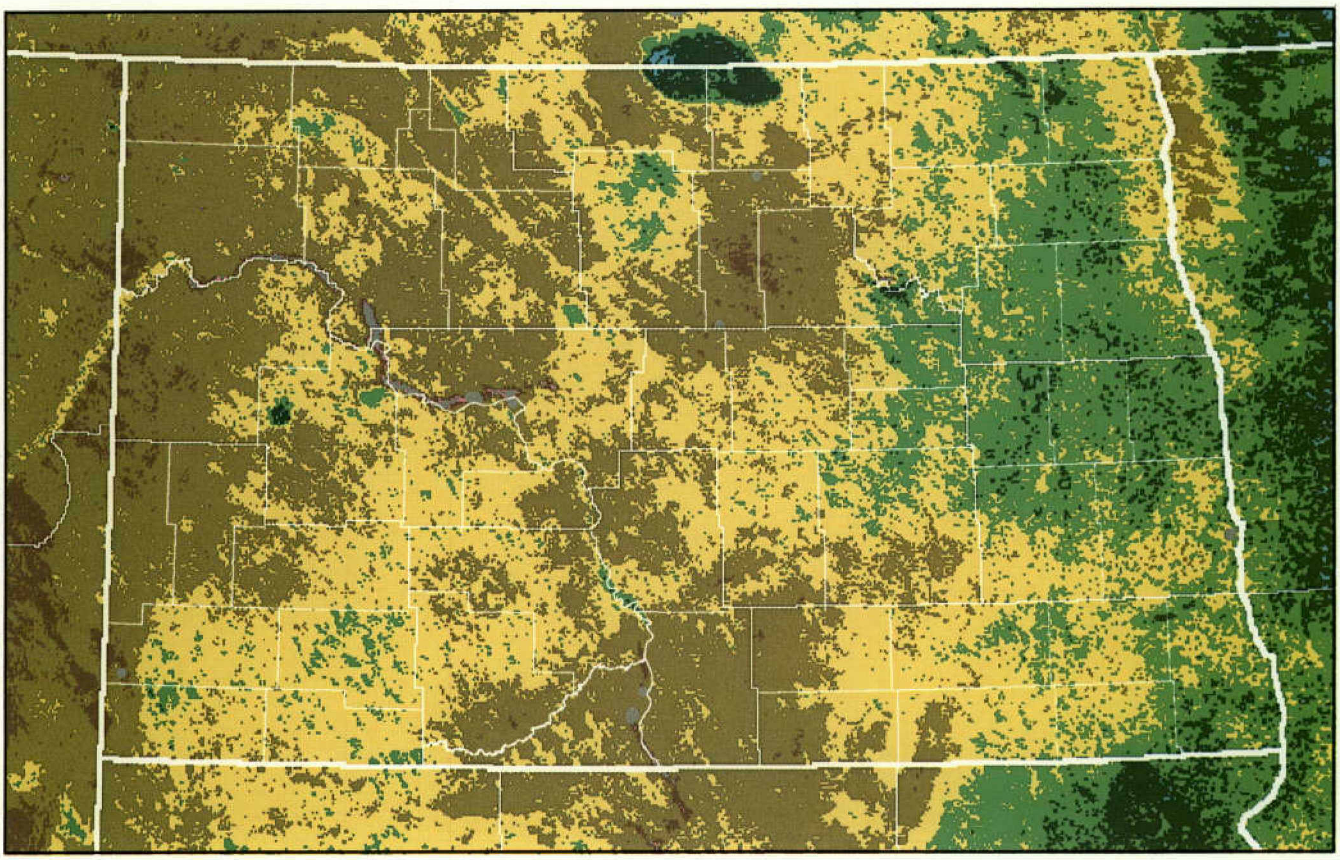
Climatic and Hydrologic Aspects of the 1988-1992 Drought and the Effect on People and Resources of North Dakota



North Dakota State Water Commission
Water Resources Investigation 29

Prepared by the
U.S. GEOLOGICAL SURVEY
in cooperation with the
NORTH DAKOTA STATE WATER COMMISSION

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U.S. Geological Survey
Sioux Falls, SD

CLIMATIC AND HYDROLOGIC ASPECTS OF THE 1988-92 DROUGHT AND THE EFFECT ON PEOPLE AND RESOURCES OF NORTH DAKOTA

By Tara Williams-Sether, Kathleen M. Macek-Rowland, and Douglas G. Emerson

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Bismarck, North Dakota
1994

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS, Continued

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
bushel per acre	0.0870743	cubic meter per hectare
cubic foot per second	0.02832	cubic meter per second
degree Fahrenheit	1	degree Celsius
foot	0.3048	meter
gallon	3.785	liter
inch	25.4	millimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

[1]Temp °C = (temp °F-32)/1.8.

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

Milligrams per liter (mg/L) is a unit expressing the concentration of a chemical constituent in solution as weight (milligrams) of solute per unit volume (liter) of water; 1 mg/L equals 1,000 µg/L.

Climatic and Hydrologic Aspects of the 1988-92 Drought and the Effect on People and Resources of North Dakota

By Tara Williams-Sether, Kathleen M. Macek-Rowland, *and* Douglas G. Emerson

Abstract

The severity of the 1988-92 drought in North Dakota was described by documenting the drought as a climatic and hydrologic event, documenting the effect of the drought on people and resources, and comparing the drought to previous droughts. Annual precipitation and average summer (June-August) temperatures for the nine climatic divisions in North Dakota were ranked for the 98-year period from 1895 through 1992. A rank of one indicates the driest year or the warmest summer of the 98-year period, and a rank of 98 indicates the wettest year or the coolest summer. During the more intense period (1988-90) of the 1988-92 drought, the rank of annual precipitation for all nine climatic divisions ranged from 2 to 54, and the rank of average summer temperatures ranged from 1 to 42. Many streams in North Dakota had record low flows, and ground-water levels also were affected. Municipal and rural water supplies were affected, the number of acres irrigated increased, crop yields decreased, the number of head of livestock generally decreased, the fire danger increased, recreation was affected, and fish and wildlife were affected. Indices such as the Palmer Drought Severity Index, drought recurrence intervals, and Devils Lake water levels were used to compare the 1988-92 drought to previous droughts. The number of months during the 1930's to early 1940's drought that were classified as extreme (Palmer Drought Severity Index values less than or equal to -4.0) ranged from 33 to 59, the number of months during the 1950's to early 1960's drought ranged from 1 to 32, the number of months during the mid- to late 1970's and early 1980's drought ranged from 7 to 18, and the number of months during the 1988-92 drought ranged from 14 to 48. Recurrence intervals for the 1930's to early 1940's drought ranged from 25 to 74 years, recurrence intervals for the 1950's to early 1960's drought ranged from 26 to 50 years, recurrence intervals for the mid- to late 1970's and early 1980's drought ranged from 5 to 58 years, and recurrence intervals for the 1988-92 drought ranged from 19 to 54 years. Precipitation records, streamflow records, the Palmer Drought Severity Index, and Devils Lake water levels indicate that the most severe droughts to have occurred in North Dakota for which records are available occurred during the 1930's to early 1940's, the 1950's to early 1960's, and 1988-92. The severity of the late 1980's to early 1990's drought was greater than that of the 1950's to early 1960's drought. The 1988-92 drought was the second most severe drought since 1930.

INTRODUCTION

The United States and other parts of the world are afflicted intermittently by droughts. A drought is primarily a natural event, but human activities can significantly affect the severity of a drought. A severe drought occurred in North Dakota in 1988-92. Because local, State, and Federal water-resource managers need up-to-date information to evaluate and manage current and future programs during hydrologic extremes, it is necessary to describe the severity of the 1988-92 drought and the effect on people and resources of North Dakota.

This report, which was prepared by the U.S. Geological Survey in cooperation with the North Dakota State Water Commission, describes the severity of the 1988-92 drought in North Dakota by documenting the drought as a climatic and hydrologic event, documenting the effect of the drought on people and resources, and comparing the drought to previous droughts. Selected information that relates to the drought in North Dakota is presented in this report; further information can be obtained from publications cited in the Selected References section.

DEFINITIONS AND RAMIFICATIONS OF DROUGHT

The definition of drought varies on the basis of the situation or area for which drought is being defined. Definitions of drought are given by Nace and Pluhowski (1965), Palmer (1965), Hershfield and others (1973), World Meteorological Organization (1975), Matthai (1979), Rosenberg (1980), and Ripley (1988). A simple definition of drought is a period of water shortage. However, a period of water shortage can range from a few days or weeks for some crops to a few years for large reservoirs or ground-water aquifers. Similarly, the water shortage can range from as little as an inch of precipitation for shallow root crops to as much as several feet of precipitation for water supplies that rely on streamflow or ground water. Unlike the effects of other weather-related hazards, such as floods, the effect of a drought can develop slowly.

A drought is the result of many natural and human factors that affect the environment. Matthai (1979, p. 5) stated that

> "Among the natural factors are the climate of the area; antecedent conditions as exemplified by the amounts of soil moisture, rain, and snow; the distribution of rain and snow in time and space; water-table levels during the drought; water quality; and soil type. Human factors include the degree of development of water storage and distribution systems; the number, location, and depths of wells; the patterns of water use and per capita consumption; the legal aspects relating to property rights, project operating rules, water-quality standards, and service contracts; economic considerations; and many more. Therefore, a definition of a drought must be tailored to the conditions in an area at a given time."

The World Meteorological Organization identified five general types of drought (Subrahmanyam, 1967):

1. Meteorologic drought--defined only in terms of precipitation deficiencies, in absolute amounts, for a given period.

2. Climatological drought--defined in terms of precipitation deficiencies, in percentages of normal values.

3. Atmospheric drought--defined not only in terms of precipitation deficiencies but possibly in terms of temperature, humidity, or windspeed.

4. Agricultural drought--defined principally in terms of soil moisture and plant behavior.

5. Hydrologic drought--defined in terms of reduction of streamflow, reduction in lake or reservoir storage, and lowering of ground-water levels.

An additional type of drought, the water-management drought, was added by Matthai (1979) to characterize water-supply shortages caused by the failure of water-management practices or facilities, such as an integrated water-supply system and surface or subsurface storage, to bridge normal or abnormal dry periods and equalize the water supply throughout the year. In general, drought can be defined as an interval of time, generally in months or years, when the water supply at a given location is consistently short of the expected climatic and hydrologic norm. In this report, the term drought generally refers to a climatic and hydrologic drought.

A drought can only be described fully by the depiction of its numerous climatic and hydrologic elements. Therefore, indices have been developed to simplify and present the climatic and hydrologic information and to characterize a drought spatially and temporally as to its intensity, duration, and severity. Each of the indices has a different description of water shortage. Some commonly used indices are departure from normal precipitation, departure from normal temperature, the Palmer Drought Severity Index, accumulated departure from normal streamflow, low-streamflow frequency, changes in water storage, ground-water levels and rates of decline, and lake levels. Redmond (1991) reviewed the desirable properties of indices and stated that

> "It is important to remember that one index cannot describe everything about the original data. Indices are intended to serve as approximations to real-world phenomena. Decisions regarding which information to retain and incorporate into the index are governed by the way the index is expected to be used. This point should always be borne in mind when using any summarized quantity."

The indices used in this report are departure from normal precipitation, departure from normal temperature, the Palmer Drought Severity Index, accumulated departure from normal streamflow, ground-water levels, and lake levels.

CLIMATIC AND HYDROLOGIC ASPECTS OF THE 1988-92 DROUGHT

Serious drought conditions occurred in North Dakota during the 1930's to early 1940's, the 1950's to early 1960's, the mid- to late 1970's, the early 1980's, and the late 1980's to early 1990's. The most recent drought (1988-92) in North Dakota actually began during the later half of 1987. However, the drought was not considered serious until 1988 when low soil moisture, crop stress and failure, and diminishing water supplies were noticed.

North Dakota is divided into nine National Climatic Data Center climatic divisions (fig. 1). Precipitation generally was greater than normal throughout North Dakota during 1986 and during the early months of 1987. Normal precipitation is defined as the average from 1895 through 1992. In general, negative departures from normal monthly precipitation began in July and August 1987 and continued through 1992 for all nine climatic divisions (fig. 2). Precipitation was greater than normal for several months during 1988-92, particularly during 1991, but total precipitation during 1988-92 was much less than normal. The departures from normal annual precipitation during 1986-92 for the nine climatic

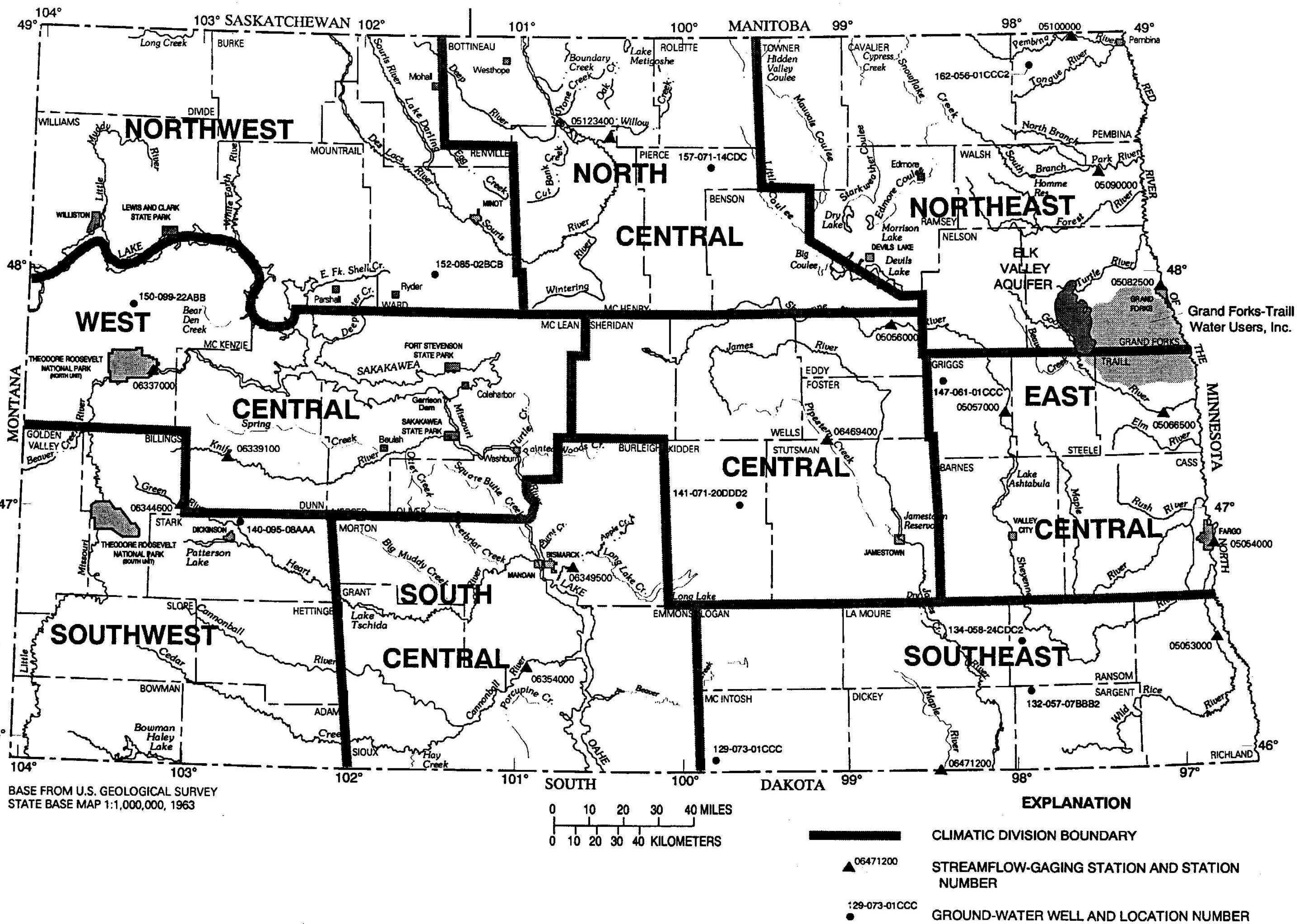


Figure 1. Location of climatic divisions, representative streamflow-gaging stations, and ground-water wells in North Dakota.

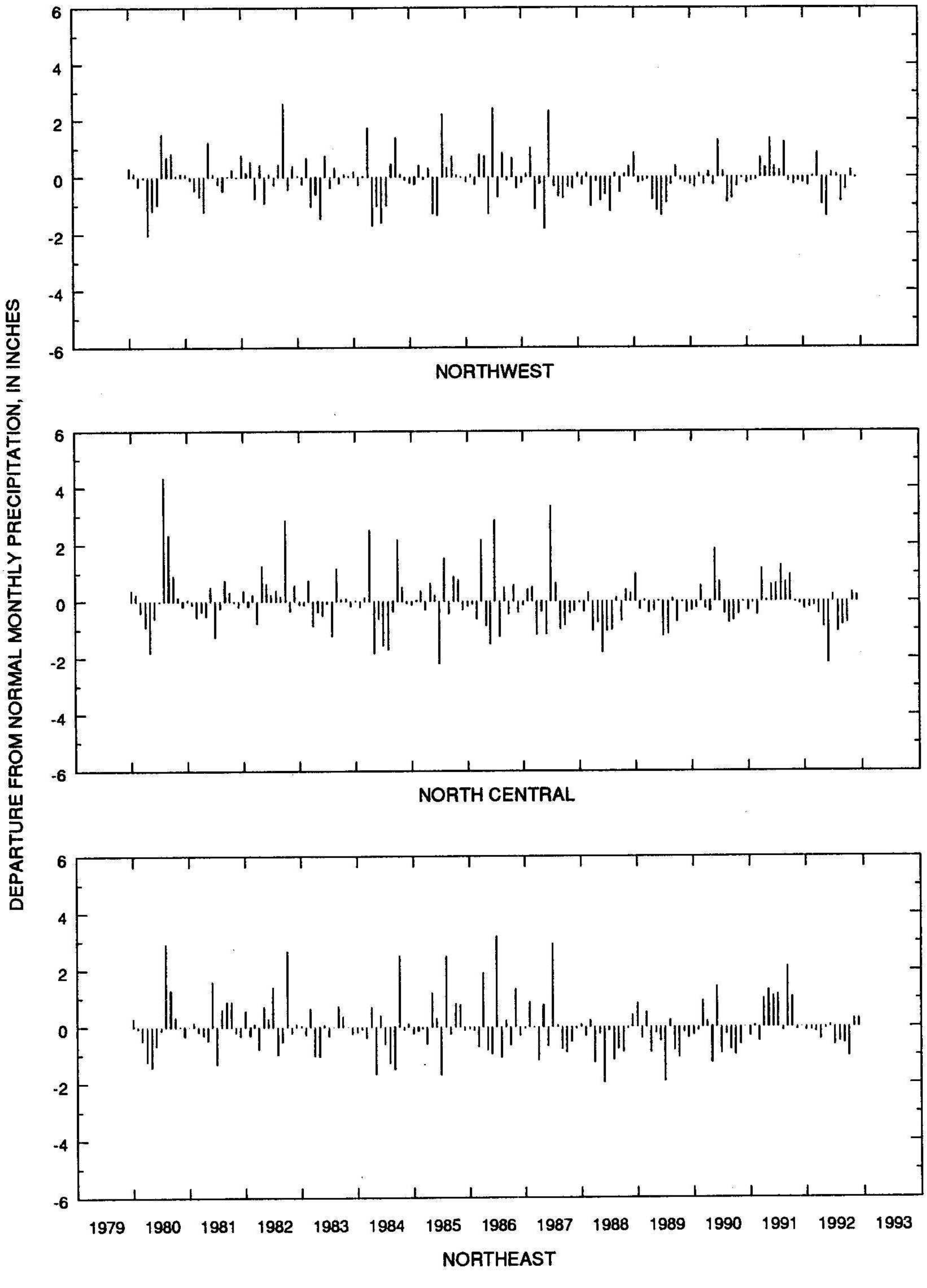


Figure 2. Departure from normal monthly precipitation during 1980-92 for each climatic division in North Dakota.

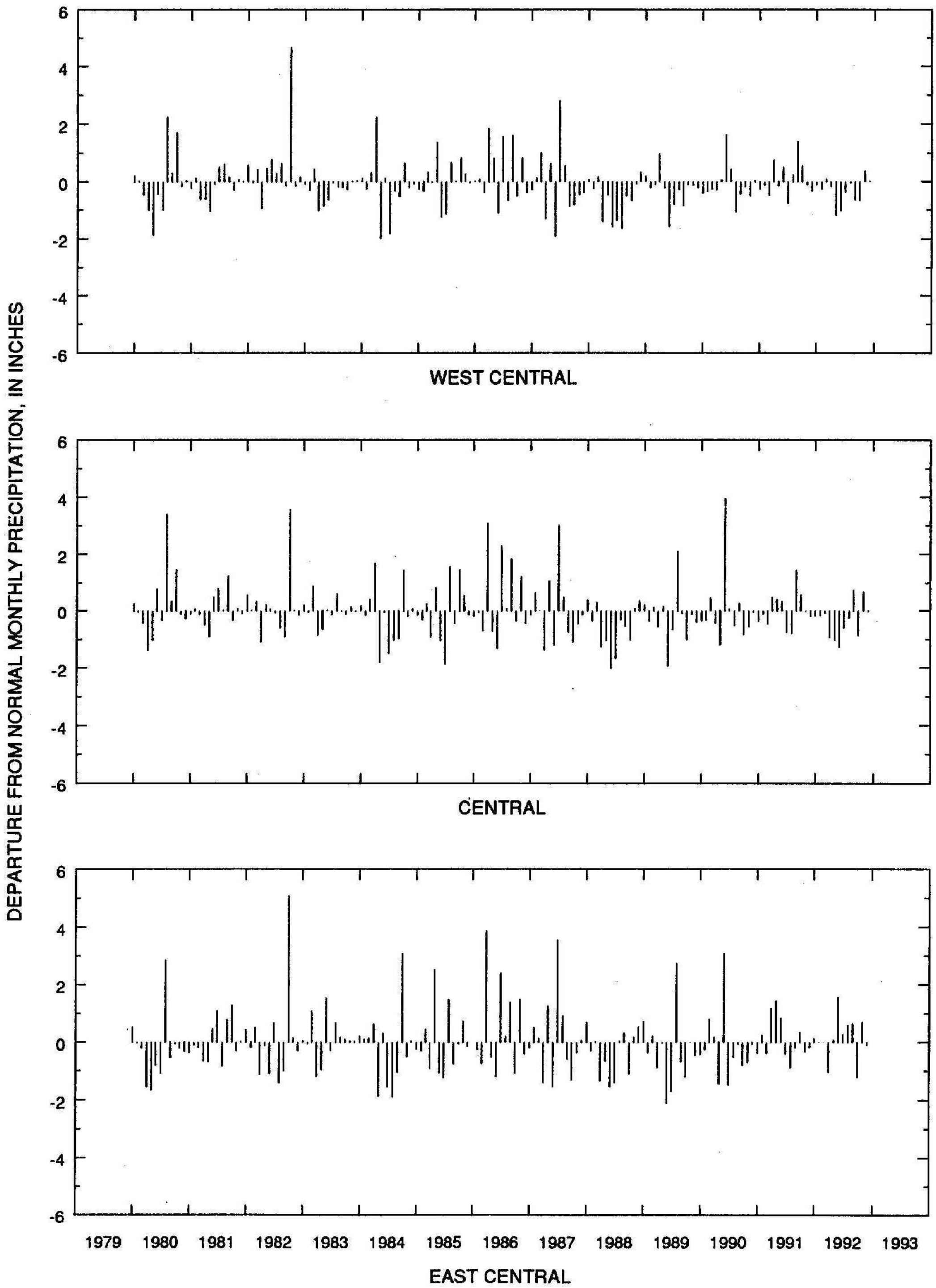


Figure 2. Departure from normal monthly precipitation during 1980-92 for each climatic division in North Dakota--Continued.

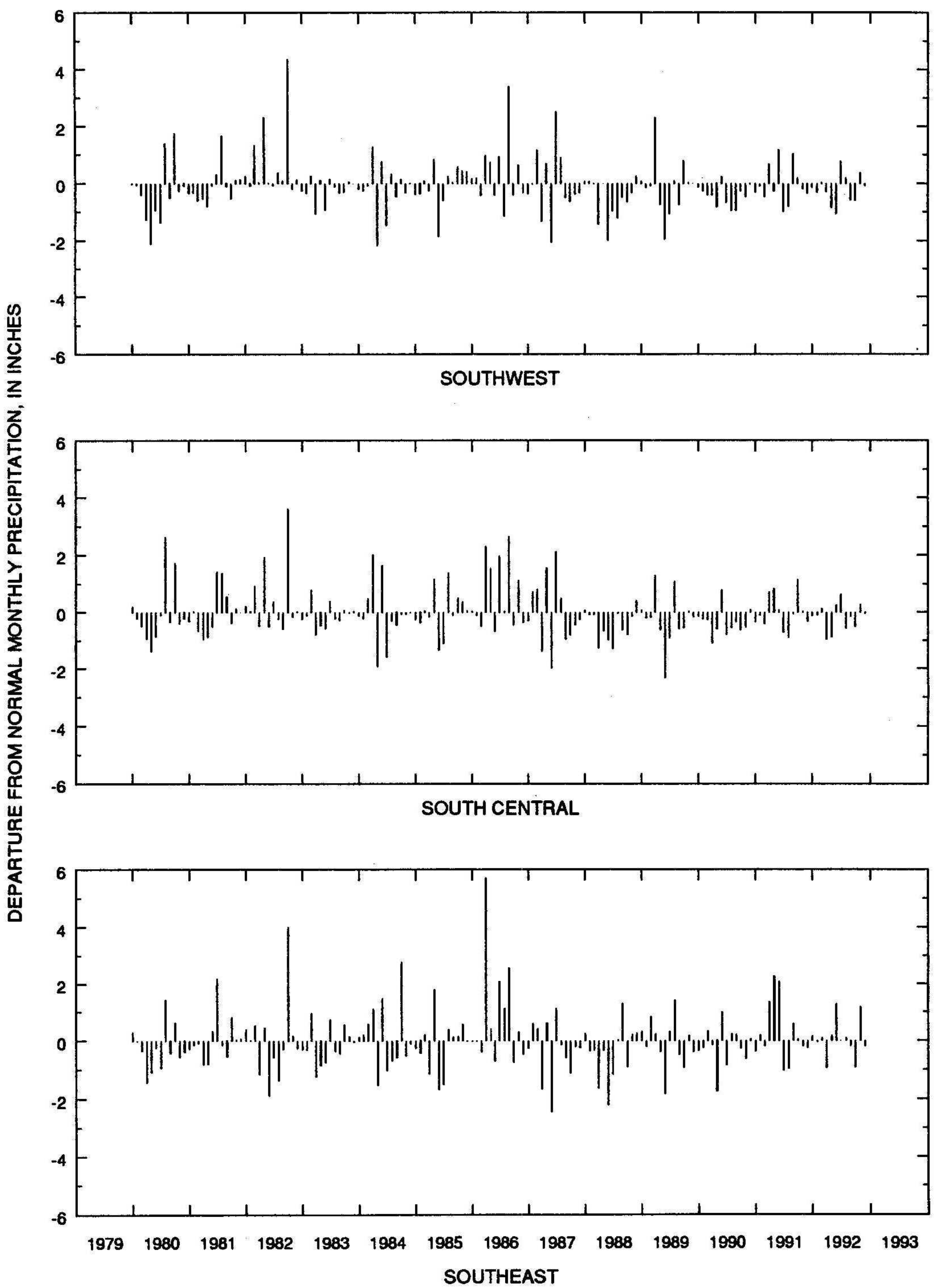


Figure 2. Departure from normal monthly precipitation during 1980-92 for each climatic division in North Dakota--Continued.

divisions are shown in figure 3. Annual precipitation ranged from 52 percent greater than normal to 44 percent less than normal during 1986-92. The two largest negative departures from normal annual precipitation for the northwest, northeast, and east-central climatic divisions occurred during 1988 and 1989; the two largest negative departures for the north-central, west-central, and central climatic divisions occurred during 1988 and 1992; the two largest negative departures for the southwest and south-central climatic divisions occurred during 1988 and 1990; and the two largest negative departures for the southeast climatic division occurred during 1987 and 1988.

Annual precipitation for all nine climatic divisions in North Dakota was ranked for the 98-year period from 1895 through 1992. The rank of 1986-92 annual precipitation is shown in figure 4. A rank of one indicates the driest year of the 98-year period, and a rank of 98 indicates the wettest year. Ranks for all nine climatic divisions during 1988-92 ranged from 2 to 96. In 1988, the central climatic division had the second driest year of the 98-year period; and, in 1986, the south-central and southeast climatic divisions each had the wettest year.

The departure from normal for average summer (June-August) temperatures from 1895 through 1992 for each climatic division is shown in figure 5. Except during 1992, average summer temperatures were greater than normal during 1988-92. The largest departure from normal for average summer temperature occurred during 1988 for the northwest, north-central, northeast, west-central, and central climatic divisions. The second largest departure from normal occurred during 1988 for the east-central, southwest, south-central, and southeast climatic divisions.

The average summer (June-August) temperature for all nine climatic divisions in North Dakota also was ranked for the 98-year period from 1895 through 1992. The rank of 1986-92 average summer temperatures is shown in figure 6. A rank of one indicates the warmest summer of the 98-year period, and a rank of 98 indicates the coolest summer. Ranks for all nine climatic divisions during 1988-92 ranged from 1 to 97. In 1988, the northwest, north-central, northeast, west-central, and central climatic divisions had the warmest summer of the 98-year period, and the east-central, southwest, south-central, and southeast climatic divisions had the second warmest summer. One of the coolest summers of the 98-year period occurred in 1992 in all nine climatic divisions.

Runoff in North Dakota is dependent largely on climatic conditions, such as rainfall, snowfall, and temperature, and edaphic conditions, such as soil moisture and land use. Because of the variability in climatic and edaphic conditions, runoff can be greater than normal one year and nonexistent the next. Streamflow-gaging stations (fig. 1) that represent various drainage areas and record lengths are used to demonstrate the spatial and temporal effect of the 1988-92 drought.

During the 1988-92 drought, many streams in North Dakota had record low flows or ceased to flow entirely. Streamflows at 12 representative gaging stations throughout North Dakota are shown in figure 7. Streamflow at most of the gaging stations during 1988-92 was at or below the 25th percentile. Some streams, however, had normal or greater-than-normal flow during the 1988-92 drought. Streamflow at the Red River of the North at Fargo, N. Dak., gaging station (05054000), the Goose River at Hillsboro, N. Dak., gaging station (05066500), the Park River at Grafton, N. Dak., gaging station (05090000), the Pembina River at Neche, N. Dak., gaging station (05100000), the Willow Creek near Willow City, N. Dak., gaging station (05123400), and the Maple River at North Dakota-South Dakota State line gaging station (06471200) was at or above the 50th percentile for one or more of the years during 1988-92.

The percentage of years in the period of record in which consecutive days of no flow occurred at selected streamflow-gaging stations is shown in figure 8. Some streams have no flow very few days, and others have no flow more than 50 percent of the time during the period of record. The variability in occurrence of no-flow conditions among streams, particularly for the larger number of consecutive days, is largely because of varying base-flow contributions. For example, the Sheyenne River near Warwick,

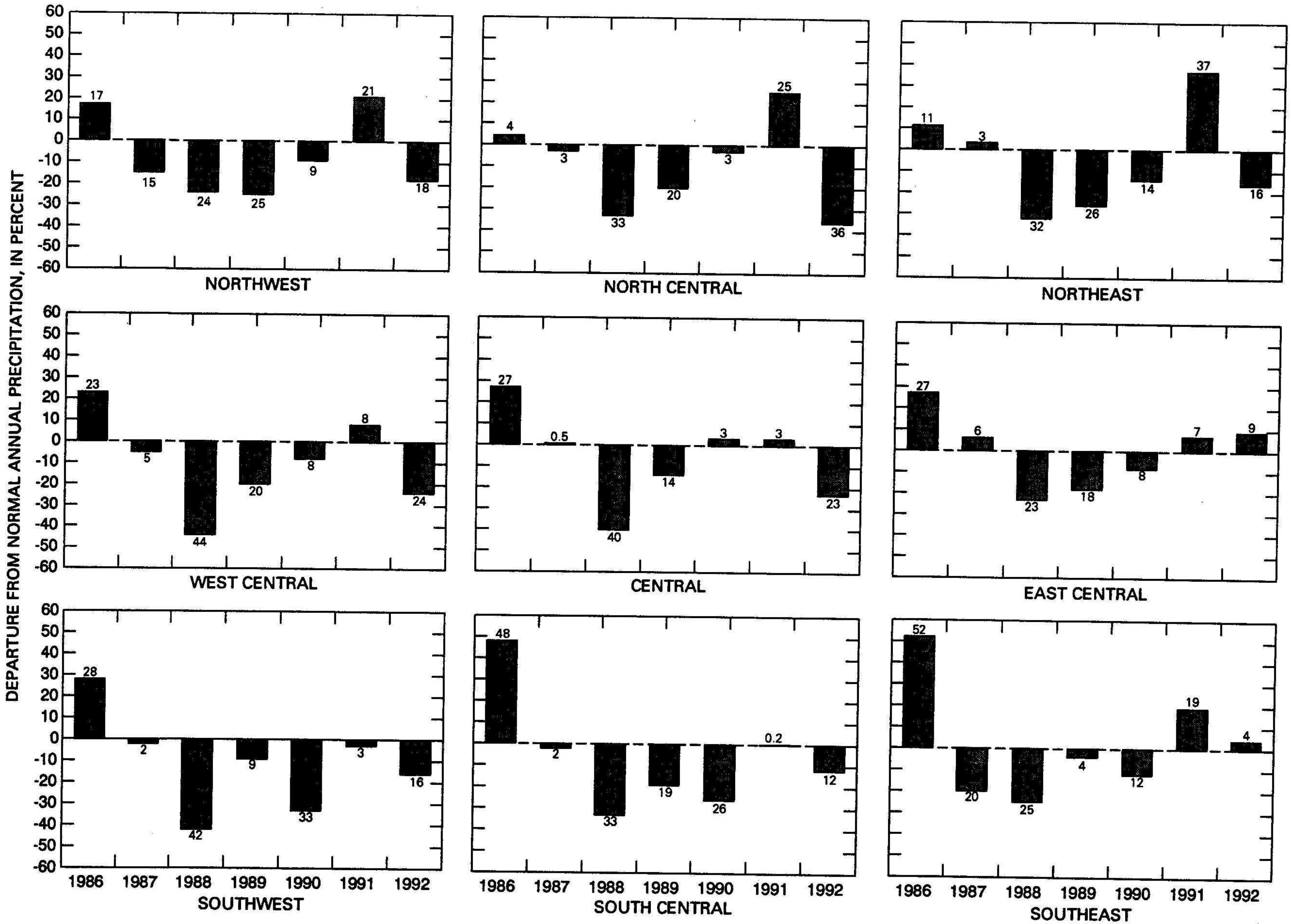


Figure 3. Departure from normal annual precipitation during 1986-92 for each climatic division in North Dakota.

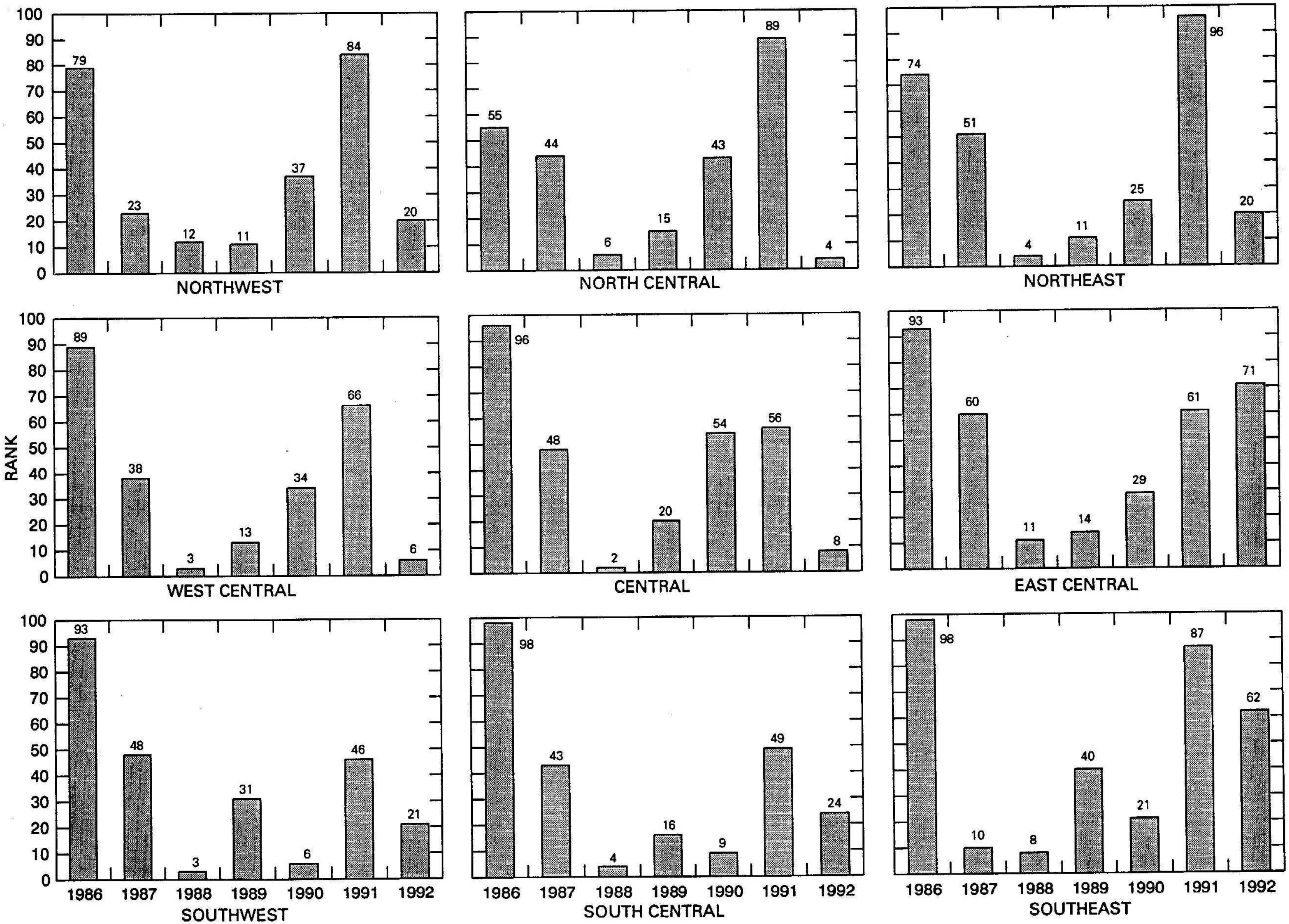


Figure 4. Rank of 1986-92 annual precipitation from 1895 through 1992 for each climatic division in North Dakota (1 indicates driest year, 98 indicates wettest year).

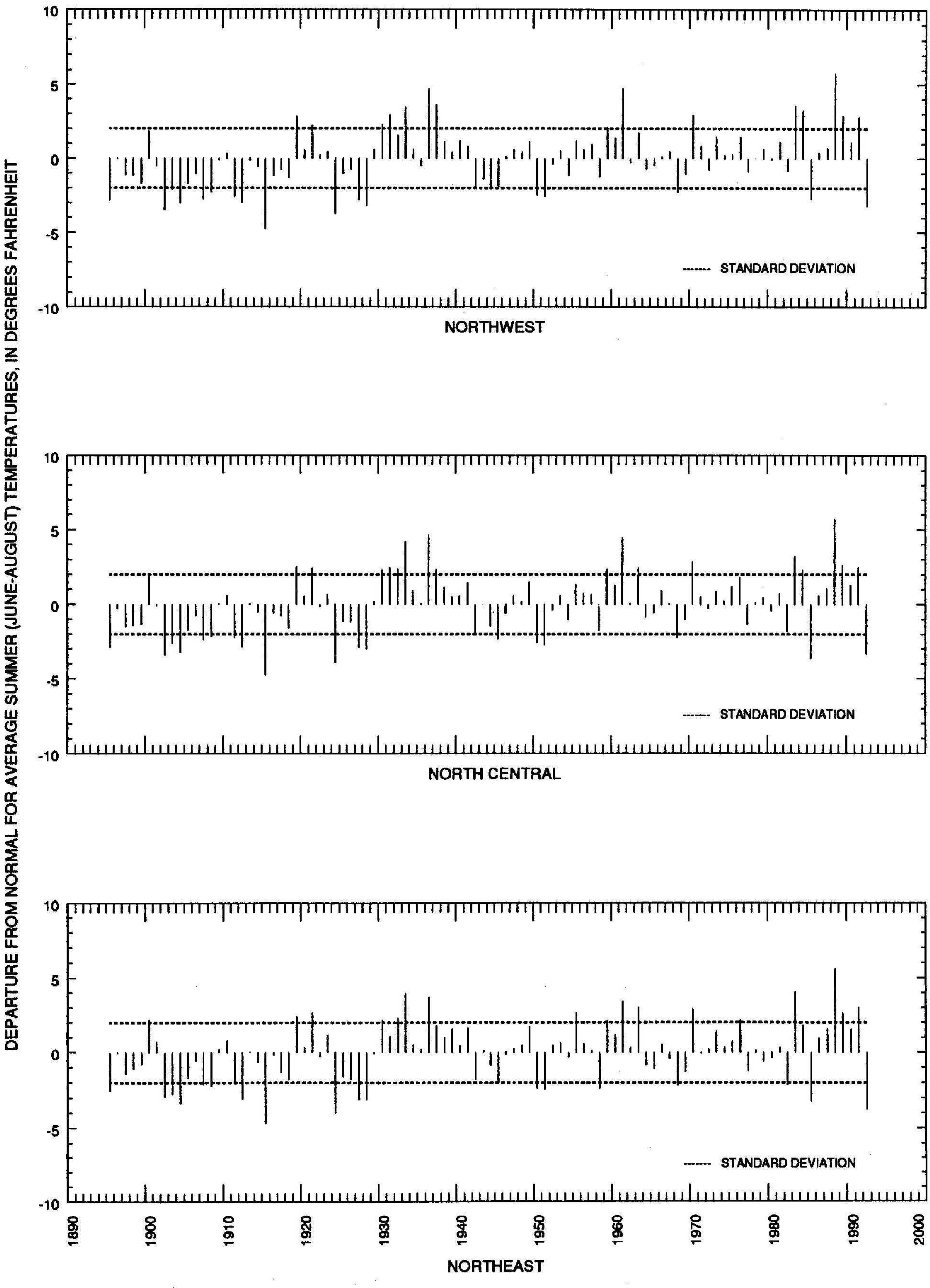


Figure 5. Departure from normal for average summer (June-August) temperatures from 1895 through 1992 for each climatic division in North Dakota.

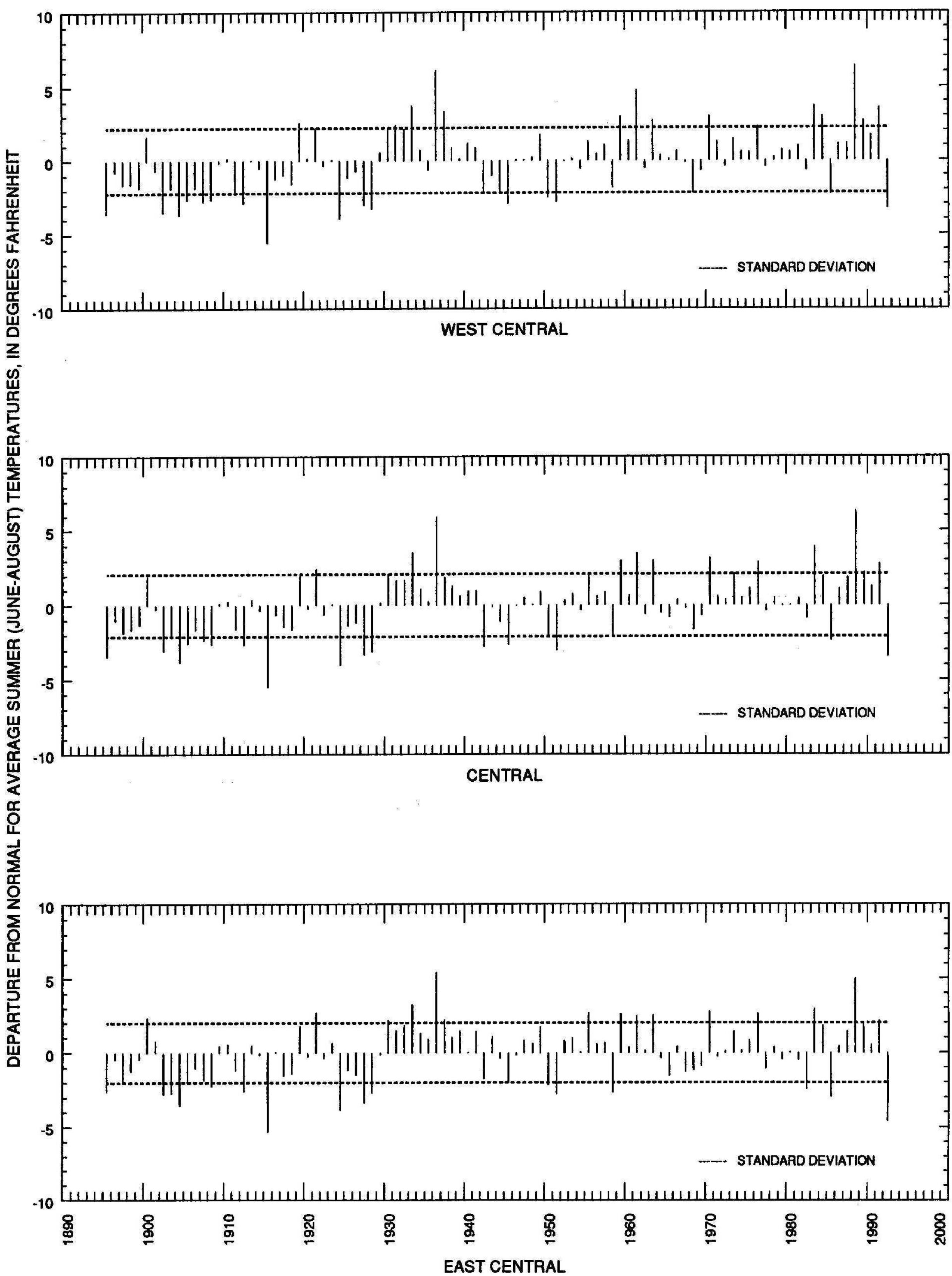


Figure 5. Departure from normal for average summer (June-August) temperatures from 1895 through 1992 for each climatic division in North Dakota--Continued.

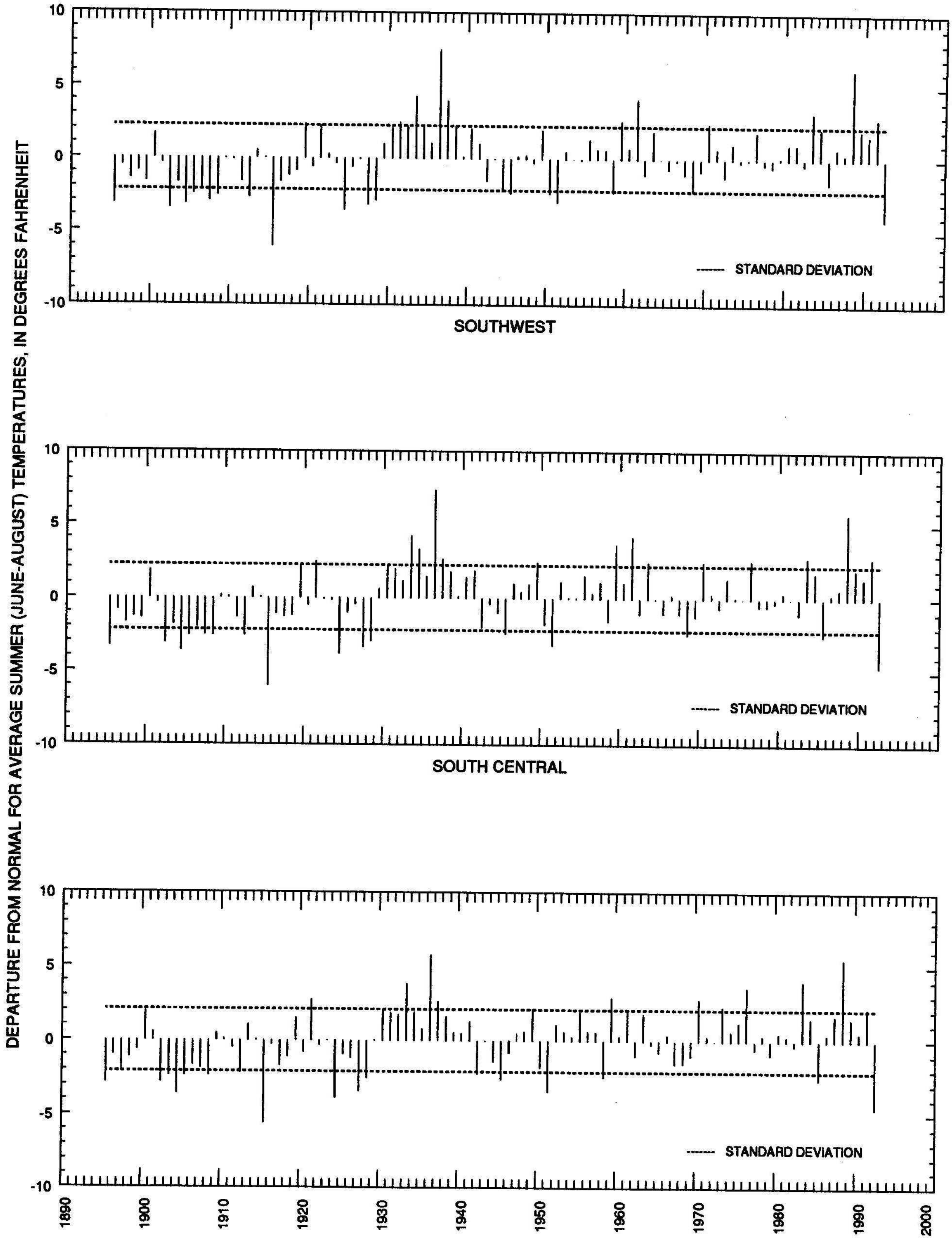


Figure 5. Departure from normal for average summer (June-August) temperatures from 1895 through 1992 for each climatic division in North Dakota—Continued.

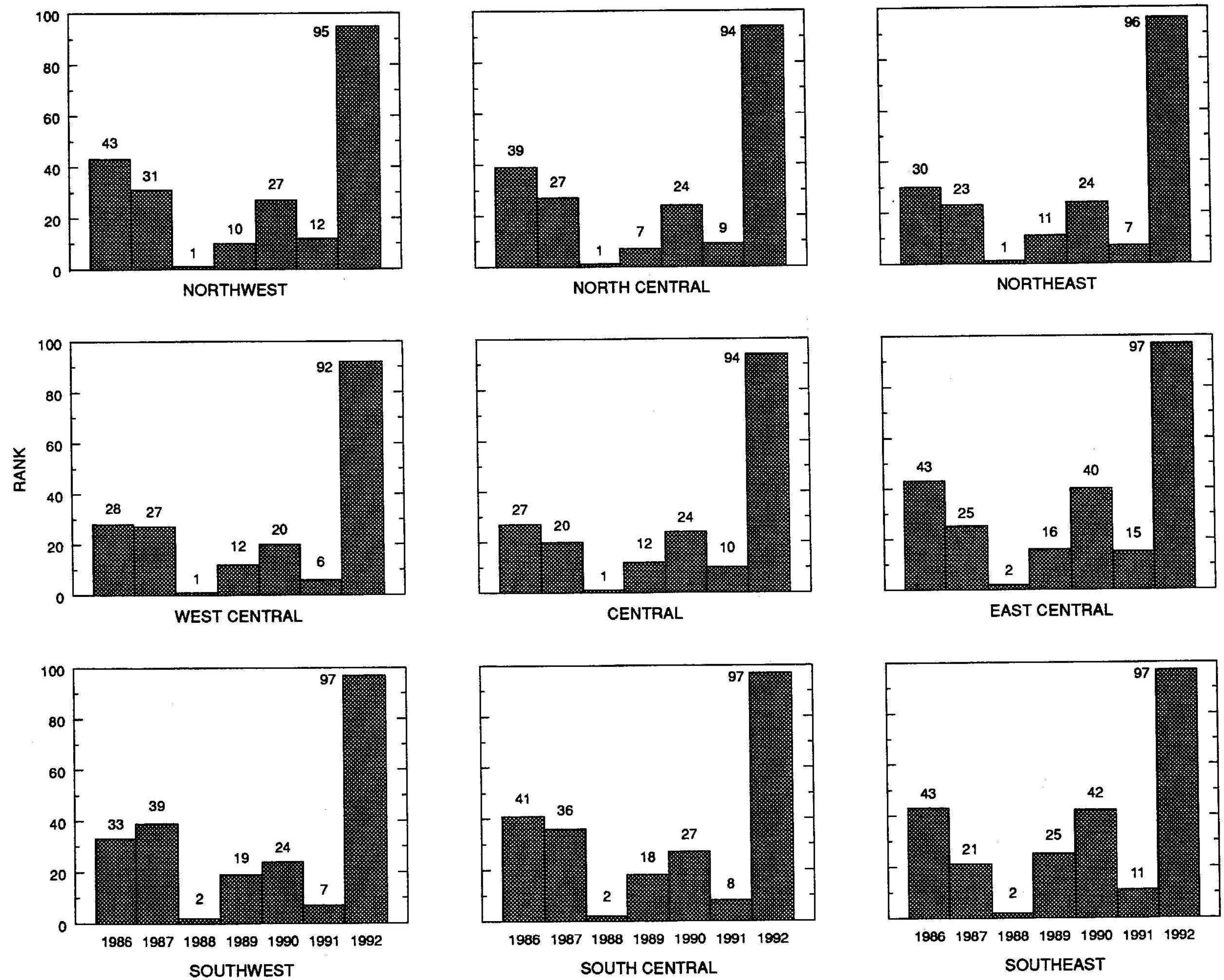


Figure 6. Rank of 1986-92 average summer (June-August) temperatures from 1895 through 1992 for each climatic division in North Dakota (1 indicates warmest summer, 98 indicates coolest summer).

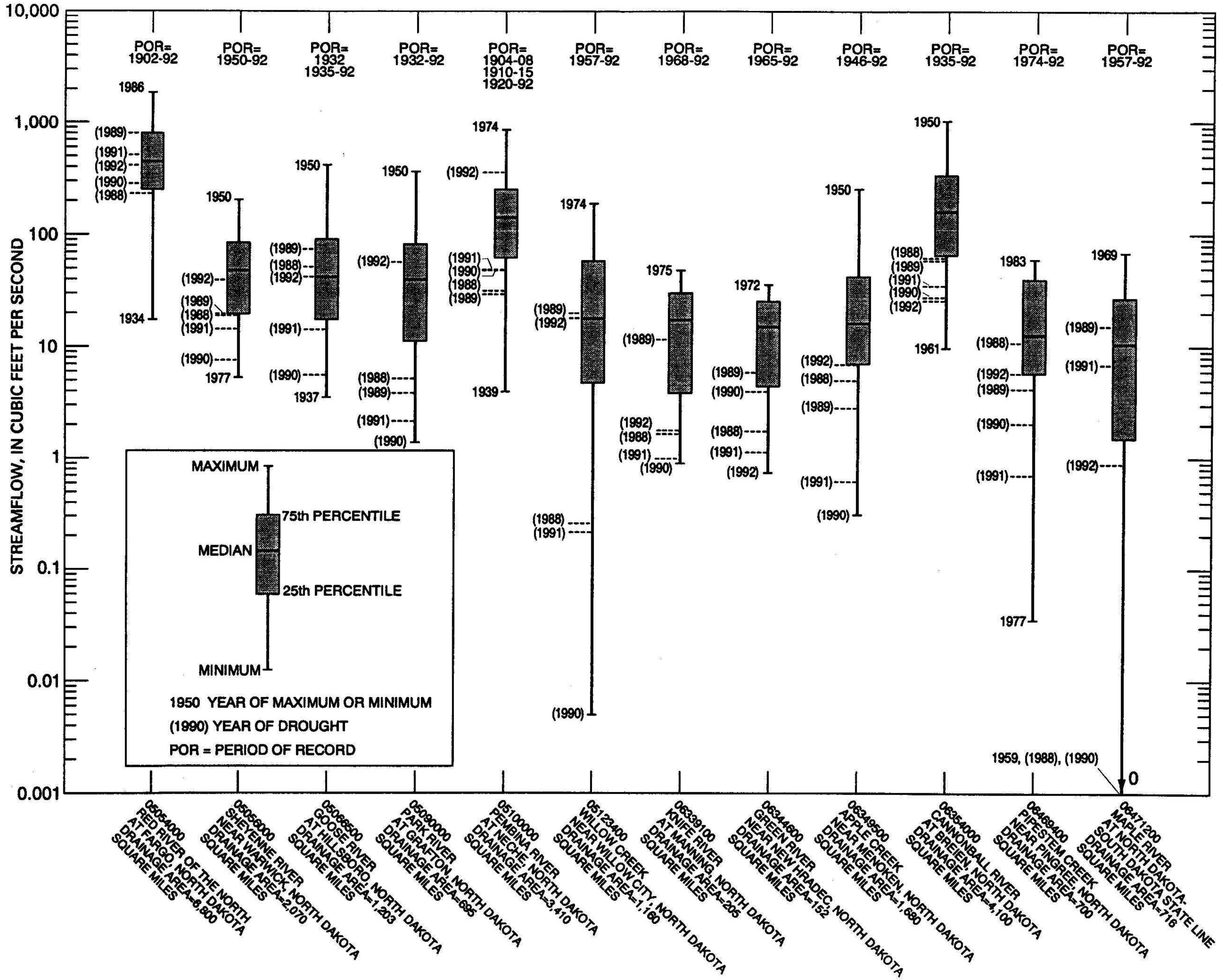


Figure 7. Streamflows at selected gaging stations in North Dakota.

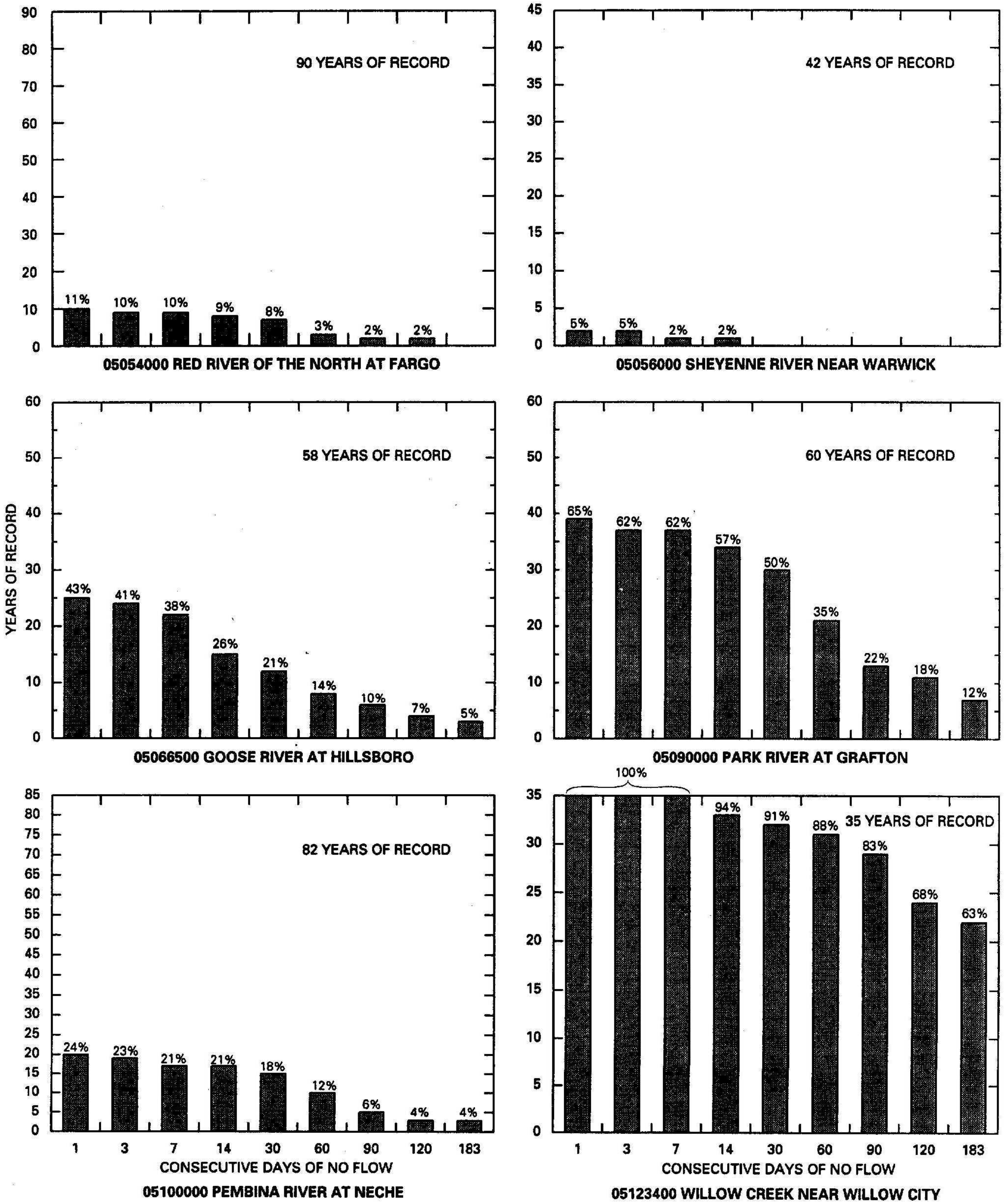


Figure 8. Percentage of years in period of record in which consecutive days of no flow occurred at selected streamflow-gaging stations in North Dakota.

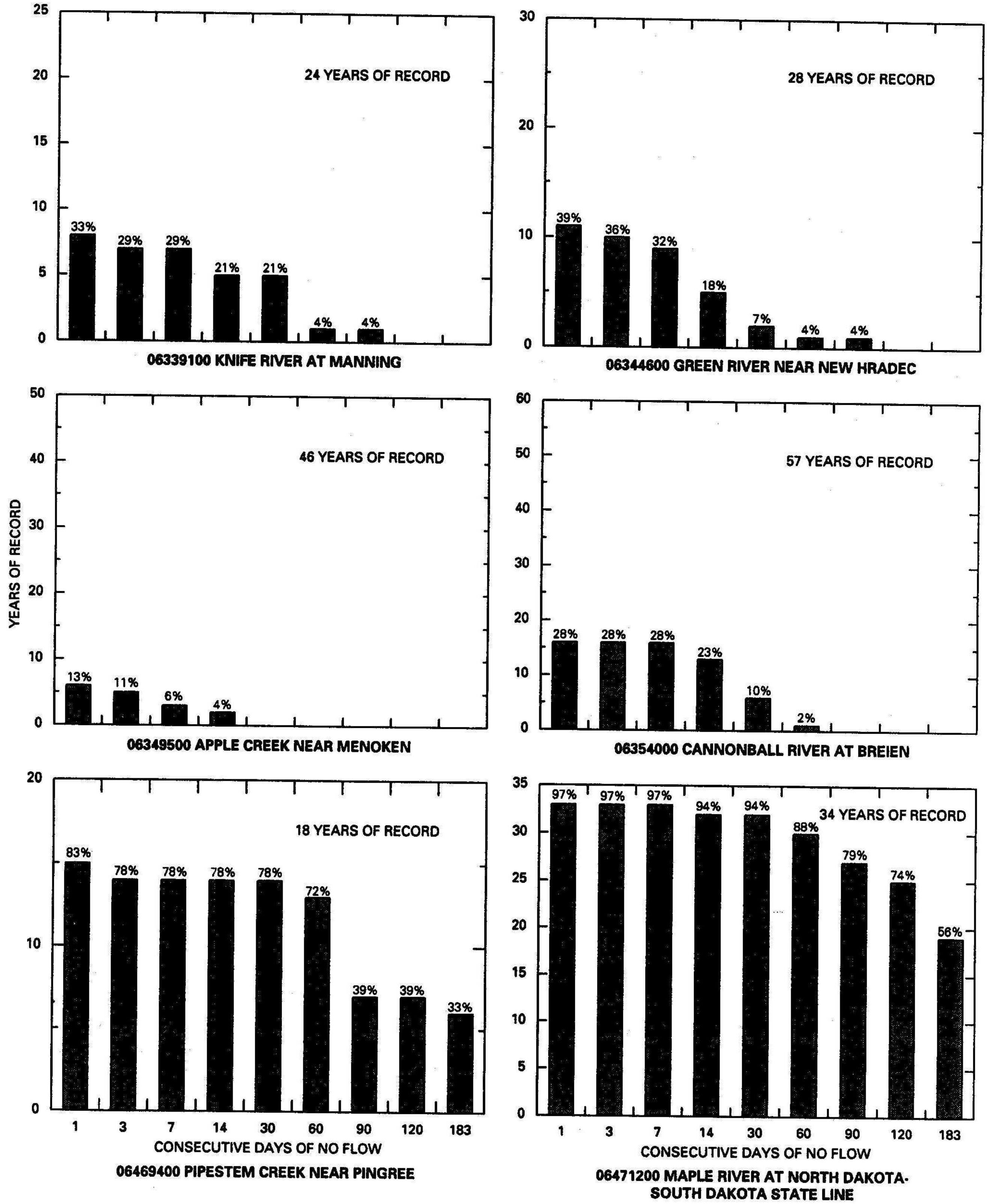


Figure 8. Percentage of years in period of record in which consecutive days of no flow occurred at selected streamflow-gaging stations in North Dakota--Continued.

N. Dak., gaging station (05056000) did not have 60 consecutive days of no flow, but the Willow Creek near Willow City, N. Dak., gaging station (05123400) had 60 consecutive days of no flow for 31 of the 35 years of record. Base-flow conditions on the Sheyenne River contribute more to sustaining low flow than base-flow conditions on Willow Creek. The percentage of time no flow occurred at the selected streamflow-gaging stations during the 1988-92 drought ranged from zero to 100 percent (table 1). The maximum number of consecutive days no flow occurred at the selected streamflow-gaging stations during the 1988-92 drought ranged from zero to 366 days (table 2). Most periods of no flow shown in figure 8 occurred during major drought years although no flow may occur during wet years as well as during drought years. Some small streams, such as Willow Creek, Pipestem Creek, and Maple River, had periods of no flow throughout the entire period of record, including during known wet years, and some large streams, such as the Red River of the North at Fargo, had no flow during drought years. The Red River of the North at Fargo had periods of no flow during the 1930's. Although regulation began during the 1950's, periods of no flow also occurred during 1976-77.

Table 1. Percentage of time no flow occurred at selected streamflow-gaging stations in North Dakota during the 1988-92 drought

Streamflow-gaging station	1988	1989	1990	1991	1992
05054000, Red River of the North at Fargo, North Dakota	0	0	0	0	0
05056000, Sheyenne River near Warwick, North Dakota	0	0	0	0	0
05066500, Goose River at Hillsboro, North Dakota	2	13	30	18	10
05090000, Park River at Grafton, North Dakota	23	35	67	42	23
05100000, Pembina River at Neche, North Dakota	0	50	25	14	0
05123400, Willow Creek near Willow City, North Dakota	83	82	99	96	76
06339100, Knife River at Manning, North Dakota	32	17	32	24	29
06344600, Green River near New Hradec, North Dakota	26	4	8	11	18
06349500, Apple Creek near Menoken, North Dakota	0	0	0	0	0
06354000, Cannonball River at Breien, North Dakota	0	4	3	6	0
06469400, Pipestem Creek near Pingree, North Dakota	46	32	49	62	31
06471200, Maple River at North Dakota-South Dakota State line	100	74	100	74	88

The effects of the drought on ground-water levels in North Dakota varied during 1988-92. Natural and man-induced effects on ground-water levels in selected wells (fig. 1) are given in table 3 and shown in figures 9 and 10. In areas of no significant pumping, confined aquifers generally show a lack of response to climate variability (129-073-01CCC, fig. 10), and unconfined aquifers generally show rapid response and greater variability (132-057-07BBB2, fig. 10). Unconfined aquifers often show rapid water-level declines at the beginning of a drought because the amount of recharge is small and the amount of evapotranspiration can be very large (157-071-14CDC, fig. 9). However, as water levels decline, the amount of evapotranspiration is sharply reduced and water levels decline very slowly (162-056-01CCC2, fig. 9). The greatest effect of drought on ground-water levels occurs in areas of significant pumping. In well 147-061-01CCC (fig. 9), seasonal changes were caused by increased water usage in 1988 and 1989. Large water-level declines occur as the demand for water increases (150-099-22ABB, fig. 9; 134-058-24CDC2, fig. 10).

Table 2. Maximum number of consecutive days no flow occurred at selected streamflow-gaging stations in North Dakota during the 1988-92 drought

Streamflow-gaging station	1988	1989	1990	1991	1992
05054000, Red River of the North at Fargo, North Dakota	0	0	0	0	0
05056000, Sheyenne River near Warwick, North Dakota	0	0	0	0	0
05066500, Goose River at Hillsboro, North Dakota	7	27	67	65	38
05090000, Park River at Grafton, North Dakota	35	55	190	127	89
05100000, Pembina River at Neche, North Dakota	0	82	83	53	0
05123400, Willow Creek near Willow City, North Dakota	217	209	183	186	217
06339100, Knife River at Manning, North Dakota	48	38	99	55	56
06344600, Green River near New Hradec, North Dakota	96	13	25	40	34
06349500, Apple Creek near Menoken, North Dakota	0	0	0	0	0
06354000, Cannonball River at Breien, North Dakota	0	15	12	15	0
06469400, Pipestem Creek near Pingree, North Dakota	148	68	114	86	29
06471200, Maple River at North Dakota-South Dakota State line	366	195	365	135	158

EFFECT OF THE 1988-92 DROUGHT ON PEOPLE AND RESOURCES

North Dakota's economy depends on agricultural activities, Federal activities, energy, manufacturing, and tourism, including recreational activities on area rivers and lakes. If precipitation is inadequate, many resources in North Dakota may be adversely affected. Agricultural activities and recreation, in particular, are dependent on timely and sufficient amounts of precipitation. Less-than-normal precipitation can result in low soil-moisture conditions that are detrimental to crop production, pastureland development, and water supplies. Less-than-normal precipitation results in lower lake levels and lower streamflow levels. The lower levels have an effect on the water supplies, recreational activities, and fish and wildlife in North Dakota.

To alleviate the effect of the drought on people and resources of North Dakota, a procedure for implementation of drought mitigation measures was developed by the State. This procedure became part of the North Dakota emergency management multi-hazard mitigation plan (North Dakota Division of Emergency Management, 1989a). The scope of this plan is statewide. The plan was used to establish a State drought mitigation organization led by the Governor who designates task forces that include local, State, and Federal agencies or groups. The task forces are responsible for information pertaining to the following categories: public information; data; agriculture; municipal and industrial; recreation, fish, and wildlife; economics; and fire (Bismarck Tribune, written commun., 1991; fig. 11). For example, the National Weather Service and the U.S. Army Corps of Engineers have data needed to evaluate drought conditions; the Department of Agriculture has information on the State's agricultural status; and the National Weather Service and the Fire Marshal have information on drought conditions conducive to fires. By combining data and resources, the task forces can give a comprehensive assessment of the drought situation as it pertains to each of their areas of expertise.

Table 3. Natural and man-induced effects of drought on ground-water levels in selected wells in North Dakota

Climatic division	Location number	County	Aquifer	Screened interval (feet)	Type of aquifer	Effect on ground-water levels
Northwest	152-085-02BCB	Ward	Douglas	90 to 100	Unconfined	Strongly affected by Rice Lake.
North central	157-071-14CDC	Pierce	Pleasant Lake	58 to 61	Unconfined	Slightly affected by Rugby well field.
Northeast	162-056-01CCC2	Pembina	Icelandic	37 to 40	Unconfined	Responds to climate.
West central	150-099-22ABB	McKenzie	Tobacco Garden	68 to 74	Confined	May respond to Watford City municipal wells.
Central	141-071-20DDD2	Kidder	Marstonmoor Plain	33 to 39	Unconfined	Responds to climate.
East central	147-061-01CCC	Griggs	Spiritwood	237 to 240	Confined	Responds to irrigation pumpage. Seasonal changes are caused by increased water usage in 1988 and 1989.
Southwest	140-095-08AAA	Stark	Sentinel Butte Member	[1]80	Unconfined	Responds to climate. Continued decline of water levels because of little base flow to Green River and Russian Spring Creek.
Southeast	129-073-01CCC	McIntosh	Zeeland	108 to 111	Confined	General lack of response to climate. Pumping effects are not significant.
Southeast	132-057-07BBB2	Sargent	Englevale	13 to 16	Unconfined	Responds to climate. Pumping effects are not significant.
Southeast	134-058-24CDC2	Ransom	Englevale	54.5 to 59.5	Unconfined	Responds to irrigation pumpage.

[1]Open end; no screen.

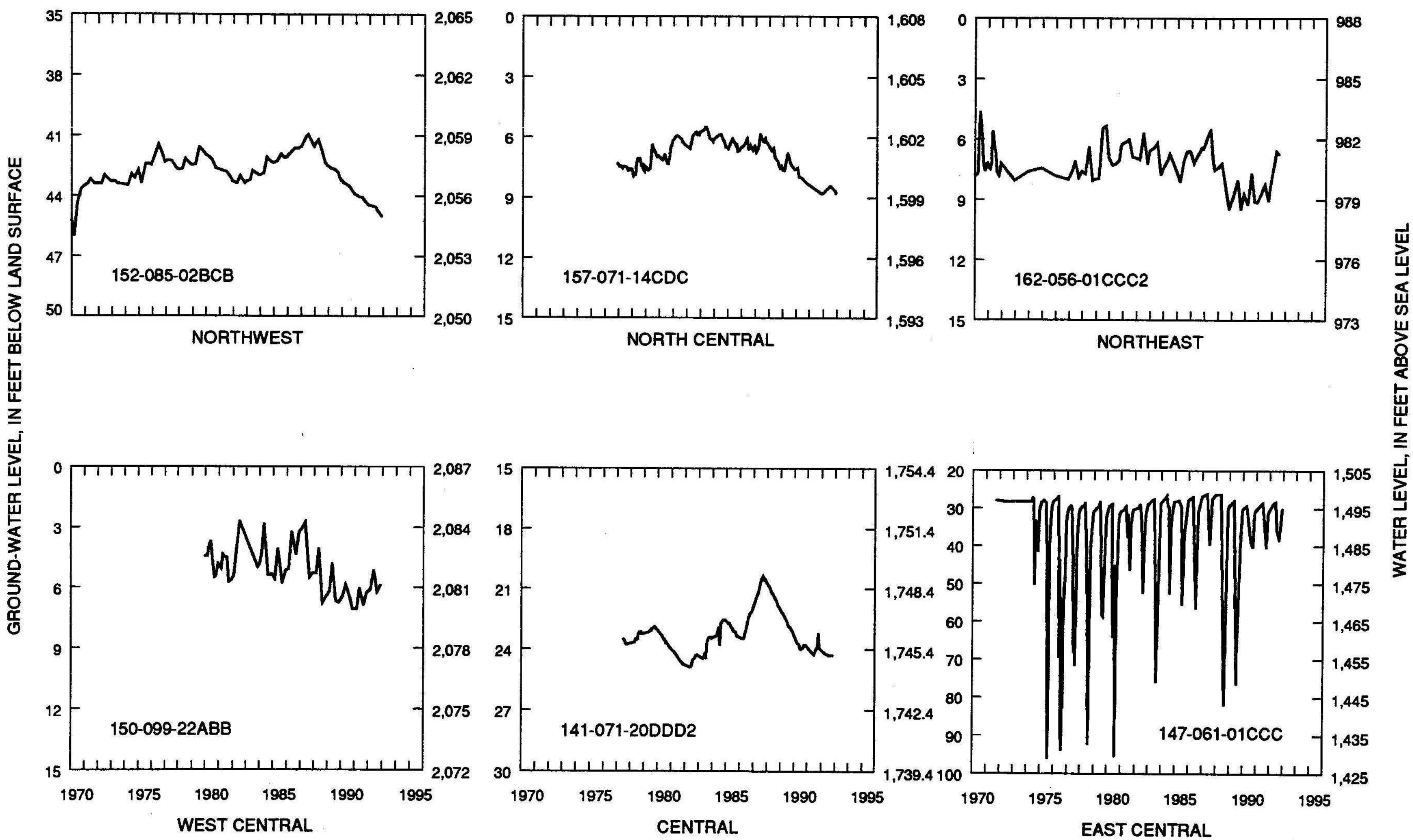


Figure 9. Ground-water levels in selected wells during 1970-92 for northwest, north-central, northeast, west-central, central, and east-central climatic divisions in North Dakota.

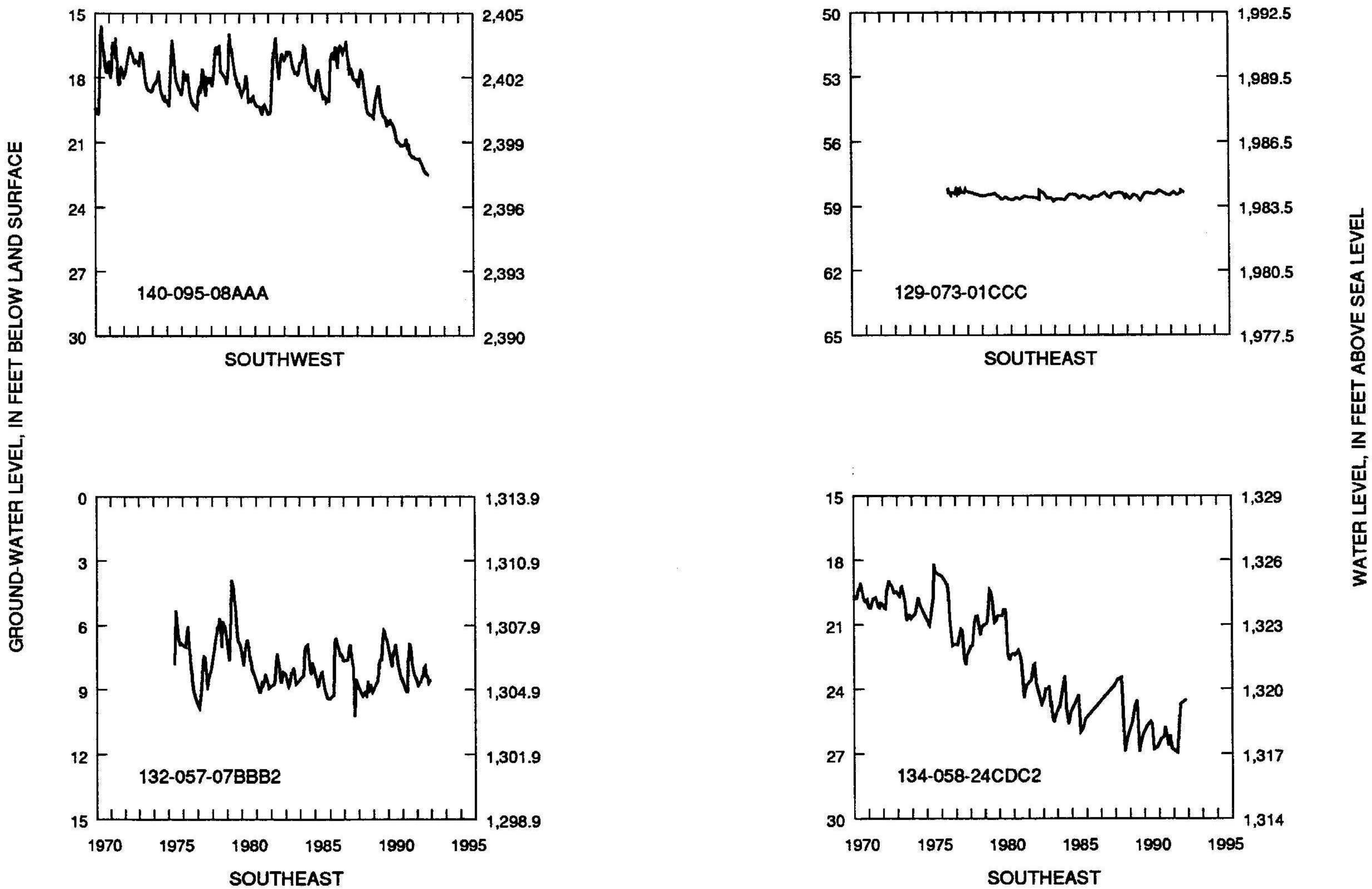


Figure 10. Ground-water levels in selected wells during 1970-92 for southwest and southeast climatic divisions in North Dakota.

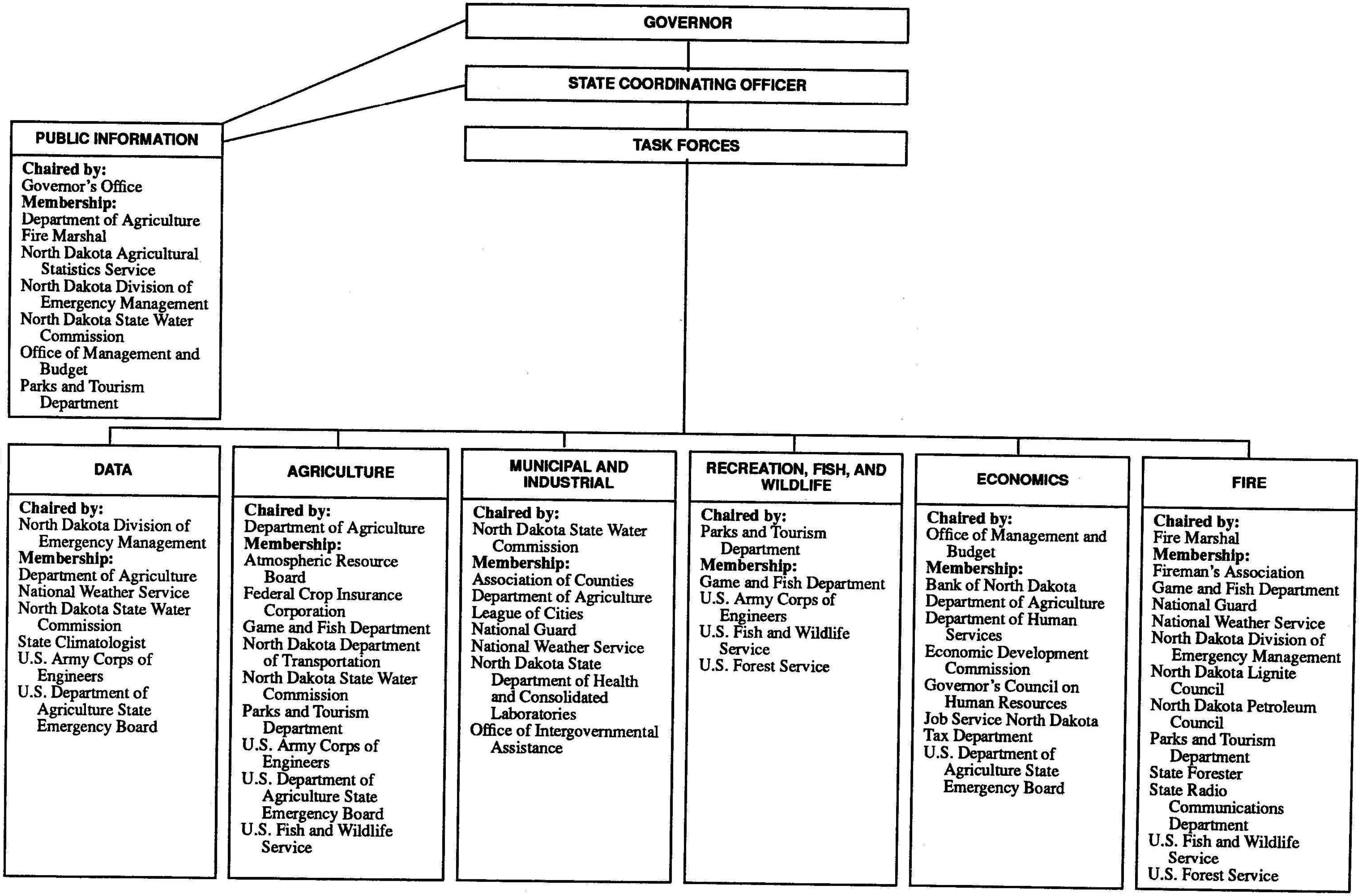


Figure 11. Drought mitigation organizational chart. (Modified from North Dakota Division of Emergency Management, 1989a.)

The North Dakota Division of Emergency Management is responsible for coordinating data supplied by various members of the drought mitigation task forces. After these data are collected and reviewed, the North Dakota Division of Emergency Management issues drought situation reports to the Governor of the State. These reports describe the nature of the disaster, death and injuries sustained as a result of the disaster, damage assessed, resources committed to alleviating problems as a result of the disaster, volunteer actions, major actions taken (for example, proclamations by the Governor), assistance needed, outside help on the scene, and other additional information. The reports give an overall view of the drought situation throughout the State and the mitigation actions needed to alleviate the situation. A total of seven situation reports were issued during the 1988-92 drought in North Dakota. The situation report numbers, the incident numbers, and the dates the reports were issued are given in the following table:

Situation report number for year	Incident number	Date report issued
1	88-52	May 20, 1988[1]
2	88-52	June 3, 1988
3	88-52	July 14, 1988
1	89-24	July 13, 1989[1]
1	90-18	April 25, 1990[1]
2	90-18	May 11, 1990
1	91-17	April 26, 1991

[1]The Governor proclaimed a statewide drought emergency.

Because the Governor proclaimed a statewide drought emergency, many people were able to receive local, State, or Federal assistance. Without the proclamation, many relief programs could not be initiated and Federal assistance could not be rendered to the State.

The drought mitigation organizational chart (fig. 11) was used as a basis for obtaining data on the 1988-92 drought in North Dakota. Various agencies and groups listed on the chart already were collecting data or information on the drought. As these agencies and groups were contacted, other data sources were identified and many of those sources also were contacted. Data obtained from the various sources were used to give an overview of the direct or indirect effect of the drought on municipal and rural water supplies, irrigation and agriculture, livestock, fire, recreation, and fish and wildlife. The effect of a drought is determined on the basis of whether the result would have occurred if there had not been a drought. The data obtained are indicators of the effect of the drought on some of the State's resources.

Municipal and Rural Water Supplies

In 1980, the population of North Dakota was 652,717; by 1990, the population had decreased to 638,800 (North Dakota Census Data Center, written commun., 1990). About 75 percent of the population receives its water from municipal water supplies and 25 percent of the population receives its water from rural water sources such as individual wells. Of those who receive water from municipal water supplies, 60 percent receive water from surface water and 40 percent receive water from ground water (Solley, Pierce, and Perlman, 1993).

During the 1980's, the population of North Dakota shifted from rural areas to urban centers. The increase in population in cities and towns combined with the increase in water demand during the drought greatly increased the need for municipal water supplies. When a municipal water supply is affected by a drought, it affects many people in a short time. In North Dakota, the first municipal water supplies affected by the drought were those provided by surface water. As the drought continued, municipal water supplies provided by ground water began to be affected. Water-supply intakes in towns such as Parshall, N. Dak., and Washburn, N. Dak., were out of water because of the declining water levels in Lake Sakakawea and the Missouri River. Bans on auxiliary water use (for example, lawn and garden sprinkling) were issued in cities such as Fargo, N. Dak., located along the Red River of the North, and Mandan, N. Dak., located along the Missouri River, when the municipal water supplies were less than normal or when water-treatment plants were burdened by the increased demand for more water (Bismarck Tribune, written commun., 1988). Alternate ground-water sources needed to be found for towns such as Mohall, N. Dak., and Ryder, N. Dak., whose water supplies are provided by wells. Towns such as these also received additional water from one of the rural water systems in the State. Municipal water supplies of many other cities and towns throughout the State were affected periodically by the drought. These municipal water supplies were monitored by the appropriate government agencies as specified in the North Dakota emergency management multi-hazard mitigation plan (North Dakota Division of Emergency Management, 1989a) so that preventive actions could be taken to minimize water shortages. Selected cities and towns where municipal water supplies were affected by the drought are given in table 4.

Table 4. Selected cities and towns in North Dakota where municipal water supplies were affected by the drought[1]

City/town	Population	Remarks
Beulah	3,363	One well went dry in 1987. Work on water problems began in 1988. Beulah was eligible to receive water from the southwest pipeline.
Coleharbor	88	Coleharbor received water from the McLean-Sheridan Rural Water Association in September 1990.
Dickinson	16,097	Dickinson had an adequate water supply in Lake Patterson for the summer and fall of 1991 but was scheduled to receive water from the southwest pipeline.
Edmore	329	Edmore received water from the Langdon Rural Water System.
Fargo	74,111	Fargo had an adequate water supply from Orwell Reservoir on Ottertail River, Minn., and backup storage in Lake Ashtabula. A ban placed on auxiliary water use (for example, lawn and garden sprinkling) in June 1988 was rescinded later in the summer.
Minot	34,544	Ground-water supplies remained fairly steady. However, in August 1990, Minot faced a serious water shortage. Because of voluntary usage cutbacks and timely cool weather and rains, the city did not have to impose water rationing.
Mohall	931	An alternate ground-water source was developed. Mohall received supplemental water supplies from the Northwest Rural Water Association.
Parshall	943	The U.S. Army Corps of Engineers installed a temporary intake to deeper water in Lake Sakakawea in December 1990.
Pembina	642	The water source was changed from the Pembina River to the Red River of the North.
Ryder	121	An alternate ground-water source was developed. Ryder received supplemental water supplies from the Northwest Rural Water Association.
Washburn	1,506	Intakes were out of water because of low water levels in the Missouri River.
Westhope	378	The water supply was dependent on the reservoir being refilled by the Souris River in the spring and fall.

[1]Data from North Dakota Division of Emergency Management (written commun., 1992, 1993) and North Dakota Census Data Center (written commun., 1991, 1992, 1993).

As the drought continued, water levels in individual wells became low or the wells went dry. In extreme cases, such as when well water supplies were depleted, rural homeowners either drilled new wells or joined a rural water users system if available. However, rural water users systems were not immune to the effect of the drought. For example, water for the Grand Forks-Traill Water Users, Inc., system (fig. 1) is obtained from the Elk Valley aquifer, which had a 4-foot water-level decline from 1987 to 1991. The volume of water pumped from 1985 to 1992, the approximate number of members billed, and the average level of the Elk Valley aquifer are given in the following table:

Year	Volume of water pumped (gallons)	Approximate number of members billed	Average level of Elk Valley aquifer (feet below land surface)
1985	237,216,400	1828	15.5
1986	219,410,410	1852	16.0
1987	249,279,400	1841	13.8
1988	278,253,000	1868	15.5
1989	284,452,000	1895	17.0
1990	[1]352,604,000	1911	17.8
1991	[1]321,867,000	1938	17.3
1992	[1]328,973,000	1966	[2]20.3

[1]The Grand Forks Air Force Base received 85,000,000 gallons of water (Randall Loeslie, System Manager, Grand Forks-Traill Water Users, Inc., written commun., 1992; oral commun., 1994).

[2]Center pivot installed near well in 1991; actual usage began in 1992.

From 1986 to 1989, the volume of water pumped increased 30 percent, but the approximate number of members billed increased only 2.3 percent. From 1989 to 1990, the volume of water pumped increased by 68,152,000 gallons. However, because this increase was caused by the delivery of 85,000,000 gallons of water to the Grand Forks Air Force Base, actual residential usage decreased from 1989 to 1992.

Irrigation and Agriculture

From 1977 to 1984, the total number of acres irrigated in North Dakota increased from 102,800 to more than 184,600 (North Dakota State Water Commission, written commun., 1994; fig. 12). Minor decreases occurred in 1979 and 1981. The overall increase was caused, in part, by a good farm economy, a drought from 1976 to 1978, and the increased use of reliable center pivots for irrigation (North Dakota State University Extension Service, 1992b). In 1986, the number of acres irrigated decreased to 171,400 because of greater-than-normal precipitation over most of the State that year. Drier conditions began to prevail across the State in 1987 and the total number of acres irrigated increased to 180,200. By 1992, the total number of acres irrigated had increased to 206,200. The increase was reflected by an increase in sales of irrigation systems and water-sprinkling systems (Tax Department, written commun., 1990).

The total volume of water used for irrigation in North Dakota during 1977-92 was dependent on climatic conditions and the availability of ground-water and surface-water sources. The total volume of water used for irrigation in 1977 was 151,000 acre-ft (North Dakota State Water Commission, written commun., 1994; fig. 13). By 1979, the total had decreased to 122,100 acre-ft and both ground-water and

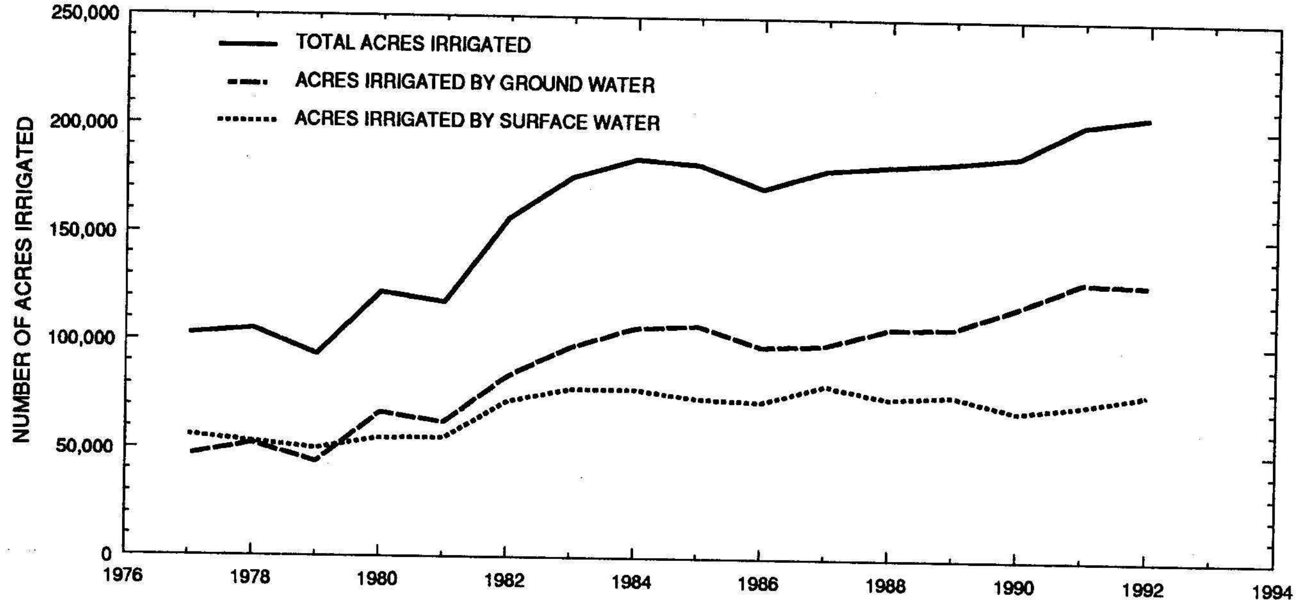


Figure 12. Number of acres irrigated in North Dakota during 1977-92.

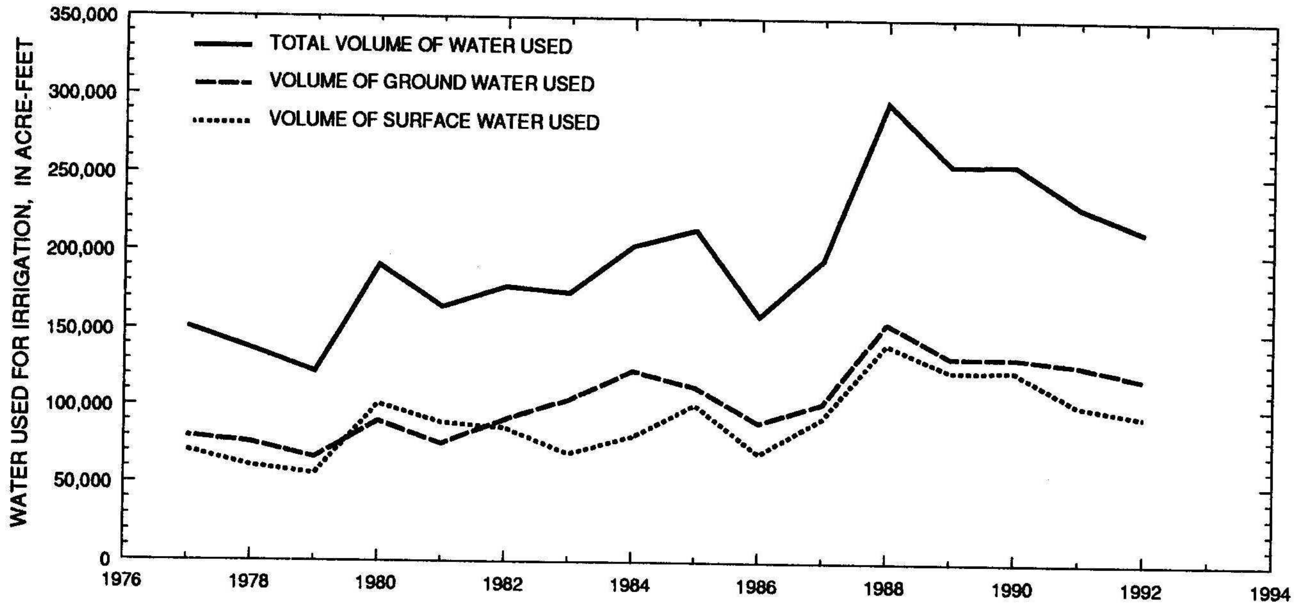


Figure 13. Volume of water used for irrigation in North Dakota during 1977-92.

surface-water usage had decreased. The decrease in the total volume of water used for irrigation in 1979 corresponded to a decrease in the total number of acres irrigated that same year. In 1980, the total volume of water used for irrigation increased to 191,000 acre-ft. The volume of surface water used to irrigate a total of 122,500 acres was slightly more than the volume of ground water used. In 1981, the volume of surface water used for irrigation was again more than the volume of ground water used for irrigation. These 2 years were the only years during the 1980's when surface-water usage was greater than ground-water usage. During the early to mid-1980's, as the total number of acres irrigated increased, the volume of ground water used for irrigation also increased. However, in 1986, the total volume of water used for irrigation decreased to 160,000 acre-ft. Both ground-water and surface-water usage also decreased because of greater-than-average precipitation across most of the State. From 1987 to 1992, the number of acres irrigated increased 14 percent. In 1988, the total volume of water used for irrigation peaked at 297,000 acre-ft and both ground-water and surface-water usage increased. The 1988 peak coincides with the driest year of the 1988-92 drought. Although the total number of acres irrigated continued to increase after 1988, both ground-water and surface-water usage decreased.

During periods of drought, surface-water sources are affected first. As the drought continues, the demand for irrigation water increases and ground-water sources also are affected. The demand for irrigation water can result in decreased water levels in aquifers, thereby causing decreased ground-water storage available for use. Farmers who had surface-water supplies, such as streams, dugouts, or shallow wells, affected by the 1988-92 drought used alternate water sources, petitioned for new water permits, or requested help from various government agencies.

The 1988-92 drought had a major effect on agriculture in North Dakota. Many farmers signed up for disaster relief or other subsidies because of the effect of the drought on crop yields. Under the Conservation Reserve Program (CRP), farmers allowed designated croplands (including some wetlands) to return to noncrop ground cover for 10 years in exchange for payments from the Federal government. Land placed in the program had to meet strict requirements. The most notable requirement was that the land be designated as highly erodable. No data are available on the number of farmers who signed up for the CRP solely because of the drought or on the number of irrigated acres placed in the program during the drought (Bob Mullenbach, Agriculture Stabilization and Conservation Service, oral commun., 1994). However, the number of CRP contracts accepted and the total number of acres in North Dakota that were placed in the program per year were larger during the drier years of the 1988-92 drought as shown in the following table:

Year	Number of contracts accepted[1]	Total number of acres in North Dakota that were placed in CRP[1]
1986	282	37,052.9
1987	3,441	562,892.9
1988	6,776	963,219.1
1989	4,882	715,090.6
1990	3,622	590,366.7
1991	76	13,347.2
1992	146	19,017.5

[1]Data from U.S. Soil Conservation Service (written commun., 1994).

Large crop yields are dependent on optimum soil conditions, ample water supplies, and proper growing temperatures. In North Dakota, crop yields were fairly consistent from the early to mid-1980's. During 1988, the effects of the drought intensified and many crop yields decreased to about half of what they were in 1987. However, by 1990, most crop yields had increased to what they were before the drought. Statewide average wheat yields from 1982 to 1992 are given in the following table:

Year	All wheat (bushels per acre)	Spring wheat (bushels per acre)	Durum wheat (bushels per acre)
1982	31.5	31.0	32.5
1983	26.9	27.0	26.5
1984	32.8	34.0	29.0
1985	36.4	37.0	35.5
1986	31.2	31.0	32.0
1987	29.5	31.0	26.0
1988	14.3	15.0	13.0
1989	23.5	24.0	22.0
1990	35.3	36.0	34.0
1991	31.0	31.0	31.0
1992	41.1	42.0	38.0

The yield trend was similar for many other crops during the drought. Crop yields were obtained from the North Dakota Agricultural Statistics Service (1981-93) in cooperation with the North Dakota State University and the U.S. Department of Agriculture.

Livestock

Livestock is an important aspect of North Dakota's agricultural industry. Because pasturelands were negatively affected as a result of decreasing water supplies, farmers and ranchers used alternate food sources, such as hay and grains, to feed livestock. The use of these alternate food sources placed a hardship on farmers and ranchers because of the higher cost, availability, and location of the alternate food sources. To ease the need for supplemental hay supplies, the North Dakota Department of Transportation and the Federal Highway Administration allowed haying of easements along highways and roads throughout the State (North Dakota Division of Emergency Management, written commun., 1990). Because of a decrease in precipitation, streams, wetlands, and stock ponds that are used to support livestock grazing became intermittent or nonexistent. As the water sources dried up, farmers and ranchers began to truck water to livestock, decrease the size of herds, or ship livestock to out-of-state locations. The number of head of inventoried livestock in North Dakota for January 1, 1981, to January 1, 1992, is given in the following table:

Year	Cattle[1] (thousands)	Hogs[1 2] (thousands)	Sheep[1] (thousands)	Chickens[1 2] (thousands)
1981	1,850	265	272	460
1982	2,000	280	280	500
1983	2,050	210	222	510
1984	2,100	260	219	625
1985	2,050	255	215	635
1986	2,000	285	180	540
1987	1,900	275	185	290
1988	1,800	320	169	315
1989	1,600	340	164	255
1990	1,700	280	186	240
1991	1,700	265	222	230
1992	1,800	290	214	210

[1]Data from North Dakota Agricultural Statistics Service (1981-93).

[2]Relates to December 1 of previous year.

With the exception of hogs, there was a general downward trend in the number of head of livestock from 1981 to 1992. In 1989, the numbers of cattle and sheep were at their lowest point of the decade, but, by 1990, the numbers had increased. The number of chickens continued a steady decline from 1985 to 1992 except during 1988.

The drought also had an effect on livestock through insect infestation and the buildup of certain chemicals in plants and water supplies. Insects, chemicals (such as nitrate) in crops, and blue-green algae in water supplies have always occurred naturally in the environment. However, during a drought, these problems may be enhanced. Certain parts of the State, such as Cass County, were plagued by an increase in the grasshopper population. As grasshopper habitats became affected by the drought, the grasshoppers moved to adjoining fields. Chemicals, such as nitrate, become more concentrated in plants that do not develop fully because of a lack of moisture. Livestock that forage on these drought-stressed crops may ingest too much nitrate, which is converted to nitrite in their digestive systems and which can be potentially lethal. Most nitrate poisoning cases in North Dakota involved drought-stressed oats, corn, and barley (Wohlgemuth and Casper, 1987). A similar scenario occurs when large concentrations of blue-green algae are found in livestock water supplies.

Fire

Fire is one of the primary hazards in North Dakota during a drought. The potential for fires, particularly rural grassland fires, is influenced by the amount and type of vegetation (fuel supply), less-than-normal precipitation, greater-than-normal temperatures, humidity, wind, topography, and human activity. Loss of human lives, livestock, and property can be considerable if action is not taken to mitigate conditions favorable to fire. The fire season in North Dakota is from April 1 to October 31; however, that time period may be extended if drought conditions persist (Bob Allen, Fire Marshal, oral commun., 1992).

The North Dakota Division of Emergency Management and appropriate State agencies assess the rural fire danger situation in cooperation with the National Weather Service. Other State and Federal agencies render assistance when warranted.

The National Weather Service assesses the rural fire danger situation daily and issues a rural fire danger index statement when warranted. The National Weather Service uses two methods to determine the rural fire danger index. In the first and primary method, meteorological data obtained by satellite are used. In the second and backup method, meteorological data and "percent-of-green data" are used. "Percent-of-green data" are obtained by observing the amount of green grass versus dry grass in a randomly selected section in an 8-inch by 18-inch rectangle. After the rural fire danger situation has been determined, the National Weather Service issues a rural fire danger index statement if conditions warrant a very high or extreme rating. The ratings are determined on the basis of a combination of climatic variables, such as relative humidity, temperature, cloud cover, fuel moisture, and windspeed (Sam Walker, Meteorologist, National Weather Service, oral commun., 1994).

Actions to be taken during normal, very high, and extreme fire danger index ratings (table 5) were issued by the North Dakota Division of Emergency Management (no date) and the Fire Marshal (1991). During the designated fire season, actions to be taken in rural areas during very high and extreme fire danger index ratings are mandatory for all public lands. If the fire danger situation worsens, the Governor can issue an emergency declaration. Actions to be taken then are mandatory for both public and private lands.

Even if necessary precautions are taken, fires still occur in North Dakota. The number of grassland fires reported in North Dakota from 1987 to 1992 is given in the following table:

Year	Number of grassland fires reported[1]
1987	472
1988	1,003
1989	652
1990	563
1991	479
1992	447

[1]Data from Bob Allen (Fire Marshal, oral commun., 1992, 1994).

The number of grassland fires reported increased 112 percent from 1987 to 1988, probably because the public did not realize how dry the grasslands were after 1987. In fact, 1988 was one of the State's worst years for rural grassland fires (North Dakota Division of Emergency Management, 1989a). After public awareness of the drought conditions rose and appropriate actions were taken to mitigate the fire danger, the number of fires declined.

Recreation

Tourism, including outdoor recreation, is the fifth major contributor to North Dakota's economic base (North Dakota Census Data Center and North Dakota State University, 1991). Many North Dakotans, as well as out-of-state visitors, enjoy water-related activities, such as boating and fishing, on the State's many reservoirs, lakes, and rivers. However, during the 1988-92 drought, water levels in most of the reservoirs, lakes, and rivers were less than normal because of low runoff and a small amount of precipitation. Because of lower-than-normal water levels, access to boat ramps was limited and, even after the ramps were extended, boating was hampered because of the shallowness of bays and inlets (Jerry Weigel, Game and Fish Department, oral commun., 1993). The lower-than-normal water levels also affected fishing in many areas and caused a decrease in the number of visitors to State parks (North Dakota Parks and Tourism Department, written commun., 1992). For example, the number of visitors to Lake Sakakawea State Park decreased 26 percent from 1987 to 1990. Because of the decrease in the number of visitors to State parks, losses were recorded at businesses in nearby towns and many lakeside concessions were closed.

Table 5. Actions to be taken during normal, very high, and extreme fire danger index ratings

[From North Dakota Division of Emergency Management (no date); Actions are cumulative (for example, actions in the extreme column include those in the very high column and actions in the very high column include those in the normal column]

	Fire danger index rating		
	Normal	**Very high**	**Extreme**
Open campfires	Cleared area around fire. Shovel and bucket recommended for campers.	Restrict campfires to constructed fireplaces in developed campgrounds.	Prohibit all campfires, including charcoal fires, in rural areas and campgrounds. Permit gas or propane stoves only.
Trash burning	Recommend a screened container.	Restrict trash burning to early morning and evening hours.	Prohibit trash burning.
Brush burning	Clearing around brush required. Attendance and tools required.	Restrict to early morning and late afternoon with low wind conditions.	Prohibit brush burning.
Field, ditch, and roadway burning	Plowed or fuel-free strip around field recommended.	Restrict to early morning and late afternoon with low wind conditions. Attendance and tools required.	Prohibit field, slough, pothole, ditch, and roadway burning.
Farm machinery	Routine maintenance to reduce debris accumulation. Carry a fire extinguisher.	Frequent maintenance during day to reduce debris accumulation. Exhaust, brake checks.	Remain at site one-half hour after operations are completed.
Personal-use fireworks	Make public aware of conditions that may contribute to fire danger.	Restrict use to late afternoon and evening hours with low wind conditions. Attendance and tools required.	Prohibit use of fireworks by individuals.

Lake Sakakawea and Lake Oahe (fig. 1), located on the Missouri River, are popular fishing, boating, and camping areas. Three State parks--Fort Stevenson State Park, Lake Sakakawea State Park, and Lewis and Clark State Park (fig. 1)--are located on the shores of Lake Sakakawea. The number of visitors to the State parks located on the shores of Lake Sakakawea and the average annual lake elevation of Lake Sakakawea from 1987 to 1992 are given in the following table:

Year	Number of visitors[1 2]				Average annual lake elevation[3] (feet)
	Fort Stevenson State Park	Lake Sakakawea State Park	Lewis and Clark State Park	Total	
1987	106,896	199,646	50,598	357,140	1,841.0
1988	120,966	195,897	43,771	360,634	1,829.3
1989	104,070	166,290	29,066	299,426	1,823.3
1990	109,620	158,859	20,470	288,949	1,820.7
1991	59,448	197,597	45,532	302,577	1,822.5
1992	68,670	195,516	50,414	314,600	1,821.8

[1]Data from Doug Eiken (North Dakota Parks and Tourism Department, written commun., 1992).

[2]Data from Donna Schouweiler (North Dakota Parks and Tourism Department, oral commun., 1993).

[3]Data from U.S. Geological Survey (1944-92).

In contrast to the number of visitors to State parks, the number of visitors to Theodore Roosevelt National Park in western North Dakota did not decrease during the drought. Although there was a very slight decrease in the number of visitors in 1988, the overall trend was a slight increase from 1987 through 1992. Water levels in the Little Missouri River were down, but the effect on park visitors varied. Because of the low water levels, the river was easier to cross during hiking and horseback riding. However, canoe trips on the river were hindered by the low water levels. The drought also had an effect on grazing and on certain vegetation in the park. Grazing generally was limited to areas near water supplies that were not depleted, such as areas near flowing wells. Berry plants that are dependent on adequate moisture may have decreased in number or disappeared entirely from certain areas within the park. These berry plants were food sources for certain birds and animals in the park (Bob Powell, National Park Service, oral commun., 1993).

Water levels on the Missouri River also were affected by regulation of Garrison Dam by the U.S. Army Corps of Engineers. The U.S. Army Corps of Engineers is responsible for the operation and maintenance of dams along the Missouri River. Scheduled releases are planned for the mutual benefit of all states and fish and wildlife in the Missouri River Basin. However, after water levels in many reservoirs and in the river were affected by the drought, the volume of water released was debated by the Missouri River Basin states and the U.S. Army Corps of Engineers (U.S. Water News, 1992). According to the upper Missouri River Basin states, the volume of water released should have been limited in order to maintain upstream water supplies and recreational activities. According to the lower Missouri River Basin states, the volume of water released should have been increased in order to maintain downstream water supplies and river traffic (Davidson, 1990). This issue resulted in numerous lawsuits, many of which are still pending (Bismarck Tribune, written commun, 1991).

Fish and Wildlife

Beginning in 1987, most, if not all, fish species were adversely affected by decreasing water levels in Lake Sakakawea and Lake Oahe. Walleye populations in North Dakota have decreased in recent years. A healthy, reproductive class of walleye is needed every 2 to 3 years to sustain a healthy fishery. During the last 11 years (1982-92), only 1982 and 1986 had healthy, reproductive classes of walleye. Walleye reproduction is dependent on a high lake elevation when walleye spawning areas can be inundated. In

Lake Sakakawea, most walleye habitats are more than 1,830 feet above sea level. The average annual lake elevation during 1987-92 ranged from 1,820.7 feet above sea level in 1990 to 1,841.0 feet above sea level in 1987. The lowest average monthly lake elevation during the 1988-92 drought was 1,815.6 feet above sea level in April 1991.

Smelt and salmon populations also are affected by changes in lake elevations. These fish require cold-water habitats, which are habitats that have water temperatures of less than 15.6°C and dissolved-oxygen concentrations of more than 5 mg/L. During the 1988-92 drought, the number of cold-water habitats in lakes was reduced. Because of this reduction, smelt species began to concentrate in remaining cold-water habitats. As a result, an estimated 300,000 smelt died in the Indian Hills area of Lake Sakakawea in 1990 (Greg Powers, Game and Fish Department, written commun., 1990). Because of the disease-free status of salmon in Lake Sakakawea, only salmon offspring from Lake Sakakawea are used to restock the lake. If the salmon population decreases because of a limited number of cold-water habitats, the number of salmon eggs available for restocking purposes also decreases.

Fish populations in cold-water habitats in the Missouri River downstream from Garrison Dam also were affected by low water levels. Not all fish kills were detrimental, however. Undesirable fish, such as bullheads, carp, and white suckers, were eliminated from some areas in the State during the drought (Jerry Weigel, Game and Fish Department, oral commun., 1993). The limited number of fish and the inaccessibility to many of the State's reservoirs, lakes, and rivers affected the number of fishing licenses issued by the State during the drought. The number of licenses issued from 1987 to 1992 is given in table 6.

Table 6. Number of North Dakota fishing licenses issued to residents and nonresidents from 1987 to 1992

Year	Number of licenses issued to residents[1]	Number of licenses issued to nonresidents[1]	Total number of licenses issued[1]
1987	141,995	19,721	161,716
1988	133,805	18,661	152,466
1989	125,172	[2]21,214	146,386
1990	113,093	16,906	129,999
1991	102,869	14,044	116,913
1992	100,256	14,324	114,580

[1]Data from Jerry Weigel (Game and Fish Department, oral commun., 1992, 1994).

[2]Increase attributed to magazine article that reported excellent perch fishing at Devils Lake, N. Dak., for this year (Jerry Weigel, Game and Fish Department, oral commun., 1992).

North Dakota issues hunting licenses for a wide variety of animals ranging from deer and elk to small game birds. The animal population is dependent on climatic and habitat conditions, including the availability of food and water.

North Dakota is part of a major flyway for a number of species of migratory game birds. Millions of migratory birds are attracted annually to the wetlands in North Dakota. These wetlands are suitable for the habitation and reproduction of many of these birds. One species of migratory game birds that can be adversely affected rather quickly by drought is waterfowl. Waterfowl include ducks, geese, and swans as well as other migratory game birds.

The duck population in North Dakota depends on the volume of water that is available. If water levels in lakes in North Dakota are high at the time of migration, the possibility exists that more ducks will nest in the State. If water levels are low, there is more competition among ducks and other waterfowl for suitable wetlands for habitation. Therefore, ducks and other waterfowl may migrate to more hospitable areas out of State. Annual surveys are conducted by the Game and Fish Department, the U.S. Fish and Wildlife Service, and other agencies to determine the population and species count of migratory birds nesting in North Dakota and the number of ponds that serve as nesting areas. The surveys also are used to determine a fall duck forecast for North Dakota and to establish waterfowl hunting regulations. The number of waterfowl hunters, the number of ponds that serve as nesting areas, and the duck population from 1986 to 1992 are given in the following table:

Year	Number of waterfowl hunters[1]	Number of ponds that serve as nesting areas[1]	Duck population[1]
1986	49,660	1,231,000	1,821,000
1987	48,400	424,200	1,624,000
1988	31,060	241,400	1,827,000
1989	35,170	344,600	1,274,000
1990	33,050	141,300	1,092,000
1991	33,790	394,400	768,300
1992	--[2]	247,300	1,357,000

[1]Data from Michael A. Johnson (Game and Fish Department, oral and written commun., 1992) and Ronald E. Reynolds (U.S. Fish and Wildlife Service, oral and written commun., 1992).

[2]Data not available.

From 1986 to 1991, the number of waterfowl hunters decreased 32 percent, the number of ponds that serve as nesting areas decreased 68 percent, and the duck population decreased 58 percent. It is uncertain how much of these decreases can be attributed only to the drought and how much can be attributed to other factors, such as human disturbance. Although the populations of certain species of waterfowl, such as ducks, have decreased, the populations of other waterfowl species, such as geese, have increased. The increase in the geese population may be attributed to the introduction of the species to suitable nesting habitats in remote areas that are free from human disturbance and that have crop lands for a food source. It is difficult to distinguish between the effect of human and environmental disturbances and the effect of drought on populations of migratory birds in North Dakota (Michael A. Johnson, Game and Fish Department, oral commun., 1992).

COMPARISON OF THE 1988-92 DROUGHT TO PREVIOUS DROUGHTS

Many droughts, some minor and some very severe, have occurred in North Dakota. Perhaps the most notable drought in recent North Dakota history occurred during the 1930's to early 1940's. Known as the "dust bowl days," this drought had a drastic effect on every aspect of life in North Dakota and in many other states as well. Other notable droughts occurred in North Dakota during the 1950's to early 1960's, the mid- to late 1970's, and the early 1980's. These droughts are compared to the 1988-92 drought by the use of various hydrologic indices.

The intensity and duration of a water-supply shortage can be used to determine the severity of a drought. For each climatic division in North Dakota, at least one year and one summer during most of the major droughts was one of the 10 driest years and 10 warmest summers from 1895 through 1992. The 10 driest years for each of the nine climatic divisions are given in table 7. Of the 90 driest years given in table 7, 29 occurred during the 1930's, 15 occurred during the 1910's, and 12 occurred during 1988-92. The 10 warmest summers (June-August average) for each of the nine climatic divisions are given in table 8. Of the 90 warmest summers given in table 8, 27 occurred during the 1930's, 17 occurred during 1988-92, and 13 occurred during the 1970's. The accumulated departure from the mean monthly precipitation for a 3-year period during each of four droughts is shown in figure 14. The 3-year period for each drought represents the driest years (table 7) and the warmest summers (table 8) that are common to most of the climatic divisions. The intensity of a water-supply shortage is indicated by the steepness (slope) of the accumulated departure line and the duration is indicated by the length of time the shortage continues. The severity of a drought is a combination of the intensity and duration of the water-supply shortage. As shown in figure 14, a severe period of the 1930's to early 1940's drought occurred during 1934-36; a severe period of the 1950's to early 1960's drought occurred during 1959-61; a severe period of the mid- to late 1970's drought occurred during 1976-78; and a severe period of the late 1980's to early 1990's drought occurred during 1987-89. The severe period of the 1950's to early 1960's drought and the severe period of the late 1980's to early 1990's drought were not as long in duration as the severe period of the 1930's to early 1940's drought, but the intensity of the three periods was very similar as indicated by the steepness of the accumulated departure line. The severity of the late 1980's to early 1990's drought was greater than that of the 1950's to early 1960's drought. The 1988-92 drought was the second most severe drought since 1930. The severity of the 1950's to early 1960's drought was similar to that of the mid- to late 1970's drought.

Table 7. The 10 driest years from 1895 through1992 for each climatic division in North Dakota

Climatic division	1	2	3	4	5	6	7	8	9	10
Northwest	1934	1931	1961	1917	1936	1958	1979	1960	1952	1967
North central	1934	1936	1917	1992	1961	1988	1931	1976	1958	1939
Northeast	1917	1952	1936	1988	1934	1933	1910	1976	1939	1938
West central	1936	1934	1988	1917	1961	1992	1979	1910	1952	1931
Central	1936	1988	1934	1917	1976	1910	1907	1992	1961	1967
East central	1936	1976	1910	1917	1934	1938	1939	1963	1967	1907
Southwest	1936	1934	1988	1917	1952	1990	1949	1980	1979	1960
South central	1936	1934	1917	1988	1952	1933	1913	1974	1990	1959
Southeast	1936	1976	1910	1952	1917	1934	1933	1988	1907	1987

The Palmer Drought Severity Index is a widely used index to characterize drought severity. This index takes into account precipitation, evapotranspiration, and soil-moisture conditions, all of which are used to determine a hydrologic drought. The Palmer Drought Severity Index is readily available and standardized to facilitate direct comparisons between regions. Values for the Palmer Drought Severity Index are given in the following table:

Palmer Drought Severity Index values	Class
≥4.00	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
.50 to .99	Incipient wet spell
.49 to -.49	Near normal
-.50 to -.99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
≤-4.00	Extreme drought

The Palmer Drought Severity Index for all nine climatic divisions from 1895 through 1992 is shown in figure 15. The major droughts occurred during the 1930's to early 1940's, the 1950's to early 1960's, the mid- to late 1970's, and the late 1980's to early 1990's. As shown in figure 15, the 1930's to early 1940's drought was the most severe drought from 1895 through 1992, and the 1988-92 drought was the second most severe. Palmer Drought Severity Index values exceeded -8.0 at times during the 1930's to early 1940's drought and during the 1988-92 drought. The number of months during each major drought that were classified as extreme (Palmer Drought Severity Index values less than or equal to -4.0) is given in table 9 for each of the nine climatic divisions.

Table 8. The 10 warmest summers (June-August average) from 1895 through1992 for each climatic division in North Dakota

Climatic division	1	2	3	4	5	6	7	8	9	10
Northwest	1988	1961	1936	1937	1983	1933	1984	1931	1970	1989
North central	1988	1936	1961	1933	1983	1970	1989	1919	1991	1931
Northeast	1988	1983	1933	1936	1961	1963	1991	1970	1921	1955
West central	1988	1936	1961	1933	1983	1991	1937	1970	1984	1959
Central	1988	1936	1983	1933	1961	1970	1963	1959	1976	1991
East central	1936	1988	1933	1983	1970	1921	1955	1976	1959	1963
Southwest	1936	1988	1933	1961	1937	1983	1991	1959	1931	1970
South central	1936	1988	1933	1961	1959	1934	1983	1991	1937	1976
Southeast	1936	1988	1983	1933	1976	1959	1970	1921	1937	1973

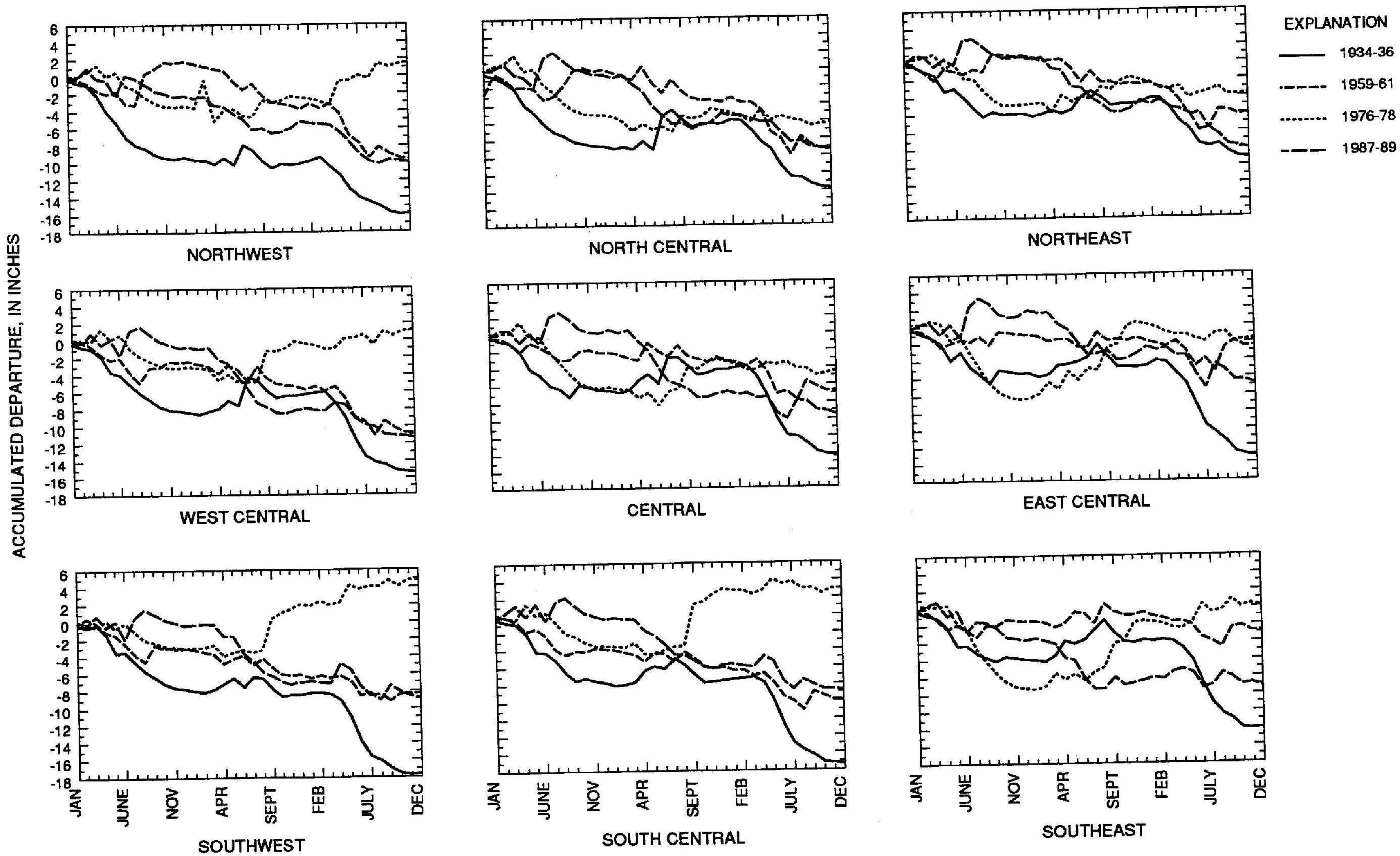


Figure 14. Accumulated departure from mean monthly precipitation for a 3-year period for each climatic division in North Dakota.

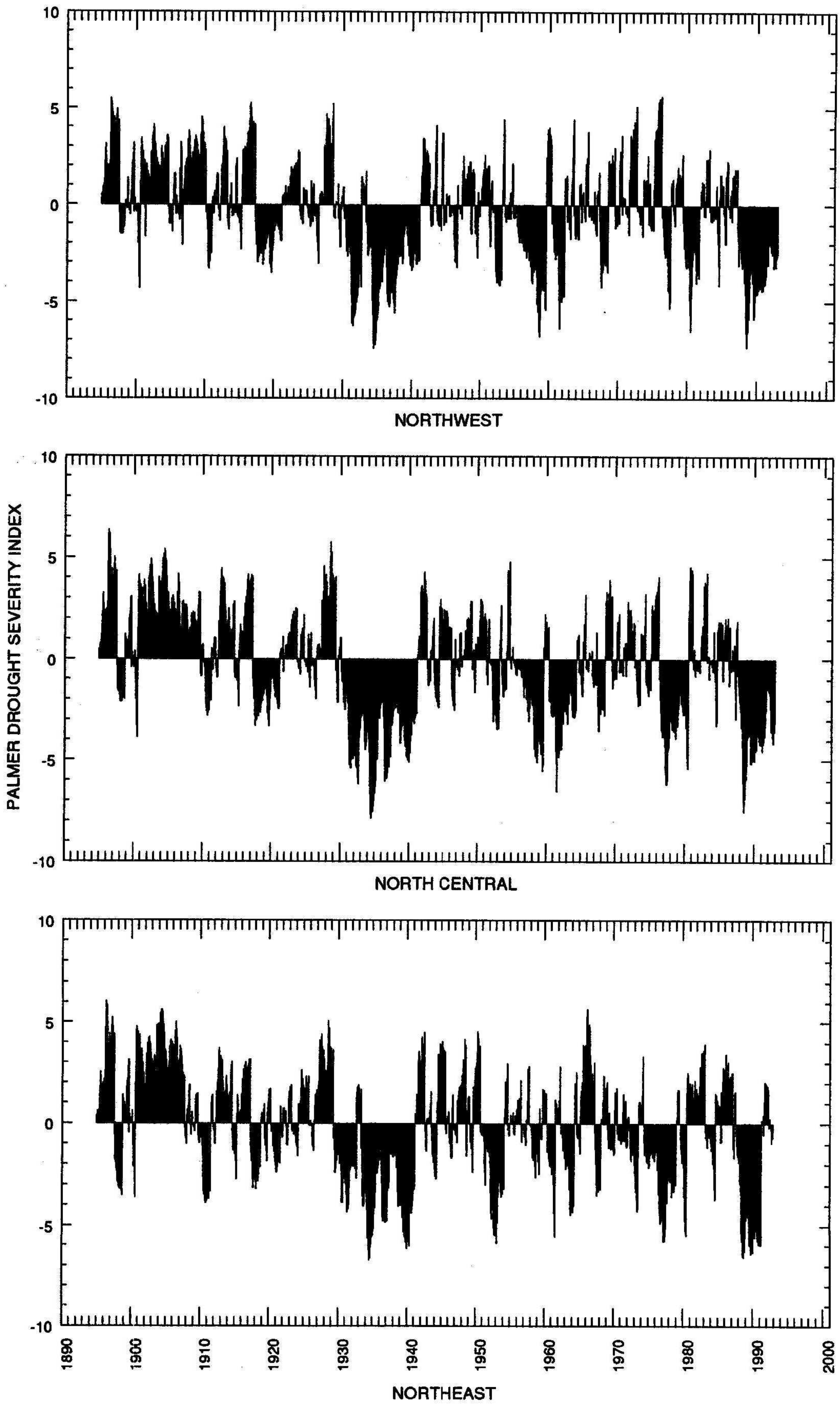


Figure 15. Palmer Drought Severity Index for each climatic division in North Dakota.

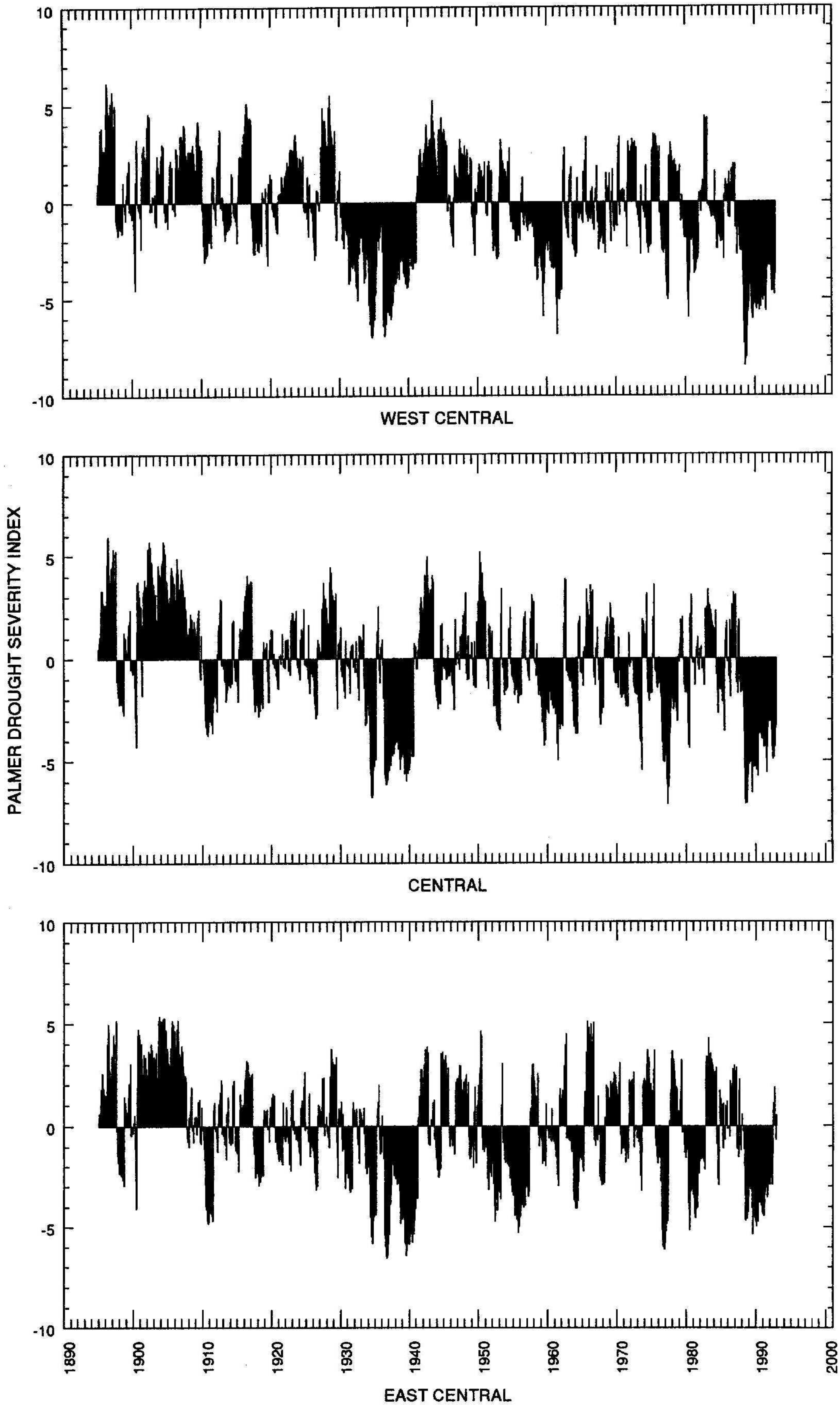


Figure 15. Palmer Drought Severity Index for each climatic division in North Dakota--Continued.

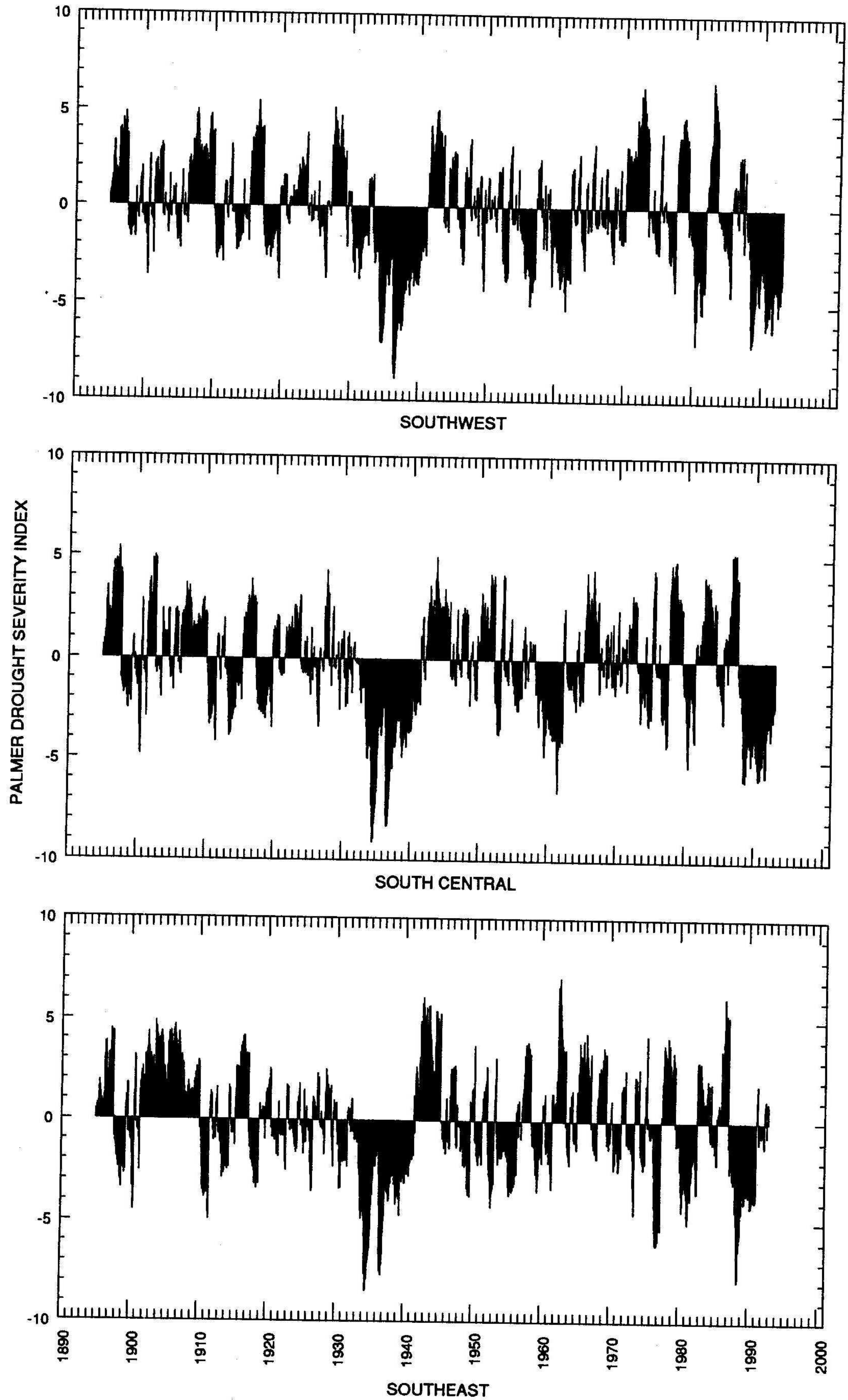


Figure 15. Palmer Drought Severity Index for each climatic division in North Dakota--Continued.

Table 9. Number of months during each major drought that were classified as extreme (Palmer Drought Severity Index less than or equal to -4.0) for each climatic division in North Dakota

Drought	Number of months
Northwest	
1930's to early 1940's	42
1950's to early 1960's	32
Mid- to late 1970's and early 1980's	11
1988-92	28
North central	
1930's to early 1940's	59
1950's to early 1960's	23
Mid- to late 1970's and early 1980's	11
1988-92	29
Northeast	
1930's to early 1940's	50
1950's to early 1960's	21
Mid- to late 1970's and early 1980's	15
1988-92	35
West central	
1930's to early 1940's	48
1950's to early 1960's	13
Mid- to late 1970's and early 1980's	8
1988-92	48
Central	
1930's to early 1940's	56
1950's to early 1960's	5
Mid- to late 1970's and early 1980's	15
1988-92	36
East central	
1930's to early 1940's	48
1950's to early 1960's	16
Mid- to late 1970's and early 1980's	18
1988-92	20
Southwest	
1930's to early 1940's	39
1950's to early 1960's	9
Mid- to late 1970's and early 1980's	14
1988-92	42
South central	
1930's to early 1940's	42
1950's to early 1960's	10
Mid- to late 1970's and early 1980's	7
1988-92	34
Southeast	
1930's to early 1940's	33
1950's to early 1960's	1
Mid- to late 1970's and early 1980's	16
1988-92	14

Streamflow records are another means of comparing droughts. The accumulated departure from mean monthly flow over time may be used to determine periods of a water-supply shortage or surplus. The accumulated departure from mean monthly flow for six representative streamflow-gaging stations is shown in figure 16. As stated earlier, the severity of a drought is a combination of the intensity and duration of a water-supply shortage. For example, the Wild Rice River near Abercrombie, N. Dak., gaging

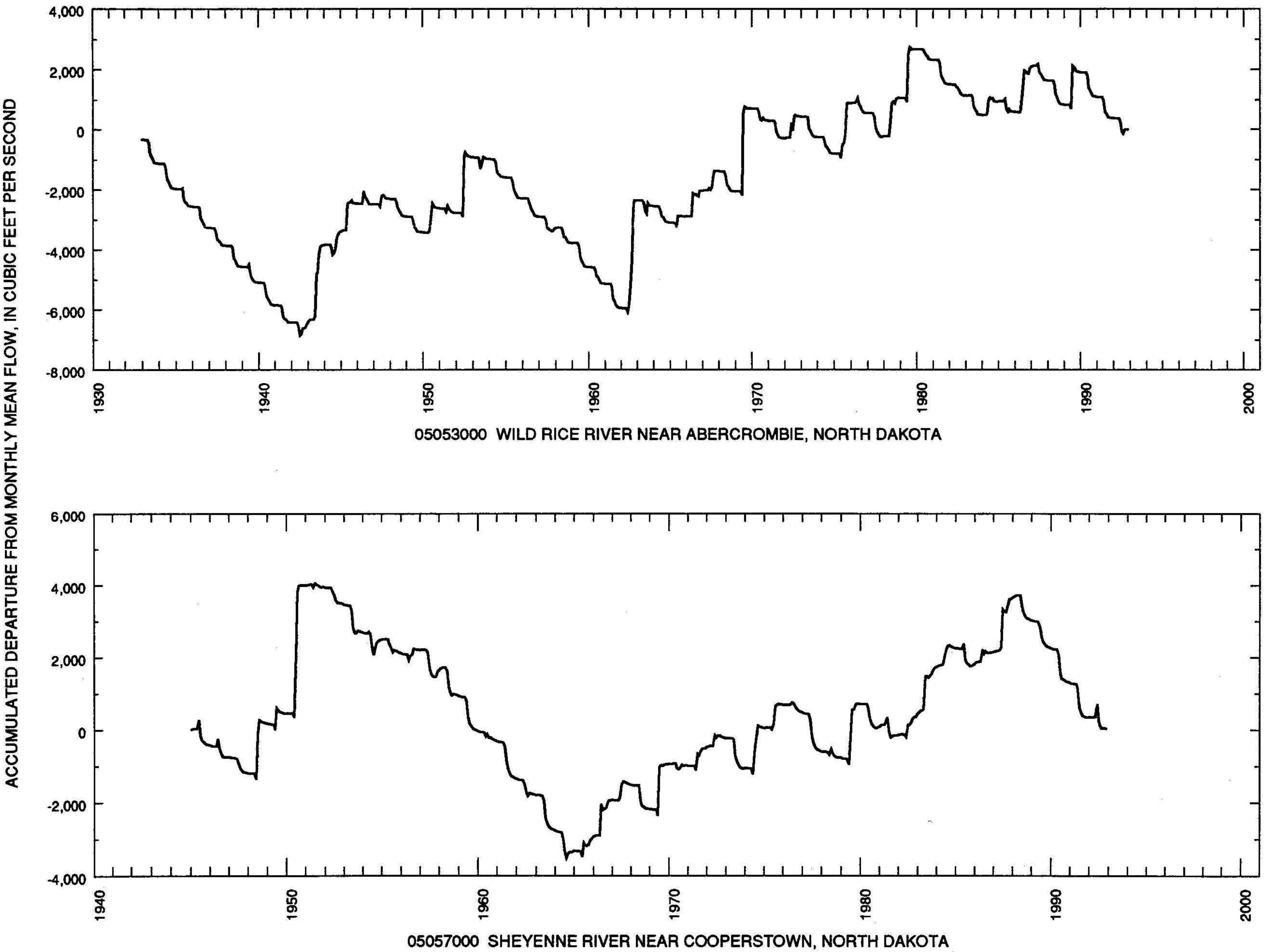


Figure 16. Accumulated departure from mean monthly flow for six representative streamflow-gaging stations in North Dakota.

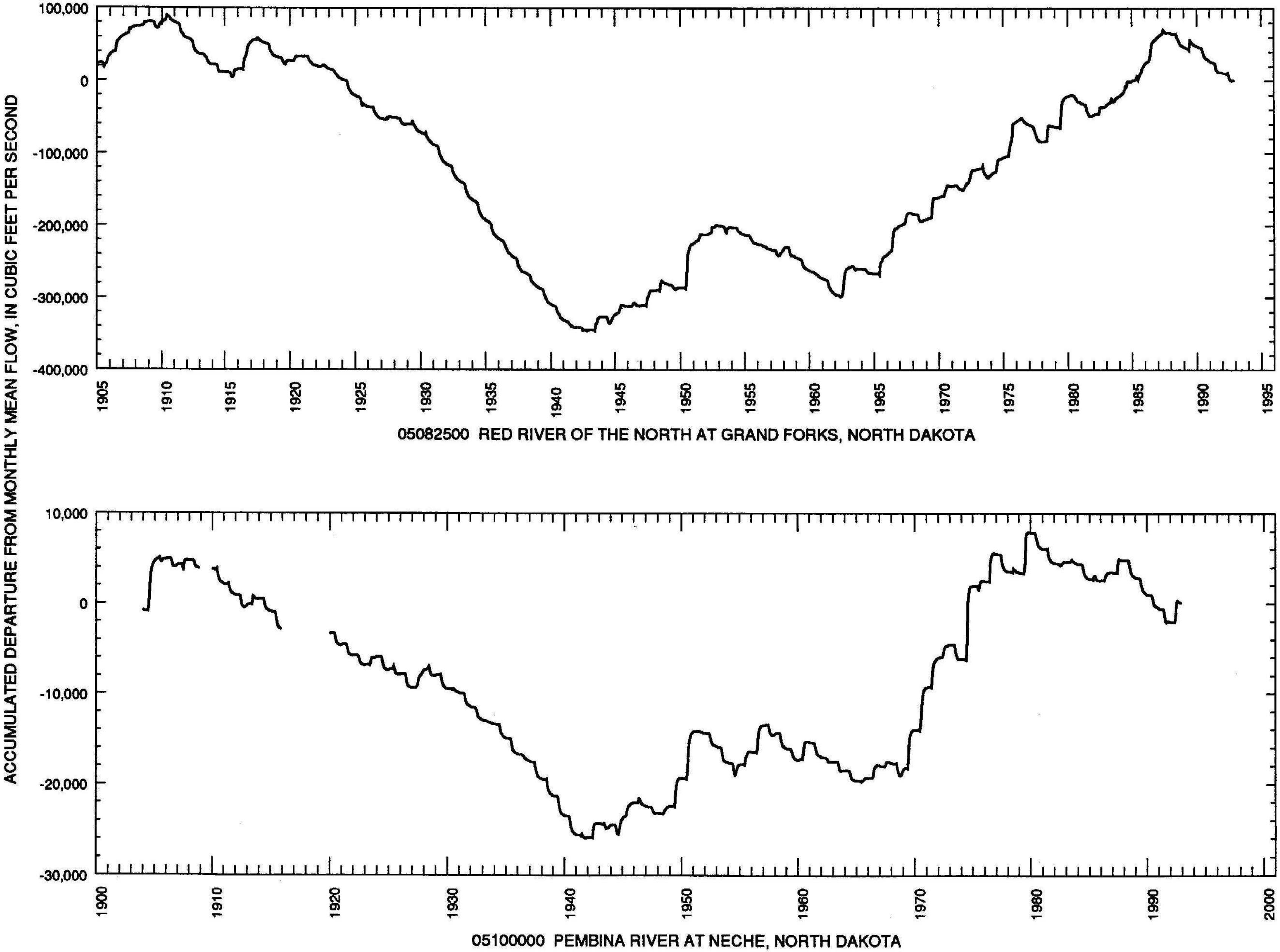
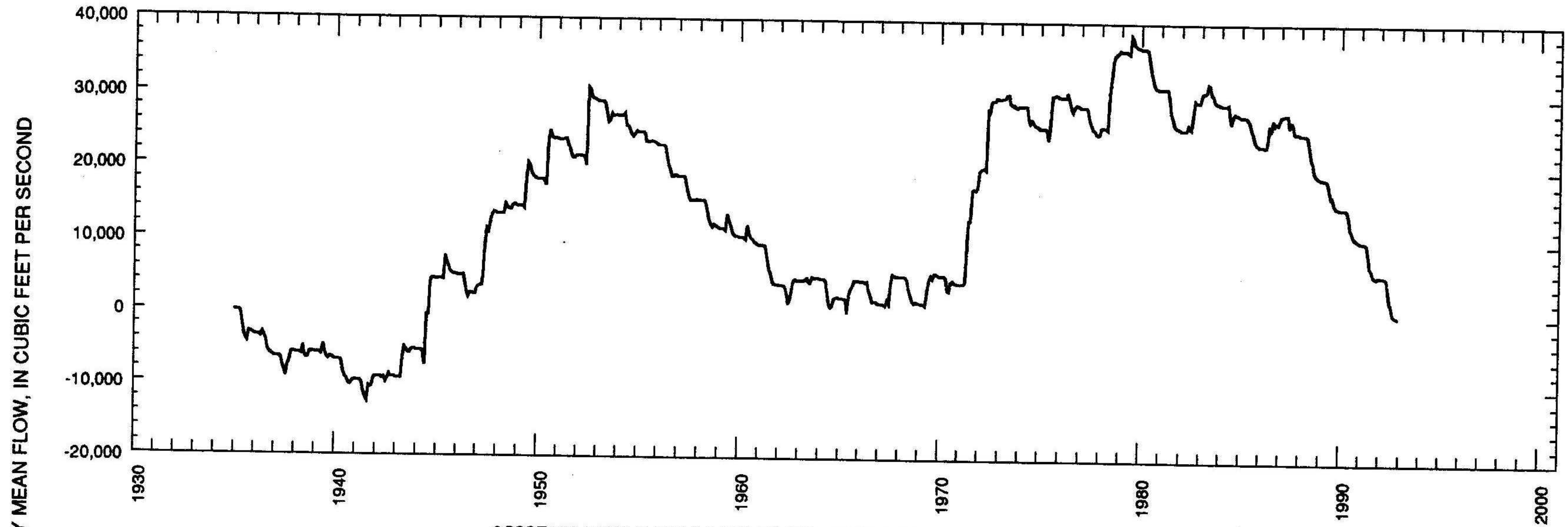
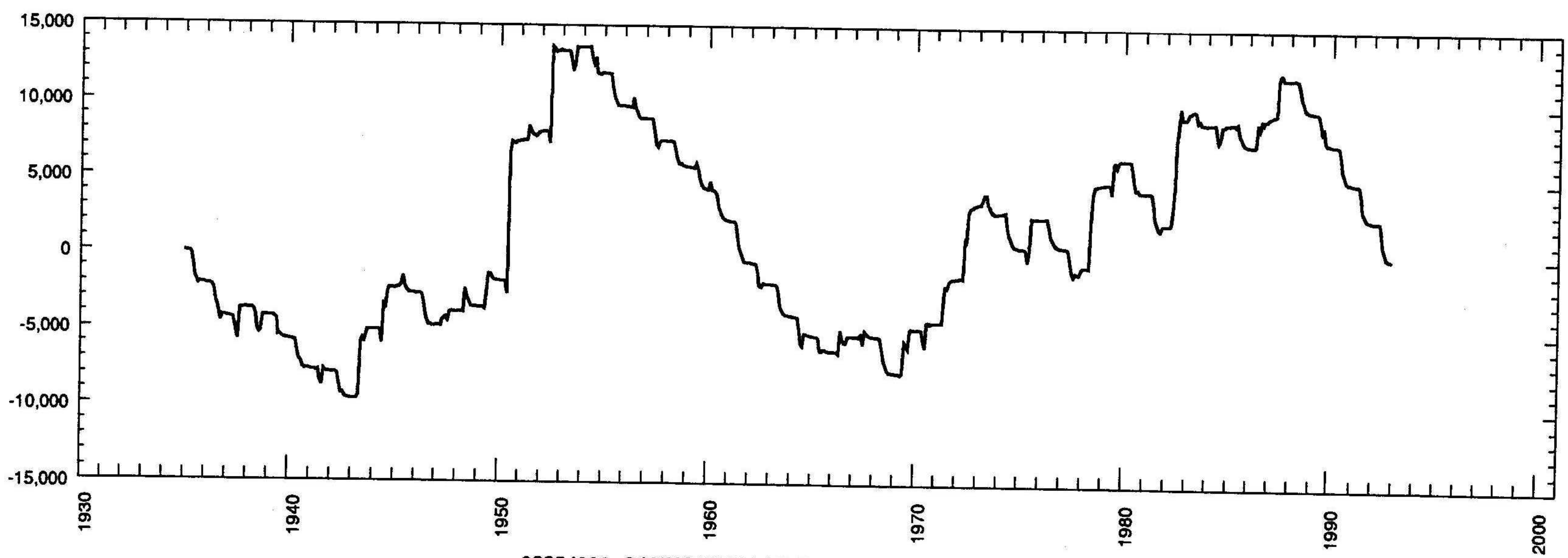


Figure 16. Accumulated departure from mean monthly flow for six representative streamflow-gaging stations in North Dakota--Continued.



06337000 LITTLE MISSOURI RIVER NEAR WATFORD CITY, NORTH DAKOTA



06354000 CANNONBALL RIVER AT BREIEN, NORTH DAKOTA

Figure 16. Accumulated departure from mean monthly flow for six representative streamflow-gaging stations in North Dakota--Continued.

station (05053000) had severe water-supply shortages during the 1930's to early 1940's drought and during the 1950's to early 1960's drought as indicated by the steepness of the accumulated departure line and the length of time the shortage continued. Statewide droughts occurred in North Dakota from about 1929 to 1942 and 1952 to 1962. The recurrence interval for both of these droughts exceeded 25 years. A drought occurred primarily in the south-central part of the State from about 1972 to 1977. The recurrence interval for that drought exceeded 10 years but did not exceed 25 years (Ryan, 1991).

The occurrence of the 1988-92 drought in North Dakota resulted in some changes in the recurrence intervals determined by Ryan (1991) because of increased years of record. Recurrence intervals were calculated from streamflow records by use of the method described by Furness (1962). Recurrence intervals for each major drought at six representative streamflow-gaging stations are given in table 10. Recurrence interval in this context refers to the average number of years before a drought of certain intensity and duration will reoccur. Recurrence intervals for the 1930's to early 1940's drought ranged from 25 to 74 years, and recurrence intervals for the 1950's to early 1960's drought ranged from 26 to 50 years. The recurrence intervals for both of these droughts were comparable to the recurrence intervals determined by Ryan (1991). Recurrence intervals for the mid- to late 1970's and early 1980's drought ranged from 5 to 58 years. Ryan (1991) used a slightly different period to determine those recurrence intervals. Recurrence intervals for the 1988-92 drought ranged from 19 to 54 years.

Table 10. Recurrence intervals for each major drought at six representative streamflow-gaging stations in North Dakota

Streamflow-gaging station	Recurrence intervals			
	1930's to early 1940's	1950's to early 1960's	Mid- to late 1970's and early 1980's	1988-92
05053000, Wild Rice River near Abercrombie, North Dakota	52	26	14	19
05057000, Sheyenne River near Cooperstown, North Dakota	--[1]	37	5	45
05082500, Red River of the North at Grand Forks, North Dakota	66	27	30	28
05100000, Pembina River at Neche, North Dakota	74	27	16	42
06337000, Little Missouri River near Watford City, North Dakota	27	50	29	54
06354000, Cannonball River at Breien, North Dakota	25	49	58	27

[1]Data not available.

Average annual streamflows for selected gaging stations during water years of the 1930's and water years from 1988 through 1992 are shown in figure 17. Generally, annual streamflows during the 1988-92 drought were as low or lower than annual streamflows during the 1930's to early 1940's drought, except at the Red River of the North at Fargo, N. Dak., gaging station (05054000) and at the Red River of the North at Grand Forks, N. Dak., gaging station (05082500). Before regulation, streamflows at these two gaging stations were severely affected by the 1930's to early 1940's drought. Regulation on the Red River of the North lessened the effect of the 1988-92 drought but may not have been the only cause of additional water.

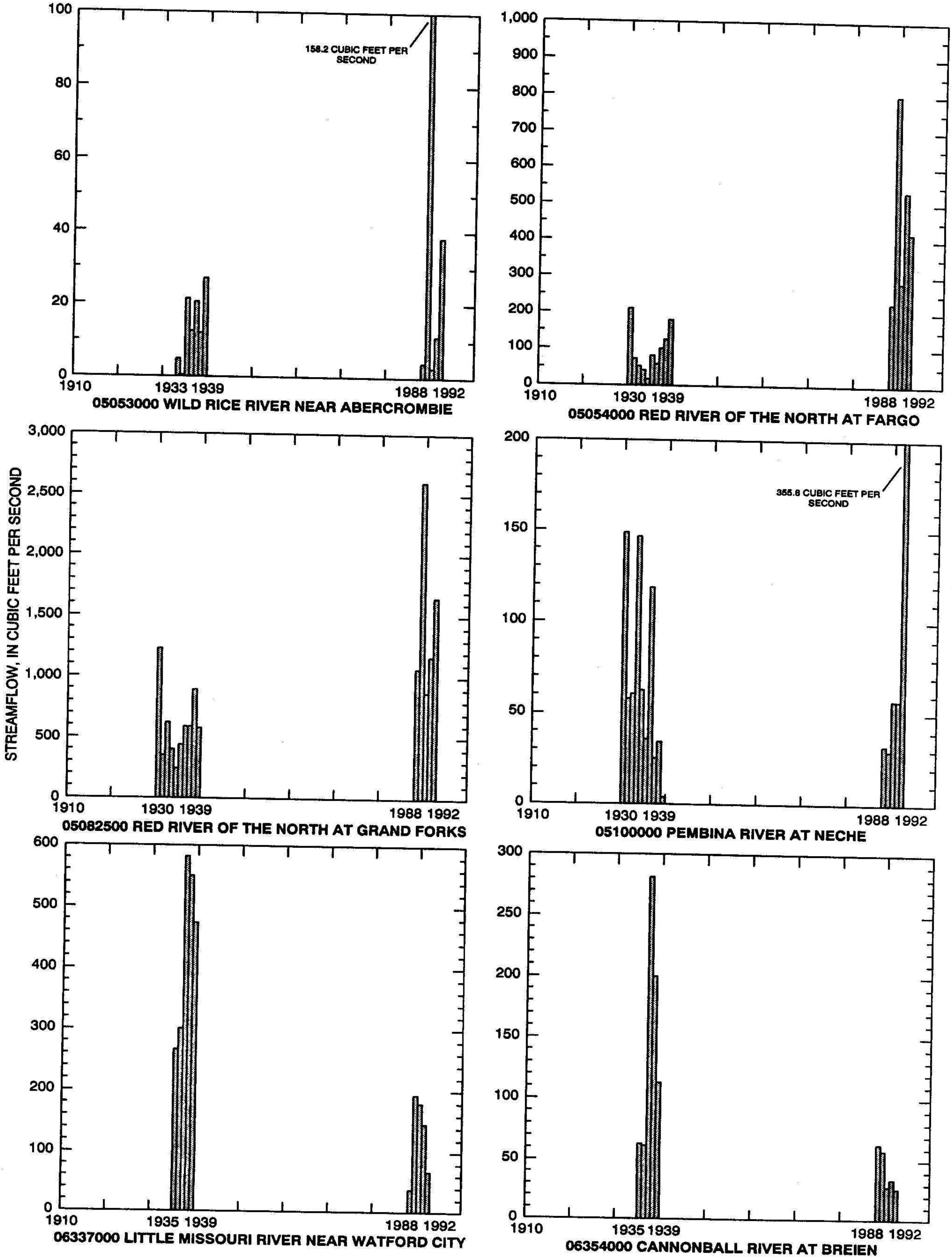


Figure 17. Average annual streamflows for selected gaging stations in North Dakota during water years of the 1930's and water years from 1988 through 1992.

Tributaries in Minnesota contributed inflow as well, indicating that the 1988-92 drought may not have affected streams in Minnesota as severely as streams in North Dakota. The high average annual streamflows that occurred during 1989 and 1992 at the Wild Rice River near Abercrombie, N. Dak., gaging station (05053000) and during 1992 at the Pembina River at Neche, N. Dak., gaging station (05100000) were the result of spring snowmelt or summer storms that occurred for only a month or two and, thus, biased the annual average streamflow.

Water levels of lakes can be excellent indicators of drought conditions provided human influence is not too great. Because water levels of lakes fluctuate according to current climatic conditions, the water level of Devils Lake, N. Dak., is a good example of the effect a drought can have on water levels. Water levels of Devils Lake from 1867-1992 are shown in figure 18. As indicated in figure 18, severe water-level declines occurred during 1902-40, 1956-69, and 1987-92. Three major droughts that occurred during the 1930's to early 1940's, the 1950's to early 1960's, and 1988-92 contributed to the severe water-level declines of Devils Lake. Corresponding precipitation records, streamflow records, the Palmer Drought Severity Index, and Devils Lake water levels indicate that the three major droughts are the most severe droughts to have occurred in North Dakota for which records are available. The intensity and duration of the three droughts vary, however. The duration of the 1988-92 drought in North Dakota may not be as long as that of the 1930's to early 1940's drought or that of the 1950's to early 1960's drought, but the intensity of the 1988-92 drought has matched or surpassed the intensity of those two droughts.

SUMMARY

The severity of the 1988-92 drought in North Dakota was described by documenting the drought as a climatic and hydrologic event, documenting the effect of the drought on people and resources, and comparing the drought to previous droughts. The definition of drought varies on the basis of the situation or area for which drought is being defined. A drought may be defined as a meteorologic drought or as an agricultural drought. In general, a drought can be defined as an interval of time when the water supply at a given location is consistently short of the expected climatic and hydrologic norm. Indices have been developed to characterize a drought spatially and temporally as to its intensity, duration, and severity. Each of the indices has a different description of water shortage. Some commonly used indices are departure from normal precipitation, departure from normal temperature, the Palmer Drought Severity Index, accumulated departure from normal streamflow, low-streamflow frequency, changes in water storage, ground-water levels and rates of decline, and lake levels.

Negative departures from normal annual precipitation during 1986-92 ranged from 2 to 44 percent. Positive departures from normal annual precipitation during 1986-92 ranged from 0.2 to 52 percent. Annual precipitation and average summer (June-August) temperatures for the nine climatic divisions in North Dakota were ranked for the 98-year period from 1895 through 1992. A rank of one indicates the driest year or the warmest summer of the 98-year period, and a rank of 98 indicates the wettest year or the coolest summer. During the more intense period (1988-90) of the 1988-92 drought, the rank of annual precipitation for all nine climatic divisions ranged from 2 to 54, and the rank of average summer temperatures ranged from 1 to 42. In general, 1988 was the driest year and had the warmest summer during the last 98 years. Many streams in North Dakota had record low flows or ceased to flow entirely. Streamflow at most of 12 representative gaging stations during 1988-92 was at or below 25 percent of normal. Some streams had no flow very few days, and others had no flow more than 50 percent of the time during the period of record. The percentage of time no flow occurred during the 1988-92 drought ranged from zero to 100 percent. The effect of the drought on ground-water levels varied. Confined aquifers generally showed a lack of response to climate variability, and unconfined aquifers generally showed rapid response and greater variability. The greatest effect on ground-water levels during the 1988-92 drought occurred in areas of significant pumping.

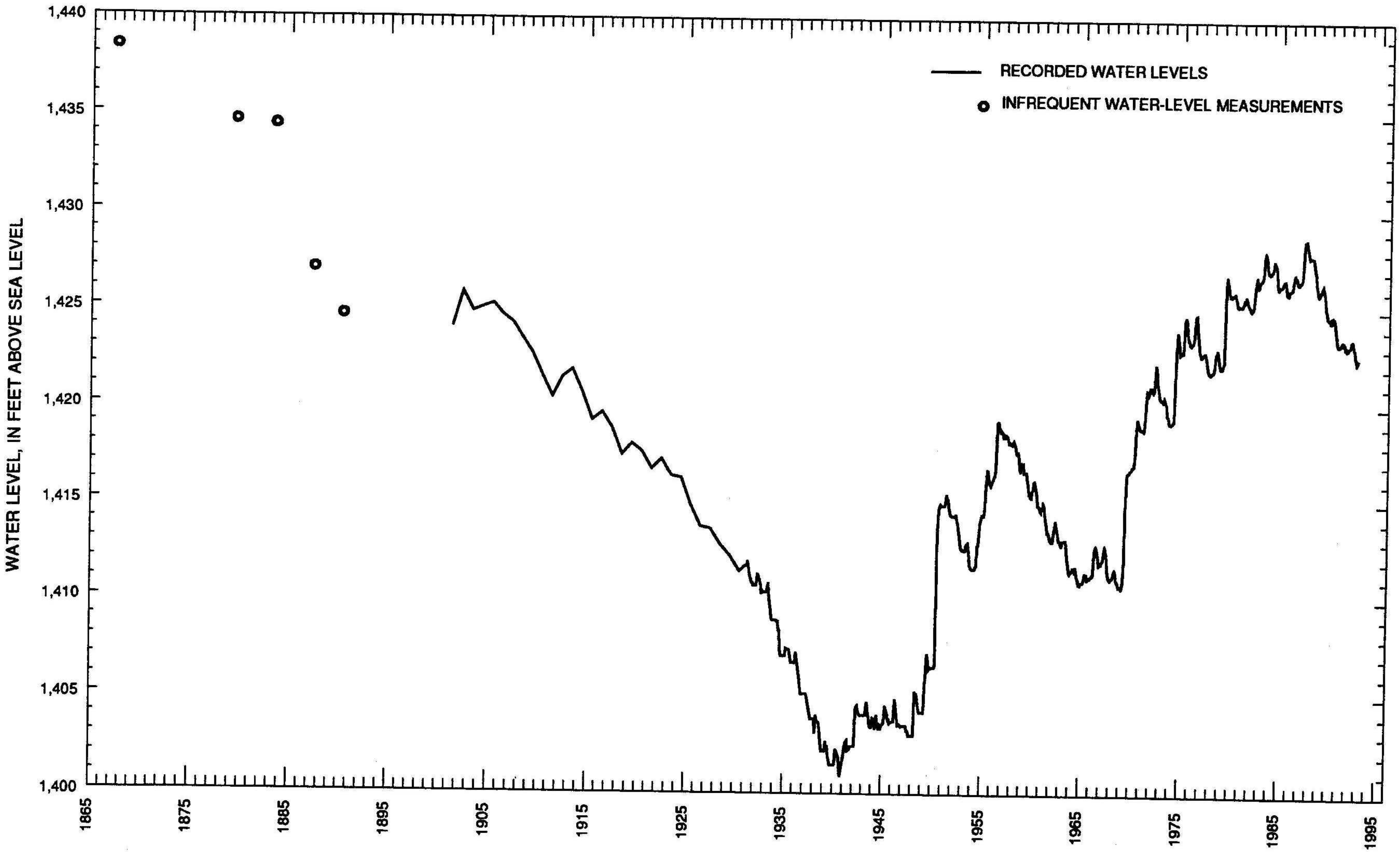


Figure 18. Water levels of Devils Lake, North Dakota, 1867-1992.

Municipal and rural water supplies were affected by the drought. Water-supply intakes for some towns where municipal water supplies were provided by surface water were out of water, and towns where municipal water supplies were provided by ground water generally had declining water supplies. The Elk Valley aquifer had a 4-foot water-level decline from 1987 to 1991, partly because the volume of water pumped increased 30 percent from 1986 to 1989.

The total number of acres irrigated increased 14 percent from 1987 to 1992, partly because of drier conditions that began in 1987 and continued through 1992. In 1988, the total volume of water used for irrigation peaked at 297,000 acre-feet. Crop yields generally decreased and natural food sources for livestock were low or completely eradicated. For example, wheat yields were at a low of 14.3 bushels per acre in 1988, and the number of head of inventoried cattle was at a low of 1,600,000 in 1989. Danger existed from the ever-present hazard of rural grassland fires. The number of grassland fires reported increased 112 percent from 1987 to 1988; 472 fires were reported during 1987 and 1,003 fires were reported during 1988.

Lower-than-normal water levels in reservoirs, lakes, and rivers affected recreational activities, such as boating and fishing. Because of the lower-than-normal water levels, access to boat ramps was limited, and the number of visitors to State parks decreased. For example, the number of visitors to Lake Sakakawea State Park decreased 26 percent from 1987 to 1990. Losses were recorded at businesses in nearby towns and many lakeside concessions were closed. Fish and wildlife habitats also were affected by the drought. Fish kills were not uncommon in area lakes and rivers where water levels decreased to dangerously low levels.

Perhaps the most notable drought for which records are available occurred during the 1930's to early 1940's. Other notable droughts occurred in North Dakota during the 1950's to early 1960's, the mid- to late 1970's, the early 1980's, and 1988-92.

At least one year and one summer during most of the major droughts in North Dakota was one of the 10 driest years and 10 warmest summers from 1895 through 1992. Severe periods of the major droughts occurred during 1934-36, 1959-61, 1976-78, and 1987-89. Palmer Drought Severity Index values exceeded -8.0 at times during the 1930's to early 1940's drought and during the 1988-92 drought. The number of months during the 1930's to early 1940's drought that were classified as extreme ranged from 33 to 59, the number of months during the 1950's to early 1960's drought ranged from 1 to 32, the number of months during the mid- to late 1970's and early 1980's drought ranged from 7 to 18, and the number of months during the 1988-92 drought ranged from 14 to 48. Recurrence intervals for each major drought at six representative streamflow-gaging stations ranged from 25 to 74 years for the 1930's to early 1940's drought, 26 to 50 years for the 1950's to early 1960's drought, and 5 to 58 years for the mid- to late 1970's and early 1980's drought. Recurrence intervals for the 1988-92 drought ranged from 19 to 54 years. The droughts that occurred during the 1930's to early 1940's, the 1950's to early 1960's, and 1988-92 contributed to the severe water-level declines of Devils Lake, North Dakota. Corresponding precipitation records, streamflow records, the Palmer Drought Severity Index, and Devils Lake water levels indicate that the most severe droughts to have occurred in North Dakota for which records are available occurred during the 1930's to early 1940's, the 1950's to early 1960's, and 1988-92. The severity of the late 1980's to early 1990's drought was greater than that of the 1950's to early 1960's drought. The 1988-92 drought was the second most severe drought since 1930.

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APPENDIX

SOURCES OF INFORMATION FOR THE EFFECT OF DROUGHT ON PEOPLE AND RESOURCES OF NORTH DAKOTA

Source	Information available
	Newspapers
Bismarck Tribune	Articles on various aspects of the drought.
Fargo Forum	Articles on various aspects of the drought.
Grand Forks Herald	Articles on various aspects of the drought.
	North Dakota State University
North Dakota Census Data Center	Census data for the State and information on trends in cultural patterns, such as housing, income, health, and business.
North Dakota State University Extension Service	Agricultural statistics and information on crops, irrigation, livestock, and insect infestation for the State.
	North Dakota State Government offices
Atmospheric Resource Board	Cloud seeding data.
Department of Agriculture	Agricultural data and information on State and Federal agricultural programs, the Palmer drought severity index, and irrigation.
Fire Marshal	Grassland-fire data and information on the rural fire danger index and the rural fire mitigation guide.
Game and Fish Department	Population data for fish and wildlife and information on breeding habits and habitats. Information on the number of licenses issued for fishing and hunting.
Job Service North Dakota	Information on jobs affected by the drought and job training available.
North Dakota Agricultural Statistics Service	Current and historical crop and livestock data.
North Dakota Department of Transportation	Information on the availability of State land for haying.
North Dakota Division of Emergency Management	Information on the North Dakota emergency management multi-hazard mitigation plan, including information collected to develop a drought mitigation plan for the State.
North Dakota State Department of Health and Consolidated Laboratories	Information on water quality, public water supplies, and wastewater-treatment facilities.
North Dakota State Water Commission	Information on the number of new water permits issued, the status of current permits, water resources, and aquifers.
Parks and Tourism Department	Information on the number of visitors to State parks and other tourist attractions and on the status of recreational concessions and facilities that may be affected by the drought.
State Climatologist	Climatological data, including historical data.
Tax Department	Results of a survey of businesses to assess the effect of drought on State economics. Information on tax revenues for the State.

Source	Information available
	United States Government offices
National Weather Service	Current and historical climatological data and information on the Palmer drought severity index and the rural fire danger index.
U.S. Army Corps of Engineers	Information on reservoirs and releases from dams. Information on the status of wildlife, land, and water administered by the U.S. Army Corps of Engineers.
U.S. Fish and Wildlife Service	Population data for fish and wildlife. Information on the number of licenses issued for fishing and hunting and on the status of boat ramps.
U.S. Forest Service	Information on land and resources administered by the U.S. Forest Service.
U.S. Geological Survey	Current and historical data on discharges and gage heights for many rivers and streams, water levels for wells, water use, and water quality for many sites throughout the State.