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Changes in Flow in the Beaver–North Canadian River Basin Upstream From Canton Lake, Western Oklahoma

Water-Resources Investigations Report 96–4304

U.S. Department of the Interior
U.S. Geological Survey

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By Kenneth L. Wahl and Robert L. Tortorelli

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Gale A. Norton, Secretary

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

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

Changes in Flow in the Beaver-North Canadian River Basin Upstream From Canton Lake, Western Oklahoma

By Kenneth L. Wahl and Robert L. Tortorelli

Abstract

This report presents the results of an evaluation of hydrologic data for the Beaver-North Canadian River basin upstream from Canton Lake in western Oklahoma. It examines the climatic and hydrologic data for evidence of trends. The hydrologic data examined includes total annual flow, base flow, and annual peak discharges.

This study was conducted to determine if there is evidence of trends present in hydrologic and climatic data. All available streamflow-gaging station data, with at least 10 or more years of record, were examined for trends. In addition, the data were divided into an "early" period (ending in 1971), representing conditions before ground-water levels had declined appreciably, and a "recent" period (1978-1994), reflecting the condition of declining ground-water levels, including the effects of storage reservoirs.

Tests for trend, moving averages, and comparisons of median and average flows for an early period (ending in 1971) with those for the recent period (1978-1994) show that the total annual volume of flow and the magnitudes of instantaneous annual peak discharges measured at most gaging stations in the Beaver-North Canadian River basin have decreased in recent years. Precipitation records for the panhandle, however, show no corresponding changes.

The changes in flow are most pronounced in the headwaters upstream from Woodward, but also are evident at Woodward and near Seiling, which represents the inflow to Canton Lake. The average annual discharge decreased between the early period and the recent period by the following amounts: near Guymon, 18,000 acre-feet; at Beaver, 68,000 acre-feet; at Woodward, 72,000 acre-feet; and near Seiling, 63,000 acre-feet. These decreases, expressed as a percentage of the average flows for the early period, were 91 percent near Guymon, 82 percent at Beaver, 49 percent at Woodward, and 37 percent near Seiling. The medians of the annual peak discharges decreased from the early period to the recent period by the following amounts: near Guymon, 98 percent; at Beaver, 86 percent; at Woodward, 80 percent; and near Seiling, 53 percent. The Guymon gage is not affected by reservoirs; the other three mainstem gaging stations are influenced by reservoirs, but the decreases in annual peak discharges are greater than can be explained by storage in those reservoirs.

Base flows have undergone substantial change, but unlike the annual volumes the base flows show some increases and some decreases. Flow duration analyses show a shift in the distribution of annual flows. Less contribution is coming from large floods that formerly added substantially to the yearly average flows. Near Seiling, for example, the magnitudes of the large flows that occur less than about 20 percent of the time were greatly reduced in the recent period.

A primary mechanism producing these decreased streamflows appears to be the depletion of ground water in the High Plains aquifer that underlies more than 90 percent of the basin. Changes in farming and conservation practices and in water use also may be having an effect.

Introduction

About half of the City of Oklahoma City public-water supply withdrawals are from the North Canadian River supplied by releases from Canton Lake. The City is concerned about the dependability of that water source since flows appear to have decreased in the North Canadian River. The U.S. Geological Survey (USGS), in cooperation with the City of Oklahoma City, conducted this study to determine if there is evidence of trends present in the hydrologic and climatic data for the Beaver-North Canadian River basin above Canton Lake.

The Beaver-North Canadian River and its tributaries in western Oklahoma are primary sources of public-water supply. Ninety-two percent of the total withdrawals of surface water in the basin upstream of Oklahoma City (fig. 1) are for public supply (calculated from Lurry and Tortorelli, 1996). Optima Lake on the Beaver River near Hardesty, Fort Supply Lake on Wolf Creek near Fort Supply, and Canton Lake on the North Canadian River near Canton provide storage of public-water supplies for western Oklahoma and for the Oklahoma City metropolitan area. Palo Duro Reservoir near Spearman, Texas, is the other large reservoir in the study area. It does not provide storage for public-water supply at this time (1996), but will provide six small Texas communities with storage in the future.

Only 5.7 percent of the total ground-water withdrawals in the same area are used for public supply. Irrigation is the largest use of ground water in the Beaver-North Canadian River basin (Oklahoma Water Resources Board and U.S. Geological Survey 1990 data, Lurry and Tortorelli, 1996). The Ogallala For-

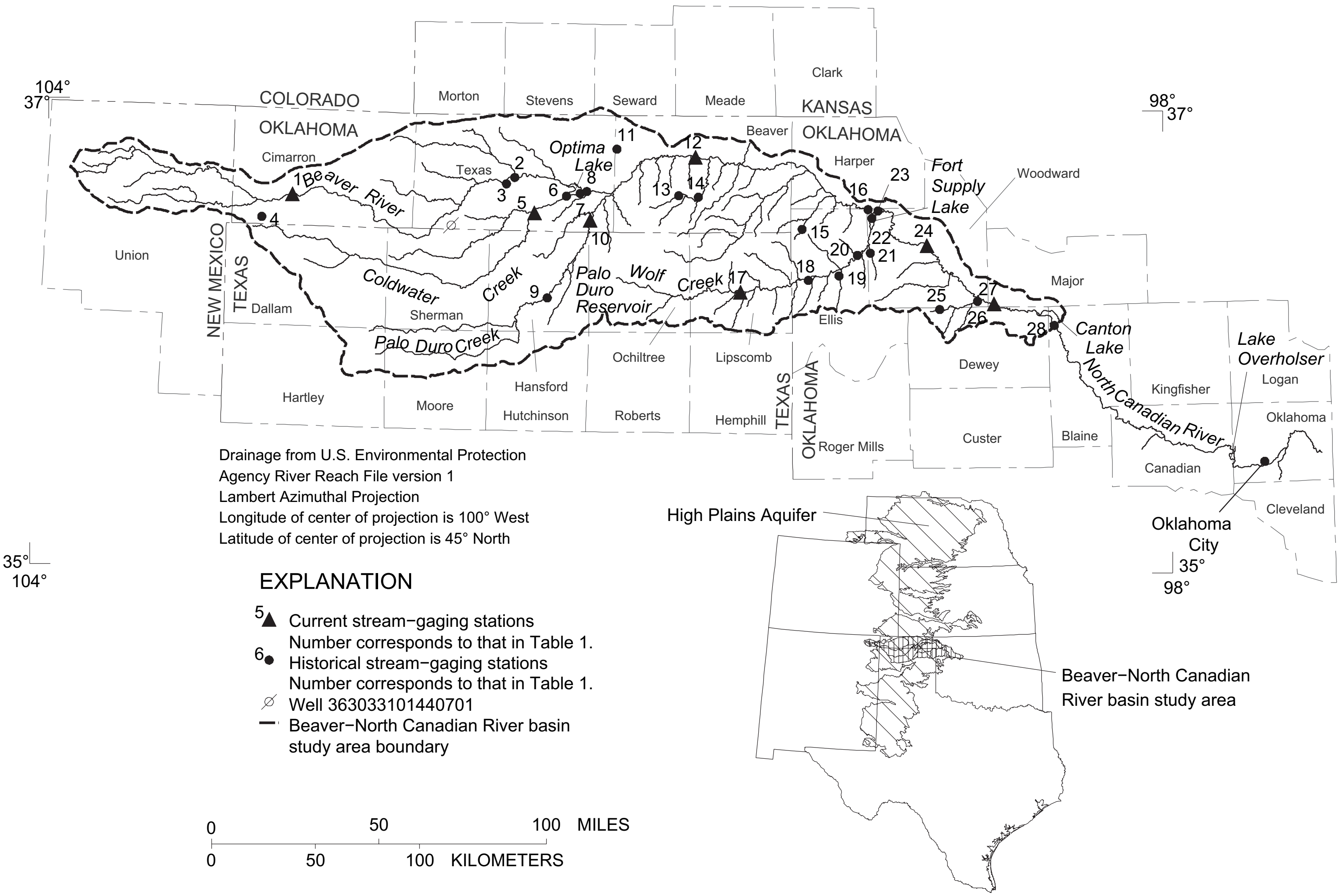

Figure 1. Location of study area, including locations of streamflow-gaging stations.

mation underlying most of the Oklahoma panhandle (Cimarron, Texas, and Beaver Counties) is part of the High Plains regional aquifer system extending from southern South Dakota to northwestern Texas (Dugan and Cox, 1994). The High Plains aquifer is primarily a water-table aquifer that is recharged by precipitation. Prior to the start of large-scale pumping for irrigation in the 1960's, the aquifer was in equilibrium. The water table in the southern part of the High Plains aquifer began to decline with extensive irrigation pumping, and no increase in natural recharge (Havens and Christenson, 1984). This depletion of ground water, which manifested itself as a decline in ground-water levels, in combination with changes in land-use practices has been acknowledged as the primary cause of decreases in the discharge of the Beaver River in the western Oklahoma panhandle (Boyle Engineering Corp., 1987; and Wahl and Wahl, 1988).

Purpose and Scope

The purpose of this report is to present the results of an evaluation of climatic and hydrologic data for the Beaver-North Canadian River basin upstream from Canton Lake in western Oklahoma. It examines the climatic and hydrologic data for evidence of trends. Monthly and annual average precipitation for 1895 to the present in the Oklahoma Climate Division 1, the panhandle area that extends eastward to the Woodward County line, were examined. All available streamflow-gaging station data in the study area, with at least 10 or more years of record, were examined. The hydrologic data analyzed includes total annual flow, base flow, and annual peak discharges. The data were divided into an "early" period (ending in 1971), representing conditions before ground-water levels had declined appreciably, and a "recent" period (1978-1994), reflecting the condition of declining ground-water levels, including the effects of storage reservoirs. Methods of analysis included tests for trend, moving averages, and comparisons of central tendency statistics including median and average.

Since depletion of the aquifer is suspected, ground-water development of the most extensive aquifer in the basin, the High Plains aquifer, is described. Descriptions of the development and water level changes of secondary aquifers, the largest of which is the North Canadian River alluvium, were outside the scope of this project because additional data collection would be required.

Description of Study Area

The study area (fig. 1) includes the drainage of the Beaver-North Canadian River upstream from Canton Lake. This drainage includes most of the Oklahoma panhandle and northwest Oklahoma (6,724 square miles [mi^2], 54 percent), along with a small part of northeastern New Mexico (746 mi^2, 6 percent), and the northern part of the Texas panhandle (5,082 mi^2, 40 percent). The Beaver River is the headwaters of the North Canadian River; the name changes at the confluence of the Beaver River and Wolf Creek near Fort Supply.

Several storage reservoirs are located in the basin. Optima Lake (capacity 129,000 acre-feet), located on Beaver River at the confluence of the Beaver River and Coldwater Creek, began water storage in 1978. Fort Supply Lake (capacity 13,900 acre-feet), located near the mouth of Wolf Creek, began water storage in 1942. Canton Lake (capacity 111,300 acre-feet), located on the North Canadian River near Canton, began water storage in 1948. Palo Duro Reservoir (capacity 60,900 acre-feet), located on Palo Duro Creek in Texas, began water storage in 1991. The storage capacity in the basin upstream from Guymon (fig. 2) in reservoirs of more than 100 acre-feet capacity has been estimated to be only 5,425 acre-feet, 5,165 acre-feet of which is in New Mexico (Canadian River Commission, 1987).

These reservoirs are primarily for public-water supply and flood control; the use of surface water for irrigation in the Beaver River basin upstream from Guymon has been minimal.

Average annual precipitation in the study area ranges from about 16 inches (in.) in the west to 24 in. near Canton in the east; the average at Guymon (fig. 2) is about 18 in., 10 percent of which falls as snow. The majority of precipitation occurs from spring through summer. Average annual lake evaporation is about 64 in., and average annual evapotranspiration is about 16 in. (Johnson and Duchon, 1994; Pettyjohn and others, 1983). Annual runoff at Canton Lake averages about 0.4 in. Historically, most runoff occurs between April and August, and the smallest streamflows usually occur from December through February.

The principal industry in the panhandle is agriculture, with the land area about evenly divided between cropland and rangeland. In 1978, about 42 percent of both Beaver and Cimarron Counties and about 59 percent of Texas County was cropland (U.S. Department of Commerce, 1978). Cropland terracing in Beaver County increased from about 20,000 acres in 1960 to about 200,000 acres (approximately 40 percent of the total cropland) in 1985 (Boyle Engineering Corp., 1987). Terracing in Texas and Cimarron Counties, however, is estimated to be less than 1 percent of the cropland area (Robert Griswald and Jerry Allan, U.S. Department of Agriculture, Natural Resources Conservation Service, oral commun., 1988).

Irrigation and public supply ground-water freshwater withdrawals in Cimarron County during 1990 totaled 108,600 acre-feet; Texas County totaled 229,600 acre-feet; and Beaver County totaled 44,800 acre-feet (Lurry and Tortorelli, 1996). These three counties comprise the Oklahoma panhandle and accounted for 47 percent of the ground-water and only 0.3 percent of the surface-water freshwater withdrawals in Oklahoma during 1990.

Background and Previous Studies

Most, more than 90 percent, of the Beaver-North Canadian basin above Canton Lake is underlain by the High Plains aquifer. The High Plains aquifer is the shallowest and most abundant source of ground water in the High Plains region of the United States and is critical to the agricultural economy of the

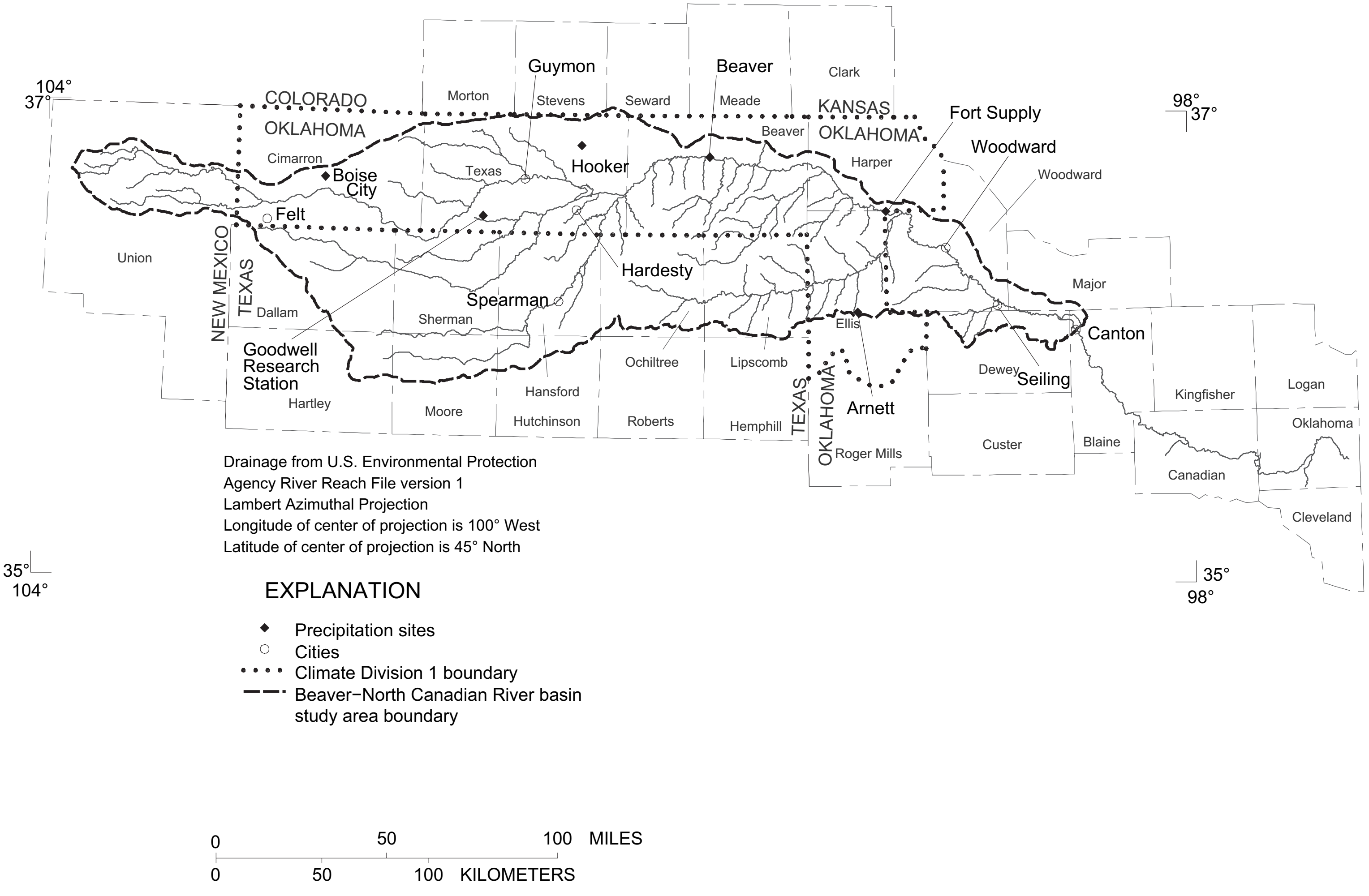

Figure 2. Location of cities and precipitation sites in the study area and Oklahoma Climate Division 1.

Nation. About 30 percent of the ground water used in the United States is pumped from this aquifer that underlies an area of about 174,000 mi^2 (Weeks and others, 1988). Cropping out in the Oklahoma panhandle, the aquifer consists of hydraulically connected interbedded siltstone, sand, clay, gravel, thin limestone, and caliche in the Ogallala Formation. Near Guymon, the saturated thickness varies from 0 to about 450 ft, and the measured water table elevation in 1980 was about 3,000 ft above sea level (Havens and Christenson, 1984). The estimated recharge rate for the Ogallala Formation in the Beaver River basin upstream from Guymon is 0.056 in. per year (Luckey and others, 1986, p. 29); this represents less than 1 percent of the mean annual precipitation. Most precipitation is consumed by vegetation or lost to evaporation.

The introduction of the center-pivot sprinkler system in the early 1960's resulted in a rapid increase in the use of ground water for irrigation. Long-term water-level monitoring for the High Plains aquifer indicates declines averaging 0.25 foot per year from 1940 to 1980 (Dugan and Cox, 1994, p. 1). Water levels continued to decline from 1980 to 1993, but at a smaller rate, averaging 0.16 foot per year. Maximum declines are in the Texas and Oklahoma panhandles where the water table has been lowered by 50 to 100 feet. As late as about 1962, there were only about 270 large-capacity wells (capacities of greater than 100 gallons per minute) in the Oklahoma panhandle; by 1980 the number had increased to about 1,500; and by 1995 the number had increased to about 2,000 (Oklahoma Water Resources Board, written commun., 1996) (fig. 3). The combination of low natural recharge and the increase of large-capacity wells produced substantial declines in water levels in large areas of the High Plains aquifer. Havens (1983) reported for the period before development to 1980 water-levels declined 25 to 50 feet in western Oklahoma; south of Guymon, water levels have declined more than 100 ft. End-of-month water-level measurements are presented in figure 4 for a long-term observation well, 363033101440701, completed in the Ogallala Formation in Texas County, Oklahoma. The water level in the well began to decline about 1968 and appears to have reached a relatively steady rate of decline, about 0.9 foot per year, in the early 1970's that continues to the present (1996).

A digital simulation model of the High Plains aquifer in Oklahoma was used by Havens and Christenson (1984) to predict future water levels through 2020. They predict that the aquifer will continue to be an important water source after 2000, but, as water levels continue to decline, ground-water discharge to streams will decrease, and, in some cases, may cease. Declines in the water levels in the High Plains aquifer in combination with changes in land-use practices has been recognized to be a primary cause of decreases in the stream discharge in the Solomon and Republican River basins in Kansas (Bureau of Reclamation, 1984, 1985).

Studies by Boyle Engineering Corp. (1987) and Wahl and Wahl (1988) defined changes in the flow regime of the Beaver River near Guymon, Oklahoma; the flow of the river near Guymon began to decline in the early 1970's, and by about 1980, the flow had noticeably decreased. Prior to about 1970, the Beaver

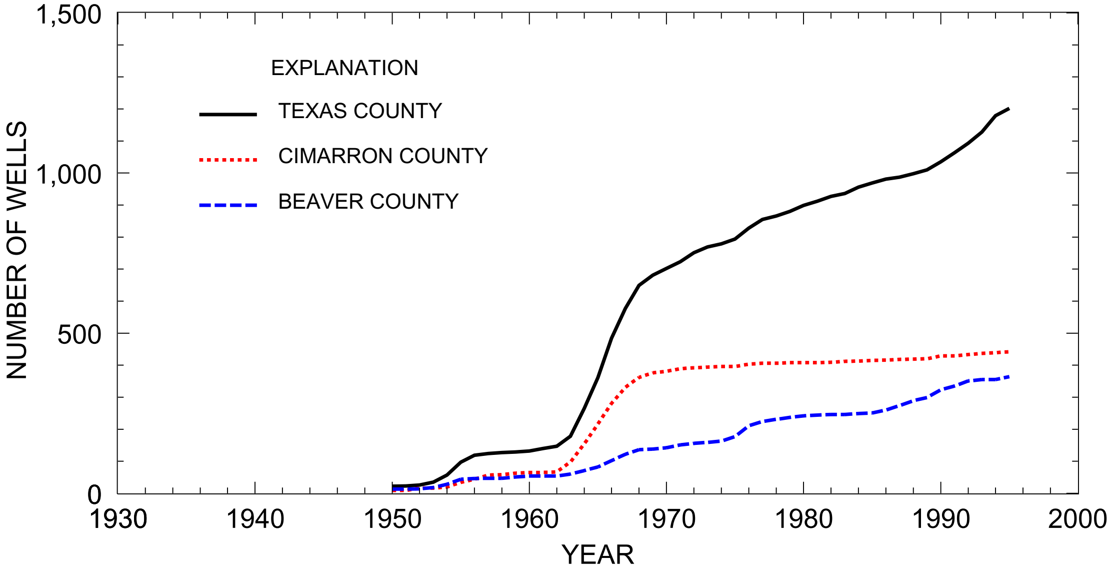

Figure 3. Numbers of large-capacity wells in Beaver, Cimarron, and Texas Counties, Oklahoma, 1950—95 (Oklahoma Water Resources Board, written commun., 1996).

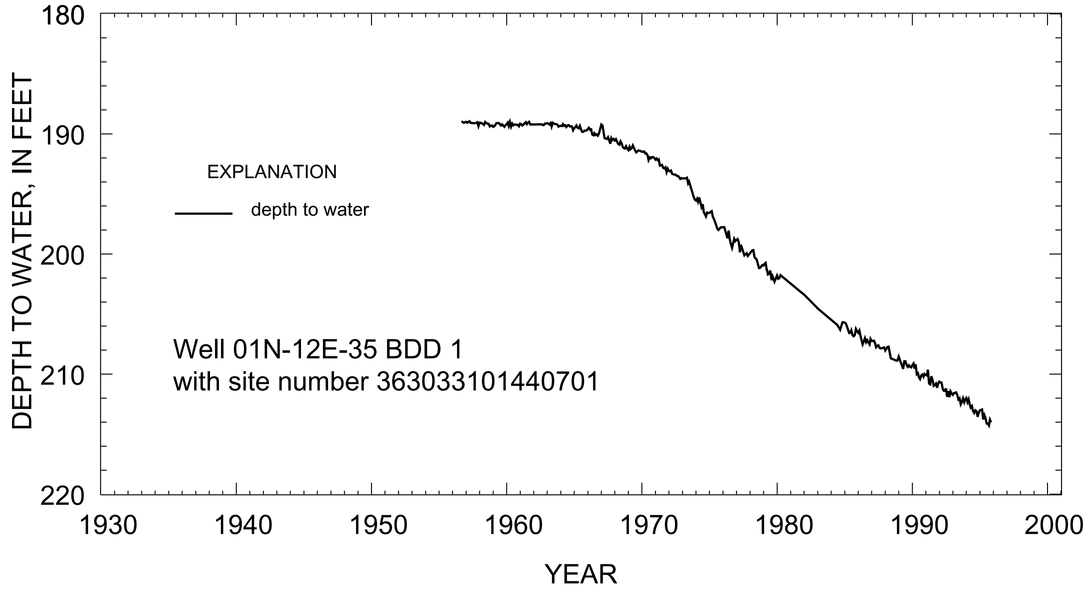

Figure 4. Water levels in a long-term observation well in Texas County, Oklahoma (1956–95).

River occasionally ceased to flow, but only for short periods; the total number of days without flow never exceeded 60 in a year. Beginning in 1970, the pattern changed; since then, the river has been dry near Guymon for more than 60 days in all years but 1971. The percentage of days without flow for each year is shown in figure 5. The number of days without flow increased steadily between about 1970 and 1988. That trend continued into the 1990's; the river has had zero flow more than 90 percent of the year. Prior to 1971, the river was not flowing less than 15 percent of the year.

This decreased flow has been attributed to a combination of ground-water level declines and land use changes (Boyle Engineering Corp., 1987; Wahl and Wahl, 1988). Wahl and Wahl (1988) suggested that ground-water level declines were the principal cause. They noted the Beaver River and the High Plains aquifer are hydrologically connected where the water table is shallow and that precipitation patterns and surface water use for the same period were unchanged.

The number of stock ponds in Cimarron and Texas Counties in Oklahoma, and Dallam and Sherman Counties in Texas, increased from about 100 in 1940 to almost 1,000 in 1985 (Boyle Engineering Corp., 1987, p. 3-21). However, the rate of increase was greatest before 1960; only about 300 ponds were constructed during 1960-1985 (fig. 6). Although the stock ponds are normally small and are located in the headwater areas, they could have affected the magnitude of peak discharges since their construction.

There are other factors that may affect streamflow in the Beaver-North Canadian River drainage. Water use in the High Plains aquifer has changed since 1980 as a result of increasing energy costs, changes in the Federal farm program, and technological advances in irrigation equipment and practice. Also, Davis and Christenson (1981) and Christenson (1983) demonstrated that the alluvium and terrace aquifer that extends from the panhandle to Lake Overholser is hydraulically connected to the river. They concluded that although historically the ground water in the aquifer discharges to the river, pumping from the aquifer has reduced the amount of this discharge and increased pumping could change reaches for the river from gaining to losing. Changes in development of the North Canadian River alluvium was outside the scope of this study. It is not known if the water consumption by phreatophytes, particularly the non-native salt cedars, has increased. Waste-water discharges to the River also will affect streamflow.

Data Analyzed

Climatic Data

Systematic precipitation and temperature records have been collected in Oklahoma by the National Weather Service and its predecessors since 1892. Long-term precipitation data

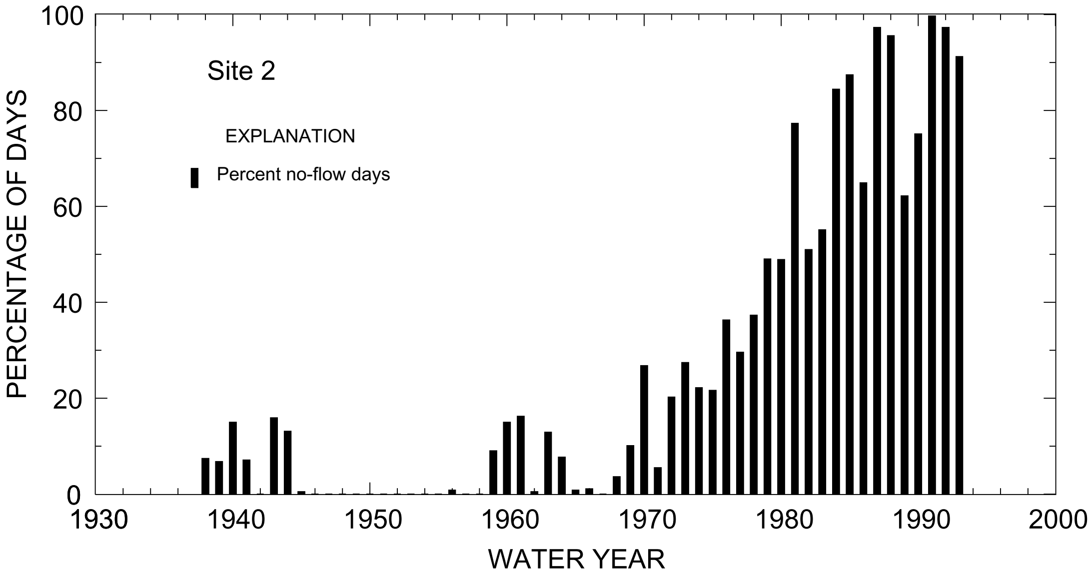

Figure 5. Annual percent of no-flow days for the Beaver River near Guymon, Oklahoma (site 2: modified from Wahl and Wahl, 1988).

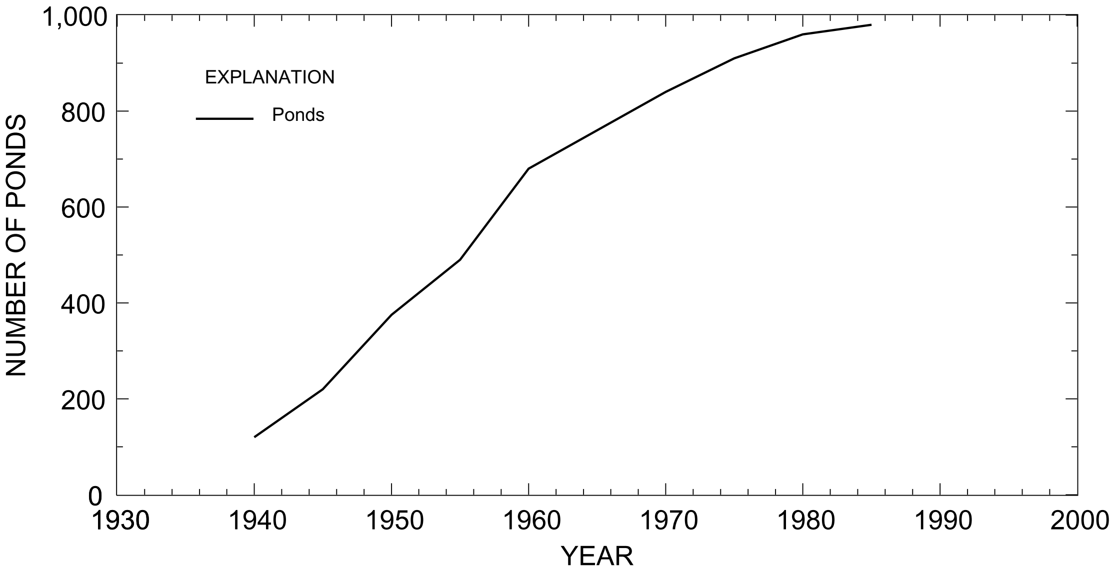

Figure 6. Total number of stock ponds in cimarron and Texas Counties, Oklahoma; and Dallum and Sherman Counties, Texas (from Boyle Engineers Corporation, 1987, p. 3-21).

are available for the following locations in the study area: Arnett, Beaver, Boise City, Fort Supply, Goodwell Research Station, and Hooker (fig. 2). In addition, the National Climatic Data Center of the National Oceanic and Atmospheric Administration (NOAA) used these and other data to produce the U.S. Historical Climatology Network (HCN) of serial temperature and precipitation data (T.R. Karl and others, NOAA, written commun., 1987). Monthly and annual average precipitation by climatic division for 1895 to the present is included as a part of the HCN data set. The bulk of the study area is included in one climatic division - Oklahoma Climate Division 1, the panhandle area that extends eastward to the Woodward County line (fig. 2).

Hydrologic Data

Hydrologic data have been collected by the U.S. Geological Survey in the study area since about 1937. Data have been collected at several kinds of streamflow-gaging station installations. At sites where continuous streamflow data are collected, daily discharge data are available as are records of the annual instantaneous peak discharge. At other sites, only peak flow data were collected. The locations of data collection, types of data collected, and periods of data collection are shown in table 1.

Methods of Data Analysis

Trend Analysis

All available streamflow-gaging station data with at least 10 or more years of record were examined for trends. Ten years were considered to be a minimum for meaningful analysis of trends.

In addition to evaluating trends for the period of record, the data were divided into two separate periods for many analyses. The two periods are referred to as the “early” period ending in 1971, representing conditions before ground-water levels had declined appreciably and the “recent” period that begins in 1978, reflecting the condition of declining ground-water levels, and the effects of storage reservoirs. The High Plains aquifer water levels began to decline about 1968 (fig. 4); the flow of the Beaver River near Guymon sharply declined in the early 1970's (Wahl and Wahl, 1988). Therefore, based on that information and on preliminary evaluations done in the current study, the 1971 water year was treated as the last year in the early period. Optima Lake, the latest of the large reservoirs in the study area, was completed and began storing water in 1978. Although storage in Optima Lake has been minimal, mainstem gaging stations downstream are potentially influenced by operations of Optima Lake. Therefore, the recent condition is represented by water years 1978 to 1994. In addition, trend tests were limited to data collected after 1942 for sites downstream from Fort Supply Lake, which began storing water in 1942. However, data for 1942 and earlier years are included in the histograms.

Kendall's tau

A procedure commonly called Kendall's tau (Kendall, 1938, 1975) was used to test for the presence of trends. In addition, a Kendall slope estimator (Sen, 1968) was used to estimate trend magnitude. The procedures are designed to identify whether monotonic changes (increasing or decreasing, but not necessarily linear) are occurring with time and to estimate the rate of change. They are not intended to test a hypothesis that a change occurred at a specific time. However, if such a change is suspected, the data for the entire period can be tested and, if a trend is detected, the data can be subdivided at the point the trend is believed to have begun. The individual periods can be tested, assuming that the subdivided record lengths are sufficiently long to permit testing. Although the methods are exploratory, they can be used in combination with other techniques (such as graphical exploration) to test hypotheses of timing and cause. The advantage of the Kendall's tau test and the seasonal Kendall slope estimator is they are nonparametric; they do not require the test variable be normally distributed. These tests are relatively insensitive to the presence of individual outliers and are applicable even when values are missing.

Kendall's tau is determined in the following manner: Given a time series x_1, x_2, -------,x_n, of length n, the differences $d_{ij}=x_i-x_j$ are determined for $1 \leq j < i \leq n$. There are n(n-1)/2 of these differences. If P is the number of positive differences and N is the number of negative differences, then:

$$\text{tau} = (P - N) / [n(n-1)/2] \tag{1}$$

If all differences are positive, tau = +1; if all the differences are negative, tau = -1. However, if the number of positive differences is equal to the number of negative differences (P = N), tau = 0. Tau is a measure of the correlation between the series of x_i and time, and the sign of tau indicates whether x is increasing (+) or decreasing (-) with time.

Slopes between individual pairs of xi are computed as $d_{ij}/(i-j)$, and the Kendall slope estimator is defined as the median of the slopes. The slope estimator is based on the same set of differences as tau and can be computed concurrently.

The procedure tests the null hypothesis that the data are random observations that are identically distributed and not time dependent; no assumption is made about the identity or form of the underlying distribution. Under the null hypothesis, tau values significantly different from zero are not expected, and their occurrence casts doubt on the null hypothesis. The test compares the observed value of tau for the sample with a critical value from the theoretical distribution for tau. If the absolute value of tau for the sample is greater than the critical value, the null hypothesis is rejected; that is, the observed value of tau is considered too great to have been obtained plausibly by random

Table 1. Streamflow-gaging stations and periods of record available for analysis

[mi^2, square miles]

Site number	Station number	Station name	County	Drainage area (mi^2)	Period of record (water years)	Type of data
1	07232250	Beaver River near Felt, Okla.	Cimarron	879	1981-94	daily
2	07232500	Beaver River near Guymon, Okla.	Texas	2,139	1938-93	daily
3	07232550	South Fork Tributary near Guymon, Okla.	Texas	0.26	1964-84	peaks
4	07232650	Aqua Frio Creek near Felt, Okla.	Cimarron	31.0	1964-75	peaks
5	07232900	Coldwater Creek near Guymon, Okla.	Texas	1,903	1981-94	daily
6	07233000	Coldwater Creek near Hardesty, Okla.	Texas	1,967	1940-64	daily
7	07233200	Optima Lake near Hardesty, Okla.	Texas	5,029	1978-93	daily
8	07233210	Beaver River near Hardesty, Okla.	Texas	5,029	1978-86	daily
9	07233500	Palo Duro Creek near Spearman, Tex.	Hansford	960	1945-79	daily
10	07233650	Palo Duro Creek at Range, Okla.	Texas	1,513	1992-94	daily
11	07233850	Sharp Creek Tributary near Turpin, Okla.	Beaver	1	1964-75	peaks
12	07234000	Beaver River at Beaver, Okla.	Beaver	7,955	1938-94	daily
13	07234050	North Fork Clear Creek Tributary near Balko, Okla.	Beaver	4.00	1964-84	peaks
14	07234100	Clear Creek near Elmwood, Okla.	Beaver	170	1966-93	daily
15	07234290	Clear Creek Tributary near Catesby, Okla.	Ellis	9.18	1966-84	peaks
16	07234500	Beaver River near Fort Supply, Okla.	Woodward	9,615	1937-50	peaks
17	07235000	Wolf Creek at Lipscomb, Tex.	Lipscomb	697	1938-42, 1962-94	daily
18	07235500	Wolf Creek near Shattuck, Okla.	Ellis	1,183	1938-46	daily
19	07235700	Little Wolf Creek Tributary near Gage, Okla.	Ellis	17.6	1964-73	peaks
20	07236000	Wolf Creek near Fargo, Okla.	Ellis	1,624	1943-76	daily
21	07236050	Wolf Creek Tributary near Tangier, Okla.	Woodward	6.23	1964-72	peaks
22	07236500	Fort Supply Lake near Fort Supply, Okla.	Woodward	1,735	1942-93	daily
23	07237000	Wolf Creek near Fort Supply, Okla.	Woodward	1,739	1938-93	daily
24	07237500	North Canadian River at Woodward, Okla.	Woodward	11,589	1939-94	daily
25	07237750	Cottonwood Creek near Vici, Okla.	Dewey	11.5	1964-84	peaks
26	07237800	Bent Creek near Seiling, Okla.	Woodward	139	1967-70	daily
27	07238000	North Canadian River near Seiling, Okla.	Major	12,261	1947-94	daily
28	07238500	Canton Lake near Canton, OK	Blaine	12,483	1948-93	daily

sampling from a single distribution without time trends. If the observed absolute value of tau does not exceed the critical value, the sample does not provide a basis for rejecting the null hypothesis. The probability that tau will exceed the critical value when the null hypothesis is true is called the significance level (alpha) of the test; thus, the significance level is the probability of erroneously rejecting a true null hypothesis. High significance is associated with small values of alpha. For this study, a trend was considered to be in evidence when the null hypothesis was rejected at the 95 percent confidence level (probability of 0.05).

Moving Averages

Moving averages of the data damp the fluctuations so trends are more readily apparent to the eye. Both streamflow and precipitation data are highly variable in this region; this variability tends to obscure any visual evidence of trend in the data. Therefore, moving averages were superimposed on histograms of the basic variables. The longer the term of the moving average, the greater the damping effect. For streamflow, a 10-year moving average was used. For precipitation, the 5-year moving average was used because Marine (1963) suggested that hydrographs of ground-water levels in the Oklahoma panhandle correlate with graphs of the 5-year moving average of precipitation. Marine's work was, of course, prior to the effect of drawdown produced by large-scale pumping.

Central Tendency Statistics

A simple, but useful trend test is to compare central tendency statistics, or measures of location, for the variables in the “early” and “recent” periods. The two most commonly-used central tendency statistics are median and average, or mean. Medians are only minimally affected by a few extreme values and are, therefore, useful in making such comparisons. The median is the central value of the distribution when the data are ranked in order of magnitude. For an odd number of observations, for example, it is the data point that has an equal number of observations above and below it. Using the medians alone, however, presumes that the distributions of flow within the two periods are similar. The average is the sum of all data values divided by the sample size. When the distribution of flow changes radically between the two periods, averages are a better indication of the relative volumes of flow. That is the case for the volumes of both total streamflow and base flow. For those variables divided into an early and recent period, the medians and, where appropriate, the averages are listed in the tables that summarize the trend tests.

Base Flow Determination

Estimates of the contributions to total streamflow from base flow requires that base flows be determined. Those determinations are usually based on hydrograph separation. Traditional manual methods of hydrograph separation are labor intensive and are not objective; different analysts given the same data could arrive at somewhat different base flow values. Computerized methods of base-flow separation easily handle large amounts of data with relative ease and are objective.

A FORTRAN program, BFI (Base Flow Index), that implements a method proposed by the Institute of Hydrology (1980a, 1980b) was used in this study. The computer program was written for studies of base flow trends in the Oklahoma panhandle (Wahl and Wahl, 1988) and has been further developed (Wahl and Wahl, 1995). The Institute of Hydrology (1980a, 1980b) procedure divides the water year into 5-day increments, and the minimum flow during each 5-day period is identified. Minimums are compared to minimums in the adjacent 5-day periods to determine turning points on a base-flow hydrograph. If 90 percent of a given minimum is less than both adjacent minimums, that minimum is a turning point. Straight lines drawn between turning points (on semilogarithmic paper) define a base-flow hydrograph; the area beneath a base-flow hydrograph is an estimate of the volume of base flow for the period. The ratio of this volume to the total volume of streamflow for the period is defined as the base-flow index. Although these procedures may not yield the true base flow, tests in Great Britain (Institute of Hydrology, 1980b), Canada (Swan and Condie, 1983), and the United States (Wahl and Wahl, 1988) suggest that the results are consistent and indicative of the base flow.

The U.S. Geological Survey (USGS) maintains a data base system of water resources data called the National Water Data Storage and Retrieval System (WATSTORE). The BFI program accepts data in USGS WATSTORE 2- and 3-card (80-column) format (Hutchinson, 1975) and can process multiple years of data from one or more gage sites. The algorithm proposed by the Institute of Hydrology uses 5-day minimum streamflows and a factor of 0.9 (90 percent) for the test to identify base-flow turning points. The program permits both parameters to be changed to calibrate to particular watersheds or to match other base-flow separation methods. The default values were used, however, for all streams in this study.

Results

Precipitation Trend Analyses

Precipitation rates and amounts are highly variable in both time and location in the study area. Therefore, areal averages are better indicators of the amounts of precipitation that may appear as runoff at a streamflow-gaging station than are the precipitation amounts measured at individual sites. Climatic data for 1936-1986 collected at the Goodwell Research Station were tested and found not to reflect any trends in an earlier study (Wahl and Wahl, 1988). Therefore, the data for individual locations were not used in this study. Instead, the monthly and annual averages for the panhandle climate division from the

HCN data set were used. The variation of precipitation both within and between seasons is shown in the boxplots of figure 7.

The year-to-year variation of the annual average total precipitation over the panhandle division and the 5-year moving average of the annual average precipitation are shown in figure 8. The annual average precipitation amounts for the panhandle range from about 9 to 33 in. and average 19.5 in. The 5-year moving average oscillates between about 13 to 24 in. and shows definite high and low periods. The droughts of the 1930's and 1950's are quite evident on the moving-average trace. However, there is no discernible long-term trend shown by the moving average.

The Kendall's tau trend test was done on the 1895-1994 HCN data for the panhandle. Tests were done on the annual precipitation and for the individual months. In addition, the annual amounts were subdivided into the period before 1972 (early period) and from 1978 through 1994 (recent period). This subdivision was done to facilitate comparisons with the tests conducted on streamflow data for those periods. The results of the trend tests on precipitation data are summarized in table 2.

The results of the Kendall's tau analyses show no indication of a change in the long-term precipitation. The medians of all three periods of the annual precipitation are almost identical. Only two of the monthly tests show a statistically significant trend: the monthly precipitation for March is increasing and for July is decreasing. Both trends are slight, however, with trend slopes of less that 1 percent of the median monthly amount per year. When precipitation data for March and July are analyzed separately for the early and recent periods, there are no statistically significant trends in either period. However, for the early period the median March precipitation is greater and the median July precipitation is less than for the recent period; the amounts of these differences are essentially equal and offsetting. Histograms of the March and July precipitation amounts and the 5-year moving average are shown in figures 9A and 9B. These analyses indicate that the amount of annual precipitation has not changed significantly and probably has not been a major factor in either declines of ground-water levels or decreases of streamflows from the panhandle.

Streamflow Trend Analyses

Annual flow records were analyzed in several ways. Analyses were done on the total annual volume of flow, on the annual volume of base flow, on the ratio of the annual base-flow volume to the total annual volume of flow (base-flow index), and on the annual instantaneous peak flows. Tests for trend, moving averages, and comparisons of median and average flows for an early period (ending in 1971) with those for the recent period (1978-1994) show that the flows measured at most gaging stations in the Beaver-North Canadian River basin have decreased in recent years. Annual flows for those gaging stations downstream from Optima and Fort Supply Lakes were adjusted for the annual changes in lake contents. Although the analyses are all interlinked, the trend tests are presented separately. However, figures 10-21 show the annual flow (unadjusted) and, where appropriate, the base flow and the base-flow index in addition to the 10-year moving averages. Sites 1 and 5 have no base flow and little annual flow data; for those sites only the annual flows are shown (figs. 10 and 12).

The histograms and moving averages of annual flow volumes, base flow, and base-flow index for selected stations (figs. 10-21) and the results of the trend tests suggest the volumes and sources of flow are changing in the Beaver-North Canadian River basin. The moving averages for both the total annual flow and the annual base flow appear to have begun to decline at the Beaver River gages near Guymon (site 2, fig. 11) and at Beaver (site 12, fig. 15) sometime in the early 1970's. The annual flow also appears to have begun to decline at the North Canadian River gages at Woodward (site 24, fig. 20) and near Seiling (site 27, fig. 21), but the moving average appears to have begun to decrease at these sites in the early 1960's. Perhaps this earlier decrease is really an artifact of the effect of the unusually high runoff in 1949-1951 that influences the 10-year moving average until 1961. The moving average of base flow at the North Canadian River gages (sites 24 and 27, figs. 20 and 21) actually increased starting about 1987, apparently the base flows for 1987-1991 were about double the average amounts for the past 30 years.

The change in the ratio of base flow to total flow is somewhat striking. The moving average of that ratio shows a rather steady increase since about 1970 at all the mainstem stations except the Beaver River near Guymon (site 2). At that location all flows declined strongly; presently there seldom is flow from any source near Guymon.

Annual Flow Volume

Total annual flows were tested for trends using the Kendall's tau. The results for 12 gaging stations are listed in table 3. The changes in flow are most pronounced in the headwaters upstream from Woodward, but also are evident at Woodward (site 24) and near Seiling (site 27), which represents the inflow to Canton Lake. Statistically significant ($P =< 0.05$) downward trends were found in the flow for seven gaging stations during at least one of the three periods tested. Of a total of 27 time periods tested, 25 show possible negative trends, and two show possible positive trends. Of these possible trends, nine are statistically significant ($P < 0.05$), and all of the statistically significant trends are negative. For the mainstem stations, the indicated trend slopes, including those possible trends that are not statistically significant, are similar from station to station. Although the trend slopes are similar, the statistical significance decreases as flows increase in the downstream direction. The slopes of the trends for the mainstem gaging stations from Beaver downstream (sites 12, 24, and 27) were about -1,100 to -8,400 acre-feet per year; the actual decreases in the average annual volumes of flow between the early period and the recent period was about 70,000 acre-feet. At the most upstream mainstem gaging station, Beaver River near Guymon (site 2), the decrease

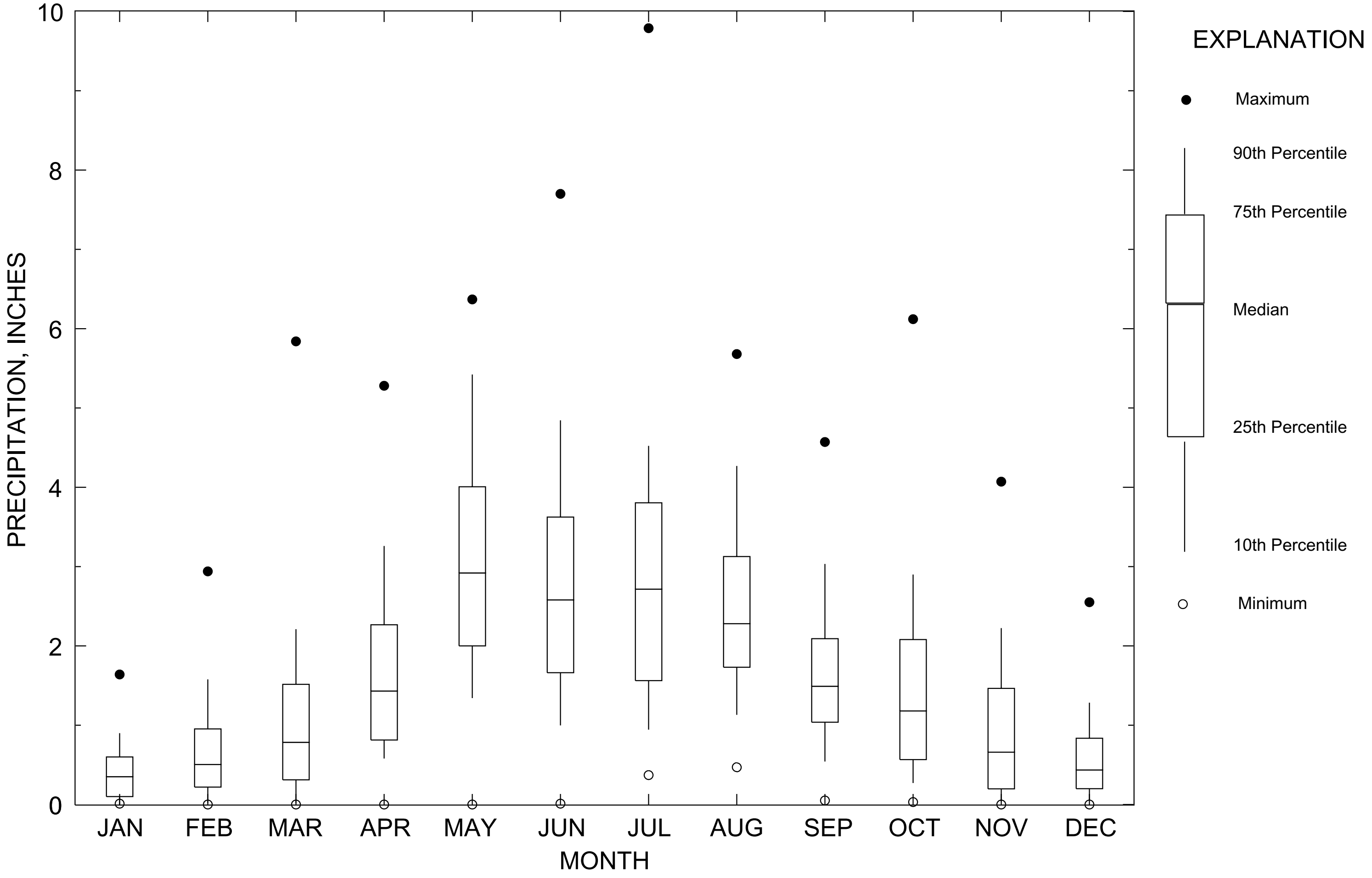

Figure 7. Boxplots of average precipitation for the Oklahoma Panhandle (Oklahoma Climate Division 1), 1895–1994.

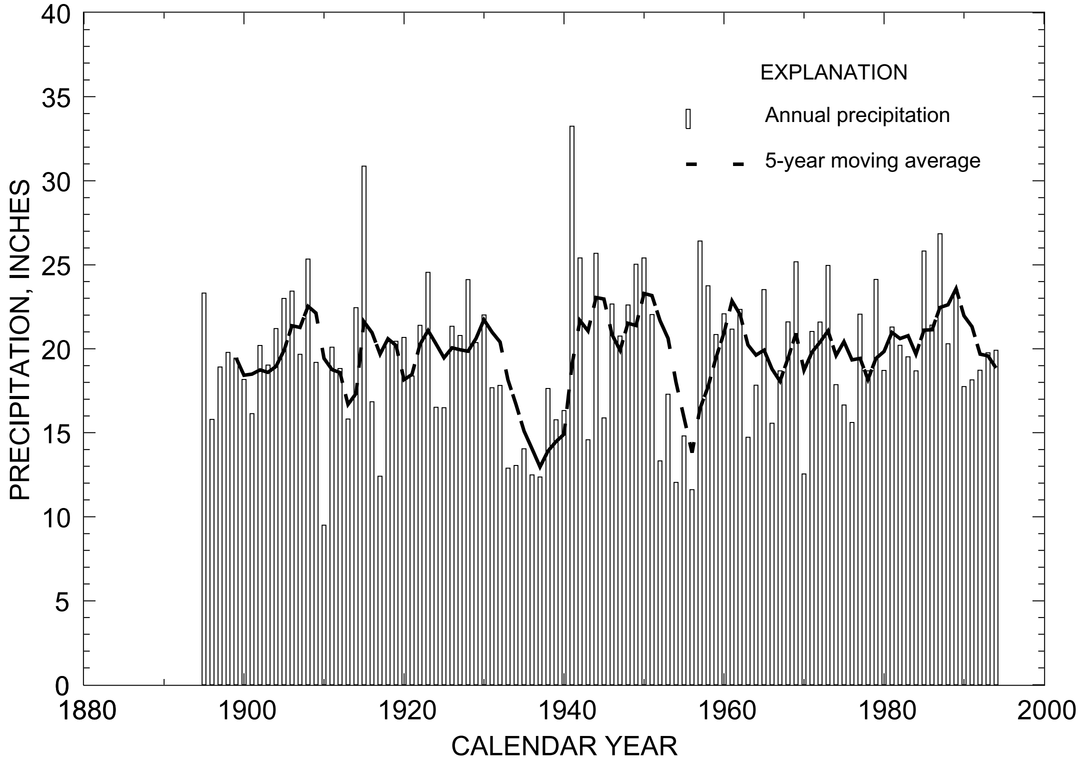

Figure 8. Histograms and 5-year moving average for average annual precipitation for the Oklahoma Panhandle (Oklahoma Climate Division 1), 1895–1994.

Table 2. Results of trend tests on precipitation data

[Tau, Kendall's tau; P, probability level; in., inches; in/yr, inches per year; the shaded values are statistically significant at the 0.05 level]

Period of record (years)	Years of record	Season	Period	Tau	P	Trend slope (in/yr)	Slope (percent of median)	Median (in.)
1895-94	100	Annual	all	.06	.397	.012	0.1	19.8
1895-71	77	Annual	early	.01	.885	.004	0	19.8
1978-94	17	Annual	recent	-.04	.837	-.041	-.2	19.9
1895-94	100	Jan.	all	.02	.750	.003	.1	.40
1895-94	100	Feb.	all	.02	.764	.005	.1	.50
1895-94	100	March	all	.20	.004	.068	.9	.78
1895-71	77	March	early	0.10	.210	.003	.5	.68
1978-94	17	March	recent	-.19	.303	-.065	-4.2	1.53
1895-94	100	April	all	-.06	.367	-.003	-.2	1.43
1895-94	100	May	all	.04	.549	.003	.1	2.92
1895-94	100	June	all	.07	.330	.005	.2	2.58
1895-94	100	July	all	-.14	.044	-.010	-.4	2.72
1895-71	77	July	early	-.09	.226	-.009	-.3	3.00
1978-94	17	July	recent	.04	.837	.025	1.1	2.29
1895-94	100	August	all	.00	.948	.002	0	2.28
1895-94	100	Sept.	all	.10	.145	.004	.3	1.49
1895-94	100	Oct.	all	-.12	.088	-.006	-.5	1.18
1895-94	100	Nov.	all	.03	.651	.007	.1	.66
1895-94	100	Dec.	all	.04	.561	.007	.2	.44

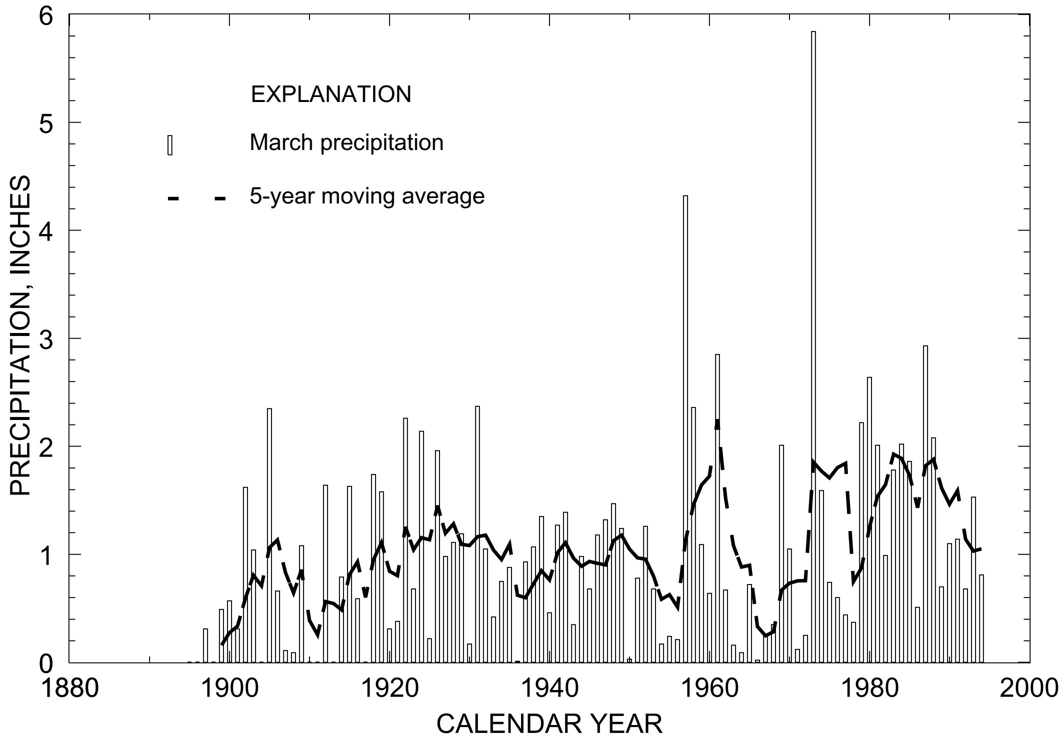

Figure 9A. Histograms and 5-year moving average for average precipitation for the Oklahoma Panhandle (Oklahoma Climate Division 1), 1895–1994, for March.

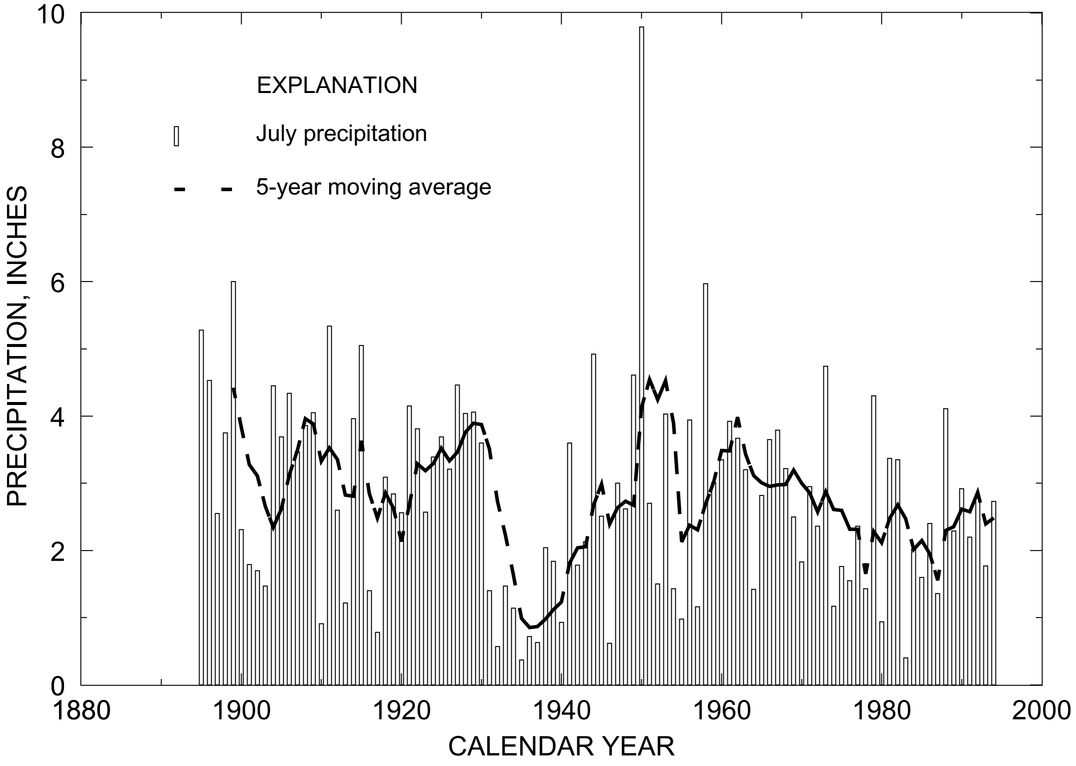

Figure 9B. Histograms and 5-year moving average for average precipitation for the Oklahoma Panhandle (Oklahoma Climate Division 1), 1895–1994, for July.

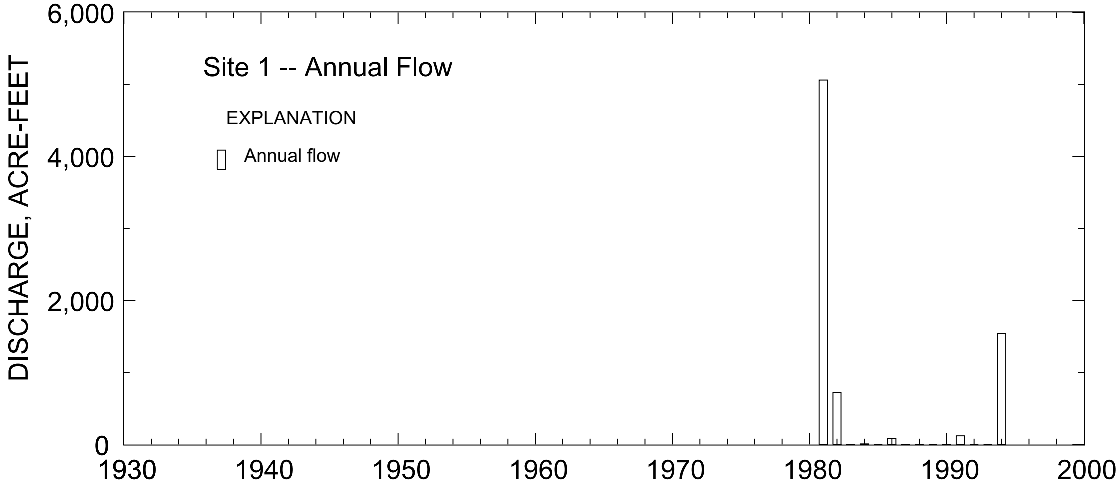

Figure 10. Histograms for annual flow, station 07232250, Beaver River near Felt, Oklahoma (site 1).

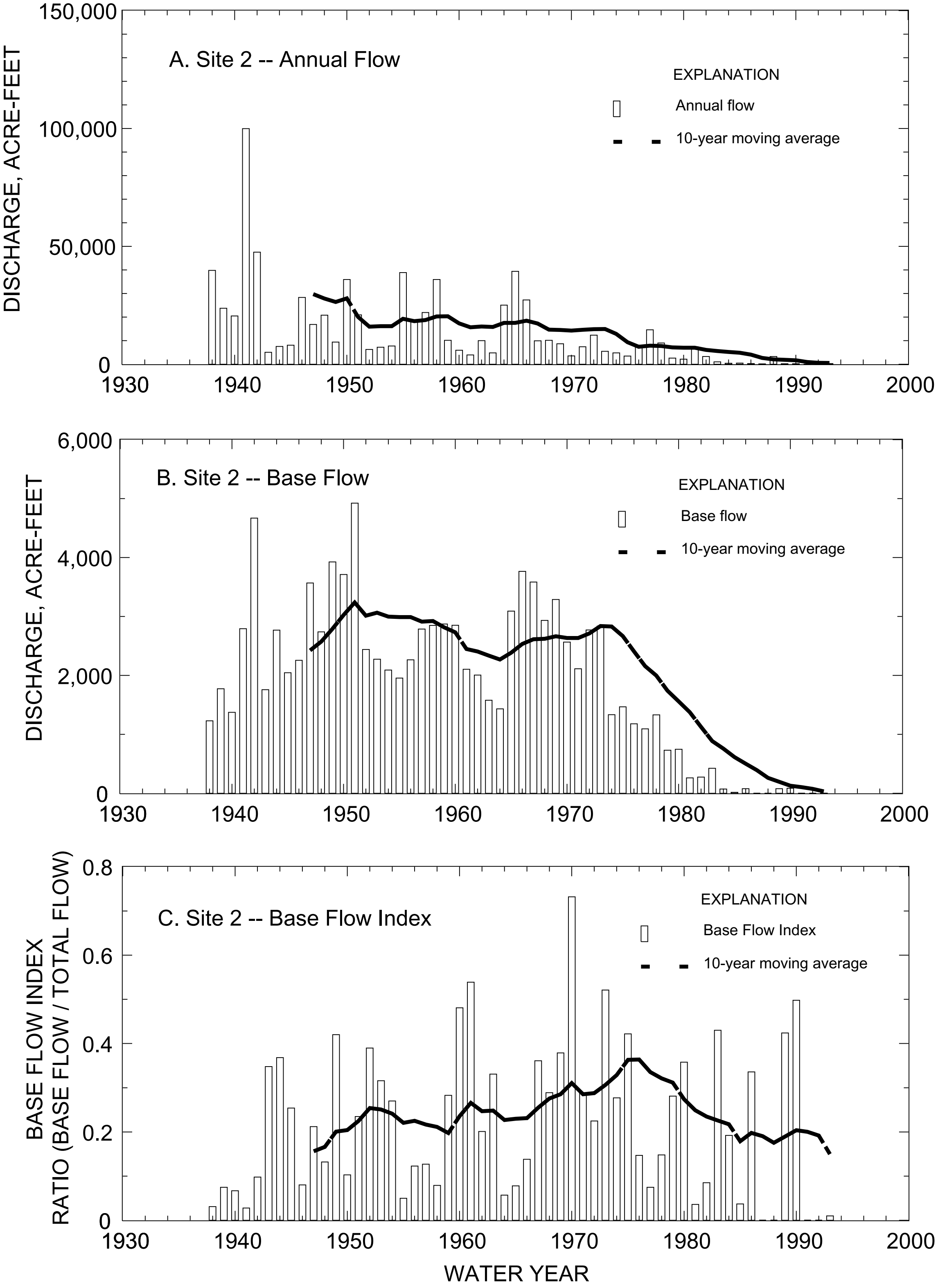

Figure 11. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07232500, Beaver River near Guymon, Oklahoma (Site 2).

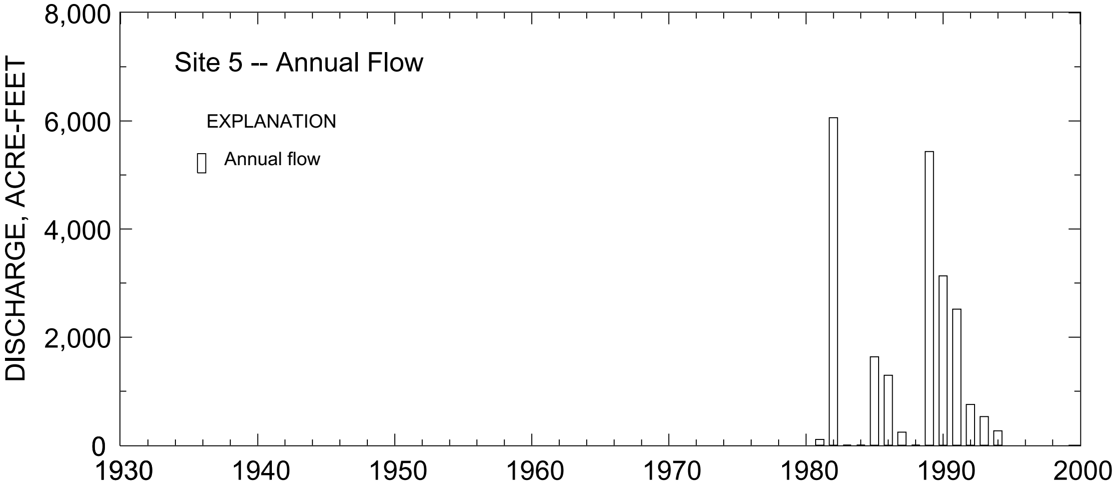

Figure 12. Histograms for annual flow, station 07232900, Coldwater Creek near Guymon, Oklahoma (site 5).

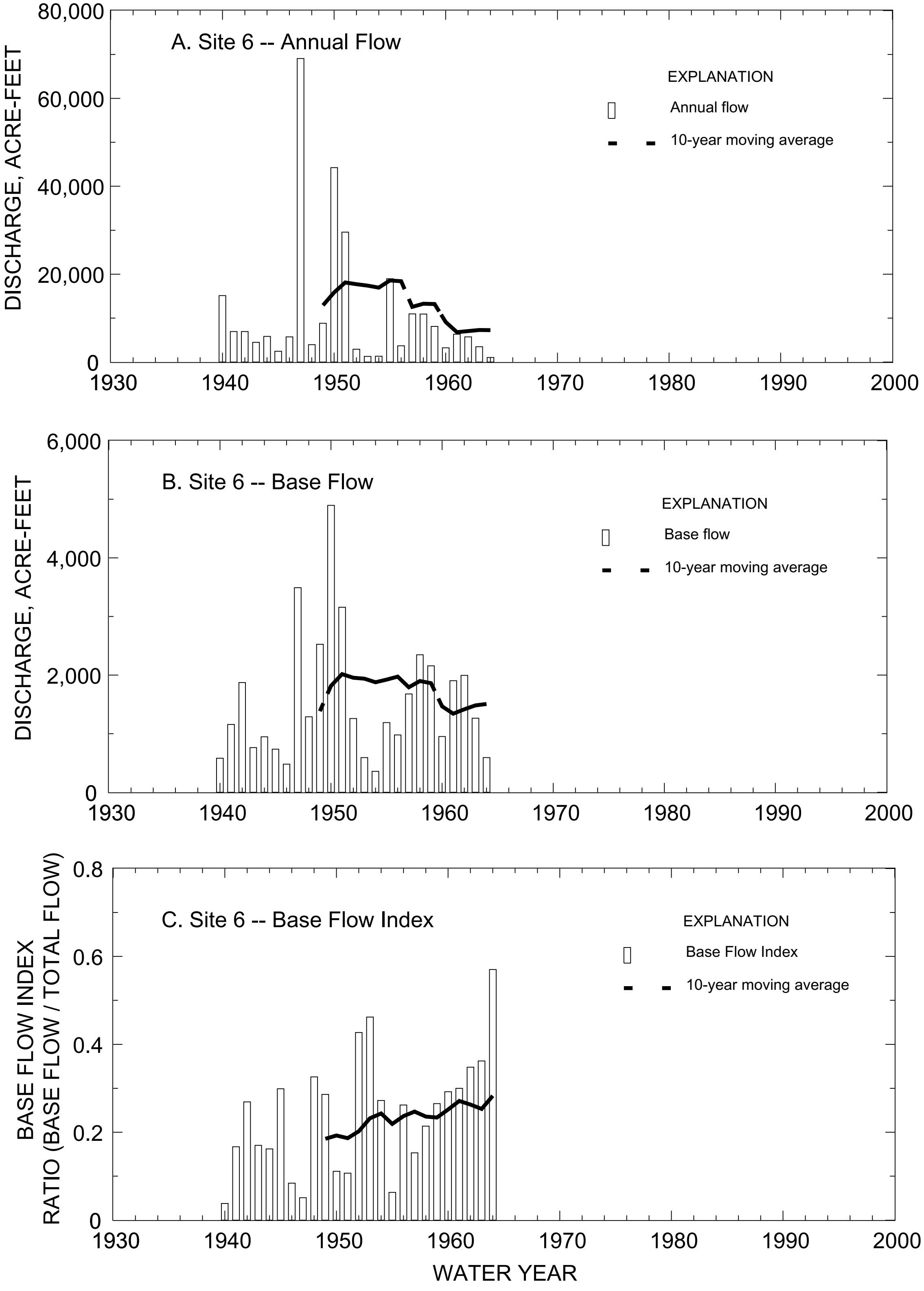

Figure 13. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07233000, Coldwater Creek near Hardesty, Oklahoma (site 6).

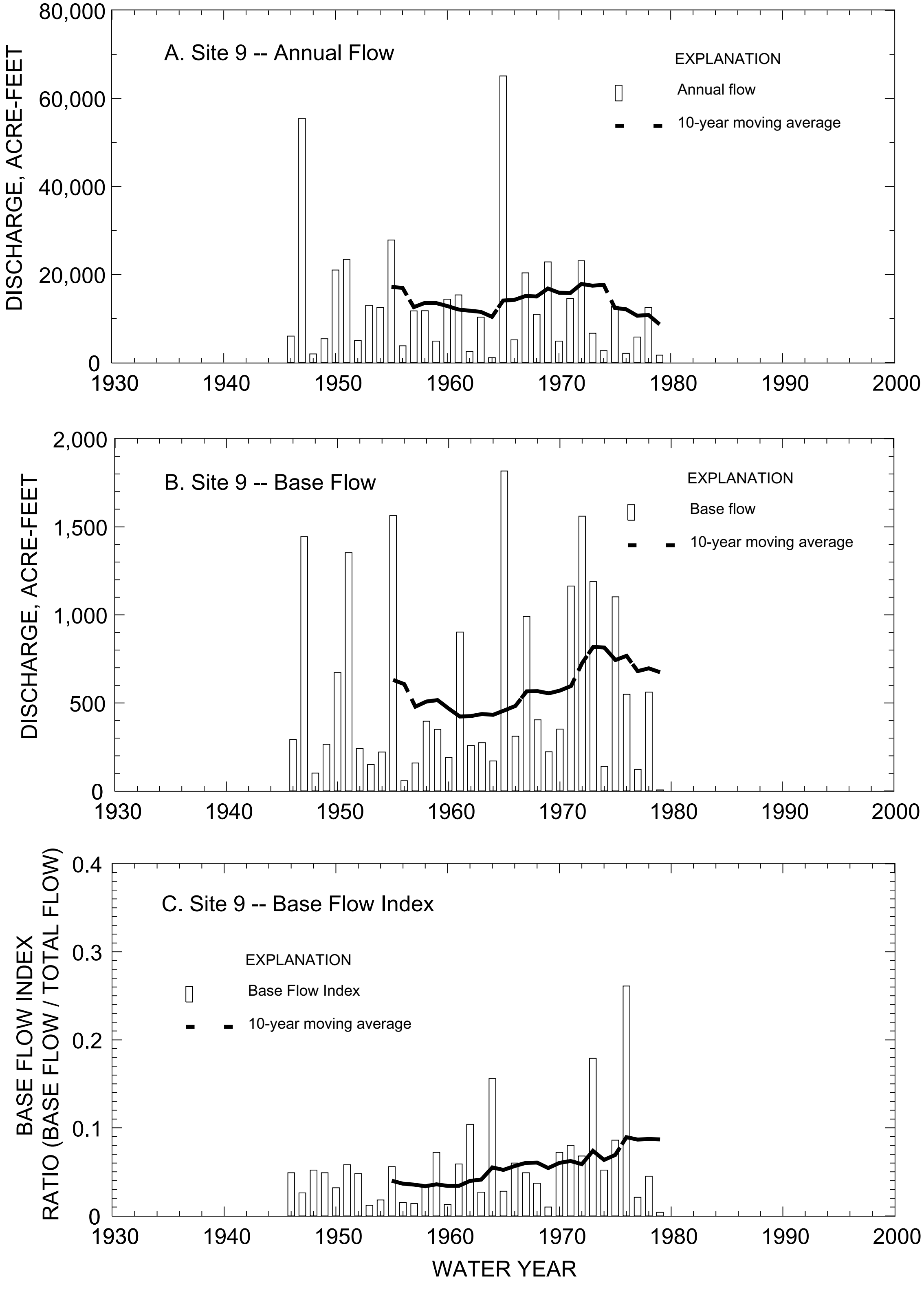

Figure 14. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07233500, Palo Duro Creek near Spearman, Texas (site 9).

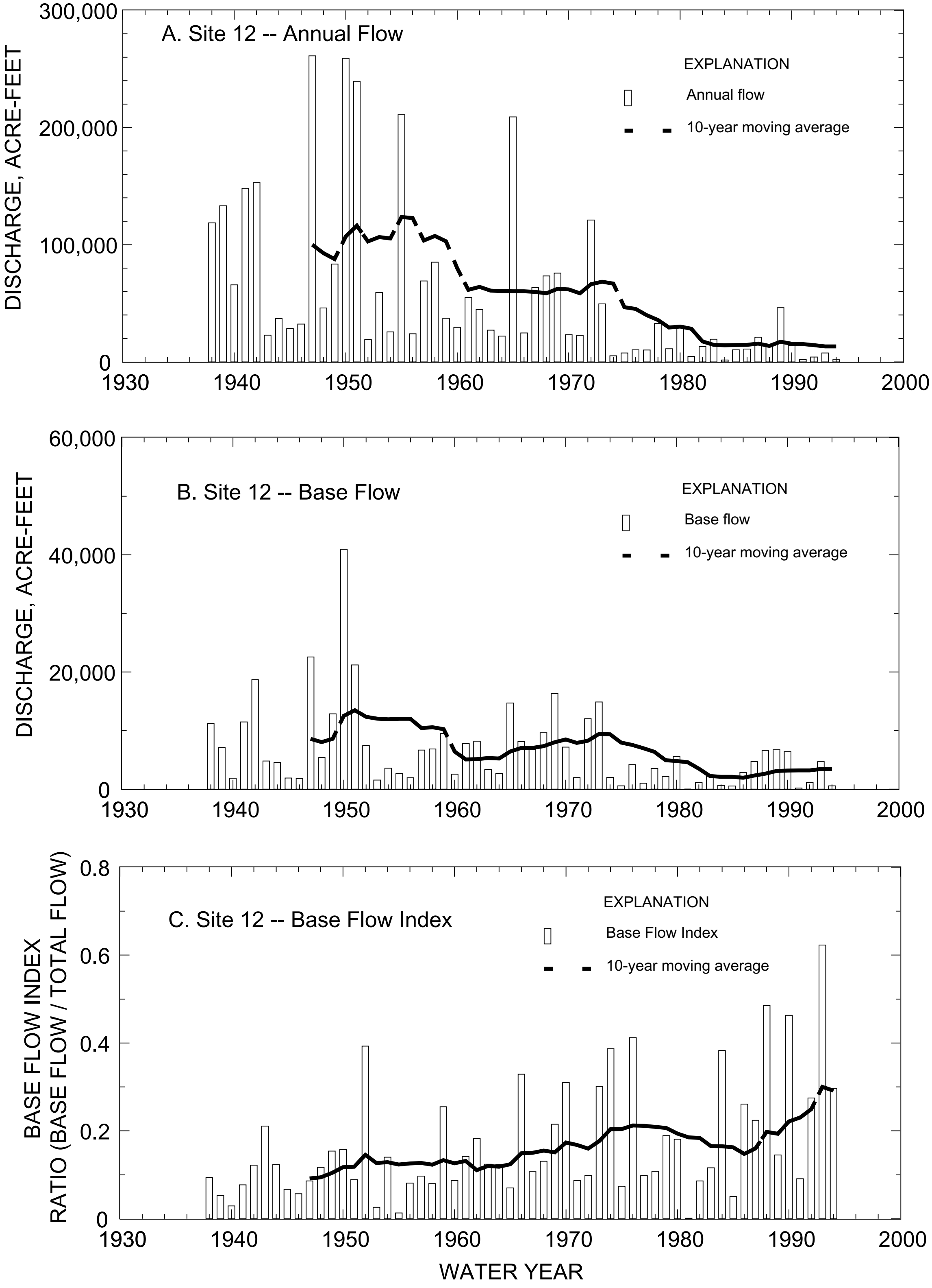

Figure 15. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07234000, Beaver River at Beaver, Oklahoma (site 12).

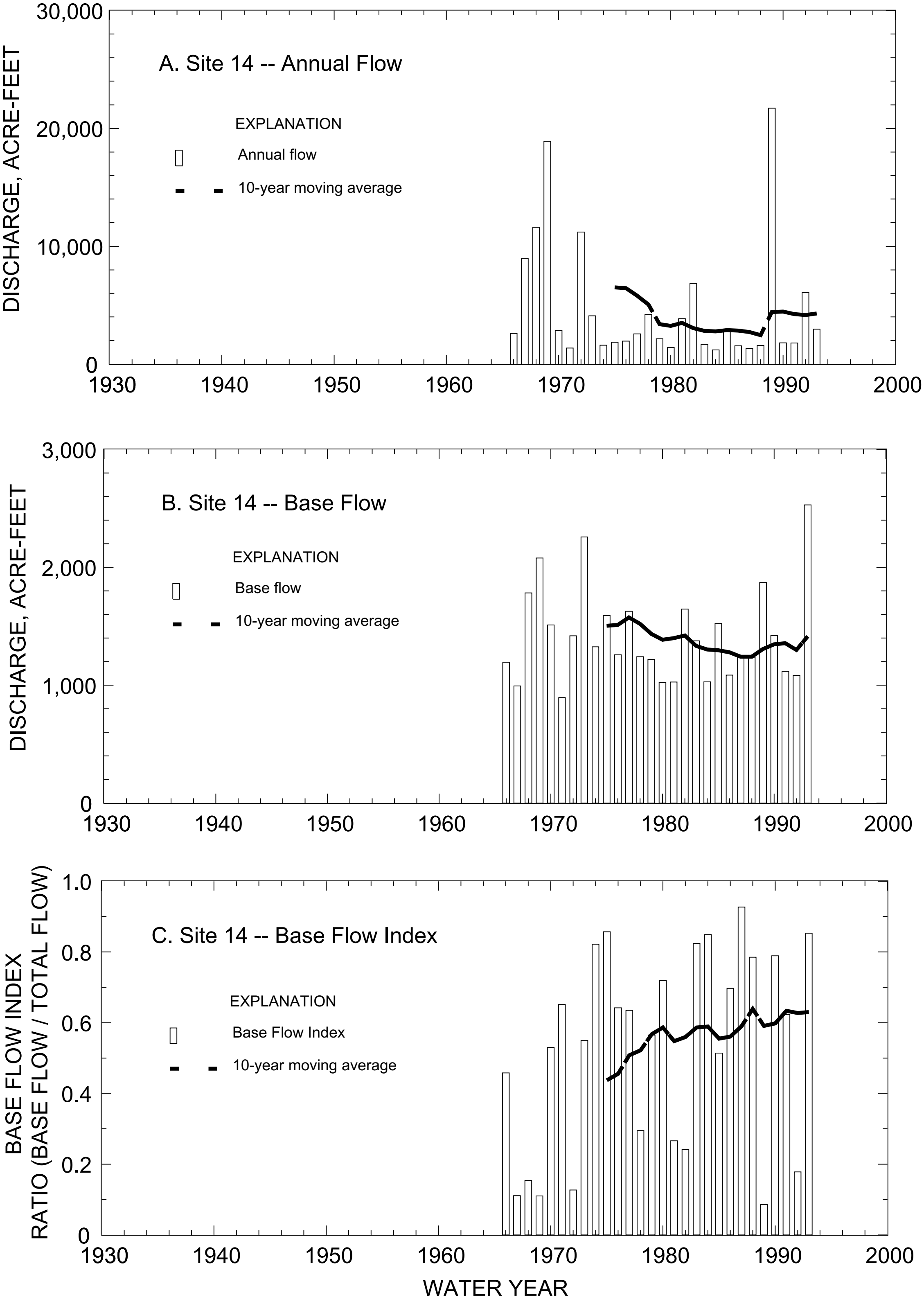

Figure 16. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07234100, Clear Creek near Elmwood, Oklahoma (site 14).

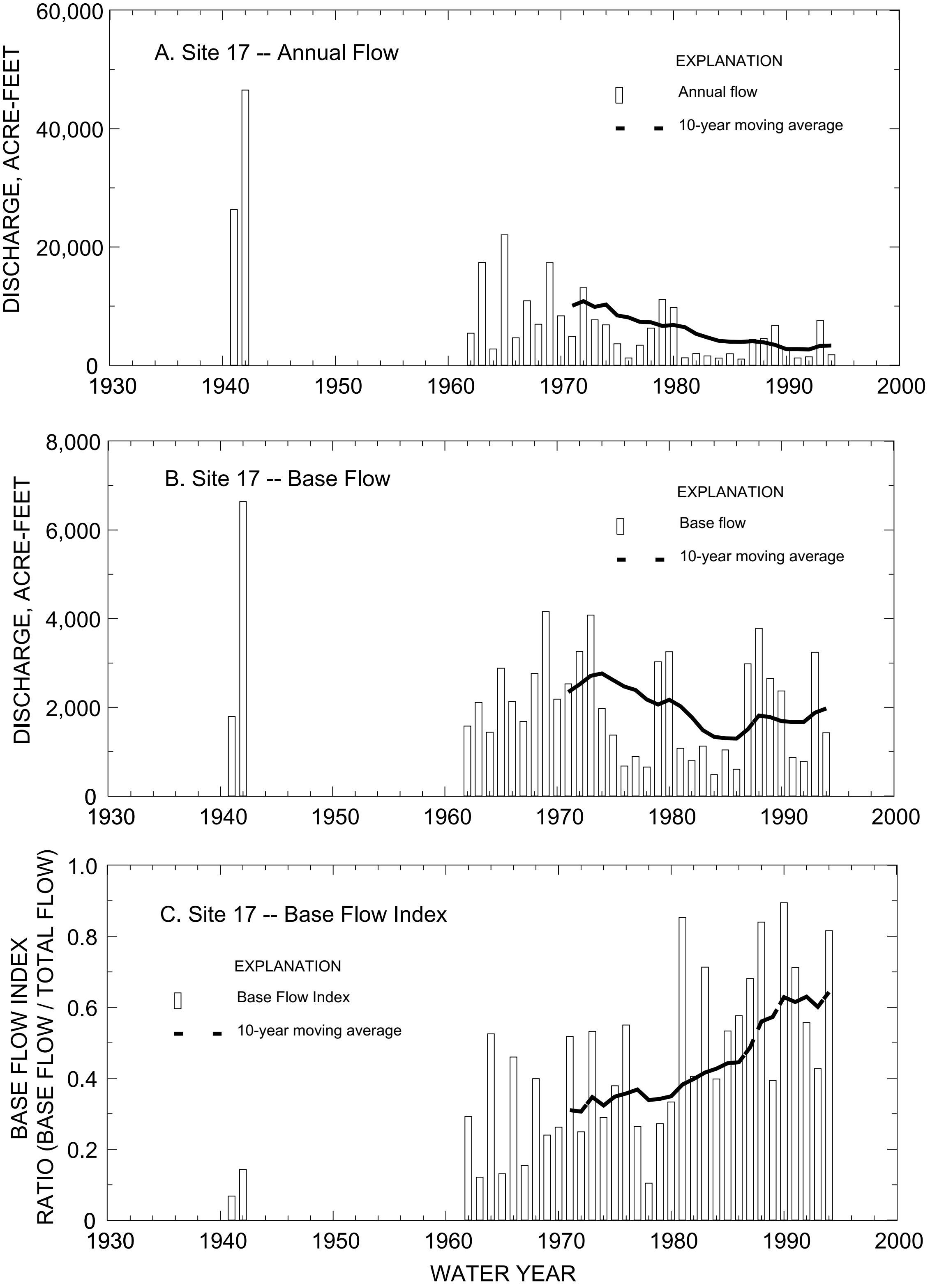

Figure 17. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07235000, Wolf Creek at Lipscomb, Texas (site 17).

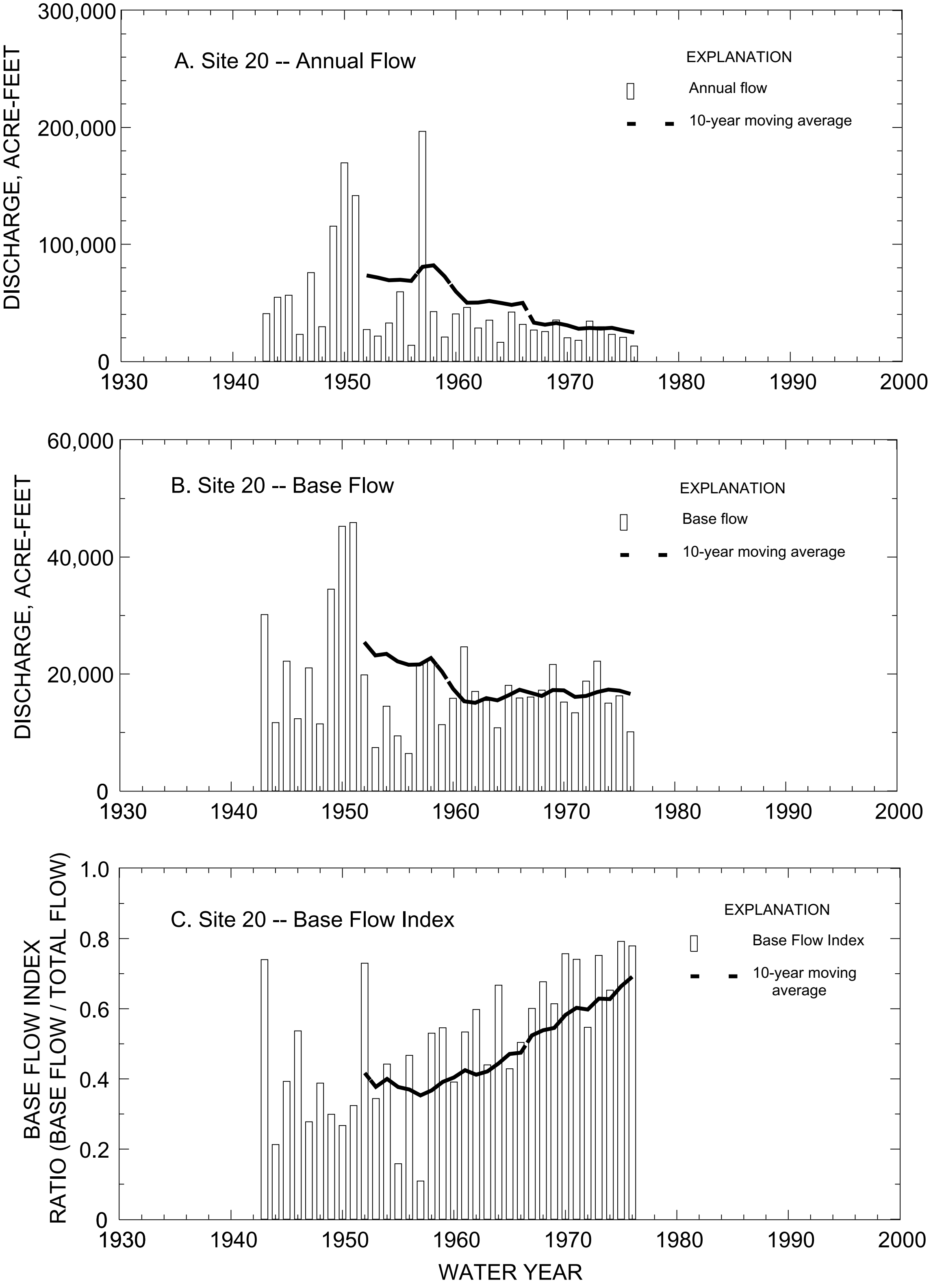

Figure 18. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07236000, Wolf Creek near Fargo, Oklahoma (site 20).

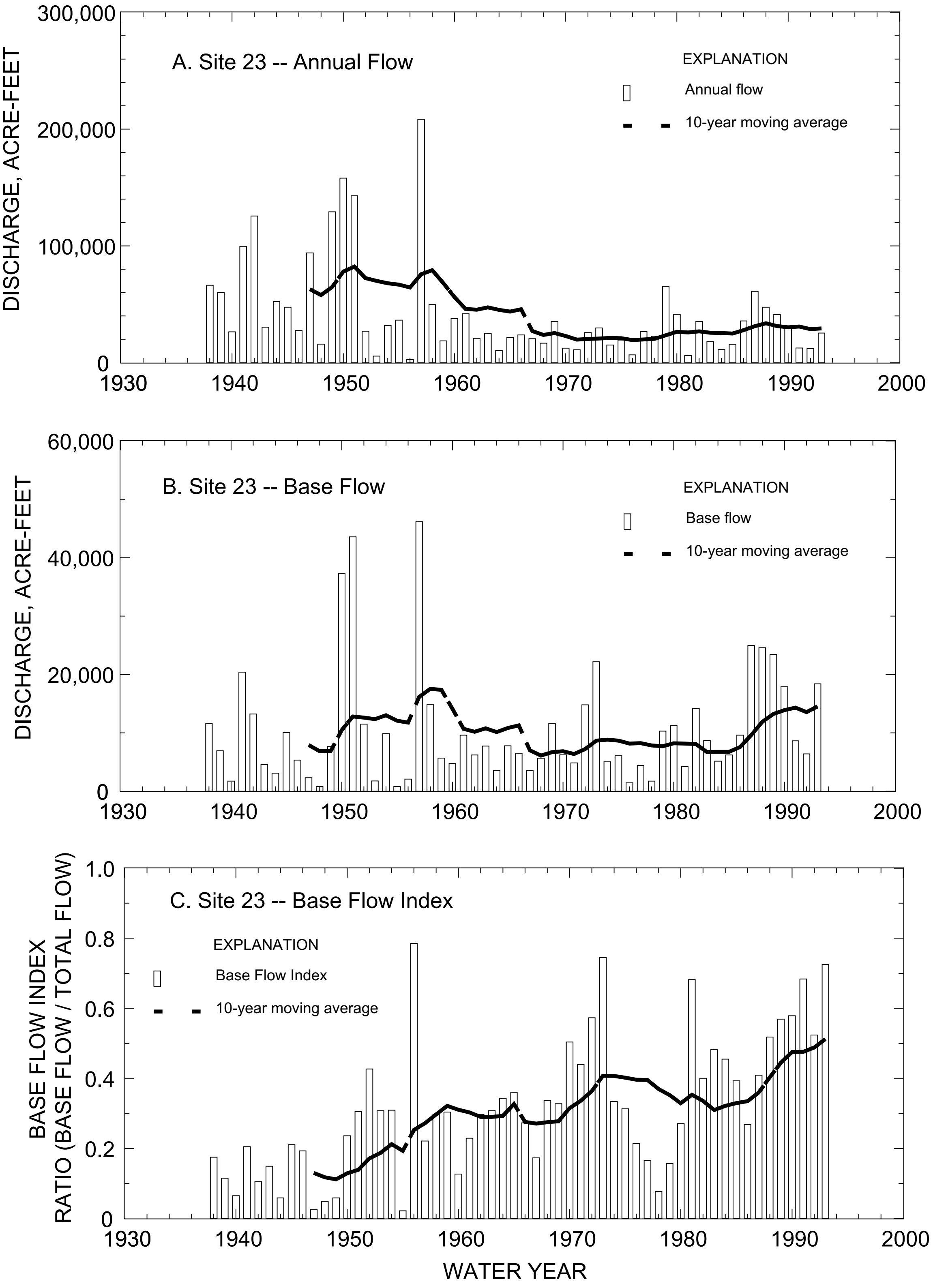

Figure 19. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07237000, Wolf Creek near Fort Supply, Oklahoma (site 23).

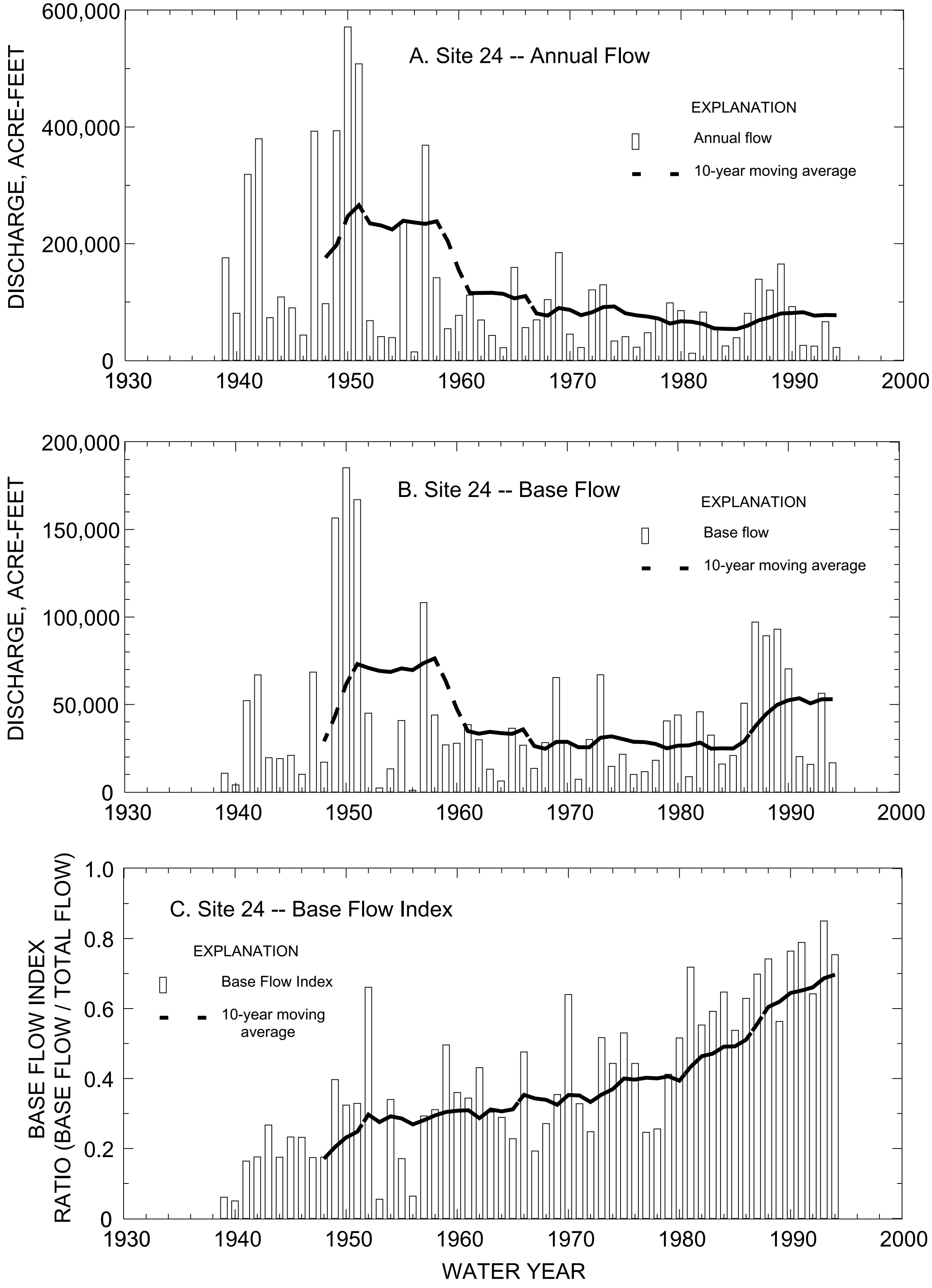

Figure 20. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07237500, North Canadian River at Woodward, Oklahoma (site 24).

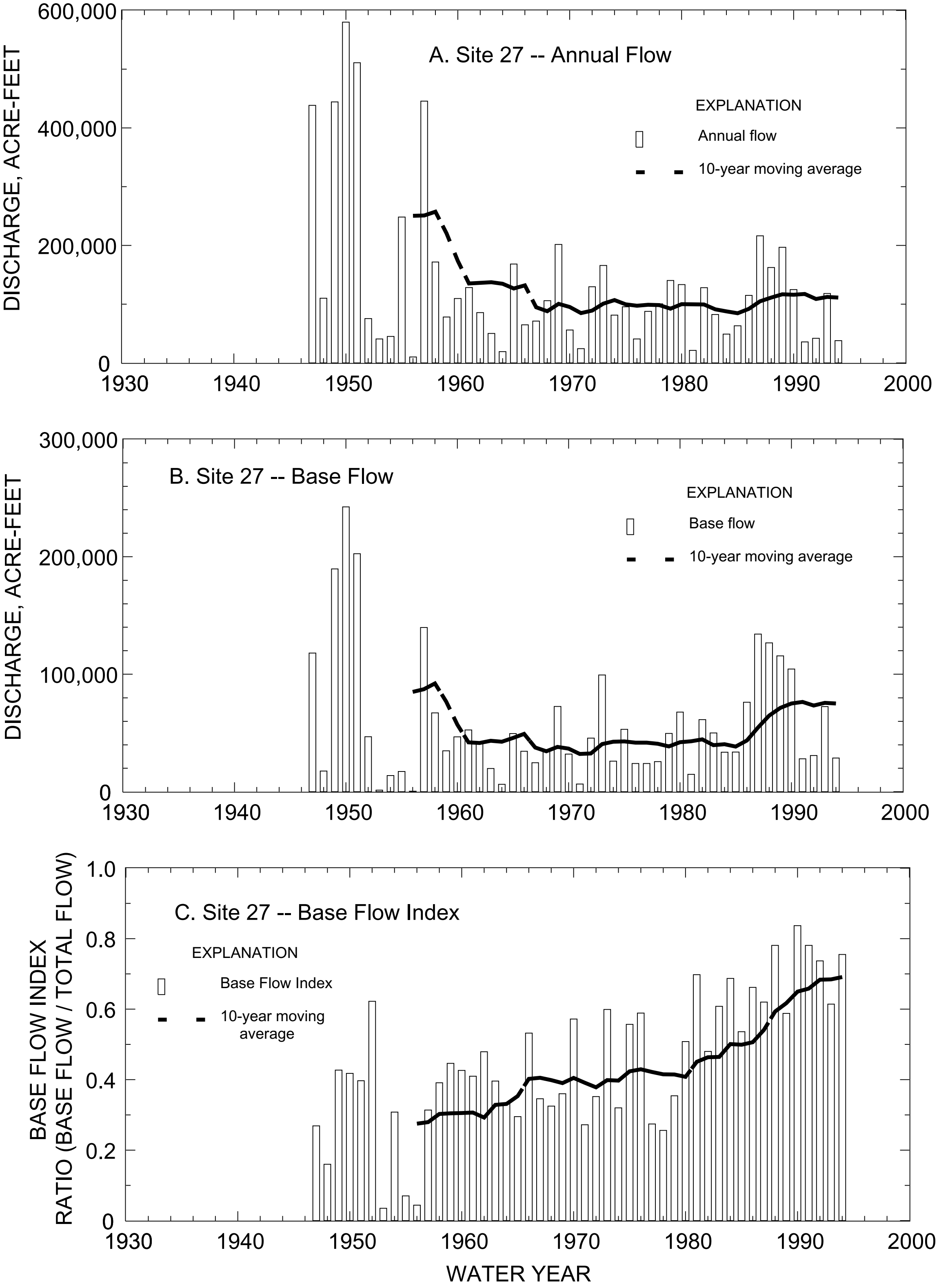

Figure 21. Histograms and 10-year moving averages for A) annual flow; B) base flow; and C) Base Flow Index, ratio of base flow volume to total annual flow volume; station 07238000, North Canadian River near Seiling, Oklahoma (site 27).

Table 3. Results of trend tests on annual streamflow volume

[Tau, Kendall's tau; P, probability level; ac-ft/yr, acre-feet per year; ac-ft, acre-feet; the shaded values are statistically significant at the 0.05 level]

Site number	Station number	Period of record (years)	Years of record	Period	Tau	P	Trend slope (ac-ft/yr)	Slope (percent of median)	Median (ac-ft)	Average (ac-ft)
1	07232250	1981-94	14	recent	-.16	.393	0	0	0	538
2	07232500	1938-93	56	all	-.58	.000	-418	-5.3	7891	13670
	07232500	1938-71	34	early	-.23	.062	-386	-2.9	13500	20190
	07232500	1978-93	16	recent	-.63	.001	-214	-54.6	392	1890
5	07232900	1981-94	14	recent	.04	.869	3.49	.5	643	1570
6	07233000	1940-64	25	early	-.21	.141	-179	-3.1	5841	11260
9	07233500	1946-79	34	all	-.13	.299	-124	-1.1	11340	13490
	07233500	1946-71	26	early	-.01	.965	-15.6	-.1	11750	15060
12	07234000	1938-94	57	all	-.49	.000	-1261	-4.3	29480	57500
	07234000	1938-71	34	early	-.21	.086	-1111	-1.9	57090	83200
	07234000	1978-94	17	recent	-.26	.149	-905	-8.1	11200	14420
14	07234100	1966-93	28	all	-.17	.213	-51.3	-2.0	2586	4740
	07234100	1978-93	16	recent	.05	.822	17.0	.9	1978	3946
17	07235000	1962-94	33	all	-.39	.002	-228	-4.9	4631	6147
	07235000	1962-71	10	early	-.02	1.000	-12.3	-.2	7641	10060
	07235000	1978-94	17	recent	-.12	.537	-50.4	-2.6	1964	3905
20	07236000	1943-76	34	all	-.37	.002	-1059	-3.3	32140	47260
	07236000	1943-71	29	early	-.31	.021	-1066	-3.0	35100	51270
23	07237000	1943-93	51	all	-.18	.069	-348	-1.3	26690	38450
	07237000	1943-71	29	early	-.33	.014	-1225	-4.4	27520	46730
	07237000	1978-93	16	recent	-.12	.558	-654	-2.3	28120	30140
24	07237500	1943-94	52	all	-.20	.035	-1110	-1.5	71910	111700
	07237500	1943-71	29	early	-.19	.160	-2337	-3.0	77320	145120
	07237500	1978-94	17	recent	-.12	.537	-1181	-1.7	70490	70810
27	07238000	1947-94	48	all	-.14	.163	-1210	-1.2	103200	138600
	07238000	1947-71	25	early	-.29	.042	-8408	-7.9	105900	171300
	07238000	1978-94	17	recent	-.12	.537	-1741	-1.5	115000	103900

between the early and recent periods was about 18,000 acre-feet and represented 91 percent of the average flow for the early period.

Changes in the discharge of the Beaver River through 1986 have been documented (Wahl and Wahl, 1988). The average annual discharge of the river near Guymon (site 2) reported in 1960 for 23 years of record (water years 1938-1960) was 23,300 acre-feet (U.S. Geological Survey, 1964). By 1993, the average discharge based on 56 years of record (water years 1938-1993) was only 13,670 acre-feet (Blazs and others, 1994). A 10-year moving average was relatively stable from about 1950 to about 1965, fluctuating within a range of about 18,000-22,000 acre-feet; by 1986, however, the average discharge for the past 10 years (water years 1977-1986), had decreased to about 5,000 acre-feet (fig. 11). By 1993, the 10-year moving average was only 500 acre-feet. The trend tests reveal declines in the annual volume of flow at most gaging stations in the basin.

Adjusted Annual Flow Volume

Changes in reservoir storage has a direct effect on annual flow amounts; an annual surplus of water stored in reservoirs upstream from a gage decreases the flow at the gage, and water released from storage increases the flow at the gage. The Guymon gage (site 2) is not affected by reservoirs; the other three mainstem gaging stations (sites 12, 24, and 27) are influenced by reservoirs. Storage began in Fort Supply Lake (fig. 1), located near the mouth of Wolf Creek, in 1942. Thus, the streamflow records for sites downstream reflect effects of operation of that reservoir. Optima Lake (fig. 1) on the Beaver River at the confluence of the Beaver River and Coldwater Creek was completed and began storing water in 1978; therefore, Optima Lake affects only the recent record. In addition, Palo Duro Reservoir (fig. 1) on Palo Duro Creek in Texas began storing water in 1991. Records of contents of Fort Supply Lake and Optima Lake are available through the 1993 water year and were used to adjust the annual flow records for sites downstream from the dams. Data were not available for Palo Duro Lake so no adjustments were made for storage changes in that lake. Only annual adjustments were made and only to reflect the changes in the reservoir contents; daily flow records were not adjusted. No adjustments were made for evaporation or for seepage from the reservoirs. The last year of record used in the adjusted record was 1993 because change-of-contents data for the lakes are not available for the 1994 water year.

The amount of annual change in storage in the upstream reservoirs is not large in relation to the annual flow totals. The medians of the adjusted and unadjusted annual total flows were approximately 2 percent for Beaver River at Beaver (site 12), Wolf Creek near Fort Supply (site 23), and North Canadian River near Seiling (site 27) and were approximately 9 percent at North Canadian River at Woodward (site 24). The range of annual percentage differences was -11.2 to +12.6 percent at Woodward and -14.2 to +8.3 percent near Seiling. Because the effects of changes in storage are slight, the adjusted annual flows were tested for trend, and the results are listed in table 4.

The trend tests results for the adjusted flows (table 4) are in general agreement with those for the unadjusted flows (table 3). Twelve periods were tested for four gaging stations; only one shows a positive trend, the recent period at Woodward (site 24), and that trend is not significant.

Separating the flow into the early and recent periods appear to have weakened the statistical significance of the trends. That occurs because a large part of the change occurred during the period 1972-1977. This can be seen by comparing the average values for the two periods. Those average flows have dropped considerably in the recent period. The recent-period averages of the annual flows adjusted for changes in reservoir storage changed from the early-period averages by the following amounts (table 4):

07234000	Beaver River at Beaver (site 12)	-68,000 acre-feet	-82 percent
07237500	North Canadian River at Woodward (site 24)	-72,000 acre-feet	-49 percent
07238000	North Canadian River near Seiling (site 27)	-63,000 acre-feet	-37 percent

The sources of the flow that ultimately passes the gaging station near Seiling (site 27) have changed over time. This is demonstrated by figure 22, which shows the adjusted annual flows at the principal upstream gages as a percentage of the flow near Seiling. Figure 22 shows the relative contributions to the adjusted annual flow near Seiling before about 1972 from the Beaver River at Beaver (site 12) and the North Canadian River at Woodward (site 24) averaged about 40 percent and 85 percent, respectively. Since 1972 those respective average contributions are about 10 percent and 65 percent. The reason for this shift may relate to changes in the proportions of flow derived from base flows and from floods.

Annual Base Flow Volume

Identifying base flow for locations downstream from reservoirs is problematic. Hydrograph separation methods recognize lack of variation in flow as an indication of base flow. Reservoir regulation, in some cases, can produce flow conditions that look very much like base flow. Thus, flow separation is usually not attempted on flow records that reflect regulation. In this case the flows affected by the reservoirs are small in comparison to the flows in the Beaver-North Canadian River at Beaver, Woodward, and near Seiling (sites 12, 24, and 27). Therefore, daily base flows were determined from the reported average daily discharges using the computer program BFI described earlier. Those estimated daily base flow discharges

Table 4. Results of trend tests on annual streamflow volume, adjusted for changes in storage

[Tau, Kendall's tau; P, probability level; ac-ft/yr, acre-feet per year; ac-ft, acre-feet; the shaded values are statistically significant at the 0.05 level]

Site number	Station number	Period of record (years)	Years 0f record	Period	Tau	P	Trend slope (ac-ft/yr)	Slope (percent of median)	Median (ac-ft)	Average (ac-ft)
12	07234000	1938-93	56	all	-.48	.000	-1278	-4.2	30230	58500
	07234000	1938-71	34	early	-.21	.086	-1111	-1.9	57090	83200
	07234000	1978-93	16	recent	-.28	.137	-936	-7.1	13190	15220
23	07237000	1943-93	51	all	-.17	.074	-364	-1.4	26140	38690
	07237000	1943-71	29	early	-.33	.014	-1338	-5.1	26140	47110
	07237000	1978-93	16	recent	-.07	.753	-534	-1.9	27780	30070
24	07237500	1943-93	51	all	-.17	.074	-1148	-1.5	78560	113700
	07237500	1943-71	29	early	-.20	.138	-2280	-2.8	82610	145500
	07237500	1978-93	16	recent	.03	.893	352	.5	74630	73810
27	07238000	1947-93	47	all	-.11	.263	-1110	-1.1	105500	140800
	07238000	1947-71	25	early	-.29	.047	-8843	-8.4	105500	171400
	07238000	1978-93	16	recent	-.03	.893	-761	-.7	116400	108000

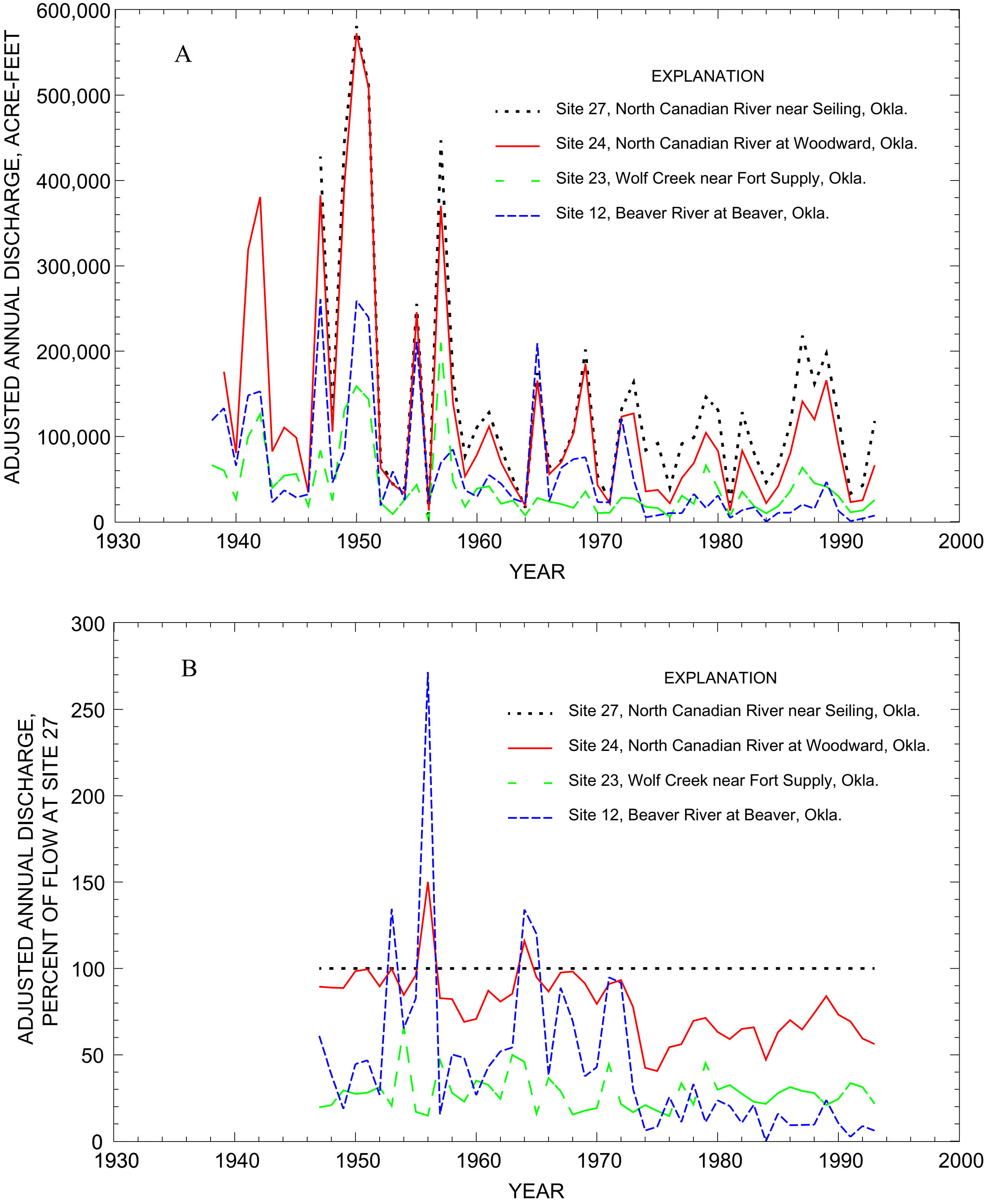

Figure 22. Adjusted annual total flow A) in acre-feet for sites 12, 23, 24, and 27; and B) for sites 12, 23, and 24 as a percentage of the flow at site 27.

were used to determine the annual base flow volumes that are shown in figures 10-21. These data also were tested for trend, and the results are listed in table 5.

Unlike the annual volume, the base flows show some increases and some decreases. Both the entire period of record and recent period show strong and statistically significant decreases at Beaver River near Guymon (site 2), confirming the results obtained earlier by Wahl and Wahl (1988). Similarly, the trend over the entire period of record at the Beaver gage (site 12) shows a significant decline. No other trends were significant.

Comparing the medians and averages for the various periods gives some insight into the changes that have occurred (table 5). At the Guymon and Beaver gages (site 2 and 12), both the medians and the averages for the recent period are much less than for the early period. The average base flow near Guymon for 1978-1993 is only 10 percent of that for the early period; the average base flow at Beaver for the recent period is only 34 percent of that for the early period. And those results may understate the decline; when the gage near Guymon was discontinued in 1993, there was no base flow passing the gage.

The average base flows at Woodward (site 24) and near Seiling (site 27) show little change between the early and recent period, but the median annual base flows have increased by about 45 percent in the recent period (table 5). This suggests a shift in the distribution of annual flows. Less contribution is coming from large floods that formerly contributed substantially to the yearly average flows. Figures 20 and 21 show that as the moving averages for annual base flows at Woodward and near Seiling appear to have increased more in recent higher flow years (1986-1990) than did those for the total annual flows.

Base-Flow Index

The ratio of base flow to total flow is called the base-flow index. The base-flow index shows the proportion of flow that is derived from base flow. Changes in this index reflect changes in the relative contributions to total flow. The base-flow index was calculated for each gaging station and is presented in figures 10-21 along with the annual flow and base flow.

The base-flow index was tested for trend, and the results are listed in table 6. Trend tests in any ratio must be interpreted with caution. Because this ratio measures the relative contribution of base flow to total flow, changes in the ratio can only be interpreted as representing differing rates of change in the components. This ratio can increase while both the numerator and denominator are decreasing if the numerator decreases at a slower rate than the denominator. Conversely, a decrease in a ratio can occur while both components are increasing if the numerator increases at a slower rate than the denominator. Thus, the results of the trend tests must be examined with the results for total flow and base flow.

The results presented in table 6 confirm that the relative contributions to the total annual volume are changing. Of 27 time periods tested, 16 show statistically significant changes in the base-flow index; all 16 trends are for an increase in the ratio. Only one of the 27 periods tested showed a negative trend, and that was for the recent period at the Guymon gage where, as noted in an earlier section, base flow has ceased. The general increase in this ratio means that the proportion of the total flow that comes from base flow is increasing relative to the other contribution to total flow - runoff from floods. It should not be interpreted to mean that there has been an increase in the total volume of base flow.

The increases in this ratio are most pronounced at the more downstream gages in the basin. These trends also are evident in the histograms and moving averages shown in figures 10-21. Further insight into the changes in the relative contributions can be gained from the flow-duration curves and hydrographs presented in a later section.

Peak Discharges

Peak flows downstream from the reservoirs are clearly influenced by the storage behind the dams. The Guymon gage (site 2) is not affected by reservoirs; the other three mainstem gaging stations (sites 12, 24, and 27) are influenced by reservoirs. However, the degree of effect has been minimized by limiting the lengths of the periods of data used in the trend tests. Wolf Creek and Fort Supply Lake (fig. 1) represent a relatively small part of the total drainage area at Woodward and near Seiling (sites 24 and 27), and the effect of the reservoir has been present since 1942. Unless operation of the reservoir has changed, the effect is a constant in the records examined. Optima Lake (fig. 1) controls a large portion of the basin, but has had a limited effect on streamflows downstream as demonstrated by the fact that since storage began in 1978, the maximum contents of Optima have been only 5 percent of capacity. By limiting the recent period to that beginning in 1978, the effects of Optima Lake are a constant for the period. That effect, however, could still be a factor in comparing the early and recent periods to each other.

Histograms of annual peak discharges and the superimposed 10-year moving averages are shown in figures 23-42; sites 1, 4, 11, 16, and 19 (figs. 23, 26, 29, 34, and 36), which have less than 15 years of record and the 10-year moving averages are not shown. The results of trend tests on the annual peak discharges are shown in table 7. Because of the large variability in annual peak discharges in this region, trends are sometimes difficult to visualize. However, the moving averages for most of the gaging stations shown in figures 24, 25, 27, 28, 30-33, 35, and 37-42 clearly show a decline. The only question is one of timing and whether that decline is statistically significant.

The trend tests results (table 7) on 35 time periods at 20 gaging stations show that 7 tests show positive changes, but none of those were statistically significant trends; also, 4 of those 7 are for records that were discontinued by the mid-1970's. There were 8 sites (and 13 time periods) that had statistically significant declines. The period “all” (table 7) for main-

Table 5. Results of trend tests on annual base flow volume

[Tau, Kendall's tau; P, probability level; ac-ft/yr, acre-feet per year; ac-ft, acre-feet; the shaded values are statistically significant at the 0.05 level.]

Site number	Station number	Period of record (years)	Years of record	Period	Tau	P	Trend slope (ac-ft/yr)	Slope (percent of median)	Median (ac-ft)	Average (ac-ft)
1	07232250	1981-94	14	recent	.00	1.000	0	0	0	0
2	07232500	1938-93	56	all	-.49	.000	-59.4	-2.9	2025	1878
	07232500	1938-71	34	early	.14	.260	12.2	.5	2652	2658
	07232500	1978-93	16	recent	-.60	.001	-44.6	-57.9	77.0	256
5	07232900	1981-94	14	recent	.00	1.000	0	0	0	0
6	07233000	1940-64	25	early	.09	.559	12.6	1.0	1259	1567
17	07233500	1946-79	34	all	.05	.678	3.09	.9	330	575
	07233500	1946-71	26	early	.13	.378	5.33	1.8	302	551
12	07234000	1938-94	57	all	-.26	.004	-95.8	-2.0	4711	6668
	07234000	1938-71	34	early	.02	.882	4.69	0.1	6966	8700
	07234000	1978-94	17	recent	.06	.773	34.4	1.5	2227	2919
14	07234100	1966-93	28	all	-.03	.828	-4.11	-.3	1292	1414
	07234100	1978-93	16	recent	.22	.260	9.93	.8	1239	1355
17	07235000	1962-94	33	all	-.14	.245	-24.5	-1.2	1971	1996
	07235000	1962-71	10	early	.42	.107	124	5.8	2159	2347
	07235000	1978-94	17	recent	.06	.773	21.1	1.9	1126	1774
20	07236000	1943-76	34	all	-.09	.441	-109	-.7	16150	18550
	07236000	1943-71	29	early	-.10	.464	-188	-1.2	16040	18910
23	07237000	1943-93	51	all	.19	.056	106	1.6	6492	10480
	07237000	1943-71	29	early	.05	.722	20.4	.3	6194	9828
	07237000	1978-93	16	recent	.27	.163	572	5.8	9932	12210
24	07237500	1943-94	52	all	.05	.619	122	.4	28020	41500
	07237500	1943-71	29	early	-.09	.512	-417	-1.5	27840	43690
	07237500	1978-94	17	recent	.12	.537	864	2.1	40570	43300
27	07238000	1947-94	48	all	.06	.564	243	.6	43350	59160
	07238000	1947-71	25	early	-.21	.141	-2092	-6.0	34800	60530
	07238000	1978-94	17	recent	.12	.537	1035	2.1	50020	62010

Table 6. Results of trend tests on base flow index, annual ratio of base flow to total flow

[Tau, Kendall's tau; P, probability level; BFI, base flow index; the shaded values are statistically significant at the 0.05 level]

Site number	Station number	Period of record (years)	Years of record	Period	Tau	P	Trend Slope	Slope (percent of median)	Median BFI	Average BFI
1	07232250	1981-94	14	recent	.00	1.000	0	0	0	0
2	07232500	1938-93	56	all	.01	.944	0	0.1	.21	.22
	07232500	1938-71	34	early	.29	.015	.007	3.0	.22	.23
	07232500	1978-93	16	recent	-.20	.296	-.006	-5.2	.12	.18
5	07232900	1981-94	14	recent	.00	1.000	0	0	0	0
6	07233000	1940-64	25	early	.37	.010	.010	3.6	.26	.24
9	07233500	1946-79	34	all	.16	.177	.008	1.7	.05	.06
	07233500	1946-71	26	early	.15	.290	.007	1.5	.05	.05
12	07234000	1938-94	57	all	.30	.001	.003	2.3	.12	.17
	07234000	1938-71	34	early	.25	.038	.002	2.1	.11	.13
	07234000	1978-94	17	recent	.38	.036	.017	9.0	.19	.23
14	07234100	1966-93	28	all	.25	.060	.013	2.2	.59	.53
	07234100	1978-93	16	recent	.13	.500	.016	2.4	.66	.58
17	07235000	1962-94	33	all	.46	.000	.014	3.5	.40	.45
	07235000	1962-71	10	early	.20	.474	.018	6.4	.28	.31
	07235000	1978-94	17	recent	.37	.044	.030	5.4	.56	.56
20	07236000	1943-76	34	all	.51	.000	.014	2.6	.53	.51
	07236000	1943-71	29	early	.41	.002	.013	2.8	.47	.47
23	07237000	1943-93	51	all	.44	.000	.008	2.4	.31	.34
	07237000	1943-71	29	early	.42	.002	.009	3.0	.30	.26
	07237000	1978-93	16	recent	.60	.001	.032	6.7	.47	.45
24	07237500	1943-94	52	all	.56	.000	.011	2.8	.38	.42
	07237500	1943-71	29	early	.22	.099	.004	1.4	.30	.31
	07237500	1978-94	17	recent	.63	.000	.025	3.9	.64	.63
27	07238000	1947-94	48	all	.48	.000	.010	2.3	.43	.46
	07238000	1947-71	25	early	.11	.469	.003	.9	.36	.35
	07238000	1978-94	17	recent	.51	.005	.023	3.8	.62	.62

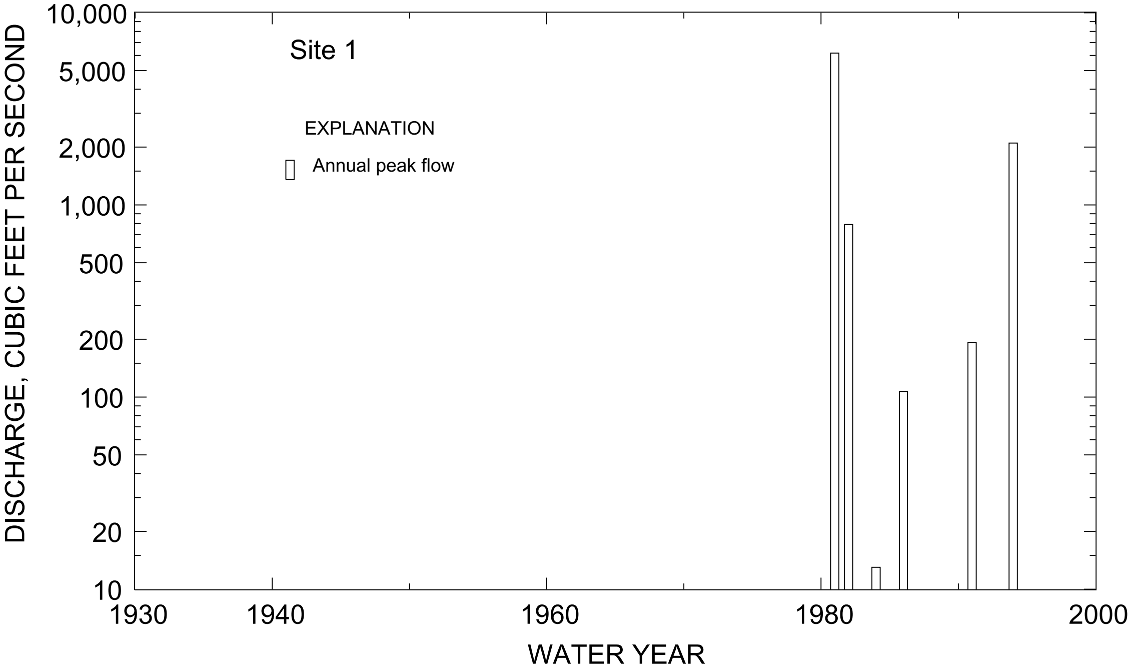

Figure 23. Histograms for instantaneous annual peak discharge for station 07232250, Beaver River near Felt, Oklahoma (site 1).

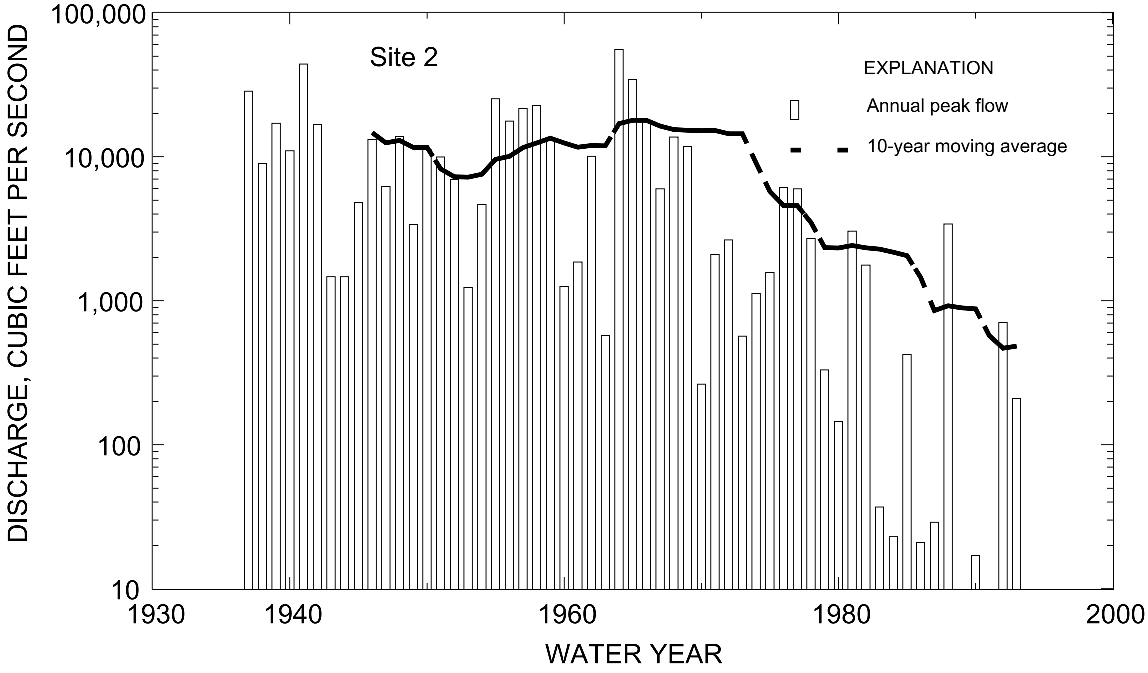

Figure 24. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07232500, Beaver River near Guymon, Oklahoma (site 2).

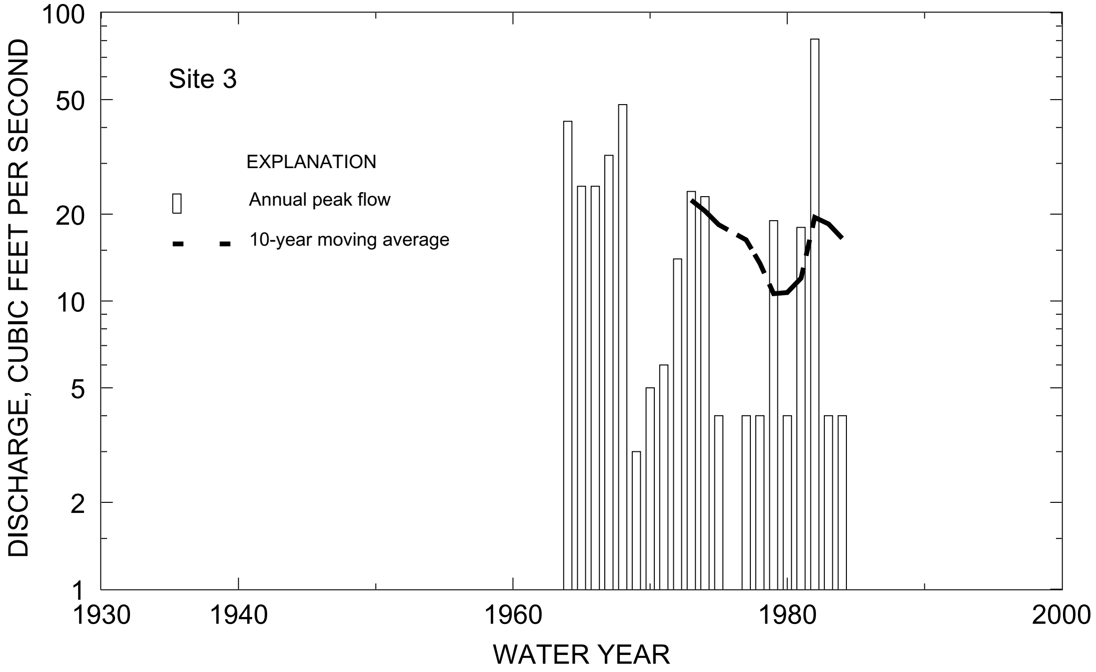

Figure 25. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07232550, South Fork Tributary near Guymon, Oklahoma (site 3).

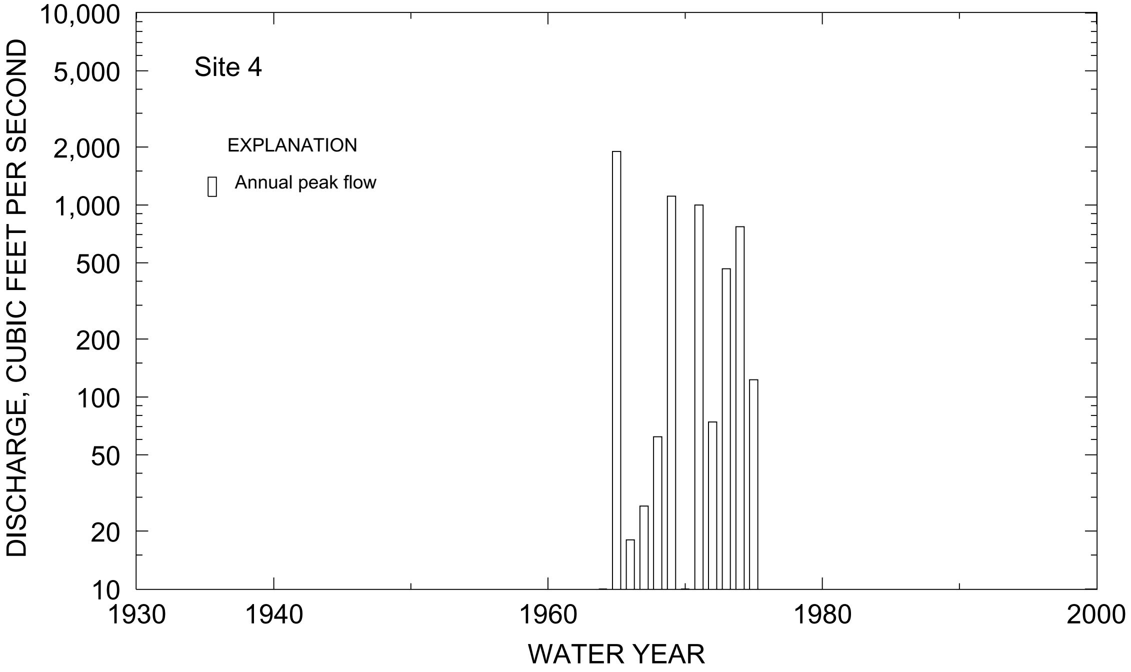

Figure 26. Histograms for instantaneous annual peak discharge for station 07232650, Aqua Frio Creek near Felt, Oklahoma (site 4).

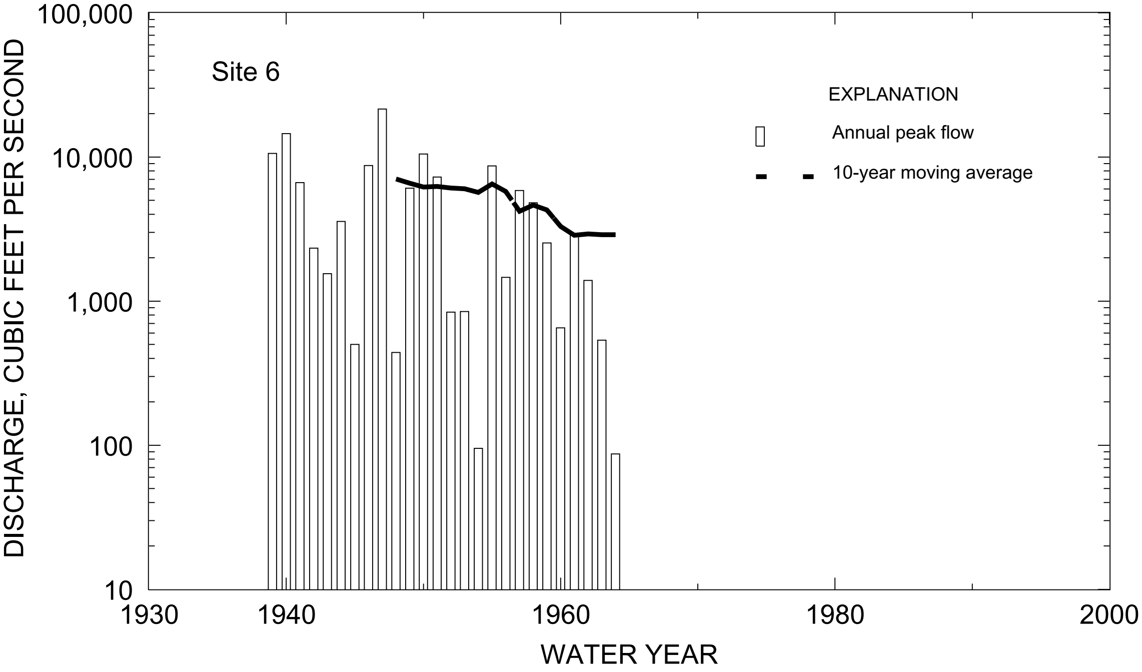

Figure 27. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07233000, Coldwater Creek near Hardesty, Oklahoma (site 6).

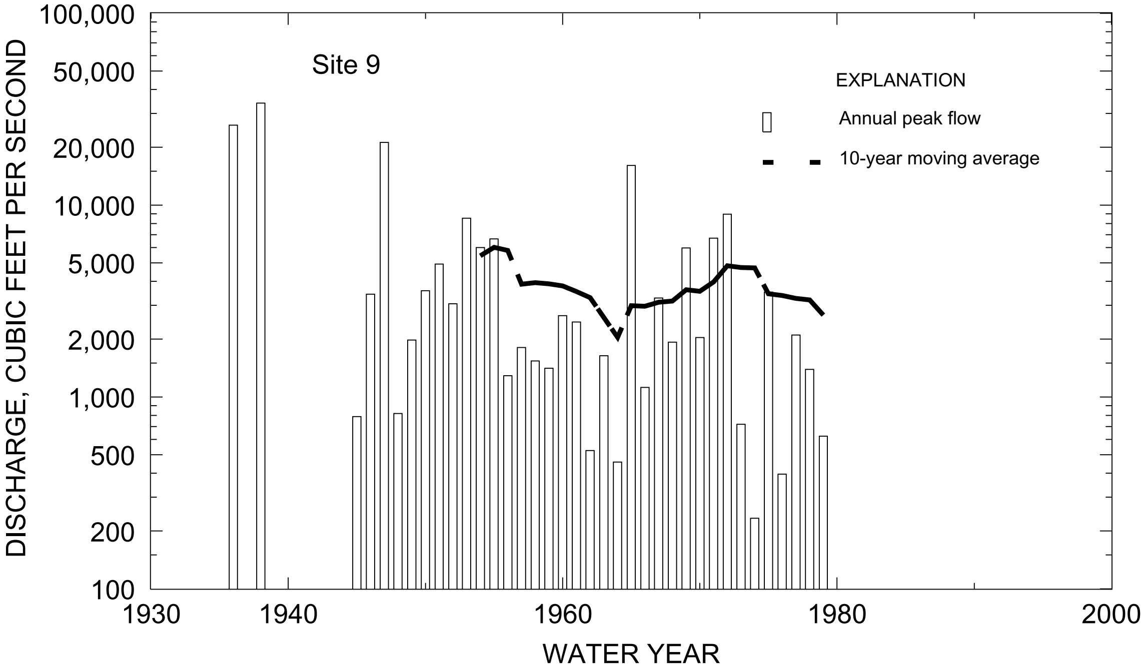

Figure 28. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07233500, Palo Duro Creek near Spearman, Texas (site 9).

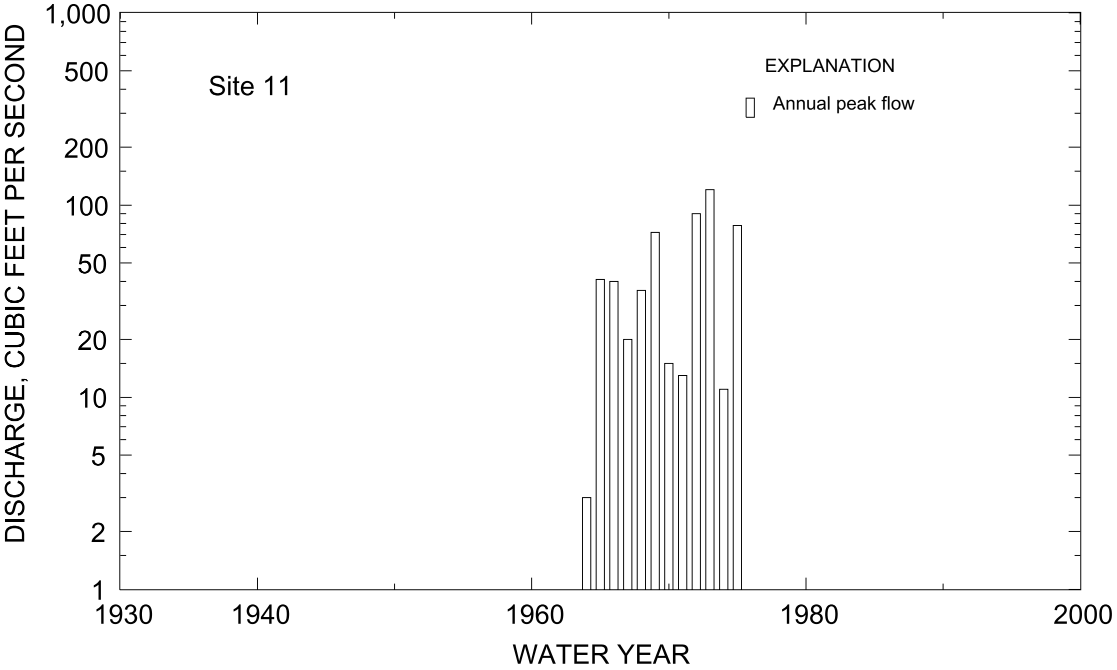

Figure 29. Histograms for instantaneous annual peak discharge for station 07233850, Sharp Creek Tributary near Turpin, Oklahoma (site 11).

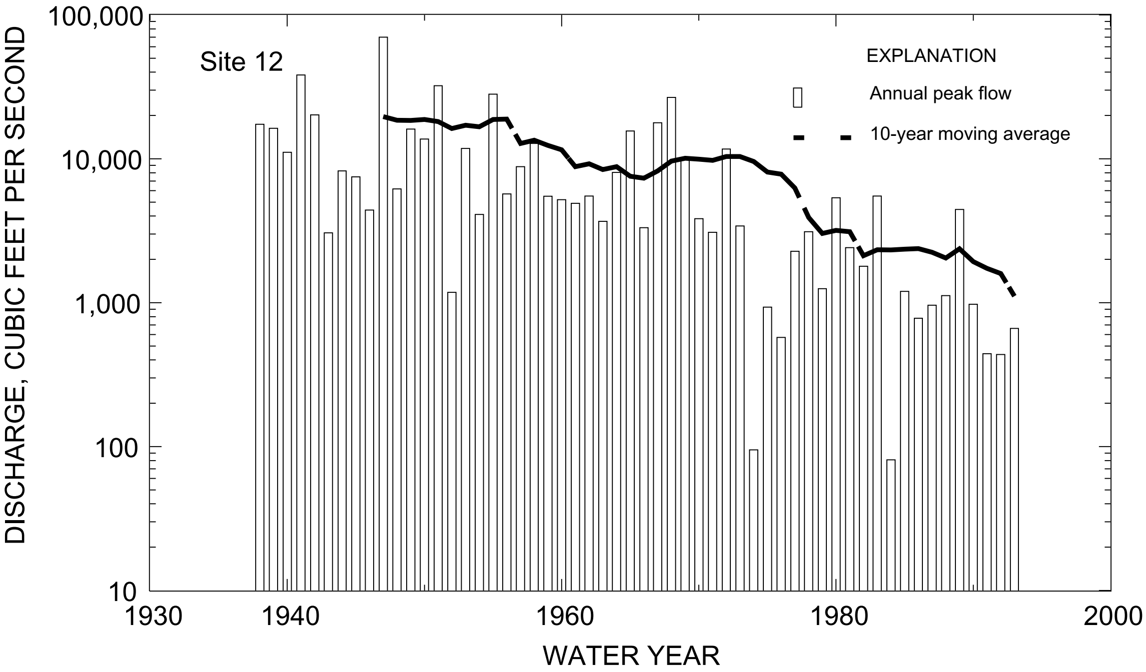

Figure 30. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07234000, Beaver River at Beaver, Oklahoma (site 12).

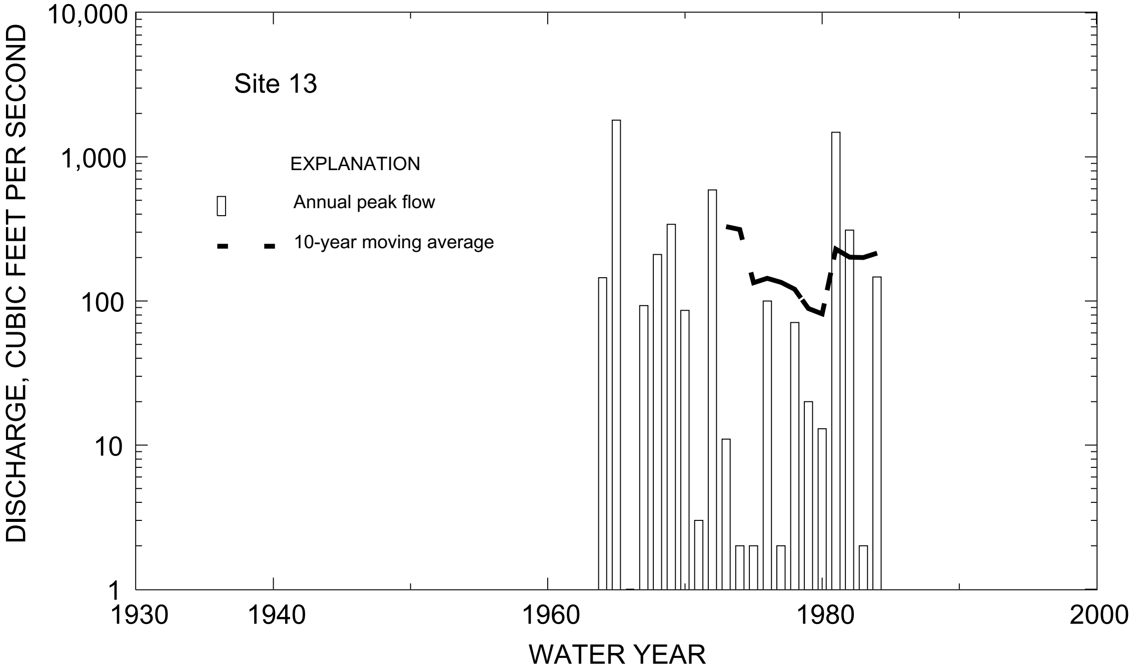

Figure 31. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07234050, North Fork Clear Creek Tributary near Balko, Oklahoma (site 13).

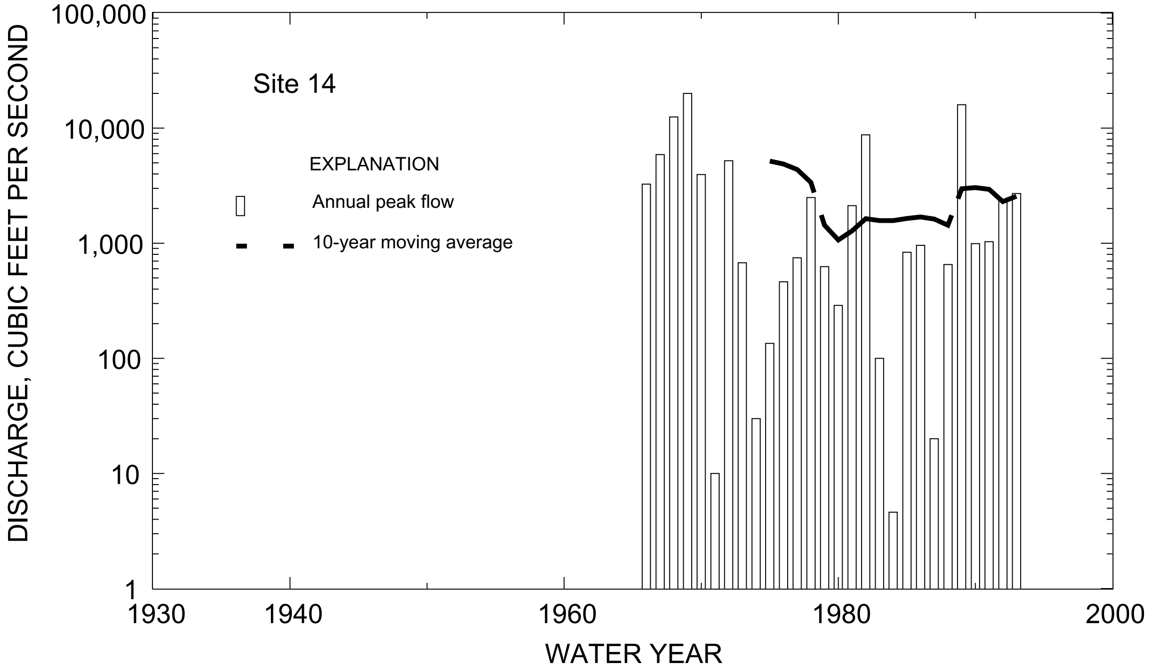

Figure 32. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07234100, Clear Creek near Elmwood, Oklahoma (site 14).

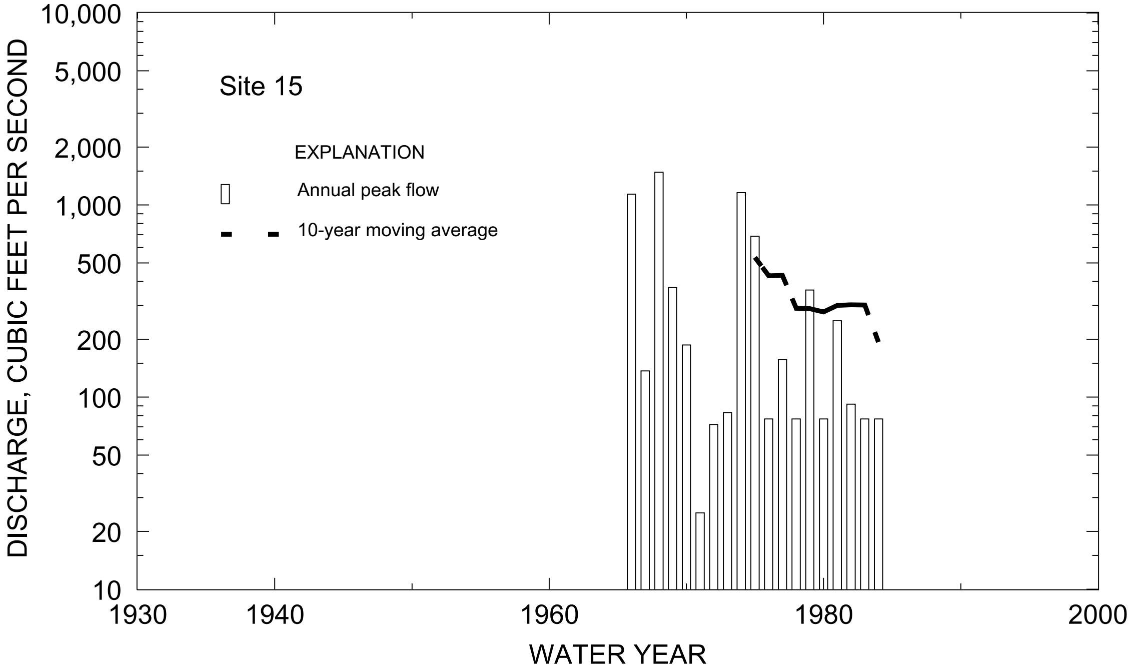

Figure 33. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07234290, Clear Creek Tributary near Catesby, Oklahoma (site 15).

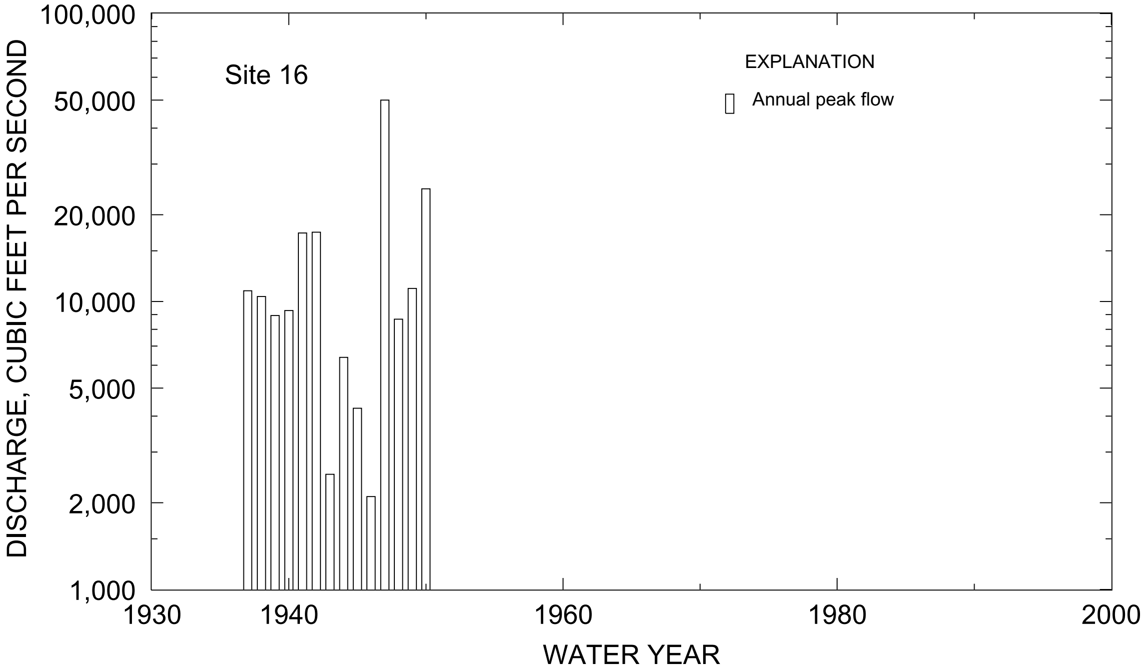

Figure 34. Histograms for instantaneous annual peak discharge for station 07234500, Beaver River near Fort Supply, Oklahoma (site 16).

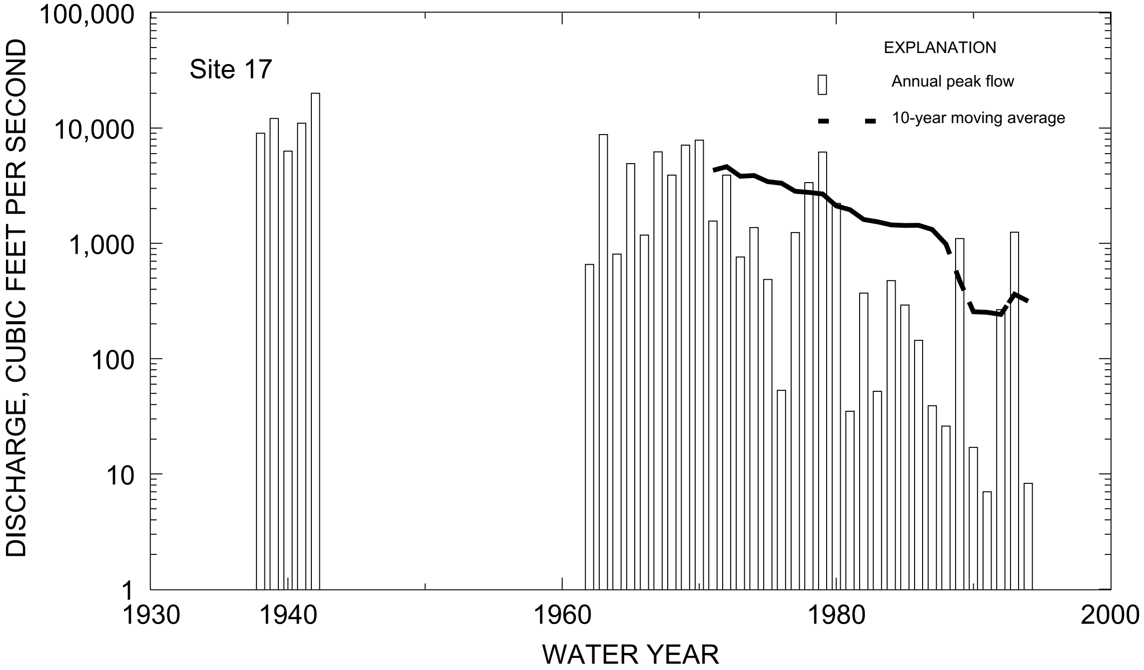

Figure 35. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07235000, Wolf Creek near Lipscomb, Texas (site 17).

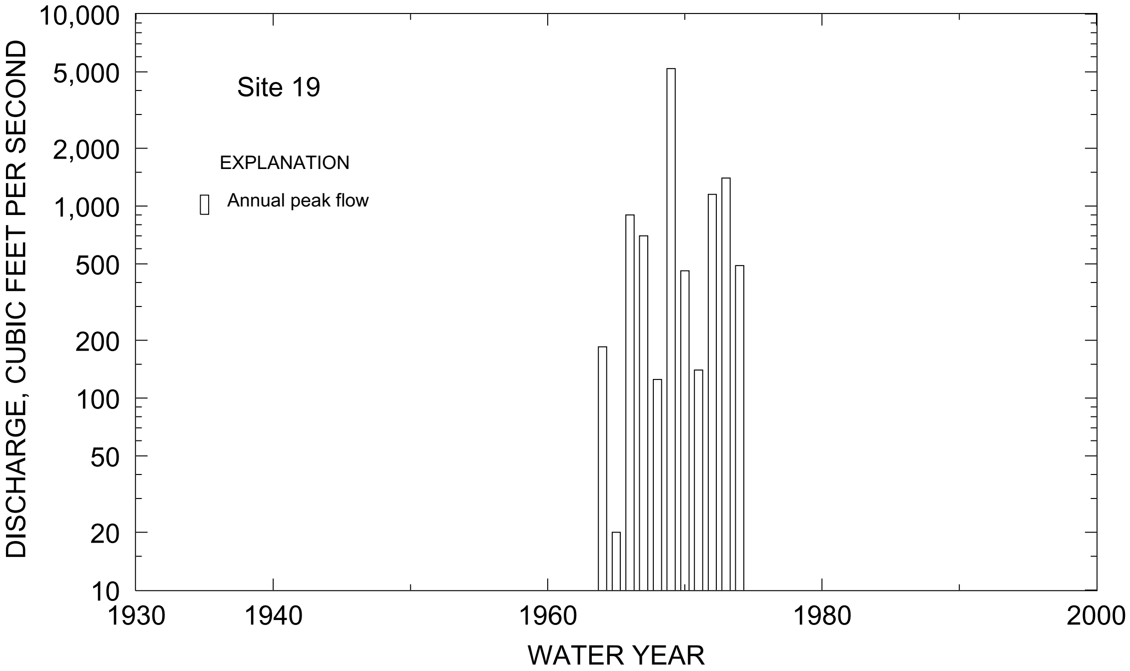

Figure 36. Histograms for instantaneous annual peak discharge for station 07235700, Little Wolf Creek Tributary near Gage, Oklahoma (site 19).

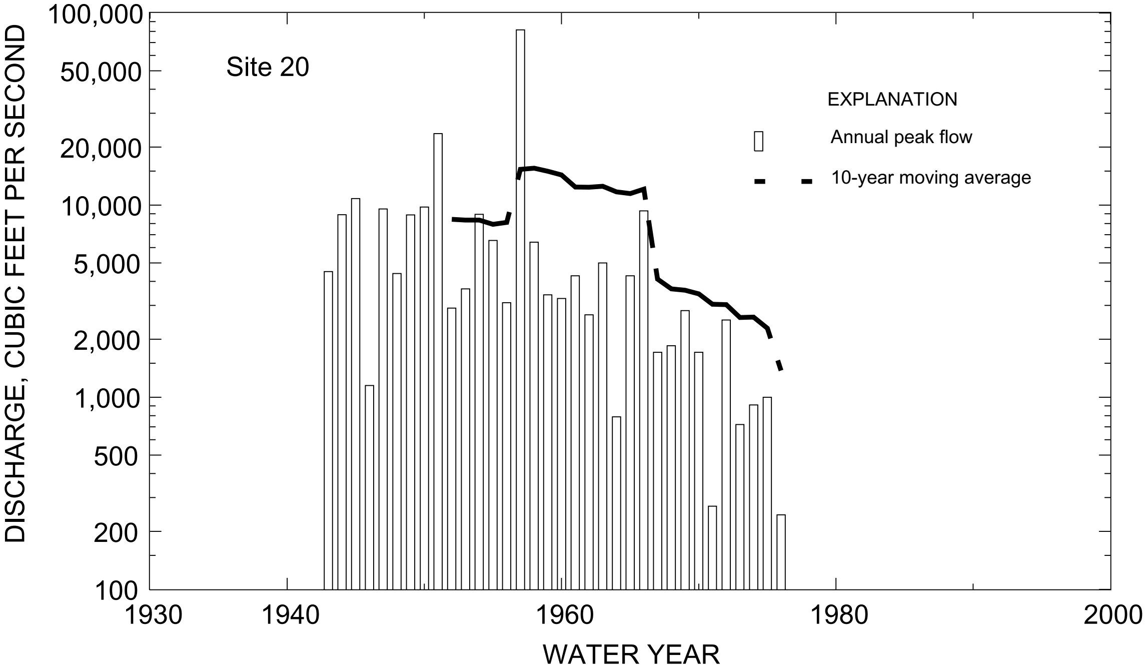

Figure 37. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07236000, Wolf Creek near Fargo, Oklahoma (site 20).

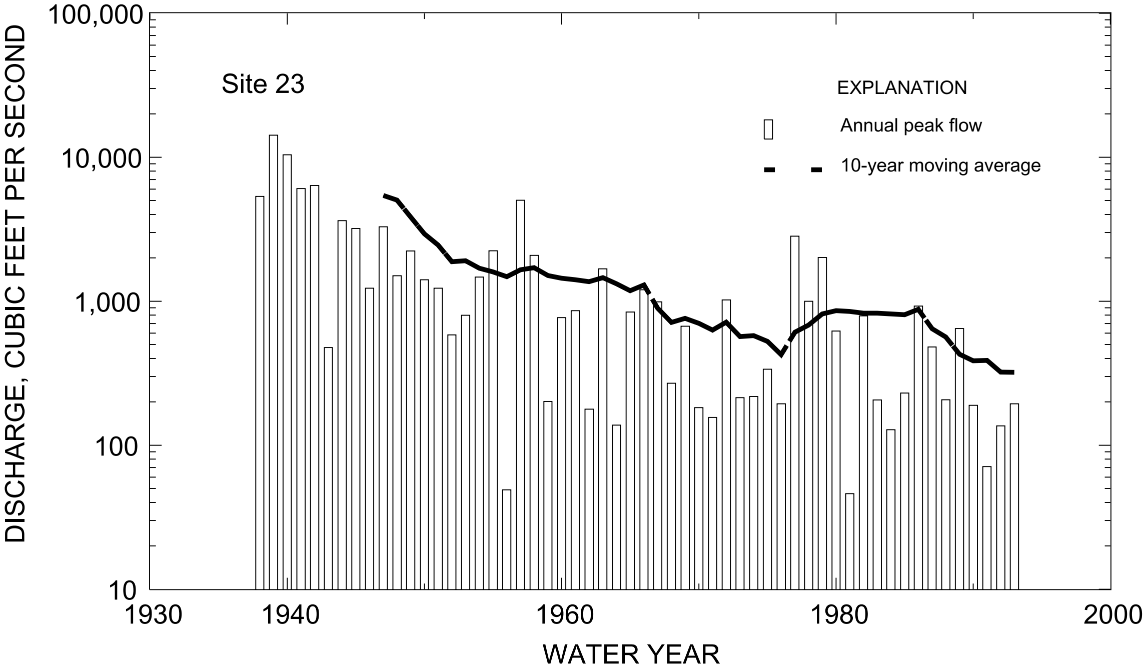

Figure 38. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07237000, Wolf Creek near Fort Supply, Oklahoma (site 23).

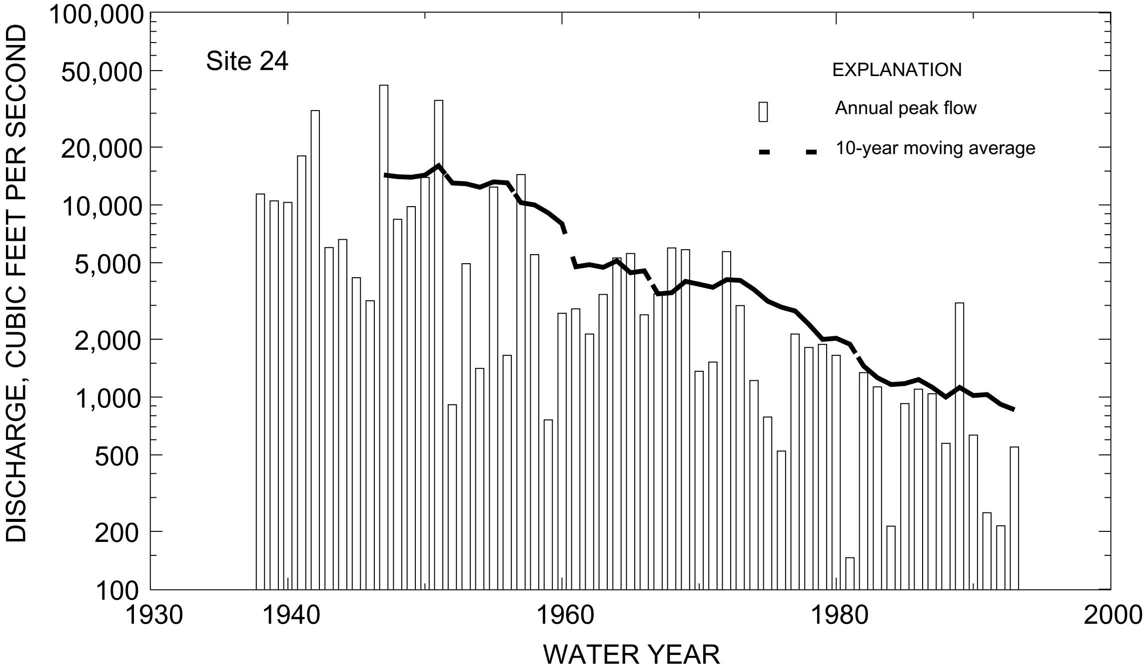

Figure 39. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07237500, North Canadian River at Woodward, Oklahoma (site 24).

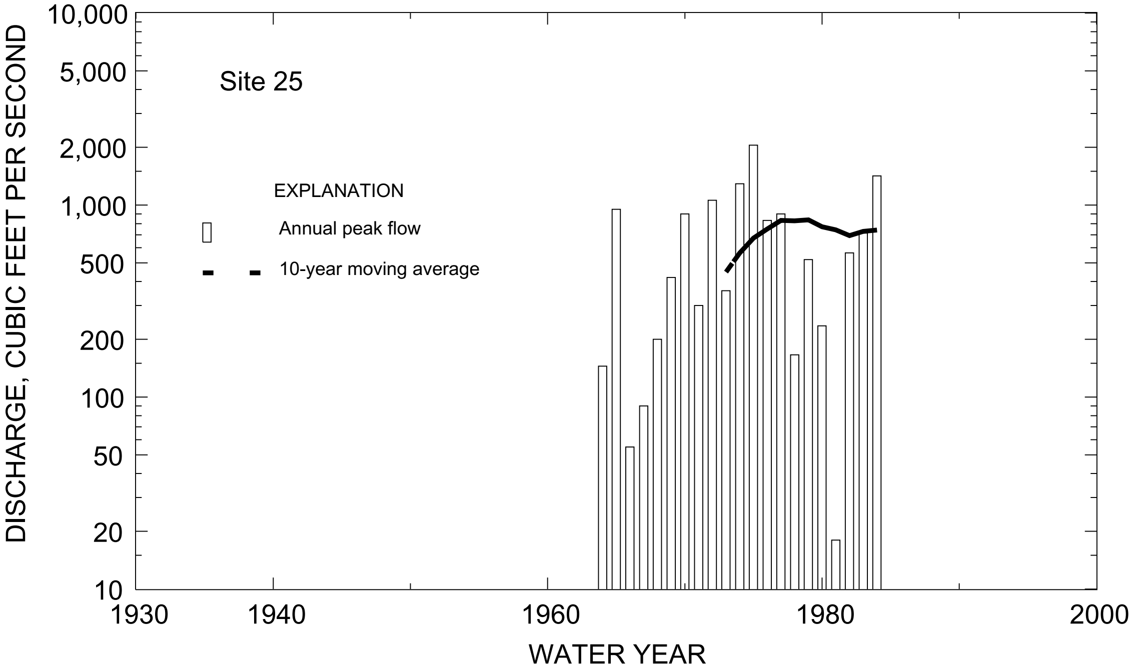

Figure 40. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07237750, Cottonwood Creek near Vici, Oklahoma (site 25).

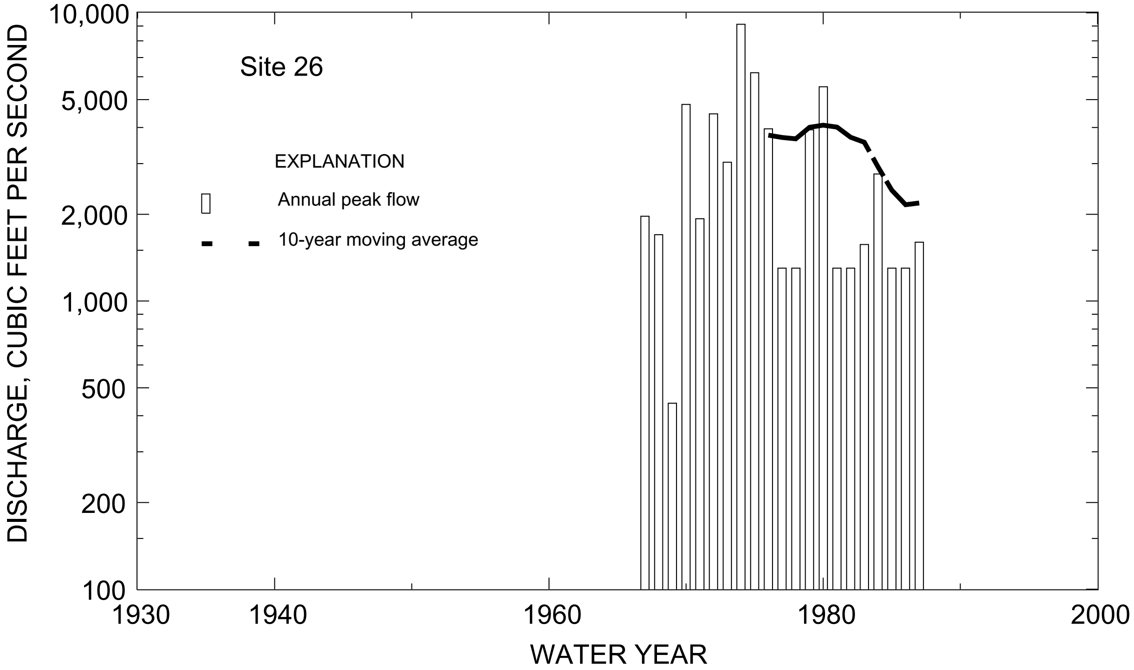

Figure 41. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07237800, Bent Creek near Seiling, Oklahoma (site 26).

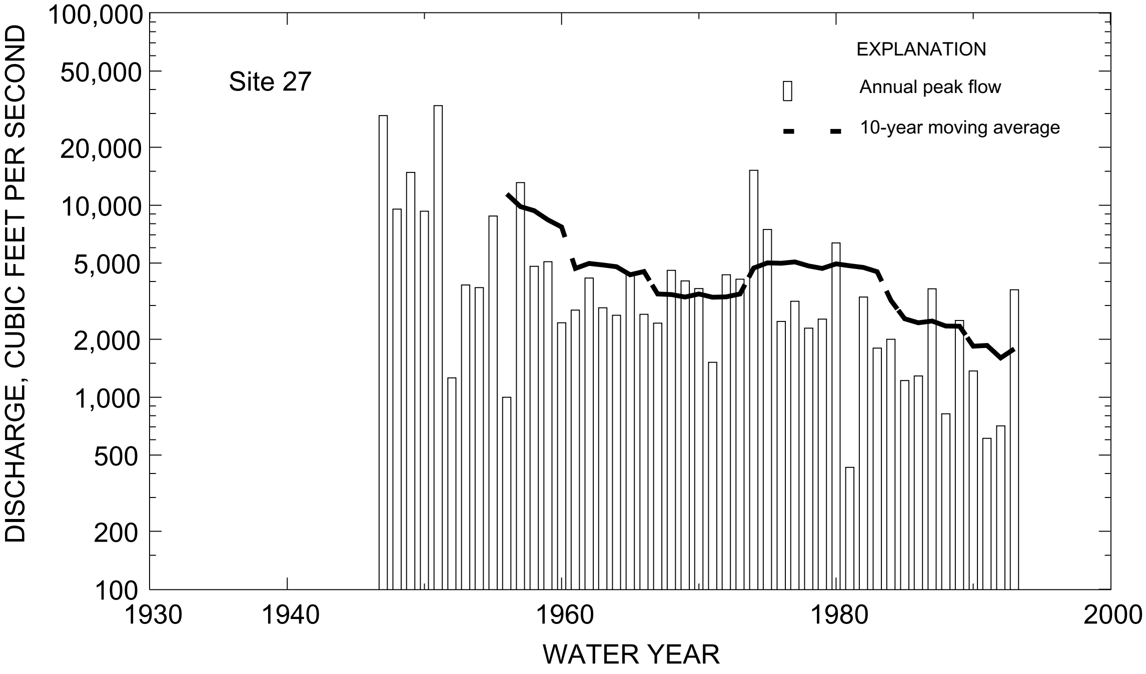

Figure 42. Histograms and 10-year moving averages for instantaneous annual peak discharge for station 07238000, North Canadian River near Seiling, Oklahoma (site 27).

Table 7. Results of trend tests on annual peak discharge

[Tau, Kendall’s tau; P, probability level; ft^3/s, cubic feet per second; the shaded values are statistically significant at the 0.05 level]

Site number	Station number	Period of record (years)	Years of record	Period	Tau	P	Trend slope (ft^3/s)	Slope (percent of median)	Median (ft^3/s)
1	07232250	1981-94	14	recent	-.16	.393	0	0	0
2	07232500	1937-93	57	all	-.48	.000	-220	-6.5	3410
	07232500	1937-71	35	early	-.08	.504	-104	-.9	11000
	07232500	1978-93	16	recent	-.33	.079	-14.6	-8.2	178
3	07232550	1964-84	21	all	-.31	.060	-0.6	-3.8	16
4	07232650	1964-75	12	all	.23	.336	+9.4	9.5	98.5
6	07233000	1939-64	26	early	-.35	.012	-269	-9.9	2715
9	07233500	1945-79	35	all	-.16	.173	-50.6	-2.5	2040
	07233500	1945-71	27	early	-.02	.900	-15.5	-.6	2460
11	07233850	1964-75	12	all	.18	.451	+4.9	13.0	38.0
12	07234000	1938-93	56	all	-.53	.000	-209	-4.1	5050
	07234000	1938-71	34	early	-.23	.054	-208	-2.5	8525
	07234000	1978-93	16	recent	-.45	.017	-128	-11.0	1160
13	07234050	1964-84	21	all	-.09	.606	-1.9	-2.3	86
14	07234100	1966-93	28	all	-.06	.678	-20.4	-2.1	976
	07234100	1978-93	16	recent	.22	.260	46.5	4.8	976
15	07234290	1966-84	19	all	-.26	.120	-9.0	-6.6	137
16	07234500	1937-50	14	early	.03	.913	+63.6	.6	9850
17	07235000	1962-94	33	all	-.51	.000	-84.0	-10.4	808
	07235000	1962-71	10	early	.29	.283	450	10.2	4405
	07235000	1978-94	17	recent	-.43	.019	-45.4	-17.1	266
19	07235700	1964-73	11	all	.27	.276	+52.2	10.7	490
20	07236000	1942-76	34	all	-.51	.000	-228	-6.4	3535
	07236000	1942-71	29	early	-.39	.003	-221	-5.2	4280
23	07237000	1943-93	51	all	-.39	.000	-26.3	-3.9	669
	07237000	1943-71	29	early	-.38	.004	-61.1	-6.2	989
	07237000	1978-93	16	recent	-.35	.065	-44.2	-20.2	218
24	07237500	1943-93	51	all	-.53	.000	-121	-5.7	2130
	07237500	1943-71	29	early	-.22	.095	-141	-2.9	4940
	07237500	1978-93	16	recent	-.40	.034	-93.3	-9.5	982
25	07237750	1964-84	21	all	.20	.227	+24.9	4.8	520

Table 7. Results of trend tests on annual peak discharge—Continued

[Tau, Kendall's tau; P, probability level; ft^3/s, cubic feet per second; the shaded values are statistically significant at the 0.05 level]

Site number	Station number	Period of record (years)	Years of record	Period	Tau	P	Trend slope (ft^3/s)	Slope (percent of median)	Median (ft^3/s)
26	07237800	1967-87	21	all	-.19	.245	-30.4	-1.6	1930
	07237800	1978-87	10	recent	-.07	.848	0	0	1435
27	07238000	1947-93	47	all	-.43	.000	-118	-3.5	3320
	07238000	1947-71	25	early	-.39	.006	-288	-7.1	4030
	07238000	1978-93	16	recent	-.20	.300	-106	-5.6	1900

stem stations (sites 2, 12, 24, and 27) were among those confirmed decreases in annual peak discharge. It appears the decreases in annual peak discharges are greater than can be explained by storage in the reservoirs. The medians of the annual peak discharges decreased from the early period to the recent period by the following amounts: near Guymon (-98 percent), at Beaver (-86 percent), at Woodward (-80 percent), and near Seiling (-53 percent).

The link between declines in ground-water levels and annual flow volume is easy to understand, but the relation between ground-water levels and annual peak discharges is not so clear. Wahl and Wahl (1988) noted that the possible effect of a dry channel on attenuation of peak discharges cannot be discounted. Durbin and Hardt (1974) reported that during a controlled release of 3,100 acre-feet over 20 hours into the dry Mojave River channel in California, none of the flow passed a point 16 river miles downstream; the channel width averaged 200 to 300 feet with a sandy stream-bed. Through much of the panhandle, the streambed of the Beaver River is more than 200 feet wide and is sandy. That channel bed is now dry most of the time as shown by data collected at the gages near Felt and Guymon. Infiltration losses into this dry, sandy streambed, combined with channel storage, might be responsible for a substantial proportion of the decrease in peak discharge. Changes in farming and conservation practices also may have an effect on the magnitudes of annual peak discharges, including the significant increase of farm ponds in the basin.

Flow-Duration Relations and Daily-Duration Hydrograph Analyses

Flow-duration relations represent the cumulative frequency distribution of the daily mean flows. Duration curves for different periods provide a convenient means of comparing discharges over the entire range of flows. Because a duration curve represents the cumulative frequency distribution of daily mean flows, the curve discloses no information about the specific sequence of flows. For example, a duration curve will show that a specified flow has only been exceeded 1 percent of the time, but will not show whether that 1 percent represents one continuous period in a certain year or periods of only one or two days in many years. Daily-duration hydrographs provide an alternative way of examining changes in the streamflow patterns. In preparing a daily-duration hydrograph, each day of the year is subjected to an individual flow-duration analysis. The result is a frequency distribution for discharges for each day of the year. A hydrograph can then be plotted of flows of a specified frequency. The daily-duration hydrographs depict the median flow for each day of the year in this study. This alternative portrayal gives a sense of the annual distribution of daily mean discharges.

Conventional flow duration curves (figs. 43-46) and daily-duration hydrographs of the median daily flows (figs. 47-50) are presented for the mainstem Beaver-North Canadian River gaging stations (sites 2, 12, 24, and 27). These duration relations were defined both for the early period ending with the 1971 water year and for a recent period, 1978-1993 water years (post-Optima Lake).

The duration analyses agree with the results of the Kendall's tau tests for the mainstem sites. There are large and obvious differences in the frequency distributions of flows for the Beaver River near Guymon (site 2) and Beaver River at Beaver (site 12). The period 1978-1993 has been one of substantially reduced flows as compared to the period before 1972. Those differences cover the entire range of flows (figs. 43-44) and persist throughout the year (figs. 47-48).

The flow-duration data used to plot the curves show that flows of all frequencies at the Beaver River gages (near Guymon, site 2; and at Beaver, site 12) have been smaller during the recent period than during the early period. There has been no flow near Guymon for more than 60 percent of the recent period; during the early period, the river was dry only about 10 percent of the time. At Beaver, the lowest flows still occur with about the same frequency as during the early period. However,

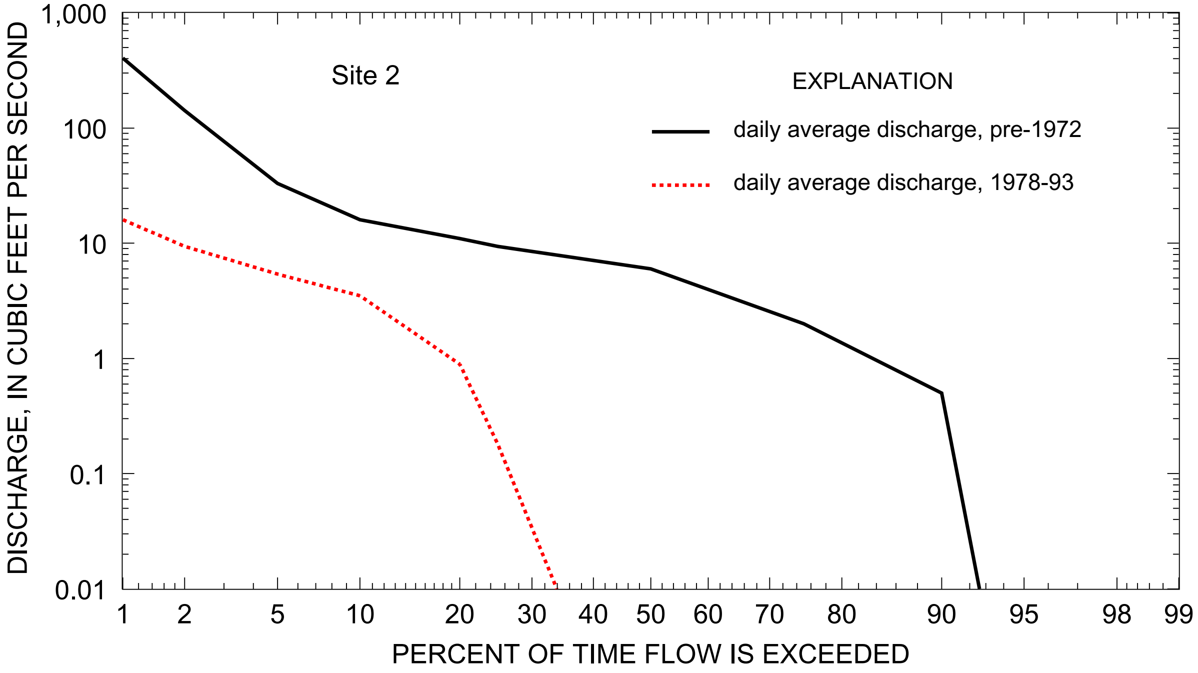

Figure 43. Flow duration curves of daily average discharge for station 07232500, Beaver River near Guymon, Oklahoma (site 2).

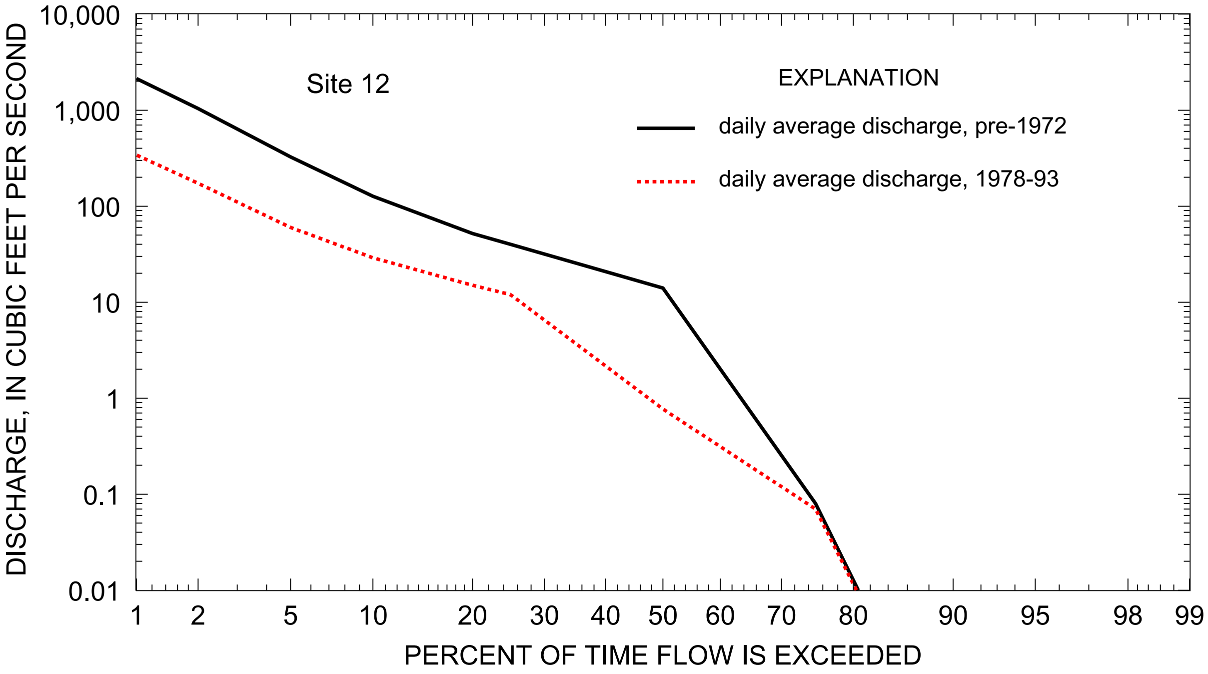

Figure 44. Flow duration curves of daily average discharge for station 07234000, Beaver River at Beaver, Oklahoma (site 12).

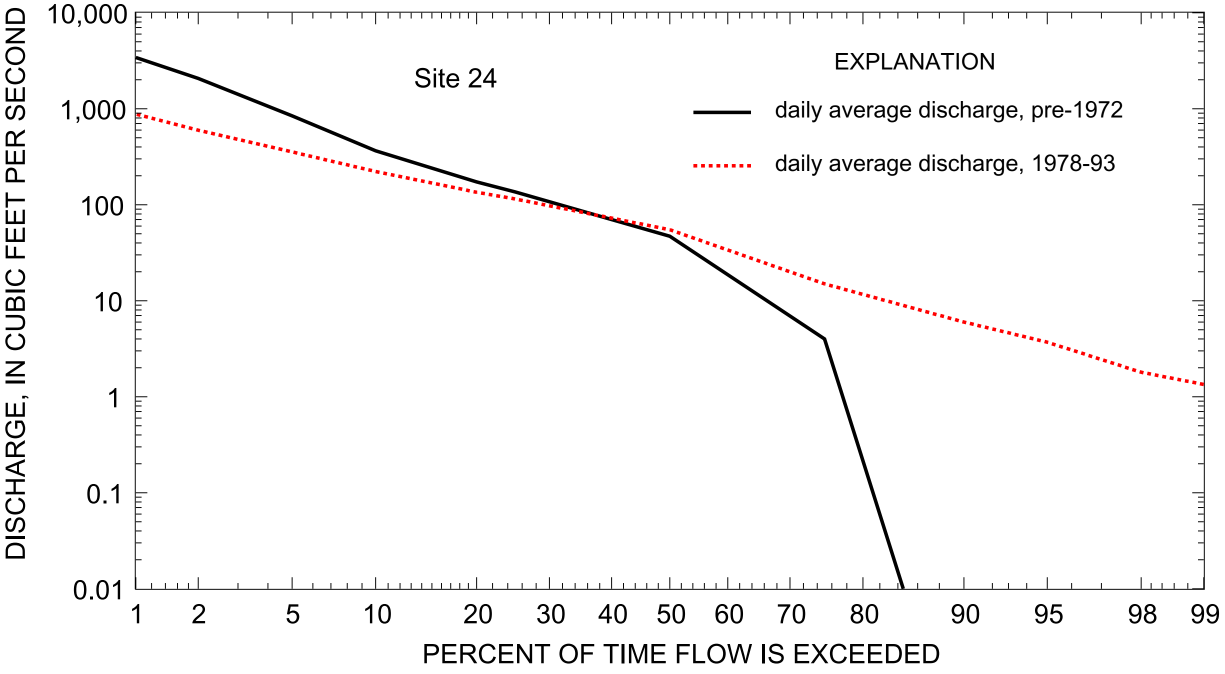

Figure 45. Flow duration curves of daily average discharge for station 07237500, North Canadian River at Woodward, Oklahoma (site 24).

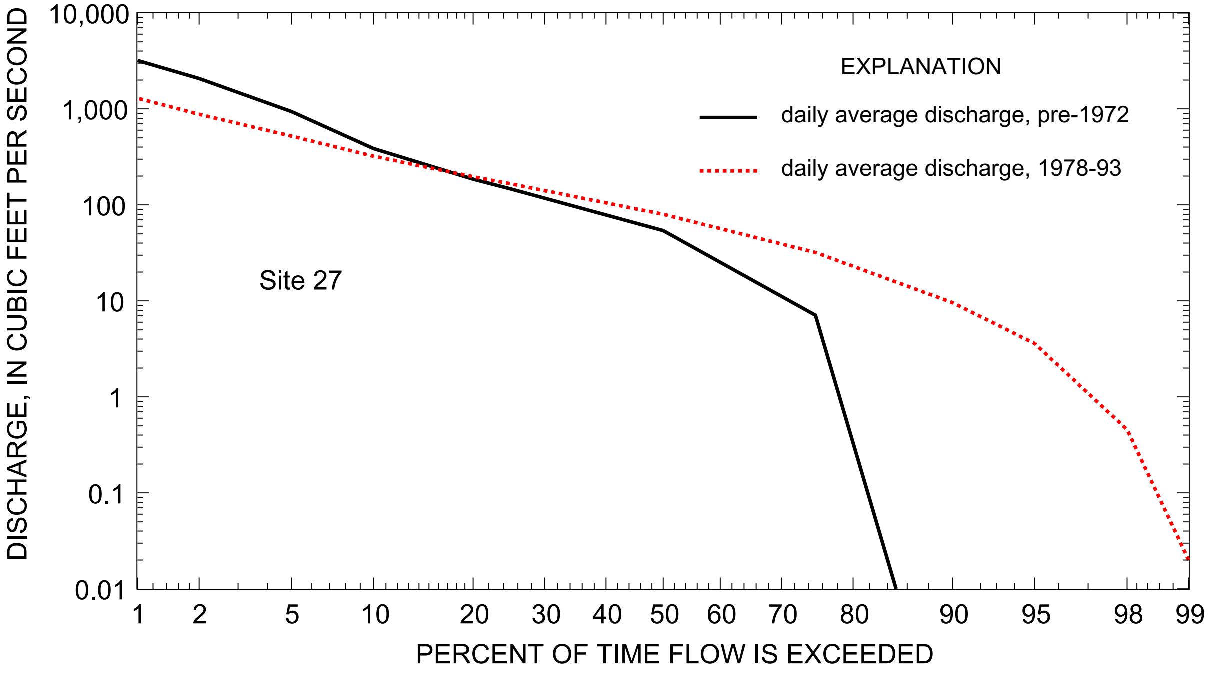

Figure 46. Flow duration curves of daily average discharge for station 07238000, North Canadian River near Seiling, Oklahoma (site 27).

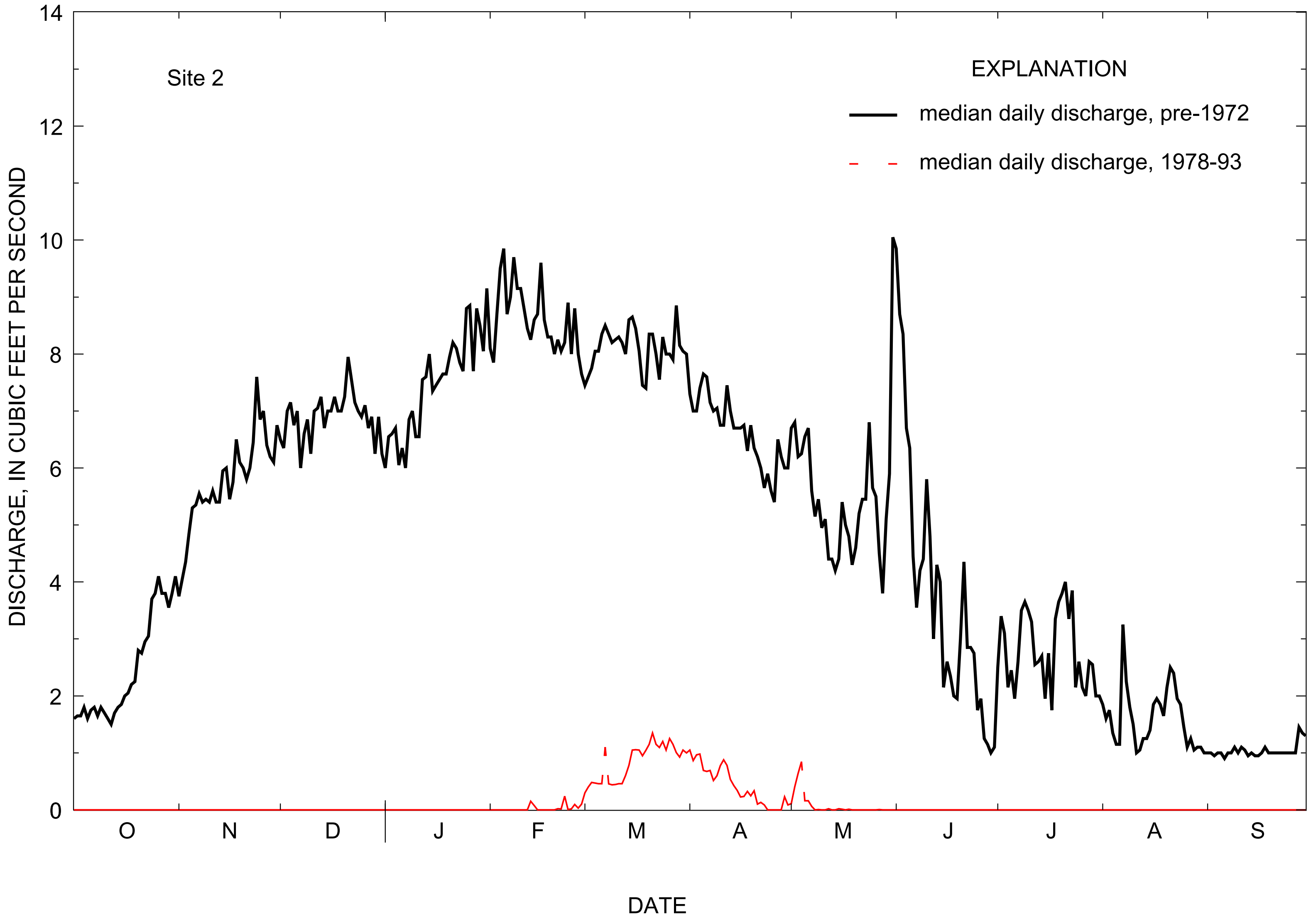

Figure 47. Daily-duration hydrographs of median daily discharges for station 07232500, Beaver River near Guymon, Oklahoma (site 2).

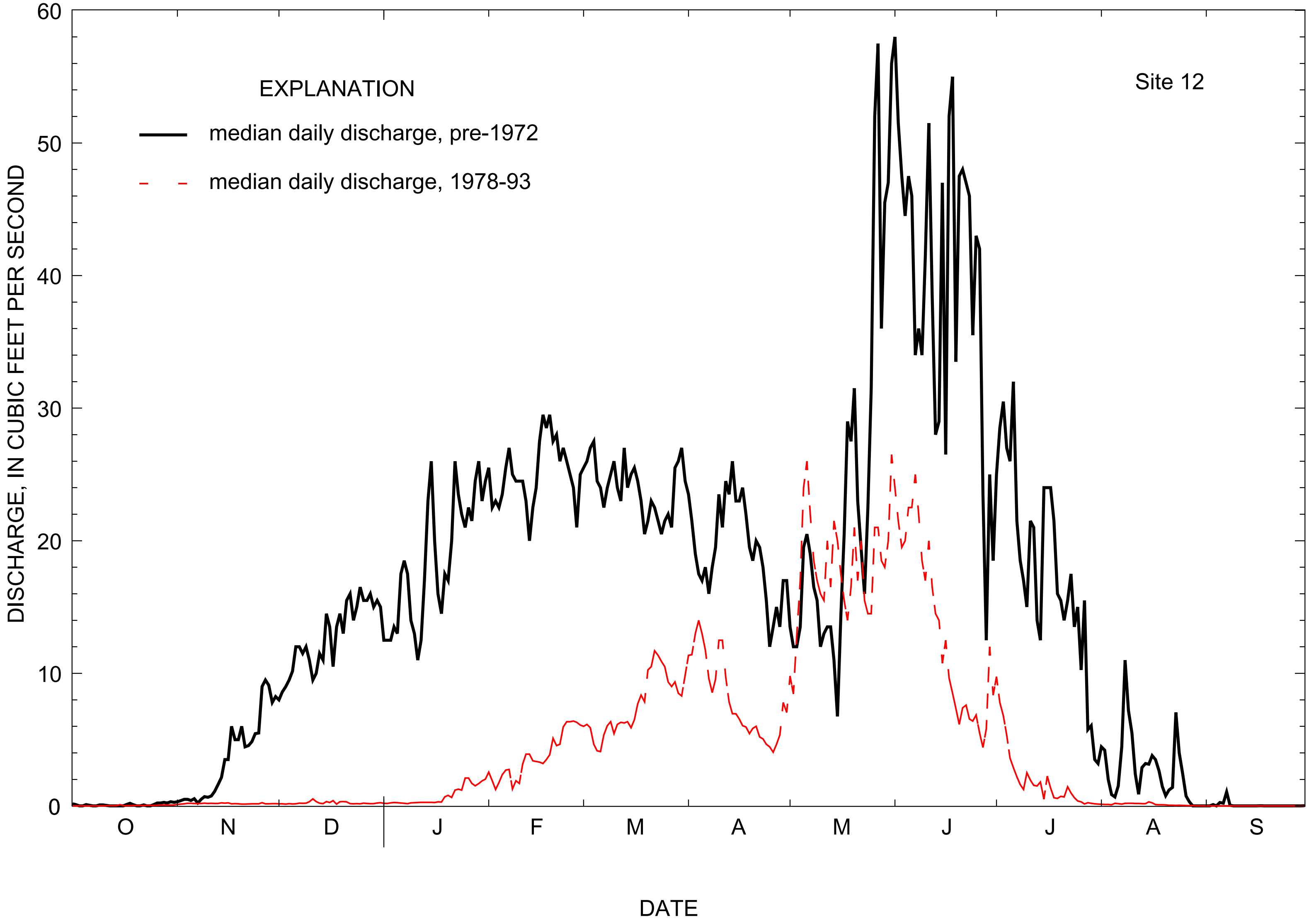

Figure 48. Daily-duration hydrographs of median daily discharges for station 07234000, Beaver River at Beaver, Oklahoma (site 12).

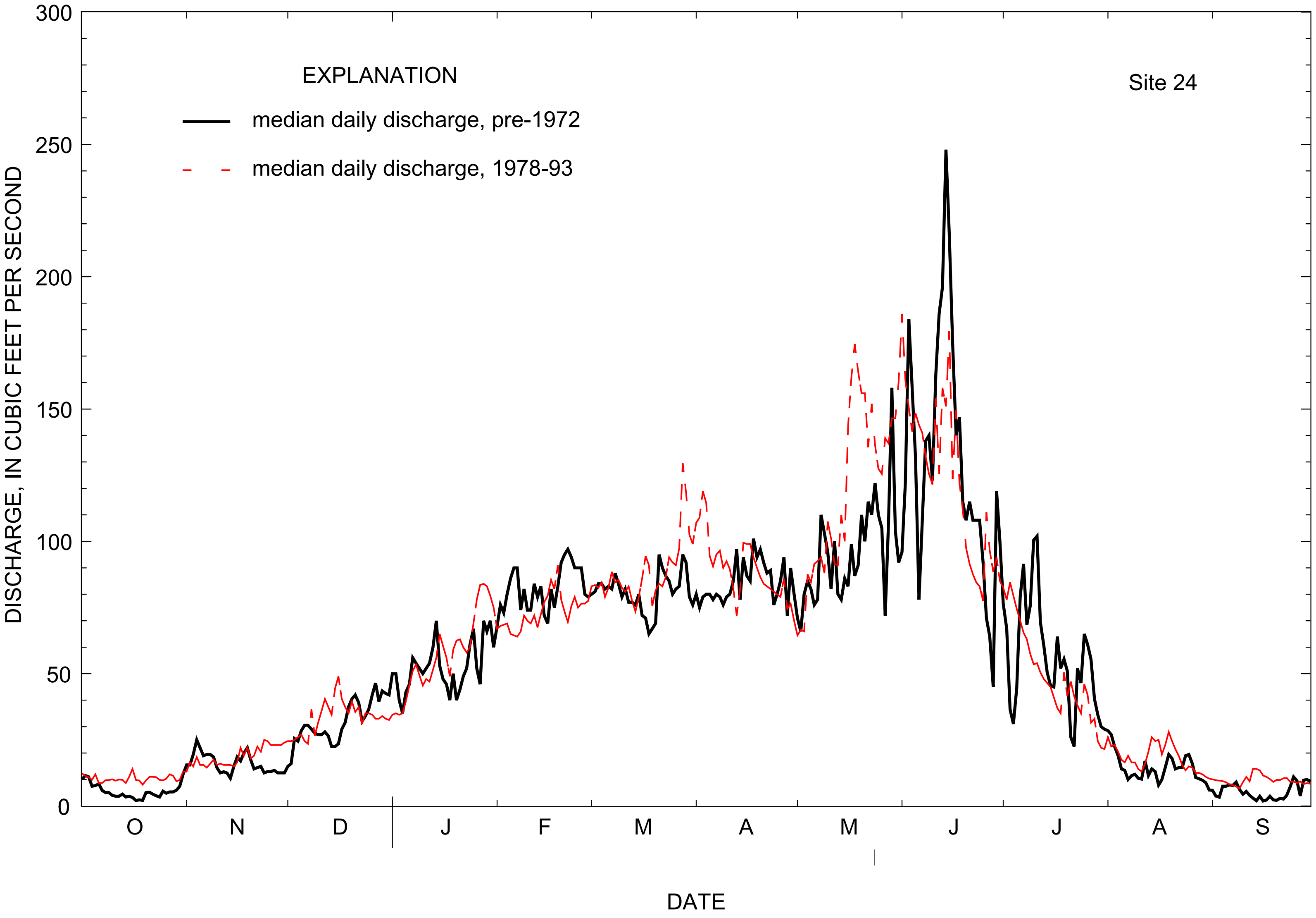

Figure 49. Daily-duration Hydrographs of median daily discharges for station 07237500, North Canadian River at Woodward, Oklahoma (site 24).

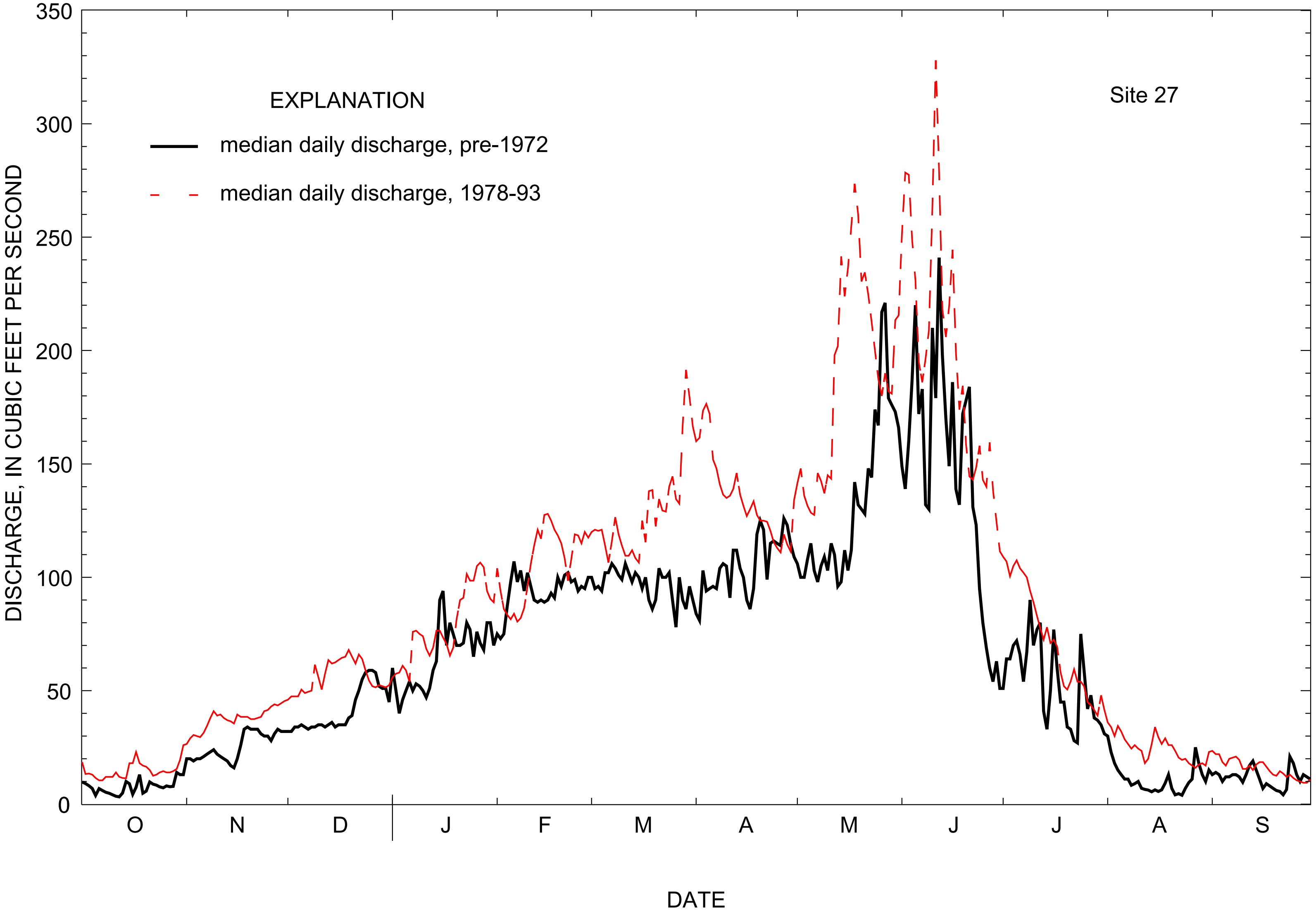

Figure 50. Daily-duration hydrographs of median daily discharges for station 07238000, North Canadian River near Seiling, Oklahoma (site 27).

flows that are exceeded 50-percent of the time or less now measure only about 20-percent of their pre-1972 values.

The flows at Woodward (site 24) and near Seiling (site 27) have undergone a different change (figs. 45-46). The low flows that are exceeded frequently (more than about 40 percent of the time at Woodward and about 20 percent of the time near Seiling) have increased in magnitude. The higher flows that occur less frequently (less than about 40 percent of the time at Woodward and about 20 percent of the time near Seiling), however, have decreased in magnitude. Those large flows occur infrequently, but contribute substantial amounts of the total annual volume of flow.

The daily-duration hydrographs (figs. 47-50) give additional perspective on the changing daily flows. The differences in the median daily discharges for the early and recent periods near Guymon (fig. 47) are extreme. Median discharges for water years 1938-1971 were greater than zero for all days of the year, and generally exceeded 5 ft^3/s from about the first of November until about the first of June. Median daily discharges for the remaining months were generally greater than 1 ft^3/s. By contrast, the median daily discharge during water years 1978-1993 was zero for almost 8 months of the year, October through January and mid-May through September; median daily flows during the remainder of the year rarely exceeded 1 ft^3/s.

For the gage at Beaver (site 12), the comparison also shows major decreases in the magnitudes of the median daily discharges for the recent period when compared to the early period (fig. 48). The median discharges for the two periods are comparable during September and October, when the river is nearly dry, and during early May. For the remainder of the year, the median discharges during the recent period are much less than those of the early period; the flows for the recent period are almost always less than 50 percent of the flows for the earlier periods.

By contrast, the median daily discharges at Woodward (site 24) in the recent period are comparable to those for the early period (fig. 49). The recent period median discharges near Seiling (site 27) are generally greater than the early period medians (fig. 50). These results, while seeming to contradict the results of the trend tests for annual flow volumes, agree with the trends noted for the base-flow index. The reason for this apparent contradiction near Seiling is explained by figure 51 that shows the daily-duration hydrograph for the maximum daily discharge in addition to that for the median daily discharge. The maximum daily discharges between the two periods compare favorably during the winter when discharges are relatively small. During the remainder of the year, however, the maximum daily discharges for the recent period are generally less, and often by an order of magnitude, than those for the early period. This agrees with the conventional flow duration curve of figure 46 that showed that flows that occur less than about 20 percent of the time were greatly reduced in the recent period. As noted earlier, those large flows that occur infrequently contribute substantial amounts of the total annual volume of flow.

The reasons for the increase in the low flows and median-daily discharges at Woodward (site 24) and near Seiling (site 27) are not known. Possible contributing factors include: 1) The influence of discharge from the alluvium and terrace aquifer that extends from the panhandle to Lake Overholser; 2) changes in discharge of wastewater; and 3) the effects of reservoir operations. Reservoirs commonly modulate flows - reducing the largest flows and increasing the smallest flows. The gaging records, however, suggest that the reservoirs are not primary factors in this change. The Beaver River gage at Beaver (site 12) is downstream from Optima Lake, but the daily-duration hydrograph (fig. 48) shows that the median daily flows there are much smaller in the recent, post-Optima Lake period, than they were before 1972. Palo Duro Reservoir has only been in place since 1991 and was assumed to be not a factor in the 1978-1993 period. The other major reservoir, Fort Supply Lake, has been in operation since 1942.

Summary and Conclusions

Moving averages, trend tests, and comparisons of median and average flows for an early period (ending in 1971) with those for the recent period (1978-1994) show that the total annual volume of flow and the magnitudes of instantaneous peak discharges measured at most gaging stations in the Beaver-North Canadian River basin have decreased in recent years. These changes are most pronounced in the headwaters upstream from Woodward, but also are evident at Woodward and near Seiling, which represents the inflow to Canton Lake. Precipitation records for the panhandle, however, show no corresponding changes.

Annual volume of flow has declined at most gaging stations in the basin. Changes in the discharge of the Beaver River through 1986 have been documented (Wahl and Wahl, 1988). The average annual discharge of the river near Guymon reported in 1960 for 23 years of record (water years 1938-1960) was 23,300 acre-feet. The 10-year moving average was only 500 acre-feet by 1993. In this study, the decrease near Guymon between the early period and the recent period was about 18,000 acre-feet and represented 91 percent of the average flow for the early period. Even larger decreases were found in the annual flow volumes between the early and recent periods at Beaver (-68,000 acre-feet), at Woodward (-72,000 acre-feet), and near Seiling (-63,000 acre-feet).

Base flows also have undergone substantial change, but unlike the annual volumes the base flows show some increases and some decreases. Both the early and recent periods show large decreases at the Beaver River near Guymon and at Beaver. The average base flow near Guymon for 1978-1993 is only 10 percent of that for the early period; the average base flow at Beaver for the recent period is only 34 percent of that for the early period. By contrast, the average annual base flows at Woodward and near Seiling show little change between the early and recent period, but the median annual base flows have increased by about 45 percent in the recent period. This indicates a shift in the distribution of annual flows. Less contribu-

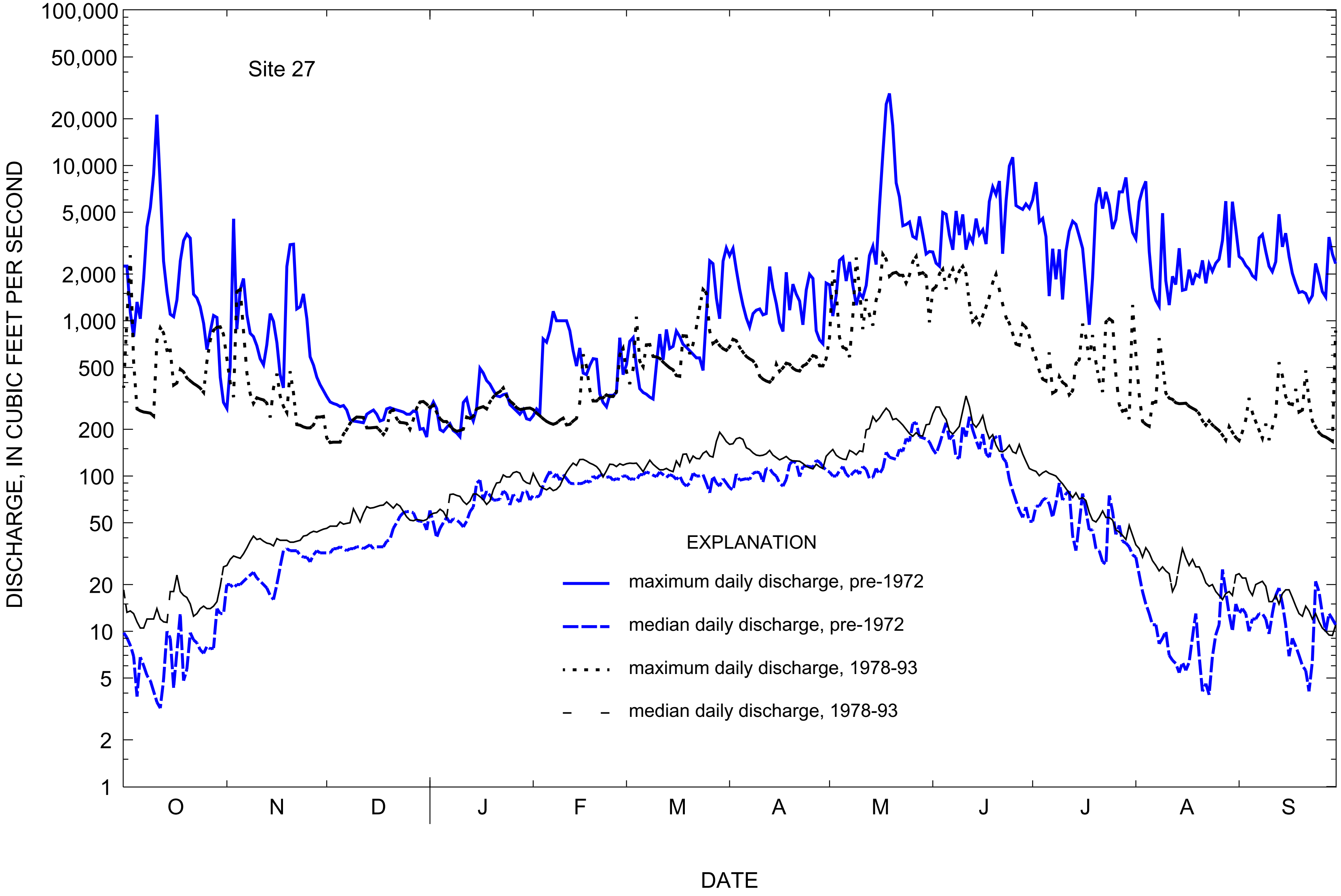

Figure 51. Daily-duration hydrographs of median daily and maximum daily discharges for station 07238000, North Canadian River near Seiling, Oklahoma (site 27).

tion is coming from large floods that formerly contributed substantially to the yearly average flows.

Widespread and significant declines in the magnitudes of annual instantaneous peak discharges also have occurred in the basin and at all the Beaver-North Canadian River mainstem stations. The median annual peak discharges decreased from the early period to the recent period by the following amounts: near Guymon (-98 percent), at Beaver (-86 percent), at Woodward (-80 percent), and near Seiling (-53 percent). The Guymon gage is not affected by reservoirs; the other three gaging stations are influenced by reservoirs, but the decreases in flow are greater than can be explained by storage in those reservoirs.

A primary mechanism producing these decreased streamflows appears to be the depletion of ground water in the Ogallala Formation that underlies more than 90 percent of the basin. Relations between decreases in base flow and daily mean flows and ground-water level declines are easy to understand. The link between declines in ground-water levels and annual peak discharges is not so clear, but the possible effect of a dry channel on attenuation of peak discharges cannot be discounted. Changes in farming and conservation practices also may be having an effect on the magnitudes of annual peak discharges.

Flow duration analyses show that although the magnitudes of low flows have increased near Seiling, the magnitudes of the large flows that occur less than about 20 percent of the time were greatly reduced in the recent period. Those large flows occur infrequently, but contribute substantial amounts of the total annual volume of flow.

The reasons for the increase in the low flows and median-daily discharges at Woodward and near Seiling are not known. Possible contributing factors include: 1) The influence of discharge from the alluvium and terrace aquifer that extends from the panhandle to Lake Overholser; 2) changes in discharge of wastewater; and 3) the effects of reservoir operations. Reservoirs commonly modulate flows - reducing the largest flows and increasing the smallest flows. The gaging records, however, suggest that the reservoirs are not primary factors in this change.

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