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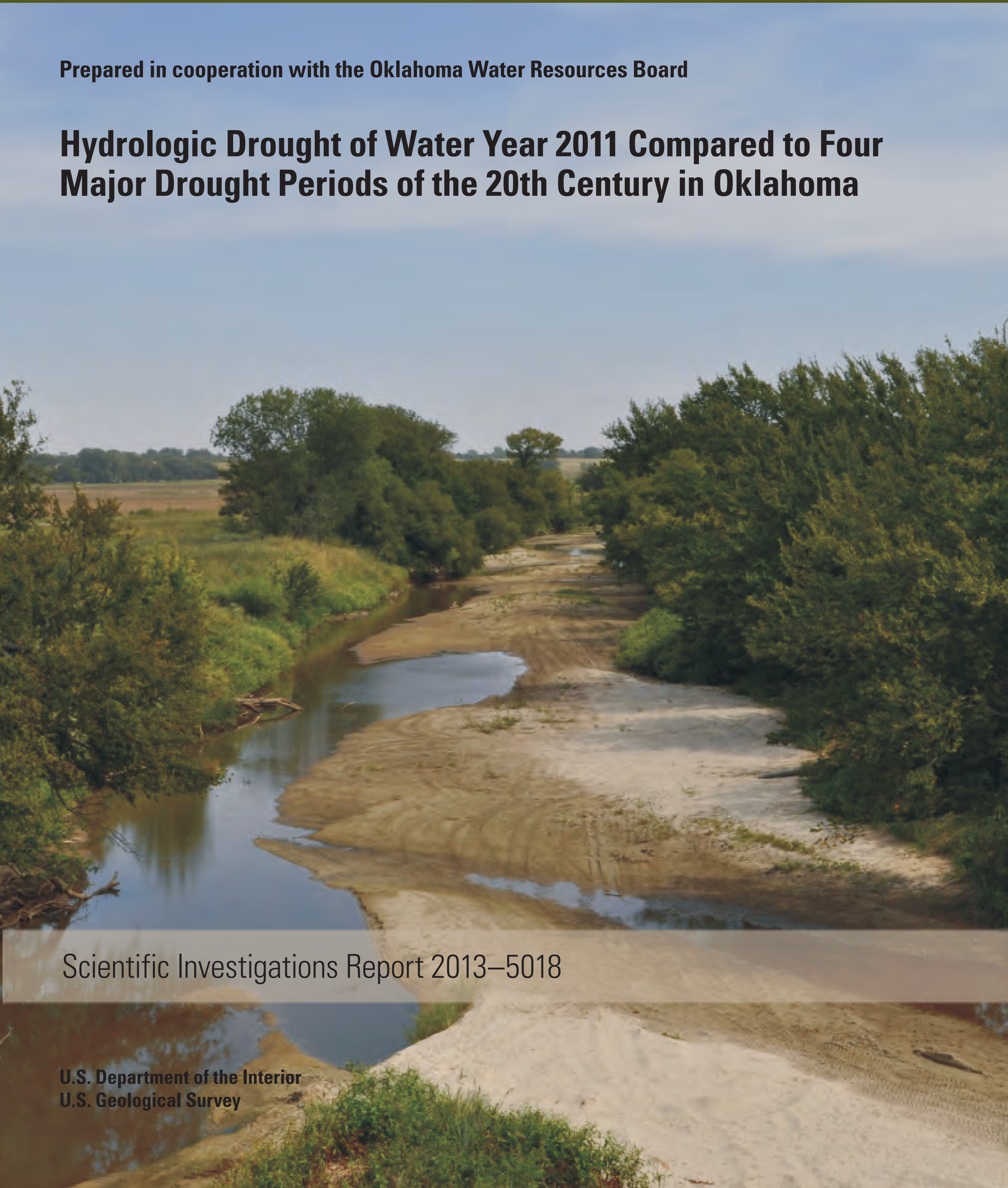

Scientific Investigations Report 2013–5018

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

Cover:

North Canadian River near Calumet, Oklahoma, during drought conditions in July 2011 (photograph by J.A. Savoia, U.S. Geological Survey).

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
	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)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)×.56

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 it ends

Hydrologic Drought of Water Year 2011 Compared to Four Major Drought Periods of the 20th Century in Oklahoma

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Abstract

Water year 2011 (October 1, 2010, through September 30, 2011) was a year of hydrologic drought (based on streamflow) in Oklahoma and the second-driest year to date (based on precipitation) since 1925. Drought conditions worsened substantially in the summer, with the highest monthly average temperature record for all States being broken by Oklahoma in July (89.1 degrees Fahrenheit), June being the second hottest and August being the hottest on record for those months for the State since 1895. Drought conditions continued into the fall, with all of the State continuing to be in severe to exceptional drought through the end of September. In addition to effects on streamflow and reservoirs, the 2011 drought increased damage from wildfires, led to declarations of states of emergency, water-use restrictions, and outdoor burning bans; caused at least $2 billion of losses in the agricultural sector and higher prices for food and other agricultural products; caused losses of tourism and wildlife; reduced hydropower generation; and lowered groundwater levels in State aquifers.

The U.S. Geological Survey, in cooperation with the Oklahoma Water Resources Board, conducted an investigation to compare the severity of the 2011 drought with four previous major hydrologic drought periods during the 20th century – water years 1929–41, 1952–56, 1961–72, and 1976–81.

The period of water years 1925–2011 was selected as the period of record because few continuous record streamflow-gaging stations existed before 1925, and gaps in time existed where no streamflow-gaging stations were operated before 1925. In water year 2011, statewide annual precipitation was the 2d lowest, statewide annual streamflow was 16th lowest, and statewide annual runoff was 42d lowest of those 87 years of record.

Annual area-averaged precipitation totals by the nine National Weather Service climate divisions from water year 2011 were compared to those during four previous major hydrologic drought periods to show how precipitation deficits in Oklahoma varied by region. The nine climate divisions in Oklahoma had precipitation in water year 2011 ranging from 43 to 76 percent of normal annual precipitation, with the Northeast Climate Division having the closest to normal precipitation and the Southwest Climate Division having the greatest percentage of annual deficit. Based on precipitation amounts, water year 2011 ranked as the second driest of the 1925–2011 period, being exceeded only in one year of the 1952 to 1956 drought period.

Regional streamflow patterns for water year 2011 indicate that streamflow in the Arkansas-White-Red water resources region, which includes all of Oklahoma, was relatively large, being only the 26th lowest since 1930, primarily because of normal or above-normal streamflow in the northern part of the region. Twelve long-term streamflow-gaging stations with periods of record ranging from 67 to 83 years were selected to show how streamflow deficits varied by region in Oklahoma. Statewide, streamflow in water year 2011 was greater than streamflows measured in years during the drought periods of 1929–41, 1952–56, 1961–72, and 1976–81. The hydrologic drought worsened going from the northeast toward the southwest in Oklahoma, ranging from 140 percent (above normal streamflow) in the northeast, to 13 percent of normal streamflow in southwestern Oklahoma. The relatively low streamflow in 2011 resulted in 83.3 percent of the statewide conservation storage being available at the end of the water year in major reservoirs, similar to conservation storage in the preceding severe drought year of 2006. The ranking of streamflow as the 16th smallest for the 1925–2011 period, despite precipitation being ranked the 2d smallest, may have been caused, in part, by the relatively large streamflow in northeastern Oklahoma during water year 2011.

Introduction

Water year 2011 (October 1, 2010, through September 30, 2011) was a year of hydrologic drought (based on streamflow) in Oklahoma, which had the second-driest year to date (based on precipitation) recorded since 1925. In Oklahoma, the drought was characterized by below-normal precipitation beginning in the fall and persisting through most of the remainder of the year, punctuated by some wet periods in eastern Oklahoma in the spring and summer. Drought conditions worsened substantially in the summer, breaking the all-time July statewide average temperature record for all States (89.1 degrees Fahrenheit [°F]). Statewide average temperatures in June were the second hottest on record for that month (83.5°F), and temperatures in August (87.7°F) were the hottest on record for that month in Oklahoma since 1895 (Oklahoma Climatological Survey 2010a–c, 2011a–i). Drought conditions continued into the fall, with all of the State undergoing severe to exceptional drought through the end of September (U.S. Drought Monitor, 2011). This drought was caused primarily by weather patterns associated with La Niña conditions in the Pacific Ocean (National Oceanic and Atmospheric Administration (2011). To assist water-resource managers in evaluating the severity of the water year 2011 hydrologic drought and in planning for future droughts, the U.S. Geological Survey, in cooperation with the Oklahoma Water Resources Board, conducted a study to summarize the water year 2011 hydrologic drought and compare it to the four previous major hydrologic drought periods of the 20th century: (1929–41, 1952–56, 1961–72, and 1976–81).

Hydrologic drought is associated with the effects of periods of below-normal precipitation on surface or subsurface water supplies. The severity of hydrologic drought is defined on a watershed or river-basin scale. Water in hydrologic storage systems of rivers and reservoirs commonly has multiple and competing purposes including flood control, irrigation, recreation, navigation, hydropower generation, and wildlife habitat. Competition for river and reservoir water escalates during droughts, and conflicts between water users can increase substantially (National Drought Mitigation Center, 2012a). Some of the consequences of the water year 2011 drought in Oklahoma are described in the following sections.

Selected Consequences of the 2011 Drought

Wildfires

Wildfires were a notable feature of the 2011 drought. Wildfires burned several hundred buildings and almost 300,000 acres in Oklahoma in 2011 (Cable News Network, 2011a and b; Dean and others, 2011; Olafson, 2011; Richter, 2011; National Interagency Fire Center, 2012). Additional effects of wildfires included closure of nearby highways and evacuations of rural and urban residents in potential wildfire paths (Cable News Network, 2011b; Olafson, 2011; Richter, 2011).

Required Water Conservation, Burn Bans, and States of Emergency

Declining streamflow and lake levels and limited pumping infrastructure caused some Oklahoma water-suppliers to issue mandatory water-conservation measures during the summer of 2011. On June 29, the City of Goldsby banned all outdoor watering because of lowered production from a city well (KWTV, 2011a). On July 7, Logan County Rural Water District 1 banned lawn watering (KOTV, 2011). On July 9, Oklahoma City instituted a mandatory odd/even outdoor watering program based on dates and street addresses (Hertneky, 2011). Oklahoma City's outdoor watering restrictions ended on August 11 after storms increased water levels in the city's water-supply lakes (Overholser and Hefner) (KWTV, 2011b). As of September 7, 2011, 40 of 113 public water-supply systems surveyed had declared mandatory water-use restrictions and 45 of those systems had asked customers to voluntarily restrict water use (Oklahoma Department of Environmental Quality, 2011).

In Oklahoma, burn bans which prohibit outdoor burning, but not cooking, can be issued by counties or the Governor. Burn bans were issued locally and by the Governor for counties across the State through the water year to prevent wildfires (Oklahoma Office of Secretary of State, 2011a and b).

As of April 6, 2011, 47 of 77 counties in Oklahoma had issued burn bans to prevent wildfires (KJRH, 2011). On August 3, 2011, Governor Mary Fallin extended a 45-county burn ban issued on July 15, 2011, to all 77 counties in Oklahoma (Hayes, 2011b). After precipitation in late September, Governor Fallin lifted the burn ban for 33 counties in the central and northern parts of Oklahoma (Associated Press, 2011).

On June 24, 2011, Oklahoma Lieutenant Governor Todd Lamb, at the request of Governor Fallin, declared a 30-day state of emergency for 33 counties in northwestern, central, and southern parts of the State because of extreme or exceptional drought conditions and associated wildfires (Oklahoma Office of Secretary of State, 2011a). On September 19, 2011, Governor Fallin amended the first declaration by issuing a 60-day state of emergency for all 77 counties in Oklahoma for exceptional drought conditions and numerous wildfires (Oklahoma Office of Secretary of State, 2011b).

Agriculture

In 2010, Oklahoma ranked first in production of rye, second in production of beef cattle, and third in production of winter wheat in the United States (Oklahoma Department of Agriculture, Food, and Forestry, 2011). The 2011 drought caused losses in crops and livestock in Oklahoma exceeding $1.6 billion (Hayes, 2011c). From April through September, soils in the State were rated as abnormally to severely dry and many cropland areas and pasture were being rated in the fair to very poor range (Oklahoma Water Resources Board, 2011d–j). Li and Hiatt (2012) estimated from satellite imagery that crop and pasture biomass losses ranged from 1.2 to 2 tons per acre over much of the State. Compared to 2010, production of corn, grain sorghum, cotton, soybeans, sunflowers, and hay in 2011 decreased 61, 87, 85, 71, 69, and 61 percent, respectively (National Agricultural Statistics Service, 2012a). Cotton acreage harvested in Oklahoma in 2011 was the smallest since 1894 (Hayes, 2011d). Resulting high feed and hay prices and dry ponds forced many ranchers to sell cattle, thereby causing a reduction of about 12 percent of the State cattle inventory by the end of 2011, which contributed to record cattle prices by the end of the year and the smallest cattle inventories in the State since 1968 (Hayes, 2011d; National Agricultural Statistics Service, 2012b).

Tourism

Tourism, the third largest industry in Oklahoma, generates more than $6.1 billion annually in expenditures and employs nearly 76,000 people in the State (Oklahoma Tourism and Recreation Department, 2011). Much of the tourism in Oklahoma is associated with outdoor recreation on streams and lakes at State parks and elsewhere (Oklahoma Tourism and Recreation Department, 2011). Decreased streamflow and lake levels likely decreased receipts from water-related tourism in 2011 (Severson and Johnson, 2011). Warnings and beach closures enacted because of potentially toxic blooms of blue-green algae (*Cyanophyta*) in warm, stagnant water at many of the State's largest reservoirs during the summer also decreased tourism (Murphy, 2011; Sewell, 2011; Lawrence, 2012).

Wildlife

In addition to effects on humans and livestock, the drought conditions and wildfires of 2011 caused wildlife to have health problems and suffer from increased mortality. Deer in Texas and Oklahoma had lower rates of reproduction and survival, and fawns and deer were in poorer condition, as shown by smaller antler sizes (Medley, 2011a; Ray, 2011). Increased numbers of dehydrated baby squirrels prematurely left nests (Medley, 2011a). Fledgling avian wildlife such as hawks and kites died in above-normal numbers from hyperthermia and thirst (Medley, 2011a). The quail population across the State in 2011 was estimated to have decreased 25 percent from the population surveyed in 2010 (Schoeling, 2011). Freshwater mussels, including three threatened species, suffered increased mortality as streams and rivers dried up in southeastern Oklahoma (Vaughn and Atkinson, 2012). Lack of berries, acorns, and water caused by the drought forced black bears in eastern Oklahoma to scavenge at higher rates in suburbs and towns (Medley, 2011b).

Purpose and Scope

The purposes of this report are to describe and document the water year 2011 hydrologic drought in Oklahoma and effects of that drought and to compare the 2011 hydrologic drought to four previous major hydrologic drought periods of water years 1929–41, 1952–56, 1961–72, and 1976–81.

This report includes: (1) a definition of drought sequence, (2) a presentation of monthly nationwide steamflow displayed in U.S. Geological Survey WaterWatch graphics for water year 2011, and (3) a comparison of annual statewide total precipitation and statewide runoff (measurement of streamflows greater than base flows that are related to storm intensity) from water years 1925–2011 in Oklahoma with the four previous major hydrologic droughts of the 20th century highlighted. Annual area-averaged precipitation totals for water year 2011 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 precipitation deficits varied from normal by region. Mean annual streamflows during water year 2011 at 12 long-term streamflow-gaging stations are compared to streamflows during four previous major hydrologic droughts of the 20th century to show how streamflow deficits from the median varied by region. Effects of the 2011 drought are described, including: (1) increased wildfires, (2) increased mandates for water conservation and outdoor burning bans, (3) reduced crop yields and sell-offs of cattle herds, (4) reduced tourism, (5) increased mortality of wildlife, (6) reduced streamflow and conservation storage at major reservoirs in the State, (7) reduced hydroelectric power generation, and (8) decreased groundwater levels in major aquifers.

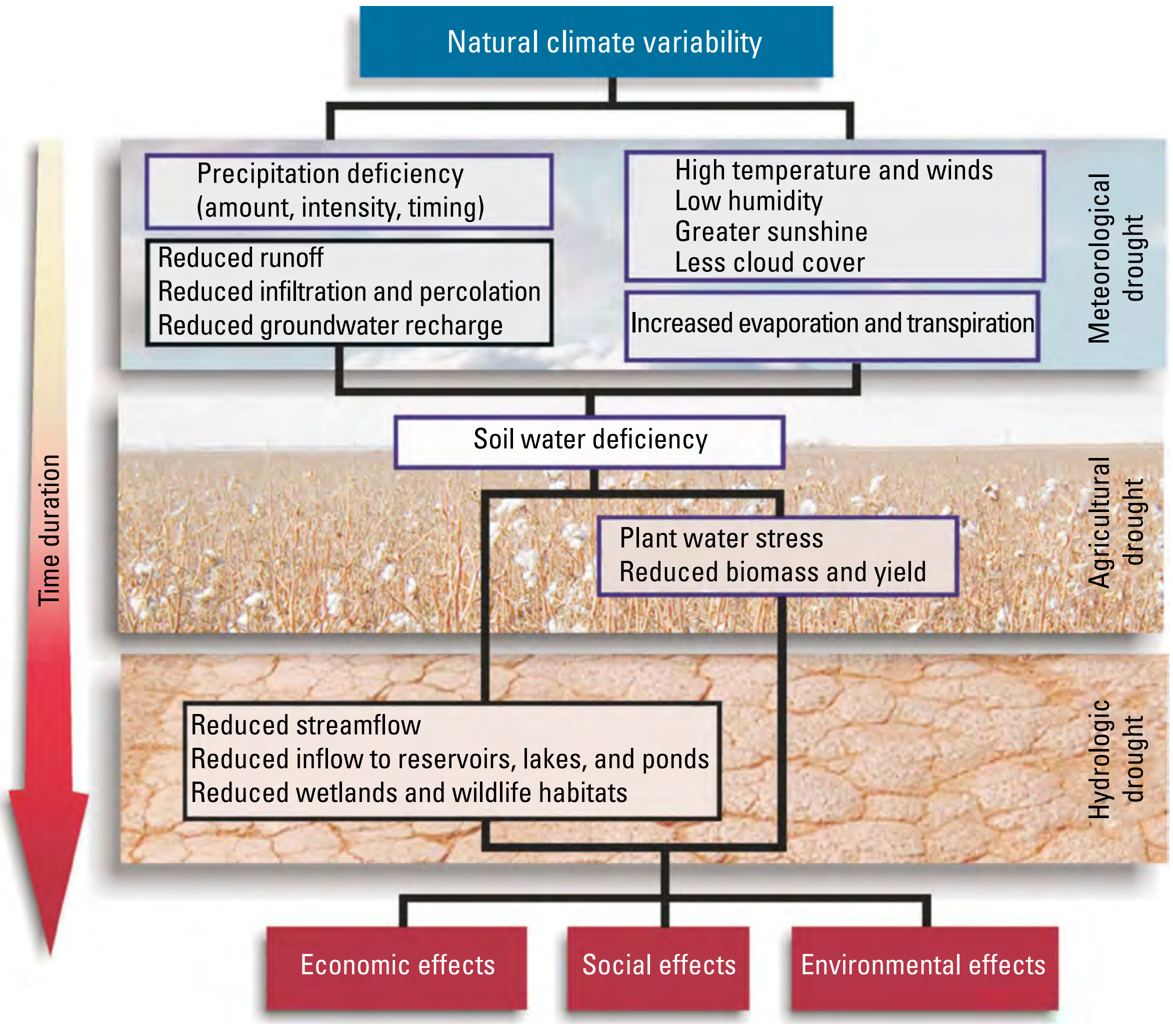
Progression of Drought

Drought Sequence

Drought-sequence development is illustrated in figure 1. 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 occurs. If the drought continues for several seasons, streamflow is reduced to critical levels and "hydrologic" drought results (National Drought Mitigation Center, 2012a).

Progression of Water Year 2011 Streamflow

The WaterWatch Webpage of the U.S. Geological Survey maps monthly streamflow across the United States by percentile class (U.S. Geological Survey, 2012a). The 50th percentile represents the median monthly streamflow for the period of record, and normal streamflow is represented by the 25th to 75th percentiles of long-term median



(Oklahoma Water Resources Board, 2007a; modified from National Drought Mitigation Center, 2012b)

Figure 1. Sequence of drought development.

monthly streamflow. Figure 2 shows the ranges of streamflow in major basins in the United States, ranging from red tones for below long-term normal streamflow to blue tones for above long-term normal streamflow. Streamflow in Oklahoma was normal for most of the State from October through December 2010, but below-normal streamflow and much-below-normal streamflow increased from the southeast and northwest to include much of the State through the remainder of water year 2011 (fig. 2). The most widespread occurrence of much-below-normal streamflow during the water year was measured during July 2011, when much-below-normal streamflows were measured in about two-thirds of the State (fig. 2).

Statewide Precipitation and Streamflow

Graphs of precipitation and estimated runoff of precipitation characterize the duration and severity of hydrologic drought by comparing annual statewide precipitation and runoff departures from long-term median annual precipitation values. Annual departures are shown as positive bars when values exceed the long-term median annual precipitation and as negative bars when values are less than the long-term median-annual precipitation. Departures that are consistently negative over several years provide a measure of drought duration or persistence, whereas the magnitudes of individual departures provide measures of severity.

The period of water years 1925–2011 was selected as the period of record for long-term drought analysis. Before 1925 few continuous record streamflow-gaging stations existed, and there were gaps when no streamflow gaging stations were operated in many parts of the State (U.S. Geological Survey, 2012b–c). Four previous major hydrologic drought periods of water years 1929–41, 1952–56, 1961–72, and 1976–81 were identified from statewide runoff (Tortorelli and others, 1991; Tortorelli, 2008).

Figures 3 and 4 show annual statewide median precipitation and annual statewide median runoff, respectively, during water years 1925–2011. In figure 3, the statewide annual median precipitation for each water year of that period (National Climatic Data Center, 2012a) is plotted as departure from the long-term median annual precipitation for the period (blue line), and a 5-year weighted-average precipitation is plotted as a red line. Statewide, water year 2011 was the second driest in the 87 years of record from 1925–2011, based on precipitation (fig. 3, table 1). In figure 4, the statewide annual median runoff for each water year of the period (U.S. Geological Survey, 2012d) is plotted as the departure from the long-term median annual runoff for the period (blue line), and a 5-year weighted-average runoff is plotted as a red line. In both figures 3 and 4, selected drought periods are indicated by differently colored bars. Statewide runoff in water year 2011 was the 42d smallest in the 87 years of record from 1925–2011 (fig. 4). In figures 3 and 4, wetter years have bars above the median line and drier years have bars below the median line. The severity of drought conditions in water year 2011 can be compared to the four previous major hydrologic droughts by the depth of the bars representing dry years. The severity of the water year 2011 drought also can be compared to the four previous major hydrologic drought periods by the 5-year weighted average line.

Comparison of the 2011 drought with previous drought periods is useful for putting the extent and severity of the 2011 drought in context. The hydrologic drought of water years 1929–41 was known as the “Dust Bowl” in the Great Plains and is documented in many references, including Hoyt (1936, 1938), Nace and Pluhowski (1965), Egan (2006), and National Drought Mitigation Center (2012b). The drought of the “Dust Bowl” years was particularly severe in western Oklahoma, with substantial runoff deficits of 2–3 inches per year and significant wind erosion over the entire State in 1936 (Nace and Pluhowski, 1965) (fig. 4). The 1929–41 drought led to development of nationwide soil conservation measures (National Drought Mitigation Center, 2012b).

Despite the widely known effects of the “Dust Bowl” of the 1930s, the lesser-known hydrologic drought of water years 1952–56 was more severe. The drought of the mid-1950s was the most widespread and the most severe for all regions of Oklahoma in terms of precipitation and for most regions in terms of runoff (Nace and Pluhowski, 1965; Tortorelli and others, 1991) (figs. 3 and 4).

The hydrologic drought of water years 1961–72 was as widespread and lasted longer than the drought of 1952–56 but generally was not as severe (Tortorelli and others, 1991) (figs. 3 and 4). By 1972, many of the major reservoirs in Oklahoma built to augment water supplies during periodic droughts had been completed (Vance, 2007). The hydrologic drought of water years 1976–81 also was widespread, but was neither as severe nor as persistent as the previous three major drought periods (Tortorelli and others, 1991) (figs. 3 and 4).

Although Tortorelli (2008) described a drought period for water years 2002–2006, that period was neither as long-lasting nor as severe as the four previous drought periods of the 20th century. In 2006, however, the drought was as severe as it had been in previous periods (figs. 3 and 4). Record large rainfalls occurred during the summer of 2007 in some parts of the state, with the subsequent years of 2008–10 having gradual decreases in above-normal precipitation and runoff (figs. 3 and 4). Water years 2006 and 2011 were exceptionally dry years in an otherwise normal-to-wet period.

Based on runoff, which increases with more intensive precipitation, water year 2011 was the 42d driest in the 87 years of record from 1925–2011 (fig. 4). Average statewide precipitation was the 2d lowest and average annual streamflow was the 16th lowest during the 1925–2011 study period (tables 1 and 2; figs. 3 and 4). Drought conditions in water year 2011 were severe, but drought duration or persistence of water year 2011 cannot yet be characterized, as of December 2012.

Regional streamflow patterns for water year 2011 (fig. 5) indicate that streamflow in the Arkansas-White-Red water resources region, which includes all of Oklahoma, was the 26th driest since 1930 (U.S. Geological Survey, 2012e). The general pattern of greater-than-normal precipitation in the northern tier of States and less-than-normal precipitation in the southern tier of States is common to seasonal precipitation patterns in autumn, winter, and spring (National Weather Service, 2012). Normal or above-normal precipitation in northern parts of the Arkansas-White-Red water resources region contributed to near-normal streamflow in the region, despite much drier conditions in the southern part of the region. As an indicator of progression of the hydrologic drought during water year 2011, for some days in November 2010 almost 50 percent of long-term (having at least 30 years of record) streamflow-gaging stations had below-normal streamflow (fig. 6). In August 2011, near the peak of drought conditions (fig. 2), almost 90 percent of long-term streamflow-gaging stations in the state had below-normal streamflow (fig. 6).

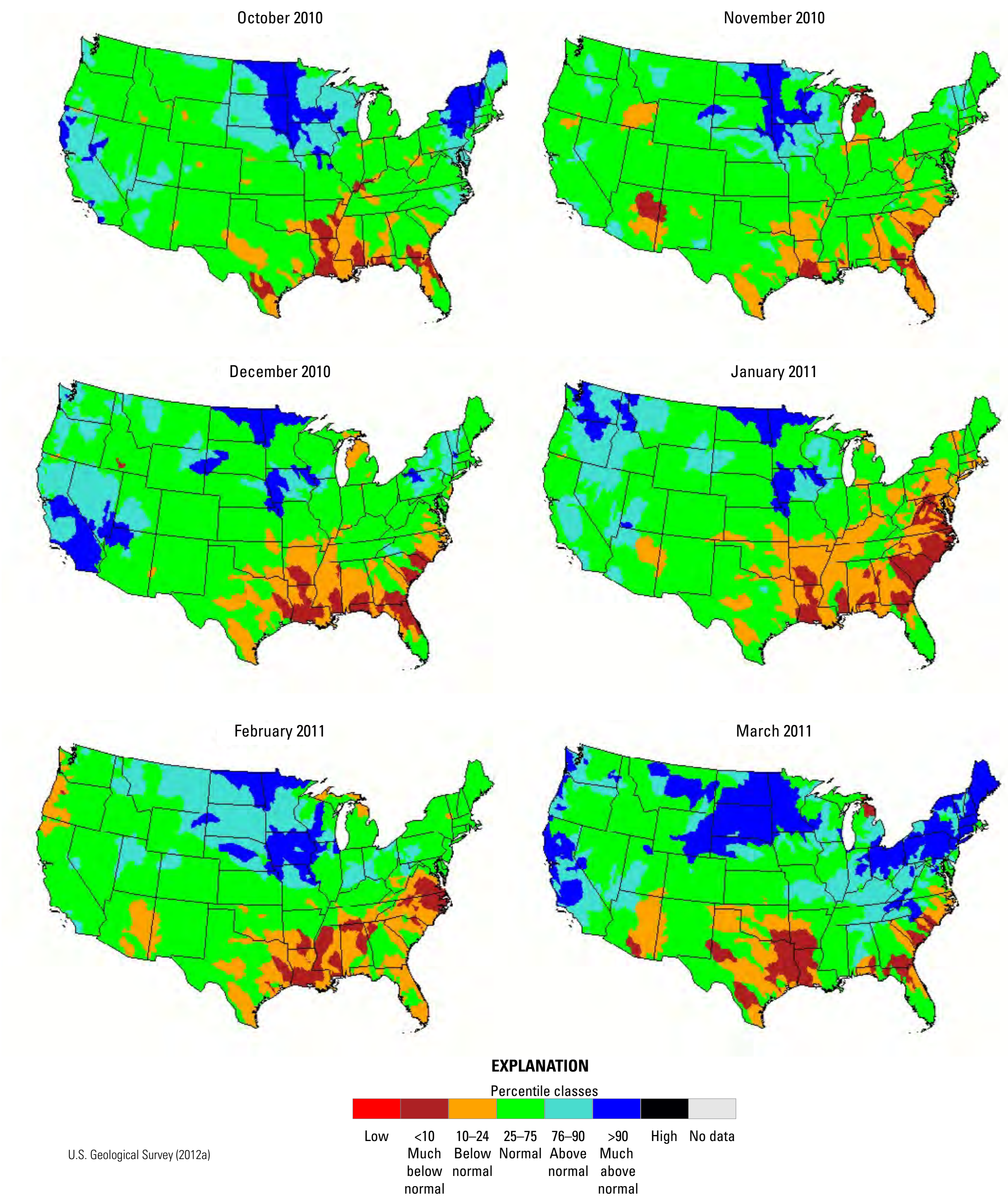


Figure 2. Monthly streamflow by percentile class, from U.S. Geological Survey WaterWatch, October 2010 through September 2011.

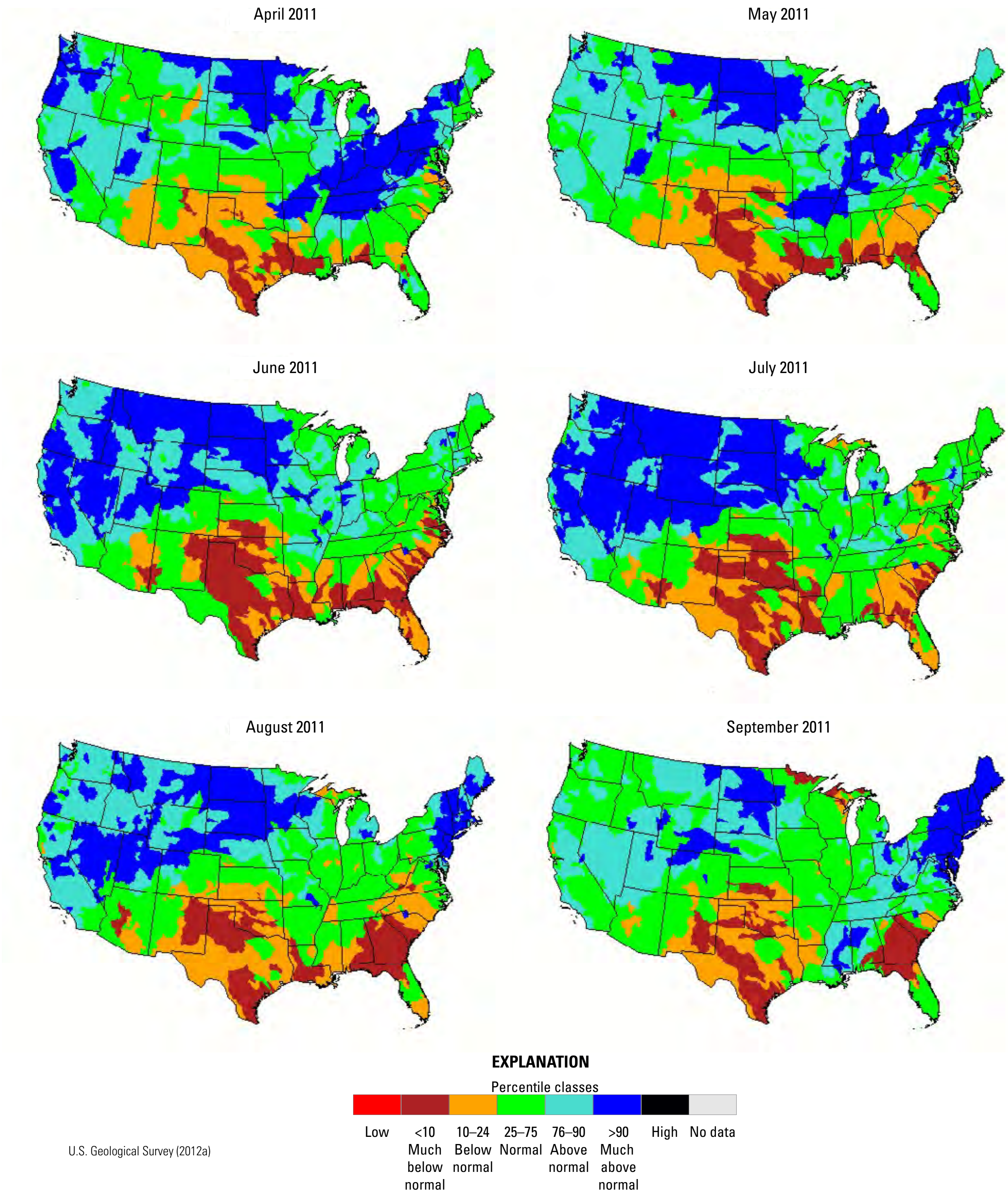


Figure 2. Monthly streamflow by percentile class, from U.S. Geological Survey WaterWatch, October 2010 through September 2011—Continued.

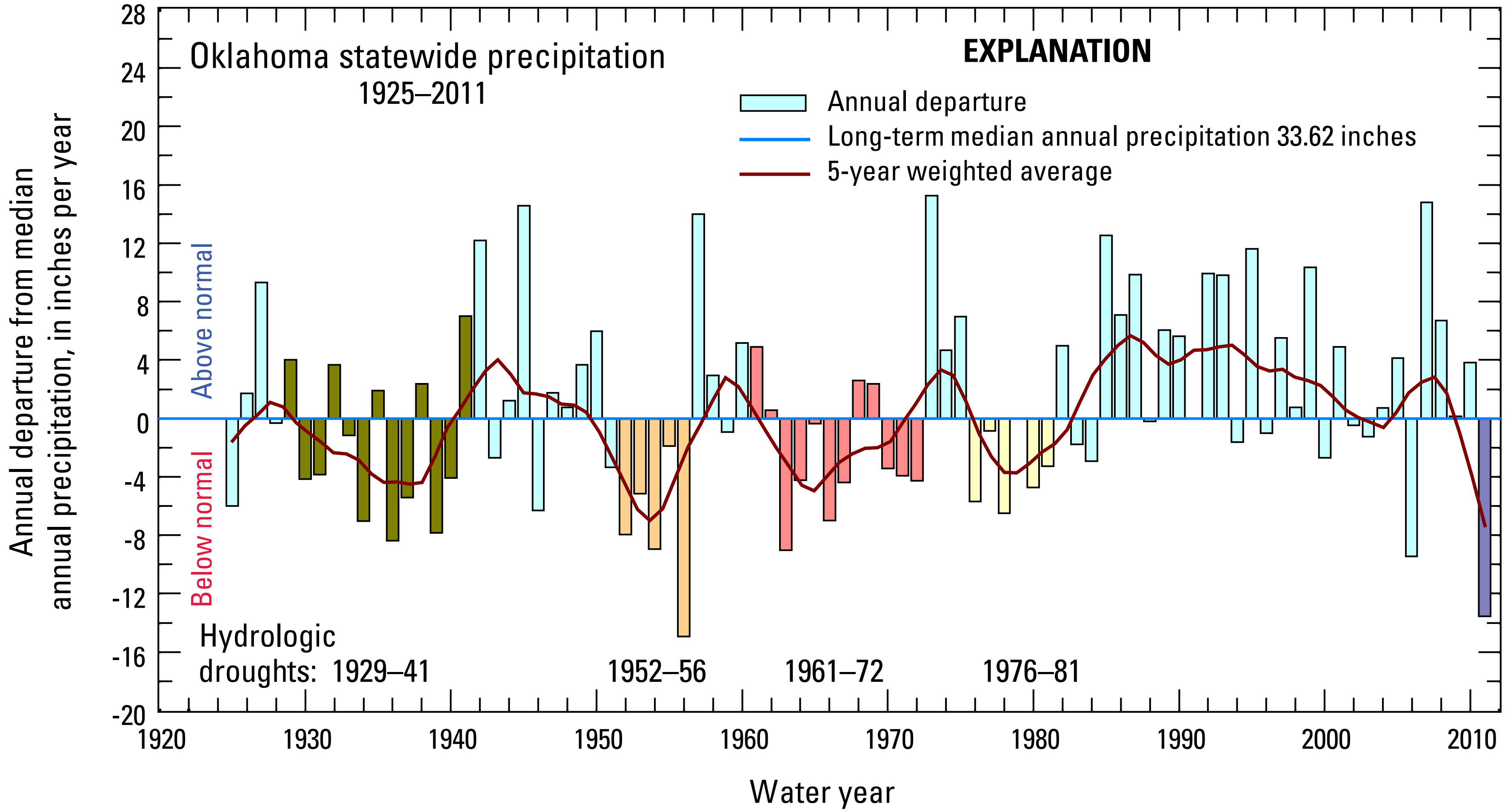


Figure 3. Annual departure from the statewide long-term median annual precipitation of 33.62 inches and a 5-year weighted average for Oklahoma, water years 1925–2011.

Table 1. Summary of precipitation at National Weather Service 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 previously documented hydrologic droughts (1929–41, 1952–56, 1961–72, 1976–81) and the recent (2011) hydrologic drought period.

[avg, average; rank, rank of driest year of drought period compared to period of record for water years 1925–2006; WY, water year; SW, statewide]

Climate division number	Climate division name	Long-term annual median precipitation (inches)	Hydrologic drought periods			
			[1]1929–41 Lowest year/rank		[1]1952–56 Lowest year/rank	
			WY avg annual precipitation (inches)	Long-term median precipitation (percent)	WY avg annual precipitation (inches)	Long-term median precipitation (percent)
SW	**Statewide**[2]	33.62	**1936**	**6**	**1956**	**1**
			25.24	75	18.68	56
1	Panhandle[3]	19.84	**1937**	**3**	**1956**	**2**
			12.24	62	11.34	57
2	North Central[3]	28.79	**1936**	**8**	**1956**	**1**
			20.16	70	15.10	52
3	Northeast[3]	39.96	**1939**	**13**	**1956**	**1**
			30.59	77	22.90	57
4	West Central[3]	26.39	**1940**	**13**	**1952**	**3**
			20.14	76	15.98	61
5	Central[3]	34.33	**1936**	**5**	**1956**	**2**
			24.03	70	19.74	58
6	East Central[3]	43.33	**1936**	**4**	**1956**	**1**
			28.11	65	23.86	55
7	Southwest[3]	27.88	**1939**	**8**	**1956**	**2**
			18.75	67	17.45	63
8	South Central[3]	37.47	**1939**	**4**	1956	1
			24.19	65	16.46	44
9	Southeast[3]	48.13	**1934**	**3**	**1956**	**1**
			30.86	64	25.10	52

Table 1. Summary of precipitation at National Weather Service 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 previously documented hydrologic droughts (1929–41, 1952–56, 1961–72, 1976–81) and the recent (2011) hydrologic drought period.—Continued

[avg, average; rank, rank of driest year of drought period compared to period of record for water years 1925–2006; WY, water year; SW, statewide]

Climate division number	Hydrologic drought periods					
	[1]1961–72 Lowest year/rank		[1]1976–81 Lowest year/rank		2011	
	WY avg annual precipitation (inches)	Long-term median precipitation (percent)	WY avg annual precipitation (inches)	Long-term median precipitation (percent)	WY avg annual precipitation (inches)	Rank long-term median precipitation (percent)
SW	**1963**	**4**	**1978**	**11**		**2**
	24.60	73	27.11	81	20.05	60
1	**1970**	**6**	**1976**	**38**		**1**
	13.05	66	17.58	89	11.09	56
2	**1966**	**7**	**1976**	**21**		**4**
	20.15	70	23.24	81	17.96	62
3	**1963**	**2**	**1981**	**21**		**11**
	24.81	62	32.89	82	30.17	76
4	**1970**	**5**	**1976**	**34**		**1**
	18.00	68	22.23	84	12.65	48
5	**1972**	**10**	**1976**	**12**		**1**
	25.08	73	25.41	74	19.59	57
6	**1963**	**5**	**1980**	**8**		2
	28.24	65	30.30	70	26.08	60
7	**1967**	**3**	**1980**	**33**		**1**
	17.46	63	23.40	84	12.05	43
8	**1963**	**8**	**1978**	**13**		**2**
	25.15	67	27.78	74	18.86	50
9	**1963**	**9**	**1978**	**5**		**4**
	35.02	73	31.95	66	31.51	65

[1]Documented drought periods are modified from Tortorelli and others (1991).

[2]Ranks from Statewide Monthly Precipitation Totals, National Climatic Data Center (2012a).

[3]Ranks from Climate Division Monthly Precipitation Totals, National Climatic Data Center (2012b).

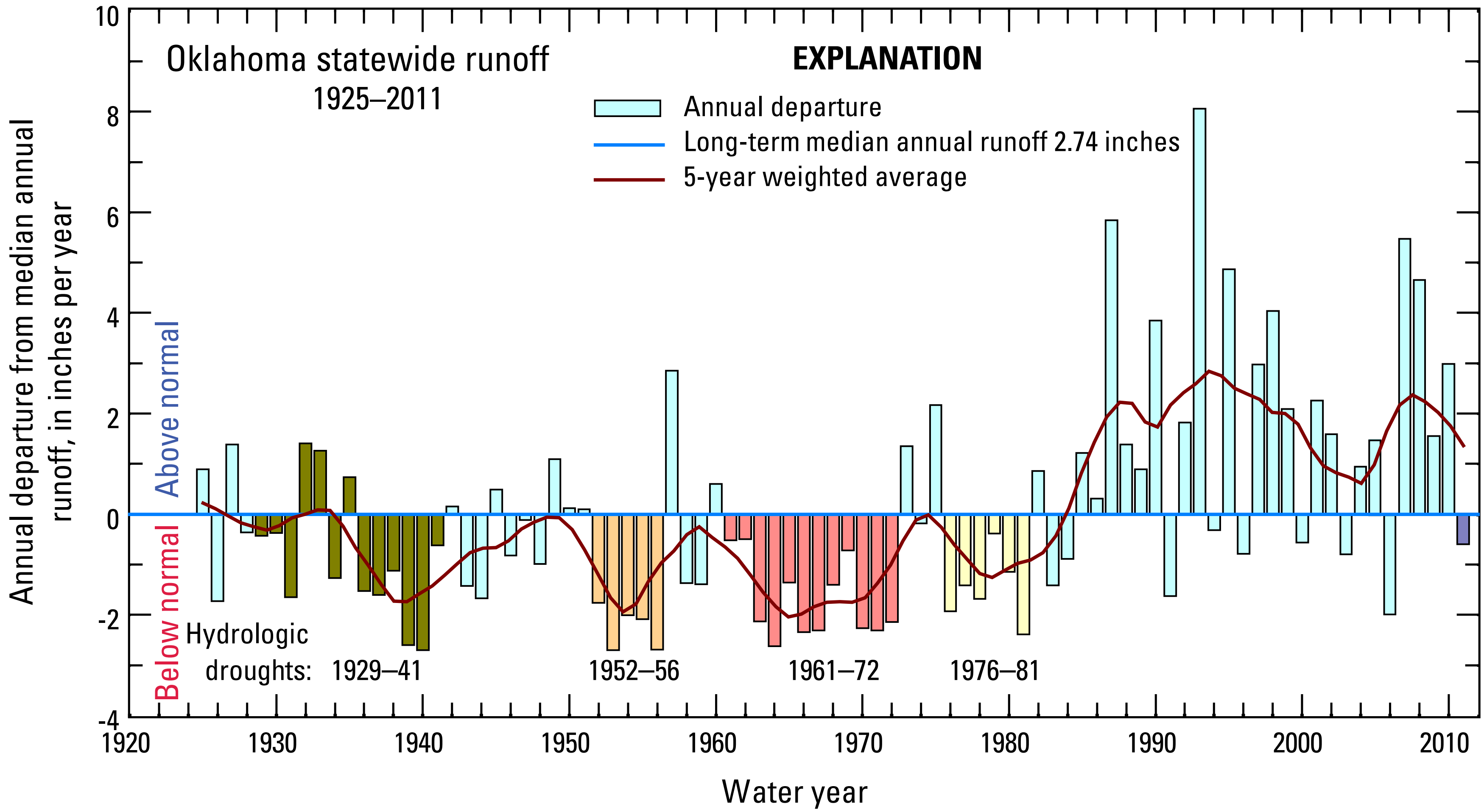
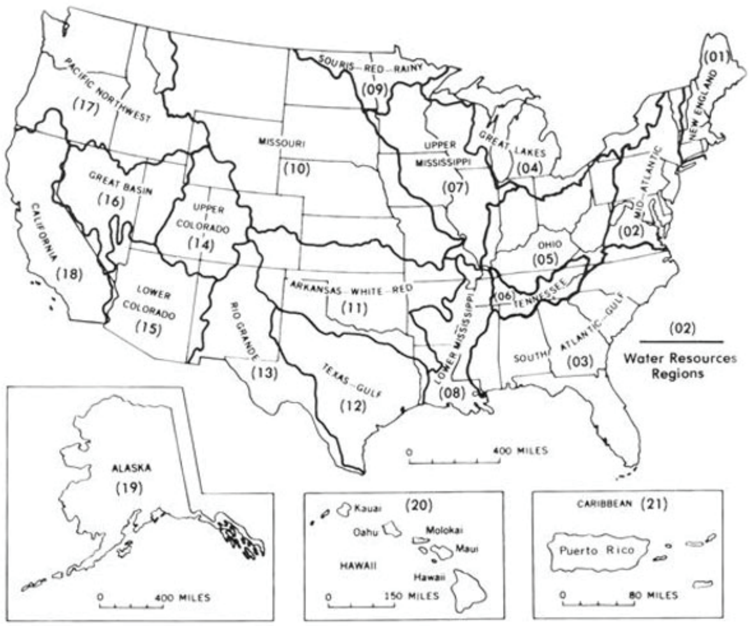
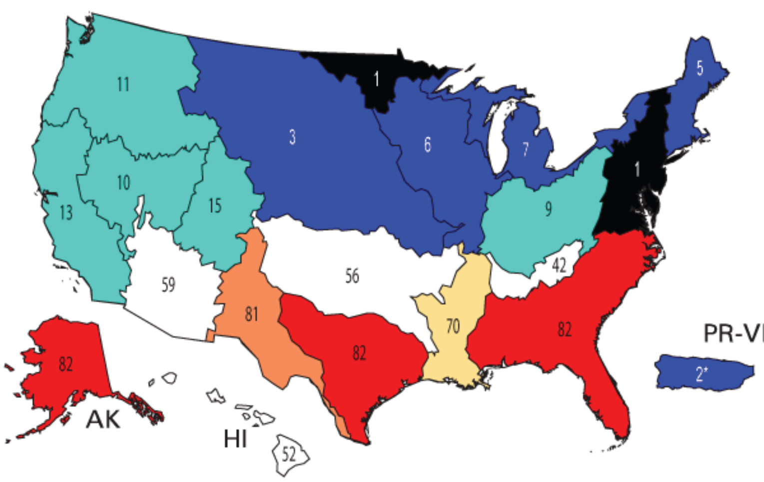


Figure 4. Annual departure from the statewide long-term median annual runoff of 2.74 inches and a 5-year weighted average for Oklahoma, water years 1925–2011.



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.



Streamflow was at record high levels (ranking 1st in 82 years) in the water resource regions of the Souris-Red-Rainy and Mid-Atlantic regions. Above normal and much-above normal streamflow occurred in all northeastern, northern, and western regions, and in the Caribbean. In contrast, streamflow was at record low levels (ranking 82nd in 82 years) in the South Atlantic-Gulf, Texas-Gulf, and Alaska regions, respectively. Below-normal and much-below normals were reported in the Lower Mississippi and Rio Grande regions.

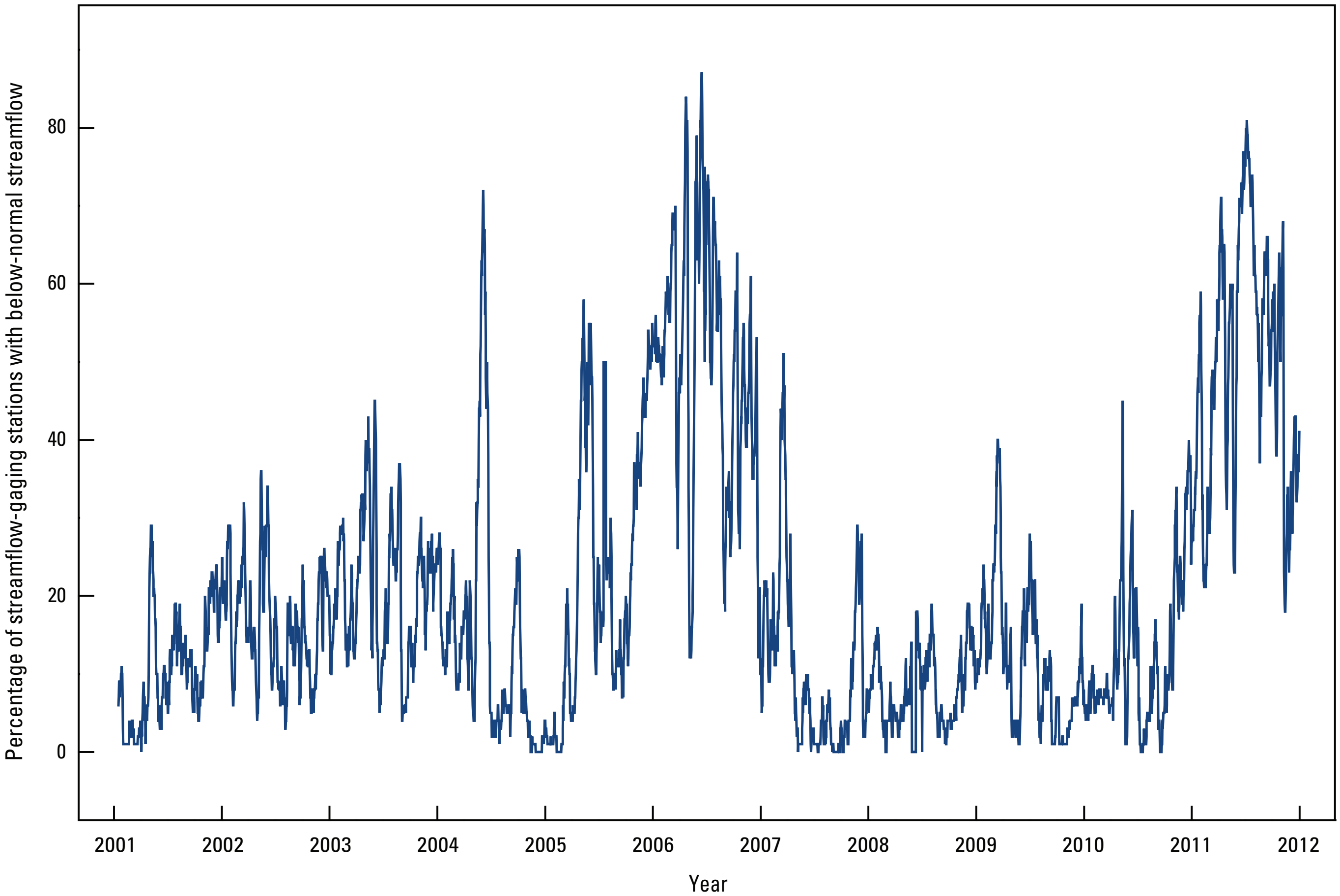
EXPLANATION

Rank

82	70–81	59–69	59–42	9–41	2–8	Highest
Lowest	Much below normal	Below normal	Normal	Above normal	Much above normal	

U.S. Geological Survey (2012e)

Figure 5. Water resources regions and regional streamflow levels in water year 2011.



EXPLANATION

The percent of streamflow-gaging stations with below-normal streamflow, plotted as the blue line in the above graph, is calculated each day as the percent of streamflow-gaging stations having below-normal flow, where the lower boundary for normal is the 25th percentile value of all historical streamflow values for all days of the year.
The percent of stations with below-normal streamflow is based only on streamflow-gaging stations in the state having at least 30 years of record (U.S. Geological Survey, 2012f).

Figure 6. Percentage of streamflow-gaging stations with below-normal streamflow from January 16, 2001, through December 31, 2011, in Oklahoma.

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, 2012a). Those data were totaled for each water year from 1925–2011, indicating annual precipitation in Oklahoma on a regional basis.

Precipitation in the nine climate divisions of Oklahoma in water year 2011 was substantially less than the long-term median annual precipitation, with 2011 being ranked as the driest water year in Southwest, Central, West Central, and Panhandle Oklahoma Climate Divisions and as the 11th driest year in the Northeast Climate Division, with precipitation amounts ranging from 43 to 76 percent of long-term annual median amounts for the period 1925–2011 (table 1). Statewide precipitation in water year 2011 was the second smallest in the 87 years of record from 1925–2011, with 60 percent of the long-term median annual precipitation falling in the State. Only one year in the 1925–2011 period was drier—water year 1956, which had 56 percent of the long-term median precipitation.

Climatic variables in Oklahoma are, in part, measured by the Oklahoma Mesonet, a statewide network of 115 automated stations covering Oklahoma that records precipitation and other climatic data at 5-minute intervals. At least one Mesonet station is located in each of the 77 counties in Oklahoma. Oklahoma Mesonet climate data have been available since 1994. In addition to data from the Mesonet, data from National Weather Service Stations (National Climatic Data Center, 2012a) were used for the period 1925–2011. Mesonet data use mean annual precipitation from calendar years 1971–2000 instead of median annual precipitation from water years 1925–2011 for comparisons of long-term data. The 1971–2000 period contained a significant wet period (fig. 3); therefore, data presented on the Mesonet Website (fig. 8*A*) indicated more severe precipitation deficits in 2011 than indicated in table 1 of this report. The departure from normal precipitation (fig. 8*B*) indicates the statewide distribution of precipitation deficits in water year 2011, as compared to the 1971–2000 period.

Climate Division 1 Panhandle

For Climate Division 1 Panhandle in far northwestern Oklahoma (fig. 7), water year 2011 was the driest in 87 years of record from 1925–2011, having received an average of 11.09 in. of precipitation (table 1). That precipitation amount was 56 percent of the long-term median annual precipitation, a deficit of 8.75 in. (table 1).

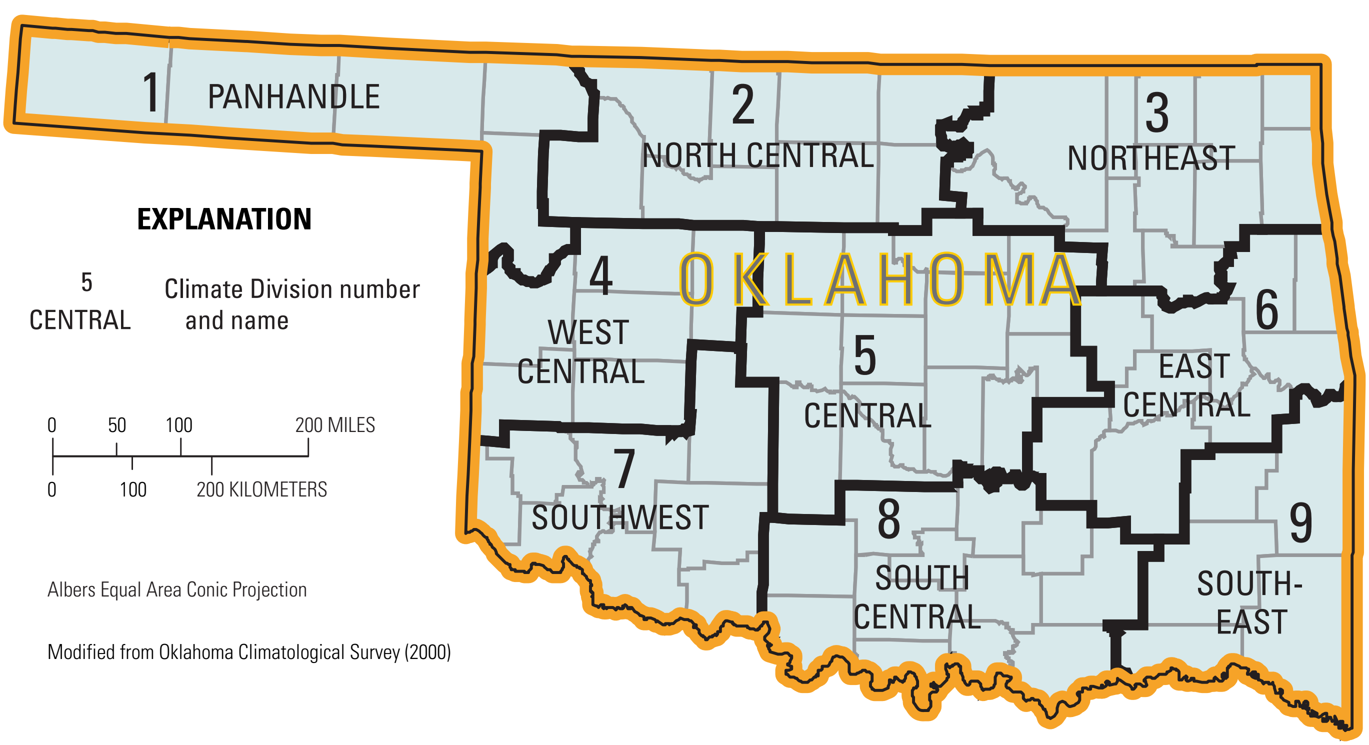
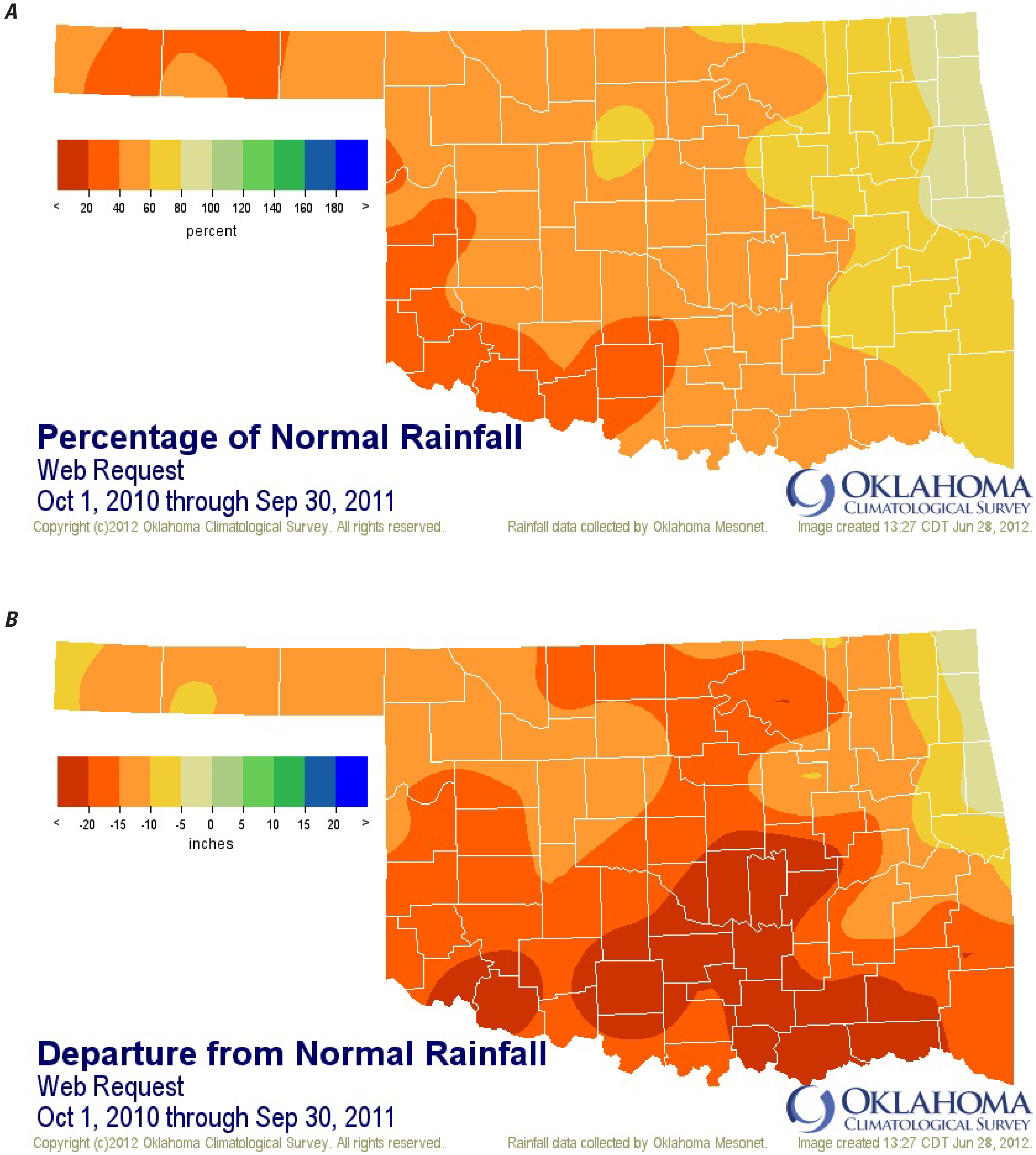


Figure 7. National Weather Service Climate Divisions in Oklahoma.



(G. McManus, Oklahoma Climatological Survey, written commun., 2012; "normal" rainfall is defined as mean annual precipitation from calendar years 1971–2000 in this figure)

Figure 8. Percentage of normal precipitation, *A*, and departure from normal precipitation, *B*, for Oklahoma, water year 2011.

Climate Division 2 North Central

For Climate Division 2 North Central in north-central Oklahoma (fig. 7), water year 2011 was the fourth driest in 87 years of record from 1925–2011, with 17.96 in. of precipitation falling, representing 62 percent of the long-term median annual precipitation, a deficit of 10.83 in. (table 1). Water year 1956 was the driest year recorded for Climate Division 2 North Central, with 15.10 in. of precipitation, 52 percent of the long-term median annual precipitation, and a deficit of 13.69 in. (table 1).

Climate Division 3 Northeast

For Climate Division 3 Northeast in northeastern Oklahoma (fig. 7), water year 2011 was the 11th driest in 87 years of record from 1925–2011, having received 30.17 in. of precipitation, 76 percent of the long-term median annual precipitation, and a deficit of 9.79 in. (table 1). Water year 1956 was the driest year recorded for Climate Division 3 Northeast, having received 22.90 in. of precipitation, 57 percent of the long-term median annual precipitation, and a deficit of 17.06 in. (table 1).

Climate Division 4 West Central

For Climate Division 4 West Central in west-central Oklahoma (fig. 7), water year 2011 was the driest in 87 years of record from 1925–2011, having received an average of 12.65 in. of precipitation (table 1). The precipitation amount for water year 2011 in Climate Division 4 West Central was 48 percent of the long-term median annual precipitation, representing a deficit of 13.74 in. (table 1).

Climate Division 5 Central

For Climate Division 5 Central in central Oklahoma (fig. 7), water year 2011 was the driest in 87 years of record from 1925–2011, having received an average of 19.59 in. of precipitation. The precipitation amount for water year 2011 in Climate Division 5 Central was 57 percent of the long-term median annual precipitation, a deficit of 14.74 in. (table 1).

Climate Division 6 East Central

For Climate Division 6 East Central in east-central Oklahoma (fig. 7), water year 2011 was the second driest in the 87 years of record from 1925–2011, having received an average of 26.08 in. of precipitation, 60 percent of the long-term median annual precipitation, and a deficit of 17.25 in. (table 1). Water year 1956 was the driest year recorded for Climate Division 6 East Central, having received 23.86 in. of precipitation, 55 percent of the long-term median annual precipitation, and a deficit of 19.47 in. (table 1).

Climate Division 7 Southwest

For Climate Division 7 Southwest in southwestern Oklahoma (fig. 7), water year 2011 was the driest in the 87 years of record from 1925–2011, receiving an average of 12.05 in. of precipitation. The precipitation amount for water year 2011 in Climate Division 7 Southwest was 43 percent of the long-term median annual precipitation, a deficit of 15.83 in. (table 1).

Climate Division 8 South Central

For Climate Division 8 South Central in south-central Oklahoma (fig. 7), water year 2011 was the second driest in the 87 years of record from 1925–2011, having received 18.86 in. of precipitation, which was 50 percent of the long-term median annual precipitation, a deficit of 18.61 in. (table 1). Water year 1956 was the driest year recorded for Climate Division 8 South Central, receiving an average of 16.46 in. of precipitation, which was 44 percent of the long-term median annual precipitation, a deficit of 21.01 in. (table 1).

Climate Division 9 Southeast

For Climate Division 9 Southeast in southeastern Oklahoma (fig. 7), water year 2011 was the fourth driest in the 87 years of record from 1925–2011, receiving an average of 31.51 in. of precipitation, which was 65 percent of the long-term median annual precipitation, a deficit of 16.62 in. (table 1). Water year 1956 was the driest year recorded for Climate Division 9 Southeast, having received an average of 25.10 in. of precipitation, which was 52 percent of the long-term median annual precipitation, a deficit of 23.03 in. (table 1).

Streamflow of Long-Term Stations

Twelve long-term streamflow-gaging stations with periods of record ranging from 67 to 83 years were selected to show how streamflow deficits varied by region (fig. 9, table 2). Two graphs are presented for each long-term station (figs. 10–21). The first graph (*A*) for each station is similar to the statewide runoff graph in figure 4. The median annual streamflow (U.S. Geological Survey, 2012b) for each water year of the period of record is plotted as a departure from the long-term median annual streamflow (blue line), and a 5-year weighted-average streamflow is plotted as a red line (all *A* graphs, figs. 10–21). Wetter-than-normal years plot above the median line and drier-than-normal years plot below the median line. Water year 2011 can be compared to dry years from the four previous major hydrologic droughts in the 20th century by comparing the magnitude of the deviations from the median value. The second graph on figures 10–21 shows comparisons of daily mean streamflow from water

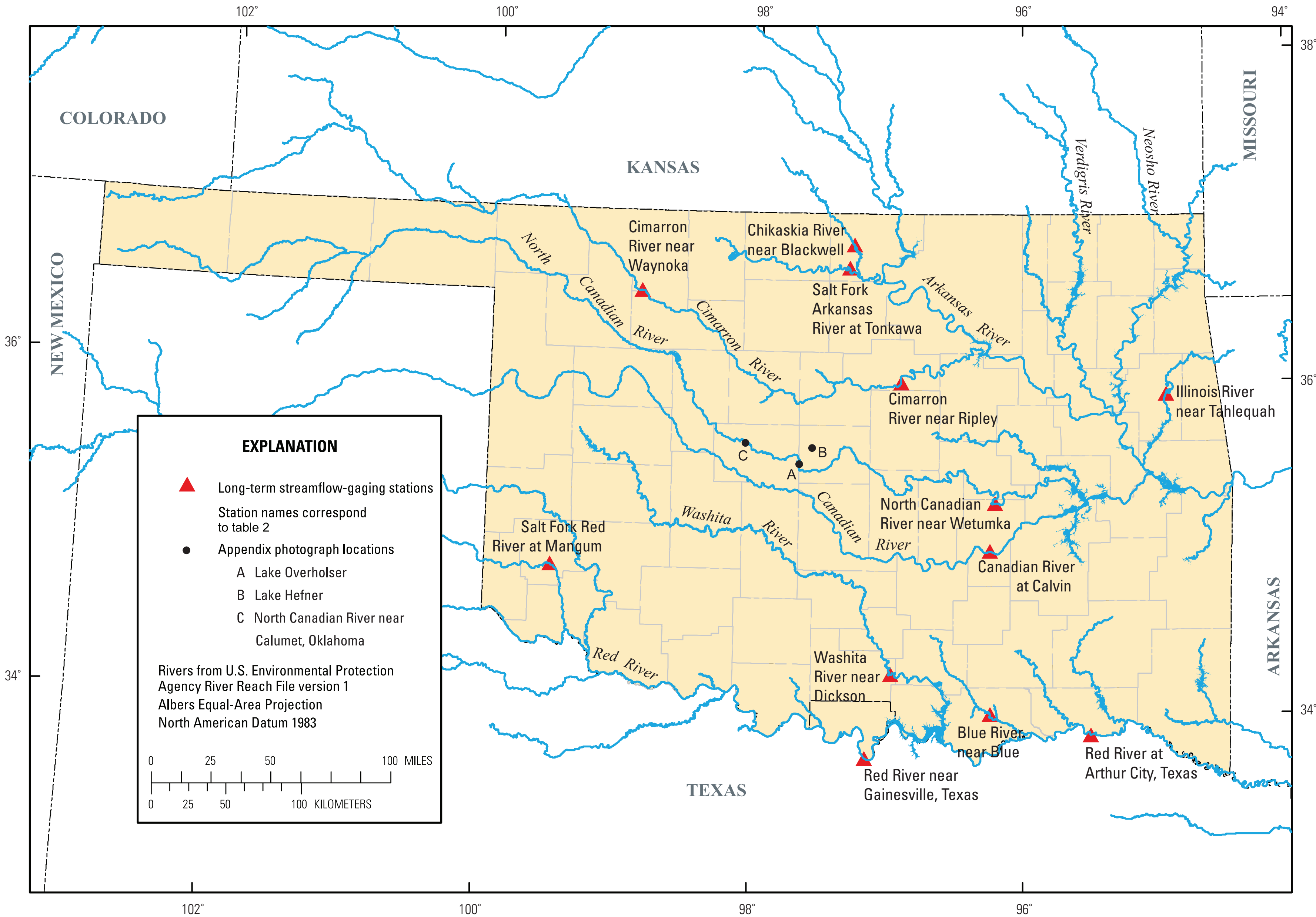


Figure 9. Selected long-term streamflow-gaging stations in Oklahoma and appendix photograph locations.

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 previously documented hydrologic droughts (1929–41, 1952–56, 1961–72, 1976–81) and the recent (2011) hydrologic drought period.

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

Site number	Station number	Station name	Contributing drainage area (mi²)	Type of record (N/R)	Continuous period of record (complete WY)	Years of record	Long-term annual median (ft³/s)
SW		**Statewide**[1]			[1]**1925–2011**	**87**	
1	07151000	Salt Fork Arkansas River at Tonkawa, Okla.	4,520	R	1942–2011	70	812
2	07152000	Chikaskia River near Blackwell, Okla.	1,859	N	1937–2011	75	499
3	07158000	Cimarron River near Waynoka, Okla.	8,504	N	1938–2011	74	223
4	07161450	Cimarron River near Ripley, Okla.[2]	13,053	N	1940–2011	72	1,347
5	07196500	Illinois River near Tahlequah, Okla.	959	N	1936–2011	76	950
6	07231500	Canadian River at Calvin, Okla.	23,151	N,R	1939–42, 1945–2011	71	1,439
7	07242000	North Canadian River near Wetumka, Okla.	9,391	R	1938–2011	74	692
8	07300500	Salt Fork Red River at Mangum, Okla.	1,357	N	1938–2011	74	67.7
9	07316000	Red River near Gainesville, Texas	24,846	N,R	1937–2011	75	2,508
10	07331000	Washita River near Dickson, Okla.	7,202	N,R	1929–2011	83	1,723
11	07332500	Blue River near Blue, Okla.	476	N	1937–2011	75	253
12	07335500	Red River at Arthur City, Texas	38,595	R	1945–2011	67	6,909

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 previously documented hydrologic droughts (1929–41, 1952–56, 1961–72, 1976–81) and the recent (2011) hydrologic drought period.—Continued

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

	Hydrologic drought periods									
	[3]1929–41 Lowest year/rank		[3]1952–56 Lowest year/rank		[3]1961–72 Lowest year/rank		[3]1976–81 Lowest year/rank		2011	
Site number	Avg annual flow (ft³/s)	Long-term median-annual streamflow (percent)	Avg annual flow (ft³/s)	Long-term median-annual streamflow (percent)	Avg annual flow (ft³/s)	Long-term median-annual streamflow (percent)	Avg annual flow (ft³/s)	Long-term median-annual streamflow (percent)	Avg annual flow (ft³/s)	Rank long-term median-annual streamflow (percent)
SW	**1940**	**3**	**1956**	**1**	**1964**	**4**	**1981**	**12**		**16**
1	NA		**1954**	**1**	**1964**	**3**	**1981**	**14**		**4**
			95.5	12	137	17	280	34	147	18
2	**[4]1940**	**2**	**1954**	**1**	**1966**	**4**	**1981**	**8**		**5**
	76.6	15	71.0	14	97.6	20	152	30	102	20
3	**[4]1939**	**30**	**1956**	**6**	**1971**	**5**	**1977**	**21**		**1**
	174	78	53.6	24	46.7	21	134	60	31.9	14
4	**[4]1940**	**4**	**1953**	**1**	**1971**	**2**	**1981**	**12**		**5**
	307	23	235	17	294	22	455	34	312	23
5	**[4]1940**	**6**	**1954**	**1**	**1964**	**3**	**1981**	**5**		**63**
	279	29	193	20	239	25	275	29	1,333	140
6	**[4]1940**	**9**	**1956**	**7**	**1966**	**3**	**1981**	**1**		**4**
	478	33	393	27	217	15	184	13	237	16
7	[4]1940	**2**	**1956**	**1**	**1963**	**3**	**1981**	**5**		**9**
	157	23	156	23	166	24	178	26	215	31
8	**[4]1940**	**1**	**1952**	**5**	**1971**	**3**	**1981**	**6**		**2**
	12.3	18	17.5	26	12.5	18	22.7	34	12.4	18
9	**[4]1939**	**6**	**1953**	**3**	**1964**	**4**	**1983**	**13**		**1**
	1,010	40	651	26	654	26	1,274	51	315	13
10	**[4]1939**	**4**	**1956**	**6**	**1964**	**2**	**1981**	**8**		**1**
	391	23	440	26	340	20	495	29	316	18
11	**[4]1939**	**2**	**1956**	**1**	**1964**	**10**	**1980**	**5**		**4**
	42.9	17	30.8	12	114	45	77.7	31	69.8	28
12	NA		**1952**	**10**	**1964**	**3**	**1980**	**4**		**2**
			4,182	61	2,754	40	2,953	43	2,008	29

[1]Ranks from U.S. Geological Survey (2012a).

[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.

year 2011 (red line) (U.S. Geological Survey, 2012b) to the long-term daily mean streamflow (blue line) (U.S. Geological Survey, 2012b) and provides an indication of how the streamflow deficits changed seasonally during water year 2011 compared to the period of record at that gage (all *B* graphs, figs 10–21). Statewide, water year 2011 had average-annual streamflow that was the 16th smallest of the period 1925–2011, more than was recorded during the drought periods of 1929–41, 1952–56, 1961–72, and 1976–81 (table 2). An average-annual streamflow ranking of only 16th smallest for this period, despite precipitation being ranked the 2d smallest, may be related to the relatively large streamflow in northeastern Oklahoma during water year 2011.

Salt Fork Arkansas River at Tonkawa

Salt Fork Arkansas River at Tonkawa, Okla. (station number 07151000) is a streamflow-gaging station in north-central Oklahoma (fig 9). Water year 2011 was the fourth driest in the 70 years of record at the station for the period 1942–2011, with 18 percent of long-term median annual streamflow being recorded (table 2). Water year 1954 was the driest year at the station, with 12 percent of long-term median annual streamflow being recorded. Zero streamflow was not recorded during water year 2011, similar to the drought year 2006 (Tortorelli, 2008), with some streamflow near the long-term daily mean streamflow being recorded in November, May, August, and September (fig. 10). The smallest daily mean streamflow during water year 2011 was 4 cubic feet per second (ft^3/s) recorded on September 13, 2011 (fig. 10) (U.S. Geological Survey, 2012c).

Chikaskia River near Blackwell

Chikaskia River near Blackwell, Okla. (station number 07152000) is a streamflow-gaging station in north-central Oklahoma (fig. 9). Water year 2011 was the fifth driest in the 75 years of record from 1937–2011 at that station, with 20 percent of long-term median annual streamflow being recorded (table 2). Water year 1954 was the driest year at the station, with 14 percent of long-term median annual streamflow being recorded. Zero streamflow was not recorded during water year 2011 at the station, similar to the drought year of 2006 (Tortorelli, 2008), with some above-median streamflow recorded in February, April, and mid-September (fig. 11). The smallest daily mean streamflow during water year 2011 was 1.5 ft^3/s recorded on September 6, 2011 (fig. 11) (U.S. Geological Survey, 2012c).

Cimarron River near Waynoka

Cimarron River near Waynoka, Okla. (station number 07158000) is a streamflow-gaging station in northwestern Oklahoma (fig. 9). Water year 2011 was the driest in the 74 years of record from 1938–2011, with 14 percent of the long-term median annual streamflow being recorded (table 2). During the drought of water year 2006, zero streamflow was recorded at this station only during early August (Tortorelli, 2008). Zero streamflow was recorded in water year 2011 in late May and early June and from late June through September, with above-mean streamflow recorded in early November 2010 (fig. 12) (U.S. Geological Survey, 2012c).

Cimarron River near Ripley

Cimarron River near Ripley, Okla. (station number 07161450, formerly named Cimarron River near Perkins, Okla., station number 0716000) is a streamflow-gaging station in central Oklahoma (fig. 9). Water year 2011 was the fifth driest in the 72 years of record from 1940–2011 at that station, with 23 percent of long-term median annual streamflow being recorded (table 2). Water year 1953 was the driest recorded year at the streamflow-gaging station, with 17 percent of long-term median annual streamflow being recorded. Zero streamflow was not recorded during water year 2011, similar to the drought year of 2006, with above-mean streamflow being measured in late May 2011 (fig. 13; Tortorelli, 2008). The smallest daily mean streamflow during the 2011 water year at this station was 16 ft^3/s recorded on September 2, 2011 (fig. 13) (U.S. Geological Survey, 2012c).

Illinois River near Tahlequah

Illinois River near Tahlequah, Okla. (station number 07196500) is a streamflow-gaging station in east-central Oklahoma (fig. 9). Water year 2011 was relatively wet, with streamflow ranking 63d smallest in the 76 years of record from 1936–2011 at the station, with 140 percent of long-term median annual streamflow being recorded (table 2). Water year 1954 was the driest year recorded at the station, with 20 percent of long-term median annual streamflow being recorded. Zero streamflow was not recorded during water year 2011, similar to the drought year of 2006, with some above-mean streamflow being recorded in late February and early March, late April, May, mid-August, and late September of 2011 (fig. 14; Tortorelli, 2008). Large amounts of precipitation produced substantial runoff in the watershed upstream from the station in April and May, contributing to the relatively large median annual streamflow at the site. The smallest daily mean streamflow during the 2011 water year at this station was 159 ft^3/s recorded on September 15, 2011 (fig. 14) (U.S. Geological Survey, 2012c).

Canadian River at Calvin

Canadian River at Calvin, Okla. (station number 07231500) is a streamflow-gaging station in east-central Oklahoma (fig. 9). Water year 2011 was the fourth driest in

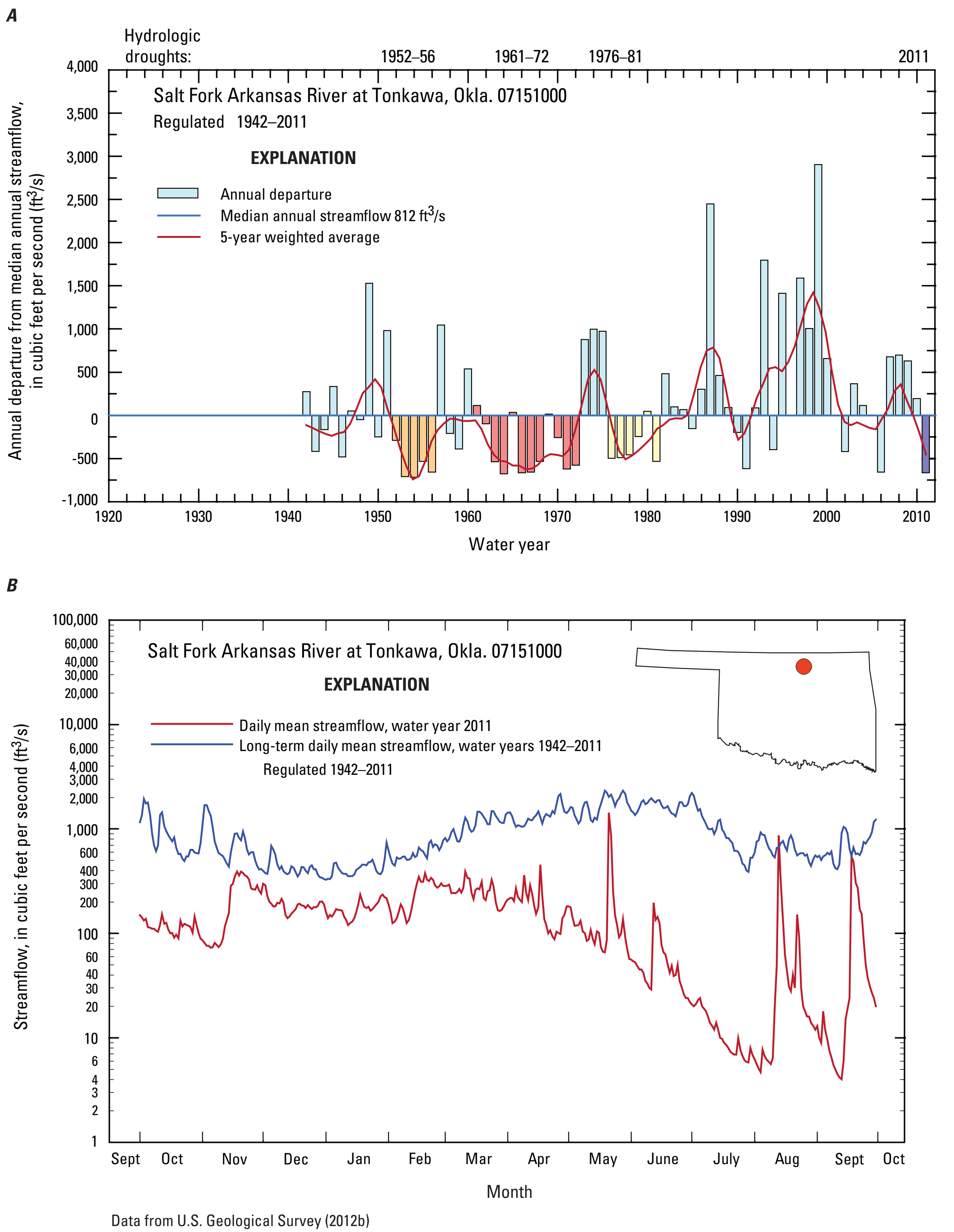
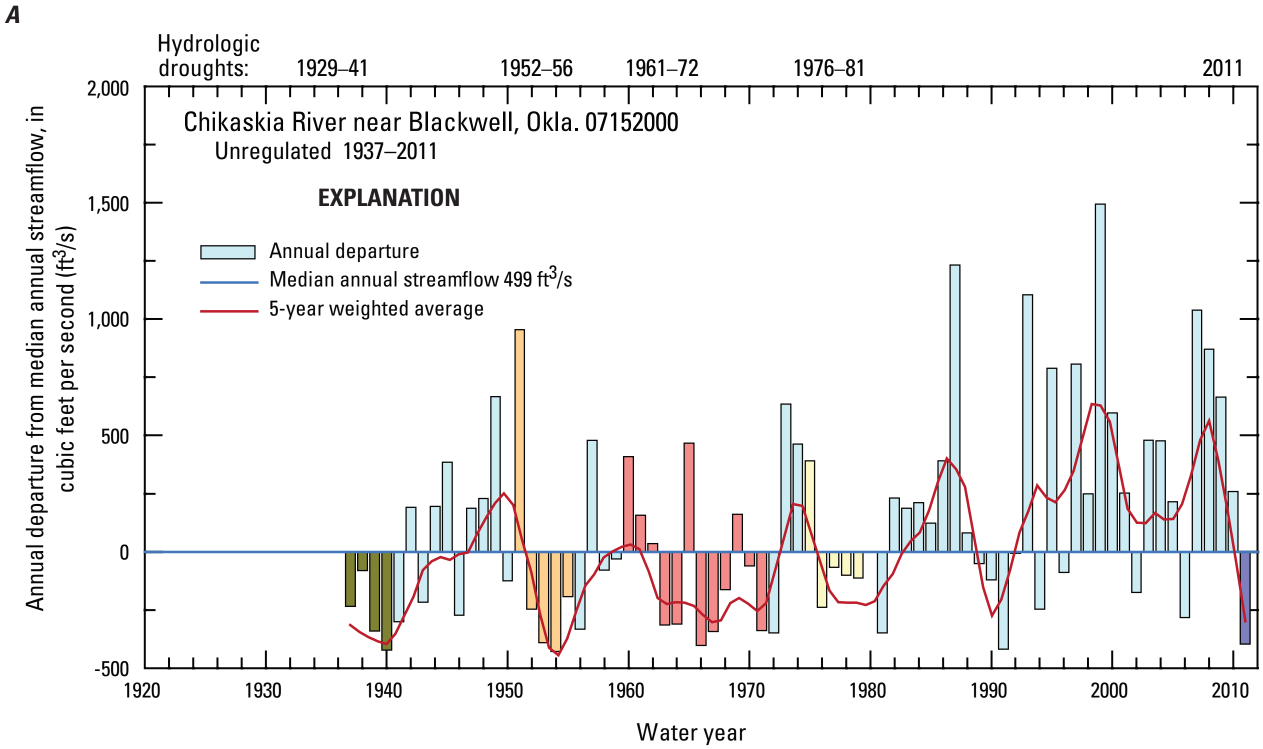
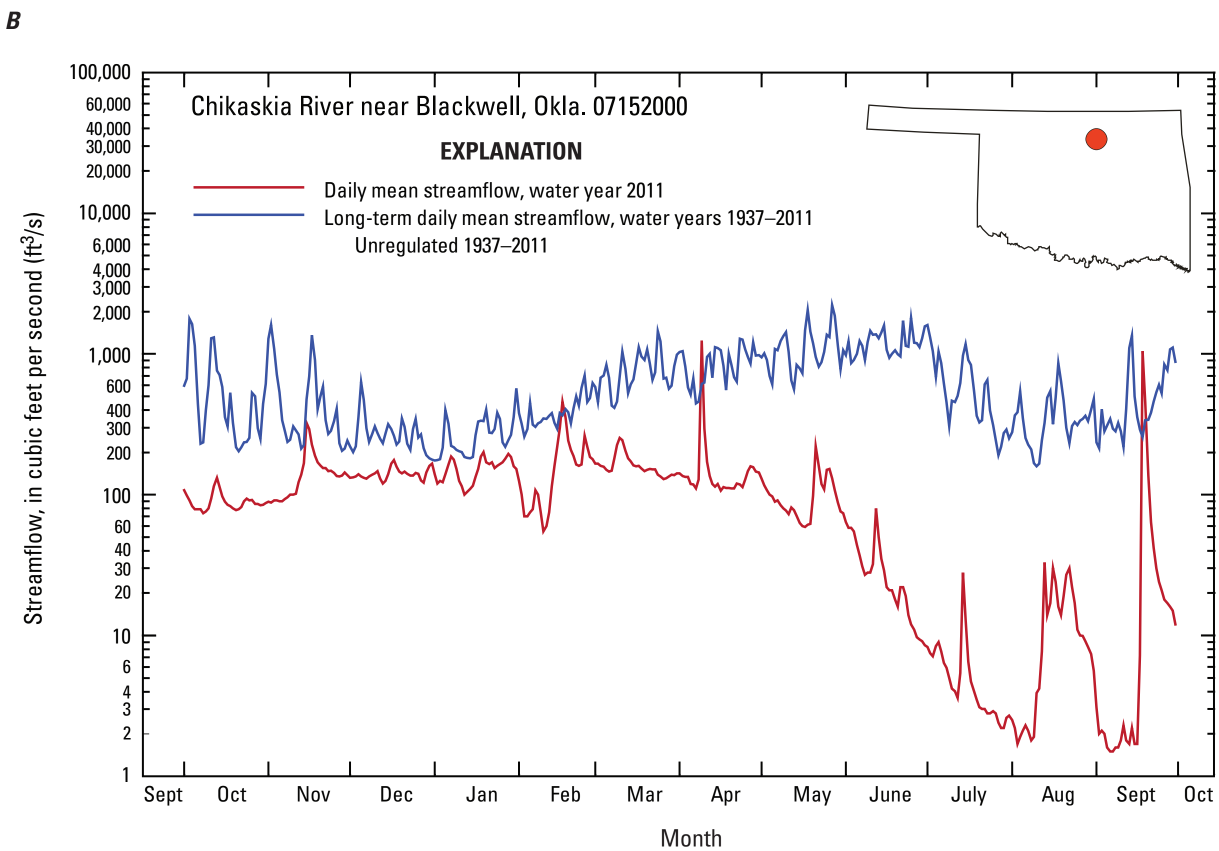


Figure 10. Streamflow data for Salt Fork Arkansas River at Tonkawa, Oklahoma, water years 1942–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.





Data from U.S. Geological Survey (2012b)

Figure 11. Streamflow data for Chikaskia River near Blackwell, Oklahoma, water years 1937–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

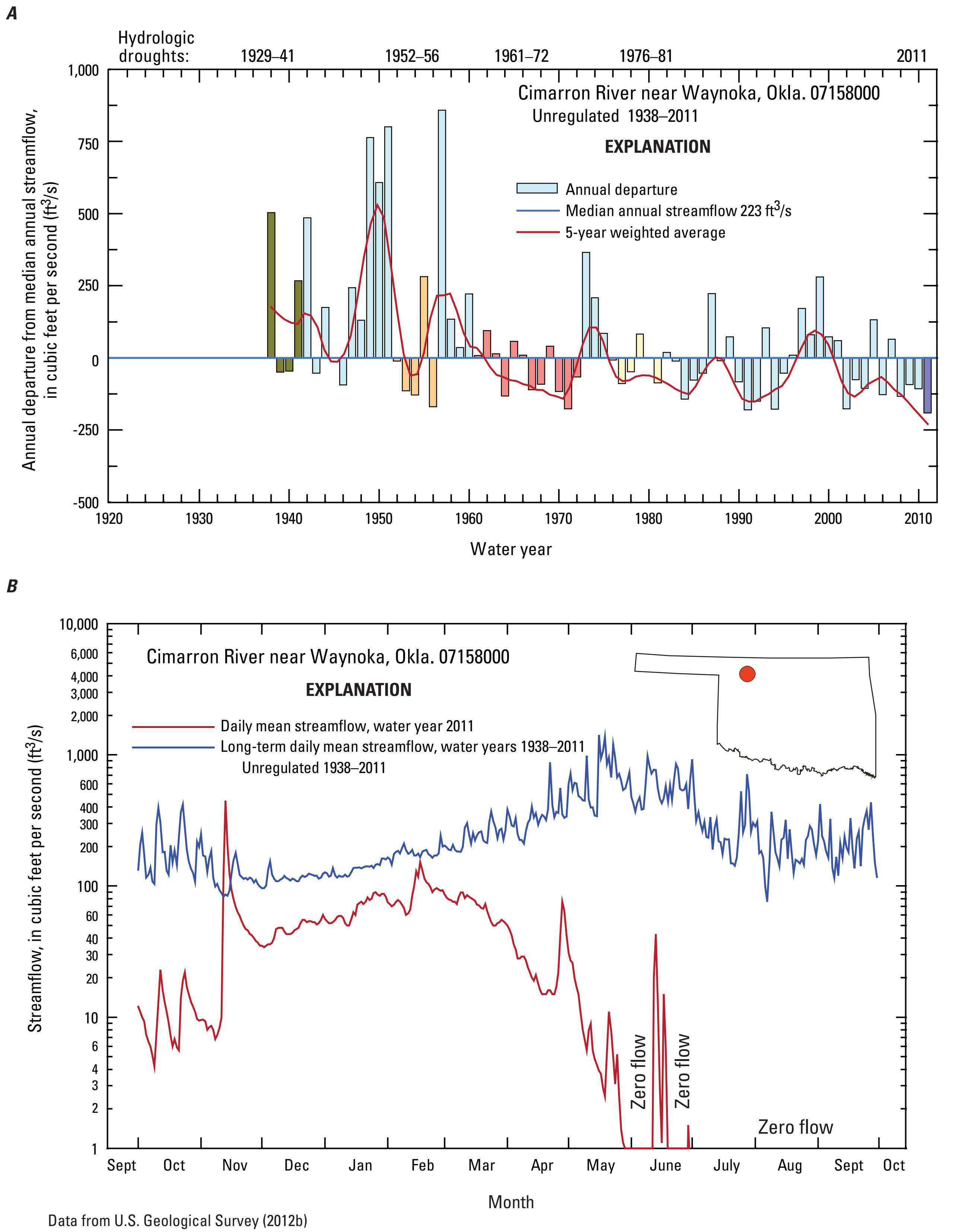
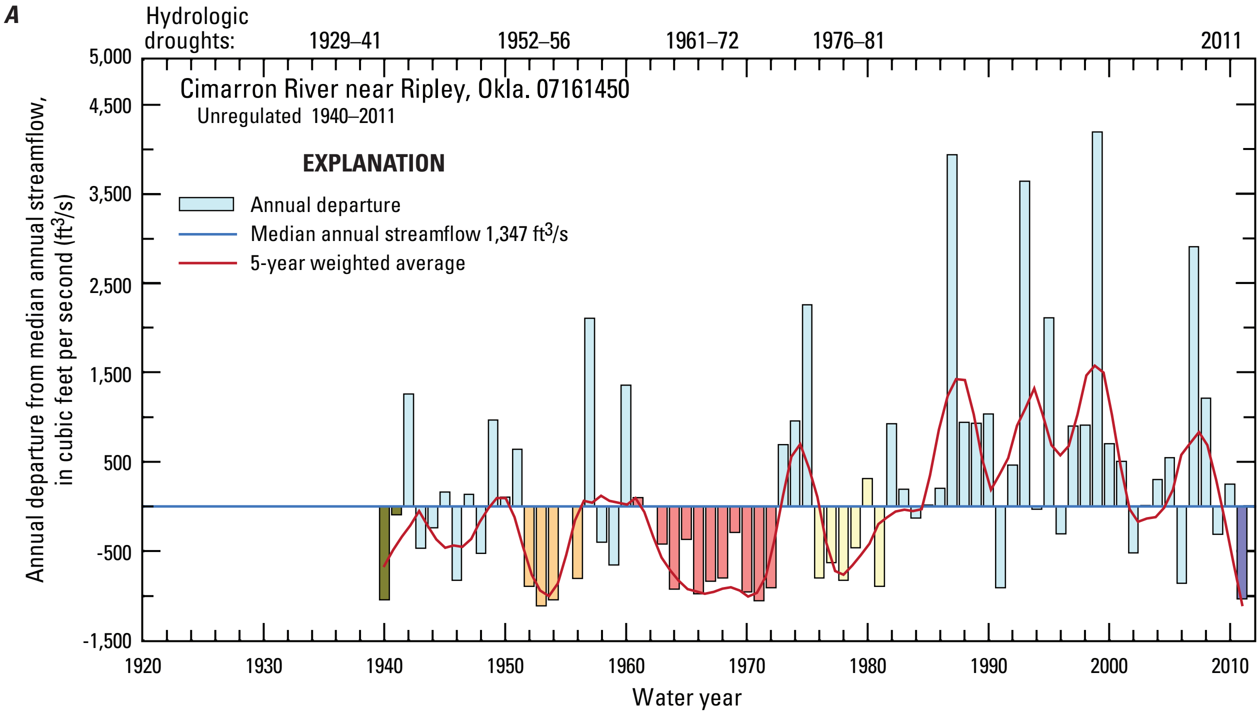
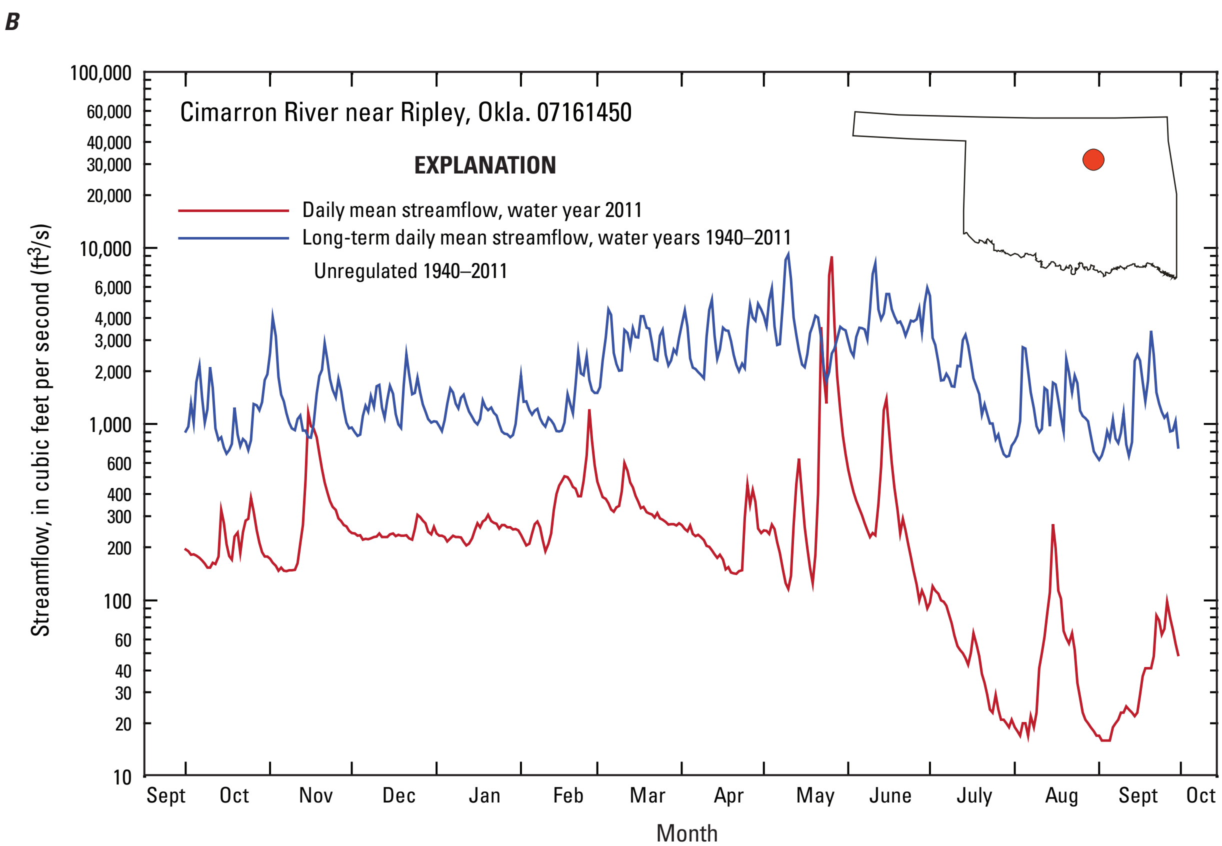


Figure 12. Streamflow data for Cimarron River near Waynoka, Oklahoma, water years 1938–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.





Data from U.S. Geological Survey (2012b)

Figure 13. Streamflow data for Cimarron River near Ripley, Oklahoma, water years 1940–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

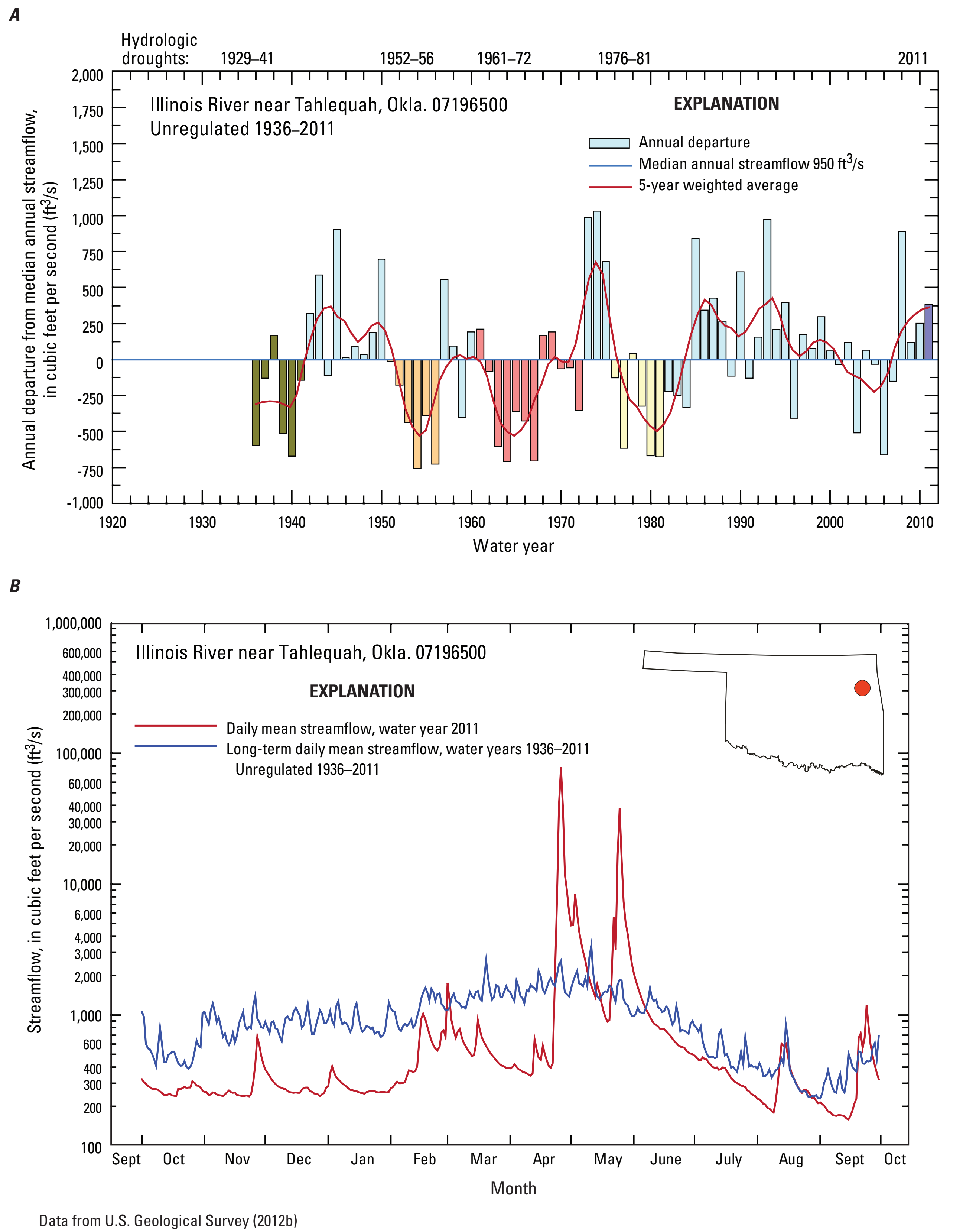


Figure 14. Streamflow data for Illinois River near Tahlequah, Oklahoma, water years 1936–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

the 71 years of record from 1939–42 and 1945–2011, with 16 percent of the long-term median annual streamflow being recorded (table 2). Water year 1981 was the driest year, with 13 percent of the long-term median annual streamflow being recorded. Zero streamflow was not recorded in water year 2011, with some brief periods of above-mean streamflow recorded in late April and late May at the station (fig. 15). Zero streamflow was recorded during most of August in the drought year of 2006 at this station (Tortorelli, 2008). The smallest daily mean streamflow at this station during the 2011 water year was 0.40 ft^3/s recorded on September 6, 2011 (fig. 15) (U.S. Geological Survey, 2012c).

North Canadian River near Wetumka

North Canadian River near Wetumka, Okla. (station number 07242000) is a streamflow-gaging station in central Oklahoma (fig. 9). Water year 2011 was the ninth driest in the 74 years of record from 1938–2011, with 31 percent of the long-term median annual streamflow being recorded (table 2). Water year 1956 was the driest year at the station, with 23 percent of the long-term median annual streamflow being recorded. Zero streamflow was not recorded during water year 2011 at this station, similar to the drought year of 2006, with some periods of streamflow near or above the long-term daily mean streamflow being recorded in February, April and May (fig. 16; Tortorelli, 2008). The smallest daily mean streamflow during the 2011 water year was 34 ft^3/s recorded at this station on August 6, 2011 (fig. 16) (U.S. Geological Survey, 2012c).

Salt Fork Red River at Mangum

Salt Fork Red River near Mangum, Okla. (station number 07300500) is a streamflow-gaging station in southwestern Oklahoma (fig. 9). Water year 2011 was the second driest in the 74 years of record from 1938–2011, with 18 percent of the long-term median annual streamflow being recorded (table 2). Water year 1940 was the driest year recorded at the station, with 18 percent of the long-term median annual streamflow being recorded. Zero streamflow was recorded in water year 2011 during part of October 2010 and from mid-May through September, with short periods of above-mean streamflow measured in October, November, and February (fig. 17) (U.S. Geological Survey, 2012c). In the drought year of 2006, zero flow was recorded for a shorter period, from late June through August at this station (Tortorelli, 2008).

Red River near Gainesville, Texas

Red River near Gainesville, Tex., (station number 07316000), is a streamflow-gaging station in south-central Oklahoma (fig. 9). Water year 2011 was the driest in the 75 years of record from 1937–2011, with 13 percent of the long-term median annual streamflow being recorded (table 2). Water year 2006 was the second driest year on record, with 23 percent of the long-term median annual streamflow being recorded at this station. Zero streamflow was not recorded during water year 2011 at this station, similar to the drought year of 2006, but streamflow remained less than long-term daily mean streamflow throughout water year 2011 (fig. 18) (Tortorelli, 2008). The smallest daily mean streamflow during the 2011 water year at the station was 24 ft^3/s recorded on September 1, 2011 (fig. 18) (U.S. Geological Survey, 2012c).

Washita River near Dickson

Washita River near Dickson, Okla. (station number 07331000) is a streamflow-gaging station in south-central Oklahoma (fig. 9). Water year 2011 was the driest in the 83 years of record from 1929–2011, with 18 percent of the long-term median annual streamflow being recorded (table 2). Water year 1964 was the second driest year recorded at this station, with 20 percent of the long-term median annual streamflow being recorded. Zero streamflow was not recorded during water year 2011 at this station, similar to the drought year of 2006, with daily mean streamflow briefly equaling or exceeding long-term daily mean streamflow in late May and mid-August of 2011 (fig. 19) (Tortorelli, 2008). The smallest daily mean streamflow during the 2011 water year was 1.0 ft^3/s recorded at this station on August 8, 2011 (fig. 19) (U.S. Geological Survey, 2012c).

Blue River near Blue

Blue River near Blue, Okla. (station number 07332500) is a streamflow-gaging station in south-central Oklahoma (fig. 9). Water year 2011 was the fourth driest in the 75 years of record from 1937–2011, with 28 percent of the long-term median annual streamflow being recorded (table 2). Water year 1956 was the driest year recorded at the station, with 12 percent of the long-term median annual streamflow being recorded. Zero streamflow was not recorded during water year 2011 at the station, similar to the drought year of 2006, with daily mean streamflow briefly equaling or exceeding long-term daily mean streamflow in late December, late April, and late May of 2011 (fig. 20) (Tortorelli, 2008). The smallest daily mean streamflow during the 2011 water year at this station was 0.24 ft^3/s recorded on August 29, 2011 (fig. 20) (U.S. Geological Survey, 2012c).

Red River at Arthur City, Texas

Red River at Arthur City, Tex. (station number 07335500) is a streamflow-gaging station in southeastern Oklahoma (fig. 9). Water year 2011 was the second driest in the 67 years of record from 1945–2011, with 29 percent of the long-term median annual streamflow being recorded (table 2). Water year 2006 was the driest year on record for this station, with

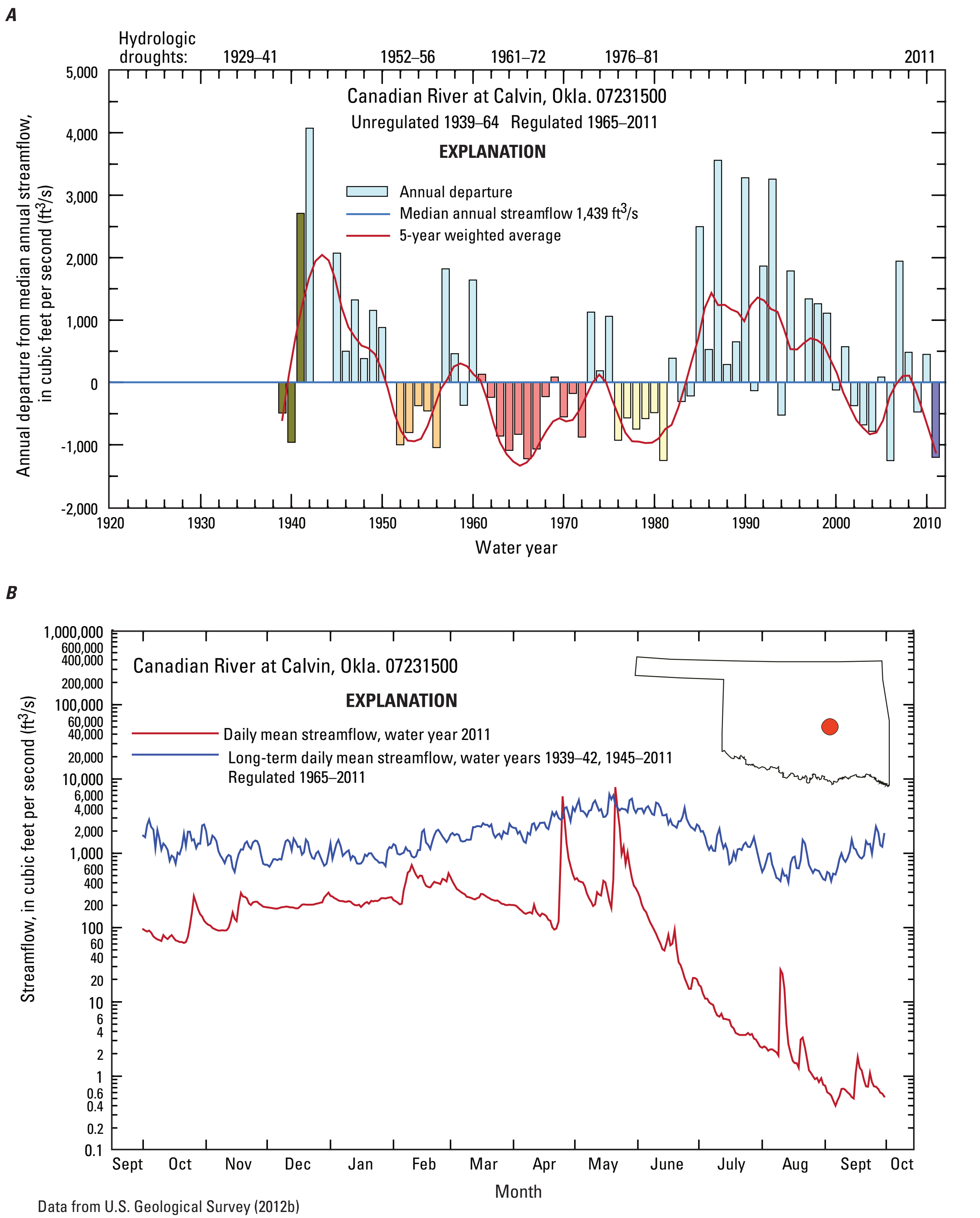
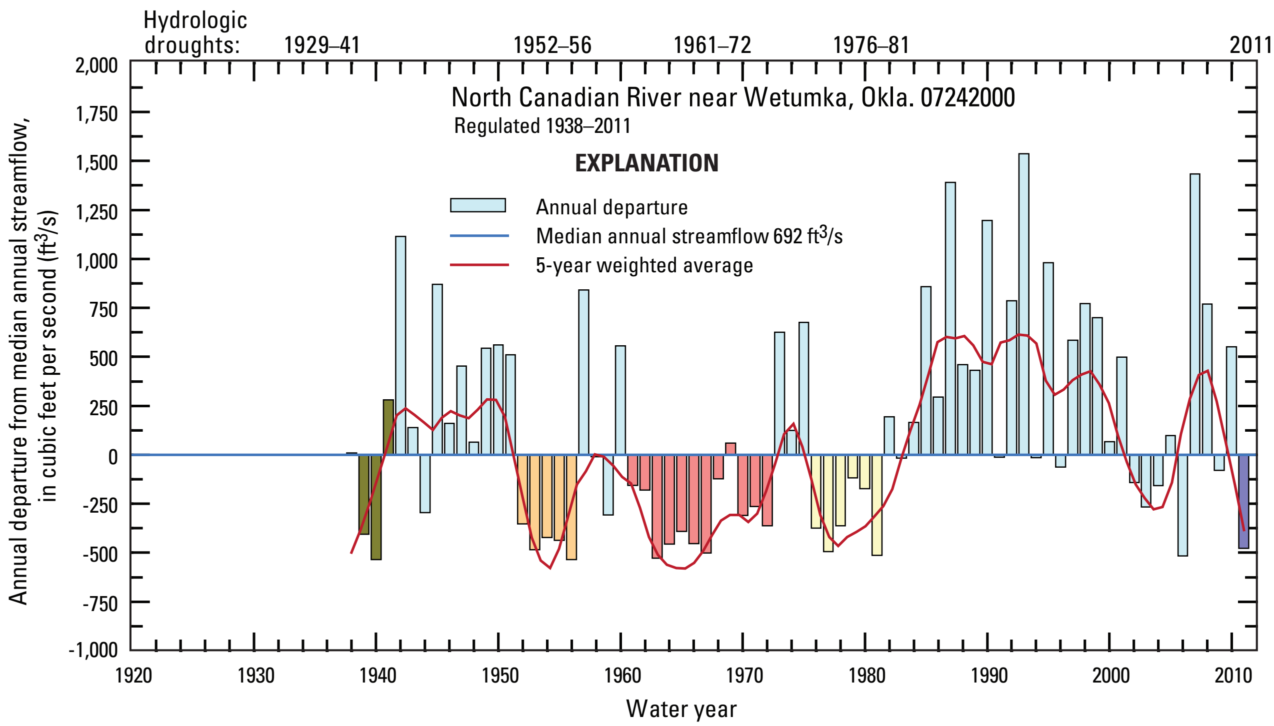


Figure 15. Streamflow data for Canadian River at Calvin, Oklahoma, water years 1939–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

A



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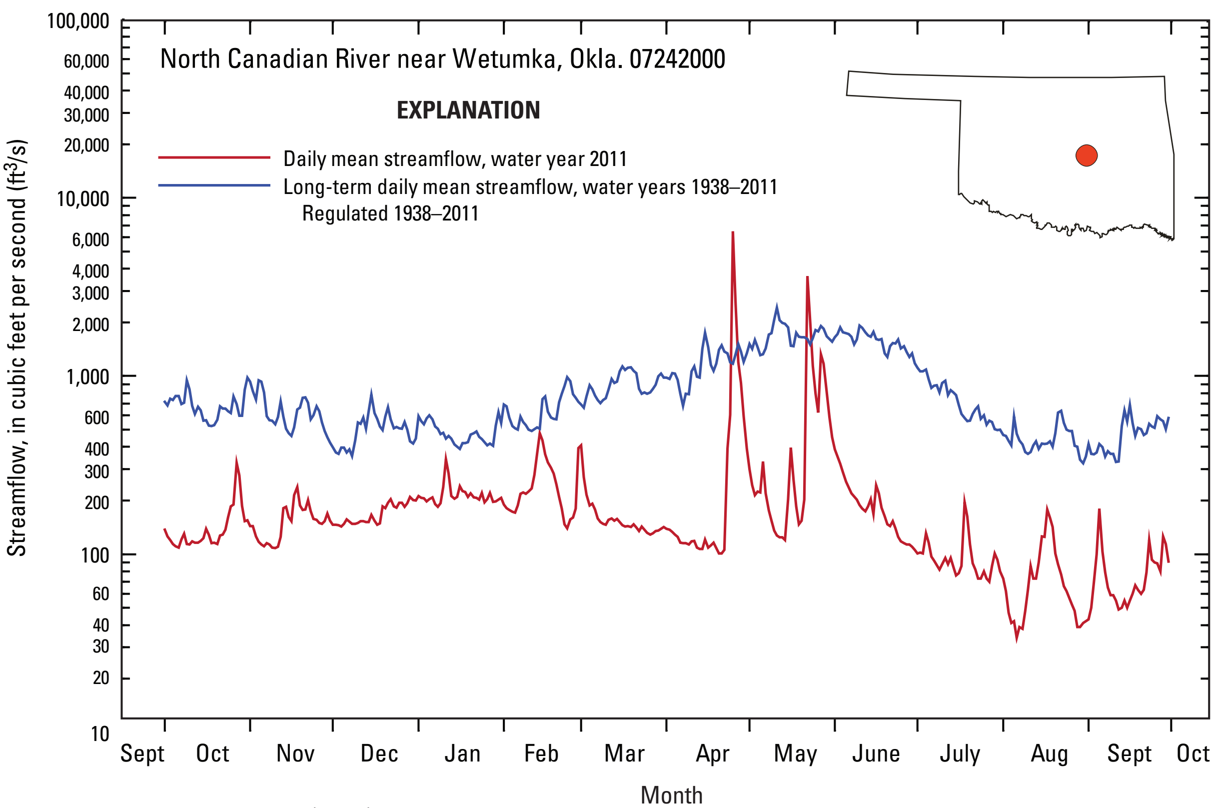
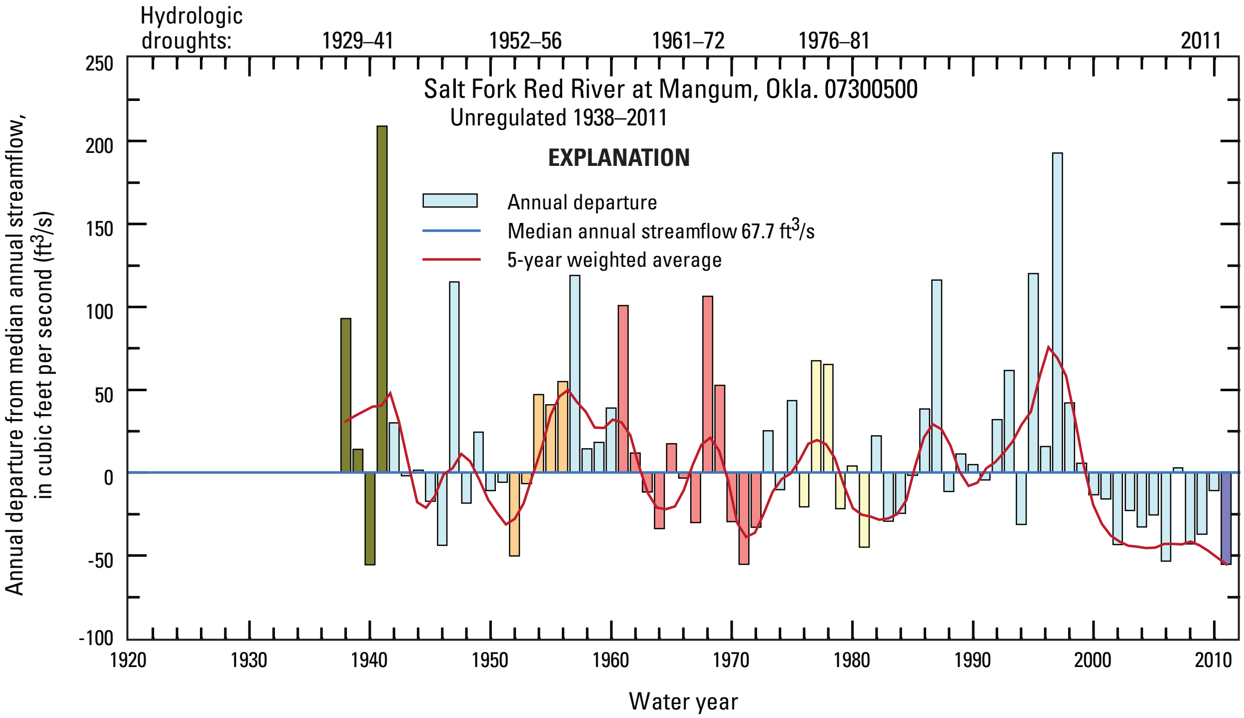


Data from U.S. Geological Survey (2012b)

Figure 16. Streamflow data for North Canadian River near Wetumka, Oklahoma, water years 1938–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

A



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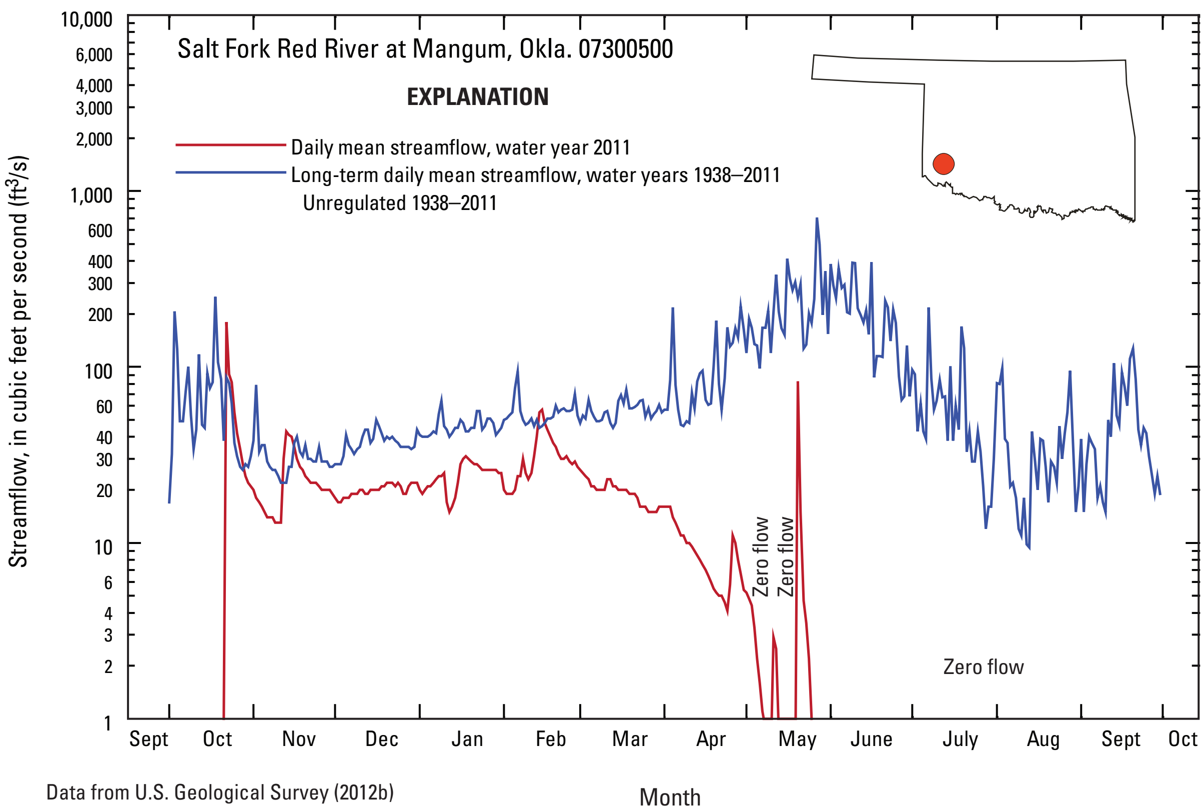

Figure 17. Streamflow data for Salt Fork Red River at Mangum, Oklahoma, water years 1938–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

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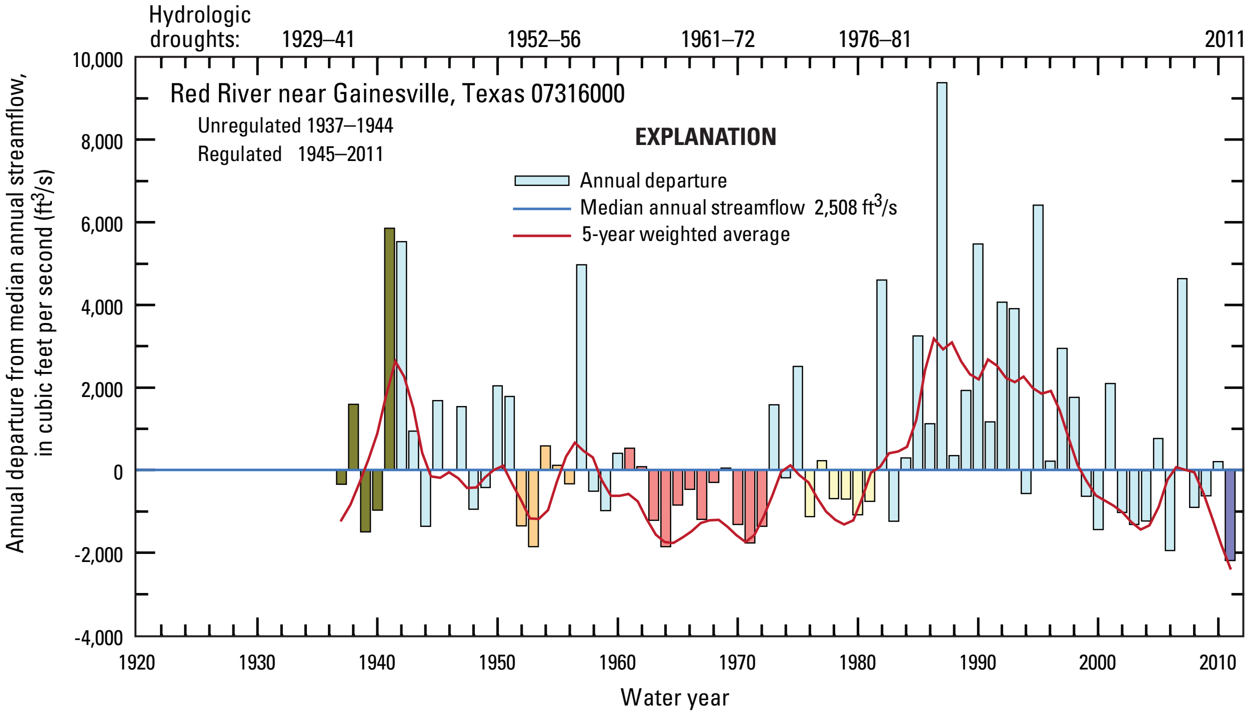

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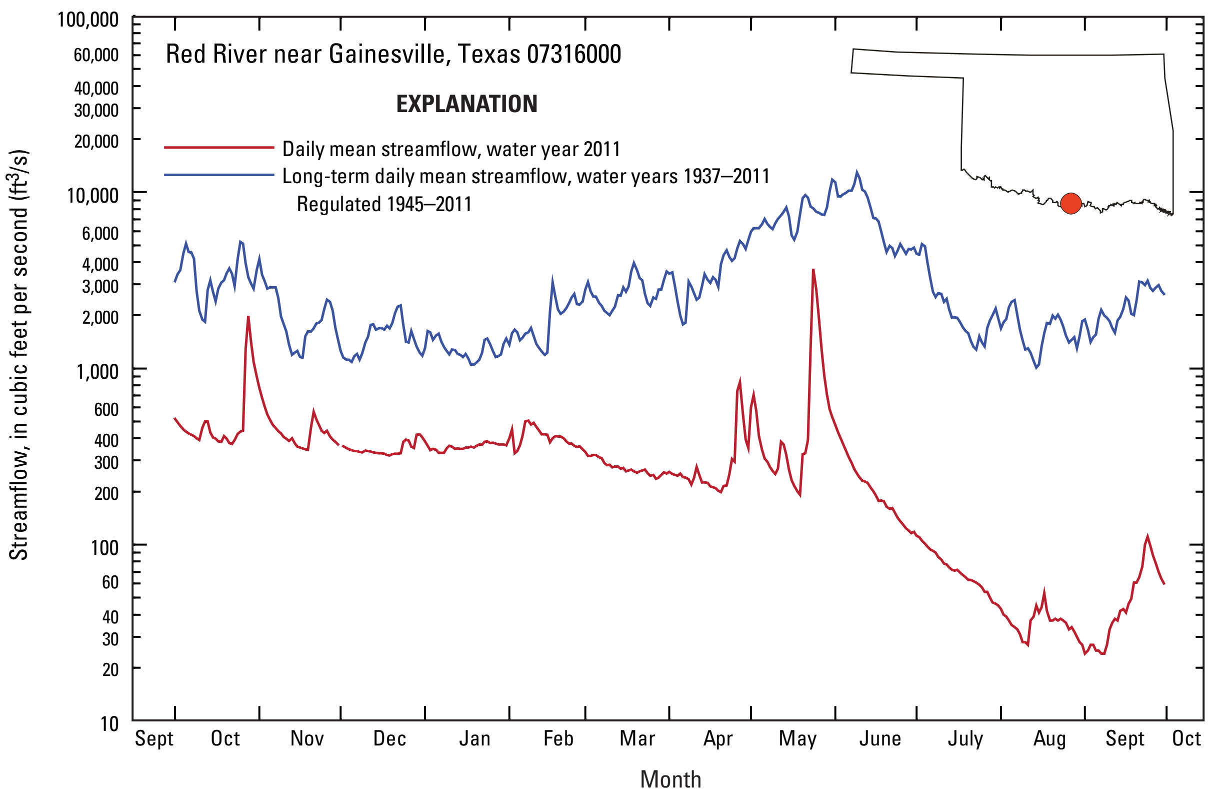


Data from U.S. Geological Survey (2012b)

Figure 18. Streamflow data for Red River near Gainesville, Texas, water years 1937–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

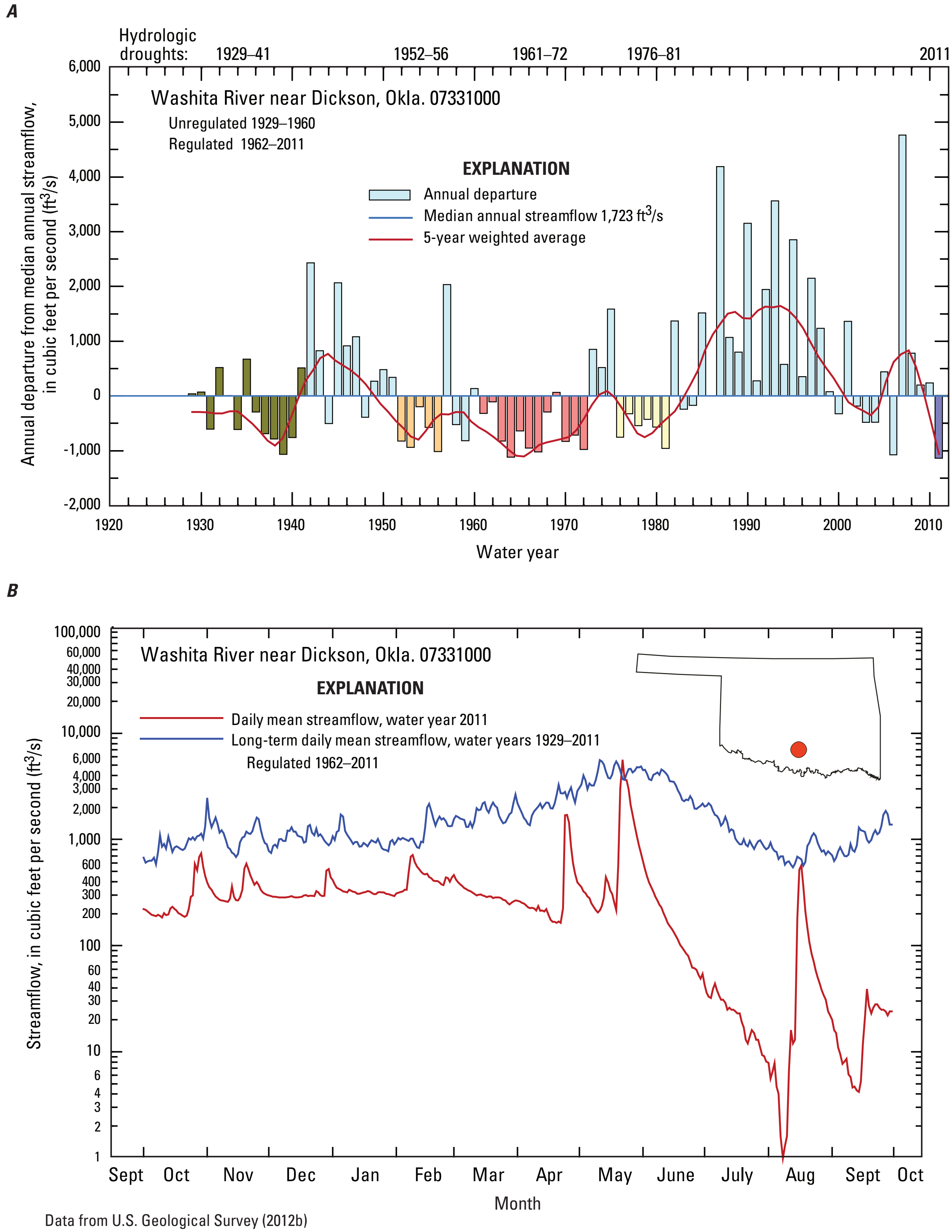


Figure 19. Streamflow data for Washita River near Dickson, Oklahoma, water years 1929–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

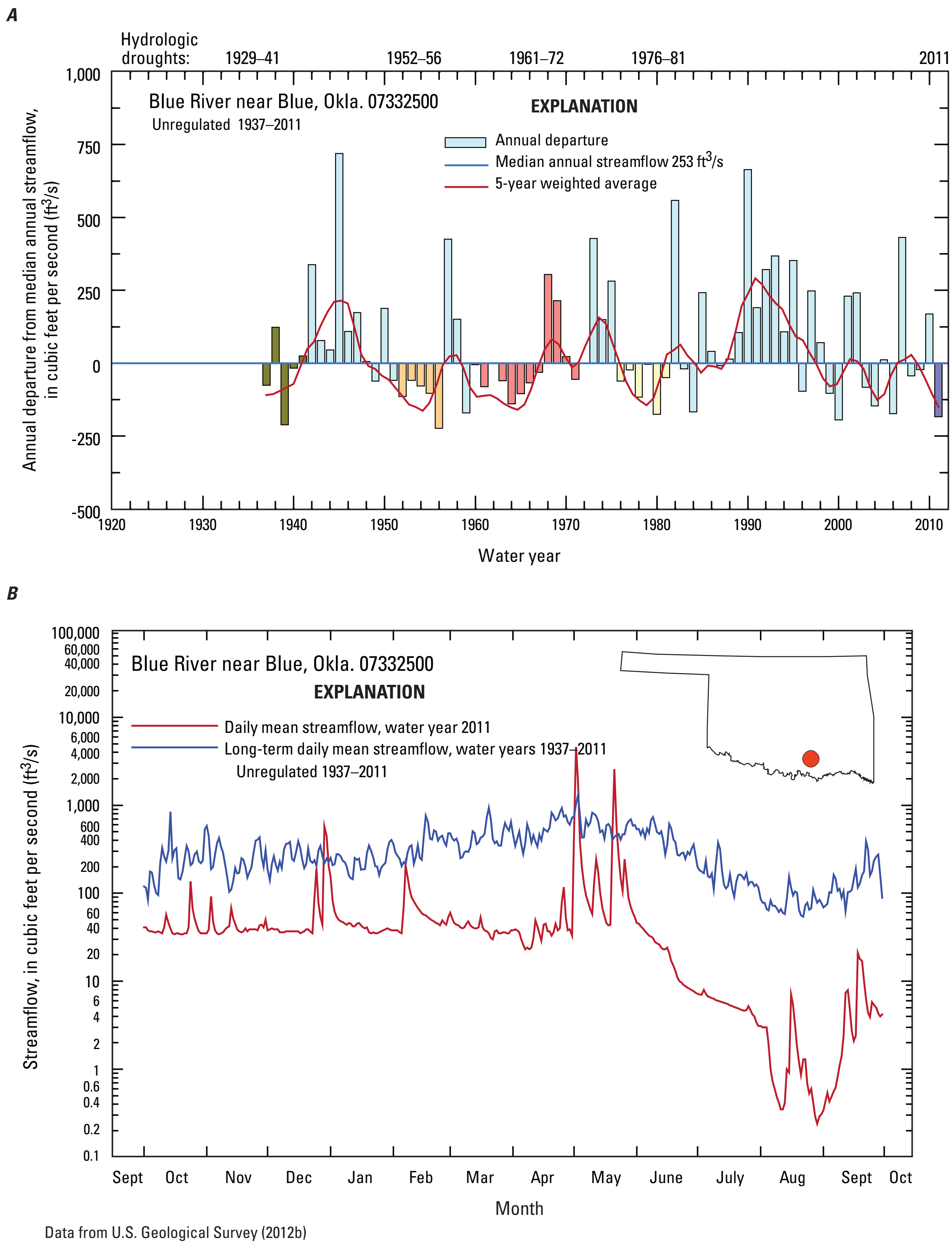


Figure 20. Streamflow data for Blue River near Blue, Oklahoma, water years 1937–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

26 percent of the long-term median annual streamflow being recorded. Zero streamflow was not recorded during water year 2011 at the station, similar to the drought year of 2006, with daily mean streamflow briefly equaling or exceeding long-term daily mean streamflow in early February and early and late May of 2011 (fig. 21) (Tortorelli, 2008). The smallest daily mean streamflow during the 2011 water year at this station was 207 ft^3/s recorded on September 26, 2011 (fig. 21) (U.S. Geological Survey, 2012c).

Effects of Low Streamflows

Hydrologic drought is associated with the effects of periods of precipitation deficits on streamflow, lake and reservoir levels, and groundwater levels. Although all droughts start with precipitation deficits (fig. 1), hydrologists are more concerned with how these deficits affect the surface-water and groundwater components of the hydrologic system. Hydrologic droughts commonly lag 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 of drought on reservoir levels may not affect water supply, hydroelectric power production, or recreational uses for several months. Water in the hydrologic storage systems of 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 can increase substantially (National Drought Mitigation Center, 2012).

Conditions at Major Reservoirs

The hydrologic drought of water year 2011 substantially affected reservoirs in the State (table 3, fig. 22) (Oklahoma Water Resources Board, 2010a–d, 2011a–j; U.S. Army Corps of Engineers, 2012). On September 29, 2011, the day before the end of the water year 2011, the statewide total conservation storage was 83.3 percent (table 3), which was the lowest statewide conservation storage recorded in water year 2011 and was slightly less than the conservation storage of 86.3 percent available at the end of water year 2006 (Tortorelli, 2008). The wettest day (having the greatest amount of conservation storage) of water year 2011 was April 14, 2011, when the statewide total conservation storage was the highest (100 percent; table 3). The northeastern region of the State consistently had the highest percentage of conservation storage, whereas the southwestern region of the State consistently had the lowest percentage of conservation storage (table 3). Lake Altus at Lugert (map identifier 20, fig. 22) in the southwestern region was the reservoir with the lowest percentage of conservation storage for the entire water year 2011 (table 3).

The condition of farm ponds across Oklahoma was more drastically affected than the major reservoirs with hundreds of farm ponds across Oklahoma having completely dried up by July 2011, which, along with lack of local hay and high feed prices caused widespread sell-offs of State cattle herds (Hayes, 2011a). In addition to low lake levels and streamflow affecting water supplies and recreational tourism, hot, stagnant, nutrient-enriched water caused widespread blooms of blue-green algae (*Cyanophyta*) in many reservoirs throughout the State, which may have caused some illnesses, impaired the clarity of water, and caused economic losses to local businesses (Cross, 2011; Lawrence, 2012; Sewell, 2011).

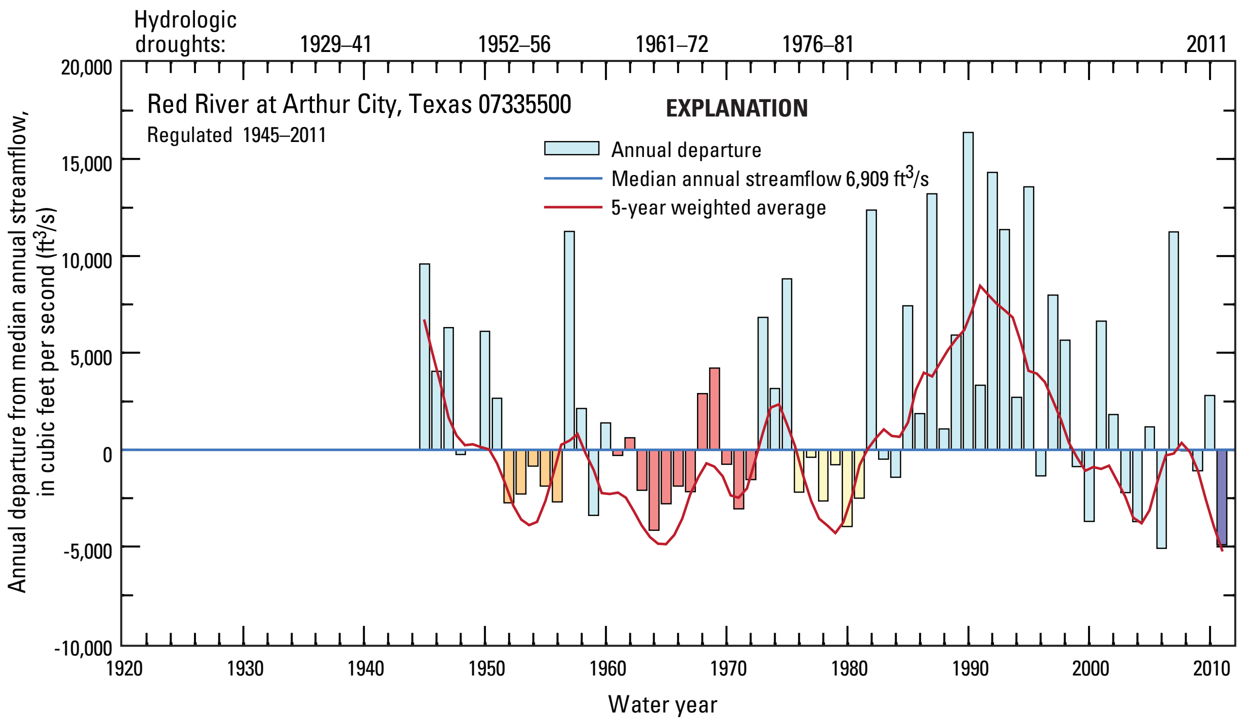
Hydroelectric Power Generation

Hydroelectric power generation in Oklahoma was substantially reduced at many reservoirs during calendar year 2011 because of a reduction in available streamflow, as a result of the hydrologic drought. Calendar year 2011 hydroelectric power generation at stations in Oklahoma ranged from 24 to 112 percent of the calendar year 2010 power generation, with the sum of hydroelectric power generation at nine reservoirs declining by 42 percent in 2011 compared to 2010 (table 4). Reduced hydropower generation during droughts in Oklahoma requires substitution of electrical generation capacity by combustion of fossil fuels such as coal and natural gas (Renewable Energy Policy Network for the 21st century, 2012). Greater power generation with coal and natural gas, typically costs more than hydropower generation and creates emissions of additional greenhouse gases and solid wastes associated with fossil fuel combustion (Renewable Energy Policy Network for the 21st Century, 2012).

Groundwater Levels at Selected Long-Term Stations

A long-term recording groundwater well that is in hydraulic connection with a stream illustrates the effect the water year 2011 drought had on groundwater levels in south-central Oklahoma. The daily mean water level recorded in a well completed to 396 feet (ft) below land surface in the Arbuckle-Simpson aquifer near Fittstown, Okla., was several feet above the long-term daily mean water level in September and much of October 2010 but had decreased to about 11 ft lower than long-term daily mean water levels by the end of water year 2011 (fig. 23*A*). A well completed to 122 ft below land surface in the Arbuckle-Simpson aquifer in an adjoining county (Johnston) had similar changes in groundwater levels during water year 2011, ending the year at about 5 ft lower than long-term daily-mean water levels measured at that well (fig. 24*A*). A well completed to 386 ft below land surface in

A



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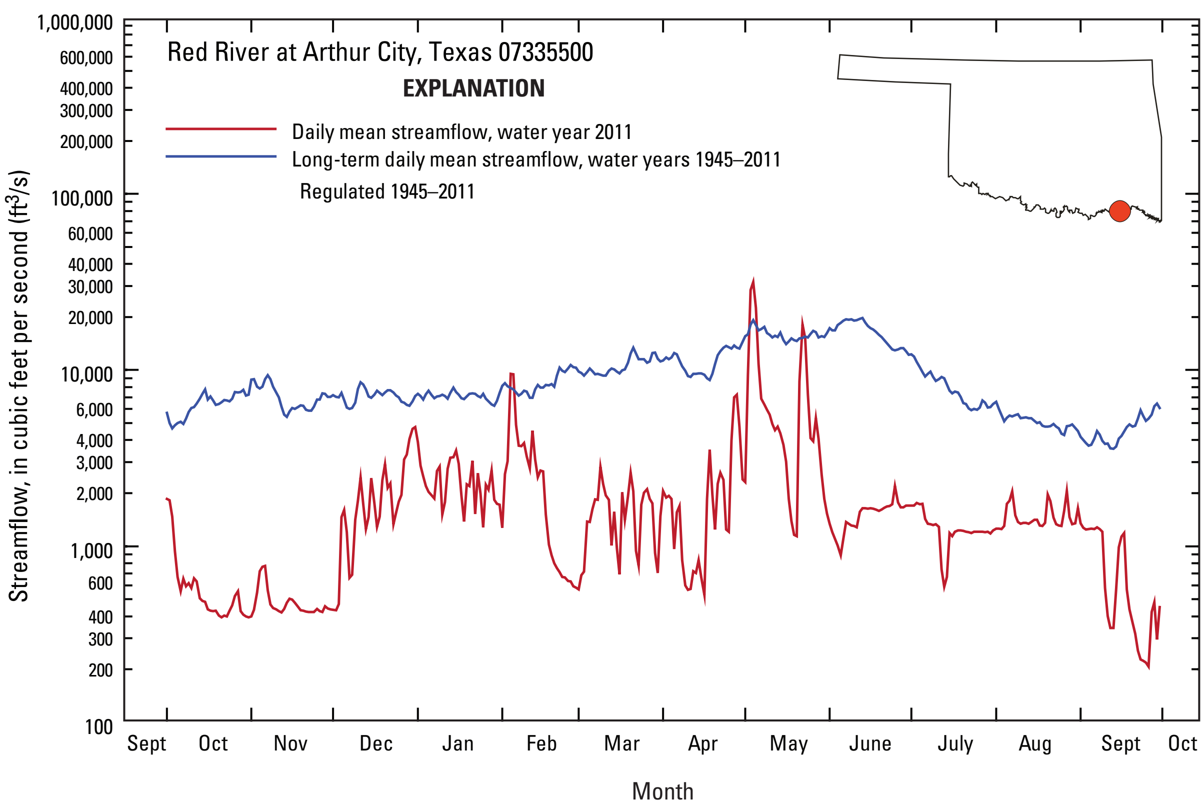


Figure 21. Streamflow data for Red River at Arthur City, Texas, water years 1945–2011. *A*, Annual departure from long-term median annual streamflow, and *B*, Comparison between daily mean streamflow, water year 2011, and long-term daily mean streamflow.

Table 3. Storage in selected major Oklahoma lakes and reservoirs on September 29, 2011, by National Weather Service Climate Division, and comparison with April 14, 2011, storage.

[Shading indicates reservoir storage below 80 percent of total conservation storage; WY, water year; Regional totals and averages are based on conservation storage in acre-feet for the lakes and reservoirs in each climate division; daily storage numbers above conservation storage amounts are rounded down to 100 percent, as storage above conservation storage is considered to be in the flood pool of a reservoir; *, indicates seasonal pool operation; actual storage figures/percents may vary]

Site number (fig. 22)	Climate division lake or reservoir	Conservation storage (acre-feet)	09/29/11 storage (acre-feet)	Percent of conservation storage		
				WY end 09/29/11	WY driest 09/01/11	WY wettest 04/14/11
	2 North Central					
1	Fort Supply	12,221	7,958	65.1	73.1	100
2	Kaw*	437,120	374,569	85.7	86.9	92.1
	Regional totals/averages	**449,341**	**382,527**	**85.1**	**86.5**	**92.4**
	3 Northeast					
3	Birch	18,221	13,611	74.7	81.0	96.3
4	Copan	34,647	30,852	89.0	94.7	100
5	Fort Gibson	365,200	353,045	96.7	98.0	100
6	Grand	1,478,860	1,495,291	100	100	100
7	Hudson	200,185	207,372	100	100	100
8	Hulah	22,565	18,395	81.5	91.5	100
9	Keystone	449,961	385,748	85.7	86.2	91.1
10	Oologah	549,300	496,410	90.4	93.3	100
11	Stiatook	323,607	220,149	68.0	62.9	84.2
	Regional totals/averages	**3,442,546**	**3,220,873**	**93.6**	**94.2**	**99.8**
	4 West Central					
12	Canton	109,742	68,740	62.6	64.9	100
13	Foss	183,092	144,095	78.7	80.9	92.6
	Regional totals/averages	**292,834**	**212,835**	**72.7**	**74.9**	**96.1**
	5 Central					
14	Arcadia	29,546	23,024	77.9	80.1	92.6
15	Heyburn	5,325	4,241	79.6	80.9	100
16	Thunderbird	119,600	91,350	76.4	79.6	84.7
	Regional totals/averages	**154,471**	**118,615**	**76.8**	**79.8**	**87.0**
	6 East Central					
17	Eufaula*	2,253,993	1,806,690	80.2	83.0	81.9
18	Tenkiller	654,246	594,260	90.8	91.5	96.3
	Regional totals/averages	2,908,239	2,400,950	82.6	84.9	85.2
	7 Southwest					
19	Fort Cobb	74,030	59,862	80.9	84.4	99.5
20	Altus	128,919	23,232	18.0	18.9	50.8
21	Tom Steed	97,520	58,046	59.5	63.2	82.0
	Regional totals/averages	**300,469**	**141,140**	**47.0**	**49.4**	**72.9**
	8 South Central					
22	Arbuckle	72,400	58,844	81.3	84.7	96.5
23	McGee Creek	113,959	97,870	85.9	91.6	93.8
24	Texoma*	2,692,553	2,042,069	75.8	78.2	84.8
25	Waurika*	191,406	147,208	76.9	79.3	93.9
	Regional totals/averages	**3,070,318**	**2,345,991**	**76.4**	**75.7**	**86.0**
	9 Southeast					
26	Broken Bow*	919,485	814,390	88.6	88.6	88.7
27	Hugo*	171,009	112,735	65.9	73.9	88.9
28	Pine Creek*	38,608	20,352	52.7	62.0	99.3
29	Sardis	274,192	246,249	89.8	92.2	94.2
30	Wister	49,441	37,364	75.6	83.0	100
	Regional totals/averages	**1,452,735**	**1,231,090**	**84.7**	**86.7**	**90.8**
	State totals	**12,070,953**	**10,054,021**	**83.3**	**85.1**	**100**
	Resevoirs below 80 percent storage			**15**	**10**	**1**

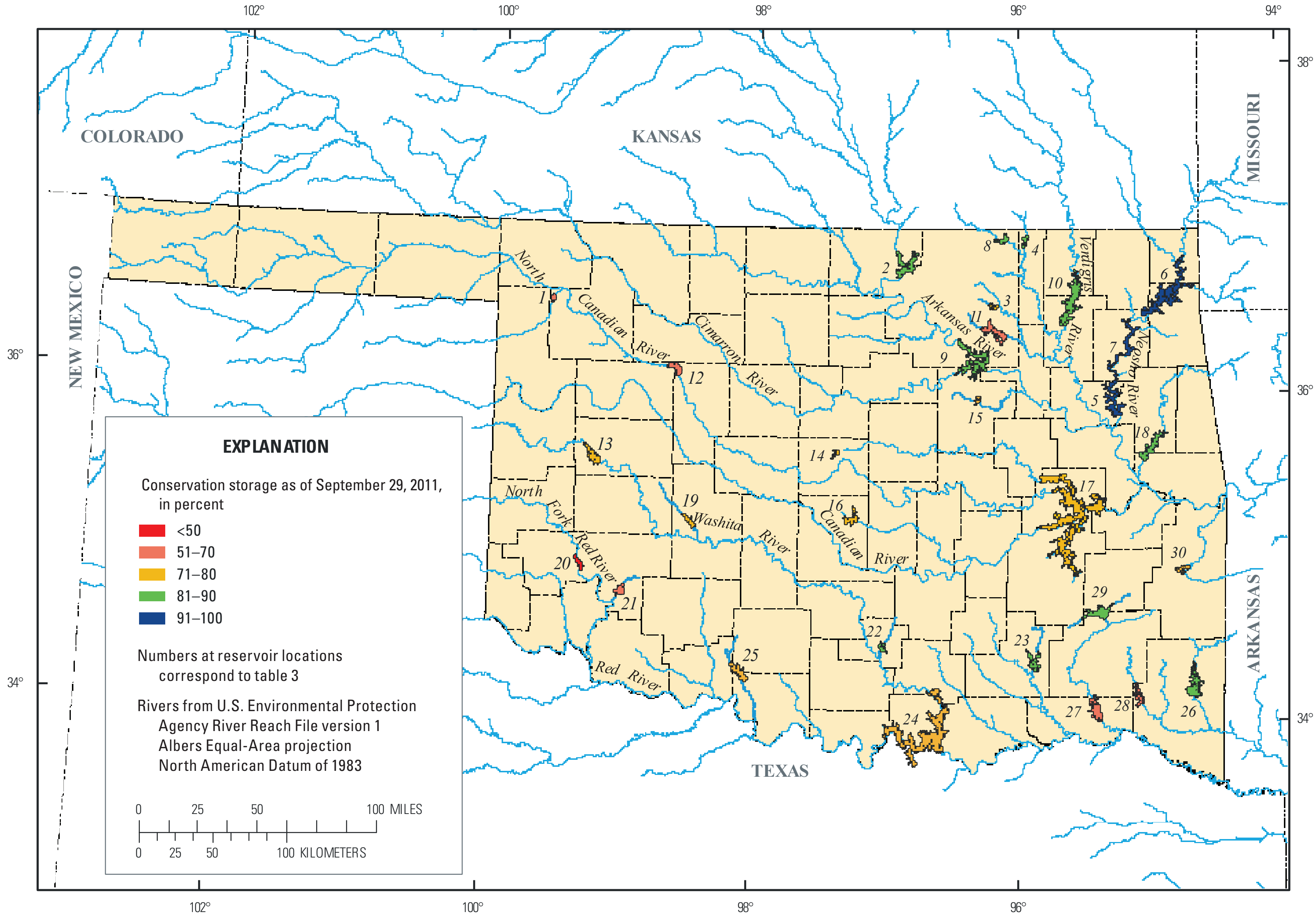


Figure 22. Locations of selected major Oklahoma lakes and reservoirs and percentage of conservation storage as of September 29, 2011.

Table 4. Comparison of hydroelectric power generation at selected Oklahoma hydroelectric plants between calendar years 2010 and 2011.

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

Site number (fig. 22)	Lake hydroelectric generation project	Climate division	Calendar year 2010 power (GWh)	Calendar year 2011	
				Power (GWh)	Percent of CY 2010 power
2	Kaw[1]	2 North Central	110	26	24
5	Fort Gibson[2]	3 Northeast	252	158	63
6	Grand (Pensacola)[3]	3 Northeast	528	321	61
7	Hudson (RS Kerr)[3]	3 Northeast	278	171	62
7	Salina[3, 4]	3 Northeast	233	229	98
9	Keystone[2]	3 Northeast	296	68	23
17	Eufaula[2]	6 East Central	328	96	29
18	Tenkiller[2]	6 East Central	120	106	88
26	Broken Bow[2]	9 Southeast	108	121	112
		Sum	**2,253**	**1,297**	**58**

[1]Data from J. Rogers (Oklahoma Municipal Power Authority, written commun., 2012).

[2]Data from A. Corker (Southwestern Power Administration, written commun., 2012).

[3]Data from D. Townsend and W. Potter (Grand River Dam Authority, written commun., 2012).

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

the High Plains aquifer in the panhandle (fig. 25*A*) did not have responses to wet and dry periods during the year, but the long-term downward trend in groundwater levels recorded since the mid-1960s continued.

The Arbuckle-Simpson aquifer is karstic, consisting of highly permeable limestone and dolomite rocks with relatively shallow water tables and good hydraulic connection to local streams, which contribute to relatively rapid responses to precipitation events and drought (Christenson and others, 2011). The High Plains aquifer of northwestern Oklahoma consists of layers of silty sands with some layers of low-permeability caliche. Materials in that aquifer tend to have relatively small permeability. Precipitation and recharge amounts also tend to be much less in the panhandle than in the rest of the State and water tables in the High Plains aquifer generally are several hundred feet below land surface (Luckey and others, 2000; Wood, 2000). All of those factors combine to attenuate short-term water-level changes in wet and dry periods in the High Plains aquifer. Long-term declines in groundwater levels in the High Plains aquifer are well-known, being caused by water withdrawals that exceed recharge in that relatively arid area (McGuire, 2011).

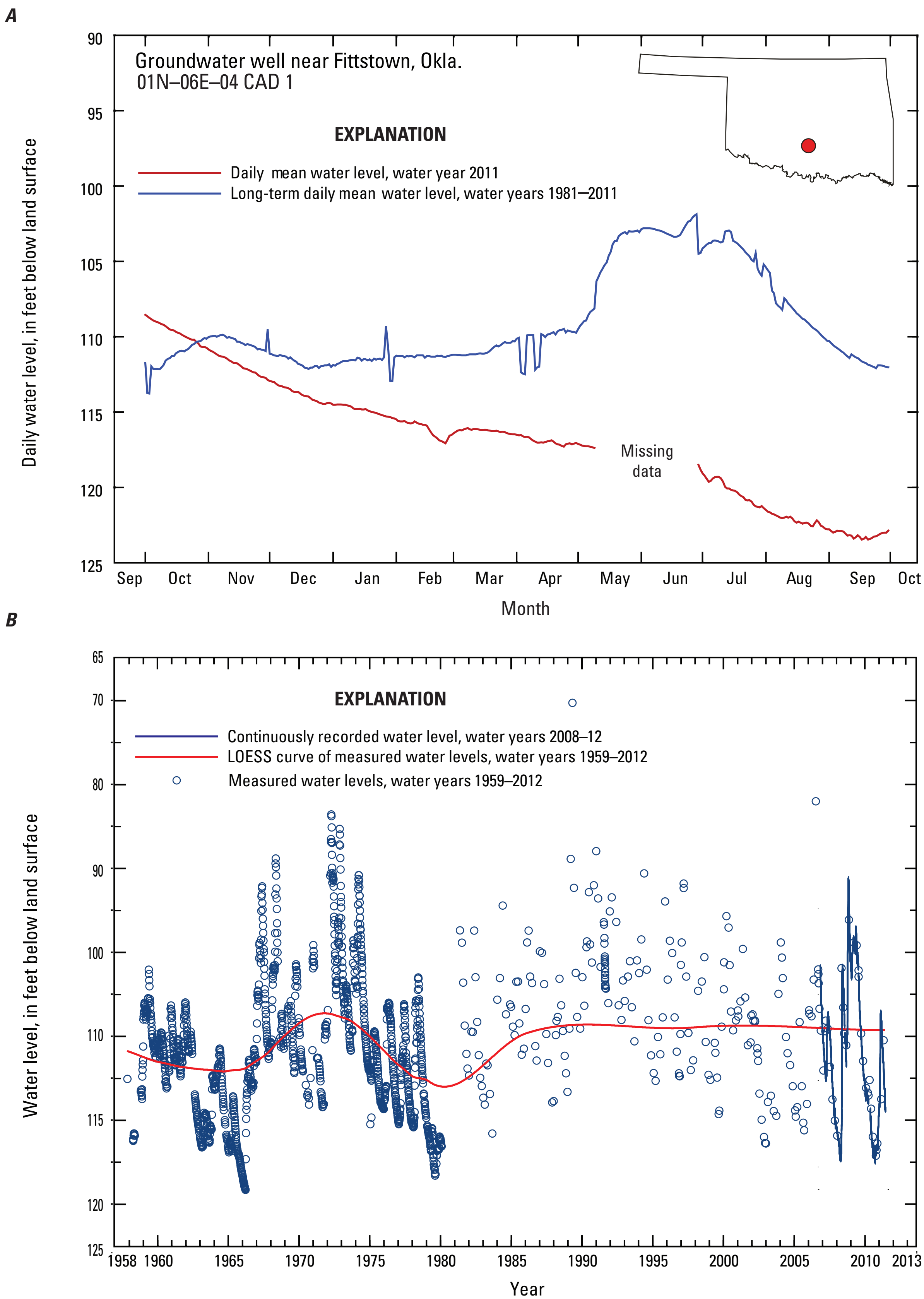
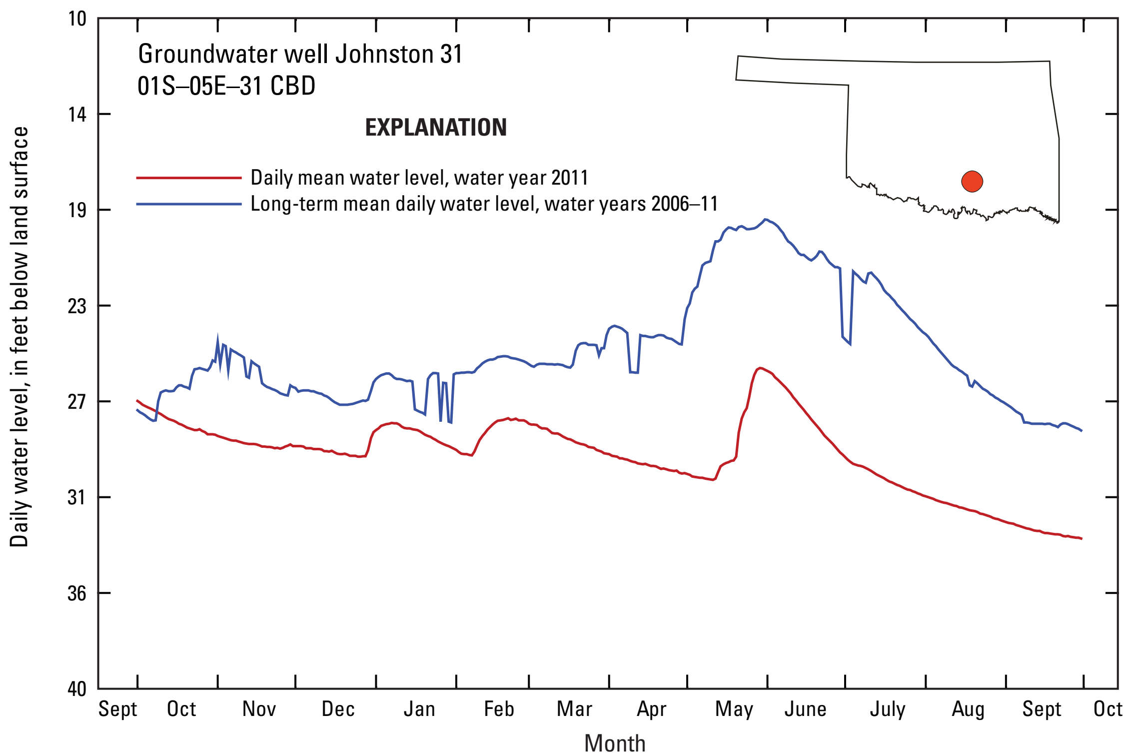


Figure 23. *A*, Daily-mean water levels, water year 2011; *B*, Long-term daily mean water levels and all water levels measured in a groundwater well near Fittstown, Oklahoma, water years 1958–2012.

A



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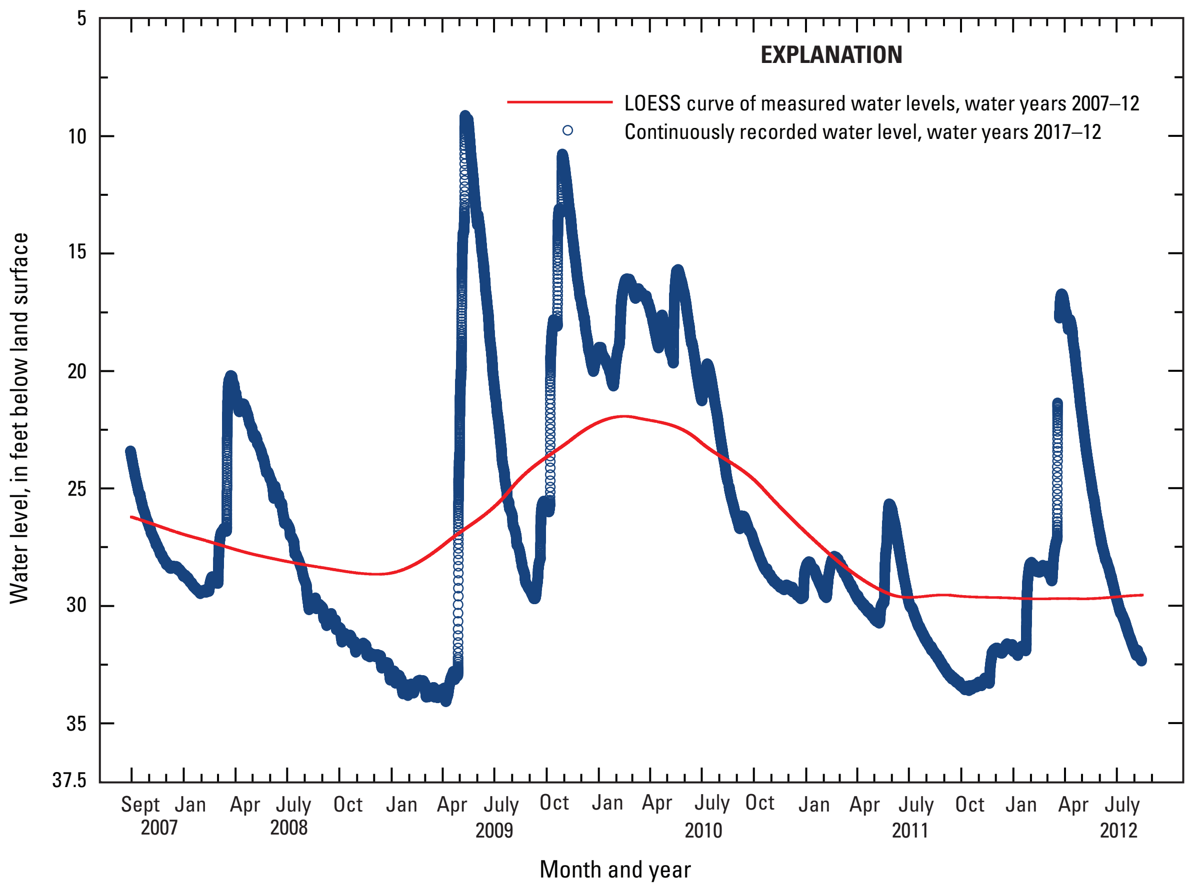
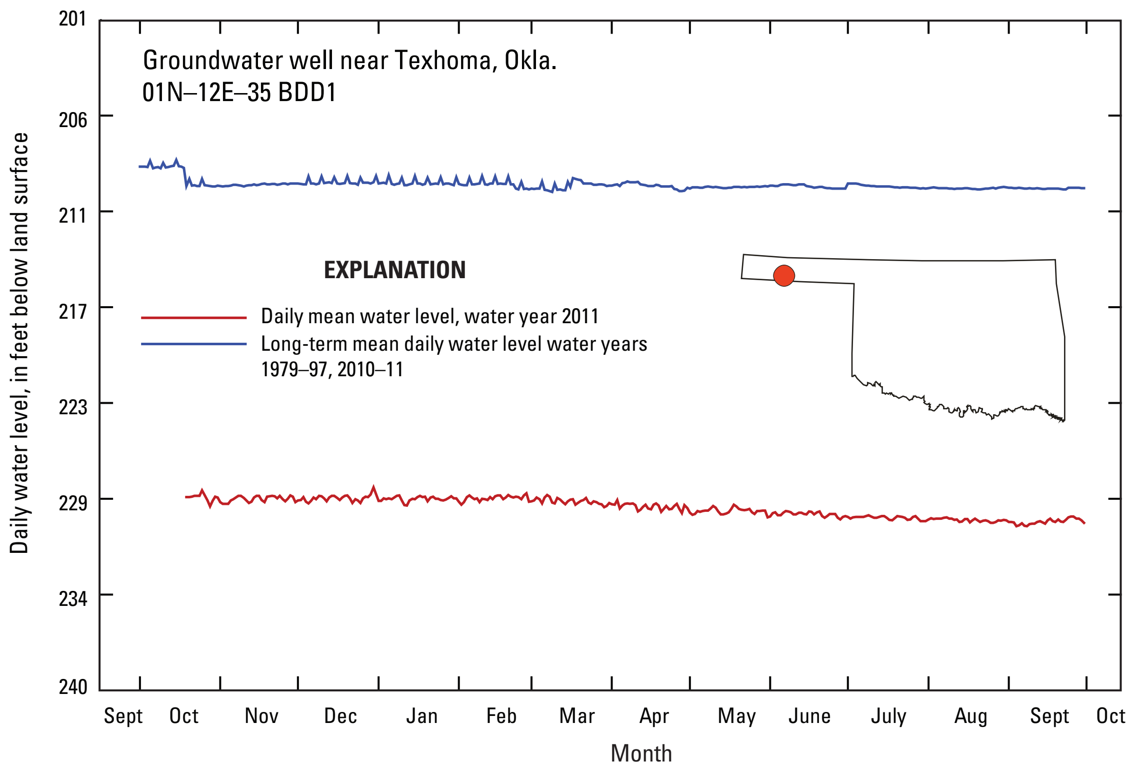


Figure 24. *A,* Daily-mean water levels, water year 2011; *B,* Long-term daily mean water levels; and continuously recorded water levels measured in a groundwater well in Johnston County, Oklahoma, water years 2006–11.

A



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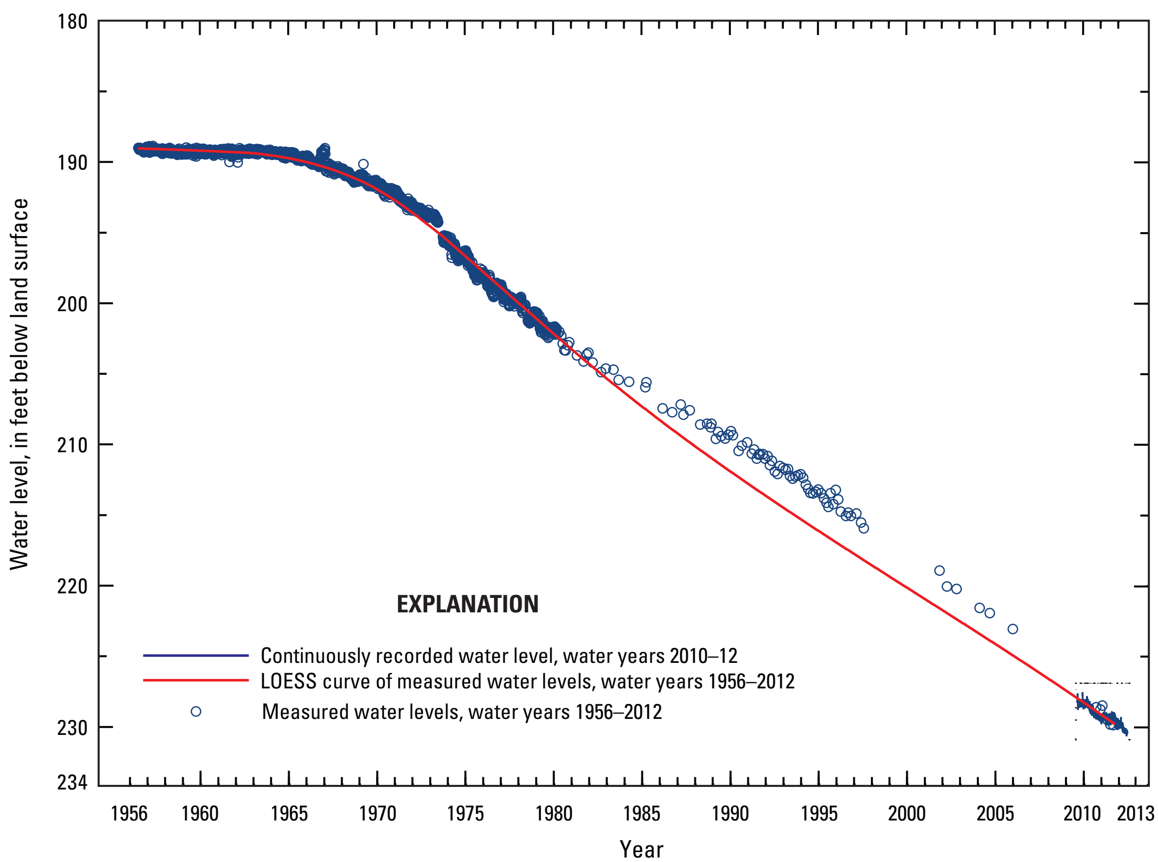

Data from U.S. Geological Survey (2012c)

Figure 25. *A,* Daily-mean water levels, water year 2011; *B,* Long-term daily-mean water levels; and continuously recorded water levels measured in a groundwater well near Texhoma, Oklahoma, water years 1956–2011.

Summary

Water year 2011 (October 1, 2010, through September 30, 2011) was a year of hydrologic drought, receiving the 2d lowest amount of precipitation and having the 16th lowest average annual streamflow and the 42d lowest statewide runoff for Oklahoma recorded for the period 1925–2011. The period of water years 1925–2011 was selected as the period of record to examine hydrologic drought in this report because before 1925 few continuous record streamflow-gaging stations existed and gaps existed where no streamflow-gaging stations were operated. In 2011, effects of the drought became particularly severe during the summer, with the statewide average temperature of 89.1°F during July being the hottest month recorded for any State since 1895. Some effects of drought during water year 2011 included:

1. streamflow being nearly the smallest recorded for the period 1925–2011, particularly in western and southwestern Oklahoma;
2. major reservoirs having only 83.3 percent of the statewide conservation storage available at the end of the water year;
3. calendar year 2011 hydroelectric power generation at stations in Oklahoma being about 58 percent of calendar year 2010 power generation;
4. groundwater levels in State aquifers having decreased;
5. wildfires burning more than 300,000 acres and hundreds of structures;
6. voluntary and mandatory water-conservation measures and mandatory outdoor burn bans being enacted in some parts of the State and states of emergency declared;
7. production of many major crops being less than half of 2010 production;
8. hay and feed prices increasing and many farm ponds drying up, forcing large sales of cattle and, thereby, decreasing cattle herds, which were down to the smallest numbers since 1968;
9. recreational tourism on Oklahoma streams and lakes decreasing because of low water levels and blue-green algae blooms; and
10. above-normal mortality and poorer condition of many species of aquatic and terrestrial wildlife being reported.

The severity of the 2011 drought can be evaluated by comparing it with four previous major hydrologic droughts, water years 1929–41, 1952–56, 1961–72, and 1976–81. Annual area-averaged precipitation totals for the nine National Weather Service Climate Divisions from water year 2011 were compared to precipitation totals for years in the four previous major hydrologic drought periods of the 20th century to show how precipitation deficits in Oklahoma varied by region. The nine climate divisions in Oklahoma had precipitation in water year 2011 ranging from 43 to 76 percent of normal annual precipitation, with the Climate Division 3 Northeast having the closest to normal precipitation and the Climate Division 7 Southwest having the greatest percentage of annual deficit. Water year 2011 was the second driest of the 1925–2011 period; only the drought period of 1952–56 had a year with less precipitation.

Regional streamflow for water year 2011 indicated that streamflow conditions for the Arkansas-White-Red water resources region, the 26th lowest since 1930, were considered to be normal, despite the very dry conditions in the southern and southwestern parts of the region in Oklahoma. Twelve long-term streamflow-gaging stations with periods of record ranging from 67 to 83 years were selected to show how streamflow deficits varied by region in the State. Statewide, water year 2011 had average annual streamflow that was the 16th lowest, and statewide runoff that was the 42d lowest of the period 1925–2011, more than was measured in years during the drought periods of 1929–41, 1952–56, 1961–72, and 1976–81. The hydrologic drought worsened from the northeast toward the southwest in Oklahoma, ranging from streamflows 140 percent above normal in the northeast to 13 percent of normal in the southwest. The Red River near Gainesville, Texas, long-term streamflow-gaging station in southwestern Oklahoma, had 13 percent of normal annual streamflow, the smallest long-term median annual streamflow recorded at that station for the period 1937–2011. In the central part of the State, the North Canadian River near Wetumka, long-term streamflow-gaging station, had 31 percent of normal long-term median annual streamflow. Conversely, in the northeastern part of the State, the Illinois River near Tahlequah, long-term streamflow-gaging station, had 140 percent of normal long-term median annual streamflow. Below-normal streamflow in much of the State resulted in major reservoirs containing 83.3 percent of the statewide conservation storage at the end of the water year.

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Appendixes 1–4

Photographs of Selected Sites at Normal/High-Flow Conditions and Drought/Low-Flow Conditions, 2007–12

W.J. Andrews, USGS Photograph

J.A. Savoia, USGS Photograph

Appendix 1. Looking east from the northwest corner of Lake Overholser near Ramsey Road in Oklahoma City, Oklahoma, during normal conditions in July 2012 and drought conditions in September 2011.

W.J. Andrews, USGS Photograph

S.J. Smith, USGS Photograph

Appendix 2. Dock on southwestern corner of Lake Hefner in Oklahoma City, Oklahoma, during normal conditions in July 2012 and drought conditions in October 2011.

W.J. Andrews, USGS Photograph

J.C. Scott, USGS Photograph

Appendix 3. Marina at the southwestern corner of Lake Hefner in Oklahoma City, Oklahoma, during normal conditions in July 2012 and drought conditions in September 2011.

J.A. Savoia, USGS Photograph

J.A. Savoia, USGS Photograph

Appendix 4. North Canadian River near Calumet, Oklahoma, during floods of July 2007 and drought conditions in July 2011.

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