Prepared in cooperation with the Oklahoma Water Resources Board

Hydrologic Drought of Water Year 2006 Compared with Four Major Drought Periods of the 20th Century in Oklahoma

Canadian River near Norman February 1952

Canadian River downstream from State Highway 99 near Ada August 16, 2006

Scientific Investigations Report 2008-5199

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

Front Cover: Picture One shows wind ripples and river silts, Canadian River near Norman, Cleveland County, Oklahoma, taken February 1952. Photographer: W.B. Hamilton, from U.S. Geological Survey Photographic Library.

Picture Two shows the dry Canadian River near Ada, Pontotoc County, Oklahoma, downstream from State Highway 99, taken August 16, 2006. Photographer: Daniel Fenner, U.S. Fish and Wildlife Service.

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DIRK KEMPTHORNE, Secretary

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Conversion Factors and Datums

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)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Energy	
gigawatt-hour (GWh)	3.6×10^{12}	joule (J)

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

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

Altitude, as used in this report, refers to distance above the vertical datum.

Water year is the 12-month period October 1 through September 30, designated by the calendar year in which the water year ends.

Hydrologic Drought of Water Year 2006 Compared With Four Major Drought Periods of the 20th Century In Oklahoma

By Robert L. Tortorelli

Abstract

Water Year 2006 (October 1, 2005, to September 30, 2006) was a year of extreme hydrologic drought and the driest year in the recent 2002–2006 drought in Oklahoma. The severity of this recent drought can be evaluated by comparing it with four previous major hydrologic droughts, water years 1929–41, 1952–56, 1961–72, and 1976–81. The U.S. Geological Survey, in cooperation with the Oklahoma Water Resources Board, completed an investigation to summarize the Water Year 2006 hydrologic drought and compare it to the four previous major hydrologic droughts in the 20th century.

The period of water years 1925–2006 was selected as the period of record because before 1925 few continuous record streamflow-gaging sites existed and gaps existed where no streamflow-gaging sites were operated. Statewide annual precipitation in Water Year 2006 was second driest and statewide annual runoff in Water Year 2006 was sixth driest in the 82 years of record.

Annual area-averaged precipitation totals by the nine National Weather Service Climate Divisions from Water Year 2006 are compared to those during four previous major hydrologic droughts to show how rainfall deficits in Oklahoma varied by region. Only two of the nine climate divisions, Climate Division 1 Panhandle and Climate Division 4 West Central, had minor rainfall deficits, while the rest of the climate divisions had severe rainfall deficits in Water Year 2006 ranging from only 65 to 73 percent of normal annual precipitation.

Regional streamflow patterns for Water Year 2006 indicate that Oklahoma was part of the regionwide below-normal streamflow conditions for Arkansas-White-Red River Basin, the sixth driest since 1930. The percentage of long-term stations in Oklahoma (with at least 30 years of record) having below-normal streamflow reached 80 to 85 percent for some days in August and November 2006.

Twelve long-term streamflow-gaging sites with periods of record ranging from 62 to 78 years were selected to show how streamflow deficits varied by region. The hydrologic drought worsened going from north to south in Oklahoma, ranging from 45 percent in the north, to just 14 percent in east-central Oklahoma, and 20 percent of normal annual streamflow in the southwest.

The low streamflows resulted in only 86.3 percent of the statewide conservation storage available at the end of the water year in major reservoirs, and 7 to 47 percent of hydroelectric power generation at sites in Oklahoma in Calendar Year 2005.

Introduction

Water Year 2006 (October 1, 2005, to September 30, 2006) was a year of extreme hydrologic drought and the driest year in the recent 2002–2006 drought in Oklahoma. A sense of the severity of this recent drought can be evaluated by comparing Water Year 2006 hydrologic drought with four previous major hydrologic droughts, water years 1929–41, 1952–56, 1961–72, and 1976–81. The effect of the drought varies in different regions of the state. Data from several long-term streamflow-gaging stations are available to assess the effect of the hydrologic drought of Water Year 2006 in Oklahoma.

Hydrologic drought is associated with the effects of periods of precipitation deficits on surface or subsurface water supply. The frequency and severity of hydrologic drought is defined on a watershed or river basin scale. Water in the hydrologic storage systems, rivers and reservoirs, commonly has multiple and competing purposes including flood control, irrigation, recreation, navigation, hydropower, and wildlife habitat. Competition for this water escalates during drought, and conflicts between water users increase substantially (National Drought Mitigation Center, 2006a).

The U.S. Geological Survey (USGS), in cooperation with the Oklahoma Water Resources Board, completed an investigation to summarize the Water Year 2006 hydrologic drought and compare it to the four previous major hydrologic droughts in the 20th century.

Purpose and Scope

The purpose of this report is to describe and document the Water Year 2006 hydrologic drought in Oklahoma and compare it to four previous major hydrologic droughts, water years 1929–41, 1952–56, 1961–72, and 1976–81.

A brief introduction includes (1) a definition of drought sequence, (2) a presentation of monthly nationwide drought monitor graphics for Water Year 2006, and (3) a comparison of annual statewide total precipitation and statewide streamflow runoff from water years 1925–2006 in Oklahoma with the four previous major hydrologic droughts in the 20th century highlighted. Annual area-averaged precipitation totals for Water Year 2006 for the nine National Weather Service Climate Divisions in Oklahoma are compared to precipitation during four previous major hydrologic droughts in the 20th century to show how rainfall deficits varied by region. Next the mean annual streamflow during Water Year 2006 at 12 long-term streamflow-gaging sites are compared to streamflow during four previous major hydrologic droughts in the 20th century to show how streamflow deficits varied by region. The effects of low streamflows are discussed to include (1) conservation storage at major reservoirs throughout the state, (2) hydroelectric power generation, (3) ground-water levels at a long-term site, and (4) wildfires.

The effects of the hydrologic drought of Water Year 2006 on agriculture are beyond the scope of this report and a discussion can be found in Oklahoma Agricultural Statistics 2007 (National Agricultural Statistics Service, 2007).

Progression of Drought

Definition of Drought Sequence

The drought sequence development is illustrated in figure 1. The start of a drought begins with precipitation deficiency, high temperatures and winds, and low humidity, collectively resulting in "meteorological" drought. As soil moisture is reduced and plants are stressed, "agricultural" drought is experienced. If the drought continues for several seasons, streamflow is reduced to critical levels and "hydrologic" drought results (Oklahoma Water Resources Board, 2007a; National Drought Mitigation Center, 2006a).

Drought Monitor

The U.S. Drought Monitor is a graphic depiction of broad-scale drought in the United States displayed on the National Drought Mitigation Center web page (National Drought Mitigation Center, 2007). Agricultural and hydrologic drought effects are displayed on a weekly graphic accompanied by tabular data and general regional narratives for that week.

Figure 2 shows the progression of the Water Year 2006 drought with 12 monthly Drought Monitor graphs from November 1, 2005, to October 3, 2006. The hydrologic drought of Water Year 2006 in Oklahoma is shown getting steadily worse from November through March, improving with some spring and summer rains from April through the beginning of July and then the drought is worst in August. Conditions improved in September and October.

Statewide Precipitation and Streamflow

Precipitation and runoff plots help to characterize the duration and severity of hydrologic drought by comparing annual statewide precipitation and runoff departures from long-term median values. Annual departures are shown as positive bars when annual departures exceed the long-term median and as negative bars when annual departures are less than the long-term median. Thus departures that are consistently negative over several years provide a measure of drought duration or persistence, while the magnitude of individual departures provides a measure of severity. Negative departure of runoff also can be characterized as runoff deficits.

The period of water years 1925–2006 was selected as the period of record for long-term drought analysis. Few continuous record streamflow-gaging sites existed and there were record year gaps where no streamflow-gaging sites were operated before 1925 (U.S. Geological Survey, 2007a). The four previous major hydrologic drought periods, water years 1929–41, 1952–56, 1961–72, and 1976–81 were identified from the statewide runoff plot and modified from a previous drought report by Tortorelli and others (1991). The 2002–2006 hydrologic drought period was identified from the statewide runoff plot.

Figures 3 and 4 show how annual statewide precipitation and annual statewide median runoff compare during water years 1925–2006. First, the statewide annual mean precipitation for each water year of the period (National Climatic Data Center, 2007a) is plotted as the departure from the median annual precipitation for the period ("normal" annual precipitation, blue line), and a 5-year weighted-average departure precipitation is plotted as a red line (fig. 3). The selected drought periods are indicated by different colored annual bars. Water Year 2006 was second driest in the 82 years of record from 1925–2006.

Second, the statewide annual median runoff for each water year of the period (U.S. Geological Survey, 2007a) is plotted as the departure from the median annual runoff for the period ("normal" annual runoff, blue line), and a 5-year weighted-average departure runoff is plotted as a red line (fig. 4). The selected drought periods are indicated by different colored annual bars. Based on runoff, Water Year 2006 was sixth driest in the 82 years of record from 1925–2006.

Wetter years plot above the median line and drier years plot below the median line. Water Year 2006 then can be compared to the dry years in the four previous major hydrologic droughts by depth of the bars. The length and severity of the water year 2002–2006 drought period also can be compared

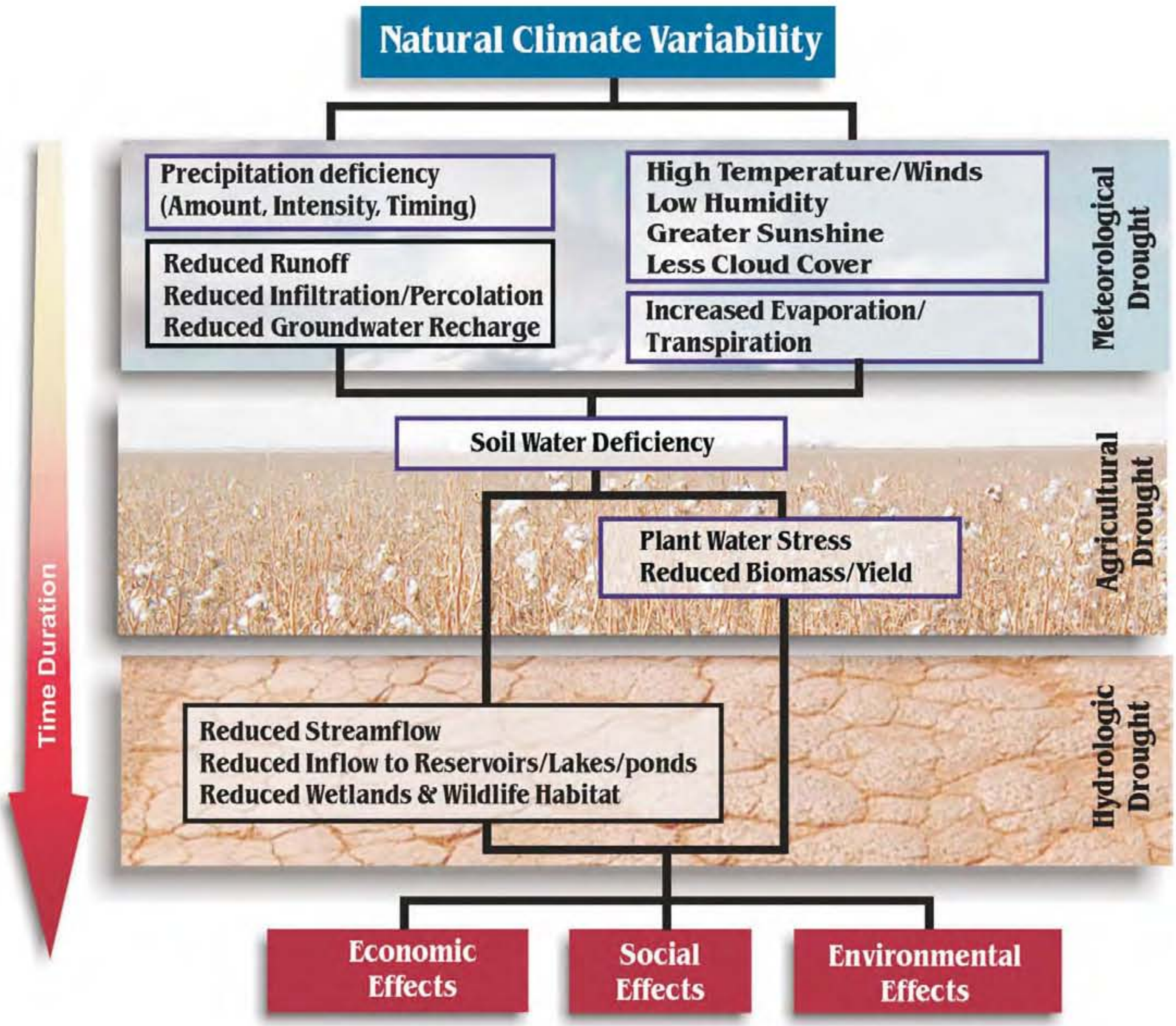


Figure 1. Sequence of drought development (Oklahoma Water Resources Board, 2007a; modified from National Drought Mitigation Center, 2006a)

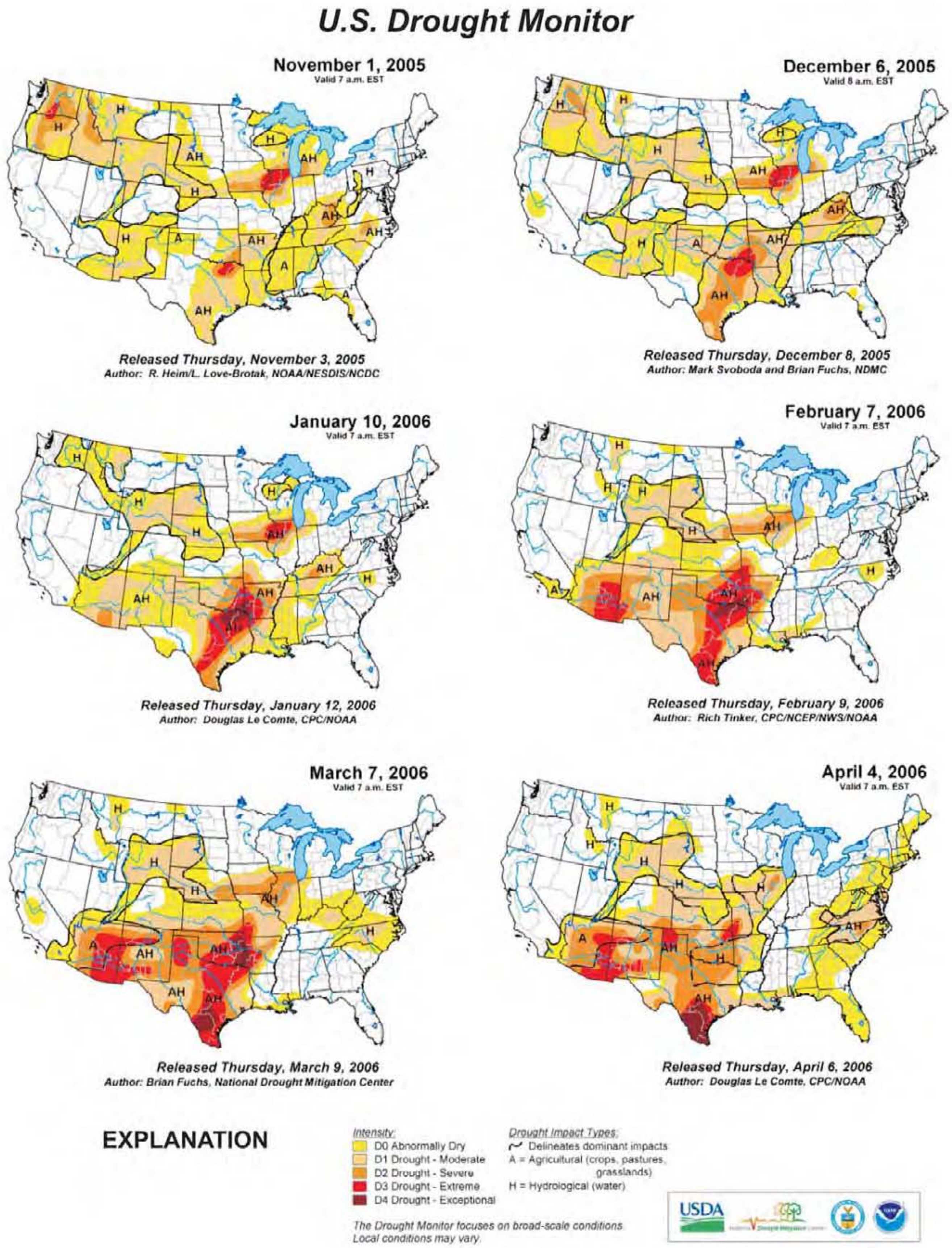


Figure 2. Monthly Drought Monitor Graphs, November 1, 2005, through October 3, 2006, (National Drought Mitigation Center, 2007)—Continued

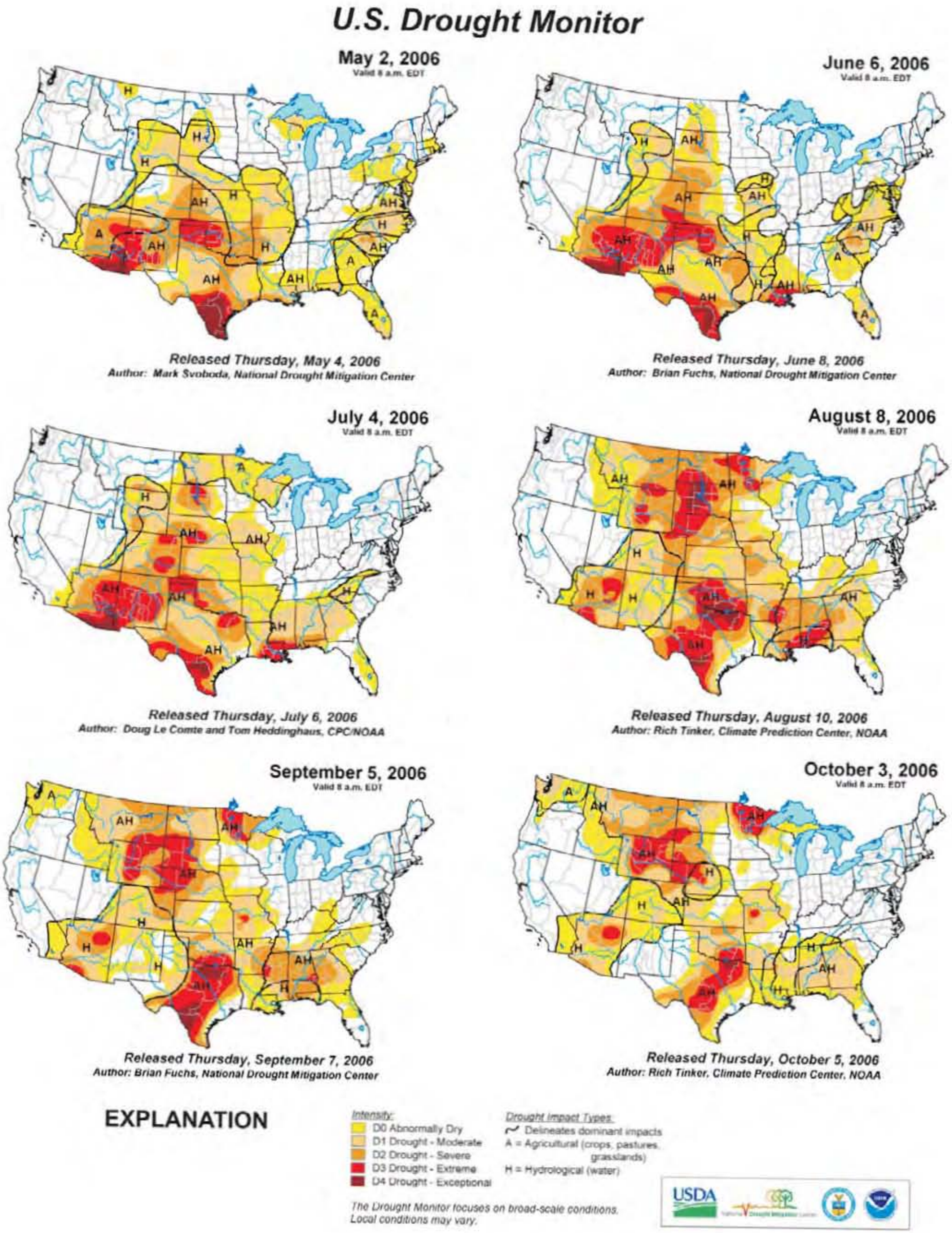


Figure 2. Monthly Drought Monitor Graphs, November 1, 2005, through October 3, 2006, (National Drought Mitigation Center, 2007).

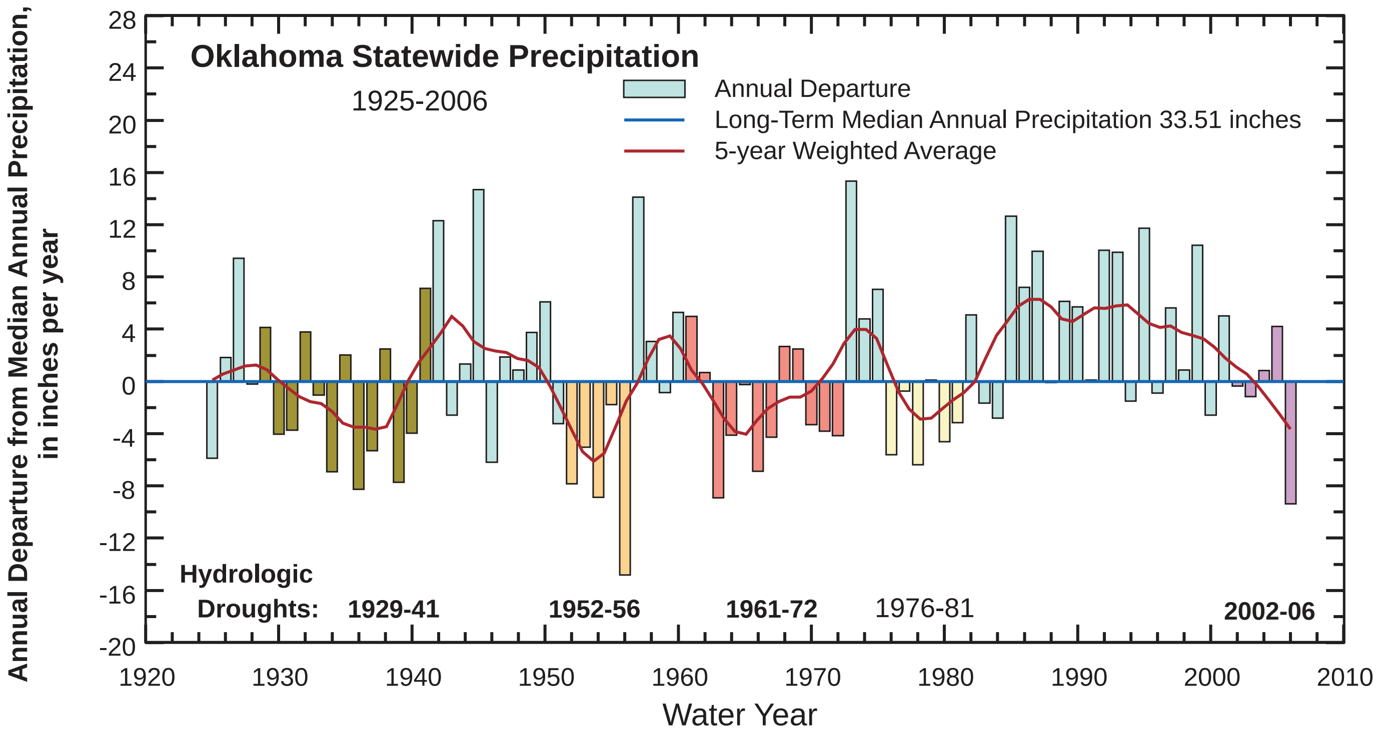


Figure 3. Oklahoma statewide precipitation showing the annual departure from the long-term statewide median of 33.51 inches (blue line) and a 5-year weighted average line for water years 1925–2006 (red line). Wetter years plot above the median line and drier years plot below the median line.

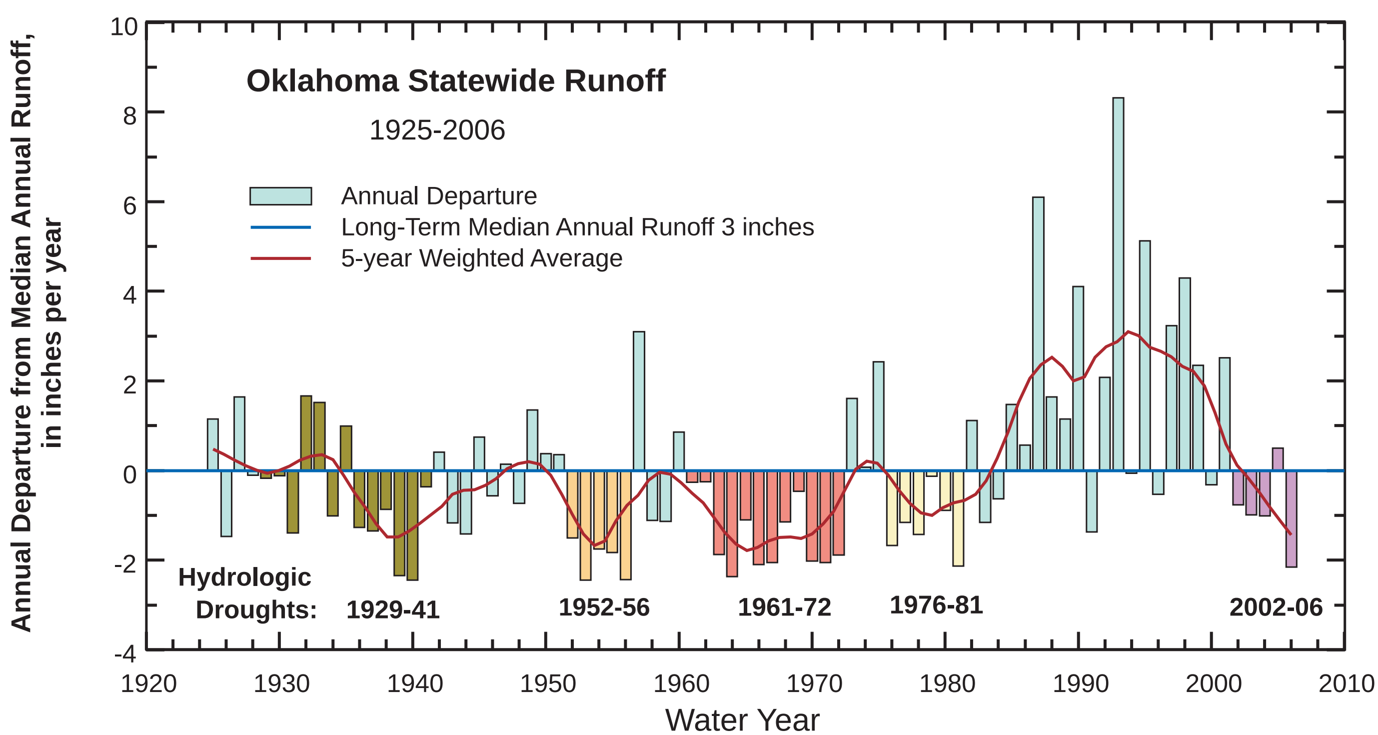


Figure 4. Oklahoma statewide runoff showing the annual departure from the long-term statewide median of 3 inches (blue line) and a 5-year weighted average line for water years 1925–2006 (red line). Wetter years plot above the median line and drier years plot below the median line.

to the four previous major hydrologic drought periods by the 5-year weighted average line.

The hydrologic drought of water years 1929–41 was known as the “Dust Bowl” years in the Great Plains and is documented in several references (Hoyt, 1936 and 1938; Nace and Pluhowski, 1965; Egan, 2006; National Drought Mitigation Center, 2006b). This drought was particularly severe in western Oklahoma with a deficit runoff in 1934; whereas, major wind erosion happened over the entire state in 1936 (Nace and Pluhowski, 1965). The 1929–41 drought triggered nationwide soil conservation measures (National Drought Mitigation Center, 2006b).

The hydrologic drought of water years 1952–56 was the most widespread and the most severe for all regions of Oklahoma for precipitation and in most regions for runoff than the other hydrologic drought periods (Nace and Pluhowski, 1965; Tortorelli and others, 1991; figs. 3–4). This drought prompted the construction of Atoka Lake to provide a reliable water supply for Oklahoma City (Johnson, 1956) and prompted many Oklahoma communities to plan for long-term water supply.

The hydrologic drought of water years 1961–72 also was widespread and lasted longer than that in 1952–56 but generally was not as severe (Tortorelli and others, 1991; figs. 3-4). By this time many of the major reservoirs in Oklahoma were completed (Vance, 2007).

The hydrologic drought of water years 1976–81 also was widespread, but was not as severe or persistent as the previous three major droughts (Tortorelli and others, 1991; figs. 3-4).

The precipitation and runoff plots in figures 3 and 4 indicate that Water Year 2006 was very dry (second lowest statewide precipitation in the 1925–2006 study period) with very low statewide runoff (sixth lowest in the 1925–2006 study period). On that basis, drought conditions in Water Year 2006 were severe, but drought duration or persistence cannot yet be characterized (October 2006).

Regional streamflow patterns for Water Year 2006 (fig. 5) indicate that Oklahoma was part of the regionwide below-normal streamflow for the Arkansas-White-Red River Basin, the sixth driest since 1930 (U.S. Geological Survey, 2008a). Figure 6 shows the percentage of 82 long-term streamflow stations in Oklahoma (at least 30 years of record) having below normal streamflow during the water year 2002–2006 drought period (U.S. Geological Survey, 2008b). As indicated by the dashed line in figure 6, about 25 percent of all stations can be expected to have streamflow below normal at any given time, where normal streamflow is considered to be within the 25^{th} and 75^{th} percentile at each site. Figure 6 shows that for some days in August and November 2006, the percentage of long-term stations having below-normal streamflow reached 80 to 85 percent.

Acknowledgments

The author thanks many people for their contributions to the data collection and data analysis presented in this report. Deke Arndt of Oklahoma Climatological Survey supplied Water Year 2006 precipitation maps and Brian Vance of the Oklahoma Water Resources Board provided a modified Drought Sequence diagram from the National Drought Mitigation Center. Additional special thanks go to Daniel Fenner of the U.S. Fish and Wildlife Service for providing photographs of low flow in August 2006 at numerous sites along the reach of the Canadian River above Calvin. Rachel Esralew of the Oklahoma Water Science Center compiled site maps. USGS personnel provided low flow photographs in August 2006 at USGS streamflow gages. The Oklahoma Publishing Company provided the photograph of Thunderbird Lake shoreline on the back cover.

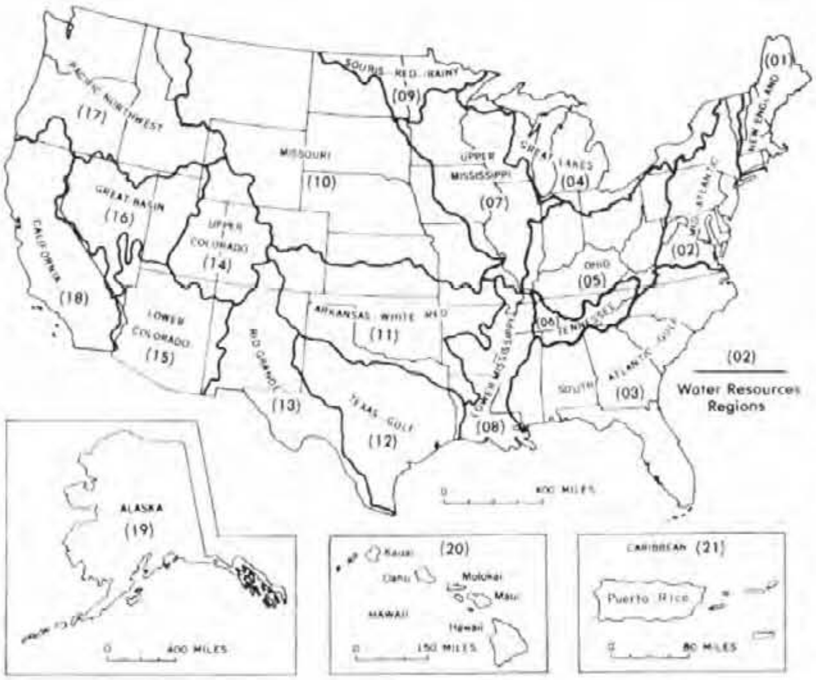
Precipitation By Climate Division

Oklahoma has nine National Weather Service Climate Divisions (fig. 7) for which monthly area-averaged precipitation data are available (National Climatic Data Center, 2007b). These data were totaled for each water year from 1925–2006. These totals give a sense of annual precipitation in Oklahoma on a regional basis.

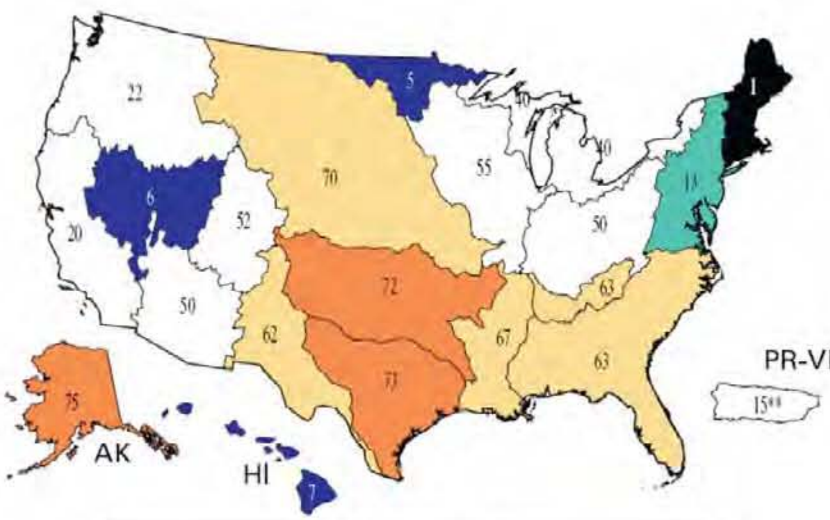
Table 1 shows how Water Year 2006 precipitation compares with that during the driest year from each of the four previous major hydrologic droughts within each of the nine National Weather Service Climate Divisions to show how rainfall deficits in Oklahoma varied by region. Table 1 also shows how the annual precipitation for the selected years compares with the long-term median annual precipitation values for water years 1925–2006 (“normal”) and the ranking (lowest ranking associated with driest year). Precipitation in water year 2006 was slightly less than the long-term climate division median in two of the nine climate divisions, Climate Division 1 Panhandle and Climate Division 4 West Central (minor rainfall deficits of 85 percent or more of normal precipitation). In all other climate divisions, Water Year 2006 precipitation was substantially less then the long-term climate division medians, with severe rainfall deficits ranging from only 65 to 73 percent of normal annual precipitation. Table 1 also shows that statewide precipitation Water Year 2006 was second driest in the 82 years of record from 1925–2006 and was only 72 percent of the normal precipitation. Only one year in the 1925–2006 period was drier, Water Year 1956 with only 56 percent of normal precipitation.

The Oklahoma Mesonet, a statewide network of environment monitoring stations, consists of 115 automated stations covering Oklahoma and provides 5-minute precipitation data. At least one station is located in each of 77 Oklahoma counties. Oklahoma Mesonet climate data are available since 1994, but were not used for this report so that data from one source (National Climatic Data Center, 2007b) for the period 1925–2006 would be used. In addition, Mesonet data uses mean annual precipitation from calendar years 1971–2000 as “normal” instead of median annual precipitation from

Regional Patterns



The United States (including Puerto Rico) is divided into 21 large drainages, or water resources regions. These hydrologic areas are based on surface topography and contain either the drainage area of a major river, such as the Columbia, the combined drainage areas of a series of rivers, such as the Texas-Gulf region which includes a number of rivers draining into the Gulf of Mexico, or the area of an island or island group. Water resources regions provide a coherent, watershed-based framework for depicting streamflow variations.



	71-76	59-70	20-58	8-19	2-7	1
Lowest	Much below normal	Below normal	Normal	Above normal	Much above normal	Highest

In 2006, notable regional streamflow differences were observed along the East Coast. The New England region, for example, recorded its highest annual flow since 1930, reflecting the record high precipitation that fell on this area during the year. The South-Atlantic Gulf region, in contrast, was below normal. Below-normal conditions also were prevalent for most the Great Plains regions and Alaska.

** Out of 63 years of historical data.

Figure 5. Regional streamflow patterns Water Year 2006 (U.S. Geological Survey, 2008a).

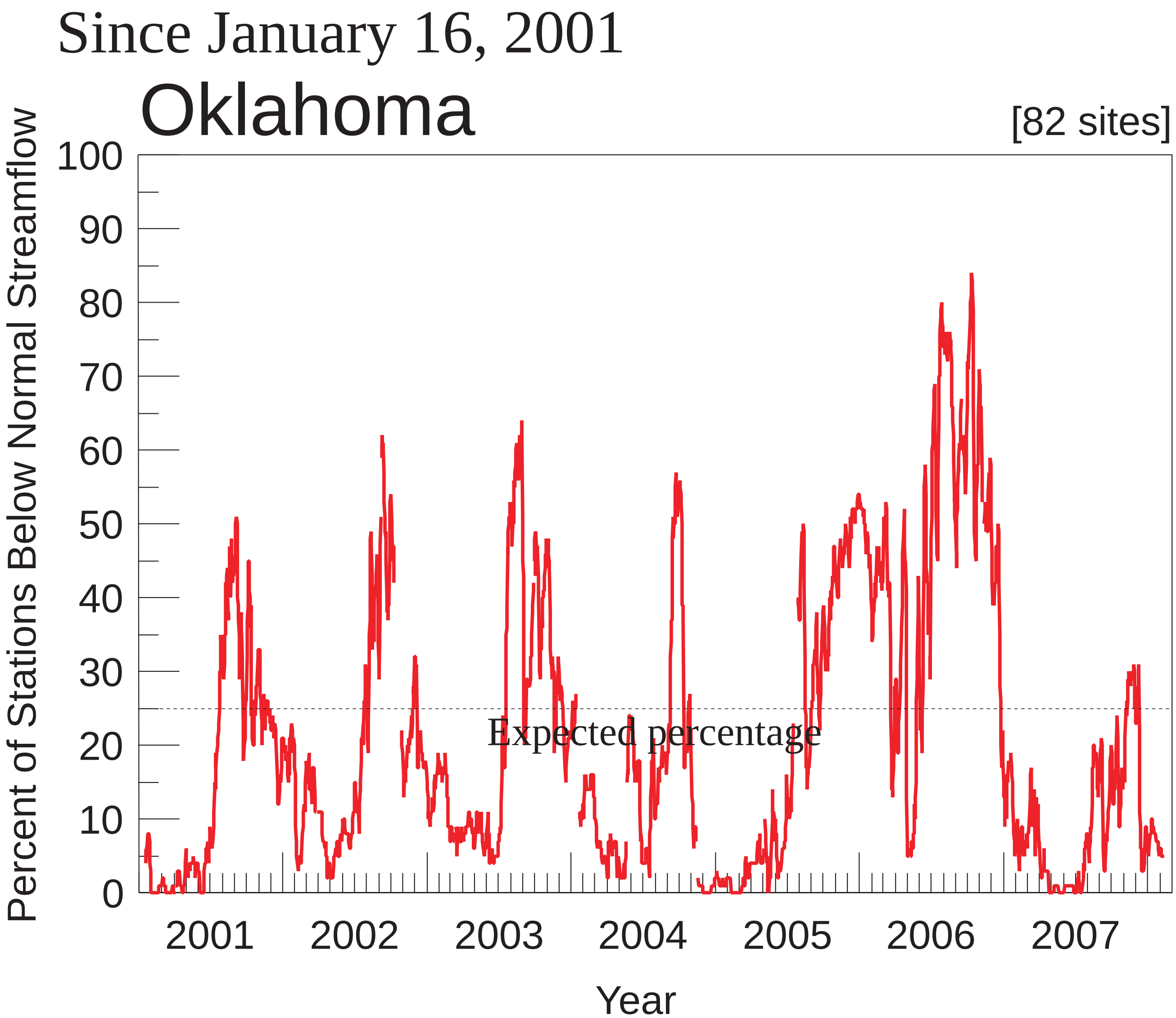


Figure 6. Percentage of stations below normal streamflow since January 16, 2001, through February 1, 2008, in Oklahoma (U.S. Geological Survey, 2007c).

Table 1. Summary of precipitation at Climate Divisions in Oklahoma comparing the median of mean annual precipitation during water years 1925-2006 (measure of "normal" precipitation) with average annual precipitation during periods of previous documented hydrologic droughts and the recent hydrologic drought period.

[avg, average; %, percent; Rank, rank of driest year of drought period out of period WY 1925-2006; WY, water year; SW, statewide]

			Hydrologic Drought Periods			
			1929-41 [3]		1952-56 [3]	
			Lowest year / Rank		Lowest year / Rank	
Climate Division number	Climate Division name	Long-term annual median (inches)	WY avg annual precipitation (inches)	Percent long-term median	WY Avg annual precipitation (inches)	Percent long-term median
SW	**Statewide [1]**	**33.51**	**1936**	**5**	**1956**	**1**
			25.24	75%	18.68	56%
1	Panhandle [2]	19.54	**1937**	**2**	**1956**	**1**
			12.24	63%	11.34	58%
2	North Central [2]	28.94	**1936**	**6**	**1956**	**1**
			20.16	70%	15.10	52%
3	Northeast [2]	38.96	**1939**	**8**	**1956**	**1**
			30.59	79%	22.90	59%
4	West Central [2]	26.55	**1940**	**8**	**1952**	**1**
			20.14	76%	15.98	60%
5	Central [2]	33.73	**1936**	**2**	**1956**	**1**
			24.03	71%	19.74	59%
6	East Central [2]	42.91	**1936**	**3**	**1956**	**1**
			28.11	66%	23.86	56%
7	Southwest [2]	27.56	**1939**	**4**	**1956**	**1**
			18.75	68%	17.45	63%
8	South Central [2]	36.63	**1939**	**2**	**1956**	**1**
			24.19	66%	16.46	45%
9	Southeast [2]	48.51	**1934**	**2**	**1956**	**1**
			30.86	64%	25.10	52%

[1] Ranks from Statewide Monthly Precipitation Totals, National Climatic Data Center (2007a)

[2] Ranks from Climate Division Monthly Precipitation Totals, National Climatic Data Center (2007b).

[3] Documented drought periods are modified from Tortorelli and others, 1991.

Table 1. Summary of precipitation at Climate Divisions in Oklahoma comparing the median of mean annual precipitation during water years 1925-2006 (measure of “normal” precipitation) with average annual precipitation during periods of previous documented hydrologic droughts and the recent hydrologic drought period.

[avg, average; %, percent; Rank, rank of driest year of drought period out of period WY 1925-2006; WY, water year; SW, statewide]

	Hydrologic Drought Periods							
	1961-72 [3]		1976-1981 [3]		2002-2006		2006	
	Lowest Year / Rank		Lowest Year / Rank		Lowest Year / Rank			Rank
Climate Division number	WY avg annual precipitation (inches)	Percent long-term median	WY avg annual precipitation (inches)	Percent long-term median	WY avg annual precipitation (inches)	Percent long-term median	WY avg annual precipitation (inches)	Percent long-term median
SW	**1963**	**3**	**1978**	**10**	**2006**	**2**		**2**
	24.60	73%	27.11	81%	24.12	72%	24.12	72%
1	**1970**	**4**	**1976**	**29**	**2002**	**15**		**22**
	13.05	67%	17.58	90%	15.34	79%	16.69	85%
2	**1966**	**5**	**1976**	**14**	**2006**	**7**		**7**
	20.15	70%	23.24	80%	20.23	70%	20.23	70%
3	**1963**	**2**	**1981**	**14**	**2006**	**5**		**5**
	24.81	64%	32.89	84%	28.29	73%	28.29	73%
4	**1970**	**3**	**1976**	**24**	**2002**	**19**		**28**
	18.00	68%	22.23	84%	21.90	82%	23.46	88%
5	**1972**	**6**	**1976**	**7**	**2006**	**3**		**3**
	25.08	74%	25.41	75%	24.17	72%	24.17	72%
6	**1963**	**4**	**1980**	**6**	**2006**	**2**		**2**
	28.24	66%	30.30	71%	27.70	65%	27.70	65%
7	**1967**	**2**	**1980**	**23**	**2006**	**3**		**3**
	17.46	63%	23.40	85%	18.59	67%	18.59	67%
8	**1963**	**4**	**1978**	**8**	**2006**	**3**		**3**
	25.15	69%	27.78	76%	24.45	67%	24.45	67%
9	**1963**	**7**	**1978**	**3**	**2006**	**6**		**6**
	35.02	72%	31.95	66%	34.89	72%	34.89	72%

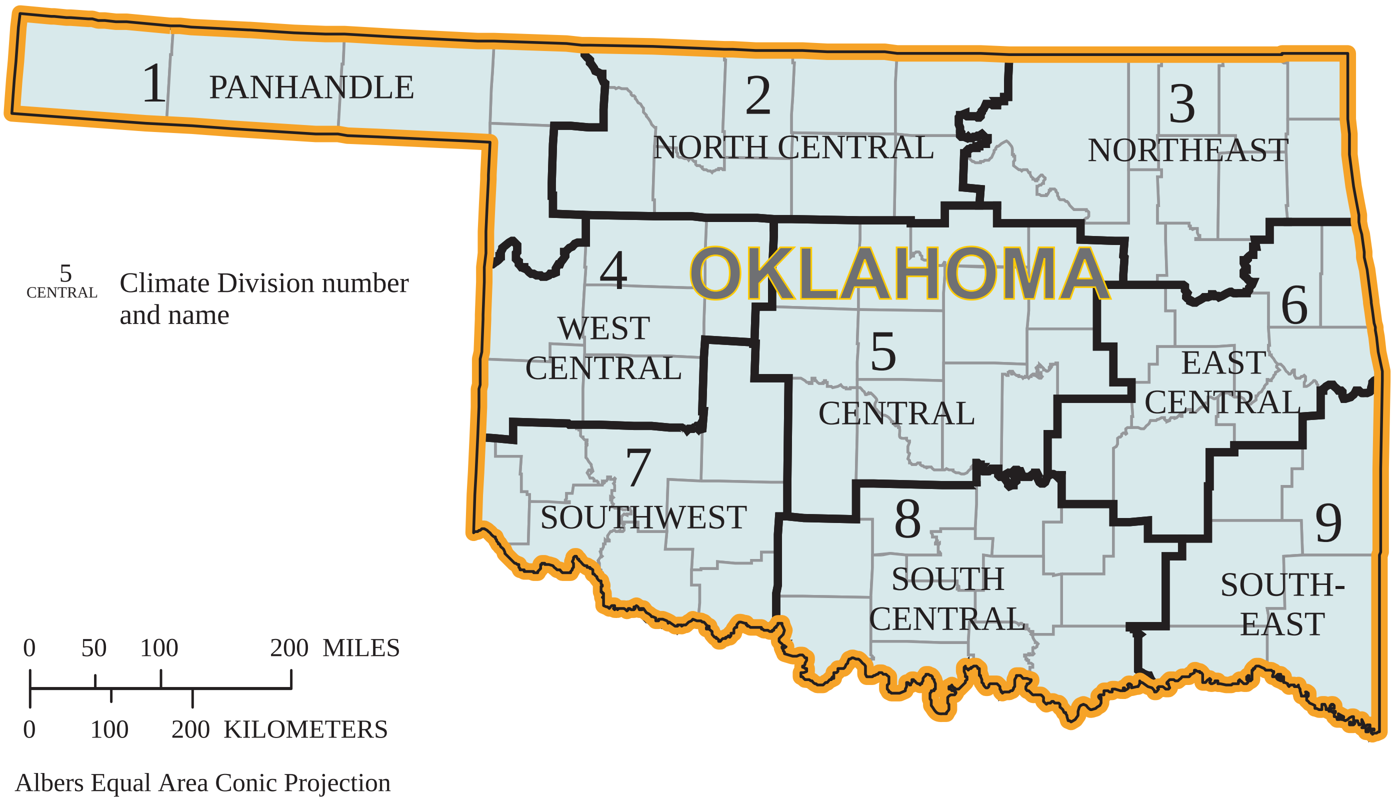


Figure 7. National Weather Service Climate Divisions in Oklahoma.

water years 1925–2006. This period contains an extremely wet period (fig. 3); therefore, data presented on the Mesonet website (fig. 8; Oklahoma Climatological Survey, 2008a, 2008b) indicated more severe precipitation deficits in 2006 than in table 1. However, these data do show how Water Year 2006 differs from normal and give a sense of regional rainfall deficits.

Climate Division 1 Panhandle

Climate Division 1 Panhandle is in far northwest Oklahoma. Water Year 2006 was the 22nd driest in the 82 years of record from 1925–2006, with 16.69 inches of rainfall, a deficit of 2.85 inches or 85 percent of normal area precipitation (table 1). Water Year 1956 was the driest year, from the 1952–56 drought period, with only 11.34 inches of rainfall, a deficit of 8.20 inches or 58 percent of normal annual area precipitation.

Climate Division 2 North Central

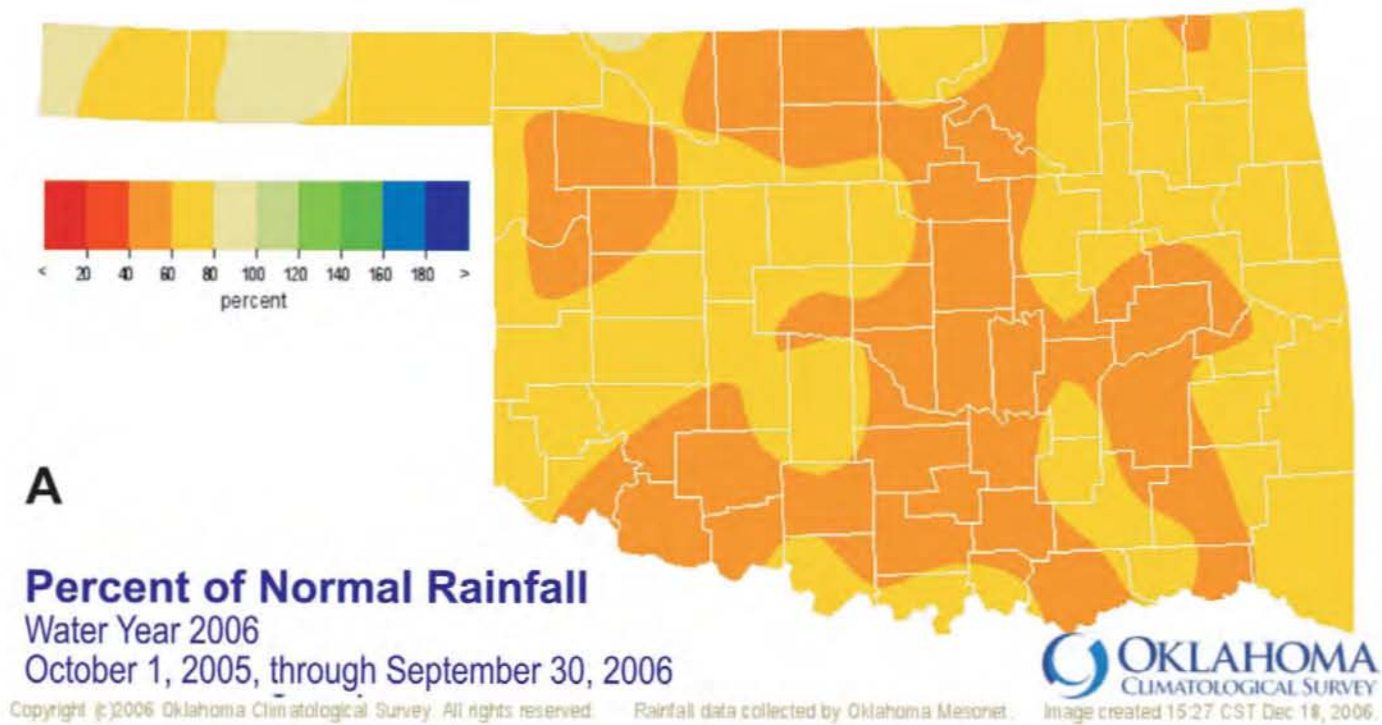
Climate Division 2 North Central is in north-central Oklahoma. Water Year 2006 was the seventh driest in the 82 years of record from 1925–2006, with 20.23 inches of rainfall, a deficit of 8.71 inches or 70 percent of normal area precipitation (table 1). Water Year 1956 was the driest year, from the 1952–56 drought period, with only 15.10 inches of rainfall, a deficit of 13.84 inches or 52 percent of normal annual area precipitation.

Climate Division 3 Northeast

Climate Division 3 Northeast is in northeast Oklahoma. Water Year 2006 was the fifth driest in the 82 years of record from 1925–2006, with 28.29 inches of rainfall, a deficit of 10.67 inches or 73 percent of normal area precipitation (table 1). Water Year 1956 was the driest year, from the 1952–56 drought period, with only 22.90 inches of rainfall, a deficit of 16.06 inches or 59 percent of normal annual area precipitation.

Climate Division 4 West Central

Climate Division 4 West Central is in west-central Oklahoma. Water Year 2006 was the 28th driest in the 82 years of record from 1925–2006, with 23.46 inches of rainfall, a deficit of 3.09 inches or 88 percent of normal area precipitation (table 1). Water Year 1952 was the driest year, from the 1952–56 drought period, with only 15.98 inches of rainfall, a deficit of 10.57 inches or 60 percent of normal annual area precipitation.



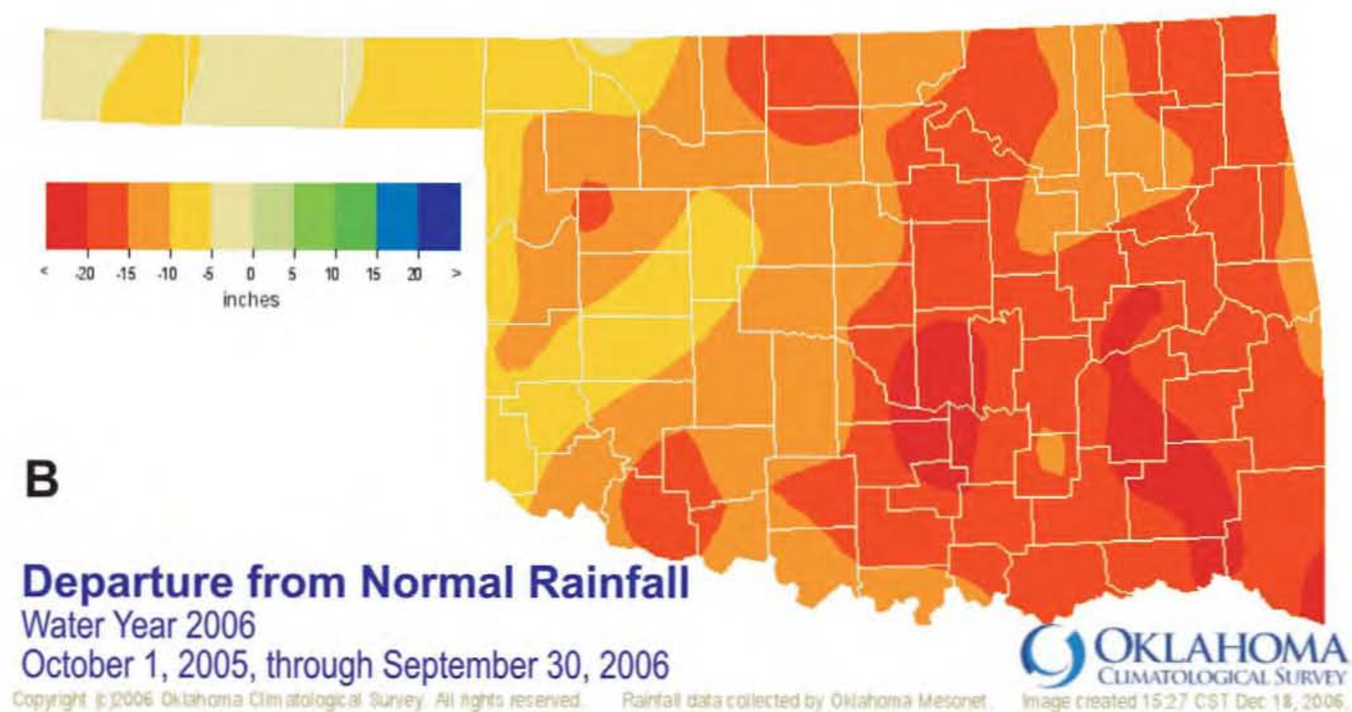


Figure 8. Oklahoma (*A*) percent of normal rainfall, Water Year 2006 (Oklahoma Climatological Survey, 2008a) (*B*) departure from normal rainfall, Water Year 2006 (Oklahoma Climatological Survey, 2008b).

Climate Division 5 Central

Climate Division 5 Central is in central Oklahoma. Water Year 2006 was the third driest in the 82 years of record from 1925–2006, with 24.17 inches of rainfall, a deficit of 9.56 inches or 72 percent of normal area precipitation (table 1). Water Year 1956 was the driest year, from the 1952–56 drought period, with only 19.74 inches of rainfall, a deficit of 13.99 inches or 59 percent of normal annual area precipitation.

Climate Division 6 East Central

Climate Division 6 East Central is in east-central Oklahoma. Water Year 2006 was the second driest in the 82 years of record from 1925–2006, with 27.70 inches of rainfall, a deficit of 15.21 inches or 65 percent of normal area precipitation (table 1). Water Year 1956 was the driest year, from the 1952–56 drought period, with only 23.86 inches of rainfall, a deficit of 19.05 inches or 56 percent of normal annual area precipitation.

Climate Division 7 Southwest

Climate Division 7 Southwest is in southwest Oklahoma. Water Year 2006 was the third driest in the 82 years of record from 1925–2006, with 18.59 inches of rainfall, a deficit of 8.97 inches or 67 percent of normal area precipitation (table 1). Water Year 1956 was the driest year, from the 1952–56 drought period, with only 17.45 inches of rainfall, a deficit of 10.11 inches or 63 percent of normal annual area precipitation.

Climate Division 8 South Central

Climate Division 8 South Central is in south-central Oklahoma. Water Year 2006 was the third driest in the 82 years of record from 1925–2006, with 24.45 inches of rainfall, a deficit of 12.18 inches or 67 percent of normal area precipitation (table 1). Water Year 1956 was the driest year, from the 1952–56 drought period, with only 16.46 inches of rainfall, a deficit of 20.17 inches or 45 percent of normal annual area precipitation.

Climate Division 9 Southeast

Climate Division 9 Southeast is in southeast Oklahoma. Water Year 2006 was the sixth driest in the 82 years of record from 1925–2006, with 34.89 inches of rainfall, a deficit of 13.62 inches or 72 percent of normal area precipitation (table 1). Water Year 1956 was the driest year, from the 1952–56 drought period, with only 25.10 inches of rainfall, a deficit of 23.41 inches or 52 percent of normal annual area precipitation.

Streamflow of Long-Term Sites

Twelve long-term streamflow-gaging sites with periods of record ranging from 62 to 78 years were selected to show how streamflow deficits varied by region (fig. 9, table 2). Two graphs are presented for each long-term site (figs. 10 to 21). The first graph is similar to the statewide runoff plot in figure 4. The annual mean streamflow (U.S. Geological Survey, 2007b) for each water year of the period of record is plotted as a departure bar from the long-term median annual flow (“normal” annual flow, blue line), and a 5-year weighted-average departure streamflow is plotted as a red line (A graphs). Wetter years plot above the median line and drier years plot below the median line. Water Year 2006 then can be compared to the dry years from the four previous major hydrologic droughts in the 20th century by the depth of bars. The length and severity of the water year 2002–2006 drought period in terms of streamflow deficit can be compared to the four previous major hydrologic droughts by the 5-year weighted average line.

The second graph shows a comparison of the daily-mean flow from Water Year 2006 (red line; U.S. Geological Survey, 2008d) to the long-term daily mean flow (blue line; U.S. Geological Survey, 2008e) and provides an indication of how the streamflow deficits changed seasonally (B graphs).

Table 2 shows how Water Year 2006 streamflow from each long-term site compares with the driest year from each of the four previous major hydrologic droughts in the 20th century, and shows the rank and percent of long-term median-annual flow (“normal”) for each low-flow year. Statewide runoff during the driest years also is ranked. Statewide runoff in Water Year 2006 was sixth driest in the 82 years of record from 1925-2006.

Salt Fork Arkansas River at Tonkawa

Salt Fork Arkansas River at Tonkawa (07151000) is a streamflow-gaging site in north-central Oklahoma. Water Year 2006 was the sixth driest in the 65 years of record from 1942–2006, with just 19 percent of normal annual flow (table 2). Water Year 1954 was the driest year, from the 1952–56 drought period, with 12 percent of normal annual flow. Zero flow was not recorded during Water Year 2006, with some wet periods in November, May, and June (fig. 10). The lowest flow was at the end of the water year in August and September (fig. 10; appendix 1; U.S. Geological Survey, 2008c).

Chikaskia River near Blackwell

Chikaskia River near Blackwell (07152000) is a streamflow-gaging site in north-central Oklahoma. Water Year 2006 was the 15th driest in the 70 years of record from 1937–2006, with 45 percent of normal annual flow (table 2). Water Year 1954 was the driest year, from the 1952–56 drought period,

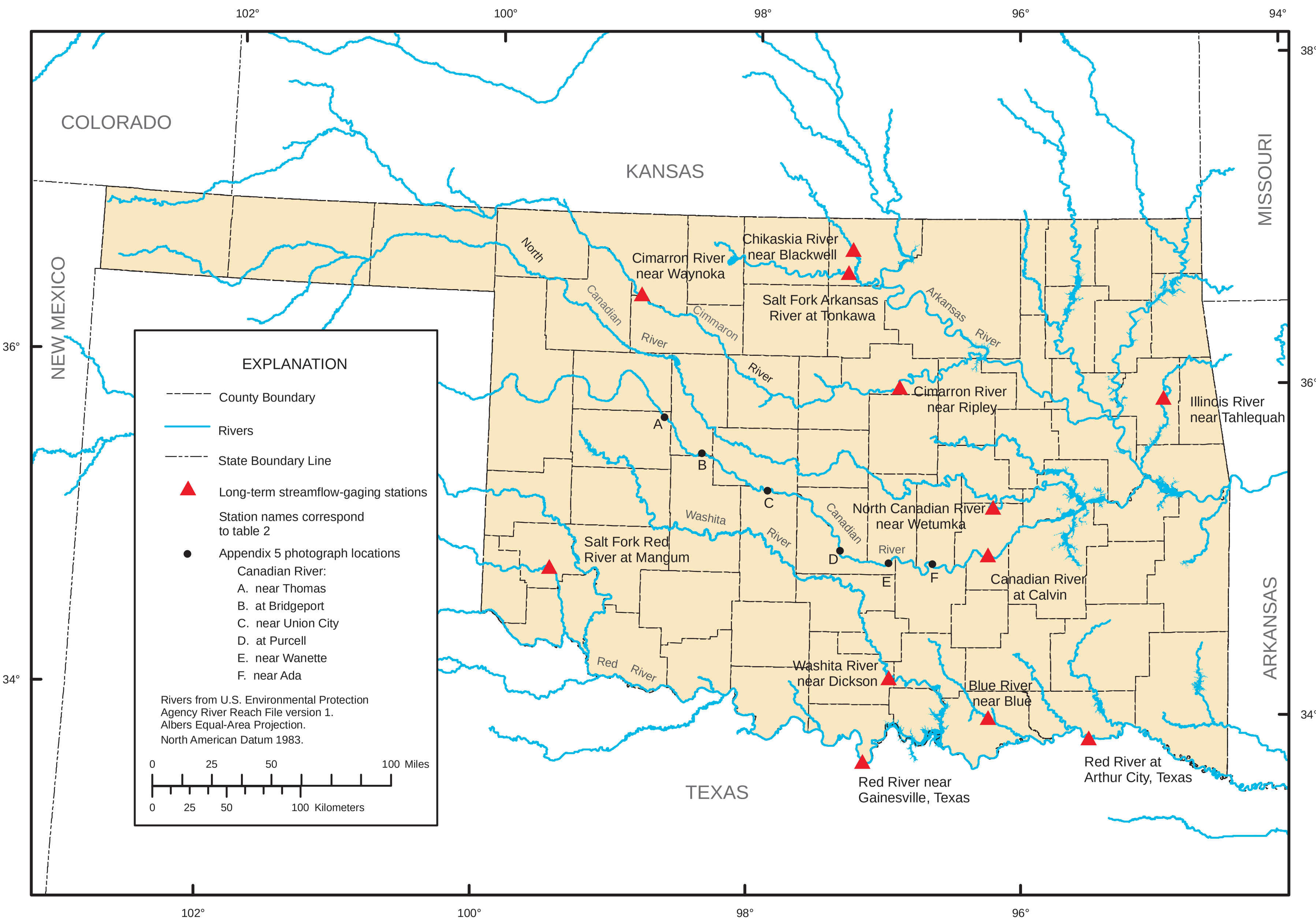


Figure 9. Selected long-term streamflow-gaging stations in Oklahoma and Canadian River photograph locations.

Table 2. Summary of streamflow conditions at selected long-term streamflow-gaging stations in Oklahoma comparing the median of mean annual streamflow (measure of "normal" streamflow) with average annual streamflow during periods of previous documented hydrologic droughts and the recent hydrologic drought period.

[yr, year; avg, average; Rank, rank of driest year of drought period out of period of record; mi², square miles; N, nonregulated; R, regulated; WY, water year; ft³/s, cubic feet per second; SW, statewide]

Site no.	Station number	Station name	Contributing drainage area (mi²)	Type of record (N/R)	Continuous record period of record (complete WY)	Years of record	Long-term annual median (ft³/s)
SW		Statewide [1]			1925-2006 [1]	82	
1	07151000	Salt Fork Arkansas River at Tonkawa, Okla.	4,520	R	1942-2006	65	808
2	07152000	Chikaskia River near Blackwell, Okla.	1,859	N	1937-2006	70	480
3	07158000	Cimarron River near Waynoka, Okla.	8,504	N	1938-2006	69	231
4	07161450	Cimarron River near Ripley, Okla. [2]	13,053	N	1940-2006	67	1,345
5	07196500	Illinois River near Tahlequah, Okla.	959	N	1936-2006	71	919
6	07231500	Canadian River at Calvin, Okla.	23,151	N,R	1939-42, 1945-2006	66	1,376
7	07242000	North Canadian River near Wetumka, Okla.	9,391	R	1938-2006	69	683
8	07300500	Salt Fork Red River at Mangum, Okla.	1,357	N	1938-2006	69	71.8
9	07316000	Red River near Gainesville, Texas	24,846	N,R	1937-2006	70	2,535
10	07331000	Washita River near Dickson, Okla.	7,202	N,R	1929-2006	78	1,400
11	07332500	Blue River near Blue, Okla.	476	N	1937-2006	70	254
12	07335500	Red River at Arthur City, Texas	38,595	R	1945-2006	62	7,223

[1] Ranks from Statewide Annual Runoff Summary USGS Waterwatch web page, U.S. Geological Survey (2007a) Although there is record from continuous streamflow gages since WY 1903, there were few operating gages and gaps where no gages were operating prior to 1925.

[2] Includes streamflow record 1940-87 from nearby station 07161000, Cimarron River at Perkins, Okla.

[3] Documented drought periods are modified from Tortorelli and others, 1991.

[4] Station records do not span entire drought period

Table 2. Summary of streamflow conditions at selected long-term streamflow-gaging stations in Oklahoma comparing the median of mean annual streamflow (measure of "normal" streamflow) with average annual streamflow during periods of previous documented hydrologic droughts and the recent hydrologic drought period.—Continued

[yr, year; avg, average; Rank, rank of driest year of drought period out of period of record; mi^2, square miles; N, nonregulated; R, regulated; WY, water year; ft^3/s, cubic feet per second; SW, statewide]

	Hydrologic Drought Periods											
	1929-41 [3]		1952-56 [3]		1961-72 [3]		1976-1981 [3]		2002-2006		2006	
	Lowest yr / Rank		Lowest yr / Rank		Lowest yr / Rank		Lowest yr / Rank		Lowest yr / Rank			Rank
Site no.	Avg annual flow (ft^3/s)	Percent long-term median	Avg annual flow (ft^3/s)	Percent long-term median	Avg annual flow (ft^3/s)	Percent long-term median	Avg annual flow (ft^3/s)	Percent long-term median	Avg annual flow (ft^3/s)	Percent long-term median	Avg annual flow (ft^3/s)	Percent long-term median
SW	**1940**	**1**	**1953**	**2**	**1964**	**4**	**1981**	**7**	**2006**	**6**		**6**
1	**NA**		**1954**	**1**	**1964**	**3**	**1981**	**13**	**2006**	**6**		**6**
			95.5	12%	137	17%	280	35%	157	19%	157	19%
2	**1940 [4]**	**2**	**1954**	**1**	**1966**	**4**	**1981**	**7**	**2006**	**15**		**15**
	76.6	16%	71.0	15%	97.6	20%	152	32%	217	45%	217	45%
3	**1939 [4]**	**26**	**1956**	**5**	**1971**	**4**	**1977**	**17**	**2002**	**3**		**10**
	174	75%	53.6	23%	46.7	20%	134	58%	46.0	20%	96.1	42%
4	**1940 [4]**	**4**	**1953**	**1**	**1971**	**2**	**1981**	**11**	**2006**	**12**		**12**
	307	23%	235	17%	294	22%	455	34%	491	37%	491	37%
5	**1940 [4]**	**6**	**1954**	**1**	**1964**	**3**	**1981**	**5**	**2006**	**8**		**8**
	279	30%	193	21%	239	26%	275	30%	289	31%	289	31%
6	**1940 [4]**	**8**	**1956**	**6**	**1966**	**3**	**1981**	**1**	**2006**	**2**		**2**
	478	35%	393	29%	217	16%	184	13%	190	14%	190	14%
7	**1940 [4]**	**2**	**1956**	**1**	**1963**	**3**	**1981**	**5**	**2006**	**4**		**4**
	157	23%	156	23%	166	24%	178	26%	176	26%	176	26%
8	**1940 [4]**	**1**	**1952**	**4**	**1971**	**2**	**1981**	**5**	**2006**	**3**		**3**
	12.3	17%	17.5	24%	12.5	17%	22.7	32%	14.4	20%	14.4	20%
9	**1939 [4]**	**5**	**1953**	**2**	**1964**	**3**	**1983**	**12**	**2006**	**1**		**1**
	1,010	40%	651	26%	654	26%	1,274	50%	567	22%	567	22%
10	**1939 [4]**	**3**	**1956**	**5**	**1964**	**1**	**1981**	**7**	**2006**	**2**		**2**
	391	28%	441	31%	340	24%	495	35%	384	27%	384	27%
11	**1939 [4]**	**2**	**1956**	**1**	**1964**	**9**	**1980**	**4**	**2006**	**5**		**5**
	42.9	17%	30.8	12%	114	45%	77.7	31%	79.5	31%	79.5	31%
12	**NA**		**1952**	**9**	**1964**	**2**	**1980**	**3**	**2006**	**1**		**1**
			4,182	58%	2,754	38%	2,953	41%	1,794	25%	1,794	25%

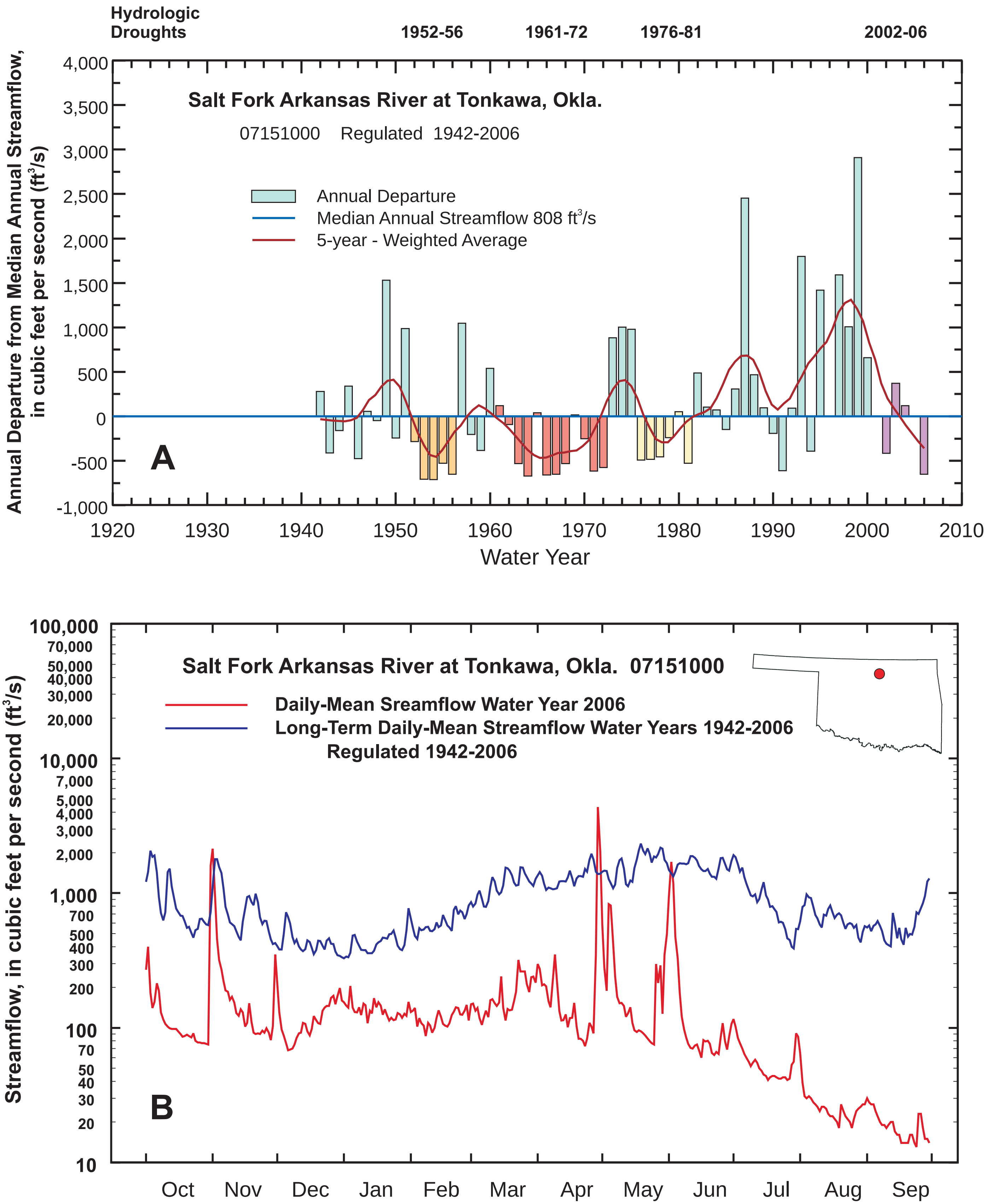


Figure 10. Salt Fork Arkansas River at Tonkawa (*A*) annual departure from long-term median annual streamflow, water years 1942–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1942–2006.

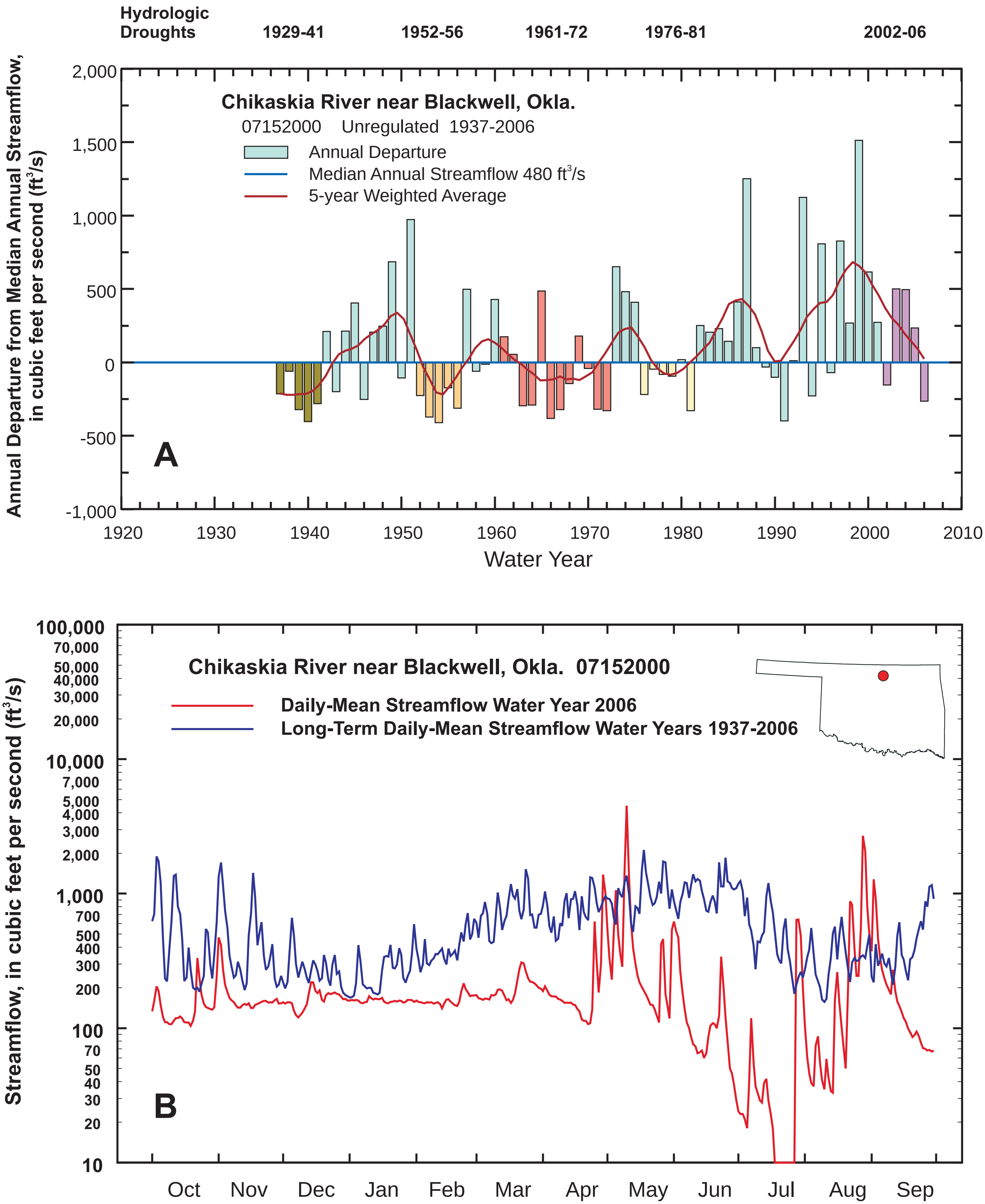


Figure 11. Chikaskia River near Blackwell (*A*) annual departure from long-term median annual streamflow, water years 1937–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1937–2006.

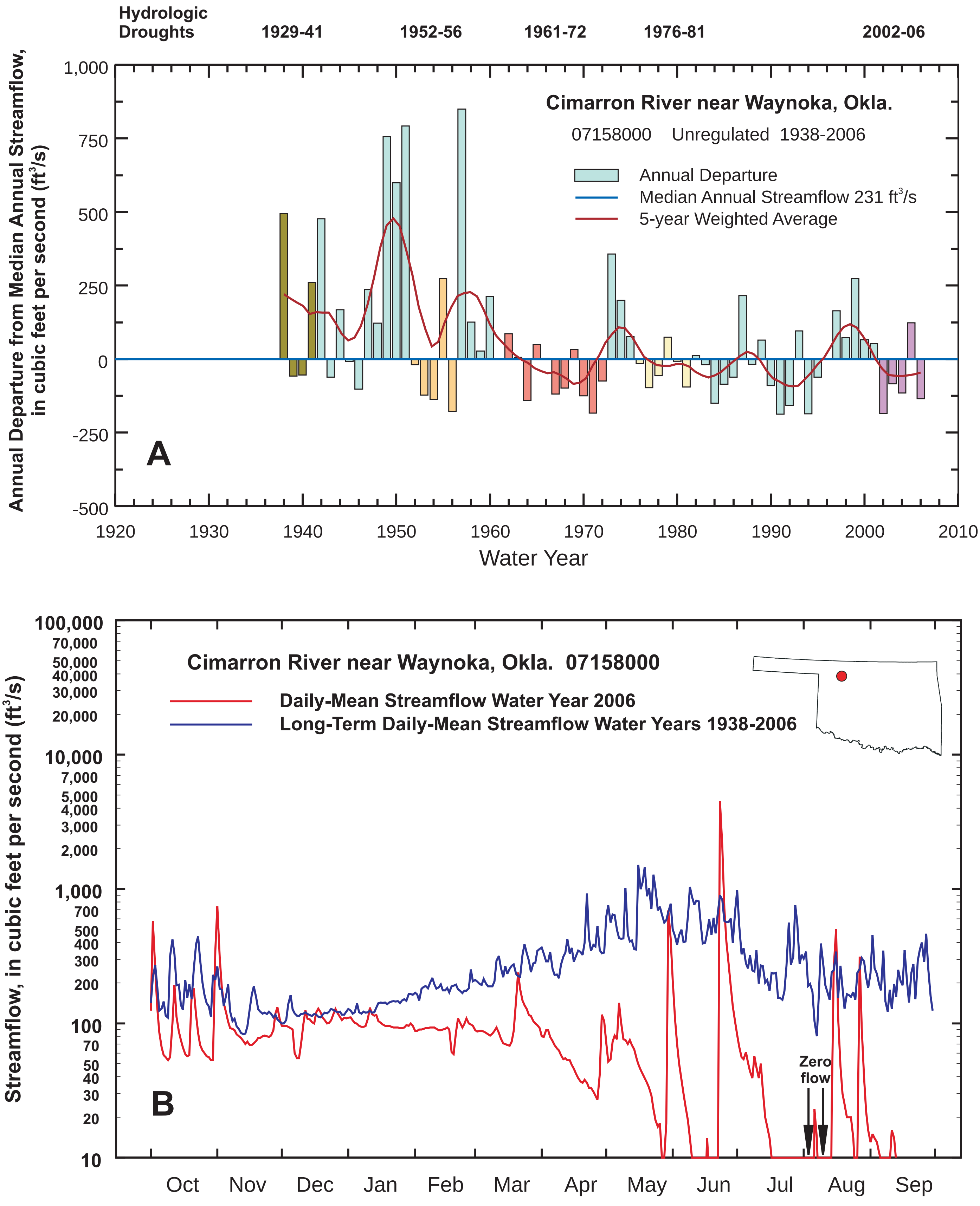


Figure 12. Cimarron River near Waynoka (*A*) annual departure from long-term median annual streamflow, water years 1938–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1938–2006.

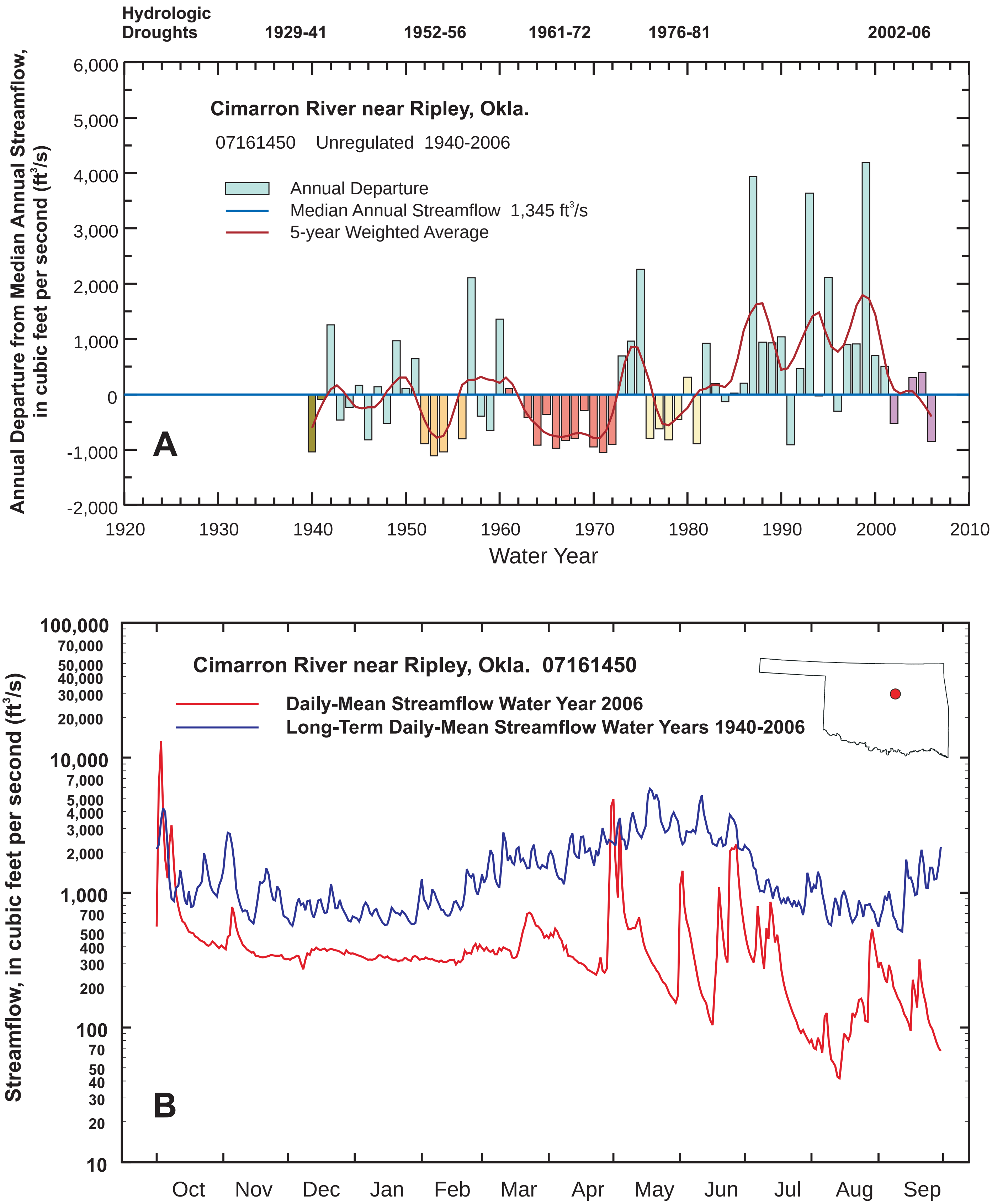


Figure 13. Cimarron River near Ripley (*A*) annual departure from long-term median annual streamflow, water years 1940–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1940–2006. Includes streamflow record 1940–87 from nearby station 0716100, Cimarron River at Perkins.

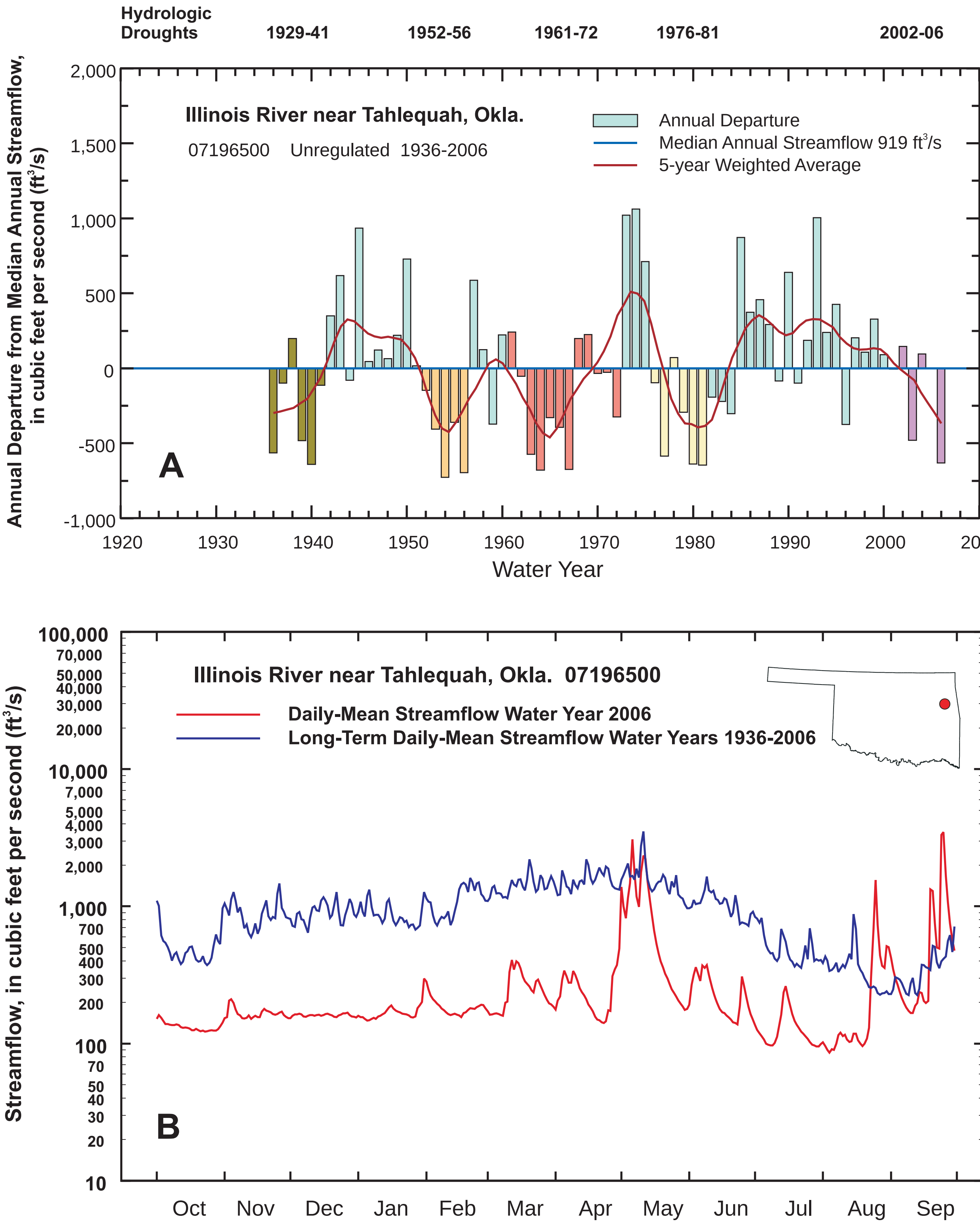


Figure 14. Illinois River near Tahlequah (*A*) annual departure from long-term median annual streamflow, water years 1936–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1936–2006.

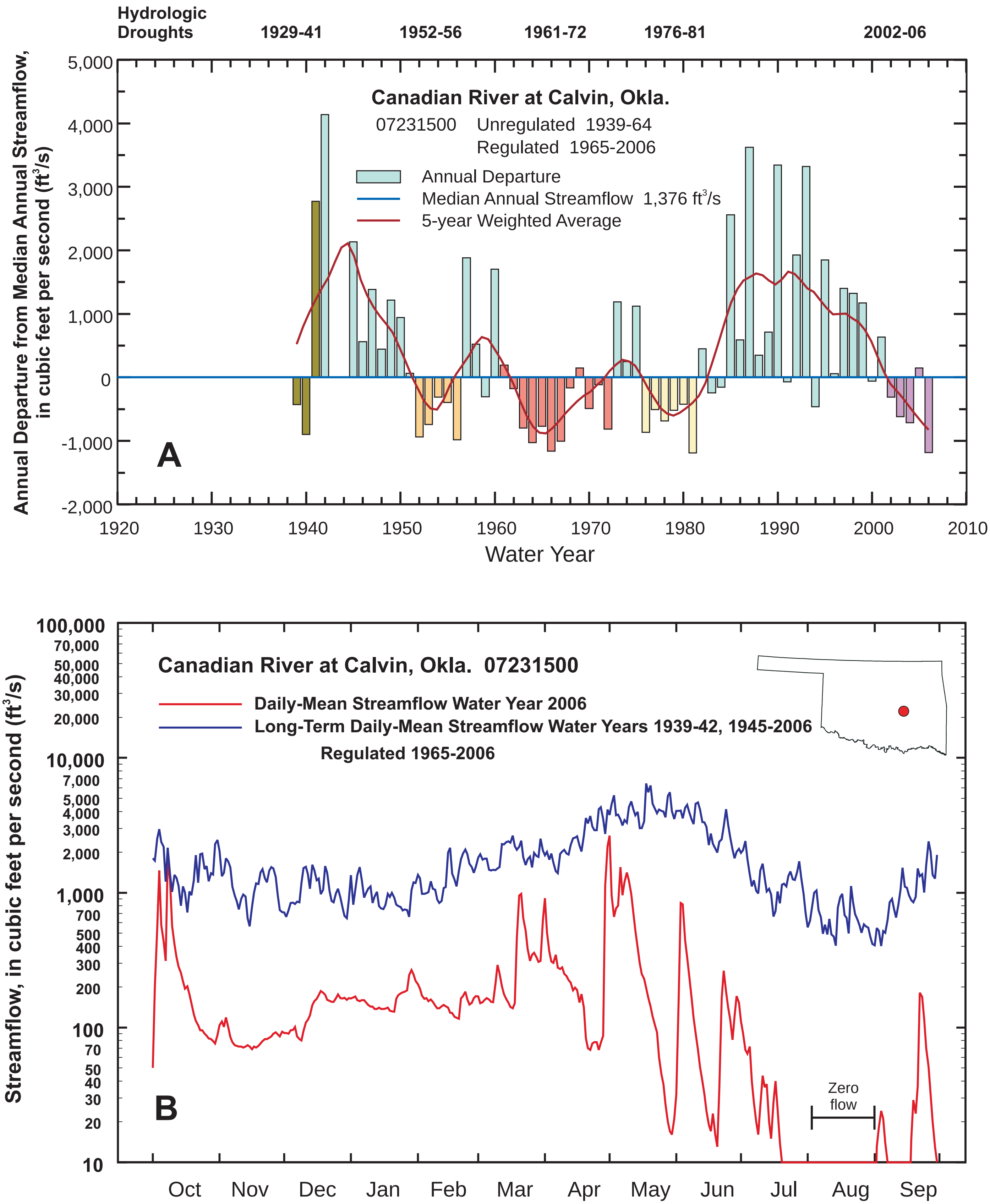


Figure 15. Canadian River at Calvin (*A*) annual departure from long-term median annual streamflow, water years 1939–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1939–2006.

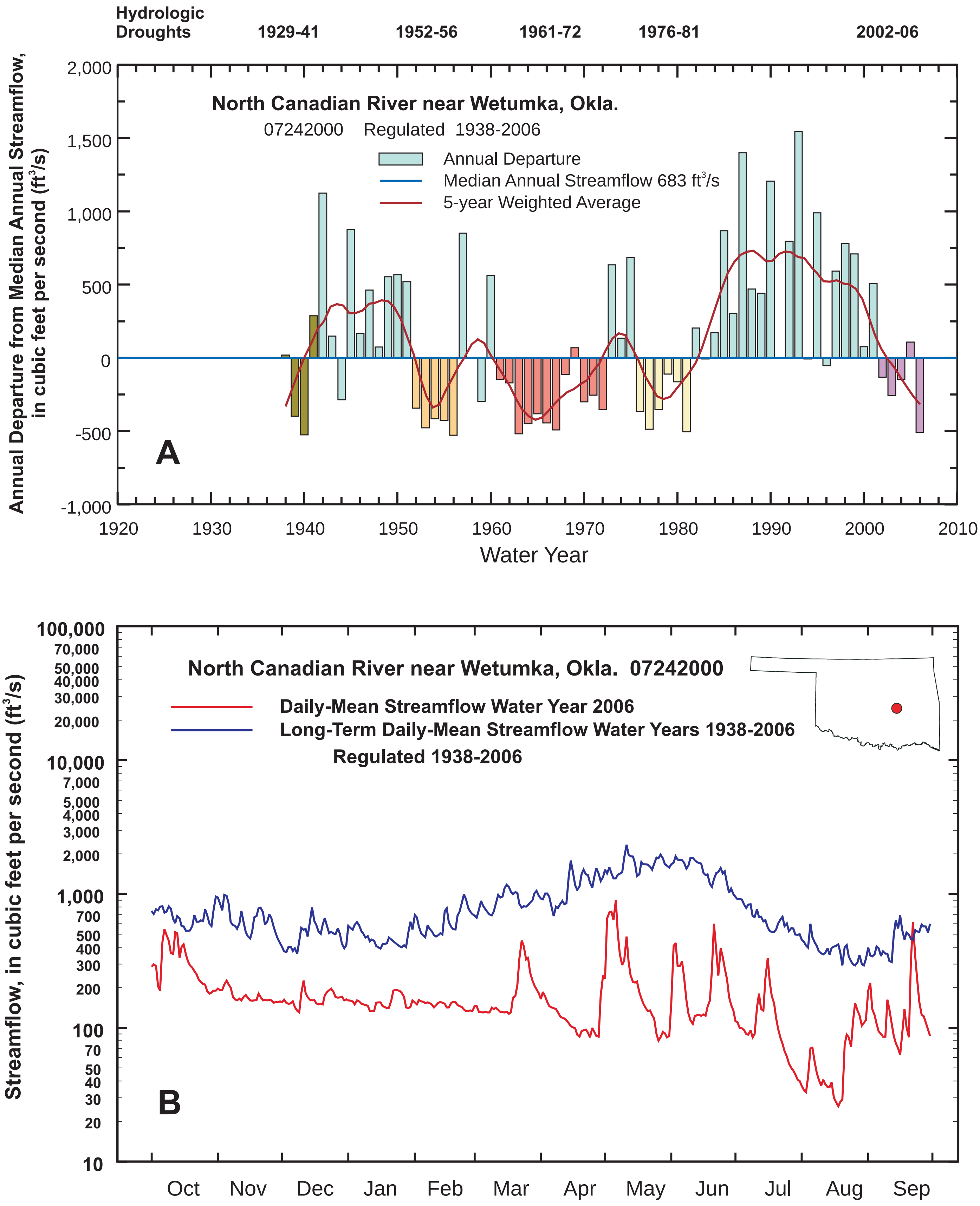
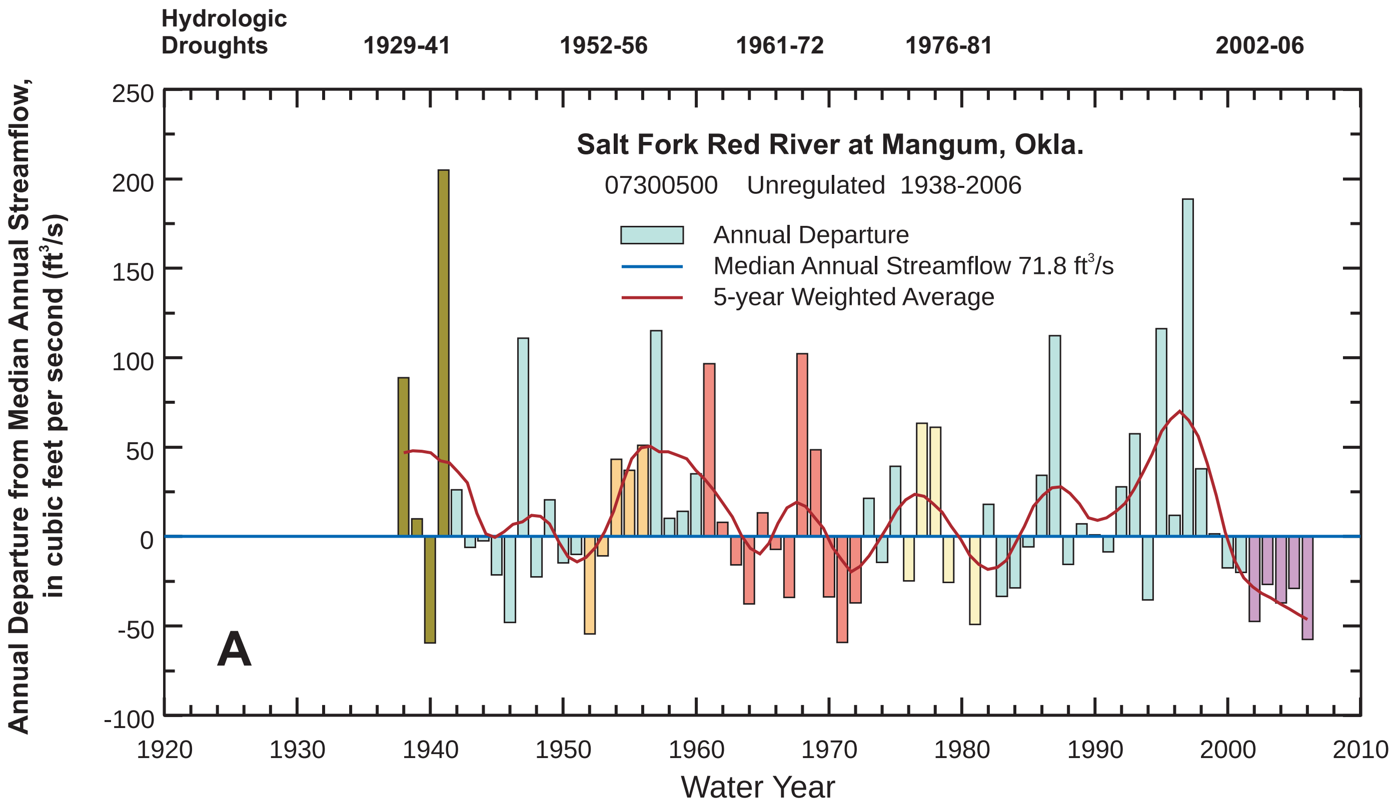


Figure 16. North Canadian River near Wetumka (*A*) annual departure from long-term median annual streamflow, water years 1938–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1938–2006.



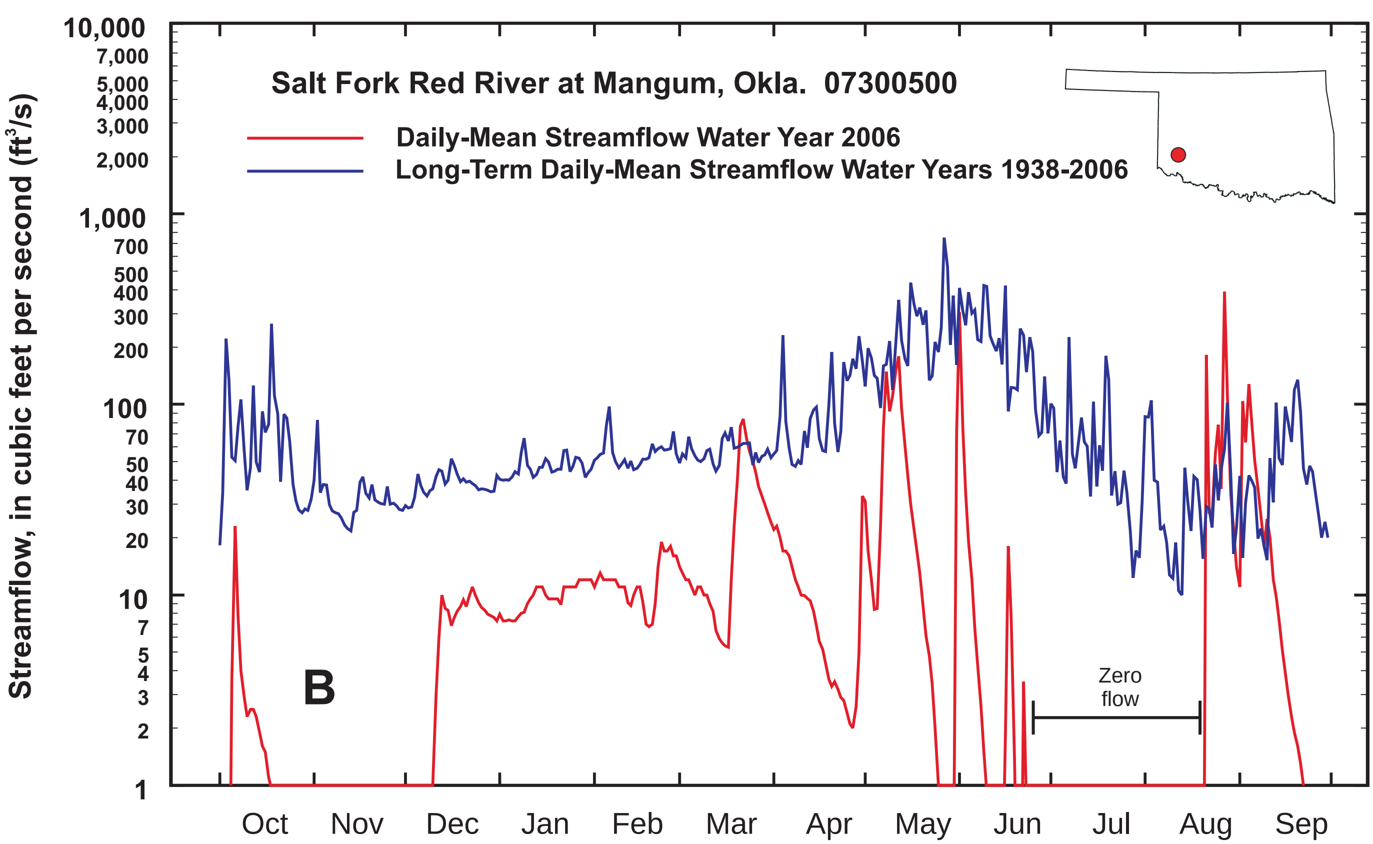


Figure 17. Salt Fork Red River at Mangum (*A*) annual departure from long-term median annual streamflow, water years 1938–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1938–2006.

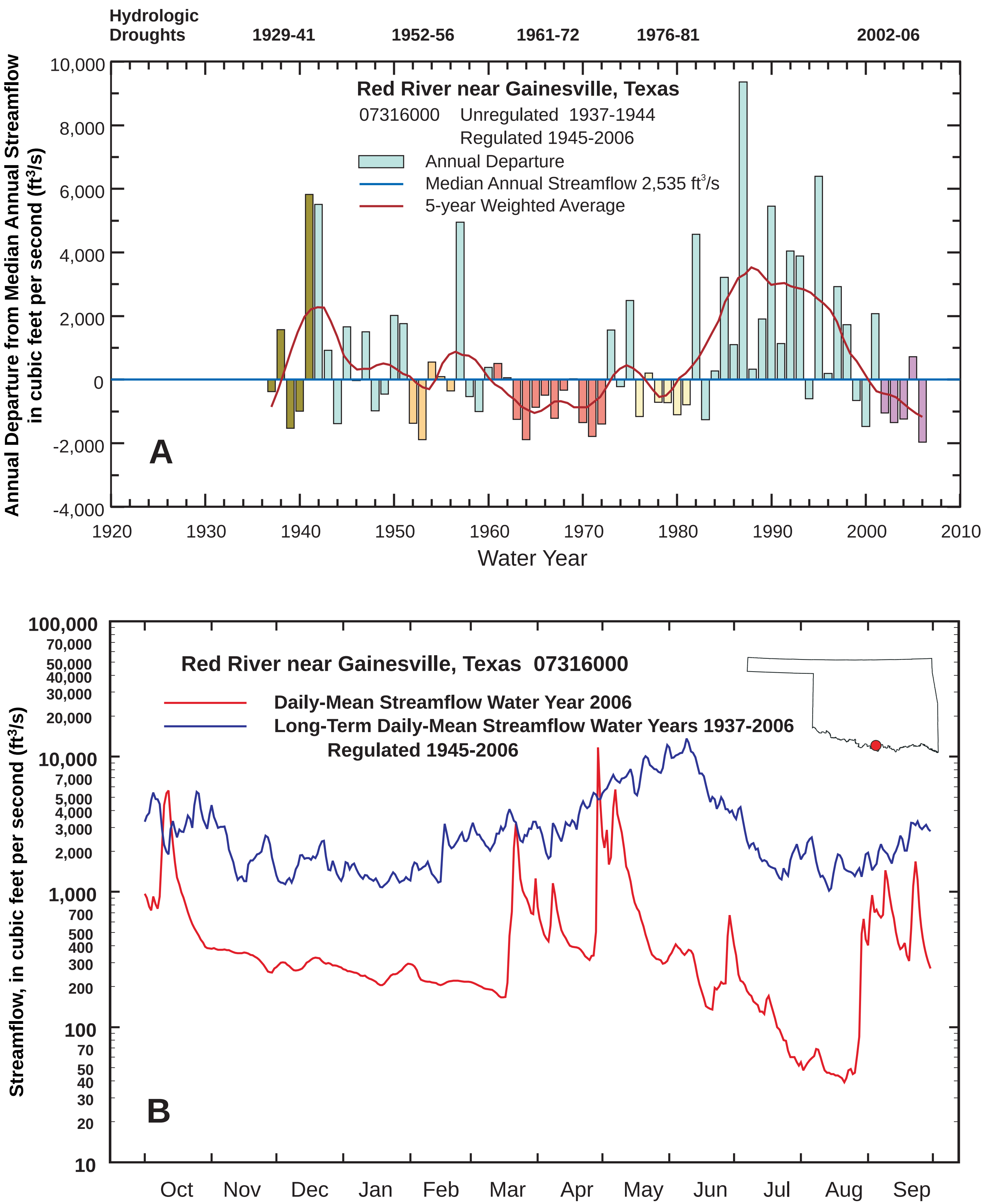


Figure 18. Red River near Gainesville, Texas, (*A*) annual departure from long-term median annual streamflow, water years 1937–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1937–2006.

with 15 percent of normal annual flow. Zero flow was not recorded during Water Year 2006, with some wet periods in November, April-May, and August-September (fig. 11). The lowest flow was near the end of the water year in July (fig. 11; appendix 2; U.S. Geological Survey, 2008c).

Cimarron River near Waynoka

Cimarron River near Waynoka (07158000) is a streamflow-gaging site in northwest Oklahoma. Water Year 2006 was the 10th driest in the 69 years of record from 1938–2006, with 42 percent of normal annual flow (table 2). Water Year 2002 was the third driest year, from the 2002–2006 drought period, with 20 percent of normal annual flow. Zero flow was recorded in Water Year 2006 during the first part of August (fig. 12). The lowest flow was at the end of the water year in first part of August and last part of September (fig. 12; appendix 3; U.S. Geological Survey, 2008c).

Cimarron River near Ripley

Cimarron River near Ripley (07161450) is a streamflow-gaging site in central Oklahoma. Water Year 2006 was the 12th driest in the 67 years of record from 1940–2006, with 37 percent of normal annual flow (table 2). Water Year 1953 was the driest year, from the 1952–56 drought period, with 17 percent of normal annual flow. Zero flow was not recorded during Water Year 2006, with some wet periods in October, May-July, and August-September (fig. 13). The lowest flow was near the end of the water year in August (fig. 13; appendix 4; U.S. Geological Survey, 2008c).

Illinois River near Tahlequah

Illinois River near Tahlequah (07196500) is a streamflow-gaging site in east-central Oklahoma. Water Year 2006 was the 8th driest in the 71 years of record from 1936–2006, with just 31 percent of normal annual flow (table 2). Water Year 1954 was the driest year, from the 1952–56 drought period, with 21 percent of normal annual flow. Zero flow was not recorded during Water Year 2006, with some wet periods in May, August, and September (fig. 14). The lowest flow was near the end of the water year in August (fig. 14; U.S. Geological Survey, 2008c).

Canadian River at Calvin

Canadian River at Calvin (07231500) is a streamflow-gaging site in east-central Oklahoma. Water Year 2006 was the second driest in the 66 years of record from 1939–42, 1945-2006; with just 14 percent of normal annual flow (table 2). Water Year 1981 was the driest year, from the 1976-81 drought period, with 13 percent of normal annual flow. Zero flow was recorded in Water Year 2006 during most of the month of August with some wet periods in October and March through June (fig. 15). The lowest flow was at the end of the water year in August and September (fig. 15; U.S. Geological Survey, 2008c).

Daniel Fenner of U.S. Fish and Wildlife Service (written commun., 2006) photographically documented no flow or little flow during mid-August on the reach of the Canadian River near Thomas upstream from the streamflow-gaging site at Bridgeport to near Ada, just upstream from the streamflow-gaging site at Calvin (fig. 9, appendix 5).

North Canadian River near Wetumka

North Canadian River near Wetumka (07242000) is a streamflow-gaging site in central Oklahoma. Water Year 2006 was the fourth driest in the 69 years of record from 1938–2006, with just 26 percent of normal annual flow (table 2). Water Year 1956 was the driest year, from the 1952–56 drought period, with 23 percent of normal annual flow. Zero flow was not recorded during Water Year 2006, with some wet periods in October, March through June and September (fig. 16). The lowest flow was near the end of the water year in August (fig. 16; U.S. Geological Survey, 2008c).

Salt Fork Red River at Mangum

Salt Fork Red River near Mangum (07300500) is a streamflow-gaging site in southwest Oklahoma. Water Year 2006 was the third driest in the 69 years of record from 1938–2006, with just 20 percent of normal annual flow (table 2). Water Year 1940 was the driest year, from the 1929–41 drought period, with 17 percent of normal annual flow. Zero flow was recorded in Water Year 2006 during late June through August, with some wet periods in October, March through June and late August and September (fig. 17; U.S. Geological Survey, 2008c). Low flow was recorded from October through March, and some days in April through September (fig. 17).

Red River near Gainesville, Texas

Red River near Gainesville, Texas, (07316000) is a streamflow-gaging site in south-central Oklahoma. Water Year 2006 was the driest in the 70 years of record from 1937–2006, with just 22 percent of normal annual flow (table 2). Water Year 1953 was second driest year, from the 1952–56 drought period, with 26 percent of normal flow. Zero flow was not recorded during Water Year 2006, with some wet periods in October, March, May, and September (fig. 18). The lowest flow was near the end of the water year in August (fig. 18, U.S. Geological Survey, 2008c).

Washita River near Dickson

Washita River near Dickson (07331000) is a streamflow-gaging site in south-central Oklahoma. Water Year 2006 was the second driest in the 78 years of record from 1929–2006, with just 27 percent of normal annual flow (table 2). Water Year 1964 was the driest year, from the 1961–72 drought period, with 24 percent of normal annual flow. Zero flow was not recorded during Water Year 2006, with some wet periods in October, March, May, and September (fig. 19). The lowest flow was near the end of the water year in August (fig. 19; appendix 6; U.S. Geological Survey, 2008c).

Blue River near Blue

Blue River near Blue (07332500) is a streamflow-gaging site in south-central Oklahoma. Water Year 2006 was the fifth driest in the 70 years of record from 1937–2006, with just 31 percent of normal annual flow (table 2). Water Year 1956 was the driest year, from the 1952-56 drought period, with 12 percent of normal annual flow. Zero flow was not recorded during Water Year 2006, with some wet periods in March through May (fig. 20). The lowest flow was near the end of the water year in August and September (fig. 20; U.S. Geological Survey, 2008c).

Red River at Arthur City, Texas

Red River at Arthur City, Texas (07335500) is a streamflow-gaging site in southeast Oklahoma. Water Year 2006 was the driest in the 62 years of record from 1945–2006, with just 25 percent of normal annual flow (table 2). Water Year 1964 was the second driest year, from the 1961–72 drought period, with 38 percent of normal annual flow. Zero flow was not recorded during Water Year 2006, with some wet periods in March through May (fig. 21). The lowest flow was near the end of the water year in August and September (fig. 21; U.S. Geological Survey, 2008c).

Effects of Low Streamflows

Hydrologic drought is associated with the effects of periods of precipitation deficits on streamflow, lake and reservoir levels, and ground water. Although all droughts start with precipitation deficits, hydrologists are more concerned with how this deficit affects the hydrologic system. Hydrologic droughts commonly lag the meteorological and agricultural droughts. During hydrologic droughts, precipitation deficiencies take longer to show up in components of the hydrologic system. For example, precipitation deficits may result in a rapid depletion of soil moisture that has an immediate effect on agriculture (Jackson, 2006a), but the effect on reservoir levels may not affect water supply, hydroelectric power production, or recreational uses for several months. Water in the hydrologic storage systems, rivers and reservoirs, commonly has multiple and competing purposes including flood control, irrigation, recreation, navigation, hydropower, and wildlife habitat. Competition for this water escalates during drought and conflicts between water users increase substantially (National Drought Mitigation Center, 2006a).

Conditions at Major Reservoirs

The hydrologic drought of Water Year 2006 substantially affected the reservoirs in the state. The effects on 31 selected major lakes or reservoirs at three times of the water year are presented in table 3 (fig. 22; Oklahoma Water Resources Board, 2006b; U.S. Army Corps of Engineers, 2007). Table 3 shows the conservation storage in these lakes, expressed both in terms of volume and percent of conservation storage, on October 4, 2006, a few days after the end of the Water Year 2006. On that day the statewide total conservation storage was 86.3 percent. Table 3 also compares levels at these reservoirs, expressed as percent of conservation storage, on two other days: (1) the levels on December 21, 2005, when the statewide total conservation storage was lowest, 84.5 percent, and (2) May 24, 2006, when the statewide total conservation storage was the highest, 96.8 percent. The north-central region of the state consistently had the highest percent of conservation storage (or wettest) while the southwest region of the state consistently had the lowest percent of conservation storage (or driest) at all three times of the water year. Lake Altus at Lugert (site 21, fig. 22) in the southwest region was the driest reservoir for the entire water year (appendix 7).

Lake Eufaula (site 18, fig. 22) is a good example of the dependence several water-use customers have on the reservoirs. Six municipalities, eight rural water districts, a hydroelectric plant, and natural gas plant all use water from the lake in addition to recreational use (Jackson, 2006b). However, it must be noted that the condition of farm ponds across Oklahoma was more drastically affected than the major reservoirs. Hundreds of farm ponds across Oklahoma had completely dried up by January 15, 2006 (Jackson, 2006b).

Hydroelectric Power Generation

Hydroelectric power in Oklahoma was greatly reduced during Water Year 2006 because of reduction in available streamflow as a result of the hydrologic drought. Table 4 illustrates the drastic reduction in hydroelectric power generation at selected hydroelectric plants from Calendar Year 2005 to Water Year 2006. Even though there was a 3-month overlap between October through December 2005, the Water Year 2006 hydroelectric power generation at sites in Oklahoma was only 7 to 47 percent of the Calendar Year 2005 power generation (table 4).

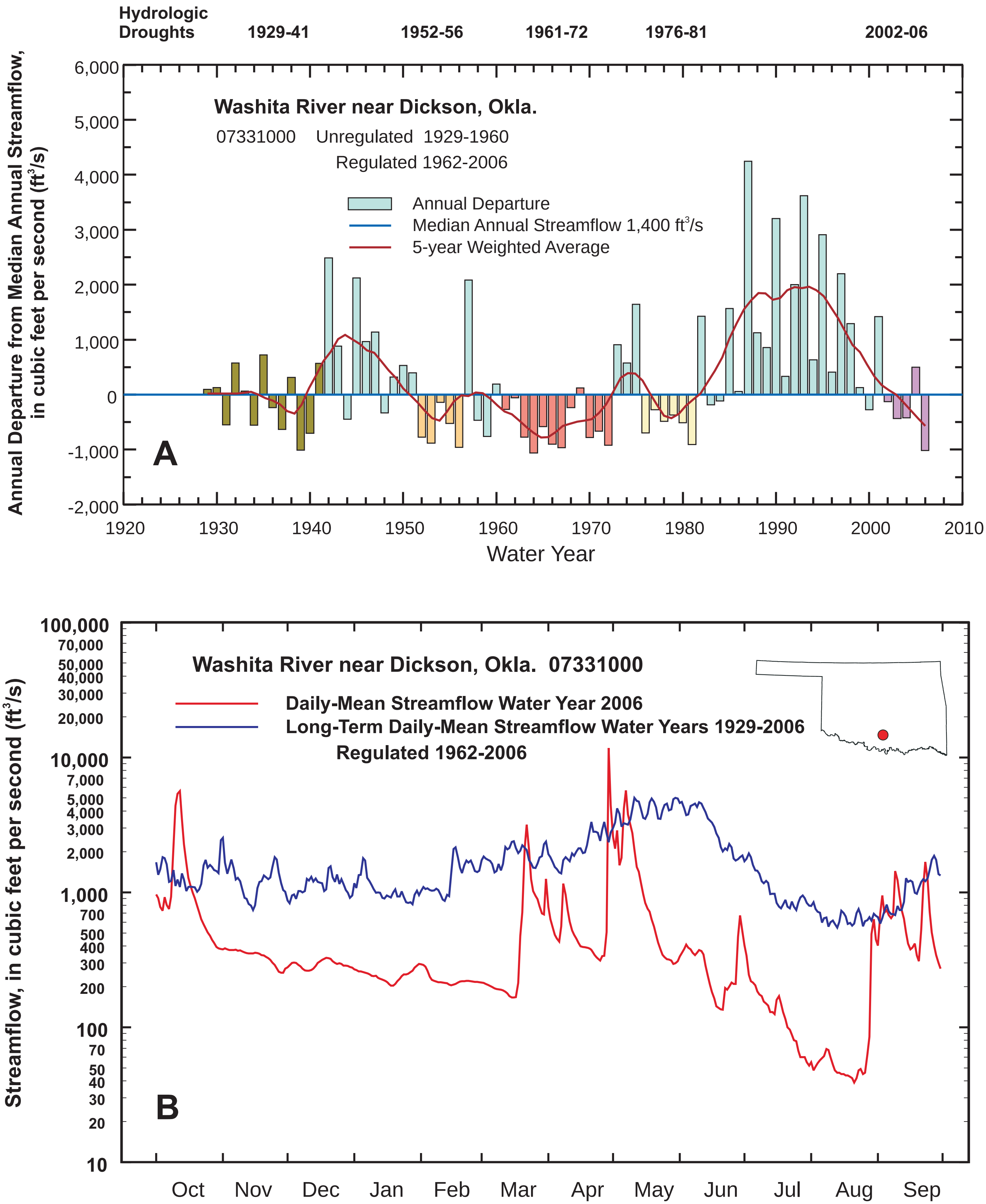


Figure 19. Washita River near Dickson (*A*) annual departure from long-term median annual streamflow, water years 1929–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1929–2006.

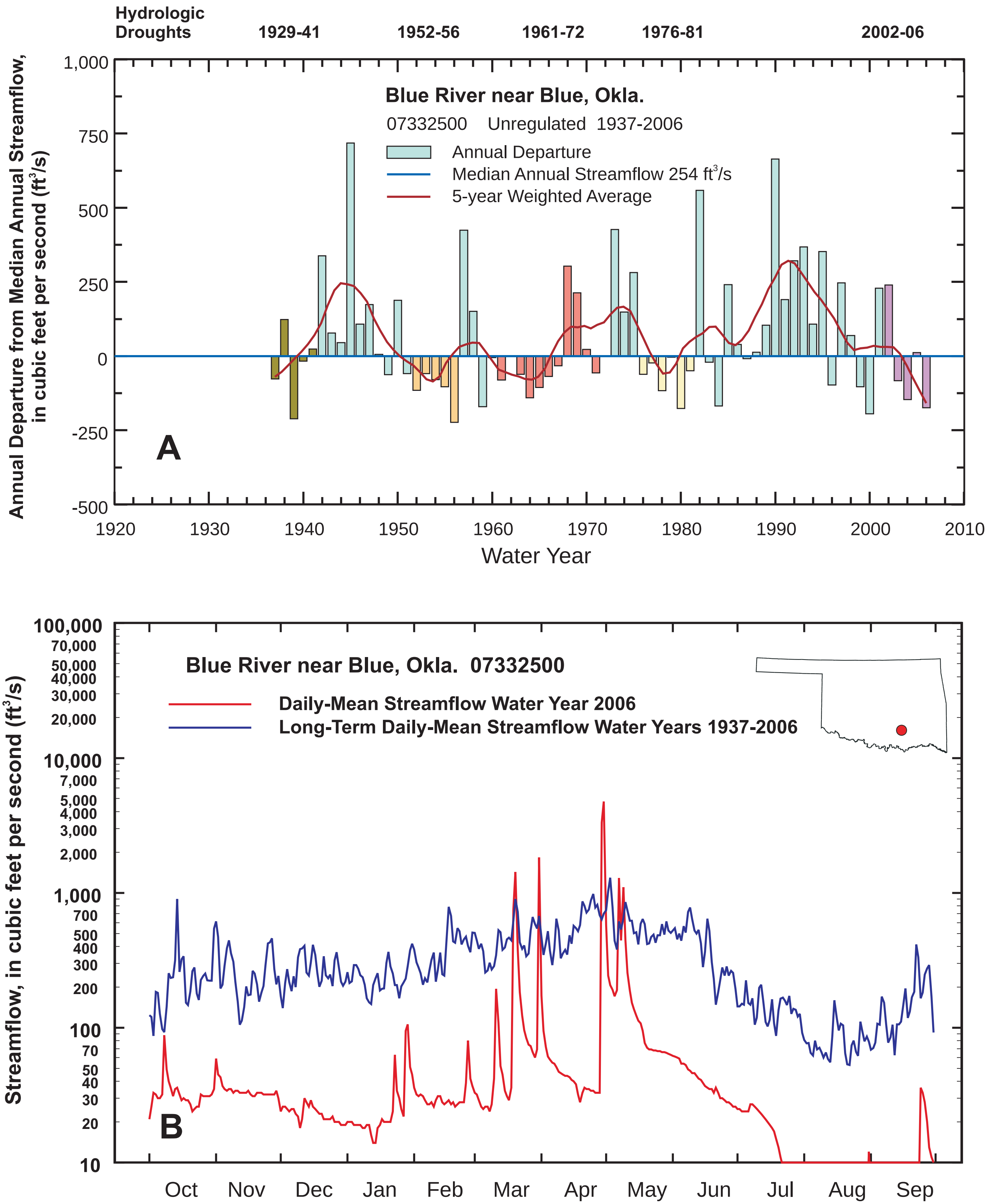


Figure 20. Blue River near Blue (*A*) annual departure from long-term median annual streamflow, water years 1937–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1937–2006.

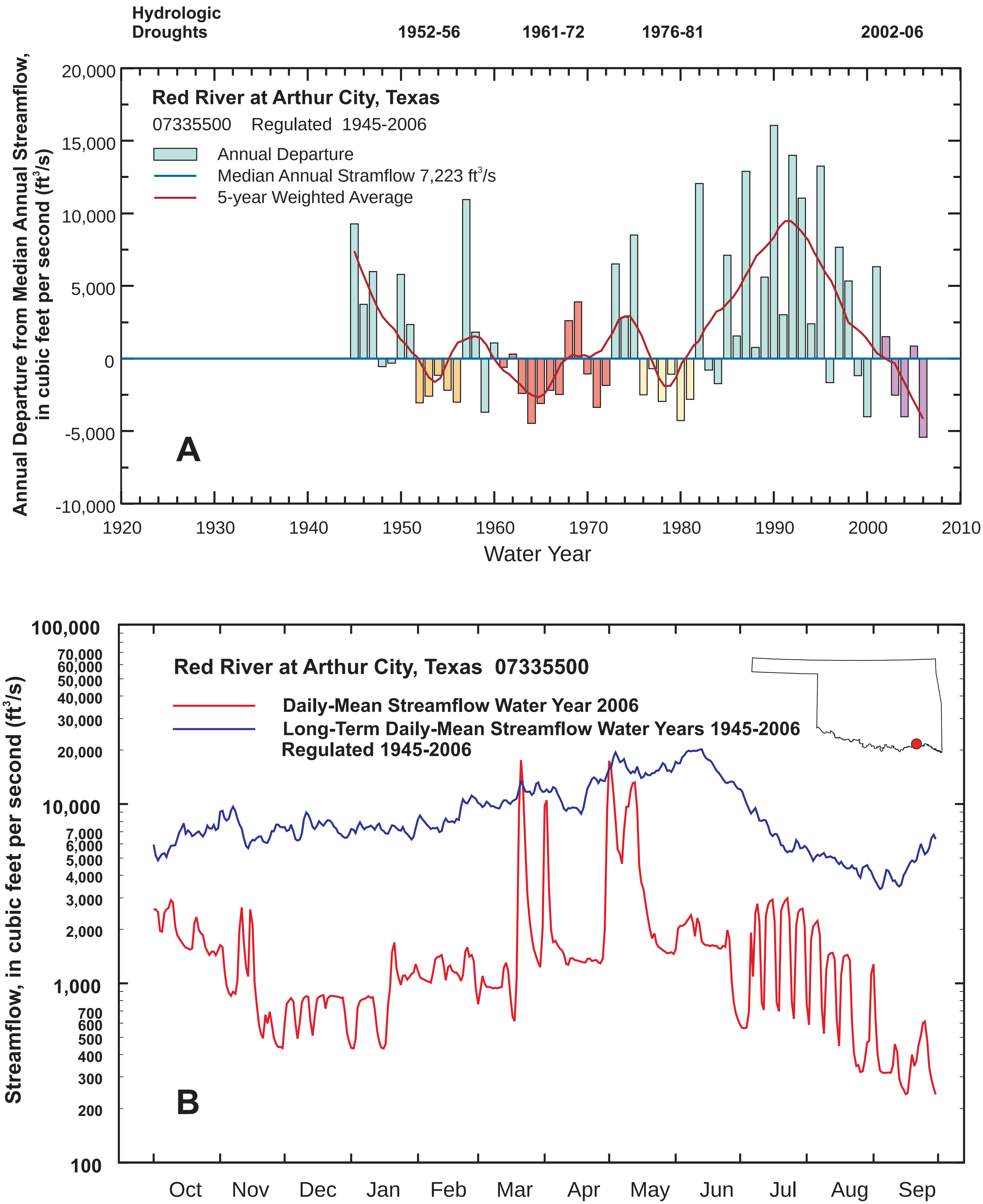


Figure 21. Red River at Arthur City, Texas, (*A*) annual departure from long-term median annual streamflow, water years 1945–2006 (*B*) comparing daily-mean streamflow of Water Year 2006 and long-term daily-mean streamflow, water years 1945–2006.

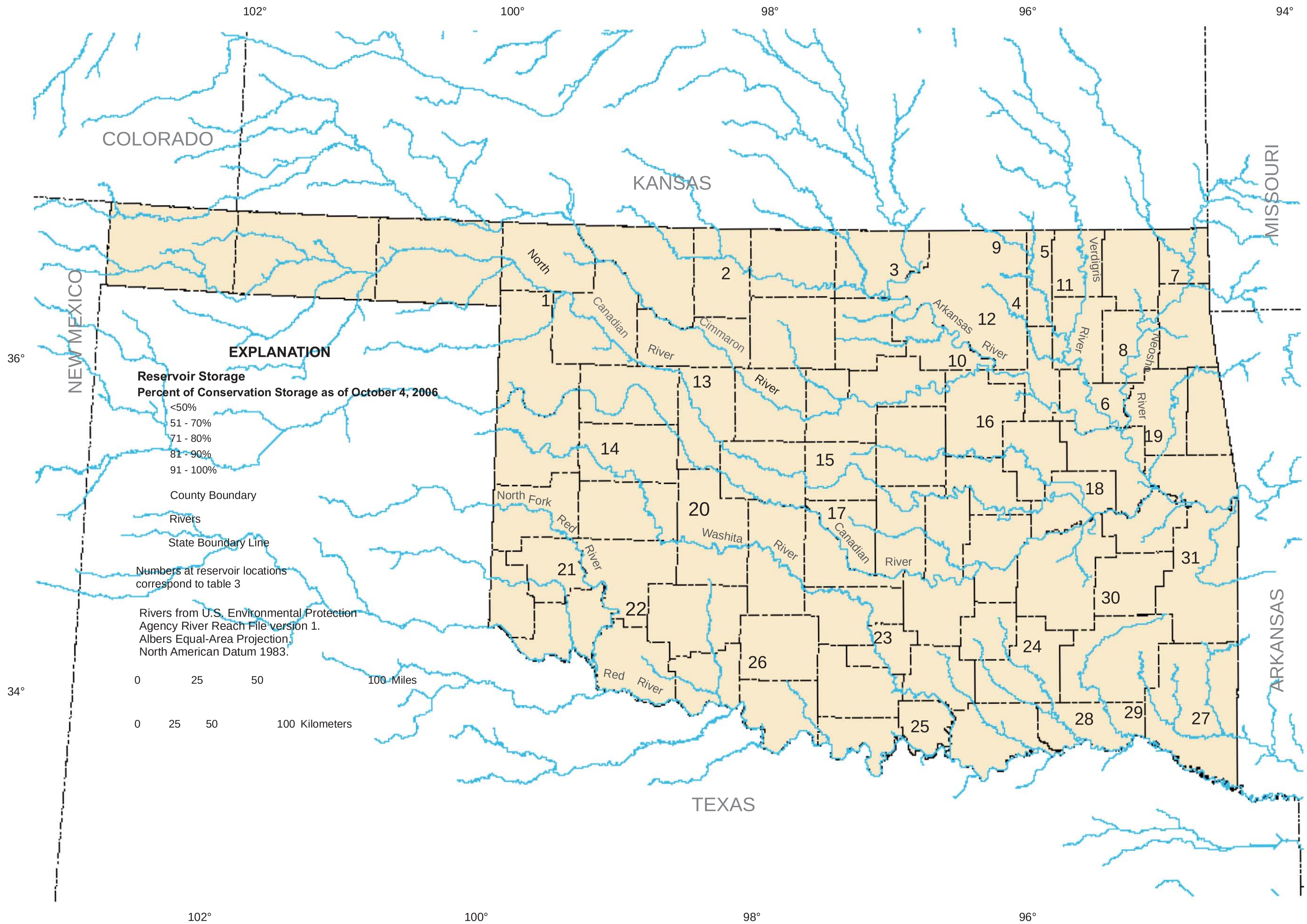


Figure 22. Locations of selected major lakes and reservoirs in Oklahoma and percent of Conservation Storage as of October 4, 2006.

Table 3. Storage in selected major Oklahoma lakes and reservoirs during October 4, 2006, by National Weather Service Climate Division, and comparison with December 21, 2005, and May 24, 2006, storage.

[Shading indicates reservoir storage below 80 percent of total conservation storage; WY, Water Year]

Site number (fig. 22)	Climate Division Lake or Reservoir	Conservation storage (acre-feet)	10/04/06 storage (acre-feet)	Percent of conservation storage		
				WY end 10/4/2006 [a]	WY driest 12/21/2005 [b]	WY wettest 5/24/2006 [c]
	2-North Central					
1	Fort Supply	13,900	9,888	71.1	98.6	97.8
2	Great Salt Plains	31,420	25,986	82.7	100.0	98.1
3	Kaw*	375,160	375,160	100.0	100.0	100.0
	Regional Totals/Averages	**420,480**	**411,034**	**97.8**	**100.0**	**99.8**
	3-Northeast					
4	Birch	19,225	16,665	86.7	71.1	97.4
5	Copan	34,634	27,817	80.3	75.9	100.0
6	Fort Gibson	365,200	361,087	98.9	98.7	100.0
7	Grand	1,672,000	1,509,910	90.3	88.9	99.6
8	Hudson	200,300	195,802	97.8	83.8	100.0
9	Hulah	22,565	20,240	89.7	66.0	100.0
10	Keystone	512,307	418,770	81.7	78.1	100.0
11	Oologah	552,219	510,351	92.4	88.8	100.0
12	Skiatook	322,700	228,371	70.8	83.9	86.7
	Regional Totals/Averages	**3,701,150**	**3,289,013**	**88.9**	**87.2**	**98.6**
	4-West Central					
13	Canton	111,310	74,178	66.6	97.1	100.0
14	Foss	165,480	136,940	82.8	91.6	92.2
	Regional Totals/Averages	**276,790**	**211,118**	**76.3**	**93.8**	**95.3**
	5-Central					
15	Arcadia	27,520	27,502	99.9	97.2	100.0
16	Heburn	7,105	5,691	80.1	88.0	100.0
17	Thunderbird	119,600	78,486	65.6	85.4	80.3
	Regional Totals/Averages	**154,225**	**111,679**	**72.4**	**87.7**	**84.7**
	6-East Central					
18	Eufaula*	2,314,583	1,967,711	85.0	74.1	92.9
19	Tenkiller	654,100	602,009	92.0	77.7	100.0
	Regional Totals/Averages	**2,968,683**	**2,569,720**	**86.6**	**74.9**	**94.4**
	7-Southwest					
20	Fort Cobb	80,010	72,710	90.9	100.0	100.0
21	Altus	132,830	10,508	7.9	37.6	48.8
22	Tom Steed	88,970	40,510	45.5	70.7	61.6

Table 3. Storage in selected major Oklahoma lakes and reservoirs during October 4, 2006, by National Weather Service Climate Division, and comparison with December 21, 2005, and May 24, 2006, storage.—Continued

[Shading indicates reservoir storage below 80 percent of total conservation storage; WY, Water Year]

Site number (fig. 22)	Climate Division Lake or Reservoir	Conservation storage (acre-feet)	10/04/06 storage (acre-feet)	Percent of conservation storage		
				WY end 10/4/2006 [a]	WY driest 12/21/2005 [b]	WY wettest 5/24/2006 [c]
	Regional Totals/Averages	301,810	123,728	41.0	63.9	66.1
	8-South Central					
23	Arbuckle	72,400	63,165	87.2	95.9	100.0
24	McGee Creek	113,930	96,505	84.7	89.6	100.0
25	Texoma*	2,556,122	2,257,985	88.3	92.4	100.0
26	Waurika*	190,200	139,059	73.1	93.3	89.2
	Regional Totals/Averages	**2,932,652**	**2,556,714**	**87.2**	**92.4**	**99.3**
	9- Southeast					
27	Broken Bow*	954,175	796,073	83.4	77.5	97.4
28	Hugo*	158,617	158,617	100.0	66.5	100.0
29	Pine Creek*	53,750	53,750	100.0	80.6	100.0
30	Sardis	274,330	252,137	91.9	90.1	100.0
31	Wister	60,162	47,915	79.6	62.6	100.0
	Regional Totals/Averages	**1,501,034**	**1,308,492**	**87.2**	**78.0**	**98.4**
	State Totals	**12,256,824**	**10,581,498**	**86.3**	**84.5**	**96.8**
	Reservoirs below 80 percent Storage			**8**	**11**	**2**

[*] indicates seasonal pool operation; actual storage figures/percents may vary

[a] WY end, 10/4/2006, approximates end of WY 2006 State Total Conservation Storage (Oklahoma Water Resources Board, 2006a).

[b] WY driest, 12/21/2005, approximates lowest State Total Conservation Storage for WY 2006 (Oklahoma Water Resources Board, 2005).

[c] WY wettest, 5/24/2006, approximates highest State Total Conservation Storage for WY 2006 (Oklahoma Water Resources Board, 2006b).

Ground Water at a Long-Term Site

A long-term recording ground-water well that has a close hydraulic connection between streams and the aquifer illustrates the effect the Water Year 2006 drought had on ground-water levels in south-central Oklahoma. Figure 23 shows the daily ground-water levels in the Fittstown well during Water Year 2006 (red line; U.S. Geological Survey, 2007f) compared to the long-term mean-daily water level (blue line; U.S. Geological Survey, 2008e). The water level was almost 17 feet lower than normal in March; although, late spring rains caused a rise in water levels in May. At the end of the water year the water level was more than 9 feet lower than normal.

Wildfires

Fire danger was critical because of the drought starting in November 2005. Hundreds of homes had been destroyed and nearly 600,000 acres were burned by January 2006 (Knapp, 2006; Slater, 2006). In a 24-hour period starting January 1, 2006, more than 30 separate fires burned more than 81,000 acres and more than a dozen homes were lost (Knapp, 2006). Governor Brad Henry issued a statewide burn ban in November 2005 that remained in effect, though discontinued several times, until the last counties were removed from the ban on December 4, 2006.

Summary

Water Year 2006 (October 1, 2005, to September 30, 2006) was a year of extreme hydrologic drought and the driest year in the recent 2002–2006 drought in Oklahoma. The severity of this recent drought can be evaluated by comparing it with four previous major hydrologic droughts, water years 1929–41, 1952–56, 1961–72, and 1976–81.

The period of water years 1925–2006 was selected as the period of record because before 1925 few continuous record streamflow-gaging sites existed and gaps existed where no streamflow-gaging sites were operated. Statewide annual precipitation in Water Year 2006 was second driest with

72 percent of normal precipitation and statewide annual runoff in Water Year 2006 was sixth driest in the 82 years of record.

Annual area-averaged precipitation totals by the nine National Weather Service Climate Divisions from Water Year 2006 are compared to those during four previous major hydrologic droughts in the 20th century to show how rainfall deficits in Oklahoma varied by region. Only two of the nine climate divisions, Climate Division 1 Panhandle and Climate Division 4 West Central, had minor rainfall deficits, with 85 percent or more of normal precipitation; while the rest of the climate divisions had severe rainfall deficits in Water Year 2006 ranging from only 65 to 73 percent of normal annual precipitation. The East Central, Southwest, and South Central Climate Divisions were hardest hit with only 65 to 67 percent of normal annual precipitation.

Regional streamflow patterns for Water Year 2006 indicate that Oklahoma was part of the regionwide below-normal streamflow conditions for Arkansas-White-Red River Basin, the sixth driest since 1930. The percentage of long-term stations in Oklahoma (with at least 30 years of record) having below-normal streamflow reached 80 to 85 percent for some days in August and November 2006.

Twelve long-term streamflow-gaging sites with periods of record ranging from 62 to 78 years were selected to show how streamflow deficits varied by region. The hydrologic drought worsened going from north to south in Oklahoma, ranging from 45 percent in the north, to just 14 percent in east-central Oklahoma, and 20 percent of normal annual streamflow in the southwest. The Chikaskia River near Blackwell and the Cimarron River near Waynoka in north-central Oklahoma had 45 and 42 percent of normal annual streamflow during Water Year 2006, respectively. The Canadian River at Calvin in east-central Oklahoma had only 14 percent of normal annual streamflow, the second driest year in 66 years; the Salt Fork Red River near Mangum in southwest Oklahoma had only 20 percent of normal annual streamflow, the third driest in the 69 years of record and the Red River near Gainesville in south-central Oklahoma had only 22 percent of normal annual streamflow, the driest year in 70 years.

Some effects of low streamflows during Water Year 2006 include (1) major reservoirs had only 86.3 percent of

Table 4. Comparison of hydroelectric power generation at selected Oklahoma hydroelectric plants between Calendar Year 2005 and Water Year 2006.

[GWh, Gigawatt-hour; CY, calendar year]

Site number (fig.22)	Lake hydroelectric generation project	Climate division	Calendar Year 2005 power (GWh)	Water Year 2006	
				Power (GWh)	Percent of CY 2005 power
3	Kaw [1]	2-North Central	130	36	28
6	Fort Gibson [2]	3-Northeast	231	46	20
7	Grand (Pensacola) [3]	3-Northeast	452	101	22
8	Hudson (RS Kerr) [3]	3-Northeast	235	40	17
8	Salina [3, 4]	3-Northeast	276	130	47
10	Keystone [2]	3-Northeast	310	113	36
18	Eufaula [2]	6-East Central	192	13	7
19	Tenkiller [2]	6-East Central	95	21	22
27	Broken Bow [2]	9-Southeast	98	29	30

[1] Data from Oklahoma Municipal Power Authority (OMPA) Calendar Year 2005 data from R. Morecroft (OMPA, written commun., 2008). Water Year 2006 data from D. Osburn (OMPA, written commun., 2008).

[2] Data from Department of Energy, Southwestern Power Administration (SWPA), Calendar Year 2005 data from J. Croton (SWPA, written commun., 2007), and Water Year 2006 data from Southwestern Power Administration (2007).

[3] Data from Grand River Dam Authority (GRDA). All data from A. Bishop (GRDA, written commun., 2007)

[4] Salina Pumped Storage Project, Chimney Rock Reservoir. Water used on the Salina Creek Arm of Lake Hudson, classified as offstream project.

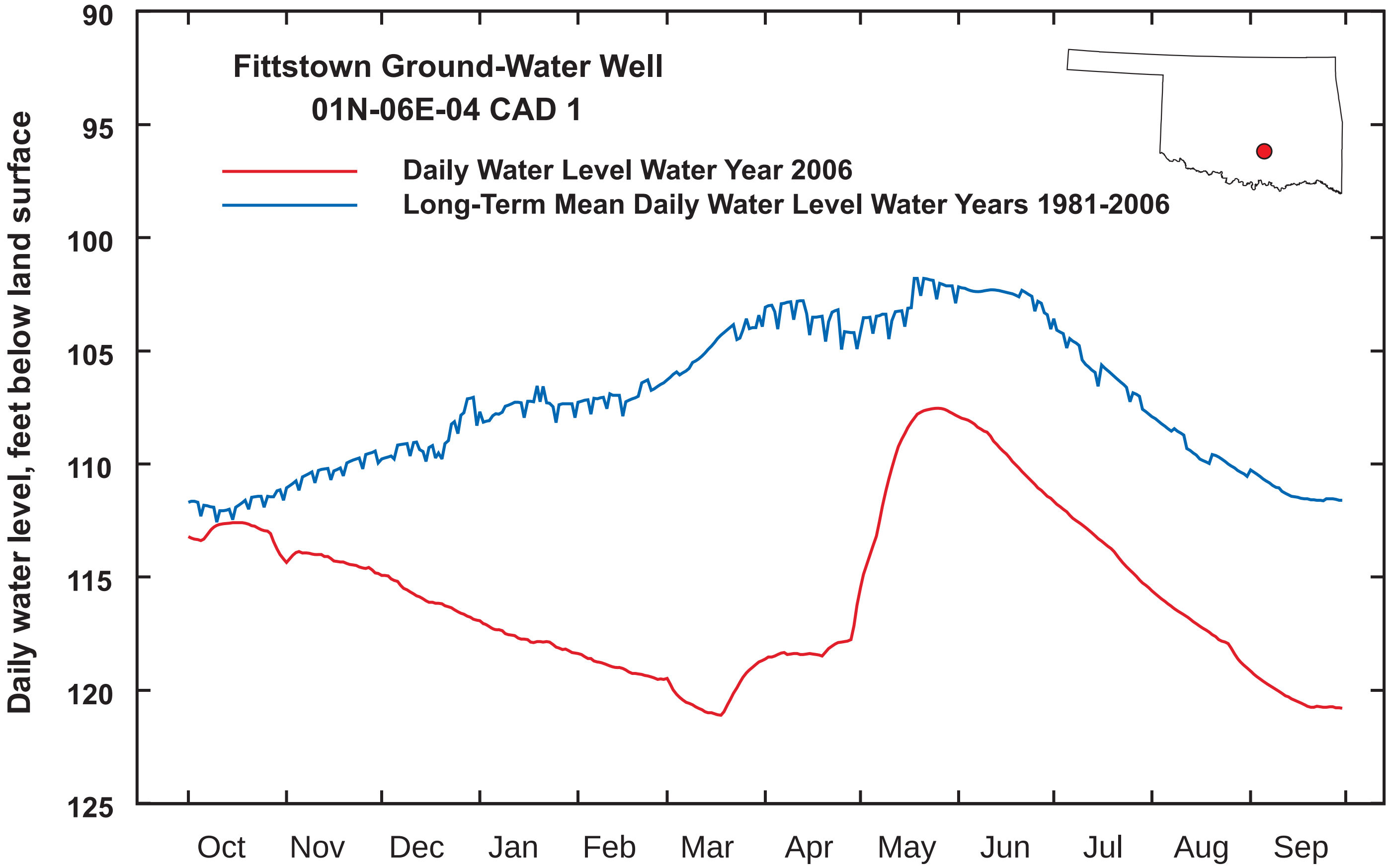


Figure 23. Fittstown ground-water well, comparing daily water levels for Water Year 2006 and long-term mean-daily water levels, water years 1981–2006.

the statewide conservation storage available at the end of the water year, (2) hydroelectric power generation at sites in Oklahoma was only 7 to 47 percent of the Calendar Year 2005 power generation, (3) ground water at a long-term site in south-central Oklahoma had a drop in water level of more than 17 feet lower than normal, and (4) wildfires burned more than 600,000 acres.

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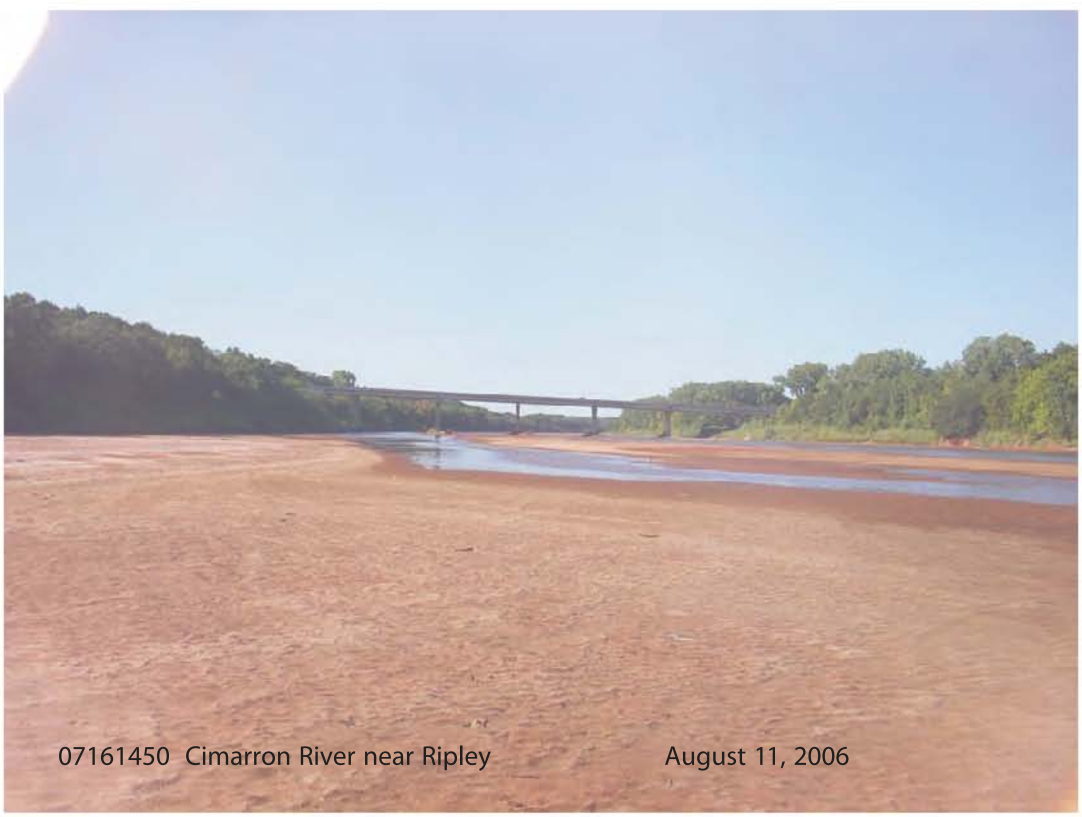
Appendixes

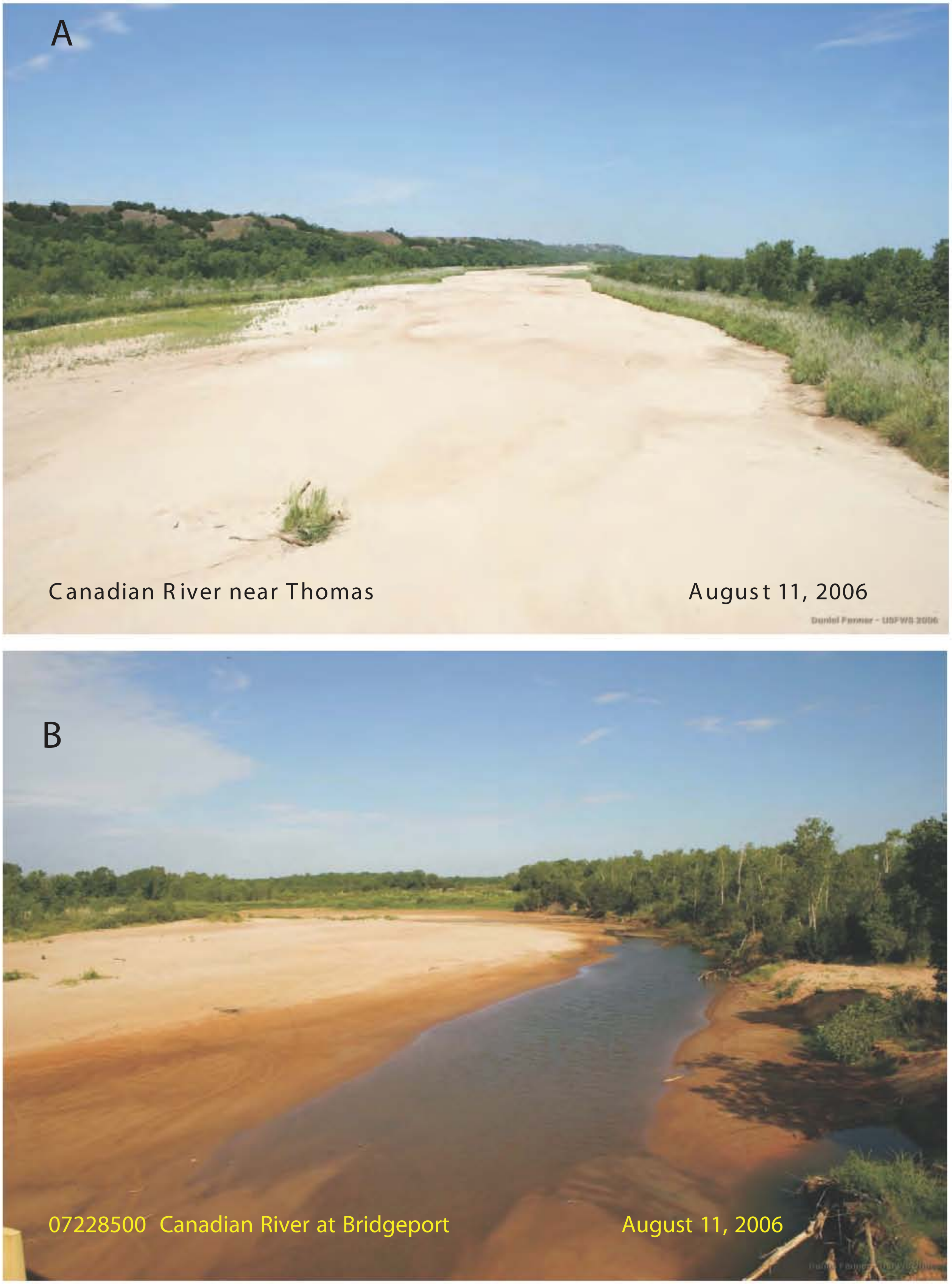
Appendix 1. Salt Fork of Arkansas River at Tonkawa (0751000), showing low flow, 30 cubic feet per second, looking upstream from U.S. Highway 77 bridge, August 6, 2006. Photographer: Jim Norvell, USGS.

Appendix 2. Chikaskia River near Blackwell (07152000), showing low flow, 74 cubic feet per second, looking downstream from State Highway 11 bridge, August 6, 2006. Photographer: Jim Norvell, USGS.

Appendix 3. Cimarron River near Waynoka (07158000), showing low flow, 0.17 cubic foot per second, looking downstream from U.S. Highway 281 bridge, August 9, 2006. Photographer: Marty Phillips, USGS.



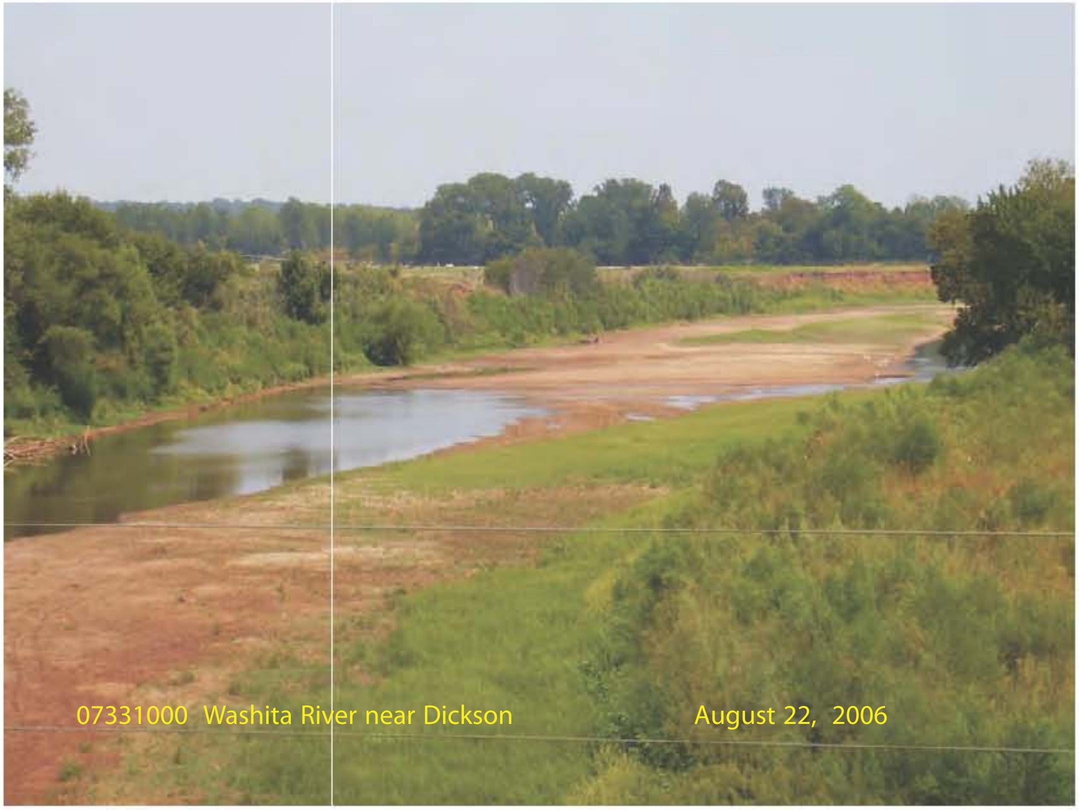
Appendix 4. Cimarron River near Ripley (07161450), showing low flow, 55 cubic feet per second, looking upstream toward State Highway 33 bridge, August 11, 2006. Photographer: Marty Phillips, USGS.



Appendix 5. Canadian River upstream to downstream, August 11, 2006: (*A*) near Thomas, showing no flow, looking upstream from State Highway 33 bridge (*B*) at Bridgeport (07228500), showing low flow and pools, 2.9 cubic feet per second, looking upstream from U.S. Highway 281 bridge. All photographs: David Fenner, USFWS, and locations are shown on fig. 9.—Continued

Appendix 5. Canadian River upstream to downstream, August 11, 2006: (*C*) near Union City, showing no flow and pools, looking upstream from State Highway 81 bridge (*D*) at Purcell (07229200), showing low flow and pools, 4.2 cubic feet per second, looking upstream from U.S. Highway 77 bridge. All photographs: David Fenner, USFWS, and locations are shown on fig. 9.—Continued

Appendix 5. Canadian River upstream to downstream: (*E*) near Wanette, showing no flow, looking upstream from State Highway 102 bridge, August 11, 2006 (*F*) near Ada, showing no flow, looking downstream from State Highway 99 bridge, August 16, 2006. All photographs: David Fenner, USFWS, and locations are shown on fig. 9.



Appendix 6. Washita River near Dickson (07331000), showing low flow and pools, 5.7 cubic feet per second, looking downstream from U.S. Highway 177 bridge, August 22, 2006. Photographer: Ernest Smith, USGS.

Appendix 7. Lake Altus at Lugert (07302500), showing very low lake elevation, 7.7 percent of conservation storage, looking upstream from dam, August 22, 2006. Photographer: Martin Schneider, USGS.

Back Cover: Picture of children in the Sam Noble Oklahoma Museum of Natural History summer program walking on Lake Thunderbird's shoreline, Cleveland County, Oklahoma, published July 2, 2006. Photographer: Steve Sisney.

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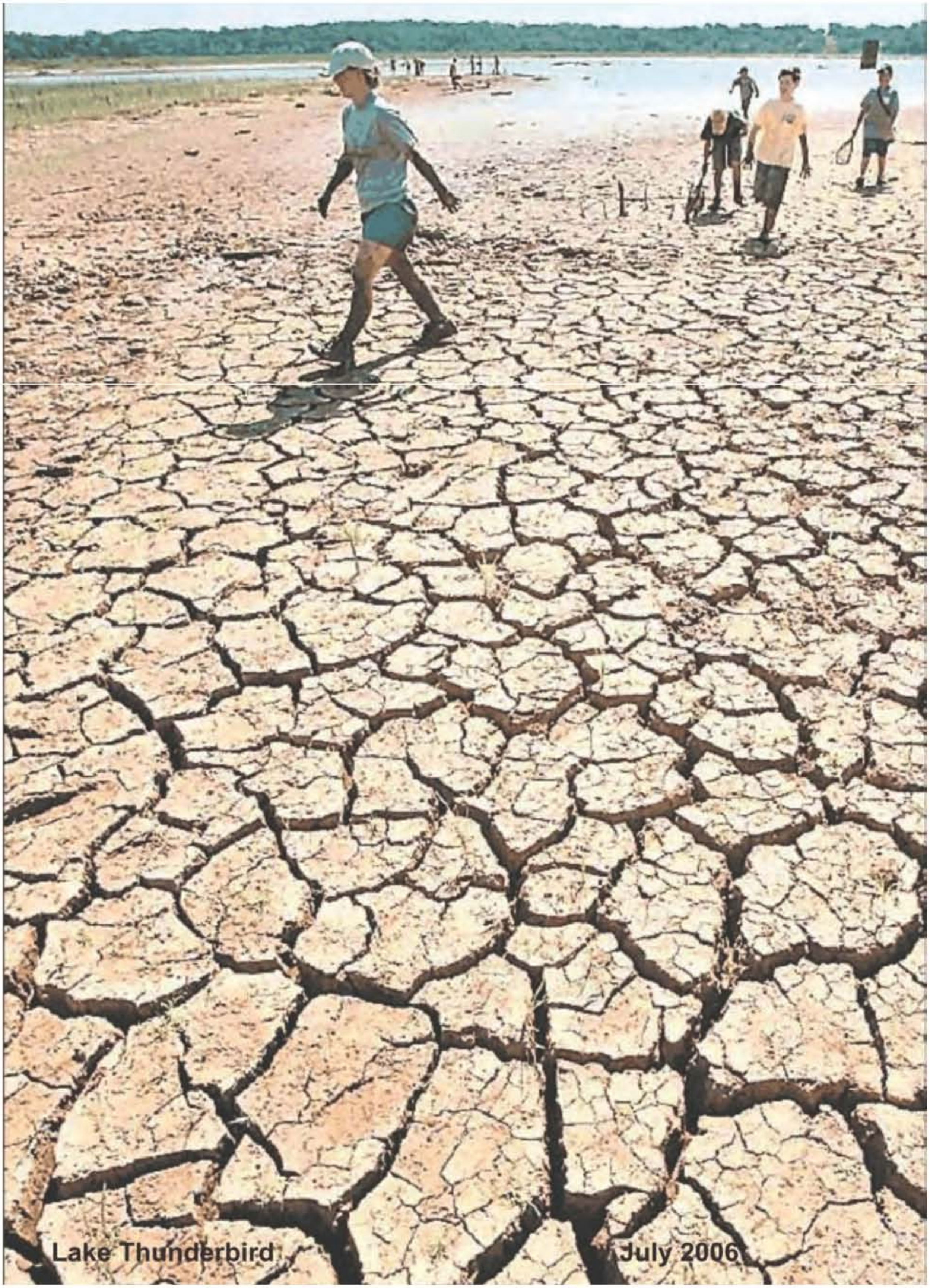

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