1.70	1.00	1.10
14	Q	506	332	1271	3606	4669	3062	717	389	1980
	Qav	3237	4477	5244	6363	5661	4475	2755	1607	994
	%R	15.6	7.42	24.2	56.7	82.5	68.4	26.0	24.2	199
	Qm	220	242	287	613	598	699	321	253	191
15	Q	7.20	5.70	34.7	94.8	32.8	59.4	4.57	8.04	21.2
	Qav	356	512	758	848	603	647	407	162	274
	%R	2.02	1.11	4.58	11.2	5.44	9.18	1.12	4.96	7.74
	Qm	3.30	5.70	30.5	22.9	20.8	21.1	3.89	2.82	1.75
16	Q	15.4	9.96	76.5	156	90.7	84.1	30.8	27.5	72.9
	Qav	624	1047	1339	1597	1171	1049	726	353	436
	%R	2.47	0.96	5.71	9.76	7.75	8.02	4.24	7.79	16.7
	Qm	13.2	9.96	61.4	116	21.3	42.5	16.1	11.4	5.13
17	Q	125	97.1	418	674	441	105	22.6	30.7	208
	Qav	509	785	895	1163	802	539	347	218	166
	%R	24.6	12.4	46.7	58.0	55.0	19.5	6.51	14.1	125
	Qm	0.80	3.60	3.80	23.1	2.90	13.6	11.9	6.90	2.38
18	Q	330	130	416	931	1402	468	43.8	25.6	129
	Qav	428	699	854	732	591	444	306	210	88
	%R	77.1	18.6	48.7	127	237	105	14.3	12.2	148
	Qm	14.2	63.4	193	85.5	103	48.0	16.8	14.9	13.5
19	Q	1503	773	2057	2577	2234	1694	1141	103	648
	Qav	1836	2321	2602	2695	2089	1651	1007	577	397
	%R	81.9	33.3	79.1	95.6	107	103	113	17.9	163
	Qm	19.0	37.4	34.7	157	94.1	61.9	42.7	25.1	18.9
20	Q	443	146	899	985	493	167	40.8	61.2	270
	Qav	616	993	1016	985	608	505	341	187	118
	%R	71.9	14.7	88.4	100	81.1	33.1	12.0	32.7	229
	Qm	6.30	9.00	11.9	56.0	12.3	15.9	2.50	7.40	2.30

Q = observed monthly average flow (cfs)

Qav = average monthly flow for the period of record (cfs)

%R = (Q/Qav) x 100%

Qm = minimum mon thly flow for the period of record (cfs)

Table 5.2. Continued

No.		*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
21	Q	115	33.0	234	193	27.3	8.51	2.27	11.4	26.9
	Qav	126	228	254	241	91	97	68	17	14
	%R	91.3	14.5	92.1	80.1	30.0	8.77	3.34	67.1	192
	Qm	0.30	9.20	6.70	16.7	5.30	0.91	1.40	0.70	0.09
22	Q	331	120	843	732	151	104	27.8	24.7	109
	Qav	347	687	767	716	245	281	136	85	69
	%R	95.4	17.5	110	102	61.6	37.0	20.4	29.1	158
	Qm	3.90	42.2	34.5	45.3	25.4	12.4	12.9	10.7	4.30
23	Q	3271	6108	4591	8787	1112	2311	513	220	489
	Qav	2651	2910	3862	3748	2899	1240	899	590	389
	%R	123	210	119	234	38.4	186	57.1	37.3	126
	Qm	17.7	22.5	21.9	50.2	71.6	5.90	18.8	0.30	2.70
24	Q	194	62.4	172	314	513	136	20.1	78.9	382
	Qav	159	239	267	290	229	162	98	59	32
	%R	122	26.1	64.4	108	224	84.0	20.5	134	1194
	Qm	0.60	4.10	76.8	35.6	36.5	14.3	9.59	0.10	0.00
25	Q	1045	742	1878	2868	2453	1054	462	295	3425
	Qav	1629	1956	2195	2166	1731	1233	730	432	329
	%R	64.1	37.9	85.7	132	142	85.5	63.3	68.3	1041
	Qm	13.4	21.6	23.4	120	78.3	65.9	18.8	11.6	7.70
26	Q	624	820	1703	1667	278	279	15.5	77.0	55.4
	Qav	617	653	794	753	564	278	146	119	70
	%R	101	126	214	221	49.3	100	10.6	64.7	79.1
	Qm	0.70	2.50	2.00	11.6	9.00	1.48	1.10	0.10	0.00
27	Q	4329	6205	7281	13960	1821	1786	357	681	1697
	Qav	3435	4335	5542	5180	3770	2027	1292	782	367
	%R	126	143	131	269	48.3	88.1	27.6	87.1	462
	Qm	50.6	62.7	25.3	176	167	44.5	40.8	22.7	3.10
28	Q	553	1648	754	576	35.5	214	51.1	11.0	7.01
	Qav	496	473	613	583	411	210	98	82	63
	%R	111	348	123	98.8	8.64	102	52.1	13.4	11.1
	Qm	1.40	7.10	12.2	40.7	10.4	1.40	1.70	0.00	0.40

Q = observed monthly average flow (cfs)

Qav = average monthly flow for the period of record (cfs)

%R = (Q/Qav) x 100%

Qm = minimum monthly flow for the period o f record (cfs)

Table 5.3. Months during 1988 with Lowest Monthly Flows on Record, and Months with Flows within 50 Percent of the Lowest on Record, for Selected USGS Streamgaging Stations

No.	*Drainage area (sq mi)*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1	6,363						a	a					
2	1,326				a		a	a	a				
3	146				a	a	a	a	a				
4	432		x		a	x	a						
5	349		x			x		x	x				
6	232												
7	5,150						a	a	x				
8	579						x	x	x	x	x		
9	1,251							x	x				
10	767					a		x	x	x			
11	1,072		x	a		x	a	x	x	x	a		
12	550						a	x	x	x	x		
13	867		x				x			a			
14	5,093		a				x	a	a	a			
15	655		x	a			x	x	x	x	x	a	
16	1,293	a	x	a	a		a	a	a	a	x	a	x
17	868						x	x		x			
18	473					a	x	x	x	x	a		
19	1,940						x	a		x			
20	735						x						
21	154					a	x	a		a	x		
22	464					a	x						
23	2,169												
24	186					a	x	x					
25	1,516										a		
26	464					a	x						
27	3,102					x	x						
28	244												

Note: x = monthly flow 3/88 – 9/89 that was the lowest on record.
a= monthly flow 3/88 – 9/89 that was within 50 percent of the record low.

Table 5.4. Number of Stations (out of 28) with Record Low Flows or Flows within 50 percent of Record Low for Each Calendar Month, 1988

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Record low	0	6	0	0	4	13	10	9	8	5	0	1
Within 50 percent of record low	1	1	3	4	7	8	8	4	4	3	2	0

Table 5.5. 7-Day Low Flows in 1988-1989 versus 7-Day, 10-Year Low Flows for Illinois Streamgaging Stations

No.	*Drainage area (sq mi)*	*7-day, 10-year low flow (Q7,10) (cfs)*	*7-day low flow (Q 7) (cfs)*	*Month and year of occurrence of Q7*
1	6,363	859	926	July 1989
2	1,326	181	245	July 1989
3	146	15.0	24.3	June–July 1989
4	432	8.1	8.3	August 1989
5 *	349	0.05	0.0	June–September 1988
6	232	32.0	32.4	October 1988
7 *	5,150	480	344	August 1988
8 *	579	1.2	0.0	Jul–Oct 1988 & Aug 1989
9 *	1,251	6.3	3.0	July–August 1988
10*	767	1.2	0.41	August 1988
11*	1,072	10.4	3.3	September 1988
12*	550	1.9	0.08	September 1988
13*	867	0.89	0.0	Jun–Aug & Oct–Dec 1988 & Jan 1989
14*	5,093	238	173	September 1988
15*	655	2.0	0.12	October 1988
16*	1,293	11.0	1.8	September 1989
17*	868	2.4	1.3	September 1988
18*	473	10.3	2.7	September 1988
19*	1,940	39.0	27.9	September 1988
20*	735	1.9	0.26	September 1989
21*	154	0.10	0.01	September–October 1988
22	464	1.0	3.3	August 1989
23	2,169	55.0	71.4	August–September 1988
24*	186	0.51	0.0	August–September 1988
25*	1,516	16.6	9.0	October 1988
26*	464	0.05	0.0	October 1988
27	3,102	6.8	17.0	October 1988
28	244	0.0	0.79	July-August 1988

*7-day low flow during the drought period (March 1988-September 1989) was less than the 7-day 10-year low flow.

Table 5.6. Historical Monthly Flow Data and Observed Flows in the Illinois and Mississippi Rivers, January 1988 through September 1989 (cfs)

Illinois River at Marseilles 05543500; drainage area 8,259 sq mi; 1920-1987

	Long-term average monthly flow	*Monthly flow for the lowest flow years* 1940*	*1964*	*1988-1989 monthly flow*	*Minimum monthly flow for the record up to 1987*	*Water year of minimum monthly flow*
1988						
Jan	9,789	4,087	3,629	12,140	3,202	1963
Feb	11,651	4,111	3,843	11,830	3,264	1963
Mar	15,189	6,819	5,153	9,305	5,153	1964
Apr	16,518	6,551	10,180	15,390	6,551	1940
May	13,850	10,380	7,407	5,649	6,211	1958
June	11,497	7,986	7,264	4,346	5,096	1977
July	9,089	5,585	7,037	4,687	5,008	1977
Aug	7,858	5,631	5,018	5,562	4,242	1939
Sept	7,700	4,768	5,131	5,066	3,522	1976
Oct	7,685	4,497	3,707	4,366	3,518	1975
Nov	8,448	4,275	4,302	8,628	3,720	1977
Dec	9.806	4,915	4,362	6,806	3,739	1944
1989						
Jan	9,789	4,087	3,629	9,179	3,202	1963
Feb	11,651	4,111	3,843	5,753	3,264	1963
Mar	15,189	6,819	5,153	9,115	5,153	1964
Apr	16,518	6,551	10,180	8,977	6,551	1940
May	13,850	10,380	7,407	6,657	6,211	1958
Jun	11,497	7,986	7,264	13,140	5,096	1977
Jul	9,089	5,585	7,037	7,830	5,008	1977
Aug	7,858	5,631	5,018	6,879	4,242	1939
Sep	7,700	4,768	5,131	17,740	3,522	1976

*With lowest annual flows of 5,583 cfs in 1964 and 5,808 cfs in 1940.

Note: Annual flows for 1988 and 1989 were 8,212 and 8,744 cfs, respectively; monthly flows in May, June, and July 1988 were the lowest on record for 1920-1989.

Table 5.6. Continued

Illinois River at Kingston Mines 05568500; drainage area 15,819 sq mi; 1940-1987

	Long-term monthly average flow	*Monthly flow for the lowest flow years** *1940*	*1964*	*1988-1989 monthly flow*	*Minimum monthly flow for the record up to 1987*	*Water year of minimum monthly flow*
1988						
Jan	13,407	4,281	4,035	23,870	3,747	1963
Feb	16,257	6,421	3,876	23,060	3,421	1963
Mar	23,074	10,050	7,000	14,710	7,000	1964
Apr	25,828	7,928	15,380	28,750	7,928	1940
May	23,474	11,970	11,240	8,943	8,090	1958
June	18,195	9,886	8,969	6,398	5,579	1977
July	12,962	6,225	8,465	6,080	4,474	1965
Aug	9,171	6,096	5,382	6,771	5,038	1944
Sept	8,685	6,242	4,886	5,722	4,027	1963
Oct	9,325	4,877	3,362	6,154	3,362	1964
Nov	10,347	4,651	4,626	10,310	4,428	1977
Dec	12,826	4,849	4,638	7,851	4,598	1944
1989						
Jan	13,407	4,281	4,035	10,580	3,747	1963
Feb	16,257	6,421	3,876	6,897	3,421	1963
Mar	23,074	10,050	7,000	11,820	7,000	1964
Apr	25,828	7,928	15,380	11,500	7,928	1940
May	23,474	11.970	11,240	7,822	8,090	1958
Jun	18,195	9,886	8,969	15,440	5,579	1977
Jul	12,962	6,225	8,465	7,631	4,474	1965
Aug	9,171	6,096	5,382	7,316	5,038	1944
Sep	8,685	6,242	4,886	23,360	4,027	1963

*With lowest annual flows of 6,820 cfs in 1964 and 6,957 cfs in 1940.

Note: Annual flows for 1988 and 1989 were 13,620 and 10,540, respectively; monthly flow in May 1989 was the lowest on record for 1940-1989.

Table 5.6. Concluded

Mississippi River at St. Louis 07010000; drainage area 697,000 sq mi; 1934-1987

	Long-term monthly average flow	*Monthly flow for the lowest flow years** *1940*	*1964*	*1988-1989 monthly flow*	*Minimum monthly flow for the record up to 1987*	*Water year of minimum monthly flow*
1988						
Jan	109,460	47,010	31,340	160,700	31,340	1940
Feb	139,070	60,320	41,900	182,500	41,900	1940
Mar	229,790	78,020	91,800	192,400	74,550	1964
Apr	306,750	110,100	129,000	240,100	110,070	1934
May	277,940	79,500	117,700	135,100	79,500	1934
June	262,460	70,260	128,200	77,140	70,260	1934
July	212,070	72,930	87,260	67,250	67,130	1936
Aug	132,130	51,010	102,600	68,910	43,510	1936
Sept	130,500	63,600	75,630	72,990	54,640	1939
Oct	139,790	68,170	44,170	73,360	44,170	1940
Nov	140,780	54,630	47,920	89,930	47,920	1940
Dec	116,960	55,250	51,380	77,390	42,130	1938
1989						
Jan	110,830	47,010	31,340	83,650	31,340	1940
Feb	140,730	60,320	41,900	81,770	41,900	1940
Mar	230,490	78,020	91,810	127,700	74,550	1964
Apr	307,460	110,100	129,000	176,200	110,100	1934
May	278,530	79,500	117,700	122,500	79,500	1934
Jun	261,420	70,260	128,200	134,900	70,260	1934
Jul	212,690	72,930	87,260	89,600	67,130	1936
Aug	133,500	51,010	102,600	87,380	43,510	1936
Sep	132,700	63,600	75,630	169,500	54,640	1939

*With lowest annual flows of 67,700 cfs in 1934 and 79,109 cfs in 1940.
Note: Monthly flow in July 1988 was very close to the record low in July 1936.

Table 5.7. Selected Water Supply Lakes and Major Reservoirs

	Luke	*County*	*Normal pool elev (ft msl)*	*Drainage area (Sq mi)*	*1990 storage (ac-ft)*	*1990 average demand (mgd)*	*1990 population served*
1	Altamont	Efflngham	582.0	1.07	940	0.261	3,724
2	Bloomington [a]	McLean	719.5	69.1	7,411	10.146	56,369
3	Carlinville	Macoupin	573.0	25.4	1,607	0.766	7,974
4	Centralia	Marion	477.0	7.0	2,709	3,869	36,504
5	Decatur	Macon	613.5	925	17,859	26,027	94,989
6	Eldorado [b]	Saline	426.2	2.23	572	0.546	7,484
7	Evergreen [a]	Woodford	715.0	40.2	11,705		
8	Georgetown	Vermilion	612.0	155	165	0.419	5,045
9	Highland Silver	Madison	500.0	49.3	5,947	0.957	8,946
10	Kinkaid	Jackson	420.0	62.3	77,388	1,923	19,627
11	Nashville	Washington	503.8	1.39	381	0.489	4,610
12	Pana	Christian	642.2	8.5	3,207	1.140	6,164
13	Paradise	Coles	684.1	18.1	1,319	2.682	20,634
14	Paris Twin Lake	Edgar	660.0	21.7	1,361	1.237	9,515
15	Pittsfield	Pike	596.0	11.1	2,606	0.435	4,063
16	Spring (Macomb)	McDonough	642.3	20.2	2,542	1.866	20,510
17	Springfield	Sangamon	560.0	265	51,387	21.274	145,709
18	Vermilion	Vermilion	576.7	298	7,985	8.041	56,234
19	Virginia	Cass	575.0	0.83	163	0.178	1,747
20	White Hall	Greene	560.0	0.97	376	0.234	2,750
21	Rend Lake	Franklin	405.0	488	170,100	14.394	116,077
22	Lake Shelbyville	Shelby	599.7 [c]	1054.0	200,000	none	
23	Carlyle Lake	Clinton	445.0 [d]	2,719	209,420	1,109	9,367
24	Crab Orchard	Williamson	405.0	196	56,638	none	

Note: 1990 storage in ac-ft was up to normal pool level according to Singh and Durguno?lu (1990); 1990 average demand is taken from Broeren and Singh (1989); 1990 population served is taken from Singh et al. (1988).

[a] Bloomington supply = supply from Lake Bloomington and Evergreen Lake.

[b] Eldorado reservoir is the backup to the primary ground-water supply.

[c] Normal pool elevation is 599.2 in May-June; 600.7 in July-September; 594.0 in December-March; and 596.0 in April.

[d] Normal pool elevation is 445 in May-November and 443 in December-April.

Table 5.8. Month-End Departures (feet) from Normal Pool Elevations for Selected Water Supply Lakes and Major Reservoirs

Lake #	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1988												
1	+0.7	-0.1	+0.1	-0.5	-1.2	-2.2	-3.0	-3.8	-4.9	-5.5	-4.7	-4.8
2	+0.6	+0.5	+0.8	+0.5	-0.3	-2.8	-6.0	-8.3	-11.1	-12.2	-11.7	-11.3
3	+0.2	+0.2	-2.0	-3.0	-3.8	-1.7	-2.5	-2.8	-4.2	-5.0	-2.3	-2.0
4	+0.2	-0.7	-0.5	-1.0	-2.0	-3.0	-3.2	-3.8	-4.0	-4.3	-1.0	-0.6
5	-1.2	-0.7	-1.0	+0.4	+0.5	-0.1	-1.6	-2.7	-4.1	-4.7	-3.9	-1.0
6	+0.1	-0.1	+0.3	-0.7	-1.2	-1.8	-2.0	-2.7	-2.6	-2.8	-1.7	-0.8
7	--	--	--	--	--	--	-4.5	-5.0	-5.1	-6.4	-7.8	-9.5
8	+0.8	+0.4	+0.2	+0.3	+0.1	0.0	-0.5	-0.3	-1.1	0.0	+0.2	+0.1
9	--	--	--	--	--	--	-1.8	-2.1	-2.6	-2.8	0.0	0.0
10	--	--	--	--	--	-1.0	-2.0	-2.0	-2.0	-2.0	0.0	0.0
11	0.0	0.0	+0.1	-0.6	-2.5	-4.0	-4.7	-5.7	-5.6	-5.8	-4.1	-2.1
12	+0.3	0.0	+0.1	-0.1	-0.8	-2.3	-2.2	-3.2	-3.9	-4.3	-3.3	-2.7
13	0.0	0.0	+0.1	0.0	-1.0	-0.5	-0.3	0.0	-0.5	-1.3	-1.0	0.0
14	+0.5	+0.2	+0.4	0.0	0.0	-0.2	-0.9	-1.7	-2.7	-3.5	+0.1	+0.1
15	--	--	--	--	--	-0.4	-1.1	-1.6	-1.9	-2.2	-1.6	-1.3
16	0.0	0.0	+1.0	0.0	-0.7	-1.2	-2.6	-3.8	-4.8	-5.0	-4.8	-4.0
17	-0.2	-0.3	+0.6	+0.2	-0.2	-1.2	-2.4	-3.5	-4.4	-5.3	-4.6	-3.9
18	-0.2	+0.2	+2.1	-0.5	+1.3	-0.2	-1.0	-2.9	-3.7	-3.2	+0.7	+0.7
19	+0.1	0.0	0.0	+0.1	0.0	-0.1	--	-0.7	-0.8	-1.0	-1.0	-1.0
20	-5.0	-4.0	-0.4	-0.7	-1.0	-2.2	-3.3	-4.1	-5.7	-5.7	-6.0	-5.5
21	+3.7	+4.3	+4.3	+3.3	+2.0	+0.8	+0.7	+0.1	+0.6	+0.1	+1.1	+1.5
22	+2.1	0.0	+1.7	+0.4	-2.4	-2.5	-2.2	-2.6	-2.9	-4.9	-3.1	+3.3
23	+4.0	+1.7	+1.8	+1.1	-0.9	-1.2	-1.5	-2.0	-2.4	-2.6	-0.6	+1.5
24	--	--	--	--	--	-0.6	-0.4	-.6	-0.5	-0.4	+0.4	+0.4
1989												
1	-4.3	-4.5	+0.2	-0.1	-0.1	-0.5	-1.0	-1.9	-0.3	-1.0	-1.3	-1.8
2	-10.9	-10.8	-9.9	-10.2	-9.2	-10.4	-11.2	-11.3	-9.0	-10.0	-11.0	-11.4
3	-0.8	-0.2	+0.2	-0.2	-0.7	-1.5	0.0	-0.5	-1.0	-1.0		
4	-0.4	-0.8	-0.2	-0.7	-0.3	-0.7	-1.5	-2.6	-3.0	-2.6	-3.1	-3.5
5	+0.5	+0.6	+1.0	+0.8	+0.6	+1.1	+0.7	-0.3	+0.8	+0.5	-0.5	-0.7
6	0.0	+0.5	0.0	-0.8	-1.3	0.0	-0.4	-1.0	-1.4	-1.9	-2.3	-2.1
7	-10.8	-12.6	-13.8	-12.8	-13.5	-13.5	-15.1	-18.1	-19.4	-21.8	-22.3	-24.0
8	+0.1	+0.2	+0.2	+0.7	+0.2	0.0	+0.2	+0.9	+0.2	+0.3	+0.3	+0.3
9	0.0	0.0	0.0	0.0	0.0	0.0	-0.5	-0.5	0.0	0.0	-0.5	-0.5
10	0.0	0.0	+1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.0	-2.0
11	0.0	0.0	+0.2	-0.7	-2.0	-1.2	-1.7	-1.9	-1.7	-2.4	-2.3	-2.4
12	-1.7	-1.4	0.0	+0.1	0.0	-0.5	-1.2	-2.0	-1.9	-2.5	-3.0	-3.3
13	+0.1	0.0	0.0	0.0	+0.3	0.0	-3.0	-3.0	-0.5	-1.5	-0.5	0.0
14	+0.2	+0.1	+0.2	+0.2	+1.0	-0.1	0.0	+0.2	+0.1	+0.1	+0.1	+0.1
15	-0.2	-1.2	-1.2	-0.7	-0.2	+0.1	-0.2	-0.8	-0.5	-1.1	-1.3	*
16	-3.3	-2.9	-2.1	-0.5	-0.8	-1.3	-2.1	-3.0	-3.3	-4.6	-5.4	-5.2
17	-2.9	-2.0	-0.4	+0.1	+0.3	-0.4	-1.2	-2.2	-2.0	-2.9	-3.7	-4.2
18	+1.0	+0.5	+1.0	+0.2	+0.7	+1.0	+0.7	+0.4	+0.5	-0.4	-0.5	-0.8
19	-1.0	-1.0	-1.1	-0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	-5.5	-5.5	-5.5	-5.5	-3.5	-3.9	-5.0	-5.8	-6.2	-7.2	-8.2	-9.0
21	+3.1	+4.6	+6.9	+4.1	+2.8	+2.6	+1.5	+0.7	+0.3	-0.5	-1.1	-1.1
22	+1.9	+1.9	+2.7	+6.5	+7.6	+4.2	-0.1	-0.2	+0.8	-1.0	-1.0	4.0
23	+0.7	+0.7	+1.6	+2.0	+2.0	+0.1	0.0	+0.1	+0.1	-0.2	-0.2	-0.2
24	+0.2	+0.6	+1.8	0.0	-0.5	-0.4	-0.5	-0.8	-4.0	-4.1	-4.1	-4.1

*Frozen, no op en-water-level reading available.

Table 5.9. Long-Term Monthly Flows and Driest Years of Record for Money Creek (cfs)

Month	*Long-term average flow*	*Flow during driest years of record* 1977	*1963*	*1966*	*1988 flow*
April	72.19	7.0(9.7%)	32.5(45.0%)	43.8(60.7%)	9.7(13.5%)
May	52.50	60.7(115.6%)	6.8(13.0%)	41.0(78.1%)	10.1(19.3%)
June	49.36	6.0(12.2%)	1.3(2.6%)	30.8(62.4%)	6.3(12.7%)

Note: Numbers in parentheses show monthly flow as percent of long-term average flow.

Table 5.10. Inflow to Bloomington PWS Reservoirs Based on Three Precipitation Scenarios (inches)

1988	*Historical average values*			*50% average precipitation*		*100% average precipitation*		*150% average precipitation*	
month	*P*	*R*	*R/P*	*R/P*	*R*	*R/P*	*R*	*R/P*	*R*
July	3.66	0.521	0.142	0.03	0.06	0.04	0.16	0.05	0.30
Aug	3.57	0.441	0.124	0.03	0.06	0.05	0.18	0.07	0.40
Sep	3.20	0.537	0.168	0.04	0.07	0.07	0.22	0.13	0.60
Oct	2.76	0.363	0.132	0.04	0.06	0.09	0.25	0.13	0.54
Nov	2.50	0.353	0.141	0.06	0.07	0.11	0.28	0.15	0.56
Dec	2.35	0.664	0.283	0.14	0.17	0.26	0.60	0.34	1.20

Note: P and R denote historical average monthly precipitation and runoff, respectively.

Table 5.11. Combined Storage Projections and Demand for Bloomington PWS Reservoirs Based on Three Precipitation Scenarios

	Projections made in early July 1988				*From actual observations*	
1988 month	*PWS demand (mgd)*	*Combined storage for P/P (ac-ft)* 0.5	*1.0*	*1.5*	*PWS demand (mgd)*	*Combined storage (ac-ft)*
June		14,015	14,015	14,015		14,015
July	14.0	12,453	13,132	14,732	14.0	12,560
Aug	13.0	11,263	12,642	15,569	10.5	11,480
Sep	12.0	10,309	12,631	17,785	9.3	10,260
Oct	10.0	9,558	12,962	18,819	8.7	9,010
Nov	9.0	9,080	13,286	19,195	8.5	8,470
Dec	9.0	9,195	13,573	overflow	8.8	7,820

6. GROUND-WATER CONDITIONS

by

H. Allen Wehrmann

This chapter extends the documentation of the 1988—1989 drought to its effects on ground-water conditions in Illinois. Those effects are governed by the variables of the ground-water budget, which is part of the general hydrologic budget. A hydrologic budget is based on the assumption that over a long time period, water gains by a drainage basin will be balanced by water losses. This balance can be expressed quantitatively in the following equation:

$$P = R + ET + U + S_s + S_g \qquad (6.1)$$

In a natural system, precipitation (P), principally in the form of rain and snow, is the only source of water gain considered. Water leaves the basin in the form of surface runoff (R), evapotranspiration (ET), and ground-water underflow (U). Water also is stored beneath the surface in the pore spaces of unsaturated soils (S_s) and as ground water in saturated geologic materials (S_g) The latter is reflected in changes in water levels in wells. Ground-water underflow (U) involves the movement of ground water out of one drainage basin and into another, and thus differs from ground-water discharge to surface streams within the same basin.

Evapotranspiration (ET) combines evaporative losses from land and water surfaces with transpiration losses from vegetation. It follows an annual pattern in response to seasonal changes in temperature and plant growth. Evapotranspiration losses are very small during the winter, increase rapidly during the spring, reach the maximum in summer, and then decrease rapidly in fall, particularly after the first killing frost. Precipitation normally is exceeded by evapotranspiration losses during the summer, resulting in decreases of water in soil (S_s) and ground-water storage (S_g).Evapotranspiration losses normally are much less than precipitation during the winter and early spring, resulting in a gain (recharge) of water to soil moisture and ground-water storage. We next consider the processes that change the ground-water storage.

6.1. Ground-Water Storage and Budget

Soil moisture (S_s) is water held in the unsaturated water (water adhering to soil particles through electrochemical attraction), capillary water (water held in the pore spaces between soil particles by surface tension), and gravitational water (water present within the pore spaces in excess of hygroscopic and capillary moisture). The combined maximum capacity of the hygroscopic and capillary waters is known as the field capacity of the soil; moisture present in excess of field capacity (i.e., the gravitational water) has the potential to infiltrate or move under the force of gravity to the water table (defined below) where it becomes ground water.

The higher the soil moisture content, the greater the potential for infiltration. Obviously, the greater the soil moisture content when precipitation occurs, the greater the potential for ground-water recharge to occur. While average annual changes in soil moisture are usually very small (Schicht and Walton, 1961), daily, weekly, and monthly changes throughout the year can be significant.

The top of the zone of saturation is known as the water table. Under natural conditions, the water table forms a surface that resembles the overlying land surface topography, except with a more subdued and smoother configuration. The water table can be approximated by the elevation of water surfaces in wells that just penetrate the saturated zone. Changes in shallow ground-water storage (S_g) are directly related to changes in ground-water levels (i.e., the water table). Lower ground-water levels mean less saturated material and thus less water in storage. Changes in ground-water storage result from the difference between recharge and discharge of water, which can be seen as a cyclical pattern of high and low ground-water levels. Most of the precipitation falling during summer months is evaporated or transpired before it is able to infiltrate to the water table. Thus the summer months normally are considered periods when ground water is taken out of storage, causing water levels to drop.

Similar in form to the more general equation 6.1, a budget that balances inputs and outputs for the ground-water system can be expressed as

$$P_{gw} = R_{gw} + ET_{gw} + U + S_{gw} \qquad (6.2)$$

This represents the fact that over a given period of time, ground-water recharge within a given basin

(P_{gw}) is balanced by ground-water runoff (R_{gw}), evapotranspiration (ET_{gw}), underflow (U), and change in ground-water storage (S_{gw}). Artificial ground-water removals, such as pumpage from wells, also could be included as an additional term on the right side of the equation.

Precipitation that infiltrates the soil to the saturated zone eventually discharges into one of the basin's streams or other surface water bodies as ground-water runoff (R_{gw}). In Illinois, most surface runoff is completed within three to five days following precipitation or snowmelt, after which time streamflow is derived principally from ground-water runoff (Schicht and Walton, 1961). Ground-water runoff is a function of several factors. It inherently depends on the slope (hydraulic gradient) of the water table and the position of the water table relative to the streambed level. If ground-water levels are below the bottom of the streambed, ground-water runoff will not occur.

Ground-water runoff is also affected by the hydraulic properties of the water-bearing formation. For example, runoff is greatest in the permeable deposits of northeastern Illinois and lowest in the claypan areas of southern Illinois (O'Hearn and Gibb, 1980), particularly in years with below-normal precipitation (Walton, 1965). There are two reasons for this geographical variation. First, the finer-grained clay materials prevalent in southern Illinois do not allow infiltration of water as easily as the more permeable materials in northeastern Illinois, and this leads to greater surface runoff. Second, once they become saturated, these finer- grained , materials do not yield water as readily as the coarser-grained sand or gravel, further reducing the rate of ground-water release to surface water bodies.

Ground-water evapotranspiration (ET_{gw}), which extracts moisture from below the water table, is closely related to the season of the year and to ground-water stage. Losses through this process are small from November through April, when air temperatures are low and plant growth is negligible. Losses are greatest between May and October, when air temperatures are high and plant growth is significant. The potential for ground-water evapotranspiration increases as the water table approaches the land surface, where the roots of plants can capture the water and soil capillaries can draw ground water nearer to the surface, allowing warm air to evaporate the water.

Ground-water recharge (P_{gw}) occurs when infiltrated precipitation exceeds surface evapotranspiration and soil moisture requirements. Most recharge occurs during the spring when evapotranspiration is small and soil moisture is maintained at or above field capacity by frequent rains. During summer and early fall, evapotranspiration and soil moisture requirements normally exceed precipitation, so little water percolates to the water table. Recharge is negligible during the winter months when the ground is frozen. Ground-water recharge is indicated by an increase in ground-water level or by a decrease in the rate of decline of a downward-trending level (Schicht and Walton, 1961).

Recharge to near-surface deposits can occur at relatively high rates, especially when these deposits contain significant amounts of sand and gravel. However, large areas of Illinois are covered by fine-grained glacial drift, which commonly exceeds 50 feet in thickness. Sand-and-gravel and bedrock aquifers are often deeply buried by this material, which typically has a low vertical permeability. Therefore, recharge to many of the deep aquifers is limited to slow leakage through the drift. Recharge to surficial deposits often exceeds the leakage to underlying aquifers, particularly during wet periods. Thus surficial deposits can act as temporary reservoirs, supplying water that can leak through the drift into underlying aquifers. In this manner, recharge to deep aquifers is buffered from short-term irregularities in precipitation by providing a lag time for reaction to drought conditions. Conversely, deeper aquifers will not recover as quickly as surficial deposits from long-term shortages in recharge.

It follows that a drought that occurs during the recharge season will tend to have a greater impact on ground-water levels than a drought that occurs during the growing season. This is opposite to the impact a summer drought has on agriculture. This is because little ground-water recharge normally occurs during the growing season, and recovery of ground-water levels from storage removals during the growing season is dependent on excess moisture (recharge) during the subsequent late fall and early spring. If recharge does not occur during this time period, ground-water levels will remain low going into the next growing season and will then fall more rapidly as ground water is taken out of storage by evapotranspiration and ground-water runoff.

Examples of the general relationship between precipitation and shallow ground-water levels are illustrated in figures 6.1 and 6.2, which show monthly precipitation and shallow ground-water levels at sites in the eastern (Swartz) and west-southwestern (Greenfield) sections of Illinois. A cyclical pattern of seasonal ground-water-level changes is clearly evident, with maxima occurring in spring and minima in fall.

Precipitation and ground-water-level data for these two sites show that moderate to high monthly rainfall amounts in summer had little effect on declines in ground-water level, whereas similar amounts of precipitation in the fall, winter, and spring caused ground-water levels to recover significantly. Note in figure 6.1, for example, that more than 8 inches of rain fell in July 1987 but caused no change in the downward trend in ground-water level, while moderate rains from November 1987 through April 1988 caused 6 feet of water-level recovery. This is principally because surface runoff and ground-water evapotranspiration limit ground-water recharge during the hot summer months, whereas conditions in the fall and spring (for example, lower evapotranspiration) are much more conducive to recharge.

Similar patterns are evident in figure 6.2. At both sites, ground-water levels approached historic low levels in the summer and fall of 1988 but recovered quickly in the spring of 1989 to near-average month-end levels. As shown later in this chapter, other parts of Illinois did not experience such an early recovery from the ground-water effects of the 1988 precipitation deficiency.

Although not discussed further here, a wide variety of other natural and human influences also can affect ground-water levels to varying degrees (Peck, 1960; Roberts and Romine, 1947; Russell, 1963). Natural causes include atmospheric pressure changes, earthquakes, changes in surface water stages, and tides. Human influences include ground-water withdrawals (pumpage), artificial recharge (e.g., impoundment leakage, fluid injection), and aquifer compression such as from train or barge traffic. However, as the hydrologic and ground-water budgets demonstrate, precipitation is the principal source of water that can be *added* to the system and that ultimately affects ground-water levels.

6.2. Shallow Ground-Water Levels during the 1988-1989 Drought

Monitoring Network and Computational Procedures

The Water Survey maintains a network of 21 observation wells to monitor the natural short- and long-term fluctuations of shallow ground-water levels (i.e., the water table) across Illinois. Typically, these wells do not extend into highly productive aquifers; rather, they are constructed in fine-grained glacial materials containing thin lenses of sand. Most are large-diameter (>36 inches), dug or bored wells of the type commonly found in areas where shallow, productive aquifers are not present.

These observation wells are purposely located in areas remote from pumping centers in order to minimize the apparent effects of human activities on ground-water levels. Other influences, particularly those of short duration (e.g., less than one day), are of minimal significance under most circumstances. The ground-water levels experienced in these observation wells are thus representative of conditions beneath nonirrigated agricultural land, and of the water levels found in many shallow, rural domestic wells in Illinois.

The locations of the 21 observation wells are shown in figure 6.3. Most of these wells have been monitored since the early 1960s, and water levels at four currently operational observation wells have been measured since the early 1950s. A summary of the significant features of each observation well is provided in table 6.1. Each well is equipped with a Stevens Type F continuous water-level recorder, which contains a 30-day chart. Therefore each well must be visited monthly so the paper chart on the recorder can be changed. The charts are changed and taped readings of ground-water levels are measured at the end of each month; hence reference is made to *month-end* ground-water levels. For this study, historical month-end measurements were used to establish mean monthly ground-water levels; historical monthly highs and lows were determined from the paper chart records for comparative purposes.

Ground-water-level data from the 21-well network were examined to determine the effects of the 1988-1989 drought on shallow ground-water resources in Illinois. Mean monthly water levels were calculated for the period of record (through 1986) at each well, and departures from those means were computed for each month from January 1987 through April 1989. These data were analyzed to showground-water levels prior to and following the drought period defined by the precipitation data presented in chapter 3.

Departures of measured ground-water levels from the corresponding mean monthly water levels were accumulated for 6-, 9-, and 12-month periods for comparison with precipitation characteristics. Similar departure accumulations were made for previous historical drought periods as a basis for comparison of drought severity. Long-term hydrographs were prepared for selected wells for further comparison with historical drought conditions.

Drought Preconditions: Ground-Water Levels for January 1987 - March 1988

In some parts of Illinois, particularly western Illinois, below-average precipitation in 1987 (see Chapter 3) caused lower than average shallow ground-water levels prior to the spring 1988 onset of the drought proper. An extreme example can be seen in the hydrograph for the observation well at Good Hope in western Illinois (figure 6.4). Total 1987 precipitation at nearby Monmouth amounted to only 72 percent of the long-term average. Precipitation for January through June, typically a high potential recharge period, totaled only 54 percent of normal.

Figure 6.4 shows that ground-water levels were slightly below the mean in February 1987, declined rapidly after April, and were almost 11 feet below average by November. Although some recovery of the ground-water level occurred between November 1987 and January 1988, precipitation from January through March 1988 amounted to only 80 percent of normal, and ground-water levels quickly fell back to almost 11 feet below average in March. For the 15 month period from January 1987 through March 1988, the precipitation deficit amounted to 11.3 inches, and new historic lows in month-end ground-water levels were established for every month after May 1987.

The spatial variation of Illinois ground-water conditions for March 1988 is documented in figure 6.5, which shows month-end water levels for that month, the change in water levels from the previous month, and the departures from the monthly mean levels. These results indicate that water levels in five of the 21 observation wells were from 0.07 to 12.09 feet below their mean March levels in 1988.

Furthermore, although 16 of the wells recorded above-average ground-water levels, 11 of them had levels less than 2 feet above normal. Of the five wells with levels more than 2 feet above average, the maximum positive departure was only 4.54 feet (Mt. Morris, northwestern Illinois). Therefore, shallow ground-water levels in some parts of Illinois were clearly low going into the 1988-1989 drought period proper. In addition, while a lag did occur between the subsequent principal period of precipitation deficit and its maximum effect on ground-water levels, the lack of a ground-water surplus going into the drought meant that the ground-water response to the drought in some areas was faster, more pronounced, and longer lasting than in other areas.

The Precipitation Drought Period: April - August 1988

Results of the type shown for March 1988 in figure 6.5 are presented for April 1988 in figure 6.6. By the end of April, ground-water levels were from 0.25 to 11.62 feet below mean monthly levels in 14 of the 21 observation wells. Four of the seven wells with water levels above average had levels less than 1 foot above average, while another well (at Crystal Lake) had a level only 1.16 feet above average. At this early stage in the year, then, ground-water levels were already being affected by 1987 precipitation deficits, by early 1988 precipitation deficiencies, or by both.

The progression of the shallow ground-water-level decline across the state through the summer of 1988 can be seen in figures 6.7 and 6.8. By the end of May (not shown), only five wells recorded above-average ground-water levels, and by the end of June (figure 6.7) this was true of only two wells. Departures below mean levels for June ranged from 0.74 to 8.41 feet; above-average ground-water levels were recorded in only two wells (0.36 foot at Mt. Morris and 0.72 foot at SWS No. 2).

All 2 1 wells reported below-average ground-water levels in August (figure 6.8). Departures from mean monthly levels for that month ranged from 0.09 foot below average at SWS No. 2 to 9.26 feet below average at Good Hope. At Good Hope (figure 6.4), the total rainfall for the five-month period April through August 1988 was 8.44 inches, only 43 percent of normal (a deficit of 11.14 inches). During this period, ground-water levels fell 6.4 feet at Good Hope. Statewide, ground-water levels fell an average of 5.6 feet between April and the end of August 1988.

Ground - Water Conditions after the Precipitation Drought

For many parts of the state, precipitation amounts began to return to normal late in the summer of 1988 (chapter 3). However, the need to replenish deficient soil moisture (chapter 4) delayed the ground-water-level recovery, and ground-water levels continued to decline through the fall of 1988. Indeed, maximum depths to water were not reached at most stations until after September 1988.

Figures 6.9-6.11 give the recorded month-end water levels, the changes in levels from the preceding month, and departures from average monthly levels for October and December 1988 and April 1989. At the end of October 1988 (figure 6.9), ground-water levels were below average October levels at all wells. The departures ranged from 0.09 foot at SWS No. 2 to 11.34 feet at Good Hope. For the period April-October 1988, maximum ground-water-level declines occurred at Mt. Morris (10.21 feet), Greenfield (10.91 feet), and Cambridge (14.19 feet). These wells are all located in western or northwestern Illinois, which were the areas of the state most deficient in precipitation.

After October 1988, ground-water levels started to recover in many areas of the state. For example, figure 6.10 shows that six wells had above-average water levels by the end of December 1988. Five of those wells were located in the southern portion of the state (Dixon Springs, Elco, Sparta, St. Peter, and SWS No. 2). Two other wells, at Janesville and Southeast Illinois College, had levels only 0.35 and 0.07 foot below average December levels, respectively. However, dry conditions persisted in western and northern Illinois, and ground-water levels continued to decline into 1989 in those parts of the state.

By the end of April 1989 (figure 6.11), the number of observation wells with above-average water levels remained at six, but these wells were in east-central to west-southwestern Illinois (Watseka, Bondville, Middletown, Janesville, and SWS No. 2), north of the area where wells previously had started to recover. Despite near-normal precipitation for January-April 1989, several of the southern observation wells, in which levels had been near- or above-average in December, were now showing declines in water levels (Elco, Dixon Springs, Southeast Illinois College, and St. Peter). April precipitation was more than an inch below normal across a broad area of southern Illinois, and this is the likely cause of those lower ground-water levels. Water levels continued to decline through April 1989 in northern Illinois at Fermi Lab, Galena, and Mt. Morris (figure 6.11), where April precipitation was 2 to 3 inches below normal.

Figure 6.12 shows the deepest month-end ground-water level observed at each well between April 1988 and September 1989. Maximum month-end depths generally occurred after September 1988, which is after the precipitation drought was considered over (chapter 3). Only the wells at Elco and Dixon Springs in far southern Illinois reported their deepest levels prior to September 1988. Between September and December 1988, levels at 16 wells reached their greatest depths. These wells are located in a broad band extending from southern to northeastern Illinois. The four remaining wells (located in western and northwestern Illinois) did not reach maximum depths until after the start of 1989.

Examina tion of when and where wells experienced their greatest departures from normal (figure 6.13) shows a pattern similar to that for the greatest observed depths to water. It is typical for maximum depths to water to occur in late summer, fall, and early winter, because of ground-water storage withdrawals during the summer. Not only were water levels low, which is normal for this time of year, they were also very much below the average for this time of year.

Only three of the 21 wells experienced their greatest departures prior to September 1988, and all of these are located in extreme southern Illinois (Elco, Dixon Springs, and Sparta). Ten of the remaining 18 observation wells registered their greatest departures from normal between September and December 1988. These ten wells are located in a broad band that extends northeastward from extreme southern Illinois and includes most of the eastern edge of the state. The remaining eight wells (Cambridge, Coffman, Crystal Lake, Galena, Good Hope, Mt. Morris, Snicarte, and Swartz) did not reach maximum departures until 1989, and in some cases not until April-June of that year. All of these wells except the one at Crystal Lake are located in western or northwestern Illinois. This pattern of temporal variation from south to north closely follows that of precipi tation, which first returned to more normal amounts in southern Illinois in late 1988, and then progressed northward during 1989 (chapter 3).

Figures 6.14-6.18 trace the month-end ground-water levels, mean month-end ground-water levels, historic month-end lows, and total monthly precipitation for five sites (Cambridge, Coffman, Galena, Mt. Morris, and Snicarte) within the region of maximum precipitation deficiency for January 1987-September 1989. These wells, which are located throughout western and northwestern Illinois, all recorded below-average ground-water levels through most of 1988 and all of 1989.

Water levels in the wells at Snicarte (figure 6.18) and nearby Good Hope (figure 6.4) responded similarly to precipitation deficits. Water levels fell below average levels from early 1987 through 1988 and into 1989. The Snicarte well actually went dry in September 1988 and remained so through September 1989. The observation wells at Cambridge, Coffman, Galena, and Mt. Morris (figures 6.14-6.17) also exhibited sizeable departures from average monthly ground-water levels. Several new record monthly lows were recorded at Good Hope and Cambridge in 1988 and 1989 (figures 6.4 and 6.14).

Other wells in southern and eastern Illinois responded similarly to the drought conditions of 1988 but recovered to near- or above-average levels in early 1989. Examples of these include the wells at Watseka (figure 6.19) and Sparta (figure 6.20). Their water levels declined significantly during the summer and fall of 1988, often to within 1 to 2 feet of record low monthly levels. But precipitation in late fall and winter 1988 and early spring 1989 produced substantial recharge at these locations.

Ground-water levels at Good Hope, Cambridge, Coffman, Galena, Mt. Morris, and Snicarte (figures 6.4 and 6.14-6.18) continued to decline or to remain far below their mean monthly levels into 1989. Only the well at Cambridge experienced recovery sufficient to bring water levels above average by September 1989; note that this was the result of a large rise in water levels from August to September 1989. Most importantly, the April 1989 water levels in these six wells were far below those of April 1988; and the hydrographs show that as the potential for recharge diminished through the summer of 1989, ground-water levels at several of these locations declined to greater depths than experienced in 1988. This was particularly true of water levels at Galena and Mt. Morris (figures 6.16 and 6.17) in extreme northwestern Illinois.

The progression of deepening shallow ground-water levels and the lingering effects of the drought can be seen regionally and statewide in figure 6.21. Departures from monthly means for the wells at Cambridge, Coffman, Galena, Greenfield, Good Hope, and Mt. Morris were averaged to provide values for the western region (the west-southwest, west, and northwest crop reporting districts). Similarly, departures from mean levels for the wells at Boyleston, Dixon Springs, Elco, Janesville, Southeast Illinois College, Sparta, St. Peter, and SWS No. 2 were averaged for the southern region (the southwest, southeast, and east-southeast crop reporting districts). Departures from monthly means for wells in the central and east crop reporting districts (Bondville, Middletown, Snicarte, Swartz, and Watseka) were used for the eastern region.

As figure 6.21 shows, average ground-water levels, both statewide and regionally, were slightly above normal at the beginning of 1988. By April, however, all regions were reporting below-normal ground-water levels. That downward trend continued through the summer and into fall. After about October 1988, water levels in the south and east started to recover, while those in the west continued to decline. Recovery was most significant in the southern part of the state, with near-average water levels being achieved by December 1988.

In eastern Illinois, ground-water levels recovered to near normal by May 1989; in southern Illinois, water levels hovered around normal throughout 1989. However, shallow ground-water levels in the west remained far below normal throughout January-September 1989. At the end of April 1989, water levels in that region were approximately 7.5 feet below normal and more than 6 feet below the April 1988 levels. The recovery shown in figure 6.21 for the western region for the summer of 1989 was greatly influenced by the 13 feet of recovery experienced between February and September 1989 at Cambridge (figure 6.14).

6.3. Ground-Water Drought Severity

For each observation well, table 6.2 offers a comparison of the lowest ground-water levels for 1988-1989 with record high and low ground-water levels. Six new record lows were set or tied in the fall and winter of 1988-1989. Three of the new lows established (at Boyleston, Southeast Illinois College, and Good Hope) may have been set because of the relatively short periods of record available for these wells. Two of the new record lows, however, were at wells that have been operated since the 1950s or early 1960s (Cambridge and Snicarte). As already noted, the Snicarte well went dry in September 1988 and remained dry through September 1989.

Finally, the well at Dixon Springs was dry in September 1987 and again in August and September 1988. These two periods are the only dry periods on record for the well in its 35-year history.

In addition to the six record lows that were set or tied, ground-water levels were close to the all-time record lows at nine additional locations. They were within 1 foot of record lows at five locations and within 2 feet of record lows at four locations.

Accumulated ground-water-level departures from normal for three periods during the drought (figures 6.22-6.24) were computed to cartographically display the spatial pattern of below-normal ground-water levels. The approach used, which is similar to that used by Olson (Changnon et al., 1982) involves summing individual monthly departures. While the maps do not represent actual ground-water recharge deficits (i.e., inches or feet of recharge needed to produce normal levels), they provide a straightforward and easily computable approach for assessing spatial and temporal trends in the ground-water manifestations of drought, as well as providing a comparison with precipitation deficits.

For the first period (April-September 1988), the greatest accumulated departures occurred in western Illinois (figure 6.22). This is due, in part, to a carryover of low ground-water levels from 1987, but the largest accumulated departures also correspond quite closely to the area of greatest precipitation deficit. Furthermore, as the time period is extended through the fall and into early winter, accumulated departures essentially double (figure 6.23), illustrating the lag effect between the precipitation deficit and ground-water-level declines. The prolonged rainfall deficit through the spring of 1989 in western and northern Illinois (essentially the northern two-thirds of the state) is also reflected in the accumulated ground-water departure pattern in figure 6.24.

To place the severity of the 1988-1989 ground-water drought in perspective, patterns of accumulated ground-water-level departures for 12.month periods for the droughts of 1963-1964, 1976-1977, and 1980-1981 are presented in figures 6.25-6.27. Unfortunately, sufficient data were not available for the 1952-1955 drought to include it in this comparison. Comparison of the patterns for the four droughts (figures 6.24-6.27) suggests that, the magnitude of the accumulated departures for 1988-1989 is greater than for any of the other drought periods. However, while the 12-month accumulated departure at Good Hope for 1988-1989 (-147 feet) was larger than that for Mt. Morris in 1963-1964 (-116 feet), this difference may be due at least partly to the short period of record (only eight years) used to establish mean monthly levels at the Good Hope well.

Figures 6.24-6.27 suggest that the droughts of 1963-1964 and 1976-1977 were geographically farther reaching than the droughts of 1988-1989 and 1980-1981 in terms of their impact on shallow ground-water levels statewide. Accumulated departures were negative across the entire state in 1963-1964 and 1976-1977 (figures 6.25 and 6.26), whereas a small area in southwestern Illinois accumulated a positive departure during 1988-1989 (figure 6.24). As pointed out by Olson (Changnon et al., 1982), the greatest effects of the 1980-1981 drought on shallow ground-water levels were in a limited area of west-southwestern Illinois (figure 6.27). Certainly, in terms of the effect on shallow ground-water levels, the dry conditions in 1988-1989 were much more severe than in 1980-1981, when most of the northern half of the state accumulated positive departures.

Interestingly, for the drought periods of 1963-1964, 1976-1977, and 1988-1989, the greatest accumulated ground-water stage departures all occurred in western and northwestern Illinois. At present, the available data are insufficient to precisely assess why these parts of the state experience the largest ground-water impacts of drought. Clearly, however, they have been areas where precipitation tends to be deficient. It is also likely that their hydrogeologic systems are especially sensitive to those precipitation deficiencies.

Four currently operational observation wells have records dating back into the drought period of the mid-1950s (Crystal Lake, Dixon Springs, Swartz, and SWS No. 2). Unfortunately, none of these four wells is located in the area most severely affected by the 1988-1989 drought. However, inspection of long-term hydrographs for these wells is useful for comparison to previous drought periods. Those for Crystal Lake and SWS No. 2 are shown in figures 6.28 and 6.29. Long-term hydrographs for Middletown in central Illinois (figure 6.30) and for two wells in the most severely affected areas of western Illinois at Cambridge (figure 6.31) and Good Hope (figure 6.32) reveal how severe the drought of 1988-1989 was in comparison to previous droughts.

At the Crystal Lake site in northeastern Illinois (figure 6.28), the 1988-1989 drought produced water-level declines similar to those in 1971-1972 and 1977-1978. Much greater declines and lower levels were experienced at this site, however, throughout the 1950s and in 1963-1964. The lowest ground-water levels experienced in 1988-1989 (almost 7 feet) did not approach the record low established in early 1957 (more than 10 feet). At the SWS No. 2 observation well in southwestern Illinois, record lows were also established in late 1956 as a result of the same drought (figure 6.29). The second largest declines occurred as a result of dry conditions in the mid-1960s.

Ground-water-level recessions occurring in 1971-1972,1976-1977, and 1979-1981 were of lesser but nearly equal magnitude. The decline experienced in 1988 approached, but was not as great as, the declines of those three periods. Note, too, that the droughts of the 1950s and 1960s spanned three to five years, while those of the 1970s and 1980s persisted for only one to two years. For this SWS No. 2 site, the 1988 conditions appear similar to those experienced in 1971: the most severe declines occurred late in the year and were followed by a return to normal or above-normal levels early the following year.

At Middletown in central Illinois (figure 6.30), for which records date back to late 1957, the record low of 10.5 feet was established in December 1957 and was approached again in late 1958. The only other portion of the existing Middletown record to feature such low levels is that for 1988. However, relatively low water levels may have occurred there during 1963-1964, when observations were not taken. An additional interesting feature of figure 6.30 is the remarkably constant water levels experienced in the 20-year period between 1966 and 1986. These were followed by a pronounced water-level decline in 1987 to levels (below 6 feet) that had not been experienced since the early 1960s, after which the even deeper levels of 1988 approached those of the late 1950s.

The records for the well at Cambridge (figure 6.31) in northwestern Illinois, which has been monitored only since the early 1960s, also reveal the full effect of the 1988-1989 drought. The record lows of over 21 feet established in 1988-1989 were more than 2 feet below the previous record lows set in 1976-1977. The only other periods when the depth to water exceeded 17 feet at Cambridge were in 1963-1964 and 1971. Note that water levels for the spring of 1989 were far below the annual lows for most other years.

A very similar situation occurred at Good Hope in western Illinois (figure 6.32). Records were begun at one observation well at Good Hope in late 1959 but had to be discontinued in 1980 when the well owner returned the site to row crops. A new well location less than 2 miles away was established prior to discontinuation of the first well. An overlap of the records of the two wells for four months in 1980 suggests that while water levels at the new site were consistently lower than at the first site, they were, on average, also within 1 foot of the other.

However, the subsequent water-level declines experienced at the new Good Hope well produced much deeper levels than occurred at the original well. The record lows established at the old well in 1963-1964 were exceeded by more than 5 feet during 1988-1989. Like conditions at Cambridge, the early 1989 water levels were far below all previous annual lows and were responsible for the slow recovery during the rest of 1989.

6.4. Summary

The available shallow ground-water-level data suggest that a moderately severe drought existed throughout most of Illinois for 9 to 24 months. Ground-water drought conditions in western and northwestern Illinois were considered severe. In southern and east-central portions of Illinois, the drought effects were greatest for a 9-month period ending in December 1988. In western and northwestern Illinois, drought conditions began as early as 1987 and continued into the summer of 1989. Recovery of water levels to near-normal levels had occurred (but not entirely) in some portions of western and northwestern Illinois by September 1989.

Clearly, the ground-water impacts of the 1988-1989 drought persisted substantially longer than the drought's effects on the other components of the hydrological cycle (precipitation, soil moisture, and surface water).

FIGURES AND TABLES

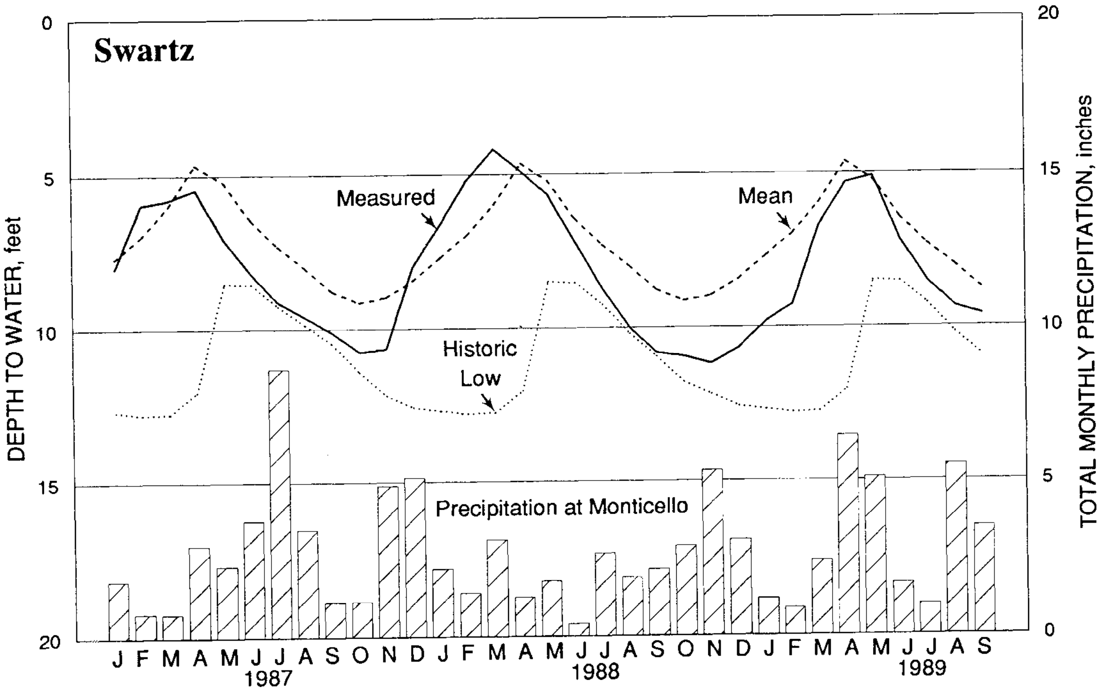

Figure 6.1. Shallow ground-water levels at the Swartz observation well, Piatt County (eastern crop reporting district), and precipitation for nearby Monticello, January 1987 - September 1989

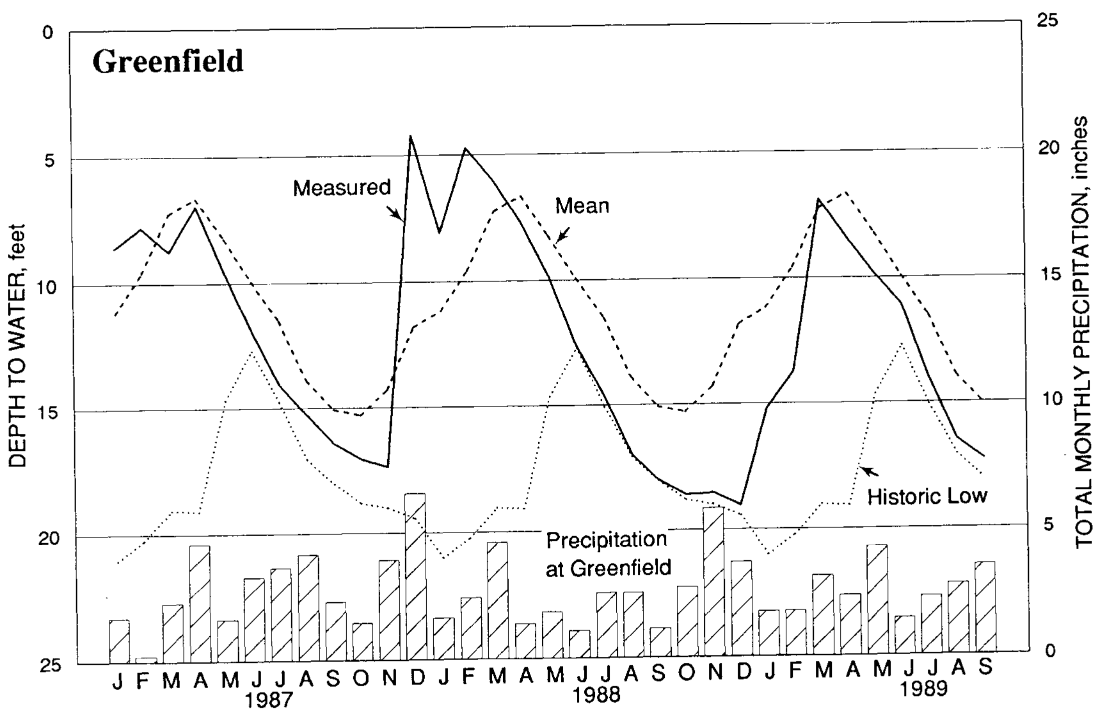

Figure 6.2. Shallow ground-water levels and precipitation at the Greenfield observation well, Greene County (west-southwest crop reporting district), January 1987 - September 1989

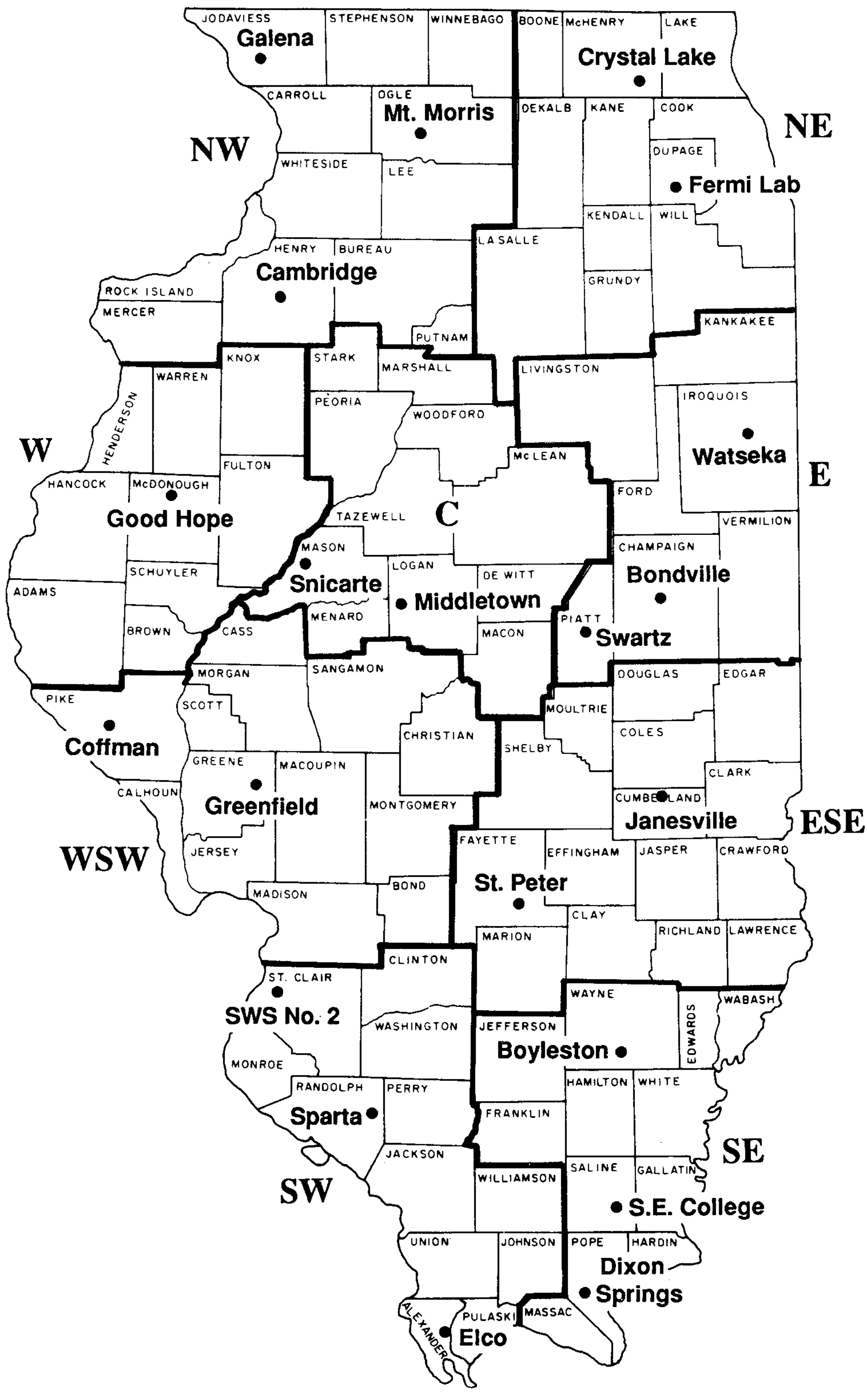

Figure 6.3. Locations of the 21 active wells in the Illinois shallow ground-water observation well network

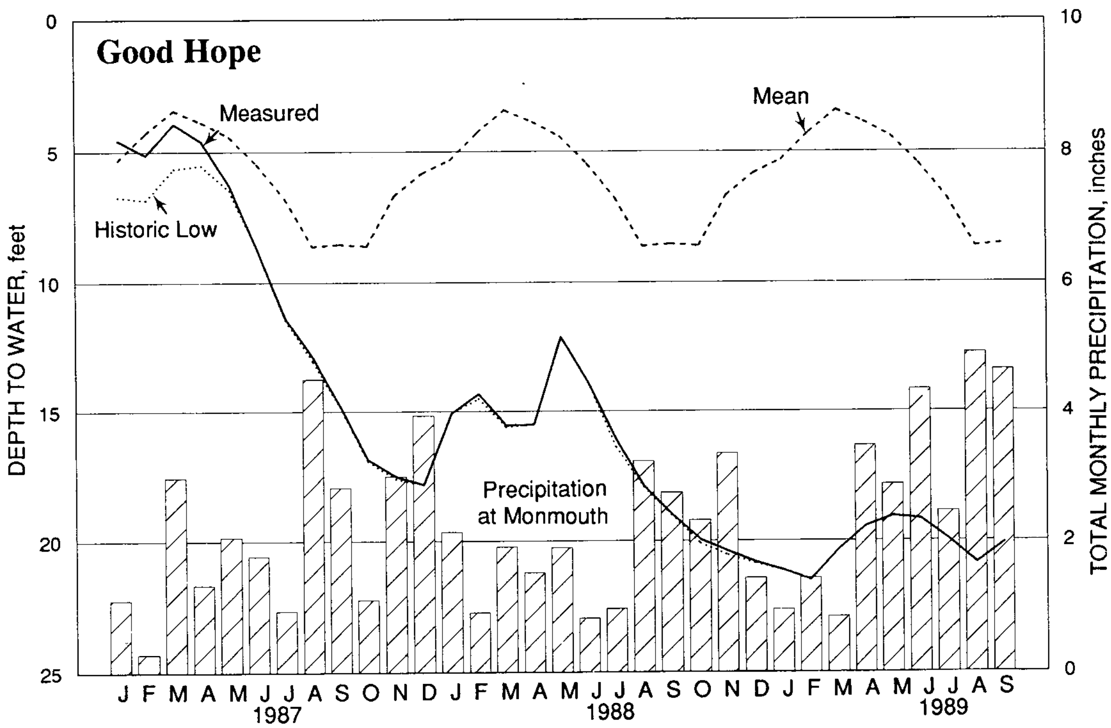

Figure 6.4. Shallow ground-water levels at the Good Hope observation well in McDonough County (western crop reporting district), and precipitation for nearby Monmouth, January 1987 - September 1989

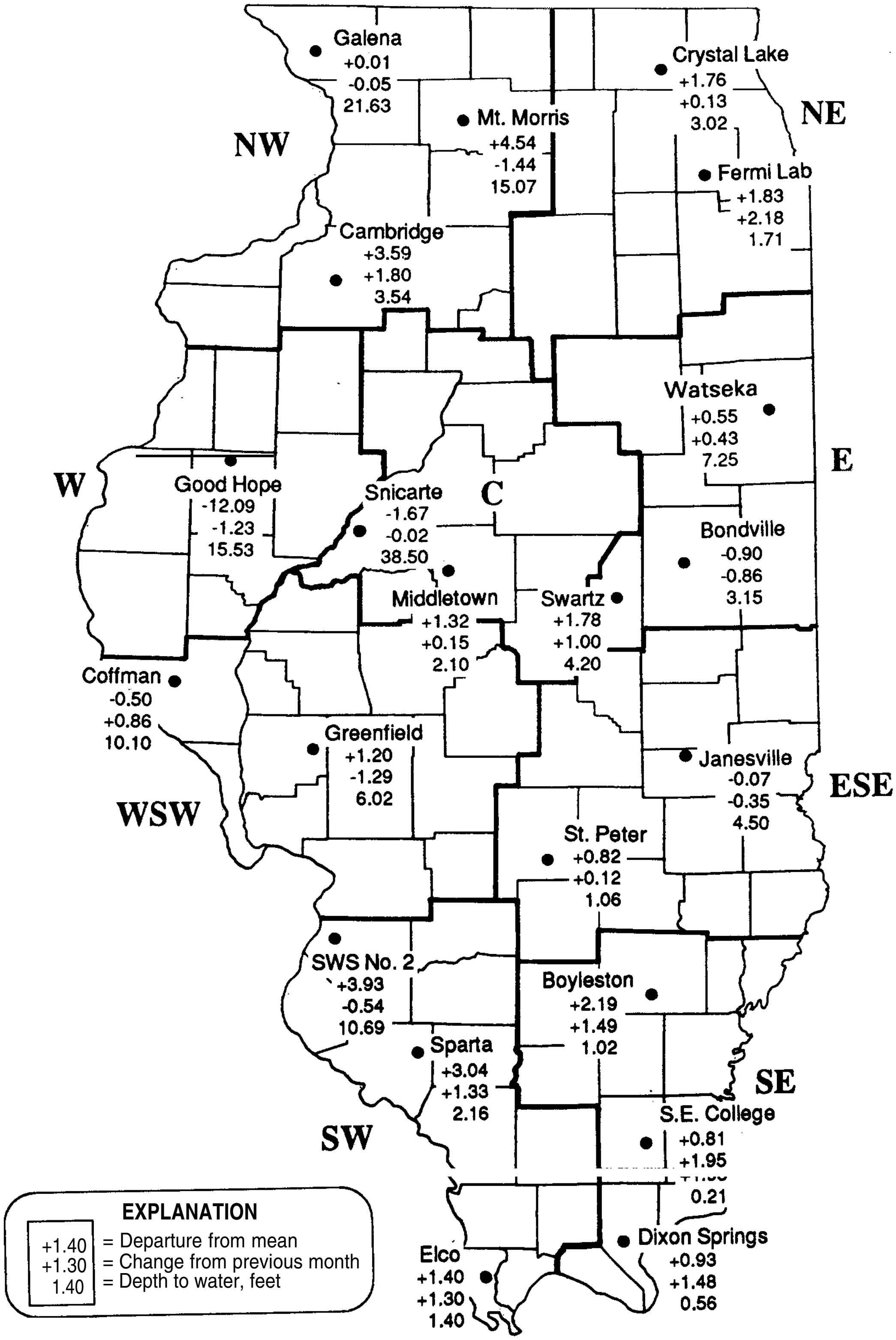

Figure 6.5. Recorded month-end water levels (depth to water), changes from previous month, and departures from mean month-end water levels, March 1988

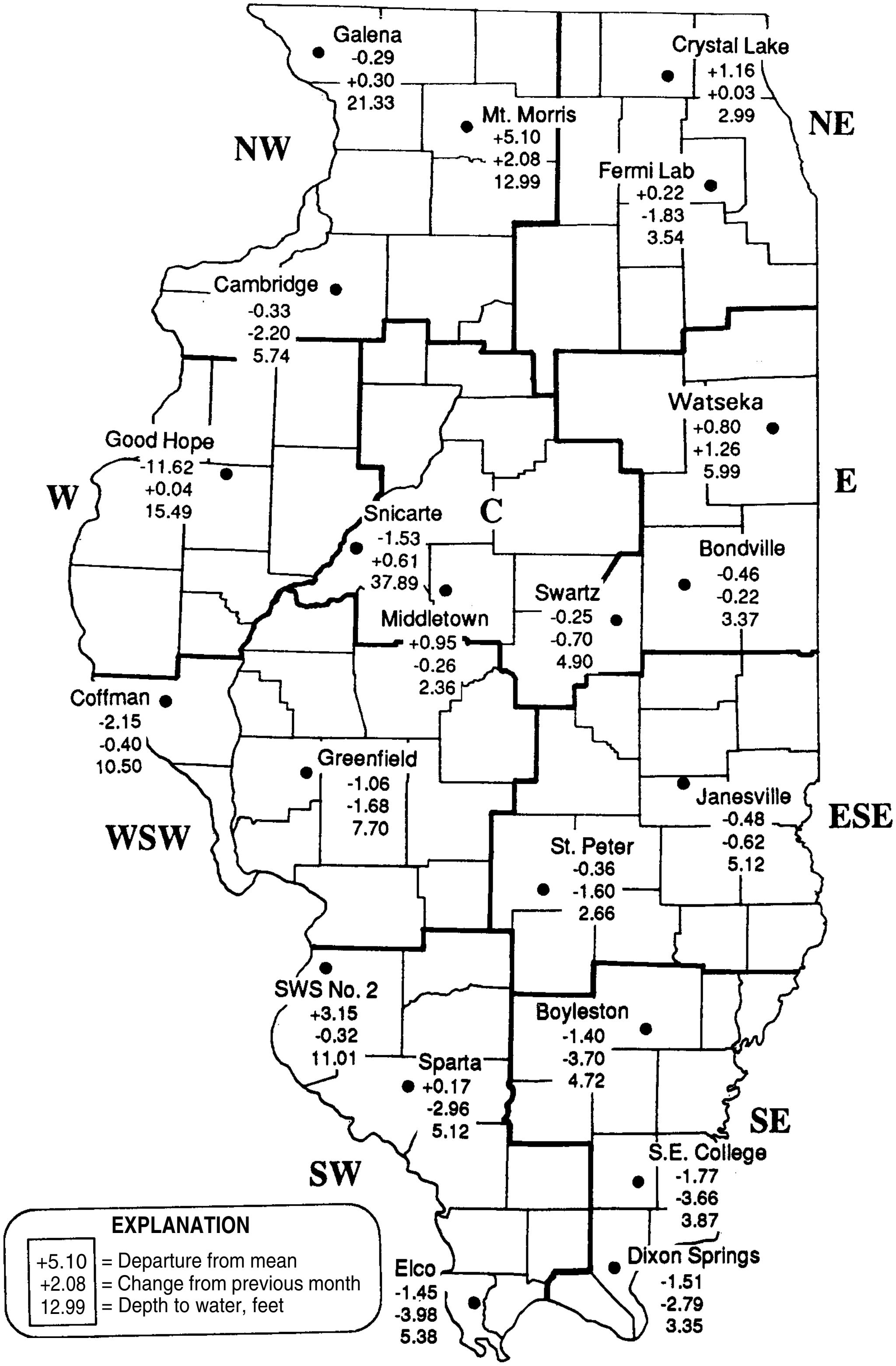

Figure 6.6. Recorded month-end water levels (depth to water), changes from previous month, and departures from mean month-end water levels, April 1988

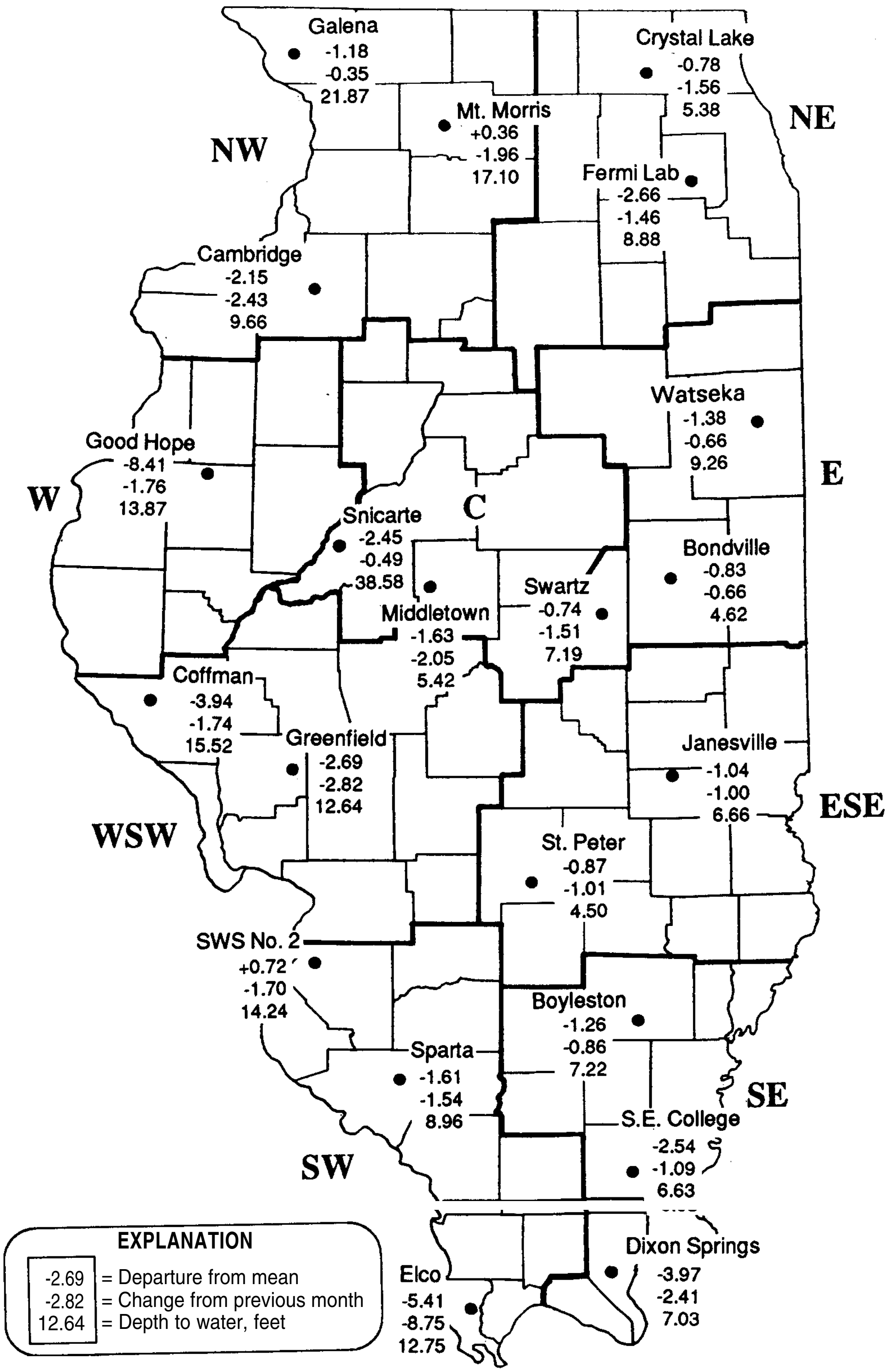

Figure 6.7. Recorded month-end water levels (depth to water), changes from previous month, and departures from mean month-end water levels, June 1988

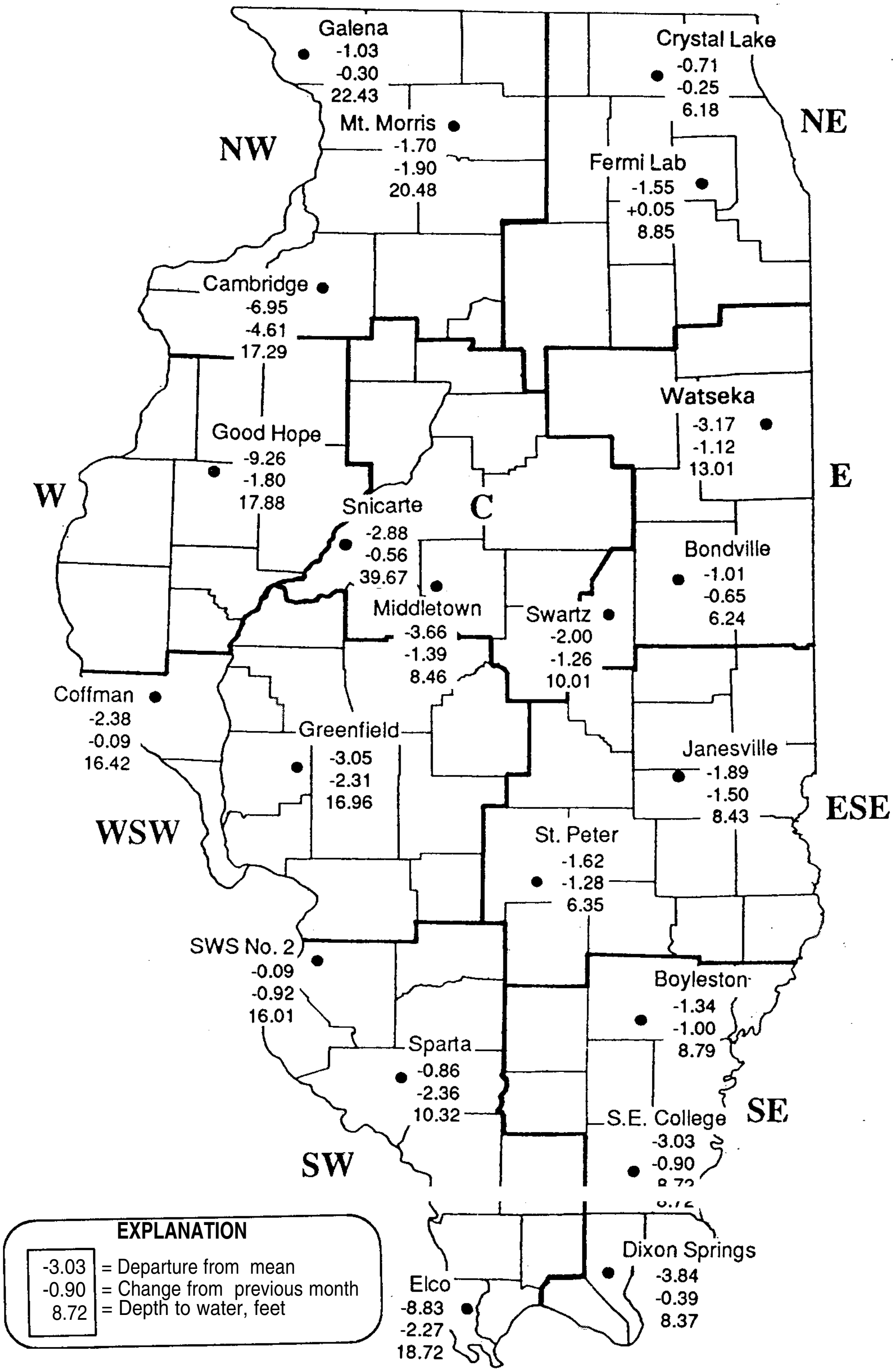

Figure 6.8. Recorded month-end water levels (depth to water), changes from previous month, and departures from mean month-end water levels, August 1988

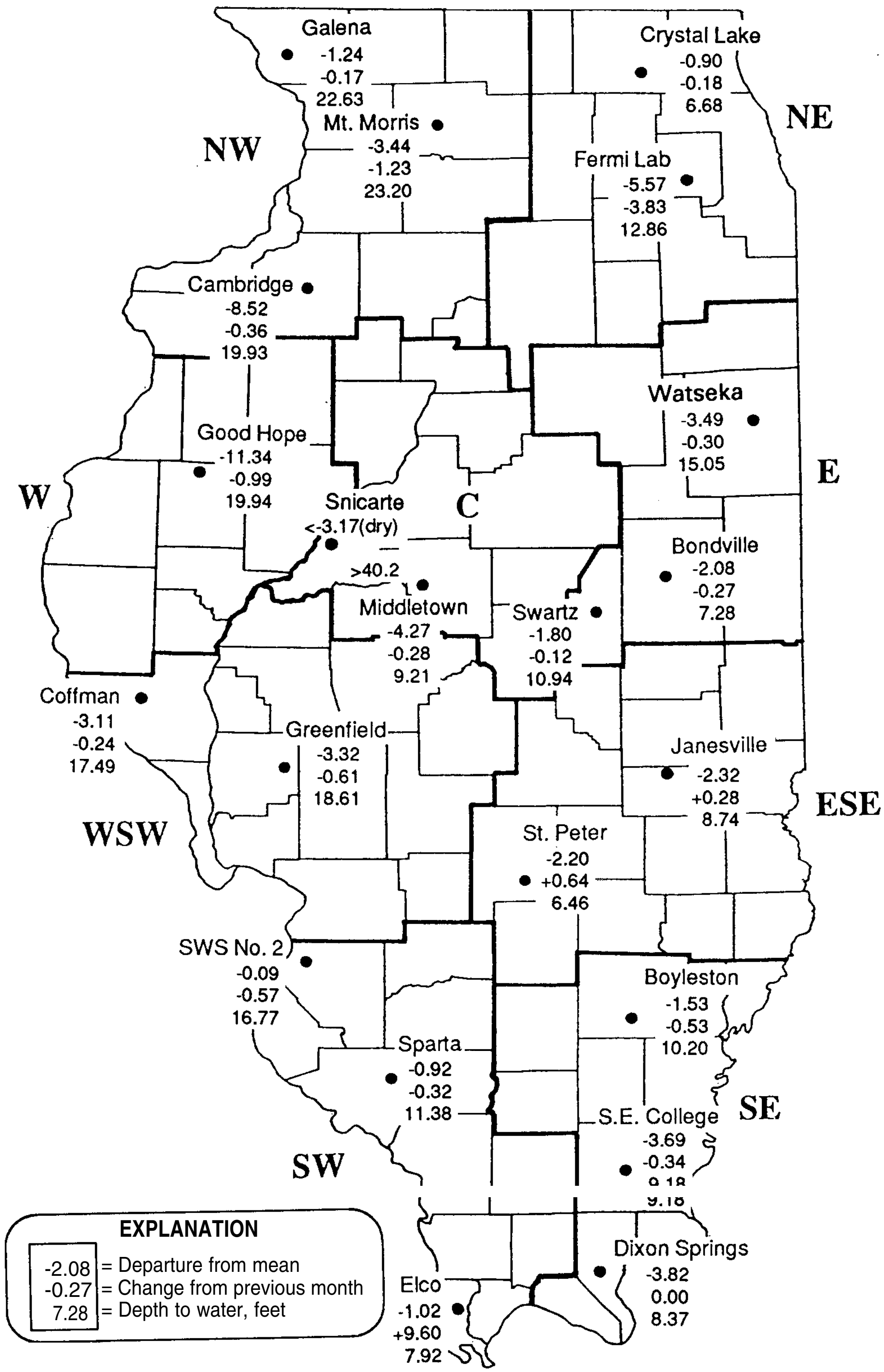

Figure 6.9. Recorded month-end water levels (depth to water), changes from previous month, and departures from mean month-end water levels, October 1988

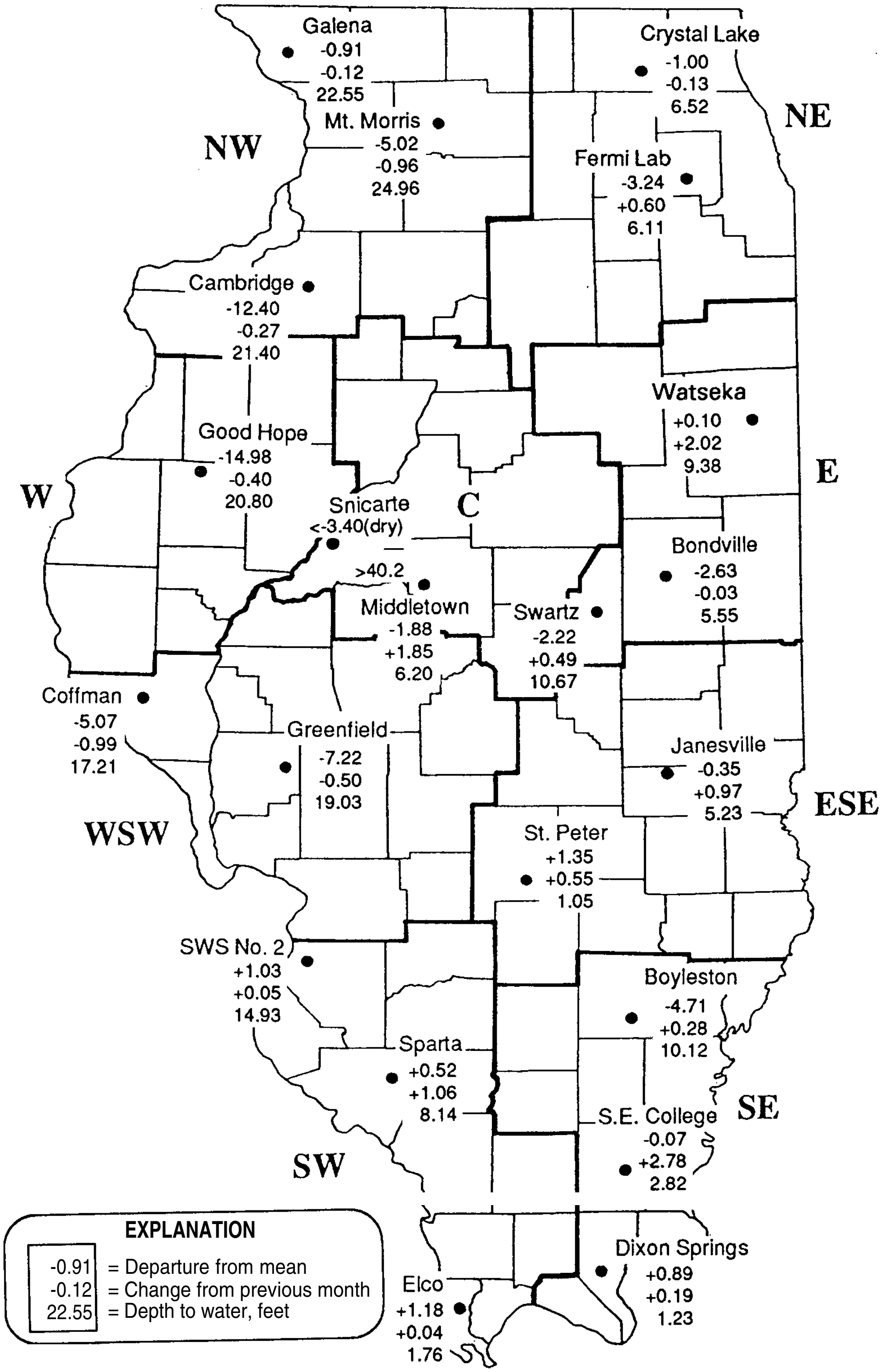

Figure 6.10. Recorded month-end water levels (depth to water), changes from previous month, and departures from mean month-end water levels, December 1988

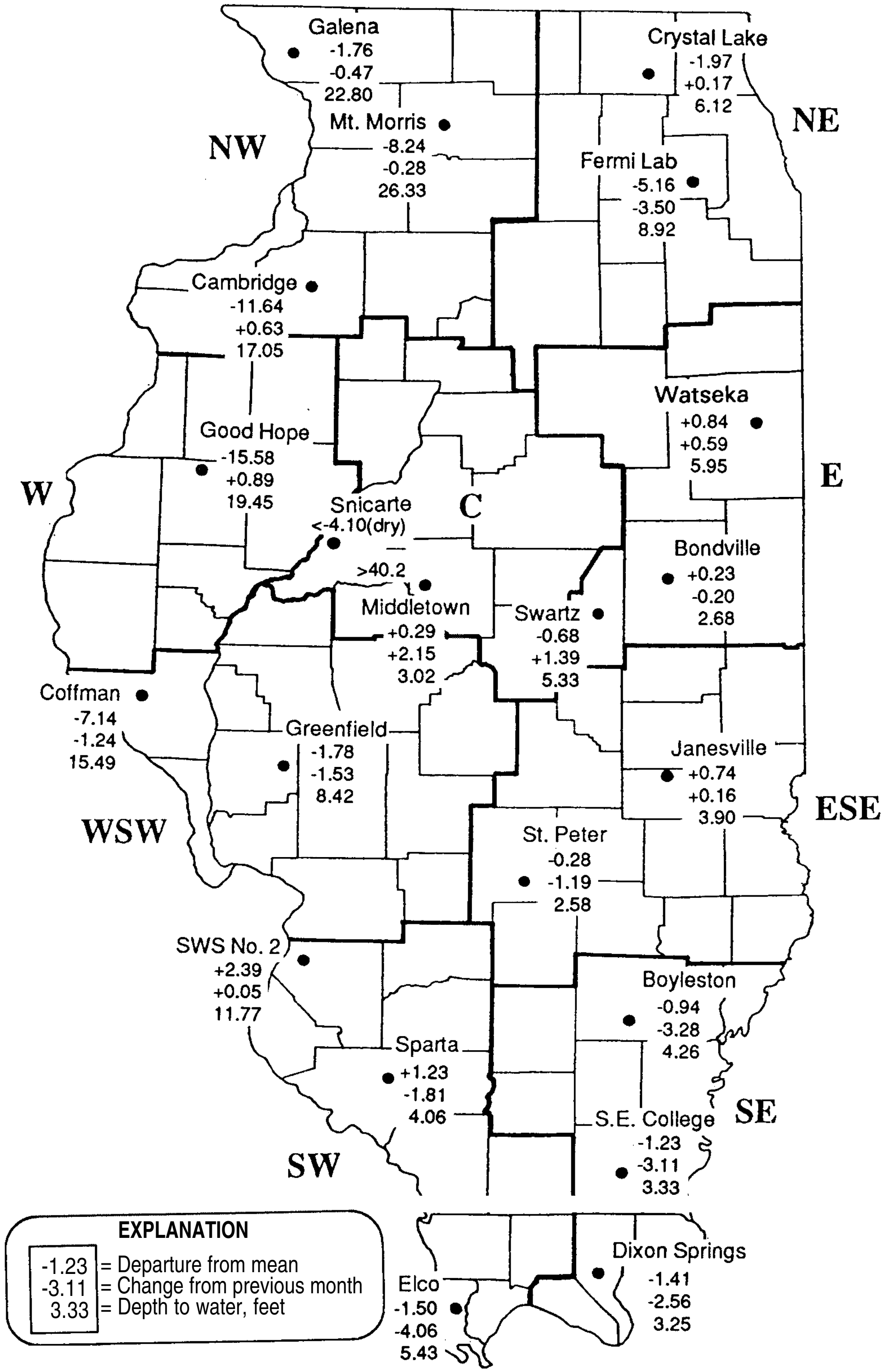

Figure 6.11. Recorded month-end water levels (depth to water), changes from previous month, and departures from mean month-end water levels, April 1989

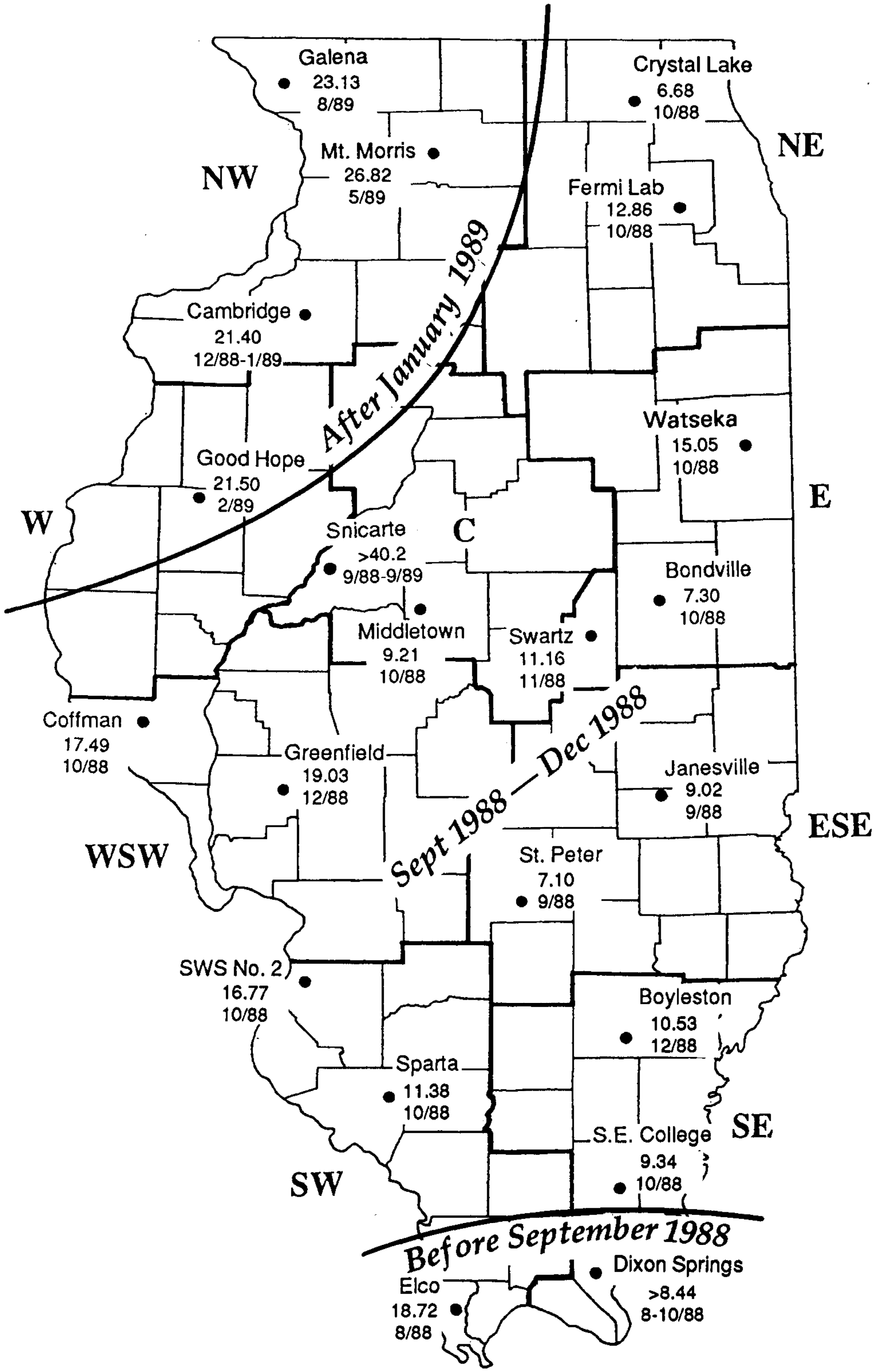

Figure 6.12. Deepest month-end ground-water levels, April 1988 - September 1989

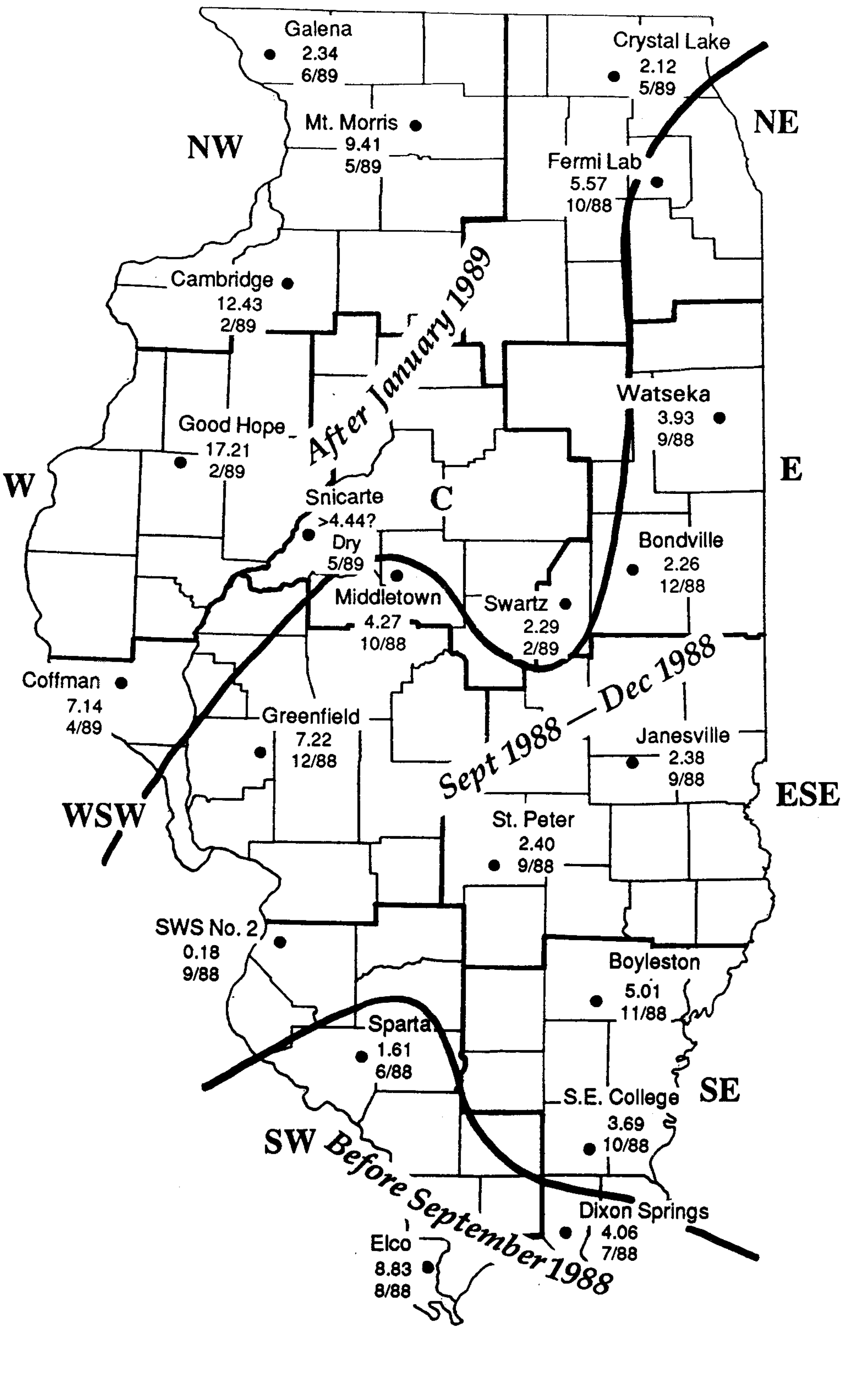

Figure 6.13. Greatest departures below mean month-end ground-water levels, April 1988 - September 1989

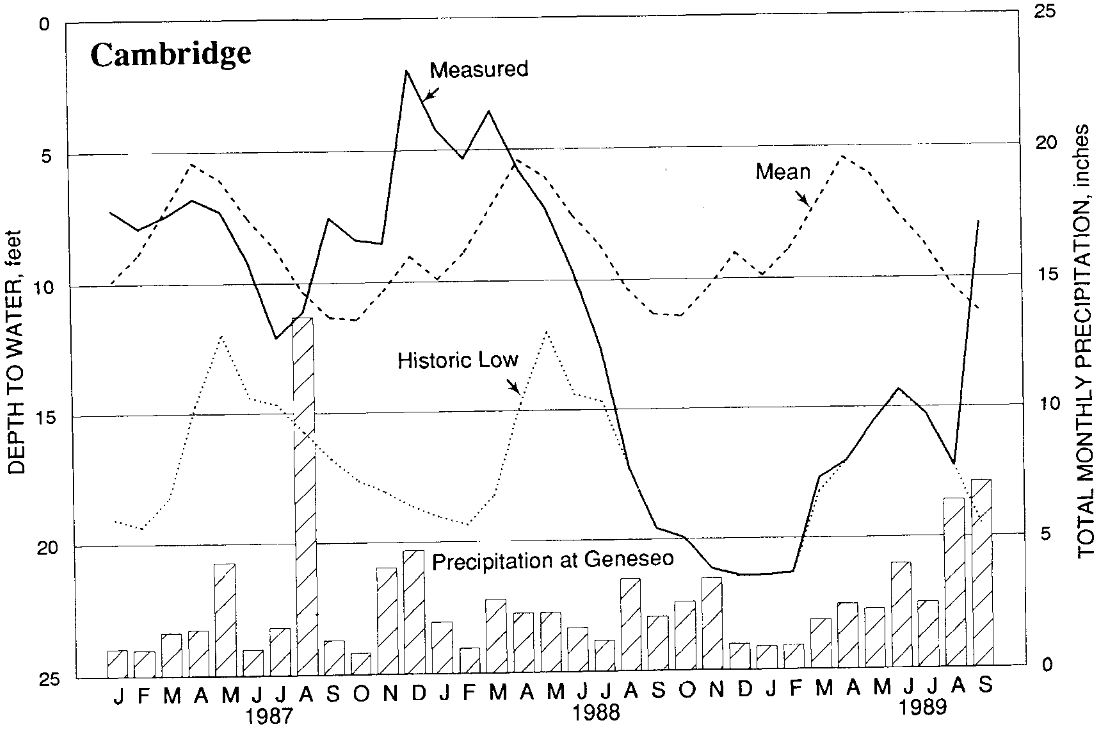

Figure 6.14. Shallow ground-water levels and precipitation at the Cambridge observation well, Henry County (northwest crop reporting district), January 1987 - September 1989

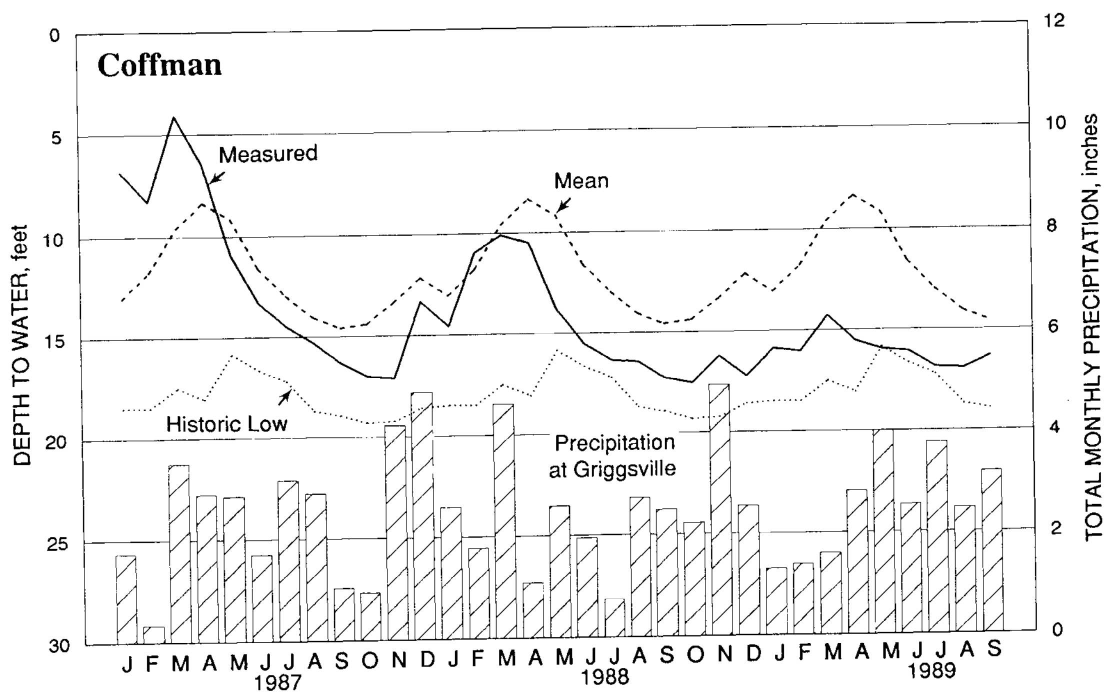

Figure 6.15. Shallow ground-water levels and precipitation at the Coffman observation well, Pike County (west-southwest crop reporting district), January 1987 - September 1989

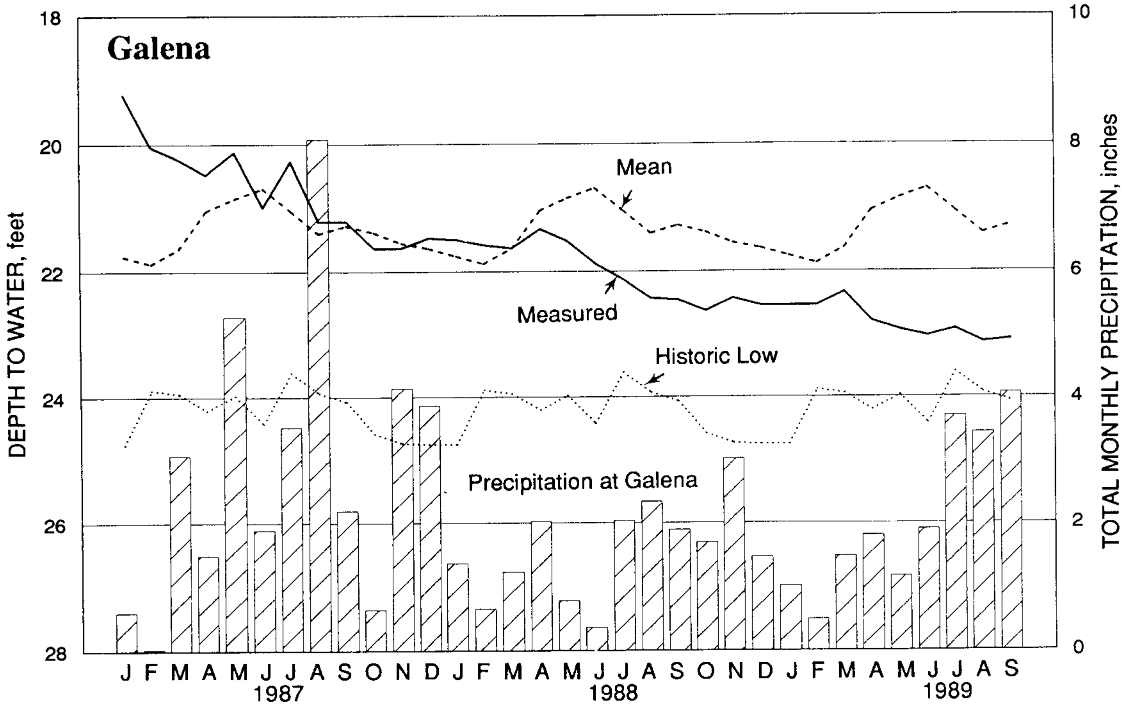

Figure 6.16. Shallow ground-water levels and precipitation at the Galena observation well, Jo Daviess County (northwestern crop reporting district), January 1987 - September 1989

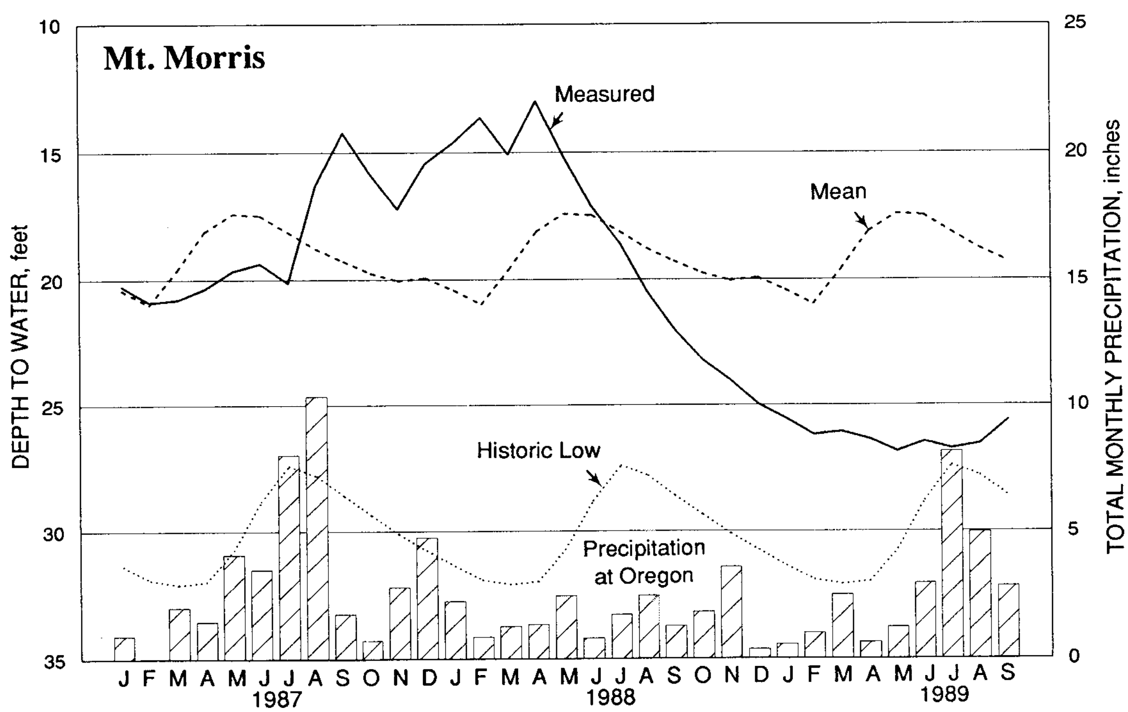

Figure 6.17. Shallow ground-water levels and precipitation at the Mt. Morris observation well, Ogle County (northwestern crop reporting district), January 1987 - September 1989

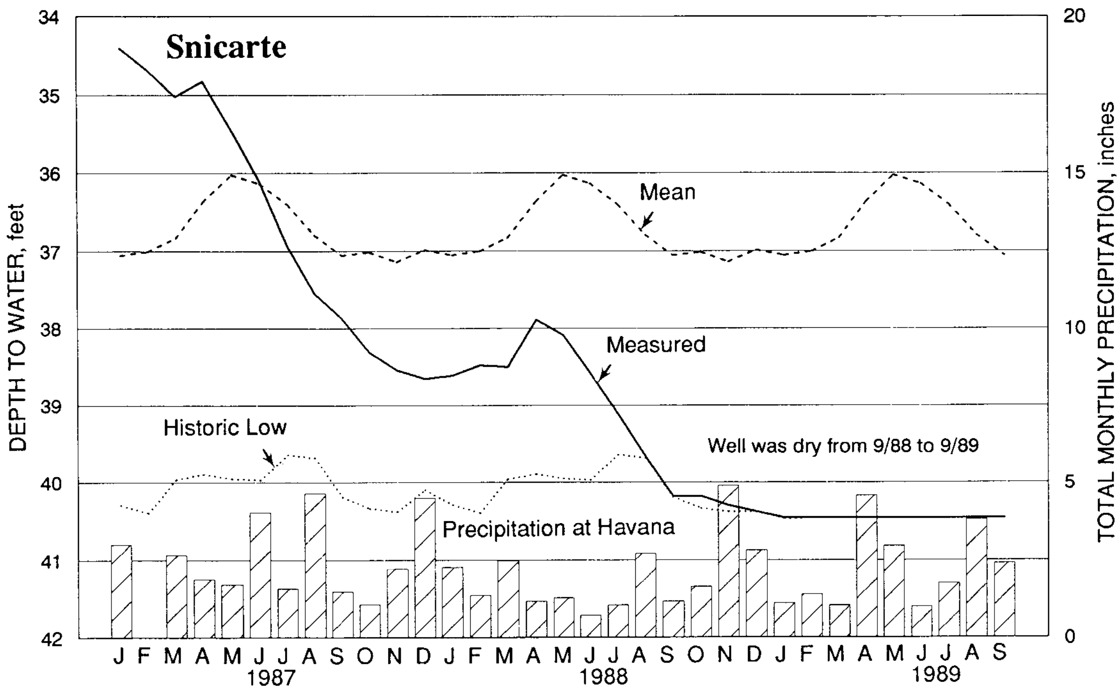

Figure 6.18. Shallow ground-water levels and precipitation at the Snicarte observation well, Mason County (central crop reporting district), January 1987 - September 1989

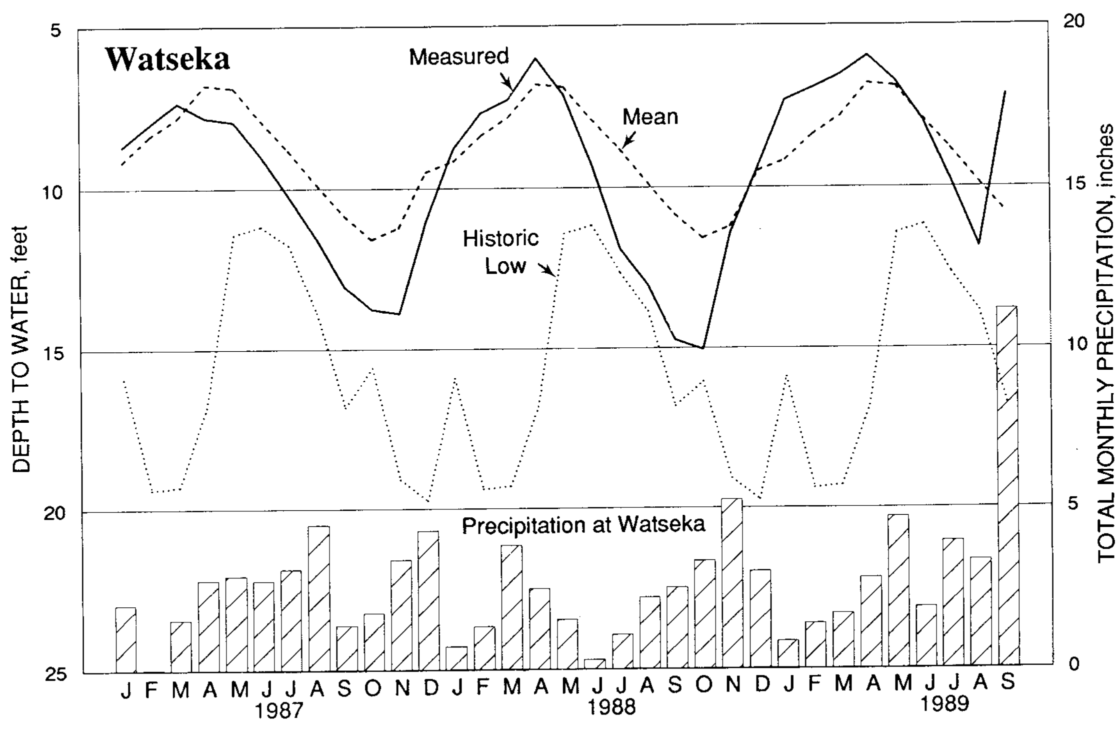

Figure 6.19. Shallow ground-water levels and precipitation at the Watseka observation well, Iroquois County (eastern crop reporting district), January 1987 - September 1989

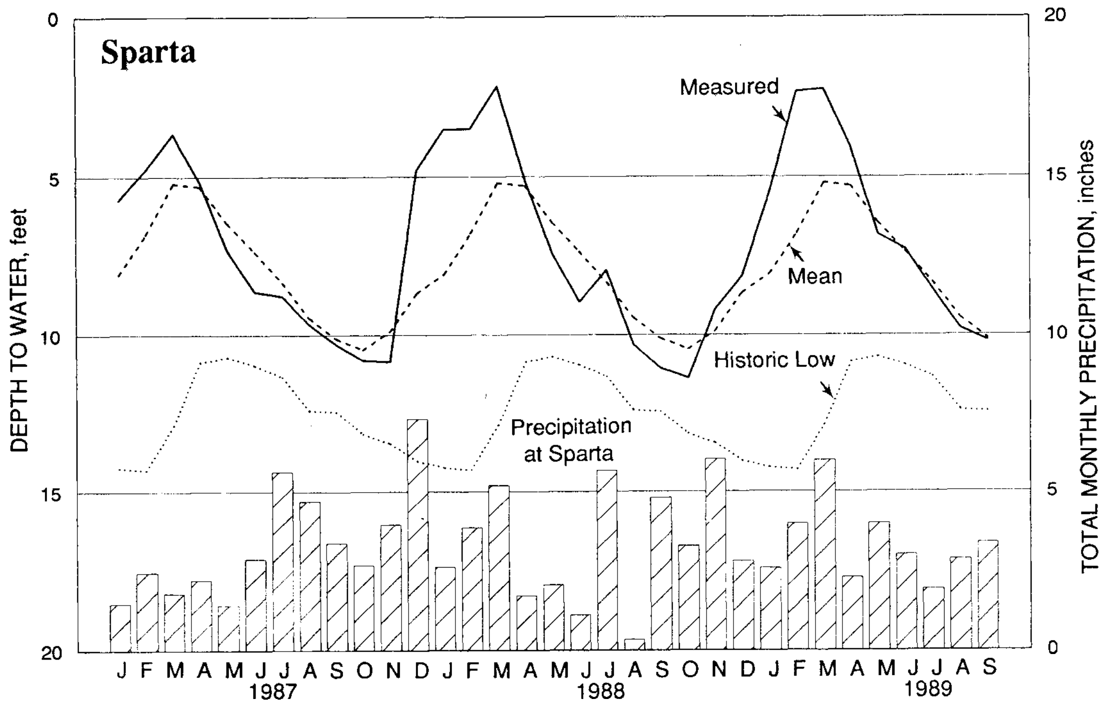

Figure 6.20. Shallow ground-water levels and precipitation at the Sparta observation well, Randolph County (southwestern crop reporting district), January 1987 - September 1989

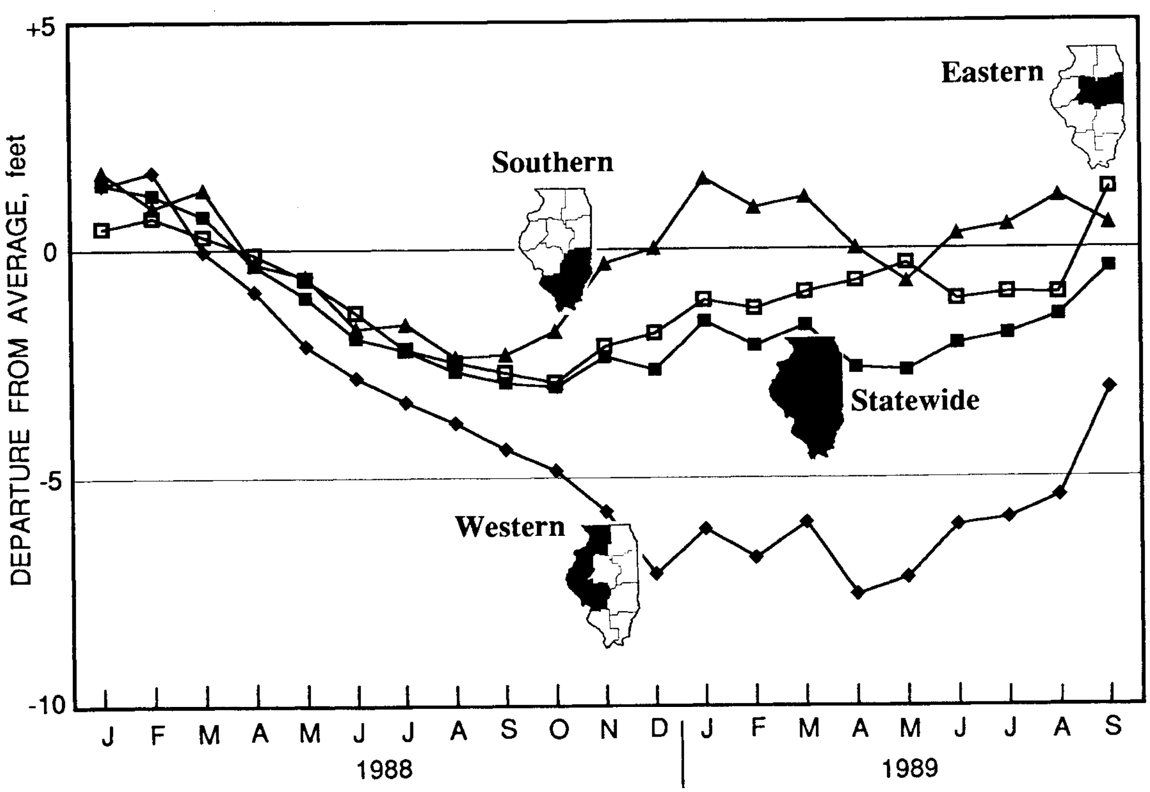

Figure 6.21. Averaged departures from mean month-end shallow ground-water levels in Illinois, January 1988 - September 1989

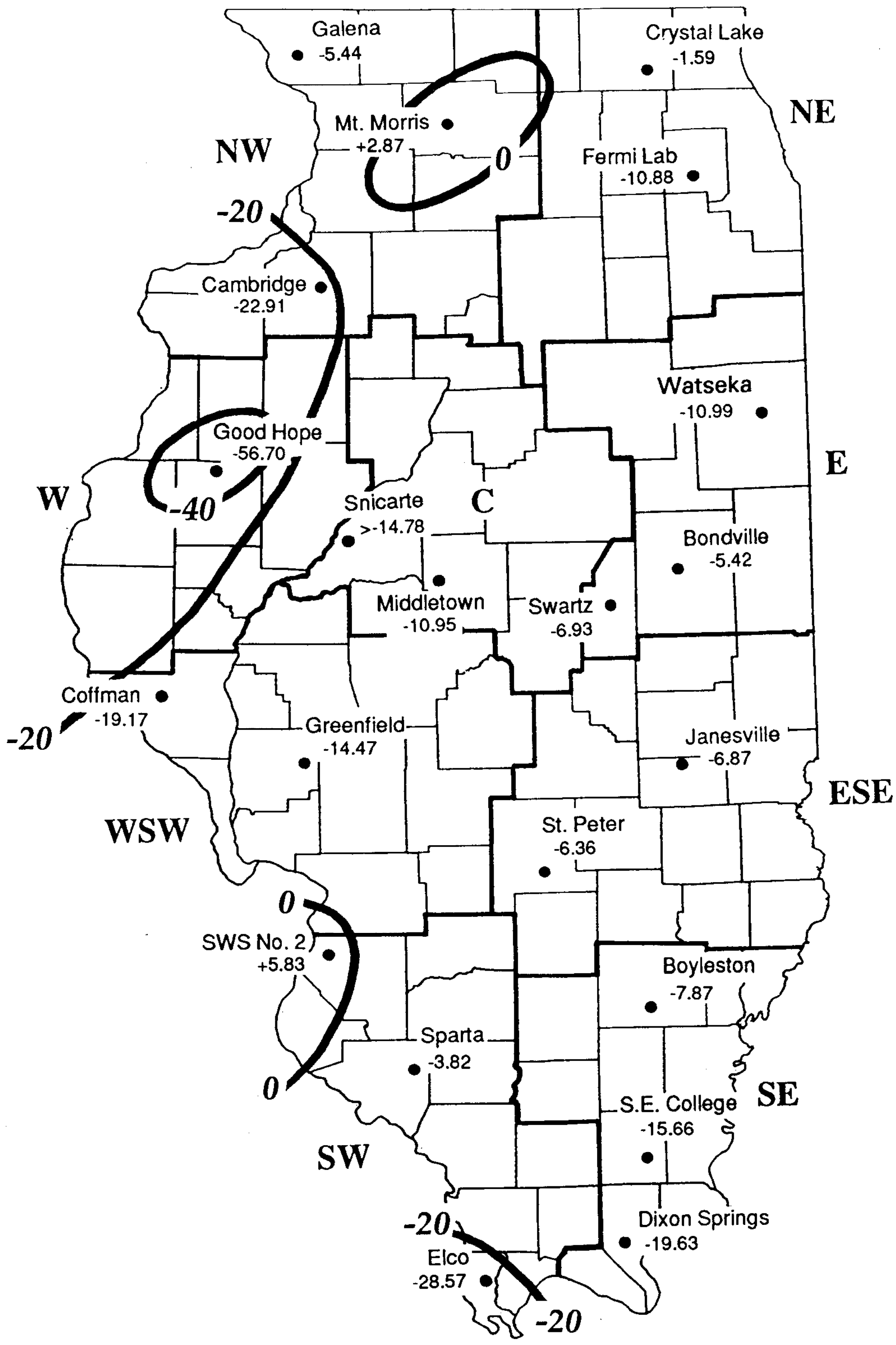

Figure 6.22. Accumulated departures from mean monthly ground-water levels in feet, April - September 1988

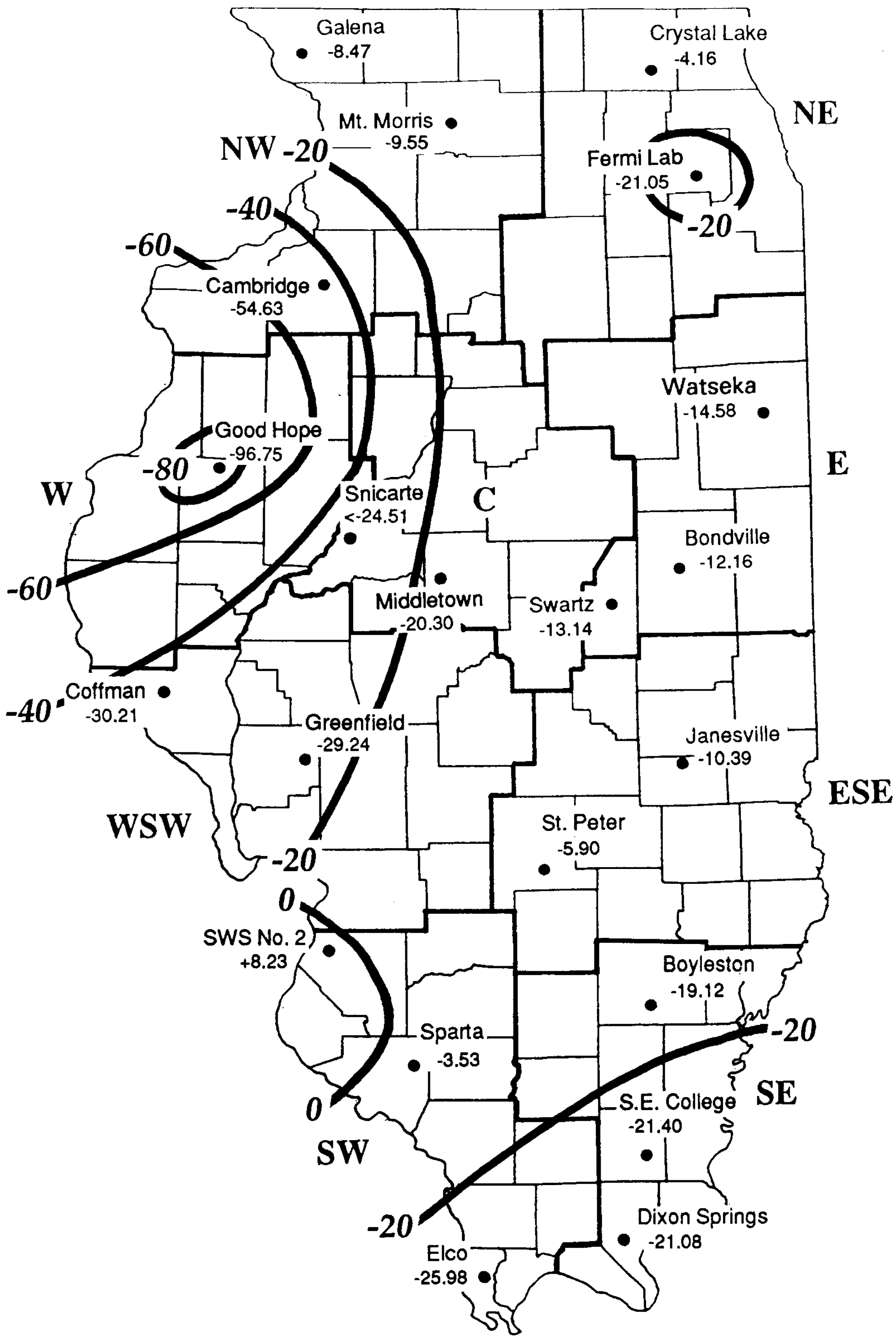

Figure 6.23. Accumulated departures from mean monthly ground-water levels in feet, April - December 1988

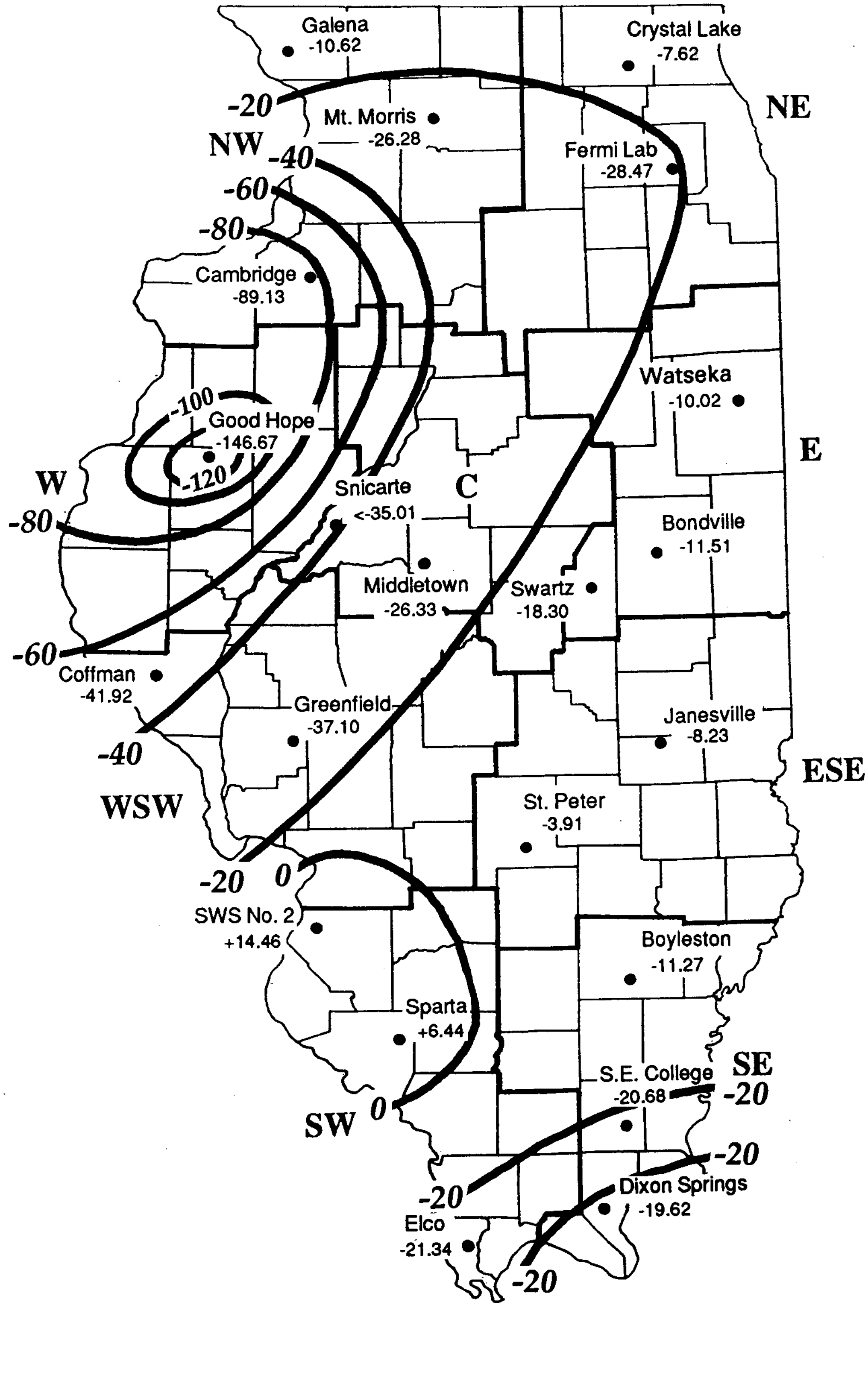

Figure 6.24. Accumulated departures from mean monthly ground-water levels in feet, April 1988 - March 1989

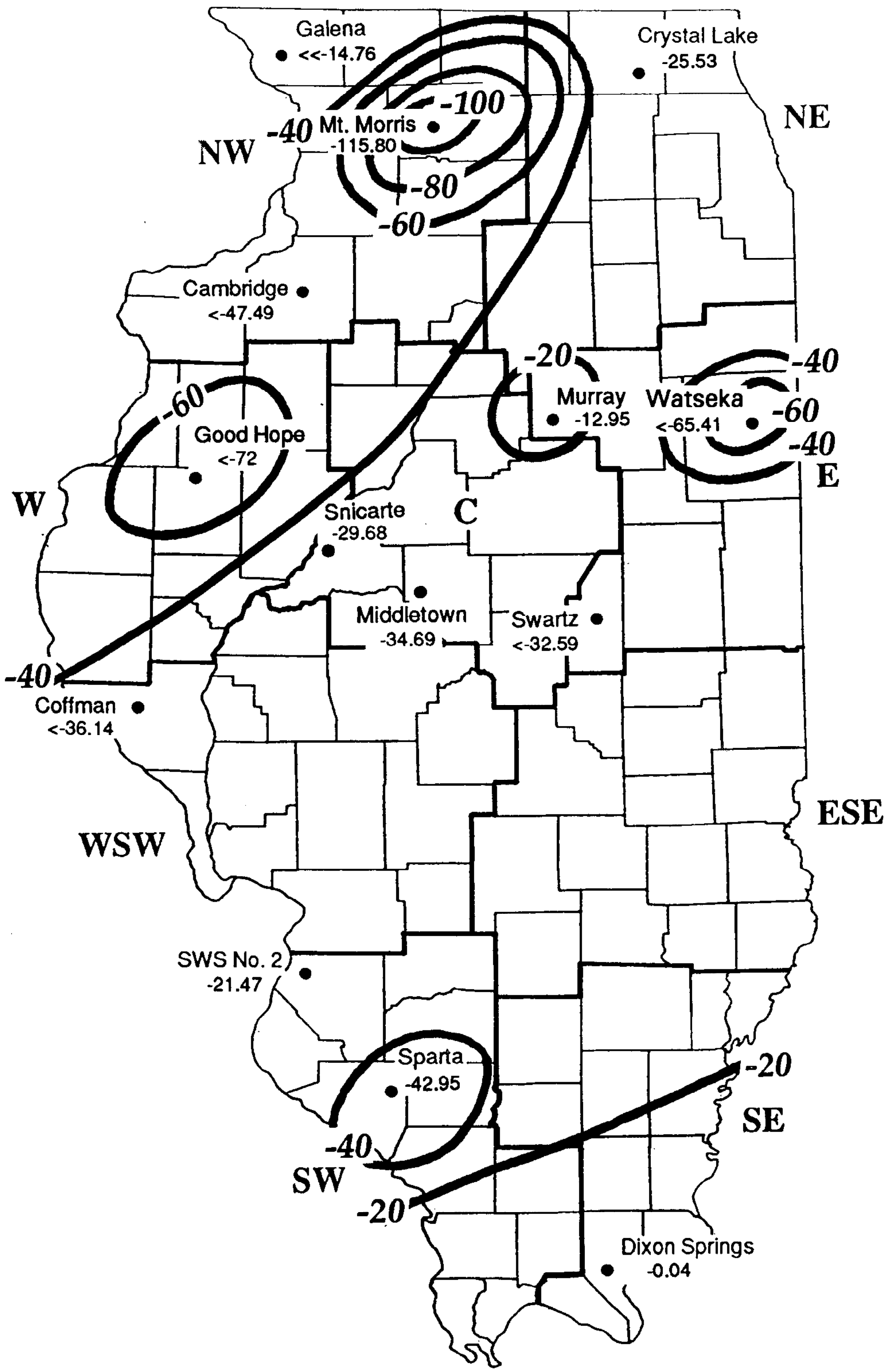

Figure 6.25. Accumulated departures from mean monthly ground-water levels in feet, April 1963 - March 1964

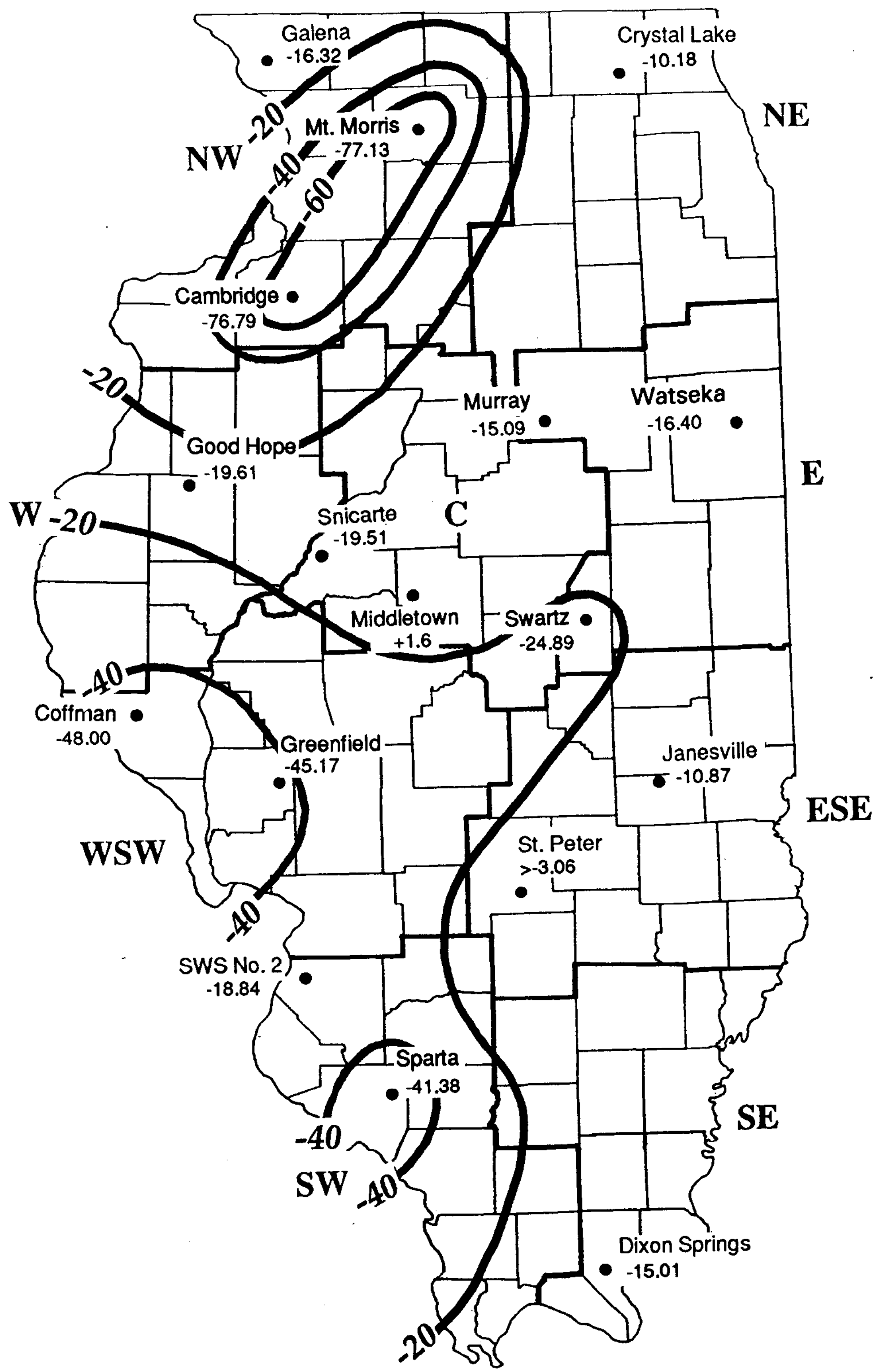

Figure 6.26. Accumulated departures from mean monthly ground-water levels in feet, August 1976 - July 1977

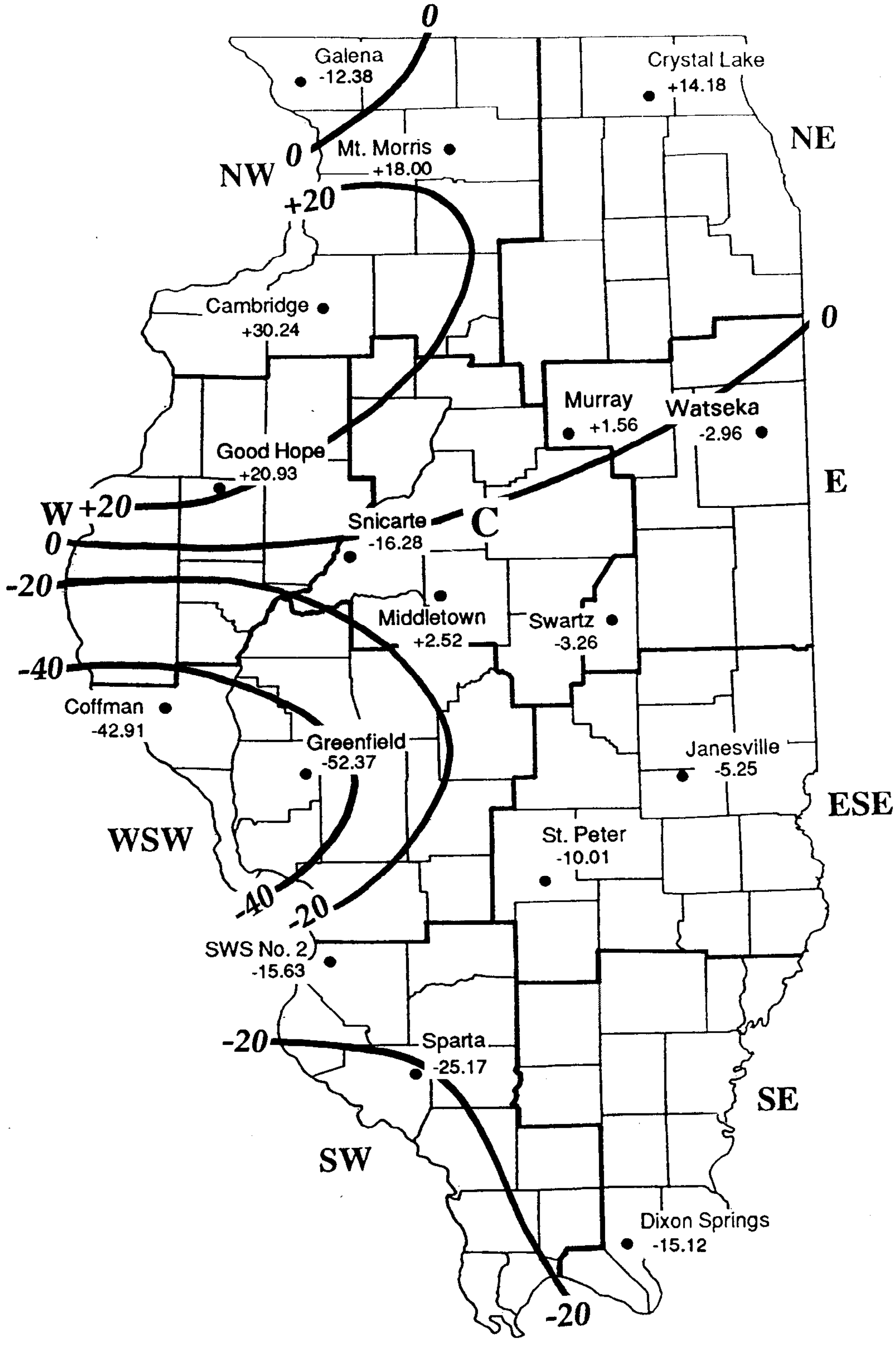

Figure 6.27. Accumulated departures from mean monthly ground-water levels in feet, April 1980 - March 1981 (after Changnon et al., 1982)

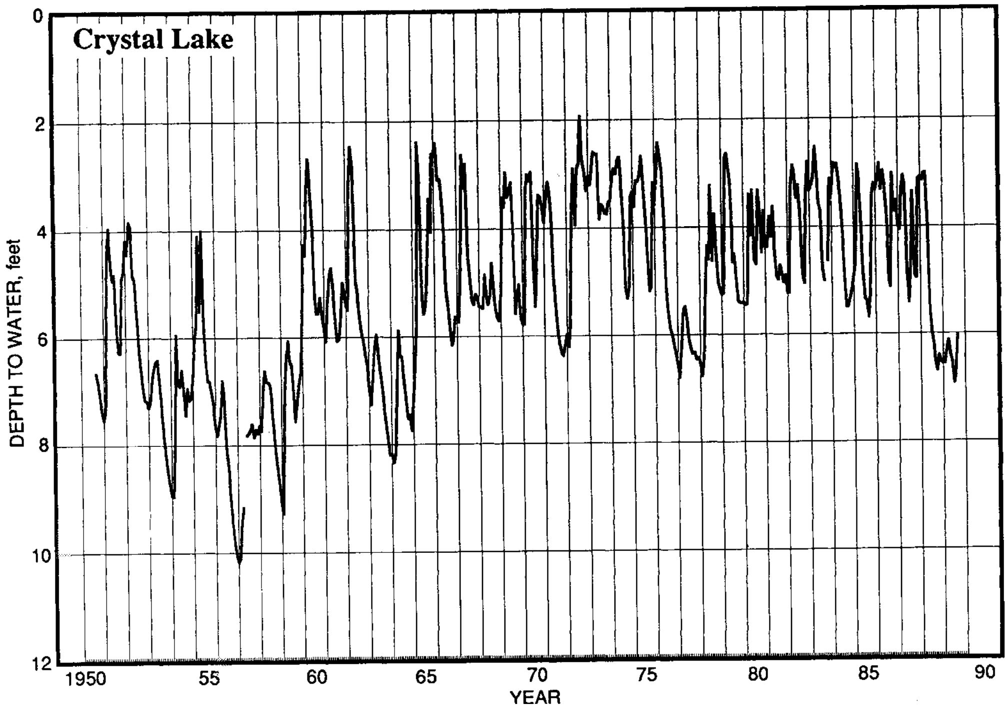

Figure 6.28. Long-term hydrograph for the Crystal Lake observation well, McHenry County, 1951-1989. Data are unsmoothed monthly values.

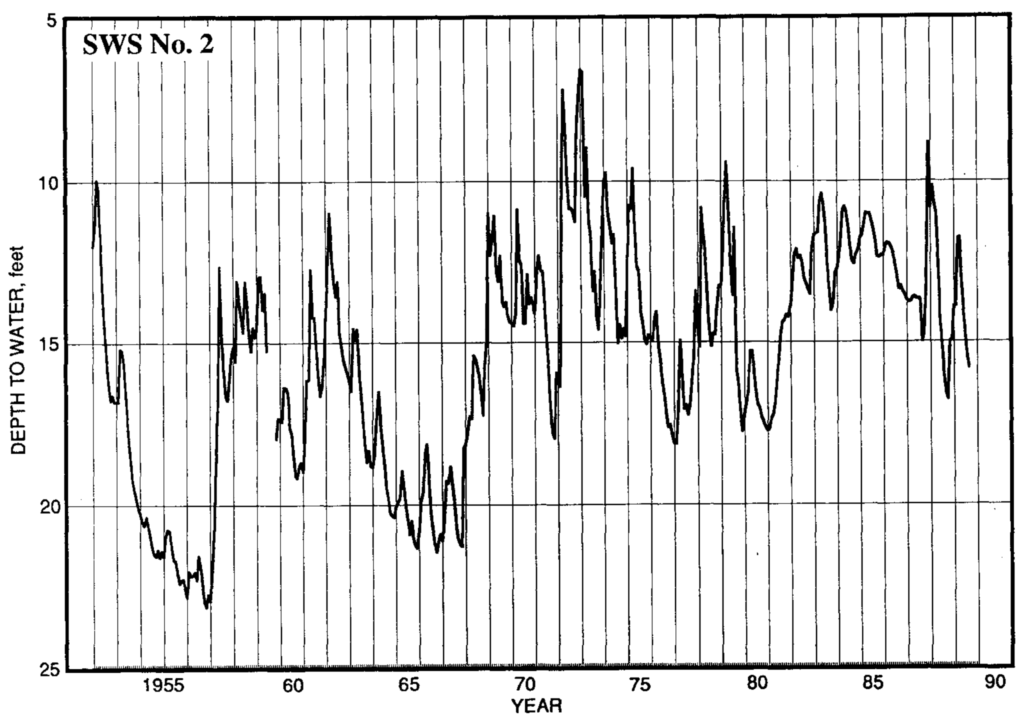

Figure 6.29. Long-term hydrograph for the SWS No. 2 observation well, St. Clair County, 1952-1989. Data are unsmoothed monthly values.

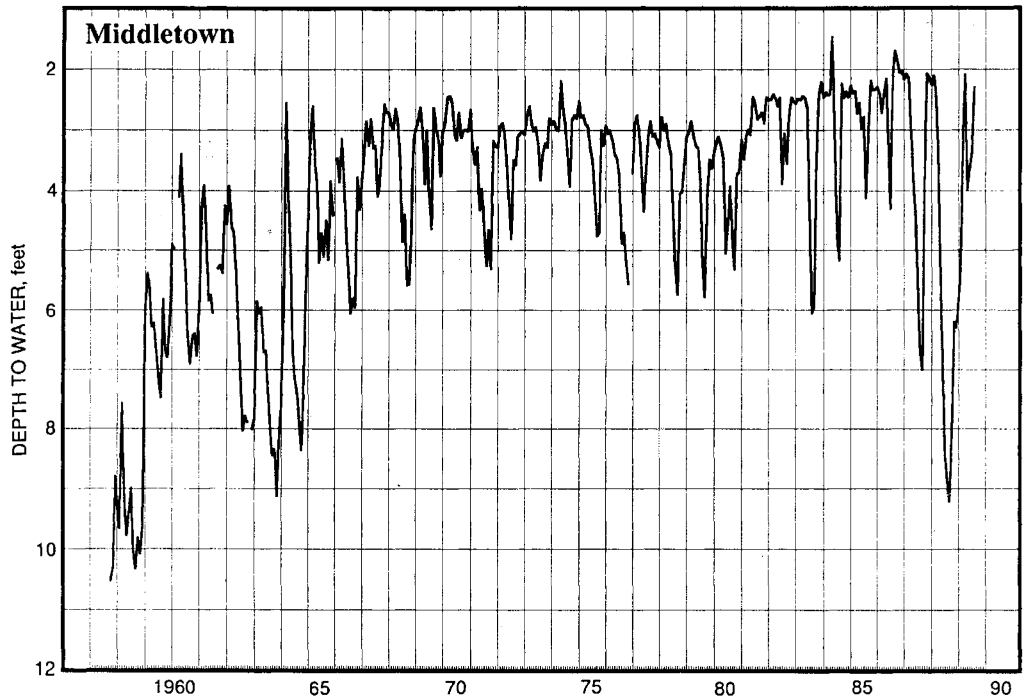

Figure 6.30. Long-term hydrograph for the Middletown observation well, Logan County, 1958-1989. Data are unsmoothed monthly values.

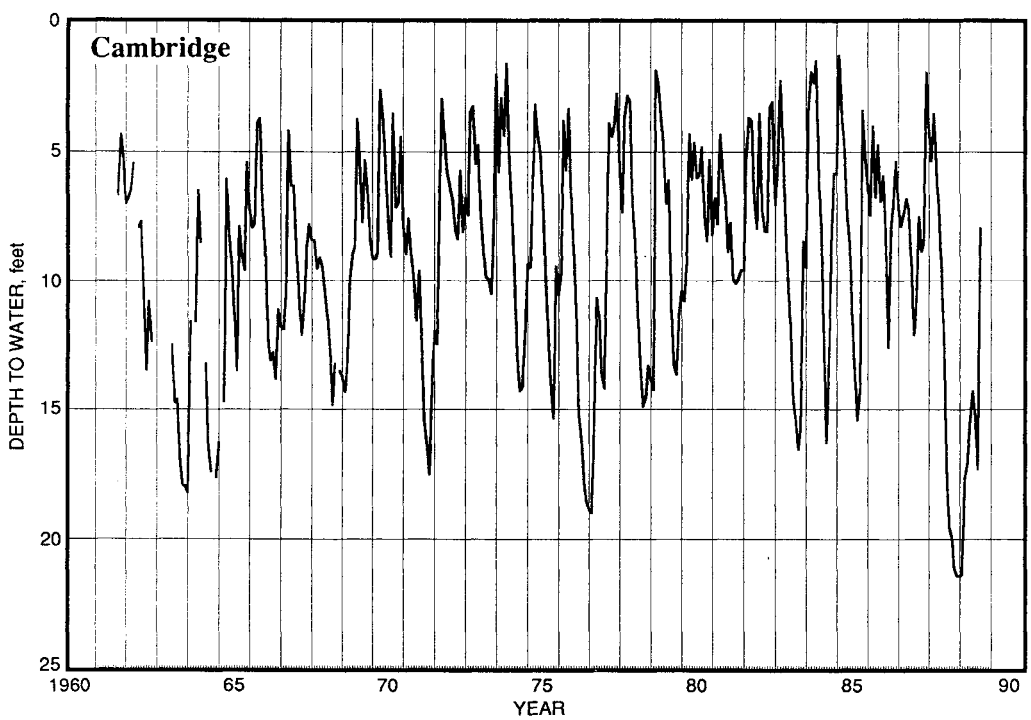

Figure 6.31. Long-term hydrograph for the Cambridge observation well, Henry County, 1961-1989. Data are unsmoothed monthly values.

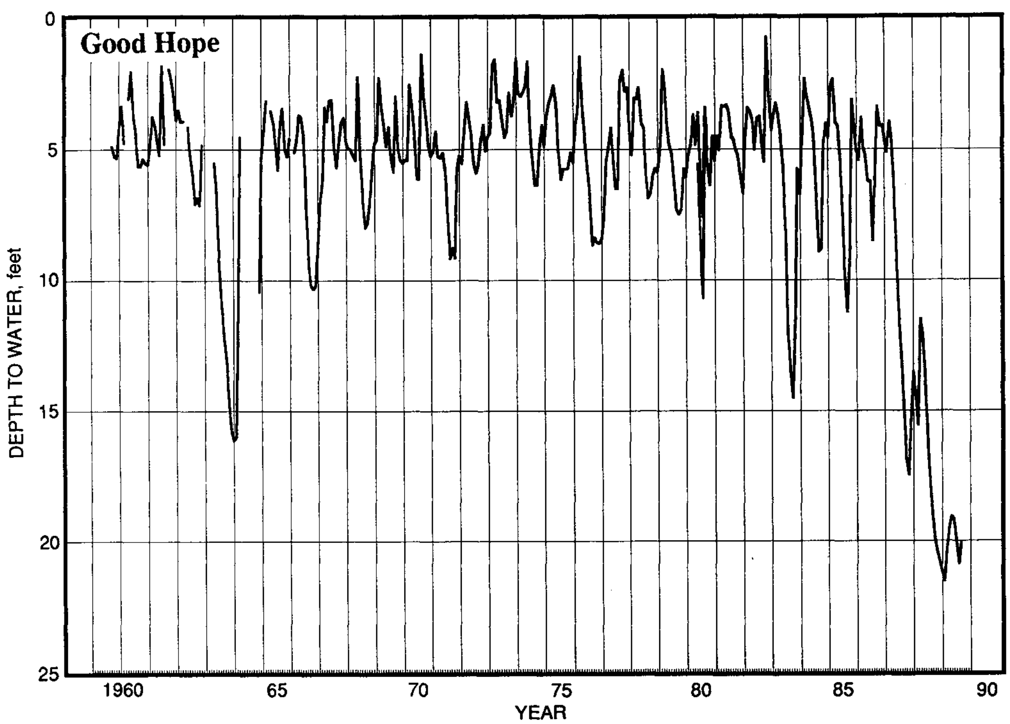

Figure 6.32. Long-term hydrograph for the Good Hope observation well, McDonough County, 1959-1989. Data are unsmoothed monthly values.

Table 6.1. Construction Features of Network Wells

	I D. number	*Date started*	*Depth (ft)*	*Diameter (in.)*	*Type of well construction*	*Aquifer type**
Northwest						
Cambridge	00011	10/61	42	78	Dug	Unconsolidated
Galena	00021	9/63	25	36	Dug	Sandstone
Mt. Morris	00031	11/60	55	8	Drilled	Unconsolidated
Northeast						
Crystal Lake	00041	9/50	1 8	6	Drilled	Unconsolidated
Fermi Lab	00052	4/84	19.5	5	Drilled	Unconsolidated
West						
Good Hope	00072	6/80	30	36	Dug	Unconsolidated
Central						
Middletown	00081	11/57	38	36	Bored	Unconsolidated
Snicarte	00091	3/58	41	36	Dug	Sand
East						
Bondville	01120	4/82	21	6	Drilled	Unconsolidated
Swartz	00111	6/54	35	48	Dug	Unconsolidated
Watseka	00122	10/62	19.5	42	Dug	Unconsolidated
West-Southwest						
Coffman	00061	3/56	28	36	Dug	Unconsolidated
Greenfield	00132	5/65	22	36	Dug	Unconsolidated
East-Southeast						
Janesville	00143	4/69	15	60	Dug	Unconsolidated
St. Peter	00153	5/65	15	60	Dug	Unconsolidated
Southwest						
Elco	00163	3/84	23	36	Dug	Unconsolidated
Sparta	00171	11/60	27	36	Dug	Unconsolidated
SWS No. 2	00181	1/52	81	8	Drilled	Sand
Southeast						
Boyleston	00221	3/84	23	36	Dug	Unconsolidated
Dixon Springs	00191	1/55	9	36	Dug	Unconsolidated
S.E. IL College	00202	8/84	11	10	Drilled	Unconsolidated

* Most dug or bored wells receive water from thin sand lenses within fine-grained unconsolidated glacial materials. Unless specifically known from a driller's log or from units correlated from other wells in the area of similar depth, all network wells are completed in such materials. The principal exceptions are at Galena (the only bedrock well in the shallow network) and at Snicarte and SWS No. 2 , which are known to be finished in major sand aquifers.

Table 6.2. Record Ground-Water Levels at Network Wells Compared with Lowest 1988-1989 Levels*

	Record high	*Mo/Yr*	*Record low*	*Mo/Yr*	*1988-1989 low*	*Mo/Yr*	*Date records started*	*Comment*
Northwest								
Cambridge	0.20	12/82	21.45	12/88	21.45	12/88	10/61	
Galena	13.38	5/74	24.75	12/64	23.13	8/89	9/63	23.88'in 2/90†
Mt. Morris	1.96	4/73	32.08	3/64	26.82	5/89	11/60	28.02'in 2/90†
Northeast								
Crystal Lake	1.75	9/72	10.30	2/57	6.68	10/88	9/50	
Fermi Lab	0.11	11/85	16.56	7/87	12.86	10/88	4/84	
West								
Good Hope	0.45	4/83	21.50	2/89	21.50	2/89	6/80	22.53'in 1/90†
Central								
Middletown	0.40	7/81	10.50	12/57	9.21	10/88	11/57	
Snicarte‡	31.30	5/85	>40	9/88-4/89	>40	9/88-4/89	3/58	
East								
Bondville	0.06	4/83	7.58	8/83	7.30	10/88	3/82	
Swartz	0.77	3/84	12.78	2/64	11.16	11/88	6/54	
Watseka	4.33	4/85	19.73	12/63	15.05	10/88	9/62	
West-Southwest								
Coffman	0.92	12/82	19.28	10/56	17.49	10/88	3/56	17.80'in 12/89†
Greenfield	0.75	2/82	21.00	1/81	19.03	12/88	4/65	
East-Southeast								
Janesville	0.05	1/73	9.67	10/72	9.02	9/88	4/69	
St. Peter	0.10	4/84	7.37	7/72	7.10	9/88	5/65	
Southwest								
Elco	0.06	5/86	19.21	11/87	18.72	8/88	3/84	
Sparta	0.27	4/83	14.31	2/64	11.38	10/88	11/60	
SWS No. 2	6.10	1/73	23.13	12/56	16.77	10/88	1/52	
Southeast								
Boyleston	0.43	2/85	10.53	12/88	10.53	12/88	3/84	
Dixon Springs‡	0.01	4/74	>8.44	9/87	>8.44	8-10/88	1/55	
S.E. IL College	0.01	3/86	9.34	10/88	9.34	10/88	8/84	

* Ground-water levels expressed as depth to water from land surface, in feet.

† Water levels in these four wells declined further after September 1989 to the depth and date noted.

‡ The Snicarte observation well went dry in September 1988 and remained so through April 1989. The Dixon Springs observation well was dry in September 1987 and went dry again from August to September 1988. These two periods are the only dry periods on record for the well in its 35-year history.

7. AGRICULTURAL IMPACTS

by

Steven E. Hollinger

Chapter 4 documented the adverse effects on Illinois soil moisture from the precipitation and temperature anomalies described in chapter 3. 'Ihis chapter is concerned with the impacts of soil moisture depletion and high temperatures on agricultural production. It thus complements the material in chapters 5 and 6 concerning the societal effects (e.g., effects on water supplies) of the hydrological component of the drought.

One of the first effects of the drought was on agriculture during the 1988 planting season, and agriculture continued to be impacted by the drought throughout the summer. The summer agricultural, horticultural, and forage crops were the agricultural enterprises most affected by the drought, as was manifest in reduced crop yields, especially for corn and soybeans. However, all sectors of agriculture were impacted in some way.

For example, livestock production was impaired by poor pastures, low water supplies, reduced feed consumption due to elevated environmental temperatures, and increasing feed costs. This resulted in reduced rates of gain in growing and fattening animals. The poorer feed quality was felt immediately by grazing livestock and by confined livestock after the crop was harvested. The delayed effect of the drought on confined livestock occurred because these animals are normally fed feed grains that were grown the previous year. Producers also observed reduced milk and egg production by dairy and poultry animals during summer 1988.

7.1. Impact of Drought Conditions on 1988 Crops

Drought conditions can affect final yield during four periods of crop growth: 1) planting and stand establishment, 2) juvenile period, 3) flowering period, and 4) grain fill period. Crop development is impacted differently during each of these periods, and plants have varying abilities to recover from drought injury depending upon their stage of development.

Planting and Stand Establishment

Drought conditions impact the crop during planting and stand establishment when the top 3 to 4 inches of soil are very dry at planting. The result is poor germination and plant stands. The lower plant population can lead to weedier fields later in the growing season. If dry topsoil conditions exist when a farmer is scheduled to begin planting, two options are open. Planting can be delayed in the hope that rain will occur before it is too late to plant, or it can proceed in the expectation that rainfall sufficient to support germination and emergence will soon develop.

In 1988, many Illinois farmers planted their corn early in the season. By May 9, 95 percent of the state's crop had been planted, compared to a five-year average of only 57 percent by that date (*Illinois Weather and Crops,* 1988). Soybeans were also planted early in 1988. Whereas the five-year average portion of the Illinois soybean crop planted by May 31 is 67 percent, 97 percent of the 1988 soybean crop was planted by that date (*Illinois Weather and Crops,* 1988). While this early planting resulted in the planting of most of the corn in relatively good soil moisture conditions, the soybeans, which were planted later, were all sown into much drier topsoil (figures 4.2-4.4).

Juvenile Period

During the juvenile period of crop development, plants are establishing roots and growing vegetatively. For corn, this involves the development of ear shoots and tassels in addition to the growth of leaves, stalks, and sheaths. Severe moisture and heat stress during this period can cause the corn plant to develop fewer kernel rows on each ear than would be developed without stress.

The 1988 corn crop was subjected to some rather severe drought conditions during this period, but the total number of kernel rows did not appear to be significantly reduced because of the more favorable soil moisture conditions in the cultivated fields (Chapter 4). Therefore the yield potential at the time of silking and pollination was not greatly diminished. However, the water stress during this period resulted in a delay in tasseling and silking.

Soybean plants grow leaves and stems during the juvenile period, with good vegetative development producing more stem nodes. Because flowers later develop at each stem node, the potential for flowering and podding on each plant increases with the number of stem nodes. Heat and moisture stresses during this period of soybean growth result in stunted plants. When the flowering process is triggered by the photoperiod response, fewer nodes are available to set flowers.

During the soybean juvenile period in 1988, the soybean crop appeared to be dormant and to have stopped growing. In spite of this condition, most of the soybean plants were green and apparently still alive. Thus, the moisture and heat stress that occurred during this period did not damage the plants as severely as might have been expected.

Flowering Period

The flowering period is the most critical period of crop growth, for it is here that the economic grain yield is determined by the number of seeds set by each plant. Corn yields can be severely reduced at this time by stress-induced desynchronization of pollen release and silking. This results in tassel emergence and in the anthers shedding their pollen before the silks have emerged from the ear. When this happens, the ear is not efficiently fertilized.

This desynchronization of tasseling and silking is due to the differing responses of tassel emergence and silk development to water stress. Silk elongation is affected more severely by water stress than tassel elongation (Herrero and Johnson, 1981). Therefore, when the corn plant is subjected to water stress, silk elongation will be stopped while tassel elongation and development continue.

Corn yiels can also be affected by high temperatures during the flowering period. When daytime temperatures exceed 35°C, corn pollen becomes less viable (Herrero and Johnson, 1980). This results in fewer kernel primordia being fertilized and thus fewer seeds being set on the plant.

For the 1988 Illinois corn crop, flowering was delayed from its anticipated time based on the date of planting. For example, only 35 percent had silked and tasseled by July 11, whereas 74 percent had silked and tasseled by the same date in 1987 (*Illinois Weather and Crops* 1988), and approximately 75 percent was expected to have done so in 1988 based on the planting dates as compared to those in 1987. This retarded development of the corn plant was due to the severe drought stress during the juvenile period and the apparent dormancy of some corn hybrids during that time.

This is well illustrated by observations from Champaign County. During early July, when the crop should have been tasseling, individual tassels seemed to stop growing just before they emerged from the top leaf of the plant. Then in mid-July, several rain events totaling 12 to 25 mm occurred over a period of a week. The smell of pollen could be detected for several hours after each of these rains. A day or so after the first rain event, the smell of pollen disappeared. But after the second rain event, the smell of corn pollen was again detectable. This aroma was accompanied by the emergence of the tassel and silks. These observations were very hybrid-dependent. Hybrids with upright leaves exhibited this behavior more than hybrids with greater horizontal leaf habits.

The flowering of Illinois soybeans in 1988 was also delayed by the drought, as shown by comparison with the 1987 situation. Soybean planting in 1987 was slightly later than in 1988, but it was well ahead of the five-year average. In contrast, the timing of the 1988 flowering was comparable to the five-year average (*Illinois Weather and Crops,* 1988). Furthermore, while soybeans continued to flower during the 1988 drought, most of the pods from the flowers were aborted. It is through the process of pod abortion that soybean yields are reduced during the flowering process.

Grain Fill Period

After flowering and during the grain fill period, corn and soybean yields are further determined by seed abortion and filling of the individual seeds. Seeds are aborted by corn plants during the first two weeks after pollination if water stress or high temperatures are experienced (Harder et al., 1982; Eck, 1986; Ouattar et al., 1987). Once the final seed number is determined, the plant attempts to grow each seed to a maximum size. If a drought occurs or continues during the grain fill period, or if the plant is attacked by insects or disease or killed by an early frost, the kernels will be smaller and lighter than normal.

The 1988 drought did not have a severe impact on corn during the grain fill period. Most of the yield loss was carried over from the vegetative and flowering growth stages. Showers and more abundant rains through late July and early August helped corn plants fill the kernels set on the ear. Also, because of the hot dry we ather, the insects that are normally problems for the Illinois corn crop were not present. Although the insect pests that usually attack the soybean plant were not present in 1988 for the same reason, spider mites became a serious problem for this crop in July and August. Control of these mites required large expenditures for insecticides by many farmers.

7.2. Impacts on Livestock

The initial major impact of the 1988 drought on livestock enterprises was the reduction of pasture for grazing livestock during that summer. This shortage forced producers to begin feeding stocks of grain and hay that were to have been used during the 1988-1989 winter. Therefore additional major impacts of the 1988 drought were felt by these enterprises during the 1988-1989 winter, as a result of higher feed prices and relatively poor livestock condition due to the reduced supply and quality of the summer-fall feed.

7.3. Comparison of 1987, 1988, and 1989 Crop Yields

The impact of the 1988 drought can be seen by comparing the corn and soybean yields for that year to those of the 1987 and 1989 summers (table 7.1). Corn yields in 1988 were 46 percent less than in 1987 in northern Illinois, 45 percent less in central Illinois, and 64 percent less in southern Illinois. This subdivision of the state into thirds is the same system used in Chapter 4. The 1989 corn yields were 86 percent greater than 1988 yields in northern Illinois, 64 percent greater in central Illinois, and 153 percent greater in southern Illinois. Soybean yields statewide averaged 7 percent less in 1988 than in 1987, and they declined by another 19 percent in 1989.

As already indicated, the low 1988 corn yields were due to the prolonged dry spell throughout that summer. However, a more complex agroclimate situation evolved during the 1989 growing season. In northern and central Illinois, the soil moisture in the 50-100 cm and 100-200 cm layers was less throughout the summer of 1989 than during the summer of 1988 (figures 4.2 and 4.3). Fortunately, this shortfall of deep soil moisture (a result of the continuation of the precipitation drought into early 1989) was offset by timely rains throughout the growing season as can be seen by the greater amount of soil moisture in the 0-15 cm and 15-50 cm layers shown in figures 4.2 and 4.3. The recovery of corn yields during 1989 was also due to the cool summer temperatures.

The decline in soybean yields from 1988 to 1989 was due to the aforementioned lack of deep soil moisture during the summer of 1989 and the shortage of soil moisture in the 0-50 cm layer during August of that year (figures 4.2-4.4). Corn yields were not affected as much by this shortage because it occurred after the critical period of silking and early grain fill.

The extreme 1987-1989 corn yield variations in southern Illinois are the result of the shallow soils of that region, whose effects can be readily seen in the soil moisture measurements in figures 4.2-4.4. In the 50-100 cm and 100-200 cm soil layers, the annual variation of soil moisture was greater in northern and central Illinois where the soils are deeper. In southern Illinois, very little deviation of soil moisture occurs from year to year, but in 1988 soil moisture declined in the 50-100 cm layer.

Yield losses in 1988 were very much a function of the management practices of individual producers and the condition of the soil as a result of the production and tillage practices used in the preceding year. This is illustrated by mid-August yield estimates made for two cornfields and two soybean fields in north-central Illinois that were located within 1.6 km of each other. One cornfield was estimated to have a yield potential of 8.2 megagrams per hectare (Mg/ha), and the other cornfield to have a yield potential of 4.4 Mg/ha. Likewise, one soybean field had a yield potential of 2.7 Mg/ha and the other had a potential of 1.3 Mg/ha.

The 1988 cultural practices used on the fields were similar; the fields were of the same soil type and each received approximately 5 cm of rain between planting and the time the yield estimates were made. The main difference between the fields was that those with the higher yields had abundant roots down to a depth of 1.52 m, whereas in the lower-yielding fields, a significant hardpan existed approximately 0.20 m below the soil surface. From this evidence and the fact that most Illinois soils have a large moisture-holding capacity, it appears that the inability to develop a deep root system was a major cause of the larger yield reductions in individual fields. Such root curtailment could have been due to a chemical impediment, to compacted layers in the soil profile, or to problems stemming from tillage operations.

7.4 Summary

The 1988 drought had major impacts on agriculture. These impacts were felt more severely in the south and central zones of the state due to drought conditions that occurred during summer 1987. Conversely, the northern zone of the state experienced lingering effects of the 1988 drought in the summer of 1989. It was only late in 1989 that the physical effects of the 1988 drought were no longer being felt, even though its economic effects were still apparent.

TABLE

Table 7.1. 1987, 1988, and 1989 Corn and Soybean Yields in Northern, Central, and Southern Illinois

	Corn yield (Mg/ha)			*Soybean yield (Mg/ha)*		
	1987	*1988*	*1989*	*1987*	*1988*	*1989*
North	8.02	4.34	8.08	2.93	2.58	2.06
Central	8.53	4.67	7.65	1.94	1.85	1.70
South	7.48	2.70	6.85	2.93	2.76	2.00

Note: Values given are based on crop reporting district (CRD) average yields. Northern Illinois includes CRDs 1 and 2; central Illinois, CRDs 3,4,5,6, and 7; and southern Illinois, CRDs 8 and 9.

8. SUMMARY

by

Richard G. Semonin

This report has provided a comprehensive analysis of the 1988-1989 Illinois drought, which was one of the most disastrous in the history of the state. It has described the meteorological conditions responsible for the lack of precipitation and discussed the impacts of the drought on the water and agricultural resources of the state. A summary of the major findings and their implications follows.

The 1988-1989 Illinois drought was initiated in early spring 1988, when the large-scale atmospheric circulation became stagnant over central North America. This reduced the number of fronts traversing the state, relative to normal, and limited the northward flow of moisture from the Gulf of Mexico. The anomalous pattern continued until late summer 1988. Paradoxically, a shift of the circulation to a pattern that allowed more frequent frontal passages in 1989 continued the drought. The frontal frequency was sufficiently great that either 1) the time between them was inadequate to allow Gulf moisture to reach the state, or 2) fronts remained stationary south of Illinois, serving as a wall to increasing moisture flow.

Meteorological conditions in 1988 resulted in the fifth driest year since records were begun in the late 1800s. Measured as a percentage of the land area in Illinois, the spring-summer drought of 1988 ranks as the third driest, with 54 percent of the state receiving 50 percent or less of the long-term average rainfall. From a climatic standpoint, it is important to note that about 51 years had elapsed since a comparable growing-season drought occurred in the state in 1937. Illinois farmers who began their careers in the late 1940s or later had no previous experience with a drought of the magnitude of that of 1988.

Soil moisture was depleted rapidly under the dry, warm conditions of spring 1988, a process that accelerated when the crops began to exert their need for water. The warm, cloud-free days increased plant evapotranspiration until the soil moisture was exhausted and the plants effectively shut down by leaf curling. This decrease in evapotranspiration may also have contributed to drought conditions, since this moisture source is important for the midwestern summer atmospheric water budget. Coupled with the blocking of moisture from the Gulf by atmospheric circulation patterns, the lack of moisture from growing plants may have prolonged the drought.

A hydrologic drought is triggered by a meteorological drought, but streams and lakes experience a lag in responding to precipitation shortages. The Water Survey monitors 21 significant rivers and streams in Illinois with 28 streamgaging stations. By May 1988, all 28 stations reflected flows less than the long-term monthly average. During the drought of 1988-1989, many observed monthly flows established new low-flow records, and many were 50 percent or less of the average flow. Only three stations escaped setting a record or falling below the 50 percent average flow value: the DesPlaines River in Lake County, the Big Muddy River in Jackson County, and the Cache River in Johnson County

The control dams on the Illinois lessened the impact of the drought, but the general conditions of the river limited the hauling capacity of barge tows, especially in late summer. For example, the months of June, July, and August of 1988 saw new low-flow records for Marseilles. As a result, the farming community had to use alternate transportation for grain, primarily rail and truck.

The Mississippi River did not set new records, but barge traffic was hampered considerably by low flows, particularly below Alton lock and dam 26. Here flows were about 50 percent of the long-term average, which made it necessary to restrict barge loads severely. During 1988, barge traffic was stopped south of St. Louis for a period while bedrock was removed from the riverbed to increase the depth of the navigation channel. Due to these restrictions on navigation, proposals were introduced to increase the diversion of Lake Michigan water at Chicago to flow down the Illinois and increase the water available below St. Louis. However, nothing came of the proposal when opposition to greater diversion surfaced in the U.S. Congress.

The public water supply lakes in central and southern Illinois experienced serious storage problems during the 1988-1989 drought. Reduced storage in reservoirs caused many towns and cities to restrict water use, to augment water supplies by withdrawals from abandoned quarries, to reactivate old wells, and to import water from other available municipal supplies. The Governor's Drought Contingency Task Force assisted water-short communities in implementing these various alternatives to ensure adequate water for public health and safety.

Lake Michigan had been experiencing high levels since 1977, and they peaked in early 1987. The ensuing drought lowered the lake to the long-term average elevation, and concerns about severe shoreline erosion ended with a return to these near-normal conditions.

The network of shallow ground-water wells routinely monitored by the Water Survey during 1988-1989 showed that a moderately severe drought existed throughout most of Illinois for 9 to 24 months. In western and northwestern Illinois, drought conditions began as early as late 1987 and continued into the summer of 1989. This condition affected some municipal water supplies and severely impacted rural domestic wells. Water hauling for domestic use was prevalent in the western counties, and some consideration was given to the construction of new reservoirs to meet future community demands.

Irrigation in some counties caused the interruption of supplies from some domestic wells that did not conform to state standards. Numerous water conflicts arose in late summer 1988 as reservoirs dropped to record low elevations and additional stress was placed on ground-water supplies.

Corn yields in 1988 were very low due to the prolonged dryness during the growing season, especially at the time of tasseling. In contrast, corn responded favorably to very timely rains in July 1989, and yields recovered significantly throughout the state. Somewhat cooler than normal temperatures during the growing season also contributed to relatively good yields. Soybeans, however, survived 1988 with somewhat lower yields than in the previous year, but yields were decidedly lower still in 1989. The July rains and the temperature regime that benefited corn in 1989 were not adequate to recharge deep soil moisture and stimulate soybean root development, while the dry shallow soil moisture in August inhibited soybean plant growth.

Finally, while Illinois responded in a reasonable and timely manner to the drought of 1988-1989, the state was fortunate that the moisture deficiencies abated when they did. If the drought had maintained its severity for only a few more months or into another growing season, the water use conflicts seen during 1988-1989 might have become more serious. Using the results of this report, it is essential that additional skill be acquired to forewarn the responsible agencies of impending water shortages. In turn, it is also essential that Illinois review its policies and regulatory power to enable those responsible agencies to provide an enhanced level of direct aid to meet the needs of the people and to be able to intervene in water use conflicts.

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