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REPORT OF INVESTIGATION 102
STATE OF ILLINOIS
ILLINOIS DEPARTMENT OF ENERGY AND NATURAL RESOURCES

The 1980-1981 Drought in Illinois: Causes, Dimensions, and Impacts

by STANLEY A. CHANGNON, JR.
Climatological assessment, Drought impacts, Case study of Eldorado, Use of weather modification, Summary

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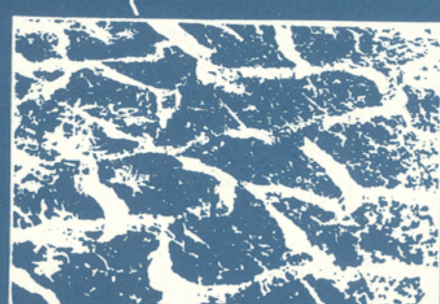

ILLINOIS STATE WATER SURVEY
CHAMPAIGN
1982

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Abstract: Hydrologic, meteorological, and climatological aspects of the 1980-1981 drought in Illinois are addressed. The drought is evaluated in terms of precipitation, streamflow, lakes and reservoirs, and groundwater 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, 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. The 1980-1981 drought was not one of the extreme droughts of record; however, it is important in that it was the most severe drought since those of the early 1950's. As such, it reflects some new types of impacts on the state's water resources due to technological, hydrological, and institutional changes since the 1950's.

Reference: Changnon, Stanley A., Jr., Gary L. Achtemeier, Steven D. Hilberg, H. Vernon Knapp, Robert D. Olson, Wyndham J. Roberts, and Peter G. Vinzani. The 1980-1981 Drought in Illinois: Causes, Dimensions, and Impacts. Illinois State Water Survey, Champaign, Report of Investigation 102, 1982.

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STATE OF ILLINOIS
HON. JAMES R. THOMPSON, Governor

DEPARTMENT OF ENERGY AND NATURAL RESOURCES
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Chapter I. Introduction

Stanley A. Changnon, Jr., and Steven D. Hilberg

Enabling legislation directs the Illinois State Water Survey "to publish the results of its investigations . . . [so] that the available water resources of the State may be better known." Within this general charge, the Survey has made extensive investigations of various water conditions of the state over the last 86 years. Among these have been investigations of past droughts, from a hydrologic standpoint (Hudson and Roberts, 1955) and from an atmospheric viewpoint (Huff and Changnon, 1963; Changnon, 1980). Although Illinois is in a humid climatic zone, it experiences droughts of varying temporal and spatial dimensions. These, in turn, affect the state's water resources (Changnon, 1981b).

This report addresses the most recent drought in Illinois, that of 1980-1981. This 15-month drought, which began in February 1980 and was centered in the southern portions of the state, was not one of the extreme droughts of record. However, its importance derives from the fact that it is the most severe drought since those of the early 1950's. As such, the 1980-1981 drought potentially reflects a new set (or new types) of impacts on the state's water resources due to many technological, hydrological, and institutional changes since the 1950's.

As noted above, droughts are a basic and important feature of the climate and water resources of Illinois. The interesting near absence of droughts in the state between 1955 and 1976 makes the drought of 1980-1981 of great interest, although it was not extremely severe.

Each new drought needs study because droughts are defined by a mixture of a) their physical dimensions (such as percent of normal rainfall or streamflow), and b) their socioeconomic impacts (Changnon, 1980). A drought cannot be truly defined until some form of human endeavors or the environment begins to experience stress from a water deficiency. The ever-changing land uses and water management facilities that are developed, such as new water supply lakes, stream channelization, and new ways of planting crops, collectively affect water quantity and quality, and these in turn are affected differently by deficiencies of moisture. A 12-month period with 60 percent of normal rainfall in 1927 would not have produced the same impacts, or drought definition, that a comparable rainfall deficiency would have produced in 1981. This concept shows the need for updated studies of new droughts and their re-definition if needed.

Drought studies serve as a basis for future planning about droughts, and as a basis for making future institutional and environmental adjustments. Illinois is currently involved in preparing a new State Water Plan. One of the 11 issues identified for attention is "drought contingency planning." Drought contingency planning, a highly desirable goal for Illinois, can be successful only with well quantified information on a) physical aspects of droughts, b) the impacts of droughts, and c) the means for addressing drought from institutional, economic, and engineering standpoints. The implementation of future engineering adjustments to meet droughts, including new well fields, new reservoirs, pipelines, etc., can be conducted properly only within an institutional framework resting on adequate data and information about droughts. Hence, studies of the temporal and spatial aspects of droughts are extremely important to Illinois.

The significance of the 1980-1981 drought, although it was concentrated in southern Illinois and was of only moderate intensity, can be further derived by studying figure 1. This

TIME SCALE FOR PEAK PERIODS OF DROUGHTS

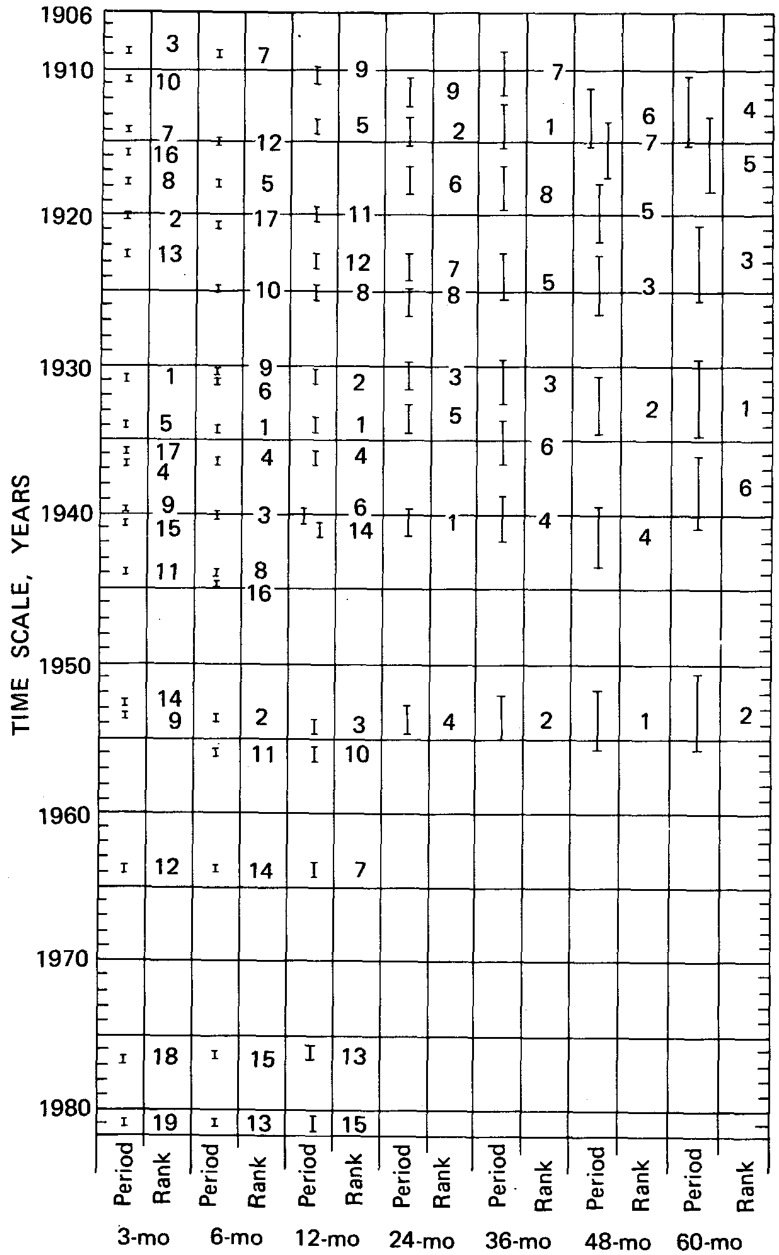


Figure 1. Droughts of varying durations in Illinois during 1906-1961, with their ranks

climatological reconstruction of all droughts in Illinois since 1905 illustrates many important features about Illinois droughts. For example, most major multi-year droughts were composed of one or more shorter-term drought periods, which were often separated by brief periods of non-drought conditions. However, one of the more important features of this temporal graph is that it reveals the unusually long time interval between the severe droughts of the early 1950's and the two moderate droughts of 1976-1977 and 1980-1981. This period of more than 20 years without any droughts of consequence in Illinois occurred in a time of rapidly changing agricultural technology, major new water resource development, and a major shift in life styles (and water use) in Illinois. If the future climate of Illinois returns to a period of more droughts, as evidenced in the 1906-1956 period, these will greatly affect the state, and in ways not previously experienced.

State Water Survey Activities during the Drought

It is worth recounting the basic activities that the Water Survey performed during the 1980-1981 drought. Our activities fell within four broad categories.

First was the *statewide release of water and rainfall status information.* Monthly reports treating all aspects of precipitation and water were prepared with the aim of informing local, state, and federal agencies, and the public via the news media. A weather-water status report was released in October 1980, after which status reports were prepared and released each month from January 1981 until the end of the drought in May 1981. Each of these monthly reports summarized the statewide status (by nine crop reporting districts) of 1) precipitation in Illinois for the past month, past 3 months, and past 12 months; 2) soil moisture conditions in Illinois; 3) surface water conditions, including lakes and rivers; and 4) shallow groundwater conditions. The reports also included the Water Survey's long-range (monthly and seasonal) predictions of precipitation, a result of our newly-developed statistical techniques. Importantly, the predictions issued for the January through May period (for each month and for the winter and spring seasons) were correct for the drought area. The monthly reports pointed to the continuance of below normal precipitation in the drought area in January, February, March, and April, and then predicted the above normal rainfall in May.

These statewide weather-water summary reports were also condensed and distributed through the University of Illinois news service and received wide public attention. The reports were helpful to the other agencies on the Illinois Drought Task Force, established by the Governor in January 1981. The Drought Task Force used these status reports in their assessment of options and actions to address the water shortages in Illinois, as well as in their development of plans for the future. As a result of these releases, we provided information on the drought in 47 radio, TV, and newspaper interviews during November 1980-May 1981.

The second major area of activity during the drought related to *increased data collection activities,* carried out to monitor the drought conditions more closely. The Water Survey increased the frequency of data collection on 1) selected southern Illinois rivers, and 2) shallow groundwater monitoring wells scattered throughout the southern half of the state. Special monthly trips were made by field personnel to collect data of these types.

As part of the data collection activities, we instigated an intensive telephone survey of 10 to 30 weather observers around the state at the end of each month. This was done to obtain up-to-date state rainfall information, particularly for the southern half of the state. The third data collection activity involved the installation, for the first time ever, of a statewide network of soil moisture measuring stations. The Water Survey began installation of an 8-station climate network across the state during the spring of 1981. The data from this network provided extremely useful measures of the soil moisture conditions in the state. These soil moisture measurements will be maintained to develop a historical record of these conditions to provide continuing monitoring and input for the water supply and agricultural interests of the state.

A third general area of activity related to our *provision of data and information* in response to various specific questions about the water supply conditions in southern Illinois. The Water Survey received about 170 calls seeking advice on a multitude of problems. For example, the staff gave advice and instructions on how to suppress evaporation from farm and orchard ponds, and materials were provided at no cost for this purpose. We handled requests from 34 communities about their water supplies and alternate sources. Most advice was given on potential sites of wells for short-term supplies. We responded to some 43 letters requesting data about the drought, including data on water quantity and quality. Our staff gave talks in four drought-stricken communities.

Extensive advice and assistance were provided to the Saline Valley Water Conservancy District in southeastern Illinois, which was preparing to assist Eldorado and Harrisburg with their very short water supplies. In conjunction with the State Geological Survey, we helped locate the best site for their new well field, and we conducted aquifer tests to verify that adequate groundwater resources were available.

The fourth area of effort during the drought related to *supplying general drought information,* The increasing frequency of requests for drought-related data and information that were received by both the Water Survey and the University of Illinois College of Agriculture (Cooperative Extension Service) led the two groups to plan, in March, a drought workshop for June. This was the earliest date that speakers and facilities could be arranged. Although a program was arranged, the advent of record-breaking heavy May rainfalls (greater than 12 inches) in southern Illinois led to the cancellation of the workshop. The need for information on making long-term adjustments to drought remains, but responses indicated that the heavy rains had in fact "washed out" most interest in the workshop. This situation reflects one of the basic problems of planning and dealing with drought – a lack of interest when there is no drought.

Scope of Report

This report focuses on the hydrologic, meteorological, and climatological aspects of the 1980-1981 drought. The drought is evaluated in terms of the precipitation, streamflow, lakes and reservoirs, and groundwater resources of the state. The meteorological conditions that produced the drought are also addressed. Finally, certain impacts and problems resulting from the drought, with its effects on municipal and agricultural water supplies, are addressed along with various actions taken to ameliorate the problems.

Although the primary goal of the study of the 1980-1981 drought was to quantify the drought, primarily in a physical sense, an important secondary goal was to assess the impacts and the actions employed to derive information needed in future institutional planning and actions to handle Illinois droughts. The report thus ends with a set of recommendations for coping with future droughts.

Acknowledgments

This report has been prepared with the advice and assistance of many people. The data and assistance provided by various state and federal agencies, including the U.S. Geological Survey, are appreciated. Ronald King, Utility Engineer of the Illinois Commerce Commission, reviewed the text on the Eldorado drought, and his helpful comments are appreciated. Various directors of research within the Water Survey reviewed the text, including James P. Gibb of the Groundwater Section. The many graphs and maps were prepared by John Brother, Jr., William Motherway, Jr., and Linda Riggin. Debbie Hayn typed the original manuscript, Gail Taylor edited the manuscript, and Marilyn Innes prepared the camera copy.

Chapter II. Climatological Assessment

Peter G. Vinzani and Stanley A. Changnon, Jr.

Introduction

The precipitation and other climatic variables associated with the 1980-1981 drought, which occurred during the 15-month period of February 1980 through April 1981, have been investigated. This was the third drought to occur in the state since the mid-1950's, and the most severe in southern Illinois since that time. A minor drought occurred in central Illinois in the early 1960's (see figure 1), and a moderate drought occurred in south-central Illinois in 1976-1977.

The first perception and most fundamental aspect of droughts is the lack of precipitation. Hence, precipitation conditions were studied extensively. The departure of the precipitation from the 1951-1980 normal precipitation values at 57 National Weather Service (NWS) reporting stations was the principal criterion by which the precipitation was analyzed for its relative statewide severity.. The rank of the drought based on the precipitation departures is discussed in a separate section in this chapter. Long-term droughts contain dry periods interspersed with short wet periods. In this analysis, the driest 3-, 6-, and 12-month periods, along with the warmest summer month occurring within the drought, were analyzed.

Temperature conditions were also studied, and their departures were computed using the 1951-1980 normals for 46 NWS reporting stations during the drought period. The warmest 1-month and driest 12-month periods were analyzed.

The temperature data, in the form of average mean monthly and annual temperatures, were used in computing potential evapotranspiration. Evaporation data from those four reporting stations in Illinois with class A evaporation pans were also investigated. Total evaporation and wind movement were computed on a monthly basis. Lake evaporation can be estimated using pan evaporation data.

Wind data collected from seven first-order stations in and around Illinois during the drought period were compiled and examined. Departures from average wind speed and mean prevailing direction were computed, along with the number of days with gusts greater than 20, 30, and 40 mph. These wind data aid in the interpretation of the climatic conditions associated with the 1980-1981 drought. Wind information was also important in the investigation of those months with blowing dust, a problem in 1981.

Precipitation Conditions

The temporal and spatial characteristics of the precipitation during the drought of 1980-1981 conformed, in many respects, to those of previous droughts that have occurred in Illinois during this century. The inverse relationship between mean annual precipitation and drought severity in Illinois is well documented (Huff and Changnon, 1963). In Illinois, the average annual precipitation amounts increase as you move from the northern to the southern part of the state. The 1980-1981 drought was most severe in southern Illinois, where the highest average annual precipitation amounts occur. Below normal precipitation occurred in the southern half of Illinois in 12 of the 15 months in the drought. In the February 1980 through April 1981 drought period, precipitation statewide averaged above normal in August 1980, September 1980, and April 1981, although amounts in the southern third of Illinois were near or below normal for these 3 months.

The driest 6-month period (October 1980-March 1981), driest 12-month period (April 1980-March 1981), and total 15-month drought all had their lowest percent of normal precipitation in southwest, west-southwest, and southeast crop districts of the state (figure 2). As shown in figures 3 and 4, the precipitation patterns of the drought's warmest month (July 1980) and the driest 3-month period (January-March 1981) show their greatest departures in the central and western districts, not in the south. [See crop district locations in figure 6.]

The heavy precipitation that occurred in April in the northern two-thirds of Illinois signaled the end of the drought. The southern Illinois drought ended suddenly with record-breaking above normal precipitation across the state in May. Southern Illinois received between 8 and 14 inches of rain in May 1981.

The geographical placement of the lowest amount of precipitation found in western and southwestern Illinois (figure 2c) fits well with that for other 12-month droughts. Although dryness was experienced in northern Illinois during this period, near or above normal precipitation for the entire period is indicated. This has occurred in several past droughts (Huff and Changnon, 1963).

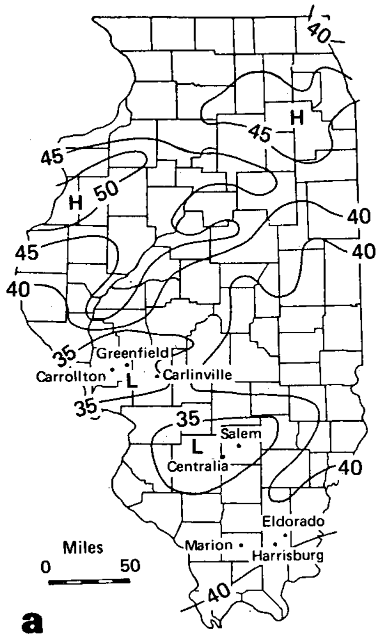
The driest 6-month period in the drought (October 1980-March 1981) has small areas of dryness (60 percent of normal precipitation) in the northwest and northeast districts (figure 2f), but large areas with 60 percent and less exist in the west, southwest, and east districts. The geographic distribution of the areas of lowest precipitation does not show the typical decrease in severity, from southwest to northeast, found with most other 6-month droughts. In general, the entire state was affected by dryness during this 6-month period.

The driest 3-month period of drought (January-March 1981) has a pattern (figure 4) indicating a small core of dryness in the northwest, a large dry area in the southwest, and a large dry area in the northeast and east districts. The geographic distribution of the driest areas generally follows the typical pattern of other 3-month droughts. The entire state experienced a precipitation deficiency during this driest 3-month period.

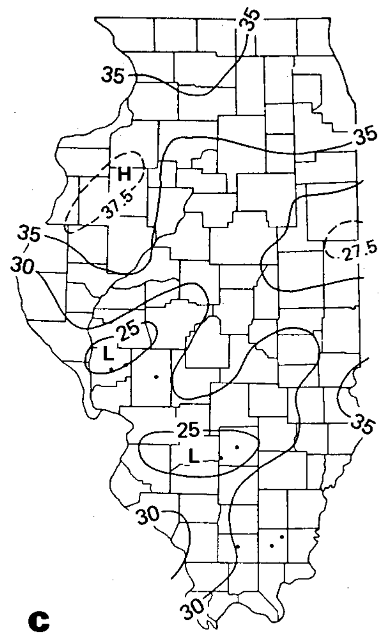
Temperature and Potential Evapotranspiration

Temperature departures for the driest 12-month period (figure 5) indicate that the greatest above normal departures occurred in the dry southwest and west districts. The greatest below normal temperature departures were in northwest and northeastern Illinois districts, where precipitation was near normal to above (figure 2d). Except for a small area of near normal temperatures in the southwest, there is the expected inverse correlation between precipitation amounts and temperatures during this 12month drought period.

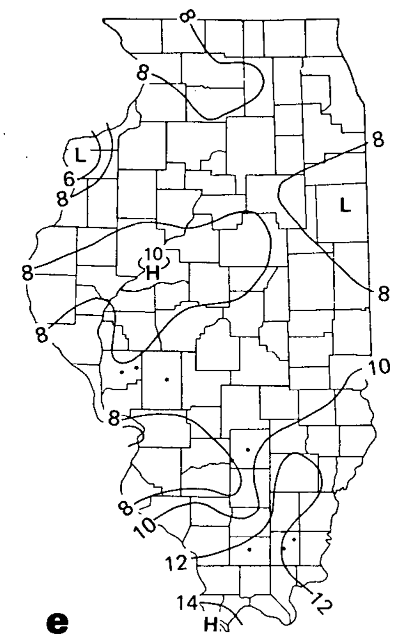
The July 1980 temperature departures (figure 3c) occurred in the cores of lowest percentages of normal precipitation (figure 3b). Conditions in July 1980 were selected for presentation because of the extensive damages from the heat wave conditions which persisted in Illinois and much of the Great Plains during this month. The greatest economic loss from the 1980-1981 drought in central Illinois occurred during this month. The combination of high temperatures and lack of rainfall greatly reduced crop yields in central Illinois and stressed humans and livestock in many areas of the state.



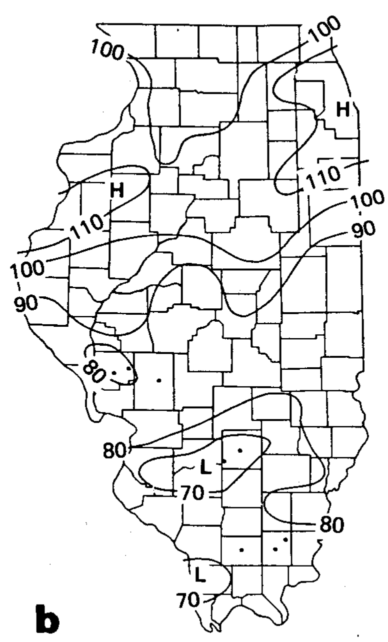
Precipitation in inches for
February 1980 – April 1981
Drought period



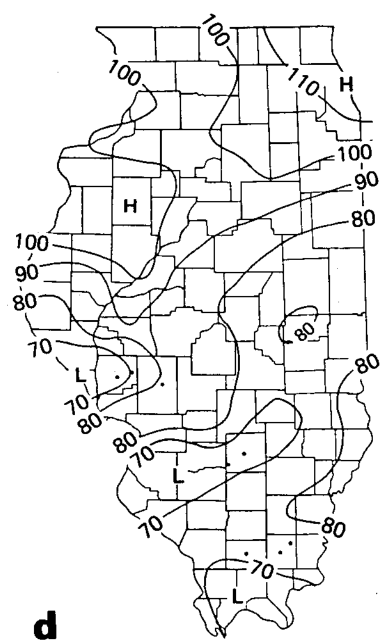
Precipitation in inches for
April 1980 – March 1981
12-month period



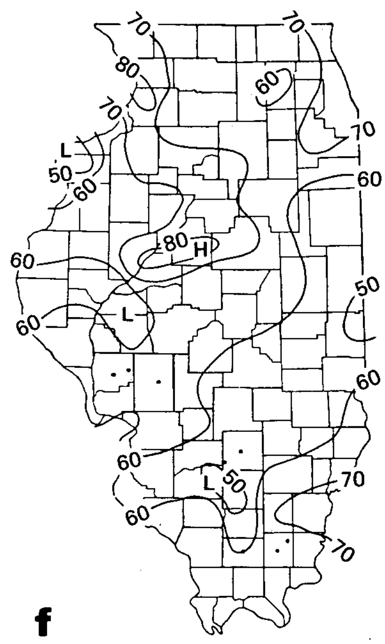
Precipitation in inches for
October 1980 – March 1981
6-month period



Percent of normal precipitation for
February 1980 – April 1981
(based on 1951-1980 normals)
Drought period

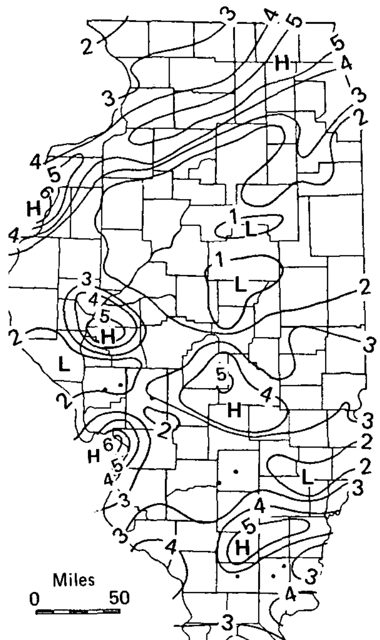


Percent of normal precipitation for
April 1980 – March 1981
(based on 1951-1980 normals)



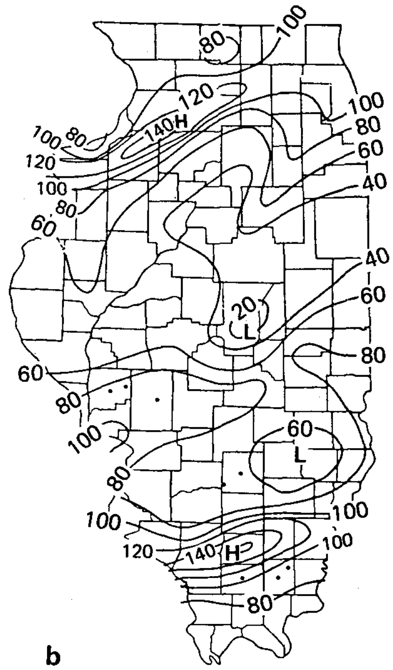
Percent of normal precipitation for
October 1980 – March 1981
(based on 1951-1980 normals)

Figure 2. Precipitation patterns for driest 6-month period, driest 12-month period, and total drought period



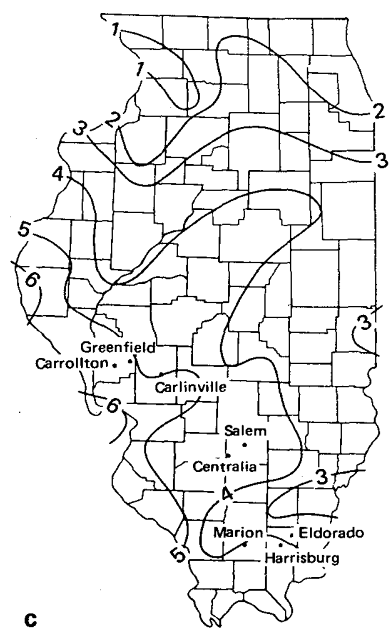
a

Precipitation in inches for July 1980



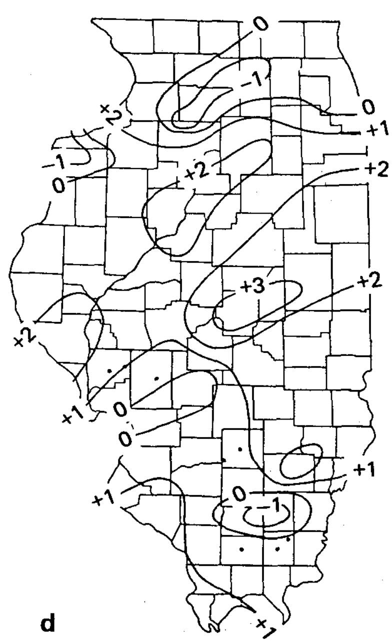
b

Percent of normal precipitation
for July 1980
(based on 1951-1980 normal)



c

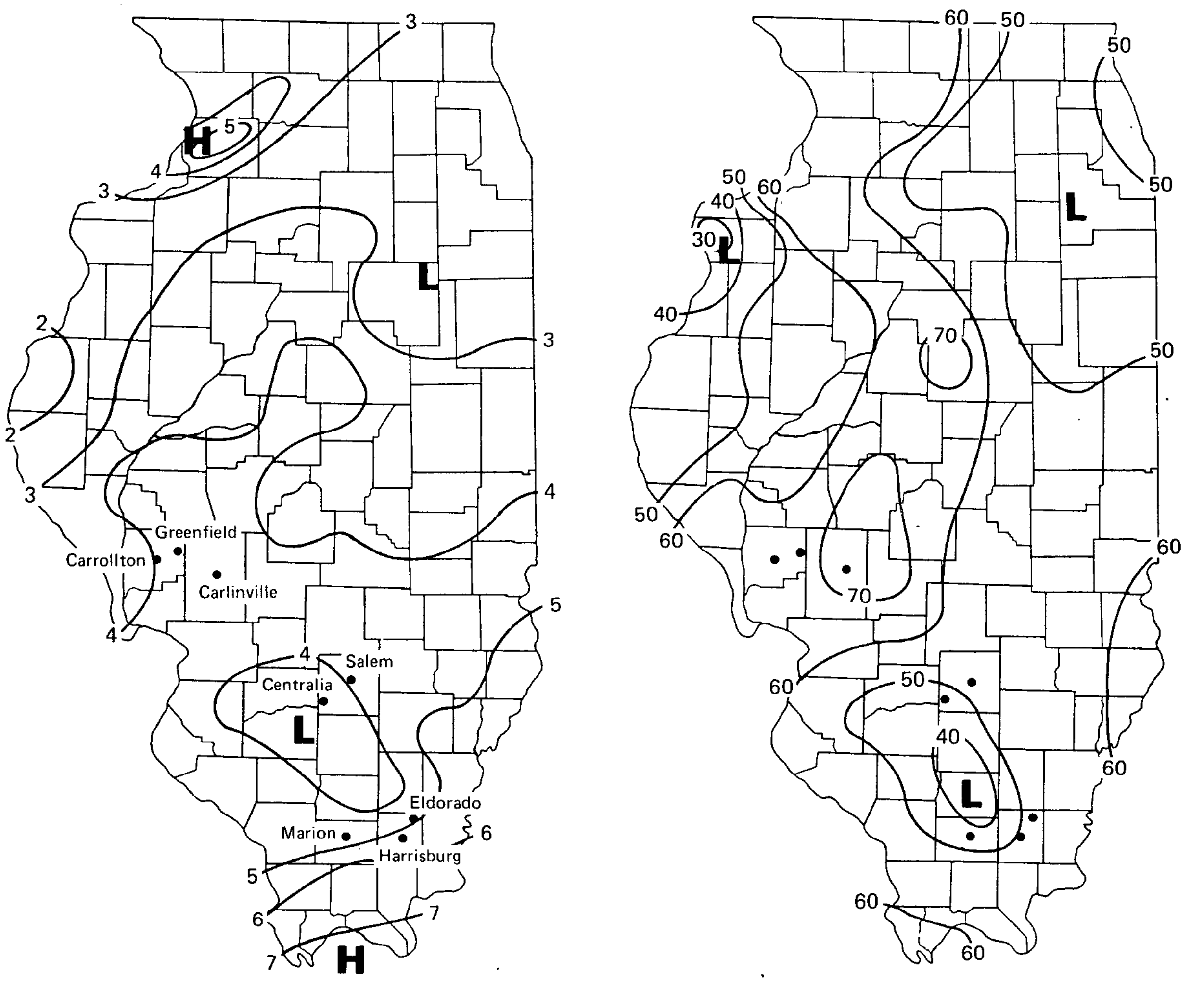
July 1980 departure from
average mean temperature
(based on 1951-1980 normal)



d

Departure for July 1980 of potential
water deficit (inches) from normal
(difference between normal deficit
and July 1980 deficit)

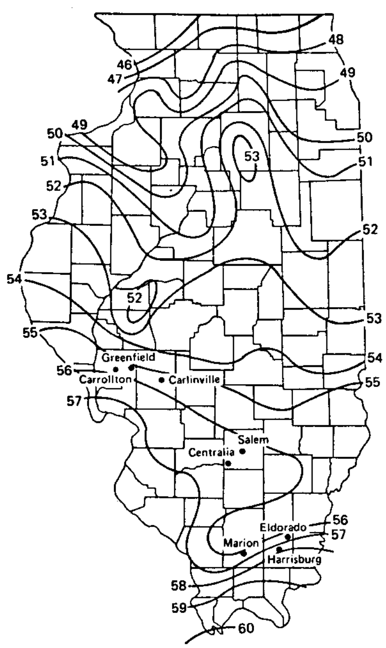
Figure 3. Precipitation, temperature, and water surplus/deficit patterns for July 1980



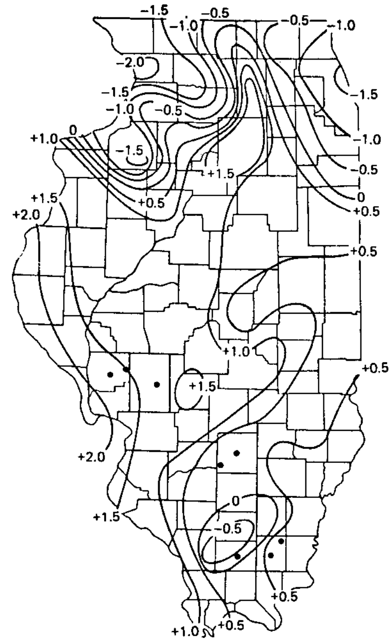
a. Precipitation in inches for January 1981–March 1981
3–month period

b. Percent of normal precipitation for January 1981–March 1981
(based on 1951–1980 normals)

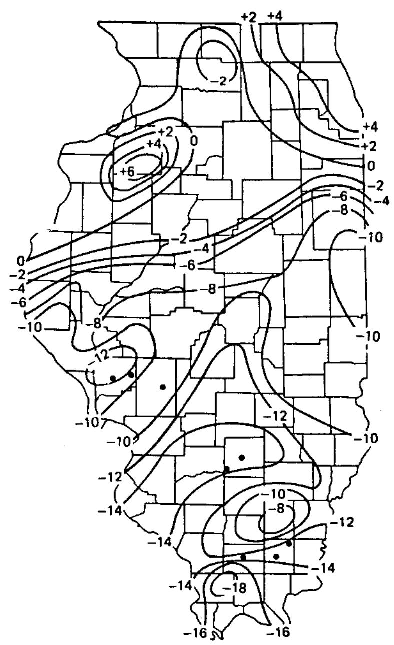
Figure 4. Precipitation patterns for driest 3-month period of the drought



a. April 1980–March 1981, 12–month average mean temperature in °F



b. April 1980–March 1981 departure from 12–month average mean temperature, °F (based on 1951–1980 normals)



c. Departure for April 1980–March 1981 of potential water surplus (deficit) from normal 12–month surplus (Difference between normal surplus and April 1980–March 1981 surplus (deficit) in inches)

Figure 5. Temperature and water surplus/deficit patterns for driest 12-month period of the drought

Potential evapotranspiration (PE) was analyzed for July 1980 and for the driest 12-month period. PE is defined as the water extracted from the supply of soil moisture by an extensive short green crop cover, completely shading the ground and never short of water. It has been shown (Jones, 1966) that the Hamon PE Equation in the form below is a suitable means for computing PE in Illinois:

$$PE = 0.0055\ D^2\ p_T$$

PE is the daily potential evapotranspiration in inches; 0.0055 is the coefficient; D is the day length factor in units for a standard 12-hour day; and p_T is the saturation vapor density in grams per cubic meter of the daily mean temperature.

The difference between precipitation and computed PE is termed "potential water surplus" if precipitation is greater, or "potential water deficit" if the PE is greater (Jones, 1966). These terms quantify the amount of moisture available in excess (surplus) of the maximum needs of evapotranspiration, or below them (deficit).

In most years a potential water deficit is normal in Illinois in July. However, in July 1980 the potential water deficit was in excess of the normal July deficit. The difference from the normal water deficit was computed (figure 3d), and it was determined that the greatest departures from normal occurred in central Illinois, with values 2 to 3 inches more than usual deficits.

The PE was also computed for a normal 12-month period and the driest 12-month period (April 1980-March 1981). The differences from the normal water surpluses and deficits were computed for this period (figure 5), showing the greater departures in the south and west sections.

Pan Evaporation and Wind Conditions

Evaporation data were available from four class A evaporation pans. These were located at Hennepin Power Plant (NW district), Urbana (East district), the Springfield Weather Service Office (WSW district), and Carlyle Reservoir (SW district). Monthly totals of evaporation from these pans and their departures from normal, along with wind movement data, were assembled for the drought period (table 1). Pan evaporation can be related to lake evaporation through the use of pan-to-lake coefficients, and computed values of lake evaporation can be applied to a wide range of Illinois water bodies. It must be noted, however, that evaporation from a specific lake can vary because of exposure, shape, depth, and other factors.

Pan evaporation data were available for most locales from April-October 1980 and April-May 1981, and normal monthly pan evaporation values were derived from Roberts and Stall (1966). As shown in table 1, the greatest above average evaporation occurred at Hennepin Power Station (NW district) in May 1980, with large departures in other months. These large above average departures do not correlate with other local climate conditions and are suspect as poor values.

The largest amount of evaporation occurred at Carlyle Reservoir (SW) in July 1980. This is in the area of greatest precipitation deficiency (figures 2 and 4). With the exception of May 1980, Carlyle Reservoir experienced above average evaporation throughout the drought period. An interesting comparison of the pan evaporation at Carlyle is between the April 1980 value of 4.84 inches (at the beginning of the drought period) and the evaporation of 7.02 inches recorded in April 1981 at the end of the drought period. The Carlyle site is located in that part of Illinois where the 1980-1981 drought was most severe, and the site experienced the greatest above average departure of evaporation for the drought period. Urbana and Springfield both experienced their largest amount of evaporation in July 1980, the same month the drought was most severe in central Illinois.

Table 1. Illinois Pan Evaporation Data

	Monthly total evaporation (inches)	*Departure from normal (inches)*	*Monthly total wind (miles/month)*
April 1980			
Urbana (E)	3.51	+0.20	1806
Carlyle Reservoir (SW)	4.84	+0.50	2397
May 1980			
Hennepin Power (NW)	8.85	+2.72	996
Urbana (E)	4.94	+0.01	1328
Carlyle Reservoir (SW)	5.99	−0.32	1558
June 1980			
Hennepin Power (NW)	6.55	−0.78	659
Urbana (E)	5.88	−0.22	1068
Springfield WSO (WSW)	7.57	−0.12	2142
Carlyle Reservoir (SW)	9.24	+2.04	2097
July 1980			
Hennepin Power (NW)	7.92	−0.02	836
Urbana (E)	6.75	+0.94	884
Springfield WSO (WSW)	9.23	+0.53	2203
Carlyle Reservoir (SW)	9.80	+1.42	1689
August 1980			
Hennepin Power (NW)	7.00	+0.06	802
Urbana (E)	5.22	−0.74	883
Springfield WSO (WSW)	7.15	+0.06	2109
Carlyle Reservoir (SW)	9.41	+2.42	1744
September 1980			
Hennepin Power (NW)	5.04	+0.16	790
Urbana (E)	3.59	−0.76	824
Springfield WSO (WSW)	5.65	+0.41	1731
Carlyle Reservoir (SW)	5.90	+0.61	1454
October 1980			
Hennepin Power (NW)			1538
Urbana (E)	3.35	+0.52	1055
Springfield WSO (WSW)	4.12	+0.59	1939
Carlyle Reservoir (SW)	4.38	+0.87	1837
April 1981			
Urbana (E)	4.13	+0.82	1852
Carlyle Reservoir (SW)	7.02	+2.68	2906
May 1981			
Urbana (E)	3.92	−1.01	1143
Springfield WSO (WSW)	6.36	+0.08	3141
Carlyle Reservoir (SW)	4.67	−1.64	1953

The average departures from normal evaporation (in inches) were determined to be:

Urbana (E)	+0.09 (April-October 1980, April 1981)
Carlyle Reservoir (SW)	+1.28 (April-October 1980, April 1981)
Hennepin Power Plant (NW)	+0.43 (May-September 1980)
Springfield (WSW)	+0.29 (June-October 1980)

As shown, Urbana experienced the lowest average departure of evaporation for the drought period. However, the Hennepin values are suspect and might realistically be comparable to those for Urbana rather than to those for Springfield.

One of the more unusual aspects of the drought of 1980-1981 was the blowing dust that occurred in many parts of Illinois in March and April of 1981 (Changnon, 1982). Record numbers of blowing dust days occurred in central and eastern Illinois. Soil moisture at this time was very low due to a dry fall, winter, and March, and much valuable topsoil was lost. The worst conditions occurred where fall plowing is most prevalent, an area of prairie soils particularly susceptible to wind erosion.

Average seasonal wind speed and extreme wind data for the drought period were investigated for seven first-order stations (table 2). Wind speeds averaged over the entire 15-month drought period indicated that St. Louis had the largest departure above normal: 1.3 mph. Peoria had the largest below normal departure: 0.9 mph. Springfield experienced its largest above normal departure in April 1981, during the period of extreme blowing dust. In six of the seven stations under study, the largest number of days with gusts greater than 20 and 30 mph occurred in April 1981, also coinciding with the period of blowing dust. The higher average speeds and gustiness of surface winds at the end of the drought (spring 1981) reflected the intensity of the driest most intense part of the drought.

Rank of Drought

Driest 3-Month Period, January-March 1981

An important part of the assessment of the 1980-1981 drought was to examine the relative climatic severity of the 3-month, 6-month, and 12-month periods with the lowest precipitation. The driest 3-month period, based on the lowest 3-month precipitation values during the 15-month drought, was the period ending in March 1981. The statewide average precipitation was 55 percent of normal for this 3-month period. Compared to the 19 prior 3-month droughts during the 1906-1981 period, this 3-month drought was found to rank as the 19th driest drought (based on percent of normal precipitation) during this 75-year period (Huff and Changnon, 1963). Its relative rank and position in time can also be noted in figure 1. The worst 3-month drought in Illinois on record was one ending in February 1931, and it had a statewide average of 36 percent of normal precipitation.

The lowest percent of normal rainfall in the 3-month 1981 drought occurred at Benton with a value of 33 percent of normal. The value of 33 percent at Benton ranked as the 5th lowest 3-month value there. Other greater 3-month departures at Benton included 20 percent in the 1941 drought, 25 percent in 1908, 27 percent in the 3-month drought ending in 1914, and 31 percent in the 1953 drought. The lowest 3-month point value ever recorded in Illinois was 11 percent of normal in the 1953 drought.

Temporal aspects of the January-March 1981 drought are of interest. It occurred 4 years after the 3-month drought in the winter of 1976-1977. This 4-year difference between droughts

Table 2. Seasonal and April 1981 Wind Conditions at Selected Illinois Locations

	Average speed (mph)	*Departure from normal (mph)*	*Number of days with gusts*		
			≥20 mph	*230 mph*	*≥40 mph*
Chicago O'Hare					
Spring 1980	11.4	−0.1	42	3	0
Summer 1980	8.0	−0.5	25	3	1
Fall 1980	9.4	−0.4	25	1	0
Winter 1980-81	11.0	−0.3	40	3	0
Spring 1981	11.6	+0.1	45	5	0
April 1981	12.2	+0.1	15	2	0
Evansville, IN					
Spring 1980	9.3	−0.1	29	1	0
Summer 1980	7.3	+0.3	14	1	0
Fall 1980	7.5	+0.1	13	1	0
Winter 1980-81	9.0	−0.4	15	2	0
Spring 1981	9.1	−0.4	35	3	0
April 1981	10.5	+0.6	16	2	0
Peoria, IL					
Spring 1980	10.0	−1.5	32	0	0
Summer 1980	7.9	−0.4	21	3	1
Fall 1980	8.9	−0.3	20	1	0
Winter 1980-81	10.4	+0.7	24	2	0
Spring 1981	10.6	−0.9	35	4	0
April 1981	11.9	−0.2	18	3	0
St. Louis, MO					
Spring 1980	11.4	+0.4	30	7	0
Summer 1980	10.4	+2.3	29	0	0
Fall 1980	10.2	+1.3	25	1	0
Winter 1980-81	11.9	+1.4	35	2	0
Spring 1981	11.7	+1.0	41	13	0
April 1981	13.6	+1.7	17	7	0
Rockford, IL					
Spring 1980	11.5	−0.5	42	1	0
Summer 1980	9.0	−0.2	25	3	0
Fall 1980	10.0	+0.4	27	2	0
Winter 1980-81	11.6	+1.1	37	3	0
Spring 1981	11.9	+0.9	46	7	0
April 1981	13.0	+1.4	19	6	0
Moline, IL					
Spring 1980	11.2	−0.3	37	5	0
Summer 1980	8.4	+0.3	26	6	3
Fall 1980	10.1	+0.7	30	3	0
Winter 1980-81	11.2	+0.4	32	0	0
Spring 1981	11.8	+0.3	43	7	1
April 1981	13.3	+1.1	15	5	1
Springfield, IL					
Spring 1980	11.6	−1.4	42	3	0
Summer 1980	8.9	+0.1	17	1	0
Fall 1980	9.4	+1.3	11	0	0
Winter 1980-81	12.7	+0.0	46	1	0
Spring 1981	13.8	+1.4	60	9	0
April 1981	15.7	+2.2	24	6	0

Table 3. Precipitation in Driest 3-Month Period (January-March 1981)

Crop district	Actual precipitation (inches)	Departure from normal (inches)	Percent of normal	Return frequency (years)
Northwest	3.2	–2.0	61	2
Northeast	3.2	–2.6	55	3
West	3.3	–2.8	54	2
Central	3.6	–2.6	58	2
East	3.2	–3.1	51	3
West southwest	4.4	–2.2	66	
East southeast	3.8	–4.3	47	4
Southwest	5.0	–5.1	48	3
Southeast	5.2	–5.5	48	3

Note: Normal values are based on 1951-1980 values

is relatively long for 3-month droughts, occurring only 35 percent of the time. That is, 65 percent of the time the duration between 3-month droughts has been less. The ending of the drought in March is in a different month than that for most 3-month droughts. Only 6 percent of past 3-month droughts ended in March, with most terminating in the October-February period. The time of year with the highest probability for the ending of 3-month droughts in southern Illinois, where the 1981 drought was most severe, is the fall. The time of year with the highest probability in central and northern Illinois is fall-winter.

Various crop district statistics relating to the precipitation in the driest 3-month period appear in table 3. They show that the actual precipitation ranged from as low as 3.2 inches (northern districts) up to a maximum of 5.2 inches in the southeast. This latitudinal distribution (lowest in the north and greatest in the south) is typical for this season of the year. However, the departure from normal and the percentages for the southwest and southeast districts indicate that southern Illinois values were more extreme than elsewhere in the state. Percentages were less than 50 percent of normal in the east, southwest, and southeast. As shown in table 3, values this low are expected to occur once every 3 to 4 years. The Huff-Changnon (1963) study of Illinois droughts indicated that the severity of 3-month droughts in Illinois is greater in southern Illinois than in northern Illinois. The 2-year return interval pattern developed by Huff and Changnon (1963) shows that the value expected once in 2 years in extreme southern Illinois is 46 percent of normal precipitation, whereas 64 percent of normal is the 2-year value in northeastern Illinois. The frequency values of table 3 and the statewide rank (19th of 19) of the driest 3-month period during the drought of 1980-1981 reveal it was not a very severe event.

Driest 6-Month Period, October 1980-March 1981

The driest 6-month period during the 15month drought began in October 1980. The statewide average precipitation departure from normal was 64 percent. Comparison of this with prior 6-month droughts in Illinois shows that it ranked as the 13th worst among the 17 6-month droughts of the 1906-1981 period (Huff and Changnon, 1963). The greatest point deficiency occurred at Nashville, which had a 6-month value of 48 percent of normal (Paris had 50 percent and Hoopeston 52 percent). The lowest point value on record anywhere in Illinois in another 6-month drought was 26 percent in 1934. Greater departures for 6-month droughts in Nashville include 34 percent in the 1953 drought, 39 percent in the 1930 drought, 40 percent in the 1936 drought, and 45 percent in the 6-month drought ending in 1940.

Table 4. Precipitation in Driest 6-Month Period (October 1980-March 1981)

Crop district	*Actual precipitation (inches)*	*Departure from normal (inches)*	*Percent of normal*	*Return frequency (years)*
Northwest	8.0	−3.7	68	3
Northeast	9.0	−3.4	72	2
West	8.5	−4.4	66	4
Central	9.1	−4.2	68	3
East	7.5	−6.0	56	7
West southwest	8.9	−5.2	63	4
East southeast	11.2	−5.2	67	4
Southwest	9.4	−9.8	49	10
Southeast	11.6	−8.6	55	6

Note: Normal values are based on 1951-1980 values

The temporal aspects of the driest 6-month period are of interest. Its ending in March exactly fits the climatology of prior 6-month droughts. Seventeen percent of all 6-month droughts ended in March in southern Illinois, with 20 to 25 percent of those in northern Illinois ending in March. Thus, the 6-month drought ending in March 1981 was a typical 6-month drought. It had been slightly less than 4 years since the ending of the 6-month drought during the fall-winter of 1976-1977. Approximately 60 percent of the time the duration between 6-month droughts is less than four years.

The pattern of the driest 6-month period of the 1980-1981 drought is revealed in figure 2. Historical studies of 6-month droughts in Illinois show a great tendency for them to be most severe and most frequent in southwestern and southern Illinois (Huff and Changnon, 1963). Table 4 shows that the two districts with the greatest departures from normal were the southwest and southeast districts with 49 and 55 percent of normal, respectively. Although their area average precipitation values were higher than most of the other district averages, the normal precipitation in the south during the cold season (October-March) is much greater than elsewhere, as reflected in the sizes of the departures shown in table 4. As shown in table 4, all districts of the state had 6-month values that had return periods of 2 years or more.

The climatology of 6-month Illinois droughts indicates a greater severity in southern Illinois. For example, the value expected once every 2 years in southeastern Illinois is 68 percent of normal precipitation, as compared to 86 percent in northeastern Illinois (Huff and Changnon, 1963). The 5-year return interval value expected in southeastern Illinois is 55 percent of normal, as compared to 64 percent in northeastern Illinois. Thus, 6-month droughts in extreme southern Illinois are much more severe from a precipitation standpoint. The greater severity of the 6-month drought in extreme southern Illinois is revealed in the return interval values shown in table 4. The 9.4-inch value in southwestern Illinois, which was 49 percent of normal, ranked as an event apt to occur only once every 10 years. The value in southeastern Illinois was a 6-year event and that in eastern Illinois a 7-year event; elsewhere the 6-month values rated as 2-, 3-, or 4-year events.

The driest 6-month period of the 1980-1981 drought was drier than the driest 3-month and 12-month periods, as will be seen. In most aspects, the driest 6-month period in the 1980-1981 drought was very typical of past 6-month droughts in Illinois, being most severe in extreme southern Illinois and occurring totally within the colder half-year. Although it was more severe than the driest 3-month and 12-month portions of the 1980-1981 drought, it still was not an exceptional event, ranking as the 13th worst 6-month drought in the past 76 years.

Driest 12-Month Period, April 1980-March 1981

Evaluation of the driest 12-month period in the 1980-1981 drought revealed that the precipitation statewide was 81 percent of normal. This value ranks this 12-month period as the 15th most severe among the 15 12-month droughts identified in the 1906-1981 period. In other words, it was not a very severe 12-month drought. The 12-month dry period in 1976-1977 also was not very severe (80 percent of normal precipitation). The most severe 12-month drought on record (1933-1934) had a statewide average of 58 percent of normal.

The driest portions of the state in 1980-1981 were in southwestern Illinois at Belleville and Nashville. The rainfall at these stations – 23.05 and 23.47 inches, respectively – ranked as 63 percent of their 12-month normals. Both of these stations had lower values in 5 prior 12-month droughts, including 46 percent in the drought ending in 1954, 52 percent in 1931, 55 percent in the 1936 drought, 56 percent in the 12-month drought ending in 1940, and 59 percent in 1941. The lowest point value in Illinois during any 12-month drought was 41 percent in 1931.

Examination of the termination times of 12-month droughts in Illinois reveals that the most common time of termination is the May-September period, with 10 of 13 ending in the warm season. Hence, the termination in March 1981 indicated a rather unusual dry 12-month period. There were 3.5 years between the end of the 1976-1977 12-month drought and the beginning of this 12-month drought in 1980. This separation is very near average (Huff and Changnon, 1963).

As shown in figure 2, the most severe portion of the driest 12-month period ending in March 1981 occurred in the southwestern portions of Illinois where precipitation values were less than 70 percent of normal. This is the area where past 12-month droughts have typically been most severe (Huff and Changnon, 1963). Examination of the area1 frequency of severe 12-month droughts by crop districts shows that 7 of the prior 12 12-month droughts were severe in the west-southwestern, southeastern, and southwestern crop districts. Two of these 3 districts were affected by the 1980-1981 drought. In that sense, the pattern and areas of greatest severity of the 1980-1981 drought were typical. Another pattern feature of the 1980-1981 drought (from a 12-month standpoint) was typical of prior droughts: the extension of the drier areas from out of Missouri and Illinois, denoting occurrences that were part of larger more extreme droughts to the west and southwest of Illinois (figure 2).

The crop area mean 12-month precipitation values of each crop district appear in table 5, along with their departures from normal. These are based on 30-year normals, 1951-1980. Inspection of the 12-month precipitation totals and their departures (table 5) reveals the near normal to above normal values in central and northern Illinois, with a confinement of the large negative departures to the southern half of the state. The departures, as a percent of normal, show that the southwest and southeast districts (each with 71 percent) were most severely affected. These percentage departures ranked as events expected to occur at least once in 7 years (Huff and Changnon, 1963). Return interval analysis based on prior droughts of this century indicated that the once in 2-year events were least severe in northeast Illinois. There 80 percent is a 2-year value, whereas 74 percent is the 2-year value in the southern end of the state.

Table 5. Precipitation in Driest 12-Month Period (April 1980-March 1981)

Crop district	*Actual precipitation (inches)*	*Departure from nomal (inches)*	*Percent of normal*	*Return frequency (years)*
Northwest	37.2	+2.2	106	
Northeast	38.3	+5.2	112	
West	37.1	+0	100	
Central	35.8	−0.2	98	
East	33.5	−2.5	93	
West southwest	30.8	−6.5	82	3
East southeast	33.1	−6.6	83	3
Southwest	30.6	−12.5	71	7
Southeast	31.5	−12.5	71	7

Note: Normal values are based on 1951-1 980 values

Thus, 12-month droughts, as with 3- and 6-month droughts in Illinois, are a) more severe on the average in extreme southern Illinois, and b) most often in the extreme southern Illinois and west southwest districts. In most respects, the driest 12-month period of the 1980-1981 drought typified past 12-month droughts but was not exceptionally severe, either on a point or a regional basis.

Chapter III. Meteorological Conditions during the 1980-1981 Drought

Gary L. Achtemeier and Steven D. Hilberg

Introduction

Similarity to Past Droughts

Illinois had no serious long duration (1-year or longer) droughts between the mid-1950's and 1975. However, following this 20-year period, there have been two moderate droughts in the state and in adjacent parts of the Midwestern agricultural areas, in 1976-1977 and 1980-1981. The 1980-1981 drought, the focus of this report, covered the southern half of Illinois. It began during February 1980 as dry weather extended southeastward from the northern High Plains into the Middle West (Dickman, 1980). The cool, dry spring was followed by a hot, dry summer as a severe heat wave spread from the southern plains (Wagner, 1981) into the Middle West upon a circulation pattern that was a close match to the high pressure centers aloft described by Namias (1955) as associated with extensive summertime drought over the United States. Klein (1953) also associated the upper level anticyclones with dryness and intense heat.

Following a brief interlude of above normal rainfall in August and September 1980, the dryness resumed from October 1980-January 1981. February's near normal rainfall was followed by an unseasonably dry March. Finally, copious rainfall in May 1981 brought an end to the drought over most of the affected areas.

The 1980-1981 drought consisted of prolonged dry periods separated by periods of near or above normal rainfall. The welcome wet periods kept the drought from becoming more severe but were insufficient to relieve the drought. This sequence of prolonged dry spells separated by wet spells is typical of other droughts in Illinois (Huff and Changnon, 1963).

Scope of This Investigation

The 15-month drought spanned five seasons and it was supposed that there were several contributing meteorological factors. Therefore, the meteorological analysis included investigations of motion scales ranging from planetary waves to cold fronts. The meteorological study was divided into two parts. The first dealt with a) the movements of air masses in response to planetary scale circulations; b) their persistence; and c) the relationship between the circulation and precipitation during the drought. Subsynoptic scale circulations were the subject of the second section of the study. The meteorology of the July 1980 heat wave was also examined in detail, and precipitation-producing weather systems prominent during the wet periods were compared with dry period rain systems. Frontal frequencies were also compared with historical frequencies.

The Drought of 1980-1981 in Relation to Planetary Scale Circulations

Long Waves

In the temperate latitudes (30-50° north), which include the Middle West, the prevailing wind direction is westerly. Superimposed upon this westerly flow are a number of disturbances which cause the winds to depart from their mean course and blow from some other direction, usually from the northwest or southwest depending upon the location of the wind measurement relative to the disturbance.

The meandering course of the westerly wind flow through and around the disturbances, as viewed on a hemispheric weather map or on satellite film strips, gives the impression of a series of superimposed waves of varying amplitudes and wavelengths. The jet stream, a current of high speed air separating cold polar air masses from warm tropical air masses, is pushed southward at the wave troughs and is pushed northward at the wave ridges. The location and orientation of major storm tracks closely correspond to those of the jet stream. Further, precipitation is more probable in those areas ahead of the troughs, while those areas behind the troughs and in the ridges tend to be drier due to the lack of precipitation-producing cyclones (Klein, 1949).

Although often accompanied by storminess and precipitation, the long waves are most noted for the movement of large air masses. The moisture, temperature, and stability of these air masses determine the synoptic weather conditions that prevail over any given area. The movement and dynamics of long waves have been documented by Rossby (1939). The time it takes for the passage of long waves is about one week. However, Rossby has shown that under certain not-too-infrequent wind conditions the eastward movement of the long waves may be retarded to the extent that the waves become stationary or move westward. When these conditions occur, the long wave and its associated air masses may stagnate over prolonged periods of time.

The translation speed for long waves of a given wavelength and at a given latitude is a function of the mean zonal wind speed of the current flowing through the wave. The mean zonal wind is a function of the north-south temperature contrasts (baroclinicity). If the zonal wind blows at a certain critical speed, the wave will become stationary. The likelihood for long waves to become stationary is greatest in both winter and summer when the baroclinicity is relatively constant, and is least in the fall and spring when the baroclinicity is changing rapidly. Dry spells occurring in the fall and spring are frequently interrupted by stormy periods as a stationary long wave breaks up and is either re-established or is replaced by a long wave of differing wavelength for which the baroclinic conditions favor its becoming stationary.

Dry Spell Air Masses That Accompany Long Waves

Several types of air masses accompany dry spells caused by long waves. Type 1W is a cold, dry polar air mass. It is driven from its source region in central Canada into the Middle West by strong northwesterly flow when a long wave locates with the ridge to the west and the trough to the east of Illinois. When the wave has large amplitude, the storm track is pushed far to the south of Illinois and the likelihood of significant precipitation is greatly decreased.

Type 2W, a second winter air mass, moves into the Middle West when the long wave is positioned as with the Type 1W air mass but with a smaller wave amplitude. Air of Pacific origin, dried out by crossing the western mountain ranges and warmed by descent along the leeward slopes, brings warm, dry weather conditions into the Middle West. The storm track is usually through the northern Middle West, a condition that is unfavorable for significant precipitation in Illinois.

A hot, humid air mass (Type 1S) associates with summer dry spells when a long wave becomes stationary with troughs located along the west and east coasts and the ridge located through the Middle West (Tannehill, 1947; Klein, 1953). The storm track is pushed further to the north than normal, and the cold fronts that pass through Illinois are weaker than normal (Huff and Vogel, 1977). Subsidence within the ridge aloft dries the air mass and increases its stability. Warm dry air advected eastward from the High Plains overruns the humid air masses and confines them

Table 6. Monthly Normals and 1980-1981 Mean Precipitation for the Southern Two-Thirds of Illinois (Drought Area) and the Northern Third of Illinois*

(Precipitation is in hundredths of an inch)

	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Normal south	217	329	413	430	442	381	326	334	285	272	243	232	217	329	413
1980-81 south	130	412	229	276	4.51	270	453	444	221	145	154	38	232	134	487
Normal north	134	251	371	372	423	398	319	349	266	212	184	172	134	251	371
1980-81 north	120	152	309	303	417	377	757	566	207	82	250	12	222	60	569

**As indicated in figure 6*

to a shallow layer near the ground. The dry air dispels cloudiness, and the shallow surface layer is heated to hot temperatures. These conditions with high stability and weak frontal systems are unfavorable for significant rainfall.

A second summer dry spell air mass (Type 2S) flows into the Middle West when the long wave pattern is similar to the winter dry spell pattern, i.e., a ridge to the west and a trough to the east of Illinois. Cool dry air masses of Canadian origin keep Gulf moisture well to the south of Illinois. The Canadian air mass is usually too dry to yield significant rainfall.

Data for the Long Wave Study

The monthly precipitation data for the southern two-thirds of Illinois (table 6) show prolonged dry spells that were temporarily relieved by months with normal or above normal precipitation. The stormy periods, lasting for a few days to a week, often produced the bulk of precipitation for the wet months. One week is the typical passage period for planetary waves. Thus, it was decided that the week is the best time frame for the analysis of the influence of long waves upon precipitation during the 1980-1981 drought.

The data used for this study consisted of the summaries of weather and circulation published monthly in *Monthly Weather Review* and the published monthly and annual climatological data. The 5-day mean 700 mb circulation maps were ideal for identifying stationary long waves because the faster-moving short waves that produce low pressure systems, frontal systems, and storminess were smoothed. Progressing long waves also tended to be filtered from these charts.

The weekly precipitation maps corresponding to the 5-day 700 mb circulation maps were used to calculate mean rainfall for the southern two-thirds of Illinois, and the 7 crop districts affected are shown in figure 6.

The weekly rainfall values were then summed to get monthly averages, which in turn were "calibrated" against monthly averages taken from the climatological data. Finally, the weekly normal precipitation was interpolated from a plotted curve of the monthly normal precipitation. These weekly normals were then used with the actual 1980-1981 weekly precipitation to calculate the weekly precipitation departures from normal.

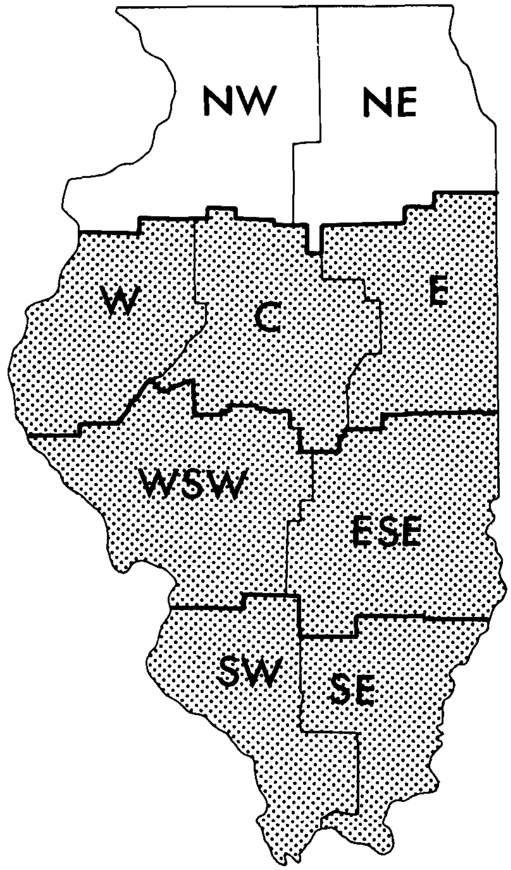


Figure 6. Crop districts of Illinois affected by the 1980-1981 drought

Results: Duration of Long Wave Circulation Types

The locations, frequencies, and persistences of long waves can be used to identify circulations associated with the drought. The weekly 700 mb circulation maps were used to classify the circulation over the central United States during the peak of the Illinois drought (April 1980-March 1981) into four categories: 1) stationary long wave number 6 (LW-6); 2) stationary long wave number 4 (LW-4); 3) transition; and 4) other. The waves LW-4 and LW-6 were treated separately because they appeared frequently during the drought.

Wave number 6 means that six waves can fit around the northern hemisphere. Likewise, wave number 4 means that four waves can fit around the hemisphere. The calculations of Rossby (1939) show that for the long waves to become stationary, the speed of the mean wind flow must be stronger for LW-4 than for LW-6. Thus, stationary LW-4 is more likely to occur during the cold season when the baroclinicity is stronger. Stationary LW-6 is more likely to occur during the warm season with weaker baroclinicity and weaker zonal wind.

An example of LW-6 is shown in figure 7a. The ridge was located over the central United States and the troughs were located near the east and west coasts. (This pattern was identified by Namias [1955] as associated with the 1952-1954 drought over much of the central United States.)

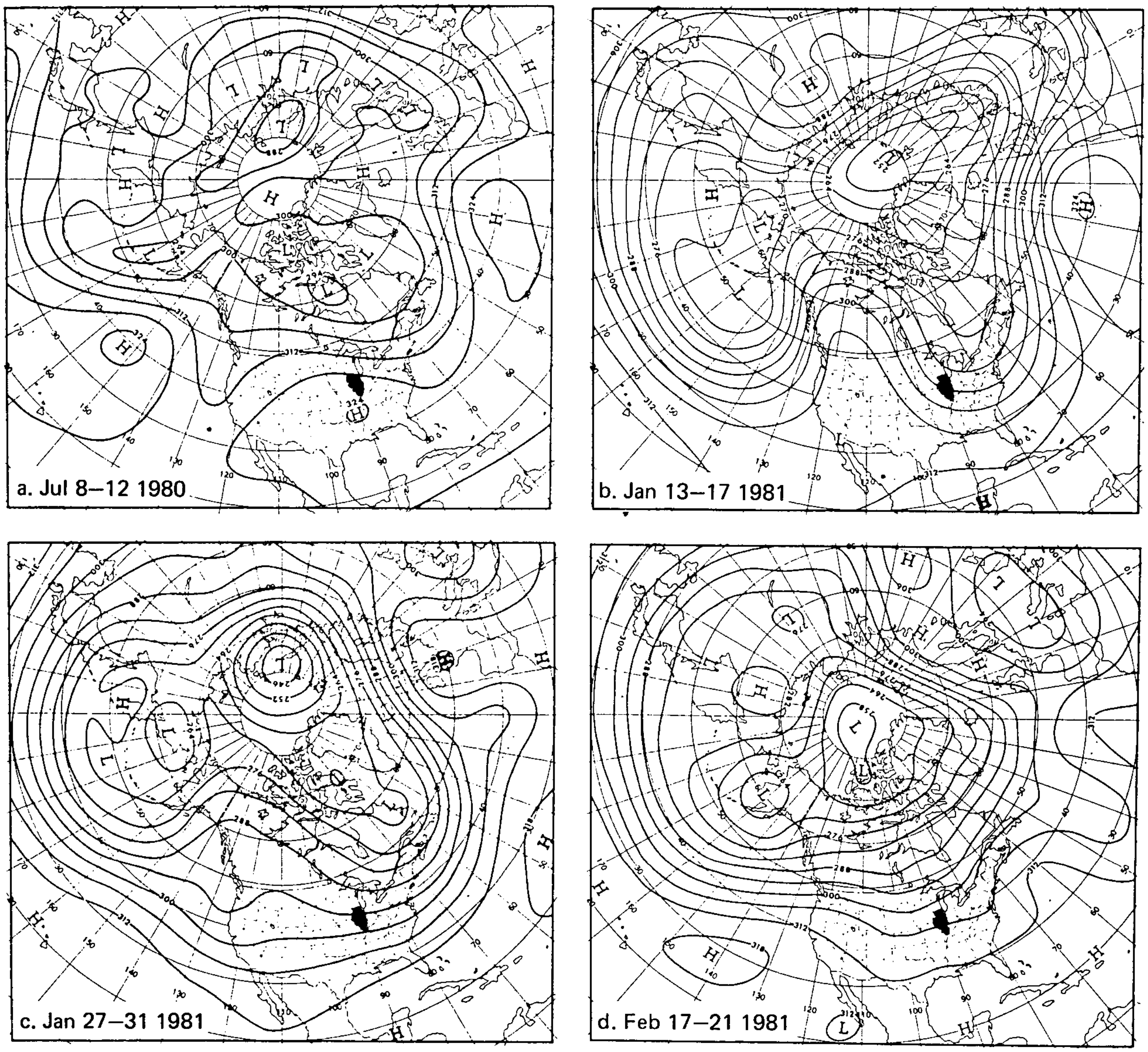


Figure 7. Examples of the four circulation types defined in the 1980-1981 drought analyses: a = LW-6; b = LW-4; c = transition; d = other

The wave became established during the third week of April 1980 and lasted through the first week of May (22 days). With the exception of a brief breakdown near the end of June, LW-6 was entrenched from the last week of May through the end of July. A total of 12 weeks during the spring and summer of 1980 were thus classed as having circulation influenced by LW-6.

The LW-4 pattern with the ridge to the west and the trough to the east placed Illinois within northwesterly flow aloft (figure 7b). Both cold season dry air masses were observed during the 13 weeks of LW-4, but the most frequent air mass over Illinois was cold type 1W. LW-4 was present during three October weeks and became firmly entrenched from the second week in December 1980 through the fourth week of January 1981. It reappeared for a week in February and for two weeks during the middle of March.

The 15 transition weeks occurred when the stationary waves gradually broke down (figure 7c). They either marked the transition from a stationary long wave pattern to some other circulation, or reflected a brief interruption in the circulation controlled by long waves. Transitions occurred most frequently during the fall and spring, periods when the baroclinicity normally would be undergoing rapid change.

Twelve weeks were classed as having "other" circulation types (figure 7d). These occurred mostly during August, September, and November 1980 and during February and March 1981. Patterns often varied greatly from one week to the next and included circulations influenced by short waves and by long waves not in the positions to satisfy the LW-6 and LW-4 criteria.

In summary, LW-6 and LW-4 influenced the circulation over Illinois for 25 of the 52 weeks of the driest part of the 1980-1981 drought, according to our subjective classification criteria. Given that some fractions of the transition weeks also had long wave circulations, the total amount of time that Illinois was under the influence of the stationary long waves may have been more than one-half year.

Results: The Relationship between Stationary Long Waves and Precipitation

The weekly precipitation values in the 1980-1981 drought were classed according to circulation type. Their distributions are presented in a stem and leaf diagram (figure 8). The differences in their distributions are plainly evident. There were a large number of light amounts and a dearth of moderate and heavy amounts in the circulations influenced by LW-4 and LW-6. By contrast, moderate to heavy weekly amounts were mostly found in the "transition" and "other" category, and there was a dearth of light amounts. Table 7 summarizes the weekly precipitation amount distributions of figure 8. Sixteen of eighteen, or 89 percent, of the weekly precipitation amounts less than 0.25 inch fell in association with circulations influenced by LW-4 and LW-6. By contrast, 71 percent of the 0.25-0.49 inch amounts, 80 percent of the 0.50-0.99 inch amounts, and 67 percent of the ≥1.00 inch amounts fell within the transition and other circulations.

Interestingly, some precipitation fell in 22 of the 25 LW-4 and LW-6 weeks. Precipitation-producing disturbances were regularly moving through Illinois during all phases of the dry spell. Huff (1961) has shown that frontal passages through Illinois during droughts are about 90 percent of normal.

Not all rainfalls associated with LW-4 and LW-6 were light amounts. The major rainstorm of the 1980-1981 drought occurred within a circulation influenced by LW-6. It lasted for 3 days during the first week of June 1980 and produced a mean rainfall of 2.50 inches over the southern two-thirds of Illinois. There were rainfall amounts ranging from 5 to 7 inches over large areas of

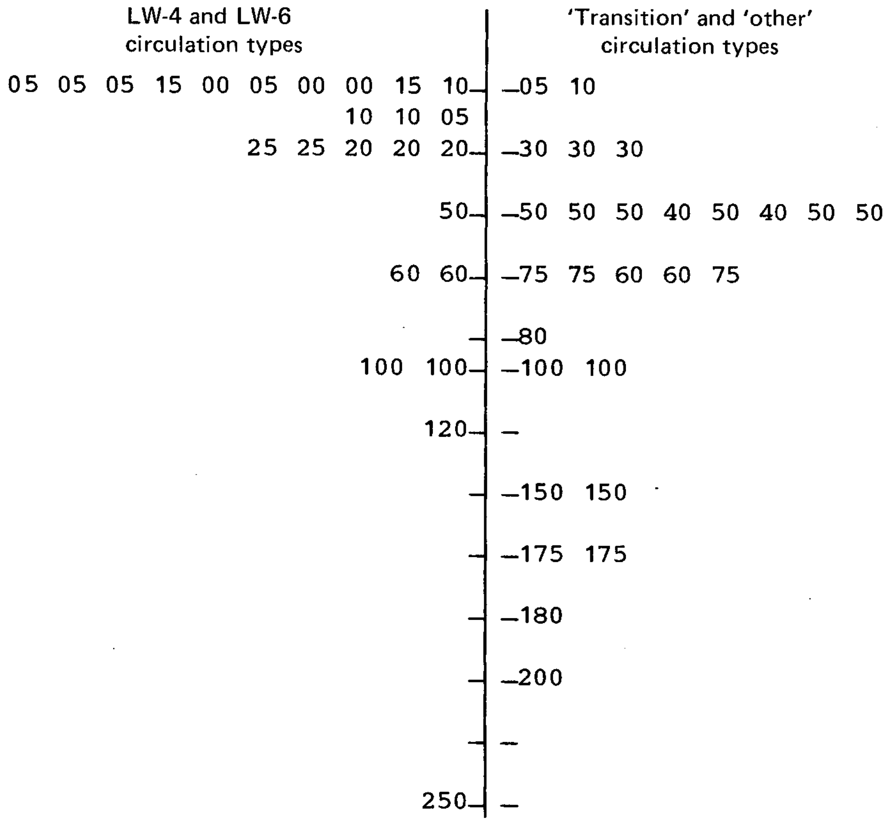


Figure 8. Stem and leaf diagram showing distribution of estimated weekly precipitation for 1) LW-4 and LW-6 circulation types and 2) all other circulation patterns (rainfall amounts are in hundredths of an inch and are grouped by increments of 0.2 inch, increasing downward)

Table 7. Frequencies of Weekly Rainfall Amounts Associated with LW4, LW6, and Other Circulation Types (by Amount Categories)

Amount category (inches)	*LW-4 and LW-6 circulation types*	*'Transition' and 'other' circulation types*	*Total*
0.00-0.24	16	2	18
0.25-0.49	2	5	7
0.50-0.99	3	12	15
1.00+	4	8	12
Total	25	27	52

western, central, and eastern Illinois. Lesser amounts fell over southern Illinois. This storm was the single most important factor causing June 1980 to have near normal rainfall.

The weekly normal precipitation amounts for the southern two-thirds of Illinois were subtracted from the actual weekly rainfall amounts, and the resulting departures were classed according to circulation type. These seasonally adjusted figures (table 8) show that relatively light and heavy rainfalls occurred within all four circulation types. However, on the average, the LW-4 and LW-6 positive departures were smaller than the positive departures for the other circulation types. Only one of four LW-6 and none of two LW-4 positive departures exceeded 0.25 inches. In comparison, four of six transition-type positive departures and three of four positive departures in the "other" category exceeded 0.25 inches.

Table 9 shows some selected statistics derived from the weekly rainfall data. A precipitation deficit of 3.86 inches was found for the 12 weeks influenced by LW-6. LW-4, the driest circulation pattern, produced a deficit of 5.76 inches. Slight excesses in precipitation were found for the two other patterns. The average weekly rainfall deficit was 0.32 inch for LW-6 and 0.44 inch for LW-4. In comparison with the normal weekly rainfalls, only 66 percent of the normal rainfall fell in association with the LW-6 circulations. The extreme dryness within the LW-4 circulations was made apparent by the mean departure from normal; only 27 percent of the normal weekly precipitation fell. These 13 LW-4 weeks produced only 2.10 inches of precipitation. The transition circulation type produced 101 percent of normal precipitation, and the "other" circulation type produced 108 percent of normal.

Weather Conditions in the Northern Third of Illinois

The drought of 1980-1981 affected the southern two-thirds of Illinois, and yet the same long wave patterns governed the circulation over the northern third of the state. Why, then, did this area escape the drought? The differences in the severity of the dryness in the two regions are related to: 1) the intensity of the dry spells; 2) the excess precipitation in the wet spells; 3) the timing of the wet and dry spells; and 4) the warm season temperatures. All of these factors are related to the demands placed upon the water resources by the biosphere.

The monthly precipitation for the northern third of Illinois during the 15-month period of the drought is given in the bottom row of table 6. The 15-month rainfall was 1.87 inches above normal for the northern region. This compares with 7.86 inches below normal for the southern two-thirds of the state. Thus, it was much wetter in the northern third of the state.

Northern Illinois experienced a 6-month dry period from October 1980 through March 1981. However, this period followed a late summer wet spell during which the August-September rainfall was 13.23 inches. This amount was 6.55 inches above the 2-month normal. Further, the dry period occurred during the cold season when the demands upon the water resources by the biosphere were at their minimum.

The summertime temperatures also reveal why northern Illinois escaped the drought. June temperatures were below normal over all of Illinois. The July-August temperatures for the southern two-thirds averaged 3.8°F above normal. The temperatures for the same period over northern Illinois were only 1.6°F above normal. Thus, the summer of 1980 was cooler and wetter over northern Illinois. The weather patterns that led to this situation are described in a later section.

Table 8. Weekly Precipitation, Weekly Normal Precipitation, and Departures from Normal (in inches) for the Four Circulation Types during the Driest 12 Months of the 1980-1981 Illinois Drought

LW-6

Week	*Actual rainfall*	*Normal rainfall*	*Departure*
3	.50	.98	−.48
4	.05	1.00	−.95
5	.10	1.02	−.92
9	1.20	1.03	.17
10	2.50	1.02	1.48
11	.20	1.00	−.80
12	.10	.98	−.88
14	1.00	.89	.11
15	.25	.84	−.59
16	.10	.81	−.71
17	1.00	.78	.22
18	.25	.76	−.51
Number of positive departures			4
Number of negative departures			8

LW-4

Week	*Actual rainfall*	*Normal rainfall*	*Departure*
27	.15	.65	−.50
28	.00	.63	−.63
31	.60	.60	.00
37	.60	.53	.07
38	.00	.53	−.53
39	.20	.53	−.33
40	.05	.52	−.47
41	.20	.51	−.31
42	.00	.50	−.50
43	.15	.50	−.35
45	.05	.61	−.56
50	.05	.87	−.82
51	.05	.88	−.83
Number of positive departures			2
Number of negative departures			11

Transition

Week	*Actual rainfall*	*Normal rainfall*	*Departure*
2	1.50	.97	.53
6	.10	1.03	−.93
7	1.00	1.03	−.03
8	.50	1.03	−.53
13	1.80	.94	.86
19	1.75	.76	.99
21	.50	.78	−.28
26	.40	.68	−.28
29	1.00	.63	.37
30	.50	.62	−.12
32	.05	.58	−.53
34	.40	.55	−.15
36	.75	.54	.21
44	.50	.54	−.04
46	.80	.70	.10
Number of positive departures			6
Number of negative departures			9

Other

Week	*Actual rainfall*	*Normal rainfall*	*Departure*
	.30	.95	−.65
20	1.75	.77	.98
22	.60	.78	−.18
23	1.50	.75	.75
24	.50	.75	−.25
25	2.00	.71	1.29
33	.30	.56	−.26
35	.60	.54	.06
47	.75	.77	−.02
48	.30	.83	−.53
49	.75	.85	−.10
52	.50	.90	−.40
Number of positive departures			4
Number of negative departures			8

Note: Week numbers identify 7-day periods beginning with March 31-April 6, 1980, that correspond with the weekly 700 mb circulation maps

Table 9. Precipitation Departures from Normal (in inches) for the Four Circulation Types

	LW-6	*LW-4*	*Transition*	*Other*
Total departure	–3.86	–5.76	0.17	0.69
Number of weeks	12	13	15	12
Average departure	–0.32	–0.44	0.01	0.06
Percent of normal	66	27	101	108

Mesoscale Weather Systems during the Drought

Introduction

It was also desirable to examine the smaller scale meteorological factors related to precipitation deficits that caused the drought in southern Illinois. Subsynoptic (mesoscale) systems, such as fronts and low pressure centers, are responsible for most precipitation, either in a direct or indirect way. It then becomes necessary to know if the lack of precipitation previously shown to be generally related to circulation types is also reflected in a change in the frequency or type of mesoscale systems affecting Illinois.

The investigation of the mesoscale systems during the drought included the study of 1) the frequency of frontal passages through the state, 2) the climatology of the fronts, and 3) the types of weather systems producing precipitation across the state during the drought. Part of the investigation was to determine what type of system was responsible for the major precipitation events (≥0.50 inch) during the dry months.

Frontal Frequencies during the 12 Driest Months

The number of times a particular type of front was present in Illinois was determined for each month from April 1980 through March 1981, the 12 driest months of the 15-month drought. The method used to determine the frontal frequencies was similar to that used in an earlier study of the climatology of surface fronts (Morgan et al., 1975). The Daily Weather Map Series was used for the period. Printed surface maps for 1200 GMT (Greenwich Mean Time) are available for each day. A 4 x 6 grid using squares 150 nautical miles on a side was overlain on the surface maps, and the squares through which fronts passed were tabulated as to type of front. The number of times any front occurred in each grid square was counted by type of front. The data were smoothed by averaging values of four adjacent squares and then plotting the number at the midpoint. This had the effect of increasing the grid size to 300 nm x 300 nm. This matched the grid size used to establish the 10-year climatology of fronts (Morgan et al., 1975). Grids were plotted for cold, warm, and stationary fronts. Occluded fronts were not plotted since their occurrence during the 12-month period was very infrequent and their normal climatological frequency is also very small, on the order of about one front per month per square.

To establish a base for a comparison of the frequencies during the 1980-1981 drought with the average or climatological frequencies, the frontal frequency at a point was read off the climatological map. This point was approximately central to the southern two-thirds of Illinois. Frequency values for that point were determined from the 10-year climatology, and these values were then compared to a frequency read from the drought period at the same point. The tabulation of the results was very interesting (table 10). First, all 12 months experienced a "frontal

Table 10. Frontal Frequencies in the Center of the Southern Two-Thirds of Illinois during the Driest 12-Month Period, April 1980-March 1981

	Cold fronts		*Warm fronts*		*Stationary fronts*		*Totals*	
	Actual	*Normal*	*Actual*	*Normal*	*Actual*	*Normal*	*Actual*	*Normal*
1980								
April	3	5	2	3.5	0	5	5	13.5
May	4	6	1	3	1	7	6	16
June	2	6	1	2	1	7	4	15
July	4	6	3	2	3	9	10	17
August	2	7	2	2.5	4	7	8	16.5
September	4	7	2	2	1	5	7	14
October	4	7	1	2.5	2	3	7	12.5
November	3	6	1	2.5	0	2	4	10.5
December	5	5	2	2.5	0	3	7	10.5
1981								
January	2	6	1	2	2	3	5	11
February	3	5	1	2	1	4	5	11
March	3	5	1	2	1	3	5	10
Totals	39	71	18	28.5	16	58	73	157.5

deficit." That is, fewer fronts than normal occurred. Second, there was a deficit within each type. Warm fronts were near or above normal in four months, whereas cold fronts reached normal frequencies in only one month, December 1980. Stationary fronts were below normal in every month. Perhaps the most striking result of this study is that the stationary frontal frequency (16) was only 28 percent of normal. The largest deficits in terms of numbers occurred during the three months normally experiencing the greatest amounts of precipitation, April through June 1980. In most months, the number of fronts was less than 50 percent of the normal number.

Analysis of Frontal Passages

Because of the limitations of the frontal frequency analysis discussed above, a second analysis of frontal systems was undertaken. The frequency of frontal passages during the driest 12-month period in the drought area was determined (as opposed to the point frequencies). An analysis of the frontal passages is more subjective than the grid-determined frequencies, but it is more representative of the actual frontal activity during the drought period. Frontal passages were determined by again using the Daily Weather Map series. Frontal positions on a given day were compared to those of the preceding and following days to determine if, in fact, a front moved through the southern two-thirds of the state. For the purposes of this analysis the study area considered is that south of 41°N latitude (approximately the shaded area in figure 6). A frontal passage was counted if it appeared that a particular system passed through the entire southern two-thirds of the state. The presence of stationary fronts was also tallied as a check against the frequencies determined by the grid analysis. There was no attempt to ascertain whether a front became stationary during the 24 hours between map times.

The number of cold and warm frontal passages are shown in table 11. Their frequencies exceeded the point frequencies produced (Morgan et al., 1975). However, the two analyses are not directly comparable, and the differences in the two types of analyses are reflected in the above results. Stationary frontal frequencies were the same with both analyses. The frequencies of stationary fronts are likely to be more representative of actual conditions since the fronts lack a transient nature.

Table 11. Number of Frontal Passages in the Southern Two-Thirds of Illinois during the Driest 12-Month Period, April 1980-March 1981

	Cold fronts	*Warm fronts*	*Stationary fronts*
1980			
April	6	2	1
May	6	3	1
June	6	1	1
July	5	4	4
August	4	3	3
September	6	3	2
October	7	1	2
November	6	2	1
December	8	3	0
1981			
January	8	2	2
February	7	3	0
March	7	3	0
Totals	76	30	17

It appears that during the driest 12-month drought period in 1980-1981, the frequency of transient frontal systems was near normal. Similar results were found in another study of Illinois droughts (Huff and Vogel, 1977). However, stationary fronts were observed much less frequently than climatological studies would suggest. In most drought months, the mean stationary frontal position was near its normal position.

Precipitation-Producing Systems during the Drought

The number of transient frontal systems was near normal during the drought, and yet precipitation was well below normal. The questions then raised related to the systems producing low and heavy amounts of rainfall. An attempt was made to identify and study those systems which produced 0.50 inch of rain or more, as averaged over the southern two-thirds of the state.

The monthly precipitation from April 1980 through March 1981 was ranked as dry (below normal), near normal, and wet (above normal) to sort and study the rain-producing systems. Near normal monthly precipitation was defined as an amount ±25 percent of the normal. By this classification, three months (June 1980, October 1980, and February 1981) had near normal precipitation in the southern two-thirds of the state (see table 6). August and September 1980 had above normal precipitation, whereas the other seven months were all well below normal (table 6). January 1981 was the driest month, with only 16 percent of normal precipitation in the southern two-thirds of Illinois.

The types of weather systems producing significant precipitation were stratified into three types: frontal, front with wave, and low pressure systems. Low pressure was defined as a system with an identifiable cyclonic circulation, but not a frontal wave.

Table 12 shows the distribution of the types of weather systems for the driest 12-month period. There were 15 systems that produced precipitation of ≥0.50 inch in the 7 dry months, of which only 4 were not low pressure systems or fronts. No stratification was made as to the type of front producing the precipitation. Three of the five frontal systems in the 7 dry

Table 12. Number of Precipitation Events of 0.50 Inch or Greater Produced by Three Types of Weather Systems during the Driest 12-Month Period, April 1980-March 1981

	Fornts	*Fronts with waves*	*Low pressure systems*	*Total*	*Monthly average*
Dry months (7 total)	5	4	6	15	2.1
Near-normal months (3 total)	4	2	3	9	3.0
Wet months (2 total)	4	0	1	5	2.5
Totals	13	6	10	29	2.2

months occurred in one month, July 1980, apparently helping to cause an average of about 3.0 inches of rain across the southern third of Illinois. However, rain was quite deficient in the central section (figure 3). The temporal distribution of precipitation-producing systems was fairly even during the seven dry months.

There were only two months with above normal rainfall (August and September 1980). The frequencies in table 12 suggest that the frontal passages were the primary systems producing 0.50-inch rain events during those months.

The total number of "events" for the 12 driest months was 29 (table 12). An "event" was a precipitation episode of ≥0.50 inch over the area resulting from an identifiable weather system, possibly spanning more than one day. It is not possible to state whether this frequency is normal. Some comparisons can be made, however, between the frequencies in the dry, normal, and wet months. In the dry months, frontal activity (fronts and fronts with waves) resulting in ≥0.50 inch made up 11 percent of the total frontal passages (table 11). In both the near-normal and wet months of the drought the frontal frequency of 0.50-inch events was close to 20 percent of the total frontal passages.

Possible Causes for the Drought Reflected in Mesoscale Weather Conditions

Previous studies of Illinois droughts have shown that frontal frequencies have tended to be near normal during the drought periods (Huff and Changnon, 1963). This was attributed to a relatively large number of fast but weak cold fronts moving through Illinois, in contrast to strong, slow-moving fronts that are more frequent in wet years. To a certain extent this pattern was evident in the 1980-1981 drought. Cold frontal passages were about 107 percent of normal and warm front passages 105 percent of normal in the 1980-1981 drought area. This compares to an 89 percent frequency of cold fronts found by Huff and Changnon (1963) for the 1953-1954 drought, and 98 percent of normal fronts for all categories. It should be noted, however, that the means of determining frontal passages in this study were different from those used to determine frequencies in previous studies.

The stationary front frequency during the 1980-1981 drought was very low, only 28 percent of normal. The months that normally have the highest number of stationary fronts occurring in southern Illinois, May through August, all had large deficits. This suggests that the absence of stationary fronts in the drought area was a critical factor.

The 10-year climatology of fronts (Morgan et al., 1975) depicted a well-defined band of maximum stationary front frequencies through the central U.S. with an east-west orientation. On the average, one could expect higher frequencies of convective rainfall and squall lines south of this band, with lower frequencies to the north. The shifting of this band north or south, or the lower occurrence of stationary fronts within this band, could account for greater or lesser amounts of precipitation in certain sections of the state.

In most drought months the stationary front band was close to its normal position. During August 1980 it appeared to shift north to the northern third of the state (figure 9). This month was one of two months when precipitation was above normal in the drought area. Even though the frequency of stationary fronts was below normal in the drought area, August had the highest stationary frontal frequency of any month in the April 1980-March 1981 drought period. A pattern similar to that in August existed in July 1980 (figure 10), the month with the second highest frequency of stationary fronts. While July 1980 was a very hot month, there was near-normal rainfall in the southern third of Illinois (figure 3). Central Illinois was very dry. Overall, rainfall in the southern two-thirds of Illinois was 71 percent of normal in July, the highest of the seven dry months. The absence of stationary fronts was a cause of the drought in 1980-1981.

The Sultry Conditions during July 1980

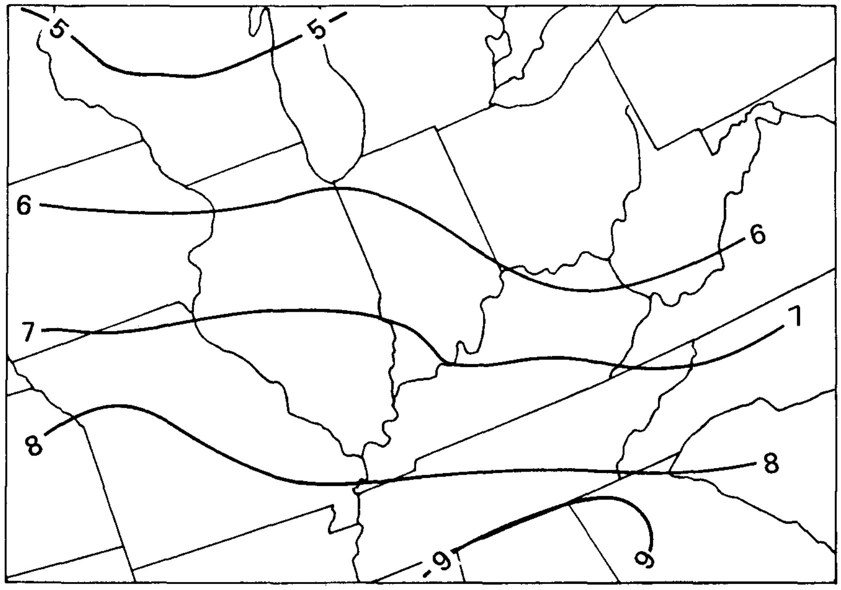
Introduction

The heat wave of July 1980 equalled or exceeded temperature records at many locations in the southern and central Plains and in the south central United States. New records for the persistence of daily, temperatures above 100°F (38°C) also were set in these areas (Wagner, 1980). These extremes received broad coverage in the national news media; however, the sultry conditions over parts of Illinois, Missouri, Indiana, and Iowa largely escaped notice.

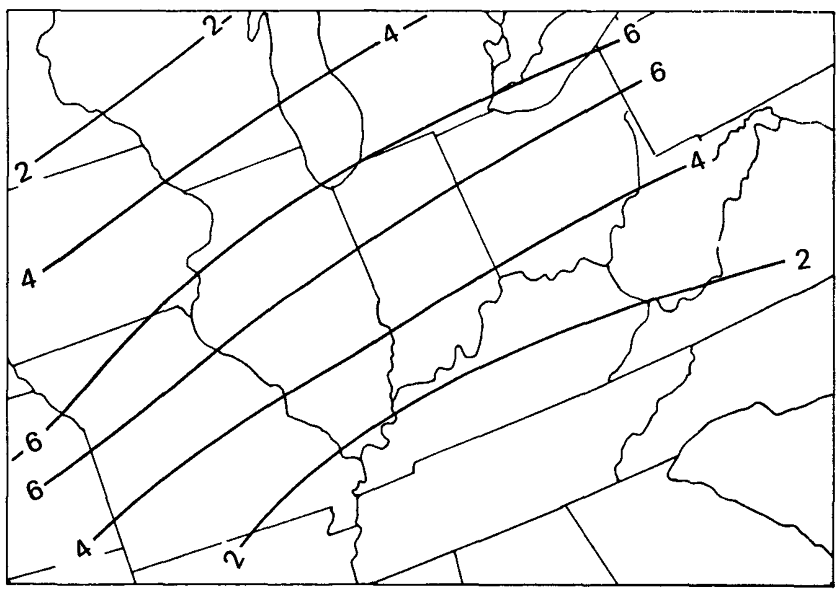
The high temperatures had moved northeastward from the southern Plains into Missouri by July and occupied large parts of Illinois on several occasions during July 1980 (figure 3). However, the 100°F-plus temperatures were largely recorded west of the Mississippi River. Nevertheless, Illinois did not escape the misery of the heat wave. Unusually humid air masses developed over parts of Illinois and Iowa at various times during July. Dew point temperatures exceeded 76°F over wide areas throughout the month. There were also an anomalously large number of reports of dew point temperatures equalling or exceeding 80°F.

Sultry conditions (high temperatures and humidity and calm air) developed on July 4 when dew points in the range of 80°F appeared in southern Illinois by midday. The air with high humidity spread northward through western Illinois and eastern Iowa by 1800 CDT. The sultry conditions were dissipated by the passage of a line of severe thunderstorms early on July 5. Before the storms provided relief, Springfield, Illinois (SPI) had recorded eleven consecutive hours with dew points of ≥80°F, including six hours with fog when the dry bulb temperature was 83°F.* The high humidities with dew point temperatures of at least 80°F somewhere in Illinois or surrounding states occurred again during July 6-12, 14-15, 19, and 31.

*It has been found that the Springfield NWS weather station was located near a cornfield. The likely impacts upon the dew point temperatures were 1) to increase the dew points by at least 1°F; 2) to increase the duration of high dew points; and 3) to delay instrument response to air mass changes. These effects have been taken into consideration in the analysis that follows.

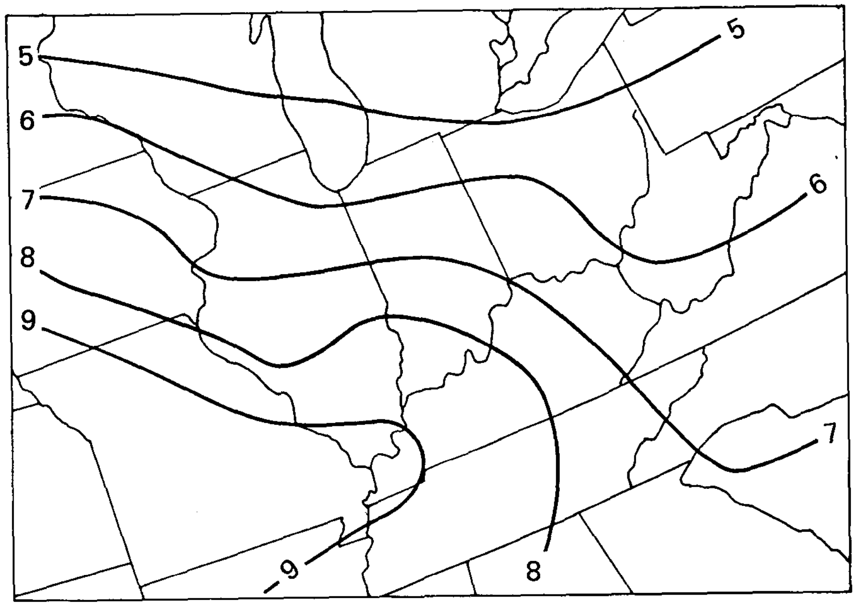


a. Normal frequency in August

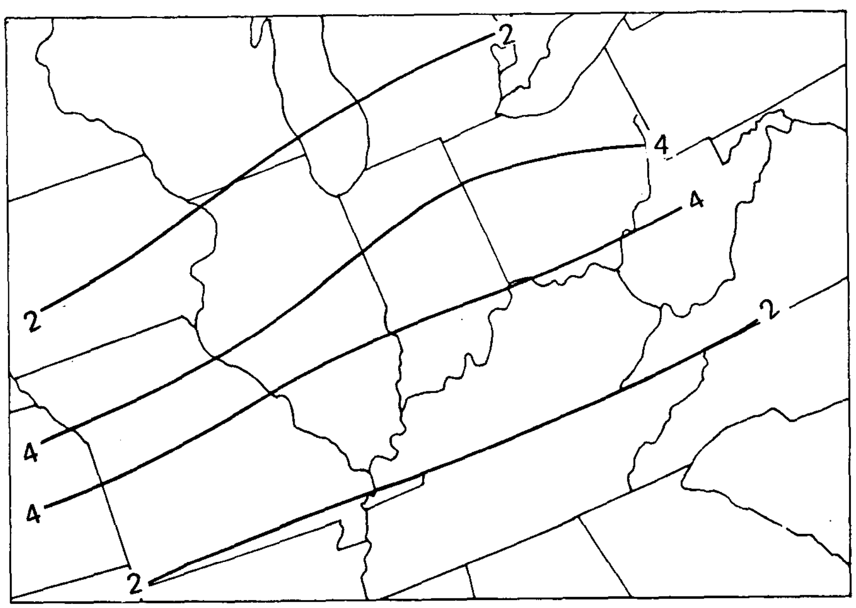


b. August 1980

Figure 9. Frequency of stationary fronts in August



a. Normal frequency in July



b. July 1980

Figure 10. Frequency of stationary fronts in July

The purposes of this phase of the drought study were to determine the course of events that combined to produce the sultry air masses, and to develop a conceptual model of the prevailing weather systems.

Data

The data used for this study included the 5-day mean 700 mb circulation charts published monthly in the *Monthly Weather Review.* Three-hourly surface maps and 12-hourly upper air charts were also analyzed along with 9 years (1967-1975) of 3-hourly surface data. Hourly surface data for July 1980 were studied along with rawinsonde data.

There were concerns regarding the quality of the surface values. The Water Survey was conducting a field program, as part of the Precipitation Augmentation for Crops Experiment (PACE), during late July and August 1980 (Changnon and Semonin, 1980). Objective products used for operational forecasting of cloud and rain conditions were derived from hourly surface observations within the region shown in figure 11.

The unusual sultriness was apparent in the project forecasting efforts during August. Decreases in forecast accuracy were traced to the high humidities taken from the surface observations. The tendency at first was to discard the high dew points as observational error because, when combined with the dry bulb temperature, the convective temperature was far exceeded. Yet the prevailing weather conditions were mostly clear skies or a few cumulus clouds with little vertical development.

There were several reasons for accepting the high humidities as valid, however. First, high dew points also were measured with sling psychrometers and with the meteorological instruments on the University of Wyoming King-Air aircraft. Second, high dew points were often reported at several surface stations and were advected through the region by the prevailing winds. Third, other observations, such as reports of fog with dry bulb temperatures in the lower 80's, were supportive of the high humidities. Finally, measurements taken by the aircraft showed that the high humidities were confined to a shallow surface layer, giving an explanation for the lack of convective clouds.

The extremely high dew point temperatures at Springfield were suspected of not being representative because the instrument shelter was located near a cornfield. If a first-order NWS site could be located so as to affect the observation, the quality of the data from the other surface stations was also suspect. Using August 1980 as a baseline, the monthly average dew points were calculated for the sites within the region shown in figure 11. Since the corn was taller and the ground more moist in August than in July, the modulating effects of poor exposure, at least near cornfields, should have been evident in the August data. The July dew points were calibrated with the August mean dew points, and the following corrections were found necessary: Springfield (SPI), -1° F; Decatur (DEC), +1° F; and Terre Haute (HUF), –2° F.

Synoptic Conditions

As seen in figure 7, long wave number 6 (LW-6) with troughs located along the west and east coasts, and the ridge located through the central U.S., prevailed throughout July (Livezey, 1980). Namias (1955) has associated this circulation pattern with extended drought over the central part of the country. Subsidence heated the column of air within the ridge, and record-breaking hot temperatures were found over the southern Plains.

The slow anticyclonic circulation within the ridge advected the hot, dry air mass into the Middle West. This air mass became entrenched over Missouri for most of July. As the hot air mass

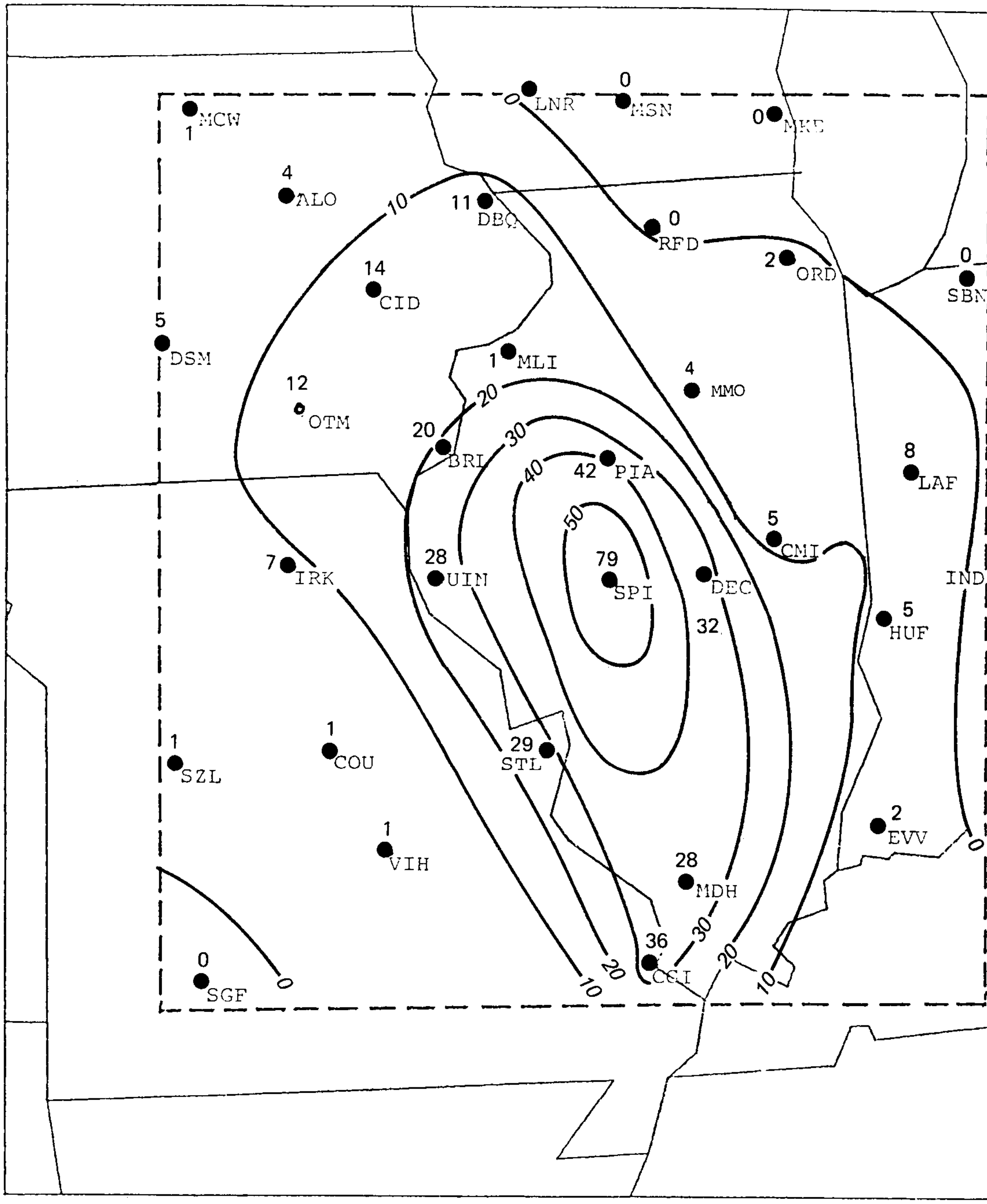


Figure 11. Number of hours dew point temperatures were ≥78°F during July 1980

moved eastward, it overran a shallow, relatively cooler (daytime temperatures in the 90's) but more humid air mass over Illinois. The stable layer at the interface of the two air masses impeded mixing of the drier air from aloft with the humid air near the surface.

Concurrently, weak mid-tropospheric weather disturbances moving north of Illinois, and around the rim of the upper level ridge, trailed weak cold fronts into the state. Several of these fronts provided temporary relief from the sultry heat wave. However, the prevailing large-scale circulation favored the re-establishment of the sultry heat wave in the Middle West.

Climatological Aspects of the Sultry Air Masses

Was the sultry heat wave of July 1980 an extreme event? Figure 11 shows a spatial analysis of the total number of hours (reports) the dew point temperature equalled or exceeded 78°F over the region, as determined after corrections with the August average dew points. The moisture extremes were most frequent within a 200-km elongated area from southern Illinois into eastern Iowa. The western boundary of the humid air marked the general eastern boundary of the hot, dry air masses. The northeastern boundary marked the approximate extent of southwestward penetration of cool polar air masses. This area was also the one with the greatest positive departures in the dry bulb temperatures (figure 3c).

Dew points of at least 80°F (figure 12) were concentrated within western Illinois and southeastern Iowa. Figures 11 and 12 both show that the frequencies were greatest at Springfield, an indication that the Springfield dew points were likely still erroneously high in spite of the calibration with the August averages. However, the Springfield peak may also reflect a meteorological explanation, as will be shown later.

July dew points for Illinois and the surrounding states for nine summers (1967-1975) were used as baseline data for assessing the moisture extremes of July 1980. The July 1980 data were made compatible with the 9-year data by removing Carbondale (MDH) with its 10 reports of $T_d \geq 80°F$, and then retabulating the July 1980 reports at 3-hour intervals.

The historical data (table 13) show that the 80°F dew points have occurred over parts of the Midwest, but they are not frequent. There was, on the average, about one report of $T_d \geq 80°F$ per July somewhere within the 6-state region. Illinois had one report every 2 years, and Iowa had one report every 3 years. There were 2 reports in Indiana and no reports in Missouri, Kentucky, or Wisconsin during the 9-year period.

The number of reports of dew points of 80°F or greater during July 1980 was 20 times greater than in prior years. If the 9-year baseline period was representative, it may be concluded that the 1980 sultry heat wave was an extreme event for the Middle West.

Origin of the Sultry Air Masses

How did the sultry air masses originate? Were they advected into the Middle West or did weather events combine to produce the humid air masses locally? Three-hourly surface charts for

Table 13. Number of 3-Hourly Reports with Dew Point Temperatures of 80°F or Greater for Six States during the Month of July

Period	*Illinois*	*Iowa*	*Missouri*	*Kentucky*	*Indiana*	*Wisconsin*	*Total*
1967-1975	5	3	0	0	2	0	10
1980	11	6	1	2	0	0	20

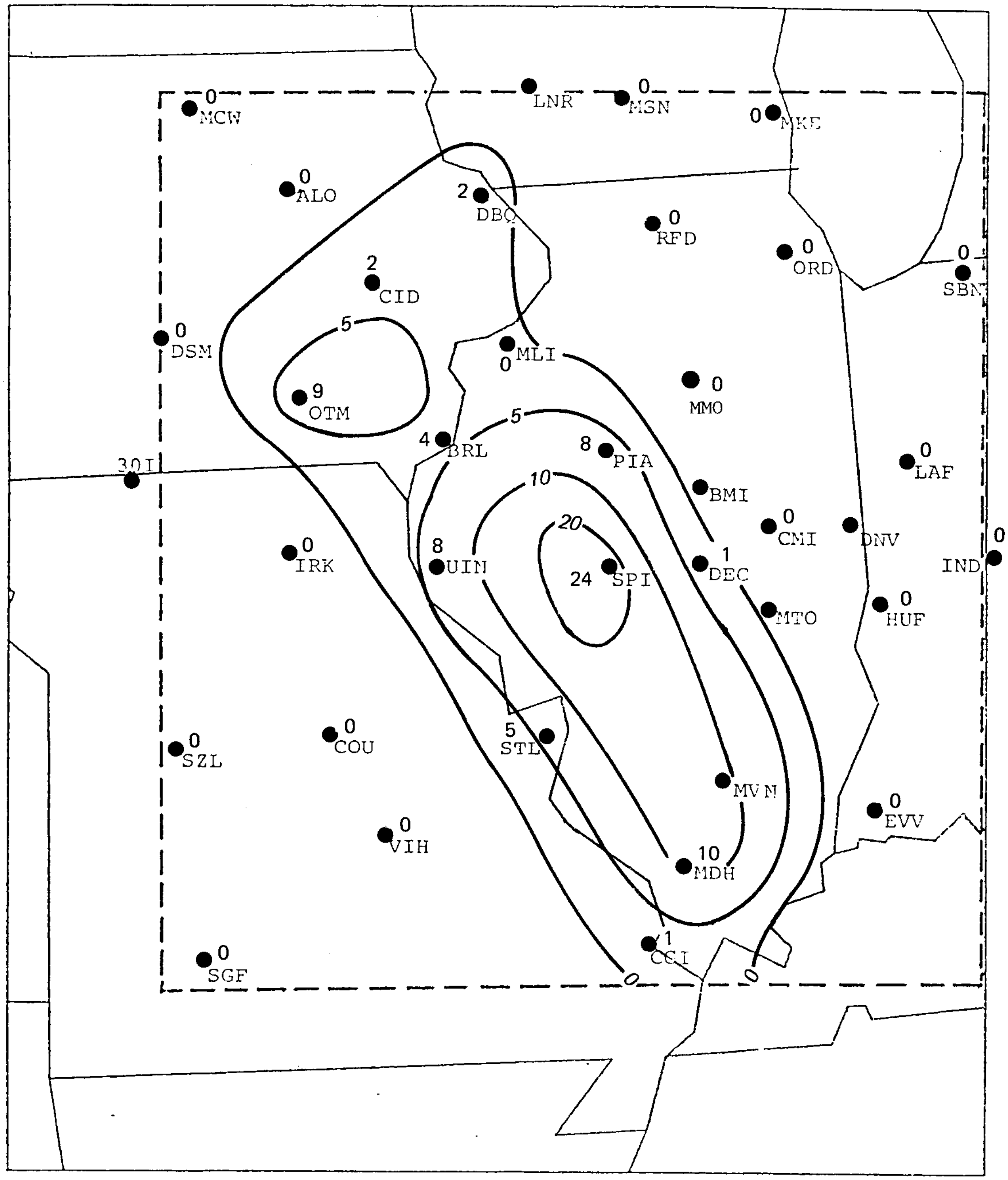


Figure 12. Number of hours dew point temperatures were ≥80°F during July 1980

the U.S. were examined to find the source region of the humid air masses. The diurnal moisture oscillation (early morning dew points were usually several degrees lower than late afternoon dew points) complicated the interpretation of the temporal dew point patterns. Space does not permit presentation of the number of surface charts necessary to describe the formation and movement of air masses. Therefore, the events are described with the aid of summary charts.

The sultry air mass that moved into the upper Middle West on July 4 originated in the central Gulf States. Air with dew points in the middle 70's was drawn northward toward a general area of low pressure over Iowa and Minnesota. High dew points ($T_d \geq 280°F$) were reported in southern Illinois near midday and by 1800 CST had covered much of western and central Illinois and southeastern Iowa (figure 13). Areas of precipitation during the period 0000-1500 CST are shaded.

The highest dew points appeared over the Middle West, not the source region. These 80°F-plus dew points represent increases of 2-3°F over the maximum dew point temperatures observed within the source region during the previous day (July 3). Regional moisture sources are necessary to explain these increases.

The sultry air mass over parts of Illinois, Missouri, Iowa, and Minnesota at 1800 CST on July 6 (figure 14) formed apart from the humid region over Mississippi and Alabama. The existence of regional moisture sources over the Middle West was further confirmed by dew point analyses for the period of July 11-16. By July 11, the hot, dry heat wave had covered the Gulf Coast states and had eliminated that area as a source region for humid air masses (figure 15a).

A sultry air mass formed over Illinois and Iowa on July 11 and was advected into the southern half of Illinois on the 12th by northwesterly flow following a weak low pressure system (figure 15b). A humid air mass reformed over Iowa and Minnesota on the 13th in advance of a weak frontal wave (figure 15c). That air mass was advected into Wisconsin while local sources increased the moisture within the air mass over Illinois (figure 15d). Cooler air pushed the humid air out of Wisconsin (figure 1 Se) and finally swept the sultry air out of the Middle West on July 16. Figure 15f shows the remaining sultry air over portions of southern Illinois, Indiana, and Ohio at 1800 CST July 16.

Initially, then, some moist air reached the Middle West via advection from the usual summertime source region near the Gulf of Mexico. Toward mid-July, however, this source region was cut off by hot, dry air masses. Sultry air masses continued to form over the Middle West, thus establishing that the source region was endemic to the Middle West.

The Sultry Air Mass Moisture Budget

The time-rate of change of moisture at an observation site can be expressed as the sum of the horizontal and vertical advection of moisture and the moisture sources and sinks. Possible moisture sources are evaporation from falling rain, evaporation from wet surfaces, and evapotranspiration. Moisture sinks are daytime redistribution by the mixing of surface boundary layer air with drier air above the moist air mass, and nocturnal loss to the underlying surface through condensation (dew formation). Hilberg's (1978) moisture studies for an agricultural section of the Middle West have shown that the diurnal variation of moisture in the absence of advection can be considerable depending upon the relative contributions of the sources and sinks (figure 16).

As the surface heats up during the morning, dew deposited overnight is evaporated and the dew point is increased. During the afternoon and evening on rainless days, the relative con-

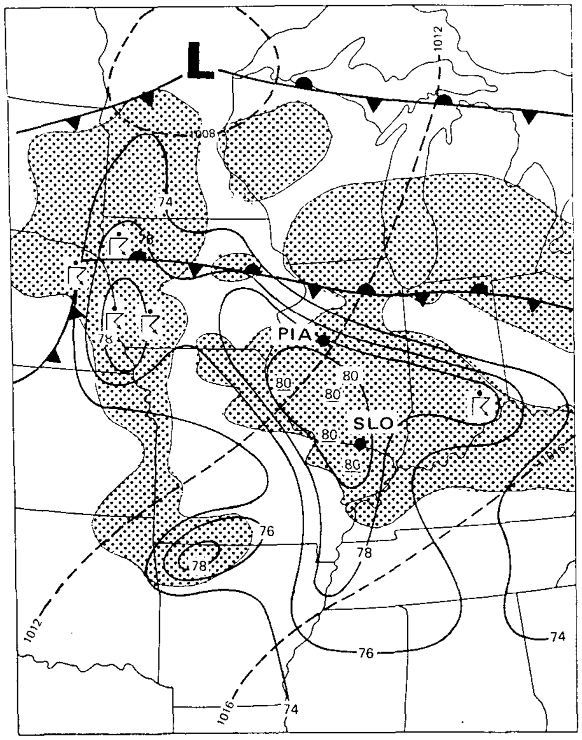


Figure 13. Dew points (solid lines), isobars (dashes), and frontal systems at 1800 CST on July 4, 1980 (shaded areas indicate precipitation areas during 0000 to 1500 CST)

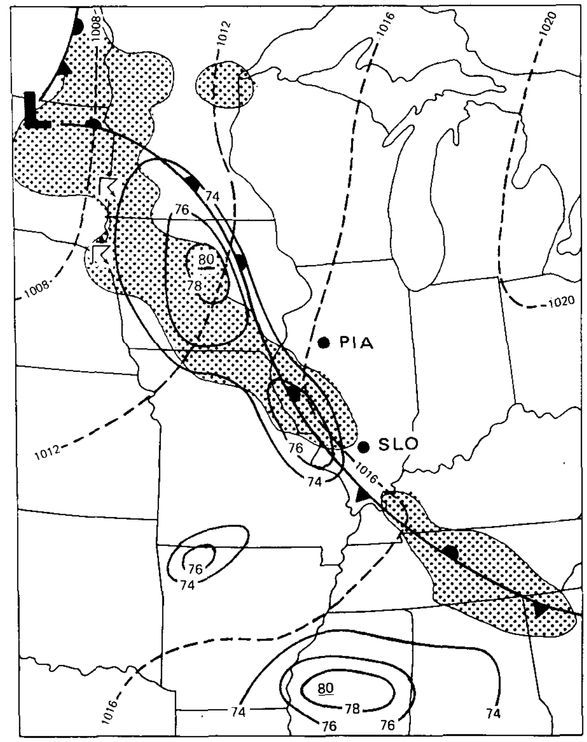


Figure 14. Dew points (solid lines), isobars (dashes). and frontal systems at 1800 CST on July 6, 1980 (shaded areas indicate precipitation areas during 0000 to 1500 CST)

tributions of evapotranspiration and mixing determine whether the dew point will continue to rise throughout the daylight hours or will fall slightly. When evapotranspiration is large, the dew point temperature continues to rise, and the maximum usually occurs in the early evening when slight cooling and increased stability in the boundary layer have decreased mixing. Dew deposition decreases the moisture during the night and the cycle is ready to repeat during the next day.

When the moisture sink is large, dew points may decrease during the afternoon when mixing is usually best established. Then, toward early evening as mixing decreases in response to surface cooling and before dew deposition takes over at night, the dew point may increase to a second peak during the period the evapotranspiration moisture source is essentially unopposed.

Rainfall can lead to either moisture increases or moisture decreases depending upon the relative magnitudes of moisture sources and moisture advection. Certain moisture sources are the evaporation of falling rain and the evaporation from wet surfaces. These sources are functions of air temperature and are most effective in warm conditions. However, rainfall is often accompanied by the vertical advection of rain-cooled, relatively dry (with respect to pre-rain surface moisture) downdraft air masses to the surface. In many situations, air mass transitions by vertical advection dominate all moisture sources to produce drying.

Evapotranspiration, evaporation from falling rain and wet surfaces, mixing, and air mass transitions all contributed to the formation of the unusually moist air masses during July 1980.

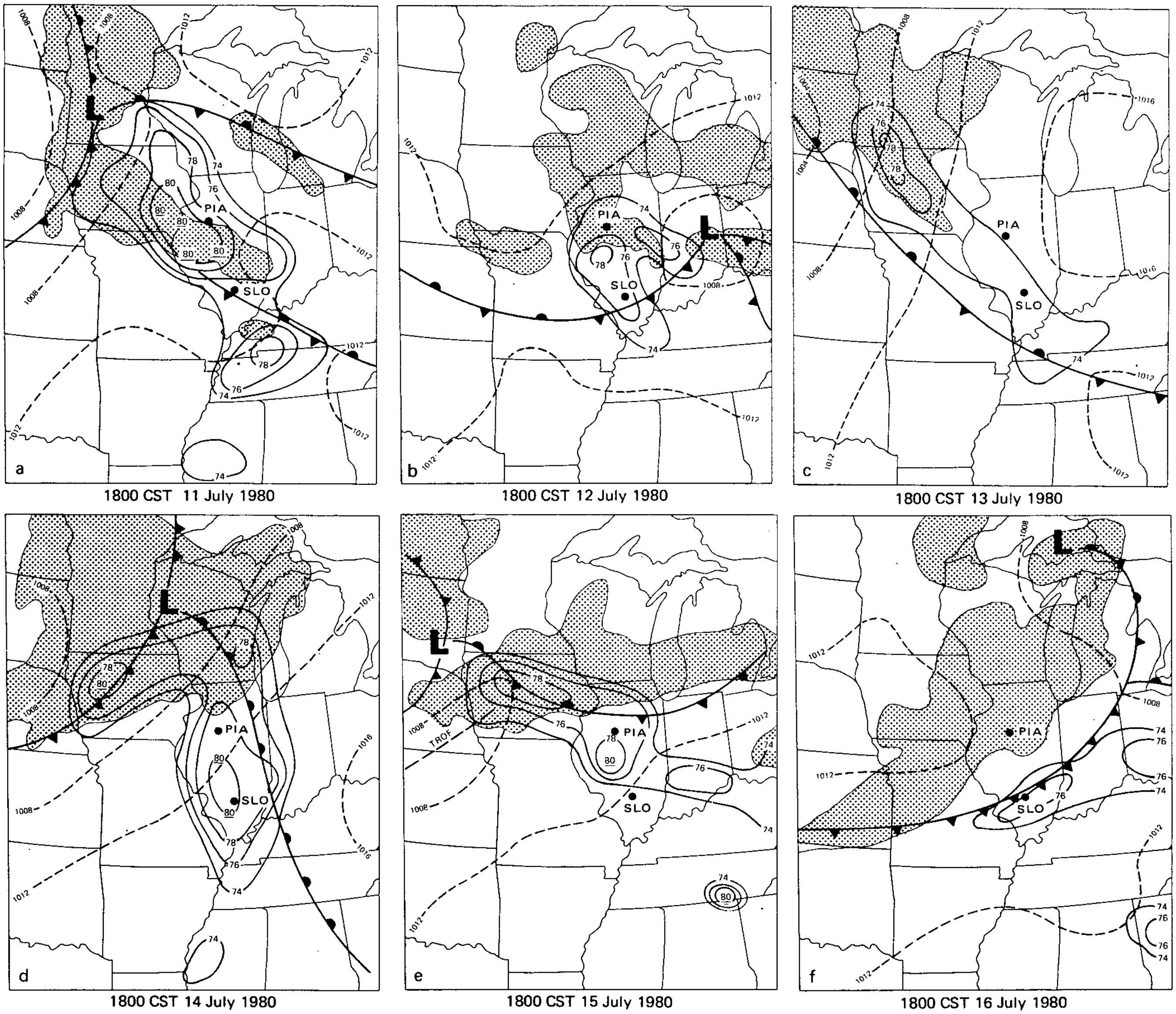


Figure 15. Dew points (solid lines), isobars (dashes), and frontal systems at 1800 CST on July 11-16, 1880 (shaded areas indicate precipitation areas during 0000 to 1500 CST)

On the basis of the available data sets, qualitative inferences have been made regarding the relative contributions of these sinks and sources to the moisture budget of the sultry air masses.

Evapotranspiration. Corn and soybeans are major cash crops grown in the Middle West. Corn, with its large leaf surface area, is known to lose large amounts of water through evapotranspiration. Soybeans also lose water to the atmosphere, but in lesser amounts than corn.

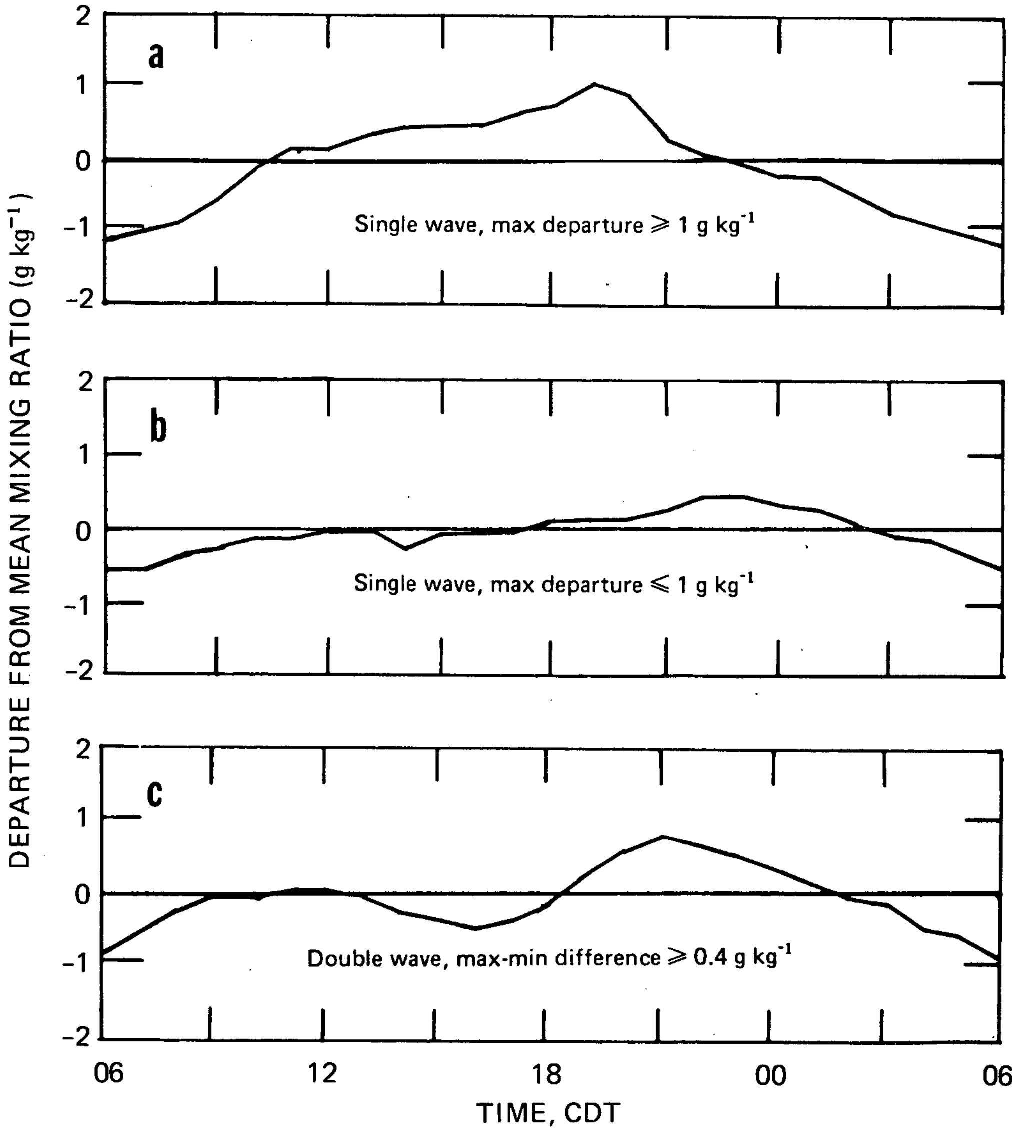


Figure 16. Examples of mixing ratio curves representative of three types of diurnal distributions (from Hilberg, 1978)

Did agricultural practices lead to the development of the sultry air masses? Was a disproportionately large area of western and southern Illinois planted in corn in 1980? The total acreage of each crop district in Illinois, and the acreage and percent of each crop district planted in corn and soybeans are presented in table 14. The areas committed to these cash crops ranged from 36 to 86 percent with the largest acreage and highest percentages in the northwest, central, and eastern districts (figure 17) rather than in the sultry western and southern areas. The humid

Table 14. Total Acreage, and Acreage and Percent of Each Crop District Planted in Corn and Soybeans for 1980

(Acreage in millions of acres)

crop district	*Total acres*	*Corn*		*Soybeans*		*Total percent*
		Acres	*Percent*	*Acres*	*Percent*	
NW	4.58	2.11	46	0.65	14	60
NE	4.19	1.31	31	0.86	20	51
W	3.52	1.13	32	0.78	22	54
C	3.91	1.77	45	1.19	30	75
E	3.63	1.71	47	1.42	39	86
WSW	4.77	1.33	28	1.38	29	57
ESE	4.73	1.35	29	1.54	33	62
SW	3.40	0.46	14	0.74	22	36
SE	2.96	0.53	18	0.72	24	42

air masses were observed to form over those areas with the lowest percentage acreage in corn. Thus agricultural crops and practices apparently were not a major factor in the persistence of sultry air masses over western and southern Illinois.

Evaporation from Falling Rain and Wet Surfaces. The saturation vapor pressure over a water surface is a function of the temperature of the surface. The warmer the surface, the higher will be the saturation vapor pressure (Hess, 1959). Evaporation rate is dependent upon the difference between the ambient and saturation vapor pressures. Thus, the most suitable time for rapid evaporation from wet surfaces is the hottest part of the day, i.e., afternoon. Figures 13-15 show sultry air masses at 1800 CST in relation to frontal systems at 1800 CST and precipitation areas from 0000-1500 CST (shaded areas). Areas wetted during the morning or early afternoon are prime areas for rapid evaporation and high humidities when the sun comes out and the land surfaces heat up. Thus for the evaporation source to be most efficient, there must exist a crucial timing between the rainfall, the clearing away of clouds, and the time of day.

On July 4 (figure 13), humid air masses covered those areas that had received rainfall a few hours earlier. The relationship between precipitation and high dew points was even more evident on July 6 (figure 14) and on July 11 (figure 15a). The sultry air masses over Illinois on July 12 were immediately downstream from a wetted area (figure 15b). High dew points were again found within a rain-wetted area on July 13 (figure 15C) and also on July 14-15 (figure 15d-15e). Sultry air masses that formed over Illinois on July 14 did not appear to be associated with previous rains. Increasing westerly flow near a developing frontal system advected the sultry air masses out of their source regions on July 16 (figure 15).

With only one exception, the locations of the humid air masses correspond closely with areas that had received precipitation earlier the same day. Thus it is inferred that evaporation from wet surfaces was a major contributor to the moisture budget of sultry air masses. However, other areas in the Middle West received precipitation during the same periods but were not source regions for sultry air masses. Why then, did evaporation appear to be so effective in raising humidities in some areas but not in other areas? The relative contributions of the moisture sinks provided some answers to this question.

Mixing. The magnitude of the moisture sink (the mixing of humid boundary layer air with drier air aloft) is dependent upon the lapse rate of moisture, the stability across the air mass

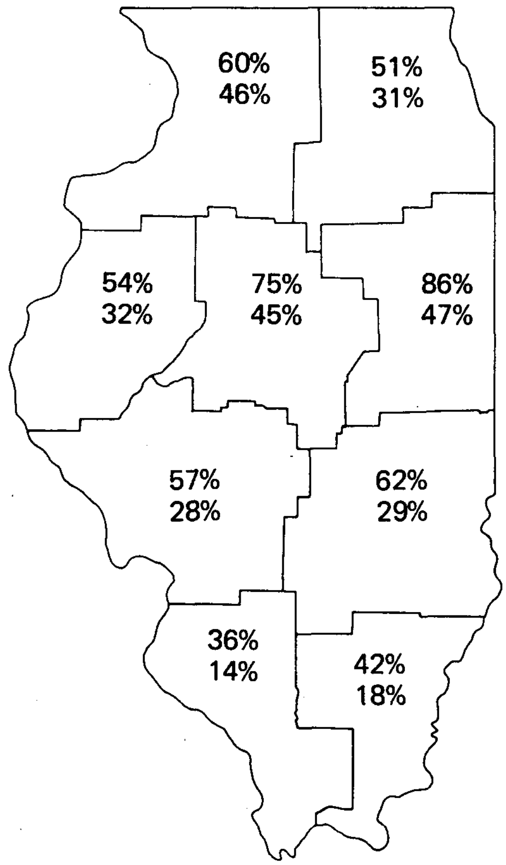


Figure 17. Percentage of land planted in cash crops (top value is for corn and soybeans combined, and lower value is for corn only)

interface, and heating from below. Table 15 gives several moisture lapse rate and stability variables calculated for eight sultry air mass days, The input data were the 1800 CST (0000 GMT) soundings taken within, or in close proximity to, the sultry air masses when possible and taken a few hours after the time of peak temperature when the boundary layer was still adiabatic. In interpreting table 1.5, one should review figures 13 to 15 because several humid air masses developed and remained between rawinsonde sites.

The boundary layer features were found to be highly variable during the eight days. The placement of the soundings relative to frontal systems (given by synoptic, code) were as follows: four soundings were taken within warm sectors (WS), two were taken in advance of warm fronts (PW), and two were taken after the passage of cold fronts (PC). The cold front of July 12 was more a weak wind shift line; by 1800 CST, cooler and dryer air had not reached Peoria, some 200 km behind the front. Further, the height of the boundary layer ranged from 568-1546 meters. Dew points varied from 71-80°F.

There were some air mass similarities also. Large negative moisture lapse rates (L_{SW}) defined the air mass interfaces for the first six proximity soundings. These lapse rates ranged

Table 15. Characteristics of the Boundary Layer and the Interface at the Top of the Boundary Layer at 1800 CST on Eight Sultry Air Mass Days

station	*July 1980 date*	*Surface temperature (°F)*	*Surface dew point (°F)*	*Height of boundary layer (meters)*	L_{BW}*	*Depth of capping stable layer (meters)*	*Lapse rate within capping stable layer (C/KM)*	L_{SW}**	*synoptic code*
Peoria	4	87	76	1191	–2.5	481	+2.1	-31.5	WS
Peoria	6	82	74	880	–2.4	456	+2.6	-41.1	PW
Peoria	11	87	80	568	–13.7	271	+5.2	-33.9	WS
Peoria	12	93	79	1546	–5.0	870	Isothermal	-36.7	PC
Peoria	13	88	71	999	0.2	362	+11.6	-137.6	PW
Salem	14	94	78	591	–5.1	164	+8.5	-95.1	WS
Peoria	15	97	74	1027	–4.0	628	-3.2	-8.2	WS
Salem	16	94	74	1360	–3.8	No prominent stable layer			PC

*L_{BW} *is the mixing ratio lapse rate through the boundary layer (gm/kg/km)*
** L_{SW} *is the maximum mixing ratio lapse rate through the capping stable layer (gm/kg/km)*

from –31.5 to –137.6 gm/kg/km and should have contributed to significant boundary layer drying if mixing across such moisture gradients existed.

However, there were also strong capping stable layers across the air mass interfaces. These ranged in depth from 164-870 meters and were inversions save for one isothermal layer. It can be reasonably inferred that mixing on these sultry air mass days was inhibited by these stable layers.

Table 15 also shows that the boundary layer was well mixed on only one of the eight sultry air mass days (see L_{BW}). On July 13 Peoria had a surface dew point of 71° F; the sultry air masses had formed northwest of Peoria over parts of Iowa and Minnesota (figure 15). Further, the l-km-deep boundary layer was capped by a strong inversion layer 362 meters deep. Thus with little dry air mixed in from above and no appreciable moisture input from sources below, mixing was able to distribute the moisture throughout the boundary layer (L_{BW} = 0.2).

Negative moisture lapse rates, indicating fluxes of moisture from the surface to the top of the boundary layer, were present on the remaining seven sultry days. The largest negative lapse rates occurred on July 11, 12, and 14; the highest surface dew points also were observed on these days.

Given that the sultry air mass boundary layers were usually capped by strong stable layers that tended to suppress downward transport of dry air through vertical mixing, strong surface layer moisture sources probably developed the large moisture gradients within the dry adiabatic boundary layers.

Air Mass Transition. Summertime rainfall in the Middle West is often accompanied by the downward transport of rain-cooled air masses. These downdraft air masses, though humid, are cooler and usually drier than the air masses they displace. The downdraft air masses in July 1980 were either nonexistent or very shallow over the areas that formed sultry air masses. These conditions, combined with clearing skies, allowed for rapid heating after morning and early afternoon showers. The result was rapid evaporation and increasingly extreme surface humidities.

These conclusions were reached after a comparison of dew point and dry bulb temperatures with cloudiness and precipitation data. The results are summarized in tables 16 and 17.

Table 16. Temperature Ranges within the Sultry Air Masses at 1800 CST

July 1980 date	*Number of stations with T_d ≥76°F*	*Temperature range (°F)*
4	13	84-95
6	6	83-91
11	11	85-96
12	5	90-97
13	2	88-93
14	13	87-98
15	6	89-98
16	2	92-98

Note: Data are from the region shown in figure 11

Table 17. Sky Conditions within the Sultry Air Masses at 1800 CST

July 1980 date	*Number of stations with T_d ≥76°F*	*Number of stations with clear skies*	*Number of stations with scattered clouds*	*Number of stations with broken clouds*	*Number of stations with overcast skies*
4	13	5	6	1	1
6	6	3	2	1	0
11	11	4	1	4	2
12	5	1	2	2	0
13	2	2	0	0	0
14	13	6	3	1	3
15	6	4	1	1	0
16	2	0	0	2	0
Total	59	25	15	12	6

Note: Data are from the region shown in figure 11

Table 16 shows the temperature ranges within the areas where T_d ≥76°F. "Cooler" temperatures were found in cloudy areas. Hottest temperatures were located along the south and west flanks of the sultry air masses, areas located nearest the boundary with the hot, dry heat wave over Missouri. Table 16 also shows that the highest dew points tended to be found in the areas of highest temperature, the areas where temperature-dependent source functions had the longest time to contribute to the air mass moisture budget.

Table 17 gives a breakdown of sky conditions for stations within the area of the sultry air masses. As expected, there was a good correspondence with temperature. Clear skies and scattered clouds, conditions that permit plenty of sunshine and surface heating, were found in the hotter southern and western parts of the humid air masses. Clouds, often remnants of showers, were found over the eastern areas by 1800 CST.

In summary, then, the sultry air masses formed in response to regional moisture sources. The primary moisture source was evaporation from wet surfaces at high temperatures. (Sultry air masses did not form in cooler regions despite the presence of abundant moisture.) Evapotranspiration provided additional moisture. Strong capping stable layers inhibited mixing of dry air aloft into the boundary layers. These stable layers also confined heat within a sometimes shallow boundary layer, causing a rapid warm-up after showers had passed and skies had cleared.

Maintenance of Sultry Air Masses

The formation and persistence of sultry air masses over parts of the Middle West during July 1980 were possible because several meteorological systems of widely varying dimensions merged in space and time. The planetary motion scales contributed wave number 6, positioned so that the troughs were located along the east and west coasts and the ridge was located throughout the Middle West. The wave, which remained essentially stationary throughout July, determined the location and persistence of the synoptic scale storm track.

Synoptic scale subsidence within the planetary scale ridge warmed air masses over the Southern Plains. Slow anticyclonic circulation advected the hot, dry air masses into Missouri. Moving eastward, the dry heat wave overran a relatively cooler but more humid air mass over Illinois and parts of Iowa. This synoptic circulation created an air mass structure that was a shallow, moist layer overlain by a deep warm, dry layer, which in turn was overlain by a sometimes moist air mass above about 10,000 feet. The air mass configuration favored hot and humid conditions.

Subsynoptic scale weak low pressure disturbances moved through the upper Middle West and trailed weak frontal systems through the Iowa-Illinois region. Several of these fronts were so weak as to more closely resemble wind shift lines. They provided little or no relief from the sultry siege because humid air masses from Iowa were advected into Illinois in the weak northwesterly flow following the "fronts." Then the winds shifted to southeasterly in advance of the next weak low pressure disturbance and the humid air was recycled northwestward.

In this "sloshing back and forth" cycle, cooler and drier air masses occasionally invaded the Peoria area, and hot, dry air masses from Missouri moved through the St. Louis area at times. Springfield, Illinois was located near the "pivot" within the sultry air masses and thus recorded more frequent periods of sultriness than did the surrounding stations.

The subsynoptic systems were timed to pass through the sultry air mass genesis areas during the mornings and early afternoons. Figures 13 to 15 show that areas of precipitation frequented the Middle West on sultry air mass days.

Lines of thunderstorms developed along and ahead of the weak pressure disturbances as they approached Iowa from the northwest. Drawing from moisture in the layer above 10,000 feet, these storms generally produced light rainfall from middle level clouds as they passed over Illinois during the morning and early afternoon. They cleared out by late afternoon, thus having supplied the moisture and post-storm sky conditions favorable for sultry air mass genesis.

Chapter IV. Streamflow Conditions during the 1980-1981 Drought

H. Vernon Knapp

Introduction

Daily and monthly streamflow data for six gaging stations in southern Illinois (see figure 18) were used to evaluate streamflow conditions during the 1980-1981 drought. These six gaging stations have drainage basins which geographically represent the area affected by the drought. The lengths of the streamflow records for the six basins range from 36 to 57 years. There is some overlapping streamflow information, as the Skillet Fork Basin falls within the Little Wabash River Basin. The streamflow data used for the 1981 water year are provisional, having been obtained from the U.S. Geological Survey before final revision prior to publication. Precipitation data for these basins were from the stations shown in figure 18.

1. Macoupin Creek near Kane, 1940-1981
2. Shoal Creek near Breese, 1945-1981
3. Beaucoup Creek near Matthews, 1945-1981
4. Skillet Fork at Wayne City, 1928-1981
5. Little Wabash River at Carmi, 1939-1981
6. Cache River at Forman, 1924-1981

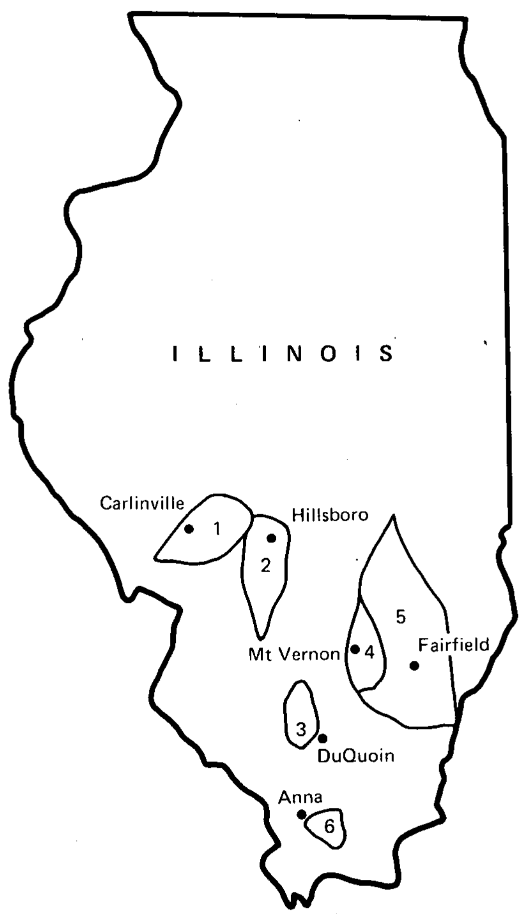


Figure 18. Drainage basins and rainfall stations usad in the streamflow analysis

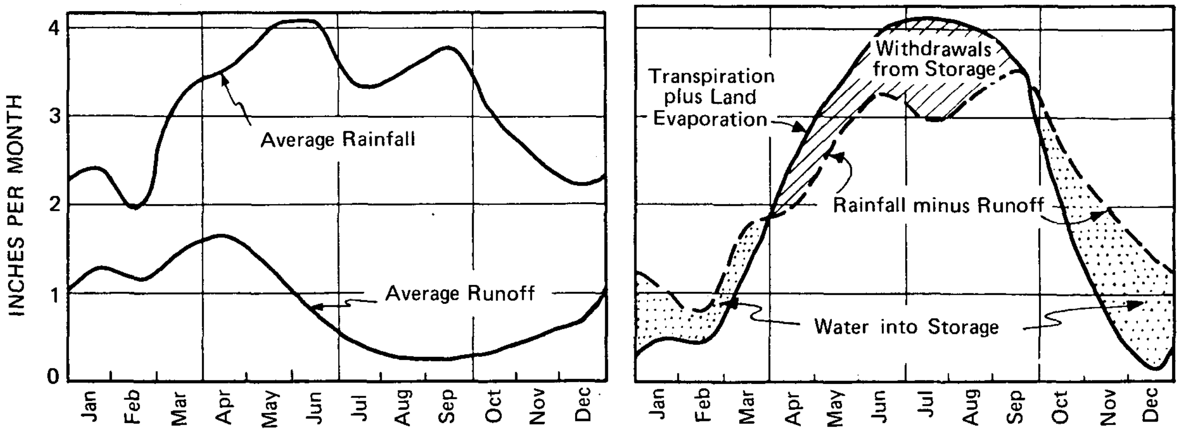


Figure 19. Seasonal variations in the hydrologic cycle, southern Illinois (from Hudson and Roberts, 1955)

Water Budget Aspects of Low Flow Conditions

The amount of streamflow which occurs during a given period is dependent not only upon the amount and character of the precipitation, but also upon the average soil moisture conditions and evapotranspirative demands associated with that period of time. This relationship is described by the water budget equation:

$$P = Q + ET + \Delta S \quad (1)$$

in which P is precipitation, Q is streamflow, ET is evapotranspiration, and AS is the change in storage for both groundwater and soil moisture.

Figure 19 illustrates the relationship of streamflow and precipitation during a normal year in southern Illinois. In the period between April and September, evapotranspiration is high, causing groundwater and soil moisture levels to be reduced (ΔS is negative) in order to meet the increased use of water. Between October and March, evapotranspiration is low, allowing the soil moisture storage to increase up to nearly saturated levels. By the months of February and March, the soil moisture storage normally is very high, and this allows a large percentage (normally 60 percent) of the precipitation to become runoff. Conversely, in August and September, when evapotranspiration is high and the soil moisture storage needs replenishment, streamflow volume is normally less than 10 percent of the rainfall volume.

The average water budget for southern Illinois shown in figure 19 is greatly modified during a drought. During the initial stages of a drought, the soil moisture is depleted because of a period of below normal rainfall. Once the soil moisture storage sinks below normal levels, a greater percentage of the precipitation is used for replenishing soil moisture; consequently storm runoff is reduced. In northern Illinois the reduction of storm runoff would not immediately have a detrimental effect on streamflow because a large proportion of the streamflow in that part of the state comes from groundwater discharge into the stream (Huff and Changnon, 1964; O'Hearn and Gibb, 1980). However, in southern Illinois the groundwater contribution to streamflow is very small, and streamflow during drought periods is generally less than 10 percent of the normal flow. Months of normal precipitation often occur during periods of drought, but the rainfall from these months usually temporarily replenishes soil moisture and does little for the recovery from low flow conditions.

Characteristics of the Streamflow

Pattern of Streamflow Deficiencies, 1979-1981

Deficient streamflow existed for each of the six streams indicated in figure 18 for a period of approximately two years, May 1979 to April 1981. As shown in table 18, the low flows in year 1 ranged from 28 to 90 percent of normal, but fell to 7 to 22 percent of normal in the second and drier year. However, the temporal distribution of the streamflow deficits followed two different patterns. The Macoupin Creek and Shoal Creek Basins (in the west-southwest district) first experienced one moderately dry year and then a second drier year. In contrast, the four basins in southernmost Illinois experienced very little deficit during the first 12 months of this period, and then sustained extremely low streamflow during the latter 12 months. Of the four southernmost basins, only the Cache River Basin had extremely low precipitation during the May 1980-April 1981 period. However, each of these basins encountered much lower streamflow the second year. This situation is likely a result of the soil moisture shortages which had developed during the first year of precipitation deficit, mid 1979-early 1980.

Figure 20 illustrates the Cache River streamflow during part of this 2-year period. In the period of August 1980 to April 1981 the streamflow volume was only 7 percent of normal, even though rainfall was 67 percent of normal. Rainfall was average or above average during October 1980 and February 1981; however, streamflow for these months remained lower than 20 percent of normal. The dry conditions present by May 1981 required an unusual surplus of precipitation to allow for recovery from the low flow conditions. The 10-inch rainfall of that month at Anna accomplished this recovery, but of the 10 inches of rain, only 3.5 inches resulted in runoff.

For most of southern Illinois, the cumulative precipitation deficits (actual deviations from normal) experienced in the years 1979-1981 were almost equally matched by the cumulative streamflow deficits. For instance, in the period of May 1979 to April 1981, the Macoupin Creek Basin experienced 11.2 inches of cumulative rainfall deficit. The streamflow deficit during this period of time was 12.4 inches. The patterns of both the rainfall and streamflow cumulative deficits are very similar (see figure 21). Huff and Changnon (1964) showed the close relationship between low precipitation and low runoff in these basins when the event return frequencies exceeded once in 5 years. Only during May and June of 1981, when there was a delay in the recovery from low streamflow conditions, did the two patterns diverge. Similar close relationships are shown in figures 22 and 23 for the Skillet Fork and the Cache River Basins, respectively. Because the streamflow and precipitation deficits are alike in magnitude, the water budget equation

Table 18. Rainfall and Streamflow for May 1979 – April 1981, Expressed as Percent of Normal

	First year May 1979-April 1980		*Second year May 1980-April 1981*	
	Precipitation	*Streamflow*	*Precipitation*	*Streamflow*
Macoupin Creek	83.6	27.9	85.7	16.1
Shoal Creek	73.8	35.2	91.4	22.1
Beaucoup Creek	81.3	63.8	75.6	9.9
Skillet Fork	93.1	71.4	79.5	6.9
Little Wabash River	91.0	90.3	72.4	16.9
Cache River	91.0	74.7	59.0	8.4

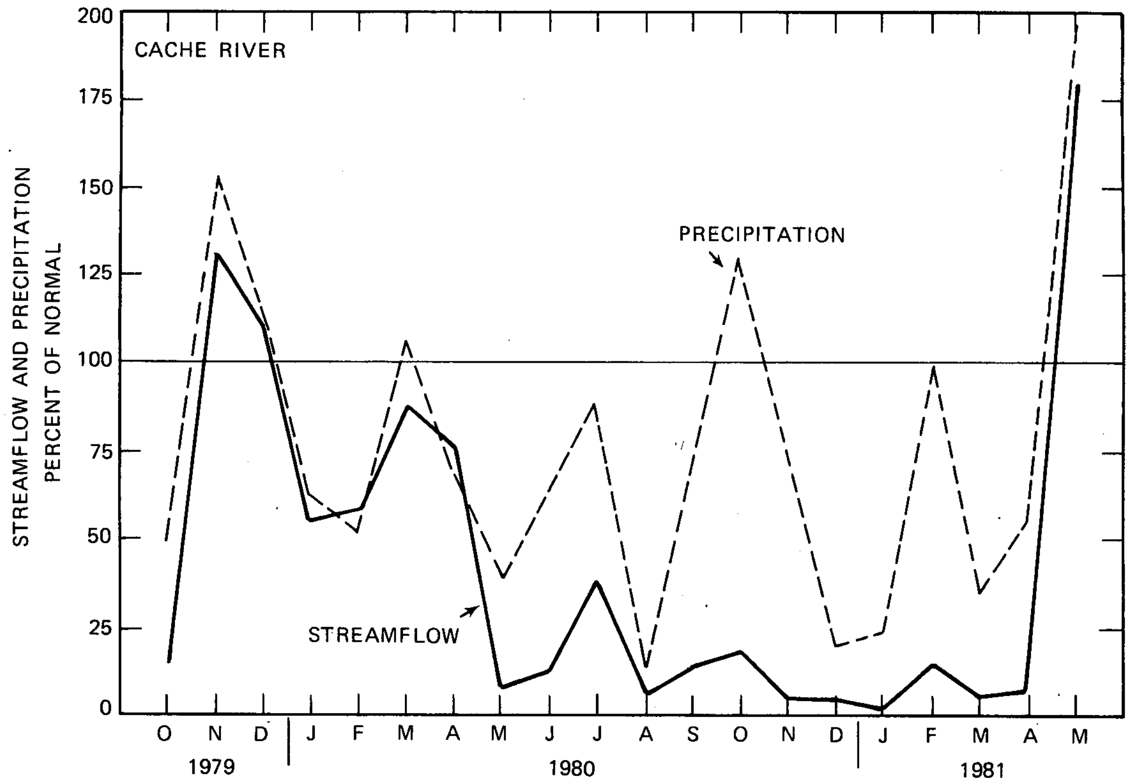


Figure 20. Cache River Basin precipitation and streamflow; percent of normal, October 1979-May 1981

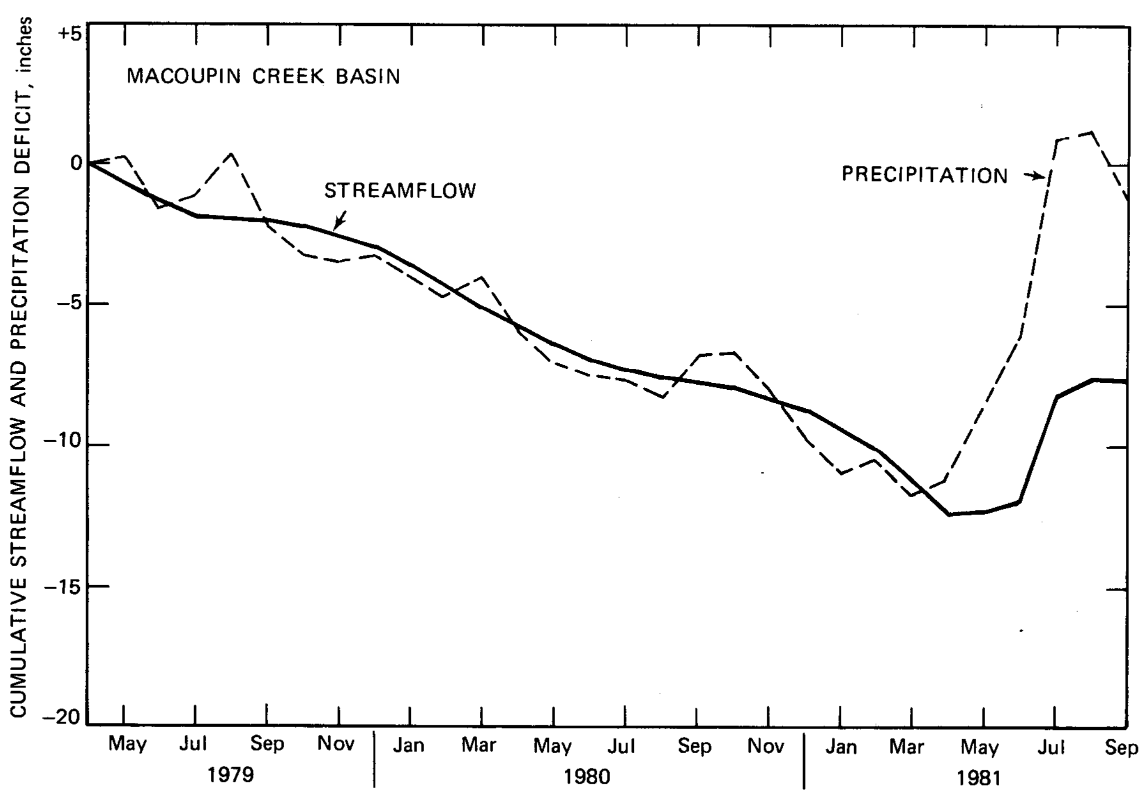


Figure 21. Macoupin Creek Basin precipitation and streamflow; cumulative deviation from normal

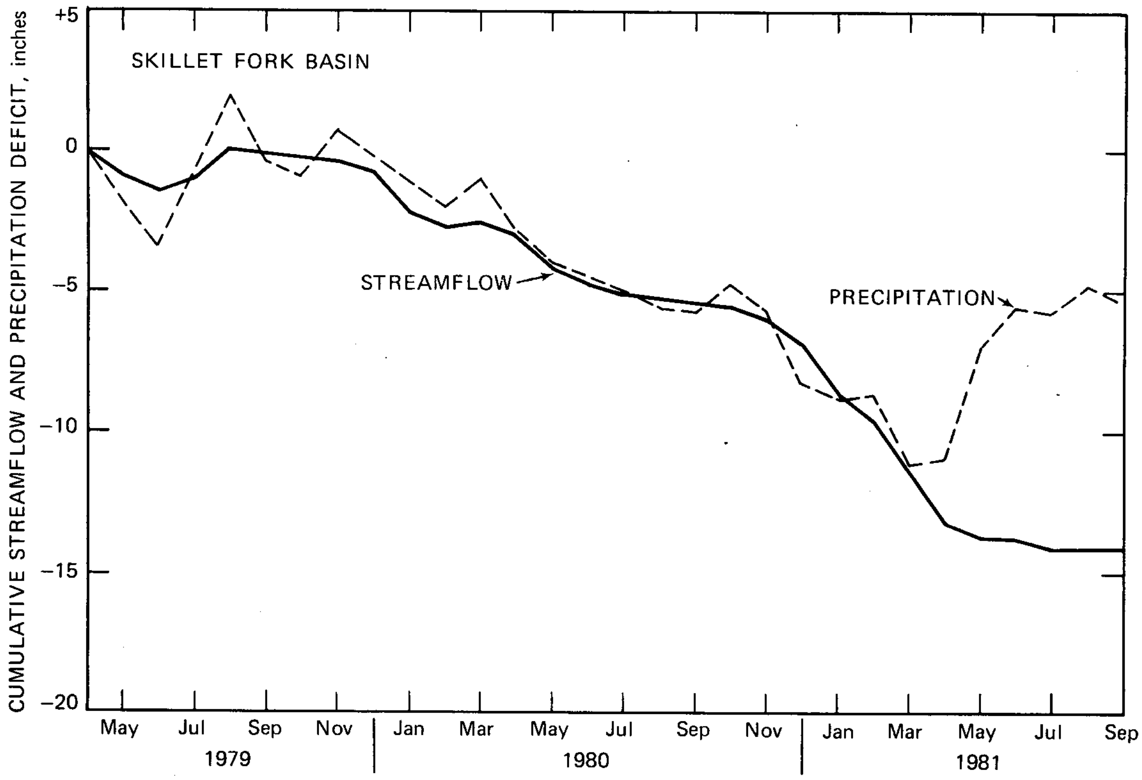


Figure 22. Skillet Fork Basin precipitation and streamflow; cumulative deviation from normal

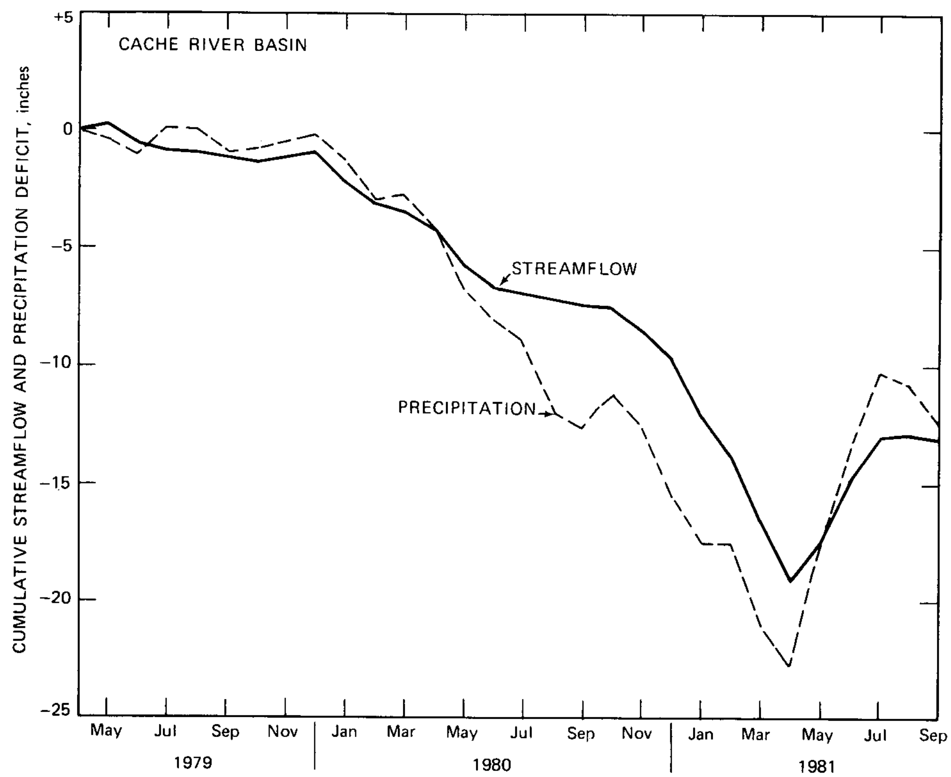


Figure 23. Cache River Basin precipitation and streamflow; cumulative deviation from normal

Table 19. Minimum Average Streamflow for Short Durations, 1979-1981

	Minimum flow (cfs)	*Percent of normal*	*Recurrence interval (yrs)*
Macoupin Creek near Kane			
7 days	3.51	45.1	4.5
15	3.58	37.2	4.5
30	4.61	36.2	4.5
60	4.63	21.8	6.1
90	5.23	14.6	7.4
Shoal Creek near Breese			
7 days	4.60	48.8	5.2
15	5.47	48.0	4.7
30	8.46	51.1	3.3
60	11.61	37.3	4.7
90	15.67	29.4	4.7
Beaucoup Creek near Matthews			
7 days	3.03	216.4	1.6
15	3.84	172.7	1.6
30	5.20	156.6	1.6
60	6.65	100.6	2.0
90	7.89	60.1	2.8
Skillet Fork at Wayne City			
7 days	.10	14.5	4.0
15	.42	44.2	2.7
30	.68	43.6	3.0
60	1.35	35.0	4.4
90	1.49	18.7	8.0
Little Wabash River at Carmi			
7 days	34.9	145.5	1.5
15	38.9	105.6	1.7
30	40.4	81.4	2.1
60	58.2	57.3	2.5
90	63.8	44.8	4.2
Cache River at Forman			
7 days	.21	52.5	2.8
15	.47	75.8	2.8
30	3.21	150.7	2.3
60	5.77	86.9	2.2
90	6.64	57.6	4.5

(equation 1) suggests that the decreases in groundwater and soil moisture storage measured during the drought period are most closely associated with concurrent increases in evapotranspiration. The results in Chapter II suggest that evapotranspiration was quite large in this area.

Intensity of Low Flows

Table 19 shows the minimum average streamflow experienced in the years 1979-1981 for various durations of less than 90 days on the six streams. The return intervals given for the observed flows indicate that the short-term minimum flows which occurred during the drought period are flows that are expected on the average of once every two to five years. Most of the short-term flows shown in table 19 also occurred during or around the time of the year when flows are ordinarily lowest in magnitude.

Table 20. Monthly Streamflow for January – April 1981

	Monthly flow (inches)	Percent of normal	Recurrence interval (yrs)
Macoupin Creek near Kane			
January	.01	1.2	14.0
February	.10	12.1	4.7
March	.03	2.7	21.0
April	.20	15.4	7.0
Cumulative, January-April	.34	8.7	21.0
Shoal Creek near Breese			
January	.03	3.2	12.3
February	.25	20.4	4.1
March	.14	9.6	18.5
April	.24	17.2	9.2
Cumulative, January-April	.66	13.0	18.5
Beaucoup Creek near Matthews			
January	.03	1.9	9.2
February	.45	26.3	4.6
March	.10	4.1	18.5
April	.02	.9	37.0
Cumulative, January-April	.60	7.6	18.5
Skillet Fork at Wayne City			
January	.003	.1	54.0
February	.19	15.4	5.4
March	.04	2.3	27.0
April	.11	5.7	18.0
Cumulative, January-April	.34	5.2	27.0
Little Wabash River at Carmi			
January	.02	1.2	14.3
February	.30	21.9	4.8
March	.14	7.1	14.3
April	.14	7.9	14.3
Cumulative, January-April	.60	9.3	21.5
Cache River at Forman			
January	.02	.6	29.0
February	.32	16.2	7.2
March	.19	6.1	19.3
April	.19	7.0	58.0
Cumulative, January-April	.72	7.0	58.0

If the low streamflow conditions are considered not in terms of absolute volume but also in terms of volume relative to expected conditions, the flows of January through April 1981 were the worst of the drought period (see table 20). Collectively these four months were the driest first four months of any year on record with the exception of 1954. In summary, low flows were not severe at any particular time within the drought period. However, the carry-over of low flow conditions into the spring of 1981 is unusual.

Frequency and Duration of Low Flows

The minimum cumulative streamflow for each of the six basins for durations ranging from 6 to 36 months is given in table 21. From this information, it appears that the 1980-1981 low flows had an average recurrence interval of from 8 to 10 years. The flow period most affected

Table 21. Minimum Cumulative Streamflow for Selected Durations, 1978-1981

	Cumulative streamflow (inches)	*Percent of normal*	*Recurrence interval (years)*
Macoupin Creek near Kane			
6 months	.11	5.4	8.4
9	.42	9.7	14.0
12	1.24	16.1	8.4
18	2.31	23.7	14.0
24	3.38	21.9	10.5
36		59.7	10.5
Shoal Creek near Breese			
6 months	.41	18.4	4.6
9	1.16	23.3	6.2
12	2.00	22.1	9.2
18	3.38	29.9	9.2
24	5.18	28.6	9.2
36		62.7	7.4
Beaucoup Creek near Matthews			
6 months	.34	11.8	6.7
9	.73	10.4	14.8
12	1.31	9.9	18.5
18	7.10	43.9	5.3
24	9.78	36.8	9.2
36		81.0	6.2
Skillet Fork at Wayne City			
6 months	.03	1.6	27.5
9	.28	5.6	18.0
12	.75	6.9	27.0
18	4.14	32.2	8.0
24	7.81	35.7	18.3
36	26.65	81.2	2.5
Little Wabash River at Carmi			
6 months	.37	16.9	8.1
9	.95	17.0	12.2
12	1.82	16.9	14.9
18	7.32	56.3	8.4
24	11.57	53.6	11.4
36	28.72	88.6	5.3
Cache River at Forman			
6 months	.22	7.1	10.5
9	.92	10.6	19.3
12	1.38	8.4	58.0
18	10.55	54.2	9.7
24	13.61	41.5	14.0
36	26.65	79.3	6.4

by the drought is that for a duration of 12 months. The 12-month runoff from May 1980 to April 1981 was extremely low as a result of the abnormal low flows experienced from January to April in 1981. The 12-month return intervals in extreme southern Illinois ranged from 14 years on the Little Wabash to 58 years on the Cache.

The total amount of streamflow deficits occurring during specific drought periods from 1931 to 1981 are listed in table 22 as a measure for comparing the 1980-1981 streamflow with

Table 22. Total Streamflow Deficits for Historical Droughts

	Streamflow deficit (inches)	*Duration of deficit (months)*
Macoupin Creek (1941-1981)		
May 1952-Mar 1957	30.80	59
Apr 1962-Mar 1966	18.09	48
May 1979-Apr 1981	12.05	24
May 1975-Feb 1977	7.73	22
Shoal Creek (1946-1981)		
May 1952-Mar 1957	32.25	59
Jun 1963-Jan 1966	16.36	32
May 1979-Apr 1981	12.94	24
Jun 1975-Feb 1977	10.33	21
Beaucoup Creek (1946-1981)		
May 1952-Mar 1957	42.59	59
May 1964-Apr 1967	27.99	36
May 1979-Apr 1981	16.78	24
May 1975-Feb 1977	13.53	22
Skillet Fork (1929-1981)		
May 1952-Feb 1955	20.10	34
May 1939-Jan 1942	18.24	33
Jul 1964-Feb 1967	15.05	32
Aug 1979-Jul 1981	14.09	23
Mar 1930-Jul 1931	13.71	17
May 1975-Feb 1977	12.87	22
Little Wabash River (1939-1981)		
May 1952-Mar 1957	29.82	59
Apr 1962-Nov 1967	28.08	68
May 1939-Sep 1941 (EST)	16.79	29
Jun 1975-Jul 1977	15.52	26
Jul 1970-Mar 1972	11.06	21
May 1980-Apr 1981	8.98	12
Cache River (1924-1981)		
Apr 1952-Feb 1955	31.67	35
May 1939-Jan 1942	26.76	33
Mar 1930-Dee 1931	21.70	22
Jun 1979-Apr 1981	19.33	23
Apr 1964-Mar 1966	16.59	24
Jun 1975-Feb 1977	11.91	21

historical drought flows. The streamflow deficits shown are for the maximum drought period, within which no three consecutive months have a cumulative streamflow which is greater than normal. The streamflow deficit of the 1980-1981 drought was the second greatest since the 1952-1955 drought, surpassed only by the low flow conditions during the mid-1960's. However, each drought is unique in the character of its intensity and duration, and in some cases the streamflow deficit may not be an accurate measure of the effect of the drought. For example, even though the 1964-1965 drought had a large streamflow deficit, the spring seasons during this drought were only moderately dry, and enough streamflow occurred to allow some recharge of surface water impoundments.

Effects of the 1980-1981 Drought on Water Supplies

Without the occurrence of low flow conditions in the spring months of 1981, the dry conditions present in 1979-1980 would hardly merit special attention. However, extended low flow conditions in the spring are very uncommon, and are usually associated with serious drought conditions. Many small water supply facilities, such as small reservoirs and ponds, are heavily dependent on spring streamflow surpluses, and some of these facilities experienced severe shortages during the spring of 1981. Selected cases of these shortages are described in Chapter VI. None of the large reservoirs in southern Illinois experienced shortages during this period, and flow in the major streams did not reach levels low enough to affect the facilities which intake water directly from the stream.

The great danger posed by the occurrence of an extremely dry spring, such as the early spring of 1981, is that low flow conditions will continue into the summer and fall without relief. The burden of withstanding two full years of withdrawal without substantial recharge would undoubtedly produce shortages in all but the largest or most dependable water supply facilities of the region.

Quality of Streamwater during Low Flows

At times of low flow, the relative contribution of groundwater to streamflow increases. In most cases the groundwater is more highly mineralized than is the surface runoff, allowing for a chemical overloading of the stream during low flow periods. During low flows there is an increase in stream alkalinity, as well as increases in the concentrations of minerals such as calcium, phosphate, potassium, fluoride, chloride, and sodium constituents (Crown and Flemal, 1978). The increase of these latter minerals equates with an increase in stream salinity. A few minerals, however, tend to precipitate out of the stream when the discharge is not high, and during times of low flow the concentrations of these minerals will be low. Included among this latter group are iron and manganese. Average measurements of five water quality parameters taken on the Cache and Big Muddy Rivers during the drought period support the expected changes in mineral concentrations (see table 23). Only the decrease in the average chloride concentration measured on the Big Muddy River conflicts with the expected increases or decreases in concentrations. The turbidity and the amount of suspended sediment in the streamflow are related to discharge and therefore are relatively low during low flow periods.

Table 23. Average Streamwater Quality for the Cache and Big Muddy Rivers, May 1980-April 1981

(Concentrations in milligrams per liter)

	Calcium	*Sodium*	*Chloride*	*Iron*	*Alkalinity*
Cache River at Forman					
1980-1981	37.2	16.5	18.8	3.47	
Normal	22.2	9.7	7.5	6.88	
Big Muddy River at Murphysboro					
1980-1981	79.2	116.9	42.1	.89	94.8
Normal	59.3	53.2	50.8	4.48	60.7

Chapter V. Groundwater Conditions

Robert D. Olson

Drought Effects on Aquifers: The Groundwater Budget

The effects that droughts have on the groundwater aquifers of Illinois are governed by the variables of the groundwater budget, which is but a part of the general hydrologic budget. A detailed description of these budgets is beyond the scope of this report; however, a general description is relevant to understanding the extent and impact of the drought on the state's groundwater resources.

Illinois can be divided into a number of groundwater drainage basins corresponding roughly to the surface water drainage basins. The general hydrologic cycle can be stated in the form of a simple equation (Schicht and Walton, 1961):

$$P = R + ET + U \pm \Delta S_s \pm \Delta S_g \tag{2}$$

where:

P = precipitation
R = streamflow
ET = evapotranspiration
U = subsurface underflow
ΔS_s = change in soil moisture
ΔS_g = change in groundwater storage

Precipitation (P) in the form of rain and snow is the only water source for these basins and is the only water gain in the budget. As stated earlier in this report average precipitation increases from north-to-south across Illinois. Streamflow can be divided into surface runoff, R_s, and groundwater runoff, R_g. Surface runoff consists of precipitation that finds its way to a stream without infiltrating into the soil. Precipitation which infiltrates into the soil or water table and eventually discharges into a stream is groundwater runoff. All surface runoff is completed 3 to 5 days after precipitation or snow melt, after which time streamflow is derived entirely from groundwater (Schicht and Walton, 1961). Streamflow is normally high in winter and spring, and low in the summer and fall seasons.

Water is lost from the basins directly to the atmosphere through evapotranspiration, a process combining evaporative losses from land and water surfaces with transpiration losses from vegetation. Evapotranspiration can be divided into surface and soil evapotranspiration, ET_s, and groundwater evapotranspiration, ET_g. The surface and soil evapotranspiration is derived from soil moisture and evaporation from water, vegetation, and object surfaces; the water table is the source for groundwater evapotranspiration. Evapotranspiration losses follow the same general yearly pattern; they are very small during the winter, increase rapidly during the spring, reach maximum in early summer, and then decrease rapidly in fall around the time of the first killing frost (figure 19). Precipitation normally is exceeded by evapotranspiration losses during the summer, but losses are much less than precipitation during the winter and early spring.

Subsurface underflow, U, is the movement of groundwater out of one basin and into another. Soil moisture (S_s) is the water held in the soil by molecular attraction. Soil particles attract water molecules around them up to a point where no more water molecules can be attracted. At this point the field capacity of the soil has been reached. The higher the soil moisture content, the greater the potential for infiltration. Average annual changes in soil moisture are very small (Schicht and Walton, 1961); however, daily, weekly, and monthly changes throughout the year can be significant. Soil moisture is near field capacity during January of most years.

Groundwater storage, S_g, also known as "gravity yield," refers to the amount of water saturated subsurface materials will release under natural gravitational forces. Changes in groundwater storage are directly related to changes in the groundwater levels. Lower groundwater levels mean less saturated materials and thus less water in storage. The yields of various materials vary in accordance with their porosity and field capacity (Wisler and Brater, 1959). Changes in groundwater storage result from the difference between recharge and discharge of water, which produces a secular pattern over a period of several years. Generally storage is at a maximum during above normal precipitation years and at a low during below normal precipitation years. The minimum storage levels (minimum water levels) should be used as a basis for designing water supply systems.

A portion of the hydrologic budget can be excerpted to represent a groundwater budget. The groundwater budget can also be expressed as a balanced simple equation of the form:

$$P_g = R_g + ET_g + U \pm \Delta S_g \tag{3}$$

where:

P_g = groundwater recharge
R_g = groundwater runoff
ET_g = groundwater evapotranspiration
U = subsurface underflow
ΔS_g = change in groundwater storage

This equation states that, over a given period of time, that portion of precipitation falling on a given basin that percolates down through the soil and becomes groundwater (recharge) must be balanced by groundwater runoff, underflow, and evapotranspiration along with an addition to or subtraction from groundwater storage.

Groundwater runoff is dependent upon several factors. Inherently, it depends on the position of the water table and its hydraulic gradient, and their relation to the stream bed level. Obviously, if groundwater levels are below the stream bed, little groundwater runoff can occur. Groundwater runoff is also affected by topography, soil permeability, surficial geology, climatology, and evapotranspiration. Evapotranspiration during the summer months can be very effective in limiting groundwater runoff. In general, groundwater runoff is greatest in northeastern Illinois and lowest in the clay pan areas in southern Illinois (O'Hearn and Gibb, 1980). This relationship appears to be even stronger in years with below normal precipitation (Walton, 1965).

Groundwater evapotranspiration is closely related to the season of the year and the groundwater stage. Losses through groundwater evapotranspiration are small from November to April, and high during early summer. The potential for groundwater evapotranspiration increases as the water table approaches the land surface where the roots of plants and soil capillaries can capture the water.

Groundwater recharge occurs whenever precipitation exceeds evapotranspiration and soil moisture requirements. Groundwater recharge occurs whenever the mean groundwater level rises, or declines less than necessary to balance groundwater runoff, evapotranspiration, and underflow (Schicht and Walron, 1961).

Recharge to surface deposits can occur at relatively high rates, especially when these deposits contain significant amounts of sand and gravel. However, large areas in Illinois are covered by 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 of surficial deposits may far exceed the leakage to the deep aquifers during wet periods. Thus the surficial deposits act as temporary reservoirs until the groundwater can leak through the till and into the deep aquifers. Hence recharge to deep aquifers is buffered from short-term irregularities in precipitation, and a lag time exists for reaction to drought.

Effects of Precipitation Droughts on Water Levels

In the hydrologic and groundwater budgets, precipitation is the chief variable which will ultimately affect groundwater levels and the amount of groundwater available for use. Other natural and human influences on groundwater levels exist in varying degrees. Atmospheric pressure changes, earthquakes, changes in surface water stages, and earth tides are some of the natural causes. Human activities such as surface loading due to train or barge traffic, and groundwater pumpage, also affect groundwater levels.

Groundwater levels used in this study are from observation wells remote from pumping centers and streams; thus some of the effects of these variables are eliminated. The remaining variables are of minimal significance under normal circumstances, particularly when considering an area as large as the state.

Examples of the general correlation between precipitation patterns and groundwater levels are illustrated in figures 24 and 25. These figures show monthly precipitation amounts and shallow groundwater levels at two sites in the west-southwest (Greenfield) and southwest (Sparta) sections of Illinois. Some generalizations about the groundwater budgets at these sites can be made.

Precipitation and groundwater level data for Greenfield and Sparta show that moderate monthly rainfall amounts caused groundwater levels to recover during the fall and winter months; however, during the late spring and summer months, water levels declined despite similar rainfall amounts. This is chiefly due to the effects of surface and soil evapotranspiration in limiting groundwater recharge, along with the depletion of groundwater storage by groundwater evapotranspiration and groundwater runoff. Only in cases of excessive precipitation during summer months do groundwater levels recover during that time of the year, as occurred in May-July 1981.

Groundwater Levels during the 1980-1981 Drought

The State Water Survey maintains a statewide observation well network to monitor shallow groundwater levels remote from pumping centers. A network of 20 shallow wells, each equipped with an automatic water level recorder, is maintained (see figure 26a). The objective of the network is to monitor the natural short- and long-term fluctuations of the state's water table. Most of these wells have been monitored since the early 1960's, and data for 5 of them go back to the 1952-1955 drought. In addition, the Water Survey maintains observation wells in regional aquifer systems and selected areas of pumpage to provide data for different studies on groundwater and its development.

The data from the 20-well network was studied extensively to discern the short-term and long-term trends during the drought period. A 15-year moving average (normal) was computed

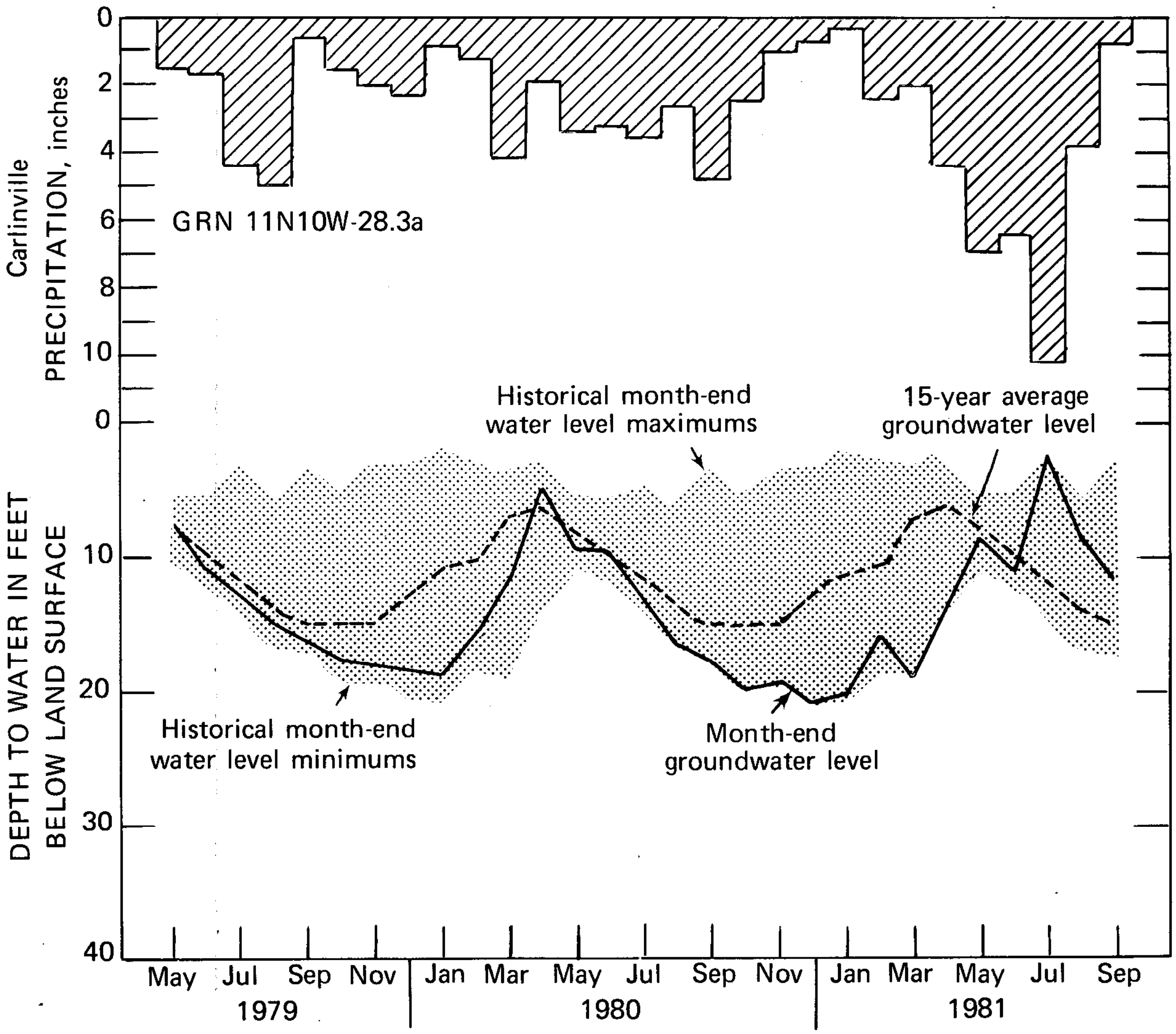


Figure 24. Groundwater levels at Greenfield observation well

for each well along with departures from normal for each month during parts or all of the years 1979-1981. Data from May 1979 to September 1981 were analyzed to show groundwater levels prior to and following the drought period defined by the precipitation data. Departures of measured groundwater levels from their corresponding normal water levels were accumulated for the same time periods used in the precipitation analysis. In addition, monthly groundwater levels were compared to the record high or low groundwater stages. Monthly groundwater levels reported on or immediately before the last day of each month were used in the analysis for each well.

The climatological assessment (Chapter II) noted that the drought of 1980-1981 had many features similar to droughts of the past. Precipitation deficiencies were most severe in southern Illinois. Comparisons were made between the precipitation for the 3-month, 6-month, 12-month, and total drought period, and the accumulated groundwater departures from normal.

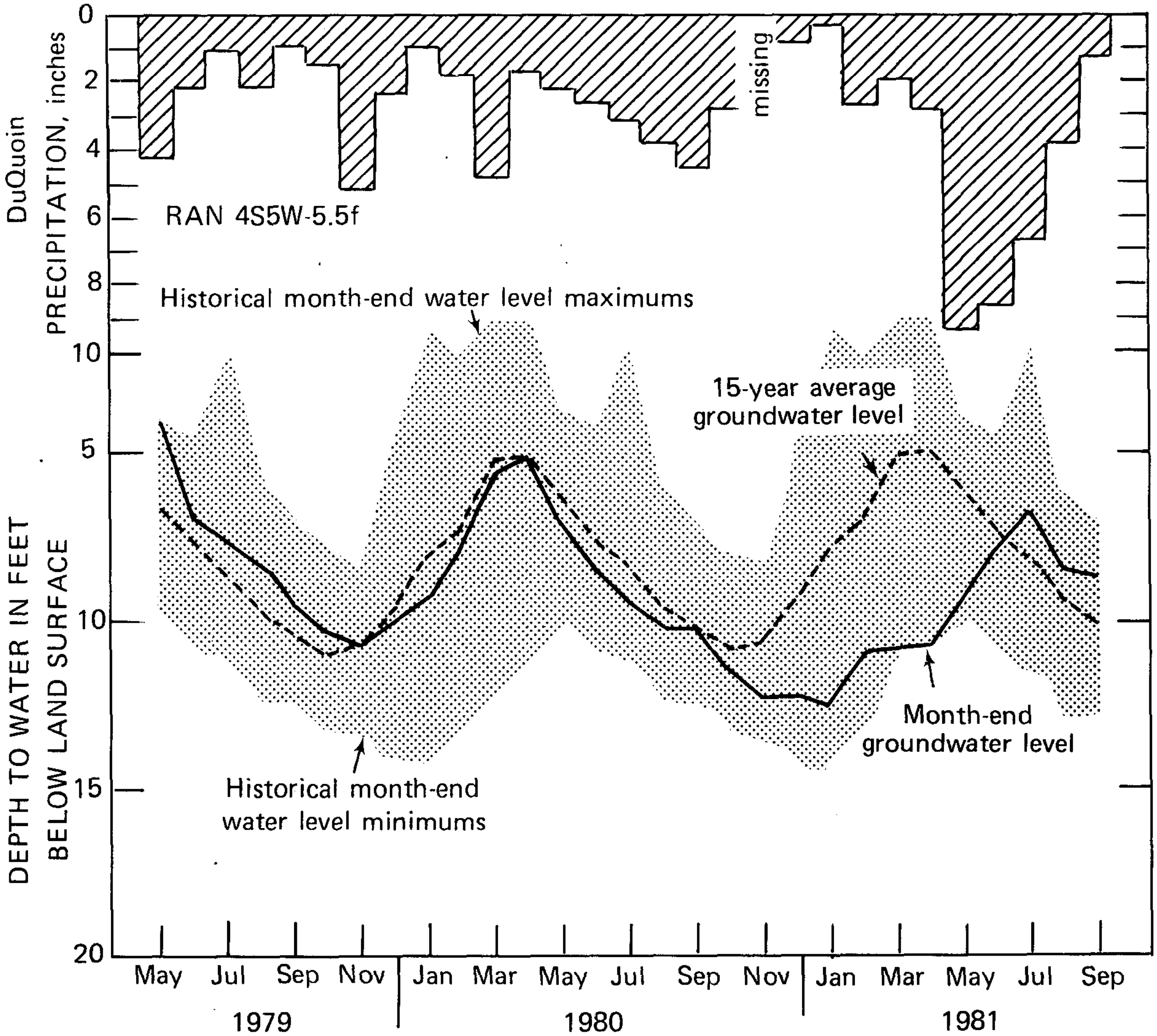


Figure 25. Groundwater levels at Sparta observation well

Groundwater level departures from normal were computed for the same time periods as for precipitation.

Drought Period, February 1980 to April 1981

The accumulated groundwater level departures from normal for the drought period (figure 26a) indicate a general north-to-south increase in severity. The zero contour, at which groundwater levels were normal, separates the northern third of the state from the southern two-thirds. Furthermore, the largest departures were concentrated in southwestern Illinois, roughly corresponding to the largest precipitation deviations below normal (figure 2).

An interesting note is the large departure from normal occurring at the observation well near Cairo. The month-end groundwater levels for this well for the period from May 1979 to

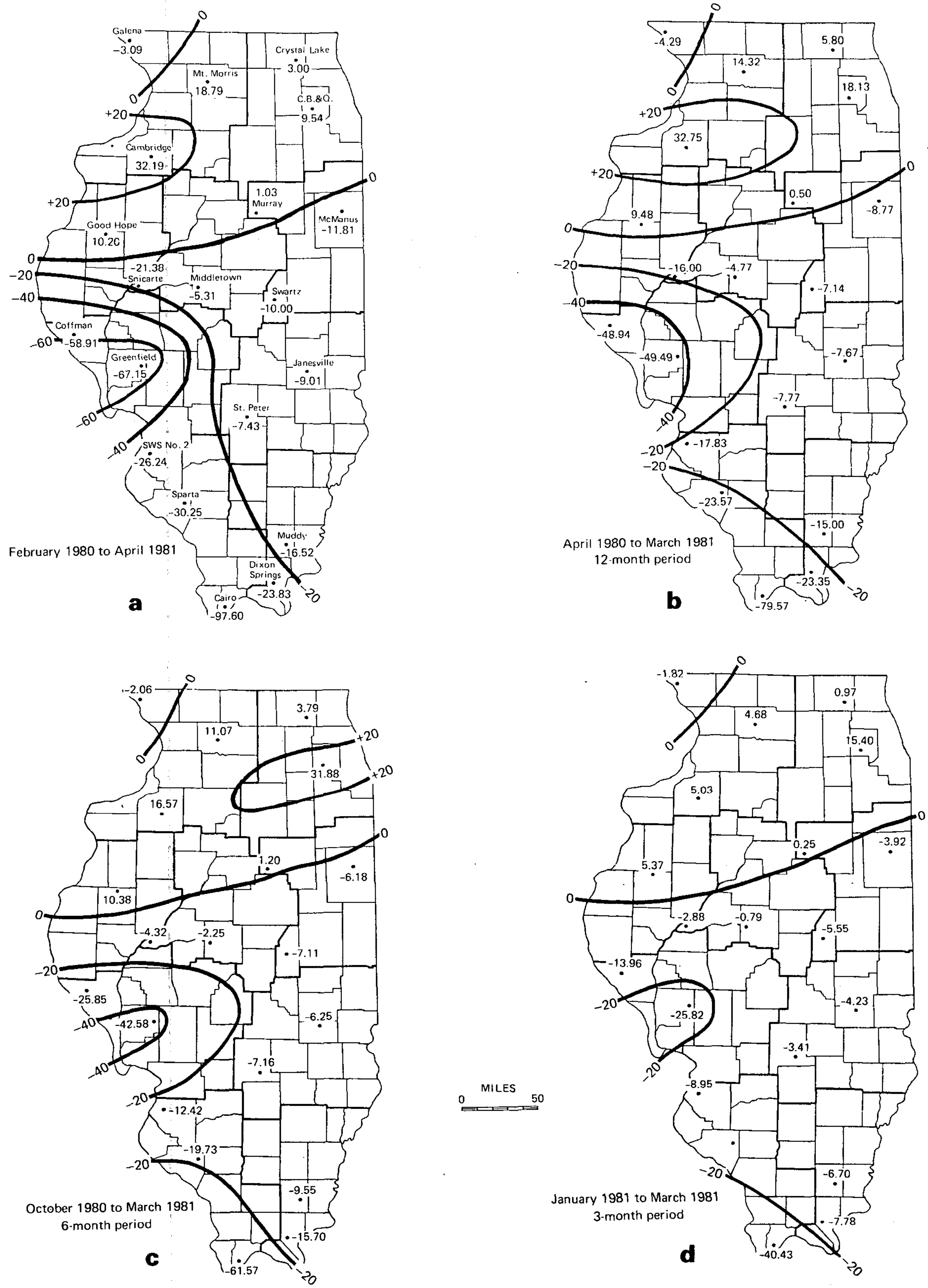


Figure 26. Accumulated groundwater stage departures from normal (in feet) for different periods of the 1980-1981 drought

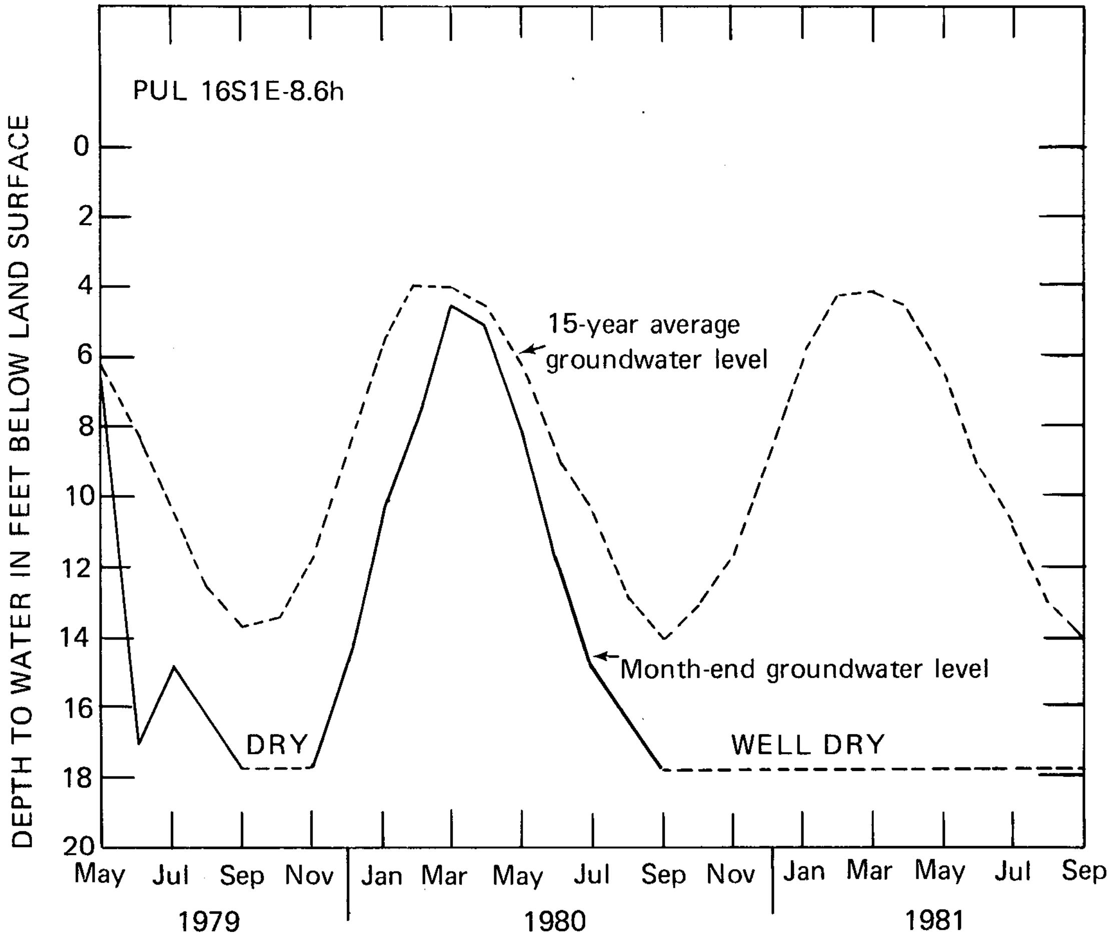


Figure 27. Groundwater levels at Cairo observation well

September 1981, along with the long-term average levels, are plotted in figure 27. It can be seen that shallow groundwater levels near this well were below normal for the entire period.

In fact, groundwater levels in this area had not fully recovered from the drought of 1976-1977. Since February 1976, monthly groundwater levels had been at normal during only four months. Except for 1978, precipitation in the area had been near normal or below. In 1978 when precipitation was 123% of normal, a significant amount of the precipitation fell during the summer months when evapotranspiration was high and the soil moisture content was low as a result of the previous dry months. Thus, recharge was somewhat limited during 1978.

12-Month Drought Period, April 1980-March 1981

Accumulated groundwater level departures from normal for the driest 12-month period (figure 26b) followed the same general pattern as those for the entire drought period. Groundwater deficiencies show that the drought was most severe in the west-southwest area of Illinois, with the extreme southwest the second most affected area. Departures in the north appear to have been nearly the same as for the entire drought period, with groundwater levels above average, except at Galena where groundwater levels were slightly below normal.

6-Month Drought Period, October 1980-March 1981

During this time period, the area of greatest above normal groundwater level departures shifted from northwestern to northeastern Illinois (figure 26c). It is worth noting that groundwater levels were above normal in the northern third of the state, whereas precipitation was well below normal (80 percent or less). This shows the importance of evapotranspiration in the hydrologic budget. During the time period of October through March, losses due to surface and groundwater evapotranspiration are at a minimum. Thus most of the precipitation that does not run off as surface water percolates down to add to groundwater storage. During this period, declines in groundwater storage are limited to groundwater runoff to streams and subsurface underflows.

The general lack of response of groundwater levels to precipitation also can be explained by the nature of the groundwater infiltration and runoff processes which tend to average out short-term changes in precipitation over longer periods of time. Thus, as smaller time periods are considered, extremes in precipitation may be masked by slow responses in groundwater storage.

As in the total and 12-month drought periods, the groundwater levels in the west-southwest section of Illinois were most affected by the drought (figure 26c). Likewise, an area of moderate influence existed in the extreme southwest.

3-Month Drought Period, January-March 1981

The zero departure contour line remained in nearly the same location for all four drought periods examined (figure 26). Effects of the 3-month drought on groundwater levels (figure 26d) were very similar to those of the 6-month drought. Groundwater levels in the northern third of the state were above normal, while precipitation was little better than 50 percent of normal (figure 4). As before, the minimal evapotranspiration and slow response/averaging effect of groundwater to precipitation are the probable explanations. Oddly, the areas where precipitation was closest to normal (approximately 75 percent) roughly corresponded to areas where groundwater departures were largest. Here, soil moisture was low from lack of precipitation in previous months and most of the precipitation not lost to surface runoff was utilized in replenishing the soil moisture.

The drought severity was concentrated in the west-southwest and extreme southwest areas of the state, This is the general pattern seen throughout the drought periods studied.

End of Groundwater Drought

By the end of April 1981, defined as the last month of the precipitation drought, groundwater levels were well below normal throughout southern Illinois and most other areas of the state (figure 28). However, recharge was noted in many areas and most groundwater levels had reached their deepest levels for the drought period. By July 1981 (figure 28) recovery was complete as all groundwater levels were above or very near normal. The north-to-south pattern of wet-to-dry conditions so vivid throughout the 1980-1981 drought had completely disappeared.

Groundwater Drought Severity

Groundwater levels recorded throughout the drought period indicate that the groundwater drought was generally mild. However, some local areas may have experienced severe depletion of groundwater storage for short periods of time.

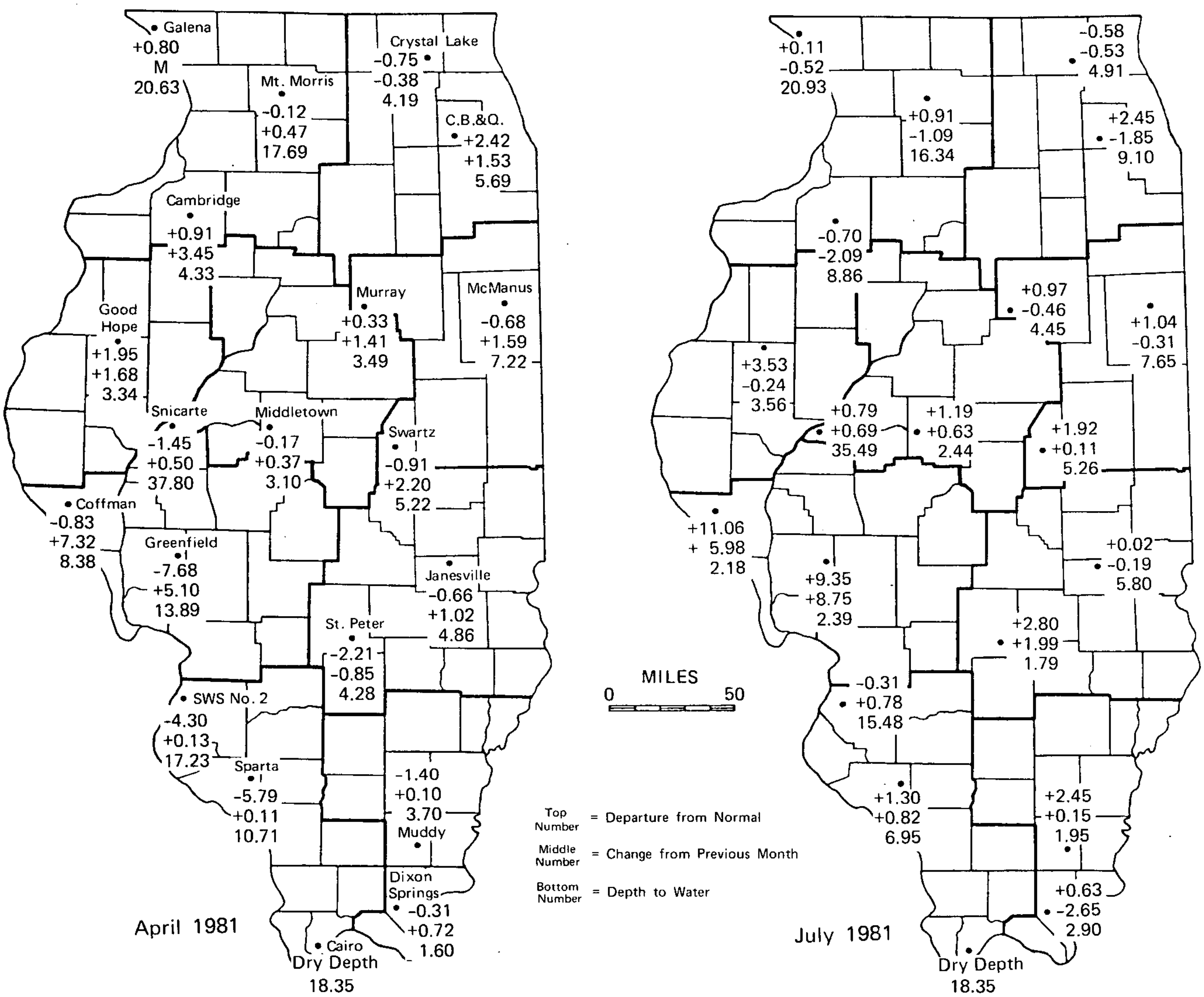


Figure 28. Groundwater levels at 20 observation wells (in feet). April and July 1981

The greatest monthly departure below normal and the deepest monthly groundwater level for each observation well during the period May 1979 to September 1981 are shown in figure 29. The greatest monthly departures occurred in the latter stages of the precipitation drought period throughout most of the southern half of the state. However, maximum monthly depths in this same area occurred in earlier stages of the drought period. This trend is expected, as many of these maximum depths occurred in late summer, fall, and early winter when the normal water levels are naturally low. Through the late winter and early spring of 1981, a period when normal groundwater levels are usually high, groundwater levels remained low and large departures from the 15-year average resulted.

A comparison of groundwater levels for the period from May 1979 to September 1981 with the record high and low groundwater levels for each observation well (see table 24) shows

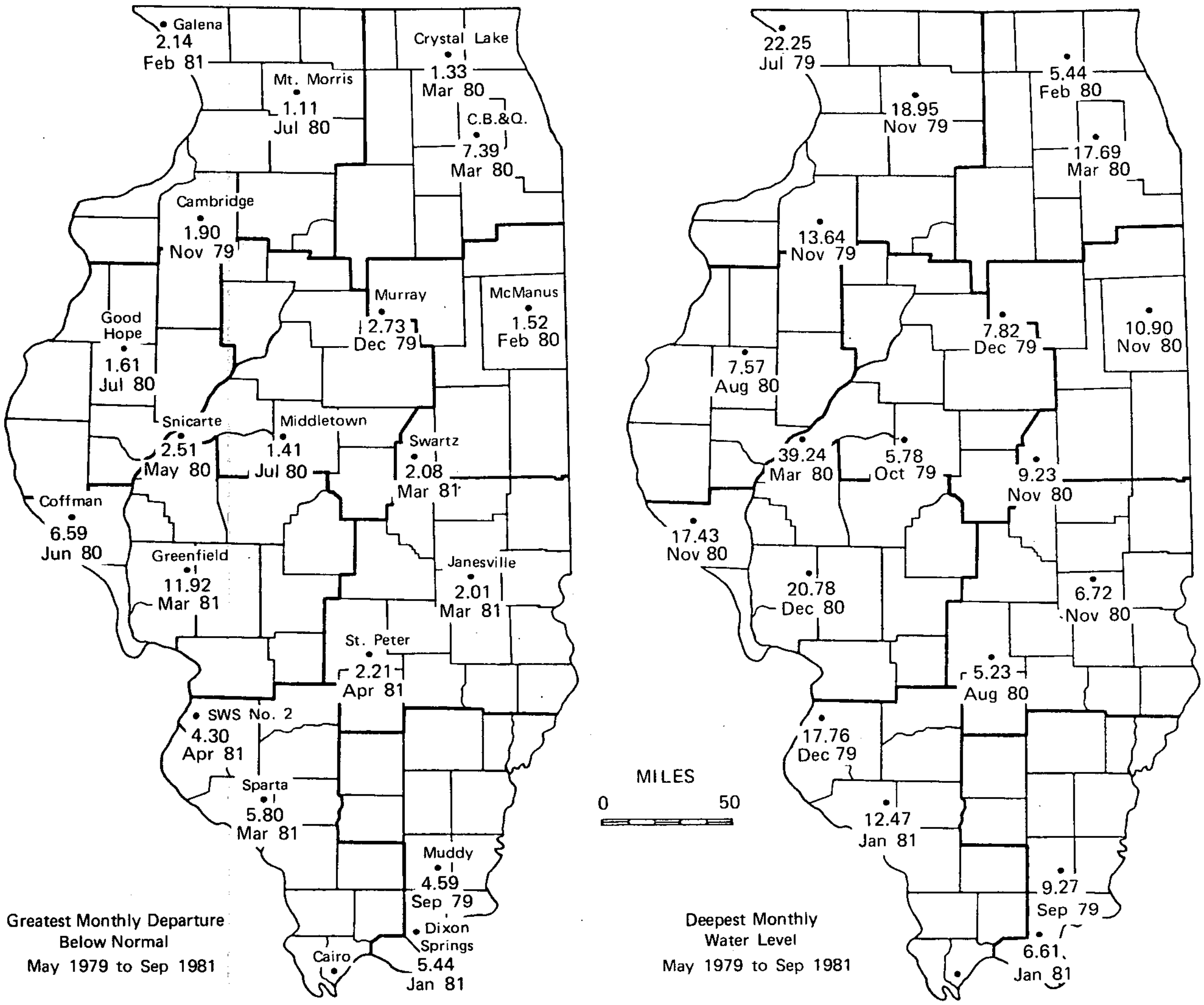


Figure 29. Greatest monthly departures below normal and deepest monthly water levels at 20 observation well; (in feet), May 1979 to September 1981

that three new record lows and one new record high were established. The record lows occurred in west-southwest and extreme southeast Illinois near the areas where the precipitation drought was most severe. Several other maximum depths at various sites in southern and central Illinois for this period approached (within 2 feet) the record low groundwater levels. However, groundwater levels at most of the sites remained well above the record lows.

Month-end groundwater levels and 15-year average groundwater levels for selected sites analogous to areas with maximum precipitation drought severity (Greenfield, Sparta, Cairo, Dixon Springs, Muddy, and St. Peter) were plotted for the period from May 1979 to September 1981. The plots are shown in figures 24, 25, 27, 30, 31, and 32, respectively. Historical month-end water level maximums and minimums also are shown, except for Cairo (figure 27). These

Table 24. High and Low Record Groundwater Values at Network Wells, Compared with Low Values from May 1979 to September 1981

District	*High*	*Mo/Yr*	*Low*	*Mo/Yr*	*Low during 5/79 to 9/81*		*Date records began*
Northwest							
Cambridge	1.62	5/74	18.99	2/77	13.64	11/79	10/61
Galena	15.13	6/74	27.25	3/65	22.25	7/79	9/63
Mt. Morris	5.04	5/74	31.92	3/69	18.95	11/79	11/60
Northeast							
Crystal Lake	1.93	9/72	9.45	1/57	5.44	2/80	9/50
CB & QRR	3.66	3/67	22.12	11/70	17.69	3/80	12/58
West							
Good Hope	3.09	9/61	18.07	1/64	7.57	8/80	10/59
Central							
Middletown	2.00	1/74	9.12	12/63	5.78	10/79	12/58
Snicarte	34.05	8/74	40.29	1/64	39.24	3/80	3/58
East							
McManus	2.82	3/62	19.73	12/63	10.90	11/80	7/60
Murray	1.65	12/51	9.45	11/56	7.82	12/79	8/50
Swartz	1.72	4/79	12.95	12/56	9.23	11/80	6/54
West-Southwest							
Coffman	2.18	7/81	18.27	1/61	17.43	11/80	2/56
Greenfield	2.03	1/63	20.78	12/80	20.78	12/80	7/60
East-Southeast							
Janesville	0.60	1/68	9.65	10/72	6.72	11/80	1/61
St. Peter	1.06	2/79	11.19	10/61	5.23	8/80	9/61
Southwest							
Cairo	0.83	1/69	Dry		Dry		11/60
Sparta	0.98	4/79	14.25	1/64	12.47	1/81	11/60
SWS No. 2	6.58	1/73	24.85	11/56	17.76	12/79	7/52
Southeast							
Dixon Springs	0.15	2/67	6.69	1/81	6.69	1/81	1/55
Muddy	0.76	2/72	9.27	9/79	9.27	9/79	9/61

hydrographs show that groundwater levels during the May 1979-September 1981 period were generally below normal. Observation wells nearest the centers of lowest precipitation (Greenfield, Sparta, and Dixon Springs) show water levels well below normal, approaching their record lows several times throughout the time period. The Cairo observation well, also near a center of low precipitation, was below normal the entire period and dry during 16 of the 29 months.

Comparison with the 1952-1955 and 1976-1977 Droughts

A comparison of groundwater levels in southern Illinois for the 1980-1981 precipitation drought with those for the 1976-1977 drought reveals very similar declines in groundwater levels. Groundwater levels in the extreme southern sections of Illinois declined more in the 1980-1981 drought than during the 1976-1977 drought. In the remaining drought areas (south central Illinois), declines were about equal for the two periods.

Five observation wells have records dating back to the 1952-1955 drought, of which two – the well at Dixon Springs and SWS Well No. 2 near East St. Louis – are near drought centers.

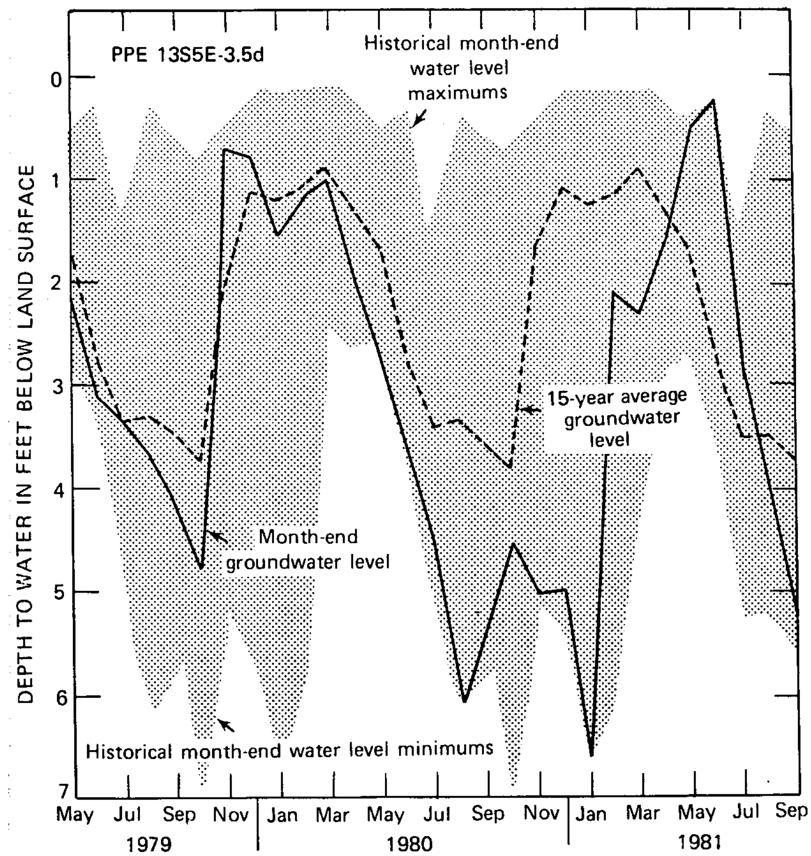


Figure 30. Groundwater levels at Dixon Springs observation well

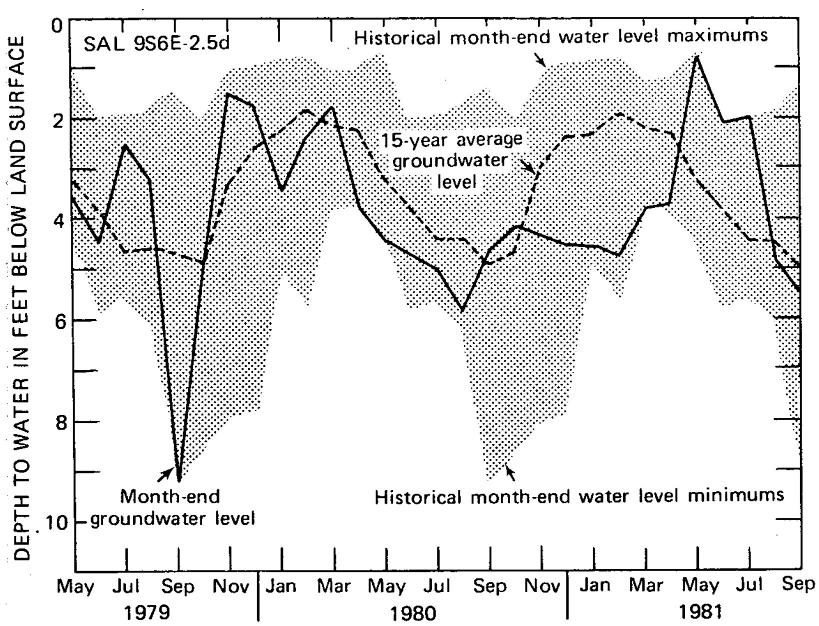


Figure 31. Groundwater levels at Muddy observation well

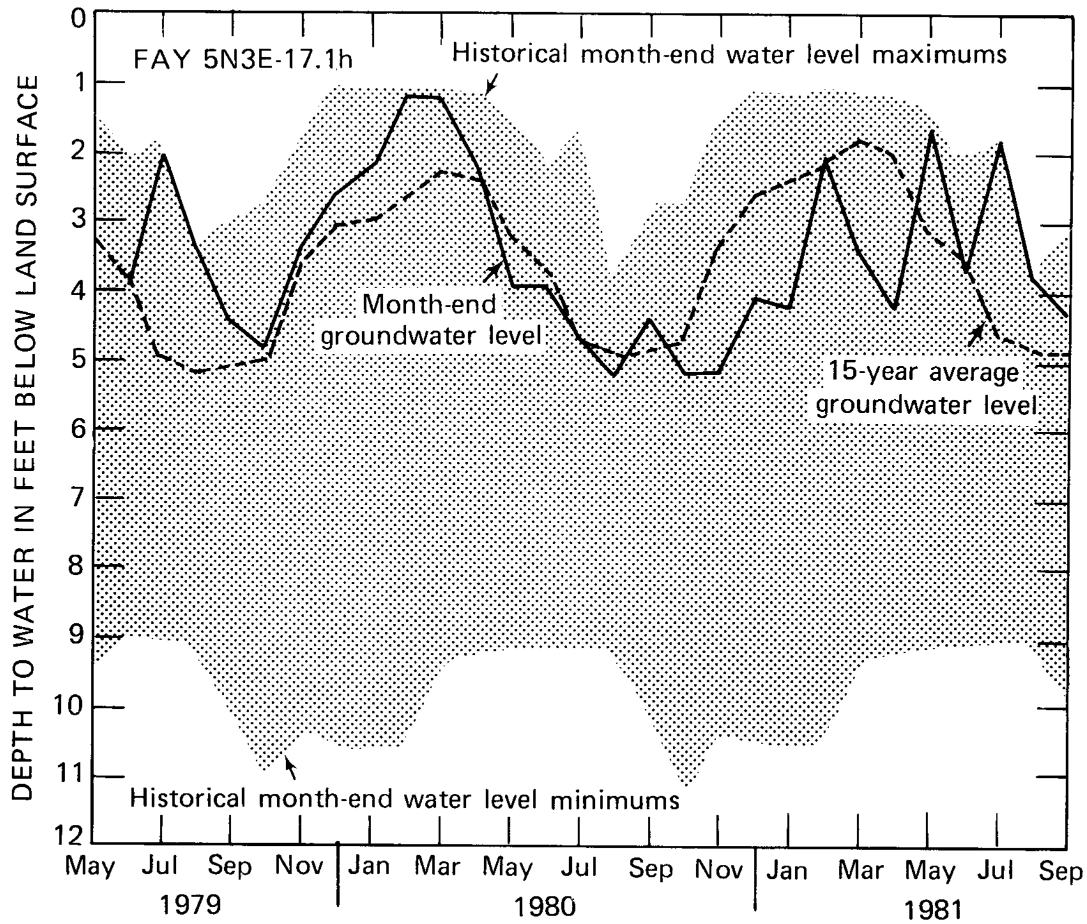


Figure 32. Groundwater levels at St. Peter observation well

The hydrograph for the Dixon Springs well is shown in figure 33a, and the hydrograph for SWS Well No. 2 (Ritchey et al., in press 1982) appears in figure 33b.

At the Dixon Springs site, in the extreme southern section of Illinois, the 1980-1981 drought caused the greatest decline in groundwater levels (figure 33a), and the 1976-1977 event caused less of a decline. Data collected since September 1981 show that groundwater levels declined to a new record low in late 1981. This area had recovered from the 1952-1955 drought by the time records began in February 1955.

The SWS No. 2 observation well site in southwestern Illinois has groundwater level records dating back through the 1952-1955 drought (figure 33b). The records show that water levels reached their record lowest level as a result of the 1952-1955 drought. The second largest groundwater level declines occurred as a result of a dry period in the mid-1960's. Groundwater recessions occurring in 1971-1972, 1976-1977, and 1980-1981 follow and were of about equal magnitude. The declines of 1976-1977 and 1980-1981 were of about the same duration (2 years), while in 1971-1972 the condition lasted for less than one year.

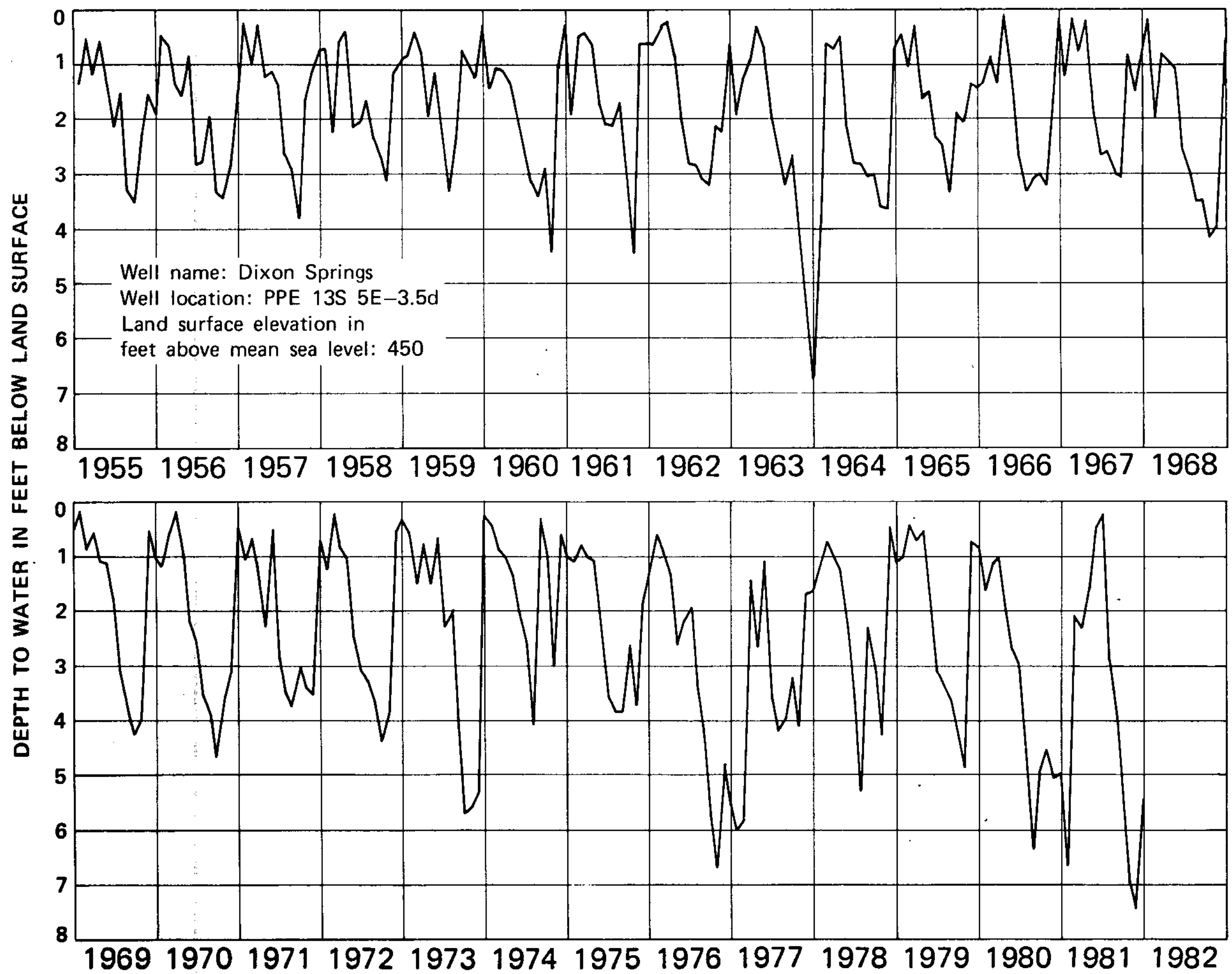


Figure 33a. Groundwater levels at Dixon Springs

Data from the remaining three long-term observation wells, which are in the east and northeast areas of Illinois (at Murray, Swartz, and Crystal Lake) show that groundwater levels in these areas of the state during the 1980-1981 precipitation drought were well above water level lows experienced during the 1952-1955 drought and other periods of precipitation deficiency.

In summary, available groundwater data suggest that a moderate to moderately severe drought existed in the west-southwest and extreme southwest sections of Illinois for about 6 to 24 months. Groundwater drought conditions in the remaining areas of the state could be described as nonexistent to perhaps moderately dry for periods of 6 months or less.

Drought Effects on Water Levels in Pumping Centers

In areas of pumpage, groundwater level changes caused by pumpage are superimposed on the seasonal and long-term fluctuations due to natural groundwater decline and recharge. When a well is pumped, water levels decline, forming a funnel-shaped depression or cone with the lowest

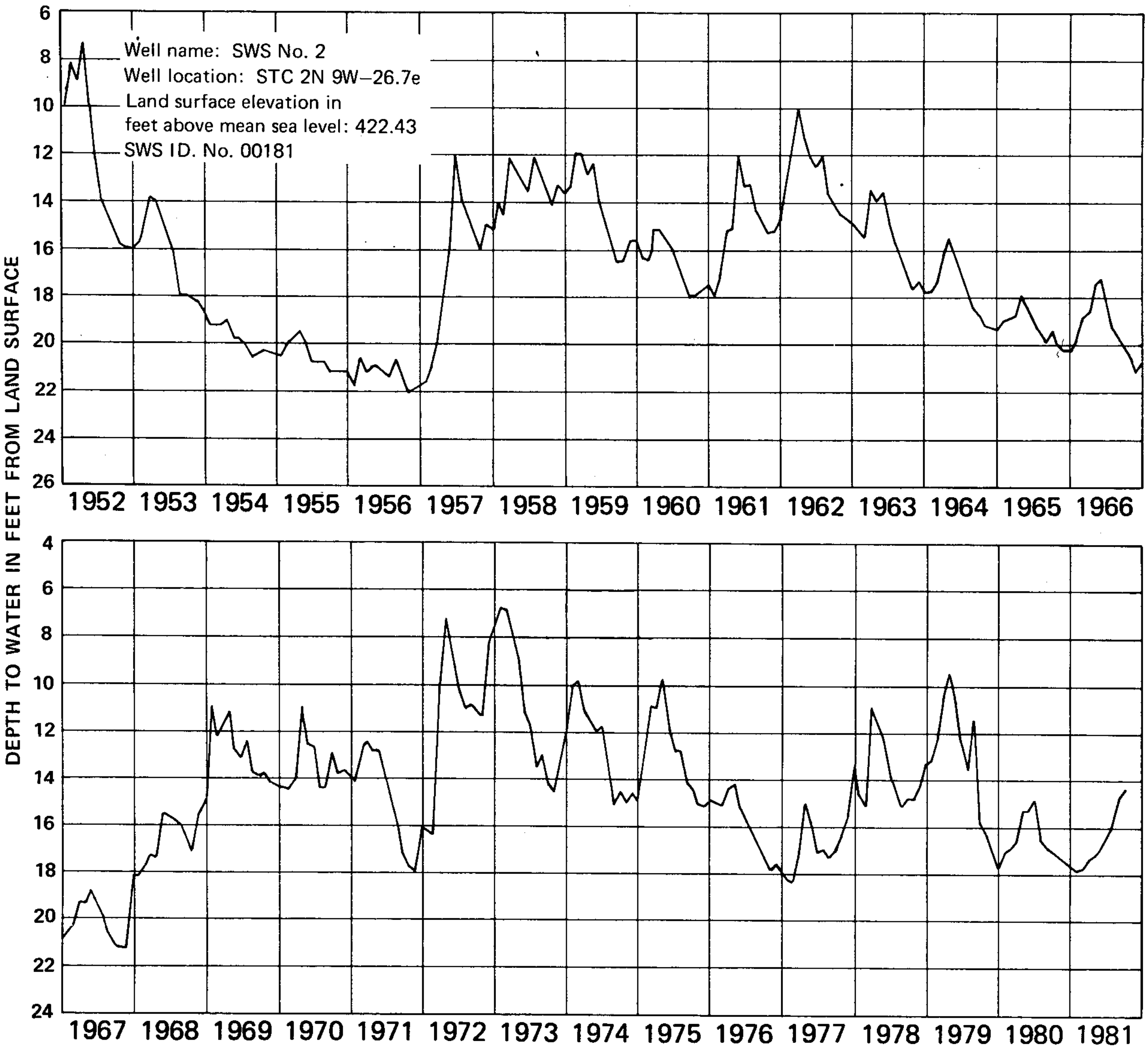


Figure 33b. Groundwater levels at SWS well number 2 (after Ritchey et al., 1982)

point at the well borehole. The shape and depth of this cone depend on the amount and rate of pumpage and the hydraulic properties of the aquifer. Water level declines are directly proportional to pumpage. The hydraulic properties of an aquifer remain essentially unchanged with time; however, pumpage normally exhibits seasonal fluctuations. Increases in pumpage usually occur during late spring and summer in response to increased demands, lowering groundwater levels. During late fall, winter, and early spring pumpage generally decreases and groundwater levels recover.

The 1980-1981 drought had a two-fold effect on groundwater levels. First, natural climatic conditions limited recharge, and water levels were lowered. Second, drought conditions coupled with extremely high temperatures during the summer of 1980 caused above normal increases in summer pumpage, thereby increasing summer water level decline.

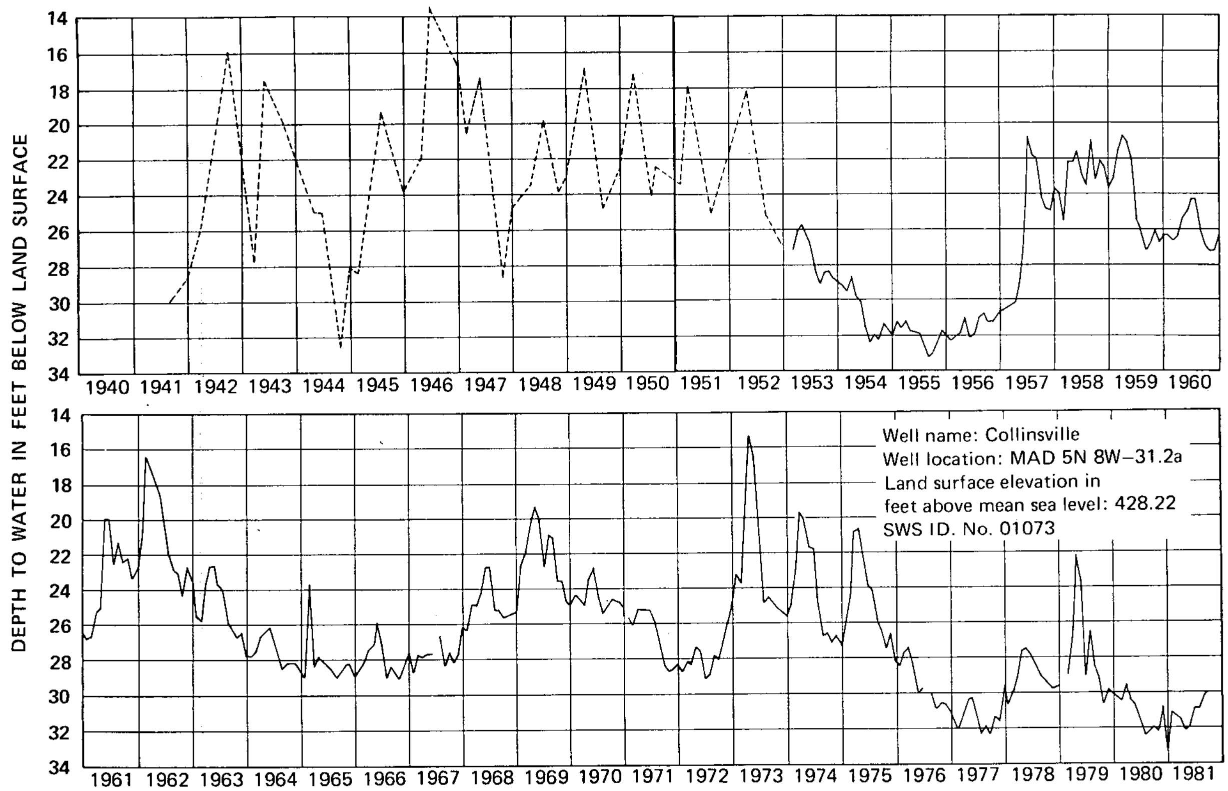


Figure 34. Groundwater levels at Collinsville

The hydrograph of groundwater levels in a pumping center located in southwestern Illinois appears in figure 34. Wells in this area supply the city of Collinsville and several other communities. The aquifer being utilized is a thick sand and gravel deposit with a maximum depth of about 100 feet, which is part of an extensive regional aquifer system known as the American Bottoms. Although these communities did not experience water supply problems due to the 1980-1981 drought, it is evident that water levels in the aquifer did respond to the dry conditions. In fact, groundwater levels in the area during the 1980-1981 drought were at record low levels. Pumpage in this area has increased only gradually during the period of water level record; thus, these changes are primarily due to climatic conditions. The droughts of 1952-1955, 1976-1977, and 1980-1981 are clearly reflected by the groundwater levels.

Public and Industrial Water Supplies

Groundwater availability in central and southern Illinois is largely limited to aquifers associated with large streams or rivers and buried bedrock valleys. These are widely scattered in central and southern Illinois. For most of this large area groundwater is seldom used for municipal or industrial supplies, and when used, it often provides a marginal supply at best. This is particularly true for those areas hardest hit by the 1980-1981 drought.

An additional problem for certain small communities was the limited funding available for developing more adequate water supply systems. Developing groundwater supplies in the marginal resource areas of southern Illinois usually requires considerable investments for exploration and testing. As a result, many water systems throughout the central and southern sections of the state are only marginally adequate at best. In years with average or above average rainfall, these systems usually get by with only minimal problems. Because few significant drought periods have occurred, and because of the costliness of upgrading water systems, citizens and village and city officials have had difficulty believing that significant expenditures for renovation or upgrading of their systems should be made. As a result many water supply systems had deteriorated and demands equalled or surpassed their capabilities at the beginning of the deficient rainfall period.

Domestic Water Supplies

Domestic or farm supplies developed in aquifers associated with stream valleys or buried bedrock valleys had few problems during the drought of 1980-1981. However, as mentioned above, these types of aquifers are absent in much of the area affected by the drought. Here water supplies have been developed in thin, discontinuous deposits of sand and gravel present in the drift or unconsolidated deposits above bedrock. In most cases large-diameter (36-inch) bored wells are used to develop these supplies. Wells of this type are shallow (less than 95 feet), and the thin sand and gravel deposits they tap are the first to be affected by drought. Many of these wells went dry during the 1980-1981 drought. Unfortunately, few alternatives exist for supplies in these areas.

Chapter VI. Impacts: Problems and Actions

Stanley A. Changnon, Jr., Gary L. Achtemeier, and Wyndham J. Roberts

Introduction

Economic losses from the 1980-1981 drought approached $1 billion in Illinois. This was due mainly to crop and livestock losses, increased energy consumption, efforts to get alternate water supplies, and highway damage. Much of this was incurred during the severe summer 1980 heat wave (Karl and Quayle, 1981). The drought in Illinois was part of a larger, more severe drought that included the southern plains and the southeastern states.

This chapter focuses on a series of problems and actions during the 1980-1981 drought, all of which reveal the scope of the impacts of drought. Some of these problems and actions are reflected in the headlines in figure 35. Separate sections of the chapter discuss the impacts of the drought on:

- Public water supplies
- Agriculture and rural dwellers
- Transportation
- Recreation and the environment
- Social behavior

Subsequent sections of this chapter discuss the following topics:

- The myriad of problems and activities in one seriously affected community (Eldorado), which illustrate in detail the complexity and dimension of the problems and actions during the drought (Changnon, 1981a)
- The use of a new technology – weather modification – to increase rainfall during the drought (in the summer of 1980)
- The extremely hot and humid conditions of July 1980, and their potential physiological effects on human beings

Impacts on Public Water Supplies

Illinois has about 2 percent of the 60,000 urban water supply systems in the United States. Of the 1081 Illinois incorporated communities providing public water service, 56, or only 5 percent, are investor-owned compared to 63 percent for all United States water systems. Most of the Illinois systems – about 1025 – are in public ownership. Nearly 90 percent of the systems rely on groundwater, and there are 133 that depend on surface sources. Thirteen towns have their water intakes in Lake Michigan. Chicago is the biggest user, and in addition Chicago supplies potable water to 71 neighboring communities. In southern Illinois, Rend Lake water is used by 57 towns and water districts. Fourteen other cities pump water from the Mississippi River.

Illinois in 1980-1981 experienced one of its periodic droughts. Although there are several definitions of the drought, drought as discussed in this section of this report relates to acute urban water supply shortages due primarily to inadequate precipitation. While there are often several factors that combine to accelerate water system failures, usually the primary cause is a lack of precipitation.

Reservoir Critically Low

Coulterville Officials Declare Water Emergency

Chicago Tribune, Monday, January 26, 1981

Dry soil periling Illinois crops

Carlinville Lake continues at dangerously low water level

Experts offer strategies for coping with drought

Marion city reserv... drops; council eyes ...

Above-Normal Rainfall Pre...

Moisture Levels Remain Low

By Jerri Stroud

Drought widens land price range

URBANA (AP) - The range of prices for Illinois farmland has widened in the last year, with the lowest values in areas hardest hit by the heat and drought of 1980, a University of Illinois specialist says.

Illinois' arid 'Little Egypt' thirsty for rain and snow

Farmer Charley Ludwig examining the dry soil on his 300-acre farm west of Springfield.

Farm, urban residents feel effects of drought

Thursday, Jan. 29, 1981

Centralia Officials Issue Water Shortage Alert

By J.L. SCHMIDT
Associated Press Writer

Cedar Lake: A beach but not enough water

Hauling water 'way of life' in rural area

Drought plagues Mississippi River barge traffic

Thompson names downstate drought task force

SPRINGFIELD, Ill. (UPI) — Water-short communities in central and Southern Illinois can take heart in a drought task force named by Gov. James R. Thompson.

Low rain totals near 'frightening'

By SIU-C News Service
And The Southern Illinoisan

Drought at crisis

Harrisburg to Use Pump To Ease Water Shortage

Figure 35. Examples of newspaper headlines and articles during the 1990-1991 drought

Lack of precipitation is seldom recognized by reservoir managers or city leaders as the -underlying cause of water shortage until the resource has declined to an alarming extent. Communities that depend on groundwater often believe that they "run out" of water essentially overnight. Yet a program of regular measurements of depth to water in their wells would alert responsible officials long before the emergency arrived. Since a surface water impoundment is readily visible, a decline in its water level should be obvious. Yet it is often amazing how long officials will rely on hopes for rain before resorting to emergency measures.

Numerous southern Illinois cities experienced impacts of the 1980-1981 drought (see figure 36). The drought was not sufficiently severe (departures from normal precipitation) nor prolonged to affect supplies in the Rend Lake area;, there were no water use restrictions imposed on towns and water districts within the Rend Lake distribution system. However, there were several southern Illinois towns that found their surface water supplies inadequate, and their experiences are of interest. The loss of supply in many municipalities also affects rural consumers because many rural households and farms with livestock depend on the purchase of water from municipalities, particularly during droughts.

By far the most interesting case involved Eldorado, a town with a population of 5200 located in Saline County (figure 36). A special section later in this chapter is devoted to that town's situation, to provide details of the types of problems, issues, and solutions in a single community. However, Harrisburg, Centralia, Marion, Salem, Carrollton, Greenfield, and Carlinville (figure 36) all suffered similar water shortages to varying degrees. Their problems are described in the following text. Other communities that had serious problems included Coulterville and Tilden (in Randolph County), Coffeen, and Staunton (figure 36).

Harrisburg

Harrisburg has a long history of drought-caused water shortages. In 1953, a time of extreme drought (Hudson and Roberts, 1955), the city's two side-channel reservoirs were empty. The city had to' depend on poor quality water pumped from a strip mine pond located between Ledford and Carrier Mills. The water was pumped from Pankey Creek, where it flowed to within one mile of the city filter plant. It was not until late in 1955 that rains finally provided enough water that the city had a six months' supply on hand. At the height of that drought, Harrisburg started building a new lake six miles north of the city. It was completed in December 1955. This lake had an original capacity of 900 million gallons, a pool area of 350 acres, and a watershed covering 5.4 square miles.

Lack of runoff in 1980 caused the lake level to fall so that by January 1981 the reservoir was empty. There is no pipeline connecting the lake with the filter plant. The usual procedure is to allow water to flow downstream from the lake and remove it from the river by pumps which put the water into the two side-channel reservoirs near the filter plant. When the last drop of water was released from the lake in January 1981 and transferred to the small reservoirs, it was estimated that there was sufficient water (in the side-channel reservoirs) to last for 100 days without additional runoff. No restrictions were imposed, but the city urged the public to conserve water. An emergency plan to pump water from the Endsley strip mine pond (containing 90 days' supply) was put into action in April. Tests of the pond water were made by the State EPA, and permission was given Harrisburg to use this source. The state (Emergency Services and Disaster Agency, or ESDA) arranged for emergency pumps and an 8-inch pipeline to be made available, and they began pumpage in early May. The pipeline installation cost $20,000, and pumping cost $1000

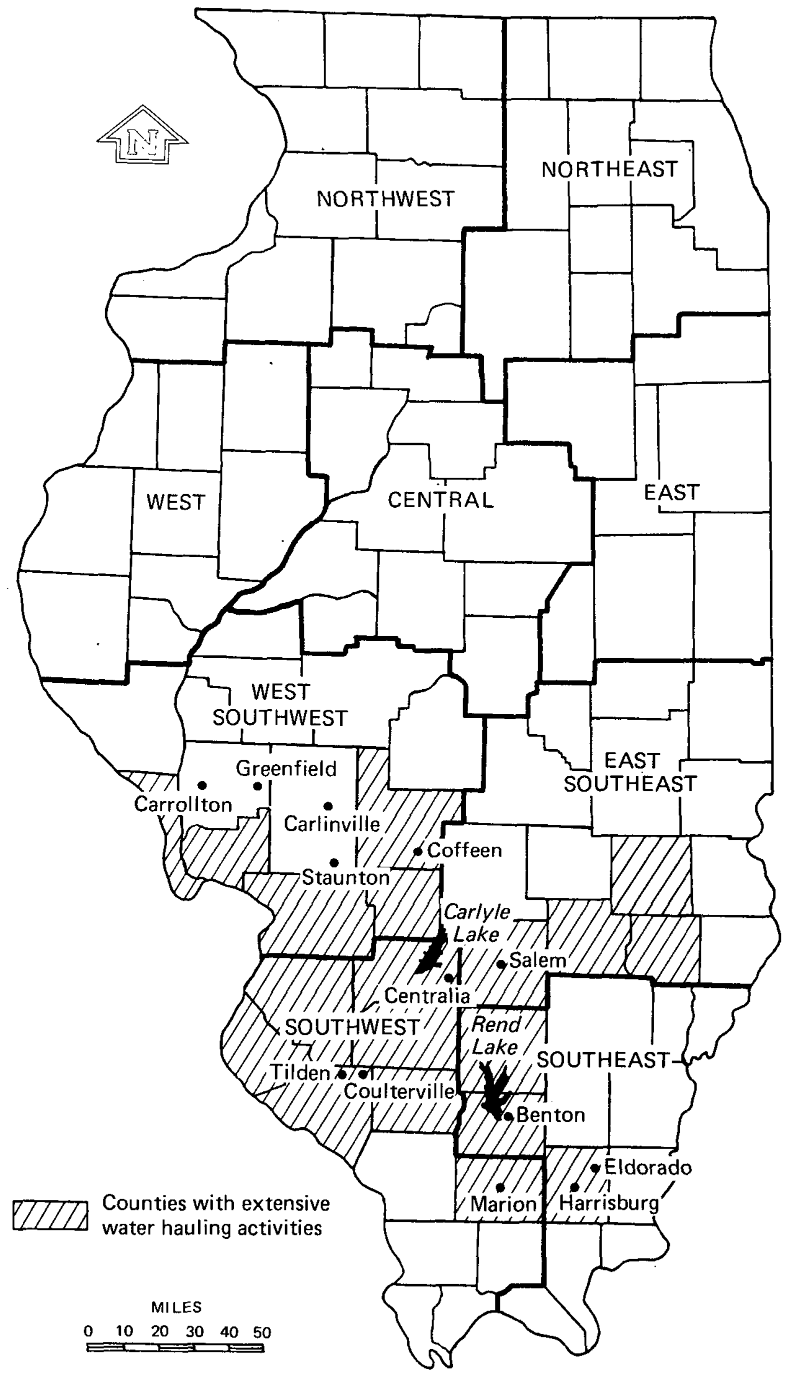


Figure 36. Areas and communities with water problems during the 1960-1961 drought

per day. This operation ended in mid-May when heavy rains came. By June 1 the lake was full and spilling (after 12 inches of rain), and another water emergency at Harrisburg had passed into history.

As the water supply situation deteriorated in Harrisburg (and nearby Eldorado) in late 1980, a cooperative effort was made by the Southeastern Illinois Regional Planning and Development Commission, the Saline County Board, and the Saline Valley Water Conservancy District to obtain funding to assist in developing a groundwater supply adequate for these two communities and others (see the section on Eldorado). Application was made to the Federal Housing and Urban Development (HUD) Administration for a grant of $1 million from the Community Development Block Grant Program. Funds were granted, but were not released immediately. The Council of Environmental Quality challenged this action after the rains had ended the local water crisis. However, the request for the grant was upheld, and well construction was scheduled to begin in the spring of 1982.

Centralia

Centralia has two water supply lakes, Raccoon Lake and Lake Centralia. Raccoon Lake, located two miles 'east of the city limits., has a pool area of 707 acres, a storage capacity of 4143 acre-feet (1350 million gallons), and a watershed area of 48.4 square miles. Lake Centralia, upstream from Raccoon Lake, has a pool area of 266 acres, a capacity of 2916 acre-feet (950 million. gallons), and a watershed area of 7 square miles. Centralia supplies treated water to Odin, Hoffman, Central City, Sandoval, Walnut Hill, and Irvington.

By January 1981, Raccoon Lake was down 7.4 feet and dropping 0.1 foot per day. Daily withdrawal from the lake was 3.1 million gallons, but 2.5 million gallons were provided daily from Lake Centralia to be released downstream for eventual pumpage into Raccoon Lake (of which about 0.5 million gallons per day was lost in transit). In January it was estimated that the city had enough water to run for 60 days without additional runoff. Actually, the level of Raccoon Lake was down 9.5 feet on January 29. The city issued a "water shortage alert" on January 28, but a ban on filling swimming pools was the only mandatory control which the city ever imposed. By March 1, local rains had raised the level in Raccoon Lake over 4 feet, and the water shortage alert was lifted after the heavy May rains on May 27.

Centralia currently has plans to construct a l-mile water line to connect with the Texaco Company's pipeline from Lake Carlyle. Water is used by Texaco for secondary oil recovery. The estimated cost of this pipeline is $370,000, and it will be used in the future to maintain the level of Raccoon Lake.

Marion

Marion, the county seat of Williamson County, has a population of 14,000. It has a reservoir that holds 400 million gallons and receives runoff from 6.5 square miles of watershed. The lake area is 110 acres.

In 1980-1981 Marion experienced a period of no appreciable runoff, and eventually had to rely on about 600,000 gallons of water pumped daily from Crab Orchard Lake into the Marion Reservoir. Pumpage began in the fall of 1980, the first time since the size of the Marion Reservoir had been increased in the early 1970's. By January 1981 the reservoir was 7.5 feet below spillway crest, and residents were urged to conserve water. The City Council considered rechanneling sewage plant discharges into the water plant as a source of water. It was not until late May that the

May rains filled the reservoir. The Crab Orchard Lake water was an emergency source, although many times in the past the city had used that source.

At present there are no plans to develop another source of public water supply.

Salem

Salem, the county seat of Marion County, has a 74-acre lake with a volume of 173 million gallons. The watershed extends over only 4 square miles, which is not sufficient for a dependable water supply for a city of 7800 people. For the past 40 years the city has been augmenting its supply in dry periods with up to 600,000 gallons of water per day supplied by the Texas Company. The Texas Company has a pipeline from Salem to the Kaskaskia River, which was built before Lake Carlyle was built.

By January 1981 the Salem Reservoir level was down 6 feet and falling 0.1 foot per day. The water demand was about 1.6 million gallons per day, and complications such as pump failure and the lowest intake being above the declining lake level created a severe local shortage. In mid-January a water shortage alert was declared by city officials and water district personnel. They requested voluntary cutbacks to include twice-a-week clothes washing, twice-a-day toilet flushing per person, S-minute showers, bathtubs only 1/4 full, no lawn watering, and checks on plumbing leaks. Residents of Salem responded and the demand lowered to 1.0 million gallons per day. Water was sought from Lake Carlyle (300,000 gallons per day), and by the end of January the lake level recovered to within 5 feet of its spillway crest elevation as the unused Lake Carlyle water was stored in the small reservoir. No restrictions were imposed on the public at any time. Mandatory water conservation was being planned in early May, but the heavy rainfall in late May eased the situation considerably.

The city is now planning to build its own 24-inch diameter pipeline to Lake Carlyle, either alone or possibly in cooperation with the city of Centralia.

Carrollton

Carrollton, in Greene County with a population of 2816, has a natural spring as its water source. Normally the city pumps 307,000 gallons per day. On February 1, 1981, facing a rapidly decreasing flow, the city began a program of periodic water cut-offs and urged conservation. The city had had similar periodic water shortages in the past. The 1981 emergency lasted for three months. The spring returned to its normal flow during April. After May there were no water restrictions.

No plans exist to alter or improve the supply.

Green field

Greenfield is in Greene County and has a population of 1090. It has an impoundment on a tributary of Rubicon Creek with a capacity of 77 million gallons. The watershed covers only 1 square mile. Interestingly, there was water left in the reservoir when the public complained of a water shortage. This was not so much a drought condition; the water famine was caused primarily by lack of sufficient pumping capacity. It is of interest that public perceptions of the drought led to the local concern.

Carlinville

Carlinville, in Macoupin County and with a population of 5439, began to suffer from the drought by January 1981 when its lake level was 4.5 feet below spillway crest. The city council shut off water to car washes and prohibited residents from washing cars or watering lawns and gardens. By mid-February water was cut off to commercial water haulers. Conservation dropped daily consumption from a pre-drought average of 800,000 gallons to 675,000 gallons in April 1981. However, in early April Carlinville voters voted down a $2.6 million referendum to purchase another local lake. By April 27 the lake level began to rise and restrictions were lifted.

The city currently is planning to raise the spillway 3 feet at a cost of $500,000. This will increase the lake capacity by one-third (160 million gallons). The 44-year old reservoir (built in 1938-1939) has lost considerable capacity due to siltation.

Impacts on Agriculture and Rural Dwellers

A multitude of problems beset farmers and rural dwellers during the middle and latter stages of the 1980-1981 drought. These impacts have been grouped into two broad categories: 1) effects on crop yields and related farming activities, and 2) effects on rural water supplies.

Impacts on Crop Yields and Related Farming Activities

Much of the drought area relies on corn and soybeans (cash grain) farming, and the impacts on these crops occurred in two years: the 1980 crop season and the 1981 crop season. The moderately deficient precipitation in Illinois during the early phases of the 1980 crop season did not particularly hurt the emerging corn and soybean crops. In fact, moderate dryness in June has been shown to benefit corn production by producing deep rooting, thus making the corn plant better able to withstand dry July and August conditions (Changnon and Neill, 1967). However, conditions in July 1980 were extremely hot and dry, and they were particularly dry in the central area (figure 3). Another section of this chapter discusses the potential physiological heat stresses of this period. Fortunately, August rainfall in these very dry July areas was normal or above, but the stress due to the above normal July temperatures and low rainfall seriously affected corn yields.

In parts of central Illinois, corn yields were 83 bushels per acre, 50 bu/acre below 1979 yields. Good soil areas of western and northern Illinois had very favorable growing conditions in 1980 with high yields (113 bu/acre in the northern fourth of Illinois), producing a statewide total corn production in 1980 that rated as near normal. However, farmers in central and eastern Illinois experienced serious yield losses, and the lowest yields since 1974, which had been the worst crop weather year since 1955.

In 1981 corn and soybean yields in Illinois were quite high in most parts of the state. Before the 1981 crop growing season had ended, the part of Illinois that had experienced drought had gone from drought conditions to excessive rainfall in the summer. In some areas of southern Illinois crops never got planted in 1981 because of the sudden transition from drought to prolonged excessive rainfalls in May and June. Those able to plant corn and soybean crops generally had average to above average yields in 1981. One benefit of the 1980 drought was reduced nitrogen usage in 1980, leading to nitrogen carry-over into 1981.

However, the dry fall of 1980, the relatively drier winter of 1980-1981, and the near record dryness of March 1981 produced a myriad of problems and difficult decisions for farmers in central and southern Illinois during February-March 1981. Uncertainty over continuation of the drought and whether the 1981 growing season would be dry produced a wide range of decision options for farmers, along with the worry that goes with difficult choices. Some decisions farmers had to make were: whether to select corn or soybeans; which varieties of corn to choose, depending on whether there would be a return to wet conditions or a prolonged drought; how to react to the need for greater weed control if the drought persisted; whether to reduce plant populations to address drought stress; and which herbicides would be most effective in dry conditions.

The late winter-early spring decision period for these and other issues was difficult because of the awareness in late January 1981 that 81 percent of Illinois had deficient soil moisture. The continued deficiency of soil moisture in Illinois is revealed in table 25. Moisture remained extremely deficient as near-record low March rainfalls occurred. The soil moisture measurements by the Water Survey at Urbana, which began in April 1981, revealed the serious deficiency of moisture from the surface down to more than 7 feet. This deficiency had begun with the crop depletion in the dry summer of 1980, followed by the prolonged below normal precipitation in the fall, winter, and March. Once soil moisture was depleted to these depths, the rains that did fall in the cold season and spring (March and April) of 1980-1981 either ran off or percolated downwards to recharge the deeper soil layers, leaving the surface layer dry. The warm and dry March conditions also allowed extensive early plowing to occur, as shown in table 26. The dry soils and early plowing led to a late March-early May period of extreme blowing dust conditions, particularly in central and eastern Illinois. A separate report on these record-breaking dust storms in the spring of 1981 has been prepared (Changnon, 1982). Central and eastern crop-districts had more days with blowing dust than in any prior year since records began in 1901.

As reflected in table 26, the mid-April rains in south central and central Illinois did not allow much corn planting. This delay in corn planting, which prevailed in various parts of southern Illinois, played a role in a second series of blowing dust conditions from late April to early May. These in turn were followed by record heavy May rains in some of these areas, which also produced conditions such that crops could not be planted.

The dry conditions in the southern half of Illinois in 1981, and in central Illinois in 1980, had other effects. Economists at the University of Illinois reported that areas with severe drought had experienced a 10 to 15 percent decrease in land values. A second problem for grain farmers in Illinois which related to the drought was the low streamflow in major rivers, which affected barge traffic and raised shipping costs. A separate later section addresses these drought impacts on barge traffic.

In the net, the cash grain farmers in central and southern Illinois experienced reduced yields, wind erosion, worry and anxiety, and a myriad of extra costs as a result of the 1980-1981

Table 25. Changing Soil Moisture Conditions across Illinois, as Assessed by Farmers in Spring 1981

	3/23	*4/6*	*4/13*	*4/20*	*4/27*	*5/4*	*5/11*
Percent of state with deficient soil moisture	87	99	86	33	12	15	15
Percent of state with adequate soil moisture	13	1	14	62	78	65	76
Percent of state with surplus soil moisture	0	0	0	5	10	20	9

Table 26. Rate of Spring Plowing and Planting for Corn in Illinois

	Percent of plowing for corn completed.				
	Date 3/23	*4/6*	*4/13*		
1981	83	92	94		
1980	69	72	78		
Average, 1977-1981	65	70	75		
	Percent of planting for corn completed				
	Date 4/13	*4/20*	*4/27*	*5/4*	*5/11*
1981	1	3	5	18	48
1980	0	0	10	45	84
Average, 1977-1981	1	4	13	34	57

drought. An economic analysis of the net effects on cash grain Illinois farmers has not been made, but the loss in yields in 1980 was estimated to have represented an income loss of more than $0.6 billion to Illinois farmers. Losses to individual farmers in central and southern Illinois were estimated at between $12,000 and $20,000. Clearly, the drought had significant impacts on grain-growing Illinois farmers and related agribusinesses.

Rural Water Supplies

Farm wells and farm ponds in southern Illinois began to dry up during the fall of 1980 and winter of 1980-1981. As a result, the amount of water hauling for rural users increased dramatically (see headline in figure 35). Estimates indicate that during February 1981, water was being hauled to 12,000 farms and rural households in the southern half of Illinois. Some water-short towns like Coulterville and Tilden, which normally sell water to rural users, found it necessary to discontinue bulk selling of water in the winter of 1980-1981. The drought and the cutoff of municipal supplies in parts of southern and southwestern Illinois produced a crisis for many rural users and livestock growers. In a normal year, rural dwellers in Illinois purchase 50,000,000 gallons of treated water from municipal water plants. In 1980 they purchased 72,000,000 from about 500 commercial water haulers. Cost of hauled water has rapidly increased, being $1 per 1000 gallons in 1970, $12 per 1000 gallons in the 1976-1977 drought, and as much as $15 per 1000 gallons in the 1980-1981 drought. Water needs for cattle and swine range between 10 and 20 gallons per day per animal, and each dairy cow requires up to 35 gallons per day.

The increase in water hauling during the 1980-1981 drought began in earnest in the fall of 1980, becoming extensive in January 1981. Counties where extensive hauling of water was reported included Bond, Calhoun, Clinton, Clay, Franklin, Jasper, Jefferson, Jersey, Marion, Madison, Monroe, Montgomery, Perry, Randolph, Richland, St. Chair, Saline, Washington, and Williamson (shown in figure 36).

As several southern Illinois communities closed their sources to rural users, farmers and commercial water haulers had to travel farther. This entire large-scale water hauling effort led to higher, or new, costs to many farmers. It also increased energy consumption in Illinois. Some cattle and swine farmers were considering an early selling of livestock as the drought worsened in the spring of 1981, but this activity never became extensive, and it ended as the late spring heavy rains occurred. Hexadecanol (a monomolecular alcohol) was employed by certain southern Illinois fruit growers in the spring of 1981 to reduce evaporation so as to preserve water in their irrigation supply ponds.

The net effect of the drought on rural households and livestock farmers was to greatly increase costs for either routine hauling or for hauling not normally required. Again, farmers and homeowners in this situation were faced with higher costs, as well as with worry and anxiety over water for human as well as for livestock consumption.

Impacts on Transportation

One impact on transportation was the increase in the use of trucks for water hauling. Other trucks were modified to haul water. The shortage of water in farm ponds and the drying up of rural wells led to a considerable increase in the hauling of water by truck from municipal supplies to rural sites.

Another major impact on transportation occurred during the winter and early spring of 1980-1981. Not only in the southern part of Illinois but also elsewhere in the Midwest, the drought led to low flows in the Mississippi River and in certain southern Illinois rivers such as the Big Muddy and the Kaskaskia, not an atypical situation for Midwestern droughts. On January 26, 1981 the Coast Guard closed the Mississippi River from Memphis to near Cairo, Illinois, for 10 days because of the inability to move barges due to shallow water. During the winter of 1980-1981, U.S. Corps of Engineer dredges also were working extensively on the Kaskaskia River above Chester and on the Mississippi River above Cairo to remove silt to make them passable for barges.

Restrictions on barge hauling along the Mississippi and Illinois Rivers were changed during the winter as a result of the drought. The maximum number of barges allowed per tow was dropped from 20 to 15, and the tonnage allowable on each barge was cut 10 to 15 percent (a loss of up to 110 tons per barge). Tows were allowed to draw only 8 feet 6 inches, not the normal 9 feet used.

This series of changes brought on a series of higher costs to shippers and to barge owners and operators. The drought meant more barges were needed to haul the same volume, also producing increased energy consumption. The delays of barges, along with these other additional costs, cost the shippers through accumulated interest rates related to the length of time that grains, oils, and other products were on the barges. Importantly, all of these additional costs related to shipping via barge were ultimately passed along to the consumer of the products. There was discussion of increasing barge rates during the winter of 1980-1981, but that did not occur. Clearly, the impact of the drought on the barge industry, not only in Illinois but elsewhere, was considerable.

Impacts on Recreation and the Environment

The 1980-1981 drought did not become extremely serious in producing low river flows and low lake levels until the fall, winter, and early spring (see Chapters IV and V). Since this is not the maximum period of usage of recreational water facilities, the drought's impact on the recreational use of lakes and rivers was not severe. However, the access of fishermen to many beaches and lakes in southern Illinois was hampered or restricted. In several of the low supply lakes, fishing was stopped. Low water levels in certain lakes, such as Horseshoe Lake and Lake Carbondale, led to fish kills. The Department of Conservation surveyed several lakes to study the detrimental effects on fish (see the section on Eldorado).

At this time, very little information is available on the effect of the drought on the flora and fauna of southern Illinois. There were concerns in the spring of 1981 that the drought and above normal temperatures would lead to an increased insect population during the summer of 1981. This was reinforced by the early appearance of the elm leaf beetle in April, several months before the normal period for it.

Effects on Social Behavior

Several of the headlines in figure 35 reveal the type of concerns that existed regarding the drought. It affected public attitudes and behavior. Headlines such as "Low rain totals near 'frightening'" and "Drought at crisis" raised anxiety levels among the public. The section of this chapter that describes the activities at Eldorado reveals the types of public concern that existed in communities with low water supplies.

In addition to increasing general levels of anxiety, the drought also caused conflicts. Strong local public sentiments over opposed water solutions, such as the new lake referendum at Carlinville, brought on sharp local divisions in attitudes. The mandatory water use limits set in certain communities like Eldorado brought on conflicts between certain individuals, particularly those who reported on others who "broke the rules."

Another area of influence on human behavior related to extra effort and work to get water. The need to conserve water in the cities and rural areas, and the need to go seek additional water, all involve extra effort. These time-consuming activities took time from other more routine activities.

There also were reports by people in drought-affected communities that the problem brought on a "community feeling" based on the feeling that everyone was suffering and also was attempting to conserve in a "team effort." This community feeling is also revealed by one headline in figure 35 that indicates the interactive plight in an area involving both farm and urban residents who felt the effects of the drought.

The Drought in Eldorado: A Case Study

Introduction

Drought has been a frequent, if irregular, visitor to Illinois. We had no droughts for 20 years, 1956-197;5, and then two moderate droughts recently in 1976-1977 and 1980-1981 (figure 1). Because of the, state's great north-south extent, and the east-west alignment of most drought areas, droughts seldom affect the entire state. In the most severe droughts of record, those in the 1930's and 1950's, some parts of Illinois had normal rainfall, whereas most of Illinois had a disaster. The point is, whether you have experienced a drought and have developed an action-oriented attitude about droughts may well depend on where you live and your age.

Drought experts have concluded that the populace and municipalities seldom have a good "memory" about droughts. When a drought ends, with all its costs and anguish over water shortages, we often do not act collectively to improve our water sources or to develop contingency plans for the next drought. Long-term solutions to droughts are generally costly and often require the involvement of a myriad of local, state and federal agencies, plus a complex of funding and regulations that can intimidate the most dedicated mayors, city engineers, and regional planners.

The problems, impacts, and remedial actions taken in one Illinois community, Eldorado, reflect the typical issues faced by municipalities in the midst of a drought. Recounting these issues at Eldorado provides lessons about local adjustments, and may help develop local and regional, if not state, insight and plans for addressing droughts.

Eldorado is a small town (population 5200) in southern Illinois. Its reaction to the drought is a story of local confusion, economic loss, anxiety; extreme conservation, rationing, and higher prices over too little water. The Eldorado situation deserves study and consideration because 1) it indicates a wide range of municipal water supply problems; 2) it reveals the various actions that can be taken by local and state agencies; and 3) as a case situation, it received wide state and national attention. The problems, the resulting remedial activities, the conflicts, and the social adjustments to the water shortage in this community offer useful input for developing drought contingency plans. They may well be precursors of activities that most in Illinois will face in the future when there is less water in non-drought times.

The Eldorado situation is reviewed using a chronological description of the events during the drought. These events are then interpreted as to 1) who and what were the forces at work, 2) who was impacted, and 3) what were the adjustments? In the summary, these findings are used to identify the errors made and to interpret their implications for addressing future drought-induced community water shortages, and for the larger future issue of less usable water in Illinois.

The Drought

Precipitation became deficient in the southern third of Illinois during the spring of 1980. The tendency of below normal rainfall existed during most of the last 11 months of 1980, although precipitation was normal in September and October 1980. The below normal rainfall persisted in 1981 with much below normal precipitation in January-April.

The extremely high temperatures in July 1980, coupled with the below normal rainfall, brought the first labeling of drought in Illinois, as defined by considerable damage to the corn crops in the southern half of Illinois. The state's average yield in 1980 was 94 bushels per acre, as compared to 112 in 1979 and 127 in 1978. In the fall of 1980 the State Water Survey assessed the water situation in the state and released a news story to the effect that an incipient drought was appearing in southern Illinois but was as yet not severe. The potential for a major water problem at Eldorado, however, was apparent in October. City officials discussed the problem and remedial actions with the state's Emergency Services and Disaster Agency (ESDA) in October. They were advised by ESDA to wait and see if normal winter rains would occur and erase the growing shortage. Here, use of long-range precipitation predictions available at the Water Survey might have helped. The prediction was for below normal winter precipitation in southern Illinois.

The normal rains never came. Analysis of the 12-month precipitation through January 1981 showed that the drought in the Eldorado area was being defined as precipitation at 75 percent of normal (Changnon, 1981b). Earlier drought studies (Changnon, 1980) had shown that 75 percent was a level where drought problems began in certain communities and with certain agricultural activities. This type of drought has a frequency of occurrence in the southern part of the state of at least once every 7 years (Huff and Changnon, 1963). It certainly was not one of the state's major droughts of the past 80 years, and it was being defined largely by a few communities with very marginal (small) reservoirs. Later in the winter and early spring of 1981, water levels in farm ponds in the area also became low and many farmers had to haul water for their farm animals.

The 1980-1981 drought ended abruptly in mid-May as near record rains fell. The official raingage nearest Eldorado reported over 12 inches of rain in May, the second largest May total on record since 1900. At the Eldorado Reservoir, 9.1 inches of rain were measured in an 1 l-day period ending on May 19. Such an abrupt end to a drought is very unusual, but as will be shown, the extreme rains were a providential event for a town that had only 8 days of water remaining.

The Eldorado Water Supply

The water for Eldorado comes from a reservoir that had an original capacity of 884.4 acre-feet (258 million gallons) with a small watershed covering only 2.2 square miles. In 1949 the Water Survey made a sedimentation survey which showed that the reservoir had lost 14 percent of its volume in 29 years, and that the storage was down to 222 million gallons. Importantly, the average annual loss to sediment was 0.48 percent. Projections made on the basis of these findings indicate that the 1981 volume was down to 546 acre-feet or 167 million gallons.

The Eldorado Water Company serves about 8000 users. Eldorado is a community with an agricultural service focus as its principal function, with only minor industry. Normal (pre-drought) pumpage, or water usage, was 600,000 gpd, as opposed to a treatment plant maximum capability of 770,000 gpd. During the spring 1981 water problems, voluntary conservation brought the pumpage to 400,000 gpd in March, and then mandatory use levels set in April reduced usage to less than 300,000 gpd, which was less than 50 percent of normal usage.

The reservoir and water system were completed in 1920 with city bonds. Problems with repaying the bonds led to the selling of the system to private investors, and it is still privately owned. (The corporation that owns the Eldorado Water Company includes some local residents.) The reservoir was reportedly cleaned of silt by the WPA in the mid-1930's, but no official records exist to prove this. The 1976-1977 drought (of lesser magnitude in Eldorado than the 1980-1981 drought) brought one month of water rationing in February 1977, but this ended with normal spring rains. Later in 1977 the issue of the purchase of the local water company by the city for $775,000 was raised and a vote taken, but this was rejected soundly by local residents (639 to 132).

At the start of the 1980-1981 drought, Eldorado possessed a water system that was 60 years old with a small reservoir which had lost 35 percent of its capacity to silt, and one barely able to provide water treatment for the average level of usage. Water rates were very low ($2.16 per 1000 gallons up to 8000 gallons, then graduated even lower) and there was little apparent concern for loss in supply. Other than the minor drought in 1976-1977, there had been no droughts of consequence in the area since 1953-1954, and certainly this 27-year, almost trouble-free period had lulled most into a sense of security. The low price of water, which had resulted in part from the lack of water shortages, led to marginal revenues which in turn limited many major maintenance projects and improvements in the water system. This situation is not atypical of many Illinois municipal water systems which do poorly in attracting local municipal attention (van Es and Quigley, 1976). In the late 1970's the Eldorado Water Company had spent about $350,000 on a new water tank and related facilities, but with these improvements to its system, the utility reached the extent of its borrowing power.

Dealing with the Drought

The problems and resulting chief actions at Eldorado, generally remedial in nature, began in November 1980 and ended in May 1981. Many of these are depicted in figure 37. This graph

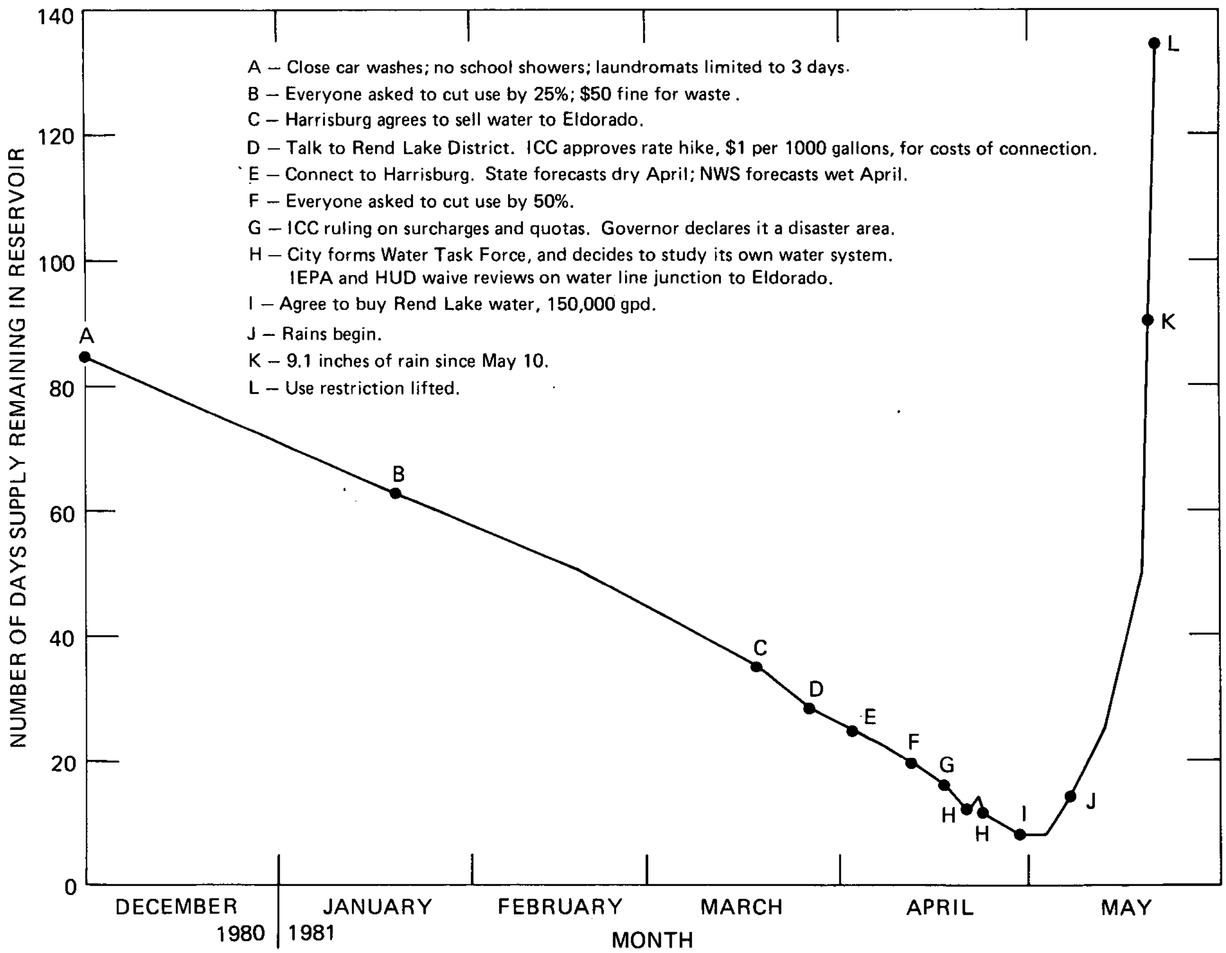


Figure 37. Temporal change in water supply at Eldorado (number of days supply remaining is determined on the basis of reduced usage)

has a curve based on the number of days of water supply remaining in Eldorado's reservoir. In November with an 85-day supply (point A), the first action was taken. The city stopped water to three local car washes, which in turn closed; the laundromats were restricted to 3 days of operation per week; and local schools were told to stop the use of showers following physical education classes.

The continuing low precipitation during the December-January period brought an ever-decreasing water supply. In January the water company asked everyone to voluntarily reduce their use by 25 percent, and the City Council passed a resolution allowing for $50 fines for anyone caught wasting water.

The worsening situation during February and early March brought action to get added water. On March 18 the Eldorado Water Company approached nearby Harrisburg about buying water, and Harrisburg agreed to sell 1 million gallons over a 60-day period. This was followed by talks with the Rend Lake Water District officials about getting water from them through a connection at nearby Galatia. On March 25, at the request of the Eldorado Water Company, the Illinois Commerce Commission (ICC) approved a surcharge of $1 per 1000 gallons for the added costs of these connections to alternate supplies. (Adjustments were later made in this rate; see the later section on adjustments made to meet the water shortage.) With the supplies down to less than 30 days (point E, figure 37), the connection was made to Harrisburg which was then suffering its own serious water shortage.

On the first of April, the National Weather Service issued its April forecast of above normal rainfall, whereas the State Water Survey issued a forecast of below normal rainfall for April. This produced local uncertainty, but by April 10 with only 19 days supply, everyone was asked to voluntarily cut their use to 50 percent of normal. However, not everyone was complying, according to the water company.

The extremely serious situation with less than 19 days supply on April 16 brought forth an ICC ruling on a mandatory quota of usage. This somewhat arbitrary action, which occurred in Chicago at an ICC meeting, was not well received in Eldorado, but it did bring lowered usage. Businesses were confused and unhappy, and the mayor declared a state of emergency on April 16. The following day, Governor Thompson declared Saline County a disaster area.

At this point, considerable local anxiety, if not panic, had set in. Rumors circulated about the possibility that the water company was going to cut off all the water. Two ditches in town were found running clear water in mid-April, and leaks in the system were suspected and repaired. On April 20, the mayor announced that he was considering a) evacuating the local hospital and nursing homes, and b) beginning to truck in water. Several of the businesses had been trucking in water for many weeks. The ESDA furnished an 8-inch pipeline ½-mile long to pump the equivalent of 3 days' water supply from Leitch Lake, a small lake 3 miles north of Eldorado.

By mid-April, several local businesses had begun constructing wells, and some had resorted to hiring people to perform "water witching" using sticks and other devices. The hospital and certain businesses had also purchased large water tanks so they could have their own supplies.

On April 17, the city formed a Water Task Force to search for solutions. The City Council also decided to study the possibility of either purchasing the water company or constructing its own water system, although the town had voted down the purchase of the water company 4 years previously: By April 19, the water supply had fallen to only 12 days remaining, and the occasional light rains did little to improve the supply (figure 37).

An important event occurred on April 23 which related to the Saline Valley Water Conservancy District. This district had been promoting the concept of supplying water through a multi-community system it proposed to build. It was to be based on wells near Junction (a town 15 miles away), a filtration plant, and a distribution system, a venture costing about $8.2 million. Some local farmers objected, fearing the heavy pumpage would remove water they desired to use for irrigation. In that sense, the drought was providential for the Water District, since the local concerns over water led to several rapid actions. The Illinois EPA waived a review period, and the federal Housing and Urban Development (HUD) agency waived a 45-day review period usually required before releasing a $1 million grant towards the construction of the system. This would be used to install a raw water line from the wells to Eldorado and Harrisburg. Construction of the line was to begin in 1981. These two waivers were announced by Representative Paul Simon on April 23.

On April 27 two further events occurred as the remaining water supply fell to only 8 days (see figure 37). First, the Eldorado Water Company signed a contract with the Saline Valley Water

Conservancy District to buy water from its system when it was completed. This represented a long-term solution to the problem of the small Eldorado reservoir. Second, the Water Company also signed an agreement to purchase 150,000 gpd from the Rend Lake District for 60 days (via the Galatia connection). With the local usage reduced to 300,000 gpd, the Rend Lake supply represented half of the daily usage.

On May 1, with 8 days of water still remaining, the City Council and the Eldorado Water Company officials met to discuss the sale of the water system to the city. Prices were offered by the company, but the two groups could not agree on a price. The city then hired a lawyer to consider a condemnation suit.

Another alternative for additional water was also under discussion. Water would be obtained from the city of McLeansboro, 20 miles north. Water would be released from its reservoir into a system of creeks (one of which would be dammed), and eventually the added water would be pumped 4½ miles overland to the Eldorado Reservoir. There was fear of pollution in the creek waters but the "McLeansboro connection" was never consummated because on May 8 heavy rains fell, In the period of May 8 through May 19, 9.1 inches of rain fell. By May 18 the reservoir supply had exceeded 90 days, as shown in figure 37, and with additional heavy rains on the 19th, the supply was at-13 5 days on May 20. The drought, as defined by the lack of water for Eldorado, had ended.

State and National Fame

The Eldorado situation was but one of many problems during a rather major national drought. Extremely dry conditions existed in New York, New Jersey, Virginia, Kansas, Colorado, and various other parts of the nation. The southern Illinois drought was much less severe than that in many other areas. Nevertheless, the Eldorado predicament became a focus of considerable national interest.

In March, the NBC-TV news staff in Chicago decided to do a feature story on the drought in the Midwest and contacted the State Water Survey. It was suggested that a trip to Eldorado might be worthwhile since the problems there were typical. An NBC crew flew to Eldorado and made a short news clip which was shown nationally. The *Wall Street Journal* then sent a reporter and ran a feature article in March. Subsequent stories about Eldorado appeared in early April in the Chicago *Tribune* and then in mid-April in the St. Louis *Globe Democrat*. The *Wall Street Journal* did a follow-up article on April 20. Eldorado was on the national map. The local supply problems, the serious impacts on businesses, the conservation efforts of the local citizens, and the controversies between the water company and the city officials became nationally known.

The "Players"

Reconstruction of the problems at Eldorado, the attempted solutions, and the actual solutions offers lessons for future drought contingency planning. The principal players, or forces, involved at Eldorado are important in understanding the outcome. In the Eldorado case, one important player was the privately owned Eldorado Water Company with Ron Boyer, its president, and Ralph Gregg, the local company supervisor. The organization played a major role in the water situation.

Another major player was the city itself and specifically Mayor Richard Moore, the City Council, and the Water Task Force. The city officials had to contend with public unhappiness and with the private water company in trying to provide and protect local water supplies.

The third group in the Eldorado drama were the local citizens. The consumers of water dealt with inconvenience, higher costs, and anxiety about the water problems.

The fourth group of players was composed of the local businesses and institutions which had to deal with the water shortage in a variety of ways. The ways of dealing with the situation cost money to many, but made money for certain individuals.

The fifth group of players were the state agencies who assisted or became involved. Foremost among these is the ESDA, which began giving advice in October 1980 and later furnished a water truck and pipelines in the severe shortage during the spring of 1981. The Illinois Commerce Commission was also involved in the rate changes and in setting the mandatory restrictions on use for the local water utility. The Illinois EPA provided tests of water from various alternate water sources considered, and the Department of Conservation checked on the health of the fish in the city reservoir during the low water period. The State Department of Commerce and Community Affairs provided information on conservation and other solutions, and made a documentary movie. The State Water Survey furnished advice on alternate water sources (groundwater in particular) and information on long-range rainfall predictions.

Impacts

As might be expected, most of the impacts were detrimental, although a few people benefited from the water shortage. First, let us address those who were adversely affected by the drought.

The major problems for local citizens and businesses were a mixture of monetary losses and constant inconveniences. Although the types of impacts will be listed, there has been no effort to attempt an economic analysis of the impacts, and particularly the losses and costs. Suffice it to say they were large and likely in excess of $2 million. The categorization of negative impacts has been organized around those on businesses, institutions, and the general public.

Businesses probably suffered a greater financial loss than any other group. They paid higher costs for water due to rate hikes, and many bore the costs of hauling water to sustain their functions or of putting in wells and water supply tanks. Many also experienced a loss of income. The businesses that are large water users such as car washes and laundromats, which had their operations curtailed in November 1980, suffered considerably. One car wash went out of business, and customers were lost to comparable services available in other nearby communities. Restaurants were particular losers. Some went to paper plates to reduce the use of water for dishwashing, and others considered restricted openings, resulting in the loss of customers who heard about possible restaurant closings and went elsewhere. Beauty shops were also detrimentally affected, as were plant stores which could not water their stock in the spring of 1981.

The institutional problems were reflected in the problems of the city government. There were constant concerns over lack of water for fire fighting, and a decision was made not to fight any major fire during the spring of 1981. The city's sewer system deteriorated because of the lack of water. The city officials were under considerable public pressure for action and held frequent council meetings to seek solutions and to consider purchase of the water company. They also had additional costs for legal services relating to a possible condemnation suit. The privately owned Eldorado Water Company also was a "loser" in the water shortage. Leaks were discovered that had not been known about, bringing additional costs for repair. There was a loss of revenue of up to 50 percent from the restricted usage, although rate hikes helped somewhat. The water company officials were also under extreme local pressure for action. Another set of institutions, the local hospital and nursing homes, who are heavy users of water, were also hurt by the shortage. The hospital installed a well and water storage tanks, and plans for moving patients were made.

The public was the third major loser in the water shortage. There were anxiety, conflict, and added costs. There was considerable unhappiness over the apparent lack of activity by the water company and over the increased water rates. There was unhappiness with the Illinois Commerce Commission, which set the quotas on water use and higher prices without local hearings. Fears that the water company would turn off the water brought anxiety, as did the declarations of states of emergencies by the Mayor and the Governor. There was conflict locally, with some of the populace voluntarily conserving and others not. People were suspected of wasting water and were reported for doing so. A major public impact was the use of water conservation activities and the many time-consuming acts to reuse water (see the section on water conservation). There also were higher costs for those who traveled to other communities to take clothes for washing and to haul water.

Although many suffered and lost financially during the water shortage, some benefited. Among these were the "water witches" who were in demand to search for new well sites. Well drillers were beneficiaries, having drilled at least six local wells for businesses and institutions. Firms with tank trucks able to haul water were beneficiaries. A local chemical firm specialized in hauling water. Companies selling water tanks also benefited. In one sense the city benefited by the shortage in that several leaks in the old water system were discovered. Presumably the Saline Valley Water Conservancy District was a major winner. The drought, as publicized at Eldorado, helped bring action to get a HUD grant ($1 million) and the FHA low-interest loan ($6.7 million) to finance the $8.2 million multi-community water supply project the district desired.

Adjustments to Meet the Water Shortage

As Changnon (1981a) has pointed out, the means used to meet the water shortage fell into three broad categories: conserving and reusing water, obtaining new sources of water, and setting higher water prices.

Conservation of water began voluntarily in November 1980 (25 percent reductions sought) and became mandatory under ICC rulings on April 16. The mandatory quotas on water use set by ICC included businesses at 50 percent of prior yearly averages, and for family dwellings, 1500 gallons per month for a family of one or two, 2000 gpm for a family of three, 2500 gpm for four, etc. All restrictions were removed on May 20 following the record heavy rains.

Conservation of water was in several forms, including fixing faucet drips and reducing the amount of water used in toilet tanks. Other ways to decrease water use included taking laundry to other communities with more water, and using shower water in toilets. Another form of water reuse involved the retention of rinse water for dishware for use on a second day. Local schools and restaurants turned to paper plates, cups, and plastic throw-away utensils to save on washing. Information and assistance on water conservation methods were provided by the State Department of Commerce and Community Affairs.

As has been noted, not everyone complied with voluntary water conservation measures. Metering of water by the water company revealed that up until the mandatory limits were set, approximately 65 percent of the users were complying at a level of 50 percent reduction, whereas 35 percent of the water users did not reduce their use at all.

A second major activity related to getting new sources of water. The remedial action for the community water system included purchasing water from Harrisburg (130,000 gpd for 60 days); purchasing from the Rend Lake District via connections with the city of Galatia (initial usage of 100,000 gpd, and then 150,000 gpd); and pumpage of water from two small surface water sources, Leitch Lake and Dering Pond, using pipelines provided by the State's Emergency Services and Disaster Agency (ESDA). A complicated overland diversion of water from McLeansboro was considered, but this was never implemented. Other ways in which the water supply was increased included the drilling of several low production wells. The Illinois State Water Survey (ISWS) provided data and advice on possible well sites and production rates, and the State Geological Survey performed an electrical earth resistivity survey to locate possible well sites. Several homes and businesses built systems to catch rainfall. Hauling of water from external communities was also used by several businesses, and water in two ditches was captured and used for a variety of purposes.

The third major effort to control water usage and to improve the supply related to higher water prices. As was stated previously, Eldorado's price of water had been low for a long time – $2.16 per 1000 gallons up to 8000 gallons, then graduated even lower. On March 25, at the request of the Eldorado Water Company, the ICC approved a surcharge of $1 per 1000 gallons for the added costs of connections to alternate water supplies. (On May 20 the surcharge was increased to $3.50 per 1000 gallons; this was later decreased to $1.50 per 1000 gallons in late June, and to $0.60 per 1000 gallons in late July 1981.) On April 16, as part of its ruling setting a mandatory quota of usage, the ICC set a penalty of $1 per 100 gallons of excessive usage up to 1000 gallons, and $5 per 100 gallons above that. There was also a $50 fine set for wasting water or tampering with the water meter.

The above-listed solutions for meeting the water shortage were all short-term solutions, meant to bring results at the time of the shortage. It should be noted that two technologies were not employed. One was the use of fatty alcohols like hexadecanol to reduce the evaporation in the reservoir. The other was the use of planned weather modification to enhance the precipitation. The lack of consideration of this alternative in 1981 was particularly interesting because the area had been the site of a rain enhancement project in the summers of 1978, 1979, and 1980, and there was considerable local belief in its efficacy. Nevertheless, it was not sought as a solution.

Interestingly, long-term solutions were also being sought. One involved consideration by the city of Eldorado of purchasing the privately-owned water company. As has been discussed, the Saline Valley Water Conservancy District also was planning a multi-community water system based on higher production wells.

Summary

If the problems and resulting activities at Eldorado are important as lessons for future planning, one must first ask whether the Eldorado situation was just an anomaly. The severity of the drought was not great, but several other southern Illinois communities (Harrisburg, Centralia, and Salem) experienced nearly comparable water shortages. They all had one common problem: small surface water reservoirs incapable of meeting a 12-month or longer moderate drought. Loss of storage due to sedimentation was an integral problem. In that sense, Eldorado was not an anomaly with activities uncommon for a community with an inadequate water supply. It was anomalous in that it became the focal point of state and national attention, an illustration of a community in distress due to drought.

The problems and decisions that led to the extreme water shortage at Eldorado deserve summarization. First, it is worth recognizing that even in humid climates such as that in Illinois there will always be droughts, and that there are various ways for municipalities to adjust to these droughts. However, another truth is that people often tend to ignore long-term solutions or adjustments in their water supplies to meet drought conditions. Solutions can be extremely costly on the local scale.

The small drainage basin and small reservoir (and its siltation) at Eldorado was a key problem inasmuch as a once in 5 to 10 year drought (70 to 75 percent of normal rain precipitation over a 12-month period) could produce the type of shortage experienced in 1980-1981. Furthermore, the water system was old, more than 60 years, and apparently had several leaks, some resulting from the installation of new sewer mains during the drought period. An integral aspect of this problem was likely the privately (and locally) owned water company. The price of water was kept quite low and the company sought profits. Until recent years, there had been relatively little investment in the maintenance of the system. The lack of dredging of the lake since the 1930's also was a major part of the storage problem. The reservoir had lost an estimated 35 percent of its storage. Clearly, the reservoir was at best very marginal. Eldorado was living on the margin.

The city and its citizens also were a problem in that they largely ignored the water problem. The utility company had spent over $350,000 on improvements since 1975 and had reached the extent of their borrowing power. What were the causes for the problems? The local population had not grown very much. It also had been a very long time since there had been a drought of any consequence, since 1953-1954. In the intervening 26 years, there had been only one moderate drought (in 1976-1977), which had led to one month of restricted water use (February 1977). However, spring rains quickly alleviated that problem. In general, the unusually long time without a drought probably led to a general view by the populace (and local decision makers) that "rains (nature) will care for us." People also had refused to pay higher taxes in order to buy the water company in 1977. Certainly the fall 1980 decision to plan for normal winter rains was the wrong strategy, but it was not unexpected. It points to the value of utilizing the long-range precipitation predictions now available., The State Water Survey forecasts issued in the summer of 1980 called for below normal precipitation in southern Illinois.

Basically, the populace had a perception, as do most people in Illinois, that water is plentiful and water is cheap. Certainly, the private water company did not help the problem by developing a better supply. This raises questions about advice to and supervision of utilities by the government – was the supply adequate to the climate? The water company over the past 20 years certainly could have proposed increased rates (to seek external supplies) but apparently was unable or unwilling to act in these directions. In one sense, no one was really responsible for the stress on the all important local water supply.

Who was to blame? A quote in the *Wall Street Journal* gives insight into the problem. A local resident, Mrs. Ligon, stated, "You can't blame anyone, because everyone's to blame. We took our water for granted, like air, until it ran out." She further explained that she took her umbrella to work every day hoping that the rains would relieve the problem (and finally they did).

Apparently, the coincidental development of the plans for the multi-community water supply system developed by the Saline Valley Water Conservancy District will yield a long-term solution for Eldorado. Before the drought ended, federal grants were agreed upon to begin the initiation of the system, and Eldorado and Harrisburg signed contracts with the district to provide water. Presumably this large groundwater supply will improve the drought tolerance for Eldorado and other local communities with inadequate reservoirs.

Many citizens of Eldorado learned how to conserve water, and higher prices of water were a part of the conservation issue. Will they remember? Will the lessons be taken into the future? On May 10, in a comprehensive story in the *State Journal-Register*, an Eldorado citizen, James Rogers, was quoted as saying, "I'll bet if you had a 10-inch rain, many of the people here would forget about it [the drought] in a week." Within 7 days after that statement there had been 9 inches of rain. Will they forget? Is the forecast correct? A news story in late June 1981 indicated that many people in Eldorado were still conservation conscious.

Use of Weather Modification during The 1980-1981 Drought

Introduction

One of the solutions sought to ameliorate the effects of deficient rainfall on crop production during the southern Illinois drought was a weather modification project conducted in a 6-county area in the summer of 1980.

During the dry summer of 1978, a group of citizens in southeastern Illinois became interested in the possibility of obtaining additional rainfall through the use of a weather modification program. By the latter part of the summer, they had formed a corporation called Southeastern Rain, Incorporated, had raised funds, and had launched a cloud seeding project carried out by a weather modification firm during August and early September 1980. No scientific assessment of this hurriedly assembled effort was attempted. The regional interest in this endeavor, and the potential for agricultural benefits deriving from additional summer rainfall in this area of Illinois, led the group to plan for a second summer season project in 1979 and a third in 1980. A local fund raising program was conducted in each year.

Interactions between the local county cooperative extension advisors and the staff of the Illinois State Water Survey, which was providing scientific and technical information on weather modification, led to the decision that the State Water Survey would plan and perform an assessment of the rainfall for the 1979 and 1980 projects (Hsu and Changnon, 1981). This would provide information to local groups and state officials. This effort would also test the evaluation techniques and concepts being evolved in an NSF-sponsored project concerned with cloud seeding operational projects (Hsu et al., 1981). The 1980 "target area" of about 1000 square miles (figure 38) was defined as that area for which funds were raised, and as such, was identified as the site for cloud seeding operations, based upon the contract between Southeastern Rain, Inc., and the cloud seeding firm. The target area embraced most of Saline and Gallatin Counties, and parts of Franklin, Hamilton, White, and Williamson Counties (figure 38). No dense raingage network was established by the County Extension Service in 1980.

It is important to appreciate that the assessment of the 1980 summer rainfall, which involved comparisons of the rainfall patterns and amounts in the target (seeded) area with those in the surrounding (non-seeded) areas, should not lead to the inference that the rainfall in the target area was either increased or decreased because of seeding. It is very unlikely, due to the great natural variability of summer rainfall in southern Illinois, that one could decide whether cloud seeding during a period of a few weeks altered the rainfall or not.

Statistics are available elsewhere (Hsu and Changnon, 1981) that 1) describe in detail the rainfall in and around the target area, and 2) compare results of three of many statistical evaluation techniques. The detailed results are not repeated here.

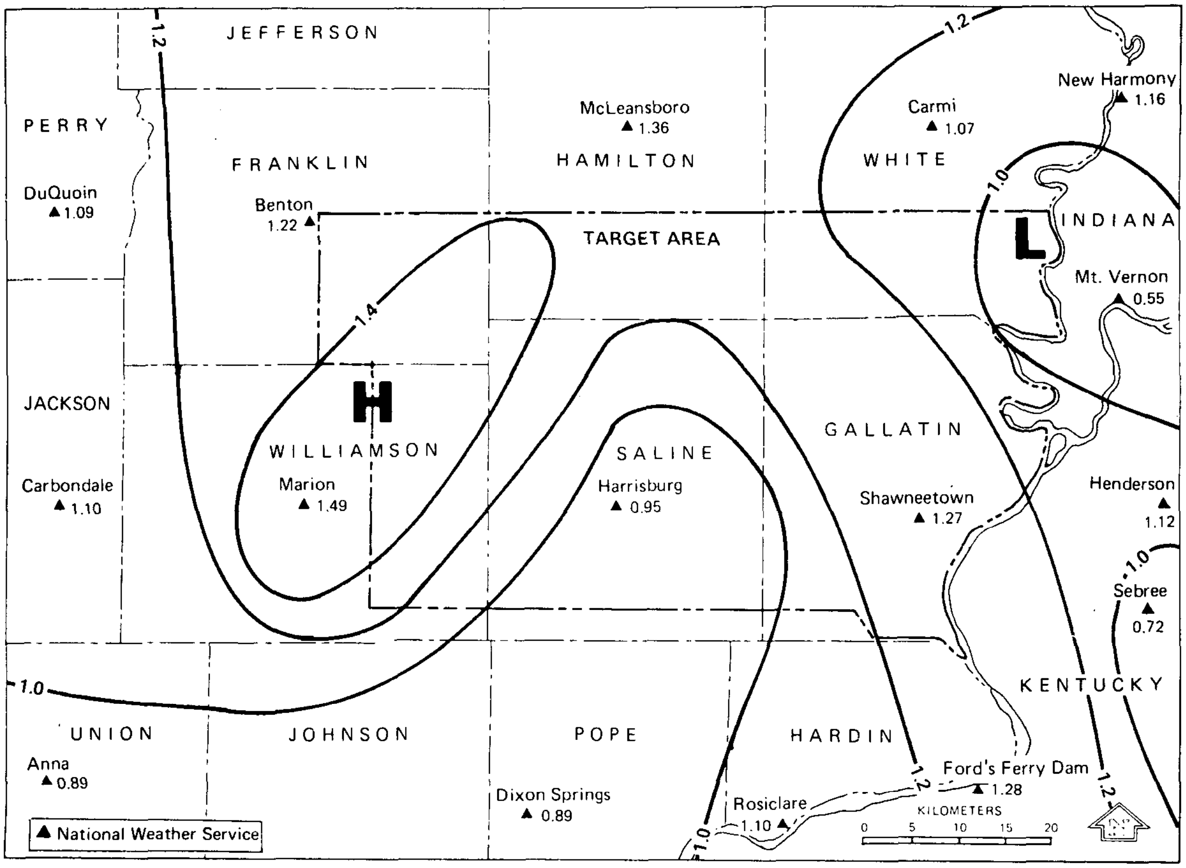


Figure 38. Rainfall ratio pattern for 1980 rainfall compared to 1949-1978 average

Data and Analyses

The cloud seeding company was available and ready to seed clouds from June 23 through July 2, 1980 (period 1), and then, after a pause because local conditions were too wet from lowland flooding, the operations were available again from July 14 through August 20, 1980 (period 2). Thus, if suitable weather conditions had been available, cloud seeding could have been conducted for a total of 48 days within this June 23-August 20 period. This period of June 23-July 2 and July 14-August 20 was subsequently called the *operational period.* On thirteen days, clouds were seeded.

A time-honored approach to rainfall evaluation of a specific area has been to compare the rainfall in the area of interest with that in regions surrounding it. The surrounding regions are typically called "control areas" for comparison with the "target area." The only National Weather Service (NWS) raingages in the target area were at Harrisburg and Shawneetown (figure 38). Prior to the seeding project, control areas to the north, west, south, and east of the target area were defined, each including from two to five NWS gages. They were areas of a size equivalent to the target area, and each had the same general raingage density.

Assessments using NWS gage data from 1949 to 1980 (excluding 1979) in and around the target area were also pursued. All the NWS stations used possess continuous rainfall records for the 31-year period. The 1979 data were excluded from the present evaluation mainly because of seeding in 1979.

Target-Control Comparisons of 1980 Area Rains

During the 1980 operational period, the target area received 5.48 inches on the seeded occasions, and the average rainfall for all four control areas on the seeded occasions was 3.82 inches. Their difference, labeled T-C (or target minus control), was equal to +1.66 inches. This difference, expressed as a percent of the control average rainfall, represented 43.5 percent more rainfall in the target area on the seeded occasions than in the control areas. This is to be expected since cloud seeding is pursued in an area during conditions most favorable to rain development in the target area. More reliable and more bias-free evaluation involves use of the historical target-control comparison, which is discussed below.

On no-seed occasions, the target area received less rainfall than did all four control areas. The difference (T-C) between the target and the averaged control was 1.05 inches less or –38.5 percent.

The total 1980 rainfall in the target area (7.16 inches) easily exceeded the averages of the four control areas (6.55 inches), and was larger than each control areal rainfall except that of the west control area. The T-C difference was +.61 inches, or +9.3 percent. Thus this effort of assessment revealed that there was a "crude" rainfall increase, though small, in the target area. The cause can not be established.

Historical Comparisons

For each NWS gage, a ratio of 1980 rain to the 1949-1978 averaged rain was calculated. It can be seen in figure 38 that there was a region of high rainfall ratios located to the west of the target area. The 1980 total rainfall amount of Harrisburg (inside the target) was close to its historical average, with a ratio of 0.95, while the 1980 total rainfall amount of Shawneetown was above its historical average, with a ratio of 1.27. However, a band of high rainfall ratios also occurred to the north and southeast of the target area, which discounts the significance of the above normal rainfall ratio at Shawneetown.

The target and control area rainfall values from 1949 to 1978 were used as "historical controls" to compare with the 1980 rainfall values. Several statistical evaluation techniques were chosen before the actual evaluation efforts were undertaken; namely, the principal component regression (PCR), multiple regression (MR), and double ratio (DR). Results for two are presented here.

A principal component analysis for the four control areas using 1949-1978 historical data was performed and the first component was retained, which was used, in turn, as an independent variable to run a regression on the target area value. The (historical) principal component regression equation was used to forecast precipitation in the target area, which in turn was compared to the observed 1980 target area precipitation. The resulting forecasted rain for the 1980 target area (by using the 1949-1978 PCR equation) was 6.88 inches. The difference between this and the actual rain value (7.16-6.88) gave an estimated rainfall increase of 0.28 inch, or +4.1 percent. The significance of this rainfall increase was 0.42. That is, the chance that the increase is due to nature (rather than to the cloud seeding) is nearly half.

The four control areas' values were used as independent variables to regress on the target area values using 1949-1978 data. The resulting (historical) regression equation was used to forecast 1980 target area rainfall. The forecasted value, 7.14 inches, and the difference between this and the actual 1980 target area rainfall (7.16-7.14), give an estimated rainfall increase of 0.02 inches, or 0.3 percent. The significance level was 0.48.

Summary

The target (seeded) area received more rainfall (based on only the three gages available to determine the area average) during the 1980 48-day operational period than did the surrounding areas. This was quite evident when one compared the target area rainfall with the surrounding control rainfall based solely on the 13 seeded rain day occasions. Investigation of the 1980 area1 rainfall in the target area, as compared to the control areas, revealed an estimated rainfall increase of 44 percent on seed occasions, and an estimated rainfall decrease of 39 percent on no-seed occasions. The total rain difference (all days) reflected a 9 percent increase in the target. However, the 1980 rainfall data alone cannot be construed as evidence of any cloud seeding effect.

A more bias-free evaluation using the surrounding control areas and the historical data indicated non-significant rainfall increases in the target area of 0.3 to 4 percent from the 1980 cloud seeding period. The probability that these were due to chance is approximately 0.5. The bottom line is that the seeded area got slightly more rainfall, on the scale of 1 to 9 percent, than would be predicted by various time and space relationships, but there is only a 50 percent chance that this was due to seeding and not natural forces.

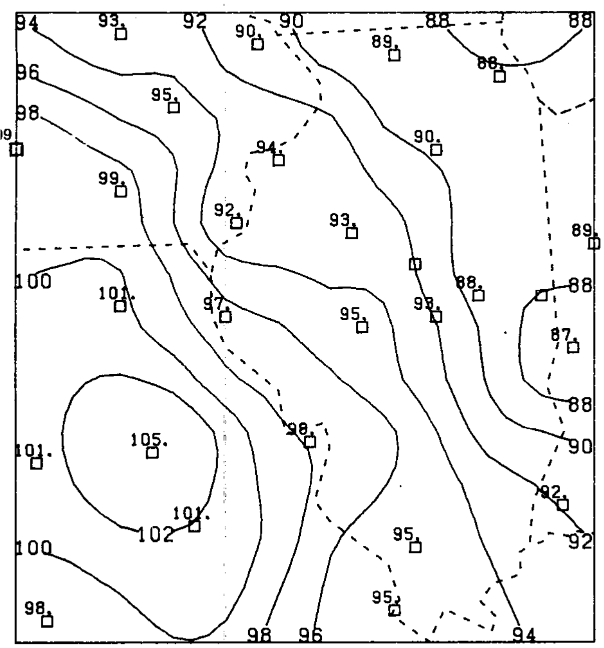
Temperature and Humidity Conditions in July 1980 Potentially Affecting Physiological Responses

The heat wave of 1980 resulted in more than 1250 heat-related fatalities in the U.S. (Quayle and Doehring, 1981). Air temperature and humidity were the most important factors that contributed to heat stress. High humidity decreases the efficiency of the human body's evaporative cooling mechanisms, causing the body to "feel hotter" than would be indicated by the dry bulb temperature.

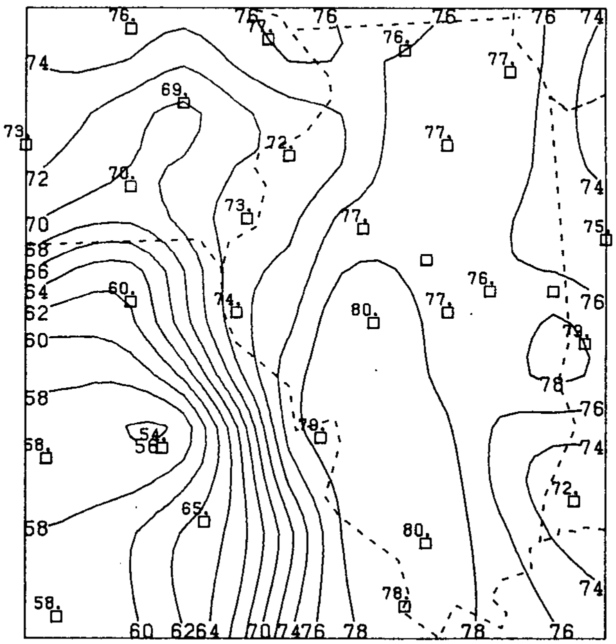
Steadman (1979) developed a single measure of the combined effects of high temperature and humidity called "sultriness." Sultriness is similar in concept to the combination of wind and low temperature referred to as "windchill." Corresponding to the windchill equivalent temperature, the "apparent" temperature is the temperature that a given combination of dry bulb temperature and humidity "feels like" to the typical human.

During July 1980, daytime high temperatures in the area of 105°F were recorded over parts of Missouri. Temperatures over western Illinois during the sultry air mass invasions (see Chapter III) were usually in the middle to upper 90's. These temperature highs occurred nearly simultaneously with the occurrence of extremely high dew points. The heat stress upon the human body under the heat and humidity within the sultry air masses in Illinois could have equalled or exceeded the heat stress within the hotter but drier air masses to the southwest.

Steadman's equations were used to calculate apparent body temperatures for the period July 11-16, 1980, for the region shown in figure 39. At 1800 CST on July 14, dry bulb temperatures to 105°F were observed over central Missouri (figure 39a). By contrast, temperatures were

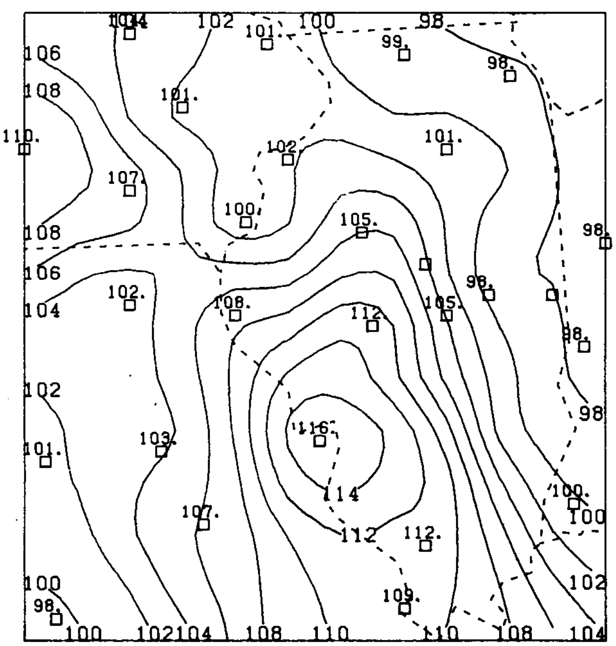


a. Dry bulb temperatures, °F



b. Dew point temperatures, °F

Figure 39. Dry bulb temperatures, dew point temperatures, and apparent body temperatures on July 14, 1980, in Illinois and portions of neighboring statas



c. Apparent body temperatures, °F

in the middle 90's over central and western Illinois. However, the cooler air mass was very humid, with dew points in excess of 76°F over much of Illinois and parts of Iowa (figure 39b). The impact of the high humidities, according to the apparent body temperatures, was to shift the conditions favoring greatest heat stress from Missouri to Illinois within the sultry air mass (figure 39c).

The misery induced by the sultry air mass extended beyond the hottest part of the day. Table 27 compares dry bulb and apparent body temperatures at Columbia, Missouri (COU), within the hot, dry air mass, with those at Quincy, Illinois (UIN), within the sultry air mass, for part of July 11. The dry bulb temperatures were 79°F for both stations at the beginning of the period, but the humidity made the temperature feel 2° warmer at Columbia and 5° warmer at Quincy. After sunrise, the temperature at Columbia rose rapidly to a mid-afternoon maximum of 106°F.

As the temperature rose at Quincy so did the humidity. Dew points reached 80°F at the time of maximum dry bulb temperature (99°F). Table 27 shows that the 0900-1800 CST dry bulb temperatures at COU were higher than those at Quincy, but the humidity at Quincy made it feel hotter there. The apparent body temperature at 1500 CST was 119°F at Quincy, as compared with "only" 108°F at Columbia. Even at night (2100 CST), the sultriness made the temperature at Quincy seem like an oppressive 101°F.

Sultry air masses moved into central Illinois on July 14. Table 28 presents dry bulb and apparent body temperatures at Columbia (Missouri), Peoria, and Carbondale. The humid air masses seemed hotter for a longer time at both Illinois stations. At 1500 CST, the combination

Table 27. Dry Bulb Temperatures and Apparent Body Temperatures at Columbia, Missouri (COU) and Quincy, Illinois (UIN) on July 11, 1980

Time (CST)	*Dry bulb temperature (°F)*		*Apparent body temperature (°F)*	
	COU	*UIN*	*COU*	*UIN*
0600	79	79	81	84
0900	91	88	94	98
1200	103	95	107	112
1500	106	99	108	119
1800	101	96	102	111
2100	89	91	91	101
0000	85	85	86	92

Table 28. Dry Bulb Temperatures and Apparent Body Temperatures at Columbia, Missouri (COU), Peoria, Illinois (PIA), and Carbondale, Illinois (MDH) on July 14, 1980

Time (CST)	*Dry bulb temperature (°F)*			*Apparent body temperature (°F)*		
	COU	*PIA*	*MDH*	*COU*	*PIA*	*MDH*
0600	80	75	77	83	79	81
0900	93	85	89	96	94	99
1200	102	95	97	103	109	114
1500	107	99	101	106	115	124
1800	105	93	95	103	105	112
2100	87	87		87	98	
0000	82	83		82	93	

of an 81°F dew point with a 101°F dry bulb temperature made the air temperature at Carbondale feel like an astounding 124°F.

The heat wave of 1980 has been compared with great heat waves of the past century, but Illinois was not included within the areas of extreme (5 percentile) temperature departures from July monthly normals (Karl and Quayle, 1981). Our analysis has shown, however, that residents of Illinois did not escape the misery of the heat wave. Although air temperatures were not as high as in some areas, air masses over Illinois became extremely humid at times and caused the air to feel hotter than indicated by the dry bulb temperatures. Using Steadman's equations for apparent body temperatures, it was found that the sultry air masses over Illinois were actually more oppressive than the hot air masses over Missouri and other areas to the southwest.

Chapter VII. Summary: Action Options, Conclusions, and Recommendations

Stanley A. Changnon, Jr.

Summary

Most people in Illinois have two basic beliefs about water. First, water is cheap, and second, water is plentiful. Why worry? If water becomes short, most believe we can buy our way out of the problem, or in the long run, some new technology or source will solve the problem.

These are common beliefs about water, but they run counter to the theme found ever more frequently in national popular magazines and scientific journals, which frequently contain articles addressing national water problems. A common comment found in them is that the water problems of the future will surpass the magnitude of the energy problems.

Nevertheless, with the "cheap and plentiful" perception, Illinoisans label most water supply problems as infrequent, isolated events with some easily attainable solution. This perception is further fueled by an oft-stated position that "Illinois is a water surplus state." However, in the past two years, Illinois newspapers and journals have carried major stories about toxic wastes in groundwater, extensive stream and lake pollution by soil sediments, attempts to remove silt from lakes and ways this silt can be used, diversion of Lake Michigan to give enough water to the Chicago suburbs until the year 2000, higher prices for Chicago water, a drought in southern Illinois, and flash floods in the suburbs of Chicago and many other communities. These headlines reflect today's water issues, which fall into three categories: worsening water quality, growing inadequacy of potable water supplies, and periods of too much or too little water.

The 1980-1981 drought in Illinois caused shortages, problems, and activities that herald future state problems. Following is a summary of the physical features of the drought (climate, meteorological factors, and streamflow and groundwater conditions). This is followed by a summary of the impacts, and then by a section on action options to use during droughts. The report ends with conclusions and a set of four recommendations.

Climate Findings

From the standpoint of climate, the 1980-1981 drought was not a severe one, lasting only 15 months. Most severe Illinois droughts have greater precipitation deficiencies and persist over periods of 3 to 5 years (Huff and Changnon, 1963). Comparison of the 1980-1981 drought with other droughts defined on a statewide basis reveals its low rank. It rated as the 19th lowest of the 19 3-month droughts of the 1906-1981 period; the 13th most severe of the 17 6-month droughts; and 15th among the 15 l-year droughts of the past 76 years. This moderate classification of the drought is reflected in the rainfall return intervals (the intervals expected between given rainfall amounts) for the areas with the most deficient precipitation. During the driest 3-month period of the drought, the greatest return interval was 4 years (for the east-southeast district). During the driest 6-month period, the greatest return interval was 10 years (southwest district). During the driest 12-month period, the greatest return interval was 7 years (southwest and southeast districts). The precipitation deficiency in the driest 6-month period of the drought (October 1980-March 1981) was more severe than that in the driest 3- and 12-month periods of the drought.

From a precipitation standpoint, the 1980-1981 drought was very typical. It was most intense in southwestern and extreme southern Illinois, with near normal precipitation in northern

Illinois, a condition found in many Illinois droughts. From a temporal standpoint it was also typical, achieving its greatest departure from normal precipitation in the colder half-year, and having at least one hot dry summer month (July 1980).

Temperatures during the 1980-1981 drought were generally above normal throughout the state, but further above normal in the southwest and south where the precipitation also was least. This is typical of drought conditions. July 1980 had extremely high temperatures, being the hottest July since July 1954. Moisture stress was great, and potential evapotranspiration calculations revealed that water deficits were 2 to 3 inches above normal in July 1980. In general, the potential evapotranspiration during the entire drought was greatest in the southwestern part of Illinois. Pan evaporation was also found to be greatest in the southwestern drought area, averaging 1.3 inches per month above normal during 1980 and the spring of 1981. Winds in Illinois were above normal during the drought, with the greatest departure (+1.3 mph per month) at St. Louis, the wind measuring station nearest to the center of the drought. The highest wind speeds and the most days with high wind speeds occurred during the spring of 1981.

In summary, the 1980-1981 drought was very typical in a climatic sense as to its placement and time of occurrence. The drought-impacted area is where Illinois experienced the lowest precipitation, highest temperatures, and greatest departures from normal wind speeds, all of which combined to produce the state's greatest evaporation and transpiration values. This in turn brought the low streamflows and groundwater deficiencies and their stress on water supplies and agricultural activities.

Meteorological Findings

Like other droughts in Illinois, the drought of 1980-1981 included 2- to 4-month periods with much below normal monthly precipitation, which were occasionally interrupted by one or two months with near to above normal precipitation. The precipitation in the wet months did not allow the drought to intensify but also did not relieve the drought.

Since the year-long drought spanned five seasons, it was supposed that there existed several contributing meteorological factors. A search of the weekly 700 mb level circulation maps led to the classification of two persistent stationary long wave patterns that tended to be associated with these dry spells in Illinois. These long waves, LW-6 (occurring in the late spring and summer) and LW-4 (occurring during fall, winter, and early spring), influenced the circulation over Illinois for at least 25 weeks during the 52-week heart of the drought (April 1980-March 1981). These two types of stationary waves influenced the circulation and accounted for all of the deficient precipitation in the 12-month period.

It would seem that the LW-4 and LW-6 circulations helped cause the 1980-1981 drought in Illinois. However, LW-6 and (particularly) LW-4 occur almost every year (although not as frequently as in 1980-1981), including years with above normal rainfall. It is possible that 1) these waves are accompanied by more seasonable rainfalls during non-drought years, or that 2) the transition and other categories are accompanied by much above normal rainfall which far exceeds the amount necessary to offset the dry spells. Studies to determine the LW-precipitation relationships during non-drought years have not yet been made but are recommended.

The low frequency of stationary fronts in Illinois, especially during the warm months when frequencies are normally high, was one of the causes of the drought in southern Illinois. Advancing air masses that stall as they pass through Illinois provide an unstable boundary favorable for the development of convective precipitation, especially to the south of the front. Without this mechanism for instability, convective precipitation is most likely to be below normal.

The low frequency of stationary fronts could be due to two factors. First, a greater frequency of fast, cold fronts passing through Illinois and stalling well to the south of Illinois could account for a lack of stationary fronts in the state. Second, it could be due to an overall low frequency of frontal activity across Illinois. The results of the frontal analysis (tables 10 and 11) suggest the former reason to be the more likely. In fact, the point frequencies and the frontal passage analysis indicate a normal number of frontal passages, but the residence times of the fronts in Illinois were short. Cold front passages were frequent during the drought period, but very few of the advancing air masses stalled in Illinois. In addition, few of these cold fronts produce significant precipitation.

The role of the stationary fronts in warm season precipitation production, particularly in the southern half of Illinois, is apparent from the relatively high climatological frequency of these fronts and their yield of rainfall. Their absence in the 1980-1981 drought resulted in precipitation deficits. This may not hold true for all drought situations, but it played a key role in the 1980-1981 drought in Illinois.

Streamflow

The analysis of the streamflow of six basins distributed throughout the drought area revealed that deficient rainfall in the fall of 1979 helped initiate a decrease in streamflow that persisted until the record rains of May 1981 ended the drought. There is a very close relationship between precipitation and streamflow in the southern physiographic regions of Illinois during droughts, with droughts defined as those occurring once in 5 years or more (Huff and Changnon, 1964). This relationship exists in that area of Illinois because of a lack of groundwater to help recharge and sustain low flows. The lowest 12-month flow values (May 1980-April 1981) ranked behind those of the early 1960's but were greater than those in 1976-1977. The 12-month low flows ranked as 8- to 10-year events in the west-southwest district, but as 1.5 to 58-year events in the southern fourth of Illinois. The Cache River at Forman experienced a once in 58-year low flow for 12 months. Lowest flows measured in shorter periods, those of 7 to 90 days duration, were rated as only 2- to 5-year events. The flows of January-April 1981 were the worst (lowest) of the drought, and were the second driest January-April values on record (ranked second only to those for 1954). The mineral contents of the Big Muddy River and Cache River showed increases during the drought.

Groundwater

Shallow groundwater levels showed the effects of the drought in west-southwest, southwest, and southern areas of the state. Most observation wells in the affected areas exhibited below normal water levels beginning in the fall of 1980, illustrating the usual delayed response of the groundwater system. Two wells located in southern Illinois experienced new record lows during the winter of 1980-1981. Although some local areas experienced severely low groundwater levels for a short period of time, an analysis of long-term records shows that the 1980-1981 drought generally had only mild impacts on shallow groundwater levels. The heavy summer precipitation that began in May 1981 replenished groundwater storage and water levels recovered quickly, so that by July 1981 the levels were above or very near normal for that time of year.

General Impacts

An assessment of the impacts and effects of the drought in various societal and economic areas (although our study was limited, often qualitative, and not comprehensive) reveals five general impacts, or effects, of the 1980-1981 drought in Illinois.

First, the drought was costly. In most instances, costs of water and water-related activities were increased, and simultaneously there was often a loss in income. There were added costs for obtaining water, decreases in crop yields, farm payments for water hauled, reductions in rural land values, increased costs in shipping farm products, municipal costs of temporary water supply solutions, and a general loss of productivity in other, areas because of attention to the drought. In a few instances there were "winners." These included well drillers (who filled needs for new wells), haulers of water, suppliers of water storage facilities, and weather modification firms. The construction industry may later experience secondary benefits as communities and rural areas seek better supply solutions (wells and lakes, new water plant facilities, etc.) in the years following the drought.

The second general area of impacts relates to effects on natural resources. As was noted in several instances, the transportation industry experienced greater activity and delays. Also, increased use of groundwater meant increased pumpage of water. Thus, the drought increased energy consumption. The dry soils relating to the absence of precipitation led to increased soil erosion and pollution of the atmosphere. Low water levels in streams and reservoirs also detrimentally affected the fish population. In general, droughts are detrimental to Illinois natural resources.

The third general area of impacts related to human behavior. It was noted that human anxiety was increased; more time was given to seeking water and conserving water; recreational opportunities (fishing, use of swimming pools, etc.) were reduced; and the number of interpersonal conflicts was increased. Public antagonism towards local water supply officials and city officials was a common reaction in water-short areas.

The fourth general area of impacts relates to local and state government entities. Many new activities were launched, meetings were held, and in general, there were increased costs to both local and state government in serving those affected by the drought. This resulted in a diversion of manpower and funds from other activities. In general, the drought produced a series of additional costs to government in many direct and indirect ways, including a loss of taxable revenue.

The fifth general area of impacts might be considered the "benefits." Some economic benefits to certain sectors of the economy have been noted. From a water resources standpoint, however, the general positive impact of a drought often is to force areas and/or local communities to seek corrections of their inadequate water sources. As has occurred after prior droughts, some severely impacted communities will improve their water systems (new mains, larger storage facilities, new filtration plants, etc.). The drought will also lead some communities and areas to seek larger and better supply systems (new well fields, larger lakes, cleaned-out lakes, etc.).

Actions and Action Options

The above summarization of impacts, also illustrated in figure 35, reveals a wide variety of actions that were taken. These, therefore, become action options that can be considered for future droughts in Illinois. As such, they deserve summarization.

Municipalities

As has been noted, there were three approaches used-in municipalities suffering water shortages during the 1980-1981 drought. These approaches were:

1) Conserving and reusing water
2) Obtaining new sources of water
3) Setting higher water prices

It is important to note that all of these solutions were sought in Eldorado. Water conservation, based on voluntary or mandatory restrictions, was employed in most water-short communities in southern Illinois.

The search for new sources of municipal water had two time-related directions. In general, the *short-term solutions* included seeking water from other nearby reservoirs, ponds, and streams by diversion through pipelines or natural water courses. In several instances, new wells were drilled.

The problems in Eldorado can be compared with the findings in the report of the Illinois Drought Task Force (1977). That report states that there are three basic truths about droughts. These include the facts that 1) municipal water shortages are essentially a local problem (which was true in 1980-1981.); 2) money alone will not solve the water problems (although, as discoverd at Eldorado and other places, money was a necessary factor in improving the water system); and 3) conservation is the best way of solving the water shortage. Extreme conservation was used at Eldorado in 1981, but it was not able to stop the growing shortage. The three basic "truths" of the 1976-1977 drought relate only to certain short-term solutions to limited local problems, and may be applicable largely to moderate drought conditions.

Also in evidence was the search for *longer-term solutions.* Droughts have invariably forced cities to action, and many of the public water supply improvements in reservoir storage have followed past Illinois droughts. In central Illinois, during the mid-1950's, several cities such as Decatur, Bloomington, Springfield, and Mattoon either built second lakes, raised spillways, or resorted to pumped storage during or after the severe drought of the 1952-1955 period (Huff and Changnon, 1963).

In southern Illinois, Mount Vernon imported water via railroad tank cars in the early 1940's. This situation led to the building of a second reservoir.

Effingham suffered a severe water shortage in the 1953-1954 drought when the Little Wabash River went dry (Hudson and Roberts, 1955). The only alternative, except for a few small local wells, was to use an oil pipeline to bring water from the Embarras River. Using the Water Authority Act, the city and a few neighboring townships formed the Effingham Water Authority. This entity built Lake Sara, a major reservoir with a capacity of over 4.5 billion gallons. A study of water-short towns affected by the 1976-1977 drought in south-central Illinois revealed that several had made adjustments in the management of their water systems after the drought (van Es et al., 1980).

Several of the communities experiencing water shortages as a result of the 1980-1981 drought are planning or actively seeking future solutions. Others apparently are not reacting. Yet municipalities exercising proper planning and management practices can evaluate alternatives that will provide adequate water supplies for future growth and prolonged drought periods. These water resources may not be available in the immediate area of use, for abundant water resources are not uniformly distributed throughout a given region. However, there are means for increasing local and regional supplies, including building reservoirs and moving water from one area to another via pipelines. Movement of water long distances from one point to another via pipelines is possible with proper engineering design and known technology.

Information available at the Illinois State Water and State Geological Surveys and at the Illinois Department of Transportation, Division of Water Resources, shows that in some areas of Illinois groundwater and surface water resources are abundant. These abundant supplies, while uneven in distribution, are in excess of the present withdrawals documented by Kirk et al. (in press 1982). Potential reservoir sites have been enumerated in a series of Illinois State Water Survey Reports of Investigation (Dawes and Terstriep, 1966a, 1966b, 1967; Roberts et al., 1957), and major groundwater resources have been pointed out in numerous reports available at the State Water and Geological Surveys. Although these reports are not sufficiently detailed to allow a municipality to build a dam or drill a well without additional investigation, they do provide valuable data and guidance to consulting engineers to assist in further development of the available water resources.

In addition to the communities mentioned previously, many other communities, including Norris City, Assumption, Jacksonville, Galesburg, Pleasant Plains, Tallula, and Normal, have launched and completed efforts to assure their residents of an adequate water supp1y source engineered to provide for future demands and reliability.

One of the action options available to groups of small communities which individually have insufficient water supplies is the formation of water districts to serve both municipal and rural areas. These have sufficient fund-raising capabilities to develop major new sources such as new well fields, permanent pipelines, new treatment plants, or new reservoirs. The services provided by the Clayton-Camp Point Water Commission, the Rend Lake Inter-City System, the ADGPTV (Auburn-Divernon-GirardPawnee-Thayer-Virden) Water Commission, and the Saline Valley Water Conservancy District are examples of the work that can be accomplished through cooperative water resource evaluation, planning, and development. Without the multi-purpose Rend Lake, which was completed in 1972, it is estimated that some 55 southern Illinois communities would have found their own water supply reservoirs grossly inadequate during the 1980-1981 drought.

Another long-term solution or option includes actions to "renovate" current water facilities and sources. Effective increases in supplies from existing reservoirs can involve the dredging of silt accumulations, or the raising of spillway or dam heights. Another municipal option to be sought over longer time horizons is the renovation and improvement of old, inadequate, and often worn-out water supply systems. This could include the repair of leaks; replacement of old pipes, and renovation of water treatment facilities.

Water price increases were sought in Eldorado and obtained by the privately owned water company. Rates, were raised with ICC permission. Water reuse was performed at the household level (saving of rinse water, etc.). Another form of water reuse, use of effluent from the city waste treatment plants, was considered at the municipal level in certain areas. Increases in the price of water should be sought as a long-term option.

Agriculture

Action options available for agricultural interests, and farmers in particular, are diverse. For the cash grain farmer, some of the options that can be considered relate to choice of crop and crop variety to grow, density of plant population, types of herbicides, and level of fertilization. All of these decisions, which must be made in the fall and/or spring before a crop season, require some information on the status of the growing season weather. The availability and use of seasonal predictions of future weather would be important to these decisions.

The farmer with a livestock-based farm also has action options related to needed water supplies. In all instances, rural households face certain questions about their water supplies. In essence, the action options relate to considerations like building or enlarging farm ponds, drilling larger more diverse well fields, and/or hauling of water, including obtaining trucks with tanks to perform hauling: There also are some new technologies available for increasing water supplies or making better management decisions, which have great relevance to agriculture; these are treated below.

Use of New Technologies

A series of action options exist that relate to use of emerging, or new, technologies, and some were employed in the 1980-1981 drought to a limited extent. Planned precipitation enhancement is as yet an ill-defined technology for the Midwest and Illinois. However, cloud seeding was employed in southern Illinois during the summer of 1980 in an attempt to increase rainfall. Its outcome cannot be determined with certainty (Hsu and Changnon, 1981), but weather modification is a new technology to be considered and used during droughts in Illinois (Huff and Vogel, 1977).

Another emerging technology relates to evaporation suppressants, an area in which research has been pursued for more than 20 years, as it has in weather modification. Techniques to reduce evaporation consistently on lakes and farm ponds have been found, but they are not yet economically satisfactory. However, when the level of water supplies becomes more critical and therefore the worth of water increases, evaporation suppressants can be considered.

Another emerging capability that found valuable but limited usage in the 1980-1981 drought was the system of long-range predictions of future seasonal precipitation. The Water Survey's predictive techniques were brought into use during the winter of 1980-1981 and predictions were made available to state and local agencies beginning in January 1981. Although these were 7.5 percent accurate (Changnon, 1982) in the southern Illinois drought area in 1981 for predicting the monthly and seasonal precipitation as normal, above normal or below normal, they were not extensively utilized in making decisions. User awareness and knowledge of how to utilize probabilistic predictions are yet to be established.

Use of State Agencies

A fourth area of actions in the 1980-1981 drought, and action options that should be considered by local and regional groups in future droughts, are the services of state agencies. In January 1981 Governor James Thompson established a Drought Task Force comprised of representatives from 9 state agencies. This was put under the direction of the Division of Water Resources, which provided general advice to municipalities about how to solve water problems.

The Illinois EPA served in assessing water quality, particularly of new water supplies in water-short areas. The Illinois State Water Survey, with its large data banks and hydrologists and meteorologists, served 1) to provide information on alternate sources (quality and quantity); 2) to assess the status of the water and weather conditions in the drought area; and 3) to provide long-range predictions of precipitation.

The Emergency Services and Disaster Agency (ESDA) provided certain facilities such as pipelines, pumps, and trucks to assist in the movement and provision of water, particularly to communities. The Department of Commerce and Community Affairs (DCCA) provided information and advice to communities on conservation and water reuse approaches.

The Illinois Commerce Commission (ICC) played a role in the setting of utility water rates and in providing for mandatory use limits. The Department of Conservation (DOC) provided information on effects of reduced water levels in lakes and reservoirs on fish populations, and on other environmental conditions.

The Department of Agriculture and the University of Illinois Cooperative Extension Service worked together to provide assistance and considerable advice to farmers on options to solve their local and individual problems.

Finally, the Office of the Governor assisted by directing that the above activities be done. When the situation got serious in Saline County, the declaration of the county as a disaster area was performed by the Governor. This action provided for emergency loans to farmers.

Thus, several state agencies have water data, expertise, information, and facilities to provide a wide range of assistance to individuals, areas, and communities during droughts. The water resource base information of the Illinois State Water Survey is also extremely important in considering long-term solutions such as new wells, renovation of lakes, and the development of new lakes and reservoirs.

Conclusions

The problems at several southern Illinois communities during the 1980-1981 drought often involved a combination of factors: old water systems with too little maintenance, inadequate silted reservoirs, water prices that were too low, failure to adjust to localized growth in water usage, and public apathy. This apathy was particularly prevalent because of the unusually long period (since 1953-1955) without a major drought in the area. Many current decision makers in local communities had not been in decision making roles 25 years before. Basically most people continue to look at water in Illinois as an unending cheap resource with an occasional shortage that can be quickly and temporarily addressed through some technological innovations or other temporary solution.

The broader question from this case study of the 1980-1981 drought is, "Will we learn?" Illinois, through a growing population, increasing water usage, increasing water pollution, continued siltation of lakes, increasing age of already old sewer systems and water supply systems, and an ever changing climate with a greater frequency of droughts, will be facing more general water shortages in the future.

The events in several southern Illinois communities such as Eldorado, Centralia, Harrisburg, and Salem should be a reminder that the current prices of water in Illinois are too low to bring about 1) awareness of the value of water, and 2) continuing use of conservation practices, both key water supply strategies.

New sources can and will be sought (new wells drilled, different aquifers tapped, water diverted from surplus areas to short areas, water reused, and sewage plants renovated). However, most of these require years to accomplish, and therefore planning, funds, and action. Dredging of silt from water supply reservoirs should be considered as a major alternative to improving local supplies.

New techniques to manage the hydrologic cycle (rain modification and evaporation suppression) hold considerable promise but need research and development and funding. Emerging capabilities to predict future precipitation trends should be utilized at all times and informational programs should be developed to educate the users of these.

The problems in southern Illinois due to the 1980-1981 drought, which was not terribly severe, are another signal to all Illinois communities and rural areas to look to their future needs and their local, municipal, and rural (district) water systems. We need to maintain these systems and to simultaneously plan so as to increase supplies as the demands increase. Changing life styles and technologies that lead to greater per capita water use need monitoring. Measuring water use and its trends is an important component of the future monitoring and planning of state resources.

We can expect that in the 1980's and 1990's 1) Illinois will need greater quantities of water; 2) cleansing systems will become more overtaxed and/or obsolete; and 3) contaminants will cause several supplies to become unusable. The public's perception that "there is plenty of cheap and clean water" must be corrected. This is a chief challenge of our water policies and the key target of public educational efforts relating to water. An informed public will support and demand the planning and expenditure of funds to provide Illinois with quality water in future years in drought and non-drought times.

Recommendations

Recent research on droughts, including this study, show how to define droughts (Changnon, 1980). Objective definition of drought is an important foundation if Illinois is to adjust sensibly to future droughts. The myriad of problems, solutions, impacts, and action options relating to droughts described in the preceding pages lead to four general recommendations.

The *first major recommendation* is for the development of better informed and organized local and state programs for addressing droughts in Illinois. Drought contingency planning is recommended in the 1981 State Water Plan; it is a key endeavor. The ability to predict future precipitation deficiencies, including the start and ending of droughts, now exists. The ability to put this information into action to help areas prepare and manage water during droughts is extremely important. The entire issue of educating the public on water conservation, the value of water, and the need for improved water sources and facilities is seen as a part of the drought contingency planning issue, and is desperately needed. Contingency planning and assistance is also dependent on accurate monitoring of usage of water. Changing life styles and new technologies alter per capita usage, and a knowledge of new use trends is an essential part of planning.

A *second major recommendation* from this study of the 1980-1981 drought is to get older water supply systems "renovated." Sediment buildup in lakes needs to be recognized and solutions sought, including dredging, higher spillway levels, or the construction of new lakes. Older water supply systems need to have new pipes installed, leaks repaired, and treatment facilities improved. Again, local education and public awareness of these problems need to be improved if we are to obtain local understanding to support these costs.

A *third major recommendation* deriving from this study relates to the need for water conservation, water reuse, and higher water prices. Moving in these directions first requires public education about the value of water, an understanding of water quality/quantity interactions, and municipal and private awareness of more correct pricing of water.

A *fourth major area of recommendations* relates to the need to develop and use new and emerging technologies to assist in increasing water supplies and in better water management. Efforts to modify the hydrologic cycle, which currently include increasing precipitation and suppressing evaporation, need research and development, as do other innovative ways of increasing water supplies: The emerging capabilities in long-range precipitation predictions hold sufficient promise and such great utility that further research to improve these would be highly beneficial.

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Reservoir Critically Low

Coulterville Officials Declare Water Emergency

Chicago Tribune, Monday, January 26, 1981

Dry soil periling Illinois crops

Carlinville Lake continues at dangerously low water level

by Becky Merrell

Experts offer strategies for coping with drought

Marion city reservoir drops; council eyes ...

Above-Normal Rainfall Pre...

Moisture Levels Remain Low

By Jerri Stroud
Of the Post-Dispatch Staff

Drought widens land price range

URBANA (AP) - The range of prices for Illinois farmland has widened in the last year, with the lowest values in areas hardest hit by the heat and drought of 1980, a University of Illinois specialist says.

Farmer Charley Ludwig examining the dry soil on his 300-acre farm west of Springfield.

Illinois' arid 'Little Egypt' thirsty for rain and snow

Farm, urban residents feel effects of drought

Thursday, Jan. 29, 1981

Centralia Officials Issue Water Shortage Alert

By J.L. SCHMIDT
Associated Press Writer

Cedar Lake: A beach but not enough water

Hauling water 'way of life' in rural area

Drought plagues Mississippi River barge traffic

Thompson names downstate drought task force

SPRINGFIELD, Ill. (UPI) — Water-short communities in central and Southern Illinois can take heart in a drought task force named by Gov. James R. Thompson.

"We have developed a plan of action to assist communities to conserve existing supplies and help identify alternative sources of water," Thompson said Friday.

Some communities are so short of water farmers have been forced to haul water to their livestock.

Frank Kudrna, director of the state Division of Water Resources, was picked to head the panel. He already has sent packets of information to 625 communities in central and Southern Illinois — areas hardest hit by the drought.

Stanley Changnon, chief of the Illinois Water Survey, said drought conditions, based on current weather predictions, could affect communities located below a line extending from Quincy to Kankakee.

Thompson called the task force "just one part of our overall state effort to promote wise water management, which is absolutely essential for our continued economic development as well as the health and safety of Illinois citizens."

Other state agencies represented in the task force include:

• The Department of Commerce and Community Affairs, which is providing materials and working with local communities in developing water conservation programs.

• The Environmental Protection Agency, which has made available a list of sewage treatments plants with discharge effluent clean enough for farmers to use in watering stock.

• The Agriculture Department, which will assist farmers in watershort areas.

• The state Water Survey, a division of the Institute of Natural Resources, which monitors drought conditions.

• The Emergency Services and Disaster Agency, which, as a last resort, will truck water or provide pumps and pipes to communities which have exhausted water supplies.

Thompson said Capital Development Board engineers are also studying ways the state can save water.

He urged communities to plan conservation measures to have more time to develop new supplies as well as to have a margin of safety to avoid more harsh measures such as rationing or closing car washes.

In January Thompson asked the federal Small Business Administration to declare 68 Illinois counties disaster areas in order to allow farmers to apply for emergency loans for reduced crop yields due to dry conditions. The agency has not yet ruled on that request.

The task force agencies are all part of a larger water plan task force which has been meeting for over a year to consider a wide variety of water use issues.

Low rain totals near 'frightening'

By SIU-C News Service
And The Southern Illinoisan

Drought at crisis

Harrisburg to Use Pump To Ease Water Shortage