OHIO
Floods and Droughts

Ohio is located in the path of precipitation-producing frontal systems and convective thunderstorms that generally move across the State from the west and southwest. Although generally beneficial, the storms occasionally cause severe floods. Widespread flooding generally is caused by precipitation from frontal systems, whereas local flooding generally is caused by precipitation from thunderstorms. Average annual precipitation is about 39 inches. Droughts are less of a problem than floods in Ohio. Extended, widespread droughts are fairly infrequent; however, brief, local droughts are commonly severe.

The great flood of March 24–April 8, 1913, was by far the most disastrous flood recorded in Ohio. The confirmed death toll was 467, and about 20,000 houses and 220 bridges were destroyed. Rainfall totaling about 10 inches fell on a 6,000-mi^2 (square mile) area during a 5-day storm that preceded the flood. The floods of January 21–24, 1959, were the result of intense rain on frozen, snow-covered ground, a condition that worsened the flooding by decreasing infiltration and increasing runoff. Damage totaled $101 million. The most destructive summer floods occurred in July 1969, when unusually widespread and intense thunderstorms released about 14 inches of rain in some locations. Maximum wind velocities were about 100 mi/h (miles per hour). Forty-one people were killed, many by falling trees or by electrocution from fallen power lines.

The drought of 1930–36 was the most severe recorded in Ohio. Precipitation totals for 1930 and 1934 were the smallest since the earliest statewide records began in 1883. Since 1930, droughts in Ohio have occurred about every 10 years, with an apparent random variation in duration and severity. A short but severe drought occurred in 1988.

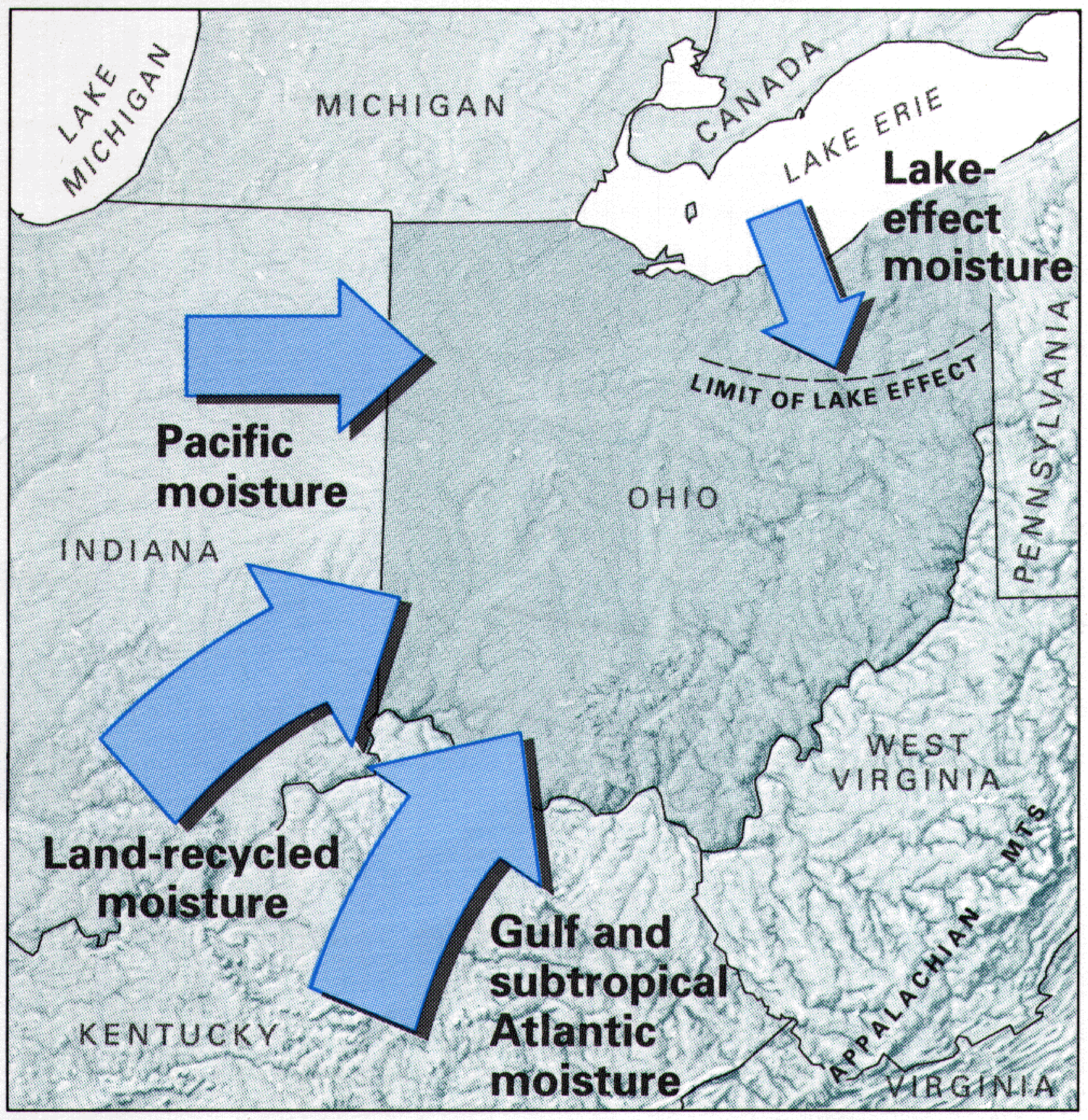


Figure 1. Principal sources and patterns of delivery of moisture into Ohio. Size of arrow implies relative contribution of moisture from source shown. (Source: Data from Douglas R. Clark and Andrea Lage, Wisconsin Geological and Natural History Survey.)

Flood-plain management in Ohio is administered by local governments with technical and financial assistance from State and Federal agencies. Almost 90 percent of the 705 communities in Ohio that were identified as flood-hazard areas participate in the National Flood Insurance Program. Flood-warning mechanisms are limited mostly to flood-stage and weather forecasts provided by the National Weather Service (NWS). Drought management, in terms of water supply, is addressed in five regional water plans prepared by the Ohio Department of Natural Resources.

Flood-control measures such as dams, levees, and retarding basins have alleviated many problems of flooding; however, tens of millions of dollars in flood damage still occur every year in Ohio, and people lose their homes, their businesses, their farmlands, and sometimes their lives. The effects of drought, such as water shortages and crop losses, are more gradual and less violent than those of floods. Both floods and droughts affect the quality of surface water. During floods, large quantities of pollutants can be washed into streams; however, because of the large volume and rapid velocity of the water, these pollutants are diluted and move quickly downstream. During droughts, streamflow volume and velocity may not be sufficient to adequately dilute effluent from sewage-treatment plants and industries.

GENERAL CLIMATOLOGY

The climate of Ohio is affected primarily by five airmasses. Tropical maritime airmasses, which form over the Gulf of Mexico and the western Atlantic Ocean, are the predominant sources of moisture for the State. Polar continental airmasses, which develop over northwestern Canada, and arctic airmasses, which develop over Siberia and the Arctic Ocean, contain little moisture. Polar maritime airmasses, which originate over the northern Pacific Ocean, contain more moisture than their continental counterparts but tend to lose moisture as they move eastward over the Rocky Mountains. Tropical continental airmasses, which form over the Southwest, are linked to hot, dry periods in Ohio.

In addition to the oceans, important moisture sources include local and upwind land surfaces, as well as lakes and reservoirs, from which moisture evaporates into the atmosphere. Typically, as a moisture-laden ocean airmass moves inland, it is modified to include some water that has been recycled one or more times through the land-vegetation-air interface. Principal moisture origin and delivery patterns for the State are shown in figure 1.

The spatial distribution of annual precipitation in Ohio is affected by proximity to the tropical maritime airmasses. Southernmost areas receive an average of 40–44 inches of precipitation annually, whereas northwestern areas receive an average of 30–34 inches. Columbus, in central Ohio, normally receives about 37 inches of annual precipitation. Recorded annual extremes for Columbus are 21.6 inches during 1930 and 51.3 inches during 1882. The driest months in Ohio tend to be February and October, whereas the wettest tend to be April through August.

Most precipitation in Ohio results from frontal systems and convective thunderstorms. During cold periods of the year, cyclonic storms form over Alberta, Canada, and move southeastward embedded in frontal systems. Their passage over the State generally is associated with small quantities of precipitation. Cyclonic storms originating over the Gulf of Mexico transport considerable moisture to Ohio as they move northward in frontal systems. The band of maximum precipitation associated with these cyclonic storms is narrow and generally covers only parts of Ohio, although moderate precipitation associated with these storms can affect much of the State. In spring and summer, precipitation from convective storms becomes more predominant. Thunderstorms occur randomly because of widespread instability in the overlying tropical maritime air or in conjunction with the movement of cyclonic storms. On occasion, moisture is transported westward from a cyclonic storm moving northward along either the Atlantic Coast or the Appalachian Mountains. Moisture from Lake Erie increases the quantity of precipitation in parts of northeastern Ohio, principally in winter; at some weather stations in this area, average annual precipitation is about 40 inches.

Ohio has not had catastrophic, long-term droughts like those that periodically occur in the Great Plains. The longest droughtlike conditions were during the 1930's when annual precipitation frequently was less than 80 percent of average at many locations. Droughts in the State commonly have durations of a few months and are characterized by intermittent precipitation. In Columbus, for example, the longest period of record having only a trace of or no precipitation is 48 consecutive days, from September 13 through October 30, 1963. The longest drought recorded during the primary growing season (June through August) was 20 consecutive days, from August 7 to 26, 1951. The driest summer was 1933, which had 4.6 inches of rain, and the second driest was 1951, which had 6.0 inches of rain.

Droughts of long duration can be attributed to either of two causes. First, the high-pressure cell that normally forms over either the Gulf of Mexico or the western Atlantic Ocean can strengthen and move northwestward over the southeastern United States. This high-pressure cell, called the Bermuda High, prevents moisture over the Gulf of Mexico from reaching Ohio as the cell transports hot, dry air from the desert Southwest into the State. Second, persistent northwesterly winds in the upper atmosphere also can keep moisture over the Gulf of Mexico from entering the State. The Bermuda High tends to form in spring and summer, whereas the northwesterly winds are more common in winter.

Figure 2. Selected geographic features, Ohio.

MAJOR FLOODS AND DROUGHTS

Most major floods and droughts discussed herein are those that have large areal extent and significant recurrence intervals—greater than 25 years for floods and greater than 10 years for droughts. Many other floods and droughts in Ohio were less widespread or less severe than those described in the text. Some of these floods and droughts, however, were significant in terms of magnitude of the peak discharge, loss of life, or property damage. These major events, and those of a more local nature, are listed chronologically in table 1; rivers and cities are shown in figure 2.

To depict floods (fig. 3) and droughts (fig. 4), six streamflow-gaging stations were selected from the statewide gaging-station network. These gaging stations have long periods of record, are currently (1988) operating, and are representative of hydrologic conditions in the principal geographic and physiographic areas of the State. All the selected gaging stations are located on unregulated streams except for the Muskingum River at McConnelsville (figs. 3 and 4, site 2), which has been regulated by 14 dams since 1938. The regulation of the river has decreased the 10- and 100-year recurrence-interval discharges to about one-half of what they were before regulation. The decrease in the flood peaks for site 2 after 1938 is evident in the annual peak-discharge graphs in figure 3. The 10- and 100-year recurrence intervals shown in figure 3 are for unregulated flow.

FLOODS

Except for the flood of March 24–April 8, 1913, which was well documented because of its exceptional magnitude, floods in Ohio were not evaluated thoroughly until 1921, when a comprehensive State-Federal program of streamflow gaging was initiated. The five major floods discussed in this section were among the most severe in Ohio in terms of magnitude, areal extent, loss of life, and property damage.

Data from as many as 130 gaging stations were used to determine the areal extent and severity of the floods shown in figure 3. Annual peak-discharge data for the six representative gaging stations and their corresponding 10- and 100-year recurrence intervals are shown in figure 3. Streamflow data are collected, stored, and reported by water year (a water year is the 12-month period from October 1 through September 30 and is identified by the calendar year in which it ends).

Some of the largest peaks for each gaging station indicate that, for floods having about the same recurrence interval, the depth of water above either flood stage, as determined by the NWS, or bankfull stage differs considerably among the stations. For example, during the March–April 1913 flood, the depth of water was 6 feet above flood stage at the Mad River near Springfield (fig. 3, site 4), whereas it was 20 feet above flood stage at Auglaize River near Defiance (fig. 3, site 5). This difference was due largely to the differences in channel characteristics between the stations.

Late winter or early spring floods in Ohio generally are the most widespread. Such floods are caused mostly by large frontal storms characterized by widespread, steady rainfall of moderate intensity. Frozen, snow-covered ground sometimes compounds the flooding. The rain melts the snow, thus increasing total runoff, and the frozen ground functions as an impervious surface, decreasing infiltration.

Summer floods, which are caused by locally intense thunderstorms, can be more destructive than floods caused by winter storms. Although floods caused by thunderstorms are infrequent in any particular area, scarcely a year passes without at least one flood of this type occurring somewhere in Ohio.

Statewide, winter floods are less frequent than summer floods; however, the total damage caused by widespread, less frequent winter floods is comparable to the total damage caused by localized, more frequent summer floods (Cross, 1947). Extreme flooding on large streams generally is caused by winter storms, whereas extreme flooding on small streams is caused by summer storms. Locally severe floods generally are caused by rain of cloudburst intensity falling on small (less than 300 mi^2) drainage areas. In small drainage areas, the severity of the flooding may diminish quickly as the flood wave moves downstream into receiving streams having greater channel capacities. Of the five major floods illustrated in figure 3, three (1913, 1959, 1963) were caused by winter storms and two (1935, 1969) by summer storms.

The flood of March 24–April 8, 1913, was caused solely by excessive rainfall. The ground was unfrozen and free of snow. The storm of March 23–27 that resulted in the flood was preceded by a storm of moderate intensity on March 22 that saturated the ground. Rainfall totaling about 10 inches fell throughout a 6,000-mi^2 area during the 5-day storm. From 4 to 10 inches of rain fell throughout the rest of the State. The storm and flood are described in detail in several reports (Alvord and Burdick, 1913; Becker and Nolan, 1988; Garrett, 1913; Henry, 1913; Horton and Jackson, 1913; Morgan, 1917; Russell, 1913). Violent weather also occurred throughout much of the United States and Europe during March 1913. For example, in Omaha, Nebr., the most disastrous tornado in the city's history killed 94 people on March 23 (Morgan, 1917). Later that day, 21 people were killed by a tornado in Terre Haute, Ind. On March 18, 80 ships were sunk by a violent storm near Hamburg, Germany (Morgan, 1917).

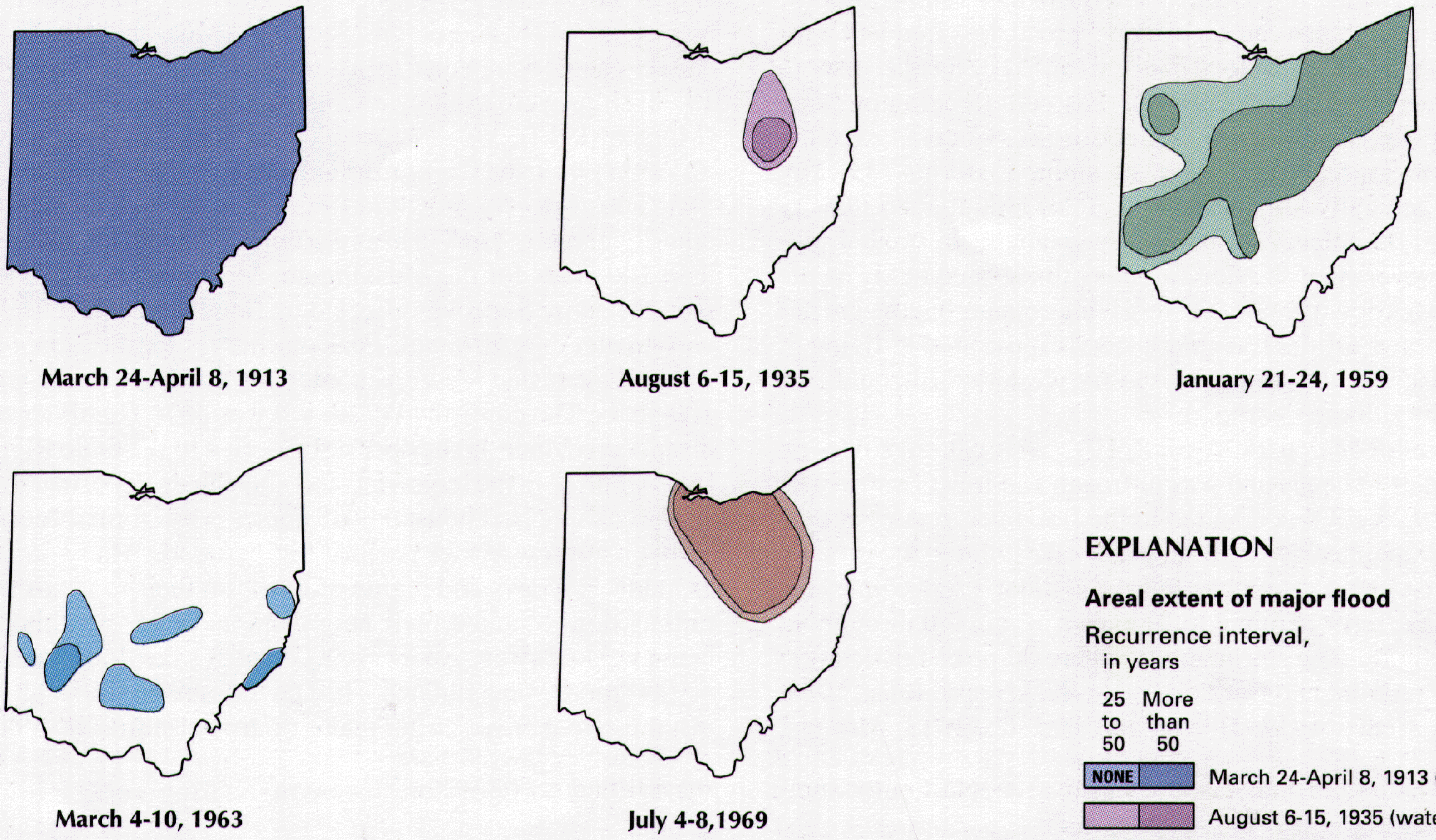
In Ohio, the storm resulted in the most severe flooding in the State's history. As shown in figure 3 (sites 2, 4, and 5), the recurrence intervals of peak discharges during the 1913 flood were greater than 100 years for the Muskingum, Mad, and Auglaize Rivers. In fact, the entire State was affected by floods having recurrence intervals greater than 50 years. Peak discharges for the Scioto and Great Miami Rivers had recurrence intervals that were much greater than 100 years. The confirmed death toll was 467. Hundreds of persons disappeared, their bodies possibly carried to the Ohio River or Lake Erie or buried in the huge sand and gravel bars deposited in the major stream channels. Thousands of horses were turned loose by their owners, but few horses reached high ground. Many families spent as many as 3 days and nights of terror on their rooftops in freezing rain as they watched their neighbors and their neighbors' houses being washed away. About 20,000 houses were destroyed, and about 41,000 more were flooded. In Dayton, great explosions and fires resulting from breaks in gas mains destroyed entire city blocks. Many

Table 1. Chronology of major and other memorable floods and droughts in Ohio, 1773–1988

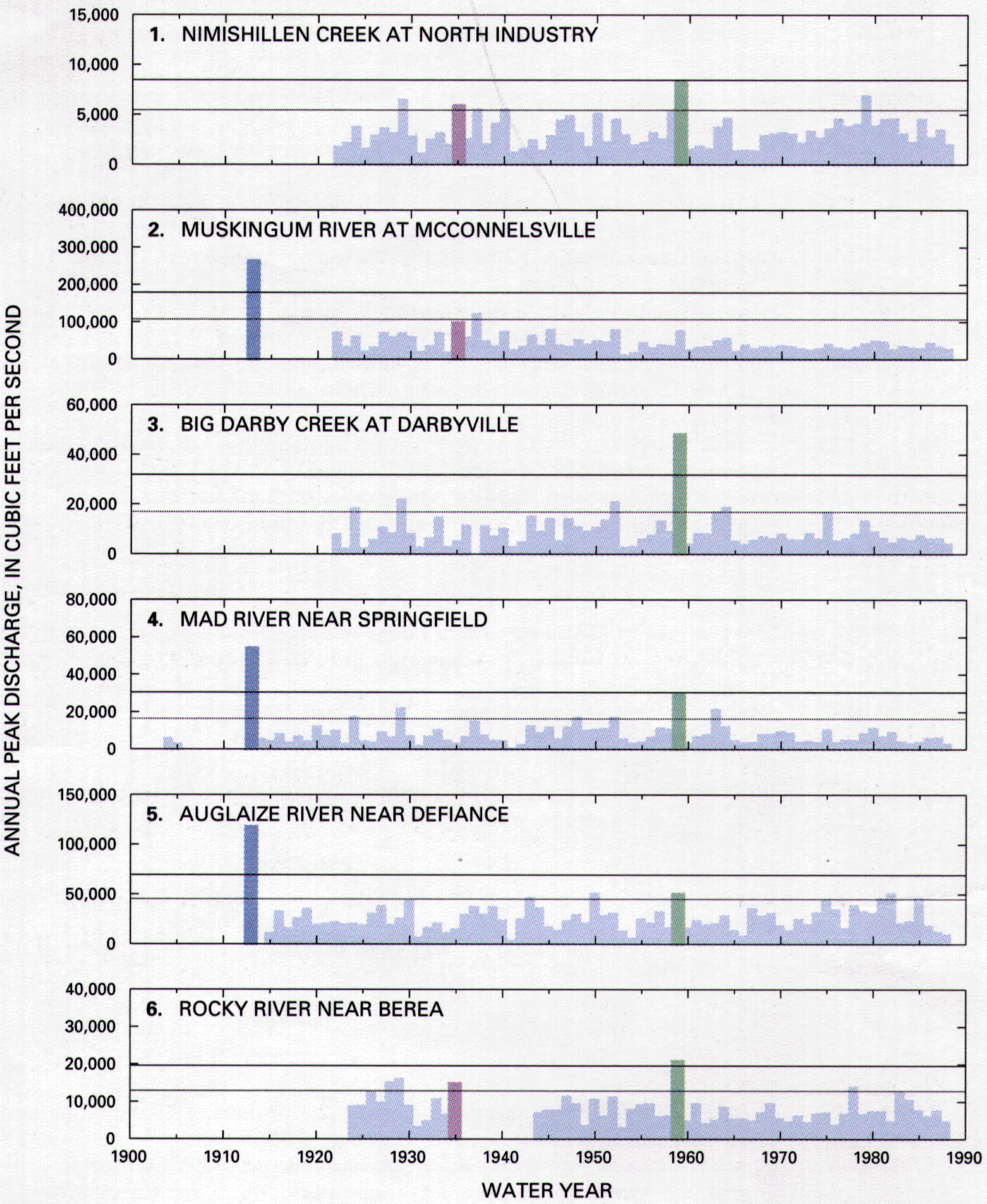
[Recurrence interval: The average interval of time within which streamflow will be greater than a particular value for floods or less than a particular value for droughts. Symbol: >, greater than. Sources: Recurrence intervals calculated from U.S. Geological Survey data; other information from U.S. Geological Survey, State and local reports, and newspapers]

Flood or drought	Date	Area affected (fig. 2)	Recurrence interval (years)	Remarks
Flood	1773	Great Miami River	Unknown	Largest of record at several sites in Great Miami River basin before great flood of Mar. 1913.
Flood	Feb. 1–25, 1884	Hocking, Scioto, Mahoning, and Muskingum Rivers.	25 to >100	Caused by combination of frozen ground, deep snowpack, and warm, intense rain.
Flood	Mar. 12–27, 1907	Hocking, Muskingum, Scioto, and Great Miami Rivers	10 to >100	Caused by intense rain on previously saturated ground. Largest discharges of record on Hocking River.
Flood	Mar. 24–Apr. 8, 1913	Statewide	50 to >100	Largest of record in Ohio. Multistate, caused by intense rain. Deaths, 467; damage, $143 million.
Drought	1930–36	Statewide	20 to 70	Regional, with serious water shortages; loss of gross farm income estimated at $58 million during 1930.
Flood	Aug. 6–15, 1935	Muskingum River basin	2 to >100	Widespread, intense thunderstorms; largest recorded summer flood to date (1935). Deaths, 6; damage, $9.5 million.
Drought	1939–46	Statewide	15 to 60	Serious water shortages.
Flood	June 16–25, 1946	Killbuck Creek	10 to >100	Intense thunderstorm. Deaths, 1; severe damage in small drainage areas.
Flood	July 21–23, 1948	Hocking River and Clear Creek	>100	Intense thunderstorm; damage, $1.2 million.
Flood	June 16–17, 1950	Moxahala Creek	50 to >100	Intense thunderstorm. Deaths, 1; damage, $1.6 million.
Drought	1952–57	Statewide	10 to 60	Regional; more severe in southwestern Ohio than drought of 1930–36.
Flood	Jan. 21–24, 1959	Wide band extending from southwestern to northeastern Ohio.	2 to >100	Intense rain on frozen, snow-covered ground. Deaths, 16; damage, $101 million.
Drought	1959–68	Statewide	10 to 60	Most severe in east-central and northwestern Ohio.
Flood	Mar. 4–10, 1963	Scattered areas in southern Ohio.	10 to >100	Intense rain on frozen, snow-covered ground. Deaths, 2; damage, $28 million.
Flood	Mar. 4–12, 1964	Muskingum, Hocking, Scioto, Little Miami, and Ohio River basins.	2 to 100	Intense rain on saturated ground. Deaths, 8; damage, $30 million.
Flood	July 4–8, 1969	Huron, Vermilion, and Black Rivers, Jerome and Muddy Forks, Killbuck, and Chippewa Creeks.	25 to >100	Most intense and widespread summer thunderstorm recorded in Ohio. Deaths, 41; damage, $66 million.
Flood	Aug. 24, 1975	Big Creek	25 to 100	Intense local thunderstorm in Cleveland area. Deaths, 4; damage, $5 million.
Drought	1975–77	Auglaize, Sandusky, Great Miami, Little Miami, and Scioto Rivers; White Oak, Ohio Brush, and Raccoon Creeks; and tributary to Black Fork.	5 to 15	Mild; interrupted period of greater than average streamflow (1968–87).
Flood	June 13–15, 1981	Blanchard River	25 to >100	Locally intense rain on saturated ground; 25 percent of Findlay flooded, 55 percent of Ottawa flooded. Damage, $35 million.
Drought	1988	Statewide	Unknown	Short but severe. Rapid declines in streamflow, ground-water levels, and reservoir levels. Mandatory water-use restrictions instituted in many municipalities.

Areal Extent of Floods

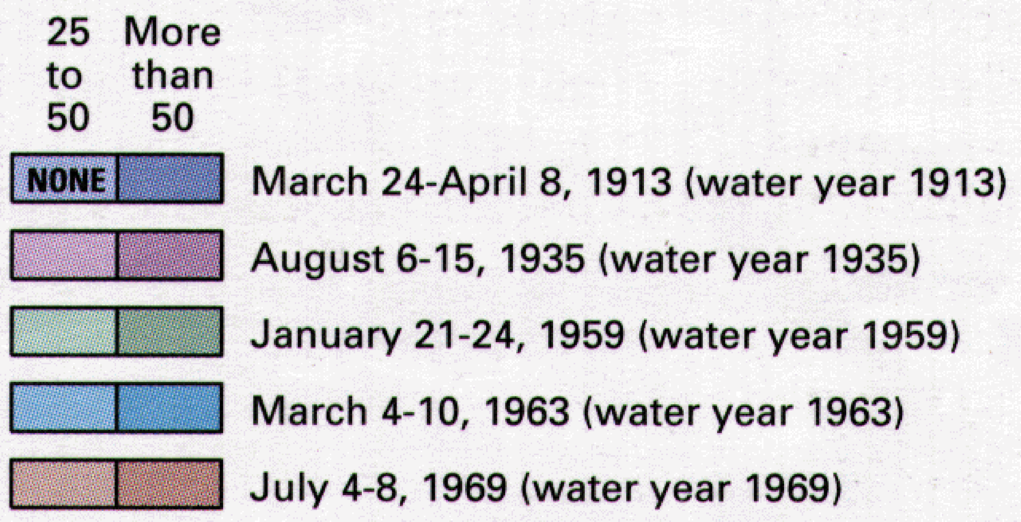


Peak Discharge

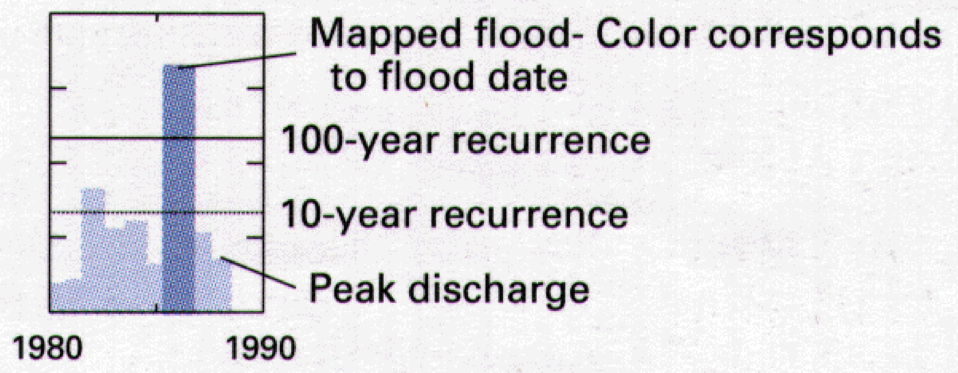


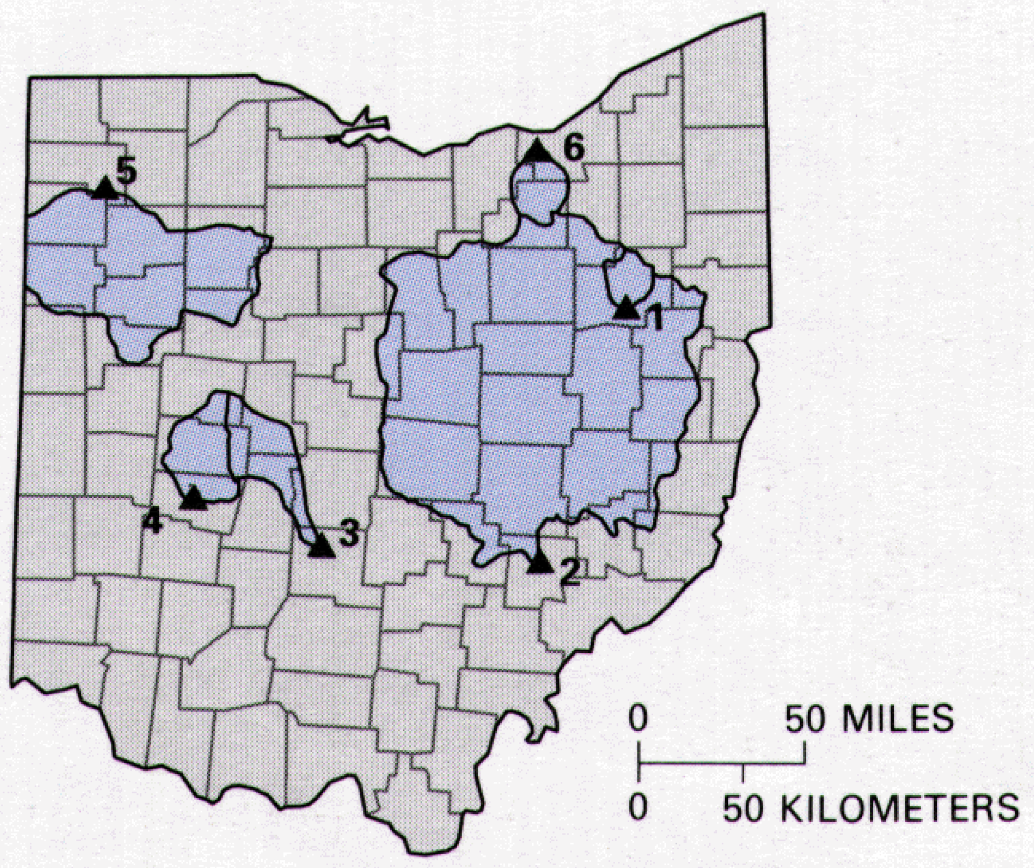
EXPLANATION

Areal extent of major flood



Annual stream peak discharge





U.S. Geological Survey streamflow-gaging stations and corresponding drainage basins — Numbers refer to graphs

Figure 3. Areal extent of major floods with a recurrence interval of 25 years or more in Ohio, and annual peak discharge for selected sites, water years 1904–88. (Source: Data from U.S. Geological Survey files.)

people died after the flood from exposure. The toll on mental health was indicated by a substantial increase in the number of people committed to institutions for the mentally ill (Morgan, 1917).

The aftereffects of the 1913 flood were widespread and lasted much longer than for most major floods in Ohio. Thousands of people were left homeless. Sanitation was a serious problem because water supplies and sewer systems were damaged or destroyed. Travel was difficult; about 220 bridges and hundreds of miles of roads were destroyed. All 15 bridges on the Muskingum River between Zanesville and Marietta (a distance of 72 miles) were destroyed. Thousands of livestock were killed, and many crops were destroyed. Thousands of acres of farmland were washed away or buried by rock and gravel. Damage was estimated at about $143 million (Horton and Jackson, 1913).

Losses were greatest in the Great Miami River valley, which had been plagued by floods even before 1913. Dayton, located at the confluence of four large streams (the Great Miami, Mad, and Stillwater Rivers and Wolf Creek), was severely damaged. After the flood, the citizens of Dayton agreed that something had to be done immediately to prevent such a disaster from recurring. Money for flood prevention was quickly appropriated, and in June 1915, the Miami Conservancy District was established. By 1922, a flood-control project consisting of a system of five retarding basins, channel improvements, and levees was completed. The design of the project was based on a flood 40 percent larger than the 1913 flood. It was the first such project of this magnitude in the United States and has been proved soundly engineered and effective, as in 1959 during the largest flood since 1913. In Dayton, the channel of the Great Miami River filled to only 60 percent of capacity, and none of the five retarding basins exceeded a maximum storage of 32 percent. Without this flood-control system, estimated water depths would have been 5.5 feet in Hamilton and 4 feet in downtown Dayton; however, there was no flooding in either city.

On August 6 and 7, 1935, about 8 inches of rain fell on 400 mi^2 in east-central Ohio within 12 hours. The storm was centered over the northern part of the Muskingum River basin (fig. 3). In the week preceding the storm, substantial rain from several showers had saturated the soil and increased discharge in the streams. This storm and the resultant flooding of August 6–15 were described in detail by Youngquist and Langbein (1941). The most severe flooding was on Killbuck and Sugar Creeks, where the estimated peak discharges exceeded the 100-year recurrence interval. Six lives were lost, and property losses were about $6 million (Youngquist and Langbein, 1941). Because the storm occurred in the summer, agricultural losses were substantial ($3.5 million) (Youngquist and Langbein, 1941).

The floods of January 21–24, 1959, were the most widespread and damaging since the flood of March 24–April 8, 1913. On some streams, the stages and discharges were greater than those recorded in 1913. From 2 to 6 inches of rain fell throughout the State on January 20 and 21; total rainfall recorded was highest in southwestern and central Ohio. Frozen ground and melting snow increased the runoff, particularly in northeastern Ohio. Flood peak discharges had recurrence intervals that were larger than 100 years in a wide band extending from southwestern to northeastern Ohio (fig. 3, sites 1, 3, 4, and 6). Floods in the rest of the State had recurrence intervals of 2 to 100 years. As a result of these floods, 16 people died, 187 buildings were destroyed and about 20,000 flooded, and 31 bridges were destroyed. Total damage was estimated at $101 million (Cross, 1961). Losses would have been much greater without the many flood-control structures in the Great Miami, Muskingum, Scioto, and Mahoning River basins.

The conditions that caused the floods of March 4–10, 1963, were similar to those that caused the January 21–24, 1959, floods. The ground was frozen and snow covered. Intense rainfall resulted in totals of 5 inches in southern Ohio, an area less affected by the more severe 1959 flooding (fig. 3). Flooding on the Little Miami and the Little Muskingum Rivers had recurrence intervals of about 100 years. Flooding in scattered areas throughout southern Ohio had recurrence intervals of 10 to 50 years. Two people drowned, 19 dwellings were destroyed and about 2,800 flooded, and about 200 State highways were closed. Total damage exceeded $28 million (Cross, 1964a). On the Sandusky River at Fremont, the flood discharge had a recurrence interval of only 5 years; however, an ice jam downstream from the town caused backwater that inundated 25 city blocks. The only other city seriously affected by flooding was Athens, where dormitories on the campus of Ohio University had to be evacuated.

The thunderstorm of July 4–5, 1969, was the most intense and widespread summer thunderstorm recorded in Ohio. About 14 inches of rain fell in less than 24 hours at several locations, and about 4 inches fell throughout an area of about 6,000 mi^2 in north-central Ohio (fig. 3). The storm was accompanied by extensive lightning and wind gusts of as much as 100 mi/h. This storm and resultant floods of July 4–8 are documented by Mayo and others (1971). Peak discharges on Killbuck Creek, Jerome Fork, and the East Branch Huron River and at 14 gaging stations had recurrence intervals that were greater than 100 years. The storm moved into Ohio from Lake Erie on the evening of July 4, while thousands of people were gathered along the shore to observe fireworks. Of the several hundred small boats on the lake, many were capsized by wind gusts, and three people drowned. Forty-one people died from the storm: 25 drowned, 8 were killed by falling trees, 6 were electrocuted by fallen wires, 1 was killed by lightning, and 1 died of other storm-related injuries. Total damage was estimated at $66 million (Mayo and others, 1971). In the Muskingum River basin, the 15 flood-control reservoirs prevented estimated damage of $45 million; actual damage was $4.6 million (Mayo and others, 1971).

DROUGHTS

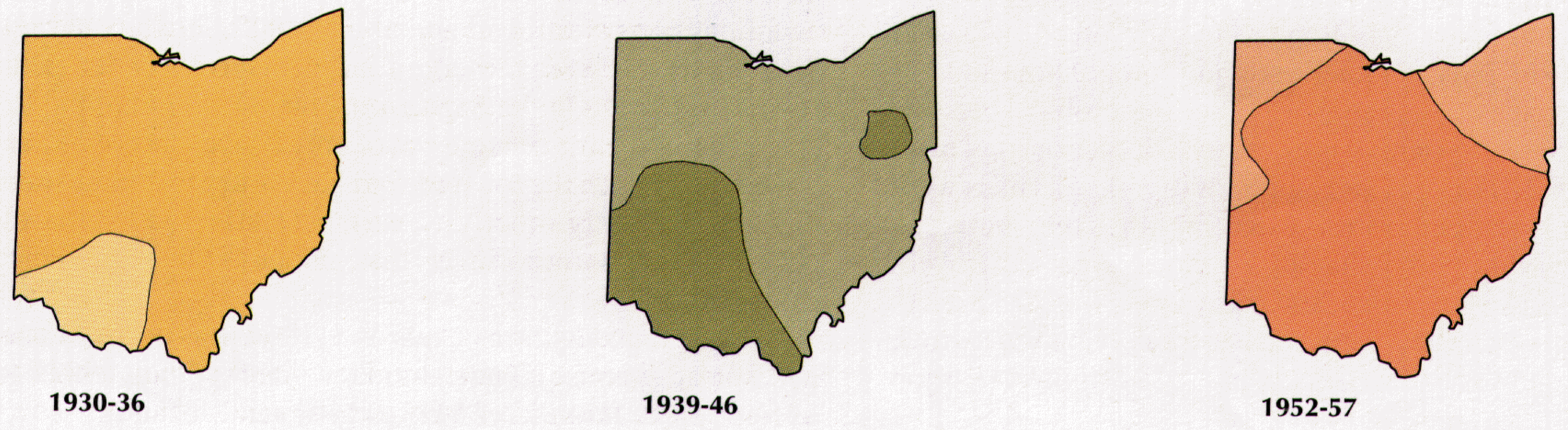
A simple definition of a drought, such as "extended period of dry weather," is easily understood. Droughts, however, differ greatly in their extent, duration, and severity; these differences make quantitative analyses and comparisons among droughts difficult. A drought can affect many States and last 5 to 10 years, as during the 1930's. A drought affecting one or two counties within a State and lasting 3 to 6 months can be more devastating locally, but could go unnoticed outside the affected area.

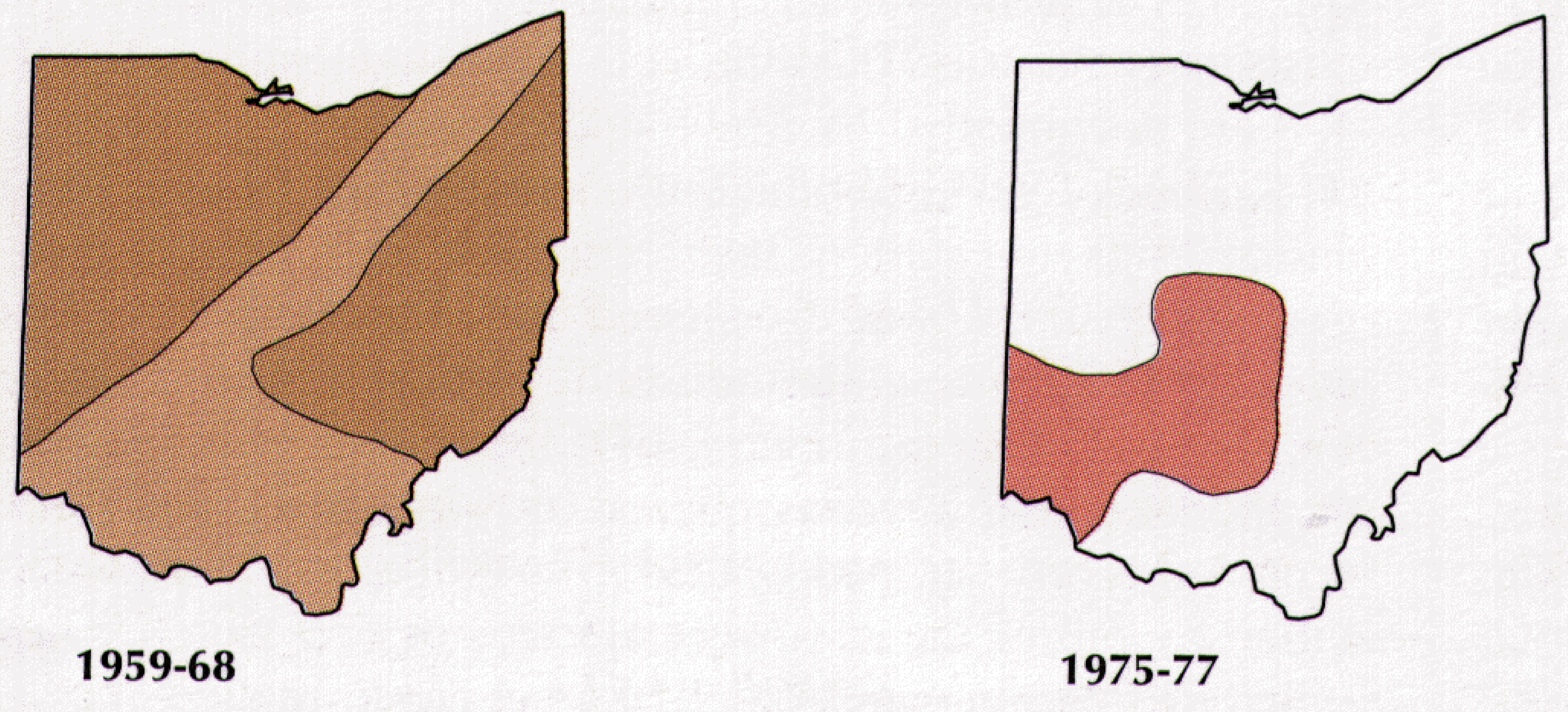
A drought analysis for Ohio is summarized in figure 4. Cumulative departures from average stream discharge at 56 gaging stations were analyzed, and recurrence intervals were assigned to five major droughts. The six graphs in figure 4 indicate the annual departures from average streamflow in six representative basins shown on the location map. Negative departures indicate periods of drought. Positive departures indicate periods of greater than average streamflow. Four severe droughts of significant extent and duration are evident: 1930–36, 1939–46, 1952–57, and 1959–68. A shorter and less severe drought during 1975–77 also affected much of southwestern Ohio.

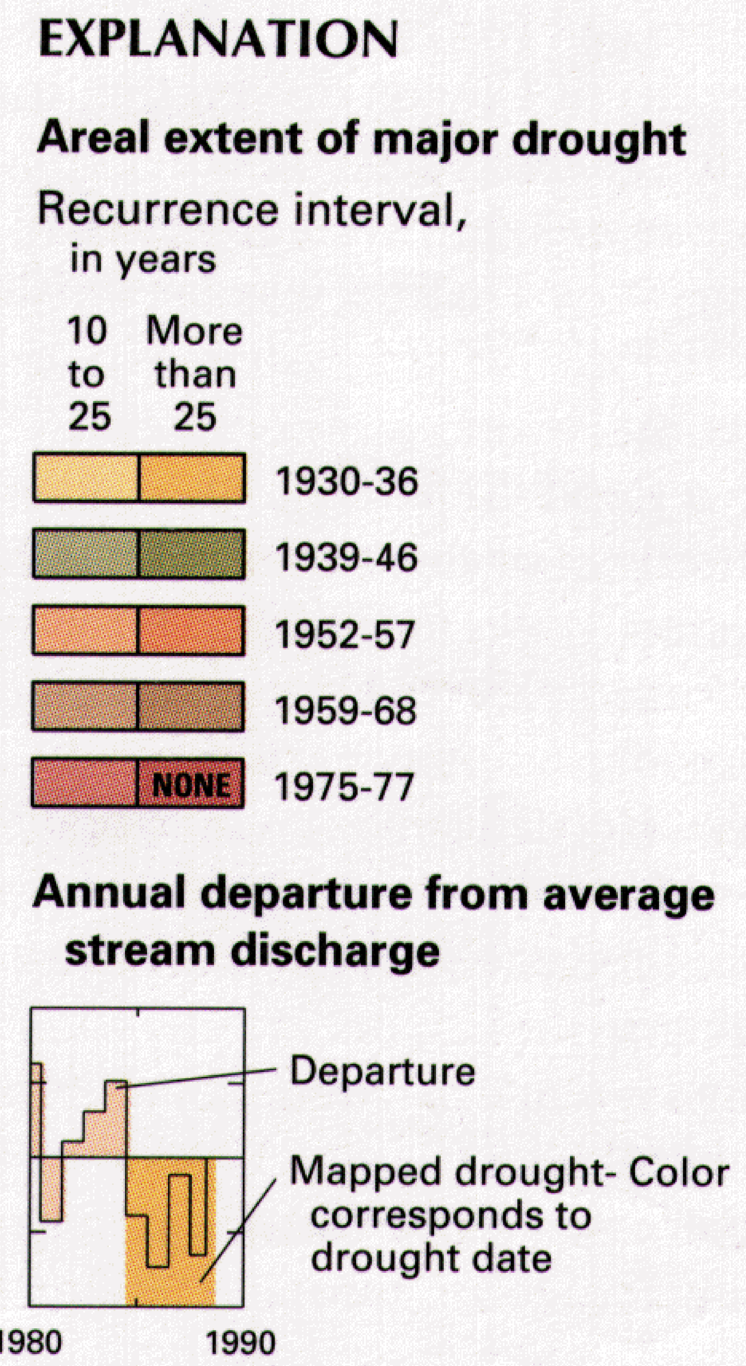
Cumulative departures of streamflow of the Mad River near Springfield and of precipitation at a weather station located near the center of the Mad River basin are shown in figure 5. Steep declines in the cumulative departure curve indicate periods of extreme drought; rises indicate periods of greater than average streamflow. The streamflow and rainfall data show that the two parameters are positively correlated and provide similar indications of long-term drought conditions.

The drought of 1930–36 (fig. 4) probably was the most severe of record in Ohio. This drought was regional in scale and affected many Midwestern and Western States. The drought had recurrence intervals of 20 years or more at all gaging stations in Ohio, and more than one-half of the State was affected by a drought

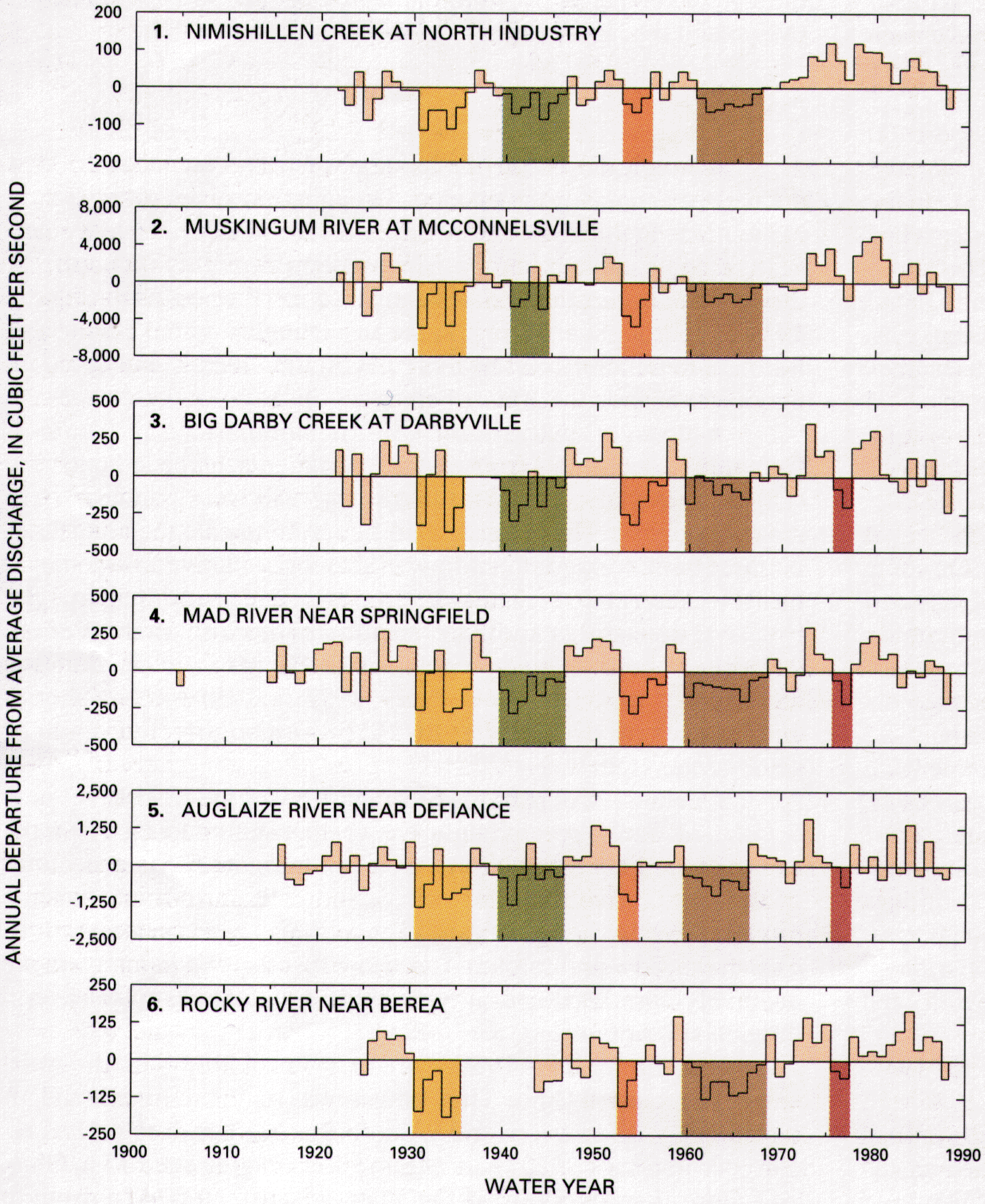
Areal Extent of Droughts

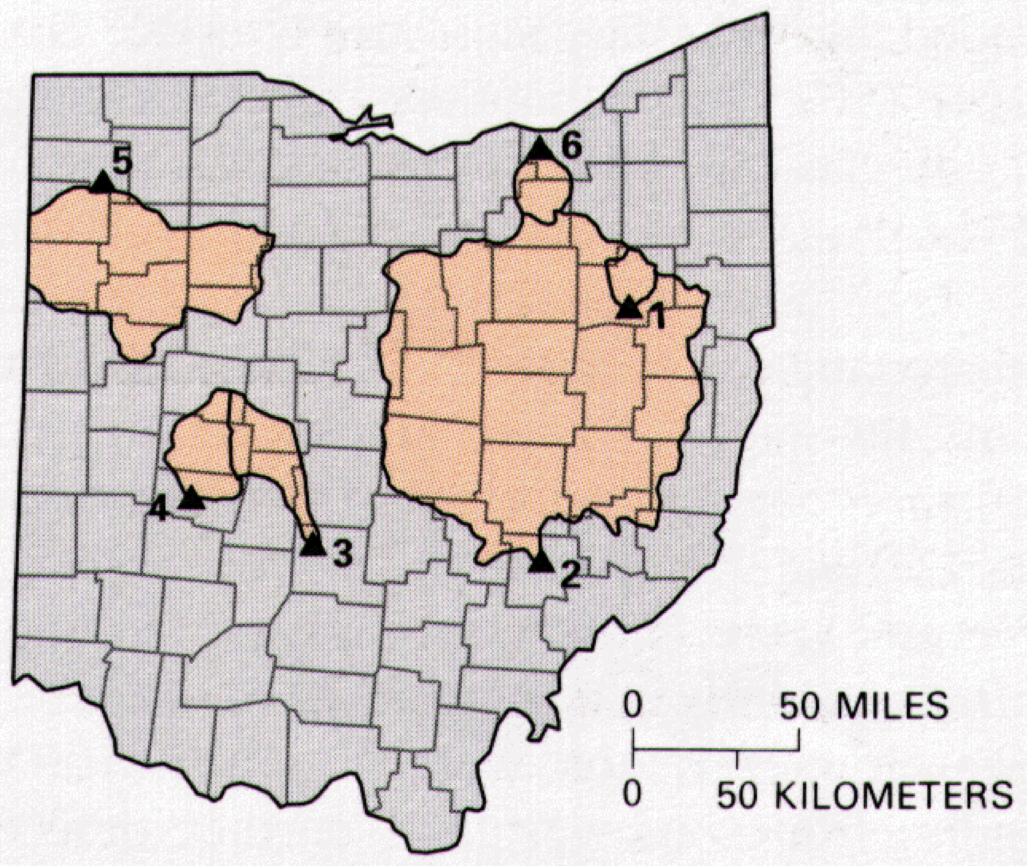






Annual Departure





U.S. Geological Survey streamflow-gaging stations and corresponding drainage basins — Numbers refer to graphs

Figure 4. Areal extent of major droughts with a recurrence interval of 10 years or more in Ohio, and annual departure from average stream discharge for selected sites, water years 1904–88. (Source: Data from U.S. Geological Survey files.)

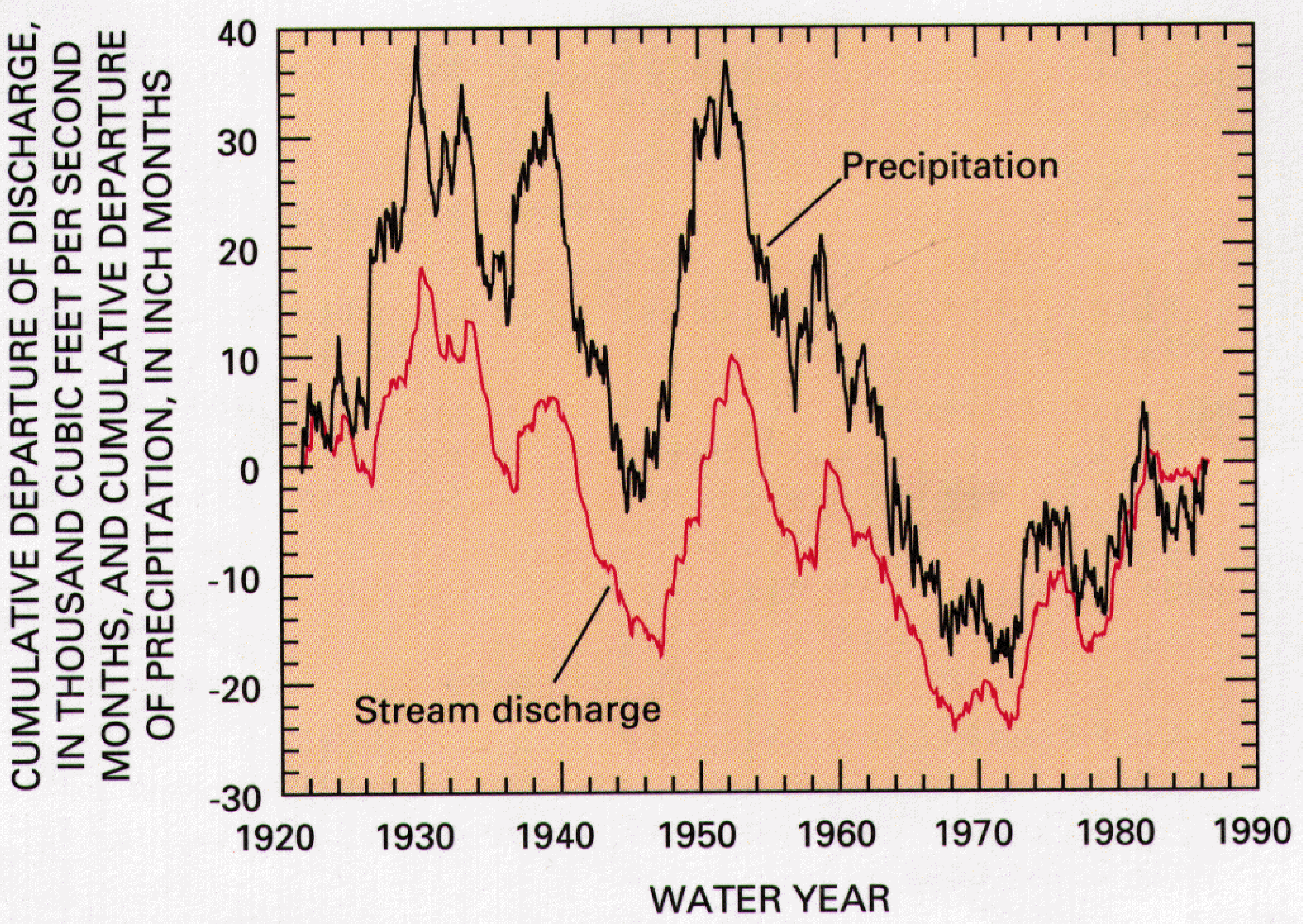


Figure 5. Relation of cumulative departure from average monthly stream discharge of the Mad River near Springfield to cumulative departure from average monthly precipitation at a weather station located near the center of the Mad River basin. Both curves are based on the period of record.

having a 50-year recurrence interval. Precipitation totals for 1930 and 1934 were the smallest since the beginning of statewide records in 1883. Loss of gross farm income during 1930 was estimated at $58 million (Mindling, 1944).

The drought of 1939–46, although less widespread than the drought of 1930–36, was severe in southwestern Ohio (fig. 4), an area that was least affected by the drought of 1930–36. Drought recurrence intervals there were as much as 60 years. In the rest of the State, recurrence intervals were about 15 to 20 years.

The drought of 1952–57 had recurrence intervals of 60 years in southern and central Ohio and 10–30 years in northeastern and northwestern Ohio (fig. 4). This drought also was the most severe in terms of annual departure from average streamflow at many gaging stations. Effects of the drought were compounded by higher than average summer temperatures.

The drought of 1959–68 was the longest of the five droughts. Annual streamflow departures were greatest in the east-central and northwestern parts of the State (fig. 4), where recurrence intervals were as much as 60 years. Throughout the rest of the State, recurrence intervals ranged from 10 to 30 years.

The drought of 1975–77 was mild, as indicated by the departure graphs in figure 4, sites 3–6. Recurrence intervals ranged from 5 to 15 years in the north-central, western, and southern areas of the State, including the Scioto, Great Miami, Auglaize, and Sandusky River basins. The drought did not affect eastern or extreme northwestern Ohio.

The drought of 1988 was short (March–July) but severe in most of the State. Average precipitation for the State during June 1988 was the least of record; 0.85 inch of rain fell, which was 21 percent of the June average for the 105 years of record. The preceding 2 months were very dry; precipitation during April, May, and June 1988 also was the least of record for that period. Streamflow and ground-water levels declined rapidly during the period. Record low streamflows were observed at several gaging stations in the northern one-half of the State. A record minimum discharge of 17 cubic feet per second was measured on the Maumee River at Waterville (fig. 2), which has a drainage area of 6,329 mi^2. Monthly record minimum ground-water levels were observed statewide, and all-time record minimum levels were observed in many areas of the State. Crops were adversely affected, as well as lawns, gardens, and other urban landscapes. Many municipalities mandated water-use restrictions by the end of June as water supplies approached critically low levels. Water levels on Lake Erie (fig. 2), which were at record high levels in 1986, were near normal at the end of 1988. Greater than normal precipitation from July to November 1988 relieved the effects of the drought in most of the State as streamflow, ground-water levels, and reservoir levels approached normal conditions in response to the precipitation.

Droughts have occurred about every 10 years between 1930 and 1970 with an apparently random variation in severity and duration (fig. 4, sites 1–6). Extreme annual departures occurred at the end of the 1959–68 drought. Since then, Ohio has not had an extended, severe drought, and streamflow generally has been greater than average. These conditions might appear to be favorable in terms of water supply; however, some rapidly expanding communities may fail to develop new sources of water at a rate sufficient to meet the increasing demand. As a result, during the next major drought, such communities could have unexpectedly severe shortages of water.

WATER MANAGEMENT

Severe floods and droughts are infrequent in Ohio. Historically, attention has been directed to the problem immediately after a major flood or drought. Preventive measures then have been discussed, and the mechanisms to lessen the disastrous effects of floods and droughts may or may not have been implemented, depending on the severity of the most recent flood or drought; the financial resources of the Federal, State, and local agencies involved; and the motivation of officials and the general public. Because of the relative abundance of both surface and ground water in Ohio, more emphasis has been placed on decreasing the effects of floods than on decreasing the effects of droughts. Fortunately, some structures, such as dams, are designed for both flood control and water supply and also provide additional wildlife and recreational benefits.

Flood-Plain Management.—Regulation of flood plains in Ohio is a function of local governments. No statutes authorize direct State regulation of flood-plain areas, and the State does not require local governments to adopt and administer such regulations. However, almost 90 percent of the 705 communities in Ohio having identified flood-hazard areas have enacted local flood-plain-management regulations to enable them to participate in the National Flood Insurance Program administered by the Federal Emergency Management Agency. Some 588 municipalities and 77 counties participate in this program.

The Division of Water of the Ohio Department of Natural Resources is the primary agency providing flood information in the State. The Division's role principally is that of technical advisor; it provides engineering data and specialized planning information to local governments and other State agencies, and it coordinates the water-resources activities of Federal agencies in Ohio. The Division also prepares model flood-plain-management ordinances, assists local governments and State agencies in reviewing proposed flood-plain construction, distributes flood maps and flood-altitude data, provides flood-preparedness and flood-recovery assistance, and coordinates the National Flood Insurance Program in the State.

Flood-Warning Systems.—The Ohio River Forecast Center, operated by the NWS and located in Cincinnati, develops and disseminates flood forecasts for seven States, including Ohio. Other responsibilities include providing information such as general river forecasts, reservoir-inflow forecasts, water-supply projections, spring flood projections, and various types of flood information for navigation, water supply, and other interests. The major objectives of the forecast center are to protect lives, to limit property damage, and to contribute to the maximum use of water resources. A hydrologic-forecast computer model develops the forecasts on the basis of river stage and discharge data and observed and forecasted rainfall, snowfall, and temperature data. In Ohio, data are collected from 225 streamflow-gaging and rainfall stations, of which about 80 percent transmit data automatically by satellite. Data also are collected from about 175 snow and temperature stations. The data are processed by the hydrologic-forecast model, which computes the time and height of flood crests for about 37 forecast points on streams having drainage areas generally greater than about 100 mi^2. Small-stream flood watches for local areas are provided on a regional basis. Flood warnings then are disseminated to the public by radio and television.

Water-Use Management During Droughts.—Water-supply needs during droughts are addressed in five regional water plans that the Division of Water has prepared for Ohio. Both current (1988) and future water-supply needs are calculated on the basis of a drought having a 50-year recurrence interval for all communities that maintain a public water-supply system. Existing and alternative water supplies are evaluated on the basis of cost effectiveness and compatibility with local and regional resource capability.

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Prepared by James M. Sherwood, U.S. Geological Survey; "General Climatology" section by Jeffery C. Rogers, Ohio State University; "Water Management" section by J. Bruce Pickens, Ohio Department of Natural Resources

FOR ADDITIONAL INFORMATION: District Chief, U.S. Geological Survey, 975 W. Third Avenue, Columbus, OH 43212