DESCRIPTION AND EFFECTS OF 1988 DROUGHT ON GROUND-WATER LEVELS, STREAMFLOW, AND RESERVOIR LEVELS IN INDIANA

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U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 91-4100

U.S. DEPARTMENT OF THE INTERIOR
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Prepared in cooperation with
INDIANA DEPARTMENT OF NATURAL RESOURCES
Division of Water

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U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon (gal)	3.785	liter
million gallons per day (Mgal/d)	0.4381	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second

Degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by use of the following formula:

$$°C = 5/9\,(°F - 32)$$

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

DESCRIPTION AND EFFECTS OF 1988 DROUGHT ON GROUND-WATER LEVELS, STREAMFLOW, AND RESERVOIR LEVELS IN INDIANA

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ABSTRACT

Documentation of the 1988 drought in Indiana was undertaken to aid water-management agencies and planners concerned with periods of below-normal precipitation and their effect on commercial, agricultural, and residential water use. Precipitation, temperature, Palmer Drought Severity Indices, and ground- and surface-water levels from water years 1988 and 1989 were compared to the historical record to evaluate severity, extent, and duration of the 1988 drought in Indiana.

Three types of drought--climatological, hydrologic, and agricultural--occurred in most of Indiana during water years 1988 and 1989. The drought began toward the end of calendar year 1987 as annual precipitation decreased to 4.6 inches below the long term mean. By the end of September 1988, statewide precipitation deficits had increased to almost 8 inches below normal. High temperatures during the summer months increased the stress on crops, livestock, and people. Northwest Indiana experienced the second warmest June-August on record. Palmer Drought Severity Indices indicated that a moderate-to-severe drought had occurred in Indiana during most of 1988.

Ground-water levels were affected substantially in many areas of the State. Record low-water levels were observed at 12 of the 20 monitoring wells included in this report. A 90-day ground-water emergency was declared in parts of northwestern Indiana. Streamflow throughout the State was affected to varying degrees by the drought. Annual mean discharge in some rivers was only slightly less than the mean annual discharge, while others flowed at less than half that value. The effects of low streamflows were felt by many as electric power plants reduced or ceased production and public-water utilities requested conservation measures by their customers. Major reservoirs in the State approached or reached record low levels, causing water supplies as well as recreational activities to be diminished.

Most major crops produced in Indiana were affected by the dry conditions. Average yields in 1988 ranged from 50 to 86 percent of 1987 yields.

INTRODUCTION

Droughts of varying severity and duration have been documented in Indiana since climatological records were first kept. The most recent drought in 1988[1] had a serious effect on the State. Above-normal temperatures and below-normal precipitation in 1987 prepared the way for the drought that occurred the following year. Documentation of this drought was undertaken in cooperation with the Indiana Department of Natural Resources (IDNR), Division of Water.

The principal factor in most droughts is a lack of precipitation. This, coupled with above-normal temperatures and increased demand for water by commercial, agricultural, and residential users during the summer months of 1988, aggravated declining water levels. The entire State was affected by below-normal water levels. Record low-water levels were recorded in many ground-water monitoring wells. Major reservoirs approached or reached the lowest levels since filling. The annual mean streamflow of many rivers and streams decreased to approximately 50 to 92 percent of mean annual amounts. Annual mean streamflow is the sum of the daily mean streamflows in a particular year divided by the number of days in that year. Mean annual streamflow is the arithmetic mean of all the annual means for the period of record or a specific amount of years.

The drought caused substantial damage to most of the major crops produced in Indiana. Yields averaged from 50 to 86 percent of 1987 yields (Gann, 1989, p. 10). Irrigation was restricted in some areas. In some locations residential and commercial users also experienced restrictions to varying degrees.

In June of 1988, the Governor of Indiana established a Drought Advisory Committee to aid residents in "* * * meet[ing] and alleviat[ing] the consequences of the lack of rain on the State's agricultural economy and communities" (Indiana Drought Advisory Committee, 1988, p. 1).

Purpose and Scope

This report documents the drought of 1988, using meteorologic and hydrologic data compiled or collected by the U.S. Geological Survey (USGS) and other State and Federal agencies. Meteorologic data were compiled from the nine National Weather Service climatic divisions in Indiana. Hydrologic data were collected from 20 ground-water monitoring wells, 24 continuous-record streamflow-gaging stations, 54 low-flow, partial-record streamflow stations, and 11 reservoirs selected throughout the State. This report makes the data available for use by water-management agencies and planners concerned with long-range water use and discusses the severity, areal extent, and duration of the drought.

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[1]In this report, indicated years are calendar years unless otherwise identified as a water year.

Cumulative departures from the mean are used to identify long-term trends in both precipitation and streamflow. Recurrence intervals of low flows in rivers and streams indicate the effects of drought conditions on streamflow. The Palmer Drought Severity Index is used to describe the relative severity of the drought. Temperature rankings compare conditions around the State with historical data. Ground- and surface-water levels indicate existing and potentially significant deficiencies in water supplies.

Acknowledgments

The author received assistance from many people during preparation of this report. Richard Giltner of the Indianapolis Water Company provided information on reservoirs supplying water to Indianapolis. Robert Lehman of the U.S. Army Corps of Engineers in Louisville, Kentucky, supplied data for eight Corps of Engineers reservoirs. Historical climatological data were obtained from Richard Heim and others at the National Oceanic and Atmospheric Administration, National Climatic Data Center, in Asheville, North Carolina. Agricultural statistics were provided by Ralph Gann, State Statistician, at Purdue University, West Lafayette, Indiana.

DESCRIPTION OF 1988 DROUGHT

A drought means different things to different people. Hydrologists think of a drought in terms of the effects of precipitation deficits on ground-water levels, streamflow, and reservoirs. To a meteorologist, a prolonged period of moisture deficit, be it 1 month or 1 year, denotes a drought of varying severity. A water manager defines a drought relative to water availability and quality. If a drought occurs during a critical phase in the growing cycle, even a very short period with a moisture deficit can become a costly drought to a farmer. Residential consumers often are unaware of drought conditions until they are affected directly by water restrictions and shortages.

A drought can be defined in general terms as "* * * a condition of moisture deficit, sufficient to have an adverse effect on vegetation, animals, and man over a sizable area" (Hanson, 1984, p. 773). Any one definition is not adequate for all situations because droughts are measured using different criteria, including precipitation and temperature statistics, ground-water levels and low-flow characteristics, soil-moisture values, and economic factors (for example, crop yields and livestock production).

Six types of drought are recognized by the World Meteorological Organization (Subrahmanyam, 1967). They are--

1. Meteorologic drought--defined only in terms of precipitation deficits in absolute amounts for specific durations.

2. Climatologic drought--defined in terms of precipitation deficits, not in specific amounts but as a ratio of actual precipitation to mean or normal values.

3. Atmospheric drought--definitions involve not only precipitation but possibly temperature, humidity, or wind speed.

4. Agricultural drought--definitions involve principally soil-moisture content and plant physiology, perhaps for a specific crop.

5. Hydrologic drought--defined in terms of reduced streamflow, reductions in lake or reservoir storage, and declining ground-water levels.

6. Water-management drought--characterizes water deficits resulting from water-management practices or facilities.

These drought types can occur separately, overlap, or be combined in different ways. For example, a small amount of precipitation (a meteorologic drought), when extended over a long period, becomes a climatologic drought. As ground-water, streamflow, and reservoir levels decline, a hydrologic drought occurs, which results in problems of water distribution and use, which then becomes a water-management drought. (See Matthai, 1979, p. 5.)

Three types of drought, climatologic, hydrologic, and agricultural, predominated in Indiana during water year 1988. The entire State experienced some, if not all six, types of drought to varying degrees and in various combinations. A statewide meteorologic drought occurred in May and June 1988 as many areas of the State recorded the lowest or second lowest rainfall amounts on record since water year 1921. (A water year begins on October 1 and ends September 30. For example, water year 1921 began on October 1, 1920, and ended September 30, 1921.) Climatologically, the drought began as monthly precipitation decreased to below-average amounts during the last 3 months of 1987, a condition that persisted through December 1988. The rest of water year 1989 (January-September) received predominantly above-average precipitation. High temperatures, particularly in northern Indiana, coupled with little precipitation during the summer of 1988 produced an atmospheric drought of short duration. The agricultural drought was felt as soil moisture was depleted and crop yields decreased during the summer and fall. Hydrologically, there were moderate reductions in annual streamflow and reservoir levels during water year 1988. Monthly mean discharges at many streamflow-gaging stations, however, were at record low levels during the summer of 1988. Ground-water levels also declined throughout the State. As ground-water levels declined, particularly in areas of extensive irrigation, problems of water distribution and use occurred. This resulted in areas of water-management drought, particularly during August and September 1988.

Precipitation

The lack of precipitation is the principal factor involved in periods of drought. Long periods of moisture deficits have significant and obvious effects on plants, animals, and people. Even short periods of below-average precipitation can have detrimental effects on crops and livestock.

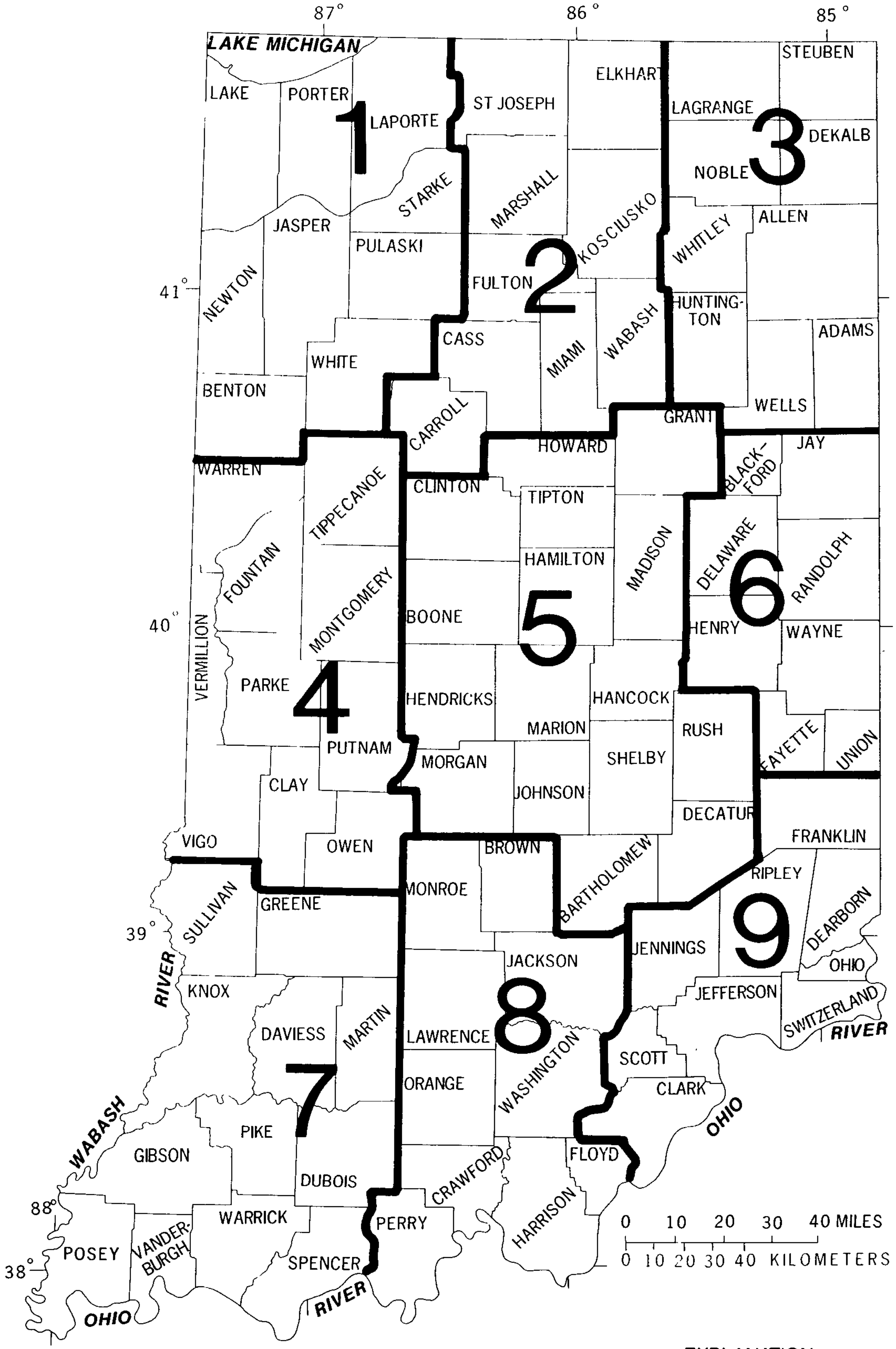
Monthly precipitation data are available since the late 1890's for each of the nine National Weather Service climatic divisions in Indiana (fig. 1). Because streamflow data are available from 1920 to the present, only precipitation data collected since 1920 were used for this report.

Determination of cumulative departures from the mean is one method of evaluating long-term climatic or hydrologic trends. By use of this method, departures of the monthly mean from the long-term mean monthly value are accumulated algebraically through the period of record and plotted against time (Hanson, 1984, p. 782). The plot of cumulative precipitation departures from mean precipitation can be constructed for the entire record, for the driest period, or for several dry periods in order to compare drought severity (Hudson and Hazen, 1964, p. 18-10).

Monthly mean precipitation data for the climatic divisions in Indiana were obtained on magnetic tape TD-9640 from the National Oceanic and Atmospheric Administration (NOAA). Cumulative departures from mean monthly precipitation were calculated for each of the nine climatic divisions for water years 1921-89. These data are shown graphically in figures 2-10. The slopes on the graphs and the change in position of the graphs from year to year are more descriptive than the vertical position. A rising or positive slope on the graph shows above-average precipitation, whereas a declining or negative slope indicates below-average precipitation. Periods with no discernible trends indicate generally average precipitation with both wet and dry years. (See Tibbals, 1990, p. E7.) For the period 1987-89, the graphs in figures 2-10 indicate a moderate drought of relatively short duration when compared to previous periods of negative departures. For example, in division 8, longer, more severe periods of negative departures (declining slope) occurred during 1941-49 and 1964-75. All climatic divisions showed similar trends for 1987-89. Departures were generally negative but of short duration. By February 1989, positive departures (rising slope) had reversed the downward trend in most of the divisions.

In 1987, precipitation statewide was approximately 88 percent of the 1951-80 average of 39.6 in. (Gann, 1988, p. 8). In January 1988, only 69 percent of the mean monthly precipitation was received. In February, the only month during the first half of the year to receive above-average amounts, precipitation was 36 percent above average. Dry weather from March to May began to increase concerns of a serious drought. In these months, 85 percent, 76 percent, and 39 percent, respectively, of the 1951-80 mean monthly precipitation was received. The 1951-80 mean precipitation for June was 4.16 in. statewide. In June 1988, 0.74 in. of precipitation was the statewide average. With May precipitation half the average amount and June precipitation the lowest on record, the "possible" drought became a fact.

Monthly mean precipitation for May and June 1988 were averaged for each climatic division. These averages were compared to the same period for each water year from 1921 through 1989 and ranked. These rankings by climatic division (fig. 11) show that May and June 1988 received the lowest amount of rainfall on record for water years 1921-89 in eight of the nine divisions. Rankings of the June, July, and August averages (fig. 12) also indicate low amounts of rainfall but not as low as May and June.



Base from Indiana Flood Control and Water Resources Commission 1 2,000,000

EXPLANATION

8 ▬ BOUNDARY OF CLIMATIC DIVISION AND IDENTIFICATION NUMBER

Figure 1.-- National Weather Service climatic divisions in Indiana.

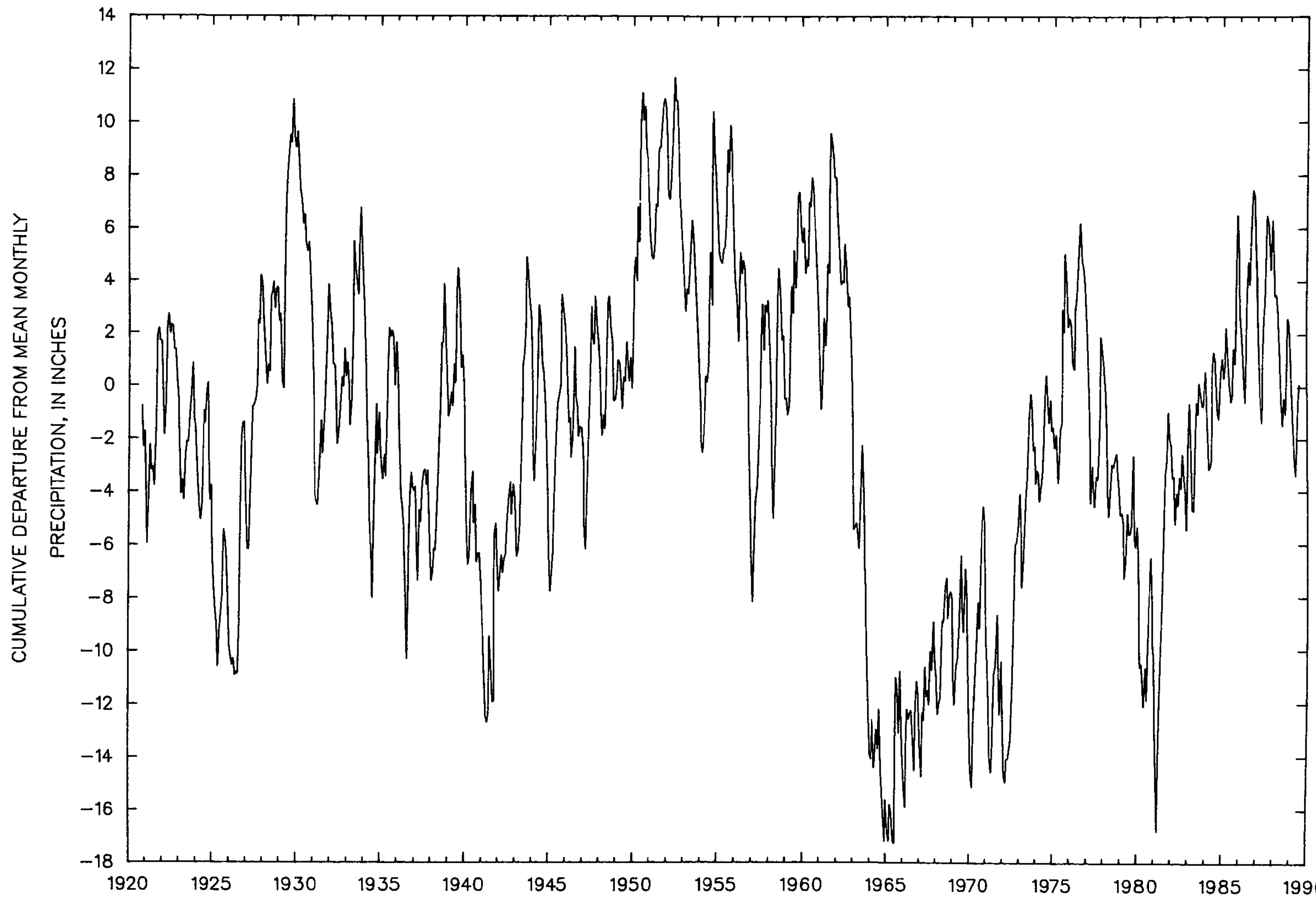


Figure 2.—–Cumulative departure from mean monthly precipitation for climatic division 1, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

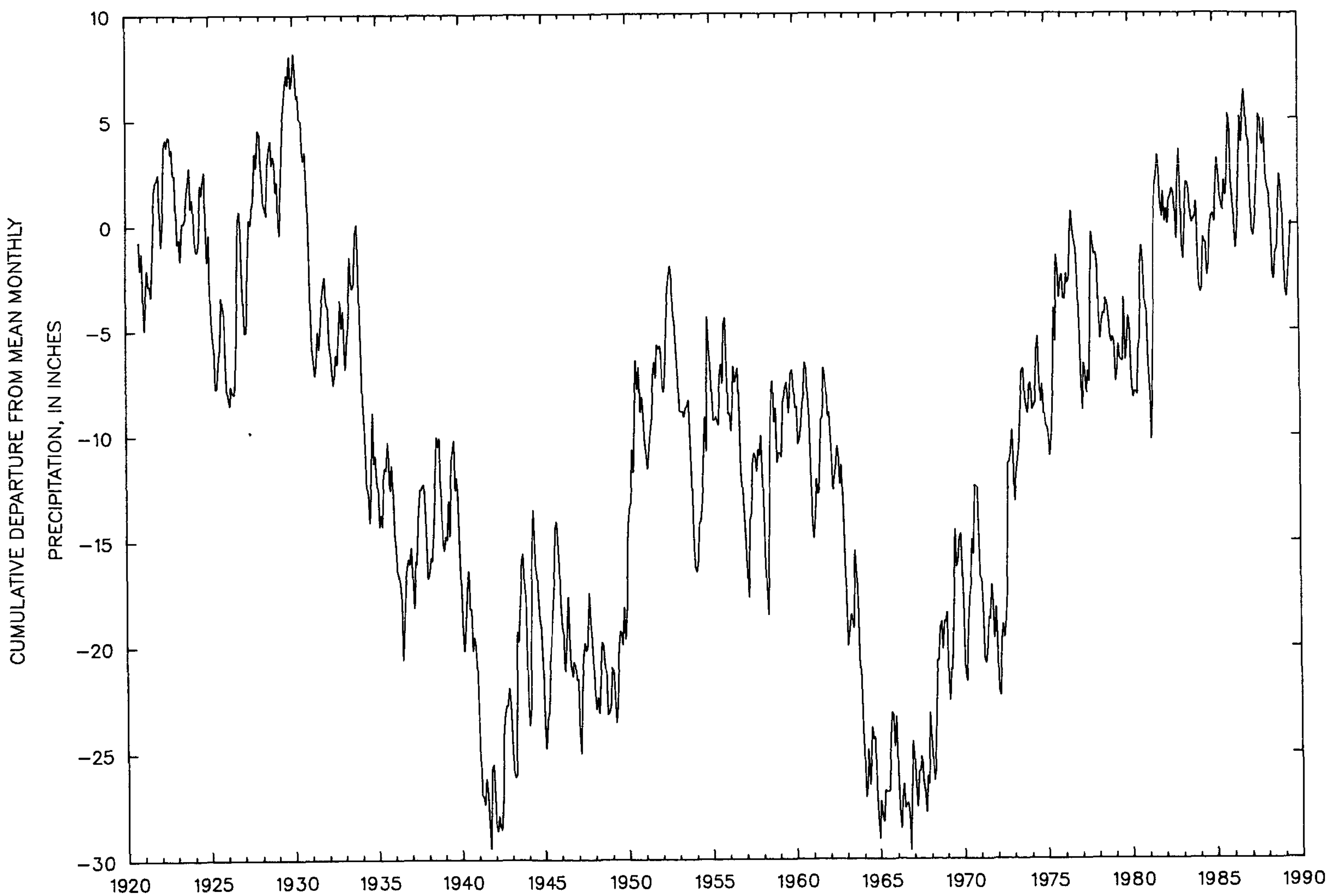


Figure 3.—–Cumulative departure from mean monthly precipitation for climatic division 2, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

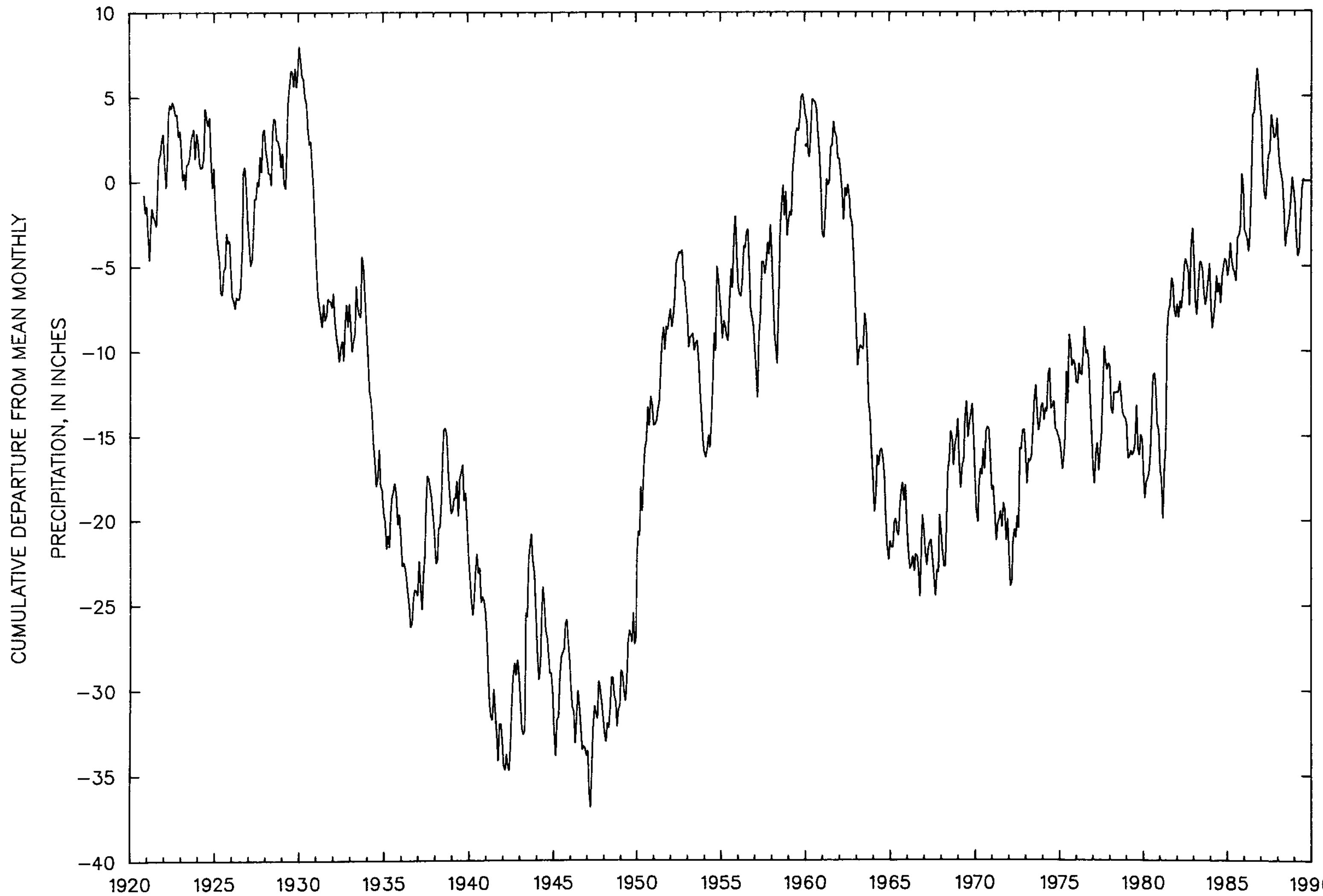


Figure 4.——Cumulative departure from mean monthly precipitation for climatic division 3, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

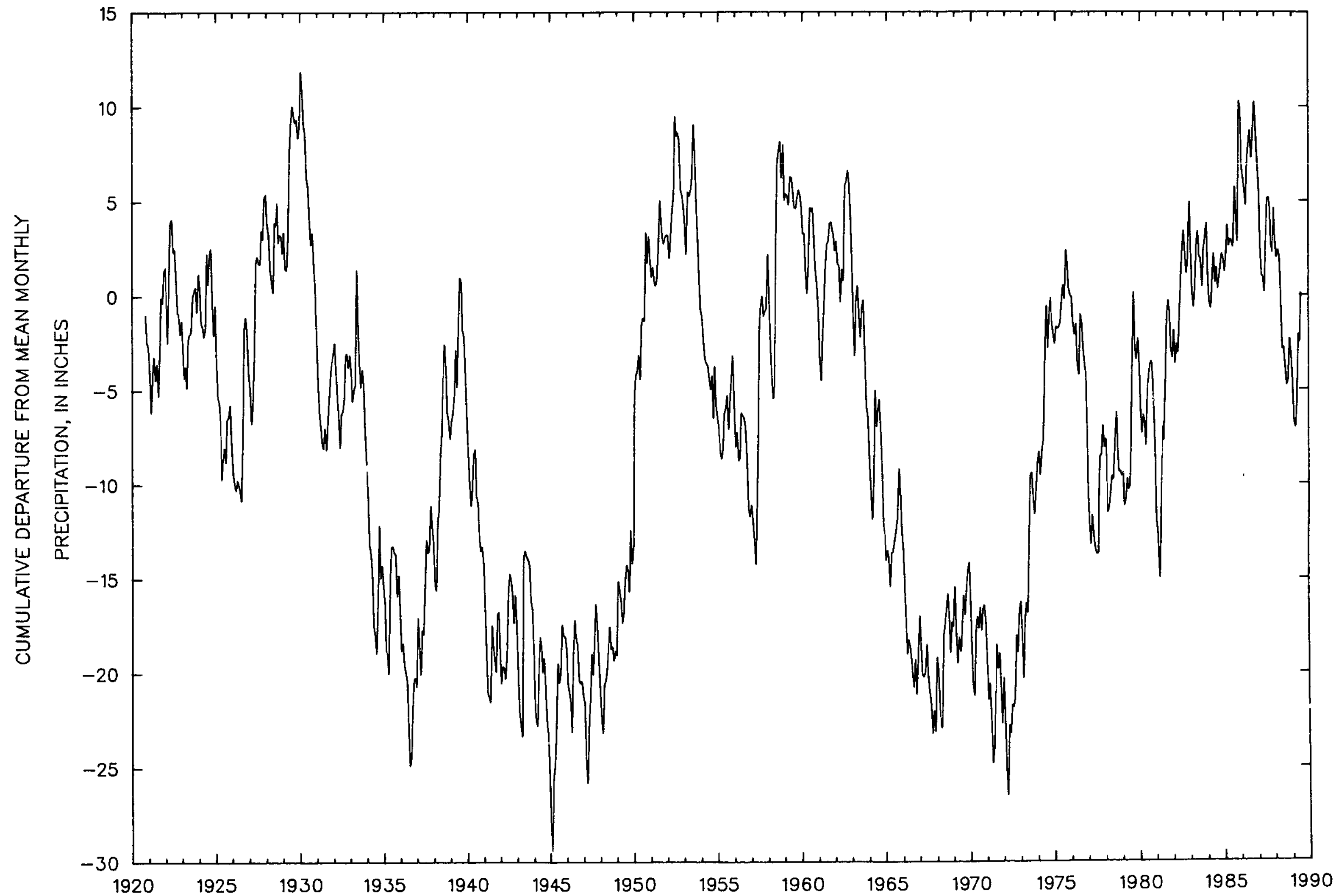


Figure 5.——Cumulative departure from mean monthly precipitation for climatic division 4, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

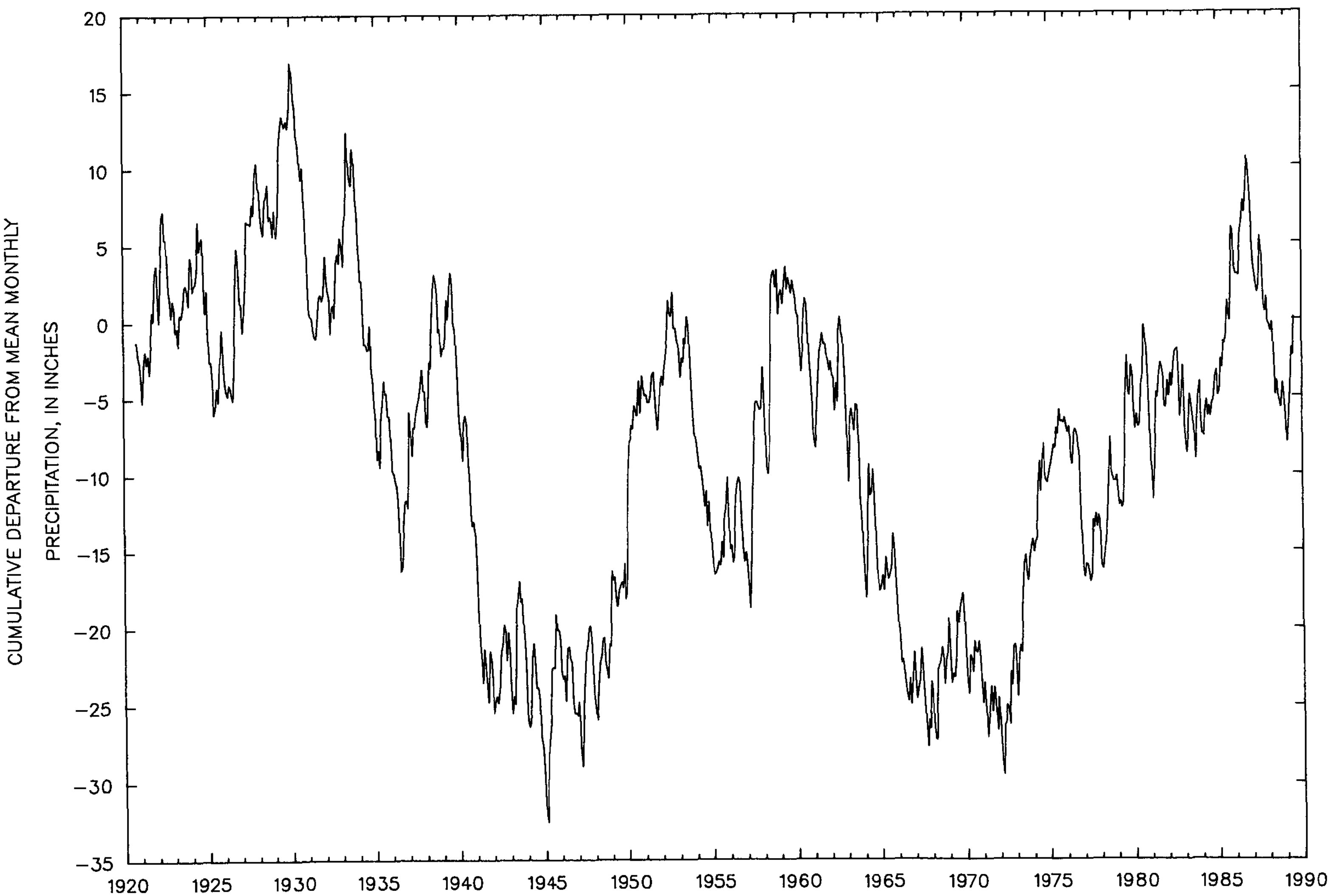


Figure 6.--Cumulative departure from mean monthly precipitation for climatic division 5, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

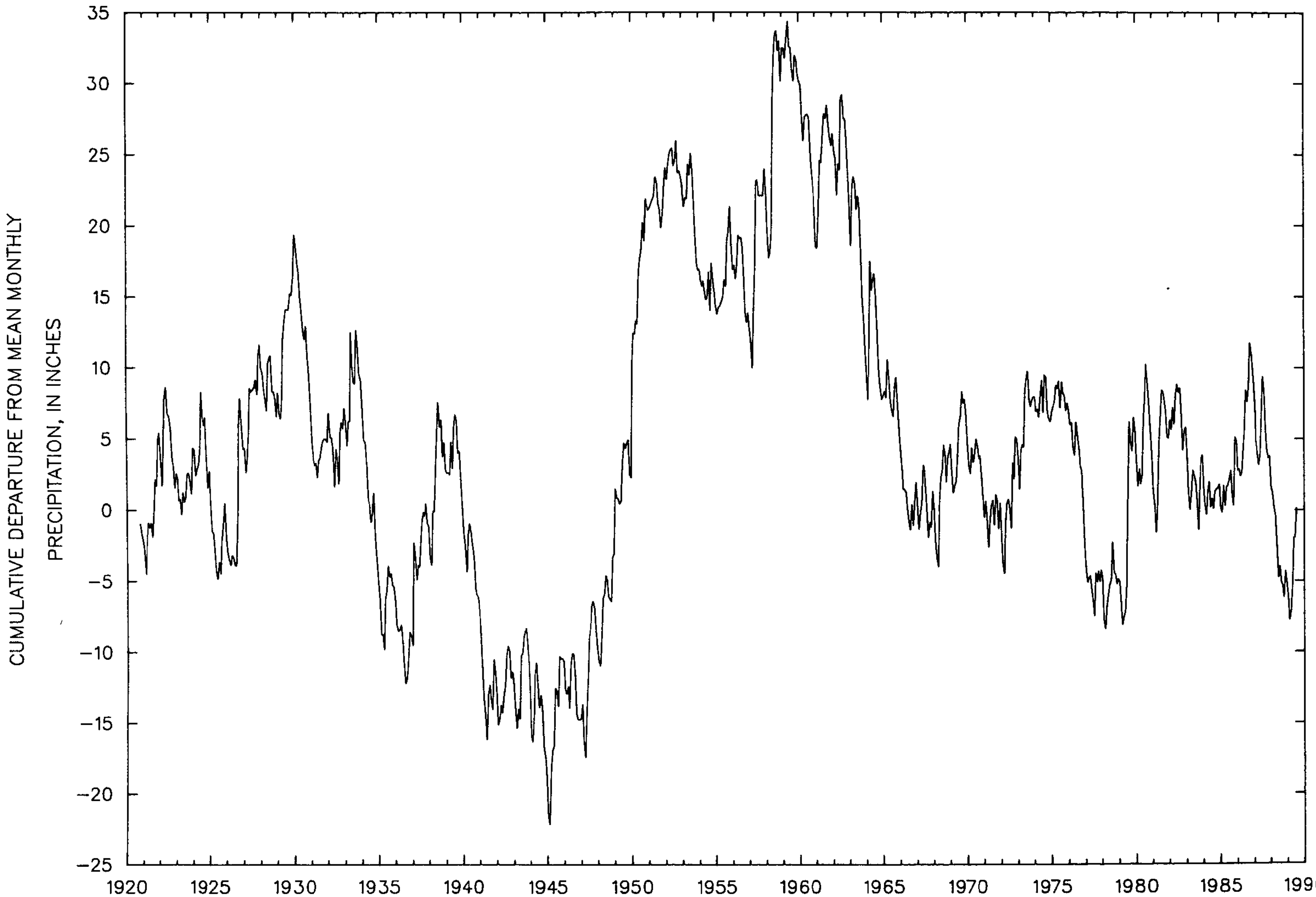


Figure 7.—Cumulative departure from mean monthly precipitation for climatic division 6, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

Figure 8.--Cumulative departure from mean monthly precipitation for climatic division 7, water years 1921-89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

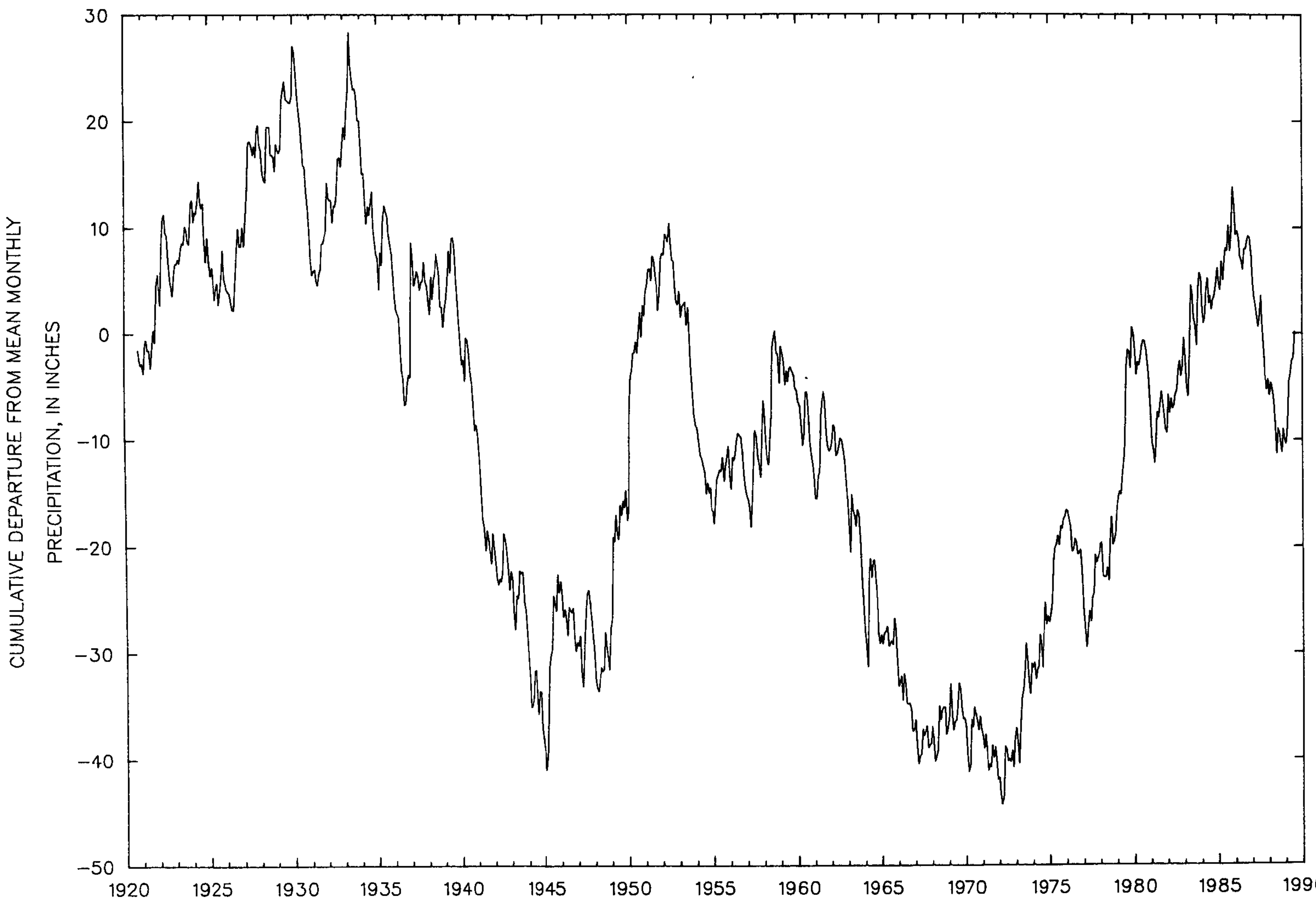


Figure 9.--Cumulative departure from mean monthly precipitation for climatic division 8, water years 1921-89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

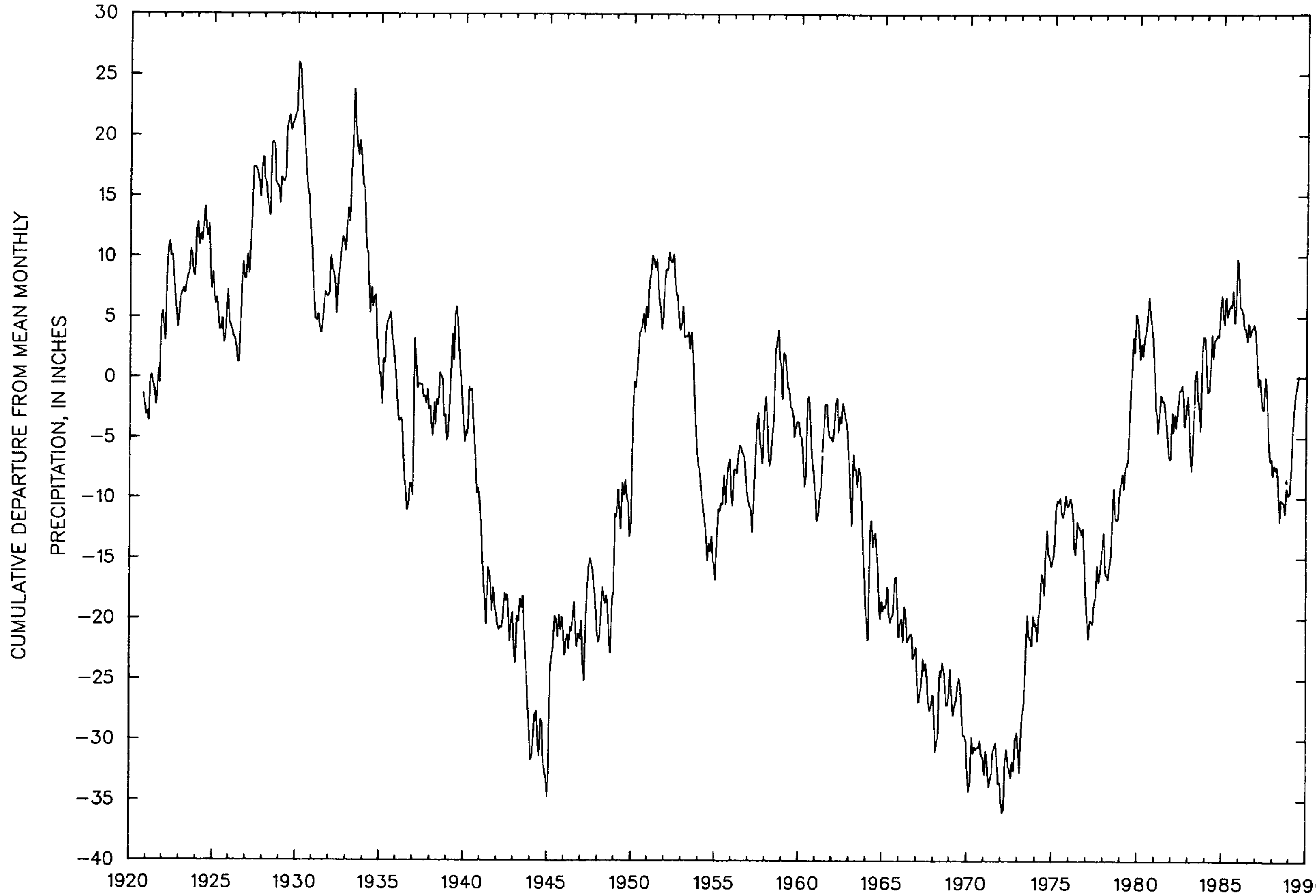


Figure 10.—Cumulative departure from mean monthly precipitation for climatic division 9, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

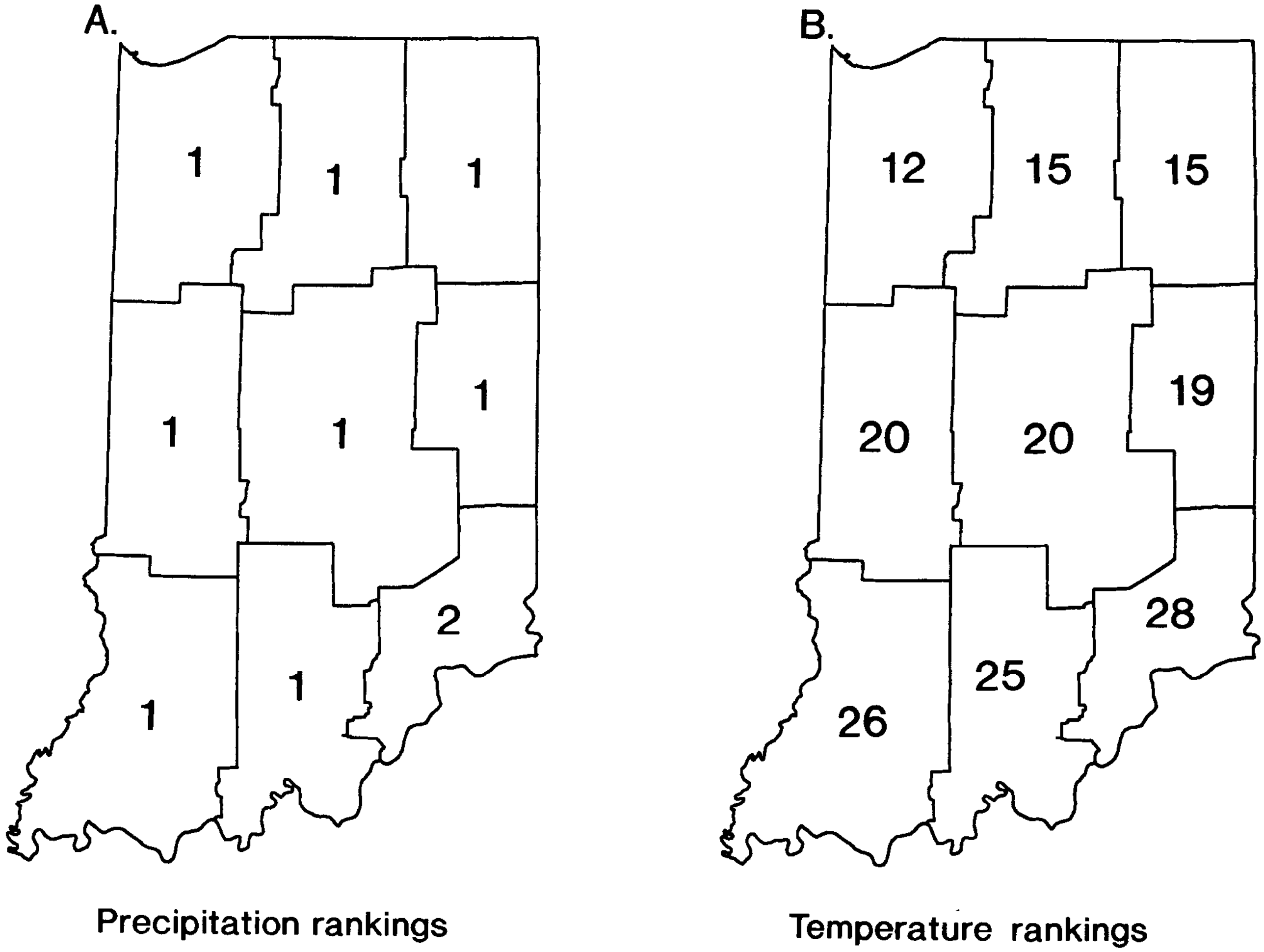


Figure 11.--(A) Precipitation and (B) temperature rankings for each climatic division, May-June 1988. (For precipitation, a rank of 1 indicates the smallest amount of precipitation on record for water years 1921-1989. For temperature, a rank of 1 indicates the highest temperature on record for water years 1921-1989. Data from National Oceanic and Atmospheric Administration, Climatic Data Center.)

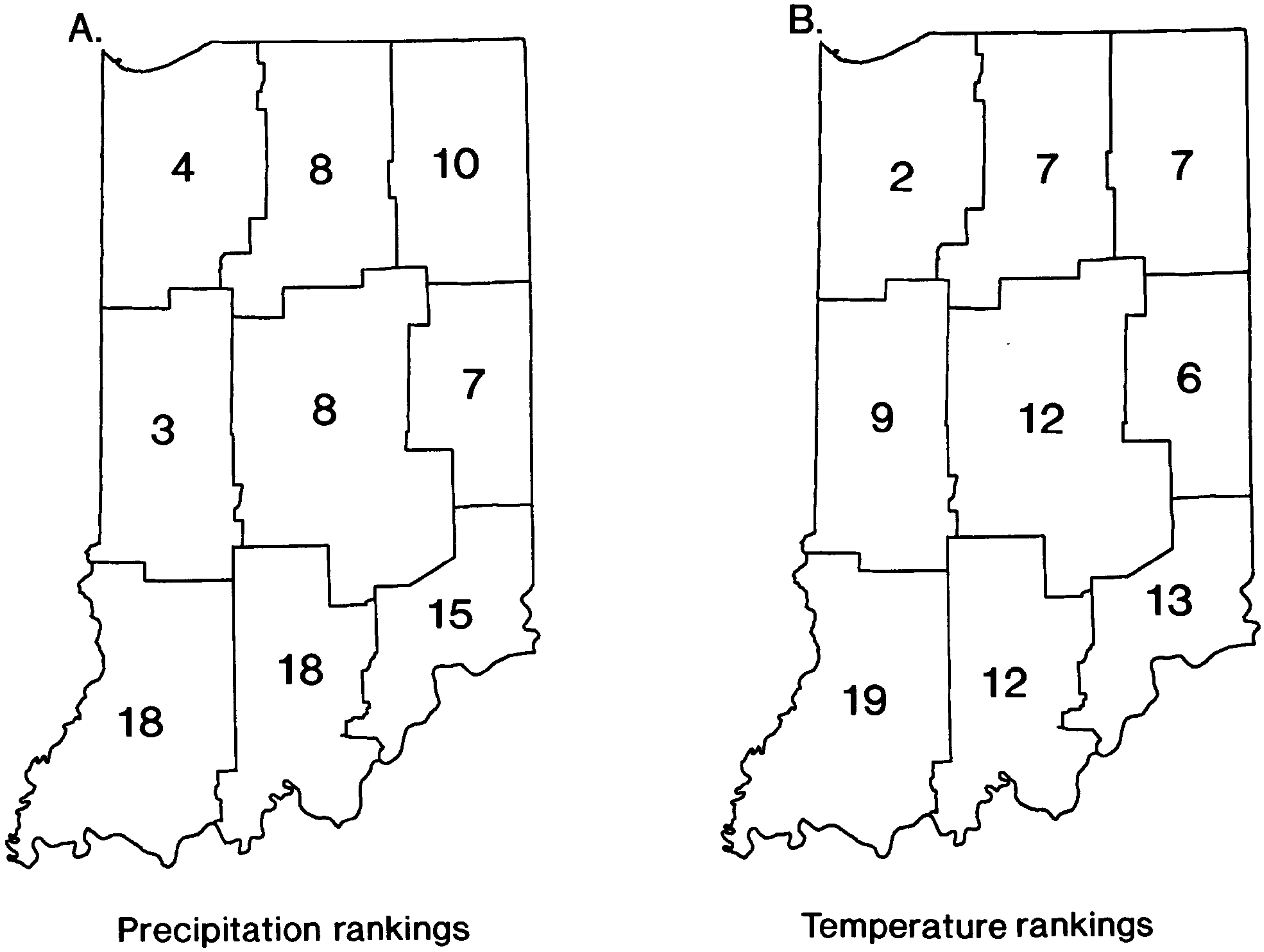


Figure 12.--(A) Precipitation and (B) temperature rankings for each climatic division, June-August 1988. (For precipitation, a rank of 1 indicates the smallest amount of precipitation on record for water years 1921-1989. For temperature, a rank of 1 indicates the highest temperature on record for water years 1921-1989. Data from National Oceanic and Atmospheric Administration, Climatic Data Center.)

July 1988 rainfall was slightly greater than average. Soil conditions, however, were so dry from previous moisture deficits that all available moisture was quickly consumed. The precipitation received in August and September was 88 percent and 96 percent of average, respectively. By the end of September, total precipitation for the year was 75 percent of average or 7.8 in. below average amounts. Dry conditions continued through mid-October. Above-average precipitation from mid-October to December reduced the deficit by 2 to 3 in., but annual totals for 1988 remained 8 to 10 in. below average over large areas of northeast and central Indiana. (See Kottke, 1989, p. 2.) The 1988 annual precipitation was 89 percent of average (4.54 in. below average) statewide (Gann, 1989, p.8). January of 1989 began with a discouraging negative departure from mean monthly precipitation. From February through May, however, above-average precipitation was received across the State. June monthly mean precipitation was 0.4 in. below average but was followed by 3 months of above-average precipitation. As water year 1989 ended, so did fears of an extended drought.

Temperature

High temperatures during the summer of 1988 increased the effects of drought conditions throughout the State. May through August temperatures were analyzed for this report. June through August frequently are grouped together in drought analyses; however, since May 1988 was particularly critical to the drought with respect to high temperatures and low amounts of precipitation, it was included. Averages of the monthly mean divisional temperatures for May and June and for June through August were computed for each water year for the period 1921-89 and ranked (figs. 11 and 12). The lower the rank, the higher the mean temperature and the lower the amount of mean precipitation for the months indicated.

The three northern climatic divisions (divisions 1-3) were affected the most by below-average precipitation and high temperatures from May through August 1988. In particular, temperatures in the northwest division (division 1) were the second warmest for June, July, and August in 69 years (fig. 12). Even the temperatures of the least affected division, the southwest (division 7), were the 19th warmest in 69 years. Extreme temperatures began toward the end of May and persisted through early September. The number of days on which temperatures of 90° F or above were recorded ranged from 45 to 60 throughout the State. These numbers were 50 percent greater than average in the southern part of the State and three times the average amount in the northern part (Kottke, 1989, p. 2).

In September 1988, monthly temperatures in six of the nine divisions were slightly below average for the first time since April. During the first 2 weeks of October, the high-temperature trend was broken by a freeze which occurred in all divisions of the State.

Palmer Drought Severity Index

The Palmer Drought Severity Index (PDSI), developed by W.C. Palmer (1964), is used by the National Oceanic and Atmospheric Administration to classify drought severity. This monthly meteorological drought index assesses the relative severity of dry periods. The method used to derive the index for each period incorporates antecedent precipitation, precipitation during the time being evaluated, and the duration and magnitude of the moisture deficiency (Matthai, 1979, p. 10). Values of the PDSI generally range from +7.0 to -7.0, with rare drought conditions approaching -8.0. An index of +2.0 or greater indicates wet conditions; 2.0 to 0.5, moist conditions; 0.5 to -0.5, near normal; -0.5 to -1.0, incipient drought; -1.0 to -2.0, mild drought; -2.0 to -3.0, moderate drought; -3.0 to -4.0, severe drought; and -4.0 and less, extreme drought (Palmer, 1964, p. 28).

Monthly Palmer Drought Severity Indices for each climatic division were obtained from NOAA, National Climatic Data Center, in Asheville, North Carolina. To be consistent with other historical data included in this report, indices for water years 1921-89 were plotted in figures 13-21. During water years 1988 and 1989, eight of the nine divisions show at least one monthly index reaching the severe range (-3.0 to -4.0). The lowest monthly index reached during this period was -4.0 in division 8 during June 1988 (fig. 20). Comparison of the 1988 and 1989 PDSI with the entire period of record shows the latest moisture-deficient conditions to be generally severe but of relatively short duration, compared to more extreme conditions of longer duration experienced in the early and mid-1930's, mid-1950's, and mid-1960's.

Water Use

All facilities in Indiana with a well or surface intake capable of withdrawing at least 100,000 gal of water per day are required to register with IDNR and to report their monthly withdrawals annually (Water Management Act, 1983, Indiana Code 13-2-6.1).

Ground- and surface-water use increased substantially during the 1988 drought. Registered facilities reported over 3.31 trillion gallons of water withdrawals during calendar year 1988 (Indiana Department of Natural Resources, 1989, p. 2). This was an increase of 4 percent over 1987 (Indiana Department of Natural Resources, 1988, p. 1), despite requested cutbacks in domestic use and temporary halts in withdrawals required for some energy-production and irrigation facilities.

Four major water-use categories and amounts withdrawn in 1987 and 1988 are shown in table 1. It should be noted that an increase in registered facilities in 1988 would account for some of the increased withdrawals.

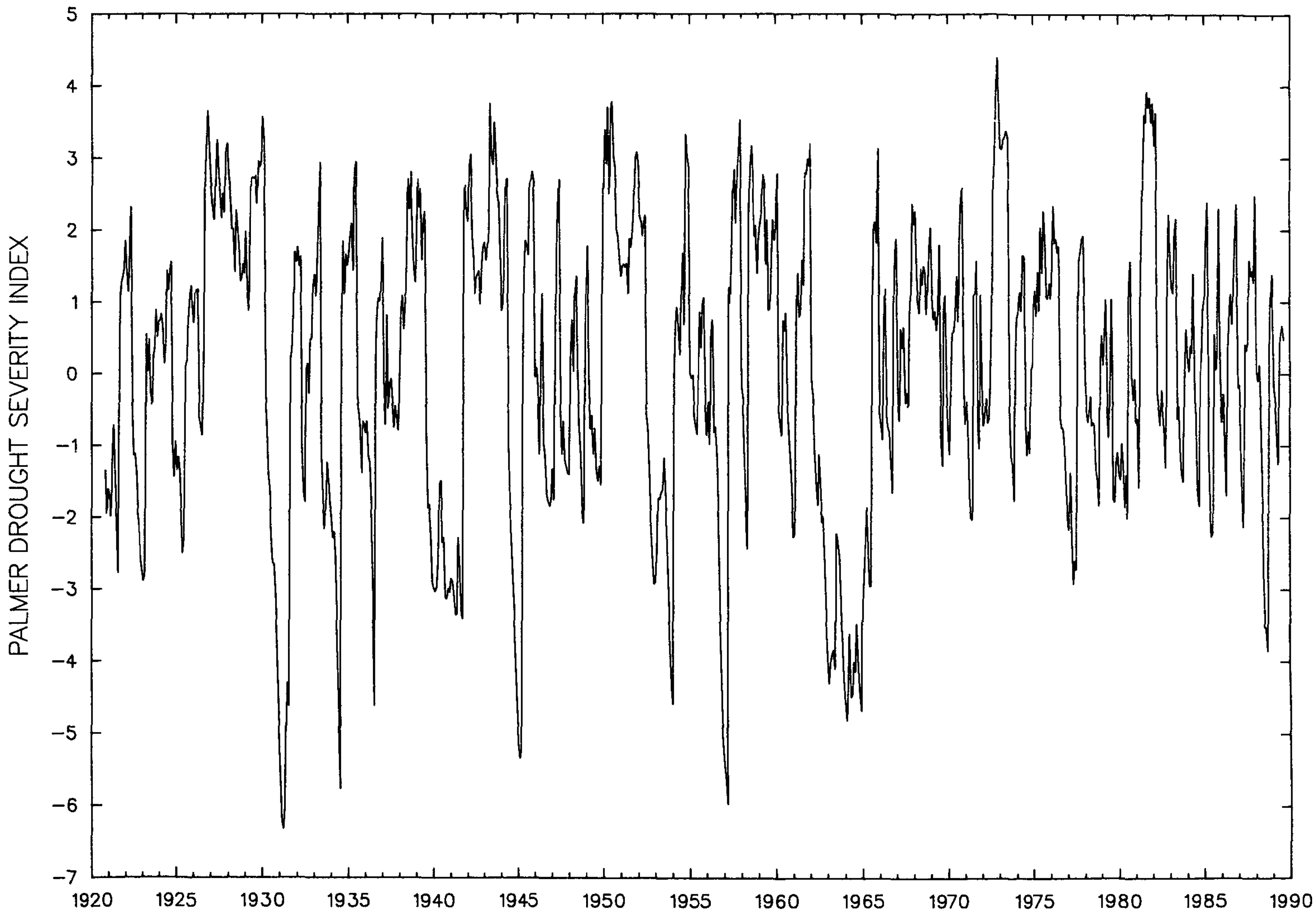


Figure 13.−−Monthly Palmer Drought Severity Indices for climatic division 1, water years 1921−89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

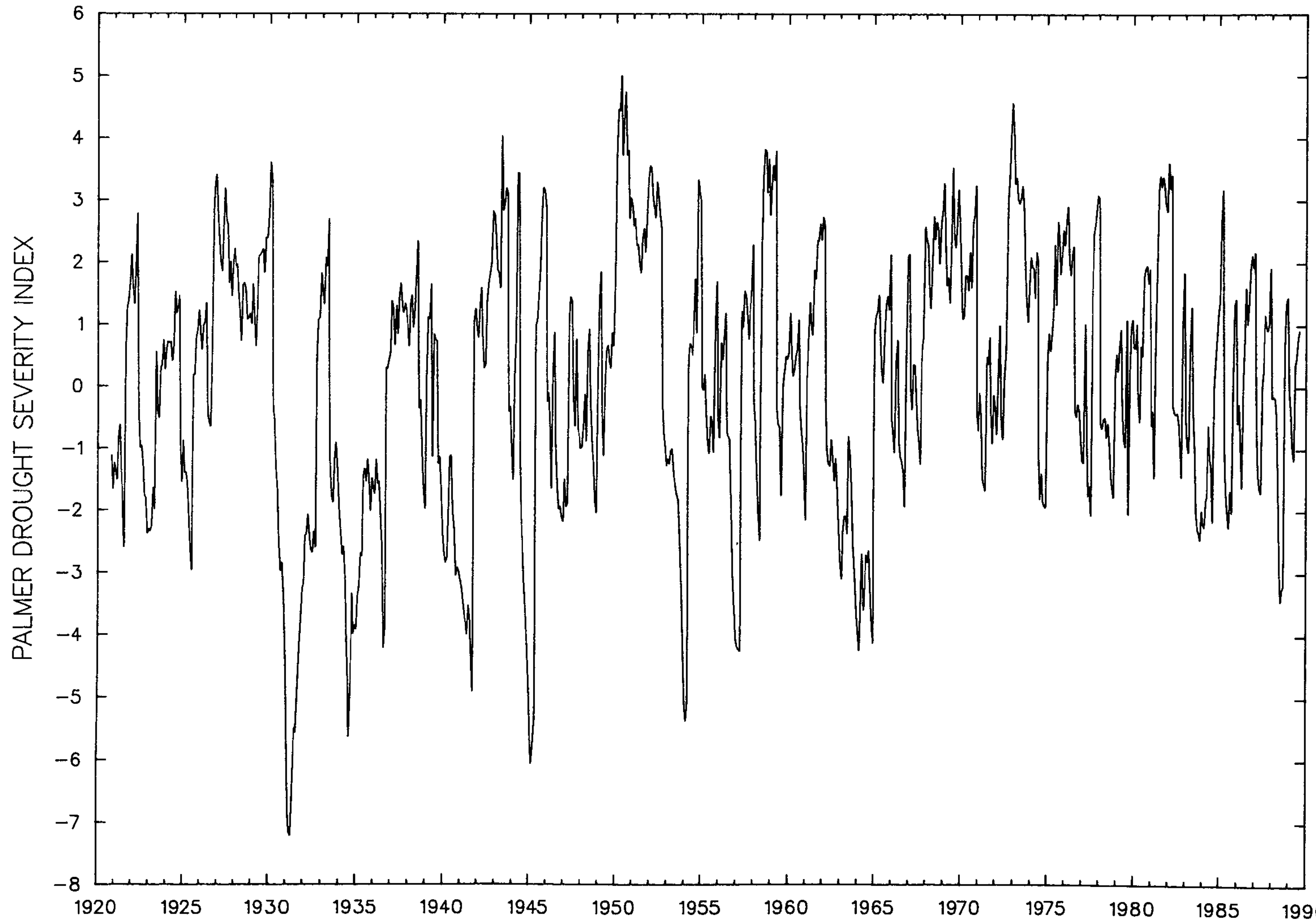


Figure 14.—–Monthly Palmer Drought Severity Indices for climatic division 2, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

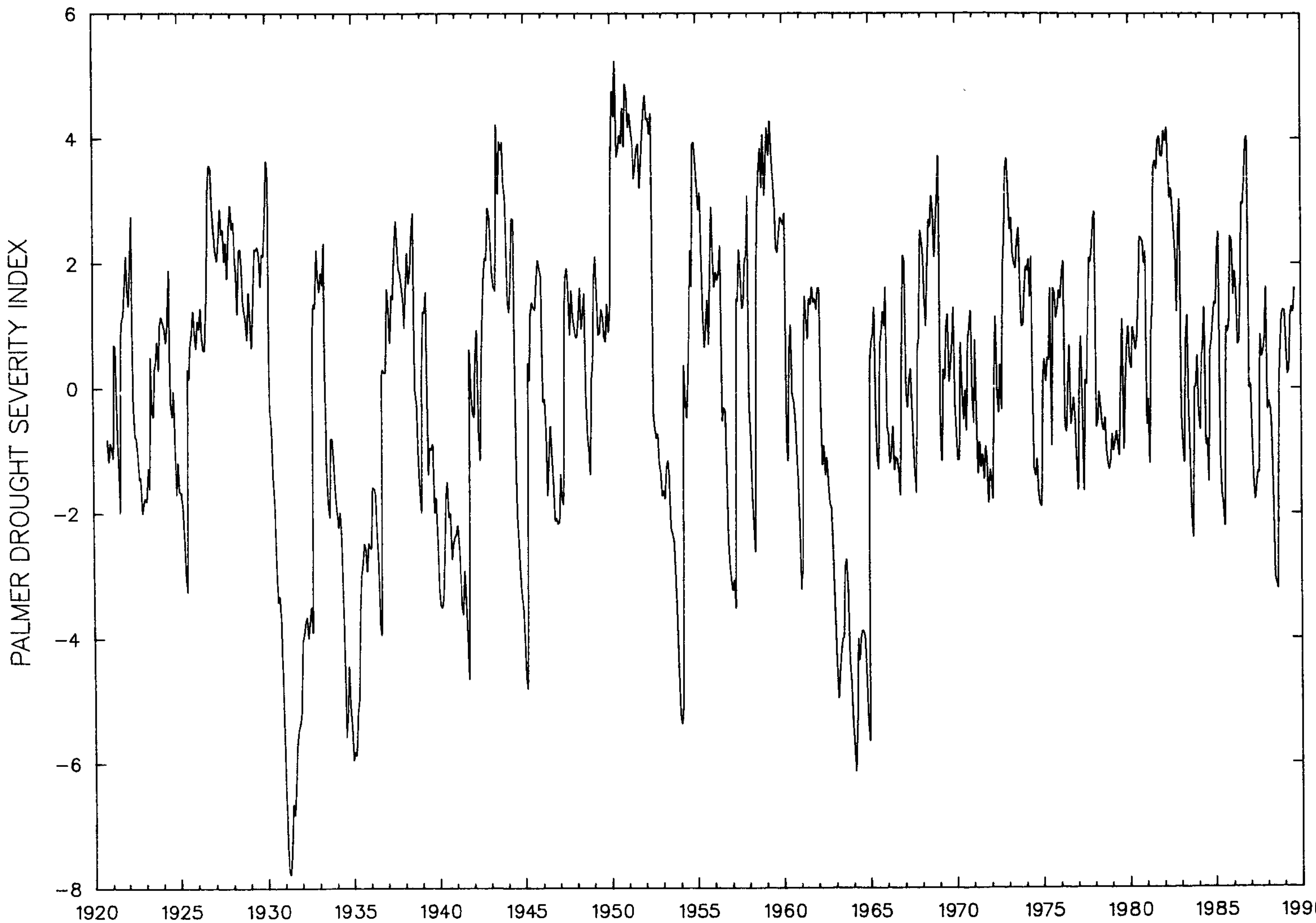


Figure 15.--Monthly Palmer Drought Severity Indices for climatic division 3, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

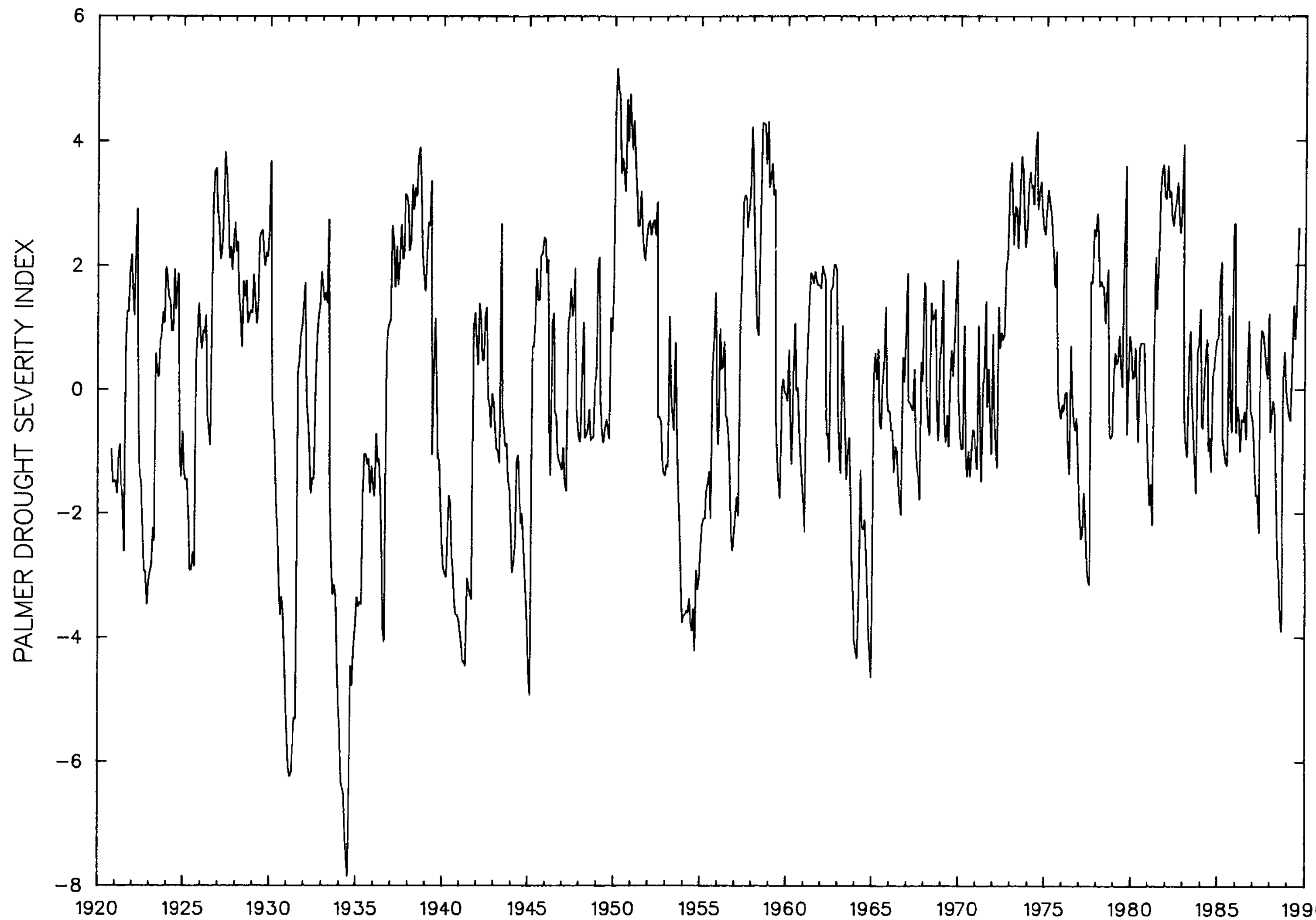


Figure 16.—Monthly Palmer Drought Severity Indices for climatic division 4, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

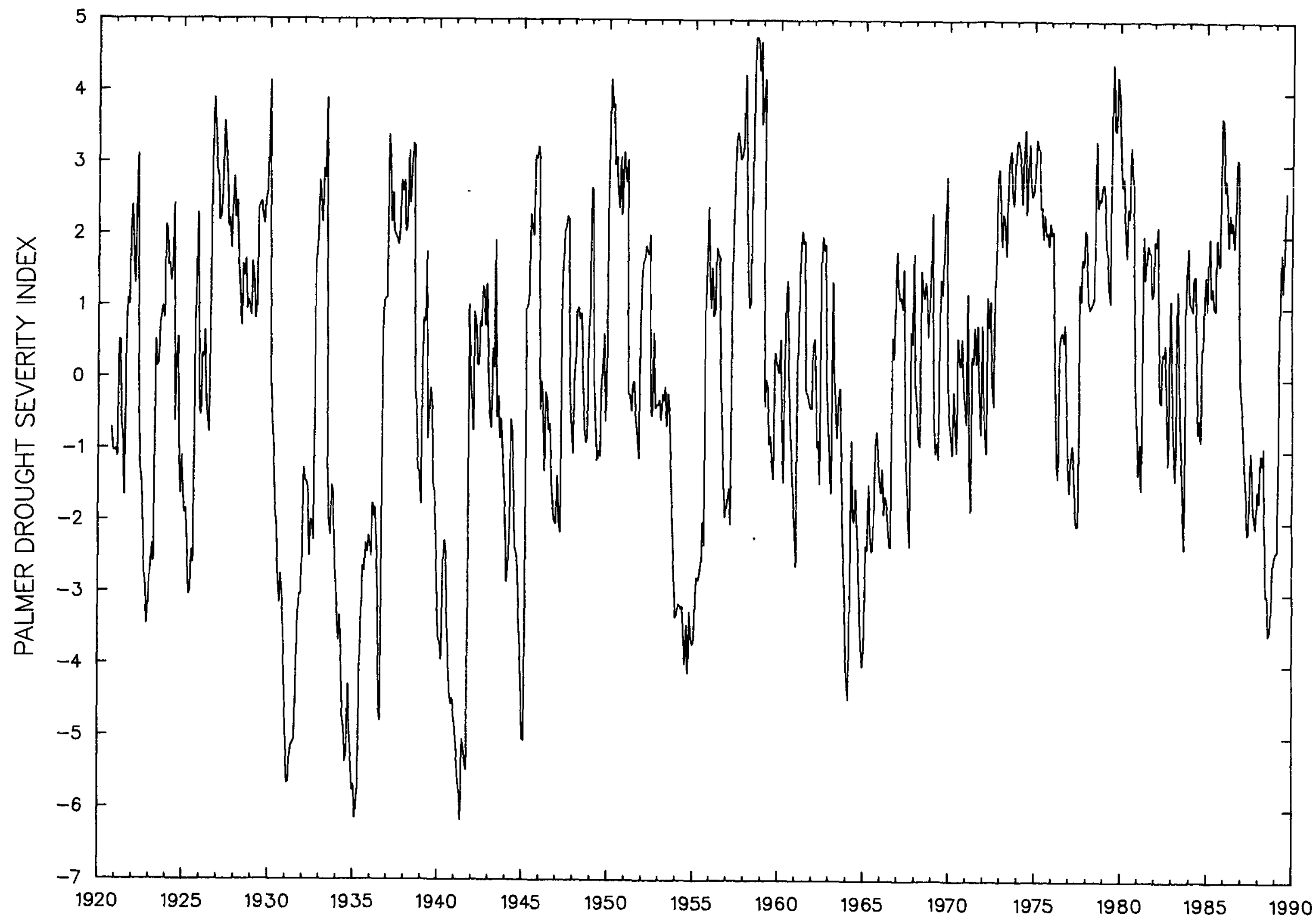


Figure 17.—–Monthly Palmer Drought Severity Indices for climatic division 5, water years 1921–89 (*data from National Oceanic and Atmospheric Administration*, Climatic Data Center).

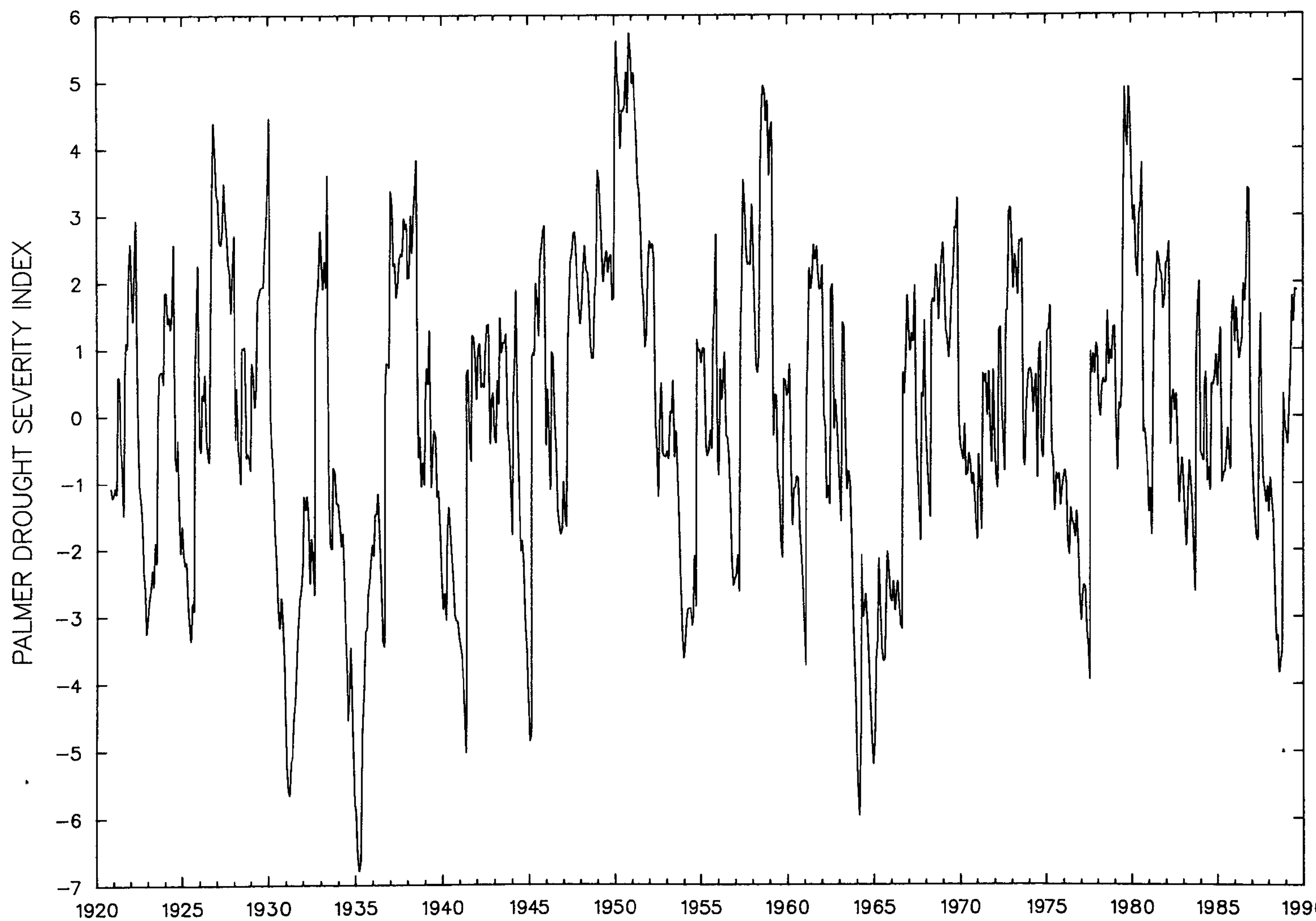


Figure 18.—–Monthly Palmer Drought Severity Indices for climatic division 6, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

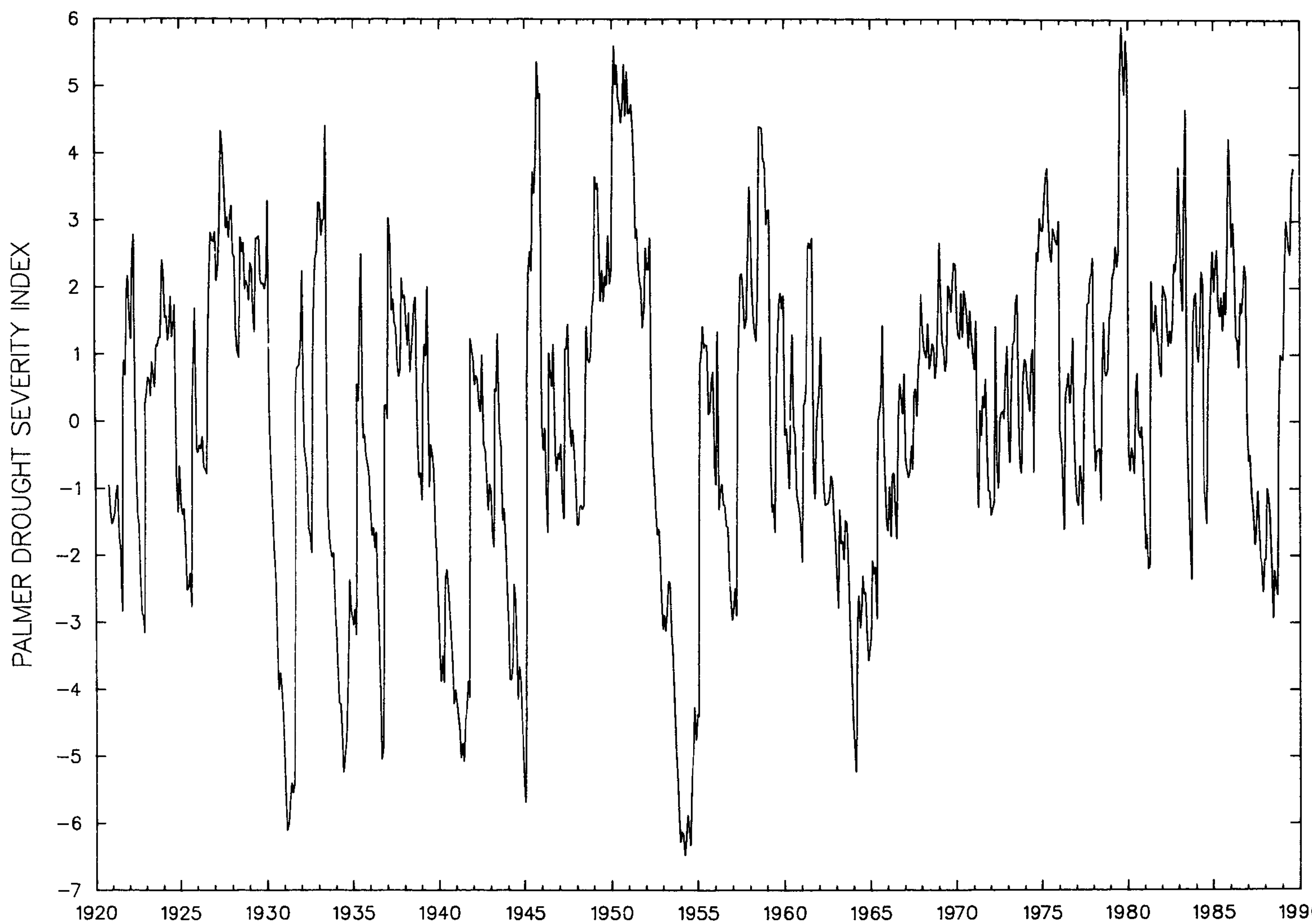


Figure 19.−−Monthly Palmer Drought Severity Indices for climatic division 7, water years 1921−89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

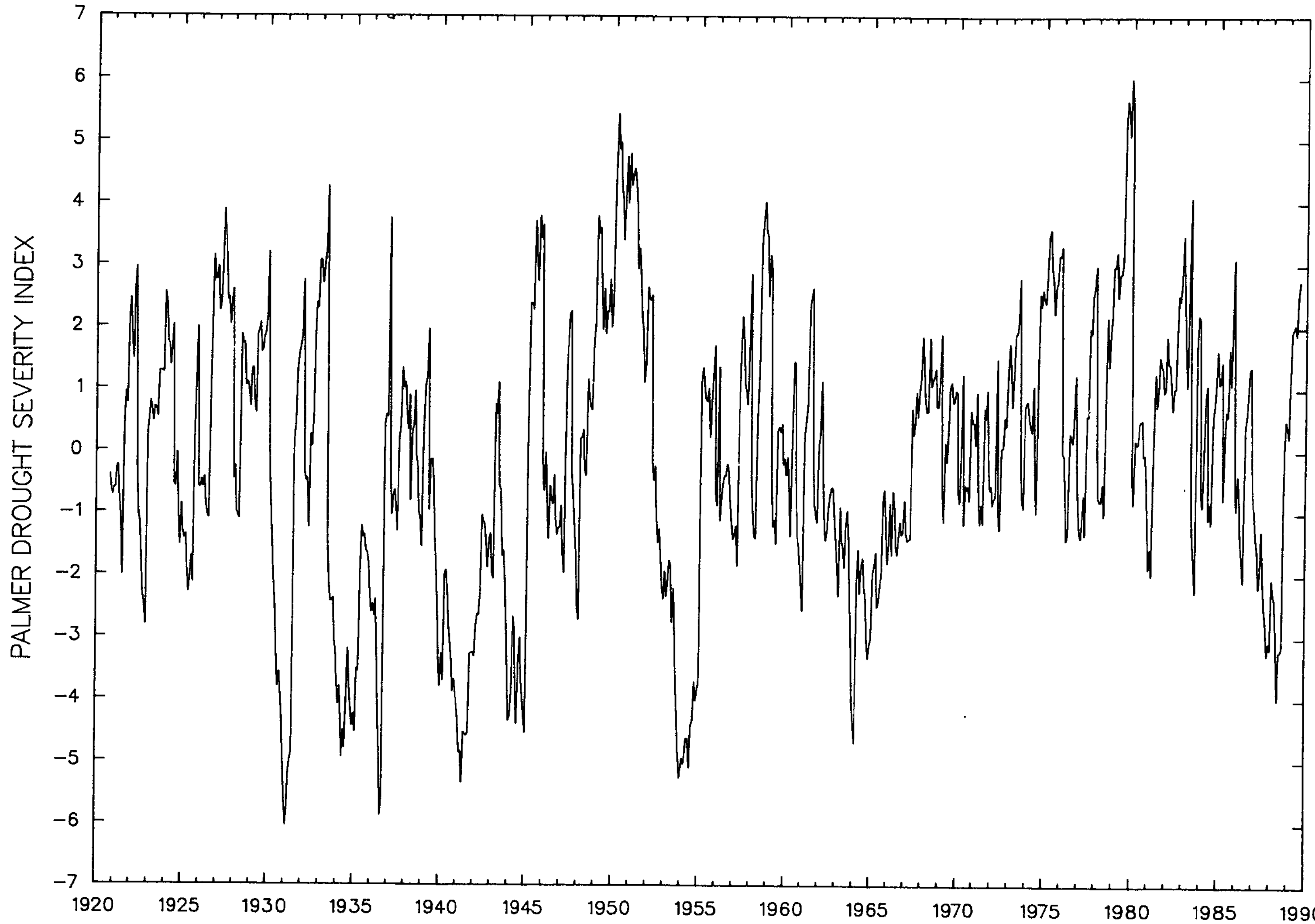


Figure 20.—–Monthly Palmer Drought Severity Indices for climatic division 8, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

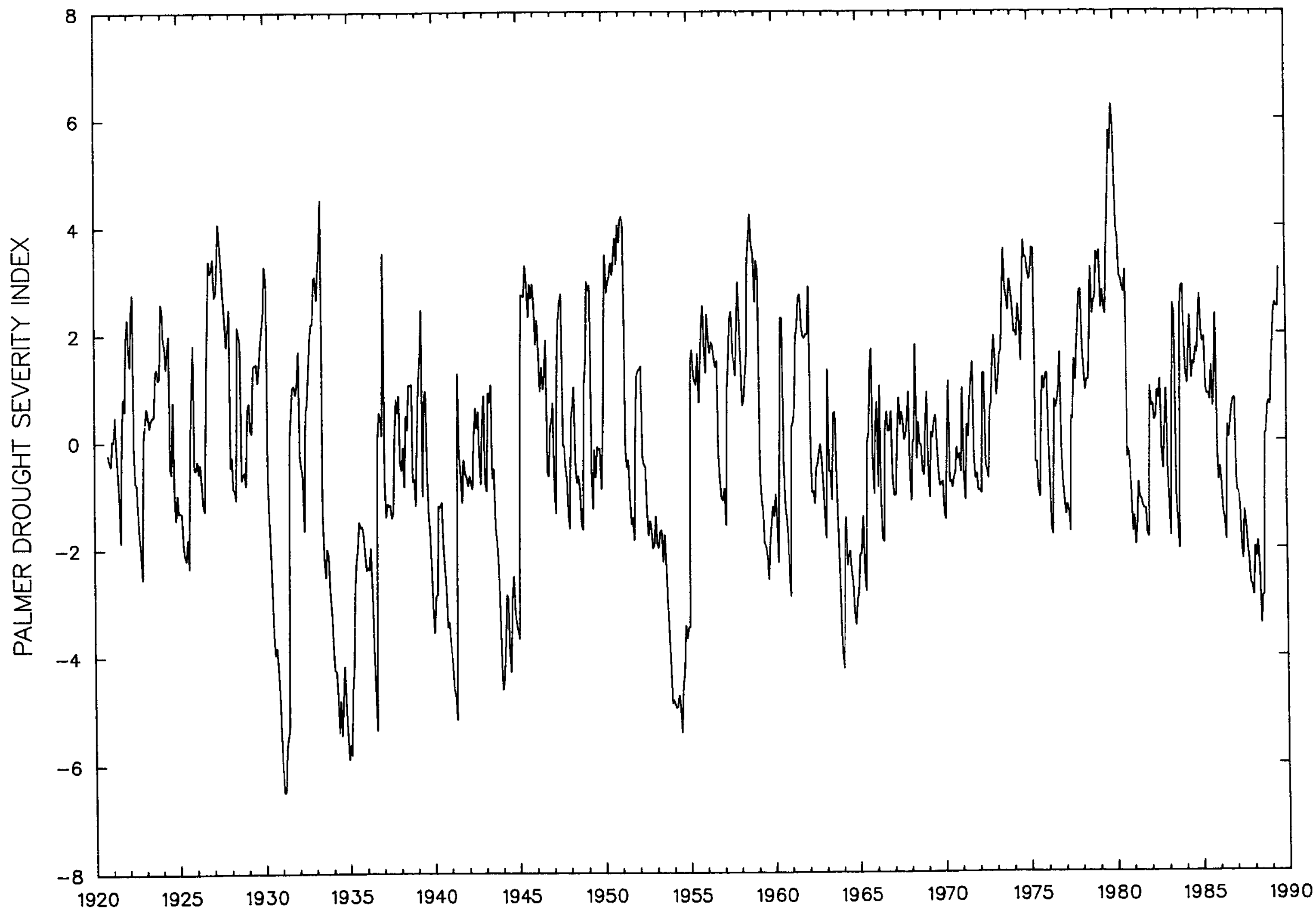


Figure 21.––Monthly Palmer Drought Severity Indices for climatic division 9, water years 1921–89 (data from National Oceanic and Atmospheric Administration, Climatic Data Center).

Table 1.--Selected water-use categories and withdrawals reported by registered users, calendar years 1987 and 1988

[Withdrawal data are from Indiana Department of Natural Resources (IDNR), Division of Water reports, "Indiana's Water Use 1987" and "Indiana's Water Use 1988"; withdrawal-point data are from Cynthia J. Clendenon, IDNR, written commun., 1990; Mgal/d, million gallons per day]

Type of water use	Withdrawals reported in 1987				Withdrawals reported in 1988			
	Ground water (Mgal/d)	Number of withdrawal points[1]	Surface water (Mgal/d)	Number of withdrawal points[1]	Ground water (Mgal/d)	Number of withdrawal points[1]	Surface water (Mgal/d)	Number of withdrawal points[1]
Irrigation[2]	36	1,182	25	606	74	1,227	57	678
Public supply	288	1,825	357	115	304	1,858	398	114
Energy production	33	167	5,468	82	35	176	5,819	124
Industrial	115	820	2,330	244	120	829	2,257	247

[1]A registered facility may have more than one withdrawal point.

[2]Most of the withdrawals occurred during June, July, and August.

EFFECTS OF 1988 DROUGHT ON GROUND-WATER LEVELS, STREAMFLOW, AND RESERVOIR LEVELS

Ground-Water Levels

Ground-water levels throughout the State were affected by the 1988 drought. Even before 1988, water levels had begun their decline. During October, November, and December of 1987, many USGS monitoring wells recorded below-average water levels. Below-average precipitation throughout the State aggravated the declining levels for most of the first 9 months of 1988. Statewide, only February and July received above-average precipitation. In July 1988, a ground-water emergency was declared by IDNR for parts of Jasper and Newton Counties in northwestern Indiana. During the emergency, high-capacity wells (wells that withdraw water at a rate of 70 gal/min or more) were prohibited from pumping on weekends. These restrictions were mandated for 90 days (Basch, M.E., Indiana Department of Natural Resources, oral commun., 1990).

Below-average precipitation, high temperatures, and increased water use through the end of August caused a further decline in water levels throughout the State. Many domestic wells were deepened and thousands of new wells were drilled. In some cases, when wells went dry, water was trucked in by the Indiana National Guard. Record low ground-water levels were first reached in some areas in August 1988, whereas most of the all-time low water levels occurred in November. By December 1988, however, statewide ground-water levels were beginning to rise.

As of September 1989, the Indiana ground-water monitoring well network consisted of 91 USGS recording wells. Twenty of these wells were selected for this report to represent ground-water levels throughout the State (fig. 22). Daily minimum ground-water level hydrographs (figs. 23-42) show the downward trend in the ground-water levels for the period just preceding and during the 1988 drought. Water in 12 of the selected 20 monitoring wells reached record low levels during calendar year 1988. During 1989, water levels gradually recovered to near average conditions.

Streamflow

Streams in Indiana showed varying effects of the 1988 drought. Some rivers had annual flows only slightly less than the 1987 mean annual streamflow (average streamflow for all water years of record up to and including water year 1987), whereas others flowed at less than one-half that value. Low flows and high temperatures caused temporary closure of some thermoelectric power plants because the need for cooling water could not be met. State regulations prohibit power plants from returning water to a river if that water would increase the temperature of the river water to more than 90° F. Numerous public water suppliers requested voluntary conservation measures by their customers, and approximately 10 utilities invoked mandatory measures (Wiercioch and Hebenstreit, 1989, p. 31). Low flows in major rivers restricted navigation, and barge traffic on the Ohio River was disrupted several times.

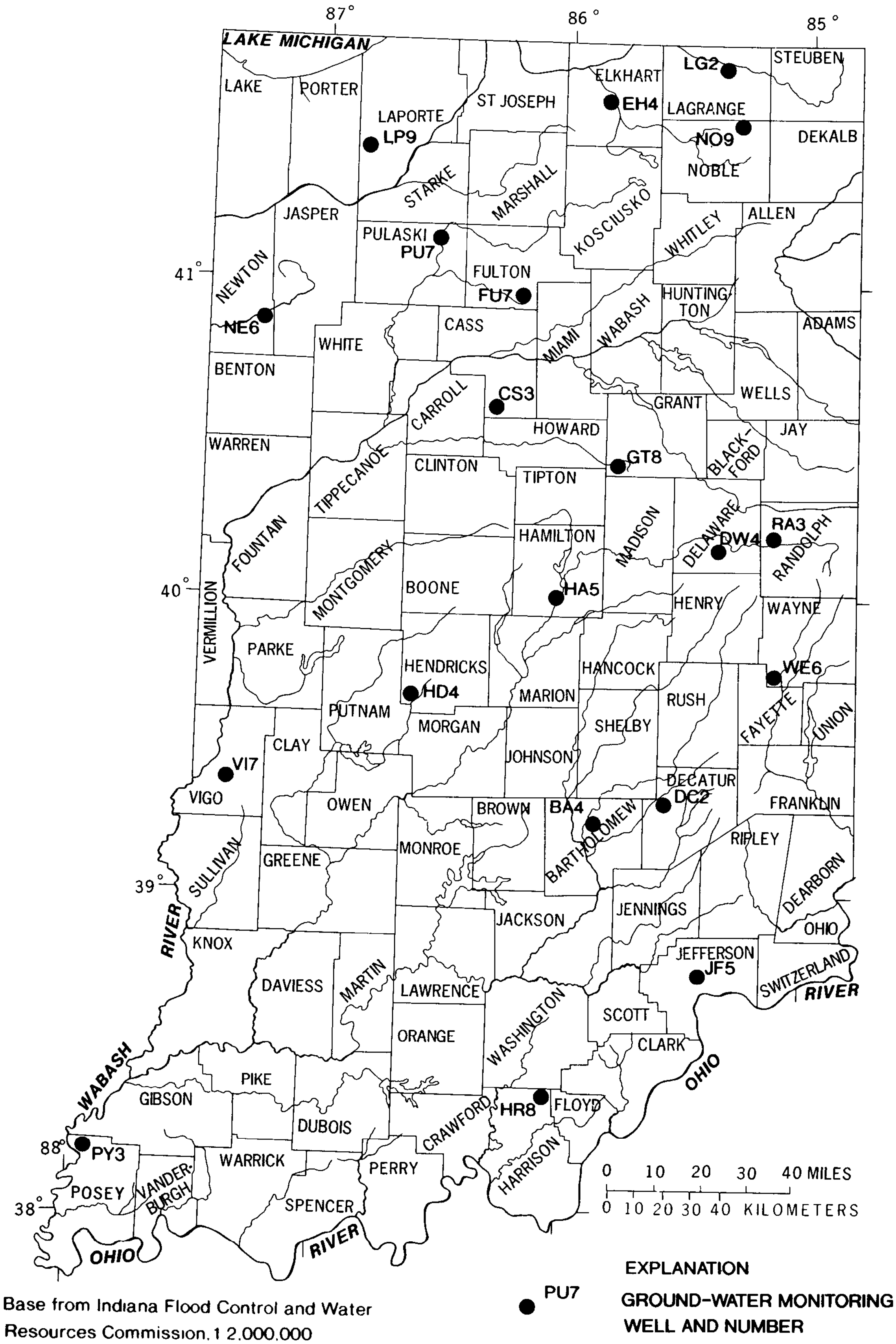


Figure 22.-- Location of selected ground-water monitoring wells.

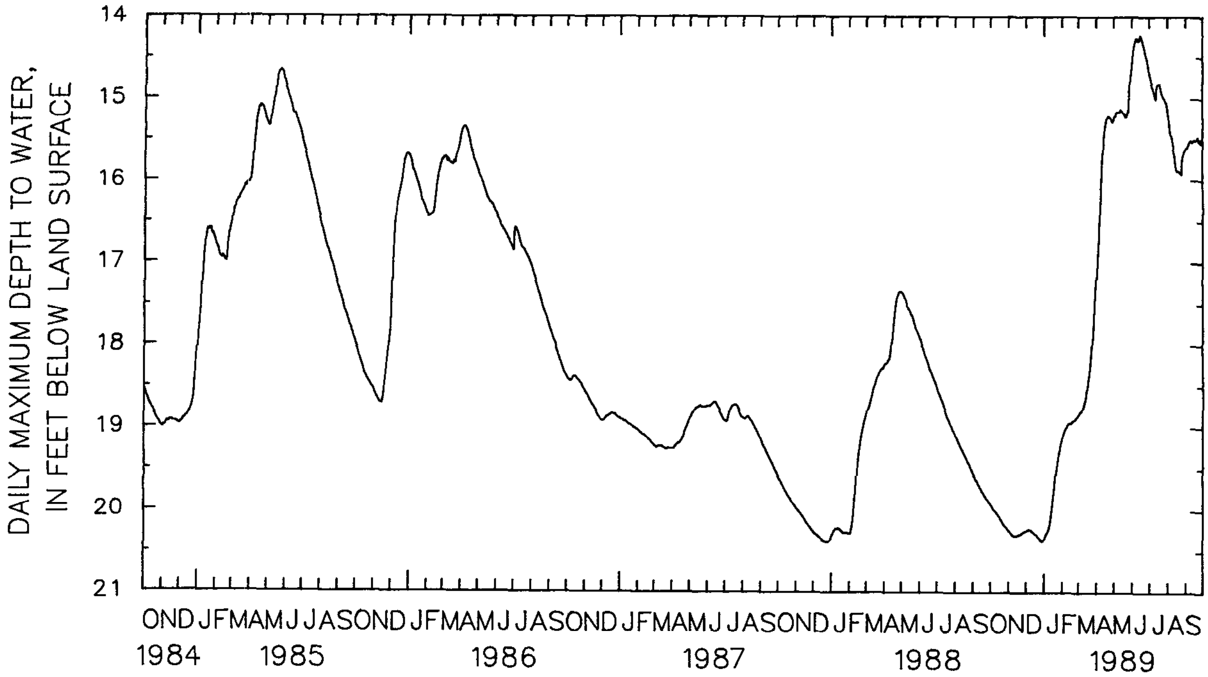


Figure 23. -- Daily maximum depth to water in ground-water monitoring well Bartholomew 4 (BA 4), October 1984-September 1989.

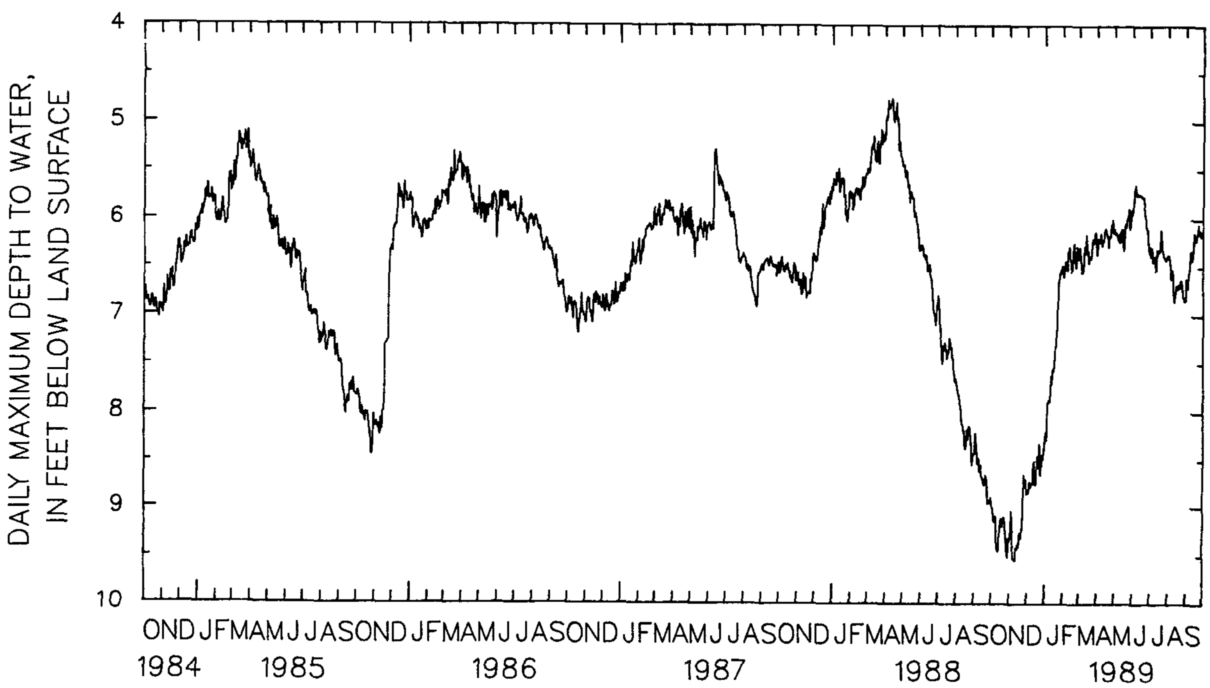


Figure 24. -- Daily maximum depth to water in ground-water monitoring well Cass 3 (CS 3), October 1984-September 1989.

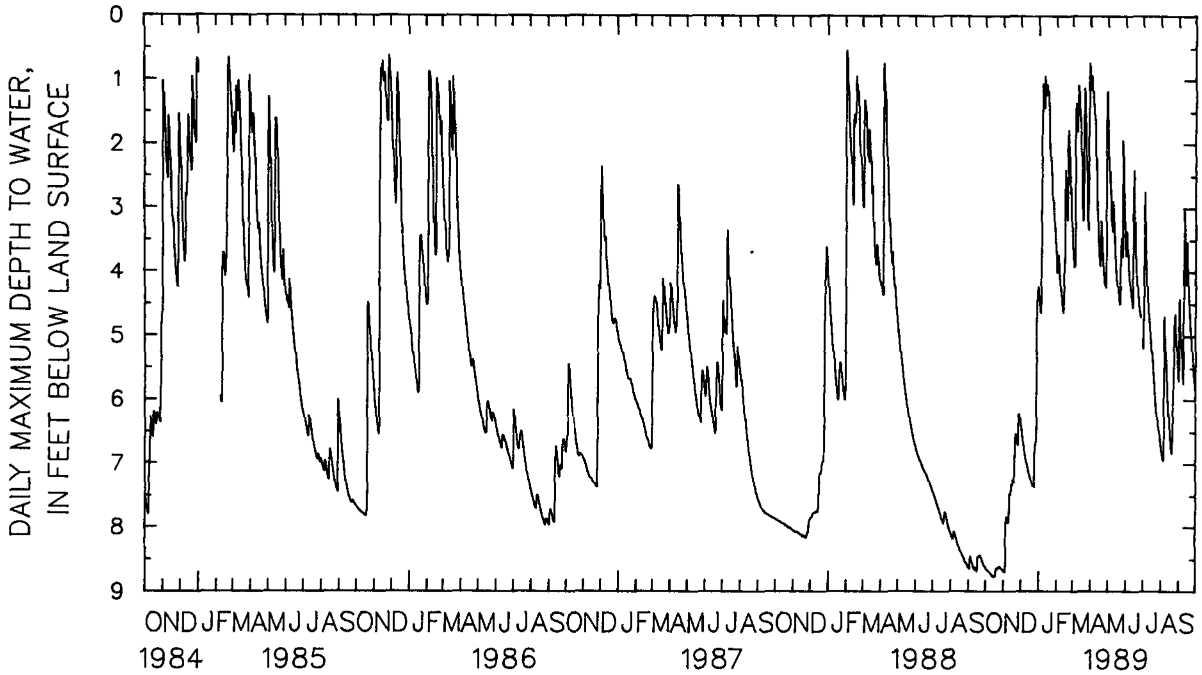


Figure 25. -- Daily maximum depth to water in ground-water monitoring well Decatur 2 (DC 2), October 1984-September 1989.

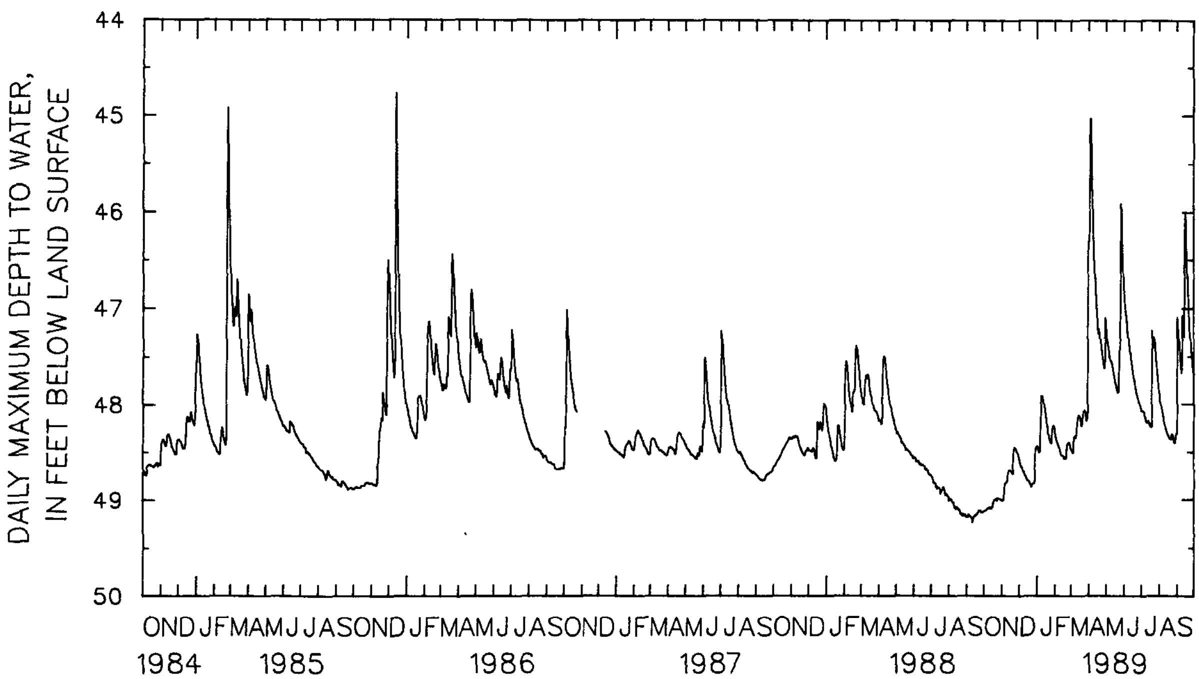


Figure 26. -- Daily maximum depth to water in ground-water monitoring well Delaware 4 (DW 4), October 1984-September 1989.

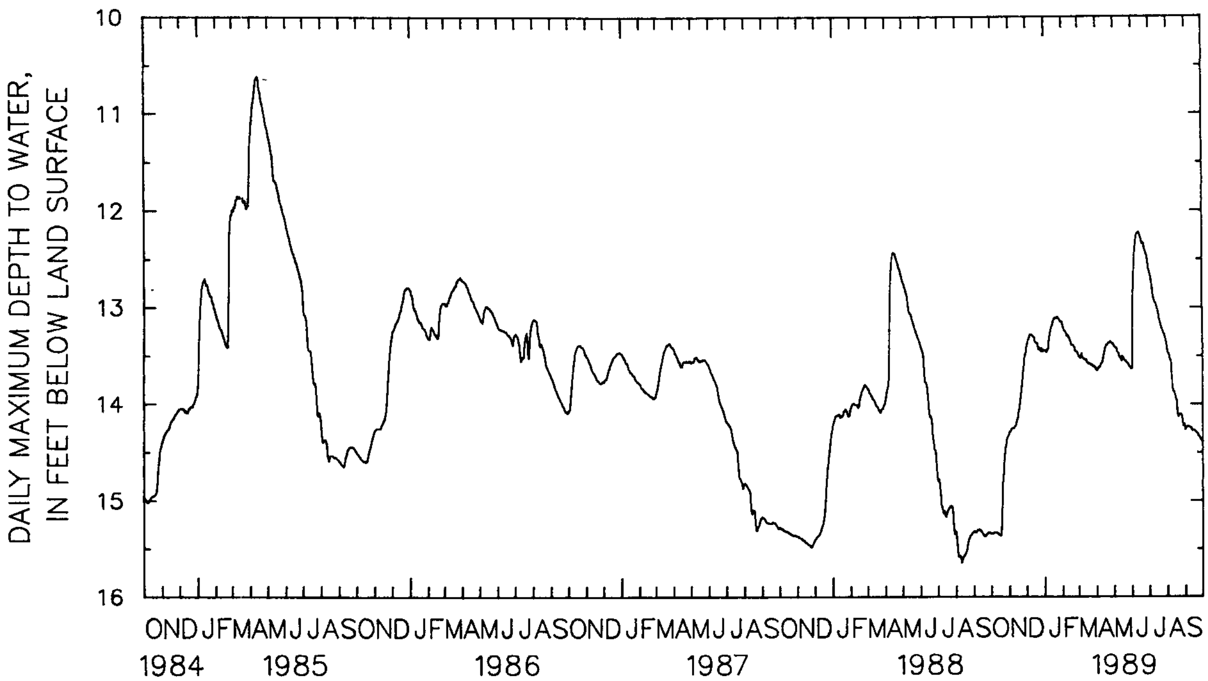


Figure 27. -- Daily maximum depth to water in ground-water monitoring well Elkhart 4 (EH 4), October 1984-September 1989.

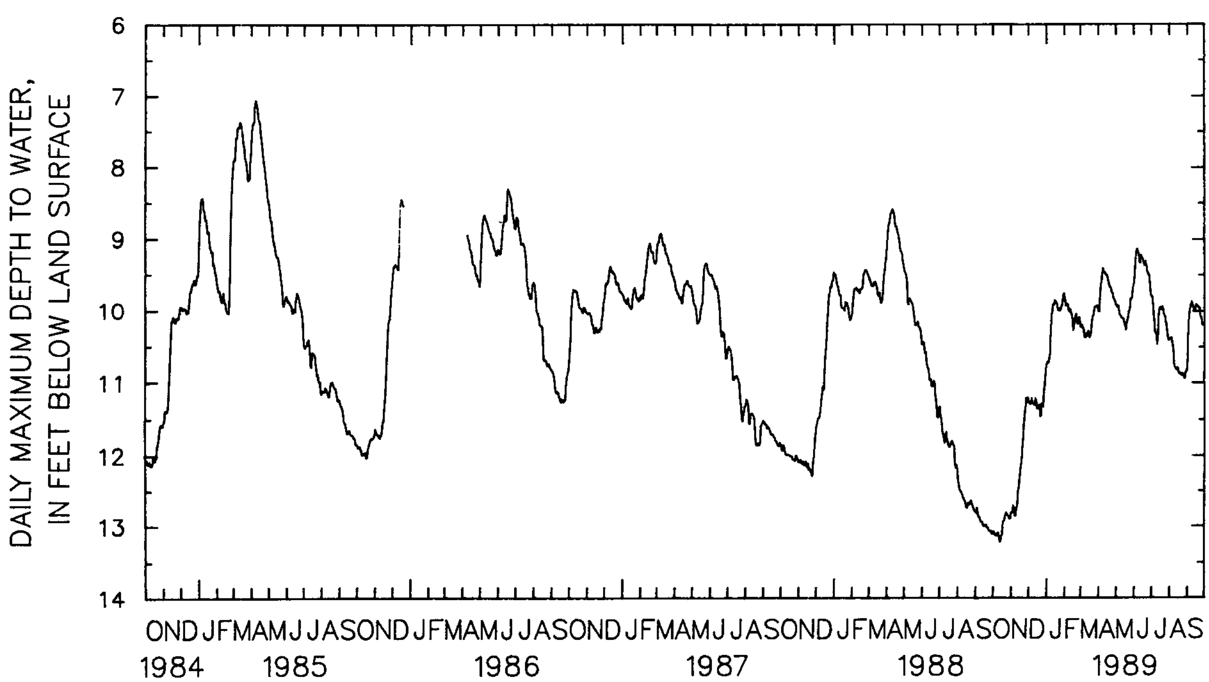


Figure 28. -- Daily maximum depth to water in ground-water monitoring well Fulton 7 (FU 7), October 1984-September 1989.

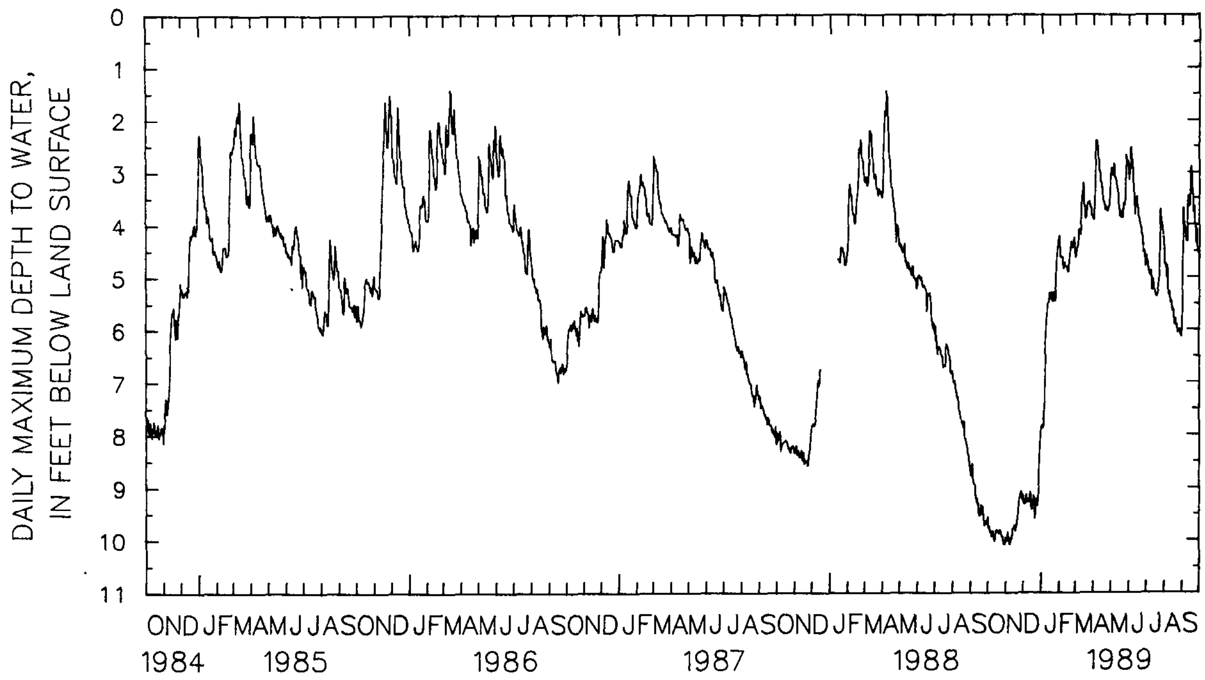


Figure 29. -- Daily maximum depth to water in ground-water monitoring well Grant 8 (GT 8), October 1984-September 1989.

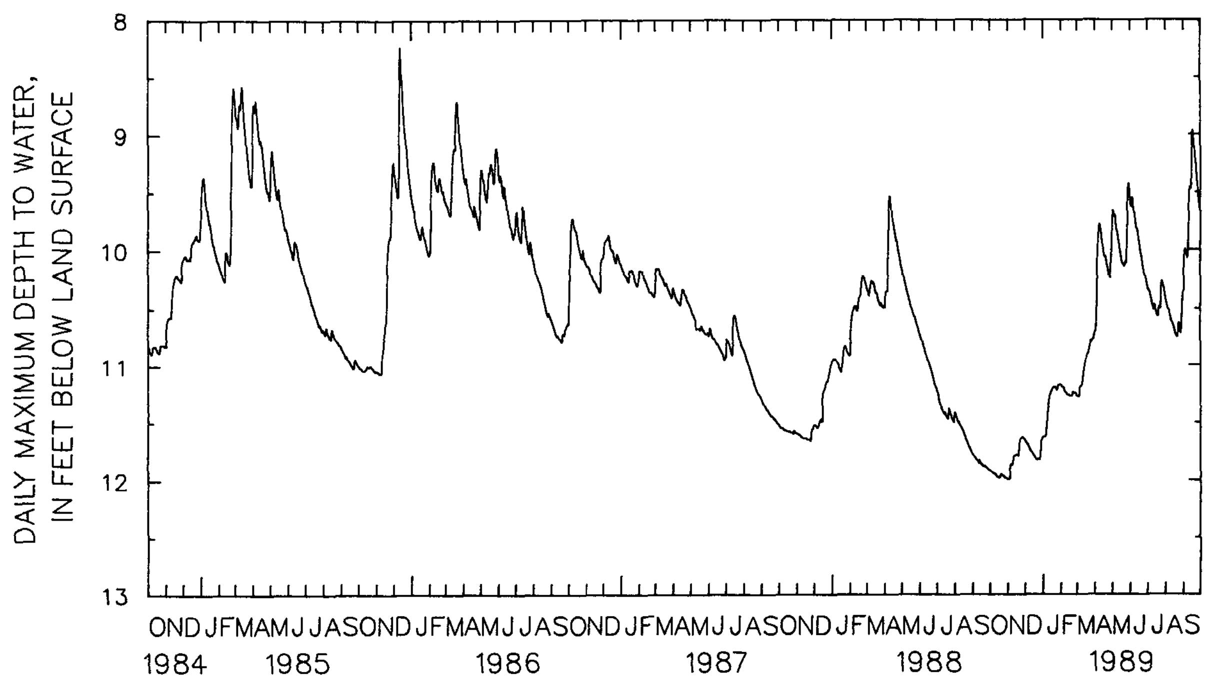


Figure 30. -- Daily maximum depth to water in ground-water monitoring well Hamilton 5 (HA 5), October 1984-September 1989.

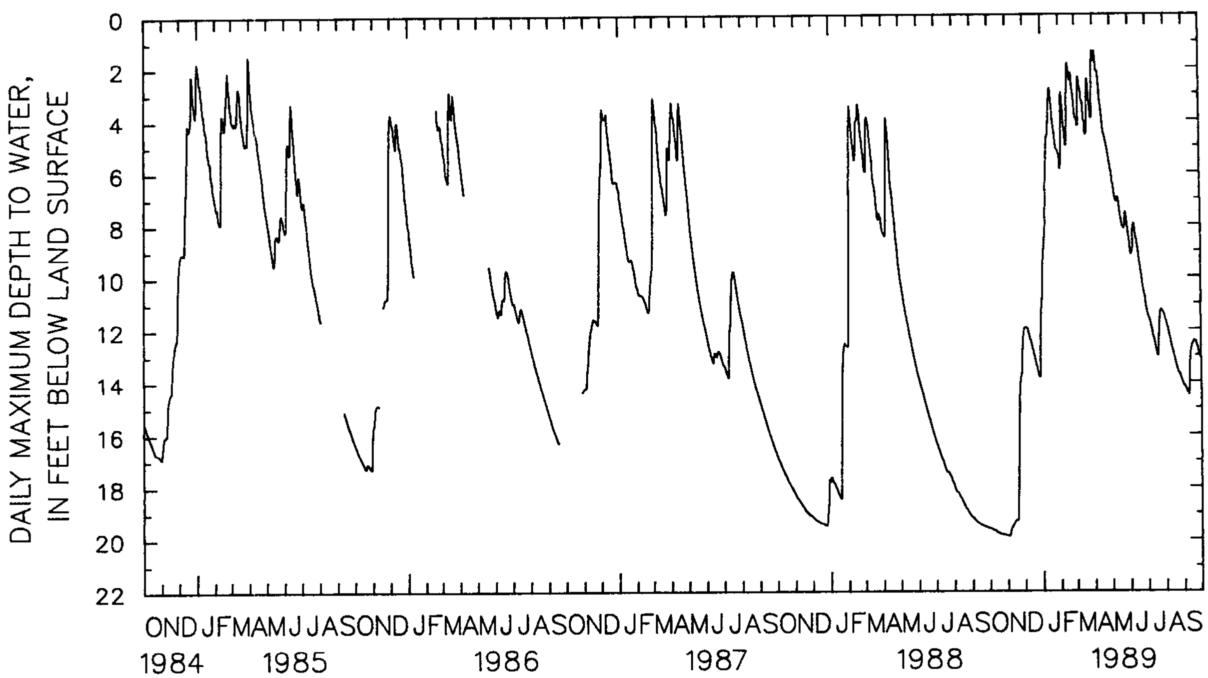


Figure 31. -- Daily maximum depth to water in ground-water monitoring well Harrison 8 (HR 8), October 1984-September 1989.

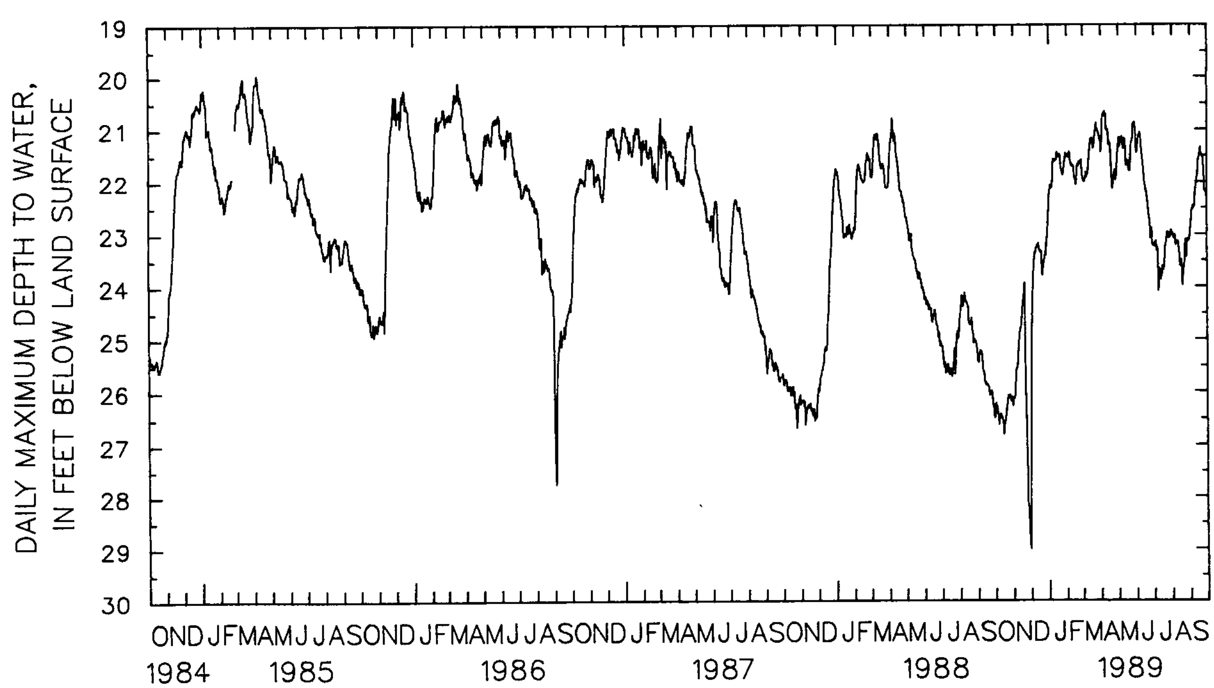


Figure 32. -- Daily maximum depth to water in ground-water monitoring well Hendricks 4 (HD 4), October 1984-September 1989.

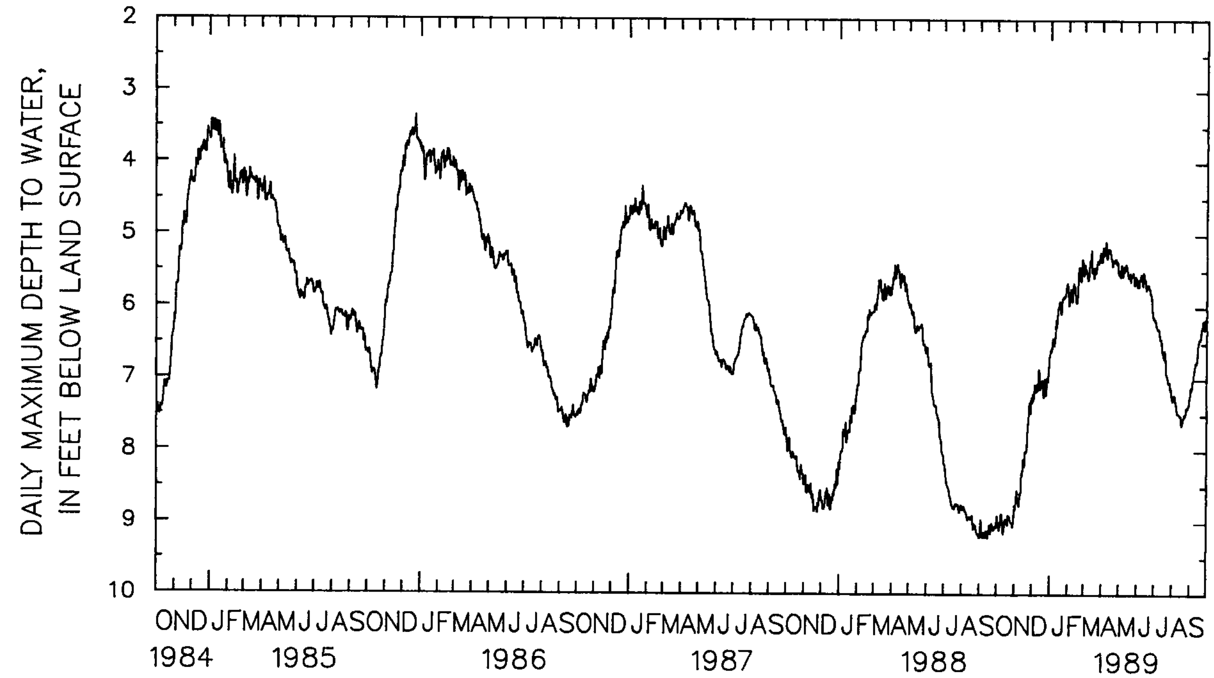


Figure 33. -- Daily maximum depth to water in ground-water monitoring well Jefferson 5 (JF 5), October 1984-September 1989.

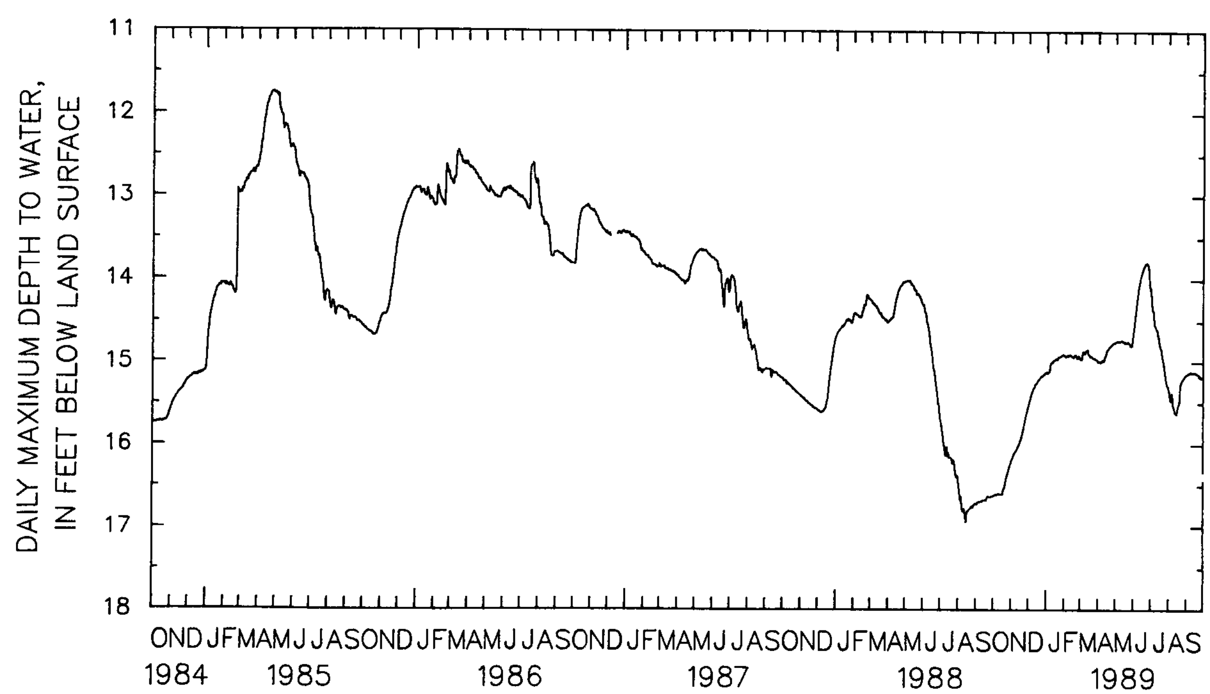


Figure 34. -- Daily maximum depth to water in ground-water monitoring well Lagrange 2 (LG 2), October 1984-September 1989.

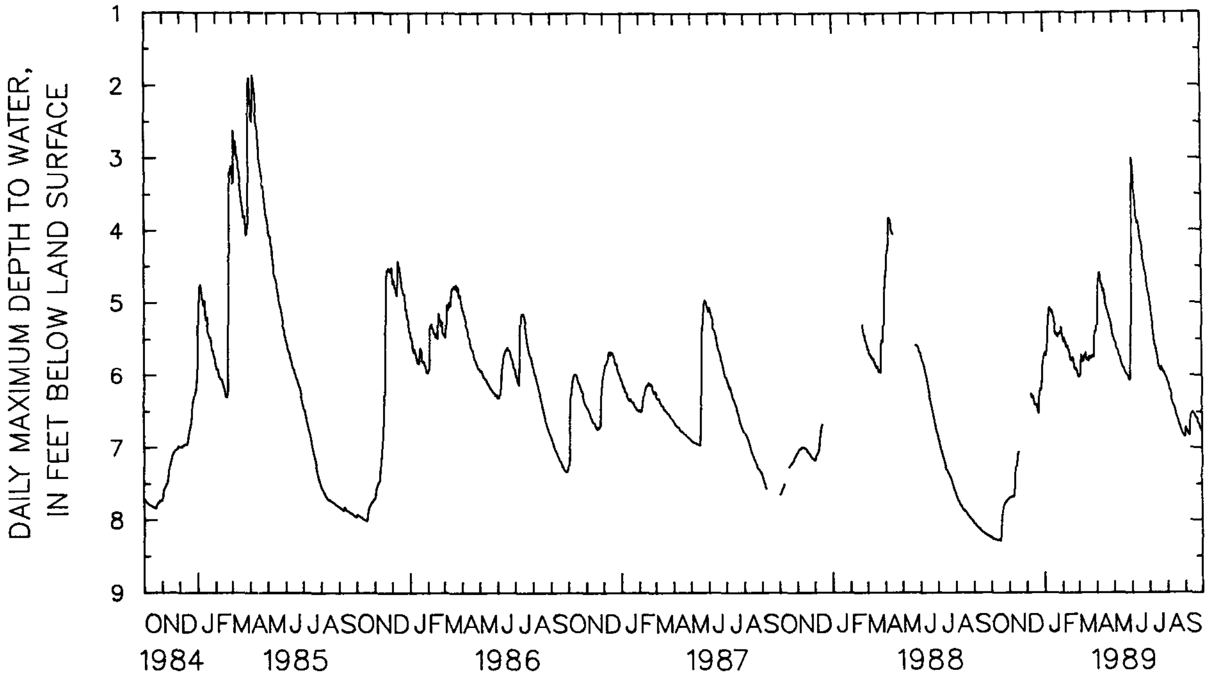


Figure 35. -- Daily maximum depth to water in ground-water monitoring well La Porte 9 (LP 9), October 1984-September 1989.

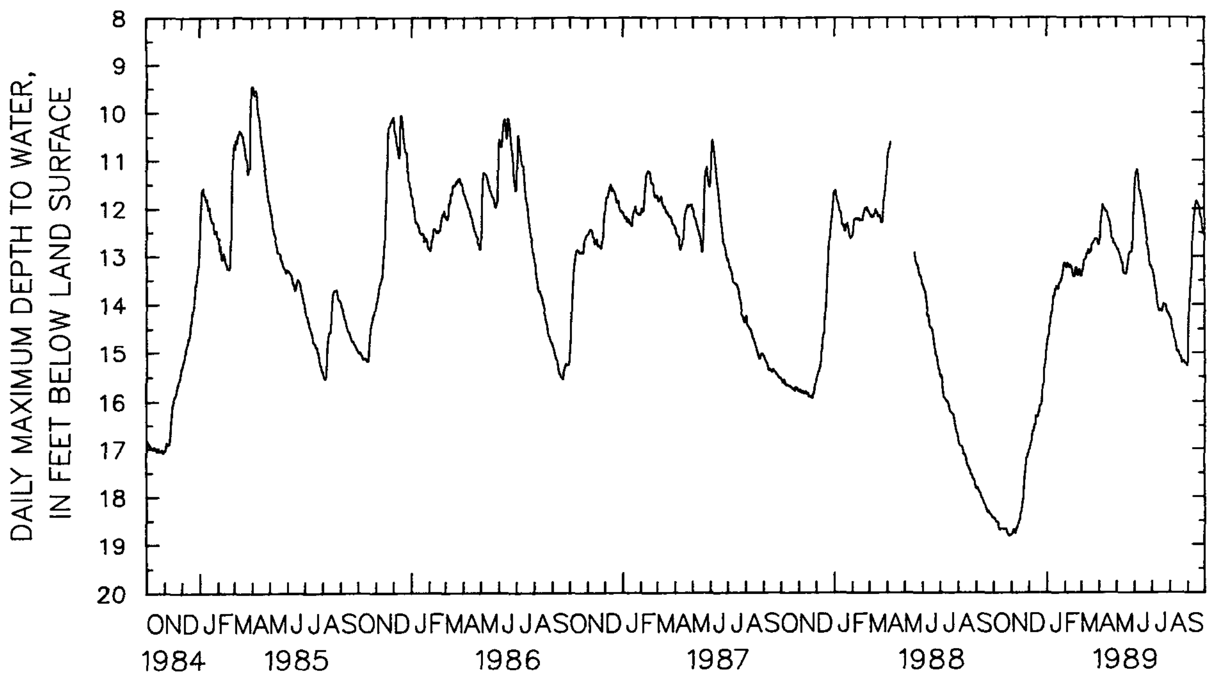


Figure 36. -- Daily maximum depth to water in ground-water monitoring well Newton 6 (NE 6), October 1984-September 1989.

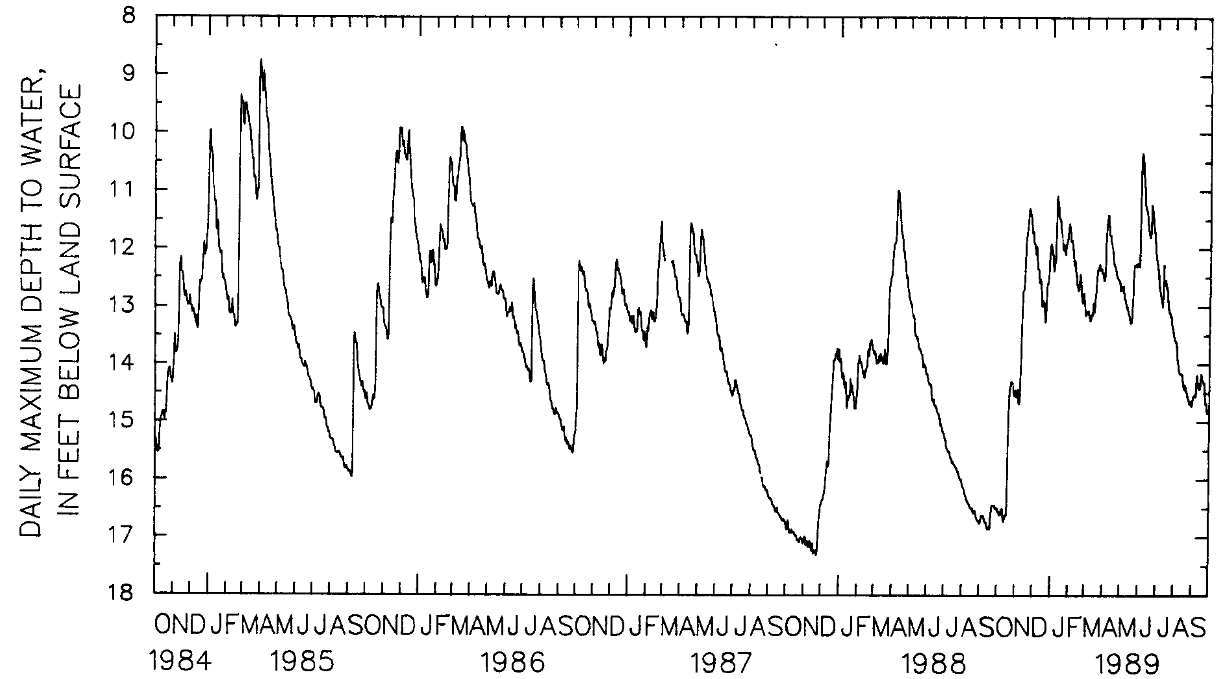


Figure 37. -- Daily maximum depth to water in ground-water monitoring well Noble 9 (NO 9), October 1984-September 1989.

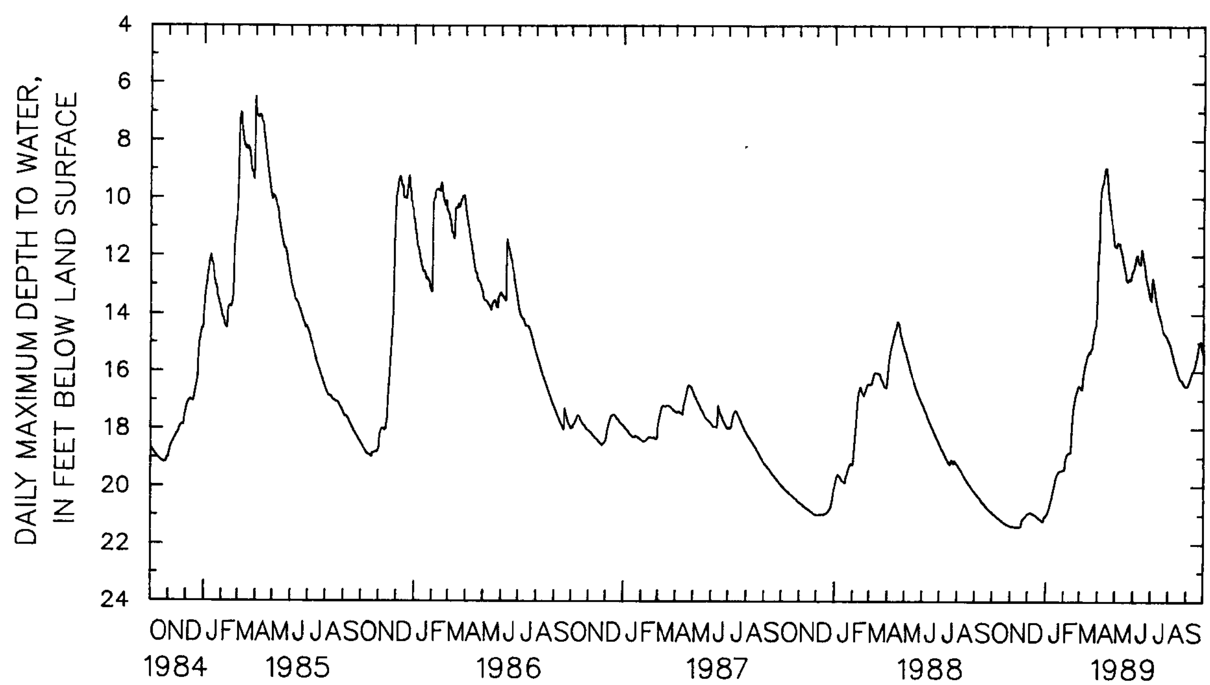


Figure 38. -- Daily maximum depth to water in ground-water monitoring well Posey 3 (PY 3), October 1984-September 1989.

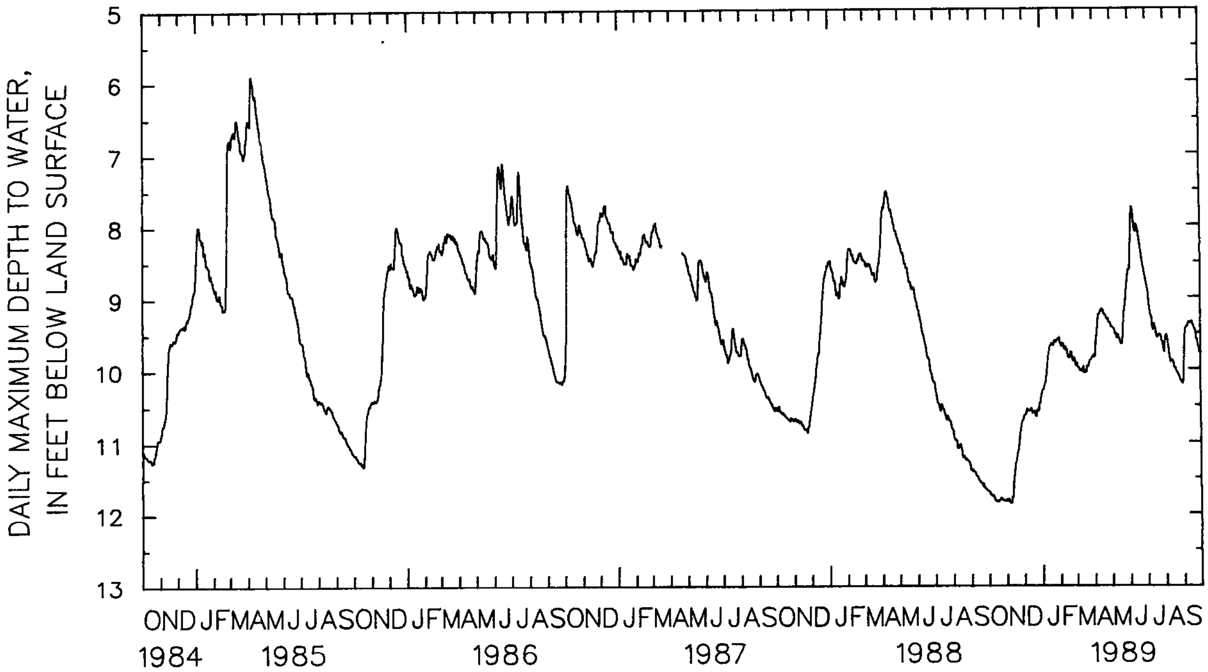


Figure 39. -- Daily maximum depth to water in ground-water monitoring well Pulaski 7 (PU 7), October 1984-September 1989.

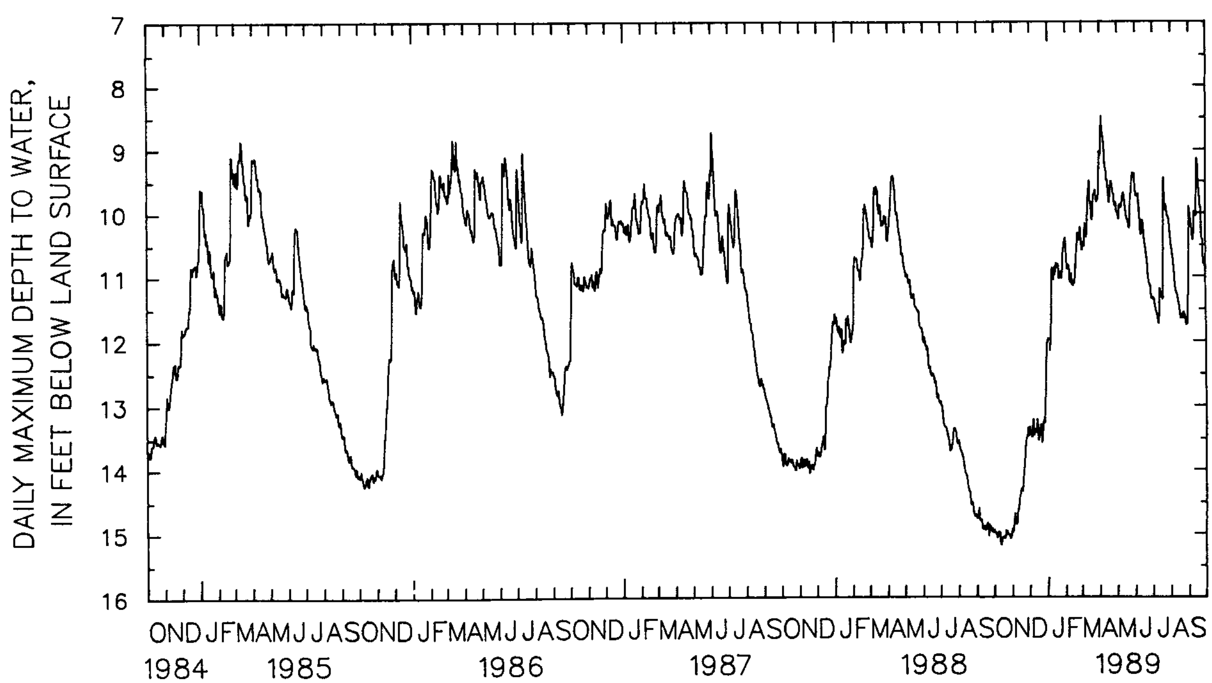


Figure 40. -- Daily maximum depth to water in ground-water monitoring well Randolph 3 (RA 3), October 1984-September 1989.

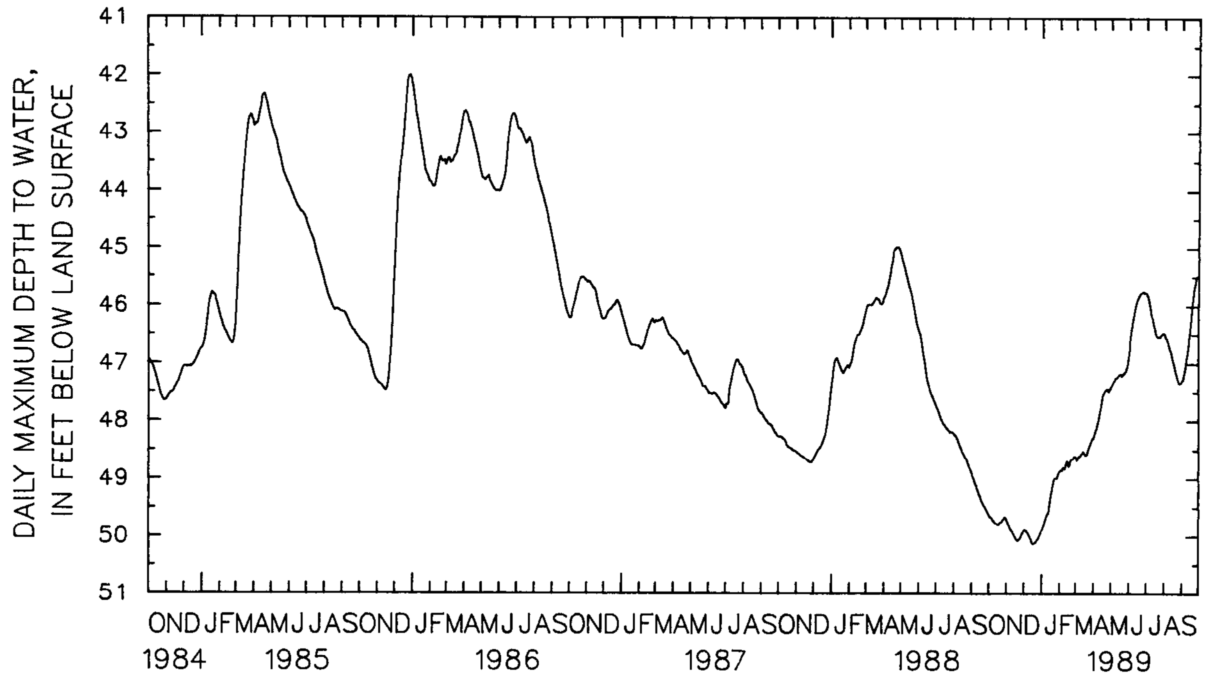


Figure 41. -- Daily maximum depth to water in ground-water monitoring well Vigo 7 (VI 7), October 1984-September 1989.

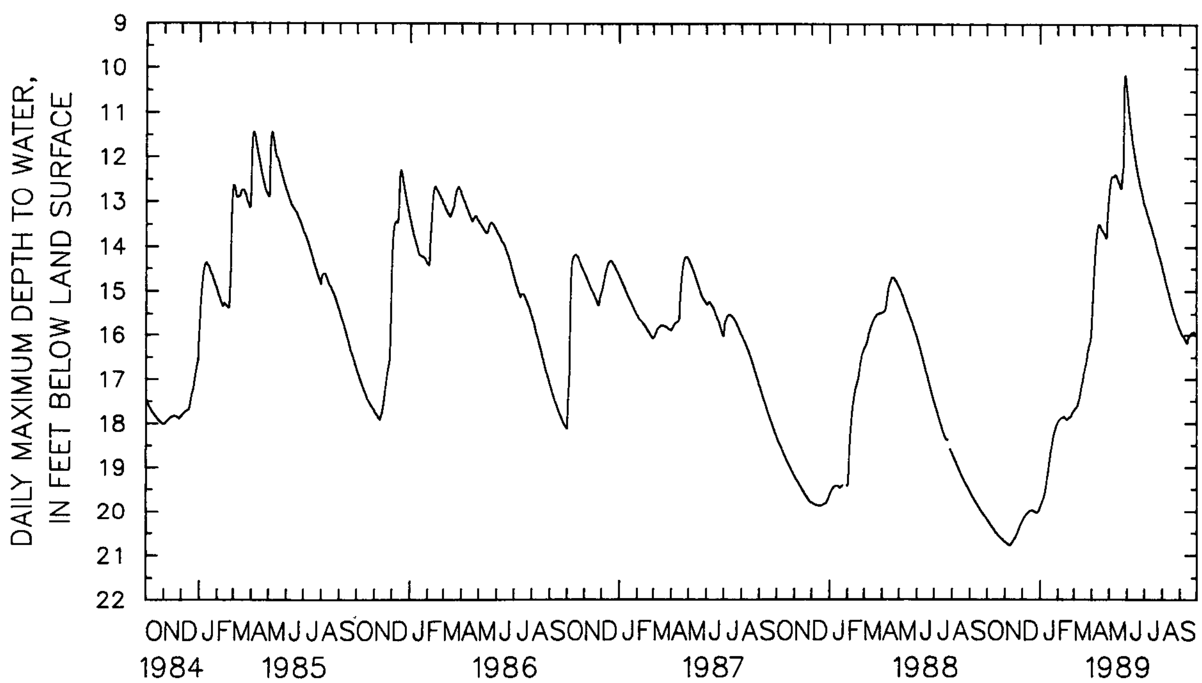


Figure 42. -- Daily maximum depth to water in ground-water monitoring well Wayne 6 (WE 6), October 1984-September 1989.

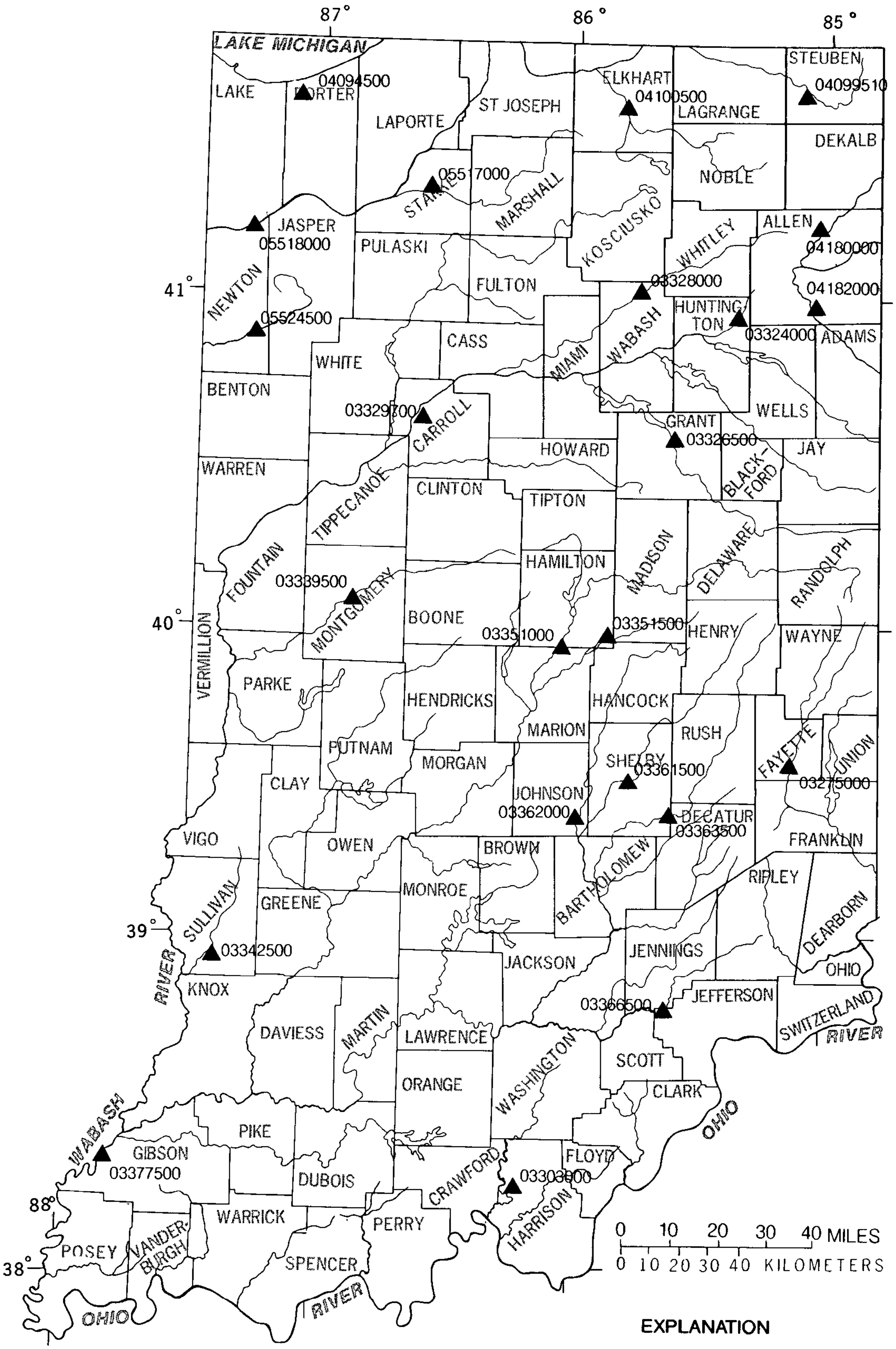
Streamflow-Gaging Stations

Twenty-four of the 176 continuous-record streamflow-gaging stations operated by the USGS in Indiana were selected for use in this report. The selected stations were located throughout the State (fig. 43) and were chosen because of their representative nature, length of record (average period of record was 51 years), and the fact that they were subject to little or no regulation. Drainage areas of the stations ranged from 28,635 mi^2 for Wabash River at Mount Carmel, Illinois (03377500), to 74.6 mi^2 for Salt Creek near McCool, Indiana (04094500).

Data from these stations were used to graph cumulative departures of monthly mean streamflow for each station's period of record through September 1989 (figs. 44-67). Cumulative departures of monthly mean streamflow for each of the stations were calculated by computing the difference between each monthly mean value and that month's long-term mean monthly value. The monthly mean difference for each January, for example, was added to the preceding year's January sum. The cumulative departures then were plotted to obtain a graphical representation of the relative severity of the 1988 drought as compared to the entire period of record. As was previously described in the "Precipitation" section, cumulative departure from the mean is one method of evaluating relative severity and long-term trends. The slope and length of the lines and the change in their positions from year to year are more important than the vertical location of the lines on the graphs (Tibbals, 1990, p. E7). A positive slope indicates that streamflow during that period was generally above average, whereas a negative slope indicates a period when streamflow was below average.

Cumulative departures of streamflow can be compared to cumulative departures of precipitation to illustrate an important feature of a stream's response to excess or deficit precipitation. Streams generally respond quickly to deficit precipitation but may respond in a variety of ways to excess precipitation, depending upon the season of the year. If excess precipitation falls during the growing season, little change is seen in the negative slope of the streamflow-departure graph because most of the available water is used by growing vegetation. For example, even though precipitation in July 1988 was greater than average statewide, monthly mean streamflow at 16 of the 24 stations included in this report was ranked from lowest to fifth lowest for the period of record (table 2). This apparent lag in streamflow response can be seen by comparing the cumulative departure of monthly precipitation for climatic division 5 (fig. 6) to cumulative departure of monthly streamflow for Fall Creek near Fortville (03351500) (fig. 54). The negative slope on the precipitation graph reverses direction toward the end of water year 1988, although positive departures of monthly mean streamflow do not begin until about January 1990, well into the 1989 water year.

All of figures 44-67 show a negative trend in cumulative departure of streamflow to varying degrees during 1987 and 1988. Most of the stations indicate a relatively moderate drought of short duration. For example, figure 47, Mississinewa River at Marion (03326500), shows negative departures from the long-term mean monthly streamflow are fairly continuous for only approximately 2 years as compared to the more prolonged droughts of 1939-42 and 1952-57. Iroquois River near Foresman (05524500) (fig. 67) also shows that slopes were longer and steeper for periods 1953-57 and 1962-67 than during the 1988 and 1989 drought period. Streamflow at few of the stations, Eel River at North Manchester (03328000) (fig. 48) for example, was affected little by prevailing dry conditions.



Base From Indiana Flood Control
And Water Resources Commission,
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EXPLANATION

▲03377500 **STREAMFLOW-GAGING STATION AND IDENTIFICATION NUMBER**

Figure 43.-- Location of selected continuous-record gaging stations in Indiana.

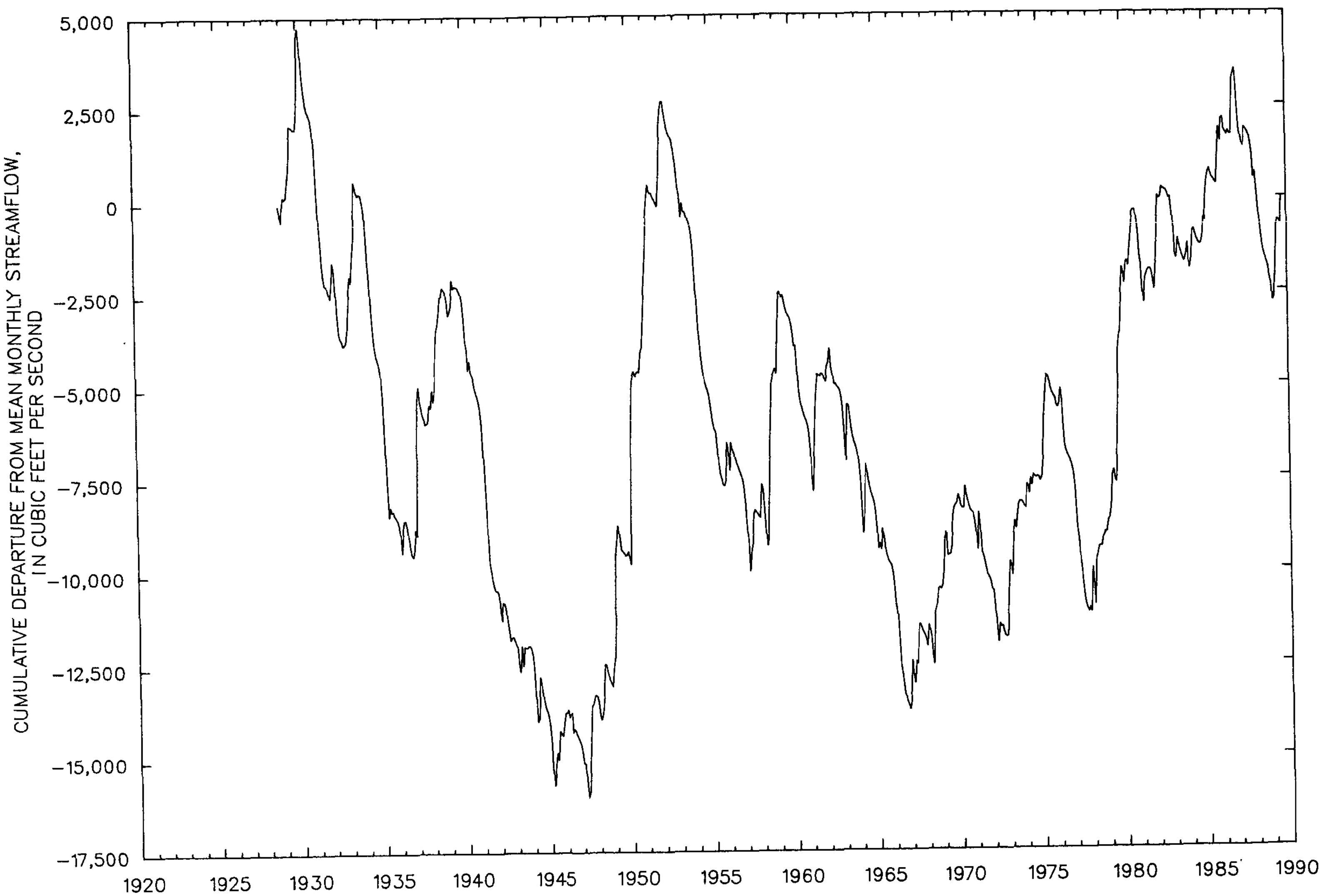


Figure 44.—–Cumulative departure from mean monthly streamflow for Whitewater River near Alpine (03275000), water years 1929–89.

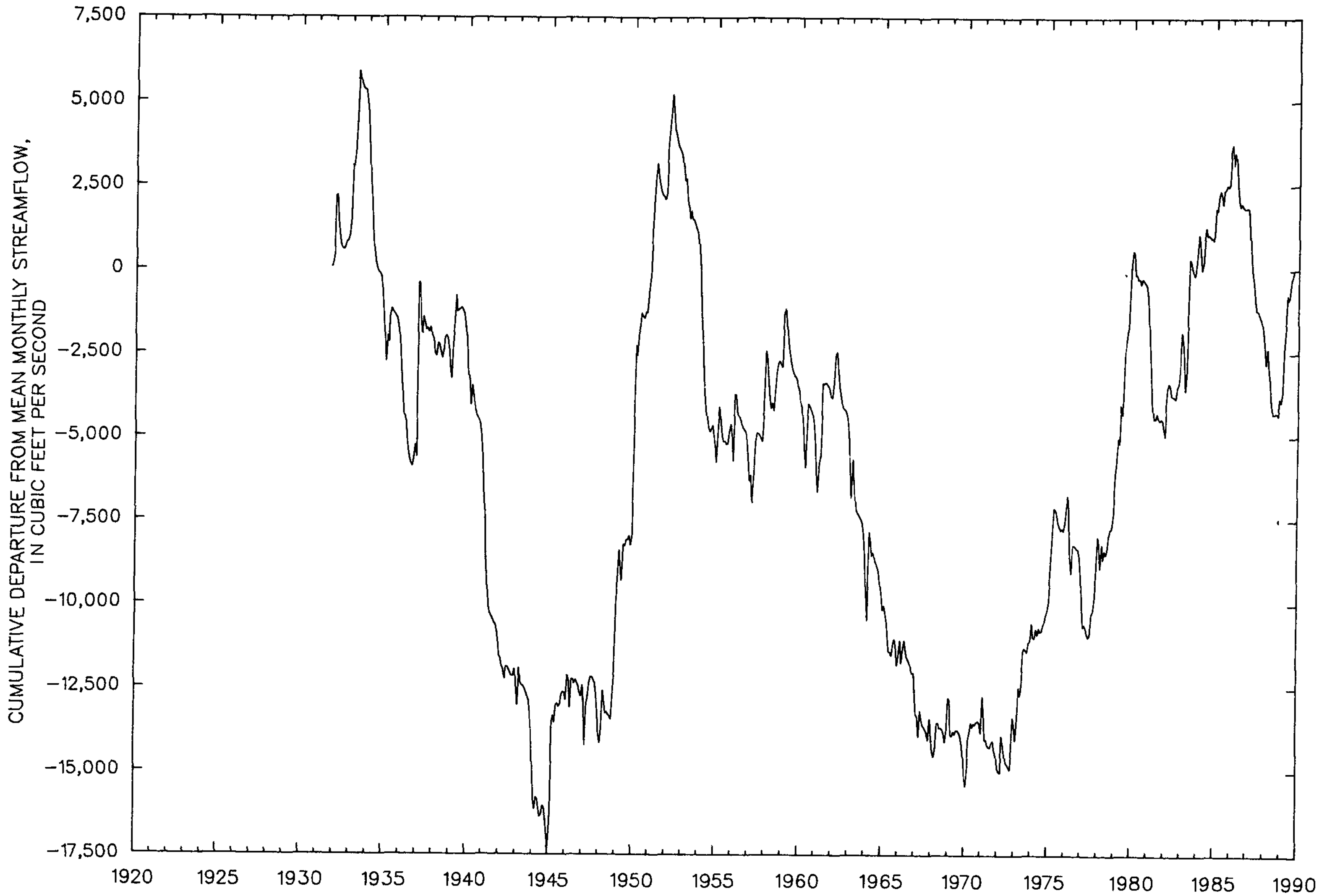


Figure 45.--Cumulative departure from mean monthly streamflow for Blue River near White Cloud (03303000), water years 1932-89.

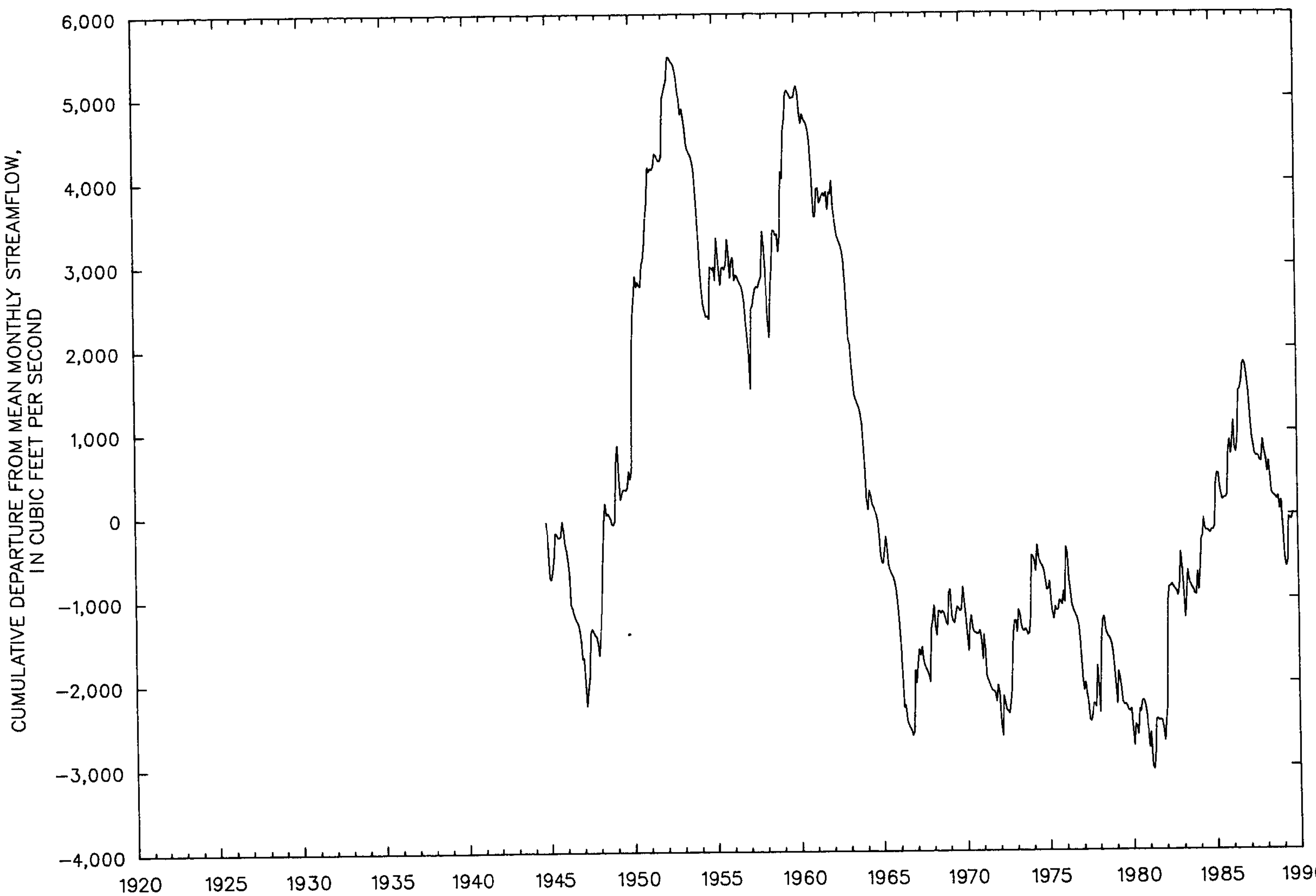


Figure 46.--Cumulative departure from mean monthly streamflow for Little River near Huntington (03324000), water years 1945–89.

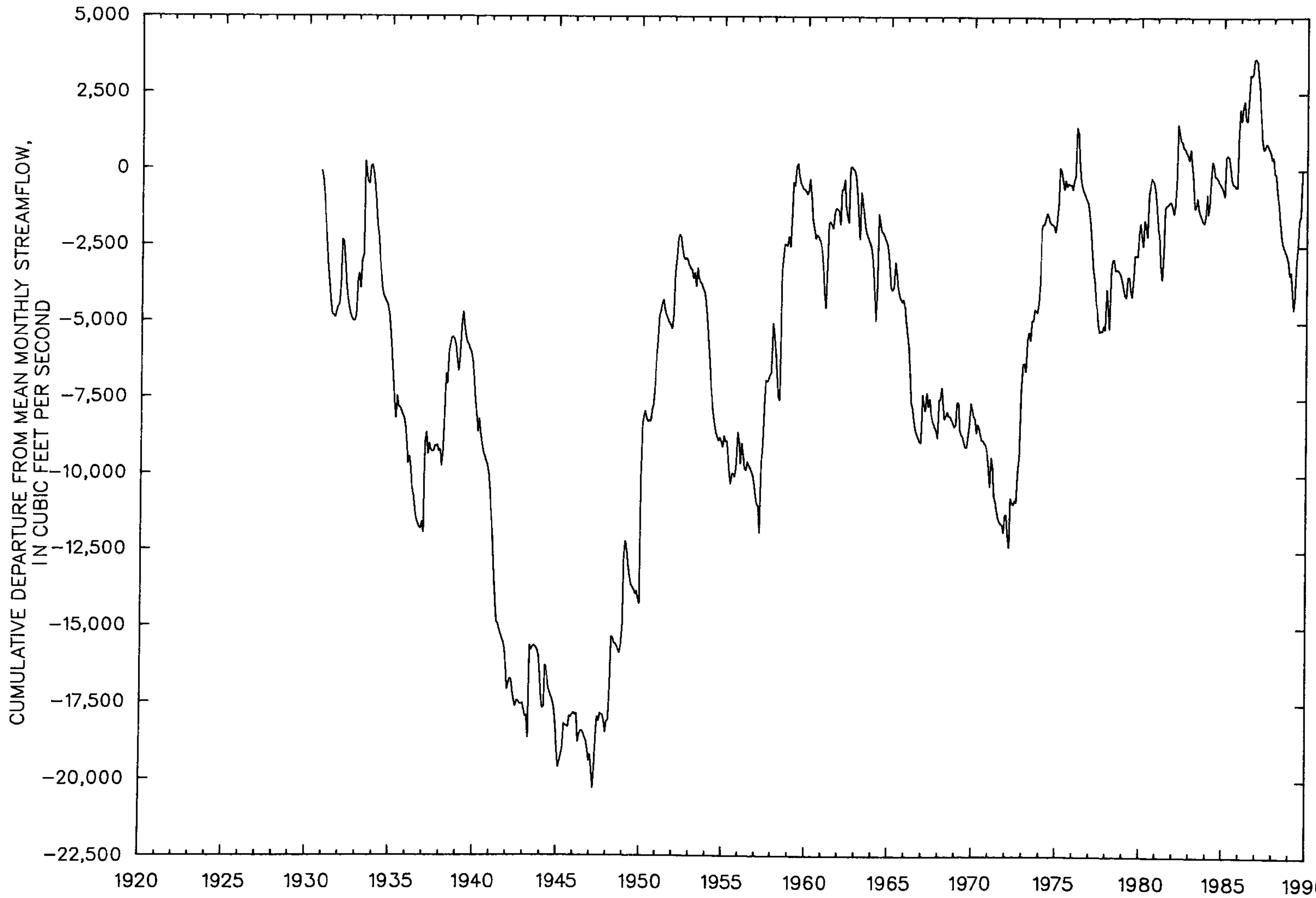


Figure 47.——Cumulative departure from mean monthly streamflow for Mississinewa River at Marion (03326500), water years 1931–89.

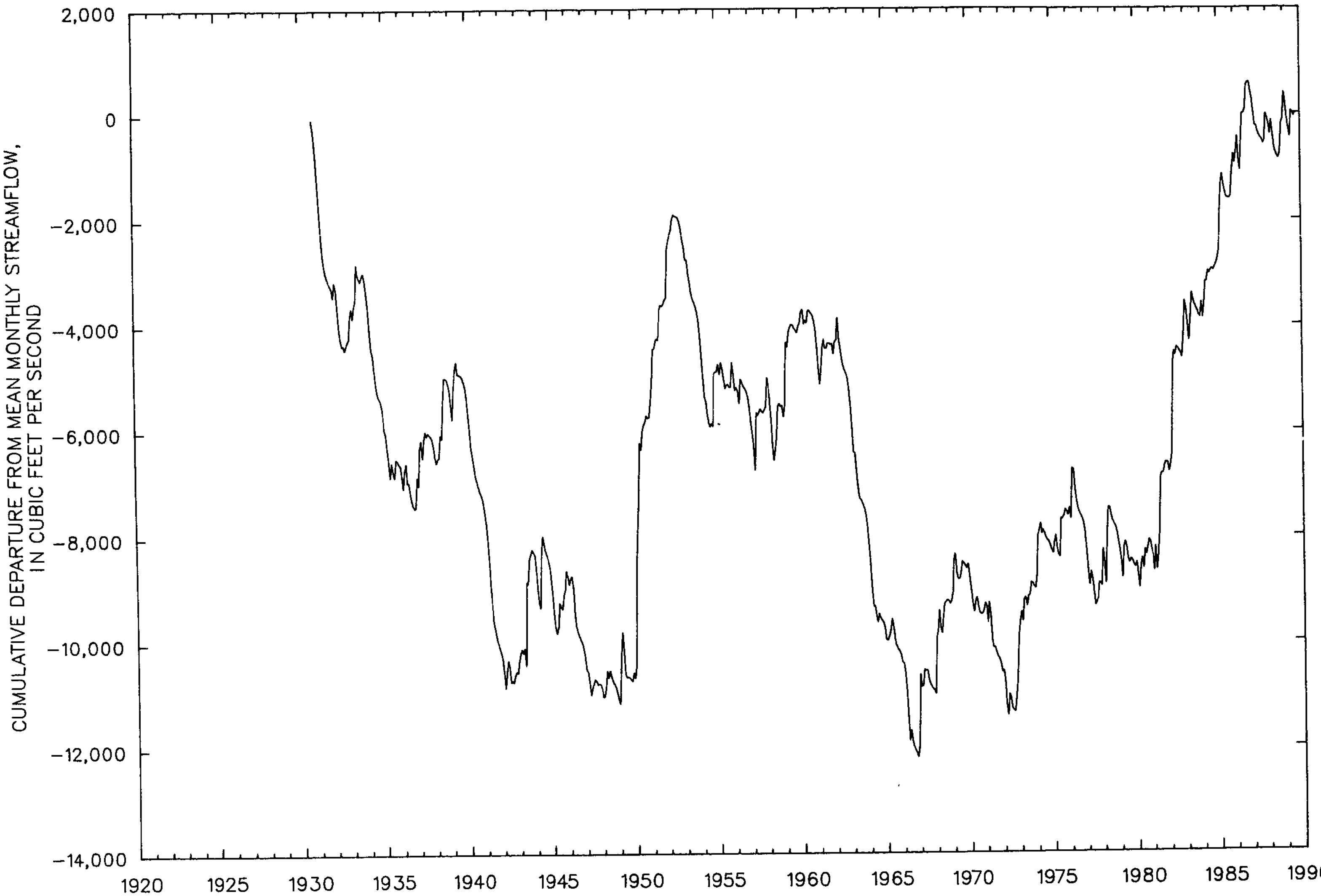


Figure 48.--Cumulative departure from mean monthly streamflow for Eel River at North Manchester (03328000), water years 1931-89.

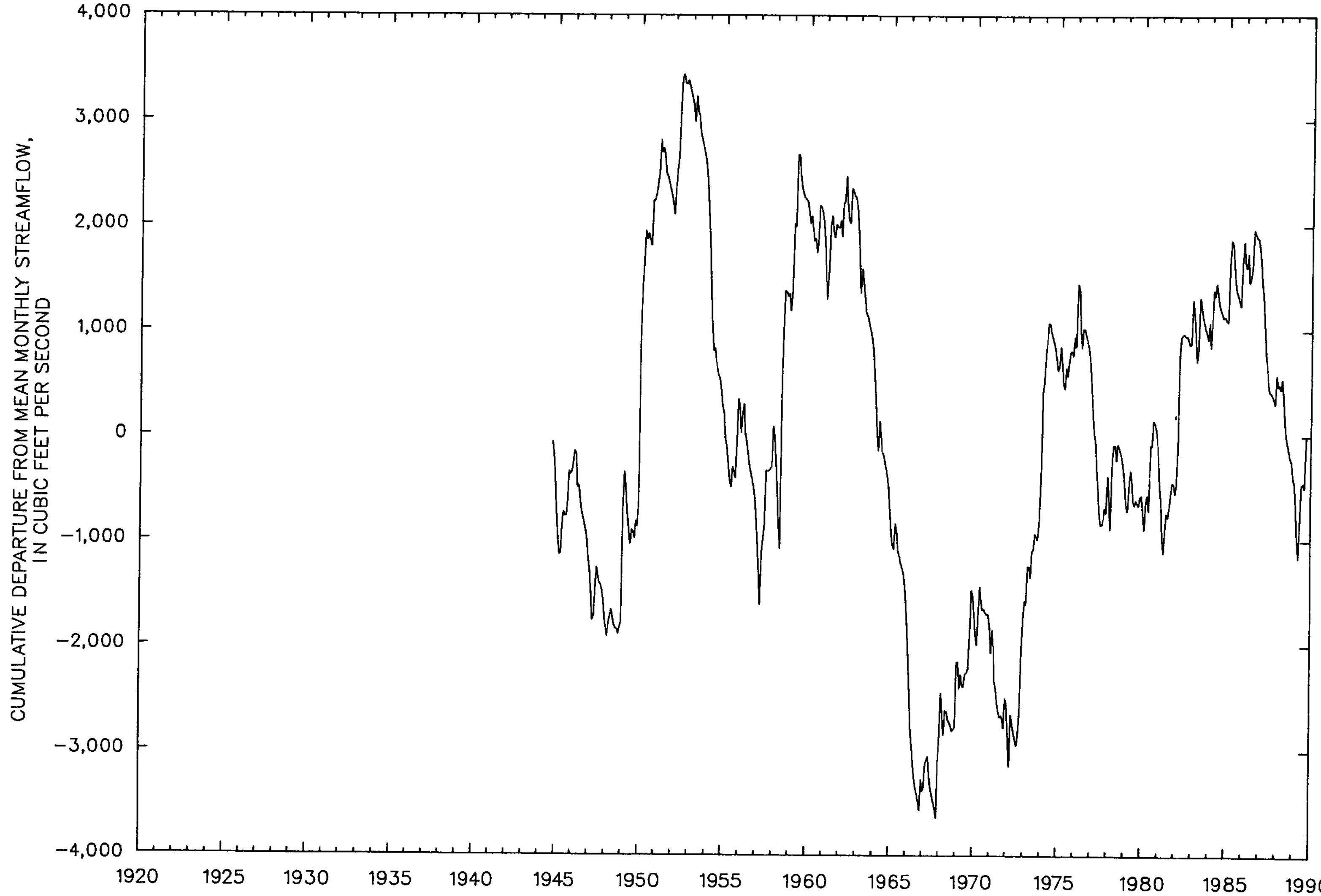


Figure 49.—Cumulative departure from mean monthly streamflow for Deer Creek near Delphi (03329700), water years 1945–89.

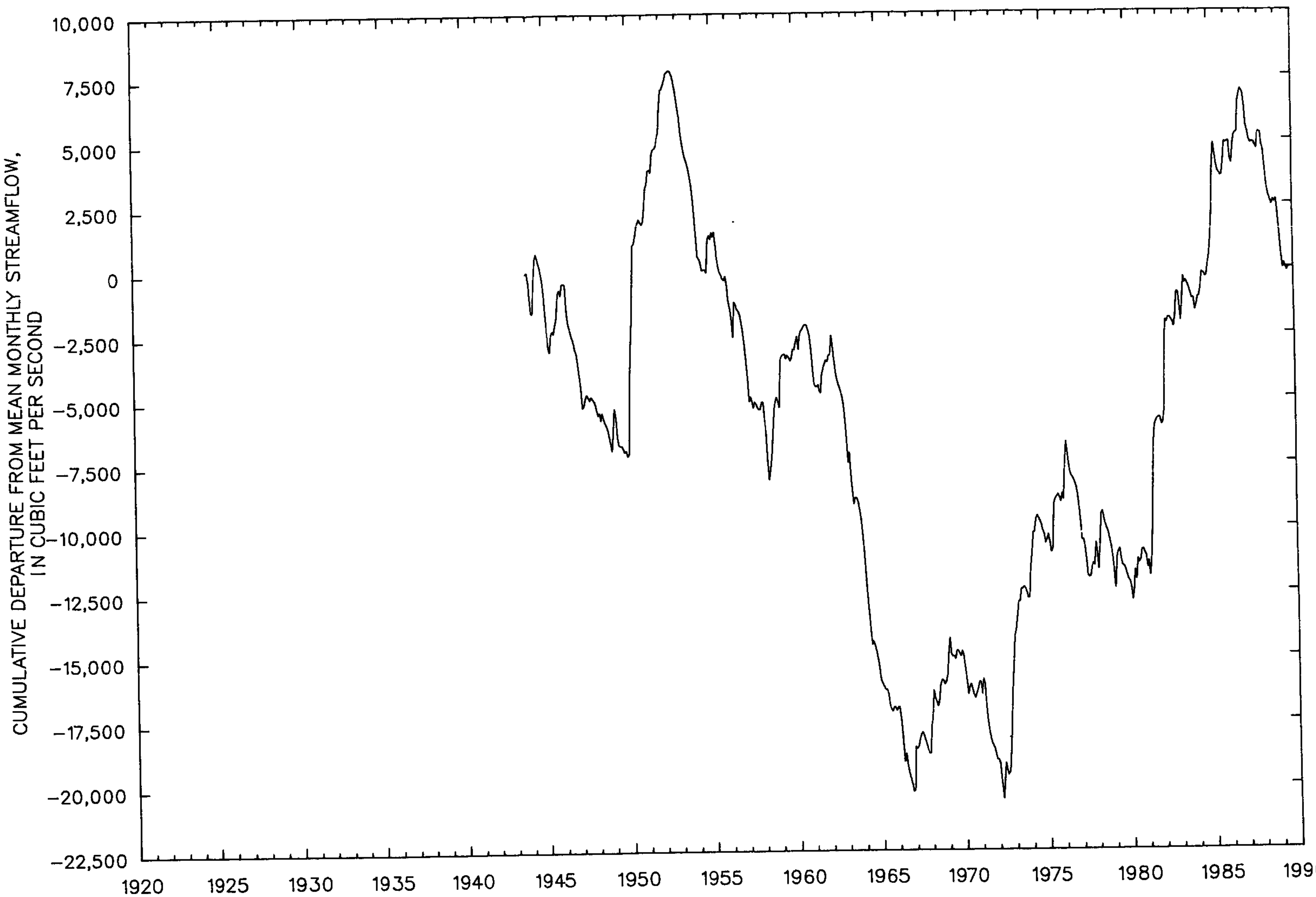


Figure 50.−−Cumulative departure from mean monthly streamflow for Tippecanoe River near Ora (03331500), water years 1944−89.

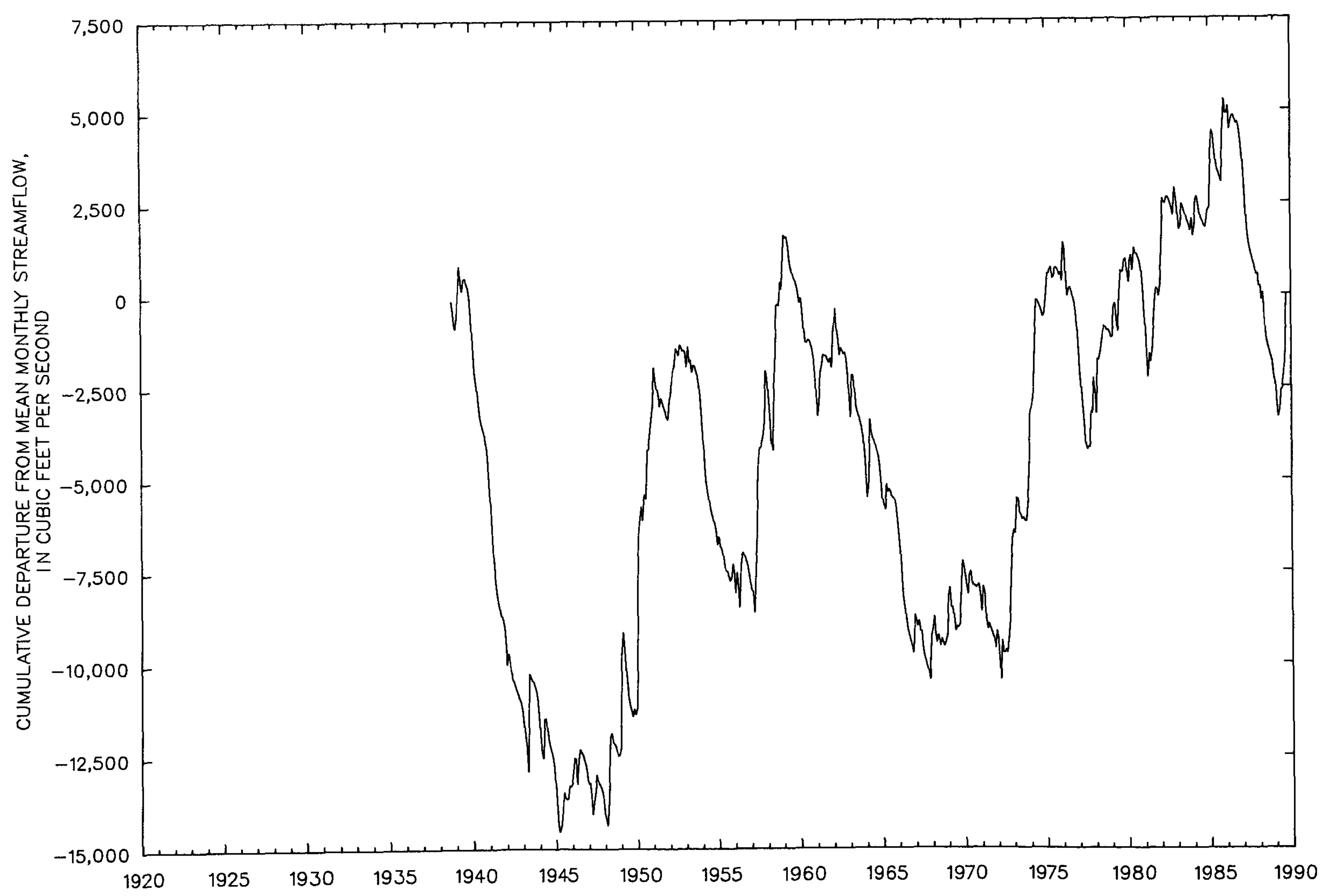


Figure 51.—Cumulative departure from mean monthly streamflow for Sugar Creek at Crawfordsville (03339500), water years 1939–89.

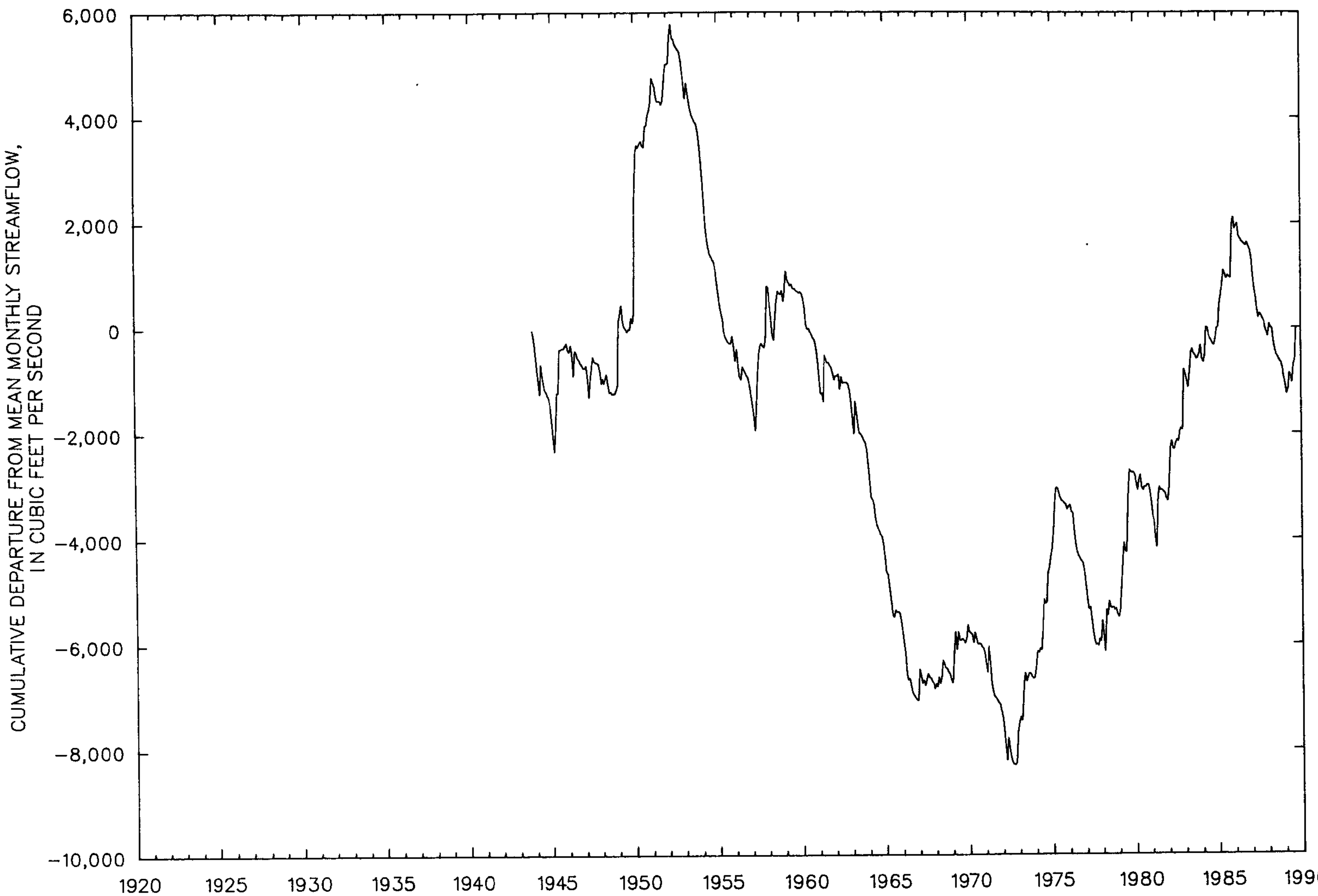


Figure 52.—Cumulative departure from mean monthly streamflow for Busseron Creek near Carlisle (03342500), water years 1944–89.

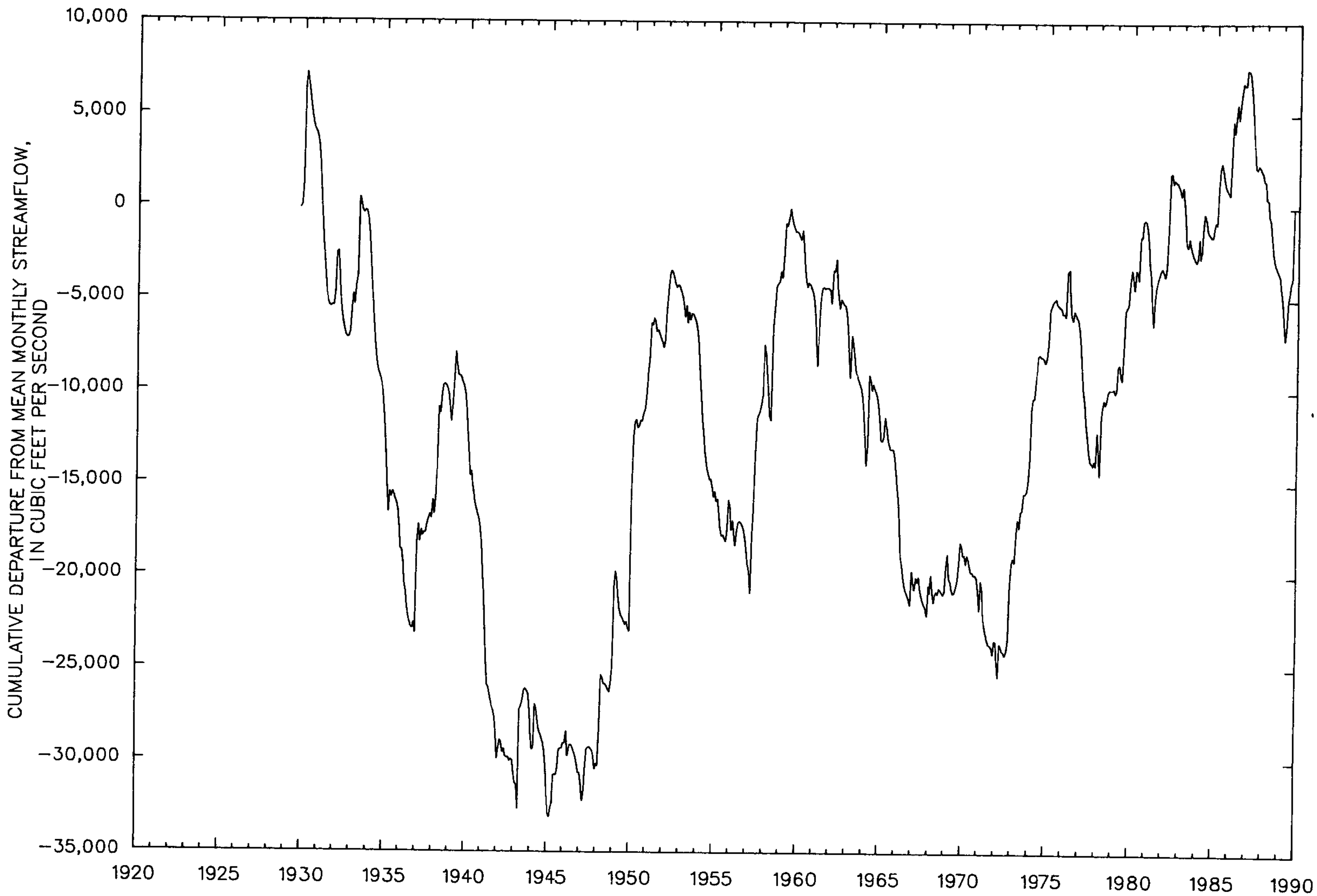


Figure 53.−−Cumulative departure from mean monthly streamflow for White River near Nora (03351000), water years 1930−89.

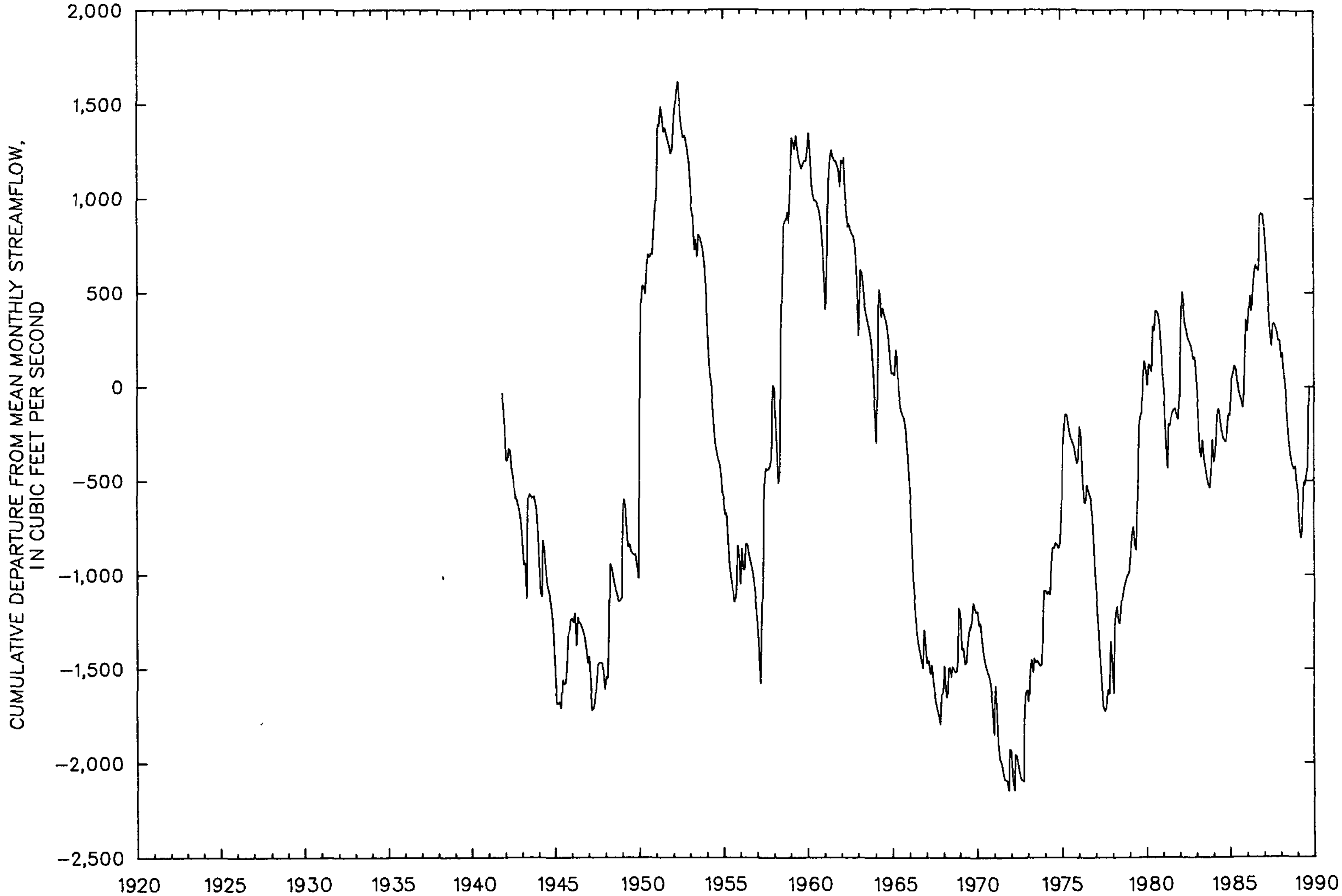


Figure 54.—–Cumulative departure from mean monthly streamflow for Fall Creek near Fortville (03351500), water years 1942–89.

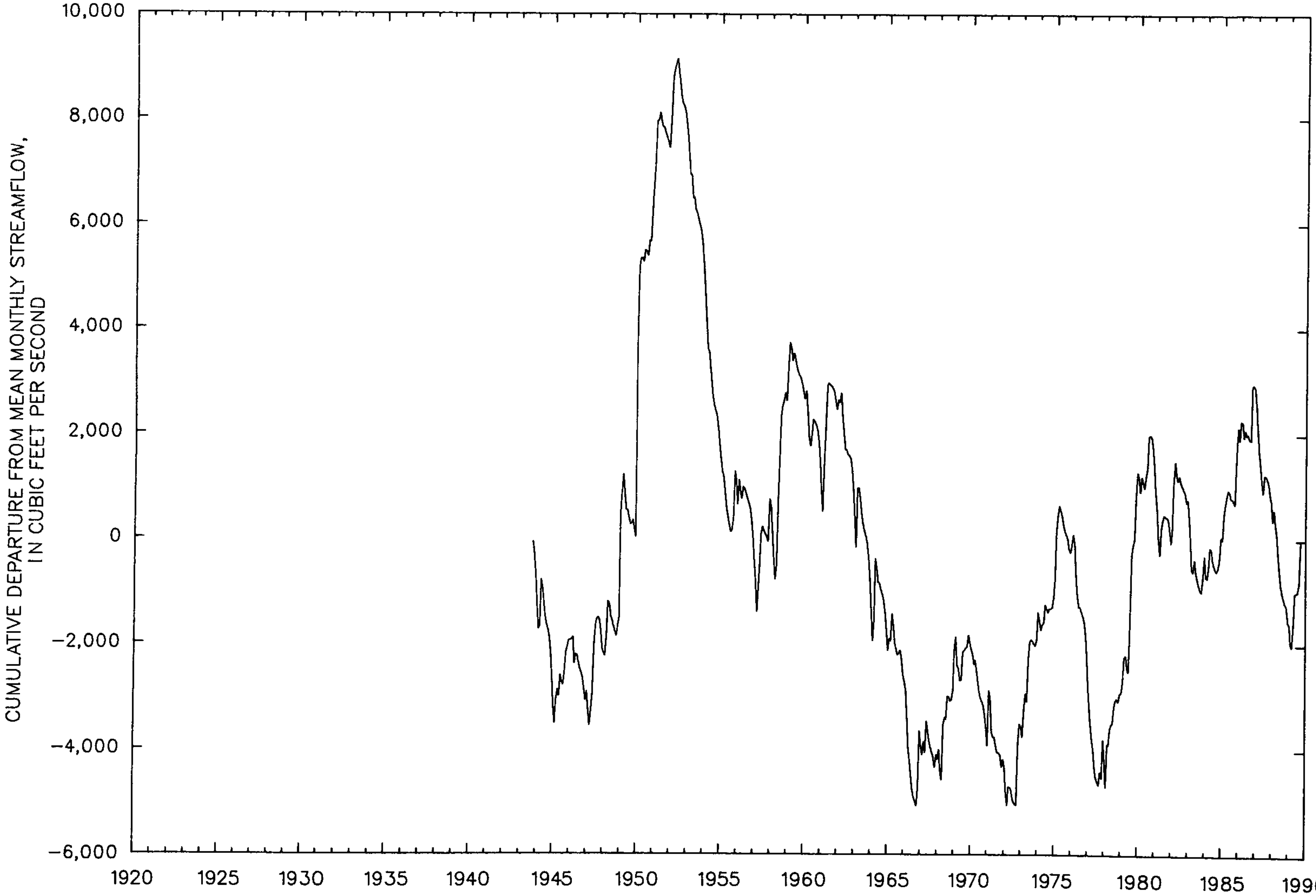


Figure 55.−−Cumulative departure from mean monthly streamflow for Big Blue River at Shelbyville (03361500), water years 1944−89.

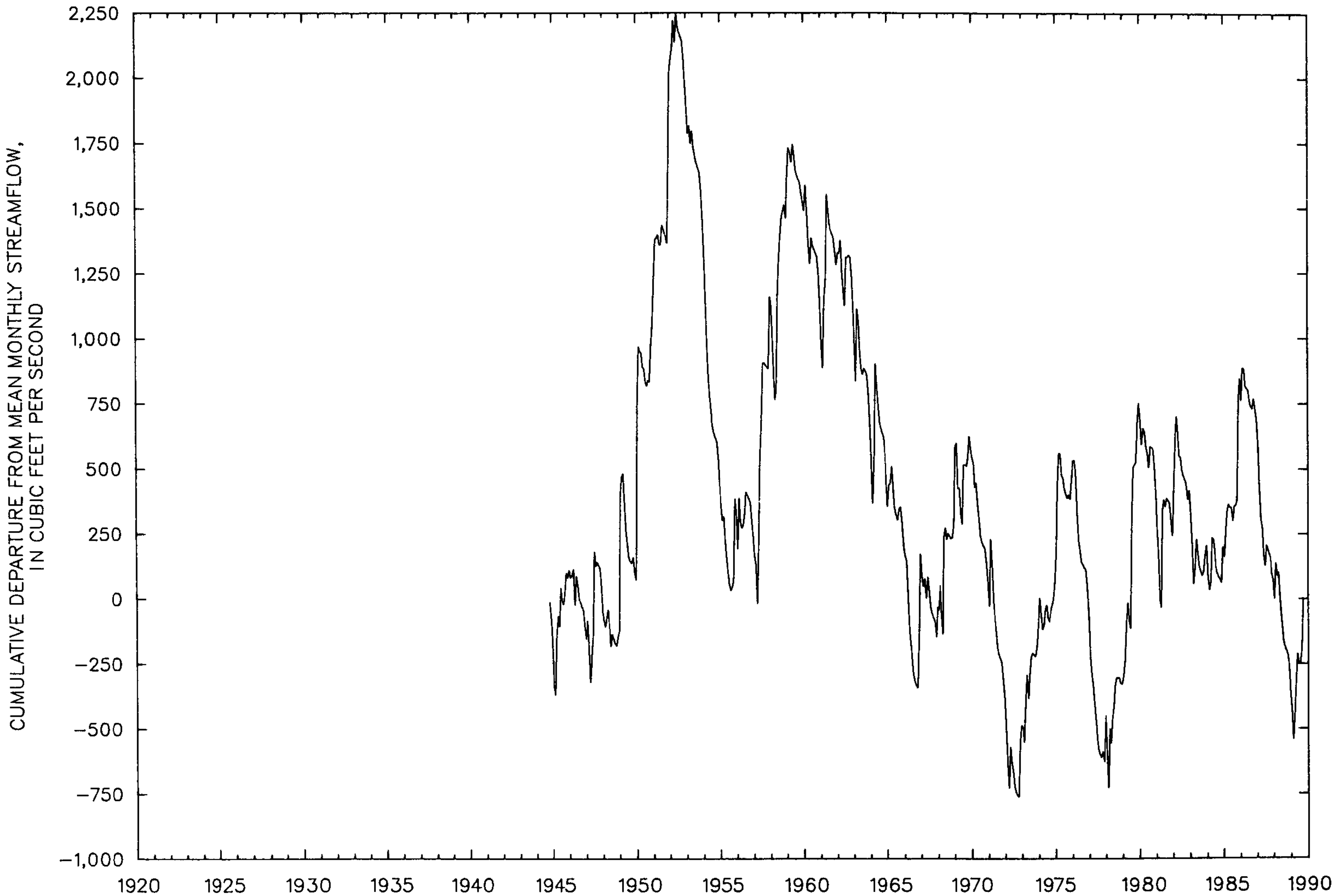
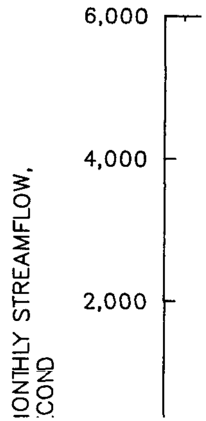


Figure 56.−−Cumulative departure from mean monthly streamflow for Youngs Creek near Edinburgh (03362000), water years 1945−89.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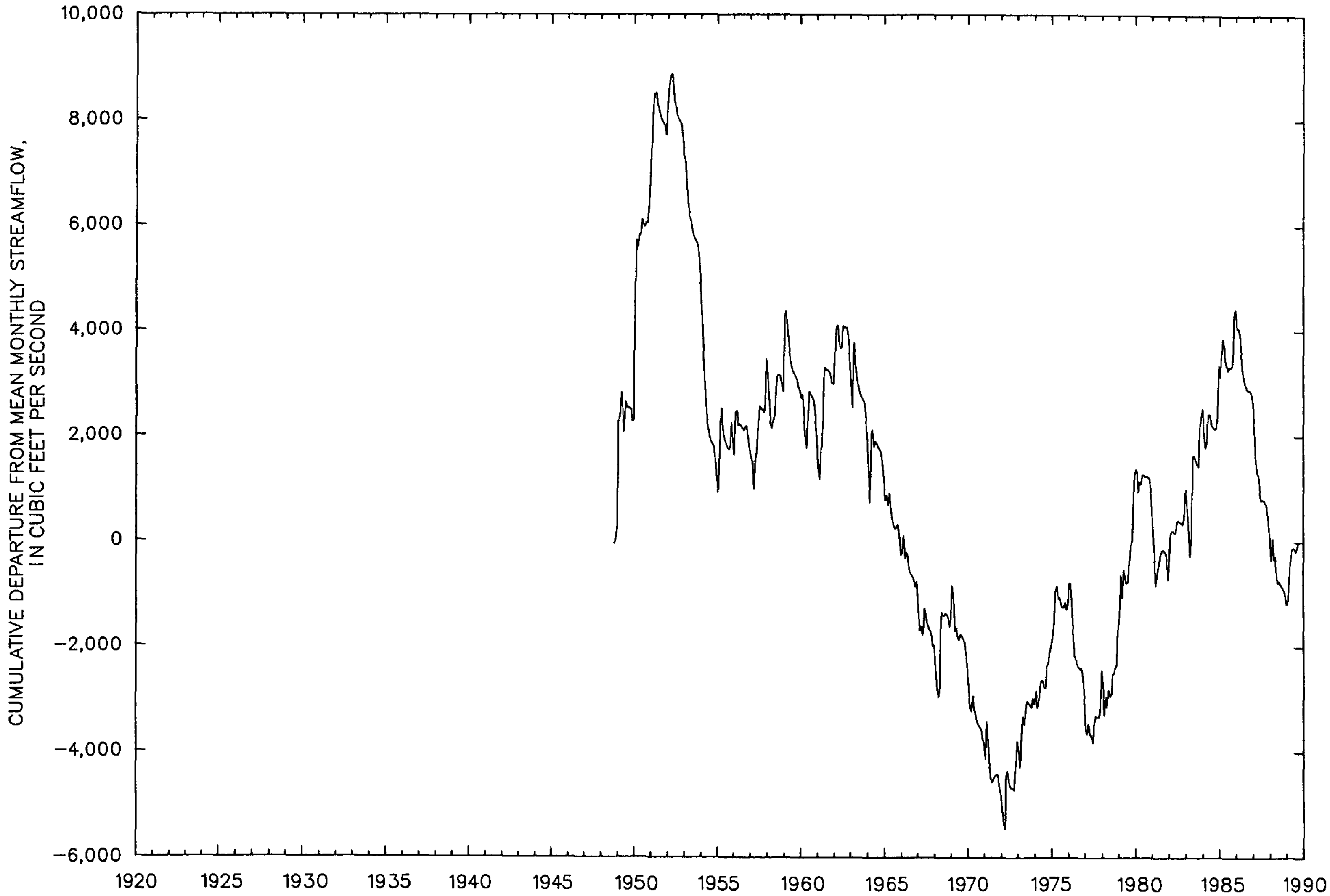


Figure 58.−−Cumulative departure from mean monthly streamflow for Muscatatuck River near Deputy (03366500), water years 1949−89.

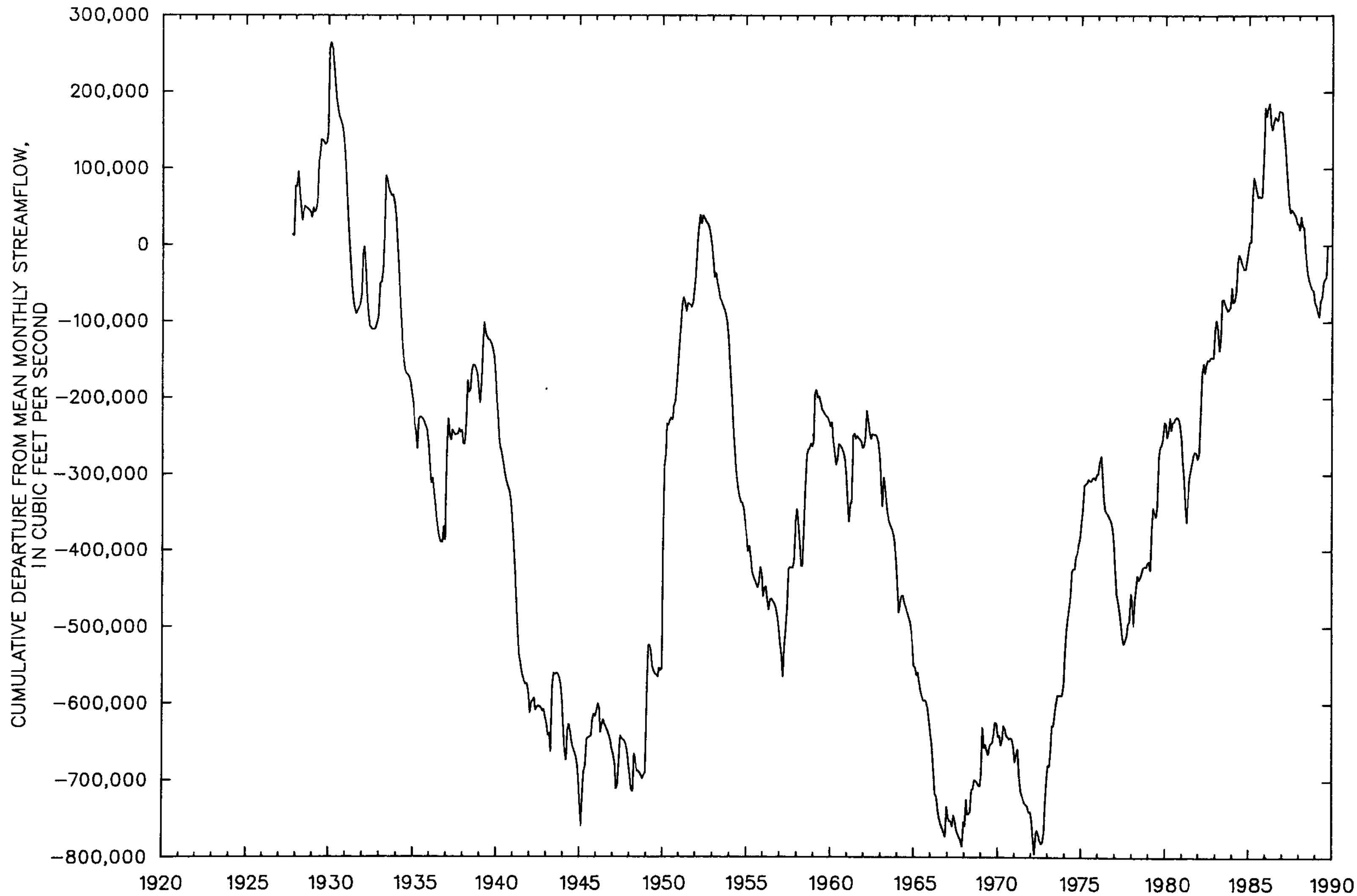


Figure 59.−−Cumulative departure from mean monthly streamflow for Wabash River at Mount Carmel, Illinois (03377500), water years 1929−89.

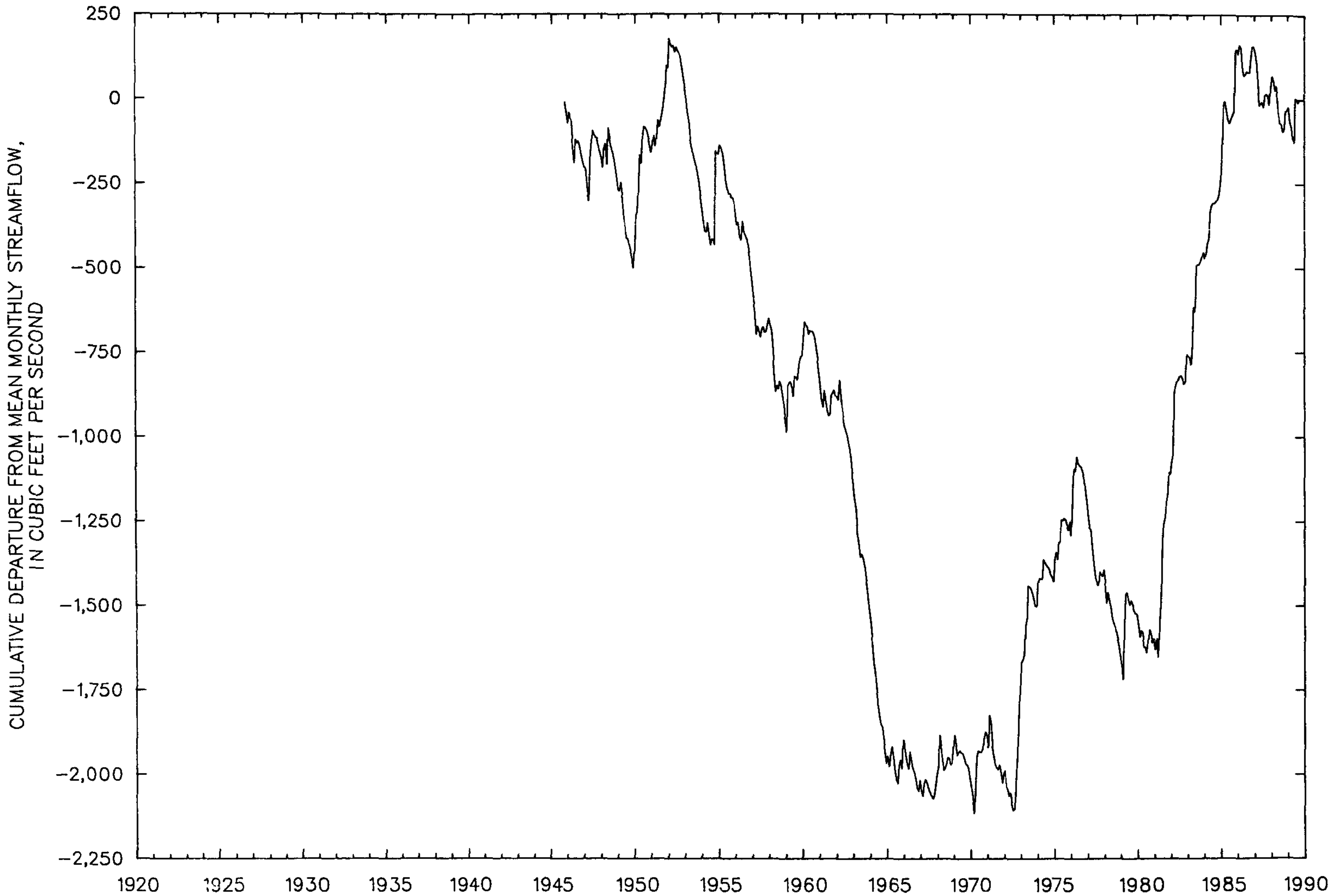
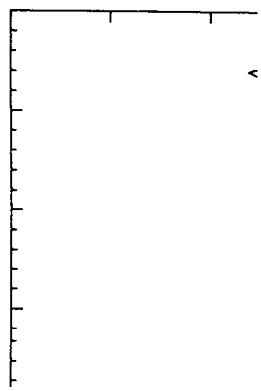


Figure 60.−−Cumulative departure from mean monthly streamflow for Salt Creek near McCool (04094500), water years 1946−89.



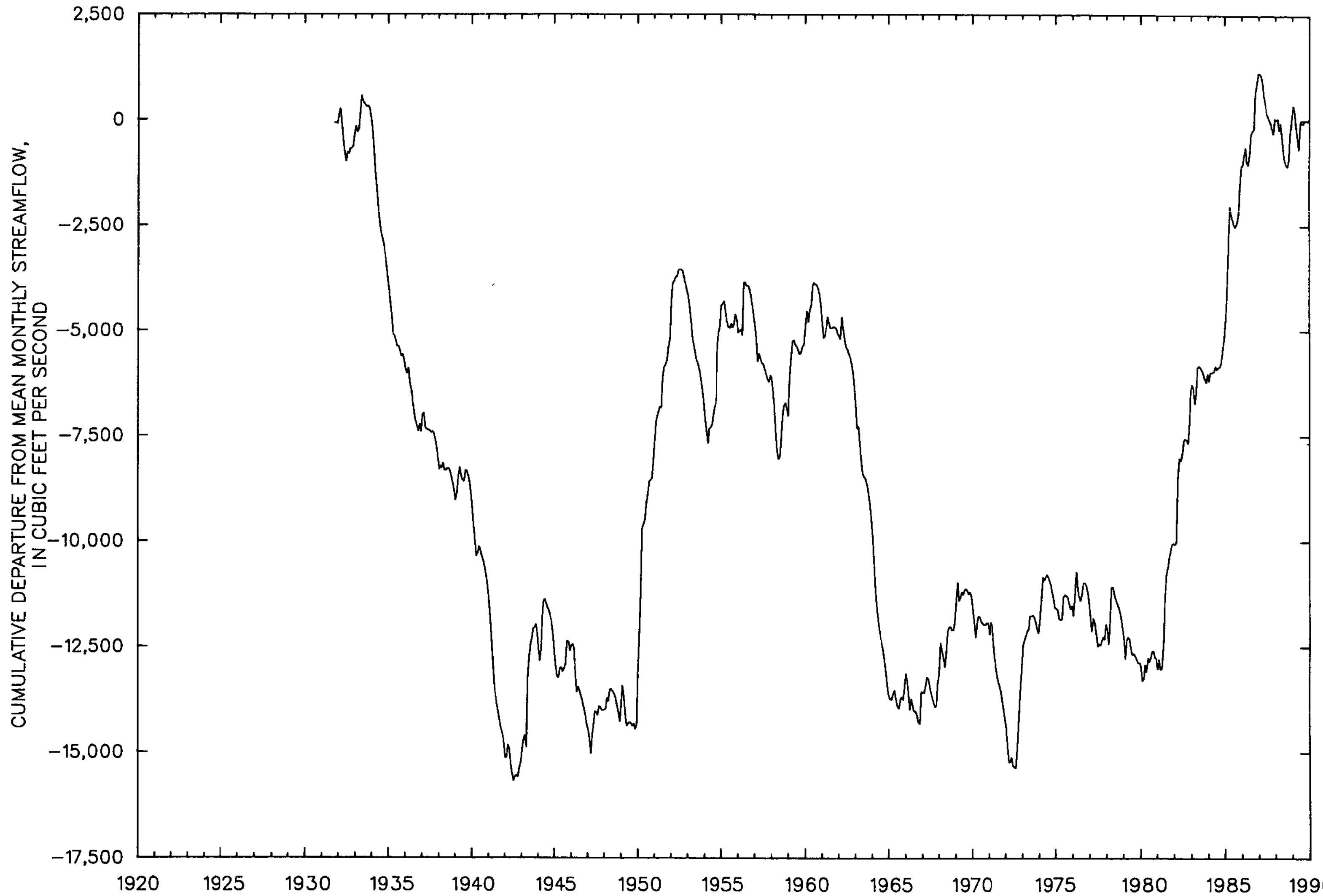


Figure 62.——Cumulative departure from mean monthly streamflow for Elkhart River at Goshen (04100500), water years 1932–89.

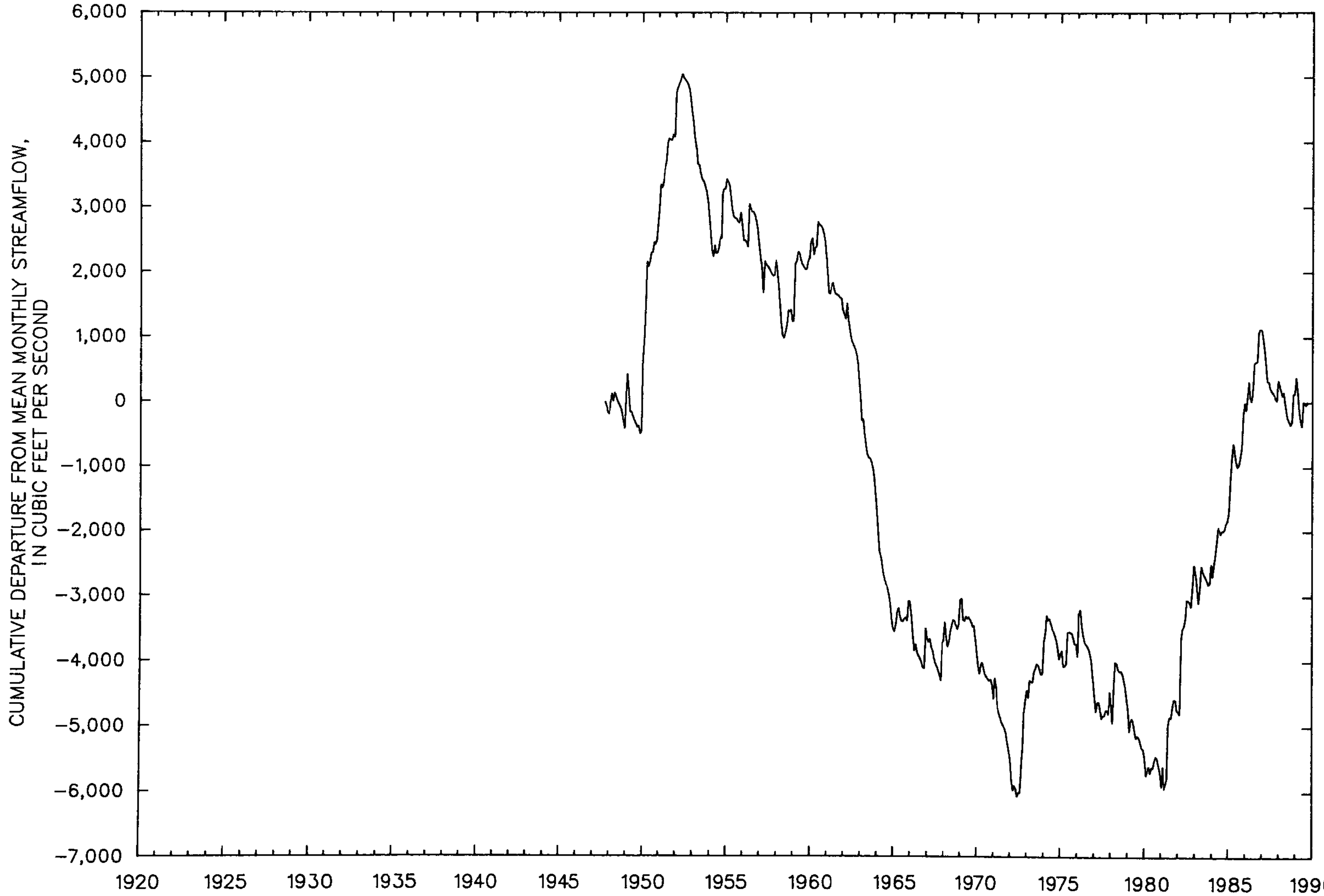


Figure 63.—Cumulative departure from mean monthly streamflow for Cedar Creek near Cedarville (04180000), water years 1948–89.

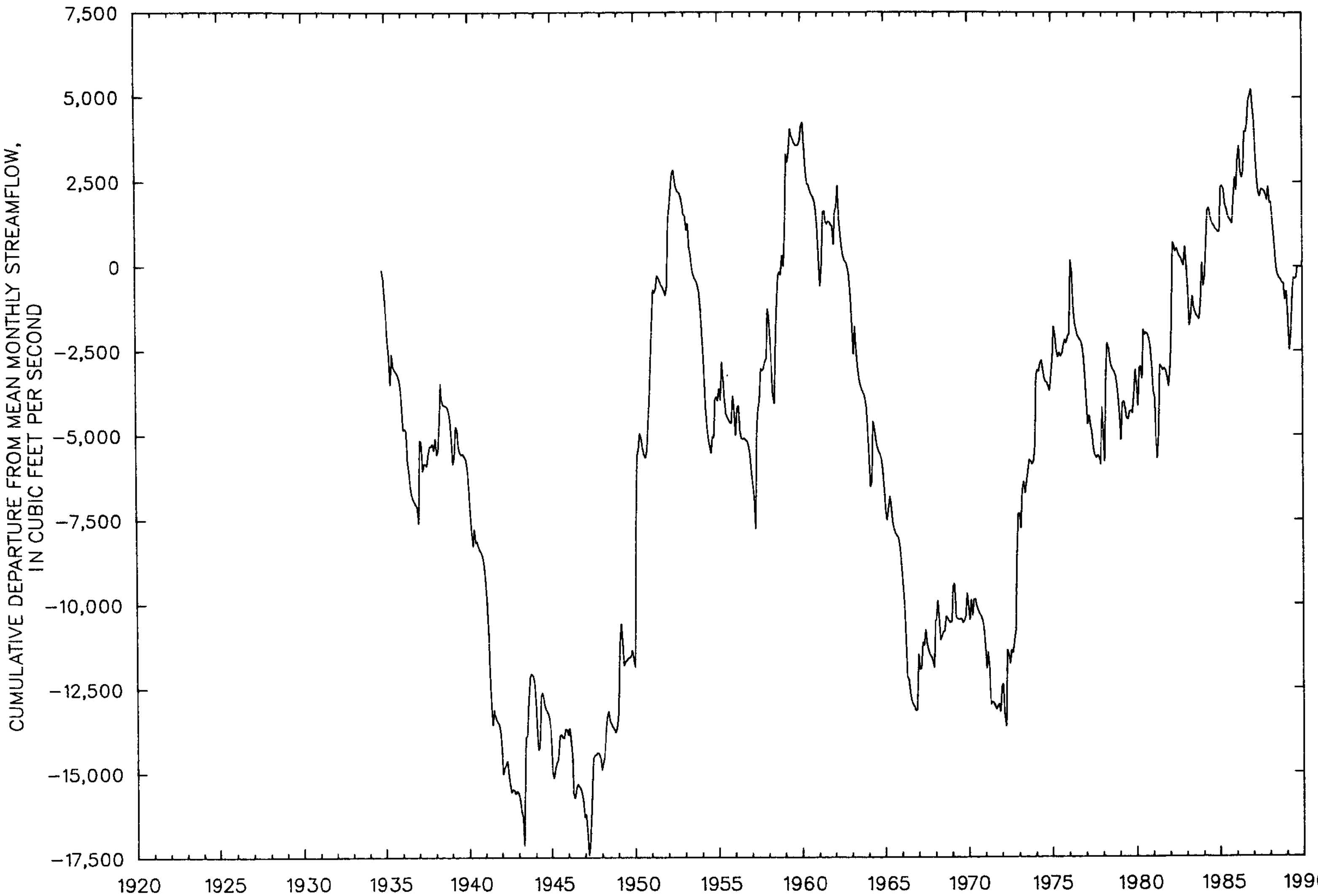
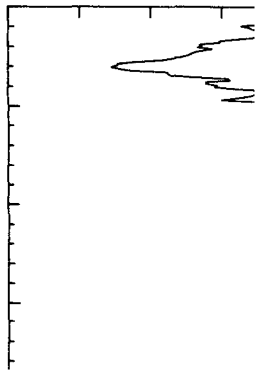


Figure 64.—-Cumulative departure from mean monthly streamflow for St. Marys River near Fort Wayne (04182000), water years 1935–89.



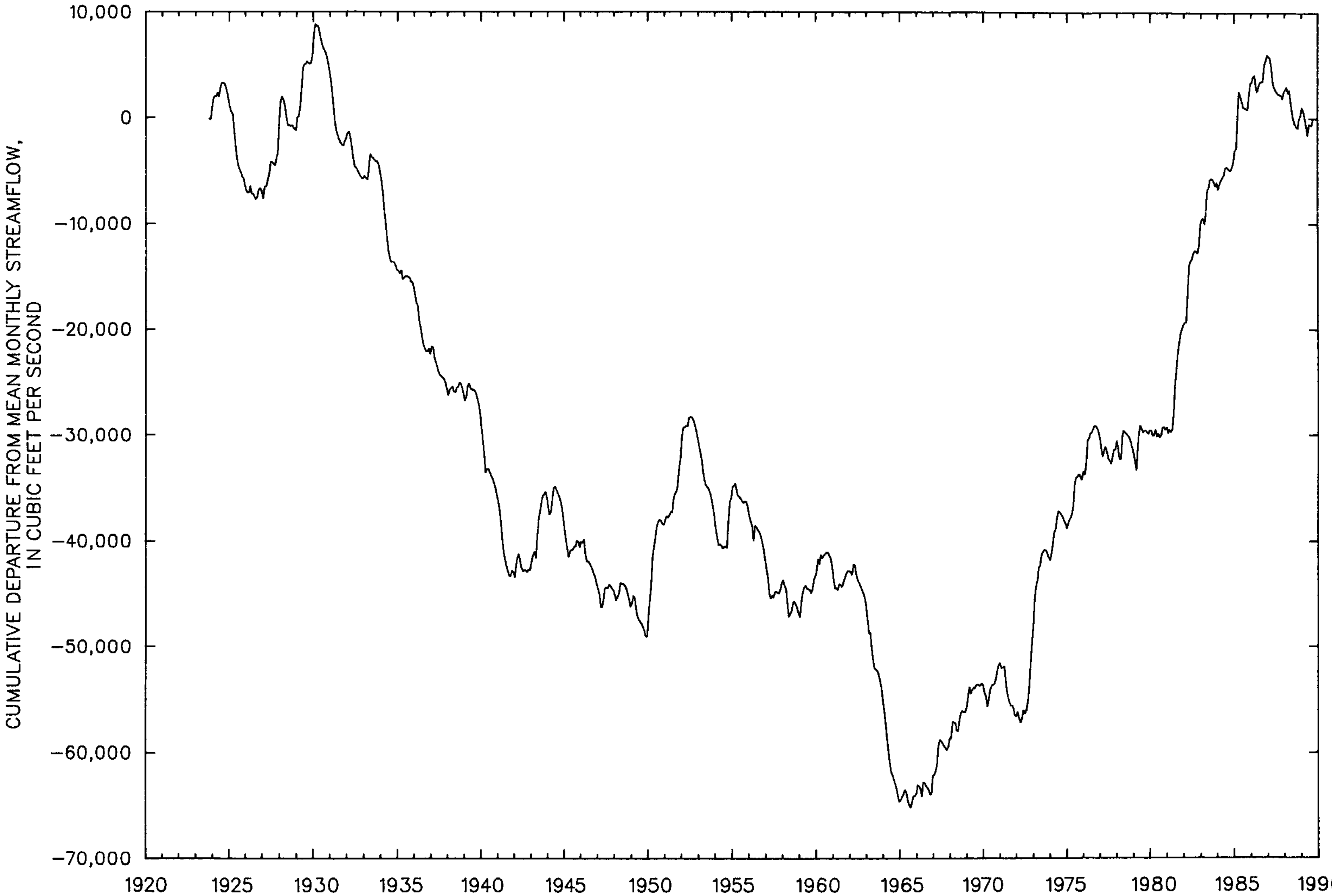


Figure 66.−−Cumulative departure from mean monthly streamflow for Kankakee River at Shelby (05518000), water years 1924−89.

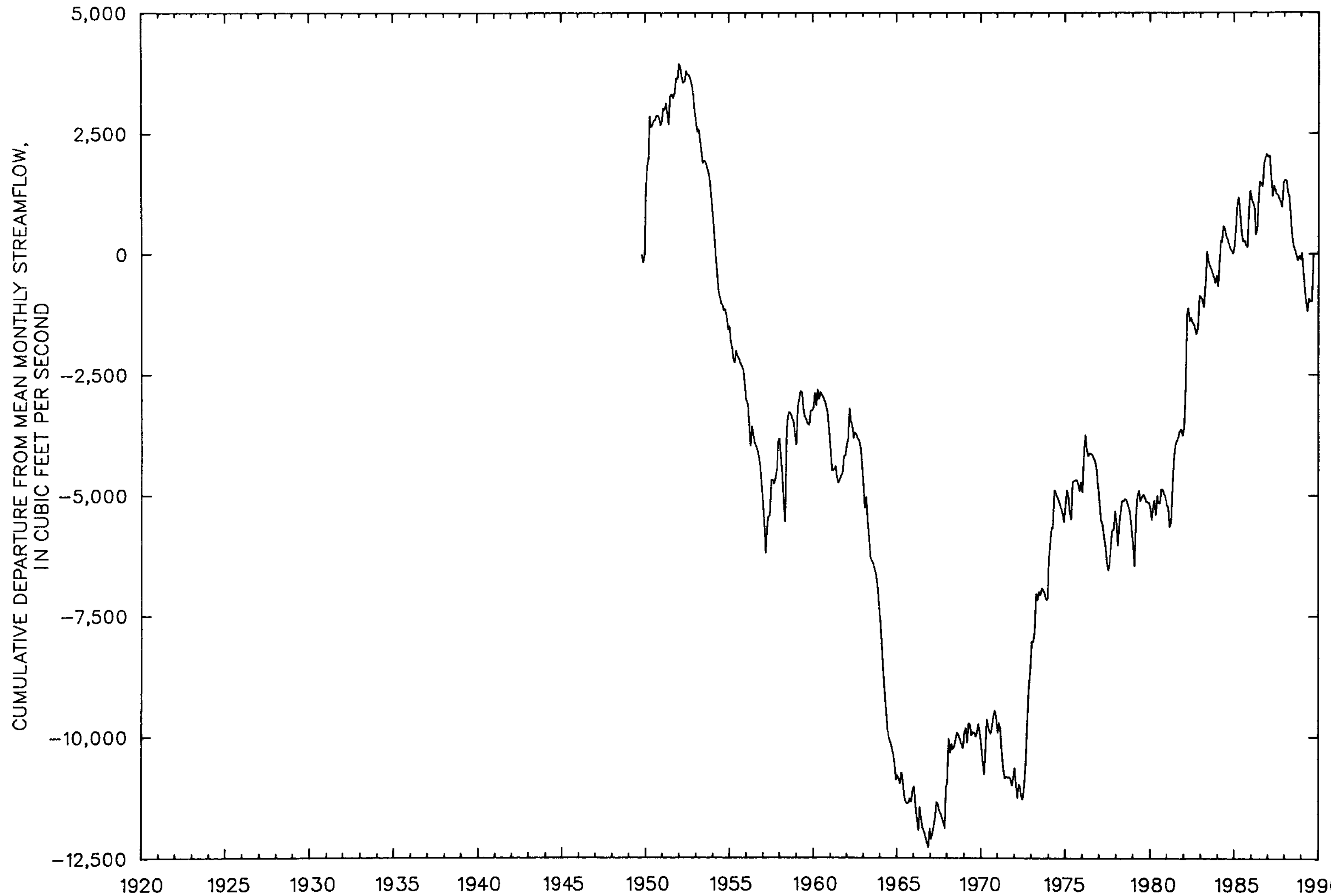


Figure 67.—–Cumulative departure from mean monthly streamflow for Iroquois River near Foresman (05524500), water years 1950–89.

Table 2.--Rank of monthly mean (May through August) and annual mean streamflow for water year 1988 at selected continuous-record streamflow-gaging stations as compared to period of record

Station number	Station name	Years of record	Rank for water year 1988[1]				
			May	June	July	August	Annual
03275000	Whitewater River near Alpine	61	3	2	2	1	8
03303000	Blue River near White Cloud	59	3	2	38	34	10
03324000	Little River near Huntington	46	4	1	30	27	14
03326500	Mississinewa River at Marion	66	4	1	11	6	10
03328000	Eel River at North Manchester	60	7	2	11	16	27
03329700	Deer Creek near Delphi	46	4	2	5	6	14
03331500	Tippecanoe River near Ora	46	3	1	1	1	9
03339500	Sugar Creek at Crawfordsville	51	3	1	1	3	7
03342500	Busseron Creek near Carlisle	46	2	2	16	19	15
03351000	White River near Nora	60	4	3	12	12	10

Table 2.--Rank of monthly mean (May through August) and annual mean streamflow for water year 1988 at selected continuous-record streamflow-gaging stations as compared to period of record--Continued

Station number	Station name	Years of record	Rank for water year 1988[1]				
			May	June	July	August	Annual
03351500	Fall Creek near Fortville	48	3	1	5	2	6
03361500	Big Blue River at Shelbyville	46	2	1	3	1	4
03362000	Youngs Creek near Edinburgh	47	1	1	5	5	10
03363500	Flatrock River at St. Paul	59	7	3	3	1	8
03366500	Muscatatuck River near Deputy	42	6	1	32	13	5
03377500	Wabash River at Mt. Carmel, Ill.	62	5	1	4	7	16
04094500	Salt Creek near McCool	44	7	2	2	24	15
04099510	Pigeon Creek near Angola	44	5	1	3	3	13
04100500	Elkhart River at Goshen	58	7	2	4	14	17
04180000	Cedar Creek near Cedarville	43	2	1	2	7	17

Table 2.--Rank of monthly mean (May through August) and annual mean streamflow for water year 1988 at selected continuous-record streamflow-gaging stations as compared to period of record--Continued

Station number	Station name	Years of record	Rank for water year 1988[1]				
			May	June	July	August	Annual
04182000	St. Marys River near Fort Wayne	59	4	1	21	29	11
05517000	Yellow River at Knox	46	5	1	2	13	7
05518000	Kankakee River at Shelby	67	11	3	1	1	15
05524500	Iroquois River near Foresman	41	3	1	1	1	8

[1]Rank of 1 indicates lowest monthly mean or annual mean streamflow during the period of record.

Many streamflow-gaging stations approached record low flows during the 1988 calendar year. However, only one of the 24 stations included in this report actually reached a record low. This station, Salt Creek near McCool (04094500), had a minimum daily flow of 10 ft^3/s on August 26, 1988 (table 3). Of greater significance, however, were the monthly mean streamflows for May, June, July, and August 1988. The rankings of these monthly mean streamflows show to what degree flow was affected during these months (table 2). Streamflows in June were particularly affected by the drought. All of the 24 stations ranked within the three lowest June streamflows on record.

Another method used to indicate relative severity of a hydrologic event is a calculation of recurrence intervals. A recurrence interval is the average length of time between occurrences of flow that are less than a given low-flow event. Mathematically, a recurrence interval is the reciprocal of the probability of recurrence. Low flows for the 24 stations were compiled for each year of record for intervals of 7, 30, 60, 90, and 120 days in the climatic year (April 1 to March 31). These flows then were arrayed, with the lowest value given a numerical rank of 1. To calculate the recurrence interval (RI) for each interval of low flow, the Gumbel equation, $RI = N + 1/M$, was used, where N is number of years of record, and M is numerical rank. The station number and name, period of record, drainage area, minimum-daily flow and date of occurrence for the period of record, and recurrence intervals are listed in table 3.

Comparisons of recurrence intervals and cumulative departures show general agreement with respect to severity of the drought period. One anomalous station is Kankakee River at Shelby (05518000), where minimum average flows were the lowest (RI is 67 years) or second lowest (RI is 34 years) for all periods calculated (7, 30, 60, 90, and 120 days), whereas cumulative departures show little impact of the drought (fig. 66). A possible explanation of the low average flows might be the intense irrigation in the area during June, July, and August that caused a decrease in ground-water recharge to the river.

Low-flow Measurements

During calendar years 1988-89, discharge measurements were made at 54 partial-record low-flow sites throughout the State (fig. 68). Measurements are made at these sites typically once a year during periods of base flow. These measurements can be compared to flows at nearby continuous-record gaging stations to estimate low-flow statistics at ungaged sites. Table 4 lists the site number, name, location, drainage area, year of establishment, date of measurement, and discharge.

Table 3.--Minimum daily flow for period of record and minimum average flow and recurrence intervals for climatic year 1988-89 at selected continuous-record streamflow-gaging stations

[mi^2, square miles; ft^3/s, cubic feet per second; RI, recurrence interval; yrs, years]

			Minimum-daily flow for period of record			Minimum average flow for indicated number of days in climatic year 1988-89 and recurrence interval									
						7-day		30-day		60-day		90-day		120-day	
Station number	Station name	Period of record	Drainage area (mi^2)	Flow (ft^3/s)	Date	flow (ft^3/s)	RI (yrs)	flow (ft^3/s)	RI (yrs)	flow (ft^3/s)	RI (yrs)	flow (ft^3/s)	RI (yrs)	flow (ft^3/s)	RI (yrs)
03275000	Whitewater River near Alpine	Oct. 1928 to Sept. 1989	522	3.0	Aug. 6, 1934	54	8	56	15	57	30	61	20	67	20
03303000	Blue River near White Cloud	Oct. 1930 to Sept. 1989	476	9.6	Oct. 17, 1964	26	2	32	2	49	2	97	2	162	1
03324000	Little River near Huntington	Oct. 1943 to Sept. 1989	263	1.1	Oct. 8, 1946	15	2	18	1	27	1	38	1	39	2
03326500	Mississinewa River at Marion	Sept. 1923 to Sept. 1989	682	3.4	Oct. 25, 1968	26	4	31	8	34	9	37	11	45	6
03328000	Eel River at North Manchester	Oct. 1929 to Sept. 1989	417	16	Oct. 19, 1956	59	2	65	2	71	3	78	3	78	3
03329700	Deer Creek near Delphi	Oct. 1943 to Sept. 1989	274	6.2	Sept. 25-28, 1954	13	5	14	9	16	9	19	7	21	7
03331500	Tippecanoe River near Ora	Sept. 1943 to Sept. 1989	856	87	Sept. 13, 1966	142	6	154	5	163	5	169	9	174	9
03339500	Sugar Creek at Crawfordsville	June 1938 to Sept. 1989	509	2.4	Sept. 24-27, 1941	7.1	10	11	8	14	13	15	17	15	17
03342500	Busseron Creek near Carlisle	Oct. 1943 to Sept. 1989	228	0	many days in 1954	5.0	2	7.0	2	7.8	3	11	3	16	3
03351000	White River near Nora	Oct. 1929 to Sept. 1989	1,219	49	Sept. 17, 1941	130	3	166	2	171	3	177	3	192	3

Table 3.--Minimum daily flow for period of record and minimum average flow and recurrence intervals for climatic year 1988-89 at selected continuous-record streamflow-gaging stations--Continued

[mi², square miles; ft³/s, cubic feet per second; RI, recurrence interval; yrs, years]

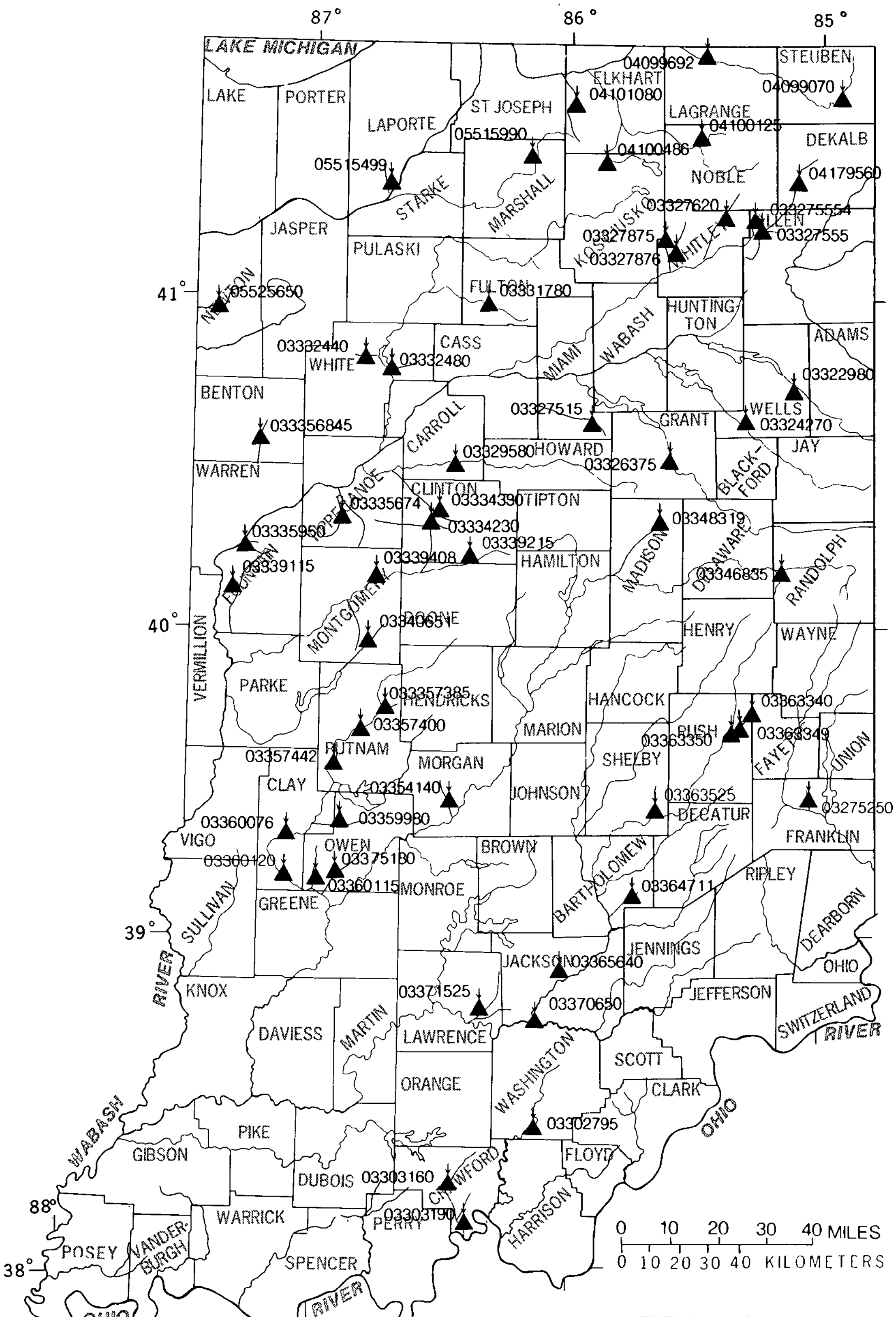
			Minimum-daily flow for period of record			Minimum average flow for indicated number of days in climatic year 1988-89 and recurrence interval									
Station number	Station name	Period of record	Drainage area (mi^2)	Flow (ft^3/s)	Date	7-day flow (ft^3/s)	RI (yrs)	30-day flow (ft^3/s)	RI (yrs)	60-day flow (ft^3/s)	RI (yrs)	90-day flow (ft^3/s)	RI (yrs)	120-day flow (ft^3s)	RI (yrs)
03351500	Fall Creek near Fortville	July 1941 to Sept. 1989	169	5.0	Sept. 23, 24, 1941	9.7	48	14	48	17	48	22	24	22	24
03361500	Big Blue River at Shelbyville	Sept. 1943 to Sept. 1989	421	27	Jan. 18, 1977	38	9	42	12	44	12	53	8	55	8
03362000	Youngs Creek near Edinburgh	Oct. 1942 to Sept. 1989	107	0.5	Sept. 29, Oct. 20, 21, 1953	2.2	5	2.9	5	3.2	9	4.6	4	5.1	6
03363500	Flatrock River at St. Paul	Oct. 1930 to Sept. 1989	303	0.6	Aug. 7, 1931	1.6	10	3.0	12	4.0	20	6.6	12	8.1	15
03366500	Muscatatuck River near Deputy	Nov. 1947 to Sept. 1989	293	0	at times many years	1.6	3	3.3	2	4.5	3	7.1	3	25	2
03377500	Wabash River at Mt. Carmel, Ill.	Oct. 1927 Sept. 1989	28,635	1,650	Sept. 27, 28, 1941	3,050	4	3,190	4	3,230	5	3,570	5	3,800	7
04094500	Salt Creek near McCool	May 1945 to Sept. 1989	74.6	10	Aug. 26, 1988	15	22	20	22	24	15	27	6	27	7
04099510	Pigeon Creek near Angola	Oct. 1945 to Sept. 1989	106	3.4	Oct. 25-26, 1964	11	4	12	5	13	6	14	6	15	6
04100500	Elkhart River at Goshen	April 1931 Sept. 1989	594	17.0	Aug. 11, 1964	93	6	106	7	126	5	144	4	158	5

Table 3.--Minimum daily flow for period of record and minimum average flow and recurrence intervals for climatic year 1988-89 at selected continuous-record streamflow-gaging stations--Continued

[mi^2, square miles; ft^3/s, cubic feet per second; RI, recurrence interval; yrs, years]

			Minimum-daily flow for period of record			Minimum average flow for indicated number of days in climatic year 1988-89 and recurrence interval									
			Drainage			7-day		30-day		60-day		90-day		120-day	
Station number	Station name	Period of record	area (mi^2)	Flow (ft^3/s)	Date	flow (ft^3/s)	RI (yrs)	flow (ft^3/s)	RI (yrs)	flow (ft^3/s)	RI (yrs)	flow (ft^3/s)	RI (yrs)	flow (ft^3/s)	RI (yrs)
04180000	Cedar Creek near Cedarville	Oct. 1946 to Sept. 1989	270	13	Oct. 3, 1949	23	5	31	2	33	3	33	3	34	4
04182000	St. Marys River near Fort Wayne	Oct. 1930 to Sept. 1989	762	3.4	Oct. 19, 1934	22	1	26	2	38	1	44	2	52	2
05517000	Yellow River at Knox	Aug. 1943 to Sept. 1989	435	50	Jan. 21-22, 1963	89	4	112	2	118	2	120	3	122	4
05518000	Kankakee River at Shelby	Oct. 1922 to Sept. 1989	1,779	260	Jan. 13-15, 1954	298	67	374	34	414	34	450	34	495	67
05524500	Iroquois River near Foresman	Dec. 1948 to Sept. 1989	449	6.3	Sept. 10, 1964	11	8	12	14	13	14	13	20	15	20

[1]Flow regulated by upstream reservoir.



Base From Indiana Flood Control And Water Resources Commission, 1:2,000,000

EXPLANATION

▲ 03275250 **PARTIAL-RECORD LOW-FLOW MEASUREMENT SITE AND IDENTIFICATION NUMBER**

Figure 68.-- Location of selected partial-record low-flow sites.

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements: Date	Measurements: Discharge (ft^3/s)
03275250	Pipe Creek near Brookville	lat 39° 25′53″, long 85° 06′38″, in SW¼NW¼SW¼ sec. 5, T. 11 N., R. 13 E., at bridge on Franklin County Road, 5.4 miles west of Brookville	66.3	1988	8/03/88 9/15/88 10/17/88	0.67 .29 .28
03302795	South Fork Blue River near Fredericksburg	lat 38° 25′51″, long 86° 09′05″, in NE¼SE¼NW¼ sec. 14, at bridge on Horners Chapel Road, 2.1 miles east of Fredericksburg	7.04	1988	8/04/88 9/22/88 10/19/88	3.9 4.3 1.3
03303160	Little Blue River near Grantsburg	lat 38° 16′53″, long 86° 28′03″, in SW¼SE¼ sec. 1, T. 3 S., R. 1 W., at bridge on State Highway 37, 0.5 miles south of Grantsburg	54.4	1979	9/22/88 10/19/88	.95 .54
03303190	Little Blue River near Beechwood	lat 38° 10′01″, long 86° 24′57″, in SW¼NE¼SE¼ sec. 16, T. 4 S., R. 1 E., 0.5 mile upstream of confluence with Turkey Fork, at Crawford County Road, 3.0 miles south of Beechwood	109	1979	9/22/88 10/19/88	3.3 .78
03322980	Sixmile Creek near Bluffton	lat 40° 42′24″, long 85° 08′16″, in NE¼NE¼SW¼ sec. 14, T. 26 N., R. 12 E., on Wells County Road 250 South, about 3 miles southeast of Bluffton	30.0	1977	10/14/88	.18

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements: Date	Measurements: Discharge (ft^3/s)
03324270	Prairie Creek near Montpelier	lat 40° 36′27″, long 85° 21′31″, in SW$^1/_4$NW$^1/_4$NE$^1/_4$ sec. 23, T. 25 N., R. 10 E., at bridge on Jeff Road in Wells County, 5.3 miles northwest of Montpelier	32.1	1988	8/01/88 9/14/88	.79 .00
03326375	Deer Creek at Marion	lat 40° 30′30″, long 85° 38′15″, in NW$^1/_4$NE$^1/_4$NE$^1/_4$ sec. 29, T. 24 N., R. 8 E., at bridge on Lincoln Blvd. in Grant County, at the south edge of Marion	45.2	1988	8/01/88 9/12/88 10/11/88 7/17/89	2.5 .20 .43 8.7
03327515	Potter Ditch near Converse	lat 40° 36′52″, long 85° 52′26″, in SW$^1/_4$NE$^1/_4$SW$^1/_4$ sec. 17, T. 25 N., R. 6 E., at bridge on State Road 513 in Miami County, 2.6 miles north of Converse	6.67	1988	7/29/88 9/12/88 10/11/88 7/17/89	.11 .13 .12 .48
033275554	Johnson Drain near Churubusco	lat 41° 11′13″, long 85° 17′32″, in SE$^1/_4$NE$^1/_4$ sec. 31, T. 32 N., R. 11 E., at bridge on U.S. 33 in Allen County, 3.3 miles southeast of Churubusco	8.67	1988	7/28/88 9/13/88 10/13/88 7/18/89	0.84 .63 .65 1.94
033275555	Eel River near Churubusco	lat 41° 11′12″, long 85° 17′34″, in SE$^1/_4$NE$^1/_4$ sec. 31, T. 32 N., R. 11 E., at bridge on U.S. 33 in Allen County, 3.3 miles south of Churubusco	43.3	1988	7/28/89 9/13/88 10/13/88 7/18/89	5.2 2.0 2.8 14

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements Date	Measurements Discharge (ft^3/s)
03327620	Blue River near Churubusco	lat 41° 13′49″, long 85° 23′27″, in $SW^1/_4SE^1/_4NE^1/_4$ sec. 17, T. 32 N., R. 10 E., at bridge on Anderson Road in Whitley County, 4 miles west of Churubusco	31.2	1979	7/27/89	1.8
					9/13/88	1.7
					10/13/88	1.9
					7/18/89	4.4
03327875	Clear Creek above Spring Creek at South Whitley	lat 41° 05′39″, long 85° 37′20″, in $SE^1/_4NW^1/_4SW^1/_4$ sec. 34, T. 31 N., R. 8 E., upstream of bridge on State Road 205 in Whitley County, 0.5 mile north of South Whitley	9.58	1988	7/27/88	.09
					9/12/88	.03
					10/13/88	.07
					7/17/89	.33
03327876	Spring Creek below Clear Creek at South Whitley	lat 41° 05′39″, long 85° 37′20″, in $SE^1/_4NW^1/_4SW^1/_4$ sec. 34, T. 31 N., R. 8 E., at bridge on State Road 205 in Whitley County, 0.5 mile north of South Whitley	44	1988	7/27/88	5.0
					9/12/88	3.7
					10/13/88	4.1
					7/17/89	6.4
03329580	Little Deer Creek near Camden	lat 40° 35′26″, long 86° 28′02″, in $SW^1/_4SW^1/_4SW^1/_4$ sec. 19, T. 25 N., R. 1 E., at bridge on County Road 300 North in Carroll County, 4.0 miles southeast of Camden	52.9	1988	7/22/88	4.4
					9/07/88	1.5
					10/06/88	1.5
					7/11/89	7.1
03331780	Mill Creek near Fulton	lat 40° 57′28″, long 86° 20′06″, in $NW^1/_4SW^1/_4$ sec. 17, T. 29 N., R. 2 E., at bridge on Fulton County Road, 1 mile north of State Road 114 and 5 miles west of Fulton	24.8	1979	7/22/88	3.2
					9/09/88	1.6

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements: Date	Measurements: Discharge (ft^3/s)
03332440	Hoagland Ditch near Monon	lat 40° 48′52″, long 86° 48′51″, in NE¼NE¼SE¼ sec. 1, on line with sec. 6, T. 27 N., R. 4 W., at bridge on White County Road, 3.8 miles south of State Road 16, and 7 miles southeast of Monon	72.8	1979	7/20/88 9/07/88 10/06/88	1.1 1.5 .96
03332480	Honey Creek near Reynolds	lat 40° 46′53″, long 86° 48′52″, in line between sections 19 and 24, T. 27 N., and on line between R. 3 W., and 4 W., at bridge on White County Road 300 East, approximately 3.0 miles northeast of Monticello	40.0	1977	7/20/88 9/07/88	1.2 .34
03334230	South Fork Wildcat Creek near Frankfort	lat 40° 19′15″, long 86° 37′06″, in SE¼NE¼SE¼ sec. 27, T. 22 N., R. 2 W., at bridge on County Road 600 West in Clinton County, 6.2 miles northwest of Frankfort	81.9	1988	7/27/88 9/06/88 10/07/88 7/11/89	8.6 6.4 7.9 16
03334330	Kilmore Creek near Frankfort	lat 40° 19′41″, long 86° 37′05″, in SE¼NE¼NE¼ sec. 27, T. 22 N., R. 2 W., at bridge on Gasline Road in Clinton County, 6.5 miles northwest of Frankfort	77.4	1988	7/27/88 9/06/88 10/07/88 7/11/89	1.3 .64 .54 6.06
03335674	Little Wea Creek near Lafayette	lat 40° 19′36″, long 86° 54′17″, in NE¼SE¼NE¼ sec. 30, T. 22 N., R. 4 W., near bridge on South Road in Tippecanoe County, 6.5 miles south of Lafayette	22.6	1988	7/26/88 9/02/88 10/05/88 7/11/89	3.2 2.1 2.3 6.8

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements	
					Date	Discharge (ft^3/s)
033356845	Darby Ditch near Oxford	lat 40° 31′45″, long 87° 10′48″, in NE$^1/_4$SE$^1/_4$NW$^1/_4$ sec. 14, T. 24 N., R. 7 W., near bridge on Benton County Road 750 E., 3.7 miles northeast of Oxford	7.3	1988	7/26/88 9/01/88 10/05/88	.17 .05 .07
03335950	Bear Creek at Fountain	lat 40° 13′11″, long 87° 20′23″, in NE$^1/_4$NE$^1/_4$SE$^1/_4$ sec. 32, T. 21 N., R. 8 W., near bridge on Fountain County Road, at the southwest edge of Fountain	10	1988	7/26/88 9/01/88 10/04/88 7/10/88	1.6 1.1 1.4 2.0
03339115	Graham Creek near Veedersburg	lat 40° 03′38″, long 87° 21′06″, in NW$^1/_4$NE$^1/_4$SW$^1/_4$ sec. 29, T. 19 N., R. 8 W., near bridge on State Road 32 in Fountain County, 5.8 miles southwest of Veedersburg	24	1988	7/26/88 9/01/88	.61 .00
03339215 .	Mud Creek near Mechanicsburg	lat 40° 10′38″, long 86° 24′50″, in SE$^1/_4$SE$^1/_4$NE$^1/_4$ sec. 16, T. 20 N., R. 1 E., near bridge on county road on the Clinton-Boone County line, 3.8 miles northeast of Mechanicsburg	26	1988	7/22/88 9/06/88	0.01 .00
03339408	Little Potato Creek near Darlington	lat 40° 09′48″, long 86° 45′08″, on line between sec. 21 and 22, T. 20 N., R. 3 W., at bridge on Montgomery County Road 800 East, 150 feet north of intersection with County Road 850 North, 5 miles northeast of Darlington	32	1979	7/18/88 9/02/88	.87 .00

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements: Date	Measurements: Discharge (ft^3/s)
03340651	Big Racoon Creek near Ladoga	lat 39° 54′32″, long 86° 47′58″, in SE¼SE¼SW¼ sec. 18, T. 17 N., R. 3 W., near bridge on Montgomery County Road, .25 mile south of Ladoga	46	1979	7/19/88 9/02/88	.29 .01
03346835	Stoney Creek at Windsor	lat 40° 09′16″, long 85° 12′28″, in NW¼SE¼ sec. 29, T. 20 N., R. 12 E., at bridge on Windsor Pike in Randolph County, at the east edge of Windsor	52	1988	8/02/88 9/14/88 10/14/88	2.5 2.8 1.7
03348319	Mud Creek near Alexandria	lat 40° 17′31″, long 85° 41′04″, in SW¼SE¼SW¼ sec. 1, T. 21 N., R. 7 E., at bridge on Madison County Road 1300 North, 2 miles north of Alexandria	3.3	1988	8/01/88 9/12/88 10/11/88	2.3 .08 .22
03354140	Lambs Creek near Martinsville	lat 39° 25′26″, long 86° 28′01″, in NE¼ NW¼ of sec. 1, T. 11 N., R. 1 W., at bridge on Morgan County Road running parallel and upstream of State Road 67, 2.5 miles west of Martinsville	31	1979	7/25/88 9/23/88	.10 .00
03357180	Fish Creek near Freedom	lat 39° 17′18″, long 86° 53′30″, in SW¼ SE¼ of sec. 18, T. 9 N., R. 4 W., approximately 40 feet upstream of bridge on Owen County Road, 1.5 miles west of Freedom	49	1979	10/21/88	.01

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements: Date	Measurements: Discharge (ft^3/s)
03357385	Miller Creek near Fillmore	lat 39° 42′52″, long 86° 45′04″, in $NW^1/_4$ $NE^1/_4$ of sec. 33, T. 15 N., R. 3 W., at bridge on Putnam County Road 300 North, 2 miles north of Fillmore	11	1979	7/18/88 8/31/88 10/03/88	.13 .07 .09
03357400	Big Walnut Creek above Greencastle	lat 39° 48′43″, long 86° 48′50″, in $SW^1/_4NW^1/_4SW^1/_4$ of sec. 1, T. 14 N., R. 4 W., at Pinhook Bridge in Putnam County, 3.5 miles northeast of Greencastle	199	1979	7/18/88 8/31/88 10/03/88	5.6 1.4 1.2
03357442	Little Walnut Creek near Greencastle	lat 39° 37′28″, long 86° 56′29″, in $NE^1/_4SE^1/_4$ sec. 27, T. 14 N., R. 5 W., at railroad bridge in Putnam County, 100 feet upstream of confluence with Big Walnut Creek, and 4.4 miles southwest of Greencastle	64	1979	10/03/88	2.6
03359980	Jordan Creek near Jordan	lat 39° 24′09″, long 86° 55′33″, in $NW^1/_4SE^1/_4SE^1/_4$ sec. 11, T. 11 N., R. 5 W., at bridge on Owen County Road, 0.5 mile northwest of Jordan	26	1979	7/18/88 8/31/88 10/03/88	1.6 1.5 1.8
03360076	Birch Creek near Old Hill	lat 39° 19′36″, long 87° 10′30″, in $NW^1/_4SE^1/_4NW^1/_4$ sec. 10, T. 10 N., R. 7 W., at bridge on Clay County Road 55 West, 2.3 miles northeast of Old Hill	71	1979	8/31/88 10/20/88	1.2 3.8

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements Date	Measurements Discharge (ft^3/s)
03360115	Lick Creek near Coal City	lat 39° 10′48″, long 86° 59′47″, in SW$^1/_4$SW$^1/_4$ sec. 29, T. 9 N., R. 5 W., at bridge on Owen County Road, 4.1 miles southeast of Coal City	47	1979	10/21/88	.23
03360120	Connelly Ditch near Jasonville	lat 39° 12′45″, long 87° 07′40″, in NE$^1/_4$NE$^1/_4$NE$^1/_4$ sec. 24, T. 9 N., R. 7 W., at bridge on Clay County Road 83 West, 5.0 miles northeast of Jasonville	31	1979	9/23/88	.96
					10/20/88	1.2
03363340	Wikoff Ditch near Rushville	lat 39° 42′06″, long 85° 21′25″, in SE$^1/_4$SW$^1/_4$SE$^1/_4$ sec. 36, T. 15 N., R. 10 E., at bridge on Rush County Road, 2.9 miles south of Raleigh	11	1988	8/02/88	.11
					9/15/88	.02
03363349	Shawnee Creek near Rushville	lat 39° 41′55″, long 85° 21′20″, in SW$^1/_4$SE$^1/_4$SE$^1/_4$ sec. 36, T. 15 N., R. 10 E., at bridge on Rush County Road, upstream of Kirkpatrick Ditch, 3.2 miles south of Raleigh	24	1988	8/02/88	0.00
03363350	Kirkpatrick Ditch near Rushville	lat 39° 41′48″, long 85° 21′19″, in NE$^1/_4$SE$^1/_4$NE$^1/_4$ sec. 1, T. 14 N., R. 10 E., at bridge on Rush County Road, 3.3 miles south of Raleigh	5.3	1988	8/02/88	0.00

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements	
					Date	Discharge (ft^3/s)
03363525	Conns Creek near Waldron	lat 39° 25′11″, long 85° 40′42″, in SE1/4NW1/4 sec. 7, T. 11 N., R. 8 E., at bridge on Shelby County Road 700 South, 2.4 miles southwest of Waldron	80	1979	8/03/88 9/16/88 10/17/88	.99 .34 .87
03364711	Little Sand Creek near Elizabethtown	lat 39° 07′44″, long 85° 51′21″, in NE1/4NE1/4 sec. 21, T. 8 N., R.6 E., at bridge on Bartholomew County Road, 2.3 miles west of Elizabethtown	43	1980	8/03/88 9/21/88 10/18/88	.13 .12 .19
03365640	Oathout Ditch near Brownstown	lat 38° 54′49″, long 86° 03′50″, in SE1/4SW1/4NE1/4 sec. 34, T. 6 N., R. 4 E., at bridge on Jackson County Road, 2.0 miles northwest of Brownstown	112	1988	8/04/88 9/21/88 10/18/88	4.3 1.5 1.7
03370650	Pond Creek near Vallonia	lat 38° 46′51″, long 86° 01′56″, in NE1/4SW1/4SW1/4 sec. 13, T. 4 N., R. 4 E., at bridge on Jackson County Road, 5.8 miles southeast of Vallonia	25	1980	8/04/88 9/21/88 10/18/88	.58 .51 1.1
03371525	Guthrie Creek near Tunnelton	lat 38° 47′22″, long 86° 21′33″, in SW1/4SE1/4SW1/4 sec. 12, T. 4 N., R. 1 E., 100 feet downstream of bridge on Lawrence County Road, 1.5 miles northwest of Tunnelton	69	1979	10/18/88	.00

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements	
					Date	Discharge (ft^3/s)
04099070	Pigeon Creek near Hamilton	lat 41° 36′16″, long 84° 56′32″, in NW$^1/_4$SW$^1/_4$SE$^1/_4$ sec. 5, T. 36 N., R. 14 E., at bridge on Hanselman Road in Steuben County, 5.1 miles northwest of Hamilton	43	1979	10/12/88	3.8
04099692	Rowe Ditch near Howe	lat 41° 42′32″, long 85° 26′32″, in NW$^1/_4$SW$^1/_4$NE$^1/_4$ sec. 35, T. 38 N., R. 9 E., at pipe culvert on Lagrange County Road 450 North, 1.9 miles southwest of Howe	7.5	1979	10/12/88	2.7
04100125	North Branch Elkhart River near Wolcottville	lat 41° 31′31″, long 85° 27′38″, in SW$^1/_4$SW$^1/_4$SW$^1/_4$ sec. 35, T. 36 N. - T. 35 N., R. 9 E., at bridge on Lagrange-Noble County Line Road, 4.5 miles west of Wolcottville	63	1979	7/28/88 9/13/88	12 7.5
04100486	Turkey Creek near Milford	lat 41° 24′57″, long 85° 51′52″, in SW$^1/_4$SW$^1/_4$NW$^1/_4$ sec. 8, T. 34 N., R. 6 E., upstream of bridge on Kosciusko County Road 1250 North, 0.75 mile west of Milford	76	1979	7/21/88 9/13/88	11 7.6
04101080	Baugo Creek at Osceola	lat 41° 38′26″, long 86° 02′31″, in NE$^1/_4$SE$^1/_4$SE$^1/_4$ sec. 22, T. 37 N., R. 4 E., at bridge on Elkhart County Road, 2.0 miles southeast of Osceola	76	1988	7/28/88 9/09/88 10/12/88	3.0 4.7 4.0

Table 4.--Discharge measurements made at partial-record low-flow sites, calendar years 1988-89--Continued

[mi^2, square miles; ft^3/s, cubic feet per second]

Site number (fig. 68)	Site name	Location	Drainage area (mi^2)	Year of establishment	Measurements Date	Measurements Discharge (ft^3/s)
04179560	John Diehl Ditch at Auburn	lat 41° 21′07″, long 85° 04′52″, in SW$^{1}/_{4}$SE$^{1}/_{4}$SE$^{1}/_{4}$ sec. 36, T. 34 N., R. 12 E., at bridge on DeKalb County Road 48, 1.6 miles southwest of Auburn	38	1988	7/29/88 9/14/88 10/12/88 7/18/89	1.6 1.4 1.6 6.3
05515499	Whitham Ditch near Hanna	lat 41° 25′08″, long 86° 42′27″, on line between SE$^{1}/_{4}$SW$^{1}/_{4}$ and SW$^{1}/_{4}$SE$^{1}/_{4}$ sec. 1, T. 34 N., R. 3 W., at bridge on LaPorte County Road 1300 South, 4.0 miles east of Hanna	43	1979	7/21/88 9/08/88	31 25
05515990	Stock Ditch near Bremen	lat 41° 25′50″, long 86° 10′48″, in NE$^{1}/_{4}$SE$^{1}/_{4}$NE$^{1}/_{4}$ sec. 4, T. 34 N., R. 3 E., at bridge on North Grape Road in Marshall County, 2.0 miles southwest of Bremen	49	1988	7/21/88 9/08/88 10/11/88 7/12/89	3.2 2.9 2.2 9.3
05525650	Beaver Creek near Morocco	lat 40° 57′57″, long 87° 27′00″, in NW$^{1}/_{4}$SW$^{1}/_{4}$NW$^{1}/_{4}$ sec. 15, T. 29 N., R. 9 W., at bridge on U.S. 41 in Newton County, 1.4 miles north of Morocco	41	1976	7/20/88	1.1

Reservoir Levels

Indiana's reservoirs are an important part of State water resources. Deficit precipitation, high temperatures, and low streamflow had adverse effects on these reservoirs during 1988 and 1989. Water supplies for many towns and cities were threatened as water levels declined. Many municipalities dependent on reservoirs for public water supply called for voluntary reductions in water use. The quality of water decreased at some reservoirs as low levels coupled with high temperatures resulted in increased aquatic growth and reduced dissolved oxygen levels. Recreation activities at most of the State's reservoirs were affected. Many beaches and marinas were left dry as water levels fell. Reduced areas of open water resulted in increased congestion for boaters and skiers. With fewer people using recreational facilities, owners and operators suffered variable amounts of economic losses.

Eleven reservoirs in Indiana (fig. 69) were selected to compare minimum pool elevations during water years 1988 and 1989 to the previous minimum levels since filling. Table 5 shows that record low levels were approached in most cases, with three reservoirs reaching record lows.

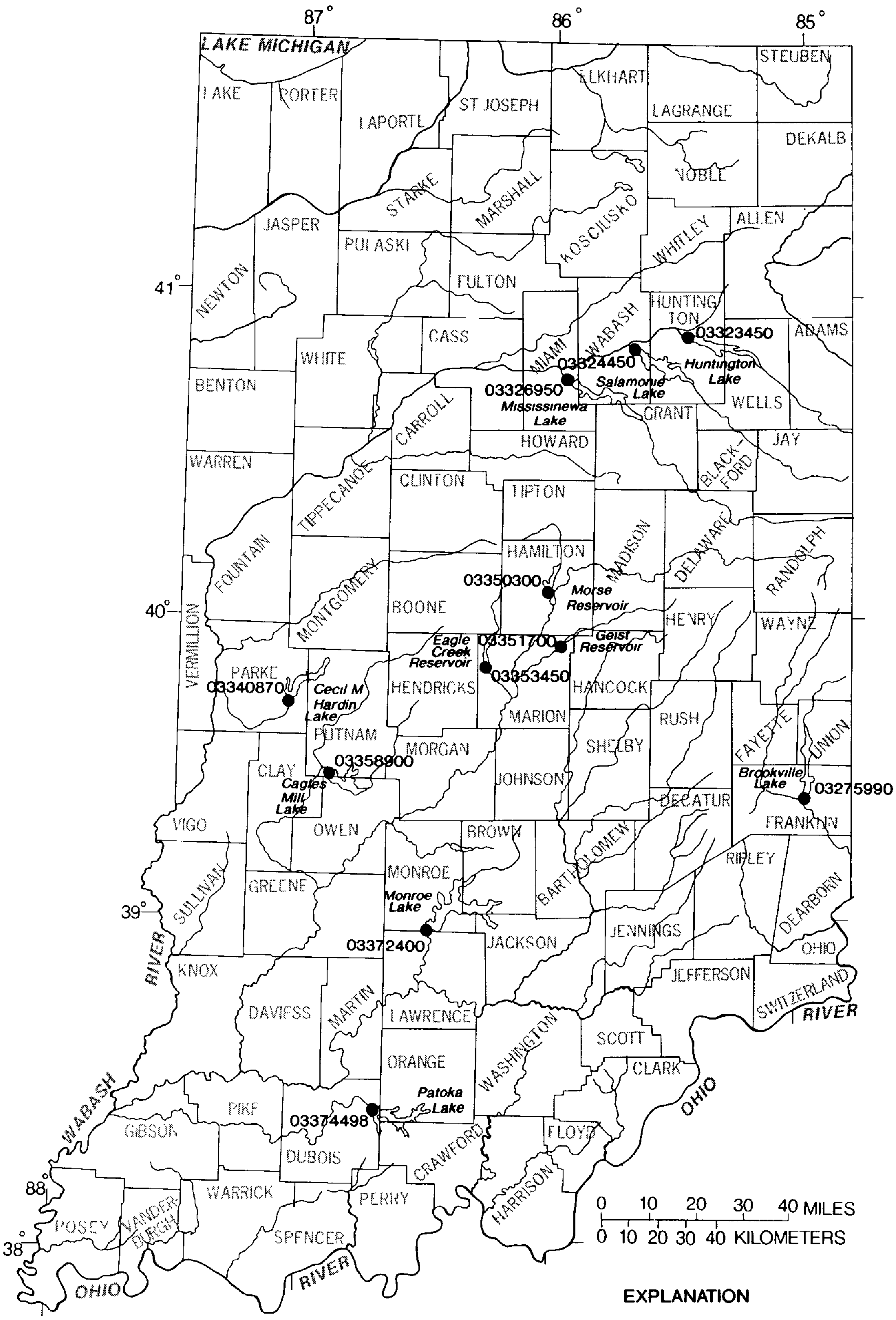
SUMMARY

Three types of drought--climatologic, hydrologic, and agricultural--predominated in most of Indiana during water years 1988 and 1989. Precipitation during this period was well below average. Streamflow and reservoir levels decreased, and ground-water levels declined. Crop yields were well below 1987 yields.

The drought began toward the end of 1987 when annual precipitation decreased to 88 percent of the 1951-80 average of 39.6 in. During 1988, January and March through June were very dry months; May received less than one-half the 1951-80 average monthly rainfall, whereas June was the driest on record. By the end of September, statewide precipitation was almost 8 in. below average for the first 9 months of the year. By mid-October, conditions began to improve with above-average monthly precipitation occurring for the rest of the year.

Cumulative departures of monthly mean precipitation from the long-term mean were calculated for each of the nine climatic divisions in Indiana. These graphs indicate a moderate drought of relatively short duration, with October 1988 the turning point toward positive departures.

High temperatures, beginning toward the end of May 1988 and persisting through early September, increased the effects of dry conditions already present across the State. The three northern climatic divisions were affected the most, with northwest Indiana experiencing the second warmest June through August on record. The number of days with temperatures of 90° F or above ranged from 45 to 60 throughout the State. These numbers were 50 percent greater than average in the southern part of the State and three times the average amount in the northern part.



EXPLANATION

● 03374498 RESERVOIR AND IDENTIFICATION NUMBER

Base from Indiana Flood Control and Water Resources Commission 1:2,000,000

Figure 69.-- Location of selected reservoirs.

Table 5. --Minimum pool elevations at selected reservoirs
[*, new record low]

Station number (fig. 69)	Reservoir name	Minimum pool elevation for water years 1988 and 1989 (in feet above sea level)	Date	Previous minimum pool elevation since filling (in feet above sea level)	Date
03275990	Brookville Lake at Brookville	737.79	Jan. 24, 1989	735.93	Feb. 3, 1976
03323450	Huntington Lake near Huntington	[1]734.01	Nov. 22, 1987	732.05	Nov. 26, 1973
03324450	Salamonie Lake at Dora	730.00	Dec. 13, 1987	726.44	Mar. 11, 1969
03326950	Mississinewa Lake at Peoria	712.02	Jan. 26, 1988	703.30	Jan. 20, 1983
03340870	Cecil M. Hardin Lake at Ferndale	639.91	Feb. 13, 1988	639.78	Feb. 10, 1977
03350300	Morse Reservoir near Noblesville	803.91*	Oct. 16, 1988	804.02	Oct. 31, 1966
03351700	Geist Reservoir near Oaklandon	778.36*	Nov. 3, 1988	778.42	Jan. 5, 1964
03353450	Eagle Creek Reservoir near Indianapolis	783.83	Nov. 3, 1988	781.25	Nov. 28, 1971
03358900	Cagles Mill Lake near Manhattan	635.87	Mar. 15, 1988	629.80	Nov. 10, 1983
03372400	Monroe Lake near Harrodsburg	534.96	Sept. 30, 1988	529.60	Feb. 27, 1984
03374498	Patoka Lake near Cuzco	531.38*	Nov. 23, 1987	532.39	Mar. 1-3, 1983

[1]Level affected by drawdown for ramp repair.

The Palmer Drought Severity Index (PDSI) was used to assess the relative severity of drought conditions in Indiana. During water years 1988 and 1989, drought conditions in eight of the nine climatic divisions reached the severe range. Comparisons of this period to historical PDSI's show the 1988 and 1989 drought conditions to be generally severe but of short duration compared to more extreme conditions of longer duration experienced in the early and mid-1930's, mid-1950's, and mid-1960's.

Ground-water levels throughout the State were affected by the 1988 drought. The decline in water levels began during the last 3 months of 1987. Below-average precipitation through most of 1988 depressed ground-water levels even further. In July 1988, the Indiana Department of Natural Resources declared a 90-day ground-water emergency for parts of Newton and Jasper Counties in northwestern Indiana. Water in 12 of the 20 ground-water monitoring wells included in this report reached record low levels. Water in most wells reached the lowest levels in November 1988. By December, ground-water levels in most areas began to rise.

Streamflow showed varying effects of the drought. Annual flows for some rivers were only slightly less than the 1987 mean annual streamflow, whereas others flowed at less than one-half that value. Low flows and high temperatures caused some thermoelectric power plants to close temporarily because their need for cooling water could not be met. Low flows in major rivers restricted navigation. Cumulative departures from mean monthly streamflow and recurrence intervals for most of the streams in this report indicated a relatively moderate drought of short duration. Record low discharges were approached at many streamflow-gaging stations during 1988; however, only 1 of the 24 stations included in this report actually reached a record low. Of greater significance were monthly mean streamflows for May through August. Rankings of these flows indicate to what degree streams were affected during the summer of 1988.

Major reservoirs in the State approached or reached record low levels. Many cities and towns dependent on these reservoirs for water supplies called for voluntary reductions in water use. The quality of water was affected in some areas as low water levels and high temperatures resulted in increased aquatic growth and reduced dissolved oxygen levels. Recreational activities also were curtailed.

Most major crops produced in Indiana were affected substantially by the 1988 drought. Average yields decreased to 50-86 percent of 1987 yields.

The drought of 1988, although severe, was of much less duration and intensity than some droughts experienced in the past. As Indiana's need for water increases, droughts of even less intensity than that of 1988 probably will result in similar water shortages and agricultural losses.

REFERENCES CITED

Gann, R.W., 1988, Indiana agricultural statistics--1987, compiled by Indiana Agricultural Statistics Service: West Lafayette, Indiana, U.S. Department of Agriculture, Purdue University, 117 p.

_____ 1989, Indiana agricultural statistics--1988, compiled by Indiana Agricultural Statistics Service: West Lafayette, Indiana, U.S. Department of Agriculture, Purdue University, 113 p.

Hanson, R.L., 1984, Droughts, in Williams, M.E., Proceedings of the Geologic and Hydrologic Hazards Training Program: U.S. Geological Survey Open-File Report 84-760, p. 773-811.

Hudson, H.E., Jr., and Hazen, Richard, 1964, Droughts and low streamflow, *in* Chow, Ven Te, ed., Handbook of applied hydrology: New York, McGraw Hill, p. 18-1 to 18-26.

Indiana Department of Natural Resources, 1988, Indiana's water use--1987: Division of Water Report, Water Use Section, 2 p.

_____ 1989, Indiana's water use--1988: Division of Water Report, Water Use Section, 6 p.

Indiana Drought Advisory Committee, 1988, Indiana Drought Advisory Committee News: Indianapolis, State Office Building, 4 p.

Kottke, J.W., 1989, Weather in Indiana during 1988, in Indiana agricultural statistics--1988, compiled by Indiana Agricultural Statistics Service: West Lafayette, Indiana, U.S. Department of Agriculture, Purdue University, p. 1-2.

Matthai, H.F., 1979, Hydrologic and human aspects of the 1976-77 drought: U.S. Geological Survey Professional Paper 1130, 84 p.

National Oceanic and Atmospheric Administration, National Climatic Data Center, 1989, Divisional averages for Indiana, magnetic tape TD-9640.

Palmer, W.C., 1964, Meteorological drought: U.S. Weather Bureau Research Paper No. 45, 58 p.

Subrahmanyam, V.P., 1967, Incidence and spread of continental drought: Geneva, Switzerland, World Meteorological Organization, International Hydrological Decade, Reports on WMO/IHD Projects, no. 2.

Tibbals, C.H., 1990, Hydrology of the Floridian aquifer system in east-central Florida: U.S. Geological Survey Professional Paper 1403-E, 98 p.

Wiercioch, Helen, and Hebenstreit, James, 1989, The drought of 1988, *in* Outdoor Indiana: Indiana Department of Natural Resources, v. 54, no. 2, p. 30-31.

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