STREAMFLOW ANALYSIS OF THE APALACHICOLA, PEARL, TRINITY, AND NUECES RIVER BASINS, SOUTHEASTERN UNITED STATES

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CONVERSION FACTORS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
mile squared (mi^2)	2.59	square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Water year is defined as the 12-month period from October 1 through September 30. The water year is designated by the calendar year in which it ends. Thus the 1988 water year ends on September 30, 1988.

Streamflow Analysis of the Apalachicola, Pearl, Trinity, and Nueces River Basins, Southeastern United States

By Karen E. Greene *and* Raymond M. Slade, Jr.

Abstract

Annual mean streamflow and annual minimum and maximum daily mean streamflows were compared with associated annual index precipitation for sites on the main channels and tributaries of four major rivers that discharge directly into the Gulf of Mexico. Long- and short-term precipitation trends were identified for selected streamflow stations with at least 40 years of record.

Long-term temporal trends in annual mean streamflow and annual maximum daily mean streamflow to the Gulf were not identified from the Apalachicola River Basin for the period of record studied. Annual mean and maximum streamflow to the Gulf increased with time from the Pearl River Basin and decreased from the Trinity River Basin. Annual mean streamflow showed varied trends and annual maximum streamflow decreased from the Nueces River Basin. Annual minimum streamflow to the Gulf increased in all of the basins studied. The annual index precipitation associated with the most downstream station also increased during the periods of record studied in all four of the basins. Short-term trends in streamflow generally corresponded to trends in associated annual index precipitation for each station. For some streamflow stations in the Trinity River Basin, short-term trends in annual minimum streamflow increased while annual maximum streamflow decreased.

Total reported surface-water withdrawals have increased more than fourfold in the Trinity River Basin since 1940. Surface-water withdrawals from the Trinity River Basin in 1988 represent about one-fourth of the annual mean streamflow near the mouth. Total withdrawals increased more than eightfold in the Nueces River Basin since 1940. Surface-water withdrawals from the Nueces River Basin in 1988 represent about one-third of the annual mean streamflow near the mouth.

Effects of selected reservoirs on streamflow in the four basins also were studied. Predicted peak streamflow into the Gulf from the Apalachicola River was about 23 percent less for the 50-year peak streamflow after reservoir construction. Although one large reservoir was built on the Pearl River and many reservoirs have been built on the Trinity River and its tributaries, peak streamflow into the Gulf of Mexico from these rivers has not been affected during the past 50 years. Estimates from a water-budget analysis showed that the annual mean streamflow to the Gulf from the Nueces River was reduced by about 24 percent from 1985 through 1990 as a result of filling and evaporation at Choke Canyon Reservoir.

INTRODUCTION

The U.S. Environmental Protection Agency initiated the Gulf of Mexico Program (GMP) to develop and implement a comprehensive strategy for managing and protecting the resources of the Gulf of Mexico. The objective of the Program is to achieve a balance between the preservation and enhancement of living marine resources and the needs and demands of human activities. One of the Program's subcommittees, the Freshwater Inflow Committee, is responsible for assessing inflow to the Gulf from streams. The quantity and temporal distribution of freshwater inflow affect the delivery of nutrients to bays and estuaries and influence other ecological factors important to the species that live in the Gulf of Mexico. This report was prepared by the U.S. Geological Survey (USGS) in cooperation with the Freshwater Inflow Committee of the GMP.

A previous report was prepared by the USGS for the Committee (U.S. Environmental Protection Agency, 1992). The report presented, for each of 44 major streams discharging directly to the Gulf, temporal trends in streamflow to the Gulf.

Purpose and Scope

The purpose of this report is to present temporal trends in streamflow and associated precipitation at selected sites in four major river basins that discharge directly to the Gulf of Mexico. Selected sites with at least 40 years of data were included in the study, which generally includes data through 1988. Trends in surface-water withdrawals in each basin also are reported where sufficient data were available, and effects of reservoirs on streamflow are presented for selected sites.

Acknowledgments

The authors thank Howard Liljestrand, a Civil Engineering teacher at the University of Texas at Austin, for reviewing this report and B.A. Moulton of the Texas Natural Resource Conservation Commission and the other members of the Freshwater Inflow Committee for their support in the preparation of this report.

APPROACH

Trends were determined for annual mean streamflow discharge and annual minimum and maximum daily mean streamflow discharges for 7 to 10 long-term streamflow stations in each of the 4 basins. Annual mean streamflow is the mean gaged streamflow at each site for each year. Annual minimum daily mean streamflow is the mean gaged streamflow for the day with the smallest mean streamflow during the year. Annual maximum daily mean streamflow is the mean gaged streamflow for the day with the largest mean streamflow during the year. Precipitation trends are based on mean values of annual precipitation for representative long-term precipitation stations in the basin upstream from each streamflow station.

The available records for streamflow, precipitation, and surface-water withdrawals vary among sites. For all of the selected stations, trends for the available period of continuous record were presented for streamflow. For sites where the length of the associated precipitation record exceeded the length of streamflow record, only the common period of record was used for comparison of the trends.

Trends were identified by straight-line regressions and "best-fit" curves of the data. Annual mean and annual maximum streamflow data tend not to be normally distributed; therefore, a robust fitting procedure was used. Curvilinear graphs of streamflow and precipitation data thus were produced without giving undue weight to outlying values.

Possible causes for changes in streamflow are inferred from trend comparisons; trends in streamflow are compared to trends in precipitation, to surface-water withdrawals (where available), and to reservoir development within each basin. The effects of reservoirs on streamflow were based on comparisons of peak streamflow for various recurrence intervals (such as 50 years) and, for two reservoirs, on comparisons of the statistical relations between precipitation and streamflow for the periods before and after the construction of each reservoir.

Selection of Basins

The four basins chosen for the study are the Apalachicola River Basin in Georgia, Alabama, and Florida; the Pearl River Basin in Mississippi and Louisiana; and the Trinity River and Nueces River Basins in Texas (fig. 1). These basins were chosen because of their geographic distribution and diversity in hydrology, climate, land use, and extent of development. A variety of factors affect streamflow in these four basins. Major factors are identified and described, and major reasons for trends in streamflow are explained.

Selection of Streamflow Stations and Precipitation Stations

Streamflow stations in each basin were selected from the long-term stations (those with more than 40 consecutive years of daily streamflow data) operated by the USGS. The most downstream long-term station on the main channel in each basin was included for analysis. Other stations on the main channel and a few on tributaries also were selected to represent areas of different geography, climate, and land use. All available data were retrieved from the USGS for each station (U.S. Geological Survey, 1981). Methods and accuracy of streamflow data collection are described by Rantz and others (1982).

For each streamflow station selected for analysis, two to seven spatially distributed long-term

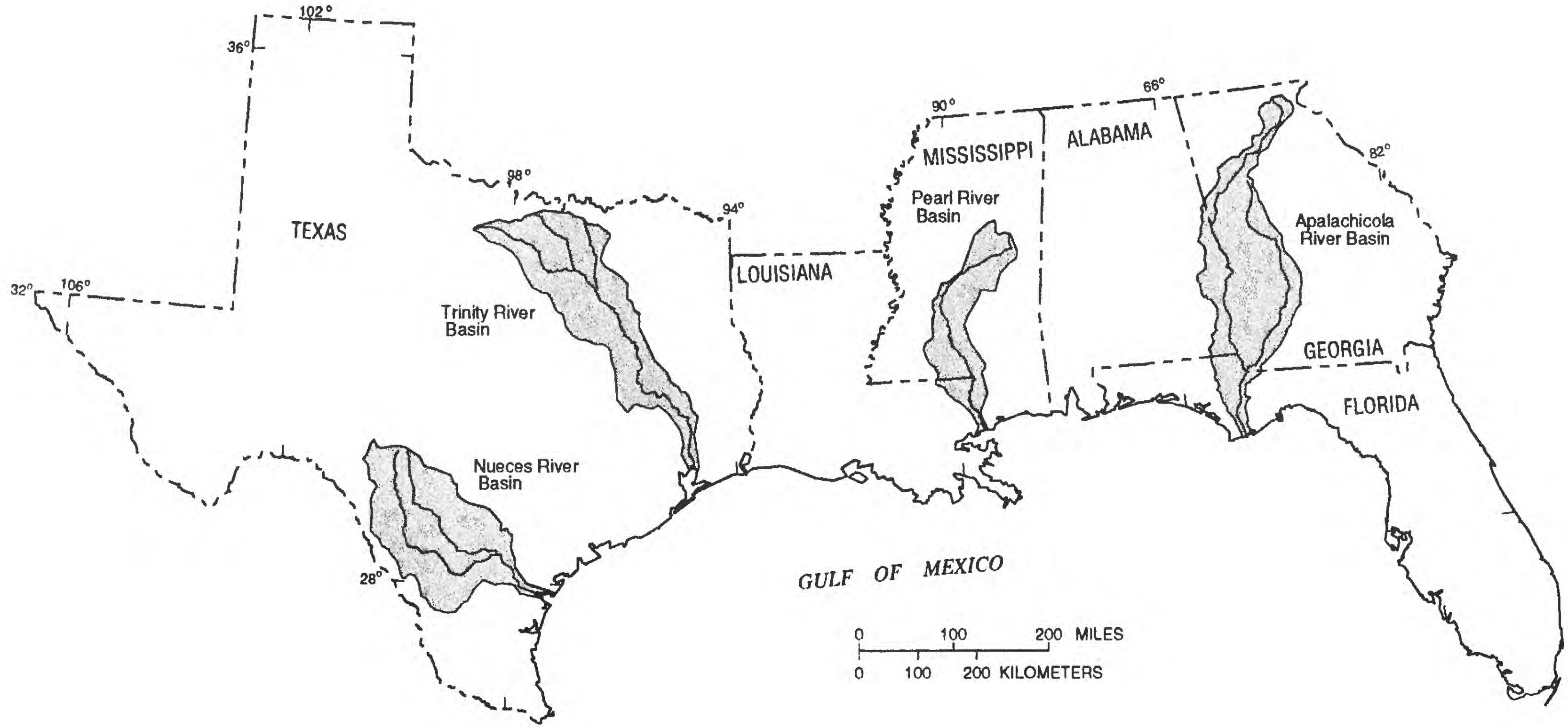


Figure 1. Location of the Apalachicola, Pearl, Trinity, and Nueces River Basins.

precipitation stations operated by the National Oceanographic and Atmospheric Administration (NOAA) were selected to represent the annual index precipitation in the basin upstream from each station. Precipitation stations were selected because of their geographic spacing and period of record coincident to the streamflow stations. Precipitation data for each station were collected by NOAA (U.S. Department of Commerce, 1889–1989). The mean of the total annual precipitation for the stations in or near the basin upstream from a streamflow station was used to estimate the annual index precipitation for that basin. Only those years with at least 11 complete months (fewer than 3 missing days) of record at a precipitation station were included. The number of stations selected for each basin was not sufficient to define the spatial variability of precipitation over the basin.

Determination of Temporal Trends

Long-term trends and short-term trends in streamflow and associated precipitation were identified for the period of record used for each streamflow station included in the study. Trends in precipitation were compared with trends in streamflow for each of the stations. Long-term trends were identified by a "best-fit" straight-line regression of the data. A positive slope of the line indicates a trend of long-term increasing values, and a negative slope indicates a trend of long-term decreasing values. To indicate a long-term trend, an increase or decrease greater than 5 percent was selected for streamflow, and an increase or decrease greater than 3 percent was selected for precipitation. These percent values probably exceed the potential gaging error in the data.

The LOcally WEighted Regression and Smoothing Scatterplots (LOWESS) technique, described by Cleveland (1979), was used to identify short-term trends in the data. For each data value, LOWESS produces a best-fit curvilinear trend using a weighting factor to consider a specific range of the data. A factor of 10 percent was used for the precipitation data, meaning that each point on the trend line was based on the 10 percent of the data surrounding that point. A factor of 25 percent was used for the streamflow data. These factors were used to produce LOWESS curves with similar amplitudes for presentation and comparison of trends. The smaller factor was used for precipitation data because precipitation values varied less than streamflow values. Short-term trends were not determined for sites for which at least about one-quarter of the annual minimum daily mean streamflow values were zero.

Analysis of Surface-Water Withdrawals

Surface-water withdrawal data were obtained from State agencies and from reports of the USGS. The data represent the reported surface-water withdrawals from basins upstream from individual streamflow stations. Data concerning return flows to the rivers were not readily available and therefore not included in the study. About one-half of the volumes withdrawn for municipal use might be returned to streams. Industrial and irrigation withdrawals are considered as consumptive uses by the Texas Natural Resource Conservation Commission.

Analysis of Selected Reservoirs by Streamflow Characteristics

One to three major reservoirs in each river basin were selected to characterize the effects of reservoir operations on streamflow. A surface-water impoundment with greater than 5,000 acre-ft of storage was considered to be a major reservoir. All reservoirs selected for analysis had at least 20 years of continuous record before and 20 years of continuous record after construction of the reservoir, at a station directly downstream from the reservoir. These records provide sufficient data for analyses of predicted peak streamflow at each station. Peak streamflow frequency analysis using U.S. Water Resources Council (1981) guidelines was performed for each station for the periods of record before and after reservoir construction. Predicted peak streamflows for the two periods of record then were compared for each station.

For reservoirs with sufficient data, the relations of streamflow to precipitation during the periods of record before and after reservoir construction were compared. For each year, the mean streamflow was converted to the depth of runoff, in inches, over the drainage area associated with the station. A linear regression was produced for each period using annual index precipitation as the independent variable and the common logarithm of runoff as the dependent variable. A water-budget analysis was performed for one reservoir to estimate the volume of streamflow that was reduced in the river downstream from the reservoir because of filling and evaporation.

STREAMFLOW ANALYSES

Apalachicola River Basin

The Apalachicola River Basin, located in Georgia, Alabama, and Florida, has a drainage area of approximately 20,500 mi^2. The annual mean streamflow at the mouth of the river basin is approximately 25,000 ft^3/s. Mean annual precipitation in the basin ranges from about 45.5 in. at Montezuma, Georgia, to about 65.7 in. at Cleveland, Georgia. The Chattahoochee River joins the Flint River at Lake Seminole on the Georgia-Florida border and becomes the Apalachicola River downstream from that reservoir (fig. 2). Five reservoirs with capacities exceeding 5,000 acre-ft were identified in the basin.

Streamflow Stations and Associated Precipitation Stations

Six streamflow stations on the main channels of the Chattahoochee, Flint, and Apalachicola Rivers and four streamflow stations on tributaries were selected for analysis. Locations of these stations and associated precipitation stations are shown in figure 2. A list of the selected streamflow stations and precipitation stations and their available periods of record is presented in table 1.

Temporal Trends in Streamflow and Precipitation

Long-term temporal trends in annual mean streamflow and annual maximum daily mean streamflow at the most downstream station (02358700) were not evident during the period of record studied (table 2). Annual minimum daily mean streamflow to the Gulf increased. Long-term trends in associated annual index precipitation indicated an increase during the period of record for the drainage basins above all but two of the selected streamflow stations. Precipitation decreased for the drainage basin above station 02353500 and did not change for the drainage basin above station 02359000. The streamflow for two stations (02339500 and 02349500) decreased while precipitation increased. For smaller watersheds, such as station 02353500, conflicting trends might be the result of changes in the patterns of precipitation over the basin and the resulting streamflow at the station.

Generally, the short-term trends identified for annual mean streamflow corresponded to those for associated annual index precipitation (figs. 3–12). During the second half of the period of record for station 02335000 (downstream from Lake Sidney Lanier) and station 02358700 (downstream from Lake Seminole), the short-term trends in annual mean streamflow corresponded with the short-term trends in precipitation (figs. 3 and 11), whereas long-term trends in annual minimum and maximum daily mean streamflow corresponded to long-term trends in precipitation for some stations (table 2). For stations 02344500 and 02349500, streamflow during the 1980's decreased while precipitation during the same period showed little change (figs. 7 and 8). For some of the stations where the period of record for streamflow is longer than the period of record for precipitation, the short-term trends for precipitation did not correspond to the trends in streamflow for the early years of the precipitation record; sufficient data probably were not available for the LOWESS procedure to identify the same trends for those years.

Surface-Water Withdrawals

Data for surface-water withdrawals are available at 5-year intervals beginning in 1970 for the entire Apalachicola River Basin (Richard Marella, U.S. Geological Survey, written commun., 1991). The data are presented in figure 13. Most of the industrial withdrawals represent thermoelectric power generation. Data are insufficient to identify trends in surface-water withdrawals from the Apalachicola River Basin.

Effects of Reservoirs on Streamflow

Streamflow measurements downstream from two reservoirs, Lake Sidney Lanier and Lake Seminole (fig. 2), were analyzed for flood frequencies before and after construction of the dams in 1956 and 1954, respectively. Predicted peak streamflow for selected recurrence intervals was calculated for the long-term streamflow station immediately downstream from each reservoir (figs. 14 and 15). The predicted peak streamflow before construction of the reservoir was compared to that after construction at each site. Predicted peak streamflow was about 74 percent and 23 percent less for 50-year floods at stations downstream from Lake Sidney Lanier and Lake Seminole, respectively, following reservoir construction.

A statistical analysis of the relations between precipitation and streamflow was made for the station on the Apalachicola River near Blountstown, Florida, downstream from Lake Seminole. Reservoirs upstream from Lake Seminole also may affect streamflow at this

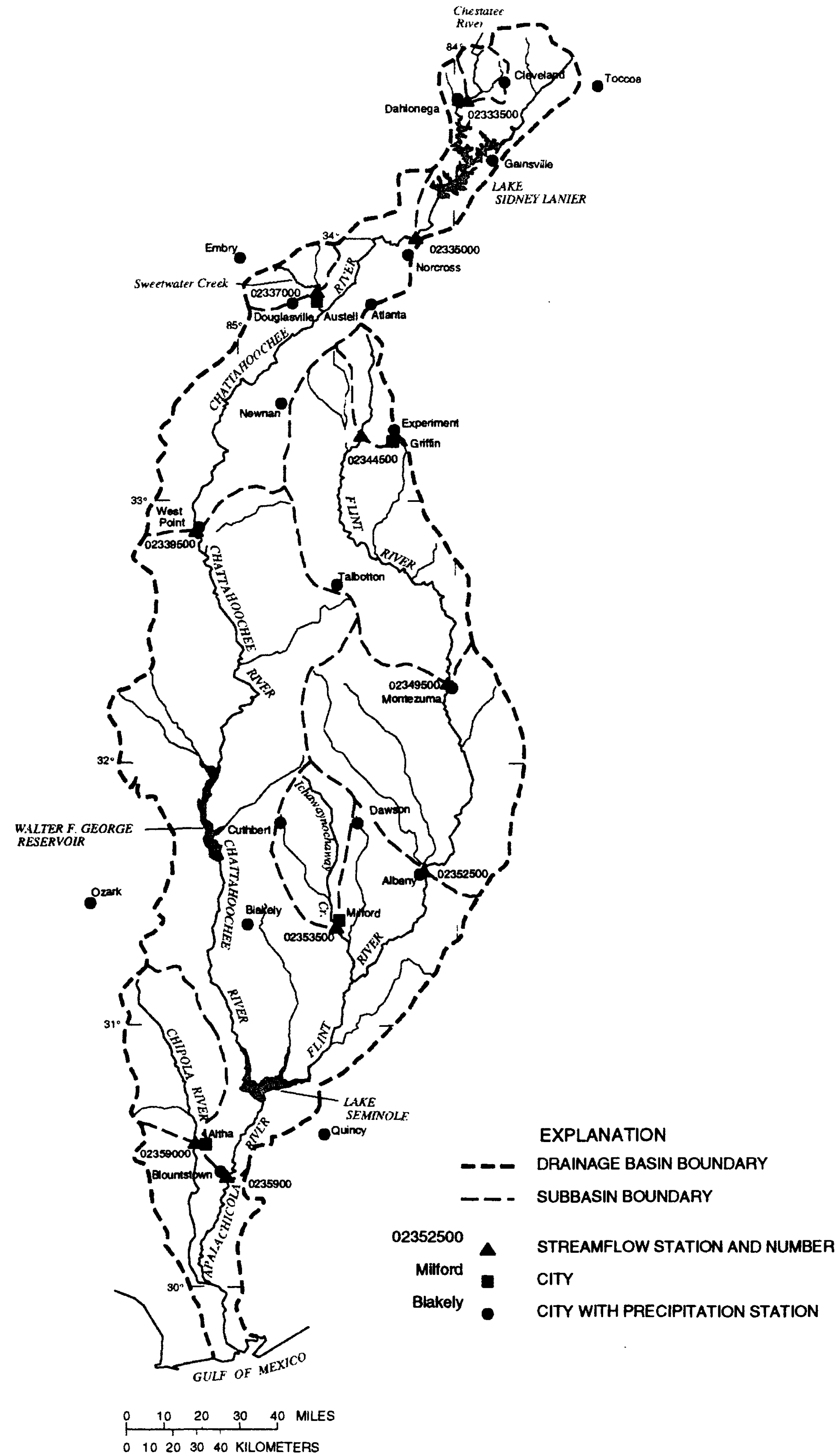


Figure 2. Location of selected streamflow stations, precipitation stations, and major reservoirs in the Apalachicola River Basin.

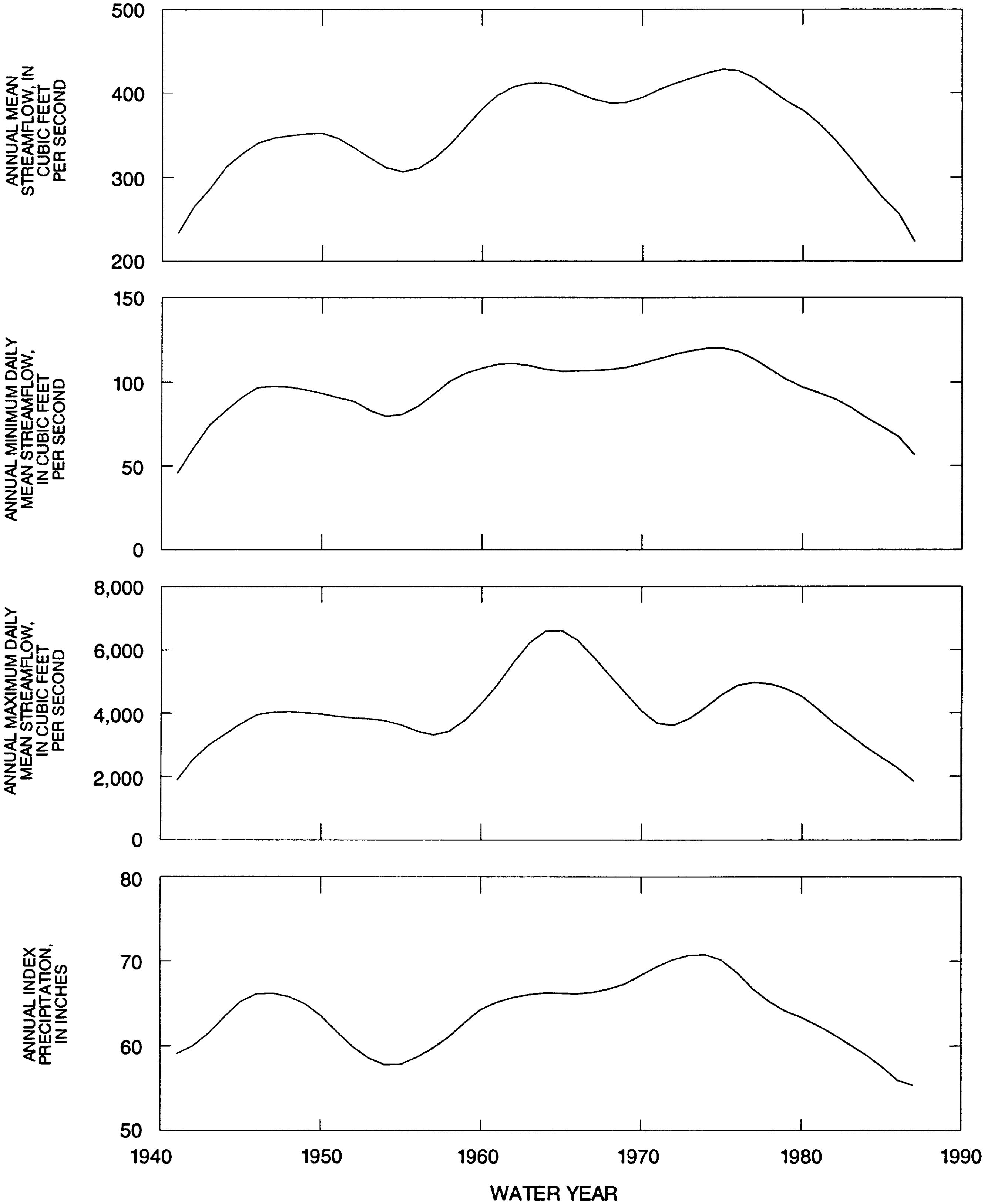


Figure 3. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02333500 on the Chestatee River near Dahlonega, Georgia, in the Apalachicola River Basin.

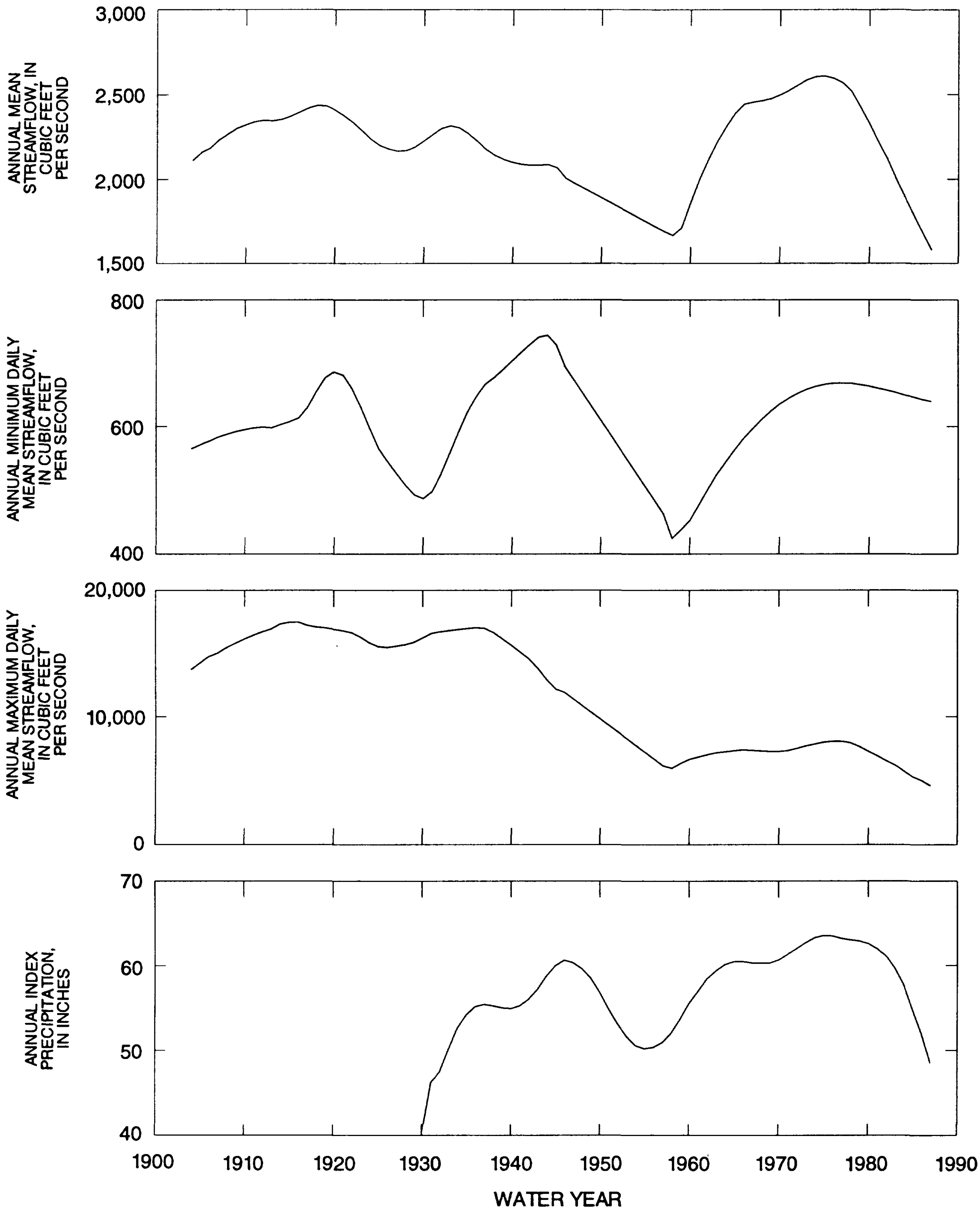


Figure 4. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02335000 on the Chattahoochee River near Norcross, Georgia, in the Apalachicola River Basin.

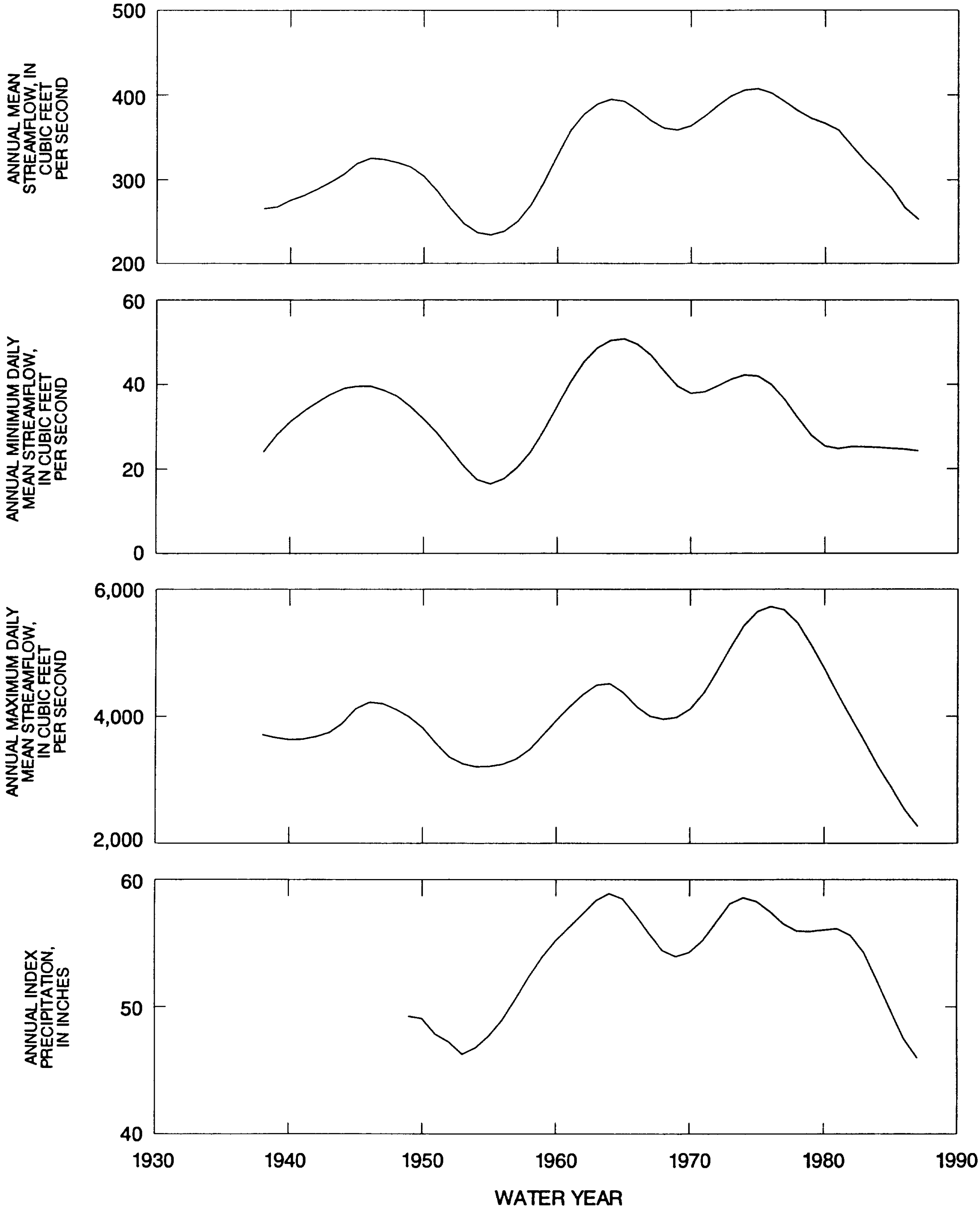


Figure 5. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02337000 on Sweetwater Creek near Austell, Georgia, in the Apalachicola River Basin.

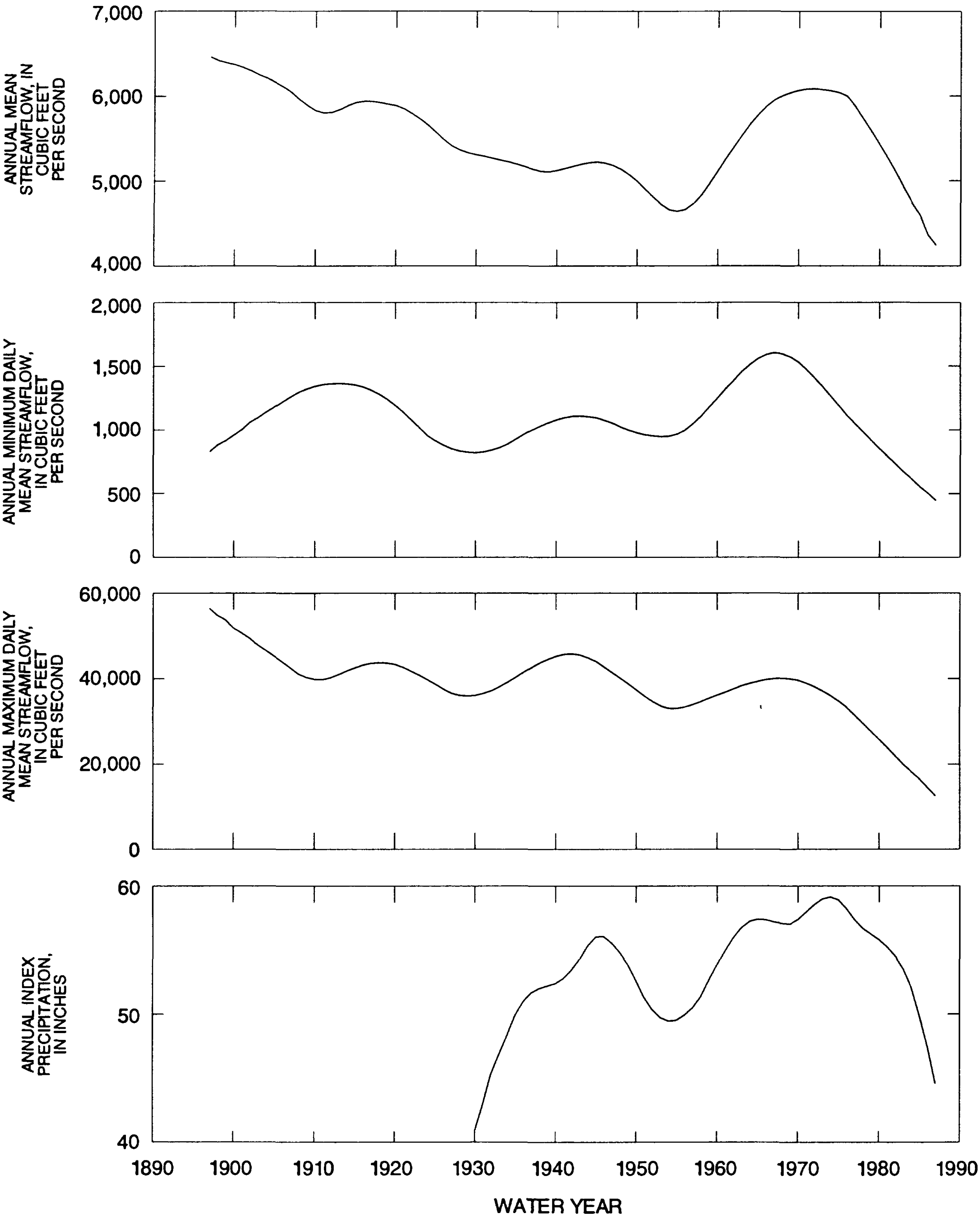


Figure 6. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02339500 on the Chattahoochee River at West Point, Georgia, in the Apalachicola River Basin.

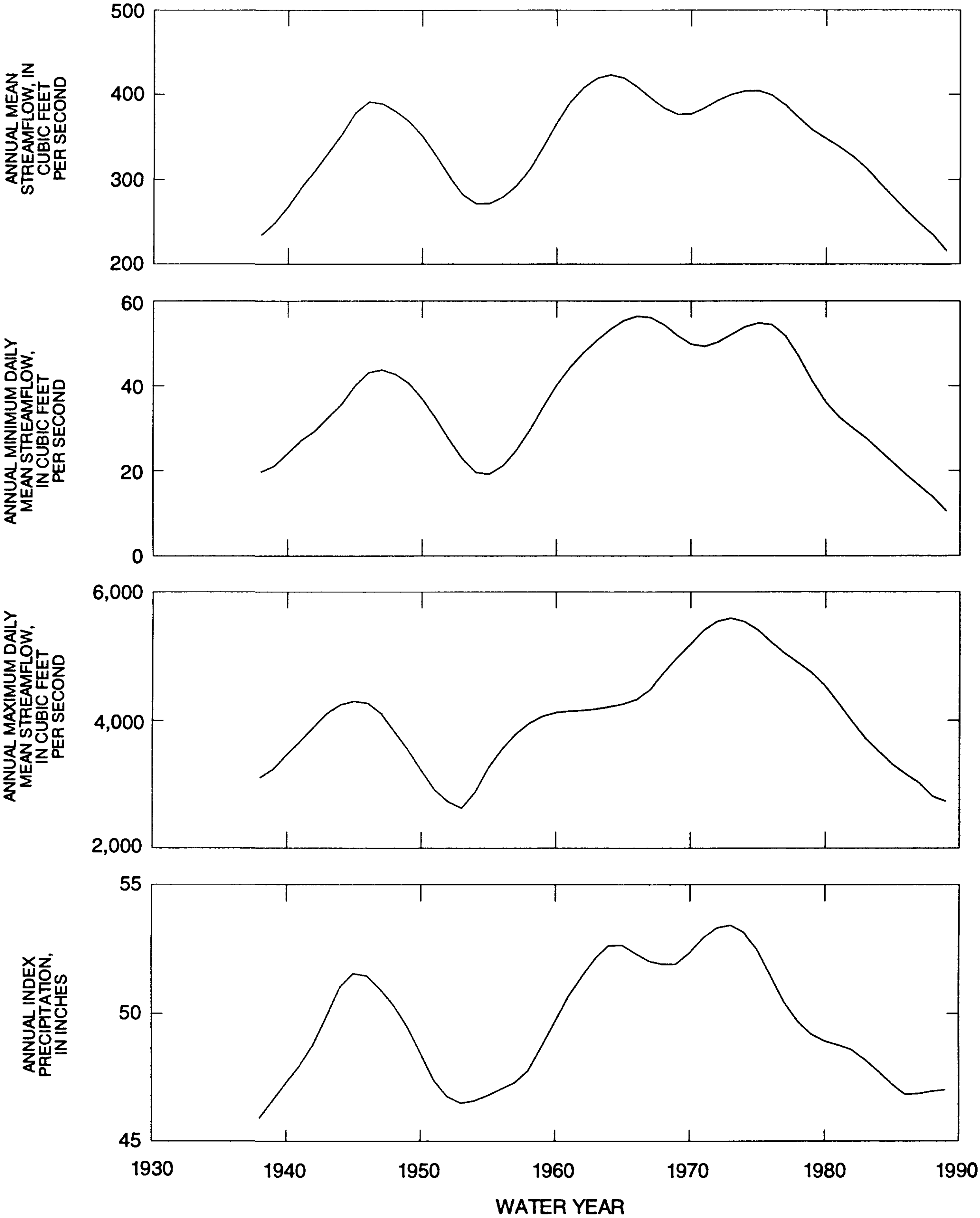


Figure 7. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02344500 on the Flint River near Griffin, Georgia, in the Apalachicola River Basin.

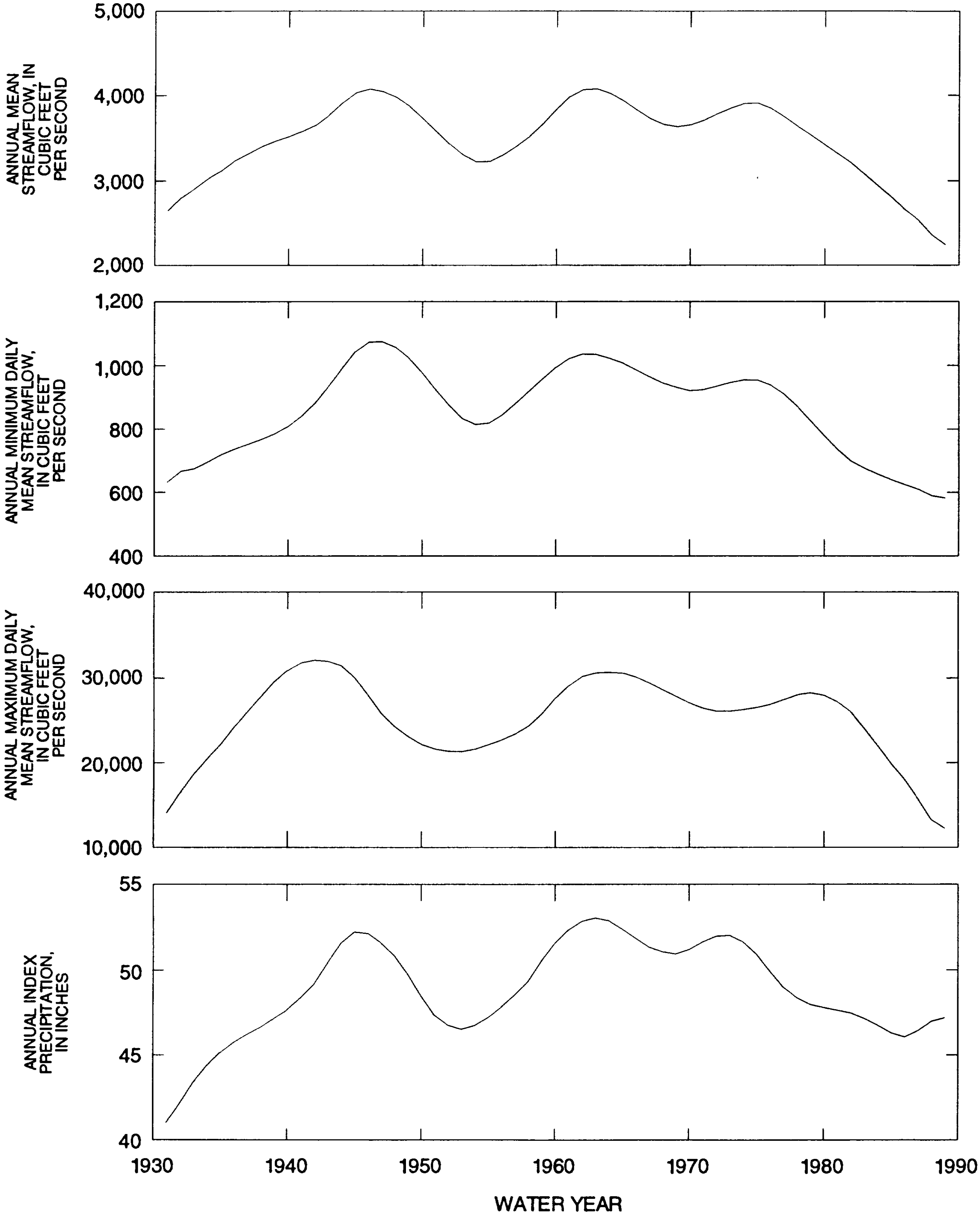


Figure 8. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02349500 on the Flint River at Montezuma, Georgia, in the Apalachicola River Basin.

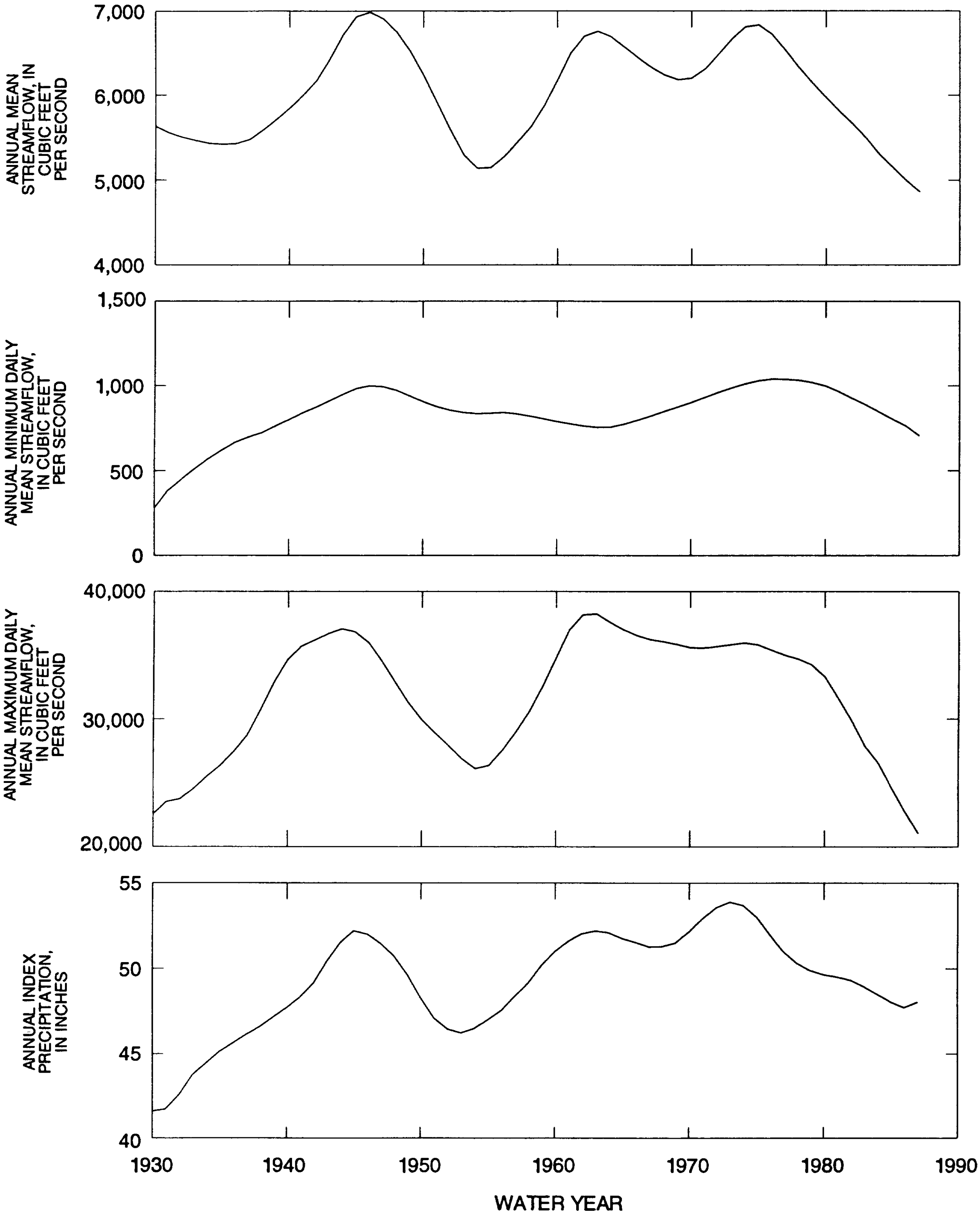


Figure 9. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02352500 on the Flint River at Albany, Georgia, in the Apalachicola River Basin.

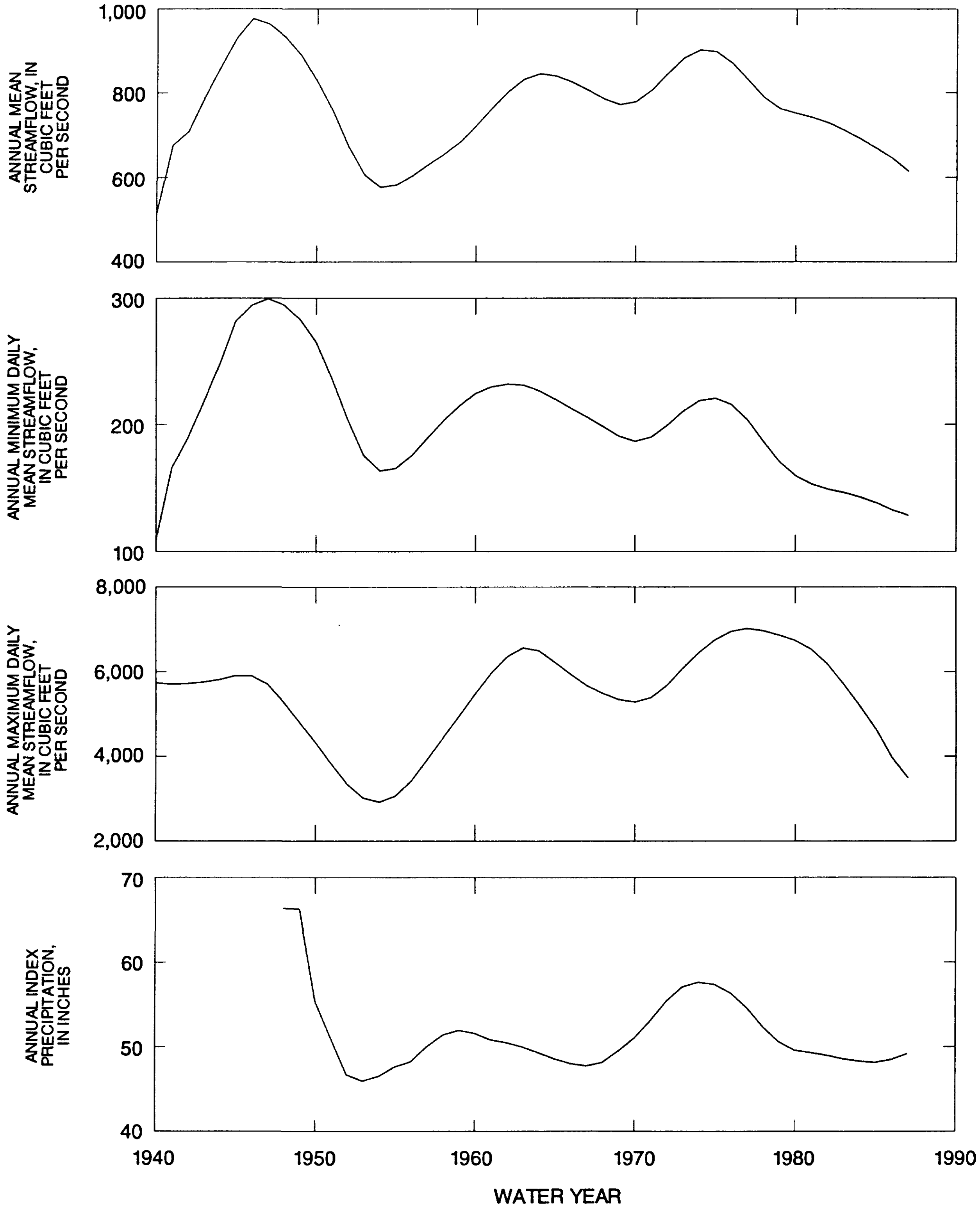


Figure 10. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02353500 on Ichawaynochaway Creek at Milford, Georgia, in the Apalachicola River Basin.

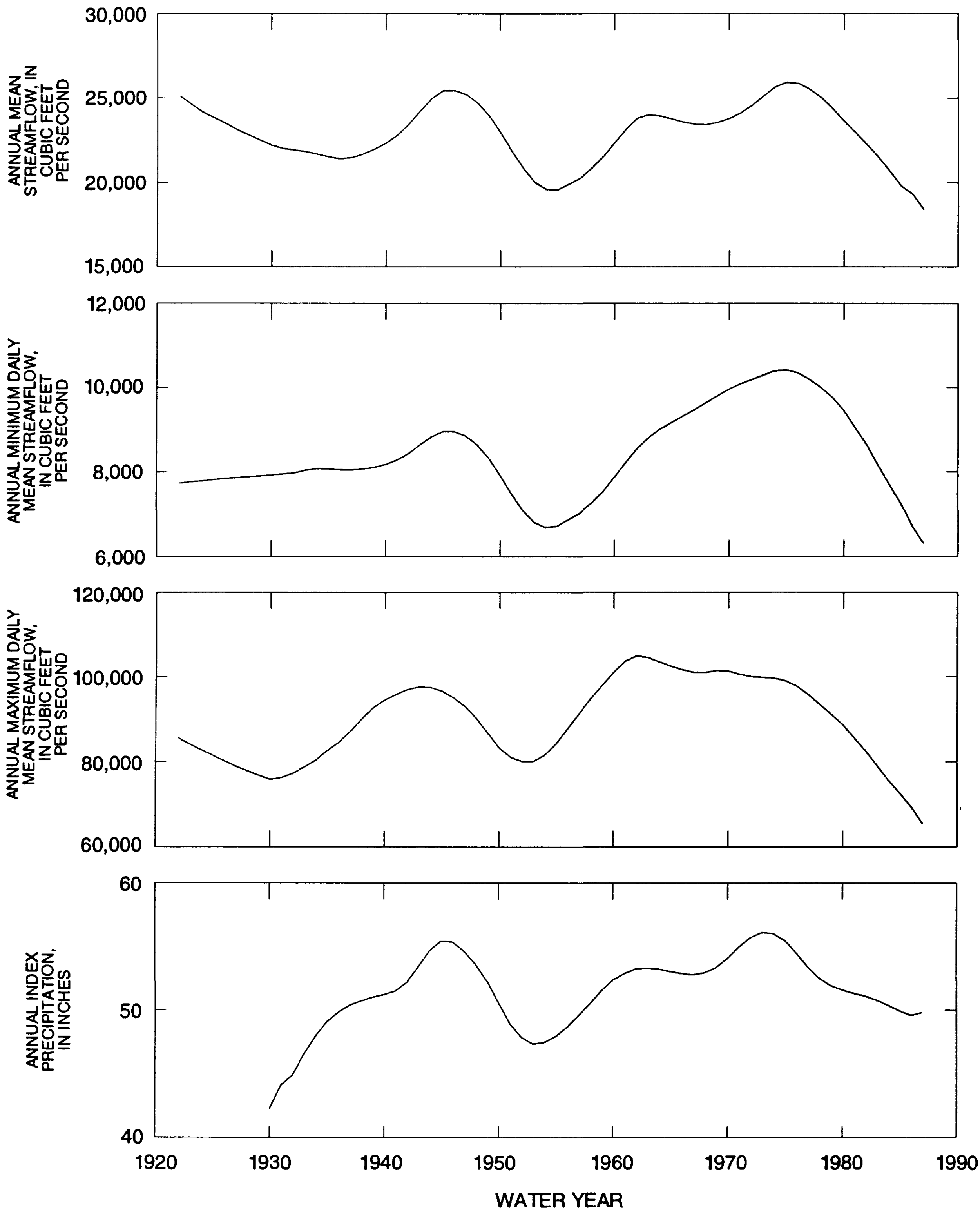


Figure 11. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02358700 on the Apalachicola River near Blountstown, Florida, in the Apalachicola River Basin.

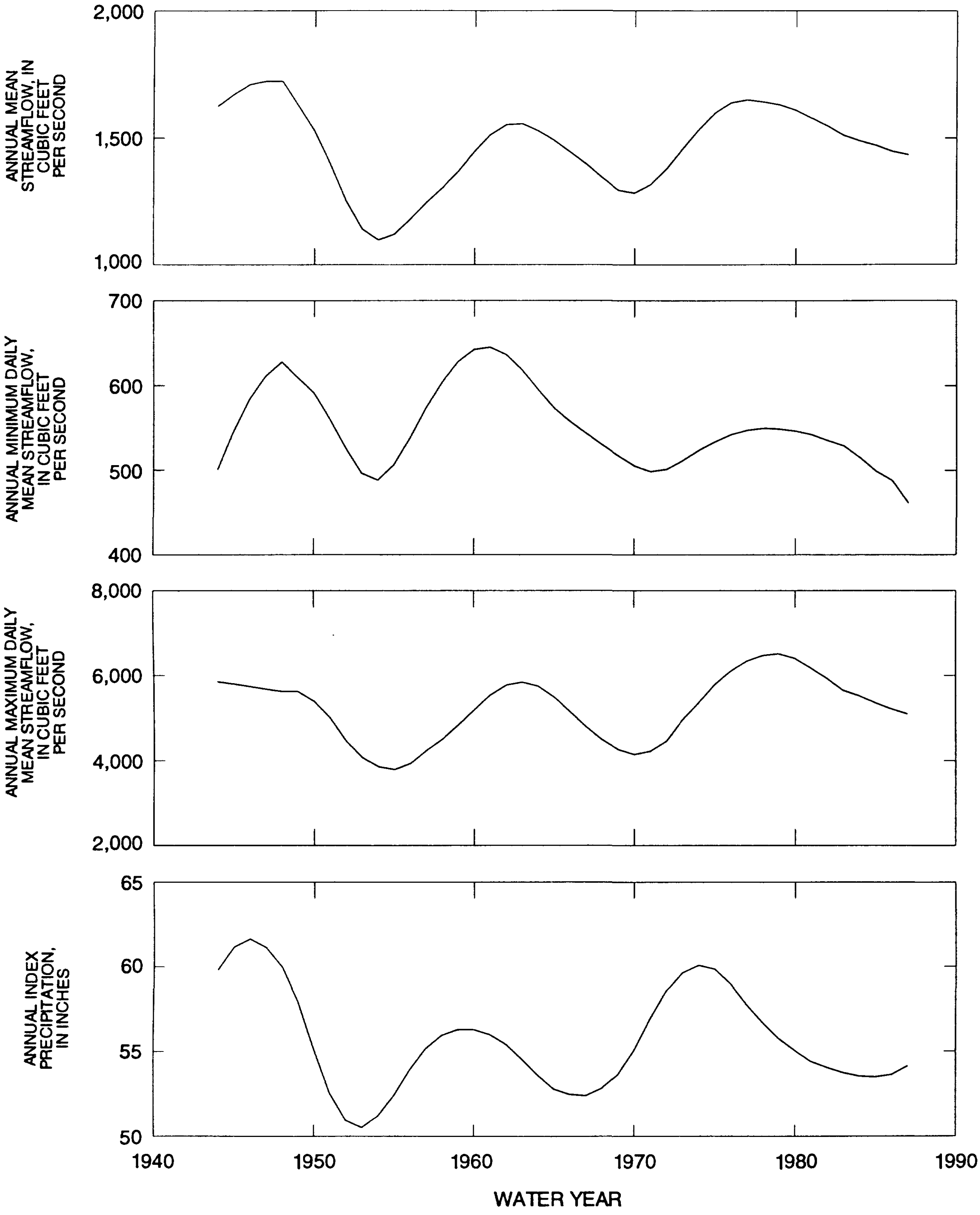


Figure 12. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02359000 on the Chipola River near Altha, Florida, in the Apalachicola River Basin.

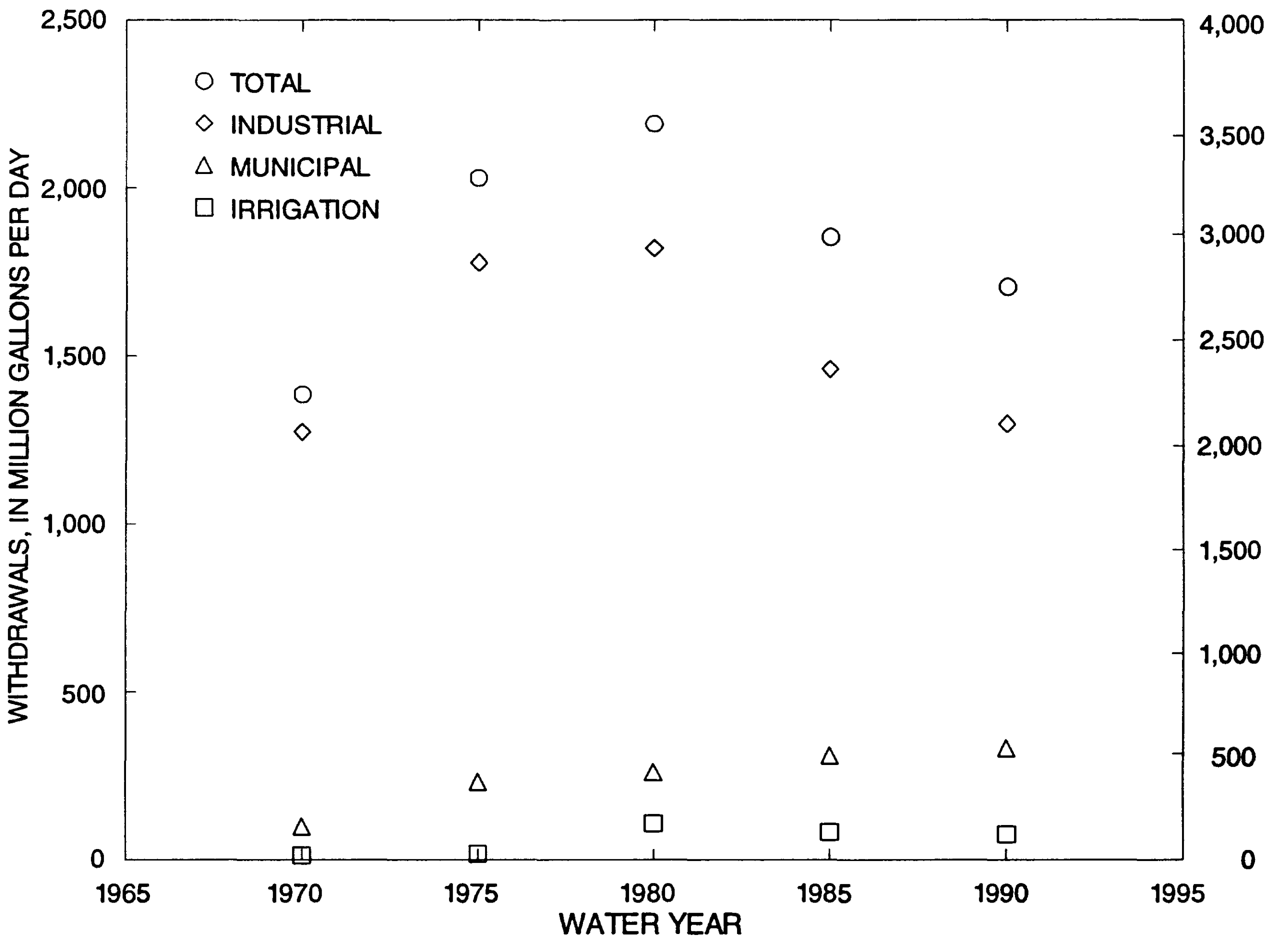


Figure 13. Reported annual surface-water withdrawals from the Apalachicola River Basin, by category of use.

station. Before construction of the reservoir, the annual mean streamflow was about 17 percent of the associated annual index precipitation; streamflow was about 16 percent of precipitation after construction of the reservoir. Therefore, streamflow as a percentage of precipitation was about 1 percent less after construction of the reservoir, which represents a decrease in streamflow of about 6 percent. This decrease, however, probably exceeds the potential error in the data, thus it is possible that no change in streamflow occurred.

Pearl River Basin

The Pearl River Basin, located in Mississippi and Louisiana, has a drainage area of approximately 8,730 mi^2. The annual mean streamflow is approximately 9,500 ft^3/s at the most downstream station (02489500) (fig. 16). Mean annual precipitation in the basin ranges from about 55.8 in. in the upstream part of the basin to about 62.3 in. in the downstream part of the basin. One major reservoir is in the basin.

Streamflow Stations and Associated Precipitation Stations

Four streamflow stations on the main channel of the Pearl River and three streamflow stations on tributaries were chosen for analysis. Locations of selected long-term streamflow stations and precipitation stations in the Pearl River Basin are shown in figure 16. The selected streamflow stations and associated precipitation stations and their available periods of record are listed in table 3.

Temporal Trends in Streamflow and Precipitation

The long-term trends indicate increases in streamflow and precipitation at all but one of the

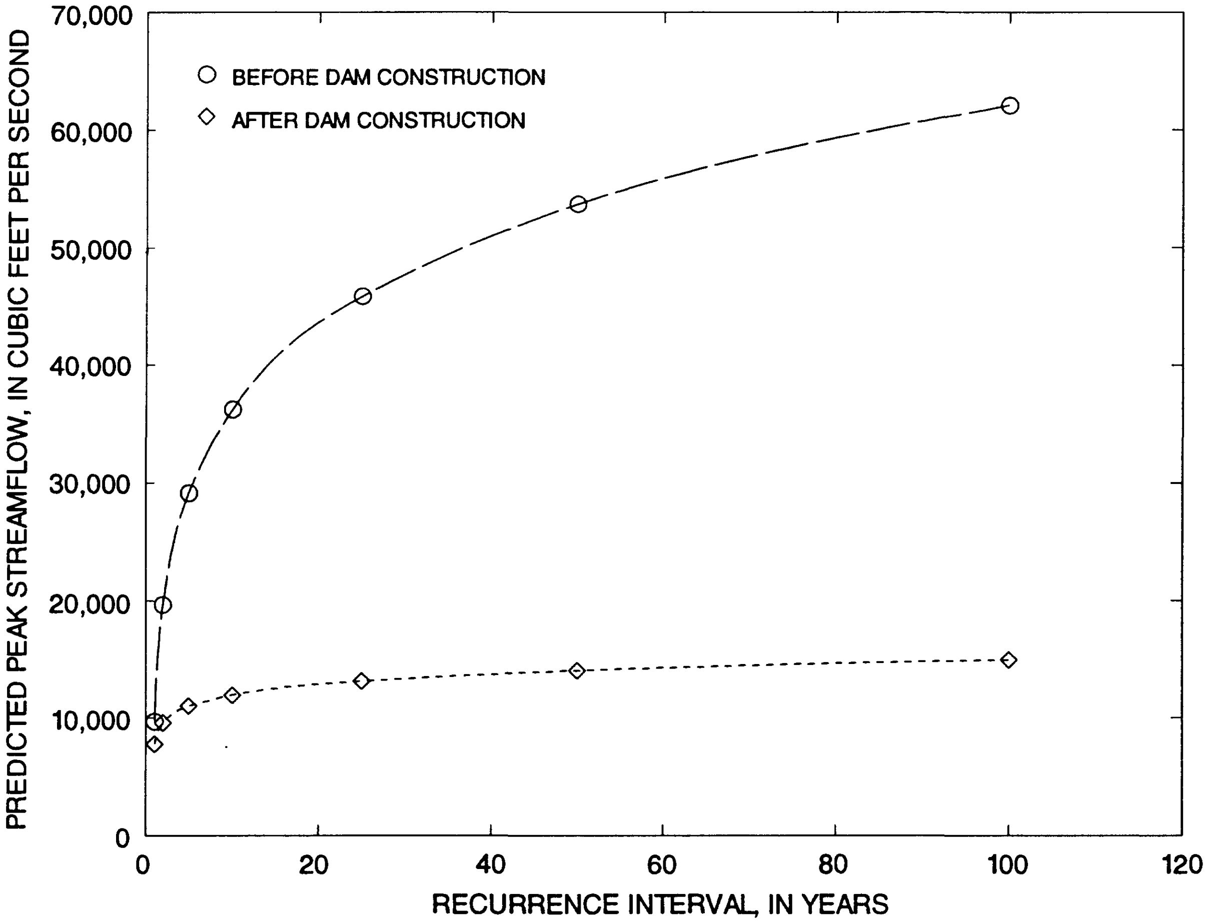


Figure 14. Predicted peak streamflow at streamflow station 02335000 on the Chattahoochee River downstream from Lake Sidney Lanier in the Apalachicola River Basin, before and after construction of the dam in 1956.

selected sites in the Pearl River Basin: annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation all increased during the period of record. The exception was streamflow station 02492000, where less than a 5-percent increase occurred in annual minimum streamflow. Increases occurred at this station for annual mean and annual maximum streamflow and for associated annual index precipitation.

The short-term trends identified for the streamflow generally corresponded to the trends in associated annual index precipitation for each station (figs. 17–23). The trends for streamflow station 02486000 (downstream from the Ross R. Barnett Reservoir) indicated an increase in annual minimum streamflow during the 1980's and a decrease in annual mean and annual maximum streamflow and in associated annual index precipitation during the same period (fig. 20). For station 02488500 (farther downstream), annual minimum streamflow increased during the late 1970's and 1980's, while annual mean and annual maximum streamflow and annual index precipitation decreased for the station during the same period (fig. 21). For station 02489500 (the most downstream station studied on the main channel), annual mean streamflow decreased during the 1980's, while annual minimum streamflow increased, and annual index precipitation and annual maximum streamflow decreased and then increased during the same period (fig. 22). Causes for these trends were not investigated; however, the increases in annual minimum streamflow could result from

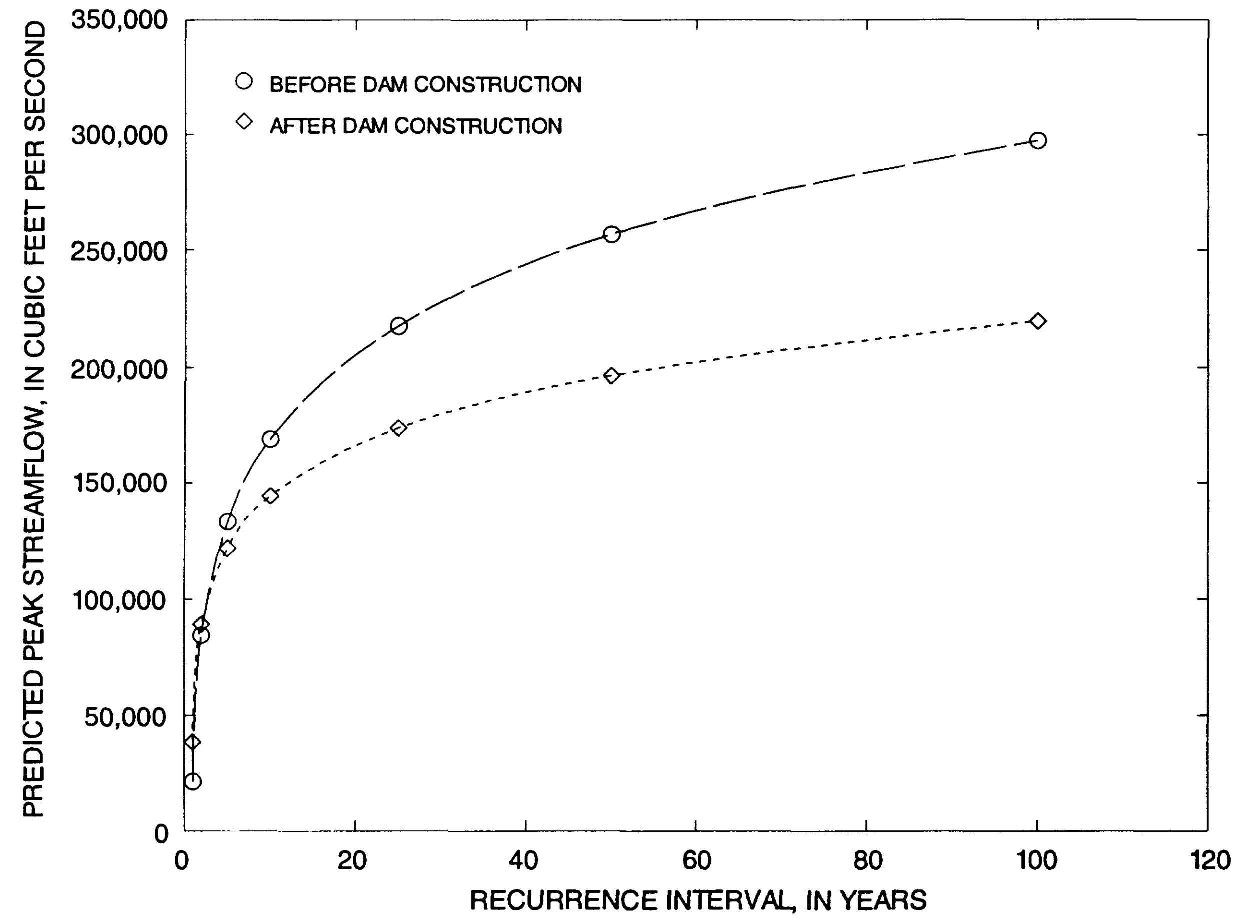


Figure 15. Predicted peak streamflow at streamflow station 02358700 on the Apalachicola River downstream from Lake Seminole in the Apalachicola River Basin, before and after construction of the dam in 1954.

reservoir operation and from return flows from Jackson, Mississippi.

Surface-Water Withdrawals

Data for surface-water withdrawals were available for only two major users: Jackson, Mississippi, and the Georgia-Pacific Co. (Nancy Barber, U.S. Geological Survey, written commun., 1991). The City of Jackson reported annual mean withdrawals from the Pearl River ranging from 38.2 to 50.4 ft^3/s from 1975 through 1985. The withdrawal for the city is used for municipal water supply, supplemented with groundwater withdrawals, and is returned to the Pearl River as treated effluent. From 1979 through 1986, the Georgia-Pacific Co. reported annual mean withdrawals from the Pearl River north of Monticello, Mississippi (fig. 16), ranging from 30.0 to 43.2 ft^3/s. Because of the limited period of record and lack of information about other possible surface-water withdrawals, these data were insufficient for determining trends in surface-water withdrawals in the Pearl River Basin.

Effect of Reservoir on Streamflow

The Ross R. Barnett Reservoir is the only major reservoir in the Pearl River Basin (fig. 16). This reservoir was built primarily for water supply and probably has not affected peak streamflow in the Pearl River. Peak streamflow frequency analyses of streamflow downstream from the reservoir before and after construction of the reservoir in 1965 indicate that the predicted peak streamflow did not change following completion of the reservoir. The annual index precipitation following reservoir construction was about 7 in. more than before construction of the reservoir;

Table 1. Selected streamflow stations, associated precipitation stations, and periods of record in the Apalachicola River Basin

[Where the period of record for the associated precipitation stations exceeded the available period of record for the streamflow station, the longest common period of record was used for analysis of trends for the streamflow station and its associated precipitation stations]

Streamflow station number and name		Precipitation station number and location		Available periods of record (water years)
02333500	Chestatee River near Dahlonega, Ga.			1929–32, 1940–88
		2006	Cleveland, Ga.	1948–88
		2475	Dahlonega, Ga.	1930–88
02335000	Chattahoochee River near Norcross, Ga.			1903–46, 1957–88
		2475	Dahlonega, Ga.	1930–88
		3621	Gainesville, Ga.	1930–88
		6407	Norcross, Ga.	1948–88
		8740	Toccoa, Ga.	1930–88
02337000	Sweetwater Creek near Austell, Ga.			1904–06, 1937–88
		2791	Douglasville, Ga.	1948–88
		3147	Embry, Ga.	1948–88
02339500	Chattahoochee River at West Point, Ga.			1896–88
		451	Atlanta, Ga.	1930–88
		2475	Dahlonega, Ga.	1930–88
		3147	Embry, Ga.	1948–88
		3621	Gainesville, Ga.	1930–88
		9291	West Point, Ga.	1930–88
02344500	Flint River near Griffin, Ga.			1937–88
		451	Atlanta, Ga.	1930–88
		3271	Experiment, Ga.	1926–88
02349500	Flint River at Montezuma, Ga.			1905–13, 1930–88
		451	Atlanta, Ga.	1930–88
		3271	Experiment, Ga.	1926–88
		5979	Montezuma, Ga.	1948–88
		6335	Newnan, Ga.	1948–88
		8535	Talbotton, Ga.	1930–88

Table 1. Selected streamflow stations, associated precipitation stations, and periods of record in the Apalachicola River Basin—Continued

Streamflow station number and name		Precipitation station number and location		Available periods of record (water years)
02352500	Flint River at Albany, Ga.			1902–21, 1930–88
		140	Albany, Ga.	1892–88
		451	Atlanta, Ga.	1930–88
		3271	Experiment, Ga.	1926–88
		8535	Talbotton, Ga.	1930–88
02353500	Ichawaynochaway Creek at Milford, Ga.			1905–08, 1940–88
		979	Blakely, Ga.	1889–1911, 1914–88
		2450	Cuthbert, Ga.	1948–88
		2570	Dawson, Ga.	1944–88
02358700	Apalachicola River near Blountstown, Fla.			1921–88
		140	Albany, Ga.	1892–88
		451	Atlanta, Ga.	1930–88
		979	Blakely, Ga.	1889–1911, 1914–88
		3261	Gainesville, Ga.	1930–88
		3271	Experiment, Ga.	1926–88
		7424	Quincy, Fla.	1896–98, 1901–04, 1916–67
		7429	Quincy, Fla.	1968–88
		9291	West Point, Ga.	1930–88
02359000	Chipola River near Altha, Fla.			1913–14, 1922–27, 1929–31, 1943–88
		804	Blountstown, Fla.	1931–82
		979	Blakely, Ga.	1889–1911, 1914–88
		6218	Ozark, Ala.	1930–86
		7429	Quincy, Fla.	1968–88

therefore, peak streamflow frequencies and statistical relations between precipitation and streamflow for the two periods cannot be compared meaningfully.

Trinity River Basin

The Trinity River, located entirely in the State of Texas, has a drainage area of approximately 18,000 mi^2. The annual mean streamflow is approximately 7,400 ft^3/s at station 08066500, about 94 mi upstream from the mouth of the Trinity River (fig. 24). Mean annual precipitation in the basin ranges from about 28.8 in. in the upstream part of the basin to about 52.2 in. in the downstream part of the basin. The Trinity River has 31 identified reservoirs in the basin with a capacity greater than 5,000 acre-ft of storage.

Streamflow Stations and Associated Precipitation Stations

Four streamflow stations on the main channel of the Trinity River and five stations on major tributaries

Table 2. Long-term trends in streamflow and associated precipitation for streamflow stations in the Apalachicola River Basin

[no change, less than 5-percent increase or decrease for 50 years of streamflow record, or less than 3-percent increase or decrease for 50 years of precipitation record]

Streamflow station number and name		Long-term trend: Annual mean streamflow	Annual minimum daily mean streamflow	Annual maximum daily mean streamflow	Associated annual index precipitation
02333500	Chestatee River near Dahlonega, Ga.	increased	no change	increased	increased
02335000	Chattahoochee River near Norcross, Ga.	no change	no change	decreased	increased[1]
02337000	Sweetwater Creek near Austell, Ga.	increased	no change	increased	increased[1]
02339500	Chattahoochee River at West Point, Ga.	decreased	decreased	decreased	increased[1]
02344500	Flint River near Griffin, Ga.	no change	no change	decreased	increased
02349500	Flint River at Montezuma, Ga.	decreased	decreased	decreased	increased
02352500	Flint River at Albany, Ga.	no change	increased	increased	increased
02353500	Ichawaynochaway Creek at Milford, Ga.	decreased	decreased	increased	decreased[1]
02358700	Apalachicola River near Blountstown, Fla.	no change	increased	no change	increased[1]
02359000	Chipola River near Altha, Fla.	no change	decreased	no change	no change

[1] Comparison of streamflow trends with the precipitation trend for this site may be affected by the shorter length of record for the precipitation stations associated with this streamflow station.

were selected for analysis. Locations of the long-term streamflow stations and precipitation stations selected for analysis in the Trinity River Basin are shown in figure 24. The selected streamflow stations, associated precipitation stations, and their available periods of record are presented in table 4.

Temporal Trends in Streamflow and Precipitation

Long-term trends indicated an increase in annual minimum daily mean streamflow and a decrease in annual maximum daily mean streamflow for all of the selected streamflow stations in the Trinity River Basin (table 5). Associated annual index precipitation either increased with time or remained unchanged throughout the basin. Annual mean streamflow decreased at six of the nine streamflow stations. Annual mean streamflow increased for station 08047500, downstream from Benbrook Lake, and for station 08057000. Annual mean streamflow did not change for station 08055500, downstream from Grapevine Lake and Lewisville Reservoir.

Short-term trends in annual mean streamflow generally corresponded to the trends identified for associated annual index precipitation (figs. 25–33).

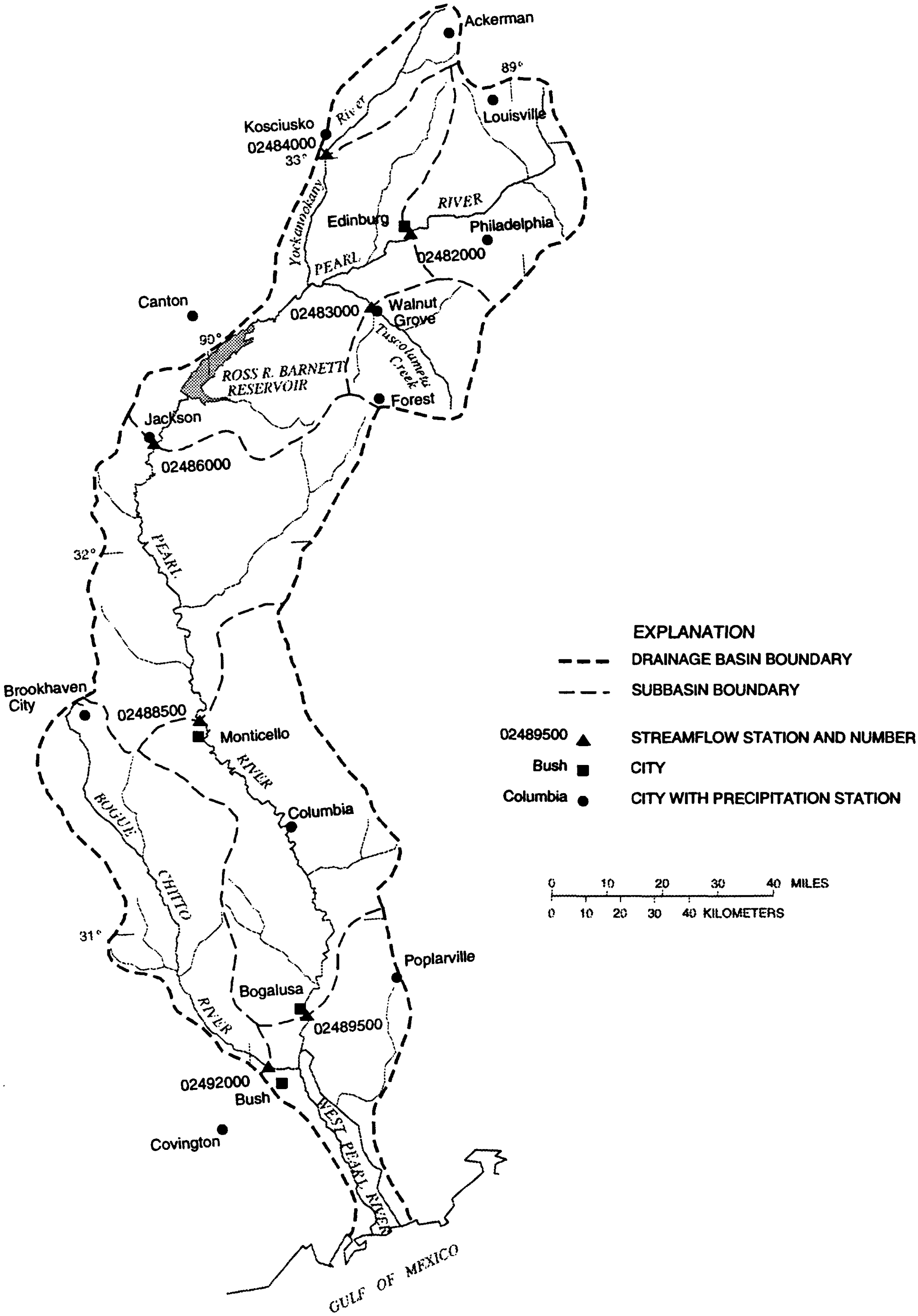


Figure 16. Location of selected streamflow stations, precipitation stations, and the major reservoir in the Pearl River Basin.

Table 3. Selected streamflow stations, associated precipitation stations, and periods of record in the Pearl River Basin

[Where the period of record for the associated precipitation stations exceeded the available period of record for the streamflow station, the longest common period of record was used for analysis of trends for the streamflow station and its associated precipitation stations]

Streamflow station number and name		Precipitation station number and location		Available periods of record
02482000	Pearl River at Edinburg, Miss.			1929–88
		5247	Louisville, Miss.	1930–88
		6894	Philadelphia, Miss.	1949–88
02483000	Tuscolameta Creek at Walnut Grove, Miss.			1940–88
		3107	Forest, Miss.	1930–88
		9326	Walnut Grove, Miss.	1948–88
02484000	Yockanookany River near Kosciusko, Miss.			1939–88
		39	Ackerman, Miss.	1948–88
		4776	Kosciusko, Miss.	1948–87, 1989–88
02486000	Pearl River at Jackson, Miss.			1902–88
		1389	Canton, Miss.	1948–88
		3107	Forest, Miss.	1930–88
		4667	Jackson, Miss.	1930–71
		4776	Kosciusko, Miss.	1948–87, 1989–88
		5247	Louisville, Miss.	1930–88
02488500	Pearl River near Monticello, Miss.			1939–88
		1094	Brookhaven City, Miss.	1930–88
		1389	Canton, Miss.	1948–88
		3107	Forest, Miss.	1930–88
		4467	Jackson, Miss.	1931–71
		5247	Louisville, Miss.	1930–88
02489500	Pearl River near Bogalusa, La.			1939–88
		1094	Brookhaven City, Miss.	1930–88
		1865	Columbia, Miss.	1930–88
		2151	Covington, La.	1930–88
		3107	Forest, Miss.	1930–88
		5247	Louisville, Miss.	1930–88
		7128	Poplarville, Miss.	1930–88
02492000	Bogue Chitto near Bush, La.			1938–88
		1094	Brookhaven City, Miss.	1930–88
		1865	Columbia, Miss.	1930–88
		2151	Covington, La.	1930–88

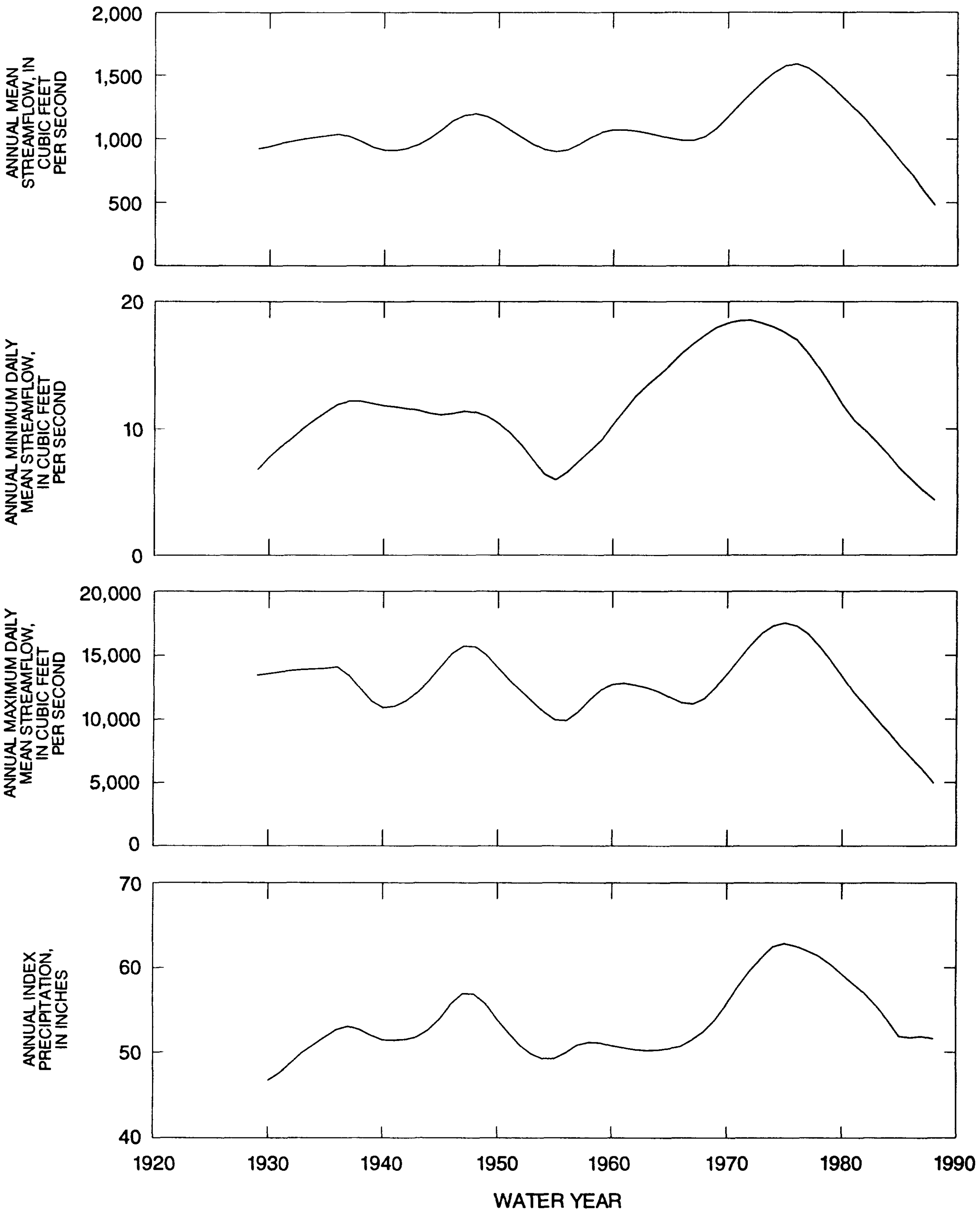


Figure 17. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02482000 on the Pearl River at Edinburg, Mississippi, in the Pearl River Basin.

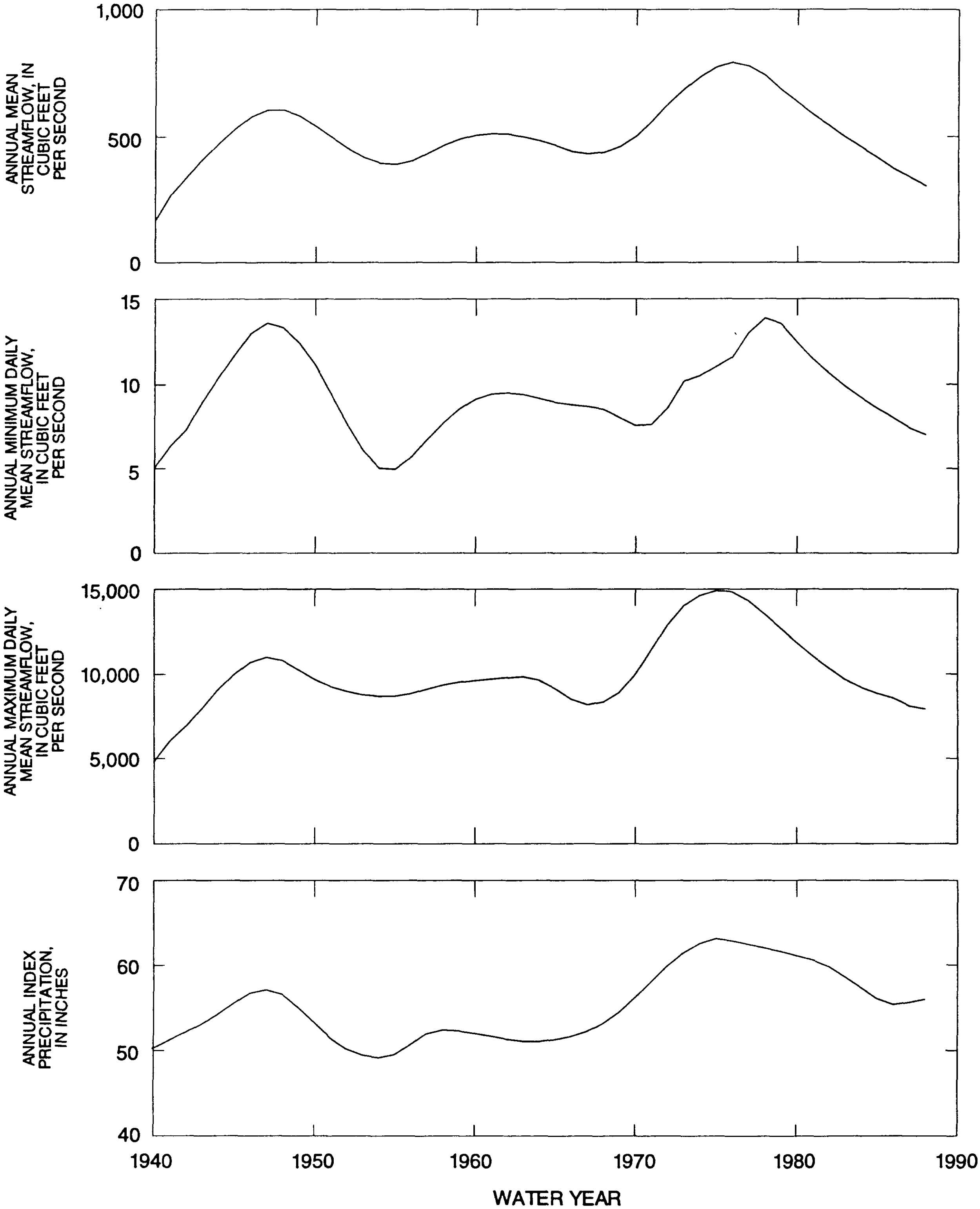


Figure 18. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02483000 on Tuscolameta Creek at Walnut Grove, Mississippi, in the Pearl River Basin.

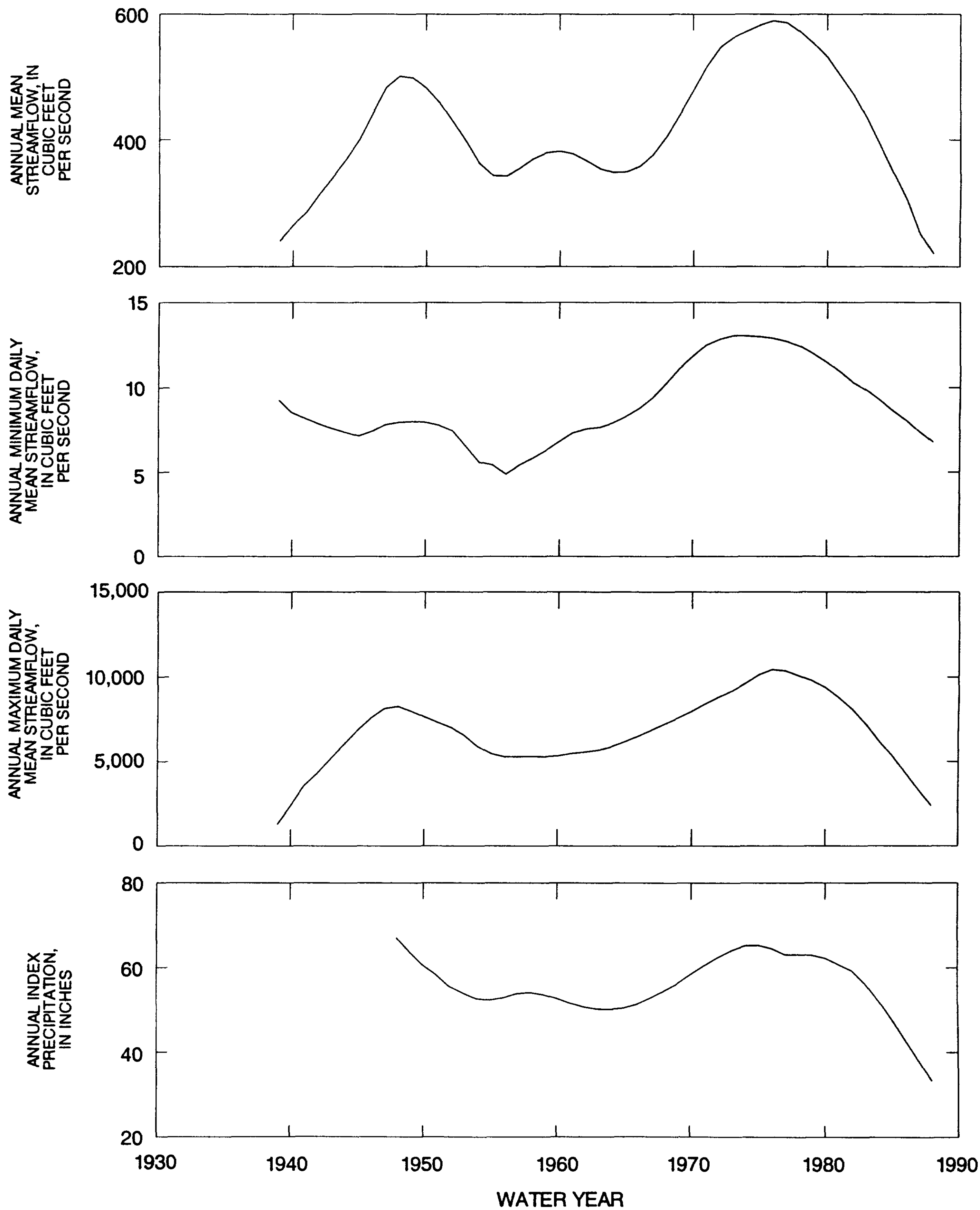


Figure 19. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02484000 on the Yockanookany River near Kosciusko, Mississippi, in the Pearl River Basin.

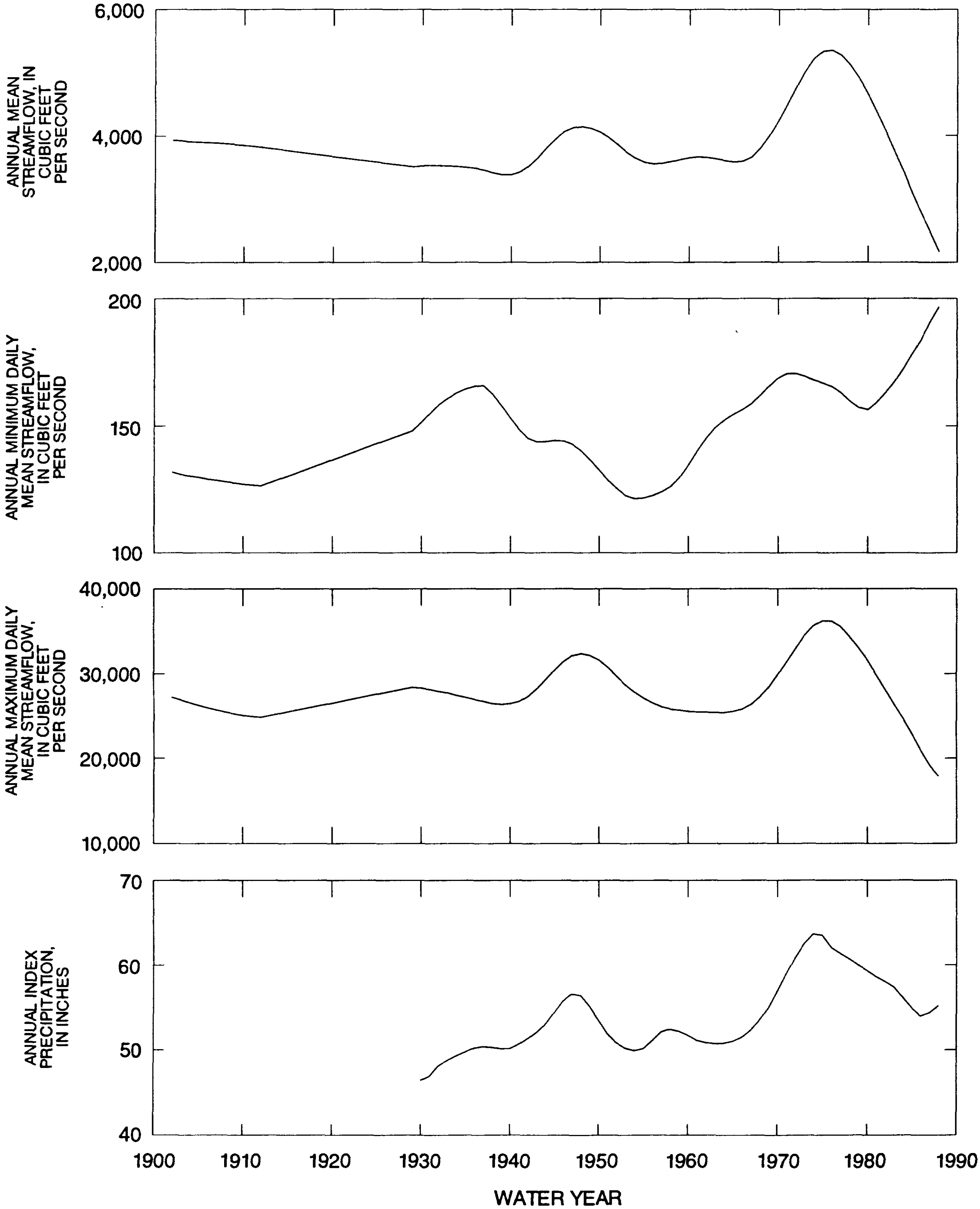


Figure 20. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02486000 on the Pearl River at Jackson, Mississippi, in the Pearl River Basin.

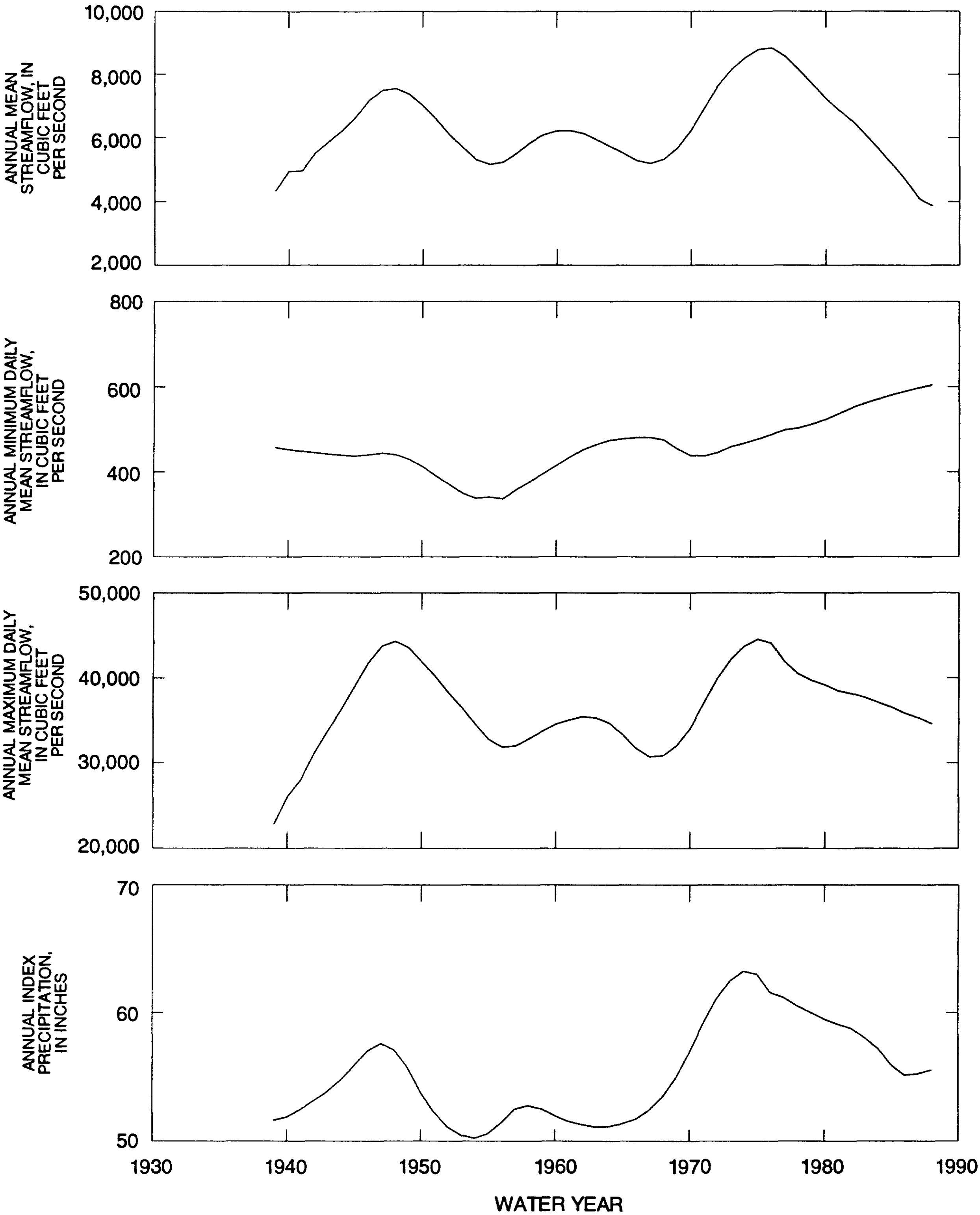


Figure 21. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02488500 on the Pearl River near Monticello, Mississippi, in the Pearl River Basin.

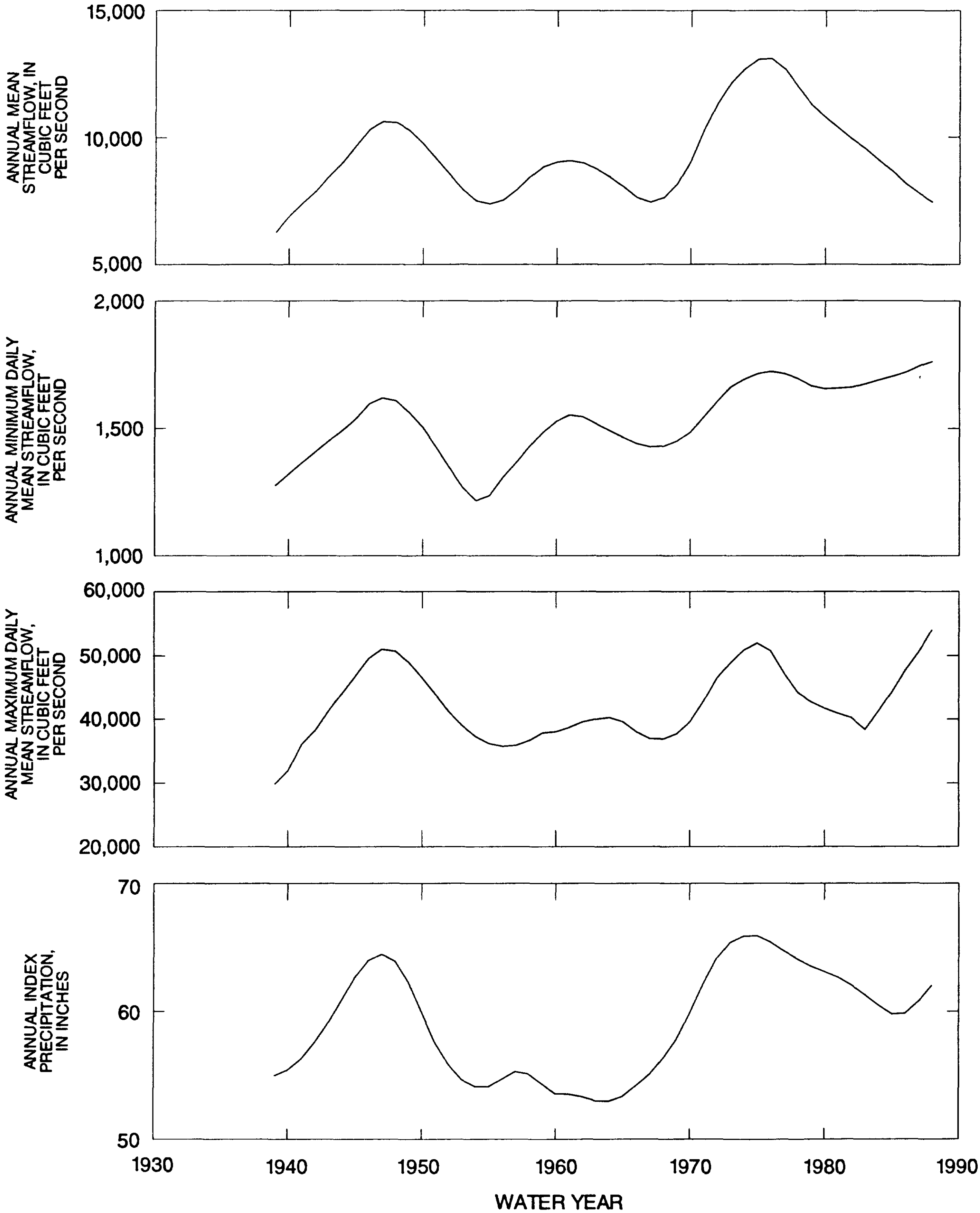


Figure 22. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02489500 on the Pearl River near Bogalusa, Louisiana, in the Pearl River Basin.

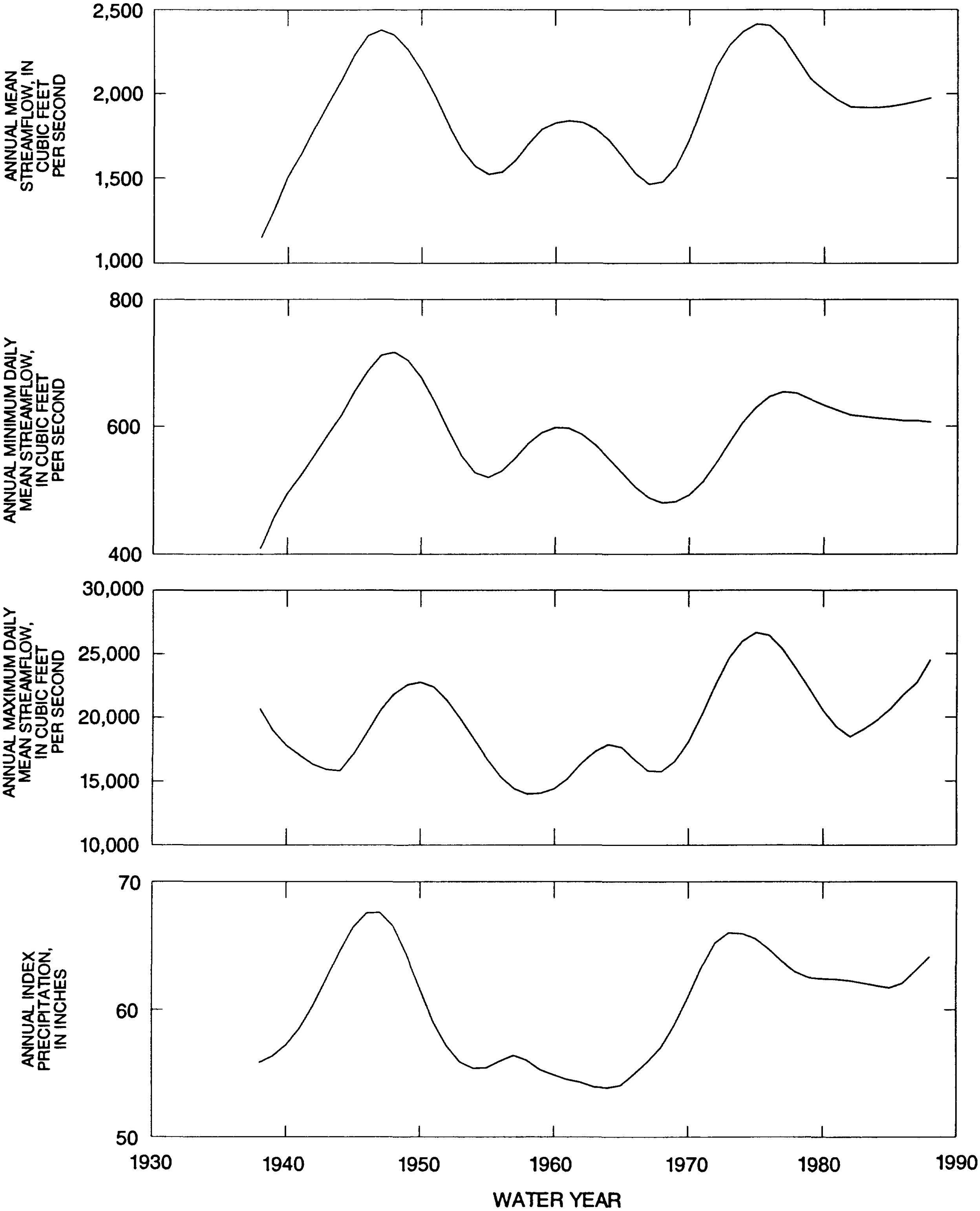


Figure 23. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 02492000 on the Bogue Chitto near Bush, Louisiana, in the Pearl River Basin.

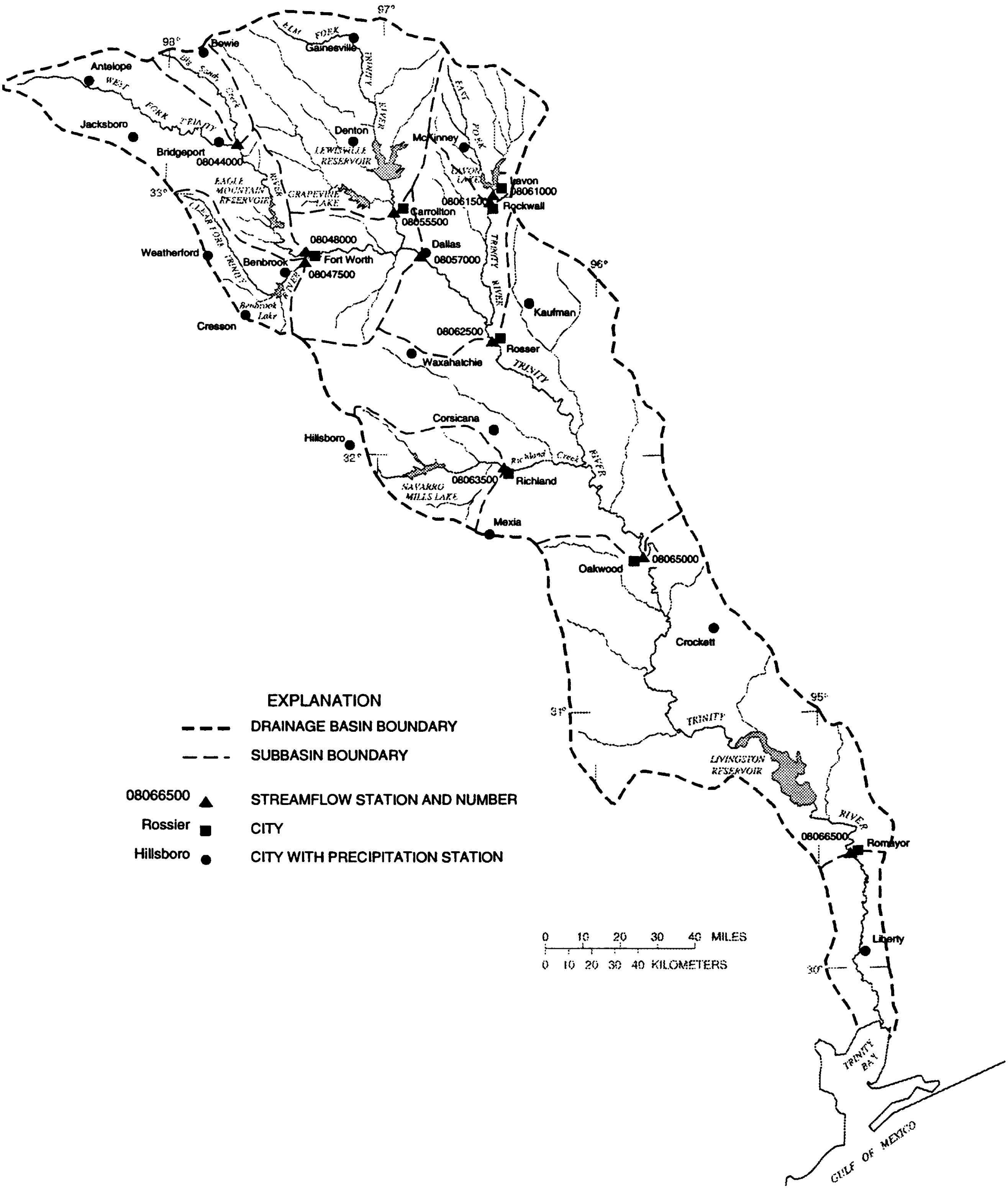


Figure 24. Location of selected streamflow stations, precipitation stations, and major reservoirs in the Trinity River Basin.

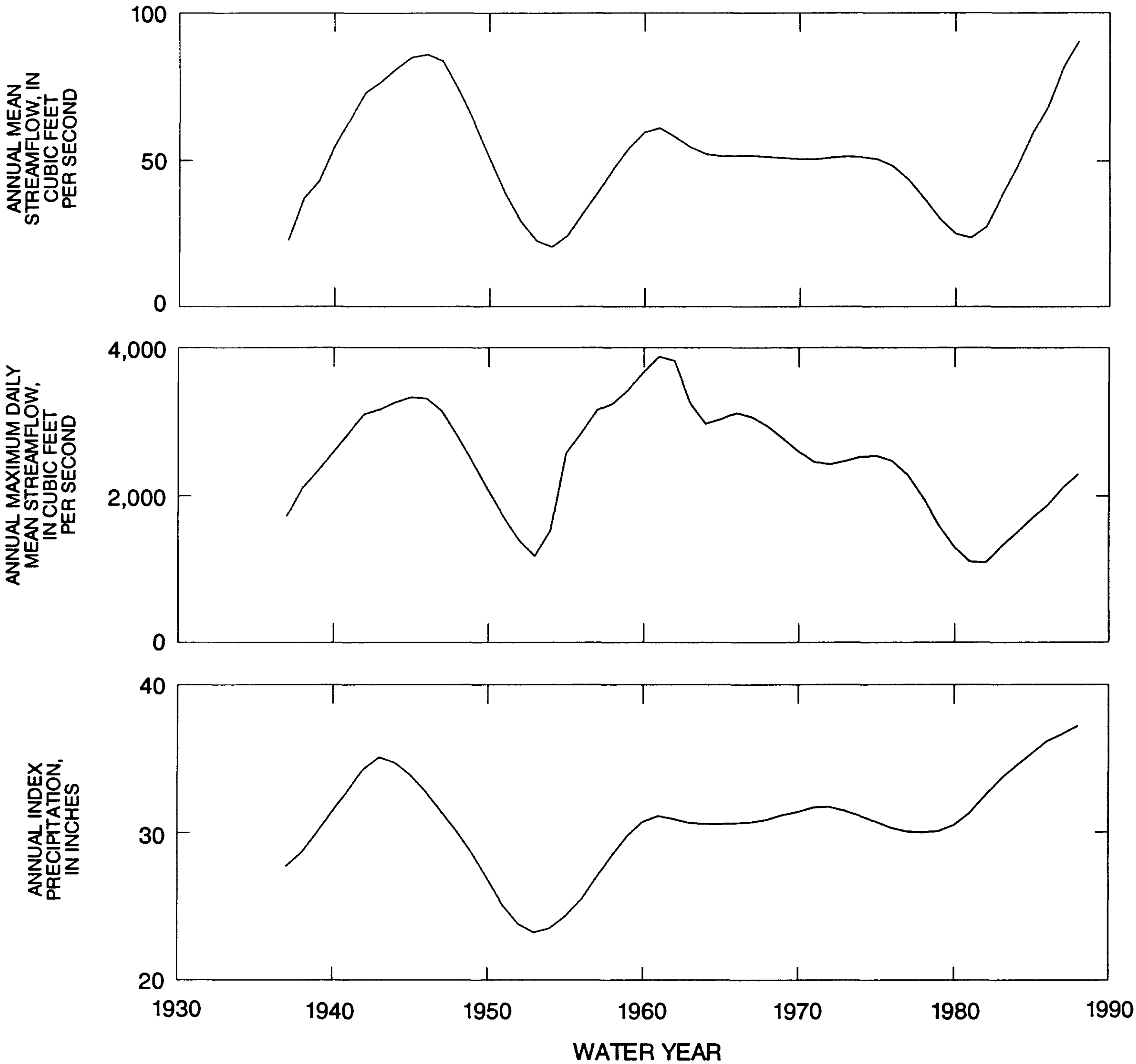


Figure 25. Short-term trends in annual mean streamflow, annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08044000 on Big Sandy Creek near Bridgeport, Texas, in the Trinity River Basin.

Trends in annual minimum and maximum daily mean streamflow generally did not correspond to trends in associated annual index precipitation. Trends in annual minimum and maximum streamflow correspond more closely to the trends in annual index precipitation for station 08066500 than for the upstream stations (fig. 33). Short-term trends were not identified for annual minimum daily mean streamflow for stations 08044000, 08047500, 08048000, 08055500, and 08063500 because of a large number of zero values present in the data.

Surface-Water Withdrawals

The Texas Natural Resource Conservation Commission has records of water use, by county, for the Trinity River Basin dating back to the early 1900's.

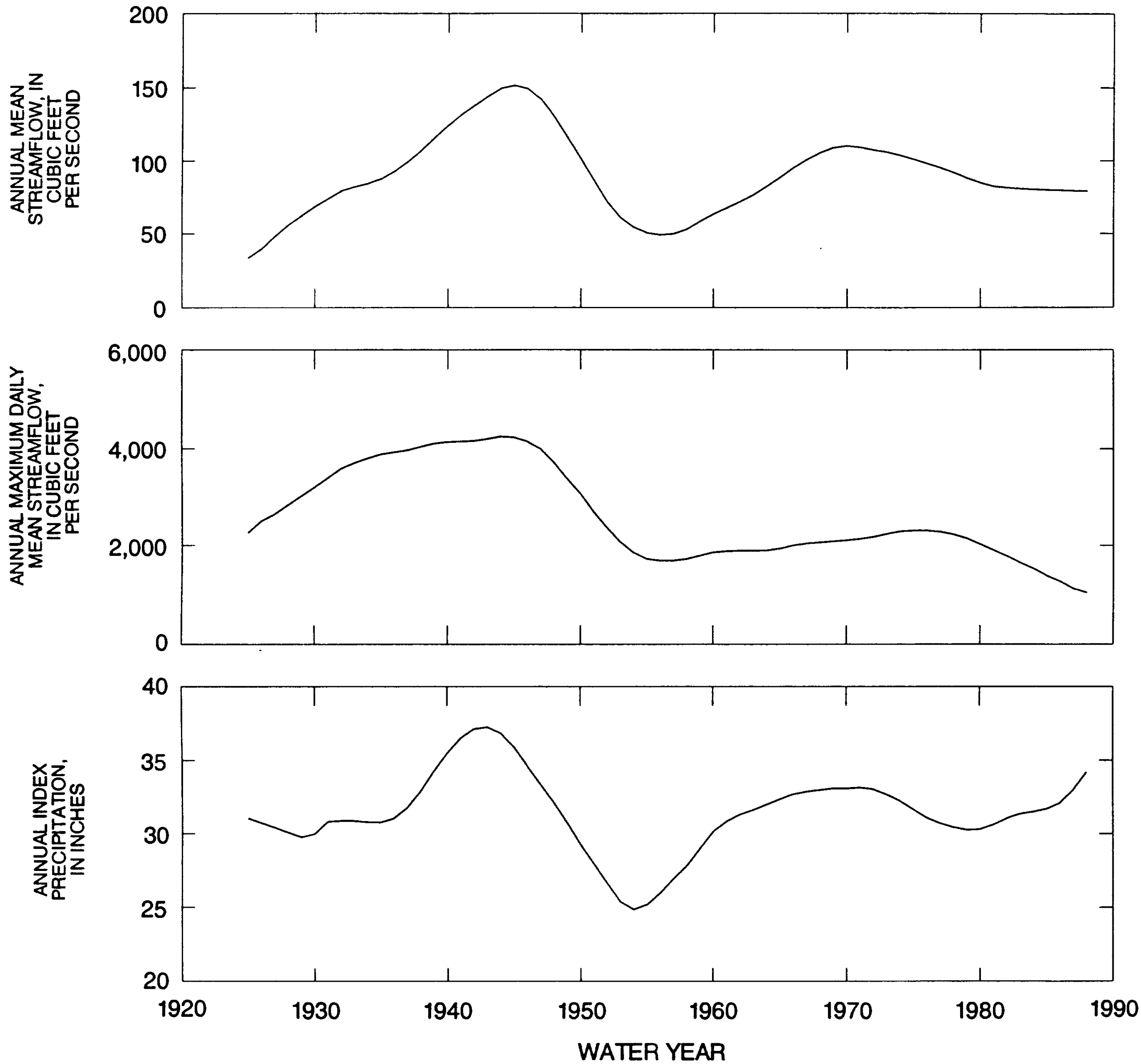


Figure 26. Short-term trends in annual mean streamflow, annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08047500 on the Clear Fork Trinity River at Fort Worth, Texas, in the Trinity River Basin.

Total reported annual surface-water withdrawals for the entire Trinity River Basin since 1940 are shown, by category of use, in figure 34. Withdrawals in the basin have increased more than fourfold since 1940. Most of this increase resulted from withdrawals for municipal water supplies; withdrawals for industrial uses also have increased. However, only about 20 percent of the reported withdrawals in 1990 were consumed and were not returned to the streams (Texas Water Development Board, written commun., 1990).

Data for surface-water withdrawals for the subbasins upstream from three streamflow stations (08057000, 08062500, and 08066500) were compared with trends in annual mean streamflow and associated annual index precipitation at each station (figs. 35–37). Withdrawals have increased in the basin upstream from

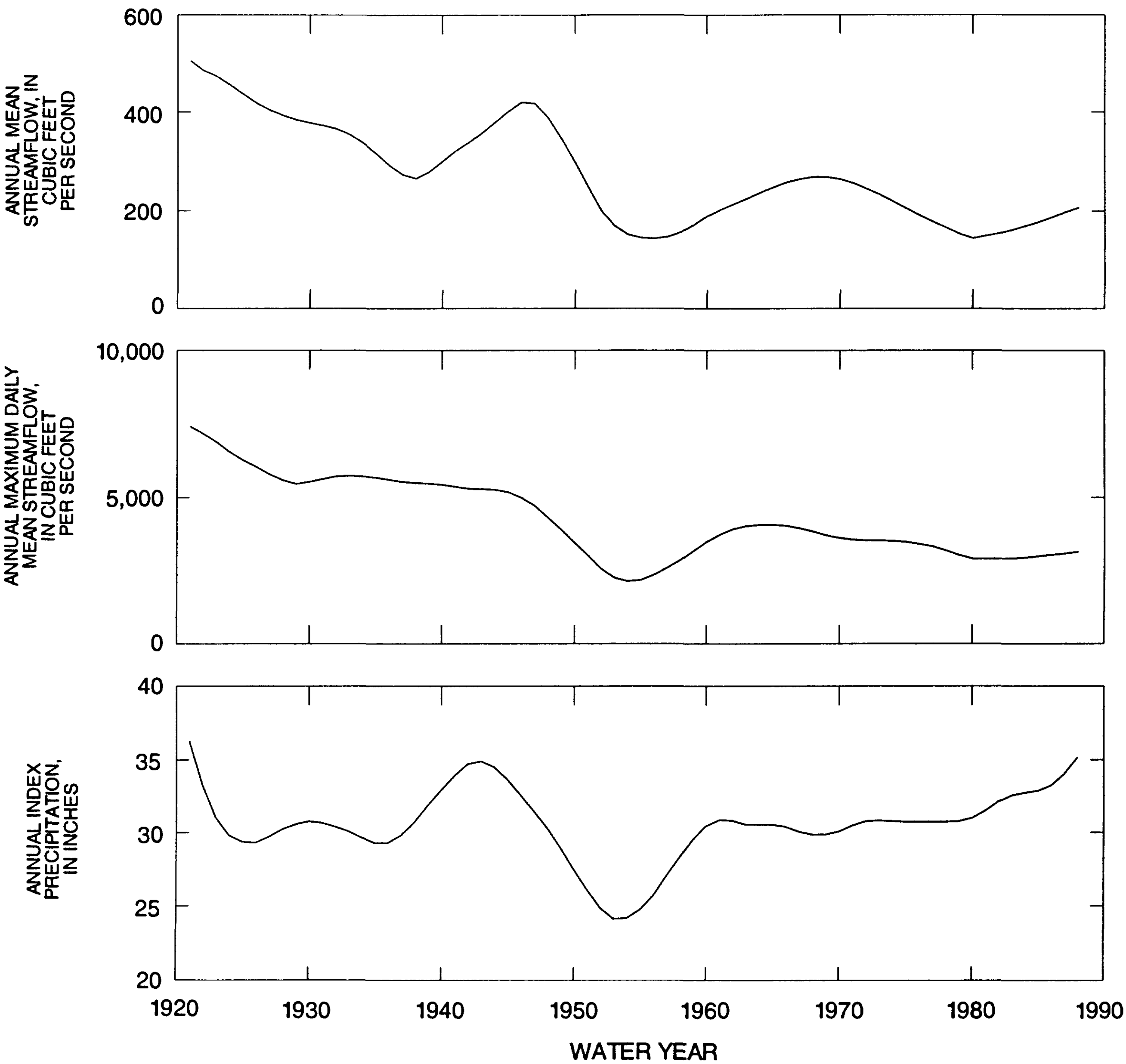


Figure 27. Short-term trends in annual mean streamflow, annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08048000 on the West Fork Trinity River at Fort Worth, Texas, in the Trinity River Basin.

each of these three stations. Total surface-water withdrawals from the Trinity River Basin in 1988 represented about one-fourth of the annual mean streamflow at station 08066500, the most downstream station on the Trinity River.

Effects of Reservoirs on Streamflow

The streamflow at all of the stations selected for analysis probably is affected by upstream regulation. Based on identified trends, annual minimum daily mean streamflow has increased and annual maximum daily mean streamflow has decreased at all of the selected stations (table 5). Numerous reservoirs in the basin have caused these trends. Increases in annual minimum streamflow resulted from releases from reservoirs to supplement low flow and, downstream from Dallas and Fort Worth, discharges of treated wastewater into the streams. Decreases in annual maximum

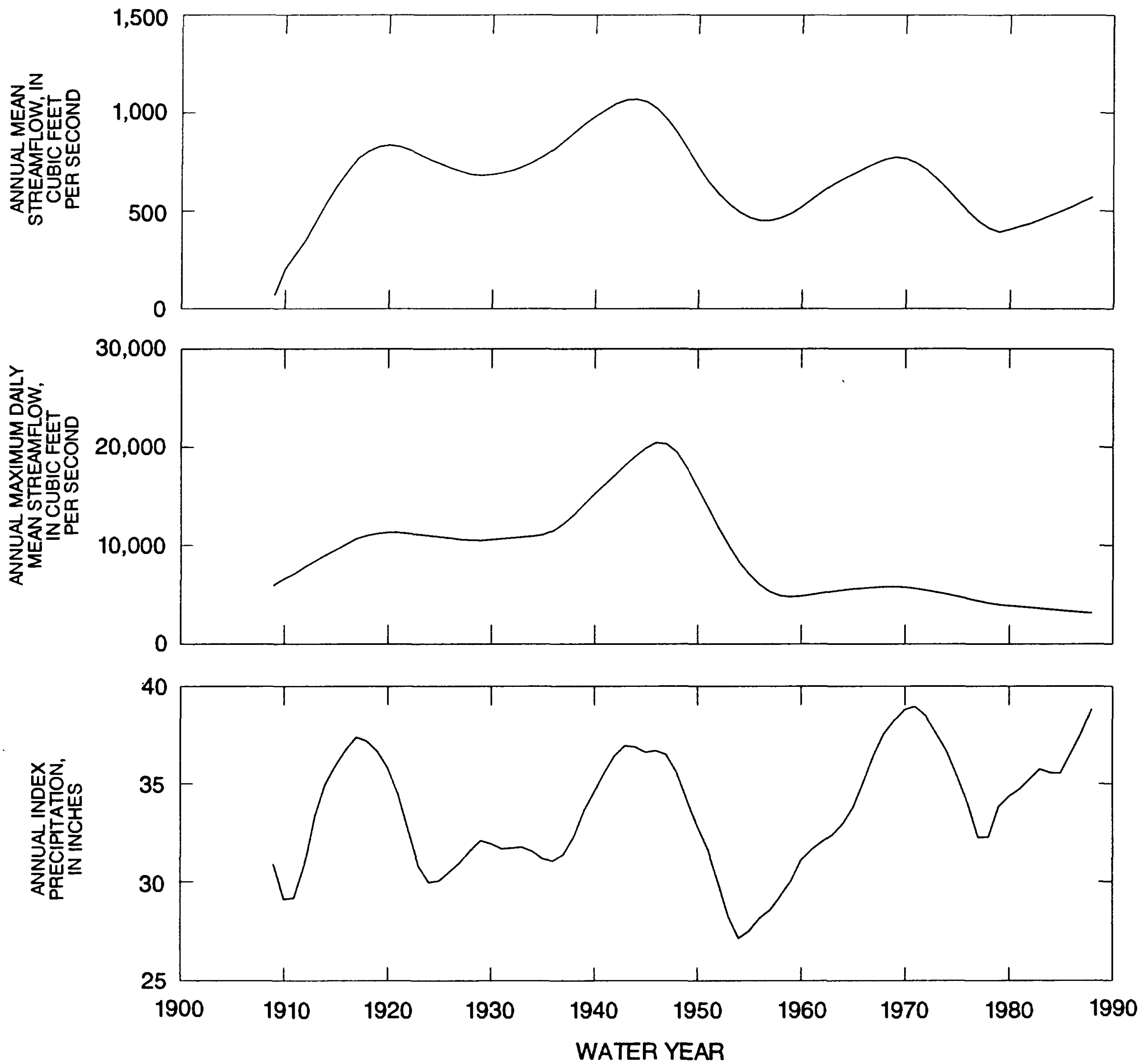


Figure 28. Short-term trends in annual mean streamflow, annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08055500 on the Elm Fork Trinity River near Carrollton, Texas, in the Trinity River Basin.

streamflow resulted from attenuation of flood peaks by the reservoirs.

The streamflow at the long-term station immediately downstream from each of three reservoirs, Benbrook Lake, Lavon Lake[1], and Livingston Reservoir (fig. 24), was analyzed for peak streamflow frequency before and after construction of the reservoirs. Streamflow at each of these reservoirs may be affected by other upstream reservoirs. Predicted peak streamflow downstream from Benbrook Lake on the Clear Fork Trinity River, for the flood peak with an expected

[1]Peak streamflow before construction of Lavon Lake was calculated based on the period of record from 1924–53 for station 08061500. Peak streamflow after construction of Lavon Lake was calculated based on the period of record from 1954–89 for station 08061000.

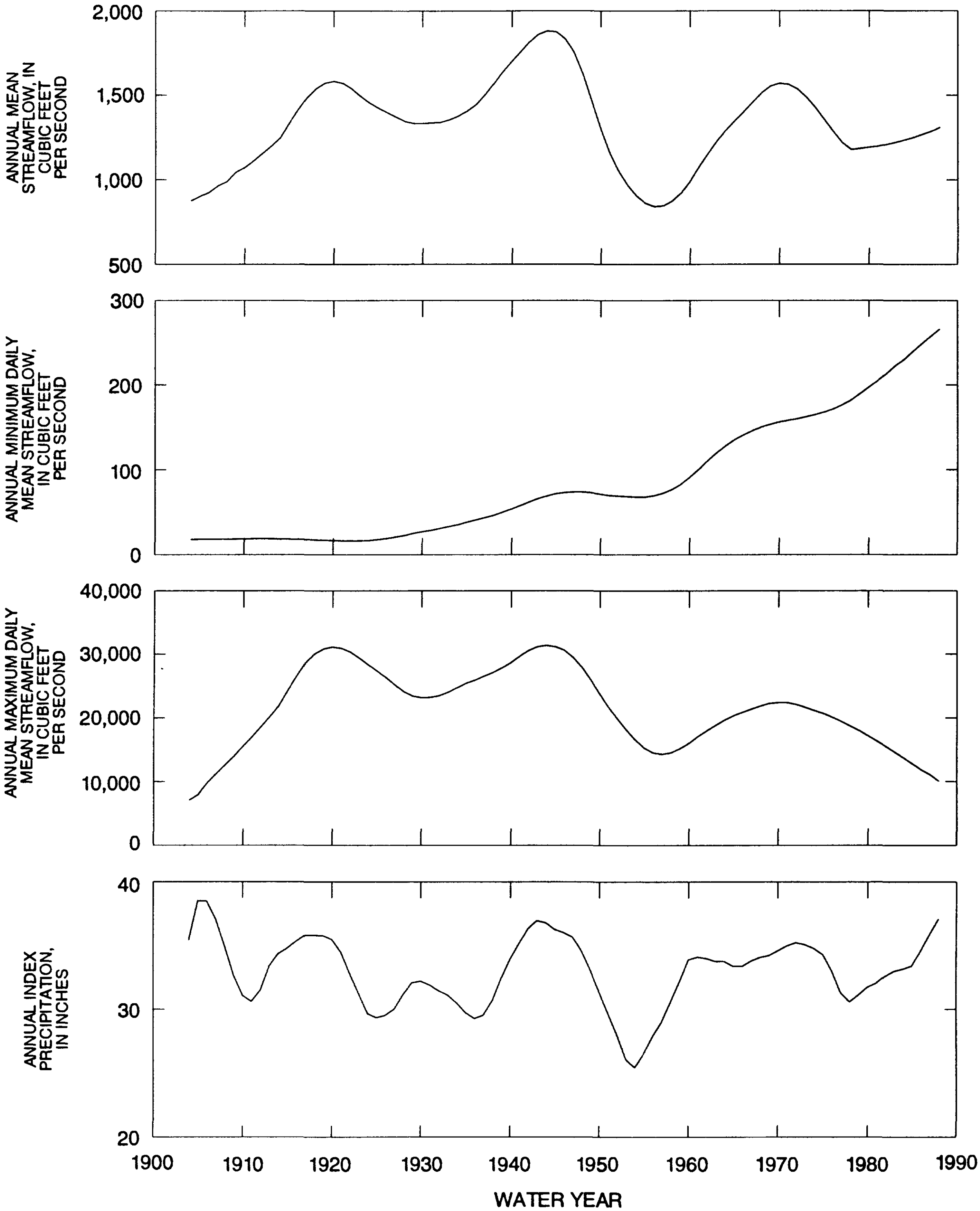


Figure 29. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08057000 on the Trinity River at Dallas, Texas, in the Trinity River Basin.

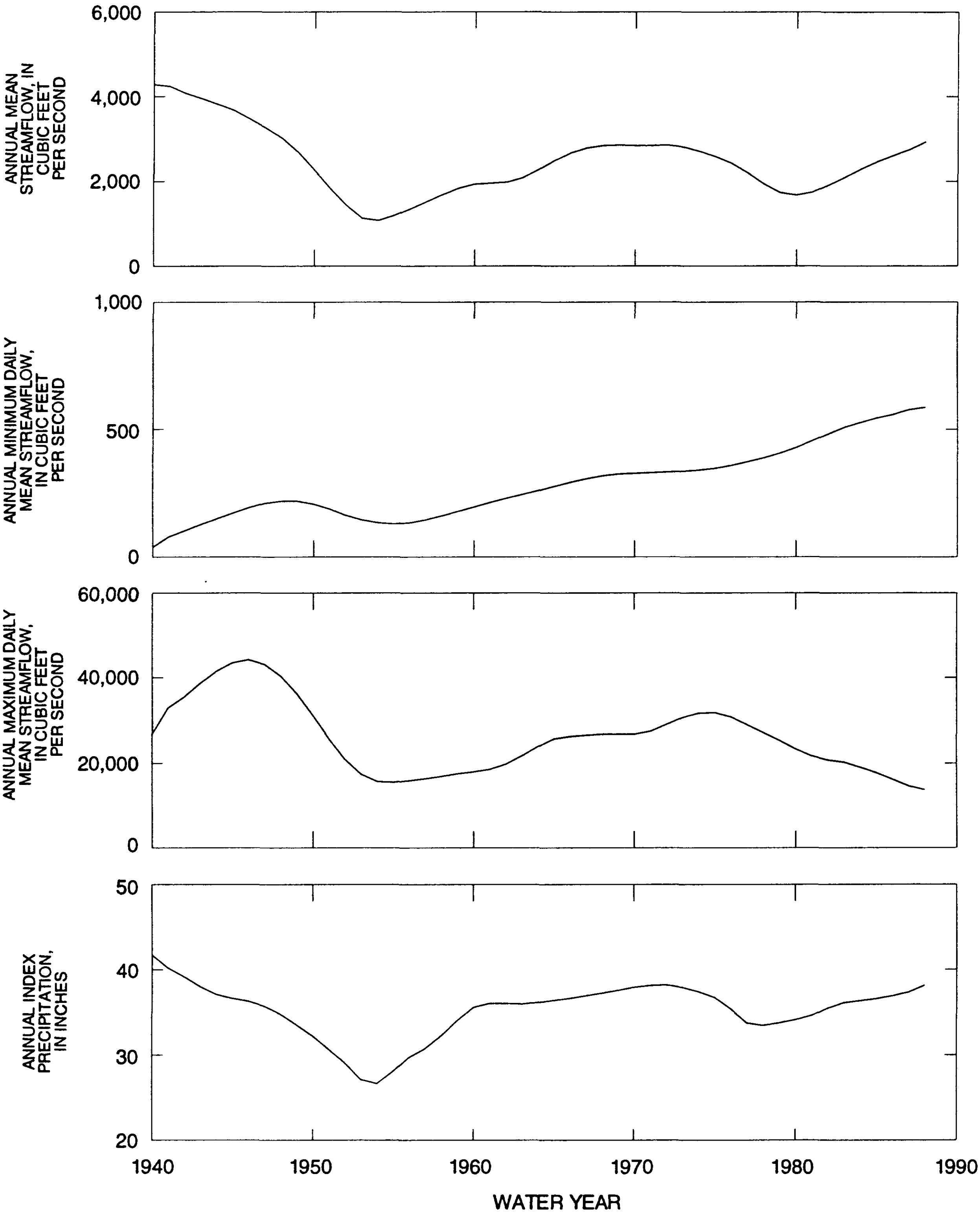


Figure 30. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08062500 on the Trinity River near Rosser, Texas, in the Trinity River Basin.

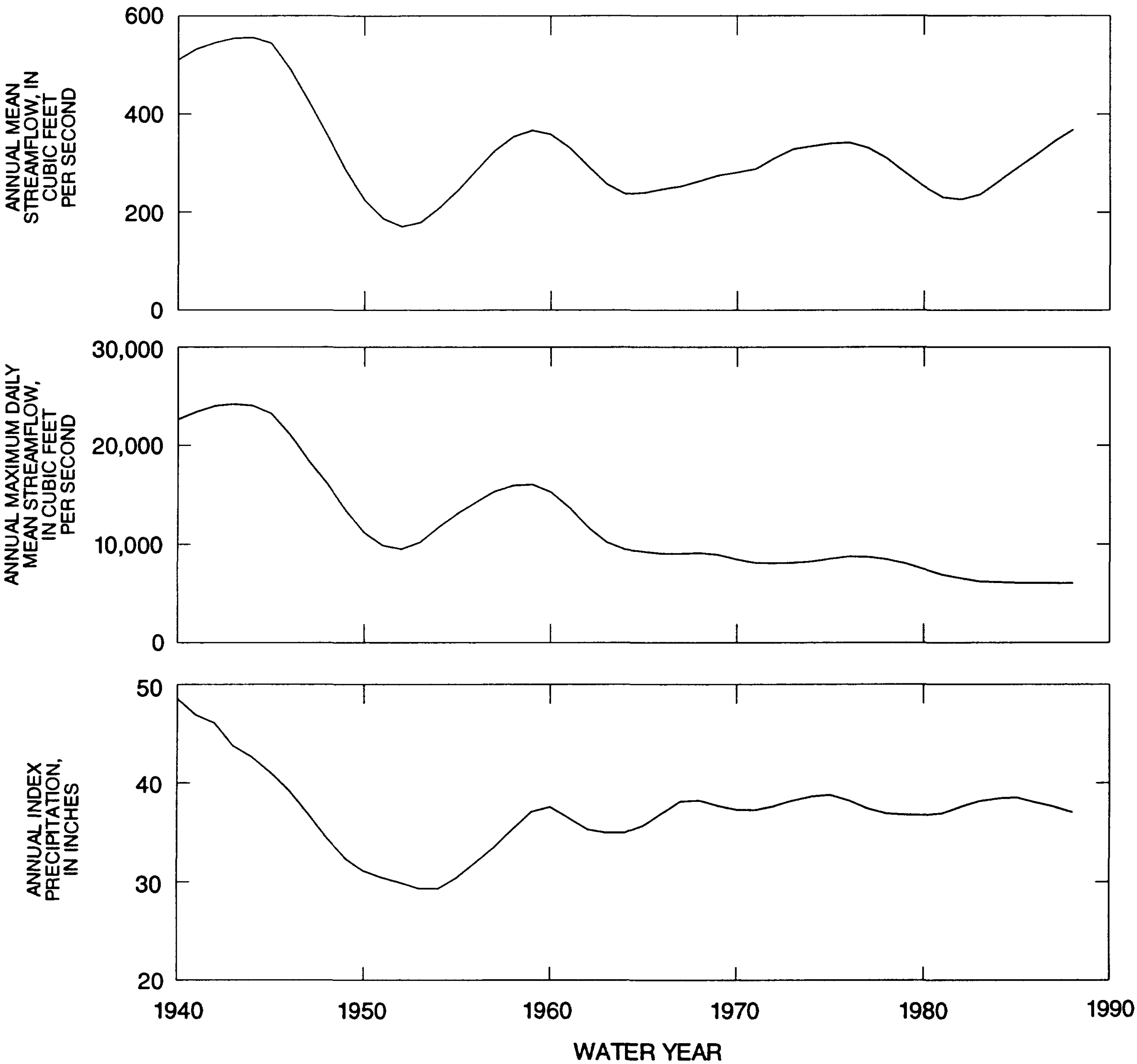


Figure 31. Short-term trends in annual mean streamflow and annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08063500 on Richland Creek near Richland, Texas, in the Trinity River Basin.

recurrence interval of 50 years, was about 44,600 ft^3/s before and about 22,900 ft^3/s after the reservoir was constructed in 1952 (fig. 38), a decrease of about 49 percent. Predicted peak streamflow downstream from Lavon Lake on the East Fork Trinity River was about 84,800 ft^3/s before and 21,300 ft^3/s after the reservoir was constructed in 1954 (fig. 39), a decrease of about 75 percent. The streamflow station downstream from Livingston Reservoir on the main channel of the Trinity River, constructed in 1969, was affected by upstream regulation for at least 15 years before the construction of the reservoir (after 1969). Peak streamflow frequency analyses were performed for the period before upstream regulation and for the period after construction of the reservoir. The predicted 50-year peak streamflow was about 112,000 ft^3/s for both periods.

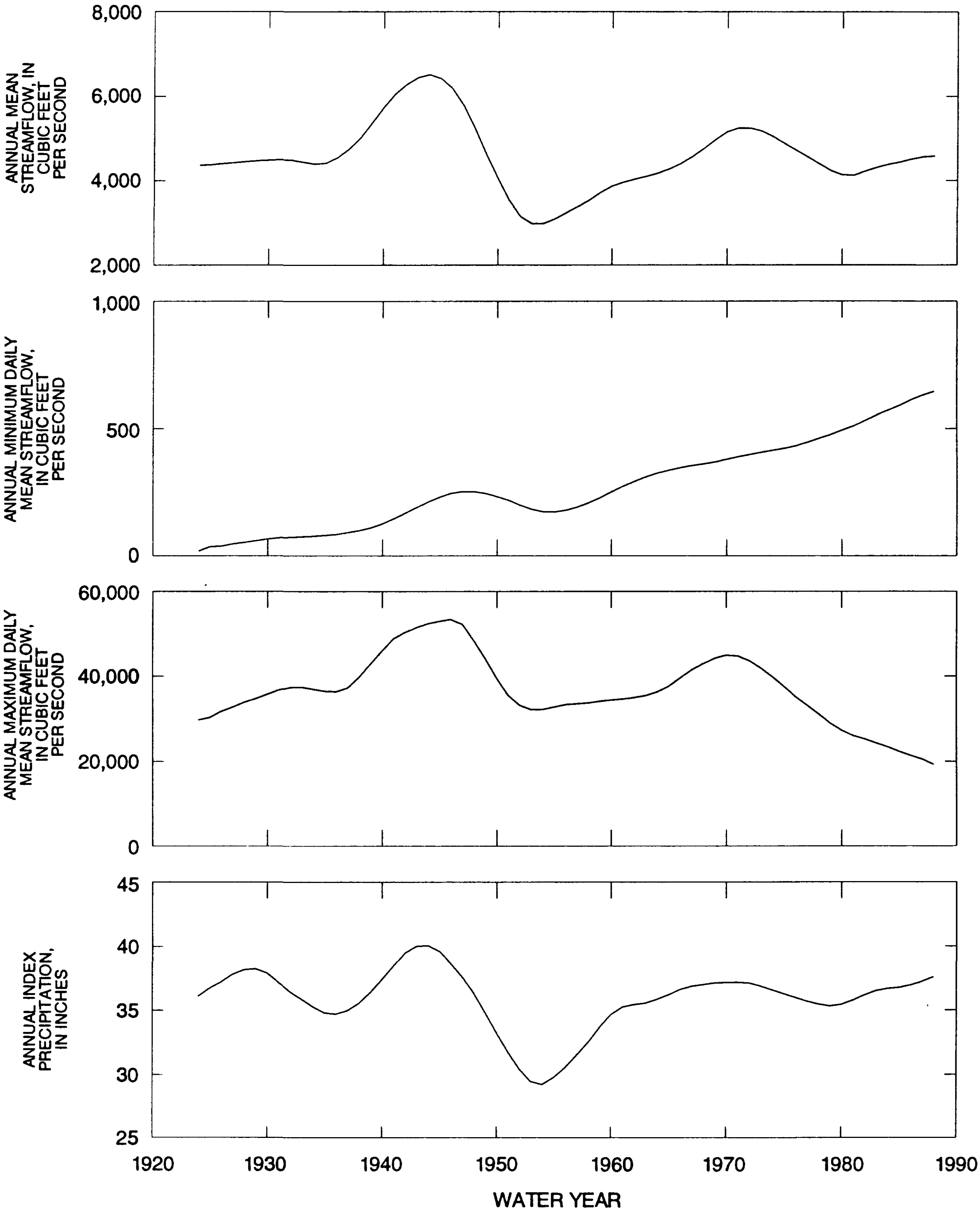


Figure 32. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08065000 on the Trinity River near Oakwood, Texas, in the Trinity River Basin.

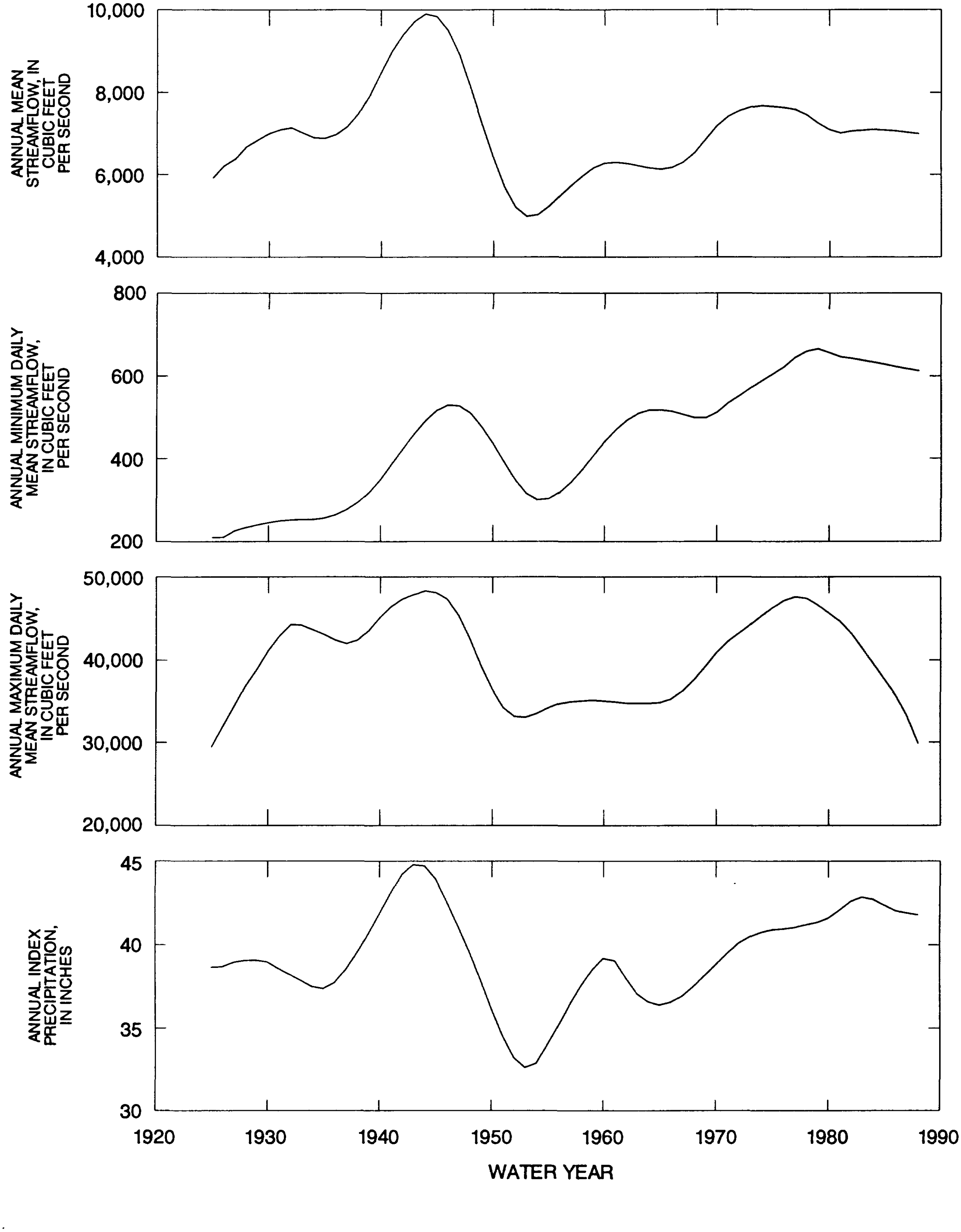


Figure 33. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08066500 on the Trinity River at Romayor, Texas, in the Trinity River Basin.

Table 4. Selected streamflow stations, associated precipitation stations, and periods of record in the Trinity River Basin

[Where the period of record for the associated precipitation stations exceeded the available period of record for the streamflow station, the longest common period of record was used for analysis of trends for the streamflow station and its associated precipitation stations]

Streamflow station number and name		Precipitation station number and location		Available periods of record
08044000	Big Sandy Creek near Bridgeport, Tex.			1937–88
		984	Bowie, Tex.	1897–98, 1900–27, 1955–88
		1063	Bridgeport, Tex.	1915–46, 1948–88
08047500	Clear Fork Trinity River at Fort Worth, Tex.			1924–88
		691	Benbrook Dam, Tex.	1949–88
		2906	Cresson, Tex.	1948–88
		9532	Weatherford, Tex.	1902–88
08048000	West Fork Trinity River at Fort Worth, Tex.			1921–88
		271	Antelope, Tex.	1910–20, 1948–88
		1063	Bridgeport, Tex.	1915–46, 1948–88
		4517	Jacksboro, Tex.	1941–88
		9532	Weatherford, Tex.	1902–88
08055500	Elm Fork Trinity River near Carrollton, Tex.			1907–88
		2404	Denton, Tex.	1913–88
		3415	Gainesville, Tex.	1897–98, 1900–26, 1928–87
		3420	Gainesville, Tex.	1987–88
08057000	Trinity River at Dallas, Tex.			1903–88
		1063	Bridgeport, Tex.	1915–46, 1948–88
		2244	Dallas, Tex.	1897–98, 1900–15, 1948–88
		3415	Gainesville, Tex.	1897–98, 1900–26, 1928–87
		3420	Gainesville, Tex.	1987–88
08062500	Trinity River near Rosser, Tex.			1924–25, 1939–88
		1063	Bridgeport, Tex.	1915–46, 1948–88
		5766	McKinney, Tex.	1903–05, 1912–88
		9522	Waxahatchie, Tex.	1897–98, 1900–88

Table 4. Selected streamflow stations, associated precipitation stations, and periods of record in the Trinity River Basin—Continued

Streamflow station number and name		Precipitation station number and location		Available periods of record
08063500	Richland Creek near Richland, Tex.			1939–88
		2019	Corsicana, Tex.	1897, 1901–88
		4182	Hillsboro, Tex.	1903–88
		5869	Mexia, Tex.	1904–57, 1960–88
08065000	Trinity River near Oakwood, Tex.			1924–88
		3415	Gainesville, Tex.	1897–98, 1900–26, 1928–87
		3420	Gainesville, Tex.	1987–88
		4705	Kaufman, Tex.	1901–88
		5869	Mexia, Tex.	1904–57, 1960–88
		9532	Weatherford, Tex.	1902–88
08066500	Trinity River at Romayor, Tex.			1924–88
		1063	Bridgeport, Tex.	1915–46, 1948–88
		2019	Corsicana, Tex.	1897, 1901–88
		2114	Crockett, Tex.	1904–17, 1924–88
		5196	Liberty, Tex.	1904–88
		5766	McKinney, Tex.	1903–05, 1912–88

Livingston Reservoir probably has had only minimal effects on peak streamflow to the Gulf of Mexico from the Trinity River.

A statistical analysis of the relations between precipitation and streamflow was done for the station on the Trinity River near Romayor, Texas (08066500), downstream from Livingston Reservoir. Before construction of the reservoir, the annual mean streamflow was calculated to be about 4.9 percent of the associated annual index precipitation for the station. After construction of the reservoir, the annual mean streamflow was about 4.7 percent of the associated annual index precipitation. Therefore, streamflow, as a percent of precipitation, was about 0.2 percent less following construction of the reservoir, which represents about a 4-percent decrease in streamflow. The decrease, however, exceeds the potential error in the data, thus any change in streamflow is not observable.

Nueces River Basin

The Nueces River Basin (fig. 40) has a drainage area of approximately 17,000 mi^2 and annual mean streamflow of about 800 ft^3/s at the most downstream station (08211000). Mean annual precipitation in the basin ranges from about 20.9 in. in the upstream part of the basin to about 27.5 in. in the downstream part. Three reservoirs in the basin have a capacity greater than 5,000 acre-ft of storage.

Streamflow Stations and Associated Precipitation Stations

Four streamflow stations along the main stem of the Nueces River and four streamflow stations on tributaries were selected for analysis. For each station, two to seven precipitation stations were selected as indices to represent the precipitation associated with the

Table 5. Long-term trends in streamflow and associated precipitation for streamflow stations in the Trinity River Basin

[no change, less than 5-percent increase or decrease for 50 years of streamflow record, or less than 3-percent increase or decrease for 50 years of precipitation record]

Streamflow station number and name		Long-term trends			
		Annual mean streamflow	Annual minimum daily mean streamflow	Annual maximum daily mean streamflow	Associated annual index precipitation
08044000	Big Sandy Creek near Bridgeport, Tex.	decreased	increased	decreased	increased
08047500	Clear Fork Trinity River at Fort Worth, Tex.	increased	increased	decreased	no change
08048000	West Fork Trinity River at Fort Worth, Tex.	decreased	increased	decreased	increased
08055500	Elm Fork Trinity River near Carrollton, Tex.	no change	increased	decreased	increased
08057000	Trinity River at Dallas, Tex.	increased	increased	decreased	no change
08062500	Trinity River near Rosser, Tex.	decreased	increased	decreased	increased
08063500	Richland Creek near Richland, Tex.	decreased	increased	decreased	no change
08065000	Trinity River near Oakwood, Tex.	decreased	increased	decreased	no change
08066500	Trinity River at Romayor, Tex.	decreased	increased	decreased	increased

streamflow. Locations of long-term streamflow stations and precipitation stations and the major reservoirs in the Nueces River Basin are shown in figure 40. The selected streamflow stations and precipitation stations and their available periods of record for the Nueces River Basin are presented in table 6.

Temporal Trends in Streamflow and Precipitation

Long-term trends in annual minimum daily mean streamflow indicated an increase for all of the selected stations during the period of record studied (table 7). Annual maximum daily mean streamflow decreased for all of the stations except for station 08198000, where the trend in annual maximum streamflow increased. Trends in annual mean streamflow and associated annual index precipitation varied for the selected stations (table 7).

The short-term trends in streamflow generally corresponded to the short-term trends identified for associated annual index precipitation (figs. 41–48). For station 08205500, the trends indicated increased precipitation during the late 1910's and 1920's, while the annual mean and maximum streamflow decreased (fig. 45). For stations 08190000 and 08211000 (the most downstream station studied), the annual minimum daily mean streamflow showed a general increase during the 1970's and 1980's, while annual mean and maximum streamflow and annual index precipitation decreased (figs. 41 and 48). Short-term trends were not identified for annual minimum daily mean streamflow for stations 08194000, 08198000, 08205500,

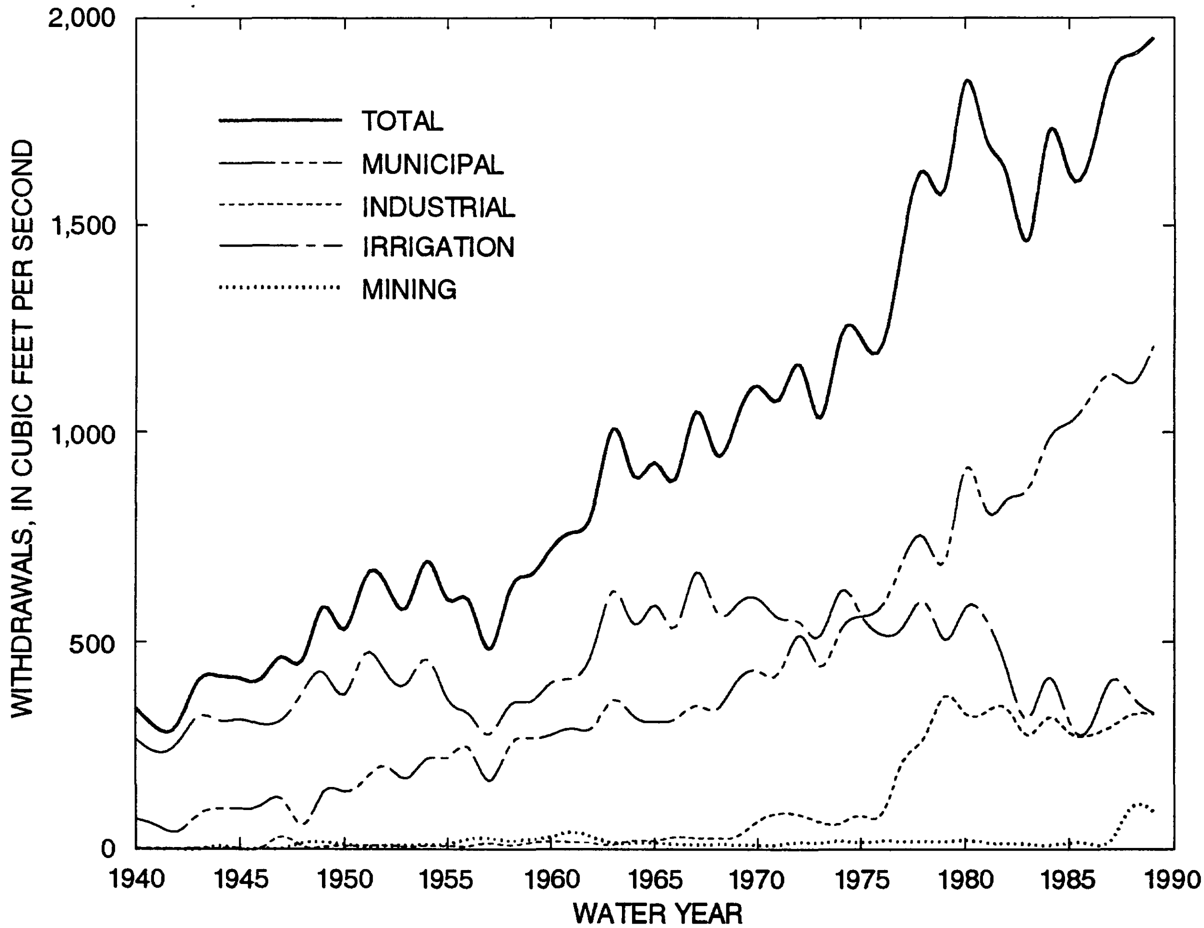


Figure 34. Reported annual surface-water withdrawals from the Trinity River Basin, by category of use.

08208000, and 08210000 because of large numbers of zero values in the data.

Surface-Water Withdrawals

Records of surface-water withdrawals, by county, in the Nueces River Basin were obtained from the Texas Natural Resource Conservation Commission. Reported annual surface-water withdrawals since 1940 from the Nueces River Basin are shown, by category of use, in figure 49. Withdrawals by Corpus Christi, downstream from station 08211000, are not considered in this report; however some of the reported withdrawals are downstream from this station. Since 1940, total surface-water withdrawals from the Nueces River Basin have increased more than eightfold. About one-half of withdrawal represents municipal use. Surface-water withdrawals from the Nueces River Basin represent about one-third of the annual mean streamflow at station 08211000.

Effects of Reservoirs on Streamflow

Three major reservoirs are in the Nueces River Basin (fig. 40). Upper Nueces Lake has a much smaller storage capacity than the other two lakes and was not included in this analysis. Lake Corpus Christi was built in 1934 and enlarged in 1958. Choke Canyon Reservoir, on the Frio River, began filling in October 1982. The available periods of record for the stations downstream from these reservoirs were insufficient for analyses of streamflow before and after construction of the reservoirs. The net evaporation rates from the reservoirs were estimated from pan-evaporation data at the reservoirs using monthly pan-net coefficients (Kane, 1967). The annual mean net evaporation from Choke

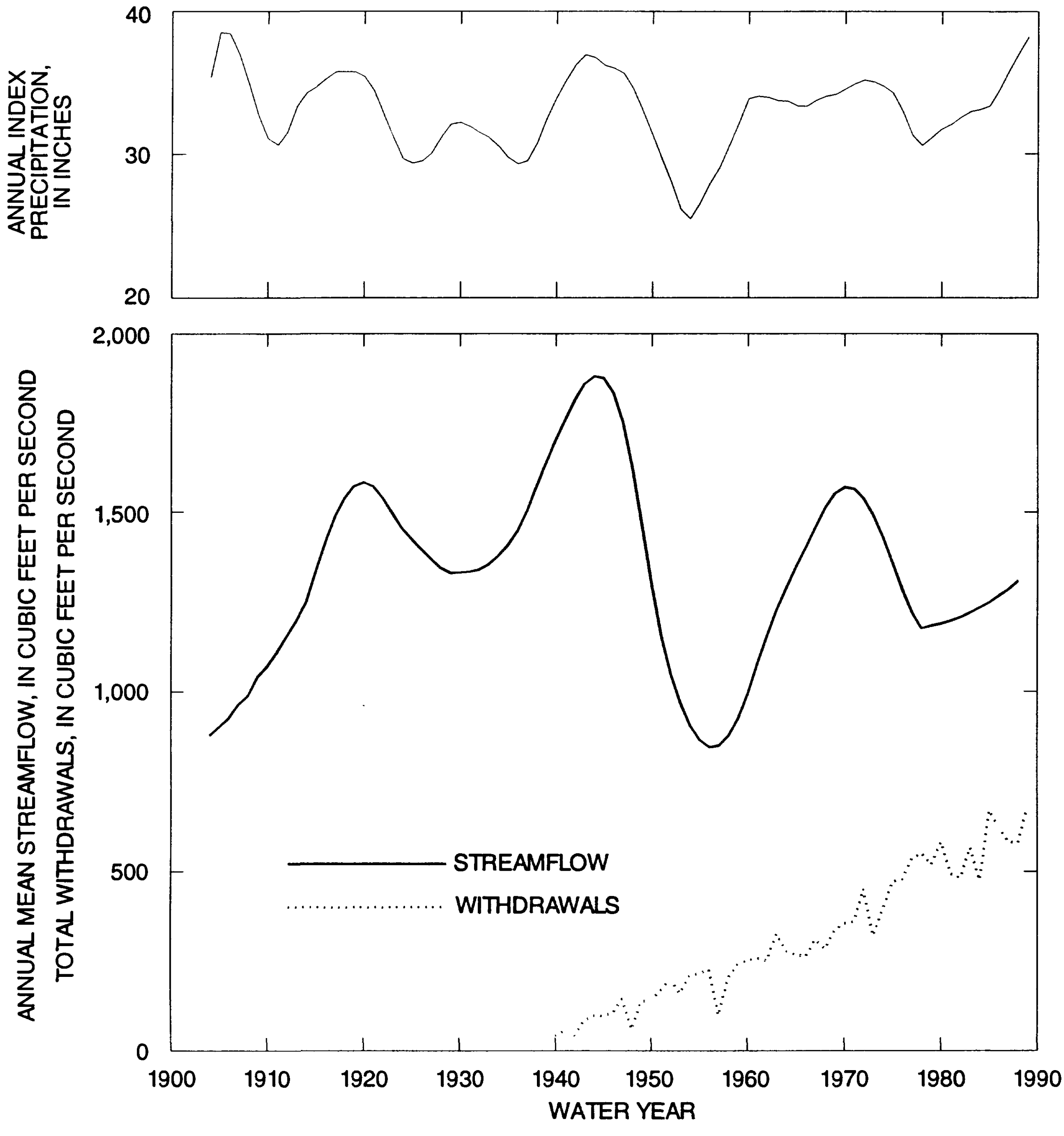


Figure 35. Short-term trends in annual index precipitation and in annual mean streamflow, and total reported annual surface-water withdrawals from the subbasin upstream from streamflow station 08057000 on the Trinity River at Dallas, Texas.

Canyon Reservoir is estimated to be about 84,000 acre-ft based on 40 in/yr of net evaporation when storage is 90 percent of the capacity at the top of the spillway gates. Annual mean net evaporation from Lake Corpus Christi is estimated to be about 62,000 acre-ft when storage is 90 percent of that at the spillway. Evaporation losses from the two reservoirs are substantial compared to streamflow from the Nueces River to the Gulf of Mexico, and the long-term mean streamflow to the Gulf is reduced by evaporation from both reservoirs.

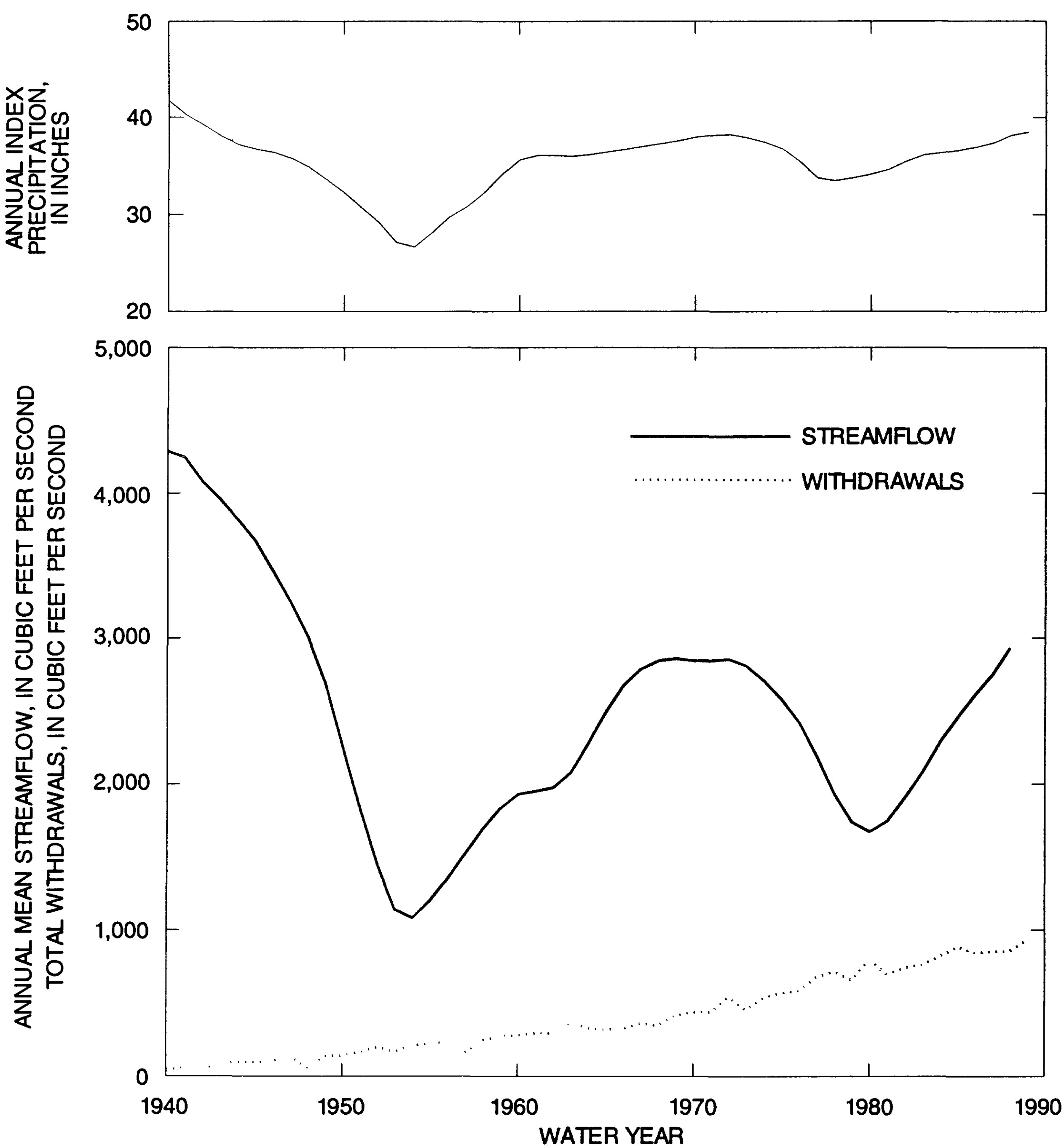


Figure 36. Short-term trends in annual index precipitation and in annual mean streamflow, and total reported annual surface-water withdrawals from the subbasin upstream from streamflow station 08062500 on the Trinity River near Rosser, Texas.

A water-budget analysis was prepared for 1965–90 to estimate the volume of streamflow that was reduced in the Nueces River downstream from Choke Canyon Reservoir resulting from filling and evaporation at the reservoir (table 8). Net evaporation losses were calculated for each year by multiplying the net evaporation depth times the mean surface area of the reservoir. Station 08210000 on the Nueces River is

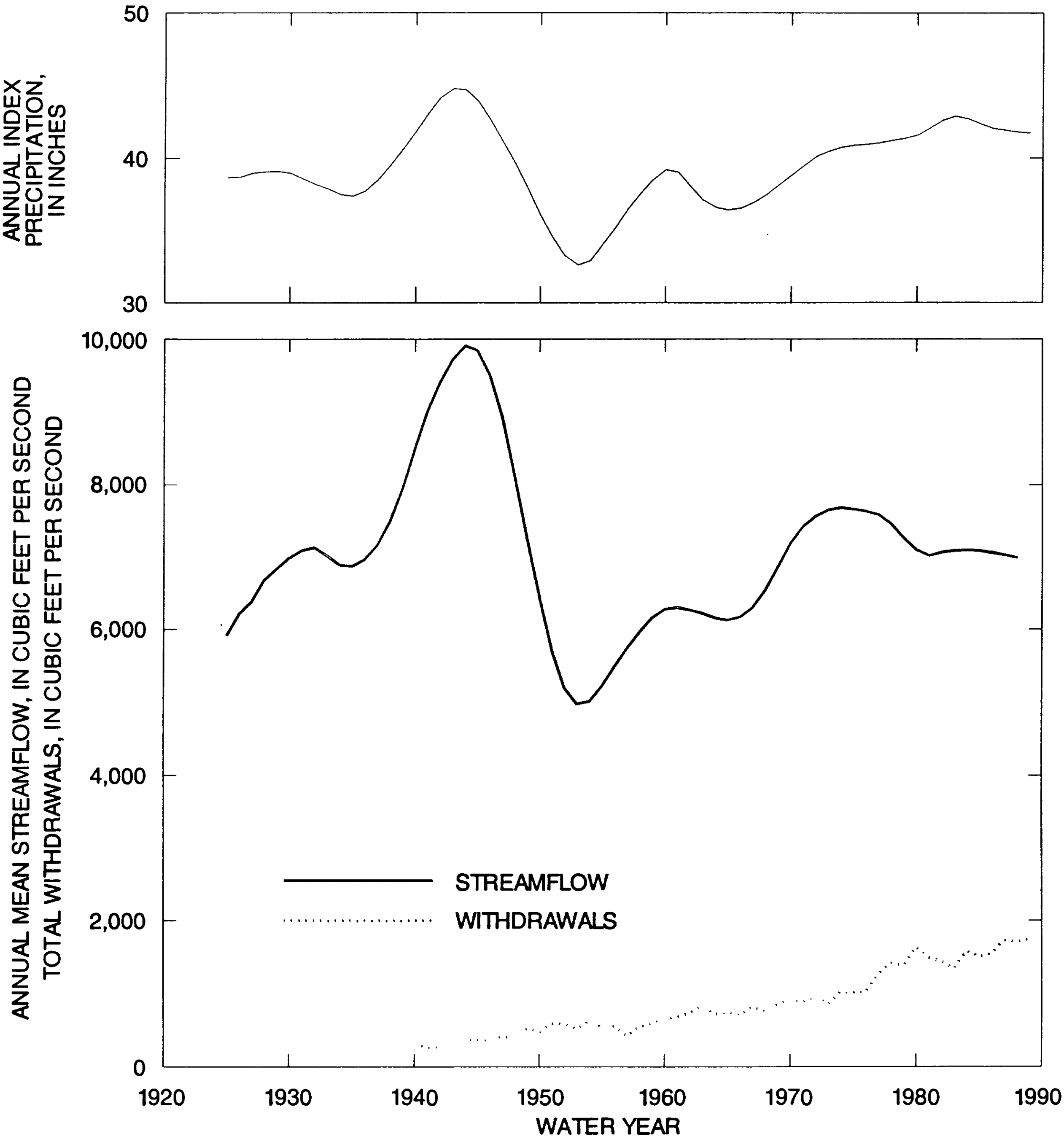


Figure 37. Short-term trends in annual index precipitation and in annual mean streamflow, and total reported annual surface-water withdrawals from the subbasin upstream from streamflow station 08066500 on the Trinity River at Romayor, Texas.

downstream from Choke Canyon Reservoir and from four upstream stations that comprise most of the flow at downstream station 08210000. Annual mean streamflow values were used in this analysis. The four upstream stations are 08194500, 08205500, 08206700, and 08208000 (fig. 40). Before the reservoir was constructed, the ratio of the downstream streamflow to the total gaged upstream streamflow was determined to be

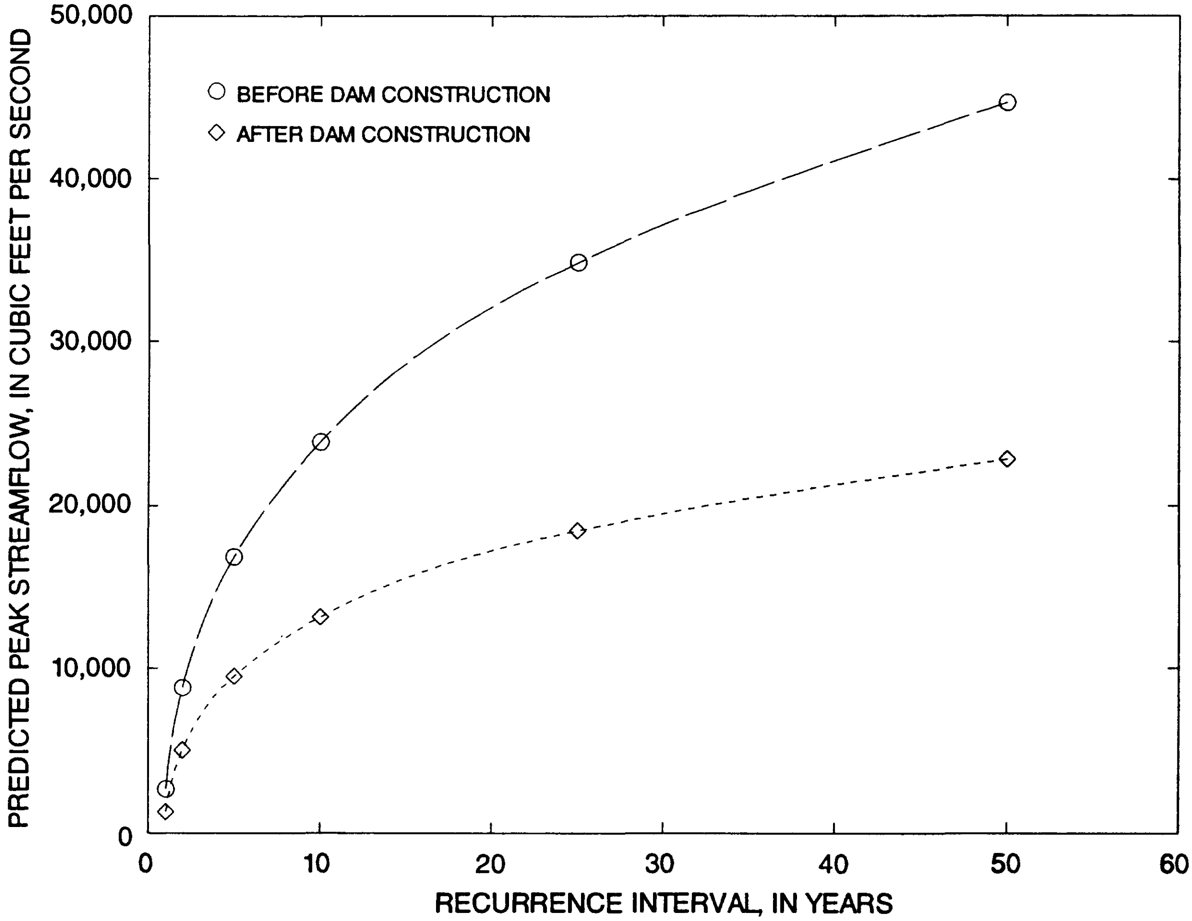
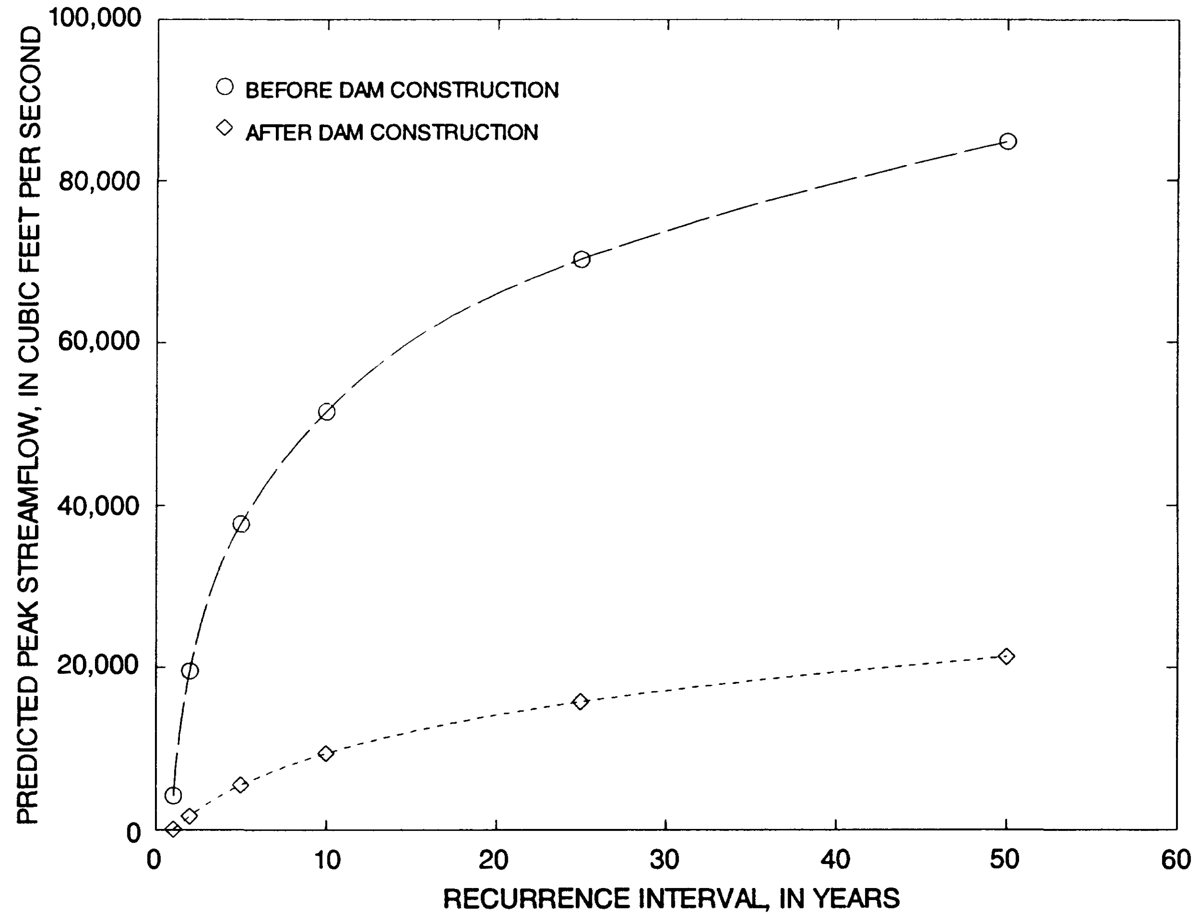


Figure 38. Predicted peak streamflow at streamflow station 08047500 on the Clear Fork Trinity River downstream from Benbrook Lake in the Trinity River Basin, before and after construction of the dam in 1952.

1.07, as explained in table 8. After the reservoir began receiving inflow, this ratio was multiplied by the total gaged upstream streamflow to estimate the expected downstream streamflow if losses had not occurred because of filling and evaporation at the reservoir. The streamflow reduction at the downstream station caused by filling and evaporation was assumed to be the expected streamflow minus the actual streamflow at the downstream station. The total volume reduction, 796,000 acre-ft (183 ft^3/s), was similar to the volume, 806,000 acre-ft (185 ft^3/s), determined for the sum of the total change in storage and the total estimated net evaporation losses for the reservoir (table 8). The streamflow reduction from 1985 through 1990 represented 24 percent of the long-term annual mean streamflow to the Gulf of Mexico as measured at the station on the Nueces River near Mathis, Texas.

SUMMARY AND CONCLUSIONS

For the Apalachicola River, long-term temporal trends in annual mean and annual maximum daily mean streamflow at the most downstream station were not evident during the study period. However, long-term trends indicate an increase in annual minimum daily mean streamflow and associated annual index precipitation. Annual mean streamflow was about 6 percent less for the period following construction of the most downstream reservoir in the Apalachicola River Basin. The 50-year peak streamflow at stations downstream from the reservoirs has been reduced by about 23 percent in the upper part of the basin and about 74 percent in the lower part of the basin. The reductions in predicted peak streamflow and the increases in annual



Note: Peak streamflow before construction of the dam in 1954 was calculated based on the period of record from 1924 to 1953 at streamflow station 08061500. Peak streamflow after construction of the dam was calculated based on the period of record from 1954 to 1989 at streamflow station 08061000 (fig. 24).

Figure 39. Predicted peak streamflow on the East Fork Trinity River downstream from Lavon Lake in the Trinity River Basin, before and after construction of the dam in 1954.

minimum daily mean streamflow probably result partly from effects of reservoir operations.

For the Pearl River, annual mean streamflow and annual minimum and maximum daily mean streamflow to the Gulf of Mexico and associated annual index precipitation in the basin increased during the period studied. The increases in streamflow are caused partly by increased precipitation on the basin. Predicted peak discharges near the mouth of the Pearl River, however, did not change as a result of the reservoir in the basin.

For the Trinity River, long-term trends for most stations indicated a decrease in annual mean streamflow to the Gulf of Mexico from the basin for the period studied, while associated annual index precipitation increased or remained unchanged. Annual minimum daily mean streamflow to the Gulf increased and annual maximum streamflow decreased, because of reservoir operations in the basin. Surface-water withdrawals have increased more than fourfold in the Trinity River Basin and as of 1988 represent about one-fourth of the annual mean streamflow at the most downstream station studied. Predicted peak streamflow in the upper reaches of the Trinity River were as much as 75 percent less following reservoir construction;

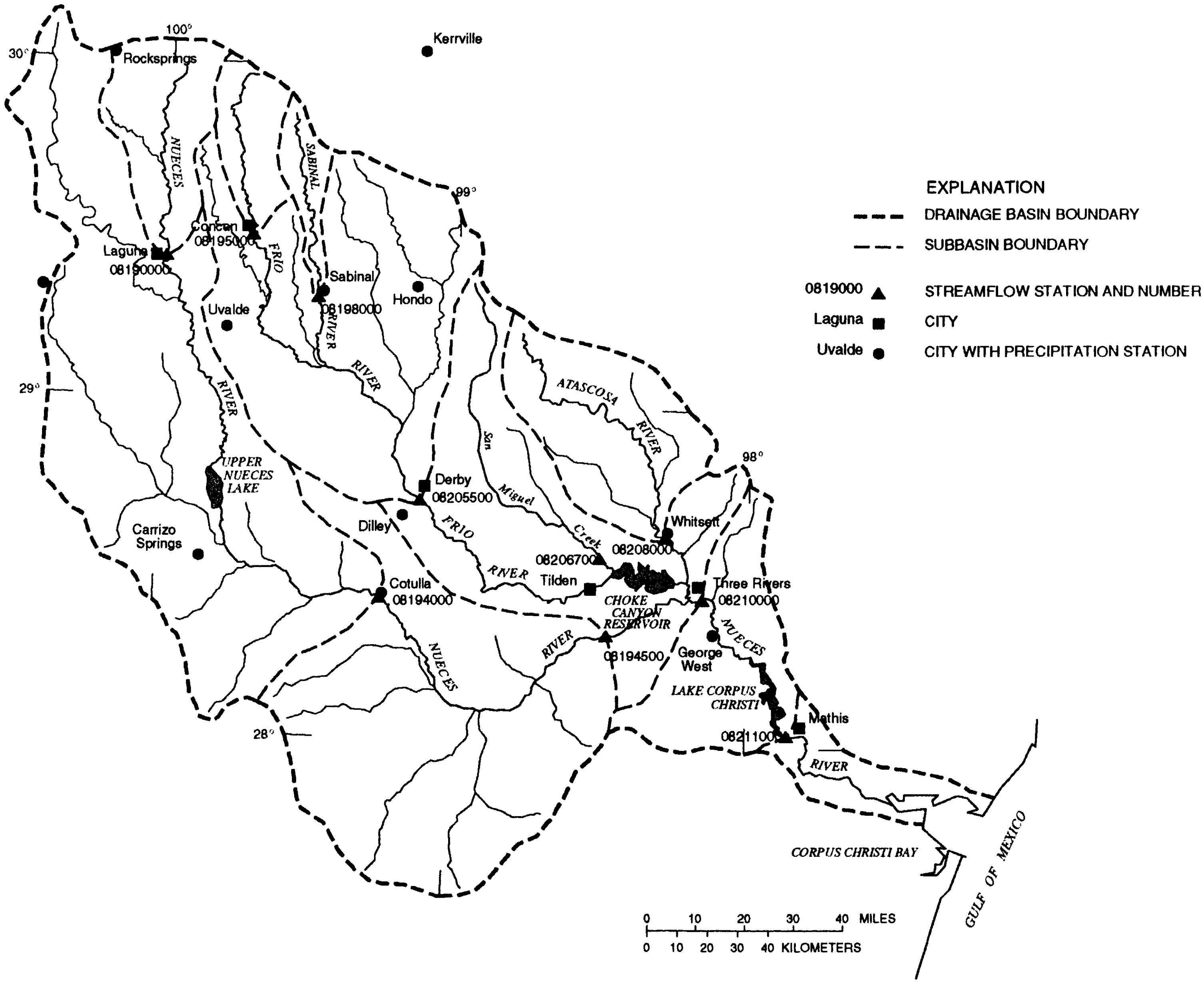


Figure 40. Location of selected streamflow stations, precipitation stations, and major reservoirs in the Nueces River Basin.

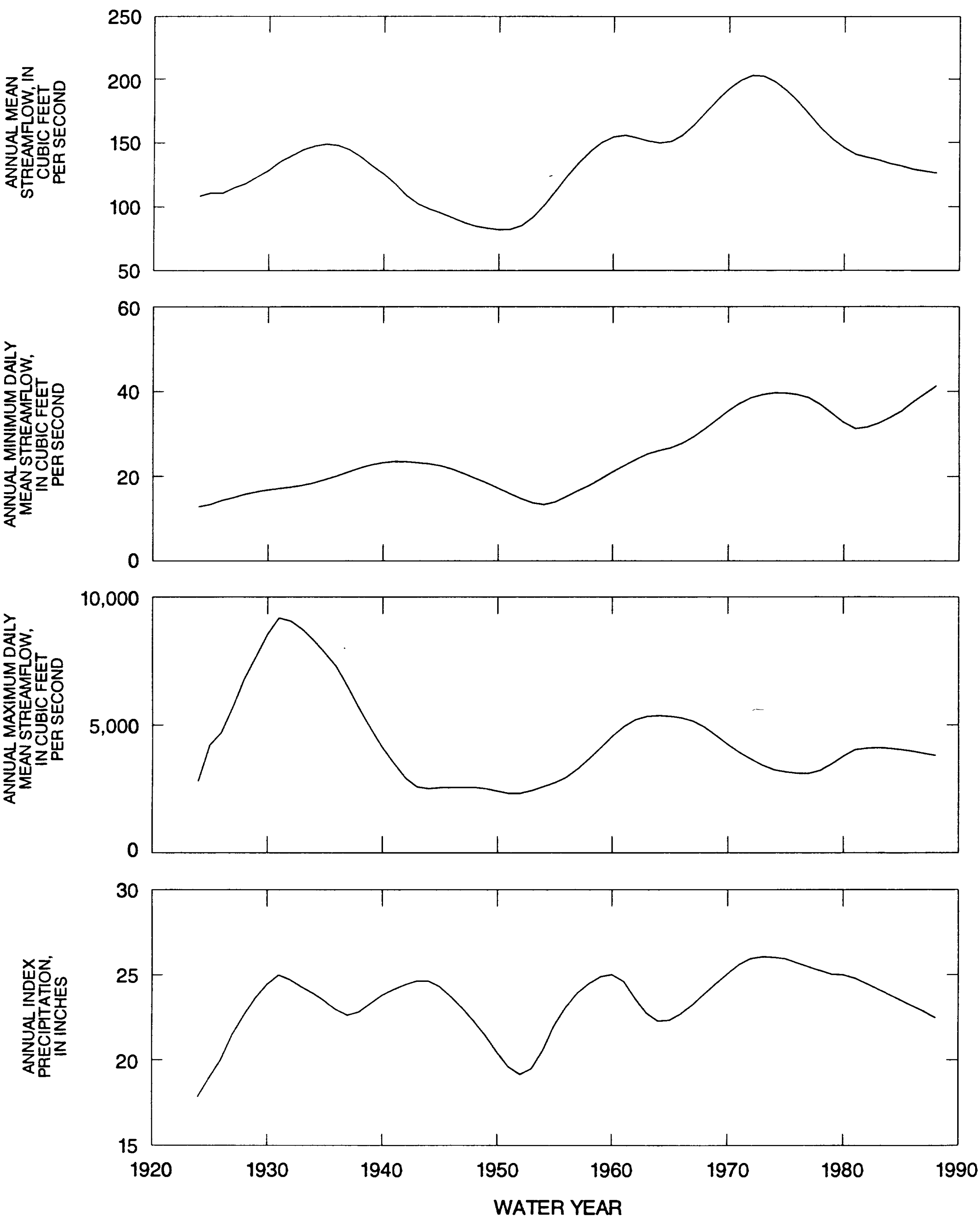


Figure 41. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08190000 on the Nueces River at Laguna, Texas, in the Nueces River Basin.

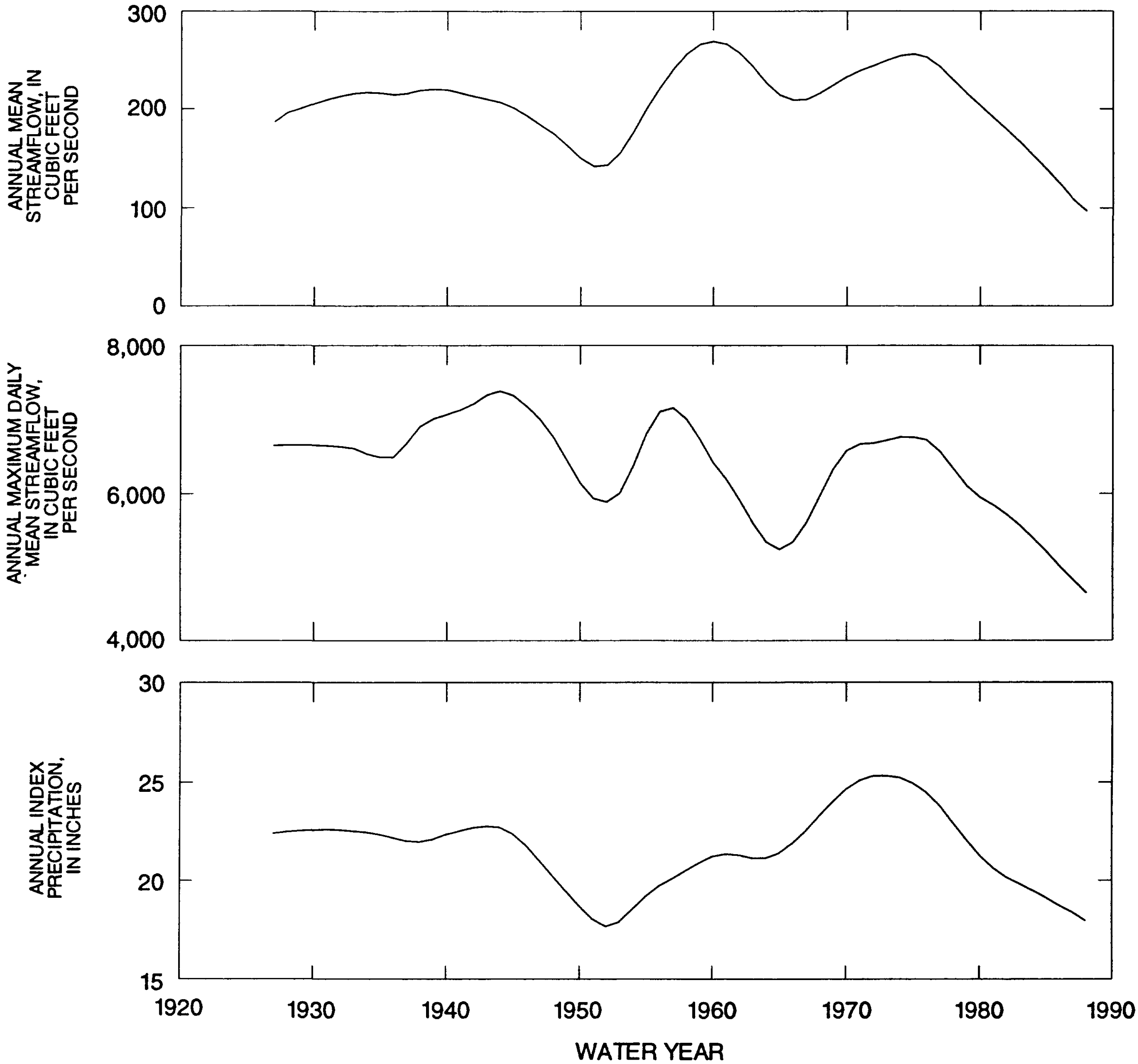


Figure 42. Short-term trends in annual mean streamflow, annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08194000 on the Nueces River at Cotulla, Texas, in the Nueces River Basin.

however, predicted peak streamflow to the Gulf did not change following reservoir construction. Predicted annual mean streamflow as a percentage of precipitation in the basin was about 4 percent less following construction of Livingston Reservoir.

For the Nueces River, long-term trends indicate decreases in annual maximum daily mean streamflow to the Gulf of Mexico from the basin, while annual minimum daily mean streamflow increased for all but one station studied. Trends in annual mean streamflow and associated annual index precipitation varied for the selected stations. Surface-water withdrawals from the basin increased more than eightfold from 1940 through 1990, and as of 1988 represent about one-third of the

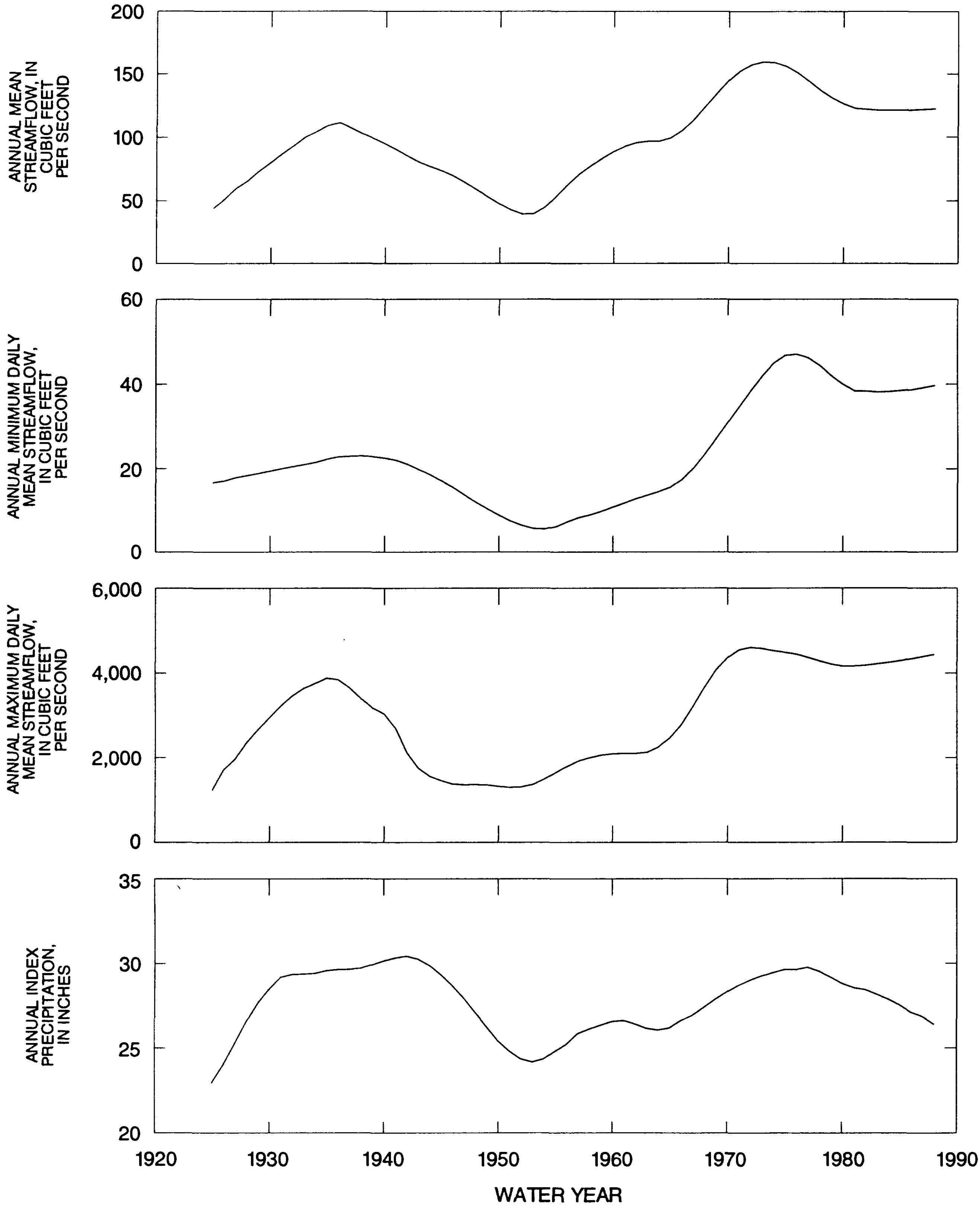


Figure 43. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08195000 on the Frio River at Concan, Texas, in the Nueces River Basin.

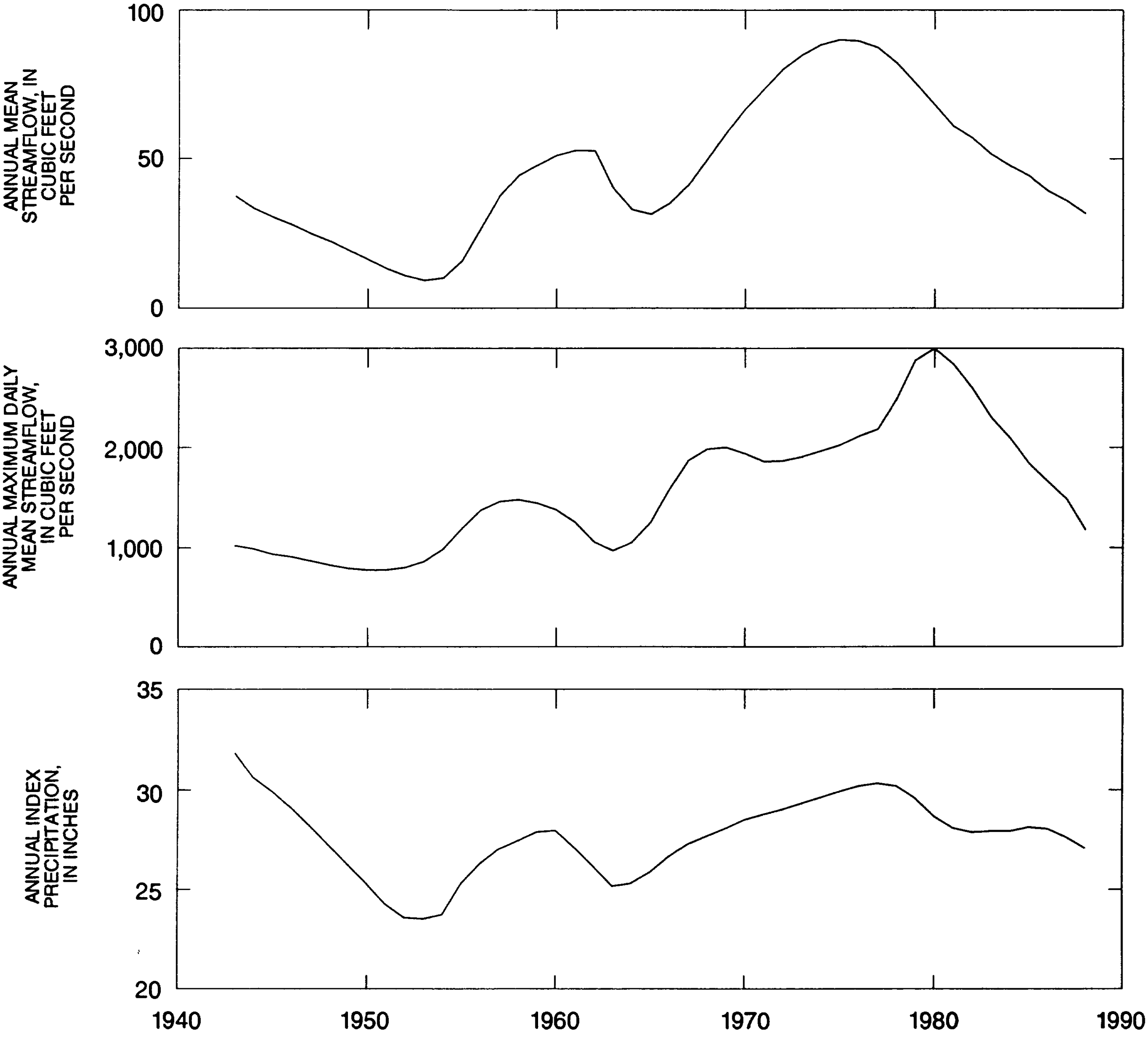


Figure 44. Short-term trends in annual mean streamflow, annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08198000 on the Sabinal River near Sabinal, Texas, in the Nueces River Basin.

mean annual streamflow from the Nueces River to the Gulf of Mexico. Filling and evaporation from Choke Canyon Reservoir from 1985 through 1990 represented about 24 percent of the long-term annual mean streamflow to the Gulf from the Nueces River. Decreases in annual maximum daily mean streamflow are caused partly by reservoir operations in the Nueces River Basin.

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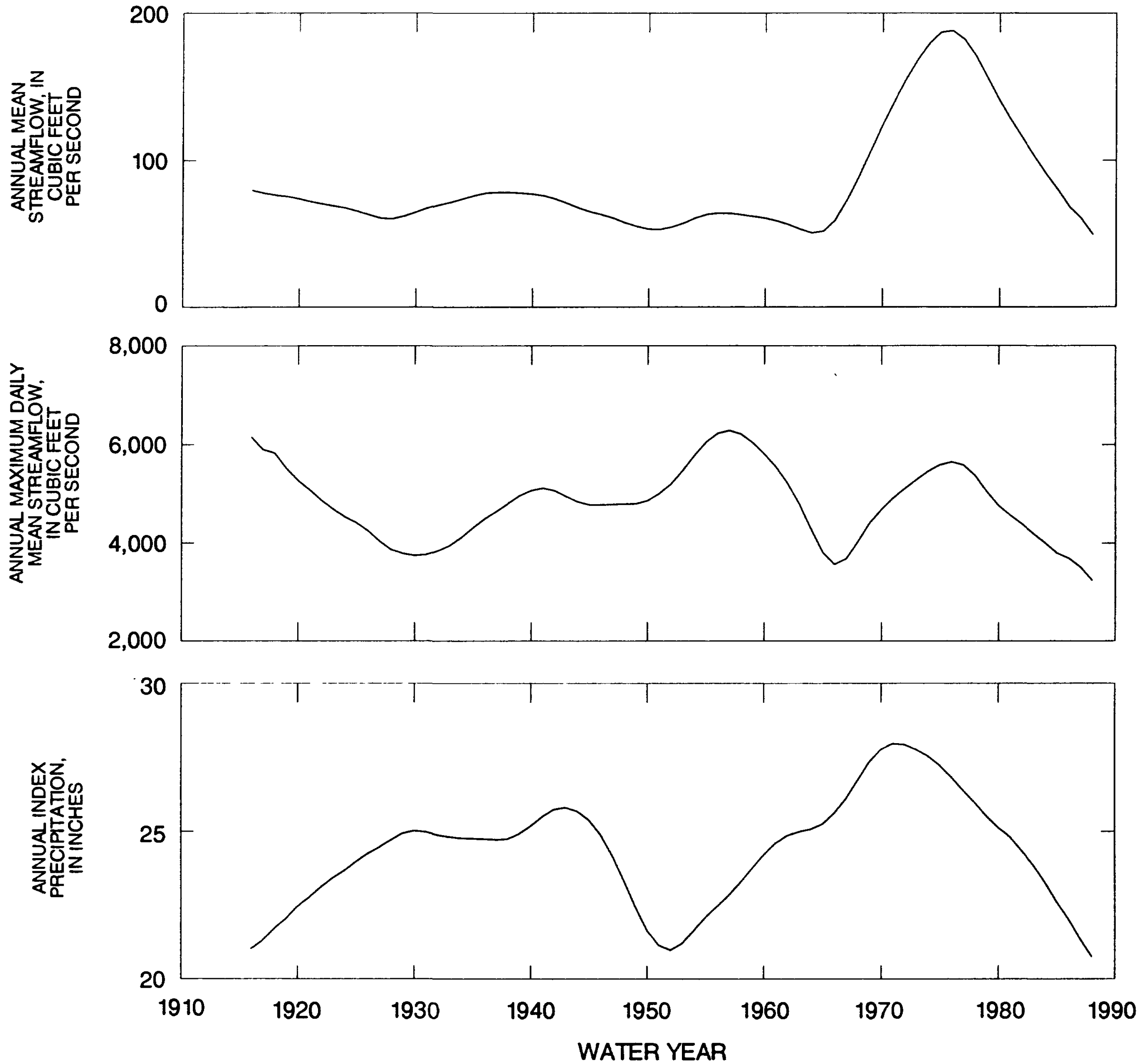

Figure 45. Short-term trends in annual mean streamflow, annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08205500 on the Frio River near Derby, Texas, in the Nueces River Basin.

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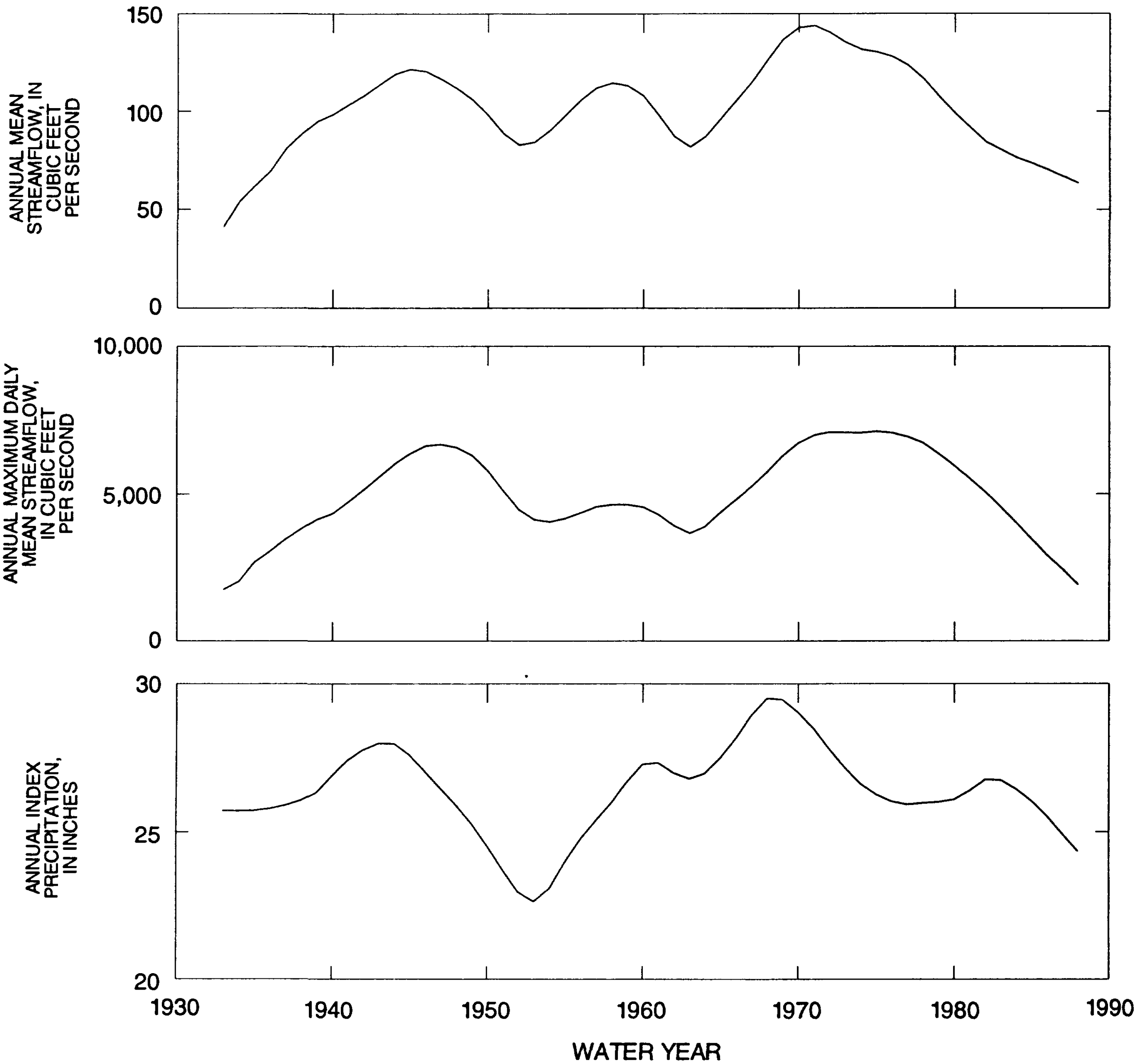

Figure 46. Short-term trends in annual mean streamflow, annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08208000 on the Atascosa River at Whitsett, Texas, in the Nueces River Basin.

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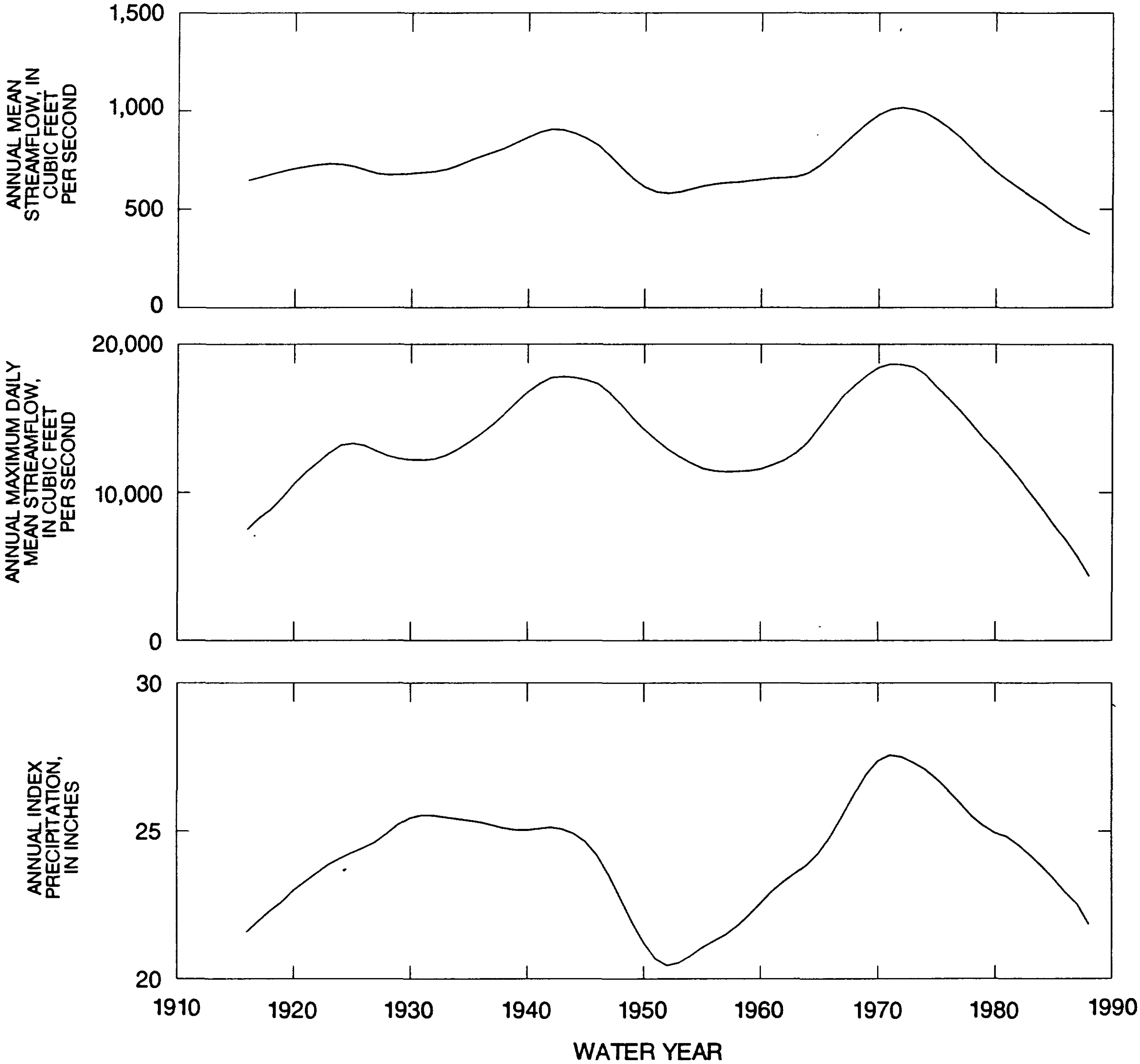

Figure 47. Short-term trends in annual mean streamflow, annual maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08210000 on the Nueces River near Three Rivers, Texas, in the Nueces River Basin.

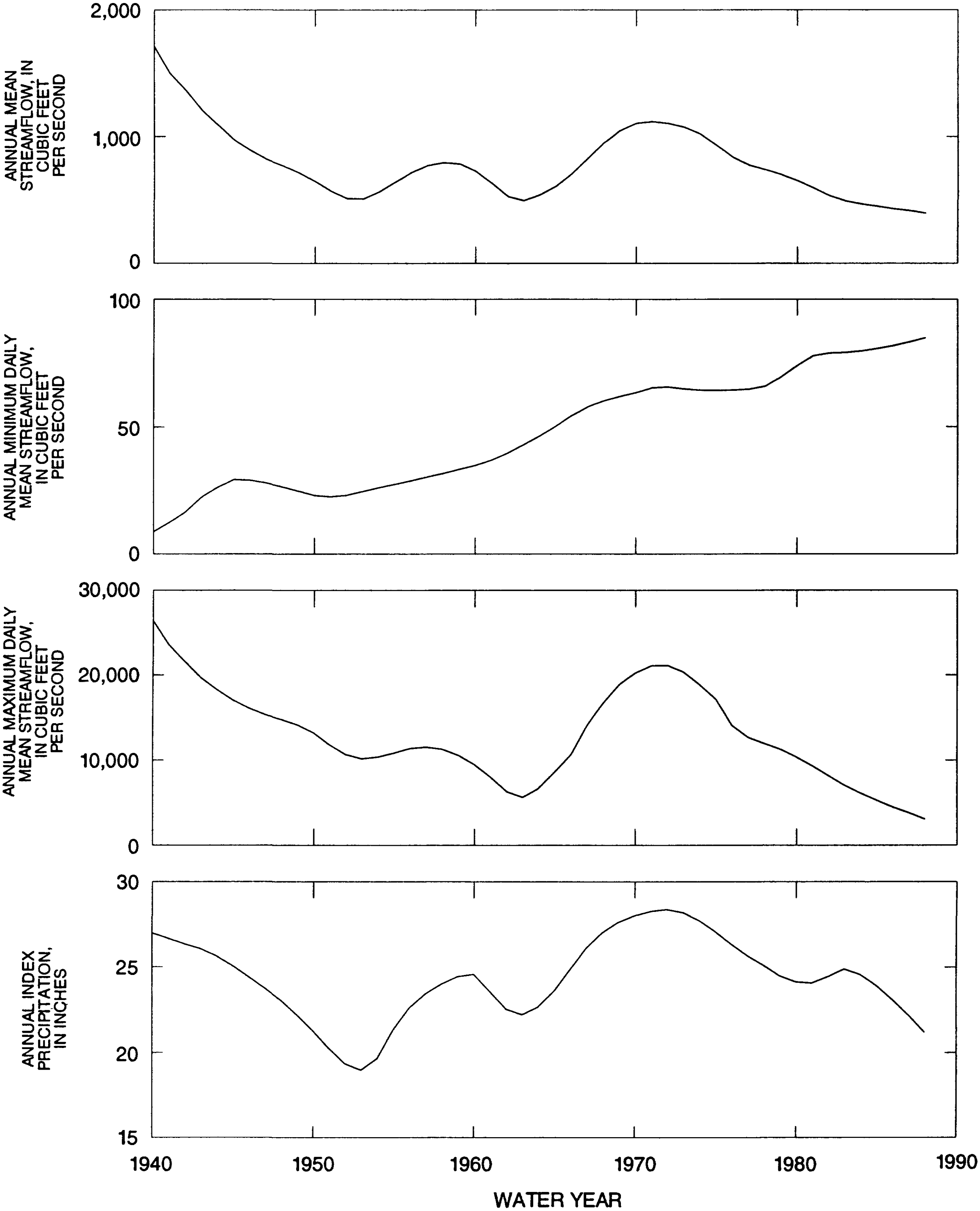

Figure 48. Short-term trends in annual mean streamflow, annual minimum and maximum daily mean streamflow, and associated annual index precipitation for streamflow station 08211000 on the Nueces River near Mathis, Texas, in the Nueces River Basin.

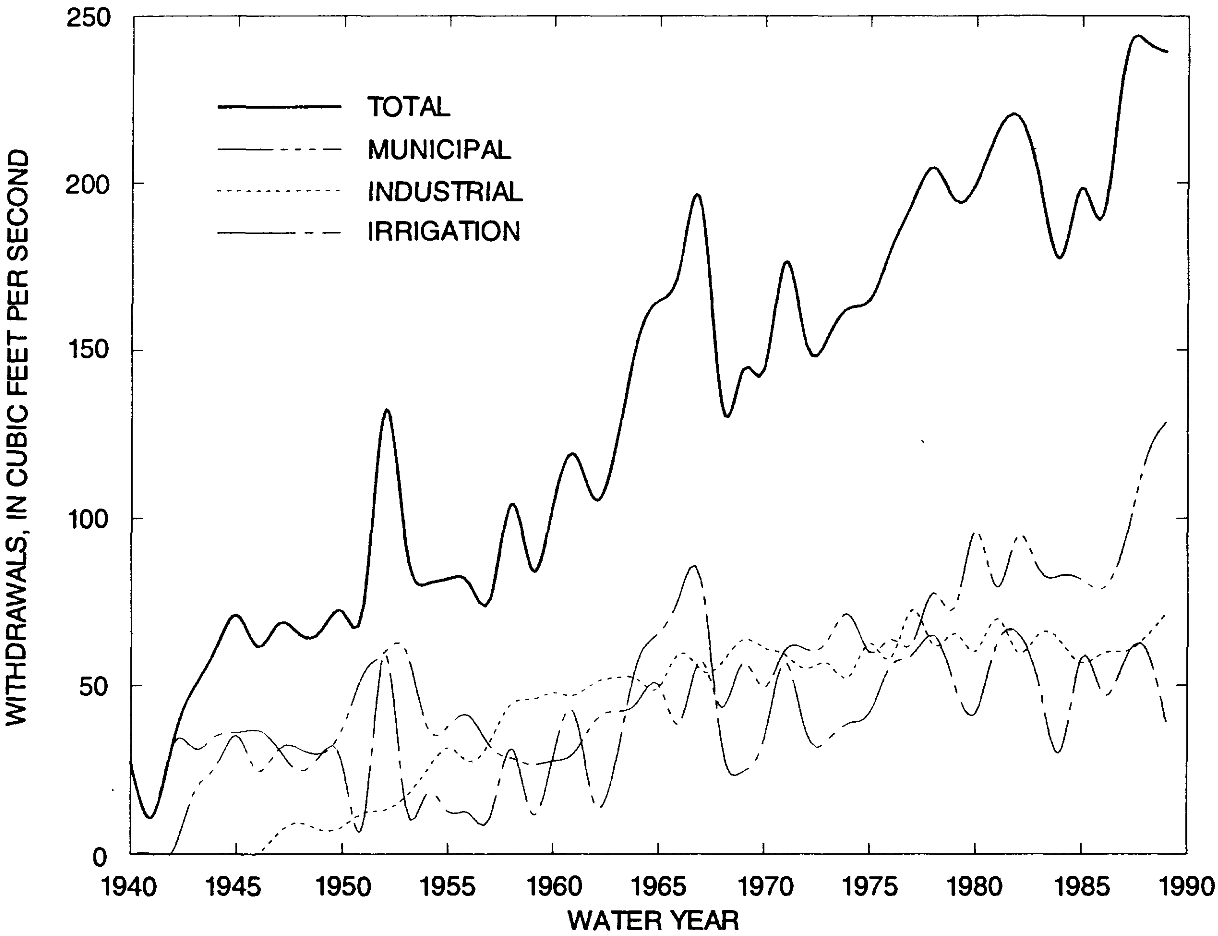

Figure 49. Reported annual surface-water withdrawals from the Nueces River Basin, by category of use.

Table 6. Selected streamflow stations, associated precipitation stations, and periods of record in the Nueces River Basin

[Where the period of record for the associated precipitation stations exceeded the available period of record for the streamflow station, the longest common period of record was used for analysis of trends for the streamflow station and its associated precipitation stations]

Streamflow station number and name		Precipitation station number and location		Available periods of record
08190000	Nueces River at Laguna, Tex.			1924–88
		7706	Rocksprings, Tex.	1932–35, 1938, 1941–86
		9265	Uvalde, Tex.	1905–85
		9268	Uvalde, Tex.	1985–88

Table 6. Selected streamflow stations, associated precipitation stations, and periods of record in the Nueces River Basin—Continued

Streamflow station number and name		Precipitation station number and location		Available periods of record
08194000	Nueces River at Cotulla, Tex.			1927–88
		1007	Brackettville, Tex.	1900–31, 1935–88
		1486	Carrizo Springs, Tex.	1912–17, 1928–72 1975–88
		2048	Cotulla, Tex.	1901–07, 1911–16 1922–88
		9265	Uvalde, Tex.	1905–85
		9268	Uvalde, Tex.	1985–88
08195000	Frio River at Concan, Tex.			1924–29, 1931–88
		4780	Kerrville, Tex.	1897, 1901–74
		4782	Kerrville, Tex.	1974–88
		7873	Sabinal, Tex.	1903–46, 1948–88
08198000	Sabinal River near Sabinal, Tex.			1943–88
		4780	Kerrville, Tex.	1897, 1901–74
		4782	Kerrville, Tex.	1974–88
		7873	Sabinal, Tex.	1903–46, 1948–88
08205500	Frio River near Derby, Tex.			1915–88
		2458	Dilley, Tex.	1910–87
		4254	Hondo, Tex.	1900–75
		4256	Hondo, Tex.	1975–88
		7873	Sabinal, Tex.	1903–46, 1948–88
		9265	Uvalde, Tex.	1905–85
		9268	Uvalde, Tex.	1985–88
08208000	Atascosa River at Whitsett, Tex.			1932–88
		4254	Hondo, Tex.	1900–75
		4256	Hondo, Tex.	1975–88
		9716	Whitsett, Tex.	1914–61, 1964
		9717	Whitsett, Tex.	1964–88
08210000	Nueces River near Three Rivers, Tex.			1915–88
		1007	Brackettville, Tex.	1900–31, 1935–88
		1486	Carrizo Springs, Tex.	1912–17, 1928–72 1975–88
		2458	Dilley, Tex.	1910–87
		3508	George West, Tex.	1916–88

Table 6. Selected streamflow stations, associated precipitation stations, and periods of record in the Nueces River Basin—Continued

Streamflow station number and name		Precipitation station number and location		Available periods of record
		4254	Hondo, Tex.	1900–75
		4256	Hondo, Tex.	1975–88
		9265	Uvalde, Tex.	1905–85
		9268	Uvalde, Tex.	1985–88
		9716	Whitsett, Tex.	1914–61, 1964
		9717	Whitsett, Tex.	1964–88
08211000	Nueces River near Mathis, Tex.			1939–88
		1007	Brackettville, Tex.	1900–31, 1935–88
		1486	Carrizo Springs, Tex.	1912–17, 1928–72 1975–88
		2458	Dilley, Tex.	1910–87
		4254	Hondo, Tex.	1900–75
		4256	Hondo, Tex.	1975–88
		3508	George West, Tex.	1916–88
		9265	Uvalde, Tex.	1905–85
		9268	Uvalde, Tex.	1985–88
		9716	Whitsett, Tex.	1914–61, 1964
		9717	Whitsett, Tex.	1964–88

Table 7. Long-term trends in streamflow and associated precipitation for streamflow stations in the Nueces River Basin

[no change, less than 5-percent increase or decrease for 50 years of streamflow record, or less than 3-percent increase or decrease for 50 years of precipitation record]

Streamflow station number and name		Long-term trend			
		Annual mean streamflow	Annual minimum daily mean streamflow	Annual maximum daily mean streamflow	Associated annual index precipitation
08190000	Nueces River at Laguna, Tex.	increased	increased	decreased	increased
08194000	Nueces River at Cotulla, Tex.	decreased	increased	decreased	no change
08195000	Frio River at Concan, Tex.	increased	increased	decreased	no change

Table 7. Long-term trends in streamflow and associated precipitation for streamflow stations in the Nueces River Basin

[no change, less than 5-percent increase or decrease for 50 years of streamflow record, or less than 3-percent increase or decrease for 50 years of precipitation record]

Streamflow station number and name		Long-term trend			
		Annual mean streamflow	Annual minimum daily mean streamflow	Annual maximum daily mean streamflow	Associated annual index precipitation
08198000	Sabinal River near Sabinal, Tex.	increased	increased	increased	increased
08205500	Frio River near Derby, Tex.	increased	increased	decreased	increased
08208000	Atascosa River at Whitsett, Tex.	decreased	increased	decreased	decreased
08210000	Nueces River near Three Rivers, Tex.	decreased	increased	decreased	no change
08211000	Nueces River near Mathis, Tex.	decreased	increased	decreased	increased

Table 8. Water-budget analysis for losses in annual mean streamflow resulting from filling and evaporation at Choke Canyon Reservoir

[ft^3/s, cubic feet per second; acre-ft, acre-feet; --, data not available or not used]

Water year	Total upstream mean streamflow (ft^3/s)	Expected mean streamflow at station 08210000 (ft^3/s)[1]	Actual mean streamflow at station 08210000 (ft^3/s)	Streamflow reduction at station 08210000 (ft^3/s)	Volume reduction at station 08210000 (acre-ft)	Change in storage at reservoir (acre-ft)[2]	Estimated evaporation from the reservoir (acre-ft)[3]
1965	661	--	749	--	--	--	--
1966	495	--	564	--	--	--	--
1967	1,456	--	2,040	--	--	--	--
1968	865	--	1,132	--	--	--	--
1969	112	--	140	--	--	--	--
1970	766	--	843	--	--	--	--
1971	2,286	--	2,110	--	--	--	--
1972	1,566	--	1,680	--	--	--	--
1973	807	--	689	--	--	--	--
1974	1,251	--	1,213	--	--	--	--
1975	719	--	668	--	--	--	--
1976	695	--	681	--	--	--	--

Table 8. Water-budget analysis for losses in annual mean streamflow resulting from filling and evaporation at Choke Canyon Reservoir—Continued

Water year	Total upstream mean streamflow (ft^3/s)	Expected mean streamflow at station 08210000 (ft^3/s)[1]	Actual mean streamflow at station 08210000 (ft^3/s)	Streamflow reduction at station 08210000 (ft^3/s)	Volume reduction at station 08210000 (acre-ft)	Change in storage at reservoir (acre-ft)[2]	Estimated evaporation from the reservoir (acre-ft)[3]
1977	1,424	--	1,586	--	--	--	--
1978	349	--	441	--	--	--	--
1979	573	--	511	--	--	--	--
1980	673	--	877	--	--	--	--
1981	1,269	--	1,237	--	--	--	--
1982	506	--	487	--	--	--	--
1983	170	182	202	--	--	--	--
1984	37	40	82	--	--	+4,000	2,000
1985	708	758	566	192	139,000	+99,000	15,000
1986	559	598	448	150	109,000	+111,000	37,000
1987	1,908	2,042	1,244	798	578,000	+479,000	50,000
1988	194	208	120	88	64,000	-33,000	98,000
1989	49	52	268	-216	-156,000	-262,000	119,000
1990	684	732	646	86	62,000	+24,000	63,000
			TOTALS[4]		796,000	+422,000	384,000

[1] The total 1965–82 streamflow at the four streamflow stations upstream from station 08210000 was 93 percent of the total streamflow at station 08210000. The long-term streamflow at station 08210000, prior to the construction of Choke Canyon Reservoir, was assumed to be 1.07 times greater than the total streamflow at the upstream four stations.

[2] Difference between storage in reservoir from beginning to end of year (data from USGS).

[3] Evaporation as calculated based on pan-evaporation data from the reservoir (U.S. Department of Congress, 1889–1989) and pan-evaporation coefficients (Kane 1967).

[4] The total estimated volume reduction at station 08210000 from October 1984 through September 1990 is 796,000 acre-ft. The total change in storage at the reservoir, 422,000 acre-ft, represents the volume impounded at the end of the 1990 water year. The sum of the total change in storage and total estimated net evaporation represents 806,000 acre-ft, which approximates the total estimated streamflow reduction of 796,000 acre-ft.