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Water Resources in the Cheyenne and Arapaho Tribal Jurisdictional Area, West-Central Oklahoma, With an Analysis of Data Gaps Through 2015

Scientific Investigations Report 2020–5105
Version 1.1, January 2021

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

Cover. Winter wheat growing in the Cheyenne and Arapaho Concho farming district, Concho, Oklahoma.

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U.S. Department of the Interior
DAVID BERNHARDT, Secretary

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Conversion Factors

U.S. customary units to International System of Units

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	
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
acre-foot per acre per year (acre-ft/acre/yr)	1,233	cubic meter per hectare per year (m^3/hectare/yr)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per day (acre-ft/d)	1,233	cubic meter per day (m^3/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

$$°C = (°F - 32) / 1.8$$

Datum

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.

Supplemental Information

Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

BUMP	Beneficial Use Monitoring Program
CATJA	Cheyenne and Arapaho Tribal jurisdictional area
EPA	U.S. Environmental Protection Agency
EPS	equal proportionate share
GMAP	Groundwater Monitoring and Assessment Program
LOESS	locally weighted smoothing
MAY	maximum annual yield
MCL	maximum contaminant level
NCDC	National Climatic Data Center
NWIS	National Water Information System
ODEQ	Oklahoma Department of Environmental Quality
OWRB	Oklahoma Water Resources Board
QC	quality control
RPD	relative percent difference
SMCL	secondary maximum contaminant level
USGS	U.S. Geological Survey

Water Resources in the Cheyenne and Arapaho Tribal Jurisdictional Area, West-Central Oklahoma, With an Analysis of Data Gaps Through 2015

By Carol J. Becker and Matthew S. Varonka

Abstract

This report provides an overview of existing hydrologic information describing the quality, quantity, and extent of the major surface-water and groundwater resources in the Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. Hydrologic information is provided for five major river systems (Cimarron River, North Canadian River, Canadian River, Washita River, and North Fork Red River), two reservoirs (Foss Reservoir and Canton Lake), and eight aquifers consisting of the alluvial aquifers associated with each of the five major river systems and three major bedrock aquifers (Ogallala aquifer, Elk City aquifer, and Rush Springs aquifer).

Types of information provided about rivers and reservoirs for the Cheyenne and Arapaho Tribal jurisdictional area include diversion sites and amounts of water allocated and diverted for permitted uses in 2015; treated wastewater discharge sites and amounts discharged in 2015; and characteristics describing water-quality field properties, major ions, nutrients, and selected trace elements. Major ions, nutrients, and selected trace elements are compared to secondary maximum contaminant levels and maximum contaminant levels for finished drinking water. Additionally, statistics are provided describing daily, monthly, and annual streamflow characteristics at 12 U.S. Geological Survey streamgages. Streamflow statistics include the magnitudes and frequencies of floods, base-flow characteristics, and long-term streamflow trends.

Types of information provided about the aquifers include amounts of water allocated and pumped for permitted uses in 2015; characteristics of groundwater describing water-quality field properties, major ions, nitrate (measured as nitrogen), and selected trace elements with comparisons to secondary maximum contaminant levels and maximum contaminant levels for finished drinking water; groundwater levels and long-term changes in water levels; and ranges of hydraulic conductivity, aquifer recharge, specific yield, transmissivity, and well yields from reports and groundwater-flow models.

Surface water is used primarily for irrigation and mining and other nonconsumptive uses in the Cheyenne and Arapaho Tribal jurisdictional area, except from the Washita and North Fork Red Rivers, where water is treated for use as a public-water supply. Large concentrations of dissolved solids are the primary limiting factor affecting the use of surface water. Median concentrations of dissolved solids in surface water range from less than 1,000 milligrams per liter (mg/L) in samples from the North Canadian River to greater than 9,000 mg/L in samples from the Cimarron River. Large dissolved solids concentrations are correlated with hard water. Median hardness as calcium carbonate concentrations in surface water ranges from 427 mg/L in samples from Canton Lake to 1,000 mg/L in samples from the Washita River.

In 2015, groundwater was used at more than twice the rate of surface water in the Cheyenne and Arapaho Tribal jurisdictional area. Although the alluvial aquifers are considered reliably good sources of water in the Cheyenne and Arapaho Tribal jurisdictional area, concentrations of nitrate (measured as nitrogen) exceed the maximum contaminant level of 10 mg/L established by the U.S. Environmental Protection Agency for finished drinking water in parts of all of the alluvial aquifers. Water from the three major bedrock aquifers is used for irrigation, mining, public-water supply, and other uses; however, large concentrations of dissolved solids, nitrate (measured as nitrogen), and naturally occurring trace elements such as arsenic and uranium may limit the use of groundwater as a source of public-water supply in some areas. As of 2015, the depletion of groundwater from the major aquifers in west-central Oklahoma is a minor concern to the Oklahoma Water Resources Board. Groundwater levels and other hydrologic information show that recharge rates exceed the rates of water pumped from aquifers, except in areas that may be affected locally by groundwater depletions.

Introduction

The Cheyenne and Arapaho Tribes (hereinafter referred to as the "Tribes") of Oklahoma want to better understand the water resources within their jurisdictional area in the interest of developing a water-resource management plan to support their water rights for economic growth, agriculture, and other water-use needs. The U.S. Geological Survey (USGS), in cooperation with the Tribes and the Bureau of Indian Affairs, compiled historical hydrologic information pertaining to the quality, quantity, and extent of the major surface-water and groundwater resources in the Cheyenne and Arapaho Tribal jurisdictional area (CATJA) (fig. 1). Data gaps were also identified where the collection of additional data could help to improve the understanding about the Tribe's water resources for future water-use needs.

Surface-water information is provided for five major river systems (Cimarron River, North Canadian River, Canadian River, Washita River, and the North Fork Red River) and two reservoirs (Foss Reservoir and Canton Lake). Groundwater information is provided for the alluvial aquifers associated with each of the five major river systems and three major bedrock aquifers (Ogallala aquifer, Elk City aquifer, and Rush Springs aquifer) (fig. 2).

Purpose and Scope

By using available historical information and data, this report provides hydrologic information describing five major river systems, two reservoirs, and eight aquifers in the CATJA and identifies data gaps. Information about the rivers and reservoirs includes diversion sites and amounts of water allocated and diverted for permitted uses in 2015; treated wastewater-discharge sites and amounts discharged into rivers during 2015; and characteristics describing water-quality field properties, major ions, nutrients, and selected trace elements. Major ions, nutrients, and selected trace elements are compared to maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs) for finished drinking water. Statistics are provided describing daily, monthly, and annual streamflow characteristics, in addition to magnitudes and frequencies of floods, base-flow characteristics, and long-term streamflow trends, at 12 USGS streamgages. Information was compiled and analyzed to help characterize the groundwater resources. Information about the aquifers includes amounts of water allocated and pumped for permitted uses during 2015; characteristics describing water-quality field properties, major ions, nitrate (as nitrogen), and selected trace elements with comparisons to MCLs and SMCLs for finished drinking water; groundwater levels and

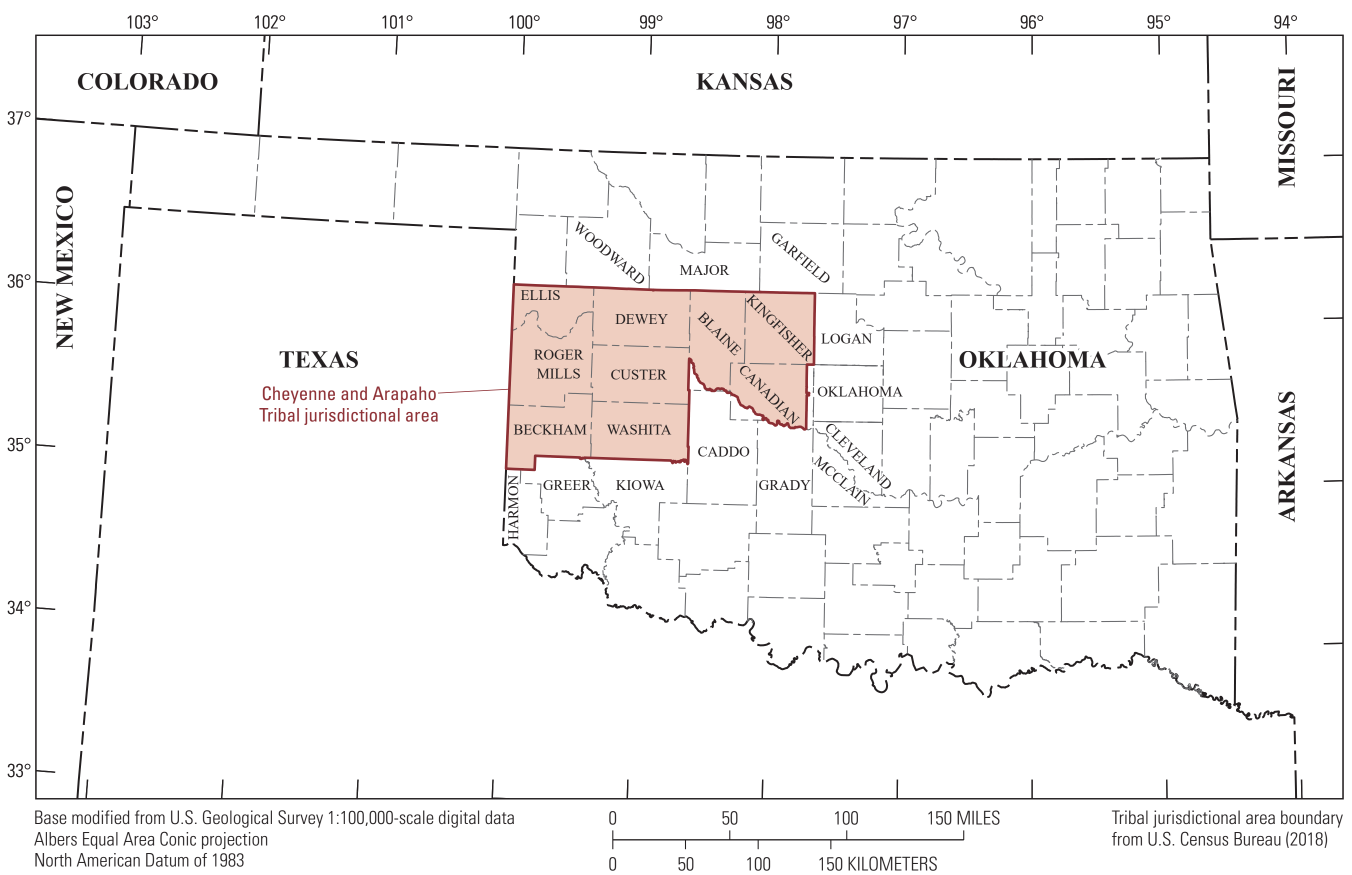


Figure 1. Location of the Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma, 2015.

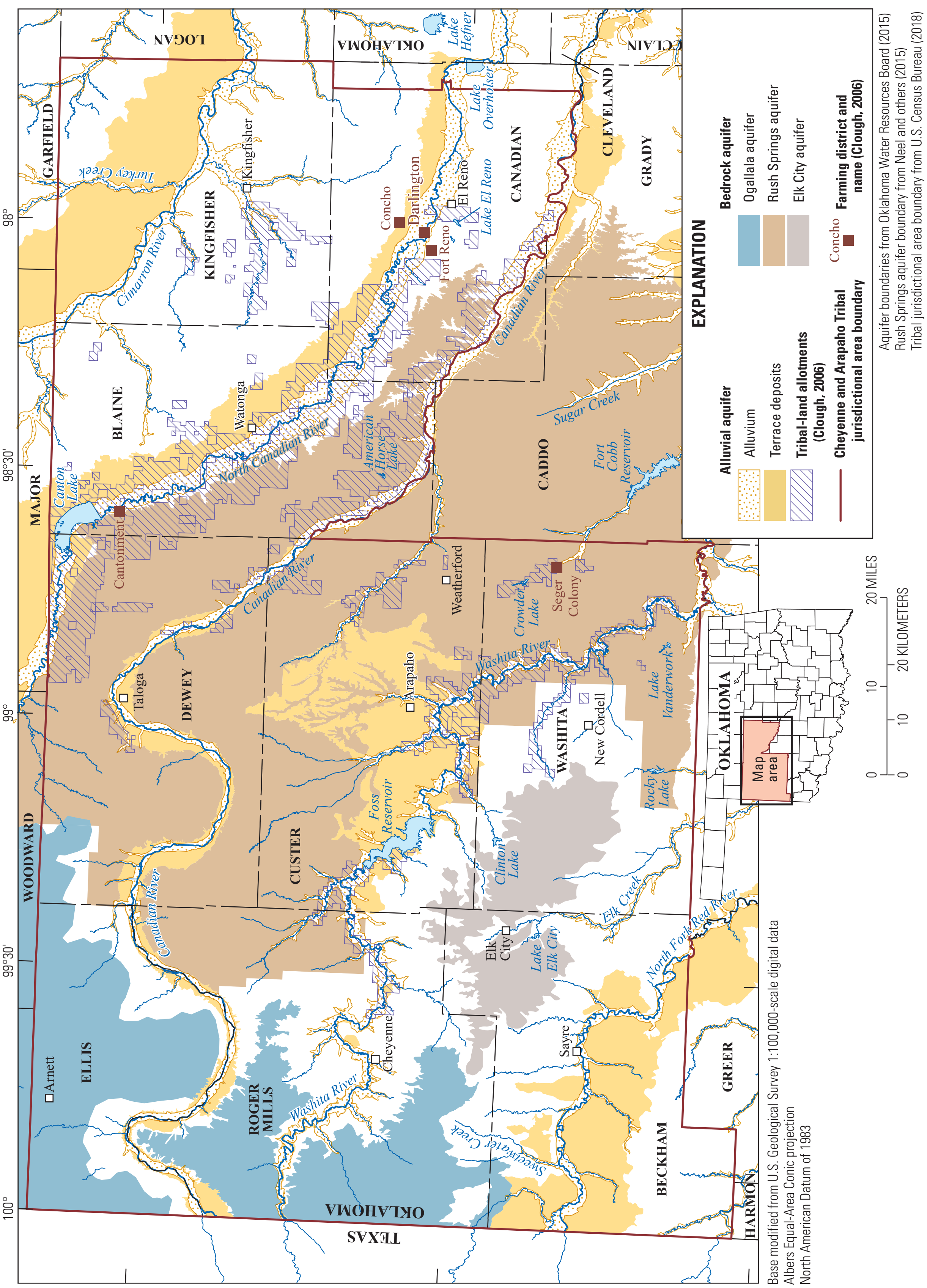


Figure 2. Locations of Cheyenne and Arapaho Tribal land allotments, farming districts, and surface-water and groundwater resources, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma, 2015.

long-term changes in water levels; and ranges of hydraulic conductivity, aquifer recharge, specific yield, transmissivity, and well yields from reports and groundwater-flow models.

Tribal Land History and Study Area Description

The CATJA encompasses about 8,175 square miles (mi^2) in all or parts of nine counties in west-central Oklahoma and was originally established to be used by the Tribes for agriculture, grazing, hunting, and fishing, along with the water resources to support these activities (fig. 1) (Rand, 2019). In the 1870s, the Tribes settled into farming districts along the North Canadian and Washita Rivers, grew crops, and learned sustainable farming and ranching practices. Five of the farming districts with land and water resources are still used by the Tribes: Cantonment, Darlington, Fort Reno, and Concho on the North Canadian River and Seger on the Washita River (fig. 2).

In 1887 the U.S. Congress enacted the Dawes General Allotment Act, also known as the Dawes Act, which abolished reservations and attempted to assimilate tribal members into non-Tribal society. As part of the Dawes Act, tribal lands were divided into individual parcels or land allotments for homesteading and distributed in a checkerboard fashion between tribal and non-Tribal members (Otis, 1973). Land parcels chosen by tribal members encompassed about 850 mi^2 and were distributed along tributaries of the Cimarron River and along the North Canadian, Canadian, and Washita Rivers (fig. 2) (Clough, 2006, p. 129). The allotment of tribal land resulted in loss of control by the Tribes over many of the water resources needed to support their present-day activities and potential future needs.

Currently (2019), the CATJA is predominately rural with small towns and low population densities that range from about 3 to 30 people per square mile except for Canadian County, which encompasses part of Oklahoma City and has a much higher population density of about 150 people per square mile. Farming practices related to agriculture and livestock and activities related to oil and gas production are important sources of income in this area (Data USA, 2019).

Climate

The climate of west-central Oklahoma in climate division 4 (fig. 3) is characterized by long, hot summers and short winters with periods of extreme cold (Oklahoma Climatological Survey, 2018; National Centers for Environmental Information, 2020). Mean monthly air temperatures from 1900 to 2015 ranged from a high of 82 degrees Fahrenheit in July to a low of 36 degrees Fahrenheit in January (National Climatic Data Center [NCDC], 2018a). Mean monthly precipitation for this same period in climate division 4 shows that May, June, and September are the wettest months and that December, January, and February are the driest. Mean monthly precipitation ranges from 0.8 inch in January to 4.2 inches in May with a mean annual precipitation of about 24 inches (NCDC, 2018b).

Long-term precipitation records measured at the National Weather Service weather station in Watonga, Okla. (Watonga weather station), were used to show wet (above-normal) and dry (below-normal) periods by calculating the deviation of the 5-year weighted moving average of the total annual precipitation from the mean annual precipitation from 1930 to January 2016 (NCDC, 2018c) (fig. 4). The long-term mean annual precipitation at the Watonga weather station is 28.7 inches. Extended periods of below-normal precipitation at the Watonga weather station were measured during 1930–37, 1943–56, 1963–72, and 1976–77. Extended periods of above-normal precipitation were measured from 1957 to 1962, 1973 to 1975, 1981 to 2000 (with exception of 1984), and 2004 to 2008 (with exception of 2006). Precipitation was once again below normal during 2011–12, whereas 2015 was a wet year with 35.6 inches of precipitation measured at the Watonga weather station.

Land Cover

Land cover information from the 2011 National Land Cover Database (Homer and others, 2015) indicates that the CATJA was dominated by grassland and shrub or scrub vegetation in the west and cultivated crops in the east (fig. 5). For example, Roger Mills County, one of three westernmost counties, was covered with approximately 25 percent shrub or scrub vegetation and 63 percent grasslands, with cultivated crops covering only 8 percent of the county. In contrast, land cover in Kingfisher County, which is the easternmost county, was approximately 58 percent cultivated crops and 32 percent grasslands, with sparse areas of shrub or scrub vegetation. Developed areas covered a total of about 5 percent of the nine counties during 2011 in the CATJA and included urban areas, roads, and other paved areas. Slightly less than 1 percent in the CATJA was covered by water and wetlands.

Dry-land winter wheat is the dominant crop grown in west-central Oklahoma, with sorghum, alfalfa, cotton, and other crops grown in minor amounts (National Agricultural Statistics Service, 2018). The acres of planted wheat during 2015 were the largest in Washita, Kingfisher, and Blaine Counties (approximately 302,250, 247,000, and 234,300 acres, respectively) among all counties in the CATJA (National Agricultural Statistics Service, 2018). Kingfisher, Canadian, and Blaine Counties supported the largest number of cattle in 2015, numbering 110,000, 86,000, and 81,000 head, respectively (National Agricultural Statistics Service, 2015).

Bedrock Geology

The youngest bedrock in the CATJA is the Tertiary-aged Ogallala Formation in Ellis County and the western half of Roger Mills County (figs. 6 and 7) (Heran and others, 2003). The Ogallala aquifer is composed of the water-bearing Ogallala Formation and any underlying water-bearing formations hydraulically connected to the Ogallala Formation (Gutentag and others, 1984). The Ogallala aquifer is part of the High Plains aquifer, a large regional aquifer system that underlies eight States in the Central United States, including Oklahoma (Gutentag and others, 1984). The Ogallala Formation consists of fine- to medium-grained sand that is interbedded with some clay, silt, gravel, and volcanic ash and caliche beds (Carr and Bergman, 1976). The rocks are semiconsolidated and generally are light tan or buff to light gray in color (Havens and Christenson, 1984). The thickness of the Ogallala Formation in the CATJA ranges from about 320 to zero feet (ft) along the eastern boundaries where the formation has been eroded away (Carr and Bergman, 1976).

Below the Ogallala Formation are the Permian-aged bedrock units in west-central Oklahoma, which underlie about 90 percent of the CATJA (figs. 6 and 7). These bedrock units also are referred to as “red beds” and dip regionally in a southwesterly direction at 10–100 ft per mile (mi) in western Oklahoma (Carr and Bergman, 1976). The bedrock units in the CATJA are composed of alternating sequences of reddish-brown shales, sandstones, and siltstones, with interbedded layers of evaporites such as gypsum, dolomite, anhydrite, and halite found in some units. These interbedded layers of evaporites in the Permian-aged bedrock units are important contributors of dissolved solids to surface water in west-central Oklahoma. With exception of the Elk City Member of the Quartermaster Formation and Rush Springs Formation of the Whitehorse Group, most of the Permian-aged bedrock units are relatively impermeable to groundwater flow and are not discussed in detail in this report.

The youngest Permian-aged rock unit is the Elk City Member in Washita and Beckham Counties with smaller areas in Roger Mills and Custer Counties (figs. 6 and 7). The Elk City Member covers an area of about 317 mi^2 (Heran and others, 2003) and consists of a weakly cemented, reddish-brown, fine-grained sandstone with minor amounts of silt and clay (Carr and Bergman, 1976). Formation thickness ranges from zero at the erosional edges to 185 ft. The Elk City Member is used extensively as an aquifer in northwestern Washita County and northeastern Beckham County.

The Doxey Shale of the Quartermaster Formation and Cloud Chief Formation underlie the Elk City Member and consist of reddish-brown, orange-brown shale interbedded with siltstone (figs. 6 and 7) (Carr and Bergman, 1976). The Cloud Chief Formation also is interbedded with sandstone, dolomite, and gypsum. Together these units are about 590 ft thick, and the units thin to the east (Carr and Bergman, 1976).

The Whitehorse Group includes the Rush Springs and Marlow Formations (figs. 6 and 7). Both formations are similarly composed of mostly orange-brown, fine-grained sandstone with some interbedded layers of red-brown shale, siltstone, gypsum, and dolomite. The total thickness of the two formations is about 430 ft, and the formations thin in a northward and eastward direction (Carr and Bergman, 1976). In parts of Washita, Custer, and Dewey Counties, the Rush Springs Formation is a major aquifer and is described as a massive to highly cross-bedded sandstone of wind-blown origin with some interbedded dolomite or gypsum (Becker, 1998).

The El Reno Group includes six formations at land surface in Blaine, Kingfisher, and Canadian Counties and consists primarily of evaporites and reddish-brown shales, with the occurrence of sandstones and siltstones increasing in the eastern part of the CATJA (figs. 6 and 7) (Heran and others, 2003). The three westernmost formations in the El Reno Group—the Dog Creek Shale, Blaine Formation, and Flowerpot Shale—consist primarily of evaporites and reddish-brown shale. These three formations have a combined thickness of about 800 ft. The three easternmost formations of the El Reno Group—the Cedar Hills Sandstone, Chickasha Formation, and Duncan Sandstone—contain shale with layers of siltstone and sandstone and are considered a minor aquifer in the CATJA (Carr and Bergman, 1976). These three formations have a combined thickness of about 980 ft.

The oldest bedrock at land surface in the CATJA is the Hennessey Group, which includes four formations in the eastern half of Kingfisher County and the far northeastern corner of Canadian County (figs. 6 and 7) (Heran and others, 2003). The four formations are the Bison Formation, Salt Plains Formation, Kingman Siltstone, and Fairmont Shale. These formations consist primarily of red-brown shale with thin layers of orange-brown to greenish-gray fine-grained sandstone and siltstone and are considered minor aquifers in the CATJA (Bingham and Bergman, 1980). These four formations have a combined thickness of about 500 ft (Bingham and Bergman, 1980).

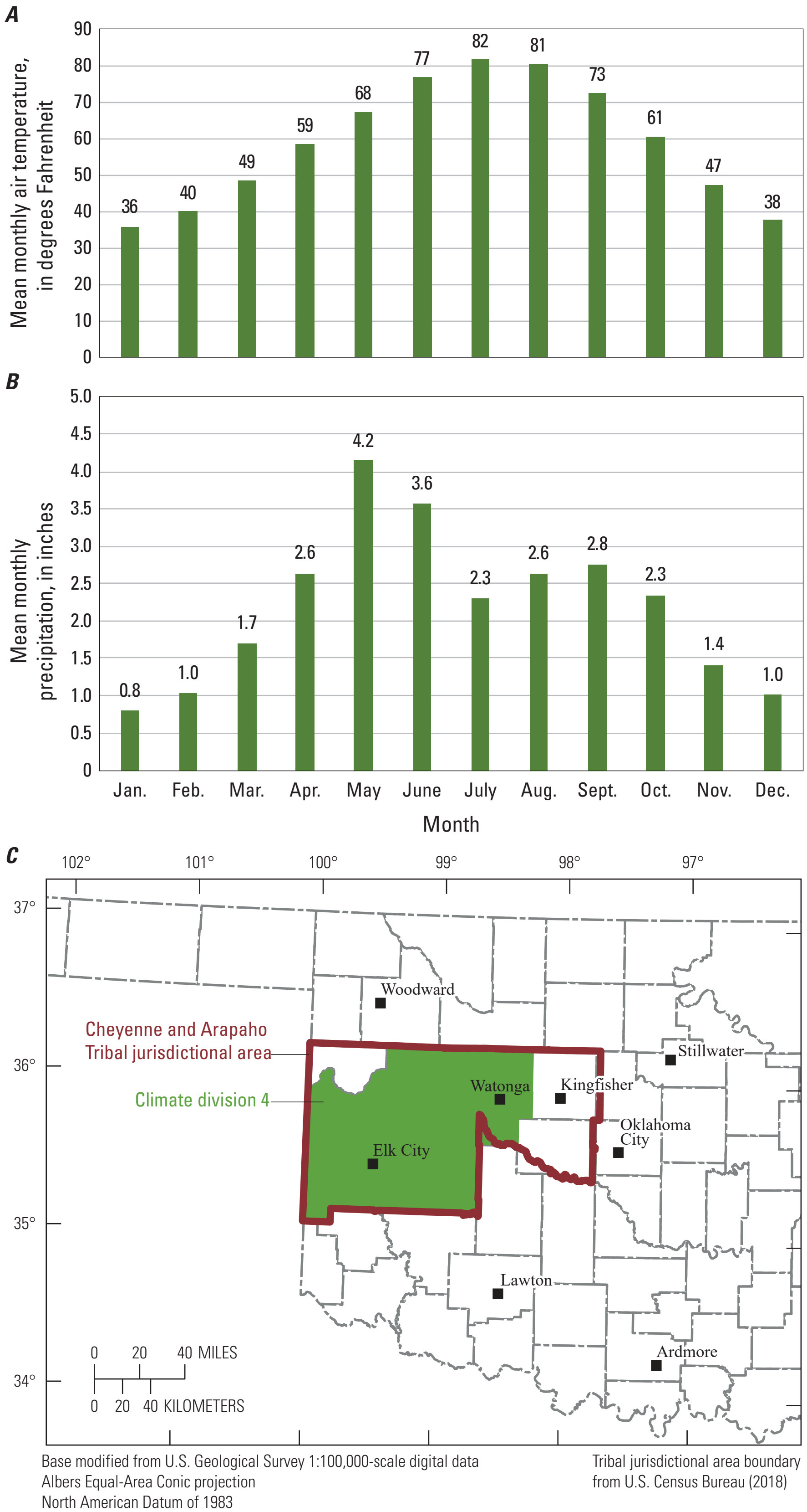


Figure 3. *A*, Mean monthly air temperatures and *B*, mean monthly precipitation from 1900 to 2015 in *C*, U.S. climate division 4, west-central Oklahoma (National Climatic Data Center, 2018a, 2018b; National Centers for Environmental Information, 2020).

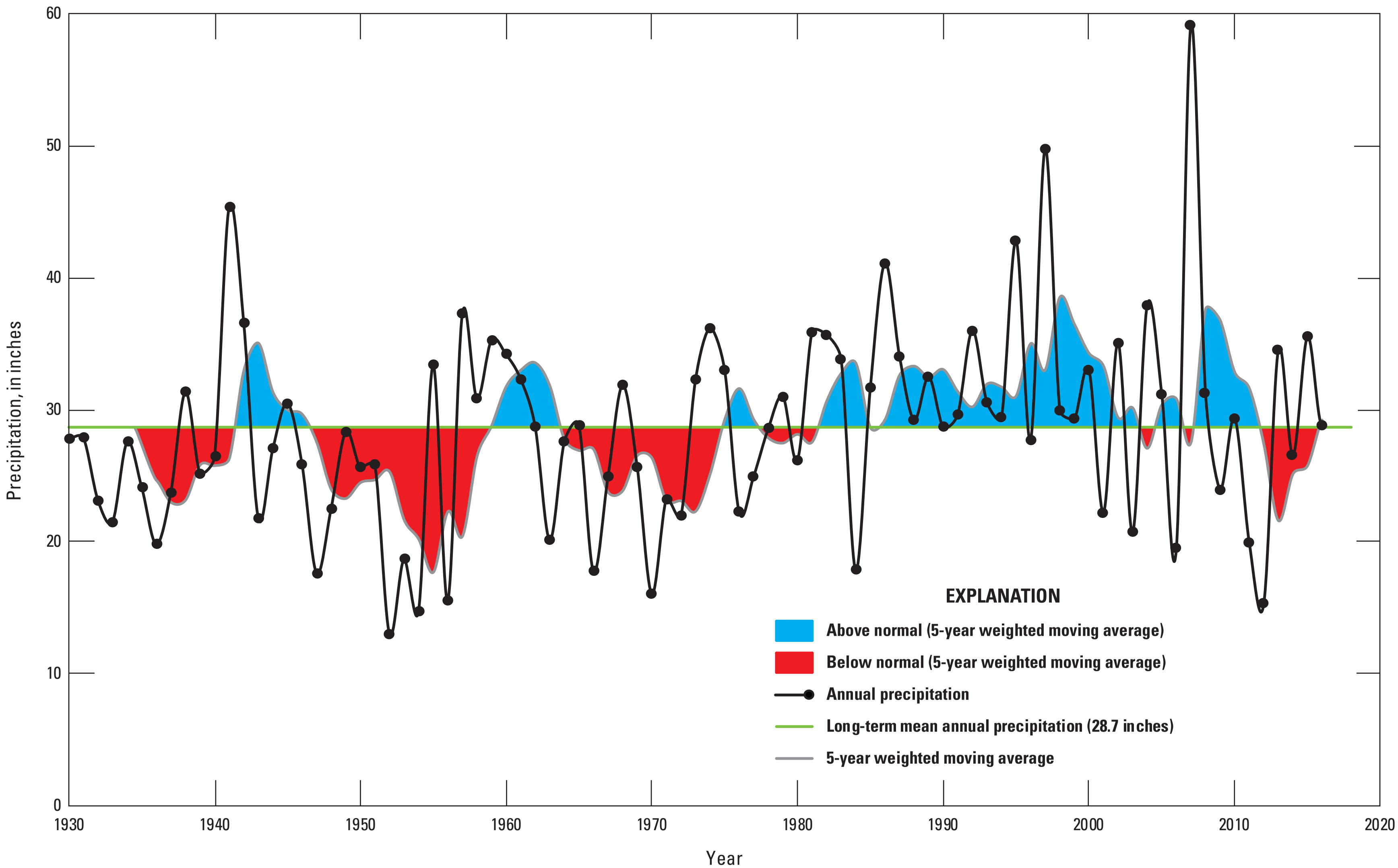


Figure 4. Measured annual precipitation and long-term mean annual precipitation from 1930 to January 2016 and calculated 5-year weighted moving average at the National Weather Service weather station in Watonga, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (National Climatic Data Center, 2018c).

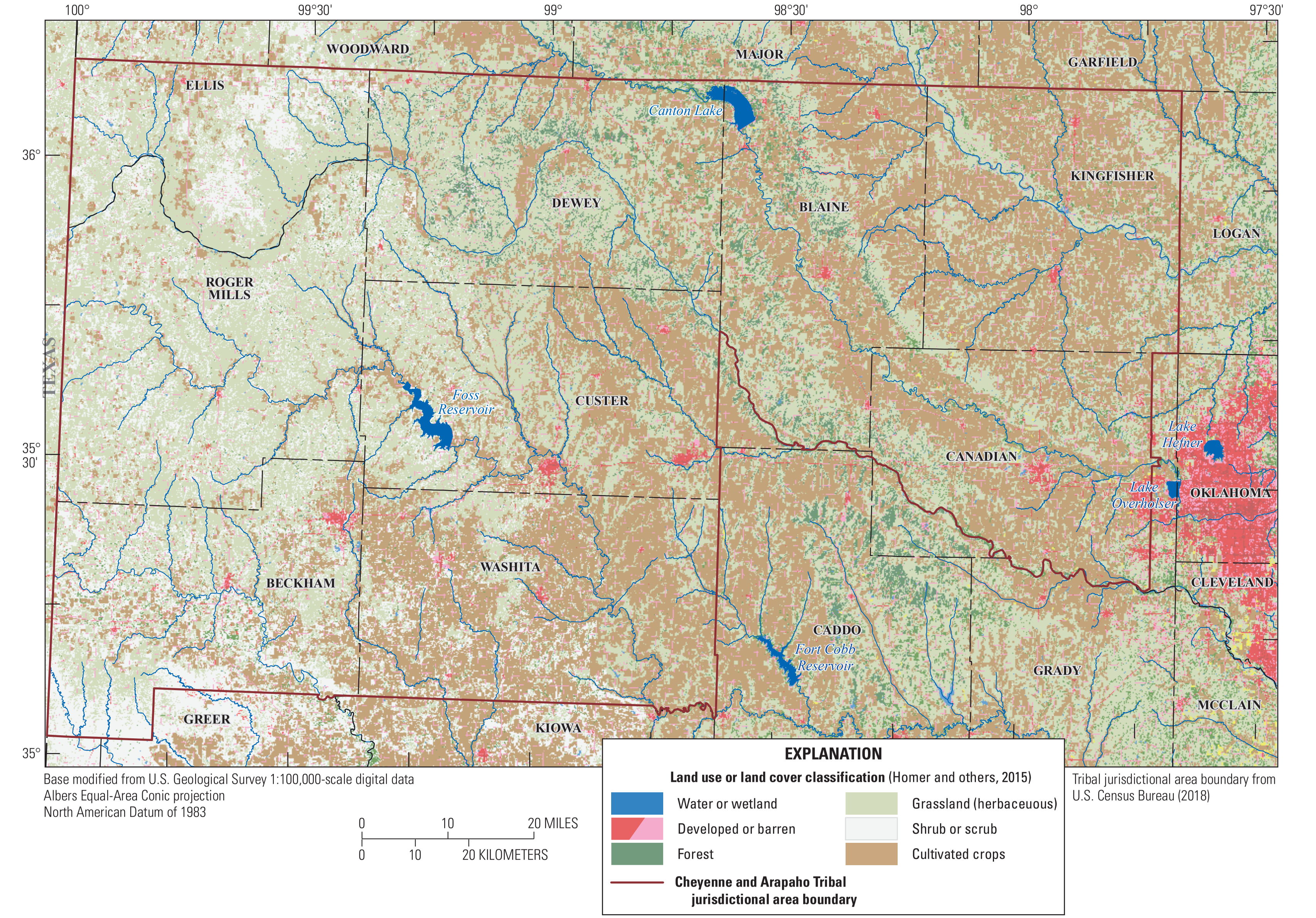


Figure 5. Land use and land cover during 2011 in the Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

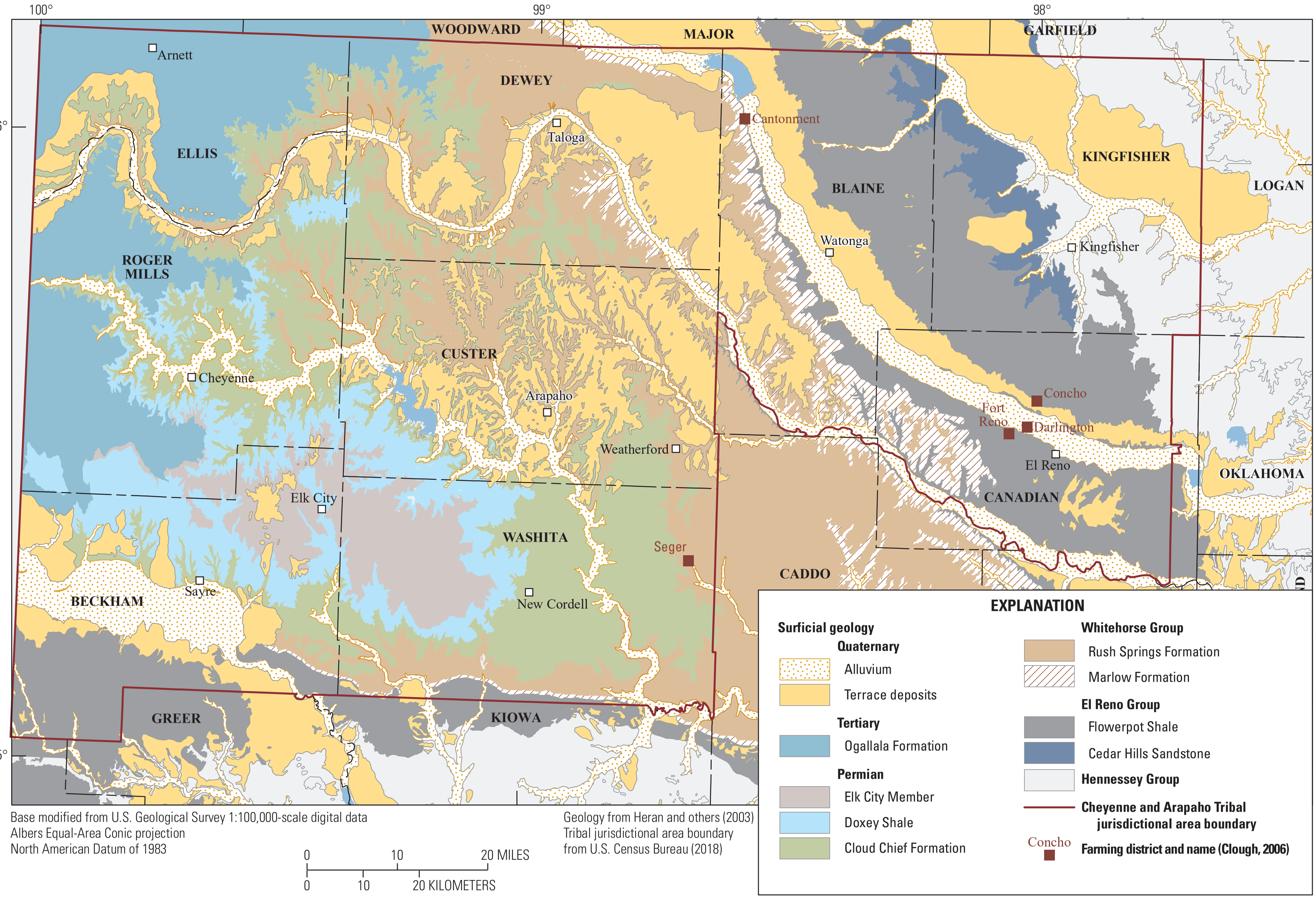


Figure 6. Surficial geology in the Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

System	Geologic unit		Hydrogeologic unit	Thickness, in feet	Description
Quaternary	Alluvium and terrace deposits (includes dune deposits)		Alluvial aquifers	0–170	Stream-laid deposits of lenticular and interfingering gravel, sand, silt, and clay. Generally light tan to gray.
Tertiary	Ogallala Formation		(High Plains) Ogallala aquifer	0–320	Light tan or buff to light gray, fine- to medium-grained sand with some clay, silt, gravel, and volcanic ash and caliche beds; semiconsolidated; locally cemented by calcium carbonate. The unit thins eastward.
Permian	Quartermaster Formation	Elk City Member	Elk City aquifer	about 185	Reddish-brown, fine-grained sandstone with minor amounts of silt and clay, weakly cemented by iron oxide, calcium carbonate, and gypsum.
		Doxey Shale		about 190	Red-brown shale and siltstone with greenish-gray calcareous siltstone at base.
	Cloud Chief Formation			175–400	Red-brown and greenish-gray shale and siltstone with some orange-brown fine-grained sandstone and siltstone. At the base are two or more thin pink to maroon to greenish-gray dolomite beds and (or) gypsum beds.
	Whitehorse Group	Rush Springs Formation	Rush Springs aquifer	about 300	Orange-brown, fine-grained sandstone commonly interbedded with red-brown shale, siltstone, gypsum, and dolomite.
		Marlow Formation		100–130	Orange-brown fine-grained sandstone and siltstone with some interbedded red-brown shale and silty shale in the upper part.
	El Reno Group	Dog Creek Shale		85–220	Reddish-brown shale with thin beds of siltstone and dolomite, gradational eastward into the Chickasha Formation.
		Blaine Formation		100–200	Alternating cyclic sequences of three or four massive gypsum beds with red-brown shales and generally with a dolomite at the base of each sequence. Gradational eastward into the Chickasha Formation.
		Flowerpot Shale		300 to 450	Reddish-brown shale containing several salt and gypsum beds in the upper part. Gradational southward and eastward into the Chickasha Formation and Duncan Sandstone.
		Cedar Hills Sandstone		about 180	Orange-brown to greenish-gray fine-grained sandstone and red-brown shale.
		Chickasha Formation		100–600	Reddish-brown to maroon mudstone conglomerate with some shale, siltstone, and fine- to coarse-grained sandstone. Gradational northward and westward into the Flowerpot Shale and the Blaine Formation and westward into the Dog Creek Shale.
		Duncan Sandstone		200	Light-gray and reddish-brown, crossbedded, fine-grained sandstone and mudstone conglomerate with some interbedded yellowish-gray and reddish-brown shales. Gradational into the Cedar Hills Sandstone northward and into the Flowerpot Shale northward and westward.
	Hennessey Group	Bison Formation		about 120	Red-brown shale with greenish-gray siltstones and orange-brown fine-grained sandstones and siltstones.
		Salt Plains Formation		about 160	Red-brown shale and orange-brown siltstones.
		Kingman Siltstone		about 70	Orange-brown to greenish-gray siltstones, fine-grained sandstones and red-brown shale.
		Fairmont Shale		about 150	Red-brown shale.

Figure 7. Surficial geologic and hydrogeologic units, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (modified from Bingham and Moore, 1975; Carr and Bergman, 1976; Bingham and Bergman, 1980; Havens and Christenson, 1984; Heran and others, 2003).

Methods

No new data were collected for this assessment; the data and information used to assess the water resources in the CATJA in this report were compiled from existing USGS reports, the USGS National Water Information System (NWIS) database, Oklahoma Water Resources Board (OWRB), and Oklahoma Department of Environmental Quality (ODEQ).

Water-quality data, streamflow information, groundwater levels, and groundwater allocation amounts are available in digital format from NWIS (USGS, 2018b) or from online databases maintained by the OWRB (2016, 2018a, 2018b, 2018c, 2018d, 2018e). Amounts of groundwater withdrawn and surface water diverted from rivers were acquired from the OWRB by request (C. Neel, OWRB, written commun., 2016). The OWRB considers permitted groundwater withdrawal and surface-water diversion information private and does not make these data publicly available but, for this assessment, allowed the use of these data to be aggregated by aquifer. Amounts of treated wastewater discharged into river basins during 2015 were acquired from ODEQ (D. Pruitt, ODEQ, written commun., 2016). These data are publicly available and can be acquired by request to ODEQ.

Details about the methods used to collect and process surface-water and groundwater samples are described in the “Surface-Water Data Collection Methods” and “Groundwater Data Collection Methods” sections, respectively. Water-quality field properties (pH and specific conductance) were measured in the field at the time that USGS personnel collected the water-quality samples by following standard USGS methods (USGS, variously dated). Water-quality constituents in surface-water and groundwater samples collected by the USGS were analyzed for major ions, nitrogen, and trace elements by following established USGS methods at the National Water Quality Laboratory in Lakewood, Colorado. USGS methods for major ions are consistent with those published in Fishman and Friedman (1989), Fishman (1993), and American Public Health Association (1998). USGS nutrient methods are consistent with those published in Fishman (1993) and Patton and Kryskalla (2003). USGS trace-element methods are consistent with those published in Fishman and Friedman (1989), Garbarino (1999), and Garbarino and others (2006).

Details about the methods used to measure water-quality field properties in surface-water and groundwater samples collected by the OWRB are described in OWRB (2017b). Water-quality constituents in surface-water and groundwater samples collected by the OWRB were analyzed for major ions and trace elements at the ODEQ State Environmental Laboratory in Oklahoma City, Okla. The analytical methods used to analyze major ions and trace elements are similar to those published in Fishman and Friedman (1989), Garbarino (1999), and Garbarino and others (2006). Nitrogen and phosphorus were analyzed for the OWRB by Accurate Environmental LLC, Oklahoma City, Okla. The analytical methods used to analyze nitrogen and phosphorus are similar to those in Fishman (1993) and Patton and Kryskalla (2003).

Water-quality data for surface-water and groundwater samples analyzed for this report were compared to U.S. Environmental Protection Agency (EPA) MCLs and nonregulated SMCLs for finished drinking water (EPA, 2018a, 2018b). Definitions and finished drinking-water standards for the water-quality field properties and constituents discussed in this report are shown in table 1.

Surface-Water Information

Surface-water information about rivers and reservoirs includes the amounts of water allocated and diverted for permitted uses in 2015; sites permitted for the discharge of treated wastewater and the amounts discharged in 2015; and characteristics describing water-quality field properties, major ions, selected trace elements, and nutrients. Major ions, nutrients, and selected trace elements are compared to SMCLs and MCLs for finished drinking water (EPA, 2018a, 2018b).

Surface-water allocations, water-use type, and the locations of diversion sites on rivers are available from the OWRB (OWRB, 2016). Reported amounts of surface water diverted during 2015 were provided by the OWRB (C. Neel, OWRB, written commun., 2016). Treated wastewater discharge site locations and amounts of wastewater discharged during 2015 were provided by the ODEQ (fig. 8) (ODEQ, 2018; D. Pruitt, ODEQ, written commun., 2016).

Most of the information about the quality of surface water in the CATJA comes from water-quality samples collected by the USGS as part of previous studies at selected USGS streamgages and stored in NWIS (USGS, 2019b) (fig. 9). A small amount of previously collected water-quality data for surface water from the OWRB Beneficial Use Monitoring Program (BUMP) (OWRB, 2018a, 2018b) were also used in this report.

Environmental and site information collected by the USGS for surface water (and groundwater) is stored in NWIS and can be accessed from the NWIS Web interface (USGS, 2018b) and by using the NWIS Mapper (USGS, 2018c). There are 16 USGS streamgages in the CATJA, 14 on rivers and 2 on reservoirs (Lake Canton and Foss Reservoir), with 1–5 streamgages on each major river (fig. 9). If water-quality data were available from more than one streamgage for a given river, the data from the streamgage where samples of a sufficient number were most recently collected were used for a statistical summary. Constituent concentrations were not statistically summarized if censored data were present. Constituents statistically summarized were water-quality field properties (pH and specific conductance), dissolved solids, hardness, the major ions having SMCLs (chloride and sulfate), nutrients (nitrogen and phosphorus), and selected trace elements (cadmium, chromium, iron, lead, manganese, arsenic, and uranium if concentrations were elevated). Nitrogen was measured as nitrate and nitrite for the surface-water sample analyses stored in NWIS. Because nitrite concentrations in water were negligible, nitrate and nitrite concentrations are referred to in this report as “nitrate (as nitrogen).”

Table 1. Sources and effects and finished drinking-water standards for water-quality field properties and constituents measured in surface water and groundwater, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma, 2015.

[MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; —, not applicable; µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligram per liter; µg/L, microgram per liter. Modified from U.S. Environmental Protection Agency (2018a, 2018b) and Driscoll and others (2002, table 4)]

Water-quality field properties and constituents (units)	Sources and effects	Maximum contaminant level[a] (MCL)	Secondary maximum contaminant level[b] (SMCL)
		Regulated in finished drinking water	Not regulated in finished drinking water
	Water-quality field properties		
pH (standard units)	A measure of the hydrogen ion concentration; pH of 7 indicates a neutral solution, pH values smaller than 7 indicate acidity, pH values larger than 7 indicate alkalinity. Water generally becomes more corrosive with decreasing pH, high alkaline water feels slippery with soda taste.	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	A measure of the waters ability to conduct an electrical current. Directly related to the concentration of conductive ions in water. Water with a high mineral content is more conductive and has a higher specific conductance than water with a low mineral content.	—	—
Hardness (mg/L as $CaCO_3$)	0–60, soft; 61–120, moderately hard; 121–180, hard; 181–240, very hard; greater than 240, extremely hard (modified from Hem, 1985).	—	—
	Major ions		
Dissolved solids (mg/L)	Dissolved solids is the sum of all dissolved mineral constituents, in mg/L. The dissolved solids concentration is also called salinity or total dissolved salts and is classified as; fresh, 0–1,000 mg/L; slightly saline, 1,000–3,000 mg/L; moderately saline, 3,000–10,000 mg/L; very saline, 10,000–35,000 mg/L; and briny, more than 35,000 mg/L (Winslow and Kister, 1956).	—	500 mg/L
Calcium and magnesium (mg/L)	Occurs naturally in evaporitic and carbonate-type rocks such as gypsum. The biggest cause of hardness and scale-forming properties of water.	—	—
Sodium and potassium (mg/L)	Occurs naturally in evaporitic-type rocks such as halite.	—	—
Bicarbonate and carbon dioxide (mg/L)	Occurs naturally in groundwater in combination with calcium and magnesium.	—	—
Chloride (mg/L)	Occurs naturally in evaporitic-type rocks such as halite. Gives water a salty taste.	—	250 mg/L
Sulfate (mg/L)	Occurs naturally in rocks. Comes from the dissolution of the evaporitic mineral gypsum. A major contributor of non-carbonate hardness. Large concentrations of sulfate have a laxative effect on some people and, in combination with other ions, gives water a bitter taste.	—	250 mg/L
	Trace ions		
Cadmium (µg/L)	Occurs naturally in rocks and sediments, runoff from waste batteries and paints. Causes kidney damage.	5 µg/L	
Iron (µg/L)	Occurs naturally in rocks and sediments. Stains laundry and fixtures. Gives water a metallic taste.	—	300 µg/L
Lead (µg/L)[c]	Occurs naturally in rocks and sediments, corrosion of lead pipes. Causes delays in mental and physical development in children.	15 µg/L	—
Manganese (µg/L)	Occurs naturally in rocks. Causes gray or black stains on fixtures and fabrics. Gives water a bitter metallic taste.	—	50 µg/L
Arsenic (µg/L)	In Oklahoma, can occur in groundwater from dissolution of rocks at pH values above 7.8. Toxic and is a cumulative poison. Skin damage or problems with circulatory systems, and may have increased risk of cancer.	10 µg/L	—
Uranium (µg/L)	Occurs naturally in rocks. Causes an increased risk of cancer and kidney disease.	30 µg/L	—

Table 1. Sources and effects and finished drinking-water standards for water-quality field properties and constituents measured in surface water and groundwater, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma, 2015.—Continued

[MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; —, not applicable; µS/cm, microsiemens per centimeter; °C, degree Celsius; mg/L, milligram per liter; µg/L, microgram per liter. Modified from U.S. Environmental Protection Agency (2018a, 2018b) and Driscoll and others (2002, table 4)]

Water-quality field properties and constituents (units)	Sources and effects	Maximum contaminant level[a] (MCL)	Secondary maximum contaminant level[b] (SMCL)
		Regulated in finished drinking water	Not regulated in finished drinking water
Nutrient compounds			
Nitrate nitrogen (mg/L)	Wastewater, runoff from feed lots, nitrogen-based fertilizers; occurs naturally in soils from decomposition of organic material. Causes eutrophication in surface water. In drinking water, infants younger than 6 months can become ill from blue-baby syndrome.	10 mg/L	—
Nitrite nitrogen (mg/L)	Wastewater, runoff from feed lots, nitrogen-based fertilizers; occurs naturally in soils from decomposition of organic material. Causes eutrophication in surface water. In drinking water, infants younger than 6 months can become ill from blue-baby syndrome.	1 mg/L	—
Phosphorus (mg/L)	Agricultural fertilizers, animal manure, municipal and industrial wastewater, soil erosion. Causes eutrophication in surface water.	—	—

[a]Maximum contaminant level (MCL): The highest level of a contaminant that is legally allowed in finished drinking water (U.S. Environmental Protection Agency, 2018a).

[b]Secondary maximum contaminant levels (SMCLs) are established as guidelines for aesthetic considerations, such as taste, color, and odor. These contaminants are not considered to present a risk to human health at the SMCL (U.S. Environmental Protection Agency, 2018b).

[c]Action level. If lead concentrations exceed an action level of 15 µg/L in more than 10 percent of customer taps sampled, the water-supply system must undertake actions to control corrosion.

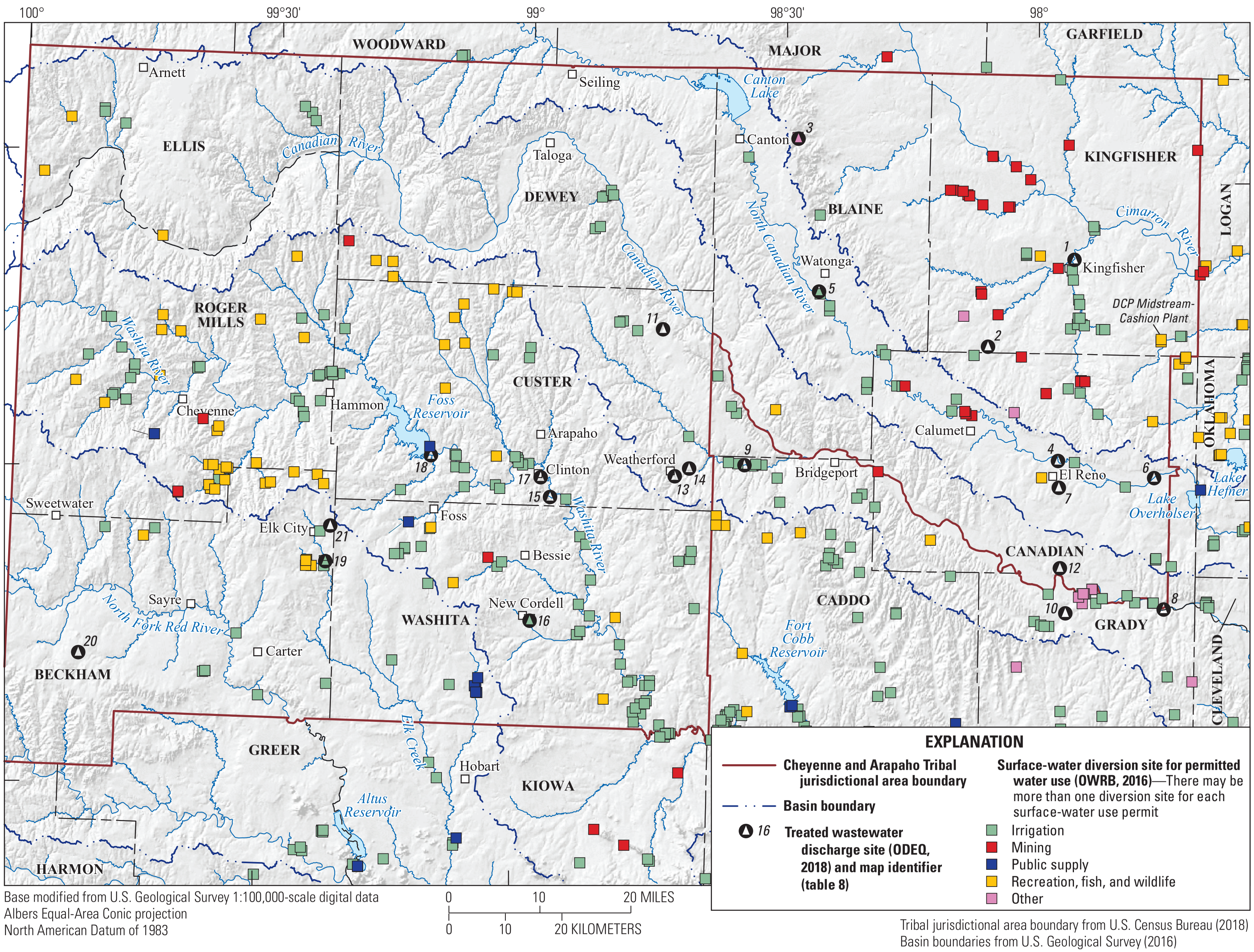
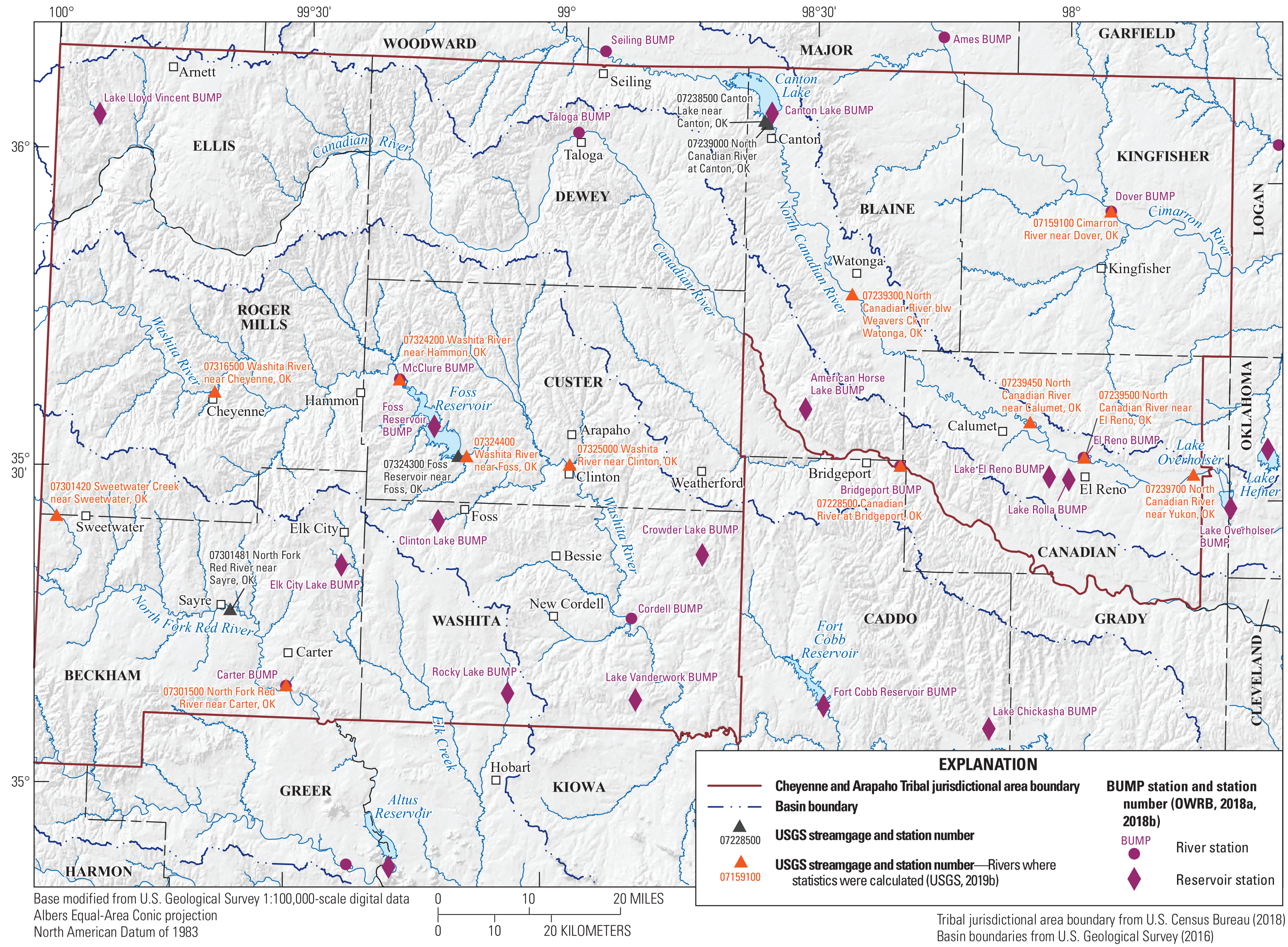


Figure 8. Locations of surface-water diversion sites for permitted water use and treated wastewater discharge sites, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma, 2015. ODEQ, Oklahoma Department of Environmental Quality; OWRB, Oklahoma Water Resources Board.



Base modified from U.S. Geological Survey 1:100,000-scale digital data
Albers Equal-Area Conic projection
North American Datum of 1983

Tribal jurisdictional area boundary from U.S. Census Bureau (2018)
Basin boundaries from U.S. Geological Survey (2016)

Figure 9. Locations of U.S. Geological Survey (USGS) streamgages and Oklahoma Water Resources Board (OWRB) Beneficial Use Monitoring Program (BUMP) stations, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma, 2015.

The OWRB monitors rivers at fixed BUMP stations and reservoirs at multiple sample sites as part of the State's surface-water-quality monitoring program (OWRB, 2018a, 2018b). The OWRB collects water-quality samples from different rivers in the CATJA six times per year, whereas water-quality samples are collected from reservoirs about four times per year during 2 nonconsecutive years on a 5-year rotation. A statistical summary is provided in this report for nitrogen and phosphorus concentrations collected at two BUMP river stations and two reservoirs. The trophic status conditions of the reservoirs also are provided in the report.

Beginning in the 1970s through 2010, most water-quality samples obtained at USGS streamgages within the CATJA were collected for short-term projects. Even though samples may have been collected intermittently over many years, the water type of rivers and reservoirs described by the major-ion proportions does not change because major-ion proportions in water reflect the mineral composition of the underlying bedrock, which does not change (Olson, 2012). Precipitation may dilute river flow, but the major-ion proportions that define water type stay relatively constant.

Pie charts were used to depict the water type of rivers and reservoirs by using water-quality data obtained from USGS samples collected at streamgage and reservoir sites. The pie charts were created from the median major-ion concentrations, expressed in milliequivalents per liter. Cations and anions were considered predominant when composing 50 percent or more of the total cation or anion concentration and were considered to be secondary when composing between 25 and 49 percent (Back, 1966). The cation-anion balances of the median-ion concentrations were all within plus or minus 7 percent, the range considered acceptable for determining water types in this report (Hem, 1985).

Surface-Water Data Collection Methods

Established USGS protocols were used by USGS personnel for the preparation, collection, and processing of water-quality samples collected from rivers and reservoirs (USGS, variously dated). From rivers, water-quality samples and water-quality field properties were collected and measured at equal-width intervals in a cross section of the river and are averaged for final values. At Foss Reservoir and Canton Lake, during 1980–91 the USGS collected discrete-depth reservoir samples from surface to bottom to describe changes in water quality with depth. Discrete-depth samples used for this report were collected at 3- to 5-ft intervals at three to five reservoir sampling sites. The sample collected at the middle depth, generally at 10–30 ft, was used for this report to represent water quality at each sampling site. Samples were collected by the USGS by using thief samplers such as Kemmerer or Van Dorn bottles (Graham and others, 2008, table 7.5–6) or by using a diaphragm or peristaltic pump. USGS standard procedures for collecting the water-quality samples from Foss Reservoir and Canton Lake were followed (USGS, variously dated).

The OWRB collects water samples from rivers and reservoirs and processes the samples by using standard operating procedures described in OWRB (2017a). Water-quality field properties are measured at equal-width intervals in a cross section of the river and are averaged for final values. Water-quality samples are collected using a depth-integrated method when stream velocity is approximately 1.5 ft per second or greater. When stream velocity is less than 1.5 ft per second, a grab composite sample is collected. Information about BUMP sites and water-quality data collected by the OWRB can be accessed online from the OWRB BUMP website (OWRB, 2018a).

Real-time data collected at USGS streamgages include instantaneous measurements of gage height and streamflow. Methods used for real-time data collection of gage height and streamflow are described in Sauer and Turnipseed (2010) and Turnipseed and Sauer (2010). Data are continuously collected at these stations in 30-minute intervals and transmitted by satellite telemetry into the USGS NWIS database. Water-quality data and streamflow characteristics collected by the USGS are stored in NWIS and can be accessed by using the NWIS Web interface or NWIS Mapper (USGS, 2018b, 2018c).

Selection and Analysis of Streamflow Data

Statistics were calculated to describe daily, monthly, and annual streamflow characteristics at 12 of the 16 streamgages in the CATJA (fig. 9 and table 2). These streamgages span the five major river systems: the Cimarron, North Canadian, Canadian, Washita, and North Fork Red Rivers. Streamflow data were obtained from the USGS NWIS database (USGS, 2018b). Rivers were designated as unregulated by dams, floodwater-retarding structures, or other human modifications of streamflow (N); controlled by dams, floodwater-retarding structures, or other human modifications of streamflow (R); or unregulated but affected by irrigation (I), in accordance with Lewis and Esralew (2009). A regulated period of record in this report is defined as the period during which at least 20 percent of the contributing drainage area upstream from a streamgage is controlled by dams, floodwater-retarding structures, or other human modifications of streamflow (Heimann and Tortorelli, 1988).

For unregulated rivers (N), the entire period of record through 2015 was used for statistical calculations. For regulated rivers (R) and rivers affected by irrigation (I), statistics were calculated for only the regulated or irrigated streamflow period through 2015 (see Lewis and Esralew, 2009, for calculations of previous unregulated periods at these stations). Monthly mean, annual mean, and annual peak flows and associated statistical calculations, including base flow, are reported on the basis of water year (October 1 to September 30, designated by the calendar year in which the water year ends). Daily mean streamflow was used to compute flow-duration data. Low-flow recurrence intervals were calculated using flow data based on climatic years (April 1 to March 31, designated by the calendar year in which the climate year

Table 2. U.S. Geological Survey streamgages, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).

[USGS, U.S. Geological Survey; stream regulation defined as N (unregulated), R (regulated), or I (unregulated, but affected by irrigation); mi², square mile; Okla., Oklahoma]

USGS station number	USGS streamgage name	Short name	Stream regulation (N/R/I)	Drainage area (mi²)	Contributing drainage area (mi²)	Period of record (complete water years)
07159100	Cimarron River near Dover, Okla.	Dover gage	N	15,809	11,734	1974–2015
07228500	Canadian River at Bridgeport, Okla.	Bridgeport gage	R	24,698	20,061	1970–2015
07239300	North Canadian River below Weavers Creek near Watonga, Okla.	Watonga gage	R	13,023	9,526	1984–2015
07239450	North Canadian River near Calumet, Okla.	Calumet gage	R	13,239	9,742	1989–2015
07239500	North Canadian River near El Reno, Okla.	El Reno gage	R	13,317	9,820	1949–2015
07239700	North Canadian River near Yukon, Okla.	Yukon gage	R	13,456	9,959	2001–15
07301420	Sweetwater Creek near Sweetwater, Okla.	Sweetwater gage	I	437	410	1987–2015
07301500	North Fork Red River near Carter, Okla.	Carter gage	R	2,652	2,073	1987–2015
07316500	Washita River near Cheyenne, Okla.	Cheyenne gage	R	775	763	1961–2015
07324200	Washita River near Hammon, Okla.	Hammon gage	R	1,367	1,355	1970–87, 1990–2015
07324400	Washita River near Foss, Okla.	Foss gage	R	1,526	1,514	1962–87, 1990–2015
07325000	Washita River near Clinton, Okla.	Clinton gage	R	1,961	1,949	1962–2015

ends) and generally have one less year of record than do the statistics calculated on the basis of water year.

Several software programs were used to calculate statistics related to streamflow data. Raster hydrographs of daily streamflow were calculated by using the raster hydrograph toolkit available on the USGS WaterWatch website (USGS, 2019a). Flood magnitude and frequency were computed according to “Guidelines for Determining Flood Flow Frequency—Bulletin 17C” (England and others, 2018) by using the PeakFQ software program (USGS, 2018d). For data from regulated rivers and rivers that are unregulated but affected by irrigation, station-record skews were used in flood frequency and magnitude calculations, as in Lewis and Esralew (2009). For data from unregulated rivers, weighted skews were calculated from station-only skews and regional skews obtained from “Guidelines for Determining Flood Flow Frequency—Bulletin 17B” (U.S. Interagency Advisory Committee on Water Data, 1982). Flood stage and major flood stage values in feet were obtained from the National Weather Service (2019a), and streamflow in cubic feet per second was calculated by using the rating curves available in NWIS. Flow-duration data and recurrence intervals of low-flow periods were calculated using the Surface-Water Statistics (SWSTAT) software program (Lumb and others, 1994; USGS, 2002) implemented through the USGS Groundwater Toolbox software program (Barlow and others, 2016). Base flows were calculated by hydrograph separation using the Base-Flow Index (BFI)-Standard method (Wahl and Wahl, 1995) implemented through the USGS Groundwater Toolbox software program (Barlow and others, 2016). Locally weighted smoothing (LOESS) curves (Helsel and Hirsch, 2002) and Mann-Kendall trend tests (Mann, 1945) were calculated by using R version 3.6.1 (R Core Team, 2016) and the Kendall R package (McLeod, 2011). The Mann-Kendall trend test is a rank-based procedure for evaluating monotonic trends in data that do not follow a normal distribution (Helsel and Hirsch, 2002).

Groundwater Information Sources

The following types of information were compiled for the different aquifers in the study area: amounts of water allocated and withdrawn for permitted uses in 2015; water-quality characteristics of groundwater describing water-quality field properties, dissolved solids, hardness, chloride, sulfate, nitrate (as nitrogen), and selected trace elements with comparisons to SMCLs and MCLs for finished drinking water; groundwater levels and long-term changes in water levels in wells; and ranges of hydraulic conductivity, aquifer recharge, specific yield, transmissivity, and well yields from reports and groundwater-flow models.

Amounts of water allocated, permitted well locations, and groundwater use type within the CATJA are from the OWRB online spatial data (OWRB, 2018c). Amounts of groundwater withdrawn during 2015 are from the OWRB (C. Neel, OWRB, written commun., 2016). Water-use information specific to the CATJA was not available prior to 2015.

Historical groundwater-level measurements are from the OWRB as part of the Groundwater Monitoring and Assessment Program (GMAP). GMAP provides a source of information about patterns in groundwater quality and quantity (OWRB, 2018d). As part of GMAP, the OWRB measures water levels annually in wells throughout the State and provides valuable information about changing water levels in relation to climate variability and groundwater use over time (OWRB, 2018e). Annual water-level measurements for GMAP wells are available online through the OWRB real-time and continuous water level wells Interactive Maps and GIS data viewer (OWRB, 2018e).

Within the CATJA, historical groundwater-level measurements made at 115 wells by the OWRB (fig. 10) were used to describe groundwater levels over long-term and short-term periods. The mean saturated thickness of the aquifer at each GMAP well location in the CATJA was calculated from well depth and the mean depths to water over the period of measurements for each well.

Groundwater-quality information was obtained from historical data collected by the USGS and OWRB. Most groundwater samples collected by the USGS were for short-term projects and not collected regularly as part of a long-term monitoring program. As a result, the coverage and extent of samples collected by the USGS vary by aquifer depending on the scope of the project for which the samples were collected. USGS groundwater-quality data used for this report are stored in NWIS and can be accessed online (USGS, 2018b, 2018c). Water-quality information from GMAP wells was acquired from the OWRB and represents a subset of GMAP wells that were sampled through September 2015 to describe general water chemistry and identify chemical concerns for future monitoring (OWRB, 2018d).

Groundwater Data Collection Methods

OWRB personnel measured water levels in wells by measuring the depth to water below land-surface datum at each well. All of the groundwater-level measurements were made by using graduated steel tapes or downhole pressure transducers by following methods similar to those described in Cunningham and Schalk (2011).

Established USGS protocols were used by USGS personnel for the preparation, collection, and processing of water-quality samples collected from wells (USGS, variously dated). Similar established protocols were used by personnel for the preparation, collection, and processing of water-quality samples. These protocols are described in the Oklahoma groundwater report for 2017 (OWRB, 2017b).

Quality Assurance

Quality control (QC) data for water-quality samples, such as replicate and equipment blank samples, are collected to ensure the collection of high-quality, unbiased data in the field. A replicate sample is a second sample that is collected several seconds after the field sample and is used to measure variability in field and laboratory procedures. Equipment blank samples consist of purified water that is processed through clean sampling equipment to determine if field procedures or sampling equipment are contaminating water samples.

Within the CATJA, there were very few QC samples collected by the USGS and available for this report (tables 3–6). Five replicate and four equipment blank samples were available. One replicate sample that was collected at the USGS streamgage 07301500 North Fork Red River near Carter, Okla. (hereinafter referred to as the "Carter gage"), was analyzed for major ions, nitrogen compounds, and trace elements, whereas only nitrate (as nitrogen) was analyzed in the other four replicate samples collected at the USGS streamgage 07239450 North Canadian River near Calumet, Okla. (hereinafter referred to as the "Calumet gage"), and at one well in the Cimarron River alluvial aquifer. One reason for such few QC samples is that QC samples for projects studying the rivers and aquifers in the CATJA were collected outside of the CATJA boundary where the river or aquifer also is present. For example, QC samples collected by the USGS for a study of the Ogallala aquifer were from an area north of the CATJA in Ellis County and in the Oklahoma Panhandle where the aquifer also is present. Another reason is that prior to 1990 the collection of QC samples was not a common practice. There were no USGS QC data available for Canton Lake and Foss Reservoir or for the Canadian River alluvial aquifer and the Elk City aquifer in the CATJA and outside of the jurisdictional area boundary.

The OWRB, as part of GMAP, collects QC samples during periods of water-quality sample rotations. During these sample rotations, an equipment blank sample and a replicate sample are collected each week (C. Adams, OWRB, written commun., 2019). All of the alluvial aquifers (except for the Cimarron River alluvial aquifer in the CATJA) and bedrock aquifers have at least one replicate sample that was collected during the sample collection rotation used in this report. Equipment blank samples were collected for all of the aquifers, except in the CATJA for the Cimarron River alluvial aquifer and North Fork Red River alluvial aquifer.

The analytical accuracy between the field and replicate samples was computed as the relative percent difference (RPD) of constituent concentrations. The RPDs were calculated for hardness, dissolved solids, the major ions having SMCLs (chloride, sulfate), nitrogen compounds, and selected trace elements by using the following equation:

$$\mathrm{RPD} = \frac{\left|C_1 - C_2\right|}{\left(C_1 + C_2\right)/2} \times 100 \qquad (1)$$

where

C_1 is the constituent concentration from the field sample, and

C_2 is the constituent concentration from the replicate sample.

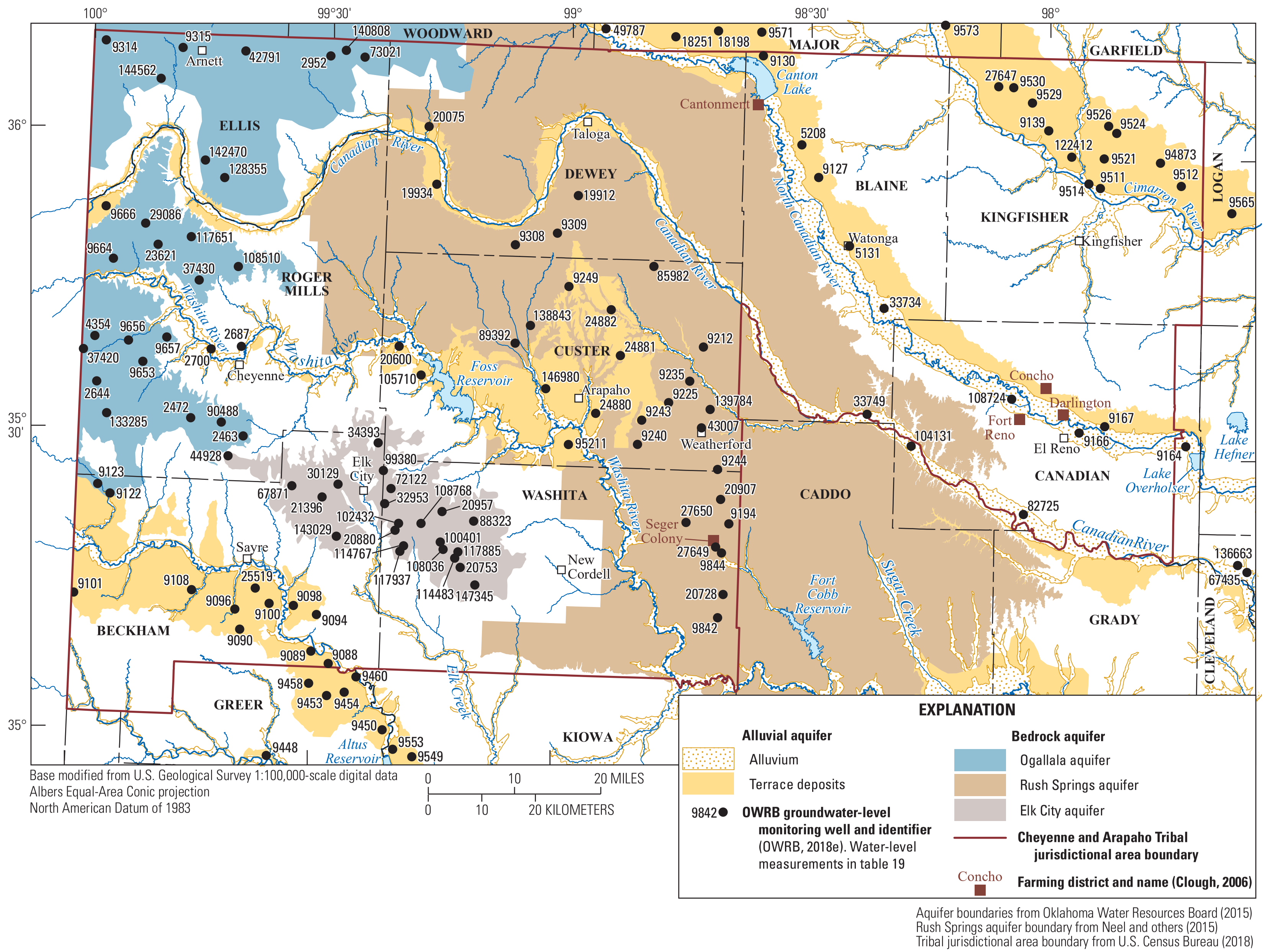


Figure 10. Locations of Oklahoma Water Resources Board (OWRB) Groundwater Monitoring and Assessment Program (GMAP) wells, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (OWRB, 2018e).

RPDs were 33 and 67 percent in one of the three USGS replicate samples collected at the Calumet gage and analyzed for nitrogen compounds (table 3). RPDs in the other two samples were not calculated because measured concentrations were less than the reporting levels. The RPD for one surface-water replicate sample collected at the Carter gage averaged about 4 percent for nitrogen compounds. The RPDs for chloride and sulfate analyses were 2.9 and 0.3 percent, respectively. Though the RPD for iron was not calculated for this replicate sample, a substantially large difference between the field sample and replicate sample concentrations (less than 30 micrograms per liter [µg/L] and 60 µg/L) showed that contamination occurred from the sampling equipment or the analysis procedure. One replicate for a groundwater sample from the Cimarron River alluvial aquifer shows an RPD of 2.4 percent for nitrogen compounds.

A USGS equipment blank sample collected at the Carter gage showed no contamination of major ions or nitrogen compounds (table 4). However, the equipment blank from the Calumet gage analyzed for chloride, lead, and arsenic showed that trace amounts of contamination occurred from the sampling equipment or the analysis procedures. One equipment blank sample from the North Canadian River alluvial aquifer was analyzed for nitrogen compounds and showed a small estimated concentration. An equipment blank from the Cimarron River alluvial aquifer showed no evidence of contamination.

RPDs for seven OWRB replicate samples collected from the alluvial aquifers showed very small variations in groundwater samples measured for dissolved solids, hardness, and the major ions, nitrate (as nitrogen), and trace elements having SMCLs and MCLs shown in this report (table 5). Overall, RPDs were less than 20, with one RPD for iron of 149 and another for chloride of 82. The large RPD for the replicate iron sample collected from a well in the Canadian River alluvial aquifer indicates an inconsistency or potential contamination during field and laboratory procedures. RPDs for nine OWRB replicate samples collected from the bedrock aquifers also showed very small variations in groundwater samples measured for dissolved solids, hardness, and the major ions, nitrogen compounds, and trace elements having SMCLs and MCLs shown in this report (table 5). Overall, RPDs were less than 20 and showed that little to no contamination occurred during the sample process or laboratory analysis.

The OWRB equipment blank samples collected during groundwater sample collection from alluvial and bedrock aquifers showed little to no contamination (table 6). Of 13 equipment blank samples, 2 samples from wells in the Canadian River alluvial aquifer showed contamination from iron (85.1 and 309 µg/L).

Surface-Water Resources

The major surface-water resources in the CATJA include the Cimarron, North Canadian, Canadian, Washita, and North Fork Red Rivers, Foss Reservoir, and Canton Lake (fig. 2). Large concentrations of dissolved solids are the primary reason when surface water is deemed unsuitable for use as a public-water supply in the CATJA (OWRB, 2012a). Median concentrations of dissolved solids in surface water, determined from USGS samples, range from less than 1,000 milligrams per liter (mg/L) (defined in Winslow and Kister, 1956, as fresh) from the North Canadian River to greater than 9,000 mg/L (moderately saline) from the Cimarron River (fig. 11 and table 7).

Large dissolved solids concentrations are indicative of hard water. Hem (1985, p. 158) explained that “because hardness is a property not attributable to a single constituent, some convention has to be used for expressing concentrations in quantitative terms. Usually, this consists of reporting hardness in terms of an equivalent concentration of calcium carbonate. In practical water analysis, the hardness is computed by multiplying the sum of milliequivalents per liter of calcium and magnesium by 50.”

In this report, water is described as hard if the hardness as calcium carbonate concentration ranges from 121 to 180 mg/L. Hem (1985) explained that, if the hardness as calcium carbonate concentration is more than 180 mg/L, the water is very hard. In this report, if the hardness as calcium carbonate concentration ranges from 181 to 240 mg/L, the water will be described as very hard, and if the concentration is more than 240 mg/L, the water will be described as extremely hard.

Rivers

The major rivers that flow through the CATJA are the Cimarron River, North Canadian River, Canadian River, Washita River, and North Fork Red River (fig. 12). The drainage areas of the five major rivers encompass parts of Oklahoma, Colorado, Kansas, New Mexico, and Texas. The upstream drainage areas in relation to the CATJA range in size from 24,698 mi^2 upstream from the USGS streamgage 07228500 Canadian River at Bridgeport, Okla. (hereinafter referred to as the “Bridgeport gage”), to 437 mi^2 upstream from the USGS streamgage 07301420 Sweetwater Creek near Sweetwater, Okla. (hereinafter referred to as the “Sweetwater gage”), on the North Fork Red River (fig. 12 and table 2) (USGS, 2019b).

Table 3. Analytical relative percent difference for concentrations of selected water-quality field properties and constituents measured in quality-control samples collected by the U.S. Geological Survey, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

[USGS, U.S. Geological Survey; mg/L, milligram per liter; µg/L, microgram per liter; Okla., Oklahoma; <, less than; nc, the relative percent difference was not calculated because a concentration was reported less than detection level or constituent was not measured]

USGS station or site number	USGS streamgage or aquifer name	Sample type	Date	Dissolved solids (mg/L)	Hardness (mg/L as calcium carbonate)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate plus nitrite (as nitrogen) (mg/L)	Nitrate (as nitrogen) (mg/L)	Iron (µg/L)	Lead (µg/L)	Manganese (µg/L)	Arsenic (µg/L)	Selenium (µg/L)
Rivers at USGS streamgages														
07239450	North Canadian River near Calumet, Okla.	Field	9/4/2002					<0.05	<0.05					
		Replicate	9/4/2002					<0.05	<0.05					
			Relative percent difference					nc	nc					
07239450	North Canadian River near Calumet, Okla.	Field	3/15/2012					0.02	0.014					
		Replicate	3/15/2012					0.01	0.01					
			Relative percent difference					67	33					
07239450	North Canadian River near Calumet, Okla.	Field	12/19/2012					<0.01	<0.010					
		Replicate	12/19/2012					<0.01	<0.010					
			Relative percent difference					nc	nc					
07301500	North Fork Red River near Carter, Okla.	Field	7/25/2000	2,120	924	414	861	0.44	0.441	60.1		6.94		
		Replicate	7/25/2000	2,100	915	426	864	0.46	0.458	<30		6.95		
			Relative percent difference	0.9	1.0	2.9	0.3	4.4	3.8	nc		0.1		
Alluvial aquifer														
360521098022501	Cimarron River alluvial aquifer	Field	6/26/2001					16.2	16.2					
		Replicate	6/26/2001					16.6	16.6					
			Relative percent difference					2.4	2.4					

Table 4. Results of equipment blank quality-control samples collected by the U.S. Geological Survey, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

[Concentrations in **boldface** show contamination of equipment-blank quality-control sample. USGS, U.S. Geological Survey; mg/L, milligram per liter; µg/L, microgram per liter; Okla., Oklahoma; <, less than; E, estimated]

USGS station or site number	USGS streamgage or aquifer name	Sample type	Date	Dissolved solids (mg/L)	Hardness (mg/L as calcium carbonate)	Chloride (mg/L)	Sulfate (mg/L)	Nitrite plus nitrate (as nitrogen) (mg/L)	Nitrate (as nitrogen) (mg/L)	Iron (µg/L)	Lead (µg/L)	Manganese (µg/L)	Arsenic (µg/L)	Selenium (µg/L)
Rivers at USGS streamgages														
07239450	North Canadian River near Calumet, Okla.	Equipment blank	11/29/2011	<20	<0.10	**0.06**	<0.09	<0.01	<0.010	<3.2	**0.119**	<0.16	**0.04**	<0.03
07301500	North Fork Red River near Carter, Okla.	Equipment blank	7/25/2000	<10	<0.11	<0.29	<0.31	<0.05	<0.050					
Alluvial aquifer														
360212097583601	Cimarron River alluvial aquifer	Equipment blank	7/2/2001					<0.05	<0.050					
353922098503101	North Canadian River alluvial aquifer	Equipment blank	6/18/2001					E0.04						

Table 5. Analytical relative percent difference for concentrations of selected water-quality field properties and constituents measured in quality-control samples collected by the Oklahoma Water Resources Board from Groundwater Monitoring and Assessment Program (GMAP) wells, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

[Concentrations in **boldface** indicate an inconsistency or potential contamination during field and laboratory procedures. GMAP, Groundwater Monitoring and Assessment Program; mg/L, milligram per liter; µg/L, microgram per liter; na, not analyzed; <, less than; nc, the relative percent difference was not calculated because a concentration was reported less than detection level or constituent was not measured]

GMAP well number	Aquifer name	Sample type	Date	Dissolved solids (mg/L)	Hardness (mg/L as calcium carbonate)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (as nitrogen)[a] (mg/L)	Iron (µg/L)	Manganese (µg/L)	Arsenic (µg/L)	Uranium (µg/L)
				Alluvial aquifer								
38283	North Canadian River alluvial aquifer	Field	09–02–2015	818	503	117	174	0.12	382	651	4.4	4.7
		Replicate		826	504	116	174	0.11	375	654	4.1	4.5
			Relative percent difference	1	0	1	0	9	2	0.5	7	4
19934	Canadian River alluvial aquifer	Field	08–21–2013	na	1,484	35.6	1,180	7.91	2,110	719	<5	19.3
		Replicate		2,120	1,574	35.2	1,050	7.91	307	<25	<5	19.5
			Relative percent difference		6	1	12	0	**149**	nc	nc	1
52044	North Fork Red River alluvial aquifer	Field	08–06–2014	389	233	14.2	23.4	7.83	<10	<2.5	2.7	<0.5
		Replicate		388	236	14.6	23.5	7.81	<10	<2.5	4.6	1.3
			Relative percent difference	0	1	3	0.4	0.3	nc	nc	52	nc
4342	Washita River alluvial aquifer	Field	08–06–2014	3,010	1,916	13	1,860	0.03	643	507	1.7	<0.5
		Replicate		3,010	1,968	31	1,880	<0.05	648	505	1.6	<0.5
			Relative percent difference	0	3	82	1	nc	1	0.4	6	nc
78093	Washita River alluvial aquifer	Field	08–19–2014	3,250	1,618	65	2,020	2.71	25.8	52	3.6	7.9
		Replicate		3,320	1,706	63	2,020	2.67	24.7	51.6	3.4	7.5
			Relative percent difference	2	5	3	0	1	4	1	6	5
107564	Washita River alluvial aquifer	Field	08–13–2014	na	1,730	84.9	2,000	0.03	691	318	4.4	6.8
		Replicate		3,190	2,090	84.4	2,020	<0.05	693	318	4.4	6.9
			Relative percent difference	nc	19	1	1	nc	0.3	0	0	1
78679	North Fork Red River alluvial aquifer	Field	07–29–2014	1,180	782	29.6	580	0.83	<10	5.4	1.6	12.9
		Replicate		1,190	790	29.9	572	0.83	<10	5.2	1.4	12.6
			Relative percent difference	1	1	1	1	0	nc	4	13	2

Table 5. Analytical relative percent difference for concentrations of selected water-quality field properties and constituents measured in quality-control samples collected by the Oklahoma Water Resources Board from Groundwater Monitoring and Assessment Program (GMAP) wells, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.—Continued

[Concentrations in **boldface** indicate an inconsistency or potential contamination during field and laboratory procedures. GMAP, Groundwater Monitoring and Assessment Program; mg/L, milligram per liter; µg/L, microgram per liter; na, not analyzed; <, less than; nc, the relative percent difference was not calculated because a concentration was reported less than detection level or constituent was not measured]

GMAP well number	Aquifer name	Sample type	Date	Dissolved solids (mg/L)	Hardness (mg/L as calcium carbonate)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (as nitrogen)[a] (mg/L)	Iron (µg/L)	Manganese (µg/L)	Arsenic (µg/L)	Uranium (µg/L)
				Bedrock aquifer								
117885	Elk City aquifer	Field	07–30–2013	436	333	11.6	30.1	7.4	<25	<25	5	10.6
		Replicate		444	333	11.8	29	7.4	<25	<25	<5	10.4
			Relative percent difference	2	0	2	4	0	nc	nc	nc	2
2762	Ogallala aquifer	Field	08–20–2013	544	327	16.5	29.4	23.4	<25	<25	<5	2.7
		Replicate		561	334	16.5	29.8	22.8	<25	<25	<5	2.7
			Relative percent difference	3	2	0	1	3	nc	nc	nc	0.0
5045	Ogallala aquifer	Field	08–13–2013	458	268	39.9	17	12.5	<25	<25	<5	1.1
		Replicate		418	268	40.4	18.1	12.5	<25	<25	<5	1.1
			Relative percent difference	9	0	1	6	0	nc	nc	nc	0
20140	Rush Springs aquifer	Field	10–01–2013	306	239	<5	30.8	0.51	<25	<25	<5	1.4
		Replicate		305	226	<5	32.7	0.49	<25	<25	<5	1.4
			Relative percent difference	0.3	6	nc	6	4	nc	nc	nc	0
37681	Rush Springs aquifer	Field	09–24–2013	740	400	36	68	59.2	<25	<25	<5	2.6
		Replicate		751	397	33.8	70.6	53.2	<25	<25	<5	2.5
			Relative percent difference	1	1	6	4	11	nc	nc	nc	4
105710	Rush Springs aquifer	Field	10–08–2013	1,010	764	86.6	460	7.43	<25	<25	<5	5.9
		Replicate		994	757	73.2	448	7.45	<25	<25	<5	5.9
			Relative percent difference	2	1	17	3	0.3	nc	nc	nc	0
95120	Rush Springs aquifer	Field	10–08–2013	678	508	18.5	115	33.9	<25	<25	<5	3
		Replicate		669	511	18.5	116	34.2	<25	<25	<5	2.9
			Relative percent difference	1	1	0	1	1	nc	nc	nc	3

Table 5. Analytical relative percent difference for concentrations of selected water-quality field properties and constituents measured in quality-control samples collected by the Oklahoma Water Resources Board from Groundwater Monitoring and Assessment Program (GMAP) wells, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.—Continued

[Concentrations in **boldface** indicate an inconsistency or potential contamination during field and laboratory procedures. GMAP, Groundwater Monitoring and Assessment Program; mg/L, milligram per liter; µg/L, microgram per liter; na, not analyzed; <, less than; nc, the relative percent difference was not calculated because a concentration was reported less than detection level or constituent was not measured]

GMAP well number	Aquifer name	Sample type	Date	Dissolved solids (mg/L)	Hardness (mg/L as calcium carbonate)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (as nitrogen)[a] (mg/L)	Iron (µg/L)	Manga-nese (µg/L)	Arsenic (µg/L)	Uranium (µg/L)
				Bedrock aquifer—Continued								
85982	Rush Springs aquifer	Field	10–14–2013	2,290	1,820	16	1,320	1.1	<25	<25	<5	6.2
		Replicate		2,270	1,840	16	1,340	1.1	<25	<25	<5	6.2
			Relative percent difference	1	1	1	2	0	nc	nc	nc	0
89392	Rush Springs aquifer	Field	10–02–2013	1,290	936	63.2	592	37.9	<25	<25	<5	27
		Replicate		1,170	942	66.4	604	38.4	<25	<25	<5	27
			Relative percent difference	10	1	5	2	1	nc	nc	nc	0

[a]Measured as nitrate plus nitrite (as nitrogen).

Table 6. Results of field blank quality-control samples collected by the Oklahoma Water Resources Board from Groundwater Monitoring and Assessment Program (GMAP) wells, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

[Concentrations in **boldface** show contamination of quality-control equipment-blank sample. GMAP, Groundwater Monitoring and Assessment Program; mg/L, milligram per liter; µg/L, microgram per liter; <, less than]

GMAP well number	Aquifer name	Sample type	Date	Dissolved solids (mg/L)	Hardness (mg/L as calcium carbonate)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (as nitrogen)[a] (mg/L)	Iron (µg/L)	Manganese (µg/L)	Arsenic (µg/L)	Uranium (µg/L)
				Alluvial aquifer								
38283	North Canadian River alluvial aquifer	Equipment blank	09–03–2015	<10	<10	<10	<0.10	<0.05	<20	<5	<1	<1
111483	North Canadian River alluvial aquifer	Equipment blank	09–16–2015	<10	<10	<10	<0.10	<0.05	<20	<5	<1	<1
19934	Canadian River alluvial aquifer	Equipment blank	08–22–2013	<10	<10	<10	<0.10	<0.05	**309**	<50	<10	<1
104131	Canadian River alluvial aquifer	Equipment blank	08–28–2013	<10	<10	<10	<0.10	<0.05	<50	<50	<10	<1
145374	Canadian River alluvial aquifer	Equipment blank	09–05–2013	<10	<10	<10	<0.10	<0.05	<50	<50	<10	<1
53528	Canadian River alluvial aquifer	Equipment blank	09–12–2013	<10	<10	<10	<0.10	<0.05	<50	<50	<10	<1
139129	Canadian River alluvial aquifer	Equipment blank	09–19–2013	<10	<10	<10	<0.10	<0.05	**85.1**	<50	<10	<1
2554	Washita River alluvial aquifer	Equipment blank	08–07–2014	<10	<10	<10	<0.10	<0.05	<20	<5	<1	<1
107564	Washita River alluvial aquifer	Equipment blank	08–14–2014	<10	<10	<10	<0.10	<0.05	<20	<5	<1	<1
42809	Washita River alluvial aquifer	Equipment blank	08–22–2014	<10	<10	<10	<0.10	<0.05	<20	<5	<1	<1
				Bedrock aquifer								
30572	Ogallala aquifer	Equipment blank	08–08–2013	<10	<10	<10	<0.10	<0.05	<50	<50	<10	<1
20790	Elk City aquifer	Equipment blank	08–01–2013	<10	<10	<10	<0.10	<0.05	<50	<50	<10	<1
3554	Rush Springs aquifer	Equipment blank	09–26–2013	<10	<10	<10	<0.10	<0.05	<50	<50	<10	<1

[a]Measured as nitrate plus nitrite (as nitrogen).

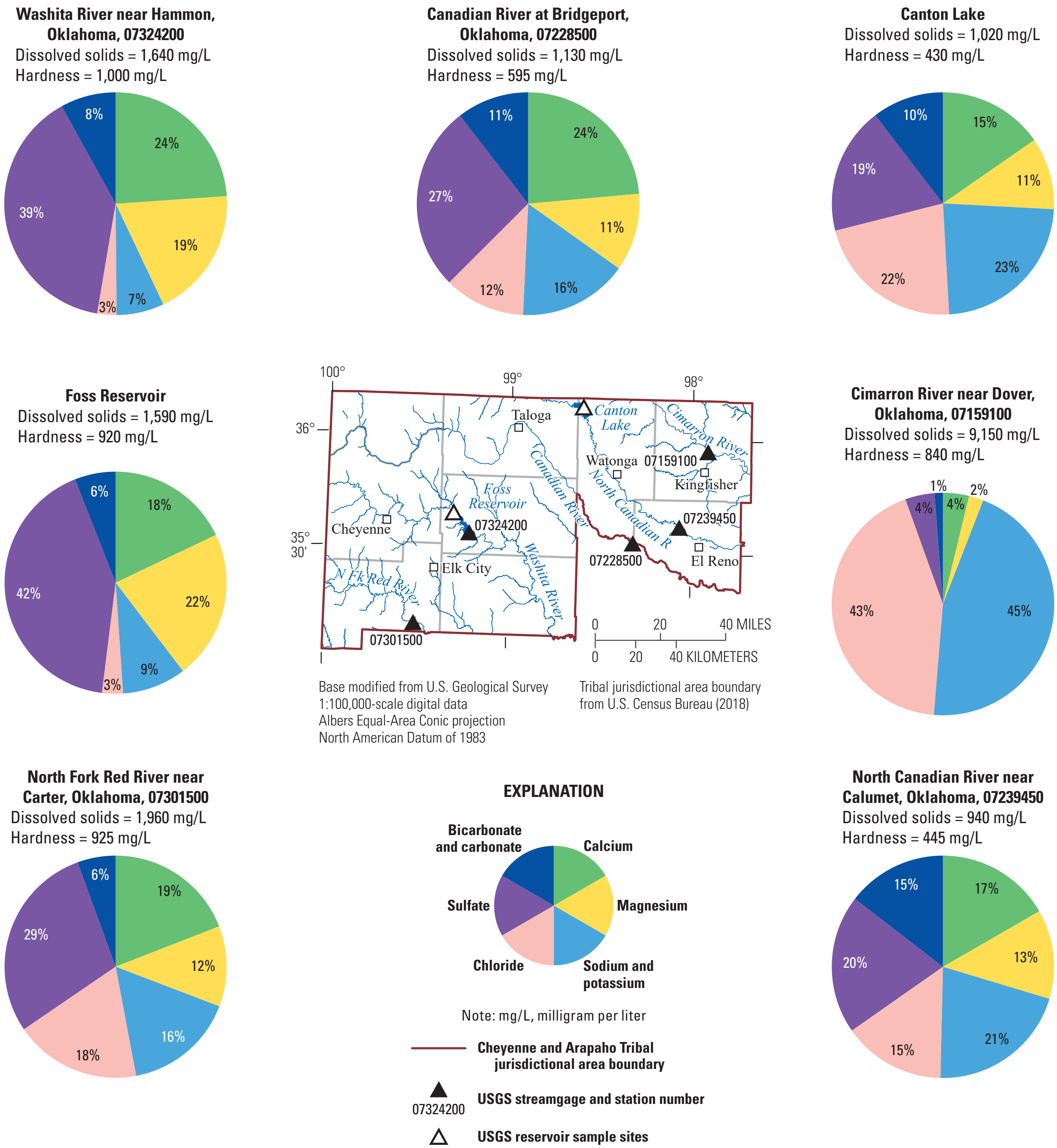


Figure 11. Median dissolved solids, hardness as calcium carbonate concentrations, and proportions of major ions of samples collected by the U.S. Geological Survey (USGS) from rivers and reservoirs, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

Table 7. Summary statistics for selected water-quality constituents measured in river and reservoir samples collected at U.S. Geological Survey streamgages and Oklahoma Water Resources Board Beneficial Use Monitoring Program (BUMP) stations, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

[Concentrations were measured in filtered water unless noted otherwise. %, percent; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; EPA, U.S. Environmental Protection Agency; Okla., Oklahoma; USGS, U.S. Geological Survey; —, not computed or does not apply; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; µg/L, microgram per liter; M, present but not quantifiable; filtered, water was filtered through a 0.15-micrometer filter; OWRB, Oklahoma Water Resources Board; <, less than]

Water-quality constituents and properties	Sample count	25%	Median	Mean	75%	Number of samples exceeding MCL-SMCL	MCL (EPA, 2018a)	SMCL (EPA, 2018b)
07159100 Cimarron River near Dover, Okla. (USGS Dover gage)								
pH	231	—	7.9	—	—	4	—	6.5–8.5
Specific conductance (µS/cm)	159	8,110	9,040	8,900	12,100	—	—	—
Dissolved solids (mg/L)[a]	163	5,620	9,150	8,930	12,100	162	—	500 mg/L
Hardness (mg/L as calcium carbonate)	163	580	840	765	980	—	—	—
Chloride (mg/L)	167	2,700	4,600	4,715	6,700	165	—	250 mg/L
Sulfate (mg/L)	169	420	580	540	685	150	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	57	0.31	0.42	0.64	0.73	0	10 mg/L	—
Cadmium (µg/L) (unfiltered)	13	—	—	—	—	3	5 µg/L	—
Chromium (µg/L) (unfiltered)	13	—	30	—	—	2	100 µg/L	—
Iron (µg/L) (unfiltered)	35	—	620	—	—	24	—	300 µg/L
Lead (µg/L) (unfiltered)	13	—	M	—	—	1	0–15 µg/L[b]	—
Manganese (µg/L) (unfiltered)	37	80	150	404	285	34	—	50 µg/L
Arsenic (µg/L) (unfiltered)	12	—	6.5	—	—	3	10 µg/L	—
620910020010-004RS Cimarron River at Ames, Okla. (OWRB Ames BUMP station) (2003–18)								
Nitrate (as nitrogen) (mg/L)[b]	120	<0.05	0.21	0.3	0.41	0	10 mg/L	—
Total phosphorus (mg/L)	120	0.016	0.027	0.051	0.042	—	—	—
Arsenic (µg/L)	4	—	24	24	—	4	10 µg/L	—
Arsenic (µg/L) (unfiltered)	4	—	26	25	—	4	10 µg/L	—
07239450 North Canadian River near Calumet, Okla. (USGS Calumet gage)								
pH	349	—	8.3	—	—	25	—	6.5–8.5
Specific conductance (µS/cm)	351	1,300	1,450	1,380	1,570	—	—	—
Dissolved solids (mg/L)[a]	106	850	940	905	1,040	101	—	500 mg/L
Hardness (mg/L as calcium carbonate)	116	405	445	430	475	—	—	—
Chloride (mg/L)	116	120	160	155	190	7	—	250 mg/L
Sulfate (mg/L)	110	250	290	280	320	82	—	250 mg/L
Iron (µg/L)	108	—	7	—	—	0	—	300 µg/L
Manganese (µg/L)	108	—	10	—	—	11	—	50 µg/L
Arsenic (µg/L)	117	3	4	4	5	0	10 µg/L	—
520530000010-001AT North Canadian River at El Reno, Okla. (OWRB El Reno BUMP station) (November 1998–2015)								
Nitrate (as nitrogen) (mg/L)[b]	163	<0.05	<0.05	0.13	0.19	0	—	10 mg/L
Total phosphorus (mg/L)	165	0.064	0.12	0.158	0.217	—	—	—

Table 7. Summary statistics for selected water-quality constituents measured in river and reservoir samples collected at U.S. Geological Survey streamgages and Oklahoma Water Resources Board Beneficial Use Monitoring Program (BUMP) stations, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.—Continued

[Concentrations were measured in filtered water unless noted otherwise. %, percent; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; EPA, U.S. Environmental Protection Agency; Okla., Oklahoma; USGS, U.S. Geological Survey; —, not computed or does not apply; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; µg/L, microgram per liter; M, present but not quantifiable; filtered, water was filtered through a 0.15-micrometer filter; OWRB, Oklahoma Water Resources Board; <, less than]

Water-quality constituents and properties	Sample count	25%	Median	Mean	75%	Number of samples exceeding MCL-SMCL	MCL (EPA, 2018a)	SMCL (EPA, 2018b)
07228500 Canadian River at Bridgeport, Okla. (USGS Bridgeport gage)								
pH	402	—	8.1	—	—	11	—	6.5–8.5
Specific conductance (µS/cm)	403	1,100	1,580	1,595	2,070	—	—	—
Dissolved solids (mg/L)[a]	304	795	1,130	1,110	1,440	290	—	500 mg/L
Hardness (mg/L as calcium carbonate)	328	485	595	580	690	—	—	—
Chloride (mg/L)	305	36	140	170	280	98	—	250 mg/L
Sulfate (mg/L)	297	340	440	430	515	267	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	148	0.25	0.51	0.64	0.93	0	10 mg/L	—
Cadmium (µg/L)	87	—	2	—	—	1	5 µg/L	—
Cadmium (µg/L) unfiltered	94	—	<1	—	—	0	5 µg/L	—
Iron (µg/L)	88	—	10	—	—	0	—	300 µg/L
Iron (µg/L) unfiltered	47	—	695	—	—	47	—	300 µg/L
Lead (µg/L)	85	—	<10	—	—	1	15 µg/L[b]	—
Lead (µg/L) unfiltered	93	—	8.5	—	—	4	15 µg/L[b]	—
Manganese (µg/L)	88	—	20	—	—	7	—	50 µg/L
Manganese (µg/L) unfiltered	47	50	60	230	170	40	—	50 µg/L
Arsenic (µg/L)	72	3	3.5	3.9	5	1	10 µg/L	—
Arsenic (µg/L) unfiltered	74	—	4	—	—	6	10 µg/L	—
07324200 Washita River near Hammon, Okla. (USGS Hammon gage)								
pH	181	—	7.9	—	—	4	—	6.5–8.5
Specific conductance (µS/cm)	186	1,650	1,965	1,920	2,250	—	—	—
Dissolved solids (mg/L)[a]	141	1,345	1,640	1,620	1,925	136	—	500 mg/L
Hardness (mg/L as calcium carbonate)	97	840	1,000	1,045	1,250	—	—	—
Chloride (mg/L)	160	37	47	46	57	0	—	250 mg/L
Sulfate (mg/L)	165	695	910	885	1,100	158	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	50	0.12	0.24	0.28	0.37	0	10 mg/L	—
Cadmium (µg/L)	6	—	<1	—	—	1	5 µg/L	—
Iron (µg/L)	15	30	40	37	50	0	—	300 µg/L
Iron (µg/L) unfiltered	9	1,260	2,020	2,390	3,700	8	—	300 µg/L
Manganese (µg/L)	14	35	41	78	110	6	—	50 µg/L

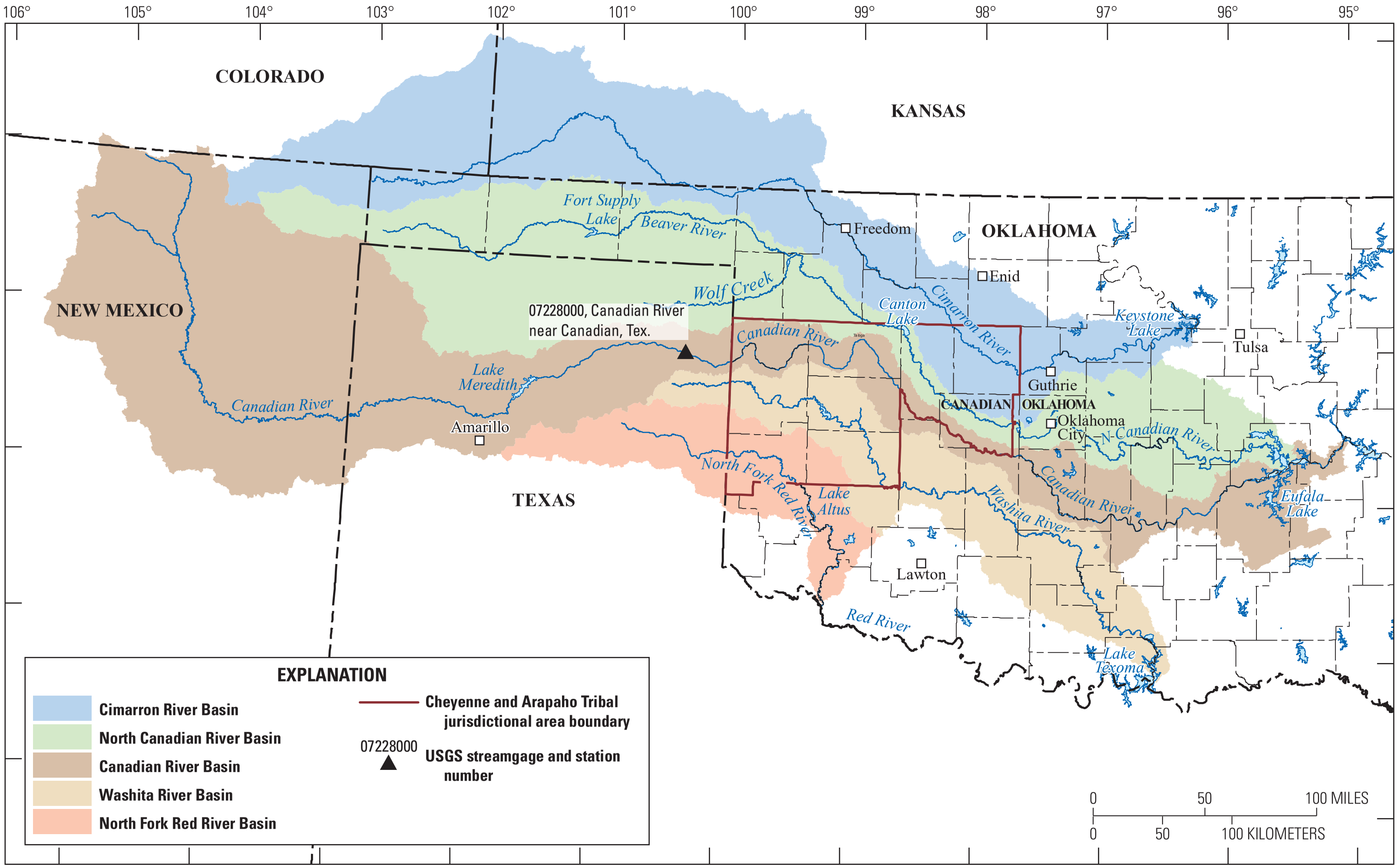
Table 7. Summary statistics for selected water-quality constituents measured in river and reservoir samples collected at U.S. Geological Survey streamgages and Oklahoma Water Resources Board Beneficial Use Monitoring Program (BUMP) stations, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.—Continued

[Concentrations were measured in filtered water unless noted otherwise. %, percent; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; EPA, U.S. Environmental Protection Agency; Okla., Oklahoma; USGS, U.S. Geological Survey; —, not computed or does not apply; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; µg/L, microgram per liter; M, present but not quantifiable; filtered, water was filtered through a 0.15-micrometer filter; OWRB, Oklahoma Water Resources Board; <, less than]

Water-quality constituents and properties	Sample count	25%	Median	Mean	75%	Number of samples exceeding MCL-SMCL	MCL (EPA, 2018a)	SMCL (EPA, 2018b)
07301500 North Fork Red River near Carter, Okla. (USGS Carter gage)								
pH	123	—	7.9	—	—	4	—	6.5–8.5
Specific conductance	216	2,320	2,700	2,710	2,970	—	—	—
Dissolved solids (mg/L)	64	1,620	1,960	1,860	2,150	64	—	500
Hardness (mg/L as calcium carbonate)	79	780	925	925	1,000	—	—	—
Chloride (mg/L)	90	300	375	480	415	74	—	250
Sulfate (mg/L)	90	640	815	855	970	88	—	250
Nitrate (as nitrogen) (mg/L)[b]	34	—	0.52	—	—	0	10 mg/L	—
Iron (µg/L)	8	—	<30	—	—	0	—	300 µg/L
Iron (µg/L) unfiltered	25	—	310	—	—	13	—	300 µg/L
Manganese (µg/L)	8	—	20	—	—	0	—	50 µg/L
Manganese (µg/L) unfiltered	24	40	50	137	183	11	—	50 µg/L
Foss Reservoir								
pH	100	—	8.2	—	—	17	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	46	1,720	1,840	1,840	1,950	—	—	—
Dissolved solids (mg/L)[a]	50	1,475	1,590	1,550	1,660	50	—	500 mg/L
Hardness (mg/L as calcium carbonate)	24	795	920	890	975	—	—	—
Chloride (mg/L)	51	47	49	50	53	0	—	250 mg/L
Sulfate (mg/L)	50	870	930	900	970	50	—	250 mg/L
Canton Lake								
pH	45	—	8.4	—	—	11	—	6.5–8.5
Specific conductance (µS/cm)	44	1,520	1,605	1,640	1,790	—	—	—
Dissolved solids (mg/L)[a]	46	915	1,020	1,010	1,080	46	—	500 mg/L
Hardness (mg/L as calcium carbonate)	46	405	430	425	445	—	—	—
Chloride (mg/L)	46	210	250	245	270	19	—	250 mg/L
Sulfate (mg/L)	46	270	290	295	325	39	—	250 mg/L

[a]Dried at 180 degrees Celsius.

[b]Analyzed as nitrate plus nitrite (as nitrogen).



Base modified from U.S. Geological Survey 1:100,000-scale digital data
Albers Equal-Area Conic projection
North American Datum of 1983

Basin extents defined by U.S. Geological Survey (2019b)
Tribal jurisdictional area boundary from
U.S. Census Bureau (2018)

Figure 12. Drainage areas of the five major river basins in the Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. USGS, U.S. Geological Survey.

Cimarron River

The Cimarron River flows for 54 mi through the CATJA in Kingfisher County and continues downstream to where it terminates at Keystone Lake (figs. 2 and 12). In the upstream drainage area in parts of Colorado, New Mexico, Kansas, and Oklahoma, streamflow is unregulated by dams and not affected by irrigation (table 2).

Diversions and Discharges

In the CATJA, there were 45 permits for diverting surface water from the Cimarron River and tributaries in 2015 (figs. 8 and 13) (OWRB, 2016). These permits were for the following water uses: irrigation; mining; recreation, fish, and wildlife; and other water uses (commercial and industrial). There were no permits for public-water supply diversions on the Cimarron River within the CATJA.

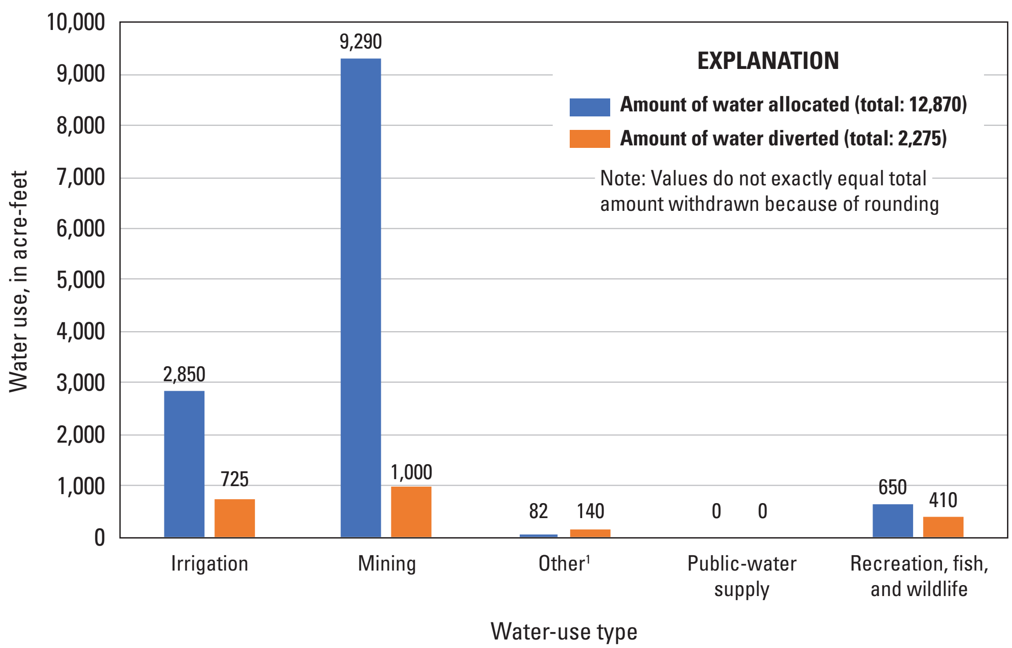
During 2015, the total amount of water allocated by the OWRB for diversion in the CATJA was 12,870 acre-feet (acre-ft) (fig. 13) (OWRB, 2016). The largest allocations were for mining activities at 9,290 acre-ft and irrigation at 2,850 acre-ft. Twenty-two permit holders reported diverting a combined total of 2,275 acre-ft of water from the Cimarron River and its tributaries in 2015 (fig. 13) (C. Neel, OWRB, written commun., 2016). Of the total that was diverted, 725 acre-ft was for irrigation, and 1,000 acre-ft was for mining. A smaller amount, 140 acre-ft, was diverted for other (commercial and industrial) use. Reported diversions from the Cimarron River in 2015 were only about 18 percent of the total amount of water allocated for diversion.

Three entities discharged treated wastewater into northeastward-flowing tributaries of the Cimarron River in the CATJA during 2015 (fig. 8 and table 8). The City of Kingfisher, Okla., released a mean of 750 acre-feet per day (acre-ft/d) of treated municipal wastewater into Kingfisher Creek in 2015 (D. Pruitt, ODEQ, written commun., 2016). The DCP Midstream gas plant in Okarche, Okla., released a mean of 9.1 acre-ft/d of treated industrial wastewater into Winter Camp Creek, and United States Gypsum Co. released a mean of 115 acre-ft/d into a small stream near Spring Creek (fig. 8) (D. Pruitt, ODEQ, written commun., 2016). This was a total inflow to the basin of about 319,000 acre-feet per year (acre-ft/yr) (table 8).

Water-Quality Characteristics

Water-quality information for the Cimarron River is available from the USGS NWIS database (USGS, 2018b) and from the OWRB BUMP (OWRB, 2018a). The USGS operates one streamgage on the Cimarron River in the CATJA, the USGS streamgage 07159100 Cimarron River near Dover, Okla. (hereinafter referred to as the “Dover gage”) (fig. 9). General water-quality and water-type descriptions for this report come from samples collected at this streamgage from 1975 to 1990 (USGS, 2018b). The OWRB also collected selected water-quality information near this location at the discontinued Dover BUMP station from 1998 to 2012 (OWRB, 2018a). Upstream from the CATJA, about 4 mi north of Kingfisher County, water quality is monitored at the OWRB Ames BUMP station on the Cimarron River. The Ames BUMP station is useful for monitoring water-quality field properties and concentrations of nitrogen, phosphorus, and the trace elements arsenic, chromium, and lead in the Cimarron River flowing into the CATJA. For this report, water-quality statistics from the Ames BUMP station provide concentrations of nitrogen and phosphorus collected from March 2003 to December 2018 and trace elements collected from November 2016 to January 2018 (OWRB, 2018a).

Samples from the Cimarron River are slightly alkaline, with a median pH of 7.9; the pH in 4 of the 231 samples that were collected exceeds the SMCL of 8.5 (EPA, 2018b) (table 7). Very large dissolved solids, chloride, and sulfate concentrations were measured in the samples collected from the Cimarron River, with 89–98 percent of all dissolved



[1]Commercial and industrial.

Figure 13. Amounts of surface water allocated and diverted for use from the Cimarron River during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2016; C. Neel, Oklahoma Water Resources Board, written commun., 2016).

Table 8. Daily and annual mean amounts of treated wastewater discharged into river basins by permitted entities during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (D. Pruitt, Oklahoma Department of Environmental Quality, written commun., 2016).

[—, no discharge reported by entity during 2015]

Permitted entity	Entity type	Map identifier (fig. 8)	Daily mean discharge (acre-feet/day)	Annual mean discharge (acre-feet/year)
	Cimarron River Basin			
Kingfisher, City of	Municipality	1	750	
DCP Midstream, Okarche Gas Plant	Industry	2	9.1	
United States Gypsum Co.	Industry	3	115	
	Total		**874**	**319,000**
	North Canadian River Basin			
El Reno, City of	Municipality	4	—	
Watonga, City of	Municipality	5	498	
Yukon, City of	Municipality	6	3,789	
Universal Trailer Horse and Livestock Group	Industry	7	23	
	Total		**4,310**	**1,573,000**
	Canadian River Basin			
Choctaw County RW&SD #1	Municipality	8	—	
Hydro, Town of	Municipality	9	63	
Minco, City of	Municipality	10	62	
Thomas, City of	Municipality	11	—	
Union City, Town of	Municipality	12	56	
Weatherford, City of	Municipality	13	1,073	
Eastman Kodak Company	Industry	14	88	
	Total		**1,342**	**489,800**
	Washita River Basin			
Clinton, City of	Municipality	15	1,040	
New Cordell, City of	Municipality	16	300	
Bar-S Foods Company	Industry	17	260	
Foss Reservoir Master Conservancy District	Effluent from desalinization	18	1,225	
	Total		**2,825**	**1,031,000**
	North Fork Red River Basin			
Elk City, City of	Municipality	19	375	
Erick, City of	Municipality	20	13.2	
Love's Travel Stops & Country Stores, Inc.	Industry	21	0.045	
	Total		**386**	**141,000**

solids, chloride, and sulfate samples exceeding their respective SMCLs for these nuisance constituents in finished drinking water (EPA, 2018b). The median concentrations for dissolved solids, chloride, and sulfate were 9,150, 4,600, and 580 mg/L, respectively. The water in the Cimarron River also is extremely hard; the 25th and 75th percentiles of hardness as calcium carbonate measured in samples collected from this river were 580 and 980 mg/L, respectively, with a median hardness as a calcium carbonate concentration of 840 mg/L.

Nutrient concentrations measured in samples collected by the OWRB at the Ames BUMP station were generally small. In 120 samples, the median concentration of nitrate (as nitrogen) was 0.21 mg/L, much smaller than the MCL of 10 mg/L allowable in finished drinking water (EPA, 2018a) (table 7). Concentrations of total phosphorus were also very small. In 120 samples collected at the Ames BUMP station, the median concentration of total phosphorus was 0.027 mg/L.

Iron and manganese concentrations were large in Cimarron River samples with 69 percent of the iron concentrations and 92 percent of the manganese concentrations exceeding their respective SMCLs for finished drinking water (EPA, 2018b) (table 7). However, iron and manganese concentrations were measured in unfiltered water, so a large proportion of these trace-element concentrations were likely associated with particulate material. Concentrations would likely be smaller in filtered water.

The trace elements cadmium, chromium, and arsenic were measured at concentrations larger than the MCLs at the Dover gage in unfiltered samples collected from 1970 to 1995. In 12–13 samples, these three trace elements exceeded MCLs for finished drinking water in at least 2 samples (table 7) (EPA, 2018a). The largest arsenic concentration measured in USGS samples at the Dover gage was 19 µg/L. Arsenic was the only trace element measured by the OWRB at concentrations exceeding the MCL. In all four samples collected at the Ames BUMP station, arsenic was measured at concentrations larger than the MCL of 10 µg/L, ranging from 17 to 32 µg/L and averaging 24 µg/L. Concentrations of arsenic measured in unfiltered samples were slightly larger, averaging 25 µg/L.

The water type of the Cimarron River is a sodium-chloride type (fig. 11). Sodium and chloride together account for about 90 percent of the major ions composing the water.

North Canadian River

The North Canadian River begins at the confluence of Wolf Creek and the Beaver River near Fort Supply Lake (fig. 12). The drainage basin of the North Canadian River and its tributaries covers about 9,275 mi^2 in New Mexico, Texas, and Oklahoma. Through the CATJA, the North Canadian River flows southeastward for 136 mi and then continues east for an additional 265 mi downstream, terminating at Eufaula Lake. The flow of the North Canadian River through the CATJA is regulated by Canton Lake and also is affected by irrigation, dams, or other human modifications in the basin upstream from the CATJA (Lewis and Esralew, 2009).

Diversions and Discharges

In the CATJA, there were 17 permits for diverting surface water from the North Canadian River and its tributaries during 2015 (fig. 8) (OWRB, 2016). These permits were for irrigation; mining; and recreation, fish, and wildlife water use. There were no permits for public-water supply diversions on the North Canadian River within the CATJA. During 2015, the total amount of surface water allocated by the OWRB for diversion in the CATJA was 4,085 acre-ft (fig. 14) (OWRB, 2016). The largest allocations were for irrigation at 2,490 acre-ft and mining activities at 1,230 acre-ft. A smaller amount, 365 acre-ft, was allocated for recreation, fish, and wildlife purposes. Five permit holders reported diverting a combined total of 850 acre-ft of water from the North Canadian River and its tributaries. Of the total that was diverted, 475 acre-ft was diverted for mining, and 375 acre-ft was diverted for irrigation water use (fig. 14) (C. Neel, OWRB, written commun., 2016). Reported diversions from the North Canadian River and its tributaries in 2015 were only about 21 percent of the total amount of water allocated for diversion.

Four entities were permitted to discharge treated wastewater into the North Canadian River Basin in the CATJA (fig. 8 and table 8); only three were active during 2015 (D. Pruitt, ODEQ, written commun., 2016). The City of El Reno, Okla., did not discharge wastewater during 2015. The Cities of Watonga and Yukon, Okla., in addition to Universal Trailer Horse and Livestock Group, released the combined mean of 4,310 acre-ft/d into the North Canadian River or its tributaries. This represents a total inflow to the basin of about 1,573,000 acre-ft during 2015 (table 8).

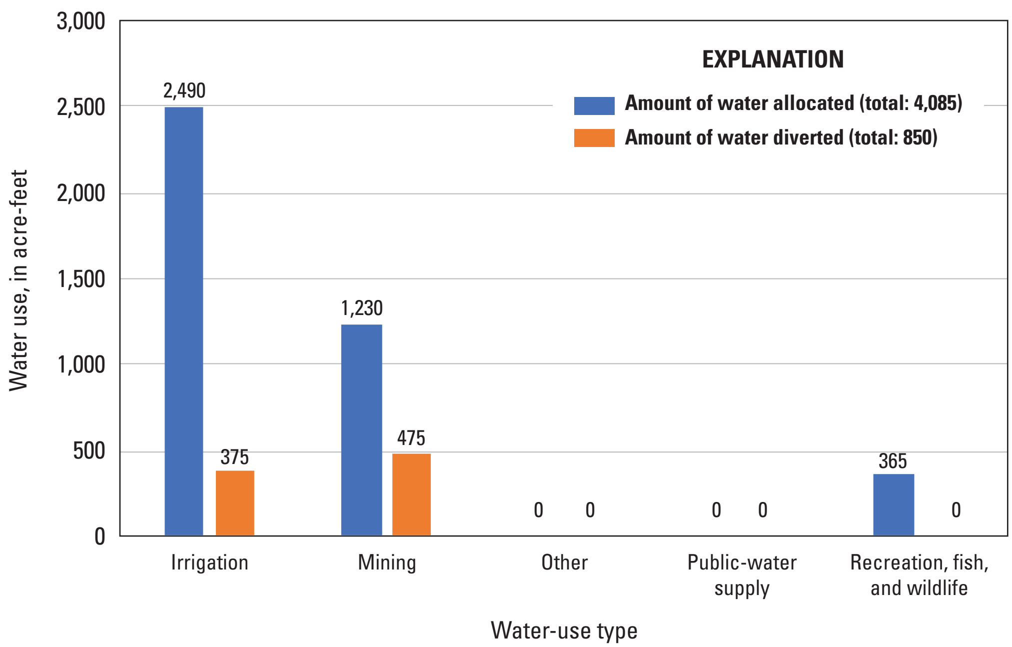


Figure 14. Amounts of surface water allocated and diverted for use from the North Canadian River during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2016; C. Neel, Oklahoma Water Resources Board, written commun., 2016).

Water-Quality Characteristics

Water-quality information for the North Canadian River is available from the USGS NWIS database (USGS, 2018b) and from the OWRB BUMP (OWRB, 2018a). There are five USGS streamgages on the North Canadian River in the CATJA where streamflow information has been collected (fig. 9). Water-quality samples have been collected at three of these streamgages for various lengths of time. At the now discontinued USGS streamgage 07239500 North Canadian River near El Reno, Okla. (hereinafter referred to as the “El Reno gage”), the first samples were collected in 1955, and the last samples were collected in 2005. Samples were collected at the USGS streamgage 07239000 North Canadian River at Canton, Okla., from November 1975 to October 1980. The most recent samples collected were at the Calumet gage from August 1988 to December 2015. The water-quality samples from this streamgage were used to characterize the general water quality of the North Canadian River described below.

Water-quality information also is available from the OWRB El Reno BUMP station, which is about 7 mi downstream from the Calumet gage (fig. 9). Beginning in November 1998, the OWRB analyzed for selected constituents that included water-quality field properties, dissolved solids, chloride, sulfate, nitrogen, and phosphorus. The El Reno BUMP station water-quality information is available online (OWRB, 2018a).

USGS samples show that water from the North Canadian River is slightly alkaline with a median pH of 8.3 (table 7). About 7 percent of 349 pH measurements exceeded the SMCL of 8.5 for finished drinking water (EPA, 2018b). The North Canadian River also has very large concentrations of dissolved solids and sulfate, with median concentrations of 940 and 290 mg/L, respectively. Compared to their respective SMCL values for finished drinking water, about 95 percent of dissolved solids concentrations exceeded the SMCL of 500 mg/L, and about 75 percent of sulfate concentrations exceeded the SMCL of 250 mg/L (EPA, 2018b). Hardness values indicate that the North Canadian River is extremely hard, with a median hardness as calcium carbonate concentration of 445 mg/L.

Nutrient concentrations measured in samples collected by the OWRB at the El Reno BUMP station were generally small (table 7). The median concentration of nitrate (as nitrogen) was less than 0.05 mg/L, much smaller than the MCL of 10 mg/L in finished drinking water. Concentrations of total phosphorus measured by the OWRB at the El Reno BUMP station have a median value of 0.12 mg/L in 165 samples (OWRB, 2018a).

All dissolved concentrations of iron (108 samples) measured in samples collected from the North Canadian River were smaller than the SMCL of 300 µg/L, and 97 of 108 manganese samples were smaller than the SMCL of 50 µg/L, with median iron and manganese concentrations of 7 and 10 µg/L, respectively (table 7) (EPA, 2018b). The median and mean concentrations of arsenic in 117 samples were both about 4 µg/L, with no samples exceeding the MCL of 10 µg/L for finished drinking water.

The water type of the North Canadian River at the Calumet gage is a mixed-ion type (fig. 11). The six major ions each account for about 13–21 percent of the major-ion composition.

Canadian River

The Canadian River enters the CATJA from Texas and flows for about 219 mi through Ellis County and Dewey County before crossing the southern part of Blaine County and the northern part of Canadian County (figs. 2 and 12). Exiting the CATJA, the Canadian River flows about an additional 200 mi before it empties into Eufaula Lake (fig. 12). Upstream from the Bridgeport gage, the river has a drainage area of 24,698 mi^2 that extends into parts of Colorado, New Mexico, and Texas (figs. 9 and 12). Canadian River streamflow has been regulated since 1965 by the dam that impounds the Canadian River to form Lake Meredith in the Texas Panhandle (Handbook of Texas Online, 2019) (fig. 12).

Diversions and Discharges

In the CATJA, there were 38 permits for diverting surface water from the Canadian River and its tributaries during 2015 (fig. 8) (OWRB, 2016). These permits were for irrigation; mining; and recreation, fish, and wildlife water uses, along with permitted withdrawals for industrial and non-irrigated agricultural water uses. There were no permits for public-water supply diversions on the Canadian River within the CATJA.

During 2015, the total amount of surface water allocated by the OWRB for diversion from the Canadian River in the CATJA was 34,200 acre-ft, with the largest allocation for irrigation at 27,410 acre-ft (fig. 15) (OWRB, 2016). Fourteen permit holders reported diverting a combined total of 24,330 acre-ft of water from the Canadian River and its tributaries in 2015 (fig. 15) (C. Neel, OWRB, written commun., 2016). Of the total that was diverted, 19,520 acre-ft was for irrigation (about 80 percent), and 4,810 acre-ft was for non-irrigated agriculture and industry (about 20 percent). Reported diversions from the Canadian River and tributaries in 2015 were about 71 percent of the total amount of water allocated for diversion.

Seven entities had permits to discharge treated wastewater into the Canadian River Basin in the CATJA during 2015 (fig. 8 and table 8) (ODEQ, 2018). The Towns of Hydro and Union City and the Cities of Minco and Weatherford, Okla., and one industrial user, Eastman Kodak Company, released a combined mean of 1,342 acre-ft/d (D. Pruitt, ODEQ, written commun., 2016). The combined discharges represented a total inflow to the basin of 489,800 acre-ft in 2015 (table 8).

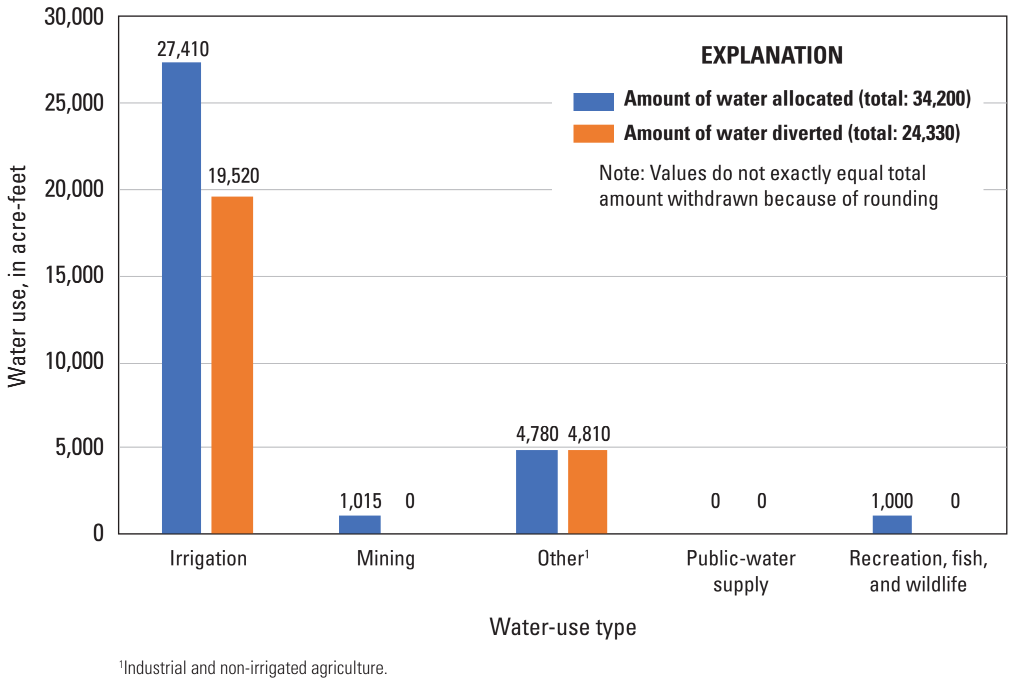


Figure 15. Amounts of surface water allocated and diverted for use from the Canadian River during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2016; C. Neel, Oklahoma Water Resources Board, written commun., 2016).

Water-Quality Characteristics

A limited amount of water-quality information for the Canadian River was available from the USGS NWIS database (USGS, 2018b) and from the OWRB BUMP (OWRB, 2018a). Along the 219 mi of the river in the CATJA, there is only one USGS streamgage, the Bridgeport gage, and two OWRB BUMP stations, Bridgeport BUMP and Taloga BUMP (discontinued in 2012) (OWRB, 2018a) (fig. 9). Upstream from the Oklahoma-Texas border, the nearest site on this river that provides streamflow and water-quality information is the USGS streamgage 07228000 Canadian River near Canadian, Tex. (fig. 12) (USGS, 2018e).

Stream samples were collected at the Bridgeport gage from 1977 to 1992 and include measurements of water-quality field properties and concentrations of the major ions, nitrogen, and trace elements (USGS, 2018b). This information is used to describe the general water quality of the Canadian River but is limited in areal scope and may not closely represent water quality of the river upstream from the Bridgeport gage.

In addition to the water-quality data collected by the USGS, the OWRB collects water-quality data at the two BUMP stations on the Canadian River. The Bridgeport BUMP station is adjacent to the Bridgeport gage, and since 1999, measurements of water-quality field properties, concentrations of major ions and nutrients, and bacteria counts have been collected by the OWRB at this station. Similar measurements were collected at the Taloga BUMP station from 1998 through 2012 (OWRB, 2018a).

Samples collected at the Bridgeport gage indicate that the Canadian River is moderately alkaline with a median pH of 8.1 (table 7). Of the 402 pH measurements, 11 exceeded the SMCL of 8.5 established for finished drinking water (EPA, 2018b). Samples show that the water has large concentrations of dissolved solids; the median concentration of 304 samples was 1,130 mg/L, and 95 percent of these samples exceeded the SMCL of 500 mg/L for finished drinking water. Water at this location also is extremely hard with a median calcium carbonate concentration of 595 mg/L.

Chloride concentrations in samples collected at the Bridgeport gage generally ranged from 36 to 280 mg/L for the 25th and 75th percentiles, and about 32 percent of samples analyzed for chloride exceeded the SMCL of 250 mg/L (table 7) (EPA, 2018b). Samples at this location also had large concentrations of sulfate; the median concentration of 297 samples was 440 mg/L, and 90 percent of these samples exceeded the SMCL of 250 mg/L for finished drinking water.

Concentrations of nitrate (as nitrogen) were very small in samples collected at the Bridgeport gage. The median concentration of 148 samples analyzed for nitrate (as nitrogen) was 0.51 mg/L, and 100 percent of sample concentrations were smaller than the MCL of 10 mg/L of nitrogen in finished drinking water (table 7) (EPA, 2018a).

Large differences in concentrations between filtered and unfiltered analyses of iron and manganese show that the bulks of these constituents are associated with sediment or other material that can be filtered out of the water. Concentrations of iron in all unfiltered samples exceeded the SMCL of 300 µg/L, whereas no filtered iron samples exceeded the SMCL (table 7) (EPA, 2018b). Similarly, for manganese 87 percent of unfiltered samples exceeded the SMCL of 50 µg/L, whereas only 8 percent of filtered samples exceeded the SMCL.

Several trace elements exceeded their respective MCLs in a small number of samples collected at the Bridgeport gage. Small concentrations of cadmium, lead, and arsenic were measured in 8.5 percent or fewer of the samples (filtered or unfiltered) (table 7). Except for cadmium, in unfiltered samples lead and arsenic had overall larger concentrations and a slightly larger number of analyses exceeding their respective MCLs for finished drinking water (EPA, 2018a).

The water type of the Canadian River at the Bridgeport gage is a mixed cation-sulfate type (fig. 11). Calcium and sulfate together account for about 50 percent of the major ions composing the water.

Washita River

The Washita River flows from Texas through Roger Mills, Custer, and Washita Counties for approximately 203 mi in the CATJA and then continues southeast to where it empties into Lake Texoma (figs. 2 and 12). The upstream basin begins in the Texas Panhandle and is relatively small compared to the basins of other rivers flowing through the CATJA. At the USGS streamgage 07316500 Washita River near Cheyenne, Okla. (hereinafter referred to as the “Cheyenne gage”) (fig. 9), the contributing drainage area is 763 mi^2. There are no regulating structures on the Washita River upstream from Foss Reservoir, which impounds the river in Custer County.

Diversions and Discharges

In the CATJA, there were 118 permits for diverting surface water from the Washita River and its tributaries during 2015 (fig. 8) (OWRB, 2016). These permits were for irrigation; mining; source water for public-water supply; and recreation, fish, and wildlife water use. There were no permits for public-water supply on the main stem of the Washita River within the CATJA; however, water from Foss Reservoir and two smaller reservoirs (Clinton Lake used by the City of Clinton and an unnamed reservoir used by the City of Cheyenne) is used as a source for public-water supply. Lake water is diverted from Foss Reservoir and treated for municipalities and power generation (additional information is provided in the “Foss Reservoir” section of this report).

During 2015, the total amount of surface water allocated by the OWRB for diversion in the CATJA was 30,730 acre-ft (fig. 16) (OWRB, 2016). The largest allocations were for irrigation at 7,140 acre-ft and public-water supply at 19,730 acre-ft. Forty permit holders reported diverting a combined total of 14,140 acre-ft of water from the Washita River and its tributaries in 2015 (fig. 16) (C. Neel, OWRB, written commun., 2016). Of the total that was diverted, 11,110 acre-ft (about 79 percent) was diverted for public-water supply, and 2,370 acre-ft (17 percent) was diverted for irrigation water use. Reported diversions from the Washita River and its tributaries in 2015 were about 46 percent of the total amount of water allocated for diversion..

Four entities had permits to discharge treated wastewater into the Washita River Basin in the CATJA during 2015 (fig. 8 and table 8) (ODEQ, 2018). Treated wastewater is discharged from two municipalities, an industrial user, and a water supplier downstream from Foss Reservoir. The Cities of Clinton and New Cordell, Okla., released a combined mean of 1,340 acre-ft/d, the Foss Reservoir Master Conservancy District released a mean of 1,225 acre-ft/d from their desalinization process, and Bar-S Foods Company discharged a mean of 260 acre-ft/d (D. Pruitt, ODEQ, written commun., 2016). Together these four entities released a mean of 2,825 acre-ft/d of treated wastewater, which equates to a total inflow of about 1,031,000 acre-ft of water into the Washita River Basin during 2015 (table 8).

Water-Quality Characteristics

Water-quality information is available for the Washita River from the USGS NWIS database (USGS, 2018b) and the OWRB BUMP (OWRB, 2018a). There are four USGS streamgages on the main stem of the Washita River and one streamgage at Foss Reservoir (fig. 9). Useful water-quality information is available from the USGS streamgages 07324200 Washita River near Hammon, Okla. (hereinafter

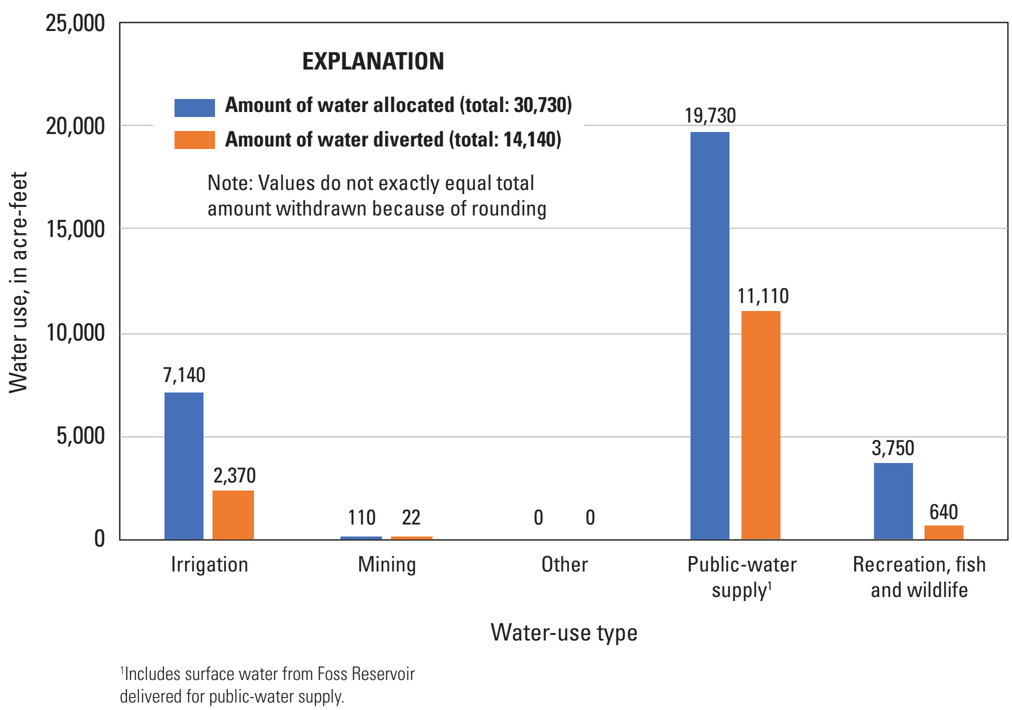


Figure 16. Amounts of surface water allocated and diverted for use from the Washita River during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2016; C. Neel, Oklahoma Water Resources Board, written commun., 2016)

referred to as the "Hammon gage"), and 07324400 Washita River near Foss, Okla. (hereinafter referred to as the "Foss gage") (USGS, 2018b). The Hammon gage is immediately upstream from where the Washita River empties into Foss Lake. Water-quality samples were collected at the Hammon gage between four and nine times annually from 1975 to 1987. During this period, water-quality field properties were measured, and samples were analyzed for major ions, nitrogen, and trace elements. Samples also were collected at the Foss gage from 1975 to 1987 and were analyzed for similar constituents (USGS, 2018b).

There are two OWRB BUMP stations on the main stem of the Washita River, the McClure BUMP station, which is adjacent to the Hammon gage, and the Cordell BUMP station, about 62 mi downstream from Foss Reservoir (fig. 9) (OWRB, 2018a). Water-quality field properties, concentrations of selected major ions and nutrients, and bacteria counts are monitored at these stations.

USGS water-quality samples collected at the Hammon gage show that the Washita River is slightly alkaline, with a median pH of 7.9 (table 7). Four of 181 pH measurements exceeded the SMCL of 8.5 for finished drinking water (EPA, 2018b). Water from the Washita River has very large concentrations of dissolved solids and sulfate, with median concentrations that exceed the SMCLs for finished drinking water, at 1,640 and 910 mg/L, respectively (EPA, 2018b). Dissolved solids concentrations in water samples collected at the OWRB BUMP stations and USGS streamgages show that the Washita River becomes more mineralized as it flows downstream in the CATJA. Median concentrations increase from 1,630 mg/L at the McClure BUMP station (upstream from Foss Reservoir) to 2,116 mg/L at the Cordell BUMP station, about 60 mi downstream from the Foss Reservoir dam (OWRB, 2018a). The Washita River gains water from tributaries and the inflow of groundwater downstream from Foss Reservoir (Kent and others, 1984). Water from the Washita River also is extremely hard. The median calcium carbonate concentration measured in 97 water samples collected at the Hammon gage was 1,000 mg/L (table 7).

Concentrations of nitrate (as nitrogen) were very small in samples collected at the Hammon gage. The median concentration of 50 samples analyzed for nitrate (as nitrogen) was 0.24 mg/L, and 100 percent of sample concentrations were smaller than the MCL of 10 mg/L of nitrogen in finished drinking water (table 7) (EPA, 2018a). Similarly, at the McClure BUMP station at the upstream extent of Foss Reservoir, the median concentration of nitrate (as nitrogen) was 1.26 mg/L (nine samples, December 2014 to November 2015) and at the downstream Cordell BUMP station was 0.16 mg/L (four samples, April to November 2015) (not shown in table 7) (OWRB, 2018a).

In one of the six samples collected at the Hammon gage, cadmium was measured at a concentration larger than the MCL of 5 µg/L allowable in finished drinking water (table 7) (EPA, 2018a). This detection of cadmium was the only one to exceed an MCL for a given trace element.

Concentrations of iron measured in samples from the Hammon gage exceeded the SMCL of 300 µg/L for finished drinking water in eight of nine unfiltered samples (table 7) (EPA, 2018b). All 15 filtered samples, however, had iron concentrations below the SMCL of 300 µg/L, indicating that much of the iron (and probably manganese) is associated with suspended sediment carried by the water.

The water type of the Washita River at the Hammon gage is a calcium and magnesium-sulfate type (fig. 11). Calcium, magnesium, and sulfate account for about 82 percent of the major ions composing the water. Water type downstream at the Foss gage also is a calcium and magnesium-sulfate type with similar percentages of major ions (not shown in fig. 11) (USGS, 2018b).

North Fork Red River

The North Fork Red River flows through the southwestern portion of the CATJA from Texas into Beckham County for about 65 mi and then continues outside the CATJA south to Lake Altus in Greer County and then to the Red River (figs. 2 and 12). Upstream from the Sweetwater gage, the river has a comparatively small drainage basin of 437 mi^2, primarily in Texas (figs. 9 and 12). Streamflow is not regulated by upstream reservoir dams but is affected by numerous floodwater-retarding structures (not shown in fig. 9) and irrigation (Smith and Esralew, 2010, fig. 5). Elk Creek, a southeastward-flowing tributary of the North Fork Red River, drains northeastern Beckham County and northwestern Washita County and flows into the river downstream in Kiowa County (fig. 9).

Diversions and Discharges

In the CATJA, there were 18 permits for diverting surface water from the North Fork Red River and tributaries during 2015 (figs. 8 and 17) (OWRB, 2016). These permits were for irrigation; public-water supply; and recreation, fish, and wildlife water use. There were no permits for mining or other uses on the river.

During 2015, the total amount of surface water allocated by the OWRB for diversion in the CATJA was 4,005 acre-ft (fig. 17) (OWRB, 2016). The largest allocations were for irrigation at 1,325 acre-ft and public-water supply at 1,730 acre-ft. Eight permit holders reported diverting a combined total of 710 acre-ft of water from the river and tributaries in 2015 (fig. 17) (C. Neel, OWRB, written commun., 2016). Of the total that was diverted, 560 acre-ft was for irrigation (about 79 percent), and 150 acre-ft (about 21 percent) was for recreation, fish, and wildlife water use. Reported diversions from the North Fork Red River and its tributaries in 2015 were only about 18 percent of the total amount of water allocated for diversion.

In the CATJA, there were two municipalities and an industrial entity with permits to discharge treated wastewater into the North Fork Red River Basin during

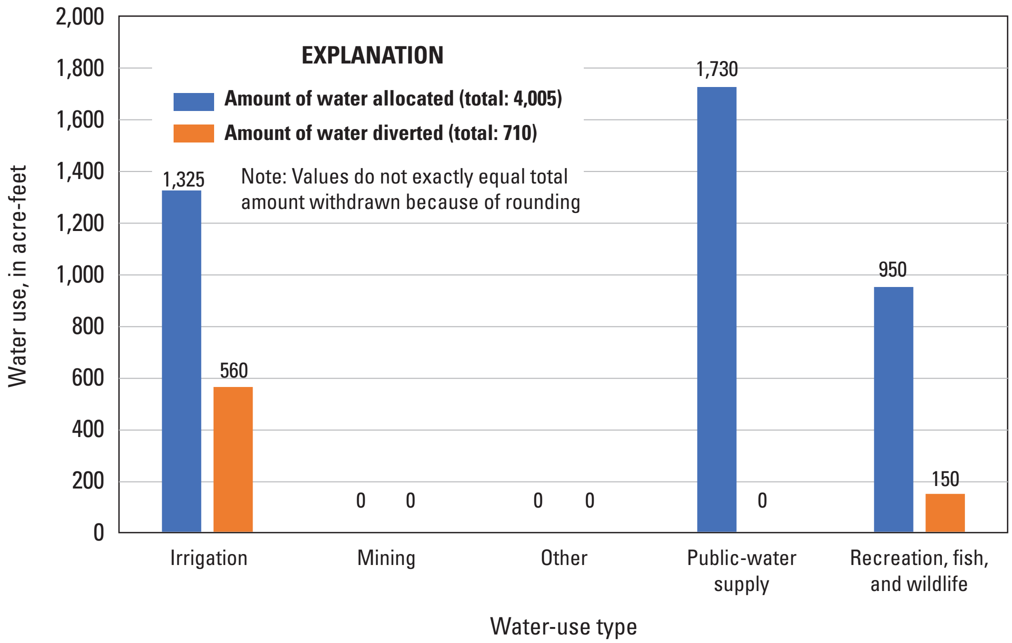


Figure 17. Amounts of surface water allocated and diverted for use from the North Fork Red River during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2016; C. Neel, Oklahoma Water Resources Board, written commun., 2016).

2015 (fig. 8 and table 8). The City of Elk City released a mean of 375 acre-ft/d and Love's Travel Stops & Country Stores a mean of 0.045 acre-ft/d into Elk Creek (D. Pruitt, ODEQ, written commun., 2016). The City of Erick released a mean of 13.2 acre-ft/d into a northward-flowing tributary of the North Fork Red River. The releases of treated water represent a total inflow of about 141,000 acre-ft into the North Fork Red River Basin during 2015.

Water-Quality Characteristics

Water-quality information is available for the North Fork Red River from the USGS NWIS database (USGS, 2018b) and the OWRB BUMP (OWRB, 2018a). There are three USGS streamgages in the river basin in Beckham County: the Sweetwater gage; the USGS streamgage 07301481 North Fork Red River near Sayre, Okla.; and the Carter gage (fig. 9) (USGS, 2018b). Streamflow is measured at all three streamgages, but water-quality samples have been collected at only the Carter gage. Water-quality samples were collected at the Carter gage from 1975 to 2000 and analyzed for concentrations of selected major ions, nitrogen, and trace elements; water-quality field properties also were measured (USGS, 2018b). These samples are summarized in table 7.

There is one OWRB BUMP station on the main stem of the North Fork Red River, the Carter BUMP station, which is adjacent to the Carter gage (fig. 9). Water-quality field properties and concentrations of selected major ions, nitrogen, and phosphorus have been measured and bacteria have been counted at the Carter BUMP station since 1998 (OWRB, 2018a). The water-quality data collected from Carter BUMP station are not summarized in this report.

USGS samples from the Carter gage show that the North Fork Red River is slightly alkaline with a median pH of 7.9 (table 7). Of 123 pH measurements, 4 exceeded the SMCL of 8.5 for finished drinking water (EPA, 2018b). Water from the North Fork Red River has very large concentrations of dissolved solids; concentrations generally ranged from 1,620 mg/L to 2,150 mg/L for the 25th and 75th percentiles and exceeded the SMCL of 500 mg/L in 100 percent of samples analyzed. Samples show that the river also is extremely hard with a median hardness as calcium carbonate concentration of 925 mg/L. Very large concentrations of chloride and sulfate were measured in the samples; median concentrations of chloride and sulfate were 375 and 815 mg/L, respectively. The SMCL of 250 mg/L for finished drinking water was exceeded in 74 of 90 samples for chloride and in 88 of 90 samples for sulfate.

Nitrogen concentrations were very small in samples collected at the Carter gage. In 34 samples the median nitrate (as nitrogen) concentration was less than 1 mg/L (table 7). Unfiltered concentrations of iron and manganese were larger than the filtered concentrations of these constituents in samples collected at the Carter gage, exceeding the SMCL for finished drinking water of 300 µg/L for iron and 50 µg/L manganese in about half of the unfiltered samples that were analyzed.

The water type of the North Fork Red River at the Carter gage is a calcium and sodium-chloride and sulfate type (fig. 11). Sulfate is the dominant anion and accounts for about 29 percent of the major ions composing the water.

Reservoirs

There are 11 reservoirs in the CATJA that are monitored by the OWRB at BUMP stations (OWRB, 2018b) (fig. 9 and table 9). Two reservoirs, Canton Lake and Foss Reservoir, have a surface area of 7,900 and 8,800 acres, respectively, and are the only reservoirs discussed in this report. The other nine reservoirs are smaller, having surface areas of less than 350 acres. Ten of the reservoirs in the CATJA are used for either flood control or recreation, and six also are used as a source of water for public-water supply when needed.

Foss Reservoir

Foss Reservoir impounds the Washita River in Custer County and was constructed from 1958 to 1961 by the Bureau of Reclamation for flood control, fish and wildlife conservation, recreation, and water supply (figs. 2 and 9) (Bureau of Reclamation, 2018). Foss Reservoir has a surface area of 8,800 acres and a storage capacity of 256,220 acre-ft (table 9) (OWRB, 2018b). The northern half of Foss Reservoir is surrounded by the Washita National Wildlife Refuge, an area of 8,075 acres that was created as a winter-feeding area for bird migration (fig. 18) (U.S. Fish and Wildlife Service, 2012). The southern half of the lake is surrounded by Foss State Park, an area of 1,749 acres used for camping, hiking, and other types of recreation (Bureau of Reclamation, 2018).

Water Use

The Foss Reservoir Master Conservancy District treats water from Foss Reservoir to provide finished drinking water to the Town of Bessie and the Cities of Clinton and New Cordell, Okla. (fig. 8) (S. Dewess, Foss Reservoir Master Conservancy District, written commun., 2016). Water also is provided to the City of Hobart in Kiowa County, south of the CATJA (not shown). Water from Foss Reservoir also is supplied to the Western Farmers Electric Cooperative for power generation. The OWRB reported that the amount of water stored in Foss Reservoir and available for use as a public-water supply during 2012 was 165,480 acre-ft (OWRB, 2012a). The conservancy district was allocated 18,000 acre-ft of water during 2012 for distribution (OWRB, 2012a) and in 2015 distributed 1,880 acre-ft, which is slightly greater than 10 percent of the allocated amount (USGS, 2018a). The amounts of treated water distributed for public-water supply and power generation from Foss Reservoir increased about 26 percent from 2000 (1,490 acre-ft) to 2015 (1,880 acre-ft) (USGS, 2018a).

Water-Quality Characteristics

Water-quality information for Foss Reservoir is available from the USGS NWIS database (USGS, 2018b) and the OWRB BUMP (OWRB, 2018b). Reservoir samples collected by the OWRB at four sampling sites (fig. 18) were used to evaluate trends in trophic status and nutrient concentrations. Reservoir samples collected by the USGS at three sampling sites (fig. 18) were used to assess reservoir water quality and water type.

Foss Reservoir is phosphorus limited and was classified as eutrophic to mesotrophic during four sampling periods by the OWRB from September 2004 to August 2016 (fig. 18 and table 10). Water clarity was rated as fair to good during this period, with turbidity ranging from 9 to 25 nephelometric turbidity units. During these sampling periods, total nitrogen concentrations ranged from 0.46 to 1.51 mg/L at the lake surface, much smaller than the MCL of 10 mg/L in finished drinking water (EPA, 2018a). Phosphorus concentrations ranged from 0.005 to 0.085 mg/L.

Samples collected by the USGS from 1980 to 1987 showed that Foss Reservoir is moderately alkaline with a median pH of 8.2 (table 7). Of 100 pH measurements, 17 exceeded the SMCL of 8.5 for finished drinking water (EPA, 2018b). The median concentrations of dissolved solids and sulfate were both very large (1,590 and 930 mg/L, respectively), much larger than the SMCLs of 500 mg/L for dissolved solids and 250 mg/L for sulfate (EPA, 2018b). The water in Foss Reservoir is extremely hard; the median hardness as calcium carbonate concentration in 24 samples collected by the USGS was 920 mg/L.

The water type of Foss Reservoir is a calcium and magnesium-sulfate type (fig. 11). Sulfate accounts for about 42 percent of the major ions, and calcium and magnesium together account for about 40 percent of the major ions composing the water.

Canton Lake

Canton Lake is on the North Canadian River in Blaine and Dewey Counties in the northern part in the CATJA (figs. 2 and 19). The lake was constructed in 1948 and has a surface area of 7,910 acres and a storage capacity of 111,310 acre-ft (table 9) (Stahl and Harper, 2008).

Water Use

Canton Lake is owned and operated by the U.S. Army Corp of Engineers and is used for flood control, public-water supply, and recreation (U.S. Army Corp of Engineers, 2017). Canton Lake is known for supporting a wide variety of fish such as *Sander vitreus* (walleye) and saugeye, a popular sport fish hybridized by crossing walleye and *Sander canadensis* (sauger) (Stahl and Harper, 2008). There were no permitted diversions from Canton Lake for water use during 2015 (fig. 8). However, the City of Oklahoma City, Okla., owns the water rights to Canton Lake and diverts released water from this reservoir through the North Canadian River (fig. 19) into the city's water-supply reservoirs when needed (Stahl and Harper, 2008). The most recent water releases from Canton Lake into the North Canadian River for Oklahoma City were in 2011 and 2013 (Barron, 2013).

Water-Quality Characteristics

Water-quality information for Canton Lake is available from the USGS NWIS database (USGS, 2018b) and the OWRB BUMP (OWRB, 2018b). Reservoir samples collected by the OWRB at three sampling sites (fig. 19) were used to evaluate trends in trophic status and nutrient concentrations. Reservoir samples collected by the USGS at four sampling sites were used to assess reservoir water quality and water type. Forty of 46 reservoir samples collected by the USGS were collected at one site (360544098354701, fig. 19), and between 1 and 3 samples were collected at each of the other three sites on Canton Lake.

Table 9. Reservoirs monitored by the Oklahoma Water Resources Board Beneficial Use Monitoring Program (BUMP), Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018b).

[na, not available]

Reservoirs	Storage capacity (acre-feet)	Surface area (acres)	Primary uses
American Horse Lake	2,200	100	Recreation
Canton Lake	111,310	7,910	Flood control, public-water supply (City of Canton), irrigation
Clinton Lake	3,980	335	Recreation, public-water supply (City of Clinton)
Crowder Lake	2,094	158	Recreation, public-water supply
Foss Reservoir	256,220	8,800	Recreation, public-water supply (Foss Reservoir Master Conservancy District)
Lake Elk City	2,583	240	Recreation, public-water supply
Lake El Reno	709	170	Flood control, recreation
Lake Vanderwork	1,578	135	Recreation
Lake Lloyd Vincent	2,579	160	Recreation
Lake Hobart (also called Rocky Lake)	4,210	347	Recreation, public-water supply (City of Hobart)
Lake Rolla	na	na	na

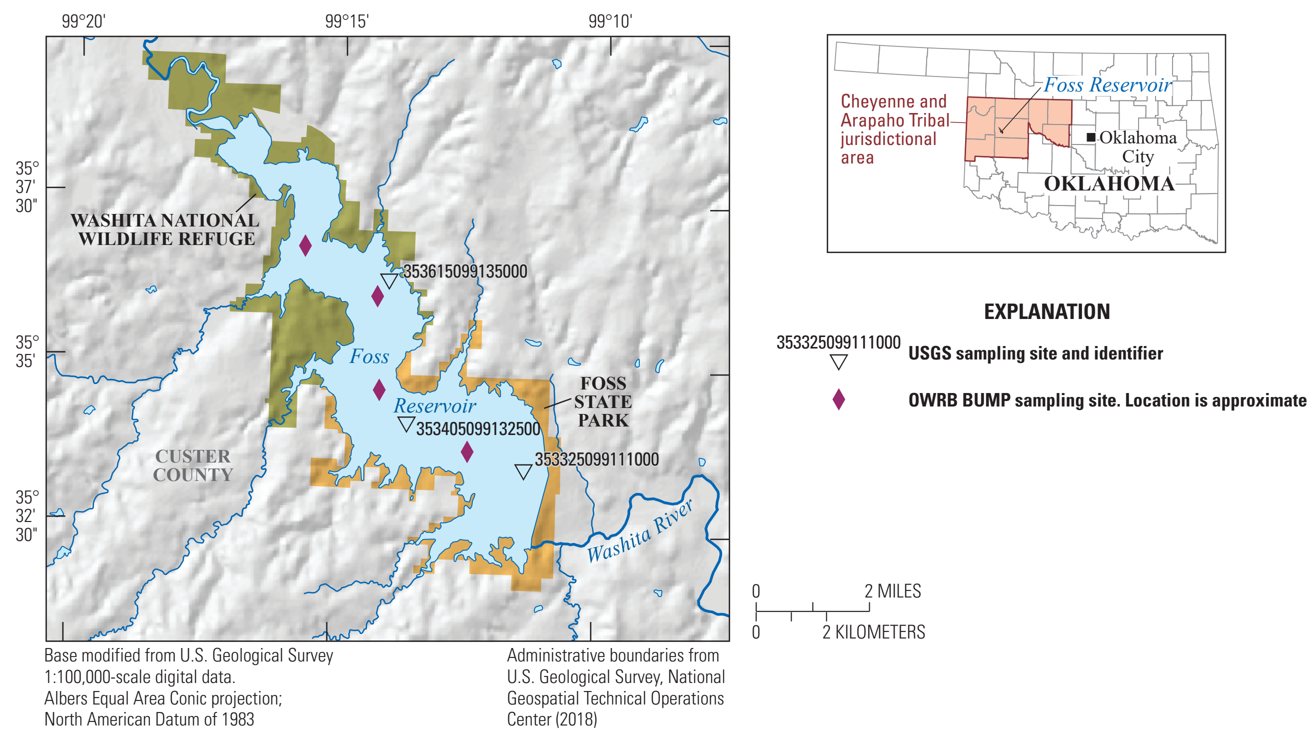


Figure 18. Locations of U.S. Geological Survey (USGS) and Oklahoma Water Resources Board (OWRB) Beneficial Use Monitoring Program (BUMP) reservoir sampling sites at Foss Reservoir on the Washita River, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

Table 10. Foss Reservoir and Canton Lake trophic status conditions and nitrogen and phosphorus concentrations measured by the Oklahoma Water Resources Board Beneficial Use Monitoring Program (BUMP), Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018b).

[NTU, nephelometric turbidity unit; mg/L, milligram per liter]

Sample period	Trophic state index	Trophic class	Nitrogen to phosphorus ratio	Total nitrogen at surface	Total phosphorus at surface	Turbidity (NTU)	Water clarity
Foss Reservoir							
September 2004–June 2005	52	Eutrophic	30:1	0.49 to 1.24 mg/L	0.014 to 0.039 mg/L	9	Average
October 2010–July 2011	49	Mesotrophic	26:1	0.46 to 0.72 mg/L	0.011 to 0.038 mg/L	11	Good
October 2012–August 2013	54	Eutrophic	47:1	0.67 to 1.51 mg/L	0.005 to 0.049 mg/L	25	Fair
October 2015–August 2016	55	Eutrophic	21:1	0.90 to 1.15 mg/L	0.019 to 0.085 mg/L	11	Good
Canton Lake							
October 2008–July 2009	60	Eutrophic	19:1	0.7 to 1.13 mg/L	0.022 to 0.065 mg/L	17	Average
November 2011–August 2012	64	Hypereutrophic	18:1	0.94 to 1.65 mg/L	0.048 to 0.091 mg/L	35	Poor
October 2013–July 2014	69	Hypereutrophic	17:1	1.04 to 2.56 mg/L	0.047 to 0.177 mg/L	39	Poor
November 2016–August 2017	56	Eutrophic	22:1	0.83 to 1.06 mg/L	0.03 to 0.061 mg/L	12	Poor

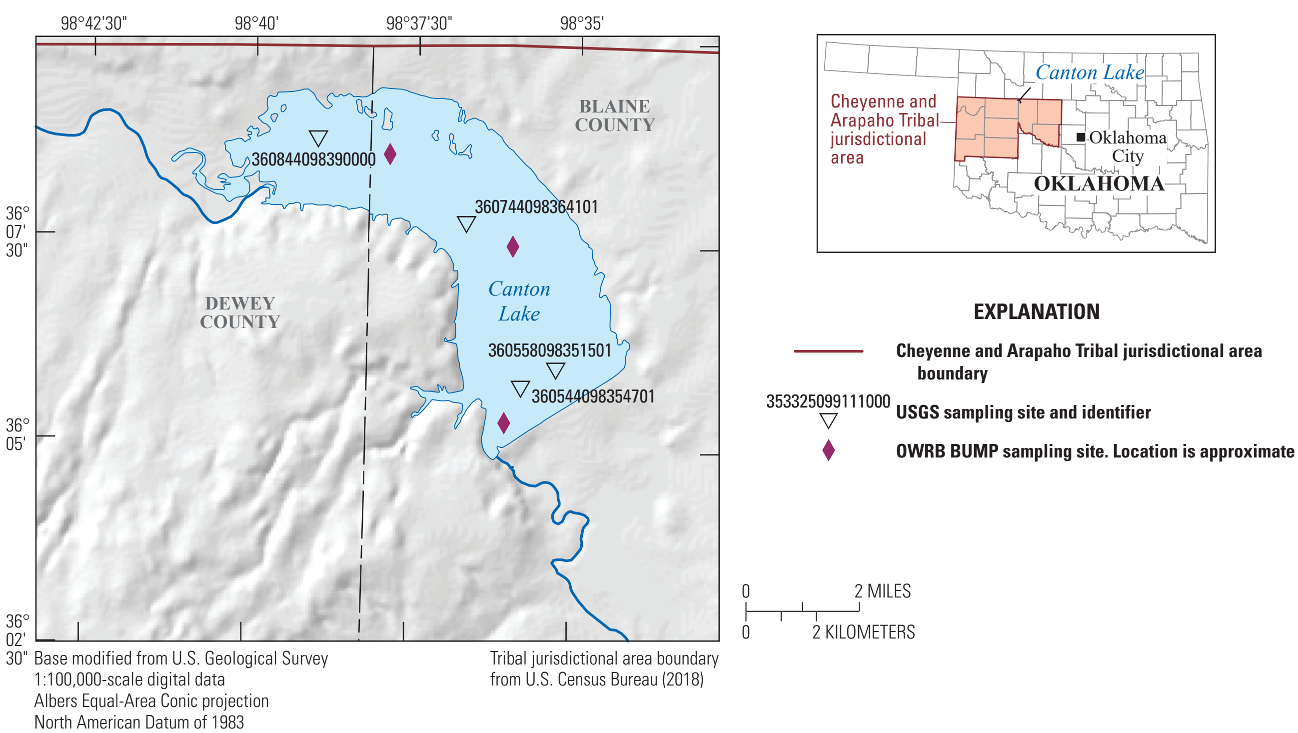


Figure 19. Locations of U.S. Geological Survey (USGS) and Oklahoma Water Resources Board (OWRB) Beneficial Use Monitoring Program (BUMP) reservoir sampling sites at Canton Lake on the North Canadian River, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

Canton Lake is phosphorus limited and was classified as eutrophic to hypereutrophic during four sampling periods by the OWRB from October 2008 to August 2017 (fig. 19 and table 10) (OWRB, 2018b). Water clarity was rated as poor to average during this period, with turbidity ranging from 12 to 39 nephelometric turbidity units. During these sampling periods, total nitrogen concentrations ranged from 0.7 to 2.56 mg/L at the reservoir surface, much smaller than the MCL of 10 mg/L for finished drinking water (EPA, 2018a). Phosphorus concentrations ranged from 0.022 to 0.177 mg/L.

Samples collected by the USGS from 1980 to 1991 (fig. 19) showed that Canton Lake is moderately alkaline, with a median pH of 8.4 (table 7). Of 45 pH measurements, 11 exceeded the SMCL of 8.5 for finished drinking water (EPA, 2018b). Canton Lake has median concentrations of dissolved solids and sulfate of 1,020 and 290 mg/L, respectively, both exceeding their respective SMCLs of 500 and 250 mg/L (EPA, 2018b). The water in Canton Lake is extremely hard; the median hardness as calcium carbonate concentration in 46 samples was 430 mg/L.

The water type of Canton Lake is a calcium and sodium-chloride and sulfate type (fig. 11). These four ions account for about 80 percent of the major ions composing the water.

Daily, Monthly, and Annual Streamflow Statistics

Statistics for 12 USGS streamgages in the CATJA are provided that describe daily, monthly, and annual streamflow characteristics, in addition to the magnitudes and frequencies of floods, base-flow characteristics, and long-term streamflow trends (fig. 9 and table 2). Tables and graphs describing streamflow characteristics for each streamgage in this report are available in appendix 1.

Raster hydrographs of daily streamflow at each streamgage were generated by using the raster hydrograph toolkit available on the USGS WaterWatch website (USGS, 2019a) to show streamflow as a color ranging from red (low flow) to blue (high flow), which allows for visual identification of flood and drought periods (fig. 20 and app. 1). The raster

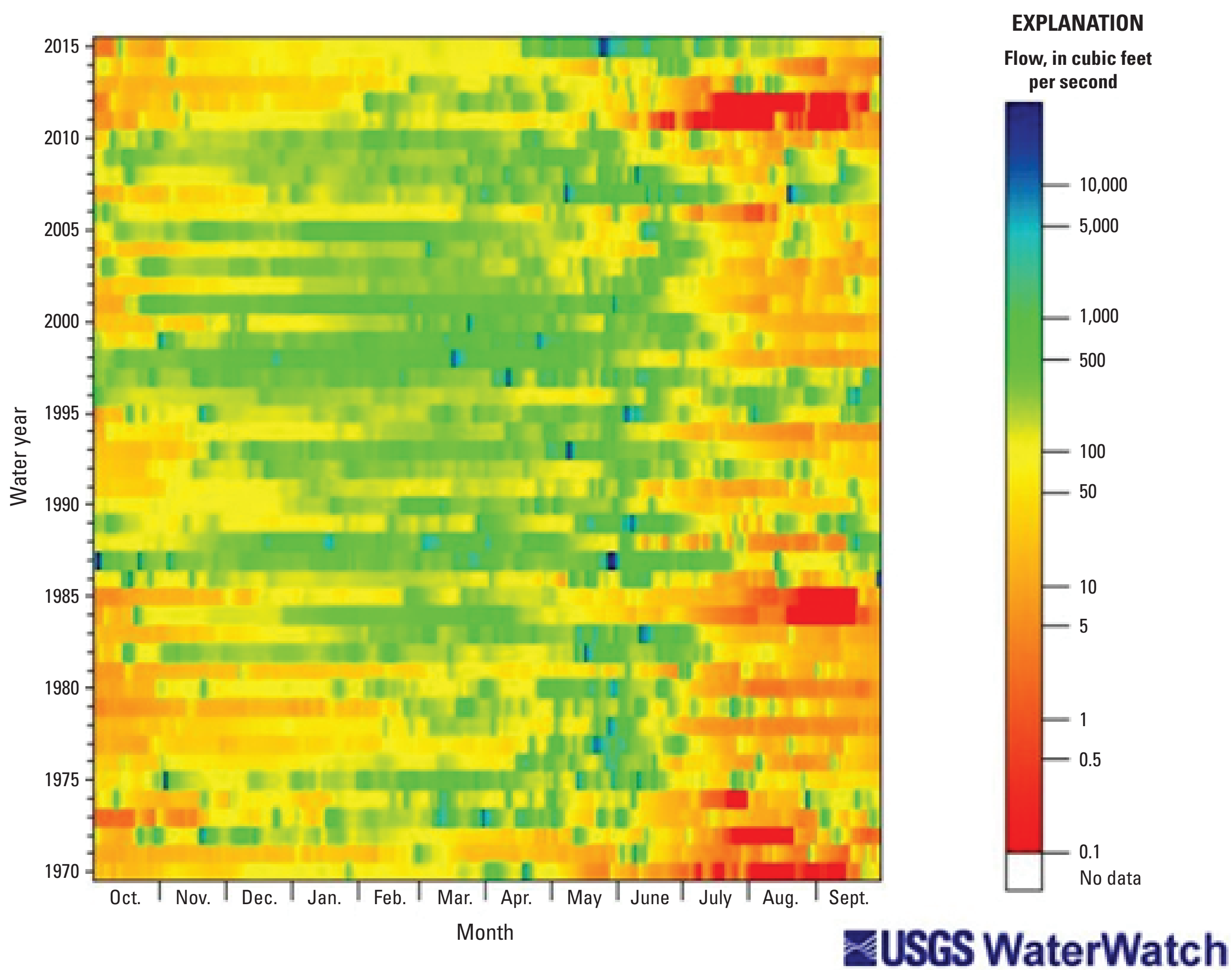


Figure 20. Daily streamflows measured at U.S. Geological Survey streamgage 07228500 Canadian River at Bridgeport, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b). The hydrograph shows monthly and annual variability of daily streamflows for 1970–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods.

hydrograph of daily streamflow at the Bridgeport gage is shown in figure 20 as an example from app. 1 (fig. 1.6). The hydrograph shows the drought during 2011–14 as areas of red, when streamflows were generally low, and shows the wet spring of 2015 as areas of green and blue, when streamflows were high.

Graphs of monthly maximum, mean, and minimum streamflows at USGS streamgages in the CATJA indicated that monthly maximum streamflows generally peak in either May or June and that monthly minimum streamflows are lowest in August and September (app. 1). An example is provided for the Sweetwater gage (fig. 21 and fig. 1.32 in app. 1).

Graphs showing monthly mean streamflow and annual mean streamflow by water year at each streamgage also were created to show general streamflow patterns (fig. 22*A* and 22*B* and app. 1). The LOESS curves in the streamflow graphs are used to help show the general patterns in streamflow over the periods of record. For example, in figure 22*A* and 22*B* (also fig. 1.23 in app. 1), graphs of the monthly mean streamflow and annual mean streamflow, respectively, at the El Reno gage show streamflow generally decreasing from the start of the period of record in 1948 through the mid-1960s. From the mid-1960s through the 1970s, streamflow at the El Reno gage was relatively unchanged. After the 1970s, streamflow started to gradually increase, and there were few months when the streamflow was less than 10 cubic feet per second (ft^3/s) in the 1980s and 1990s. The LOESS curves show streamflow decreasing after about 2000; the drought conditions in 2013 and 2014 at the end of the period of record strongly influence the downward pattern in this part of the LOESS curve. Graphs for all 12 USGS streamgages are provided in appendix 1.

The LOESS curve in figure 22*B* shows the general streamflow pattern over the period of record from 1948 to 2015. Graphs showing the percent of groundwater base flow that contributes to the annual mean streamflow for each water year with a LOESS curve also are available for each streamgage in appendix 1. An example of this graph, as shown in figure 23 (also fig. 1.24 in app. 1) from the El Reno gage, indicates that the percent of groundwater base flow that has contributed to the annual mean streamflow has increased from 1948 to 2015. Graphs showing the percent of base flow in the annual mean streamflow provide an indication of the contributions from groundwater and surface runoff to the total annual mean streamflow.

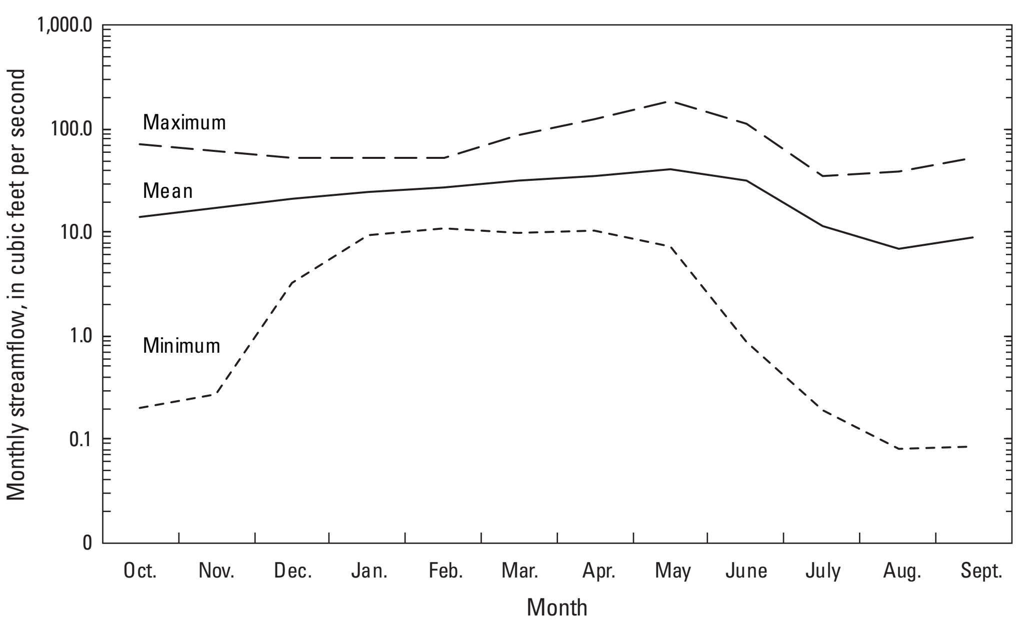


Figure 21. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07301420 Sweetwater Creek near Sweetwater, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b). Graph shows that monthly maximum streamflow peaked in either May or June and that minimum streamflow was lowest in August and September.

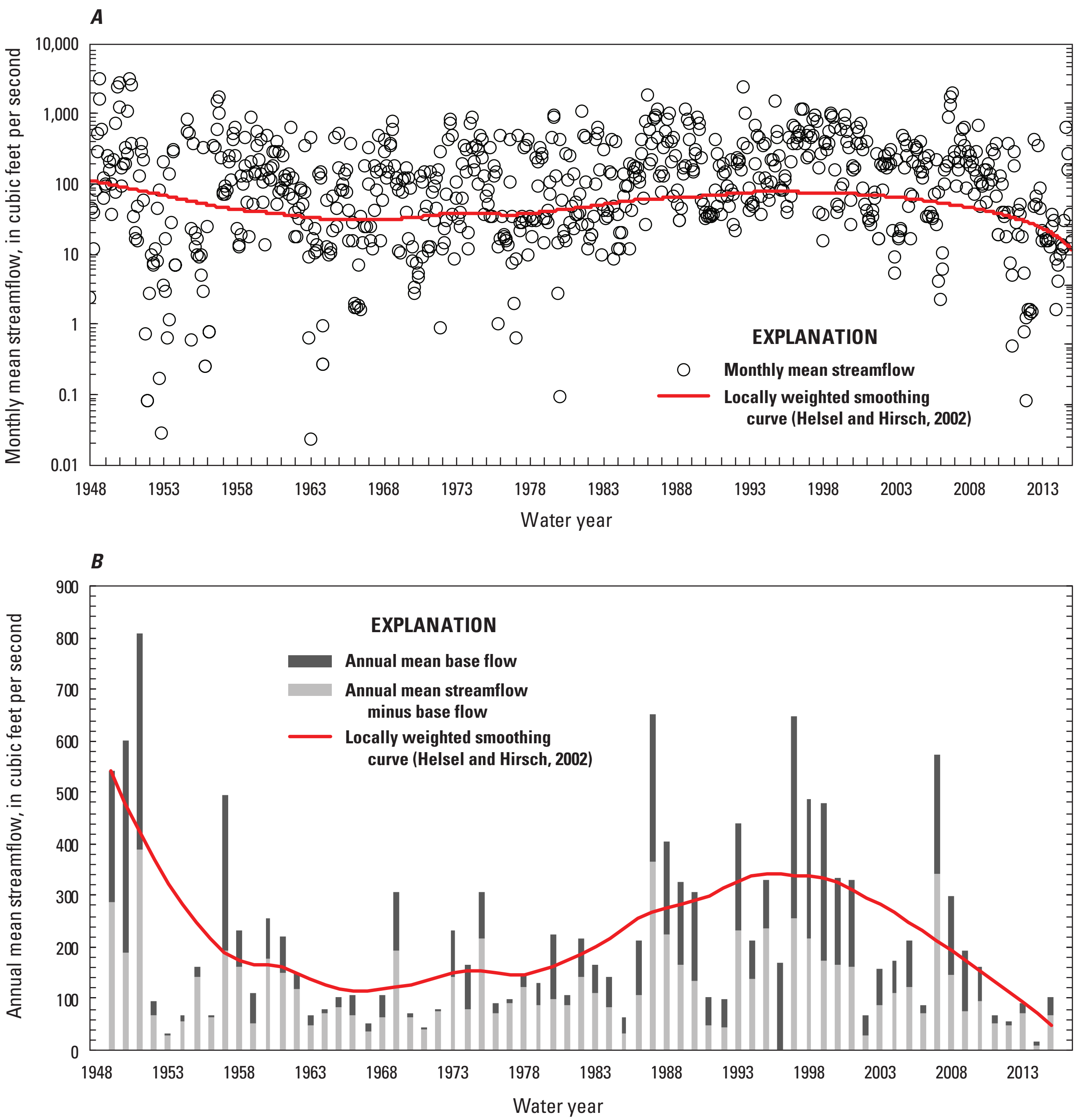


Figure 22. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07239500 North Canadian River near El Reno, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1949 to 2015.

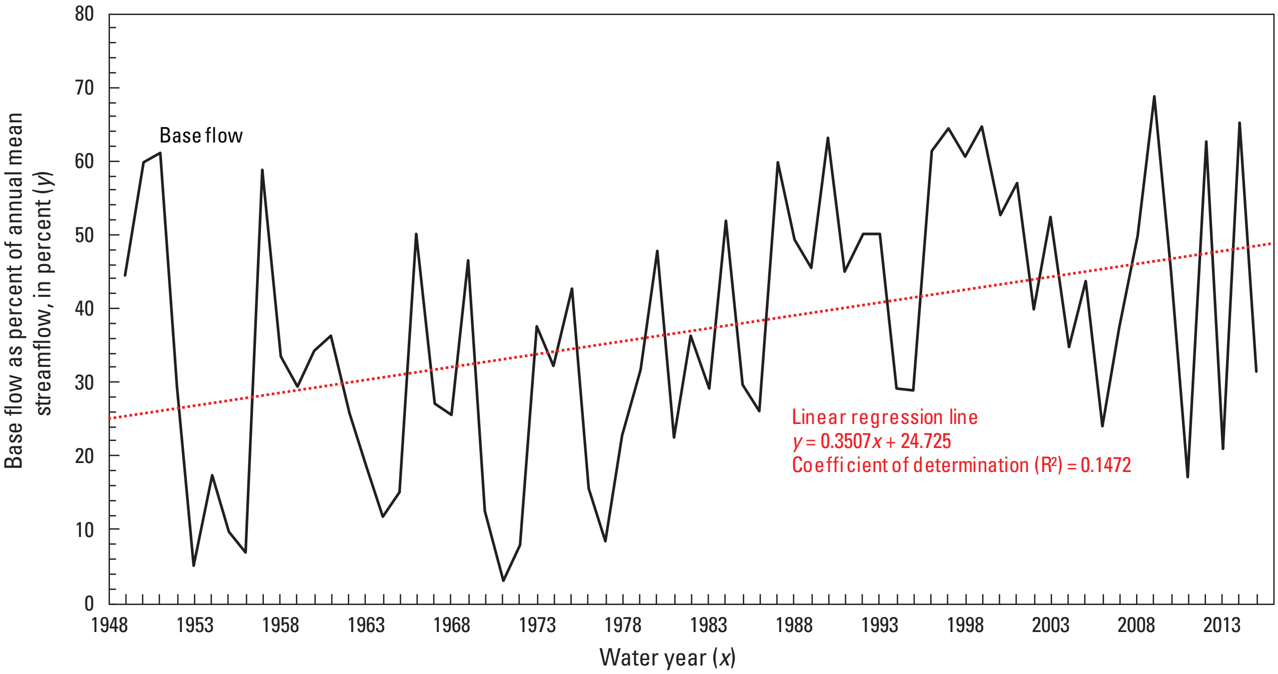


Figure 23. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1949–2015) at U.S. Geological Survey streamgage 07239500 North Canadian River near El Reno, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).

Overall trends in annual mean streamflow were assessed by using Mann-Kendall trend tests (table 11). Three streamgages, the Calumet gage, Sweetwater gage, and Carter gage, showed statistically significant (p-value less than 0.05, and tau less than 0) decreases in annual mean streamflow, and the Foss gage showed a statistically significant increase in annual mean streamflow over the analyzed periods of record.

Flow-duration data are provided for each of the streamgages in the CATJA for which daily streamflows were available (table 12). Flow-duration data represent the streamflow amounts that were equaled or exceeded for an indicated percentage of time based on the period of record. For example, at the Hammon gage, streamflow was equal to or greater than 689 ft^3/s for 1 percent of the time and was equal to or greater than 22.2 ft^3/s for 50 percent of the time.

Magnitude and Probability of Floods

Annual peak-flow data (highest streamflow measured during a water year) are used to develop data that describe the frequency of peak flows, which can be used to evaluate the magnitude of flood events. The relative magnitude of flood events at a given streamgage can be described by “flood stage” and “major flood stage” at that streamgage. Flood stage is the point at which overflow of the natural banks of a stream begins to cause damage in the local area from inundation, whereas major flood stage is when extensive flooding and substantial to catastrophic damage occurs (National Weather Service, 2019b). Gage heights and streamflow magnitudes for flood stage and major flood stage for USGS streamgages in the CATJA are provided in table 13.

The magnitudes and annual exceedance probability (AEP) of streamflow exceeding annual peak flows at each streamgage are listed in table 14. The AEP is a value from 0 to 1 that represents the probability of a flood event of a given recurrence interval in any one year. Wall and others (2014, p. 2) explained the concept of the AEP as follows:

> Frequency analysis of annual flood-peak data recorded at streamgages provides a means of estimating the probability of occurrence of a given discharge. Flood frequency is commonly expressed in terms of a recurrence interval or the probability of being exceeded (one is the reciprocal of the other). The 100-year flood, for example, has an annual exceedance probability (AEP) of 0.01, equating to a 1-percent chance of being equaled or exceeded in any given year.

Table 11. Annual mean streamflow statistics and trends in streamflow over the periods of record at 12 U.S. Geological Survey streamgages, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).

[USGS, U.S.Geological Survey; ft^3/s, cubic foot per second; tau, Mann-Kendall correlation coefficient; p-value, probability value; Okla., Oklahoma]

USGS station number	USGS streamgage name	Short name	Maximum (ft^3/s)	Minimum (ft^3/s)	Mean (ft^3/s)	Median (ft^3/s)	tau	p-value	Trend in annual mean streamflow[a]
07159100	Cimarron River near Dover, Okla.	Dover gage	2,804	119	804	703	-0.173	0.109	no trend
07228500	Canadian River at Bridgeport, Okla.	Bridgeport gage	1,018	70.2	301	261	0.026	0.806	no trend
07239300	North Canadian River below Weavers Creek near Watonga, Okla.	Watonga gage	476	13.5	169	136	-0.242	0.054	no trend
07239450	North Canadian River near Calumet, Okla.[b]	Calumet gage	635	14.9	220	166	-0.345	0.012	downward
07239500	North Canadian River near El Reno, Okla.	El Reno gage	807	18.7	220	162	0.035	0.681	no trend
07239700	North Canadian River near Yukon, Okla.	Yukon gage	771	57.8	246	204	-0.25	0.192	no trend
07301420	Sweetwater Creek near Sweetwater, Okla.[b]	Sweetwater gage	53	6.07	22.5	22.9	-0.271	0.041	downward
07301500	North Fork Red River near Carter, Okla.[b]	Carter gage	356	6.61	130	116	-0.377	0.004	downward
07316500	Washita River near Cheyenne, Okla.	Cheyenne gage	64	0.93	21.6	15.3	0.177	0.058	no trend
07324200	Washita River near Hammon, Okla.	Hammon gage	262	0.43	60.3	38.2	0.141	0.182	no trend
07324400	Washita River near Foss, Okla.[c]	Foss gage	373	3.87	54.3	20.9	0.25	0.009	upward
07325000	Washita River near Clinton, Okla.	Clinton gage	696	6.7	115	71	0.144	0.126	no trend

[a]Trends were statistically significant if the p-value was less than or equal to 0.05.

[b]Shows statistically significant decrease in annual mean streamflow.

[c]Shows statistically significant increase in annual mean streamflow.

Table 12. Flow-duration table of daily mean streamflow at 12 U.S. Geological Survey streamgages, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).

[USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; %, percent; Okla., Oklahoma. Shading shows that at the Hammon gage the streamflow was equal to or greater than 689 ft^3/s for 1 percent of the time and was equal to or greater than 22.2 ft^3/s for 50 percent of the time]

USGS station number	USGS streamgage name	Short name	Streamflow, in ft^3/s, which was equaled or exceeded for indicated percent of time							
			1%	2%	5%	10%	15%	20%	30%	40%
07159100	Cimarron River near Dover, Okla.	Dover gage	9,950	6,400	2,950	1,570	1,050	768	494	343
07228500	Canadian River at Bridgeport, Okla.	Bridgeport gage	3,220	1,790	846	528	400	330	241	179
07239300	North Canadian River below Weavers Creek near Watonga, Okla.	Watonga gage	1,000	928	785	570	403	282	144	64.0
07239450	North Canadian River near Calumet, Okla.	Calumet gage	1,530	1,150	903	671	482	341	181	103
07239500	North Canadian River near El Reno, Okla.	El Reno gage	2,500	1,550	936	640	423	280	150	90.0
07239700	North Canadian River near Yukon, Okla.	Yukon gage	2,670	1,680	877	592	423	317	190	112
07301420	Sweetwater Creek near Sweetwater, Okla.	Sweetwater gage	134	97.0	61.0	44.0	35.0	31.0	25.0	21.0
07301500	North Fork Red River near Carter, Okla.	Carter gage	1,180	713	370	243	191	158	115	87.0
07316500	Washita River near Cheyenne, Okla.	Cheyenne gage	205	123	70.1	47.3	38.0	30.0	20.6	15.0
07324200	Washita River near Hammon, Okla.	Hammon gage	689	437	232	129	93.0	73.0	50.0	33.3
07324400	Washita River near Foss, Okla.	Foss gage	718	583	352	181	50.0	19.0	13.0	9.60
07325000	Washita River near Clinton, Okla.	Clinton gage	1,150	899	551	324	189	108	59.0	40.2

USGS station number	USGS streamgage name	Short name	Streamflow, in ft^3/s, which was equaled or exceeded for indicated percent of time							
			50%	60%	70%	80%	90%	95%	98%	99%
07159100	Cimarron River near Dover, Okla.	Dover gage	256	190	135	89	50.6	33.0	18.0	11.5
07228500	Canadian River at Bridgeport, Okla.	Bridgeport gage	126	82.3	50.0	26.0	13.0	6.65	2.00	0.00
07239300	North Canadian River below Weavers Creek near Watonga, Okla.	Watonga gage	42.0	29.7	21.1	15.5	8.29	4.56	1.13	0.49
07239450	North Canadian River near Calumet, Okla.	Calumet gage	68.0	45.0	31.2	22.1	10.0	4.40	0.30	0.16
07239500	North Canadian River near El Reno, Okla.	El Reno gage	55.0	35.0	22.0	80.0	3.2	0.07	0.00	0.00
07239700	North Canadian River near Yukon, Okla.	Yukon gage	73.3	50	38.3	26.2	16.0	7.32	4.18	2.78
07301420	Sweetwater Creek near Sweetwater, Okla.	Sweetwater gage	17.0	12.9	8.96	4.50	1.10	0.38	0.16	0.07
07301500	North Fork Red River near Carter, Okla.	Carter gage	64.0	43.4	22.8	7.60	0.00	0.00	0.00	0.00
07316500	Washita River near Cheyenne, Okla.	Cheyenne gage	8.80	4.60	2.00	0.00	0.00	0.00	0.00	0.00
07324200	Washita River near Hammon, Okla.	Hammon gage	22.2	13.0	6.40	0.81	0.00	0.00	0.00	0.00
07324400	Washita River near Foss, Okla.	Foss gage	7.60	6.20	5.10	4.10	2.70	1.30	0.44	0.28
07325000	Washita River near Clinton, Okla.	Clinton gage	31.0	24.0	18.0	12.3	7.10	4.40	2.69	1.70

Table 13. Gage height and streamflow magnitude for flood stage and major flood stage at 12 U.S. Geological Survey streamgages, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).

[USGS, U.S. Geological Survey; ft, foot; ft^3/s, cubic foot per second; Okla, Oklahoma; --, no data available; >, greater than]

USGS station number	USGS streamgage name	Short name	Flood stage		Major flood stage	
			Gage height (ft)[a]	Streamflow (ft^3/s)[b]	Gage height (ft)[a]	Streamflow (ft^3/s)[b]
07159100	Cimarron River near Dover, Okla.	Dover gage	17	8,475	22	44,422
07228500	Canadian River at Bridgeport, Okla.	Bridgeport gage	14	4,922	17	20,976
07239300	North Canadian River below Weavers Creek near Watonga, Okla.	Watonga gage	15	1,995	15	1,995
07239450	North Canadian River near Calumet, Okla.	Calumet gage	--	--	--	--
07239500	North Canadian River near El Reno, Okla.	El Reno gage	17	7,552	21	12,806
07239700	North Canadian River near Yukon, Okla.	Yukon gage	14	6,413	17	26,218
07301420	Sweetwater Creek near Sweetwater, Okla.	Sweetwater gage	--	--	--	--
07301500	North Fork Red River near Carter, Okla.	Carter gage	16	6,705	18	12,721
07316500	Washita River near Cheyenne, Okla.	Cheyenne gage	13.5	1,131	17	7,526
07324200	Washita River near Hammon, Okla.	Hammon gage	22	2,507	26	> 10,000
07324400	Washita River near Foss, Okla.	Foss gage	18	1,583	22	5,472
07325000	Washita River near Clinton, Okla.	Clinton gage	18	2,090	24	5,730

[a]The water-surface elevation referred to some arbitrary gage datum (USGS, 2019c).

[b]Estimated from rating curves on February 4, 2019.

For example on table 14, at the Dover gage, there is approximately a 20 percent chance that streamflow will exceed 42,560 ft^3/s in any one year (a recurrence interval of approximately 5 years) and approximately a 1 percent chance that streamflow will exceed 136,600 ft^3/s in any one year (a recurrence interval of approximately 100 years).

The AEPs of streamflows exceeding peak flows and reaching flood stage and major flood stage are shown on graphs for each USGS streamgage in the CATJA in appendix 1. As an example, based on the frequency of peak flows, the Cheyenne gage has about a 25 percent chance of reaching flood stage (13.5 ft; 1,131 ft^3/s) in any one year (a recurrence interval of approximately 4 years) and slightly greater than a 2 percent chance of reaching major flood stage (17 ft; 7,526 ft^3/s) in any one year (a recurrence interval of approximately 45 years) (fig. 24 and fig. 1.45 in app. 1). Error bars for each data point indicate the 95-percent confidence interval for the peak-flow frequency data. All rivers in the CATJA for which the National Weather Service has determined a flood stage (National Weather Service, 2019a) were expected to exceed their flood stage at least every 10 years. The AEPs of streamflow greater than the major flood stage varied greatly between streamgages during the periods of record.

River Low-Flow Characteristics and Long-Term Trends

The AEP of 7-day annual low flows at each streamgage is shown in table 15. For example, at the USGS streamgage 07325000 Washita River near Clinton, Okla. (hereinafter referred to as the “Clinton gage”), there is approximately a 50 percent chance that an annual period of low flow lasting 7 days at a streamflow rate of 10.4 ft^3/s (a recurrence interval of approximately 2 years) will occur, whereas there is approximately a 5 percent chance that an annual period of low flow lasting 7 days at a streamflow rate of 0.50 ft^3/s (a recurrence interval of approximately 20 years) will occur on the basis of measured streamflow values over the period of record (table 15).

The AEPs for annual low flows lasting 1, 3, 7, 10, 30, and 60 days at each streamgage are shown on table 16. These data are useful in determining the frequency and magnitude of low-flow periods at each streamgage. Like all streamflow statistics, these data are limited by the length of the period of record. For example, table 16 shows that the 7-day low flows at the USGS streamgage 07239700 North Canadian River near Yukon, Okla. (hereinafter referred to as the “Yukon gage”), are

Table 14. Magnitudes and annual exceedance probabilities of annual peak flows at 12 U.S. Geological Survey streamgages, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).

[USGS, U.S. Geological Survey; regulation defined as N (unregulated by dams, floodwater-retarding structures, or other human modifications of streamflow), R (controlled by dams, floodwater-retarding structures, or other human modifications of streamflow), or I (unregulated, but affected by irrigation); skew method defined as W (weighted skew) or S (streamgage-only skew); ft^3/s, cubic foot per second; Okla., Oklahoma. This table shows the recurrence intervals in years of streamflow values exceeding the multiyear peak flows at each streamgage. Shading shows that at the Dover gage the streamflow will exceed 42,560 ft^3/s about every 5 years and 136,600 ft^3/s about every 100 years]

USGS station number	USGS streamgage name	Short name	Regulation	Peaks in record	Skew method[a]	Skew	Streamflow, in ft^3/s, for indicated annual exceedance probability, in percent (recurrence interval, in years)						
							50 (2 years)	20 (5 years)	10 (10 years)	4 (25 years)	2 (50 years)	1 (100 years)	0.20 (500 years)
07159100	Cimarron River near Dover, Okla.	Dover gage	N	42	W	-0.138	21,170	42,560	60,640	87,760	110,900	136,600	206,200
07228500	Canadian River at Bridgeport, Okla.	Bridgeport gage	R	46	S	-0.435	13,530	29,500	42,650	61,420	76,570	92,440	131,700
07239300	North Canadian River below Weavers Creek near Watonga, Okla.	Watonga gage	R	32	S	0.066	2,045	3,444	4,540	6,112	7,419	8,841	12,650
07239450	North Canadian River near Calumet, Okla.	Calumet gage	R	27	S	0.330	2,251	4,752	7,216	11,510	15,740	21,020	38,670
07239500	North Canadian River near El Reno, Okla.	El Reno gage	R	67	S	-0.015	3,127	5,875	8,160	11,580	14,500	17,760	26,730
07239700	North Canadian River near Yukon, Okla.	Yukon gage	R	15	S	0.089	3,740	7,937	11,850	18,270	24,240	31,330	52,990
07301420	Sweetwater Creek near Sweetwater, Okla.	Sweetwater gage	I	29	S	0.389	231	531	849	1,441	2,058	2,867	5,781
07301500	North Fork Red River near Carter, Okla.	Carter gage	R	29	S	-0.273	2,961	8,096	13,280	21,980	30,070	39,540	67,200
07316500	Washita River near Cheyenne, Okla.	Cheyenne gage	R	55	S	-0.047	559	1,706	3,037	5,596	8,284	11,770	23,860
07324200	Washita River near Hammon, Okla.	Hammon gage	R	44	S	-0.488	999	2,123	3,018	4,257	5,231	6,229	8,611
07324400	Washita River near Foss, Okla.	Foss gage	R	52	S	-0.364	765	1,488	2,050	2,826	3,441	4,077	5,634
07325000	Washita River near Clinton, Okla.	Clinton gage	R	54	S	-0.243	1,807	3,940	5,797	8,613	11,030	13,690	20,890

[a]Lewis and Esralew (2009); U.S. Interagency Advisory Committee on Water Data (1982).

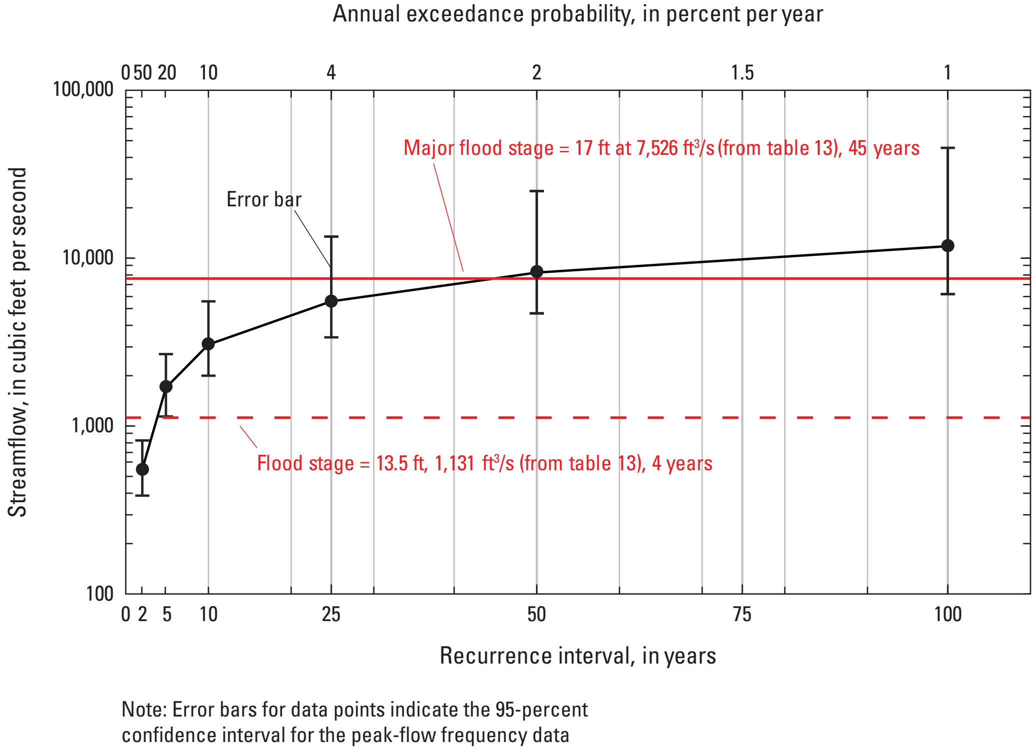


Figure 24. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at the U.S. Geological Survey streamgage 07316500 Washita River near Cheyenne, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b). ft, foot; ft³/s, cubic foot per second.

Table 15. Magnitudes and annual exceedance probabilities of 7-day annual low flow at 12 U.S. Geological Survey streamgages, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b)

[USGS, U.S. Geological Survey; ft³/s, cubic foot per second; Okla., Oklahoma. Shading shows that at the Clinton gage an annual period of low flow lasting 7 days at a streamflow rate of 10.4 ft³/s is expected to occur every 2 years, whereas an annual period of low flow lasting 7 days at a streamflow rate of 0.50 ft³/s is expected to occur every 20 years based on streamflow over the period of record]

USGS station number	USGS streamgage name	Short name	Streamflow, in ft³/s, for indicated annual exceedance probability, in percent (recurrence interval, in years)			
			50 (2 years)	20 (5 years)	10 (10 years)	5 (20 years)
07159100	Cimarron River near Dover, Okla.	Dover gage	41.3	16.9	10.2	6.57
07228500	Canadian River at Bridgeport, Okla.	Bridgeport gage	7.78	1.94	0.00	0.00
07239300	North Canadian River below Weavers Creek near Watonga, Okla.	Watonga gage	12.5	3.15	1.17	0.45
07239450	North Canadian River near Calumet, Okla.	Calumet gage	15.7	2.06	0.47	0.11
07239500	North Canadian River near El Reno, Okla.	El Reno gage	5.59	0.00	0.00	0.00
07239700	North Canadian River near Yukon, Okla.	Yukon gage	17.2	6.24	3.46	2.06
07301420	Sweetwater Creek near Sweetwater, Okla.	Sweetwater gage	0.74	0.11	0.03	0.00
07301500	North Fork Red River near Carter, Okla.	Carter gage	0.76	0.00	0.00	0.00
07316500	Washita River near Cheyenne, Okla.	Cheyenne gage	0.00	0.00	0.00	0.00
07324200	Washita River near Hammon, Okla.	Hammon gage	1.23	0.00	0.00	0.00
07324400	Washita River near Foss, Okla.	Foss gage	3.24	1.02	0.48	0.24
07325000	Washita River near Clinton, Okla.	Clinton gage	10.4	2.78	1.15	0.50

Table 16. Magnitudes and annual exceedance probabilities of lowest annual streamflow for a period of consecutive days through 2015 at 12 U.S. Geological Survey streamgages, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).

[ft^3/s, cubic foot per second; Okla., Oklahoma; tau, Mann-Kendall correlation coefficient (Mann, 1945); p-value, probability value]

Recurrence interval, in years (with corresponding annual exceedance probability, in percent)	Streamflow (ft^3/s)					
	1 day	3 days	7 days	10 days	30 days	60 days
07159100 Cimarron River near Dover, Okla. (Dover gage)						
2 (50)	35.7	37.3	41.3	44.3	64.1	104.3
5 (20)	14.1	15.0	16.9	18.2	26.5	44.8
10 (10)	8.31	8.96	10.2	10.9	15.8	27.0
20 (5)	5.27	5.74	6.57	7.01	10.0	17.2
tau	−0.004	−0.015	0.010	0.005	0.012	−0.044
p-value	0.982	0.902	0.937	0.973	0.919	0.694
Trend in annual low flows[a]	no trend	no trend	no trend	no trend	no trend	no trend
07228500 Canadian River at Bridgeport, Okla. (Bridgeport gage)						
2 (50)	6.24	6.79	7.78	8.57	16.7	23.3
5 (20)	1.39	1.57	1.94	2.32	1.56	6.41
10 (10)	0.00	0.00	0.00	0.00	0.20	2.92
20 (5)	0.00	0.00	0.00	0.00	0.02	1.44
tau	0.110	0.114	0.131	0.136	0.160	0.158
p-value	0.290	0.272	0.206	0.189	0.125	0.129
Trend in annual low flows[a]	no trend	no trend	no trend	no trend	no trend	no trend
07239300 North Canadian River below Weavers Creek near Watonga, Okla. (Watonga gage)						
2 (50)	11.6	12.1	12.5	13.0	16.6	20.6
5 (20)	2.65	2.82	3.15	3.40	4.87	6.61
10 (10)	0.86	0.94	1.17	1.33	2.09	3.16
20 (5)	0.28	0.32	0.45	0.53	0.93	1.58
tau	−0.353	−0.359	−0.351	−0.333	−0.295	−0.243
p-value	0.006	0.005	0.006	0.009	0.021	0.057
Trend in annual low flows[a]	downward	downward	downward	downward	downward	no trend
07239450 North Canadian River near Calumet, Okla. (Calumet gage)						
2 (50)	14.1	14.6	15.7	16.2	20.2	28.1
5 (20)	1.80	1.86	2.06	2.23	3.17	5.50
10 (10)	0.40	0.41	0.47	0.53	0.86	1.76
20 (5)	0.09	0.09	0.11	0.13	0.24	0.59
tau	−0.443	−0.437	−0.428	−0.422	−0.403	−0.378
p-value	0.002	0.002	0.002	0.003	0.004	0.007
Trend in annual low flows[a]	downward	downward	downward	downward	downward	downward
07239500 North Canadian River near El Reno, Okla. (El Reno gage)						
2 (50)	4.44	4.81	5.59	6.15	10.94	18.90
5 (20)	0.00	0.00	0.00	0.00	0.36	3.35
10 (10)	0.00	0.00	0.00	0.00	0.00	0.79
20 (5)	0.00	0.00	0.00	0.00	0.00	0.04
tau	0.365	0.345	0.350	0.334	0.255	0.176
p-value	0.000	0.000	0.000	0.000	0.002	0.035
Trend in annual low flows[a]	upward	upward	upward	upward	upward	upward

Table 16. Magnitudes and annual exceedance probabilities of lowest annual streamflow for a period of consecutive days through 2015 at 12 U.S. Geological Survey streamgages, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).—Continued

[ft^3/s, cubic foot per second; Okla., Oklahoma; tau, Mann-Kendall correlation coefficient (Mann, 1945); p-value, probability value]

Recurrence interval, in years (with corresponding annual exceedance probability, in percent)	Streamflow (ft^3/s)					
	1 day	3 days	7 days	10 days	30 days	60 days
07239700 North Canadian River near Yukon, Okla. (Yukon gage)						
2 (50)	14.7	15.2	17.2	17.6	21.5	26.7
5 (20)	5.48	5.70	6.24	6.38	8.06	10.6
10 (10)	3.11	3.24	3.46	3.52	4.54	6.36
20 (5)	1.89	1.98	2.06	2.09	2.73	4.14
tau	−0.219	−0.200	−0.181	−0.200	−0.181	−0.181
p-value	0.276	0.322	0.373	0.322	0.373	0.373
Trend in annual low flows[a]	no trend	no trend	no trend	no trend	no trend	no trend
07301420 Sweetwater Creek near Sweetwater, Okla. (Sweetwater gage)						
2 (50)	0.56	0.61	0.74	0.73	1.22	2.47
5 (20)	0.13	0.14	0.11	0.15	0.27	0.66
10 (10)	0.00	0.00	0.03	0.05	0.11	0.30
20 (5)	0.00	0.00	0.00	0.01	0.05	0.15
tau	−0.220	−0.209	−0.204	−0.206	−0.190	−0.233
p-value	0.105	0.123	0.133	0.128	0.161	0.086
Trend in annual low flows[a]	no trend	no trend	no trend	no trend	no trend	no trend
07301500 North Fork Red River near Carter, Okla. (Carter gage)						
2 (50)	0.15	0.38	0.76	0.96	2.26	5.85
5 (20)	0.00	0.00	0.00	0.00	0.00	0.10
10 (10)	0.00	0.00	0.00	0.00	0.00	0.00
20 (5)	0.00	0.00	0.00	0.00	0.00	0.00
tau	−0.275	−0.265	−0.265	−0.259	−0.259	−0.365
p-value	0.031	0.039	0.039	0.043	0.051	0.007
Trend in annual low flows[a]	downward	downward	downward	downward	no trend	downward
07316500 Washita River near Cheyenne, Okla. (Cheyenne gage)						
2 (50)	0	0	0	0	0.00	0.24
5 (20)	0	0	0	0	0	0
10 (10)	0	0	0	0	0	0
20 (5)	0	0	0	0	0	0
tau	0.224	0.218	0.263	0.277	0.220	0.183
p-value	0.002	0.003	0.001	0.000	0.012	0.044
Trend in annual low flows[a]	upward	upward	upward	upward	upward	upward
07324200 Washita River near Hammon, Okla. (Hammon gage)						
2 (50)	0.97	1.06	1.23	1.36	2.12	4.85
5 (20)	0.00	0.00	0.00	0.00	0.04	0.12
10 (10)	0.00	0.00	0.00	0.00	0.00	0.00

Table 16. Magnitudes and annual exceedance probabilities of lowest annual streamflow for a period of consecutive days through 2015 at 12 U.S. Geological Survey streamgages, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).—Continued

[ft^3/s, cubic foot per second; Okla., Oklahoma; tau, Mann-Kendall correlation coefficient (Mann, 1945); p-value, probability value]

Recurrence interval, in years (with corresponding annual exceedance probability, in percent)	Streamflow (ft^3/s)					
	1 day	3 days	7 days	10 days	30 days	60 days
07324200 Washita River near Hammon, Okla. (Hammon gage)—Continued						
20 (5)	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.237	0.239	0.242	0.244	0.224	0.180
p-value	0.027	0.025	0.024	0.023	0.037	0.095
Trend in annual low flows[a]	upward	upward	upward	upward	upward	no trend
07324400 Washita River near Foss, Okla. (Foss gage)						
2 (50)	2.53	2.91	3.24	3.42	3.95	4.68
5 (20)	0.74	0.89	1.02	1.12	1.39	1.83
10 (10)	0.34	0.41	0.48	0.54	0.76	1.08
20 (5)	0.17	0.20	0.24	0.28	0.45	0.69
tau	0.453	0.460	0.455	0.456	0.388	0.332
p-value	0.000	0.000	0.000	0.000	0.000	0.001
Trend in annual low flows[a]	upward	upward	upward	upward	upward	upward
07325000 Washita River near Clinton, Okla. (Clinton gage)						
2 (50)	8.95	9.51	10.4	10.4	11.8	15.1
5 (20)	2.10	2.39	2.78	3.13	5.00	7.15
10 (10)	0.68	0.89	1.15	1.46	3.21	4.99
20 (5)	0.12	0.30	0.50	0.72	2.23	3.77
tau	0.312	0.310	0.306	0.299	0.247	0.191
p-value	0.001	0.001	0.001	0.001	0.009	0.042
Trend in annual low flows[a]	upward	upward	upward	upward	upward	upward

[a]Trends were statistically significant if the p-value was less than or equal to 0.05.

much higher (6.24 ft^3/s, an AEP of approximately 20 percent corresponding to a recurrence interval of approximately 5 years) than those at the El Reno gage (0.00 ft^3/s; an AEP of approximately 20 percent, also corresponding to a recurrence interval of approximately 5 years), even though the streamgages are only about 15 mi apart. The large discrepancy in 7-day low flows at the Yukon and El Reno streamgages occurs because the period of record (through 2015) for the El Reno gage is much longer (67 years) than the period of record (through 2015) for the Yukon gage (15 years), providing a much more varied dataset on which to base the statistics.

Trends in annual low flow vary mainly by river system. Annual low flow for each period of consecutive days calculated for the four streamgages on the Washita River trended upward, except for the 60-day period for the Hammon gage, which was not statistically significant. Annual low-flow trends at streamgages on the North Canadian River were mixed. At the upstream USGS streamgage 07239300 North Canadian River below Weavers Creek near Watonga, Okla. (Watonga gage), and the Calumet gage, annual low flows trended downward, whereas the downstream El Reno gage trended upward. No significant trend was observed at the Yukon gage. For the North Fork Red River, annual low flows at the Carter gage trended significantly downward, whereas no significant trend was observed at the Sweetwater gage on its tributary. For the Cimarron River, no significant trends were observed at the Dover gage or the Bridgeport gage.

Groundwater Resources

Groundwater resources in the CATJA include the alluvial aquifers along the five major river systems and three major bedrock aquifers, Ogallala, Elk City, and Rush Springs (fig. 2). In 2015, groundwater was used at more than twice the rate of surface water in the CATJA (USGS, 2018a; C. Neel, OWRB, written commun., 2016). Currently (2019), the depletion of groundwater from the major aquifers in west-central Oklahoma is of minor concern to the OWRB; groundwater levels and other hydrologic information show that recharge rates exceed pumpage rates in the aquifers, except in areas that may be affected locally by groundwater depletions (OWRB, 2012b).

The OWRB has a statutory requirement to reevaluate the amount of water that can be safely withdrawn from these aquifers (and all of the major aquifers in Oklahoma) over a minimum of 20 years without depleting the aquifers of water (OWRB, 2018f). This amount is referred to as the “maximum annual yield” (MAY), and once it has been determined, the OWRB allots an amount of groundwater that can be withdrawn annually per acre of land, referred to as an “equal proportionate share” (EPS) (OWRB, 2018f).

Three of the five alluvial aquifers and two of the three major bedrock aquifers in the CATJA had MAYs and EPSs established at the time of this report (table 17) (OWRB, 2012a, 2018f). Users withdrawing water from aquifers for which the OWRB has not issued a final order on MAYs and EPSs are granted temporary permits that allocate 2 acre-ft per acre per year (acre-ft/acre/yr). Temporary permits allow the user to withdraw water for 1 year and must be revalidated annually (OWRB, 2018g).

All groundwater withdrawn and used in Oklahoma is regulated, with the exception of quantities less than 5 acre-ft/yr used for households, agriculture, and irrigation on less than 3 acres of land (OWRB, 2018g).

Alluvial Aquifers

The five major river systems in the CATJA (fig. 2) began forming during the Pleistocene, more than 1.5 million years ago (Johnson, 2008). Water from melting glaciers in regions northwest of present-day Oklahoma carved valleys in the bedrock and left a series of clay, silt, sand, and gravel layers. These layers of sediments are referred to as “alluvial aquifers,” which are used extensively in the CATJA for groundwater. Alluvial aquifers include both the alluvium, which is the sediment actively moving in the streambed, and the terrace deposits, which are older alluvium, usually at higher elevations, that were deposited during periods of high water or deposited over time as the streambeds lowered. The alluvium and terrace deposits usually are hydraulically connected and therefore are treated as a single aquifer in each river basin. However, some terrace deposits in Oklahoma can be hydraulically isolated (Ryder, 1996). Alluvium can be as thick as 170 ft in the CATJA, and the terrace deposits can be as thick as 120 ft (fig. 7) (Carr and Bergman, 1976). Both the alluvium and terrace deposits are composed of lenticular and interfingering lenses of clay, silt, sand, and gravel that generally become coarser with depth; gravel is predominately found near the base of the river valley (Reed and others, 1952; Burton, 1965). Overlying the terrace deposits in some areas are wind-blown deposits of dune sand that are highly permeable and range in thickness from a thin veneer to about 70 ft in the CATJA (Carr and Bergman, 1976). Dune sand is considered part of the alluvial aquifer when saturated with water.

The alluvial aquifers associated with the major rivers flowing through the CATJA are considered reliably good sources of water, with wells commonly yielding from 10 to 500 gallons per minute (gal/min) (about 16–800 acre-ft/yr); however, in some areas large concentrations of dissolved solids and nitrate (as nitrogen) may locally limit the use of groundwater as a public-water supply (OWRB, 2012a). Agriculture is common over alluvial aquifers because of fertile soils and the capacities of the aquifers to produce large volumes of water for irrigation (U.S. Geological Survey, 2018a). Precipitation and water from irrigation rapidly recharge alluvial aquifers, allowing nitrogen from fertilizers and other sources to contaminate the groundwater (OWRB, 2012a). All alluvial aquifers in the CATJA have areas where concentrations of nitrate (as nitrogen) in groundwater exceeds the MCL of 10 mg/L (EPA, 2018a).

Table 17. Maximum annual yields and equal proportionate shares for alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2012a, 2018f).

Aquifer	Maximum annual yield (acre-feet/year)	Equal proportionate share (acre-feet/acre/year)	Date of final order
	Alluvial aquifers		
Cimarron River alluvial aquifer	Not determined	2 (temporary)	No final order
North Canadian River alluvial aquifer	211,840	0.8–1.3	4/10/1990
Canadian River alluvial aquifer	Not determined	2 (temporary)	No final order
Washita River alluvial aquifer	120,320	2	11/13/1990
North Fork Red River alluvial aquifer	343,042	1	9/8/1981
	Bedrock aquifers		
Ogallala aquifer (Ellis and Dewey Counties)	1,198,512	1.4	3/12/2002
Ogallala aquifer (Roger Mills and Beckham Counties)	Not determined	2 (temporary)	No final order
Elk City aquifer	157,440	1	11/9/1982
Rush Springs aquifer	Not determined	2 (temporary)	No final order

Cimarron River Alluvial Aquifer

The Cimarron River alluvial aquifer is on the northeastern side of the Cimarron River and is considered a major aquifer in central and northwestern Oklahoma (fig. 2) (OWRB, 2012a). In the CATJA, this alluvial aquifer covers an area of about 333 mi^2 and is the primary source of water in Kingfisher County (USGS, 2018a). The thin strip of alluvium along the river is considered a poor source of groundwater, as well yields are small and the water is highly mineralized (Ryder, 1996). However, the terrace deposits which compose most of the alluvial aquifer are considered a reliably good source of water in the CATJA and are used extensively for irrigation and water supply (OWRB, 2018c).

The red beds underlying the alluvial deposits that compose the Cimarron River alluvial aquifer are part of the El Reno Group and generally are impermeable and do not yield groundwater except for the Cedar Hills Sandstone, which underlies the alluvial aquifer in the northwestern part of Kingfisher County (fig. 6) (Adams and Bergman, 1995). Wells drilled into the Cedar Hills Sandstone are reported to yield small amounts of water that are often insufficient for livestock or public-water supply needs unless also screened in the overlying terrace deposits (Adams and Bergman, 1995).

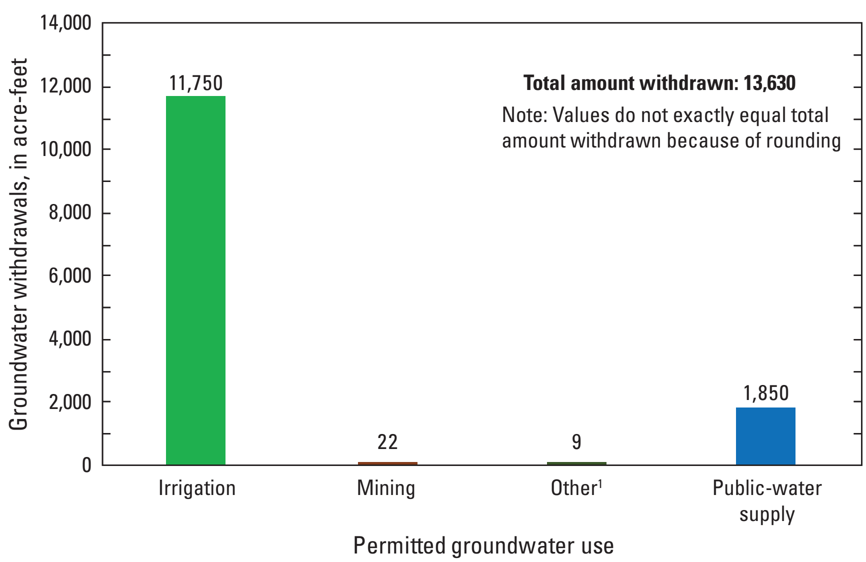
Water Use and Allocations

Groundwater from the Cimarron River alluvial aquifer is used primarily for irrigation and public-water supply and in smaller amounts for mining and other (industrial) uses (figs. 25 and 26) (C. Neel, OWRB, written commun., 2016). Irrigation was the largest use of the water withdrawn from the alluvial aquifer during 2015, accounting for about 86 percent of the total reported withdrawals (fig. 25). Reported amounts of groundwater withdrawals from the alluvial aquifer during 2015 indicate that only about 19 percent of the total amount of groundwater allocated for pumping in the CATJA was withdrawn (fig. 25 and table 18) (OWRB, 2018c). Of the total 72,830 acre-ft that was allocated, 13,630 acre-ft was reportedly used. Total allocations for groundwater withdrawal have increased about 355 percent over 35 years (1980–2015), from 15,950 acre-ft/yr to 72,830 acre-ft/yr (OWRB, 2018c) (table 18). The number of permits also increased during this period from 58 to 243.

Irrigation is the largest water use of groundwater in Kingfisher County and became widespread in the 1950s when groundwater withdrawals for growing crops and the number of irrigable acres greatly increased (table 5 in Adams and Bergman, 1995). During 2015, about 57 percent (332,950 acres) of Kingfisher County was planted in crops, with winter wheat covering the largest area, 245,143 acres (National Agricultural Statistics Service, 2018). The number of acres irrigated for 2015 is not available, but about 3 percent of total acres planted in Kingfisher County was irrigated in 2012 (National Agricultural Statistics Service, 2012).

Water Levels and Saturated Thickness

Water levels in the Cimarron River alluvial aquifer can be monitored online through the OWRB map application Groundwater Level Monitoring Wells in Oklahoma (fig. 10) (OWRB, 2018e). In the CATJA, depth to water is measured annually in wells by the OWRB as part of GMAP (table 19).



[1]Industrial.

Figure 25. Reported groundwater withdrawals for permitted uses during 2015 from the Cimarron River alluvial aquifer, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (C. Neel, Oklahoma Water Resources Board, written commun., 2016).

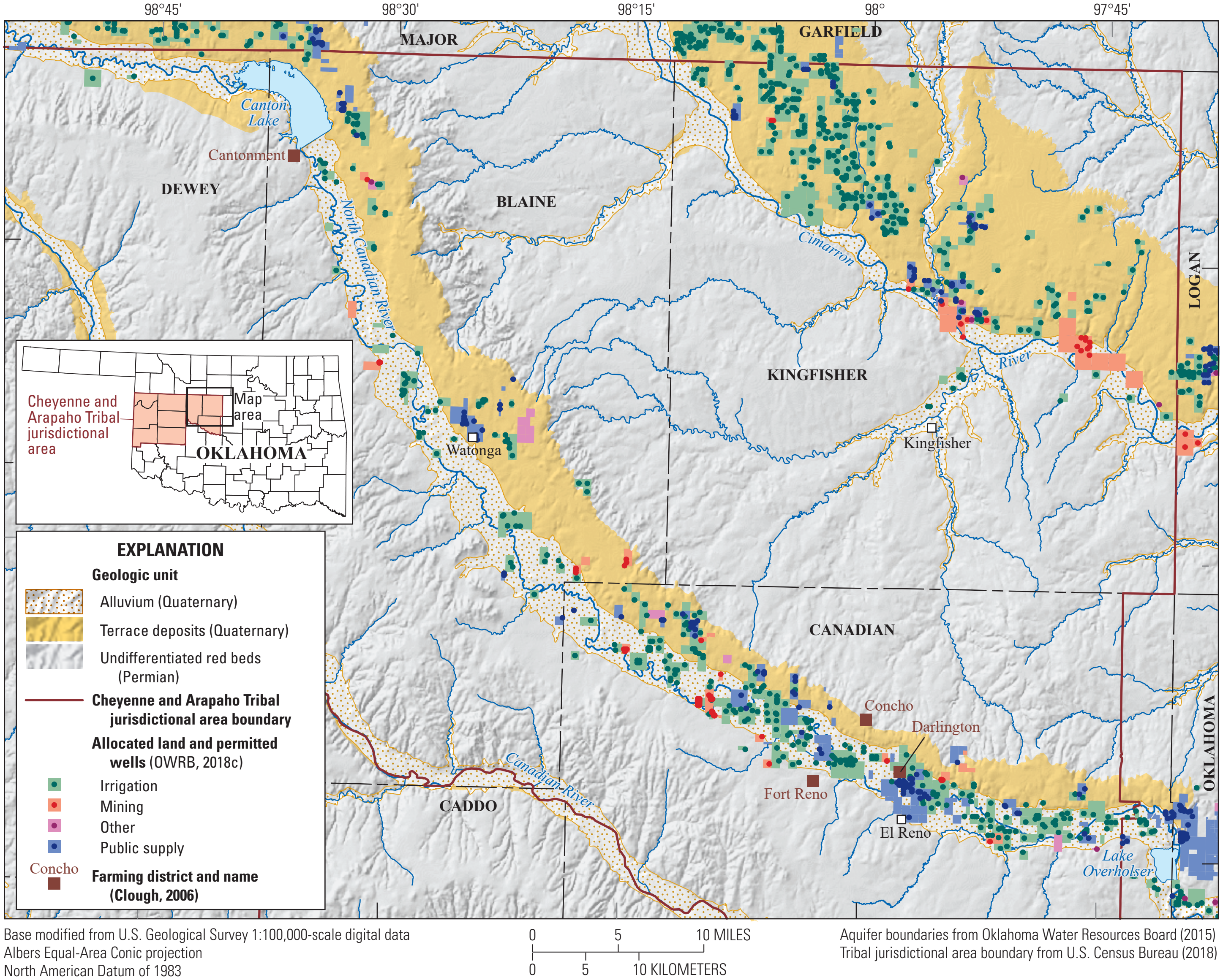


Figure 26. Allocated land and permitted wells withdrawing groundwater from the Cimarron River and North Canadian River alluvial aquifers in 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. OWRB, Oklahoma Water Resources Board.

Table 18. Permitted groundwater allocations from the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018c).

[Total allocations may not equal yearly allocations because of rounding. acre-ft, acre-foot]

Calendar year	Irrigation (acre-ft)	Mining (acre-ft)	Other (acre-ft)[a]	Public-water supply (acre-ft)	Total allocations (acre-ft)	Total number of permits
Cimarron River alluvial aquifer						
1980	15,040	0	0	905	15,950	58
1990	30,420	1,490	125	4,980	37,020	172
2000	38,110	1,490	125	6,450	46,180	195
2005	38,510	1,490	205	7,410	47,620	199
2010	44,100	2,610	565	7,580	54,860	225
2015	61,270	2,610	565	8,380	72,830	243
North Canadian River alluvial aquifer						
1980	6,400	950	0.00	4,900	12,250	66
1990	23,180	950	1,200	9,880	35,210	213
2000	31,880	990	1,200	10,220	44,290	227
2005	32,790	990	1,200	12,790	47,770	243
2010	33,190	1,790	1,390	14,560	50,930	253
2015	33,650	3,130	1,390	14,800	52,970	267
Canadian River alluvial aquifer						
1980	7,210	400	0	53	7,665	30
1990	32,310	2,920	0	350	35,580	79
2000	32,630	3,170	490	945	37,240	85
2010	40,720	3,170	490	3,220	47,600	97
2015	45,730	8,500	490	3,220	57,940	105
Washita River alluvial aquifer						
1980	3,730	130	0	20	3,880	13
1990	57,780	130	0	350	58,260	162
2000	59,120	130	0	350	59,600	166
2010	59,400	290	0	430	60,120	168
2015	62,600	290	0	430	63,320	174
North Fork Red River alluvial aquifer						
1980	5,610	0	0	2,270	7,880	53
1990	13,990	820	205	9,590	24,610	106
2000	22,850	820	225	11,820	35,720	138
2010	31,000	970	225	13,330	45,530	166
2015	37,000	970	225	13,330	51,530	185
Ogallala aquifer						
1980	10,390	0	10	830	11,230	31
1990	74,730	3,870	190	1,760	80,550	164
2000	76,010	3,870	190	2,080	82,150	168
2010	78,200	4,240	190	2,380	85,010	177
2015	81,490	4,240	510	2,380	88,620	185

Table 18. Permitted groundwater allocations from the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018c).—Continued

[Total allocations may not equal yearly allocations because of rounding. acre-ft, acre-foot]

Calendar year	Irrigation (acre-ft)	Mining (acre-ft)	Other (acre-ft)[a]	Public-water supply (acre-ft)	Total allocations (acre-ft)	Total number of permits
			Elk City aquifer			
1980	3,680	220	0	5,160	9,060	40
1990	7,490	480	130	6,670	14,770	80
2000	7,650	480	130	7,370	15,630	84
2010	8,130	480	185	7,590	16,385	90
2015	10,630	960	185	7,590	19,365	95
			Rush Springs aquifer			
1980	34,290	0	945	2,360	37,595	202
1990	147,610	0	6,300	7,070	160,980	498
2000	157,300	0	6,640	11,140	175,080	542
2015	188,950	0	18,210	13,120	220,280	634

[a]Includes water used for non-irrigated agriculture, commercial, industrial, and recreation, fish, and wildlife purposes.

Table 19. Summary of long-term annual water-level measurements and saturated thickness in Oklahoma Water Resources Board Groundwater Monitoring and Assessment Program (GMAP) wells in the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018e).

[ID, identification; min, minimum; max, maximum; ft, foot; na, not available; <, less than]

Well ID	First year	Last year	Number of measurements	Depth to water, in feet below land surface: First	Last	Min	Max	Mean	Annual mean fluctuation	Well depth (ft below land surface)	Mean saturated thickness of aquifer (ft)[a]
				Cimarron River alluvial aquifer							
9139	2/26/1991	1/6/2016	26	9.60	12.64	4.70	15.88	10.0	2.1	57	55
9511	1/21/1975	1/6/2016	41	0.18	1.57	0.18	7.48	2.9	1.5	30	29
9512	1/20/1975	1/6/2016	41	17.90	18.90	14.23	20.08	17.7	0.8	45	44
9514	1/21/1975	2/6/2016	41	11.25	11.31	7.63	16.16	12.7	1.2	33	32
9521	1/21/1975	1/21/2014	39	13.05	13.55	4.36	17.04	11.4	1.8	56	54
9524	1/21/1975	1/6/2016	41	36.59	23.30	15.72	36.59	24.9	2.5	58	55
9526	1/21/1975	1/6/2016	36	3.66	9.69	3.10	11.31	6.4	1.7	34	32
9529	1/22/1975	1/6/2016	39	7.40	18.26	0.20	21.38	8.0	2.4	na	na
9530	1/22/1975	1/21/2014	39	7.72	18.85	2.69	18.92	10.0	2.2	74	72
27647	1/24/1992	1/6/2016	25	11.83	17.11	7.92	19.50	13.1	2.0	55	53
94873	1/8/2009	1/6/2016	6	18.55	26.86	18.55	28.15	25.4	1.1	85	84
122412	1/8/2009	1/6/2016	8	8.80	12.78	8.80	16.57	12.7	2.5	54	52
				North Canadian River alluvial aquifer							
5131	3/12/1976	1/19/2016	33	30.27	11.18	6.58	30.27	14.0	2.2	53	39
5208	1/18/1989	1/19/2016	26	19.90	20.73	6.71	22.83	17.0	2.2	54	37
9127	1/11/1978	1/4/2008	37	53.10	48.35	44.29	53.93	48.2	1.2	80	32
9130	3/11/1976	2/8/2016	37	18.00	16.60	9.00	21.65	16.3	1.9	48	32

Table 19. Summary of long-term annual water-level measurements and saturated thickness in Oklahoma Water Resources Board Groundwater Monitoring and Assessment Program (GMAP) wells in the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018e).—Continued

[ID, identification; min, minimum; max, maximum; ft, foot; na, not available; <, less than]

Well ID	First year	Last year	Number of measurements	Depth to water, in feet below land surface						Well depth (ft below land surface)	Mean saturated thickness of aquifer (ft)[a]
				First	Last	Min	Max	Mean	Annual mean fluctuation		
North Canadian River alluvial aquifer—Continued											
9166	3/13/1978	2/2/2016	41	18.85	19.40	13.71	25.55	19.0	1.8	50	31
9167	2/10/1977	1/29/2016	42	12.05	7.85	4.36	14.65	9.0	2.4	45	36
33734	2/10/2000	1/11/2016	19	11.65	11.75	8.55	16.45	12.2	1.7	52	40
108724	1/31/2012	2/2/2016	7	10.75	8.07	6.00	13.47	10.0	3.5	46	36
Canadian River alluvial aquifer											
9666	3/26/1980	1/13/2016	33	8.77	3.38	2.99	8.77	4.1	0.4	na	na
19934	3/21/2001	1/20/2016	17	33.72	39.82	33.38	41.16	36.4	1.0	95	59
20075	3/21/2001	1/20/2016	16	12.53	14.12	12.53	14.96	13.8	0.4	47	33
33749	2/11/2014	1/19/2016	3	11.62	12.46	11.62	12.46	12.1	0.4	38	26
82725	2/10/2014	2/2/2016	3	12.93	10.85	10.85	13.73	12.5	1.8	55	42
Washita River alluvial aquifer											
2687	2/10/1976	1/12/2016	40	35.43	28.54	25.02	35.43	28.6	1.4	86	57
2700	3/12/1996	3/27/2003	7	2.09	1.64	−0.76	6.52	1.4	3.1	182	181
20600	2/1/2012	1/11/2016	5	24.94	22.74	22.74	25.86	25.2	1.0	100	75
105710	1/27/2014	1/11/2016	3	53.55	53.47	53.47	55.62	54.2	2.1	121	67
North Fork Red River alluvial aquifer											
9088	3/5/1980	1/14/2016	37	23.42	28.96	15.85	31.68	23.0	1.6	76	53
9089	3/5/1980	1/14/2016	35	20.48	28.22	13.02	31.49	21.1	1.6	50	29
9090	3/6/1980	1/13/2016	37	17.42	26.91	4.21	32.68	14.6	2.7	80	65
9094	3/19/1981	1/14/2016	36	64.68	51.46	32.17	64.68	42.0	1.9	210	168
9096	3/5/1980	1/13/2016	35	24.05	23.90	12.98	28.88	19.9	1.4	na	na
9098	3/5/1980	1/14/2016	37	38.65	42.71	30.77	45.92	37.5	1.4	74	36
9100	3/17/1981	1/13/2016	32	64.50	71.31	58.20	74.10	64.9	2.7	148	83
9101	3/6/1980	1/13/2016	36	42.75	44.78	33.22	53.00	42.4	3.0	70	28
9108	3/7/1980	2/21/2013	34	46.52	51.63	36.42	51.63	42.2	1.2	59	17
25519	1/30/2013	1/13/2016	4	81.24	88.83	81.24	100.07	87.9	10.0	114	26
Ogallala aquifer											
2463	1/21/2015	1/12/2016	2	75.9	76.1	75.9	76.1	76.0	0.1	97	21
2472	2/12/2014	1/12/2016	3	50.9	51.4	50.9	53.1	51.8	2.0	123	71
2644	3/27/1980	1/12/2016	36	111	91.0	89.0	116	100	1.7	205	105
2952	2/4/2014	1/25/2016	3	30.4	29.1	29.1	31.1	30.2	1.4	120	90
4354	2/5/2014	1/12/2016	3	148	148	148	148	148	<0.1	245	97
9122	3/6/1980	1/13/2016	36	19.2	20.1	14.2	23.6	18.1	1.5	32	14
9123	3/6/1980	1/13/2016	35	8.5	16.4	6.2	24.1	9.7	1.5	90	80
9314	2/5/1981	1/13/2016	36	168	158	155	179	169	2.1	290	121
9315	2/5/1980	1/13/2016	36	114	97.2	95.8	114	105	1.7	na	na

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[ID, identification; min, minimum; max, maximum; ft, foot; na, not available; <, less than]

Well ID	First year	Last year	Number of measurements	Depth to water, in feet below land surface						Well depth (ft below land surface)	Mean saturated thickness of aquifer (ft)[a]
				First	Last	Min	Max	Mean	Annual mean fluctuation		
Ogallala aquifer—Continued											
9653	3/27/1981	1/12/2016	34	35.9	33.8	28.4	37.4	33.3	1.1	125	92
9656	3/26/1981	1/12/2016	36	42.6	40.2	38.5	42.7	41.0	0.5	80	39
9657	3/27/1980	1/12/2016	36	61.8	62.7	50.8	63.1	59.0	1.1	120	61
9664	3/27/1980	1/12/2016	33	40.3	36.8	31.0	40.3	34.7	1.1	46	11
23621	3/4/1996	1/13/2016	20	112	110	106	117	110	2.5	172	62
29086	2/5/2014	1/13/2016	3	89.9	89.6	89.6	90.2	89.9	0.5	133	43
37420	2/23/2000	1/16/2016	16	37.3	35.8	35.1	37.5	36.5	0.5	100	64
37430	2/5/2014	1/12/2016	3	100	102	100	102	101	0.7	122	21
42791	2/4/2014	1/13/2016	3	146	146	146	147	146	1.2	280	134
73021	2/4/2014	1/25/2016	3	106	106	106	107	106	0.9	220	114
90488	2/12/2014	1/5/2015	2	84.8	85.7	84.8	85.7	85.2	0.8	160	75
108510	2/5/2014	1/12/2016	3	17.1	17.2	17.1	18.0	17.4	0.8	132	115
117651	2/5/2014	1/13/2016	3	41.7	40.7	40.7	42.1	41.5	0.9	90	49
128355	1/12/2012	1/25/2016	5	52.8	52.9	52.8	53.2	53.0	0.2	140	87
133285	2/12/2014	1/12/2016	3	80.1	80.2	80.1	80.2	80.2	0.1	210	130
140808	1/11/2012	1/25/2016	5	119	118	118	120	119	0.9	200	81
142470	2/4/2014	1/25/2016	3	86.9	86.6	86.6	87.9	87.1	1.1	140	53
144562	2/4/2014	1/25/2016	3	37.9	37.9	37.9	38.6	38.1	0.7	93	55
Elk City aquifer											
20753	2/3/2014	1/16/2016	3	23.7	21.2	21.2	24.4	23.1	1.7	120	97
20880	2/7/1989	1/14/2016	26	6.5	7.1	2.3	14.3	8.2	2.3	122	114
20957	2/4/2014	1/14/2016	3	42.4	39.9	39.9	43.0	41.8	1.9	117	75
21396	1/26/2010	1/12/2016	7	48.1	62.8	48.1	65.0	56.6	4.1	160	103
30129	2/10/2014	1/12/2016	3	17.5	12.0	12.0	24.9	18.1	10.1	113	95
32953	2/4/2014	1/14/2016	3	15.9	8.9	8.9	15.9	13.3	3.5	98	85
34393	3/29/2011	1/11/2016	5	11.2	10.5	10.5	14.7	12.8	1.8	80	67
44928	1/12/2016	1/12/2016	1	37.8	37.8	37.8	37.8	37.8	na	160	122
67871	2/10/2014	1/12/2016	3	35.3	33.5	32.1	36.3	35.0	1.4	154	119
72122	1/27/2010	1/14/2016	6	25.4	37.1	25.4	41.8	36.3	2.7	140	104
88323	1/27/2010	1/14/2016	7	20.2	22.8	20.2	27.2	24.1	1.9	175	151
99380	2/10/2014	1/12/2016	3	11.6	7.7	7.7	17.5	12.3	5.7	98	86
100401	2/3/2014	1/14/2016	3	17.0	7.8	7.8	17.0	13.7	4.6	153	139
102432	2/4/2014	1/14/2016	3	25.0	20.9	20.9	25.2	23.7	2.2	130	106
108036	1/26/2010	1/14/2016	7	40.6	42.5	40.6	45.1	42.7	1.2	161	118
108768	1/26/2010	1/14/2016	5	5.5	5.7	5.5	11.3	7.9	2.4	141	133
114483	2/3/2014	1/13/2016	3	19.2	13.2	13.2	19.9	17.4	3.7	122	105

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[ID, identification; min, minimum; max, maximum; ft, foot; na, not available; <, less than]

Well ID	First year	Last year	Number of measurements	Depth to water, in feet below land surface						Well depth (ft below land surface)	Mean saturated thickness of aquifer (ft)[a]
				First	Last	Min	Max	Mean	Annual mean fluctuation		
Elk City aquifer—Continued											
114767	2/4/2014	1/14/2016	3	15.8	6.9	6.9	16.3	13.0	4.9	143	130
117885	2/3/2014	1/14/2016	3	11.8	7.4	7.3	13.0	10.7	3.4	42	31
117937	2/4/2014	1/14/2016	3	19.7	14.0	14.0	20.8	18.2	4.0	80	62
143029	2/10/2014	1/14/2016	3	24.2	22.1	22.1	24.2	23.3	1.0	100	77
147345	2/3/2014	1/14/2016	3	12.8	5.9	5.9	14.5	11.1	5.2	80	69
Rush Springs aquifer											
9194	1/16/1989	1/6/2016	28	75.0	68.0	63.2	76.6	68.8	1.5	295	226
9212	1/24/1990	1/11/2016	26	40.2	46.0	31.2	46.4	37.6	1.7	225	187
9225	1/24/1990	1/7/2016	27	146	147	139	148	144	1.2	360	216
9235	1/24/1990	1/20/2016	26	42.4	48.3	38.0	48.3	42.8	1.0	300	257
9240	1/24/1990	1/7/2016	24	15.1	18.4	12.7	21.9	17.3	1.3	300	283
9243	1/24/1990	1/7/2016	27	57.0	61.0	53.6	65.2	59.0	1.5	340	281
9244	1/23/1990	1/6/2016	27	155	134	131	155	140	1.2	440	300
9249	1/24/1990	1/11/2016	27	43.7	43.7	36.0	50.5	42.4	2.1	360	318
9308	3/21/1990	1/20/2016	25	41.0	41.3	33.9	49.9	38.9	1.7	405	366
9309	1/25/1990	1/28/2014	24	35.6	39.1	29.1	39.1	34.6	1.6	400	365
9842	1/1/1961	1/6/2016	47	97.4	56.3	51.0	100.9	69.6	1.8	312	242
9844	1/1/1957	1/6/2016	54	7.3	3.4	0.8	8.0	4.4	0.8	na	na
19912	1/25/1990	1/20/2016	27	66.3	61.8	55.2	66.3	59.8	1.0	400	340
20728	2/10/2014	1/15/2016	3	102	96.8	96.8	104	101	4.4	405	304
20907	3/1/2000	2/3/2014	15	49.8	52.9	49.2	52.9	50.5	0.7	327	276
24880	1/16/1991	1/11/2016	25	60.4	70.6	52.5	72.3	62.8	2.4	400	337
24881	1/16/1991	1/11/2016	25	16.6	19.1	10.6	24.9	16.8	2.1	420	403
24882	1/17/1991	1/11/2016	24	1.8	2.8	−1.6	7.7	1.8	1.5	280	278
27649	1/15/1991	1/6/2016	26	44.8	46.8	41.3	48.6	44.5	1.0	300	255
27650	1/15/1991	1/6/2016	25	139	141	134	142	138	1.0	329	191
43007	2/24/2000	1/7/2016	17	142	143	135	143	141	1.3	425	284
85982	1/28/2014	1/11/2016	3	138	135	135	138	136	1.3	260	124
89392	1/12/2015	1/11/2016	2	56.5	54.1	54.1	56.5	55.3	2.4	180	125
95211	1/31/2012	1/11/2016	5	65.4	62.7	62.7	69.4	66.2	2.7	350	284
138843	3/15/2012	1/11/2016	4	14.1	15.3	14.1	17.8	15.4	1.3	85	70
139784	3/15/2012	1/7/2016	7	38.3	41.0	38.3	42.0	40.4	1.2	135	95
146980	1/12/2015	1/11/2016	2	56.1	60.6	56.1	60.6	58.3	4.5	142	84

[a]The thickness of the aquifer saturated with water. The saturated thickness in this report is calculated as the difference between the mean depth-to-water measurement and the total depth of the well.

Water-level fluctuations in six wells measured over 41 years in the Cimarron River alluvial aquifer are shown in a time-series hydrograph in figure 27*A*. Annual measurements from these wells show several periods of decreasing and increasing water levels in response to trends in precipitation. For example, beginning in 2008, water levels gradually decreased before increasing in 2013 in response to about 35 inches of precipitation that year (as measured at the Watonga weather station) (figs. 4 and 27*A*).

Depth to water measured in 12 OWRB GMAP wells completed in the Cimarron River alluvial aquifer has ranged from a mean of 2.9 to 25.4 ft below land surface over a range of 6 to 41 years (table 19). Water levels have exhibited annual fluctuations averaging from 0.8 to 2.5 ft in the 12 wells during the same periods. Saturated thickness of the alluvial aquifer varied depending on water levels and well location in the aquifer, ranging from 29 to 84 ft, with a mean for all 12 wells of 51 ft.

Aquifer Hydraulic Properties and Values

A two-dimensional groundwater-flow model of the Cimarron River alluvial aquifer was developed by Adams and Bergman (1995) to estimate the amount of water stored in the aquifer and to evaluate how the amount of water stored in aquifer changed in response to changes in streamflow, precipitation, and groundwater withdrawals. The groundwater-flow model covers an area of about 1,305 mi^2 from Freedom, Okla., to Guthrie, Okla., and includes the entire extent (333 mi^2) of the aquifer in the CATJA. Aquifer properties and values used in the model were estimated from aquifer tests performed by previous investigators (table 20). Large transmissivity values of as much as 10,184 feet squared per day and hydraulic conductivity values of as much as 542 feet per day are reflected in well yields that can exceed 500 gal/min (about 800 acre-ft/yr) in irrigation wells (Adams and Bergman, 1995).

The Cimarron River alluvial aquifer does not have a MAY or EPS determined by OWRB as of 2019. A temporary EPS pumping rate of 2 acre-ft/acre/yr is used for allocating groundwater for permitted uses (table 17) (OWRB, 2012a). The OWRB has determined an aquifer storage of 3,859,000 acre-ft for the alluvial aquifer extending northwest and southeast from Freedom to Guthrie (fig. 12) (OWRB, 2012a).

Water Quality

Water-quality information describing the Cimarron River alluvial aquifer is available from the USGS NWIS database (USGS, 2018b) and the OWRB GMAP (OWRB, 2018d). Within the CATJA, samples from 14 to 56 wells (depending upon constituent) collected by the USGS and from 8 wells collected by the OWRB GMAP are used to describe water quality in the alluvial aquifer (tables 21 and 22). The USGS samples were collected from 1985 to 2003, whereas the OWRB samples were collected during July and August 2016.

Water samples collected by the USGS and the OWRB that were analyzed for dissolved solids and other constituents that may limit the use of groundwater as a source of water for public-water supply are shown on figure 28. These water-quality data are used to show ranges of dissolved solids concentrations in addition to locations where nitrate (as nitrogen) exceeded the MCL of 10 mg/L in finished drinking water (EPA, 2018a, 2018b).

Groundwater from the Cimarron River alluvial aquifer in the CATJA is relatively neutral with median pH values of 7.2 and 7.0 in USGS and OWRB samples, respectively (tables 21 and 22). Of 56 USGS samples, 2 had pH values lower than the SMCL of 6.5 (EPA, 2018b).

Groundwater from the Cimarron River alluvial aquifer has large dissolved solids concentrations ranging from 330 to 770 mg/L (in the 25th and 75th percentile), with median and mean concentrations ranging from 510 to 565 mg/L in USGS and OWRB samples (fig. 28; tables 21 and 22). About 71 percent of USGS and OWRB samples exceeded the dissolved solids SMCL of 500 mg/L. Groundwater also is extremely hard in the alluvial aquifer with median and mean hardness as calcium carbonate concentrations ranging from about 280 to 325 mg/L.

Chloride and sulfate concentrations in USGS and OWRB samples from wells in the Cimarron River alluvial aquifer were all smaller than the SMCL of 250 mg/L (tables 21 and 22). Median concentrations of chloride were 75 and 100 mg/L, and median concentrations of sulfate were 44 and 42 mg/L in USGS and OWRB samples, respectively.

Similar to nitrate (as nitrogen) concentrations in other alluvial aquifers in the CATJA, nitrate (as nitrogen) occurs at concentrations exceeding the nitrogen MCL of 10 mg/L in many areas of the Cimarron River alluvial aquifer (fig. 28). Nitrate (as nitrogen) exceeded the MCL of 10 mg/L in 23 of 36 samples collected by the USGS and in 6 of 8 samples collected by the OWRB (tables 21 and 22). In addition to nitrogen-based fertilizer, confined animal feeding operations can contribute ammonium, nitrite, and nitrate to the aquifer. There are several swine production facilities in the CATJA with associated groundwater wells that are monitored by the Oklahoma Department of Agriculture, Food and Forestry. Facility locations and related groundwater-quality information can be found online from the Water Quality Portal of the National Water Quality Monitoring Council (2018).

Water from the Cimarron River terrace deposits is described by Adams and Bergman (1995) as calcium-bicarbonate to mixed cation-bicarbonate type. Of seven USGS samples evaluated for water type in the CATJA, three were calcium-bicarbonate type, three were mixed cation-bicarbonate type, and one was calcium-mixed anion type.

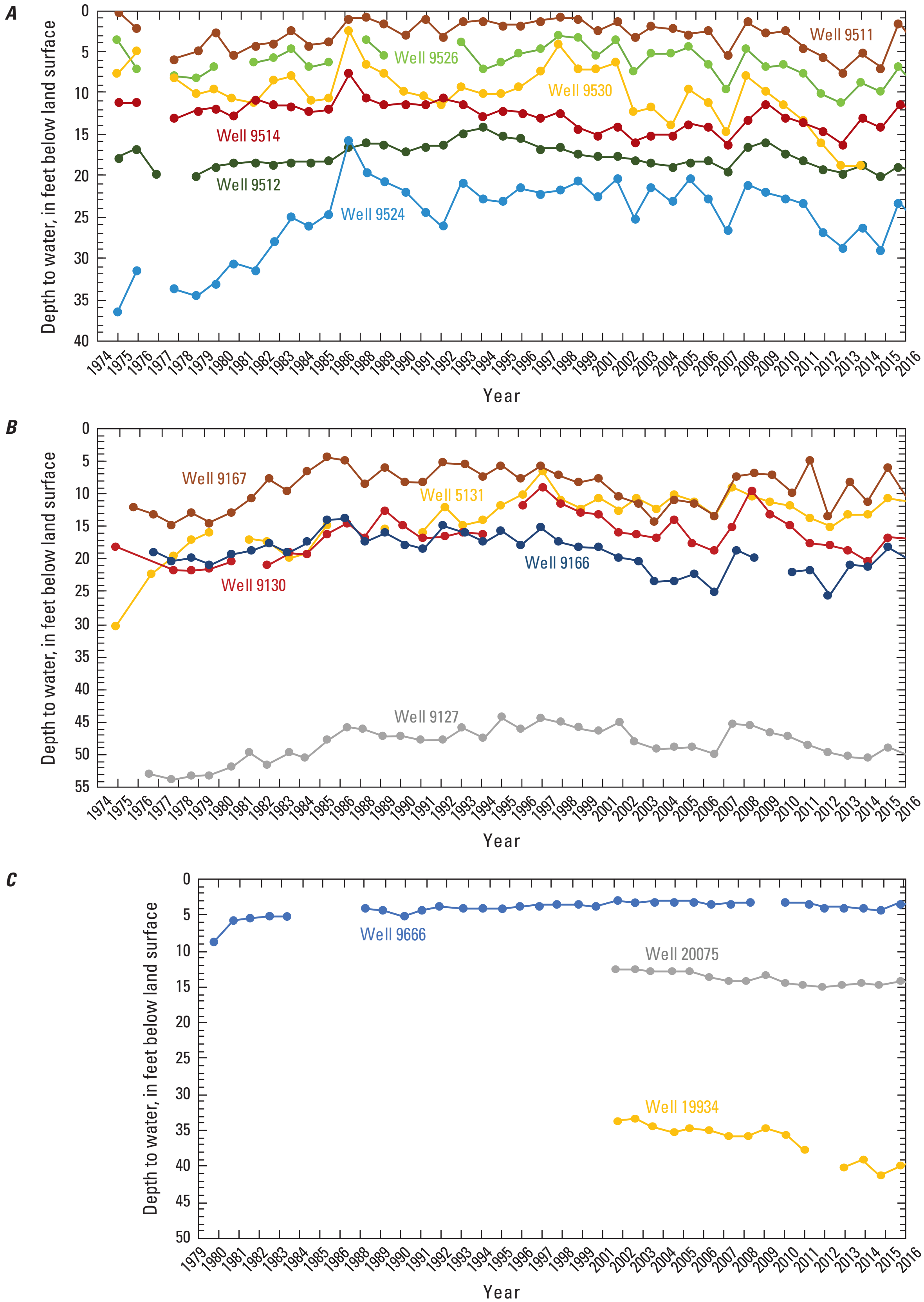


Figure 27. Long-term annual water-level measurements in Oklahoma Water Resources Board Groundwater Monitoring and Assessment Program (GMAP) wells in the alluvial aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018e). *A*, Cimarron River alluvial aquifer; *B*, North Canadian River alluvial aquifer; *C*, Canadian River alluvial aquifer; *D*, Washita River alluvial aquifer; *E*, North Fork Red River alluvial aquifer.

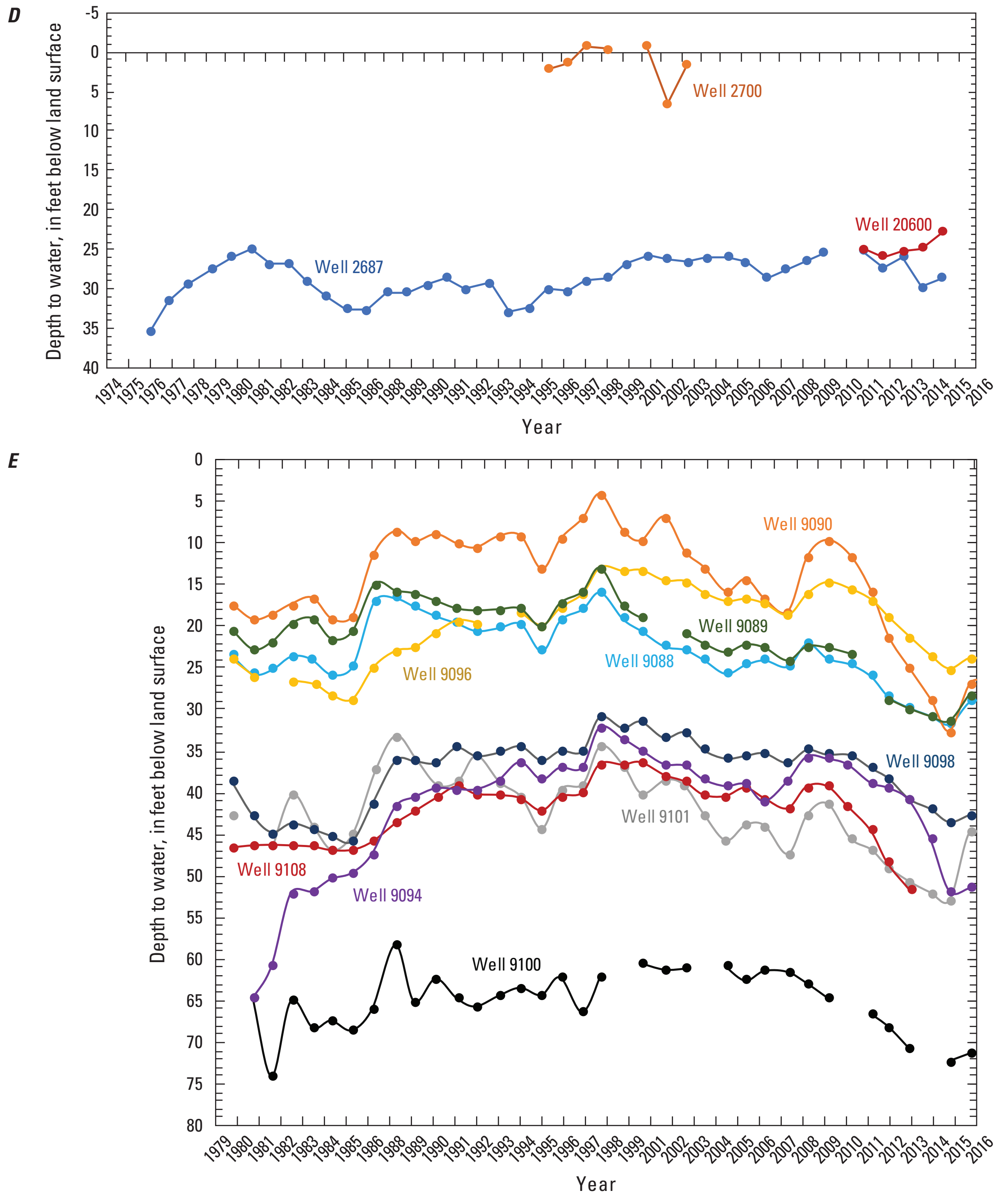


Figure 27. Long-term annual water-level measurements in Oklahoma Water Resources Board Groundwater Monitoring and Assessment Program (GMAP) wells in the alluvial aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018e). *A*, Cimarron River alluvial aquifer; *B*, North Canadian River alluvial aquifer; *C*, Canadian River alluvial aquifer; *D*, Washita River alluvial aquifer; *E*, North Fork Red River alluvial aquifer.—Continued

Table 20. Aquifer hydraulic properties and values used to describe the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

[>, greater than; <, less than; –, not available]

Aquifer		Hydraulic conductivity (feet/day)	Recharge (inches/year)	Specific yield	Transmissivity (square feet/day)	Well yield (gallons/minute)
Alluvial aquifer						
Cimarron River alluvial aquifer		15–542[ab]	2.16[c]; 2.3[d]	0.0016–0.39, median 0.067[ab]; 0.2[c]	603–10,184[ab]	5–500[c]; 10 to > 500[d]
		Terrace deposits: 98[ab]; 47.5[c]	–	–	–	–
		Alluvium: 221[ab]; 104.5[c]	–	–	–	–
North Canadian River alluvial aquifer		38.9[e]	2.5[e]	0.16[e]	–	500[e]; 10 to >500[d]
		4–279, mean 92[f]	6.3–6.9[f]	0.2[f]	–	100–300[h]
Canadian River alluvial aquifer		0.24–79, mean 19[i]	2.2[i]	22[i]	–	10 to >500[d]
Washita River alluvial aquifer		34.8[j]	3.2[j]	26.3[j]	3,148	10 to >500[d]
North Fork Red River alluvial aquifer		mean 52, median 57[k]	2.77[k]	0.12[k]	3,540–7,900, mean 5,780[k]	10 to >500[d]
Bedrock aquifer						
Ogallala aquifer		29[lm]; 19.3[n]; 61[o]	0.27[l]; 0.45[n]	<20[l]; 14.7[n]; 18.5[o]	–	>50[d]
Elk City aquifer		6.7[p]	2.78[p]	0.14[p]	815[p]	>50[d]
Rush Springs aquifer	Alluvium and terrace deposits and upper 30 feet of the Rush Springs Sandstone.	0.74 to 90; mean 48.6 (horizontal)[q]	0.01 to > 4.0; mean 3.6[g]	0.01 to 0.21; mean 0.07[q]	–	–
	Lower part of the Rush Springs Sandstone and underlying Marlow Formation.	0.01 to 90; mean 6.6 (horizontal)[q]	–	0.01 to 0.23; mean 0.07[q]	219–4,129[r]	25–400[d]; may exceed 1,000

[a]Reed and others (1952).
[b]Engineering Enterprises, Inc. (1977, 1983).
[c]Adams and Bergman (1995).
[d]Oklahoma Water Resources Board (2012a).
[e]Christenson (1983).
[f]Ryter and Correll (2016).
[g]Fay (1978).
[h]Davis and Christenson (1981).
[i]Ellis and others (2017).
[j]Kent and others (1984).
[k]Smith and others (2017).
[l]Luckey and Becker (1999).
[m]Ellis County mean.
[n]Havens and Christenson (1984).
[o]Gutentag and others (1984).
[p]Kent and others (1982).
[q]Ellis (2018).
[r]Neel and others (2015).

Table 21. Summary statistics for U.S. Geological Survey water-quality samples from wells completed in the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).

[Concentrations of constituents were measured in filtered water. MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; EPA, U.S. Environmental Protection Agency; —, not applicable; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; µg/L, microgram per liter; <, less than]

Water-quality constituents and properties	Sample count	25th percentile	Median	Mean	75th percentile	Number of samples exceeding MCL-SMCL	MCL (EPA, 2018a)	SMCL (EPA, 2018b)
Cimarron River alluvial aquifer								
pH	56	6.9	7.2	—	7.4	2	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	56	600	810	830	960	—	—	—
Dissolved solids (mg/L)[a]	20	425	510	565	650	15	—	500 mg/L
Hardness (mg/L as calcium carbonate)	25	240	280	325	390	—	—	—
Chloride (mg/L)	25	44	75	93	130	0	—	250 mg/L
Sulfate (mg/L)	25	31	44	59	70	0	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	36	6.1	13	16	18	23	10 mg/L	—
Iron (µg/L)	14	—	10	—	—	1	—	300 µg/L
Manganese (µg/L)	14	—	<10	—	—	2	—	50 µg/L
Arsenic (µg/L)	14	—	<10	—	—	0	10 µg/L	—
North Canadian River alluvial aquifer								
pH	33	—	7	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	33	630	925	1,090	1,300	—	—	—
Dissolved solids (mg/L)[a]	34	425	570	760	100	20	—	500 mg/L
Hardness (mg/L as calcium carbonate)	34	260	345	405	490	—	—	—
Chloride (mg/L)	34	25	37	71	75	0	—	250 mg/L
Sulfate (mg/L)	34	55	125	200	315	8	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	34	2.1	6.6	10	14	11	10 mg/L	—
Iron (µg/L)	34	—	40	—	—	7	—	300 µg/L
Manganese (µg/L)	22	—	155	—	—	14	—	50 µg/L
Arsenic (µg/L)	34	2.0	2.0	2.9	3.0	1	10 µg/L	—
Canadian River alluvial aquifer								
pH	12	—	7.9	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	17	765	1,700	1,700	2,320	—	—	—
Dissolved solids (mg/L)[a]	14	445	560	1,070	1,680	9	—	500 mg/L
Hardness (mg/L as calcium carbonate)	17	295	480	602	800	—	—	—
Chloride (mg/L)	17	19	42	147	288	5	—	250 mg/L
Sulfate (mg/L)	15	120	240	440	632	7	—	250 mg/L
Iron (µg/L)	3	440	540	510	540	3	—	300 µg/L
Washita River alluvial aquifer								
pH	6	—	7.2	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	6	1,220	1,730	1,700	3,000	—	—	—
Dissolved solids (mg/L)[a]	2	—	—	3,190	—	2	—	500 mg/L
Hardness (mg/L as calcium carbonate)	6	615	1,050	1,200	1,930	—	—	—
Chloride (mg/L)	6	16	30	34	53	0	—	250 mg/L
Sulfate (mg/L)	6	600	1,010	1,200	1,890	6	—	250 mg/L
Nitrate (as nitrogen) (mg/L)	6	0.07	0.41	1.9	4.8	0	10 mg/L	—

Table 21. Summary statistics for U.S. Geological Survey water-quality samples from wells completed in the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018b).—Continued

[Concentrations of constituents were measured in filtered water. MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; EPA, U.S. Environmental Protection Agency; —, not applicable; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; µg/L, microgram per liter; <, less than]

Water-quality constituents and properties	Sample count	25th percentile	Median	Mean	75th percentile	Number of samples exceeding MCL-SMCL	MCL (EPA, 2018a)	SMCL (EPA, 2018b)
North Fork Red River alluvial aquifer								
pH	24	—	7.4	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	24	710	770	920	895	—	—	—
Dissolved solids (mg/L)[a]	24	440	535	670	620	14	—	500 mg/L
Hardness (mg/L as calcium carbonate)	24	270	335	440	440	—	—	—
Chloride (mg/L)	24	14	18	30	36	0	—	250 mg/L
Sulfate (mg/L)	24	50	125	220	190	5	—	250 mg/L
Nitrate (as nitrogen) (mg/L)	22	1.9	4.4	4.7	6.2	2	10 mg/L	—
Ogallala aquifer								
pH	23	—	7.7	—	—	—	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	23	440	560	690	760	—	—	—
Dissolved solids (mg/L)[a]	23	280	360	470	470	4	—	500 mg/L
Hardness (mg/L as calcium carbonate)	23	190	220	300	250	—	—	—
Chloride (mg/L)	23	8.1	12	32	28	0	—	250 mg/L
Sulfate (mg/L)	23	10	20	92	36	1	—	250 mg/L
Nitrate (as nitrogen) (mg/L)	19	2.5	4.5	5.0	8.9	1	10 mg/L	—
Elk City aquifer								
pH	7	—	7.9	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	7	520	570	560	610	—	—	—
Dissolved solids (mg/L)[a]	7	320	340	340	380	0	—	500 mg/L
Hardness (mg/L as calcium carbonate)	7	200	280	260	310	—	—	—
Chloride (mg/L)	7	6.5	10	10	12	0	—	250 mg/L
Sulfate (mg/L)	7	7.8	16	15	21	0	—	250 mg/L
Nitrate (as nitrogen) (mg/L)	7	0.38	5.0	5.5	9.0	1 (16 mg/L)	10 mg/L	—
Rush Springs aquifer								
pH	58	—	7.4	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	53	590	940	1,660	2,640	—	—	—
Dissolved solids (mg/L)[a]	34	290	360	875	760	11	—	500 mg/L
Hardness (mg/L as calcium carbonate)	60	210	370	790	1,330	—	—	—
Chloride (mg/L)	60	9.9	17	92	46	2	—	250 mg/L
Sulfate (mg/L)	60	28	135	670	1,580	26	—	250 mg/L
Nitrate (as nitrogen) (mg/L)	37	0.6	3.2	6.6	7.2	5	10 mg/L	—
Arsenic (µg/L)	38	<10	<10	—	<10	1	10 µg/L	—

[a]Dried at 180 degrees Celsius.

[b]Analyzed as nitrate plus nitrite (as nitrogen).

Table 22. Summary statistics for Oklahoma Water Resources Board Groundwater Monitoring and Assessment Program (GMAP) water-quality samples from wells completed in the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018d).

[Concentrations of constituents were measured in filtered water unless otherwise noted. MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; EPA, U.S. Environmental Protection Agency; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; —, not applicable; mg/L, milligram per liter; µg/L, microgram per liter]

Water-quality constituents and properties	Well count	25th percentile	Median	Mean	75th percentile	Number of samples exceeding MCL-SMCL	MCL (EPA, 2018a)	SMCL (EPA, 2018b)
Cimarron River alluvial aquifer								
pH	8	6.9	7.0	7.1	7.4	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	8	750	860	920	1,250	—	—	—
Dissolved solids (mg/L) unfiltered[a]	8	330	565	560	770	5	—	500 mg/L
Hardness (mg/L as calcium carbonate) unfiltered	8	210	280	305	405	—	—	—
Chloride (mg/L)	8	63	100	110	150	0	—	250 mg/L
Sulfate (mg/L)	8	37	42	54	75	0	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	8	8.7	13	13	17	6	10 mg/L	—
Iron (µg/L)	8	50	50	50	50	0	—	300 µg/L
Manganese (µg/L)	8	0.5	0.5	1.02	0.5	0	—	50 µg/L
Arsenic (µg/L)	8	1.05	1.17	1.32	1.71	0	10 µg/L	—
North Canadian River alluvial aquifer								
pH	13	6.7	6.9	6.9	7.1	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	13	665	1,000	1,220	1,700	—	—	—
Dissolved solids (mg/L) unfiltered[a]	13	395	575	750	1,040	8	—	500 mg/L
Hardness (mg/L as calcium carbonate) unfiltered	13	280	410	445	560	—	—	—
Chloride (mg/L)	13	20	57	77	130	0	—	250 mg/L
Sulfate (mg/L)	13	68	175	190	285	4	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	13	0.03	6.6	5.2	11	3	10 mg/L	—
Iron (µg/L)	13	10	33	495	1,175	6	—	300 µg/L
Manganese (µg/L)	13	2.5	155	250	405	7	—	50 µg/L
Arsenic (µg/L)	13	0.5	2.5	3.1	5.5	0	10 µg/L	—
Canadian River alluvial aquifer								
pH	17	—	7.1	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	17	805	1,720	1,800	2,650	—	—	—
Dissolved solids (mg/L) unfiltered[a]	17	515	1,350	1,490	2,240	14	—	500 mg/L
Hardness (mg/L as calcium carbonate) unfiltered	17	385	870	1,000	1,490	—	—	—
Chloride (mg/L)	17	15	36	51	60	0	—	250 mg/L
Sulfate (mg/L)	17	98	650	785	1,320	11	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	17	0.45	2	4.5	9.2	3	10 mg/L	—
Iron (µg/L)	17	25	25	630	737	4	—	300 µg/L
Manganese (µg/L)	17	25	25	130	245	6	—	50 µg/L
Arsenic (µg/L)	17	5	5	6.3	5	2	10 µg/L	—
Uranium (µg/L)	17	3.1	5	12	22	2	30 µg/L	—

Table 22. Summary statistics for Oklahoma Water Resources Board Groundwater Monitoring and Assessment Program (GMAP) water-quality samples from wells completed in the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018d).—Continued

[Concentrations of constituents were measured in filtered water unless otherwise noted. MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; EPA, U.S. Environmental Protection Agency; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; —, not applicable; mg/L, milligram per liter; µg/L, microgram per liter]

Water-quality constituents and properties	Well count	25th percentile	Median	Mean	75th percentile	Number of samples exceeding MCL-SMCL	MCL (EPA, 2018a)	SMCL (EPA, 2018b)
Washita River alluvial aquifer								
pH	13	—	7.4	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	13	2,590	2,890	3,000	3,490	—	—	—
Dissolved solids (mg/L) unfiltered[a]	13	2,390	2,780	2,750	3,220	13	—	500 mg/L
Hardness (mg/L as calcium carbonate) unfiltered	13	1,570	1,690	1,640	1,840	—	—	—
Chloride (mg/L)	13	24	37	49	73	0	—	250 mg/L
Sulfate (mg/L)	13	1,410	1,800	1,690	2,010	13	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	13	0.03	0.4	2.4	2.8	1	10 mg/L	—
Iron (µg/L)	13	24	110	290	665	4	—	300 µg/L
Manganese (µg/L)	13	13	140	210	360	7	—	50 µg/L
Arsenic (µg/L)	13	1.8	2.8	3.3	4.7	0	10 µg/L	—
Uranium (µg/L)	13	2.7	7.7	9.5	12	1	30 µg/L	—
North Fork Red River alluvial aquifer								
pH	14	—	7.0	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	14	615	770	960	1,140	—	—	—
Dissolved solids (mg/L) unfiltered[a]	14	370	490	655	800	7	—	500 mg/L
Hardness (mg/L as calcium carbonate) unfiltered	14	235	315	440	535	—	—	—
Chloride (mg/L)	14	9.1	15	32	35	0	—	250 mg/L
Sulfate (mg/L)	14	38	92	220	315	3	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	14	4.7	7.4	7.6	10	4	10 mg/L	—
Iron (µg/L)	14	10	10	10	10	0	—	300 µg/L
Manganese (µg/L)	14	2.5	2.5	2.5	2.5	0	—	50 µg/L
Arsenic (µg/L)	14	0.5	1.4	1.6	2.2	0	10 µg/L	—
Uranium (µg/L)	14	1.7	3.6	4.0	5.1	0	30 µg/L	—
Ogallala aquifer								
pH	30	—	7.1	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	30	505	625	745	830	—	—	—
Dissolved solids (mg/L)[a]	30	295	350	440	485	7	—	500 mg/L
Hardness (mg/L as calcium carbonate)	30	205	225	265	270	—	—	—
Chloride (mg/L)	30	<5	15	29	39	0	—	250 mg/L
Sulfate (mg/L)	30	13	15	54	27	0	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	30	3.6	6.7	9.6	12	8	10 mg/L	—
Arsenic (µg/L)	27	—	<5	—	—	0	10 µg/L	—
Uranium (µg/L)	27	—	1.8	—	—	0	30 µg/L	—

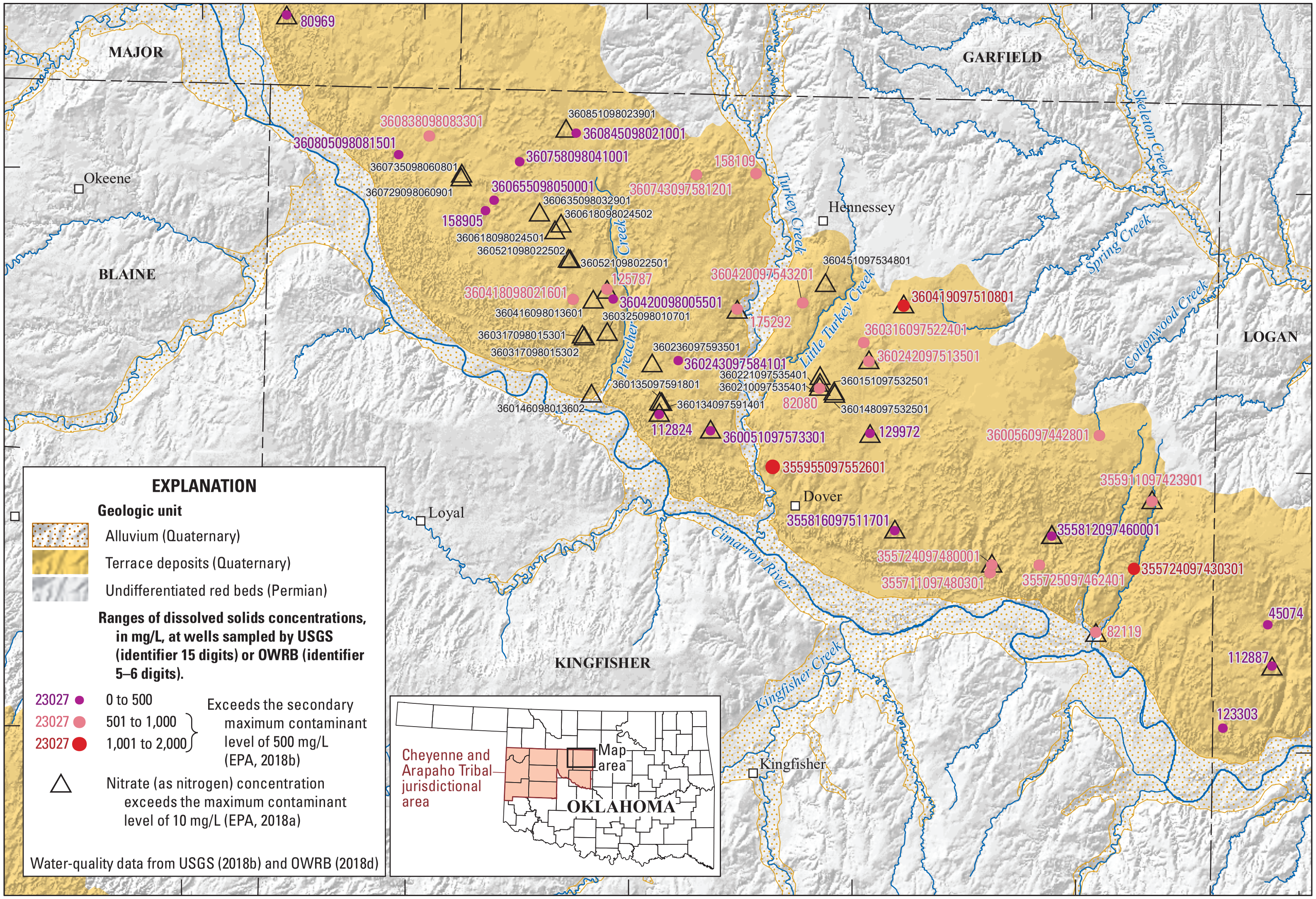
Table 22. Summary statistics for Oklahoma Water Resources Board Groundwater Monitoring and Assessment Program (GMAP) water-quality samples from wells completed in the alluvial and bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018d).—Continued

[Concentrations of constituents were measured in filtered water unless otherwise noted. MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; EPA, U.S. Environmental Protection Agency; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; —, not applicable; mg/L, milligram per liter; µg/L, microgram per liter]

Water-quality constituents and properties	Well count	25th percentile	Median	Mean	75th percentile	Number of samples exceeding MCL-SMCL	MCL (EPA, 2018a)	SMCL (EPA, 2018b)
Elk City aquifer								
pH	14	—	7.3	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	14	570	610	630	700	—	—	—
Dissolved solids (mg/L)[a]	14	330	365	360	400	0	—	500 mg/L
Hardness (mg/L as calcium carbonate)	14	255	275	280	290	—	—	—
Chloride (mg/L)	13	5	11	13	14	0	—	250 mg/L
Sulfate (mg/L)	14	5	17	15	19	0	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	14	3.3	6.6	6.4	8.3	1 (19 mg/L)	10 mg/L	—
Arsenic (µg/L)	13	—	<5	—	—	0	10 µg/L	—
Uranium (µg/L)	13	—	1.4	—	—	0	30 µg/L	—
Rush Springs aquifer								
pH	37	—	7.2	—	—	0	—	6.5–8.5
Specific conductance (µS/cm at 25 °C)	37	470	750	1,320	2,380	—	—	—
Dissolved solids (mg/L)[a]	37	290	515	1,120	2,270	19	—	500 mg/L
Hardness (mg/L as calcium carbonate)	37	205	375	785	1,660	—	—	—
Chloride (mg/L)	37	5	14	45	35	0	—	250 mg/L
Sulfate (mg/L)	37	22	71	560	1,360	14	—	250 mg/L
Nitrate (as nitrogen) (mg/L)[b]	37	1.39	3.5	8.3	9.7	9	10 mg/L	—
Arsenic (µg/L)	37	—	<5	—	—	2	10 µg/L	—
Uranium (µg/L)	37	—	1.4	—	—	0	30 µg/L	—

[a]Dried at 180 degrees Celsius.

[b]Analyzed as nitrate plus nitrite (as nitrogen).



Base modified from U.S. Geological Survey 1:100,000-scale digital data
Albers Equal-Area Conic projection
North American Datum of 1983

0 5 MILES
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Aquifer boundaries from Oklahoma Water Resources Board (2015)
Tribal jurisdictional area boundary from U.S. Census Bureau (2018)

Figure 28. Distribution of groundwater samples from wells in the Cimarron River alluvial aquifer and ranges of dissolved solids concentrations and concentrations of nitrate (as nitrogen) that exceed the maximum contaminant levels allowable in finished drinking water, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. All arsenic concentrations were smaller than the maximum contaminant level of 10 micrograms per liter (U.S. Environmental Protection Agency, 2018a). EPA, U.S. Environmental Protection Agency; mg/L, milligram per liter; OWRB, Oklahoma Water Resources Board; USGS, U.S. Geological Survey.

North Canadian River Alluvial Aquifer

The North Canadian River alluvial aquifer is on the northeastern side of the North Canadian River and covers an area of about 360 mi^2 in the CATJA (fig. 2). The alluvial aquifer extends from north of Canton Lake at the northern county lines of Dewey and Blaine Counties to about 3 mi west of the Canadian County-Oklahoma County line. The alluvium and terrace deposits are about 9 mi wide at the northern boundary of the CATJA and range from about 3.5 to 5.5 mi wide downstream to the southeastern extent of the aquifer in the CATJA. The North Canadian River alluvial aquifer is considered a reliably good source of water with overall fair water quality (OWRB, 2012a). The red beds underlying the alluvial aquifer are part of the El Reno Group and generally are impermeable and are not considered a reliable source of water (fig. 6) (Bingham and Moore, 1975).

The 2012 "Oklahoma Comprehensive Water Plan Executive Report" identified the North Canadian River Basin in the CATJA as a "hot spot" for potential future shortages in water supply (OWRB, 2012a). The demand for water is projected to increase by about 32 percent from 2010 to 2060 as a result of the anticipated increase in population and water use (OWRB, 2012a).

Water Use and Allocations

Groundwater from the North Canadian River alluvial aquifer is used primarily for irrigation and public-water supply and in smaller amounts for mining, industrial, and commercial uses (figs. 26 and 29) (C. Neel, OWRB, written commun., 2016). Public-water supply (55 percent) and irrigation (39 percent) accounted for most of water withdrawn from the alluvial aquifer during 2015 (fig. 29). Reported amounts of groundwater withdrawals from the alluvial aquifer during 2015 indicate that only about 17 percent of the total amount of groundwater allocated for pumping in the CATJA was withdrawn (fig. 29 and table 18) (OWRB, 2018c). Of the total 52,970 acre-ft that was allocated, 9,155 acre-ft was reportedly used. The total number of permits for groundwater withdrawal has increased from 66 to 267 from 1980 to 2015, with the largest increases in groundwater allocations designated for irrigation and public-water supply (OWRB, 2018c) (table 18).

Water Levels and Saturated Thickness

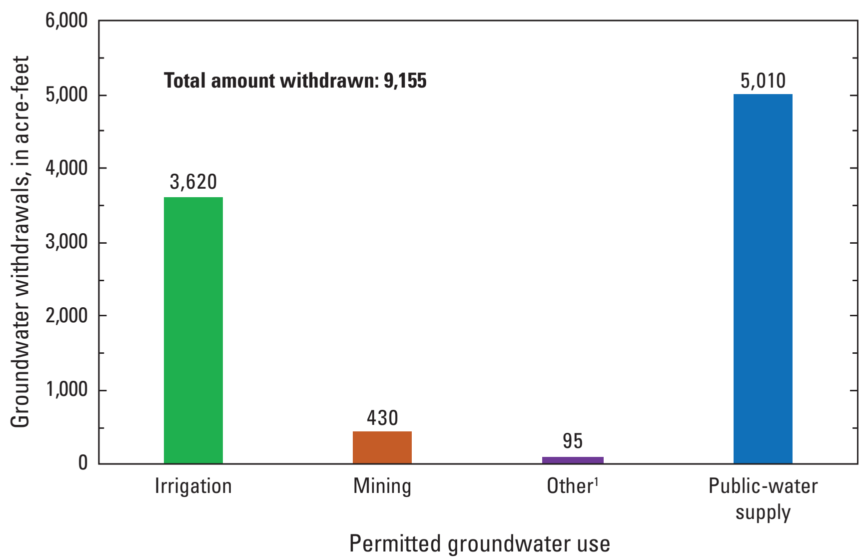
Water levels in the North Canadian River alluvial aquifer can be monitored online through the OWRB map application Groundwater Level Monitoring Wells in Oklahoma (fig. 10) (OWRB, 2018e). In the CATJA, depth to water is measured annually in eight wells by the OWRB as part of GMAP (table 19). Long-term water-level measurement records are available from five of these eight wells; measurements began between 1976 and 1978 depending on the well.

Mean depths to water ranged from 9.0 to 48.2 ft below land surface in the eight wells measured annually by OWRB; the depth of each of these eight wells ranges from 45 to 80 ft (table 19). Annual mean groundwater-level fluctuations ranged from 1.2 to 3.5 ft in the eight wells over the respective periods of measurement. The mean saturated thickness of the aquifer at these well locations ranged from 31 to 40 ft.

Ryter and Correll (2016, fig. 13) reported that groundwater in the North Canadian River alluvial aquifer moves downgradient toward the streambed of the North Canadian River. Groundwater discharging from the aquifer results in the river gaining streamflow as it flows through the CATJA (Ryter and Correll, 2016). Ryter and Correll (2016, fig. 13) also showed that the approximate depth to water throughout most of the aquifer is less than 20 ft from land surface and is deepest along the northeastern extent of the aquifer. In northwestern Harper County and southeastern Woodward County, the depth to water in the aquifer is greater than 150 ft from land surface (Ryter and Correll, 2016, fig. 13).

Aquifer Hydraulic Properties and Values

A groundwater-flow model was developed by Christenson (1983) for the part of the North Canadian River alluvial aquifer from the dam that impounds Canton Lake to Lake Overholser (fig. 10). Relying on hydrologic information published in this 1983 report, in April 1990 the OWRB made a



[1]Industrial and commercial.

Figure 29. Reported groundwater withdrawals for permitted uses during 2015 from the North Canadian River alluvial aquifer, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (C. Neel, Oklahoma Water Resources Board, written commun., 2016).

final determination on the MAY and EPS for the aquifer, setting these values as 211,840 acre-ft/yr and 0.8–1.3 acre-ft/acre/yr, respectively (table 17) (OWRB, 2012a).

More recently, an updated groundwater-flow model was developed by Ryter and Correll (2016). By using updated aquifer properties and values, this 2016 report demonstrated multiple scenarios describing the effects of groundwater withdrawals and drought on the North Canadian River alluvial aquifer. Ranges of aquifer properties and values published by Christenson (1983) and Ryter and Correll (2016) to describe the alluvial aquifer are provided (table 20).

Water Quality

Water-quality information from the North Canadian River alluvial aquifer is available from the USGS NWIS database (USGS, 2018b) and the OWRB GMAP (OWRB, 2018d). Water samples from 34 wells collected by the USGS during July and August 1980 and water samples from 13 wells collected by the OWRB GMAP during August and September 2015 are used to describe water quality in the North Canadian River alluvial aquifer in the CATJA.

Water samples collected by the USGS and OWRB that were analyzed for dissolved solids and other constituents that may limit the use of groundwater as a source of water for public-water supply are shown on figure 30. These water-quality data are used to show ranges of dissolved solids concentrations in addition to locations where nitrate (as nitrogen) and arsenic exceeded their respective MCLs in finished drinking water.

Groundwater from the North Canadian River alluvial aquifer has a neutral pH of around 7, tends to be extremely hard, and often contains large concentrations of dissolved solids, sulfate, iron, and manganese that exceed their respective SMCLs for finished drinking water (fig. 30 and tables 21 and 22). Dissolved solids concentrations were large in most samples and exceeded the SMCL of 500 mg/L in 20 of 34 USGS samples (median concentration of 570 mg/L) and in 8 of 13 OWRB samples (median concentration of 575 mg/L). Samples show that groundwater is extremely hard. More than 75 percent of the samples collected by the USGS showed that hardness as calcium carbonate concentrations were greater than 260 mg/L. Concentrations of sulfate exceeded the SMCL of 250 mg/L in 8 of 34 USGS samples and 4 of 13 OWRB samples, with median concentrations of 125 and 175 mg/L, respectively (tables 21 and 22).

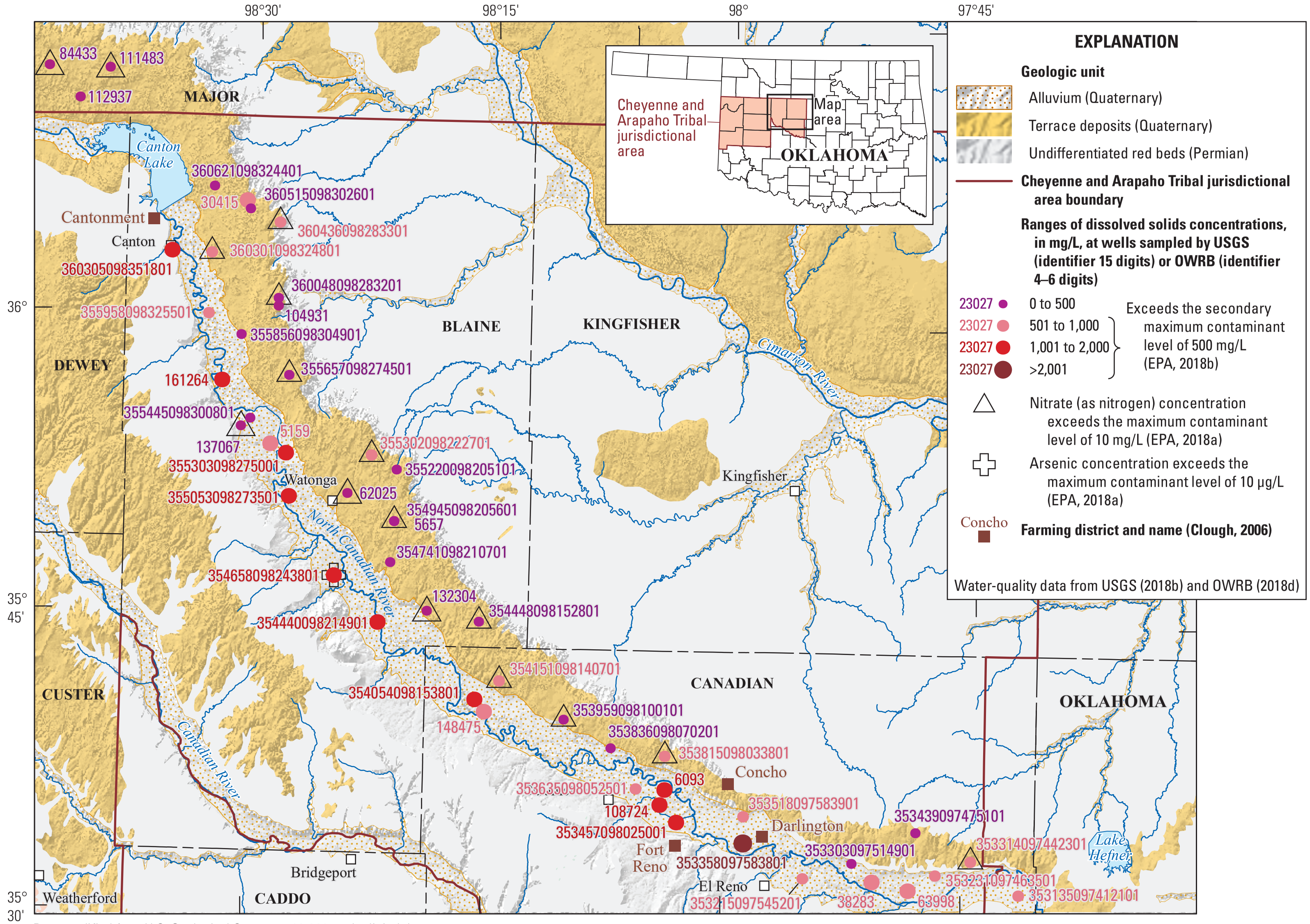
Nitrate (as nitrogen) was measured in 11 of 34 USGS samples and 3 of 13 OWRB samples at concentrations that exceeded the MCL for nitrogen of 10 mg/L in finished drinking water (fig. 30 and tables 21 and 22) (EPA, 2018a). Median nitrate (as nitrogen) concentrations of both USGS and OWRB samples is 6.6 mg/L.

Arsenic was measured in 1 sample (out of 47 samples collected by the USGS and OWRB) at a concentration exceeding the MCL of 10 µg/L (tables 21 and 22). This sample was collected from a well in the alluvium (as opposed to the terrace deposits) (fig. 30) and had an arsenic concentration of 15 µg/L.

Samples collected by the USGS indicate that the North Canadian River alluvial aquifer contains water of several different types. Of 33 samples evaluated for water type in the CATJA, 9 were calcium-bicarbonate type, 16 were mixed cation-bicarbonate type, 4 were mixed cation-mixed anion type, 2 were calcium-sulfate type, 1 was calcium-mixed anion type, and 1 was a sodium-sulfate type (USGS, 2018b).

Canadian River Alluvial Aquifer

The Canadian River alluvial aquifer lies adjacent to 216 mi of the river in the CATJA, beginning at the western edge of Ellis County and ending near the Canadian County line (fig. 2). The alluvial aquifer is relatively narrow, averaging about 1.5 mi wide and covering an area of about 360 mi^2 (fig. 2). The alluvium deposits that compose the Canadian River alluvial aquifer are underlain by the Permian-aged Cloud Chief Formation, Rush Springs Formation, and Marlow Formation in addition to the Tertiary-aged Ogallala Formation at the western edge (fig. 6).



Base modified from U.S. Geological Survey 1:100,000-scale digital data
Albers Equal-Area Conic projection
North American Datum of 1983

Aquifer boundaries from Oklahoma Water Resources Board (2015)
Tribal jurisdictional area boundary from U.S. Census Bureau (2018)

Figure 30. Distribution of water samples from wells in the North Canadian River alluvial aquifer and ranges of dissolved solids concentrations and concentrations of nitrate (as nitrogen) and arsenic exceeding the maximum contaminant levels allowable in finished drinking water, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. EPA, U.S. Environmental Protection Agency; µg/L, microgram per liter; mg/L, milligram per liter; OWRB, Oklahoma Water Resources Board; USGS, U.S. Geological Survey.

Water Use and Allocations

Groundwater from the Canadian River alluvial aquifer is used primarily for irrigation with smaller amounts used for public-water supply, mining, and other uses (figs. 31 and 32) (C. Neel, OWRB, written commun., 2016). Irrigation was the largest use of the water withdrawn from the alluvial aquifer during 2015, accounting for about 92 percent of the total reported withdrawals (fig. 31). Reported amounts of groundwater withdrawals from the alluvial aquifer during 2015 indicate that only about 20 percent of the total amount of water allocated for pumping in the CATJA was withdrawn (fig. 31 and table 18) (OWRB, 2018c). Of the total 57,940 acre-ft that was allocated, 11,730 acre-ft was reportedly used (table 18 and fig. 31). Where the alluvial aquifer overlies the Ogallala and Rush Springs aquifers (fig. 32), the reported water-use amounts may include withdrawals from these aquifers also. The total number of permits for groundwater withdrawal has increased from 30 to 105 from 1980 to 2015, with the largest increases in groundwater allocated for irrigation and mining (fig. 32 and table 18) (OWRB, 2018c).

Water Levels and Saturated Thickness

Information about water levels and annual fluctuations in the Canadian River alluvial aquifer in the CATJA is sparse. Water levels in the alluvial aquifer can be monitored online through the OWRB map application Groundwater Level Monitoring Wells in Oklahoma (fig. 10) (OWRB, 2018e). In the CATJA, depths to water are measured annually in five wells located in four counties by the OWRB as part of GMAP (fig. 27*B* and table 19).

Mean depths to water during January through March ranged from 4.1 to 36.4 ft below land surface in the five wells, four of which have well depths of 38 to 95 ft (table 19). Annual mean groundwater-level fluctuations ranged from 0.4 to 1.8 ft over the respective periods of measurement. The mean saturated thickness in the four wells with available data ranged from 26 to 59 ft.

Three of the five OWRB GMAP wells have 16–33 years of annual water-level measurements and, when plotted on a time-series hydrograph, reflect the small water-level fluctuations that have occurred over the period of measurements (fig. 27*C*). Measurements show that water levels have stayed relatively constant in GMAP wells 9666 and 20075 but have decreased in GMAP well 19934.

As reported by Ellis and others (2017), during 2013, water levels were relatively shallow, less than 30 ft below land surface, in 140 wells that were measured throughout the Canadian River alluvial aquifer from the Texas-Oklahoma border to Eufaula Lake.

Ellis and others (2017) also reported that water levels in the Canadian River alluvial aquifer can fluctuate from 2 to 10 ft in wells, depending on distance from the river, amount of precipitation, evapotranspiration, and groundwater pumpage.

Aquifer Hydraulic Properties and Values

Aquifer hydraulic properties and values used by Ellis and others (2017) to construct a groundwater-flow model of the Canadian River alluvial aquifer are shown on table 20. The resulting EPS pumping rate calculated by Ellis and others (2017) ranged from 1.31 to 1.38 acre-ft/acre/yr. However, the Canadian River alluvial aquifer does not have a MAY or EPS determined by OWRB as of 2019. A temporary EPS pumping rate of 2 acre-ft/acre/yr is used for allocating groundwater for permitted uses (table 17) (OWRB, 2012a).

Water Quality

Water-quality information describing the Canadian River alluvial aquifer within the CATJA is available from the USGS NWIS database (USGS, 2018b) and from the OWRB GMAP (OWRB, 2018c). Information from the USGS NWIS database includes samples from 17 wells collected from 1947 to 1972. These samples were analyzed for water-quality field properties and major ions but were not analyzed for nitrogen or arsenic (table 21). Water-quality samples were collected by the OWRB from 17 wells during August to September 2013. The samples were analyzed for nitrate (as nitrogen), arsenic, and other trace elements (table 22).

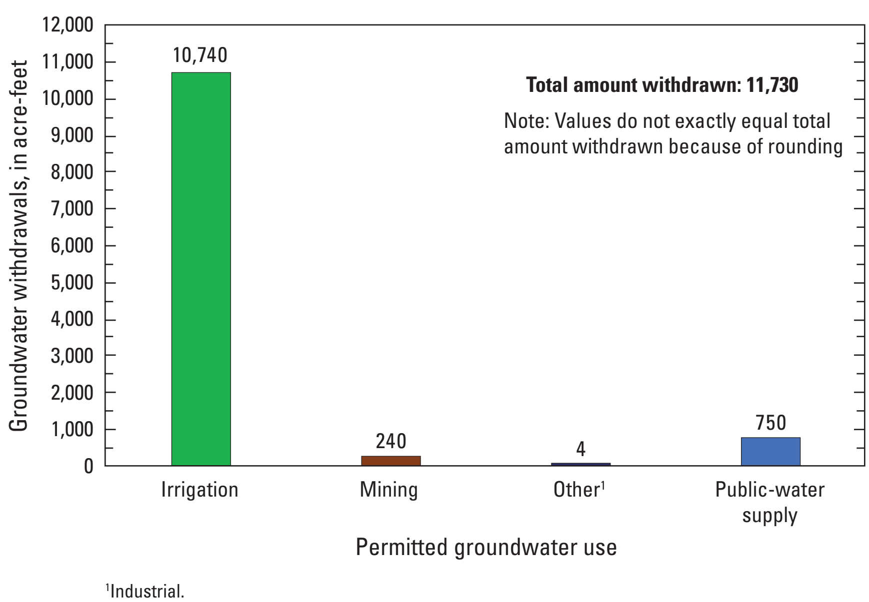


Figure 31. Reported groundwater withdrawals for permitted uses during 2015 from the Canadian River alluvial aquifer, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (C. Neel, Oklahoma Water Resources Board, written commun., 2016). Reported water-use amounts may include withdrawals from the Rush Springs and Ogallala aquifers where the Canadian River alluvial aquifer overlies these aquifers.

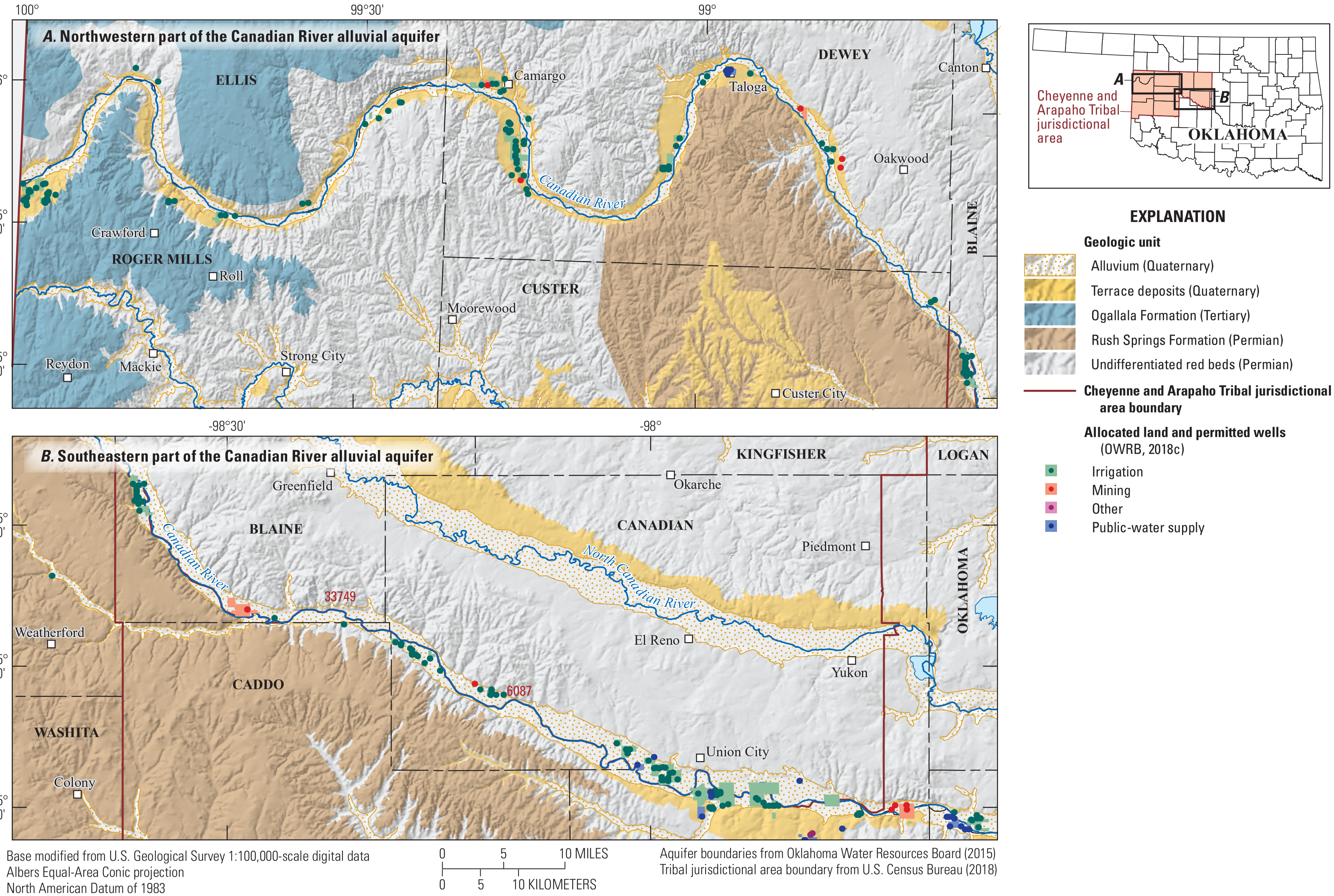


Figure 32. Allocated land and permitted wells withdrawing groundwater from the Canadian River alluvial aquifer during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. *A*, Northwestern part of the Canadian River alluvial aquifer; *B*, southeastern part of the Canadian River alluvial aquifer. OWRB, Oklahoma Water Resources Board.

Water samples collected by the USGS and the OWRB that were analyzed for dissolved solids and other constituents that may limit the use of groundwater as a source of water for public-water supply are shown on figure 33. These water-quality data are used to show ranges of dissolved solids concentrations in addition to locations where concentrations of nitrate (as nitrogen), arsenic, and uranium exceeded their respective MCLs in finished drinking water.

Samples from the USGS and the OWRB show that water from the Canadian River alluvial aquifer in the CATJA has a neutral to basic pH ranging from 7.1 to 7.9 (tables 21 and 22). Water from the Canadian River alluvial aquifer tends to be extremely hard and has large concentrations of dissolved solids, sulfate, iron, and manganese that exceed their respective SMCLs for finished drinking water in selected samples.

Dissolved solids concentrations were large in water from the Canadian River alluvial aquifer in the CATJA, exceeding the SMCL of 500 mg/L in 9 of 14 USGS samples with a median concentration of 560 mg/L and in 14 of 17 OWRB samples with a median concentration of 1,350 mg/L (fig. 33 and tables 21 and 22). Samples show that the groundwater tends to be extremely hard. More than 75 percent of USGS samples had hardness as calcium carbonate concentrations larger than 295 mg/L, which for this assessment is considered extremely hard. Sulfate concentrations exceeded the SMCL of 250 mg/L for finished drinking water in 7 of 15 USGS samples and 11 of 17 OWRB samples with median sulfate concentrations of 240 and 650 mg/L, respectively (tables 21 and 22).

Nitrate (as nitrogen) in 3 of 17 OWRB samples exceeded the MCL of 10 mg/L for finished drinking water (table 22) (EPA, 2018a). The trace elements arsenic and uranium were each measured in 2 of 17 OWRB samples at concentrations exceeding their respective MCLs of 10 µg/L and 30 µg/L allowable in finished drinking water (EPA, 2018a) (tables 21 and 22). Arsenic was measured at 12.2 and 19.9 µg/L, and uranium was measured at 35.9 and 40.8 µg/L.

Ellis and others (2017) explained that water type varies by location in the alluvial aquifer because of inflow of water from the underlying bedrock units. Where the aquifer overlies the Ogallala Formation and the Cloud Chief Formation (fig. 6), gypsum contributes calcium, magnesium, and sulfate ions to the water, making the water type in this area of the aquifer calcium and magnesium-sulfate type (Ellis and others, 2017). As the Canadian River flows southeast over the Rush Springs Formation, the water type transitions to a calcium and magnesium-bicarbonate type (Ellis and others, 2017).

Of the 13 USGS samples evaluated for water type in the CATJA, only 2 were suitable for determining water type. Of the two samples, one was a calcium-bicarbonate type, and the other was a calcium and sodium-bicarbonate type.

Washita River Alluvial Aquifer

The Washita River alluvial aquifer in the CATJA begins at the Texas-Oklahoma border and overlies the river valley in Roger Mills and Custer Counties, covering about 420 mi^2 (fig. 2). South of Custer County, the Washita River continues into Washita County, but the alluvium and terrace deposits along this section of the river are thin and are not considered a reliable source of groundwater (OWRB, 2012b). The Washita River was dammed during 1958–61, creating Foss Reservoir in western Custer County.

Water Use and Allocations

Groundwater from the Washita River alluvial aquifer is used almost exclusively for irrigation. About 99 percent of the total 4,755 acre-ft reportedly used during 2015 was used for irrigation (figs. 34 and 35) (C. Neel, OWRB, written commun., 2016). Smaller amounts of groundwater were used for mining (6 acre-ft) and public-water supply (35 acre-ft) during 2015 (fig. 35). Reported groundwater withdrawals from the alluvial aquifer during 2015 indicate that only about 8 percent of the total amount of groundwater allocated for pumping in the CATJA was withdrawn (fig. 35 and table 18) (OWRB, 2018c). Of the total 63,320 acre-ft that was allocated, 4,755 acre-ft was used.

Wells located where the alluvial aquifer overlies the Rush Springs aquifer (fig. 34) may be withdrawing water from the Rush Springs or both aquifer units and were not included in allocation totals. The total number of permits for groundwater withdrawal increased from 13 to 174 between 1980 and 2015, with the largest increases in groundwater allocated to irrigation (table 18) (OWRB, 2018c).

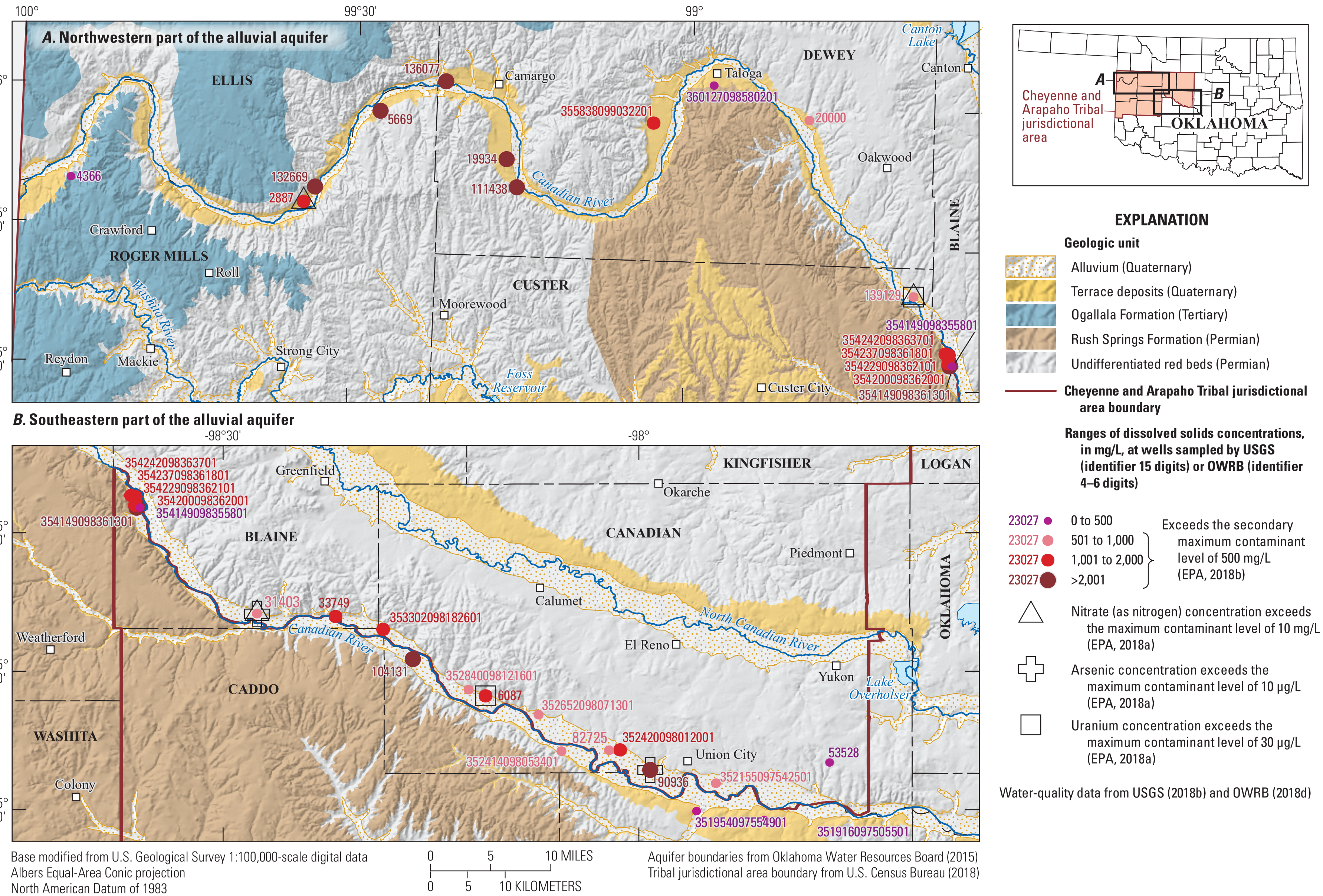
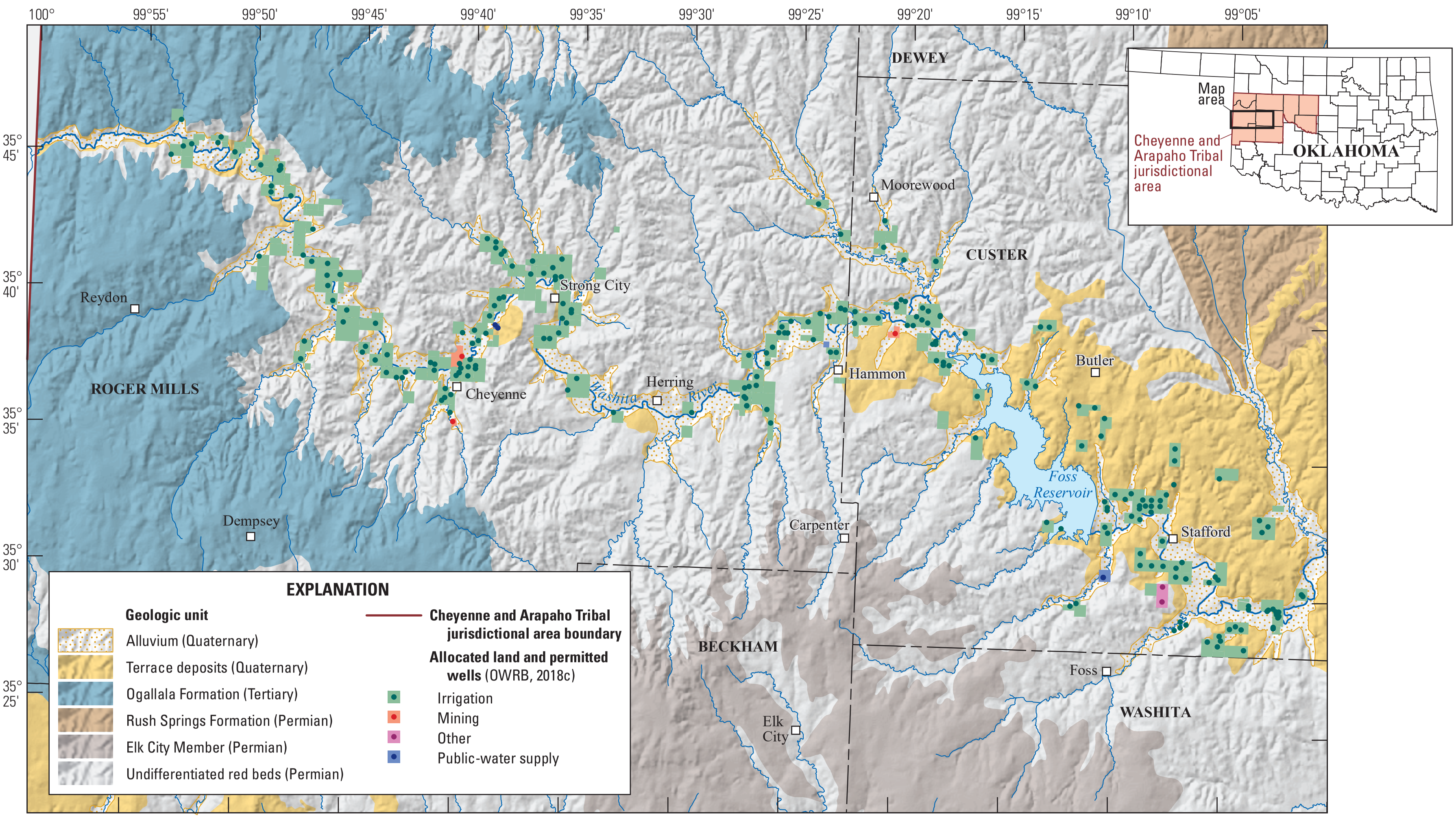


Figure 33. Distribution of water samples from wells in the Canadian River alluvial aquifer and ranges of dissolved solids concentrations and concentrations of nitrate (as nitrogen), arsenic, and uranium exceeding the maximum contaminant levels allowed in finished drinking water, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. *A*, Northwestern part of the alluvial aquifer in Ellis, Roger Mills, Dewey, and Custer Counties; *B*, southeastern part of the alluvial aquifer in Blaine and Canadian Counties. EPA, U.S. Environmental Protection Agency; µg/L, microgram per liter; mg/L, milligram per liter; OWRB, Oklahoma Water Resources Board; USGS, U.S. Geological Survey.



Base modified from U.S. Geological Survey 1:100,000-scale digital data
Albers Equal-Area Conic projection
North American Datum of 1983

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Aquifer boundaries from Oklahoma Water Resources Board (2015)
Rush Springs aquifer boundary from Neel and others (2015)
Tribal jurisdictional area boundary from U.S. Census Bureau (2018)

Figure 34. Allocated land and permitted wells withdrawing groundwater from the Washita River alluvial aquifer during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. OWRB, Oklahoma Water Resources Board.

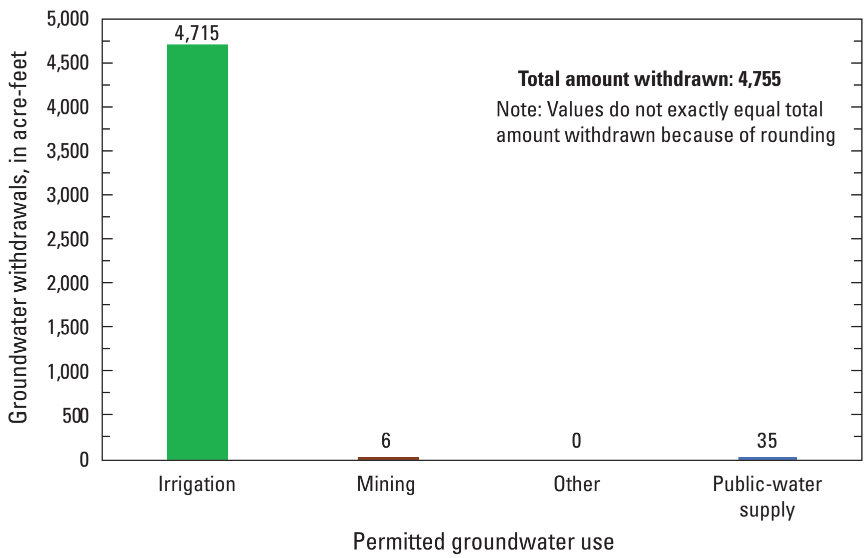


Figure 35. Reported groundwater withdrawals for permitted uses during 2015 from the Washita River alluvial aquifer, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (C. Neel, Oklahoma Water Resources Board, written commun., 2016).

Water Levels and Saturated Thickness

Information about water levels and annual fluctuations in the Washita River alluvial aquifer in the CATJA is sparse. Water levels in the Washita River alluvial aquifer can be monitored online through the OWRB map application Groundwater Level Monitoring Wells in Oklahoma (fig. 10) (OWRB, 2018e). In the CATJA, depth to water is measured annually in four wells by the OWRB as part of GMAP (table 19).

The only well completed in the alluvial aquifer for which a record of long-term water-level measurements is available is GMAP well 2687 in Roger Mills County (figs. 10 and 27*D* and table 19). Measurements show that depth to water in GMAP well 2687 has averaged about 28.6 ft below land surface and has shown an annual mean fluctuation of about 1.4 ft over the 40-year period of record (fig. 27*D and* table 19). Depths to water in the OWRB GMAP wells over shorter periods of time (2700, 20600, 105710) have exhibited annual mean fluctuations from 1.0 to 3.1 ft over 3–7 years during different periods (table 19).

Kent and others (1984) described mean depth to water in the Washita River alluvial aquifer as 17 ft from land surface and the mean saturated thickness as 118 ft with a maximum of 189 ft. Saturated thickness at the OWRB GMAP wells 2687 and 2700 has averaged 57 and 181 ft, respectively (table 19). GMAP well 20600 had a mean saturated thickness of 75 ft from 2012 to 2016, whereas well 105710, which appears to be screened in the terrace deposits, had a mean saturated thickness of about 67 ft from 2014 to 2016.

Aquifer Hydraulic Properties and Values

Aquifer hydraulic properties and values used by Kent and others (1984) to construct a groundwater-flow model of the Washita River alluvial aquifer are shown on table 20. Relying on hydrologic information published in this 1984 report, in November 1990 the OWRB made a final determination on the MAY and EPS for the aquifer, setting these values as 120,320 acre-ft/yr and 2 acre-ft/acre/yr, respectively (table 17) (OWRB, 2012a).

Water Quality

Water-quality information describing the Washita River alluvial aquifer within the CATJA is available from the USGS NWIS database (USGS, 2018b) and from the OWRB GMAP (OWRB, 2018d). Information from the USGS NWIS database includes samples from six wells collected from 1960 to 1972 that were analyzed for water-quality field properties and nitrate (as nitrogen). In a select number of samples, major ions also were measured (table 21). Groundwater samples were collected by the OWRB from 13 wells during July and August 2014 and were analyzed for major ions, nitrate (as nitrogen), arsenic, and other trace elements; water-quality field properties also were measured (table 22).

Water samples collected by the USGS and OWRB that were analyzed for dissolved solids and other constituents that may limit the use of groundwater as a source of water for public-water supply are shown on figure 36. These water-quality data are used to show ranges of dissolved solids concentrations in addition to locations where concentrations of nitrate (as nitrogen) and uranium exceeded their respective MCLs in finished drinking water.

Groundwater samples from the Washita River alluvial aquifer indicate that groundwater from this aquifer has the largest concentrations of dissolved solids, hardness as calcium carbonate, and sulfate of all aquifers in the CATJA examined in this report (tables 21 and 22). Dissolution of gypsum in the Cloud Chief Formation and in the upper part of the Rush Springs Formation where the alluvial aquifer overlies these formations (fig. 6) probably contributes to these water-quality characteristics (Kent and others, 1984).

Groundwater samples collected by the USGS and OWRB indicate that the water from the Washita River alluvial aquifer has a neutral to slightly basic pH (pH measured in the samples ranged from 7.2 to 7.4), is extremely hard, and has large concentrations of dissolved solids and sulfate that exceed their respective SMCLs for finished drinking water (tables 21 and 22). The dissolved solids concentrations in the two USGS

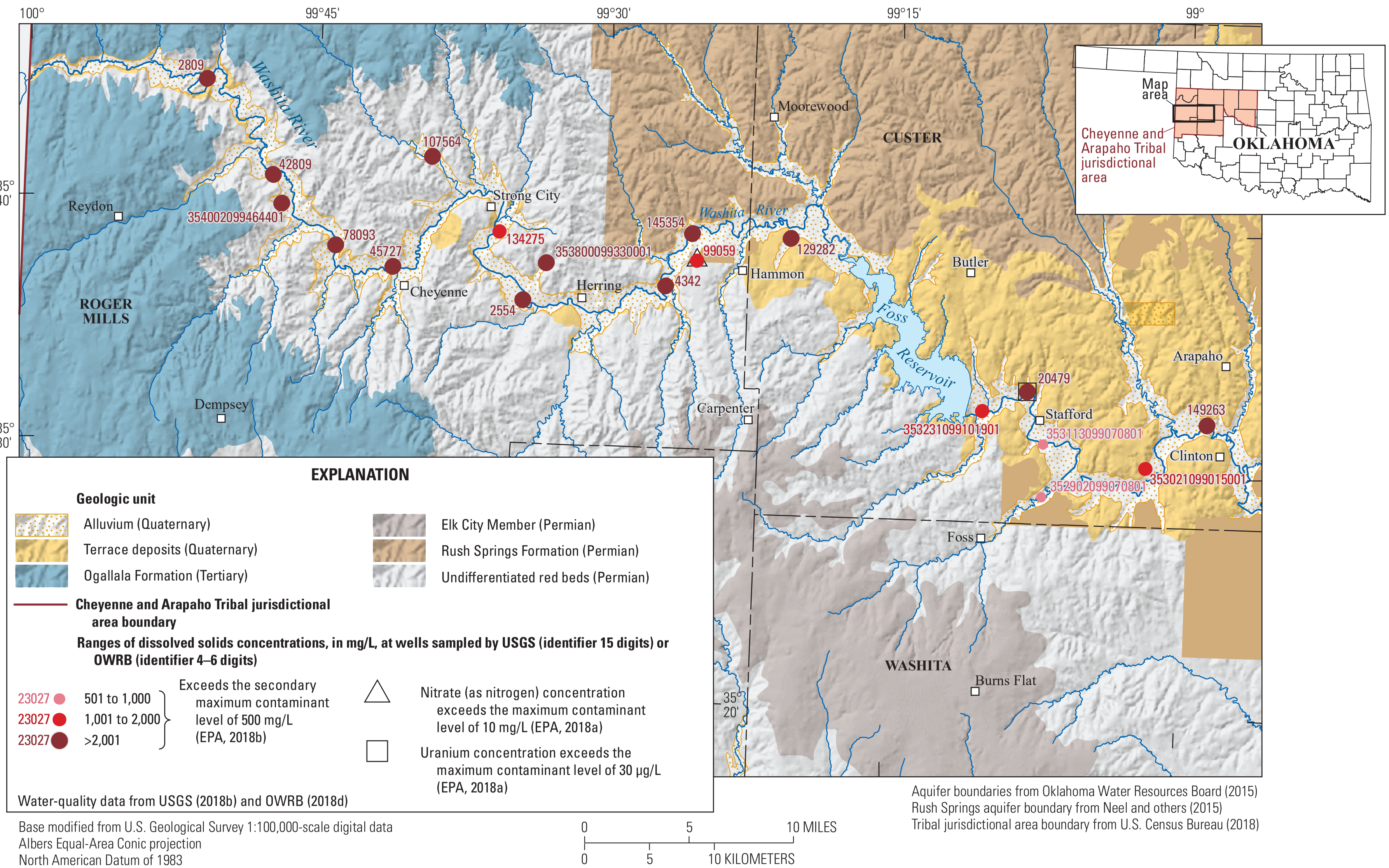


Figure 36. Distribution of water samples from wells in the Washita River alluvial aquifer and ranges of dissolved solids concentrations and concentrations of nitrate (as nitrogen) and uranium exceeding the maximum contaminant levels allowed in finished drinking water, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. Water samples collected by the U.S. Geological Survey were not analyzed for arsenic. Arsenic concentrations in all water samples collected by the Oklahoma Water Resources Board were smaller than the maximum contaminant level of 10 micrograms per liter. EPA, U.S. Environmental Protection Agency; µg/L, microgram per liter; mg/L, milligram per liter; OWRB, Oklahoma Water Resources Board; USGS, U.S. Geological Survey.

samples that were analyzed were 2,920 and 3,450 mg/L, far exceeding the SMCL of 500 mg/L for finished drinking water (EPA, 2018b). Similarly, the median concentration of dissolved solids determined from the 13 OWRB samples was 2,780 mg/L, with all 13 OWRB samples exceeding the SMCL of 500 mg/L (tables 21 and 22). Samples show that groundwater from the Washita River alluvial aquifer is extremely hard. Both the median and mean hardness as calcium carbonate concentrations were greater than 1,000 mg/L in USGS samples and greater than 1,600 mg/L in OWRB samples. Sulfate concentrations also were large and exceeded the SMCL of 250 mg/L in all USGS and OWRB samples, with median concentrations of 1,010 and 1,800 mg/L, respectively.

Nitrate (as nitrogen) was measured in 19 samples collected by USGS and OWRB, one of which had a concentration larger than the MCL of 10 mg/L in finished drinking water (fig. 36 and tables 21 and 22) (EPA, 2018a). The median concentration of iron in OWRB samples was 110 µg/L, with 4 of the 13 measured iron concentrations exceeding the SMCL of 300 µg/L (table 22). The median concentration of manganese in OWRB samples was 140 µg/L, with 7 of 13 samples exceeding the SMCL of 50 µg/L (table 22).

Uranium was measured in 1 of 13 OWRB samples at a concentration exceeding the MCL of 30 µg/L in finished drinking water (table 22) (EPA, 2018a). The OWRB well 20479 is downgradient from Foss Reservoir (fig. 36); the uranium concentration measured in the sample collected from this well was 40.1 µg/L.

There were insufficient data available from USGS samples to determine water type in the Washita River alluvial aquifer. However, Carr and Bergman (1976, plate 3) showed that two groundwater samples from the alluvial aquifer were calcium-sulfate type.

North Fork Red River Alluvial Aquifer

Within the CATJA the North Fork Red River alluvial aquifer covers approximately 315 mi^2 along the North Fork Red River and its tributaries in Beckham County (fig. 2). The alluvial aquifer supplies water to the river throughout most of the year (Smith and Wahl, 2003), though some reaches of the river and its tributaries stop flowing in late summer when demands for water and evapotranspiration are highest. The Carter gage (fig. 9) has recorded no flow for extended periods during drought conditions (USGS, 2018b). The OWRB has identified the North Fork Red River Basin in southeastern Beckham County as an area likely to have water-supply shortages by 2060 because of projected increases in population and demands for water, especially for irrigation (OWRB, 2012b).

Water Use and Allocations

Groundwater from the North Fork Red River alluvial aquifer is used primarily for irrigation with smaller amounts used for public-water supply, mining, and other uses (industrial) (figs. 37 and 38) (C. Neel, OWRB, written commun., 2016). Irrigation and public supply were the largest uses of water withdrawn from the alluvial aquifer during 2015, accounting for about 76 percent and 24 percent, respectively, of the total reported withdrawals (fig. 38). Reported amounts of groundwater withdrawals from the alluvial aquifer during 2015 indicate that only about 30 percent of the total amount of groundwater allocated for pumping in the CATJA was withdrawn (fig. 38 and table 18) (OWRB, 2018c). Of the total 51,530 acre-ft that was allocated, 15,220 acre-ft was reportedly used. The total number of permits for groundwater withdrawals has increased from 53 to 185 from 1980 to 2015, with the largest increases in groundwater withdrawals allocated to irrigation and public-water supply (table 18) (OWRB, 2018c).

Water Levels and Saturated Thickness

Water levels in the North Fork Red River alluvial aquifer can be monitored online through the OWRB map application Groundwater Level Monitoring Wells in Oklahoma (fig. 10) (OWRB, 2018e). In the CATJA, depth to water is measured annually in wells by the OWRB as part of GMAP (table 19). Long-term monitoring data are available from nine wells where the period of record ranged from 32 to 37 years (table 19). The mean depth to water in these wells ranged from 14.6 to 64.9 ft below land surface, and the annual mean fluctuations ranged from 1.2 to 3.0 ft. GMAP well 25519 has only four measurements with a mean depth to water of 87.9 ft below land surface over a 3-year period from 2013 to 2016.

Time-series hydrographs show that water levels in nine long-term monitoring wells in the North Fork Red River alluvial aquifer in the CATJA have fluctuated since the 1980s in response to climatic conditions and water use in western Oklahoma (figs. 4 and 27*E*) (NCDC, 2018b). Water levels generally increased beginning in 1985, declined starting in 1998, recovered somewhat in 2007, and then decreased again during 2008–9. Water levels began to recover again in 2015.

Kent (1980) reported that the mean thickness of the North Fork Red River alluvial aquifer is about 40 ft and has a maximum thickness that exceeds 150 ft. Mean saturated thickness in the GMAP wells ranges from 17 to 168 ft (table 19).

Aquifer Hydraulic Properties and Values

Groundwater-flow models of the North Fork Red River were constructed by Kent (1980) and Paukstatis (1981). Relying on hydrologic information published in these reports, in September 1981 the OWRB made a final determination on the MAY and EPS for the aquifer, setting these values as 343,042 acre-ft/yr and 1 acre-ft/acre/yr, respectively (table 17) (OWRB, 2012a). An updated study of the aquifer and groundwater-flow model was developed by Smith and others (2017), although at the time of this study (2019), the MAY and EPS for the alluvial aquifer have not been changed. Aquifer properties and values used for the groundwater-flow model developed by Smith and others (2017) are shown in table 20.

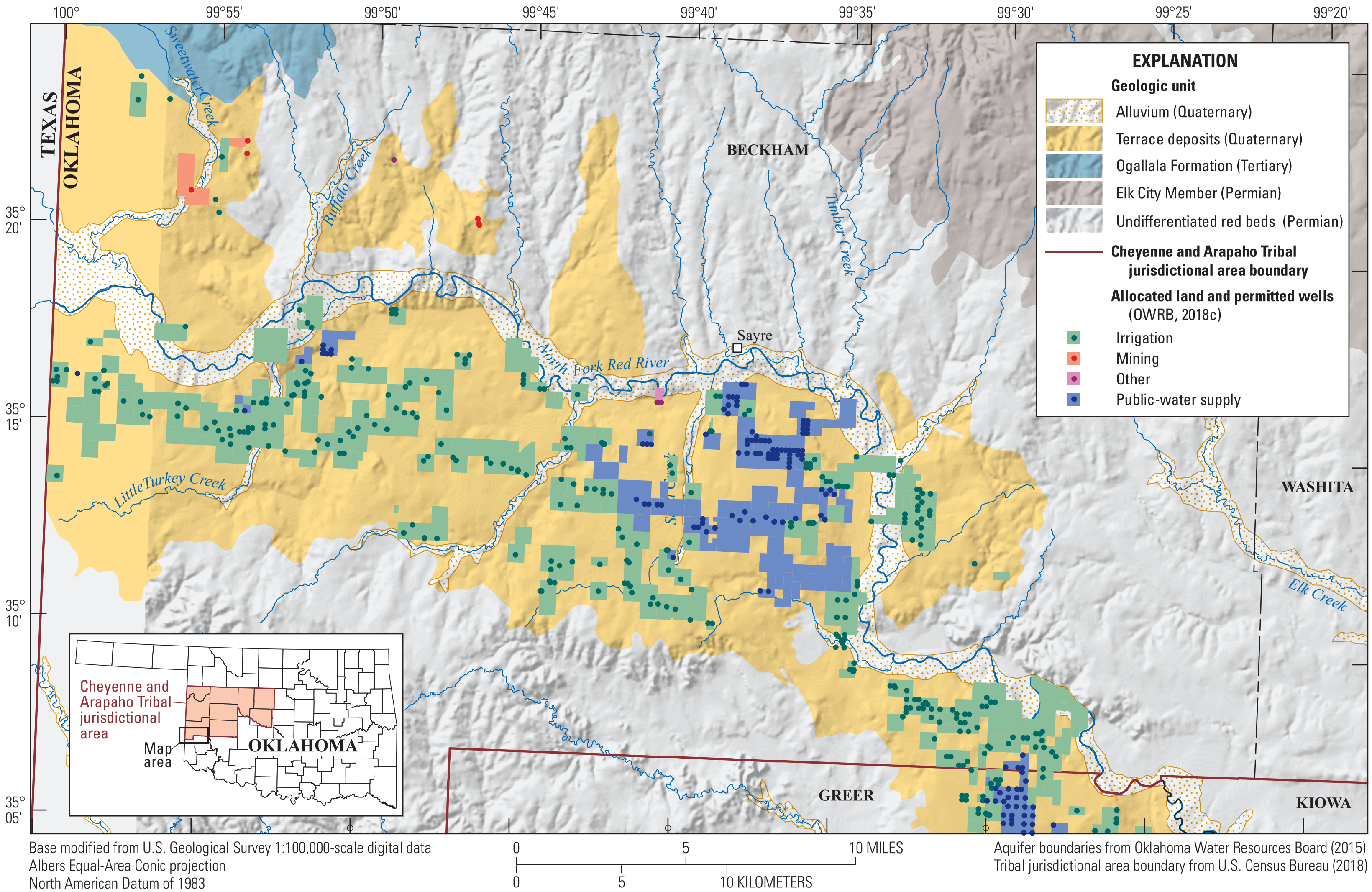


Figure 37. Allocated land and permitted wells withdrawing groundwater from the North Fork Red River alluvial aquifer during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. OWRB, Oklahoma Water Resources Board.

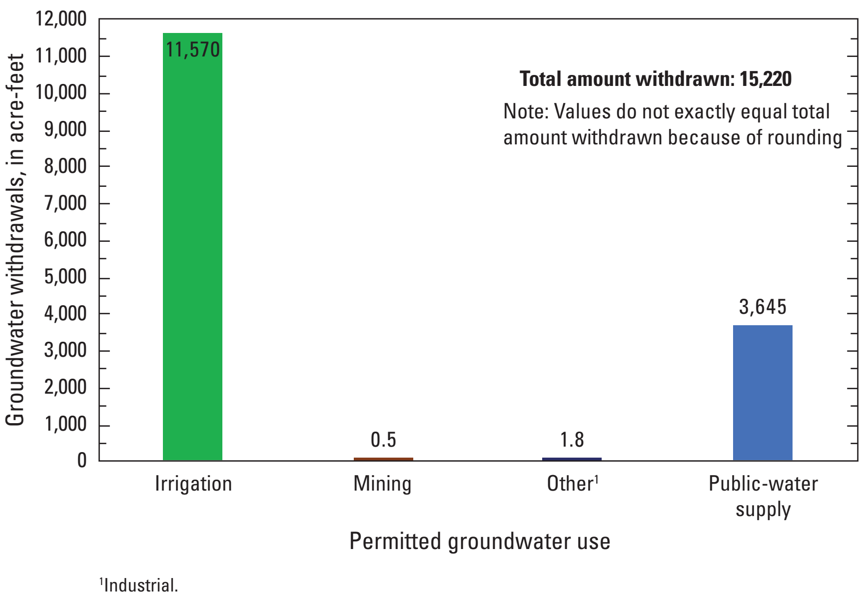


Figure 38. Reported groundwater withdrawals for permitted uses during 2015 from the North Fork Red River alluvial aquifer, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (C. Neel, Oklahoma Water Resources Board, written commun., 2016).

Water Quality

Water-quality information describing the North Fork Red River alluvial aquifer within the CATJA is available from the USGS NWIS database (USGS, 2018b) and from the OWRB GMAP (O WRB, 2018d). Water-quality field properties and major-ion concentrations were obtained from the USGS NWIS database for 24 wells that were sampled during 1951–71 (table 21).

Groundwater samples were collected, and water-quality field properties were measured by the OWRB from 14 wells during July and August 2014. These samples were analyzed for major ions, nitrate (as nitrogen), and other trace elements including arsenic (table 22).

Water samples collected by the USGS and OWRB that were analyzed for dissolved solids and other constituents that may limit the use of groundwater as a source of water for public-water supply are shown on figure 39. These water-quality data are used to show ranges of dissolved solids concentrations in addition to locations where concentrations of nitrate (as nitrogen) exceeded the MCL of 10 mg/L in finished drinking water (EPA, 2018a). There were no measured concentrations of arsenic or uranium (or other trace elements) that exceeded the MCLs of 10 µg/L and 30 µg/L, respectively, in finished drinking water (EPA, 2018a).

Samples from the USGS and OWRB indicate that water from the North Fork Red River alluvial aquifer in the CATJA has a neutral to slightly basic pH with median values ranging from 7.0 to 7.4, has large concentrations of dissolved solids, and is extremely hard in many parts of the aquifer (fig. 39 and tables 21 and 22). Dissolved solids concentrations exceeded the SMCL of 500 mg/L in 14 of 24 USGS samples (median concentration of 535 mg/L) and in 7 of 14 OWRB samples (median concentration of 490 mg/L) (EPA, 2018b). Samples show that groundwater from the North Fork Red River alluvial aquifer also is extremely hard. More than 75 percent of USGS samples had hardness as calcium carbonate concentrations greater than 270 mg/L. More than 75 percent of OWRB samples had hardness as calcium carbonate concentrations greater than 235 mg/L. Concentrations of sulfate exceeded the SMCL of 250 mg/L in 5 of 24 USGS samples and 3 of 14 OWRB samples with median concentrations of 125 and 92 mg/L, respectively.

Samples collected by the USGS indicate that the North Fork Red River alluvial aquifer contains water of several different types. Of the 21 USGS samples evaluated for water type, 4 samples were calcium-mixed anion type, 9 were calcium-bicarbonate type, 6 were calcium-sulfate type, and 2 were mixed cation-bicarbonate type.

Bedrock Aquifers

The concentrations of constituents measured in groundwater samples obtained from the three major bedrock aquifers in the CATJA, the Ogallala, Elk City, and Rush Springs aquifers, were generally smaller than the applicable SMCLs or MCLs for finished drinking water. However, in some areas, large concentrations of dissolved solids, nitrate (as nitrogen), and naturally occurring trace elements such as arsenic and uranium may limit the use of groundwater as a source of water for public-water supply.

Ogallala Aquifer

The Ogallala aquifer, also known as the High Plains aquifer, underlies eight States in the Central United States (fig. 40). The Ogallala aquifer is contained in the Ogallala Formation and covers about 860 mi^2 in the CATJA, mainly in Ellis and Roger Mills Counties with small areas in Beckham and Dewey Counties (fig. 2). The Ogallala aquifer is composed of semiconsolidated layers of sand, siltstone, clay, gravel, thin limestones, and caliche (fig. 7). The proportion and distribution of these sediments vary considerably from place to place, but poorly sorted sands and gravels are the predominate water-bearing layers in Oklahoma (Havens and Christenson, 1984). The Ogallala aquifer is a highly permeable unconfined aquifer that commonly yields 500–1,000 gal/min (about 800–1,600 acre-ft/yr) and can yield as much as 2,000 gal/min (about 3,200 acre-ft/yr) in some areas (Havens and Christenson, 1984).

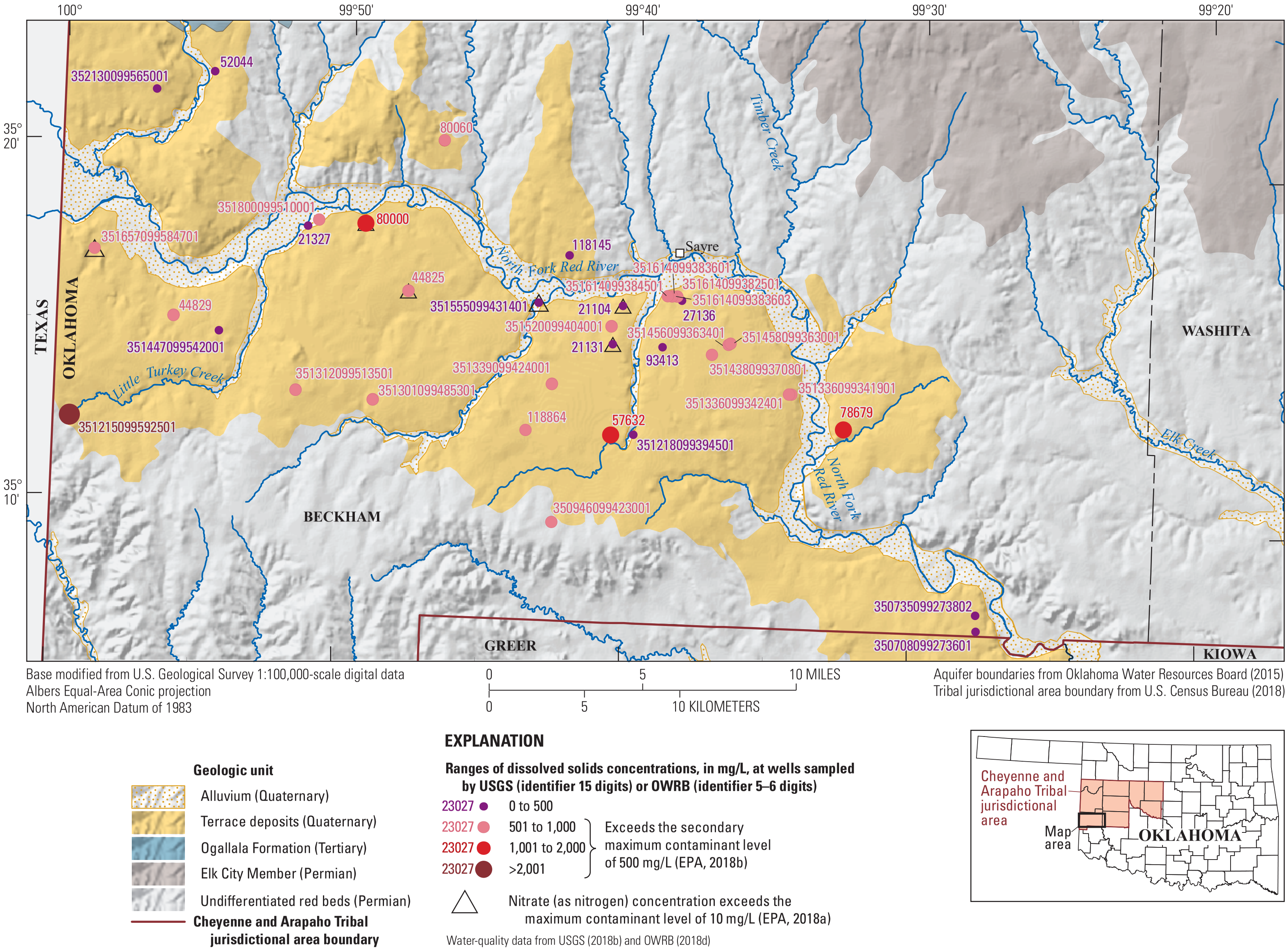


Figure 39. Distribution of water samples from wells in the North Fork Red River alluvial aquifer and ranges of dissolved solids concentrations and concentrations of nitrate (as nitrogen) exceeding the maximum contaminant level allowed in finished drinking water, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. Water samples collected by the U.S. Geological Survey were not analyzed for arsenic. Arsenic concentrations in all Oklahoma Water Resources Board water samples were smaller than the maximum contaminant level of 10 micrograms per liter (U.S. Environmental Protection Agency, 2018a). EPA, U.S. Environmental Protection Agency; mg/L, milligram per liter; OWRB, Oklahoma Water Resources Board; USGS, U.S. Geological Survey.

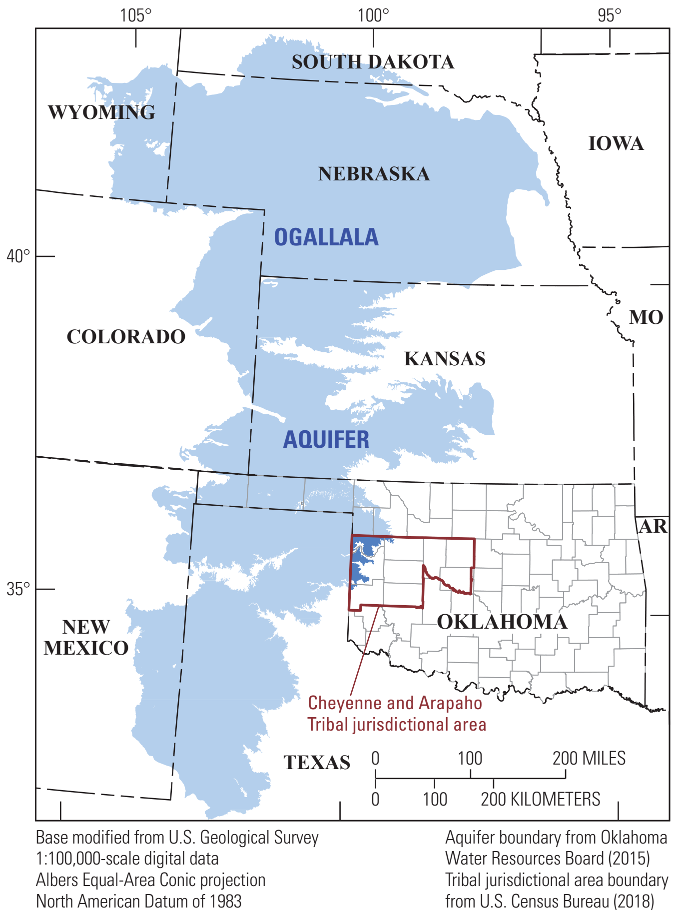


Figure 40. Location of the Ogallala aquifer, also known as the High Plains aquifer, in the Central United States.

Water Use and Allocations

Groundwater from the Ogallala aquifer is used primarily for irrigation, with smaller amounts used for public-water supply, other (industrial), and mining uses (figs. 41 and 42) (C. Neel, OWRB, written commun., 2016). Irrigation was the largest use of water from the aquifer during 2015, accounting for about 77 percent of the total reported withdrawals (fig. 42). Reported amounts of groundwater withdrawals from the Ogallala aquifer during 2015 indicate that only about 4 percent of the total amount of groundwater allocated for pumping in the CATJA was withdrawn (fig. 42 and table 18) (OWRB, 2018c). Of the total 88,620 acre-ft that was allocated, 3,475 acre-ft was reportedly used (fig. 42).

The total number of permits for groundwater withdrawals from the Ogallala aquifer have increased almost 500 percent from 31 to 185 between 1980 and 2015 (table 18). The largest increases in groundwater allocations have been for irrigation and mining.

Water Levels and Saturated Thickness

Regionally, the decline of water levels in the Ogallala aquifer (and the High Plains aquifer as a whole) has been a major concern because of the aquifer's importance for crop irrigation in the Central United States. Several geologic formations compose the High Plains aquifer, but the Ogallala Formation is the major formation in Oklahoma. In 2000, groundwater withdrawals from the High Plains aquifer accounted for about 20 percent of the total amount of groundwater withdrawn in the United States annually, of which about 97 percent was for irrigation (Maupin and Barber, 2005). Extensive crop irrigation has caused groundwater levels to drop drastically in some areas where natural recharge of water to the aquifer has not kept up with groundwater pumpage, evapotranspiration, and groundwater discharging to rivers (McGuire, 2017). The USGS, in cooperation with numerous local, State, and Federal agencies, measures water levels annually in more than 8,300 wells throughout the eight-State area to monitor water-level changes in the aquifer. From the onset of substantial irrigation (about 1950) until 2015, water-level measurements have exhibited no substantial change in some parts of the CATJA, whereas other parts of the CATJA have exhibited water-level increases of 20 ft or more (McGuire, 2017, fig. 1).

Water levels in the Ogallala aquifer can be monitored online through the OWRB map application Groundwater Level Monitoring Wells in Oklahoma (fig. 10) (OWRB, 2018e). In the CATJA, depth to water is measured annually in 27 wells by the OWRB as part of GMAP (table 19).

Annual measurements indicate that mean depths to water vary widely in the Ogallala aquifer, ranging from 9.7 to 169 ft below land surface (table 19 and fig. 10). Annual mean water-level fluctuations ranged from less than 0.1 to 2.5 ft in individual wells, with more than half of the wells fluctuating less than 1 ft (table 19). A time-series hydrograph of long-term measurements in seven of the wells shows that water levels in these wells have stayed relatively constant or have risen slightly over a 35- to 36-year period ending in 2016 (fig. 43*A*).

A generalized map showing the saturated thickness of the Ogallala aquifer during 1996–97 was published by Fischer and others (2000). Saturated thickness of the aquifer ranged from 0 ft along the eastern erosional boundaries to 200 ft or more in the northern and northwestern parts in the CATJA in Ellis County and in the western part of Roger Mills County. The mean saturated thickness measured in 26 of the 27 GMAP wells ranged from 11 to 134 ft, resulting in an overall mean of 72 ft (table 19).

Aquifer Hydraulic Properties and Values

Aquifer hydraulic properties and values from a regional study of the Ogallala aquifer and two groundwater-flow modeling reports of the aquifer are shown in table 20. A regional study of the aquifer in parts of eight States was published by Gutentag and others (1984). Havens and Christenson (1984) constructed a groundwater-flow model of the Ogallala aquifer in Roger Mills and Ellis Counties in the CATJA in addition to the Oklahoma Panhandle counties. Luckey and Becker (1999) constructed a groundwater-flow

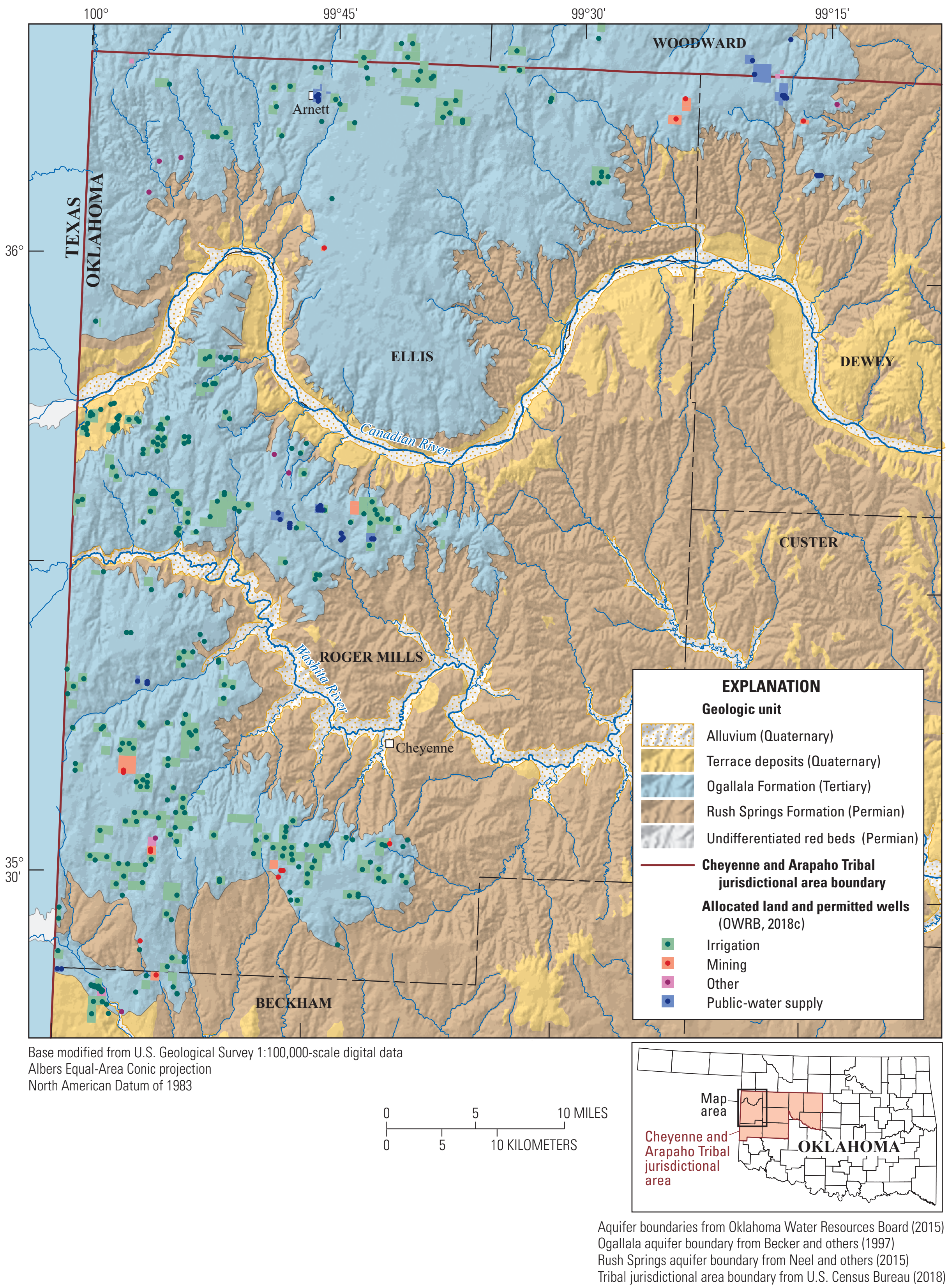


Figure 41. Allocated land and permitted wells withdrawing groundwater from the Ogallala aquifer during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. OWRB, Oklahoma Water Resources Board.

model of the Ogallala aquifer in Oklahoma, Colorado, Kansas, New Mexico, and Texas.

Relying on hydrologic information published in these reports, in March 2002 the OWRB made a final determination on the MAY and EPS for the Ogallala aquifer in counties north of the Canadian River, including Ellis and Dewey Counties in the CATJA, setting these values as 1,198,512 acre-ft/yr and 1.4 acre-ft/acre/yr, respectively (table 17) (OWRB, 2012a). A MAY has not been established for parts of the Ogallala aquifer south of the Canadian River (fig. 2), and a temporary EPS pumping rate of 2 acre-ft/acre/yr is used for allocating groundwater for permitted uses in this part of the aquifer (OWRB, 2012a).

Water Quality

Water-quality information describing the Ogallala aquifer within the CATJA is available from the USGS NWIS database (USGS, 2018b) and from the OWRB GMAP (OWRB, 2018d). Information from the USGS NWIS database includes samples from 23 wells collected from 1951 to 1972 (table 21). These samples were analyzed for water-quality field properties, major ions, and nitrate (as nitrogen). Concentrations of the trace elements arsenic and uranium also were analyzed in 3 of the 23 samples and were smaller than their respective MCLs for finished drinking water (EPA, 2018a).

Groundwater samples were collected by the OWRB from 30 wells during July and August 2013 (table 22). These samples were analyzed for major ions, nitrate (as nitrogen), and trace elements including arsenic and uranium; water-quality field properties also were measured. Concentrations of both arsenic and uranium were smaller than their respective MCLs in all samples.

Water samples collected by the USGS and OWRB that were analyzed for dissolved solids and other constituents that may limit the use of groundwater as a source of water for public-water supply are shown on figure 44. These water-quality data are used to show ranges of dissolved solids concentrations in addition to locations where concentrations of nitrate (as nitrogen) exceeded the MCL of 10 mg/L in finished drinking water (EPA, 2018a).

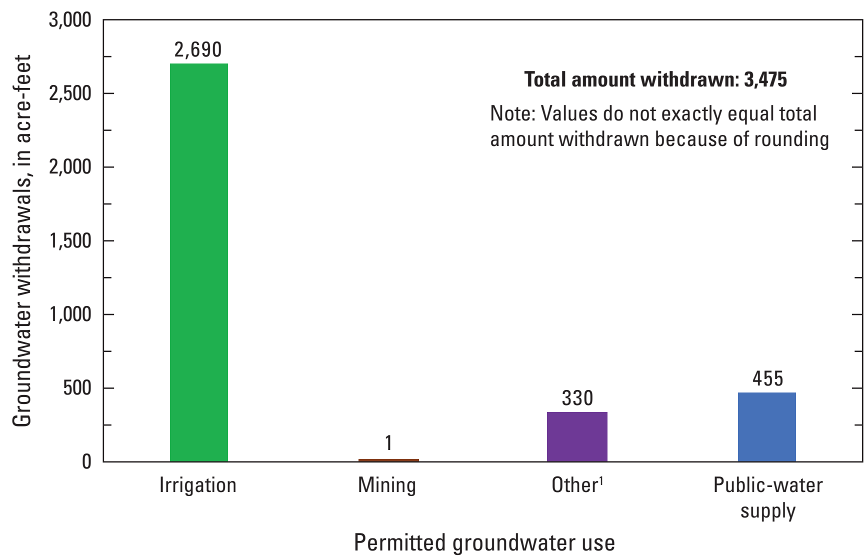
Samples from the USGS and OWRB indicate that water from the Ogallala aquifer in the CATJA is neutral to slightly alkaline with median pH values of 7.7 and 7.1, respectively (tables 21 and 22). The samples show that concentrations of most constituents in groundwater from the Ogallala aquifer were smaller than the applicable MCLs for finished drinking water in most locations, though large concentrations of dissolved solids and nitrate (as nitrogen) occur in localized areas (fig. 44). Dissolved solids concentrations exceeded the SMCL of 500 mg/L in finished drinking water in 4 of 23 USGS samples and 7 of 30 OWRB samples, with median concentrations of 360 and 350 mg/L, respectively (tables 21 and 22). Groundwater from the Ogallala aquifer ranges from very hard to extremely hard with median hardness as calcium carbonate concentrations of 220 and 225 mg/L in USGS and OWRB samples, respectively (tables 21 and 22).

Except for one sulfate sample having a concentration of 1,600 mg/L (USGS well 355608099514101), concentrations of chloride and sulfate were smaller than the SMCLs of 250 mg/L in finished drinking water in all USGS and OWRB samples from the Ogallala aquifer (tables 21 and 22) (EPA, 2018b). Median concentrations of both chloride and sulfate in USGS and OWRB samples were 20 mg/L or smaller. Nitrate (as nitrogen) concentrations in USGS samples exceeded the MCL of 10 mg/L in 1 of 19 samples, with a median concentration of 4.5 mg/L (table 21) (EPA, 2018a). Nitrate (as nitrogen) concentrations in OWRB samples had a median concentration of 6.7 mg/L and exceeded the MCL of 10 mg/L in 8 of 30 samples (table 22).

Samples from four wells in the Ogallala aquifer were deemed suitable for determining water type. One sample was a mixed cation-bicarbonate type, one sample was calcium-mixed anion type, one sample was mixed cation-chloride type, and one sample was calcium-bicarbonate type.

Elk City Aquifer

The Elk City aquifer is contained in the Elk City Member (fig. 7) and covers an area of about 246 mi^2 in Beckham and Washita Counties, with small areas of the



[1]Industrial.

Figure 42. Reported groundwater withdrawals for permitted uses during 2015 from the Ogallala aquifer, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (C. Neel, Oklahoma Water Resources Board, written commun., 2016).

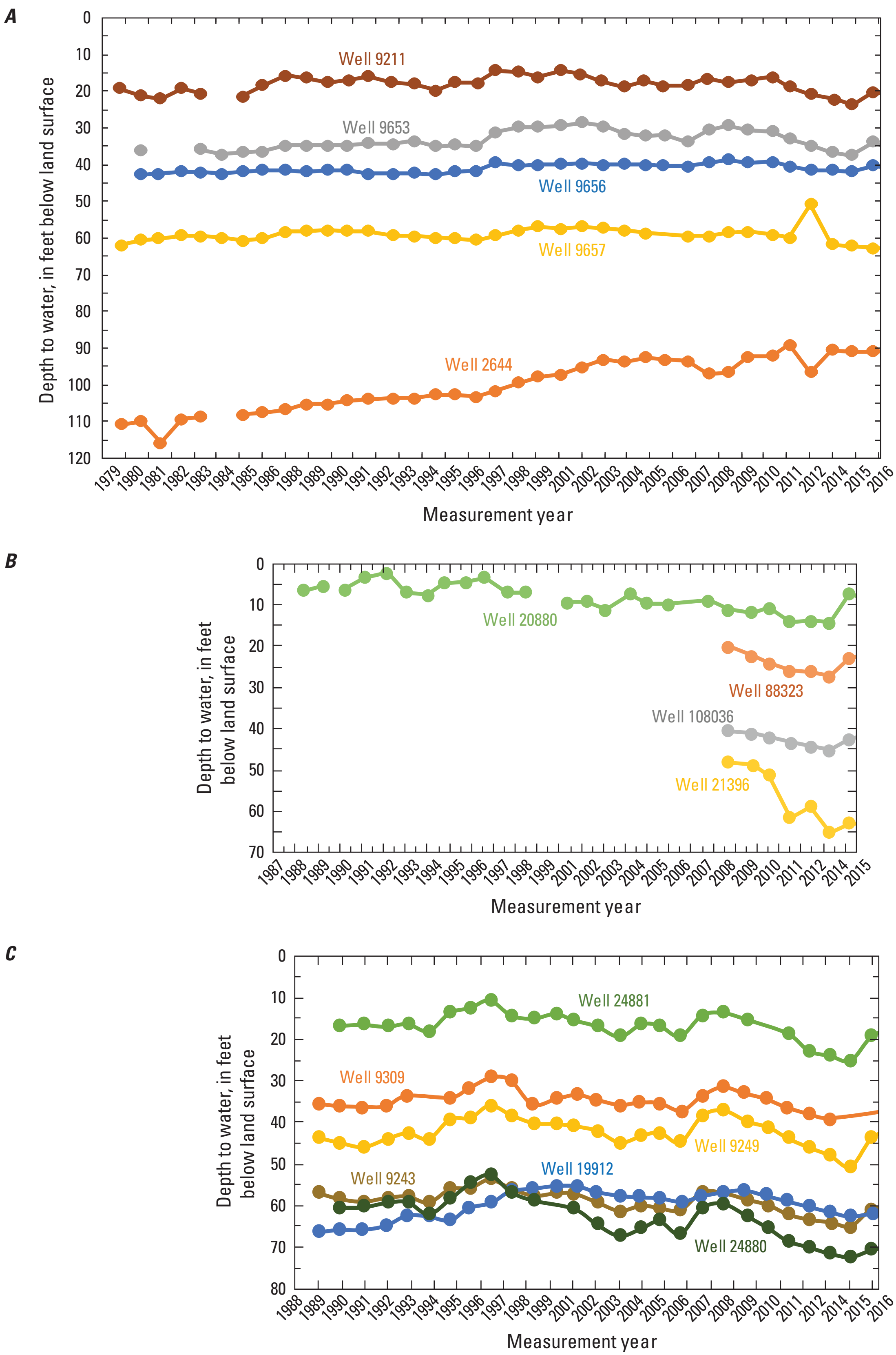


Figure 43. Annual water-level measurements in selected Oklahoma Water Resources Board Groundwater Monitoring and Assessment Program (GMAP) wells in the bedrock aquifers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (Oklahoma Water Resources Board, 2018e). *A*, Ogallala aquifer; *B*, Elk City aquifer; *C*, Rush Springs aquifer.

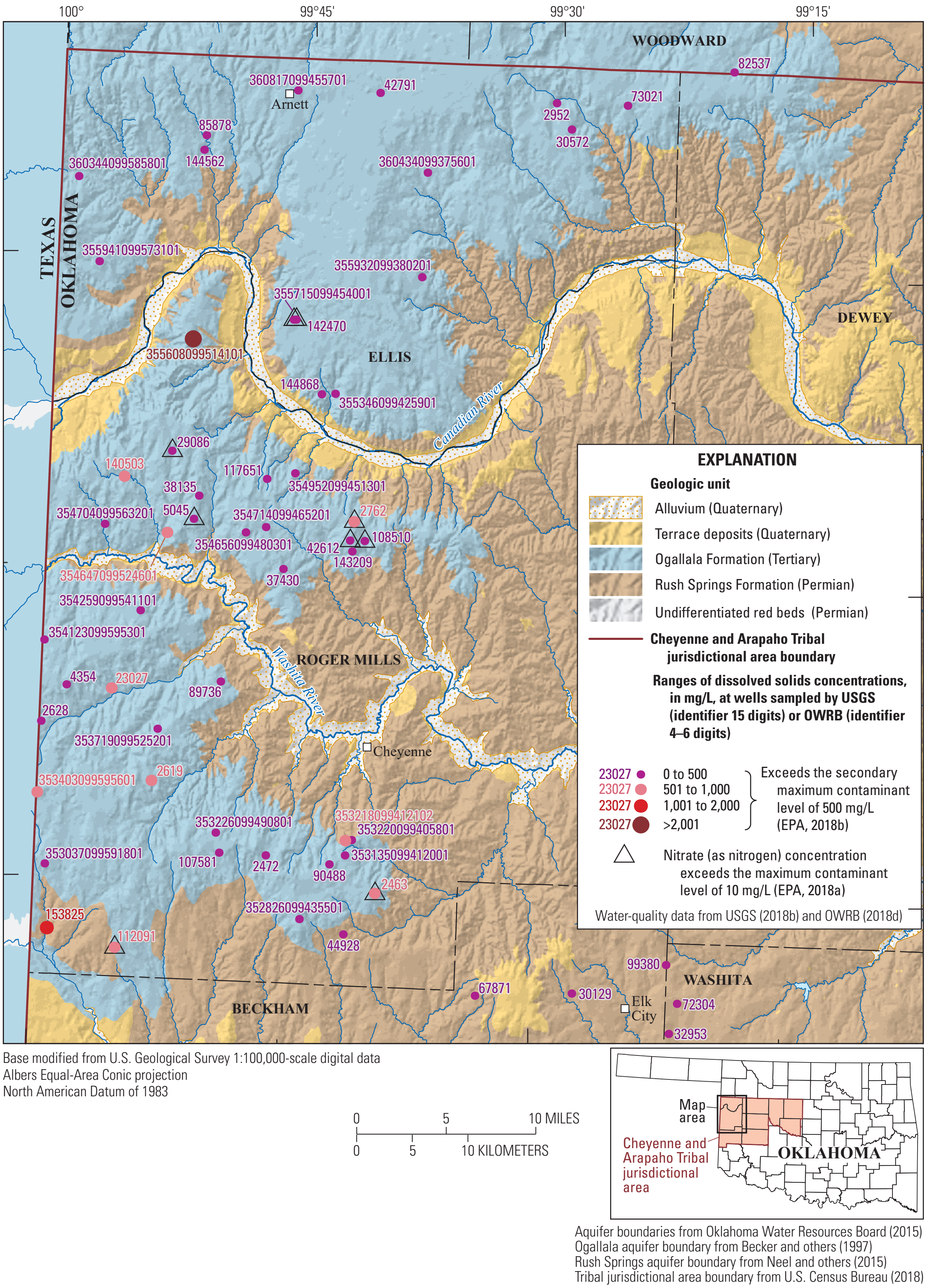


Figure 44. Distribution of water samples from wells in the Ogallala aquifer and ranges of dissolved solids concentrations and concentrations of nitrate (as nitrogen) exceeding the maximum contaminant levels allowable in finished drinking water, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. EPA, U.S. Environmental Protection Agency; mg/L, milligram per liter; OWRB, Oklahoma Water Resources Board; USGS, U.S. Geological Survey.

aquifer present in Custer and Roger Mills Counties (fig. 2). The Elk City Member is the youngest Permian-aged rock unit in the CAJTA and is located on a topographic high trending in a northwest-southeast direction (Kent and others, 1982). The aquifer is unconfined and has a maximum thickness of 220–260 ft. Underlying the aquifer is the Doxey Shale, a relatively impermeable unit that restricts the downward loss of groundwater (fig. 6). Terrace deposits and dune sands overlie the aquifer in western parts of the aquifer and are considered part of the aquifer where saturated with water (Kent and others, 1982).

Water Use and Allocations

Groundwater from the Elk City aquifer is used primarily for public-water supply and irrigation with smaller amounts used for mining and other (industrial) uses (figs. 45 and 46) (C. Neel, OWRB, written commun., 2016). Public-water supply and irrigation were the largest uses of the water withdrawn from the Elk City aquifer during 2015, accounting for about 57 percent and 44 percent, respectively, of the total reported withdrawals (fig. 46). Reported amounts of groundwater withdrawals from the aquifer during 2015 indicate that only about 9 percent of the total amount of groundwater allocated for pumping in the CATJA was withdrawn (table 18 and fig. 46) (OWRB, 2018c). Of the total 19,365 acre-ft that was allocated, 1,680 acre-ft was reportedly used. The total number of permits for groundwater withdrawals have more than doubled from 40 to 95 between 1980 and 2015, with the largest increases in groundwater allocated to irrigation and public-water supply (OWRB, 2018c) (table 18).

Water Levels and Saturated Thickness

Water levels in the Elk City aquifer can be monitored online through the OWRB map application Groundwater Level Monitoring Wells in Oklahoma (fig. 10) (OWRB, 2018e). In the CATJA, depth to water is measured annually in 22 wells by the OWRB as part of GMAP (table 19).

Mean depths to water in the Elk City aquifer in the 22 wells ranged from 7.9 to 56.6 ft below land surface with a mean depth of about 23 ft over time periods ranging from 3 to 26 years (table 19). Annual mean water-level fluctuations ranged from 1.0 to 10.1 ft with a mean fluctuation in 21 of the 22 wells of about 3.3 ft. As of 2015, when the data for this report were compiled, there were between 3 and 7 years of measurements available from the OWRB GMAP wells, except for GMAP 20880, where annual measurements have been made since 1989, and GMAP 44928, which had a single measurement in 2016. Water levels in GMAP 20880 have ranged from 2.3 to 14.3 ft below land surface, fluctuating about 2.3 ft annually.

Time-series hydrographs of water-level measurements in three wells monitored for 7 years and GMAP well 20880 monitored for 26 years show that water levels decreased over 6 years prior to 2015 (fig. 43*B*). Drought conditions persisted for several years before the spring and summer of 2015, when large amounts of precipitation fell in west-central Oklahoma (fig. 4) (NCDC, 2018b). The water levels in GMAP well 20880 tended to gradually decrease from 1989 through 2014 before sharply increasing beginning in 2015 (fig. 43*B*).

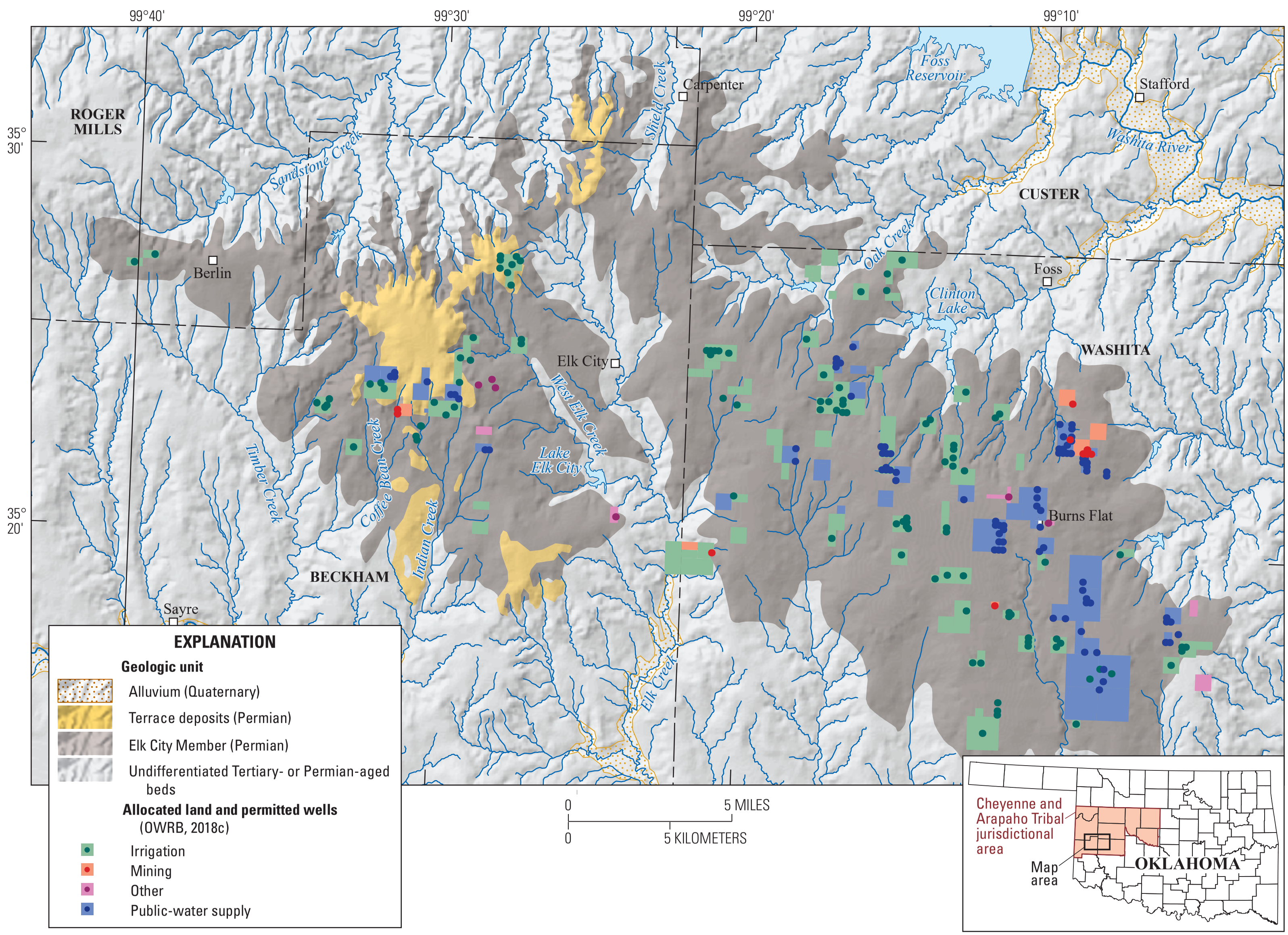
Kent and others (1982) reported that water levels in the Elk City aquifer changed relatively little between 1964 and 1973, indicating that during this period of time the aquifer reached a recharge-discharge equilibrium. Kent and others (1982) also reported a mean saturated thickness of 83 ft in the western part of the aquifer, west of Elk Creek, and of 94 ft in the eastern part of the aquifer, east of Elk Creek (fig. 45). The mean saturated thicknesses in the 22 OWRB GMAP wells ranged from about 31 to 151 ft over their respective periods of measurement (table 19).

Aquifer Hydraulic Properties and Values

A simplified groundwater-flow model was developed by Kent and others (1982) to determine the MAY for the Elk City aquifer. The aquifer hydraulic properties and values used for the groundwater-flow model are shown in table 20. Relying on hydrologic information published in this report, in November 1982 the OWRB made a final determination on the MAY and EPS for the aquifer, setting these values as 157,440 acre-ft/yr and 1 acre-ft/acre/yr, respectively (table 17) (OWRB, 2012a).

Water Quality

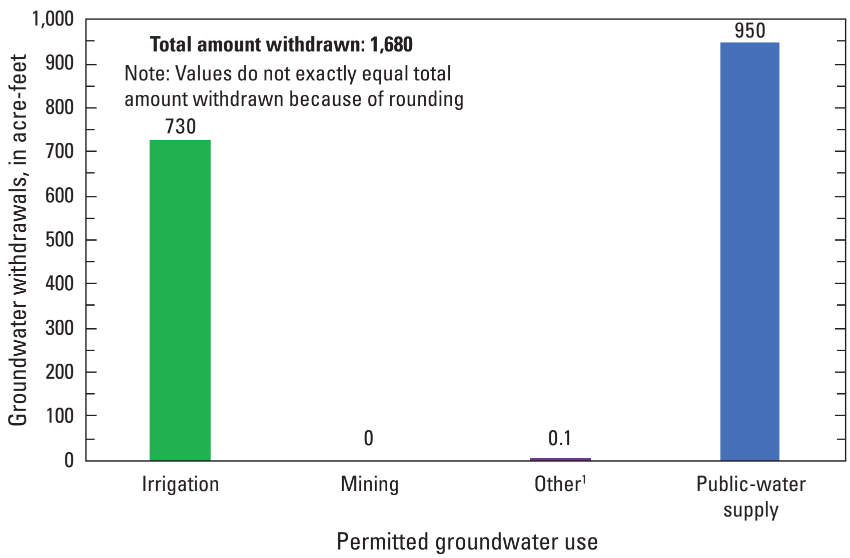
Water-quality information describing the Elk City aquifer within the CATJA is available from the USGS NWIS database (USGS, 2018b) and the GMAP (OWRB, 2018d). Information from the USGS NWIS database includes samples from seven wells that were collected from 1950 to 1972. These samples were analyzed for major ions and nitrate (as nitrogen); water-quality field properties also were measured (table 21). No trace elements were analyzed in these samples. Groundwater samples were collected by the OWRB from 14 wells during July and August 2013. These samples were analyzed for major ions, nitrate (as nitrogen), and trace elements including arsenic and uranium; water-quality field properties also were measured (table 22).



Base modified from U.S. Geological Survey 1:100,000-scale digital data
Albers Equal-Area Conic projection
North American Datum of 1983

Aquifer boundaries from Oklahoma Water Resources Board (2015)
Tribal jurisdictional area boundary from U.S. Census Bureau (2018)

Figure 45. Allocated land and permitted wells withdrawing groundwater from the Elk City aquifer during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. OWRB, Oklahoma Water Resources Board.



[1]Industrial.

Figure 46. Reported groundwater withdrawals for permitted uses during 2015 from the Elk City aquifer, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (C. Neel, Oklahoma Water Resources Board, written commun., 2016).

Water samples collected by the USGS and OWRB that were analyzed for dissolved solids and other constituents that may limit the use of groundwater as a source of water for public-water supply are shown on figure 47. These water-quality data are used to show ranges of dissolved solids concentrations in addition to two wells where concentrations of nitrate (as nitrogen) exceeded the MCL of 10 mg/L in finished drinking water (EPA, 2018a).

USGS and OWRB samples indicate that pH, dissolved solids, chloride, sulfate, and trace elements in groundwater samples obtained from the Elk City aquifer do not exceed any of their respective MCLs (tables 21 and 22). Groundwater from the Elk City aquifer is slightly alkaline with median pH values of 7.9 and 7.3 in USGS and OWRB samples, respectively. Concentrations of dissolved solids are generally less than 400 mg/L with median USGS and OWRB concentrations of 340 and 365 mg/L, respectively, and concentrations in all samples are smaller than the SMCL of 500 mg/L. Groundwater is very hard to extremely hard with median hardness as calcium carbonate concentrations in USGS and OWRB samples of 280 and 275 mg/L, respectively. Concentrations of chloride and sulfate in all samples for which they were analyzed were smaller than the SMCL of 250 mg/L for these constituents in finished drinking water (EPA, 2018b).

USGS samples from the Elk City aquifer have a median nitrate (as nitrogen) concentration of 5.0, whereas OWRB samples have a median concentration of 6.6 mg/L (tables 21 and 22). Two of the total 21 samples from the USGS and OWRB had nitrate (as nitrogen) concentrations that exceeded the MCL for nitrogen of 10 mg/L for finished drinking water (EPA, 2018b). The nitrate (as nitrogen) concentrations were 16 and 19 mg/L in the two samples that exceeded the MCL.

Samples from three wells in the Elk City aquifer were deemed suitable for determining the water type. One sample was calcium-bicarbonate type, and the other two samples were multi-cation-bicarbonate types. Carr and Bergman (1976) described water from the Elk City aquifer as a calcium and magnesium-bicarbonate type.

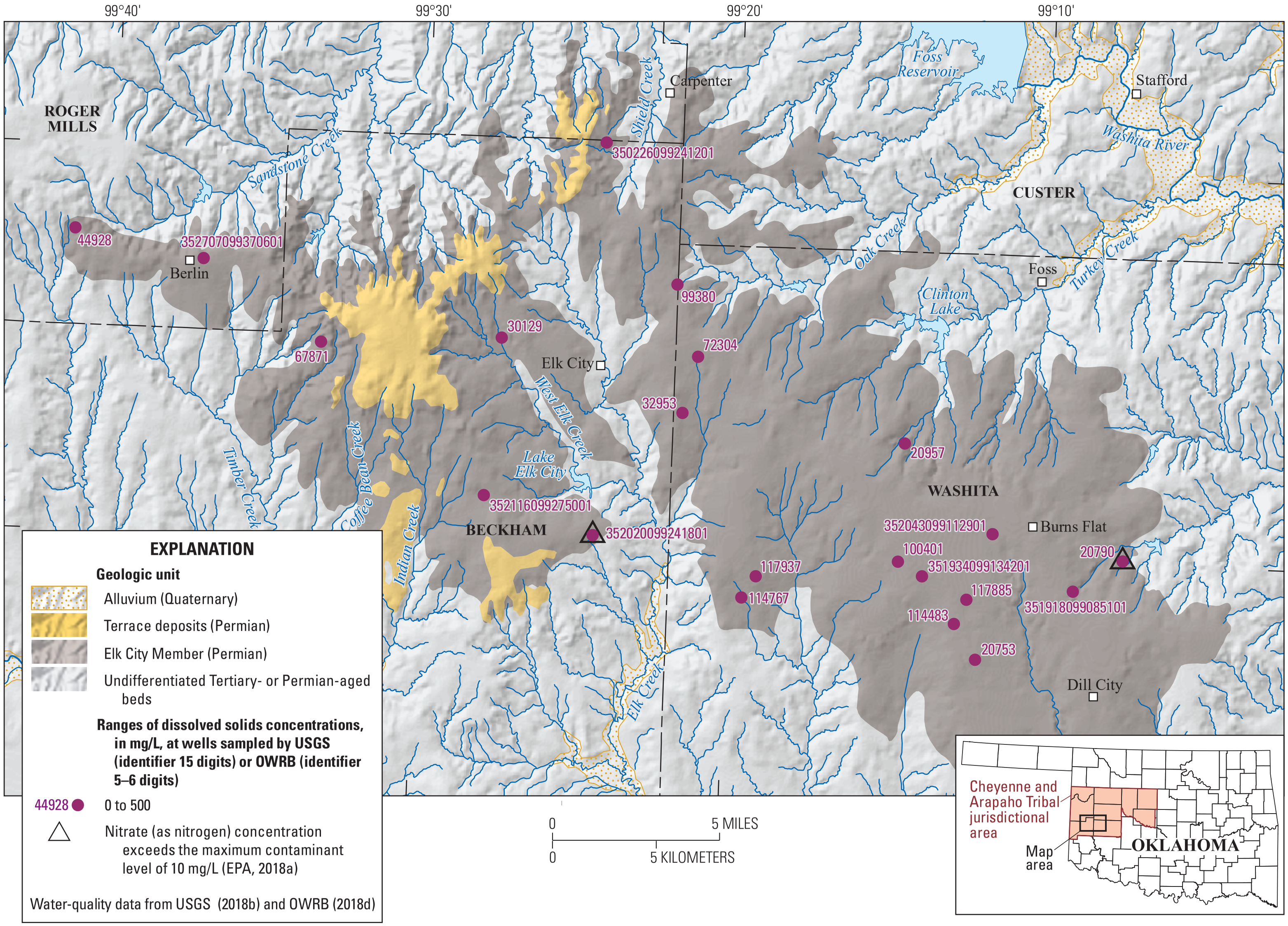
Rush Springs Aquifer

Within the CATJA, the Rush Springs aquifer covers an area of about 1,230 mi^2 in parts of Blaine, Dewey, Canadian, Custer, Roger Mills, and Washita Counties and is primarily contained in the Rush Springs Formation (figs. 2 and 6). The Rush Springs Formation is an orange-brown fine-grained sandstone, with some interbedded layers of red-brown shale, silty shale, and gypsum beds that range in thickness from less than 250 to more than 300 ft (Becker, 1998).

Alluvial deposits along the Canadian and Washita River Valleys are considered part of the Rush Springs aquifer where the units have a hydrologic connection (fig. 6). The Marlow Formation also is considered part of the Rush Springs aquifer where it underlies the Rush Springs Sandstone (Becker, 1998; Ellis, 2018). In a westerly direction, the aquifer becomes deeply buried, and groundwater has larger concentrations of dissolved solids (Becker, 1998). To the northwest, well yields from the aquifer decrease, and groundwater has larger concentrations of dissolved solids with calcium and sulfate being the dominant major ions (Becker, 1998).

Water Use and Allocations

Water from the Rush Springs aquifer is used primarily for irrigation with smaller amounts used for public-water supply, mining, and other uses (recreation, fish, and wildlife; industrial; and commercial uses) (figs. 48 and 49) (C. Neel, OWRB, written commun., 2016). Irrigation was the largest use of the water withdrawn from the aquifer during 2015, accounting for 89 percent of the total reported withdrawals (fig. 48). Reported amounts of groundwater withdrawals from the Rush Springs aquifer during 2015 indicate that only about 12 percent of the total amount of groundwater allocated for pumping in the CATJA was withdrawn (fig. 48 and table 18) (OWRB, 2018c). Of the total 220,280 acre-ft that was allocated, 26,160 acre-ft was reportedly used. The total number of permits for groundwater withdrawal more than tripled from 202 to 634 between 1980 and 2015, with total groundwater allocations increasing almost 500 percent (OWRB, 2018c) (table 18).



Base modified from U.S. Geological Survey 1:100,000-scale digital data
Albers Equal-Area Conic projection
North American Datum of 1983

Aquifer boundaries from Oklahoma Water Resources Board (2015)
Tribal jurisdictional area boundary from U.S. Census Bureau (2018)

Figure 47. Distribution of water samples from wells in the Elk City aquifer and ranges of dissolved solids concentrations and concentrations of nitrate (as nitrogen) exceeding the maximum contaminant levels allowable in finished drinking water, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. EPA, U.S. Environmental Protection Agency; mg/L, milligram per liter; OWRB, Oklahoma Water Resources Board; USGS, U.S. Geological Survey.

Water Levels and Saturated Thickness

Water levels in the Rush Springs aquifer can be monitored online through the OWRB map application Groundwater Level Monitoring Wells in Oklahoma (fig. 10) (OWRB, 2018e). In the CATJA, depth to water is measured annually in 27 wells by the OWRB as part of GMAP (table 19).

Mean depths to water in the 27 wells have ranged from 1.8 to 144 ft below land surface with an overall mean depth of 62.5 ft over periods of measurement ranging from 2 to 54 years (table 19). Mean annual water-level fluctuations in the wells ranged from 0.7 to 4.5 ft with a mean for the 27 wells of 1.7 ft.

Time-series hydrographs show annual water-level measurements in six wells with long-term measurements of 24 or more years (fig. 43*C*). Water levels in these six wells have fluctuated between 10 and 19.8 ft over multiple years resulting from changes in climatic conditions and water use (NCDC, 2018b).

Saturated thickness of the Rush Springs aquifer within the CATJA was discussed and shown in detail by Neel and others (2015, figs. 20, 21, 22, 23, and 24). During 2013, saturated thickness in the aquifer ranged from 0 to 432 ft, with a mean of 181 ft (Neel and others, 2015). These maps show that saturated thickness of the aquifer is thinnest along the erosional boundaries where the Rush Springs Formation outcrops along the east-northeastern edge and increases in a west-southwesterly direction as the aquifer slopes downward and is more deeply buried.

Aquifer Hydraulic Properties and Values

A groundwater-flow model of the Rush Springs aquifer was developed by Ellis (2018) to determine the MAY for the Rush Springs aquifer. The aquifer hydraulic properties and values used for the groundwater-flow model in addition to values from a study by Fay (1978) and Neel and others (2015) are shown on table 20. The Rush Springs aquifer does not have a MAY or EPS determined by OWRB as of 2019. A temporary EPS pumping rate of 2 acre-ft/acre/yr is used for allocating groundwater for permitted uses (table 17) (OWRB, 2012a).

Water Quality

Water-quality information for the Rush Springs aquifer is available from the USGS NWIS database (USGS, 2018b) and the OWRB GMAP (OWRB, 2018d). Information from the USGS NWIS database includes samples from 60 wells that were collected from 1971 to 2008. These samples were analyzed for major ions, nitrate (as nitrogen), and arsenic; water-quality field properties also were measured (table 21). Groundwater samples were collected by the OWRB from 37 wells during September and October 2013. These samples were analyzed for major ions, nitrate (as nitrogen), and trace elements including arsenic and uranium; water-quality field properties also were measured (table 22).

Water samples collected by the USGS and OWRB that were analyzed for dissolved solids and other constituents that may limit the use of groundwater as a source of water for public-water supply are shown on figure 50. These water-quality data are used to show ranges of dissolved solids concentrations in addition to locations where concentrations of nitrate (as nitrogen) and arsenic exceeded their respective MCLs in finished drinking water.

The quality of water from the Rush Springs aquifer ranges from acceptable for use as a public-water supply to suitable only for irrigation and livestock. In areas where the overlying Cloud Chief Formation is present in Custer, Dewey, and Washita Counties, the groundwater contains large concentrations of dissolved solids and sulfate that frequently exceed their respective SMCLs of 500 mg/L and 250 mg/L for finished drinking water (figs. 6 and 50) (EPA, 2018b). Other water-quality concerns are nitrate (as nitrogen) and arsenic, which occur in selected parts of the aquifer at concentrations that exceed their respective MCLs of 10 mg/L and 10 µg/L (fig. 50) (EPA, 2018a).

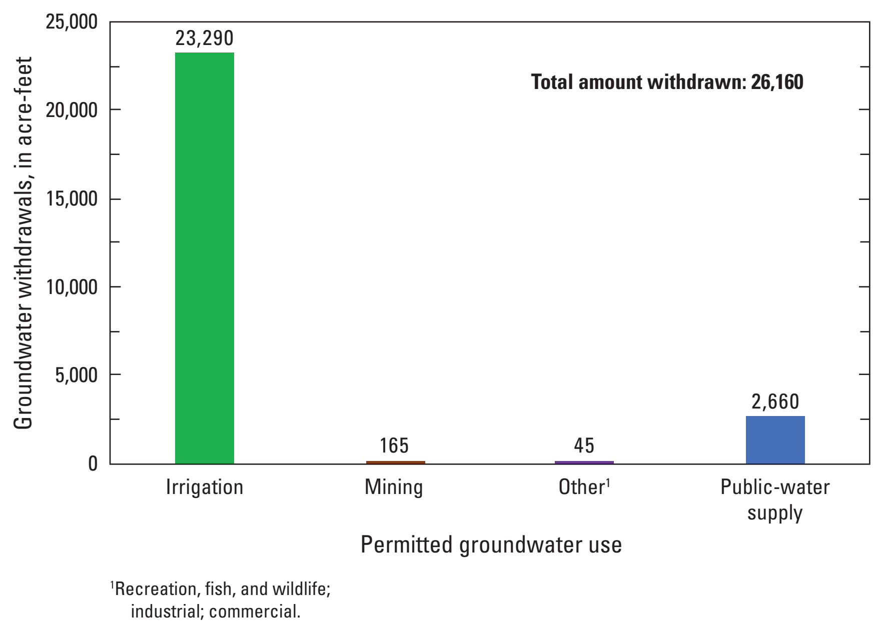


Figure 48. Reported groundwater withdrawals for permitted uses during 2015 from the Rush Springs aquifer, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (C. Neel, Oklahoma Water Resources Board, written commun., 2016).

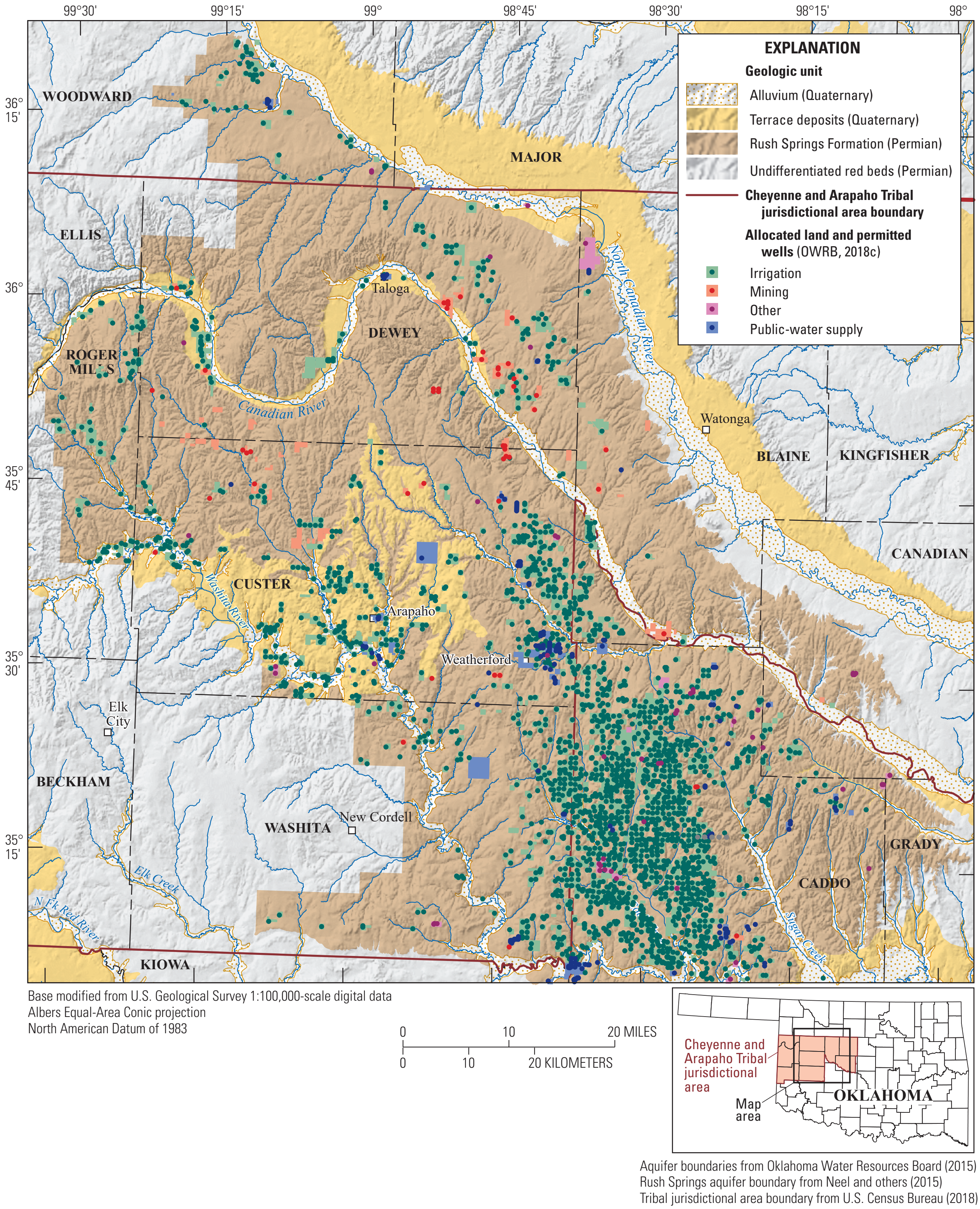
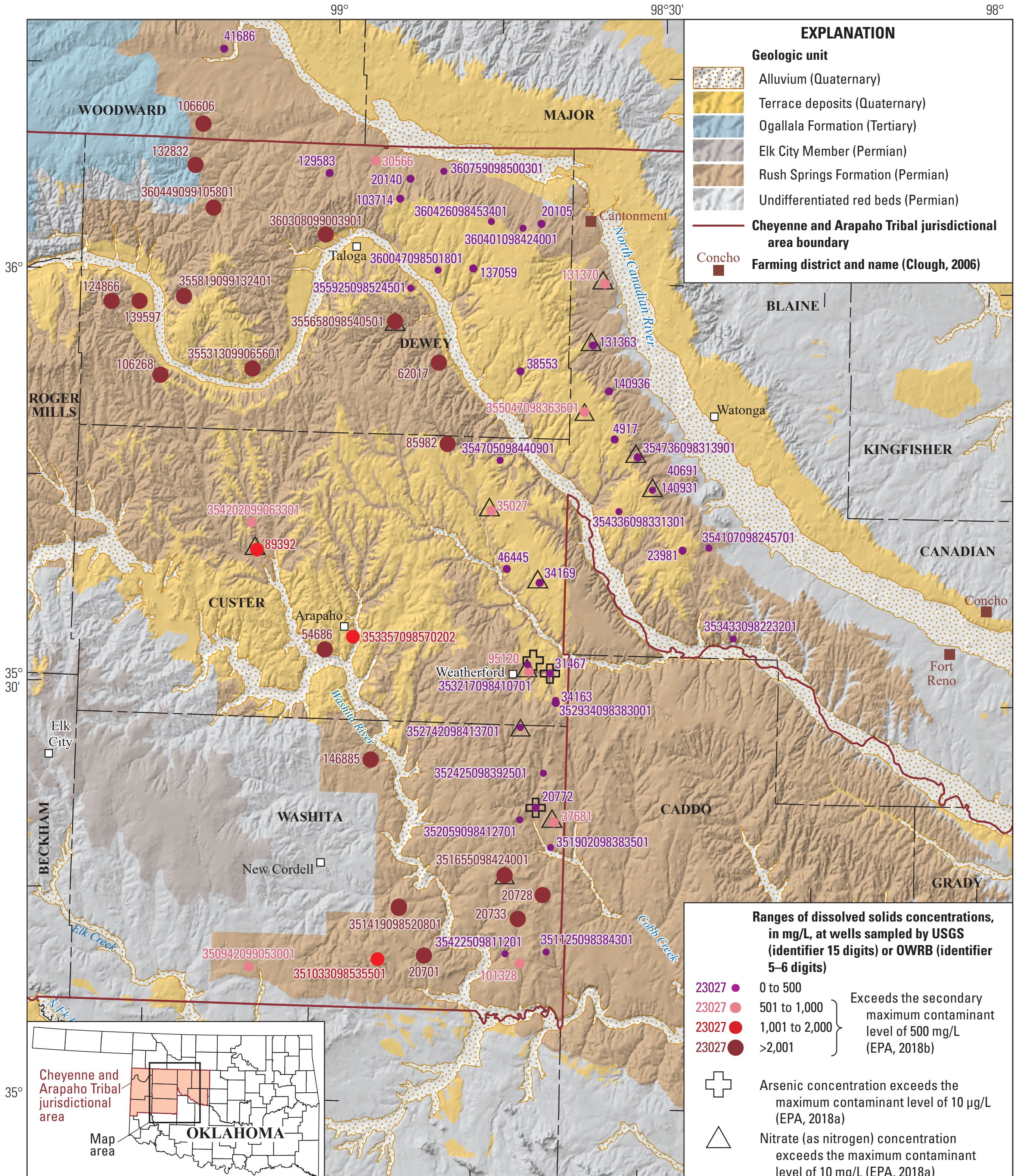


Figure 49. Allocated land and permitted wells withdrawing groundwater from the Rush Springs aquifer during 2015, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. OWRB, Oklahoma Water Resources Board.



Base modified from U.S. Geological Survey 1:100,000-scale digital data
Albers Equal-Area Conic projection
North American Datum of 1983

0 5 10 MILES
0 5 10 KILOMETERS

Aquifer boundaries from Oklahoma Water Resources Board (2015)
Ogallala aquifer boundary from Becker and others (1997)
Rush Springs aquifer boundary from Neel and others (2015)
Tribal jurisdictional area boundary from U.S. Census Bureau (2018)

Figure 50. Distribution of water samples from wells in the Rush Springs aquifer and ranges of dissolved solids concentrations and concentrations of nitrate (as nitrogen) and arsenic exceeding the maximum contaminant levels allowable in finished drinking water, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. EPA, U.S. Environmental Protection Agency; µg/L, microgram per liter; mg/L, milligram per liter; OWRB, Oklahoma Water Resources Board; USGS, U.S. Geological Survey.

Groundwater from the Rush Springs aquifer in the CATJA is slightly alkaline to neutral with median pH values of 7.4 and 7.2 in USGS and OWRB samples (tables 21 and 22). Dissolved solids concentrations in USGS and OWRB samples generally range in the 25th and 75th percentiles from 290 to 2,270 mg/L, with median concentrations of 360 mg/L in USGS samples and 515 mg/L in OWRB samples. About 33 percent of USGS samples and 50 percent of OWRB samples exceeded the dissolved solids SMCL of 500 mg/L for finished drinking water.

Groundwater from the Rush Springs aquifer ranges from soft to extremely hard with median hardness as calcium carbonate concentrations of 370 and 375 mg/L in USGS and OWRB samples, respectively (tables 21 and 22). Concentrations of sulfate exceeded the SMCL of 250 mg/L in 26 of 60 USGS samples and 14 of 37 OWRB samples with median concentrations of 135 and 71 mg/L, respectively.

The lowest concentrations of water-quality constituents were generally measured in samples collected from wells along the eastern and northeastern extent of the Rush Springs aquifer where the rocks that compose the aquifer are exposed at land surface or where the rocks that compose the aquifer are covered with terrace deposits (fig. 50). Relatively small concentrations of water-quality constituents also occur in samples collected from areas where large volumes of water are pumped from the aquifer for irrigation, such as the southeastern corner of Custer County and the northeastern corner of Washita County (Neel and others, 2015).

Nitrate (as nitrogen) was measured at concentrations exceeding the MCL of 10 mg/L in 5 of 37 USGS samples, about 14 percent (table 21). The median concentrations of nitrate (as nitrogen) in USGS samples was 3.2 mg/L (table 21). In 9 of 37 OWRB samples, about 24 percent, concentrations of nitrate (as nitrogen) exceeded the MCL of 10 mg/L (table 22). The median concentration of nitrate (as nitrogen) in OWRB samples was 3.5 mg/L (table 22).

Arsenic was measured in 1 of 38 USGS samples (well 353237098403901, 18.2 µg/L) and in 2 of 37 OWRB samples (well 20772, 10.7 µg/L; well 31467, 12.8 µg/L) at concentrations that exceeded the MCL of 10 µg/L (tables 21 and 22) (EPA, 2018a). These samples are from wells in parts of southeastern Custer County and the eastern part of Washita County (fig. 50). Large concentrations of arsenic also occur in samples from selected wells in the northern parts of Caddo County (not shown because they are outside of the CATJA). Water-quality information for the southern parts of the Rush Springs aquifer, outside of the CATJA boundaries, can be found in Neel and others (2015).

The water type in areas where the Rush Springs aquifer is overlain by the Cloud Chief Formation is most commonly a calcium-sulfate type (Becker and Runkle, 1998). The water type in areas where relatively small concentrations of dissolved solids occur is most commonly a calcium-bicarbonate type (Becker and Runkle, 1998).

Conclusions and Data Gap Discussion

Data from the OWRB BUMP and GMAP in addition to USGS data provide a synopsis of baseline conditions of surface-water and groundwater resources in the CATJA. However, there are areas where groundwater and surface water will be used where the collection of additional hydrologic data would benefit the Tribe and help improve the understanding of resources in selected areas in the CATJA.

A better understanding of streamflow and changes in water quality could be provided by establishing long-term streamflow and water-quality sampling stations on the major or minor rivers located upstream from areas of Tribal interest. The installation of continuous water-quality monitors for specific conductance, turbidity, dissolved oxygen, and temperature could provide additional information about daily and seasonal changes in surface-water quality that cannot be determined by the collection of samples several times a year, particularly in areas where changes in groundwater or surface-water use are anticipated.

The North Canadian River Basin in the CATJA is considered a “hot spot” for surface-water and alluvial aquifer groundwater shortages in the future (OWRB, 2012a). The surface-water limitations are determined by the “physical availability” (amount of surface water available based on future demands), “permit availability” (the availability of new permits based on the amount of surface water available), and poor water quality (OWRB, 2012a, p. 123). There may be options to help alleviate this shortage, which could include the development of new reservoirs, more efficient irrigation methods, the planting of crops with lower water demands, implementing methods to conserve water for public-water supply and industrial use, and the use of brackish groundwater sources.

In areas where the Tribes have a historical or present-day investment, it would be useful to monitor changes in groundwater levels and water quality in the alluvial and bedrock aquifers. Weekly, monthly, and seasonal changes in groundwater levels provide useful information about groundwater-flow directions, groundwater storage amounts, and the potential effects on water use from droughts and overpumpage. Water-level measurements can be made manually or by use of submersible pressure transducers in networks of 20 or more wells in and surrounding areas of interest to the Tribes. Water-quality information could be collected every 5 years in selected wells to assess the natural geochemistry of the aquifer and to identify constituents that are a concern. Baseline constituents could include the water-quality field properties, hardness, dissolved solids, major ions, nitrate (as nitrogen), and trace elements. Nitrate is a concern where there is the possibility of using groundwater for domestic use and public-water supply from the alluvial and bedrock aquifers and should be sampled for seasonally. Analyzing for the same constituents as the OWRB GMAP for their baseline aquifer-monitoring studies would be beneficial for comparisons (OWRB, 2018d).

In most alluvial and bedrock aquifers in the CATJA, water quality is compromised by large concentrations of dissolved solids, which usually are related to large concentrations of calcium, sulfate, and bicarbonate ions. Regular, periodic measurements of specific conductance at wells, in combination with water-level measurements, would show changes in concentrations of dissolved solids related to seasonal changes, irrigation, or types of land cover and use.

There is a large data gap concerning the groundwater levels and water quality in the Canadian River alluvial aquifer. Because this river basin covers a large area, additional hydrologic data where there are Tribal interests in Blaine and Canadian Counties and parts of Custer and Dewey Counties would be beneficial for planning future water use.

Summary

This report provides an overview of existing hydrologic information describing the quality, quantity, and extent of the major surface-water and groundwater resources in the Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma. The hydrologic information describes five major river systems (Cimarron River, North Canadian River, Canadian River, Washita River, and North Fork Red River), two reservoirs (Foss Reservoir and Canton Lake), and eight aquifers consisting of the alluvial aquifers associated with each of the five major river systems and the three major bedrock aquifers (Ogallala aquifer, Elk City aquifer, and Rush Springs aquifer).

Types of information provided about rivers and reservoirs for the Cheyenne and Arapaho Tribal jurisdictional area include diversion sites and amounts of water allocated and diverted for permitted uses in 2015; treated wastewater discharge sites and amounts discharged in 2015; and characteristics describing water-quality field properties, major ions, nutrients, and selected trace elements. Major ions, nutrients, and selected trace elements are compared to maximum contaminant levels and secondary maximum contaminant levels for finished drinking water. Additionally, statistics are provided describing daily, monthly, and annual streamflow characteristics at 12 U.S. Geological Survey (USGS) streamgages. Streamflow statistics include the magnitudes and frequencies of floods, base-flow characteristics, and long-term streamflow trends.

Types of information provided about the aquifers include amounts of water allocated and pumped for permitted uses in 2015; characteristics of groundwater describing water-quality field properties, major ions, nitrate (measured as nitrogen), and selected trace elements with comparisons to maximum contaminant levels and secondary maximum contaminant levels for finished drinking water; groundwater levels and long-term changes in water levels; and ranges of hydraulic conductivity, aquifer recharge, specific yield, transmissivity, and well yields from reports and groundwater-flow models.

Surface water is used primarily for irrigation, mining, and other nonconsumptive uses in the Cheyenne and Arapaho Tribal jurisdictional area, except from the Washita and North Fork Red Rivers, where water is treated for use as public-water supply. Large concentrations of dissolved solids are the primary reason that surface-water use is limited. Median concentrations of dissolved solids in surface water range from less than 1,000 milligrams per liter (mg/L) in the North Canadian River to greater than 9,000 mg/L in the Cimarron River. Large dissolved solids concentrations are correlated with hard water. Median hardness as calcium carbonate concentrations ranges from 427 mg/L in samples from Canton Lake to 1,000 mg/L in samples from the Washita River.

In 2015 in the study area, groundwater was used at more than twice the rate of surface water. Alluvial aquifers are considered reliably good sources of water in the Cheyenne and Arapaho Tribal jurisdictional area; however, concentrations of nitrate (measured as nitrogen) in parts of all of the alluvial aquifers exceed the maximum contaminant level of 10 mg/L established by the U.S. Environmental Protection Agency for finished drinking water. Water from the three major bedrock aquifers is used for irrigation, mining, public-water supply and other uses; however, large concentrations of dissolved solids, nitrate (measured as nitrogen), and naturally occurring trace elements such as arsenic and uranium may limit the use of groundwater for public-water supply in some areas. Currently (2019), the depletion of groundwater from the major aquifers in west-central Oklahoma is a minor concern to the Oklahoma Water Resources Board. Groundwater levels and other hydrologic information show that recharge rates exceed pumpage rates in the aquifers, except in areas that may be affected locally by groundwater depletions.

In areas where groundwater and surface water will be used, the collection of additional hydrologic data would benefit the Tribe and help improve the understanding of resources in selected areas of the Cheyenne and Arapaho Tribal jurisdictional area. There is a large data gap concerning the groundwater levels and water quality in the Canadian River alluvial aquifer. Because this river basin covers a large area, additional hydrologic data where there are Tribal interests in Blaine and Canadian Counties and parts of Custer and Dewey Counties would be beneficial for planning future water use.

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Appendix 1

Statistics describing daily, monthly, and annual streamflow characteristics at 12 U.S. Geological Survey streamgages on the Cimarron, North Canadian, Canadian, Washita, and North Fork Red Rivers, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma.

07159100 Cimarron River near Dover, Oklahoma

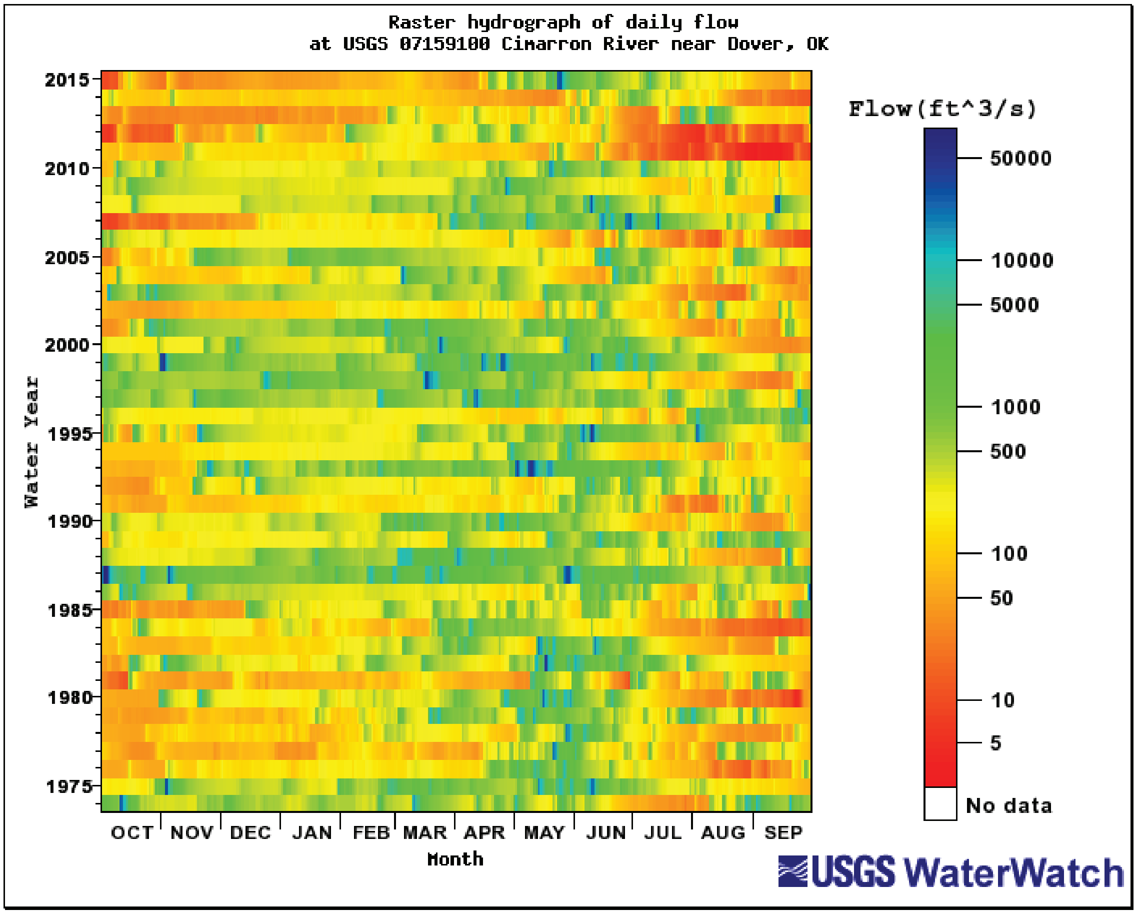
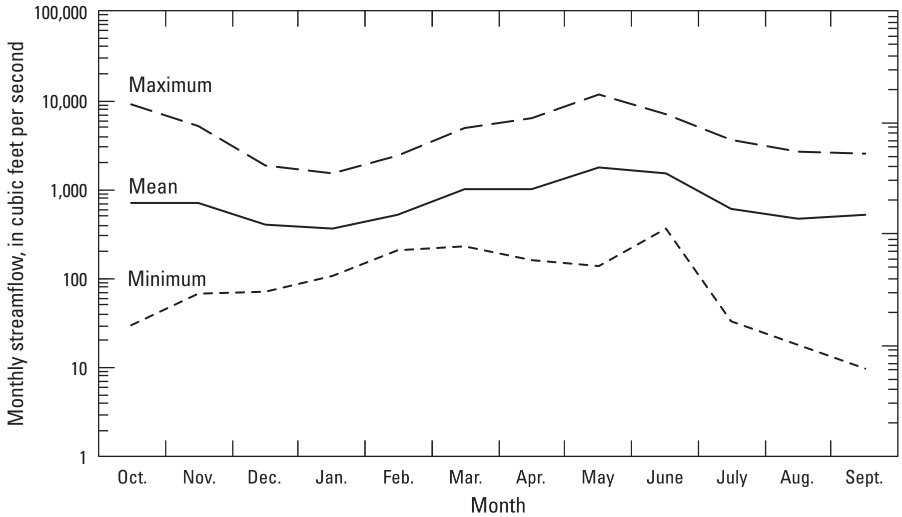


Figure 1.1. Daily streamflows measured at U.S. Geological Survey streamgage 07159100 Cimarron River near Dover, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1974–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07159100&ds=dv01d&yt=wy&bdt=1984&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	9,071	15.3	697	230
November	5,171	28.9	696	232
December	1,864	29.8	407	242
January	1,549	41.8	371	249
February	2,410	71.6	528	300
March	4,840	77.4	1,033	523
April	6,442	57.7	1,010	621
May	11,750	52.5	1,810	1,318
June	6,969	113	1,490	833
July	3,684	16.6	607	379
August	2,622	10.2	466	257
September	2,577	6.13	518	194
Annual	2,804	119	804	703

Figure 1.2. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07159100 Cimarron River near Dover, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

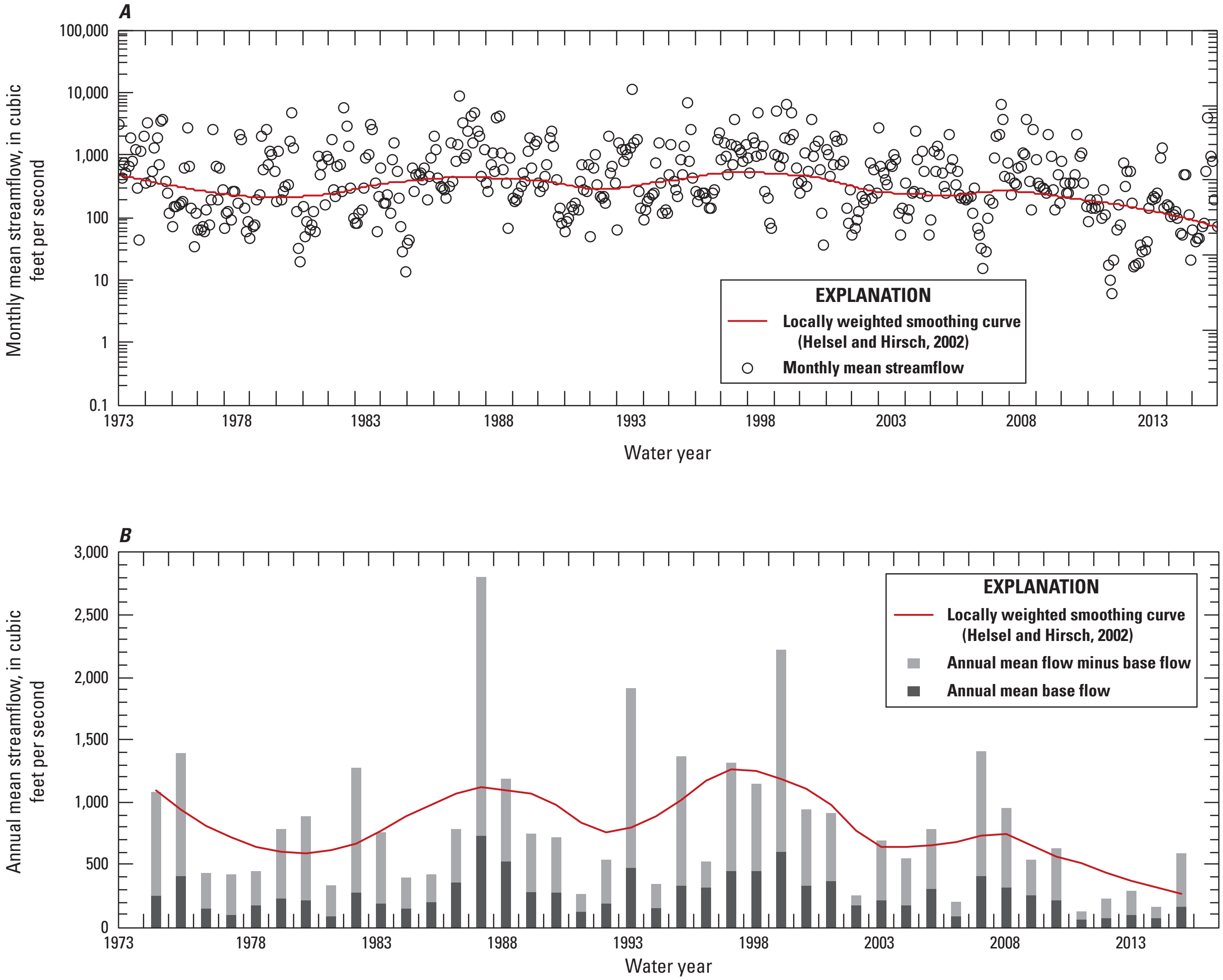


Figure 1.3. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07159100 Cimarron River near Dover, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1974 to 2015.

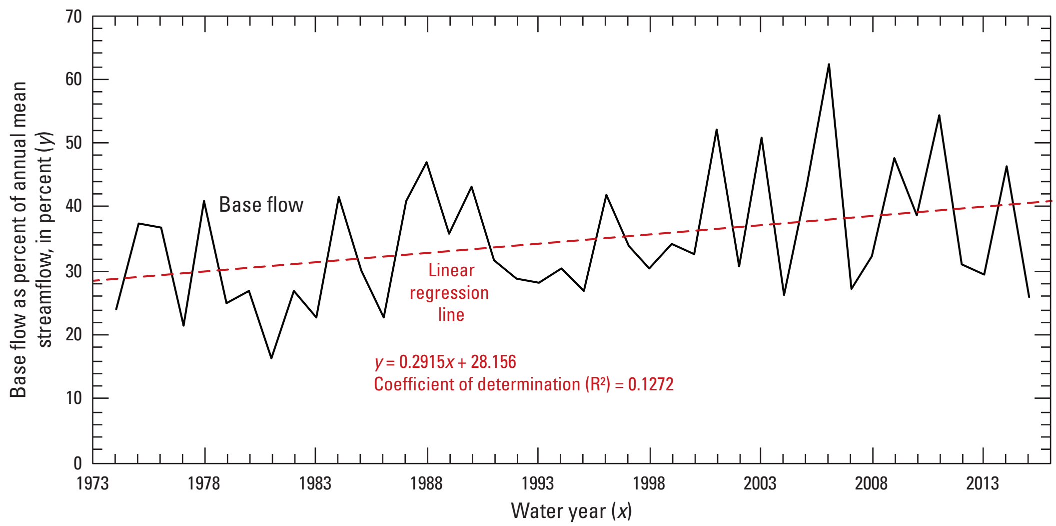


Figure 1.4. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1974–2015) at U.S. Geological Survey streamgage 07159100 Cimarron River near Dover, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

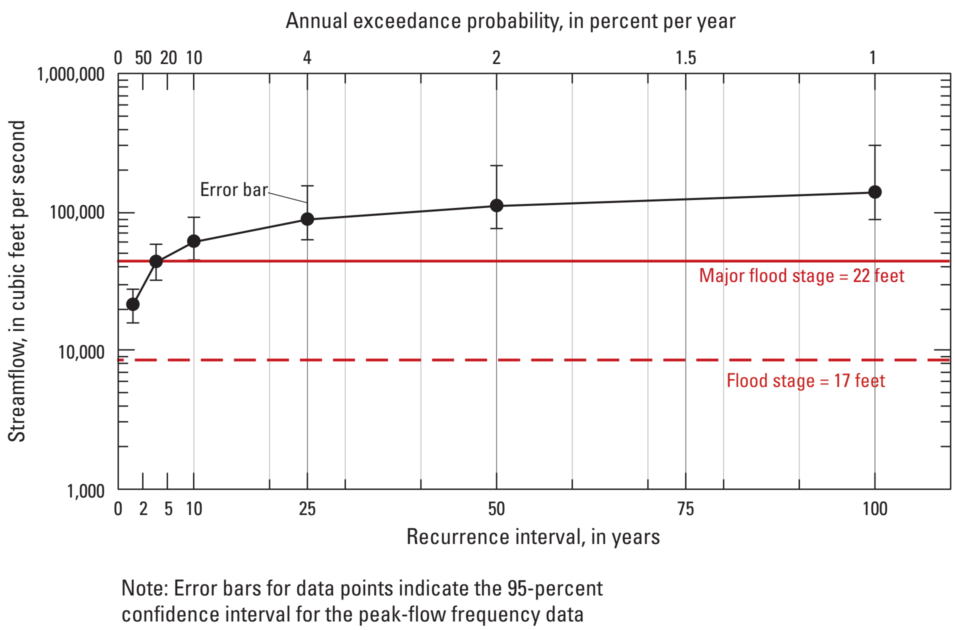


Figure 1.5. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07159100 Cimarron River near Dover, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07228500 Canadian River at Bridgeport, Oklahoma

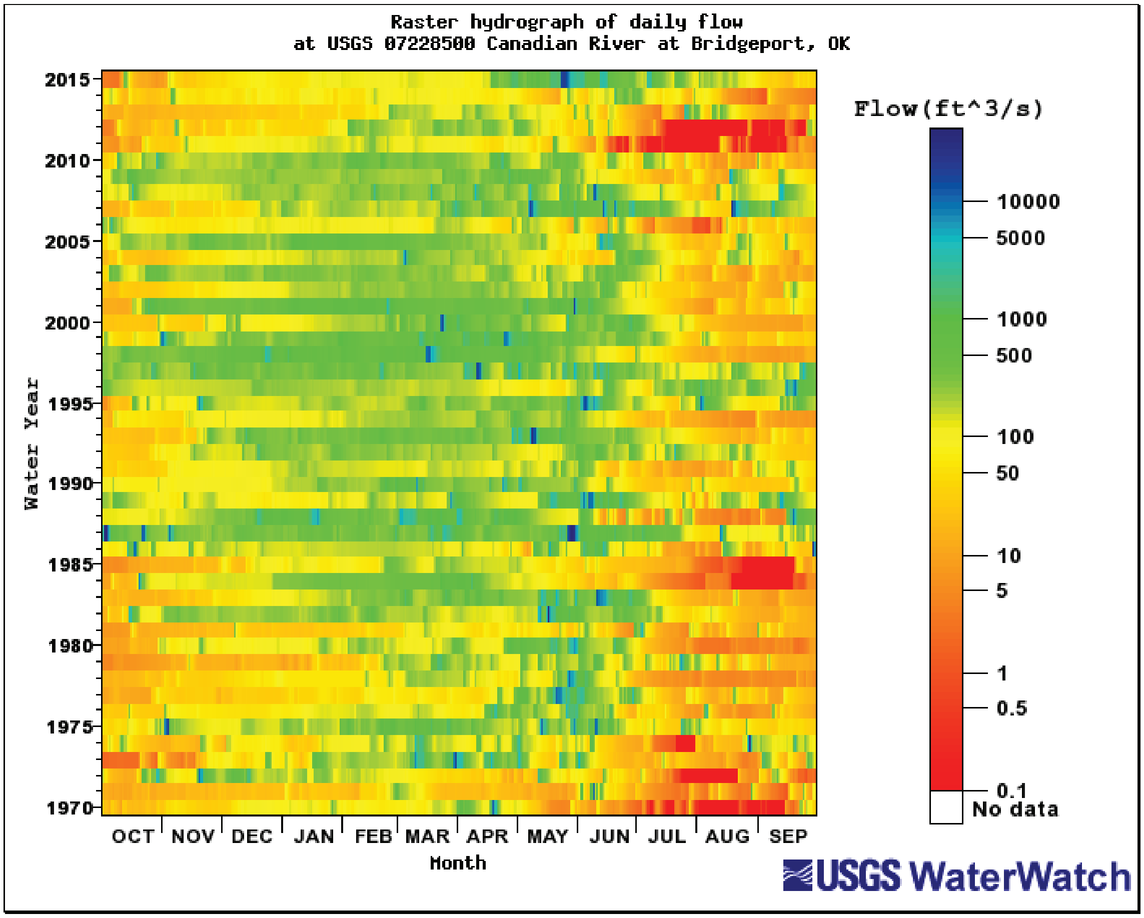
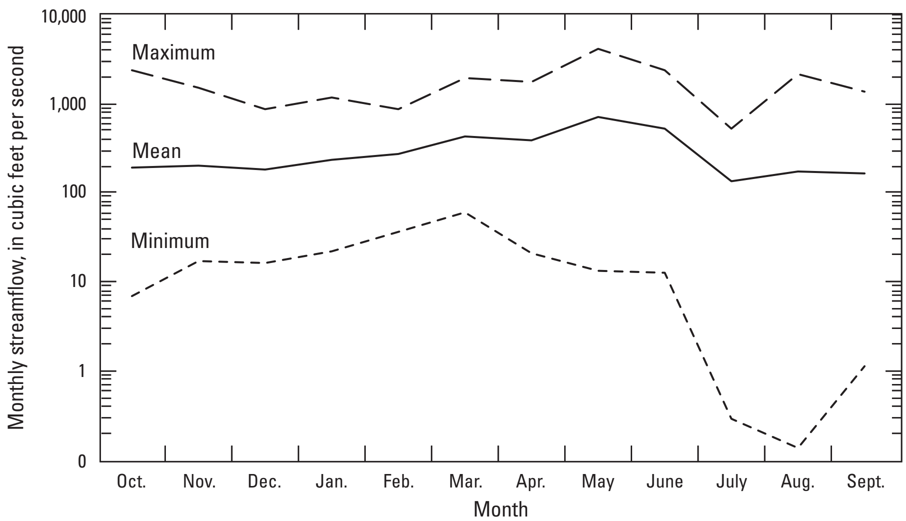


Figure 1.6. Daily streamflows measured at U.S. Geological Survey streamgage 07228500 Canadian River at Bridgeport, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1970–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07228500&ds=dv01d&yt=yv&bdt=&edt=&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	2,412	7.01	188	49.6
November	1,525	17.5	207	100
December	870	16.2	186	107
January	1,162	22.5	233	195
February	878	36.8	269	215
March	1,907	60.8	438	285
April	1,795	20.5	387	291
May	4,188	13.4	718	368
June	2,342	12.5	525	316
July	515	0.29	131	96.5
August	2,120	0.14	174	37.8
September	1,386	1.14	163	35.9
Annual	1,018	70.2	301	261

Figure 1.7 Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07228500 Canadian River at Bridgeport, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

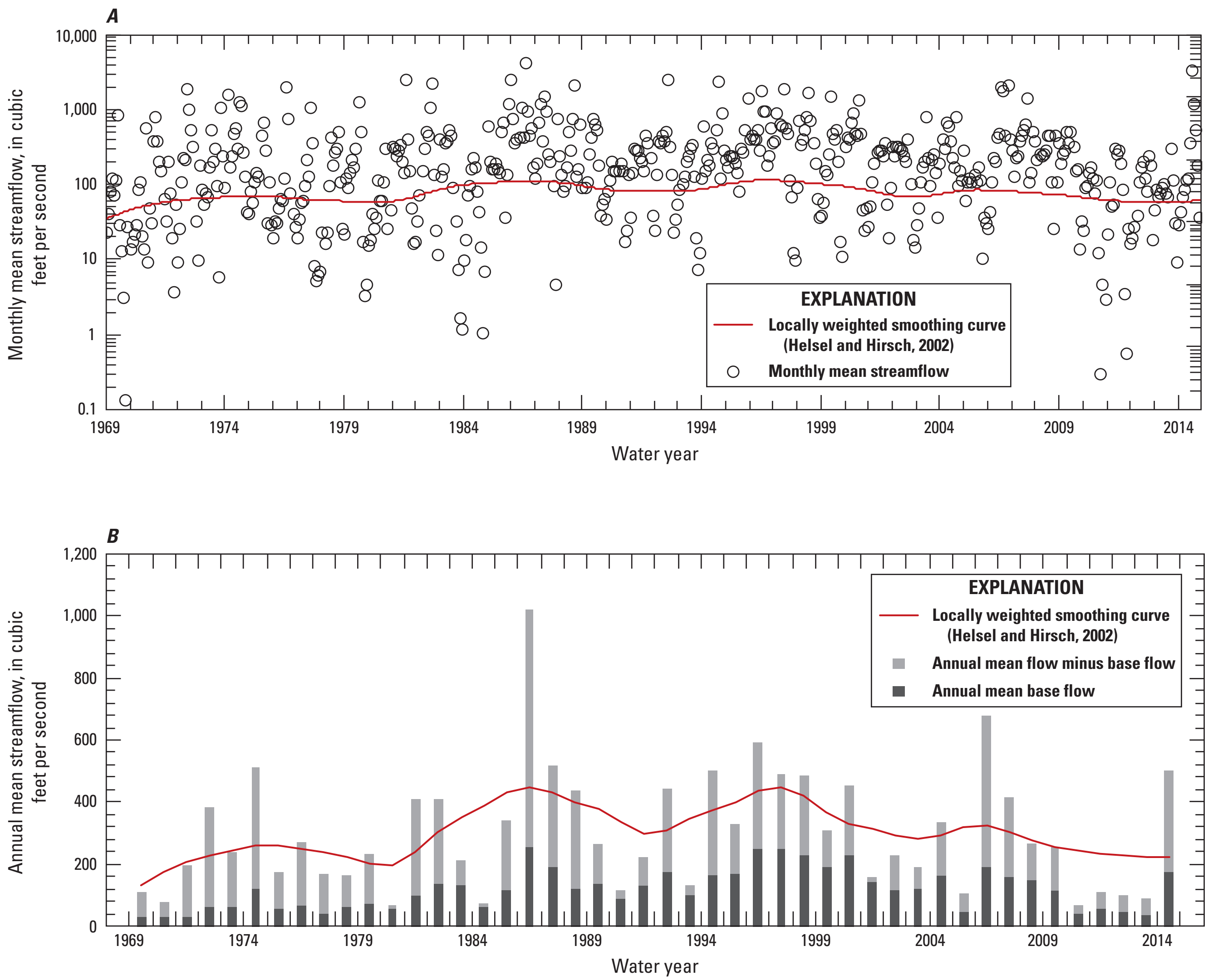


Figure 1.8. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07228500 Canadian River at Bridgeport, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1970 to 2015.

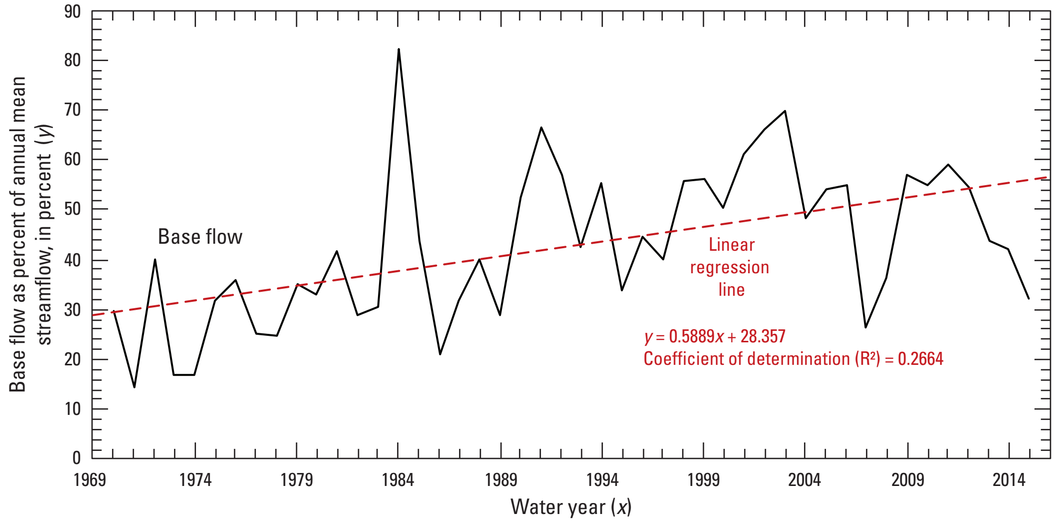
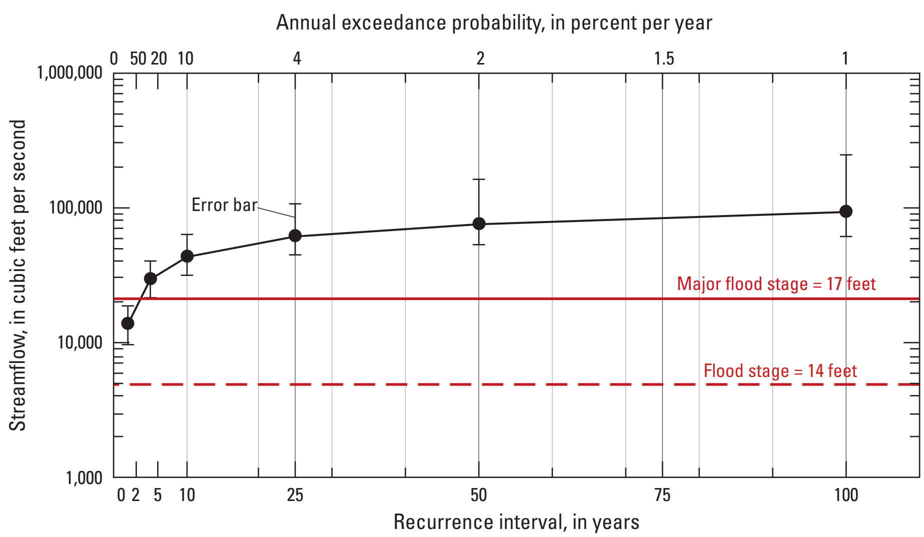


Figure 1.9. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1970–2015) at U.S. Geological Survey streamgage 07228500 Canadian River at Bridgeport, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).



Note: Error bars for data points indicate the 95-percent confidence interval for the peak-flow frequency data

Figure 1.10. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07228500 Canadian River at Bridgeport, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07239300 North Canadian River below Weavers Creek near Watonga, Oklahoma

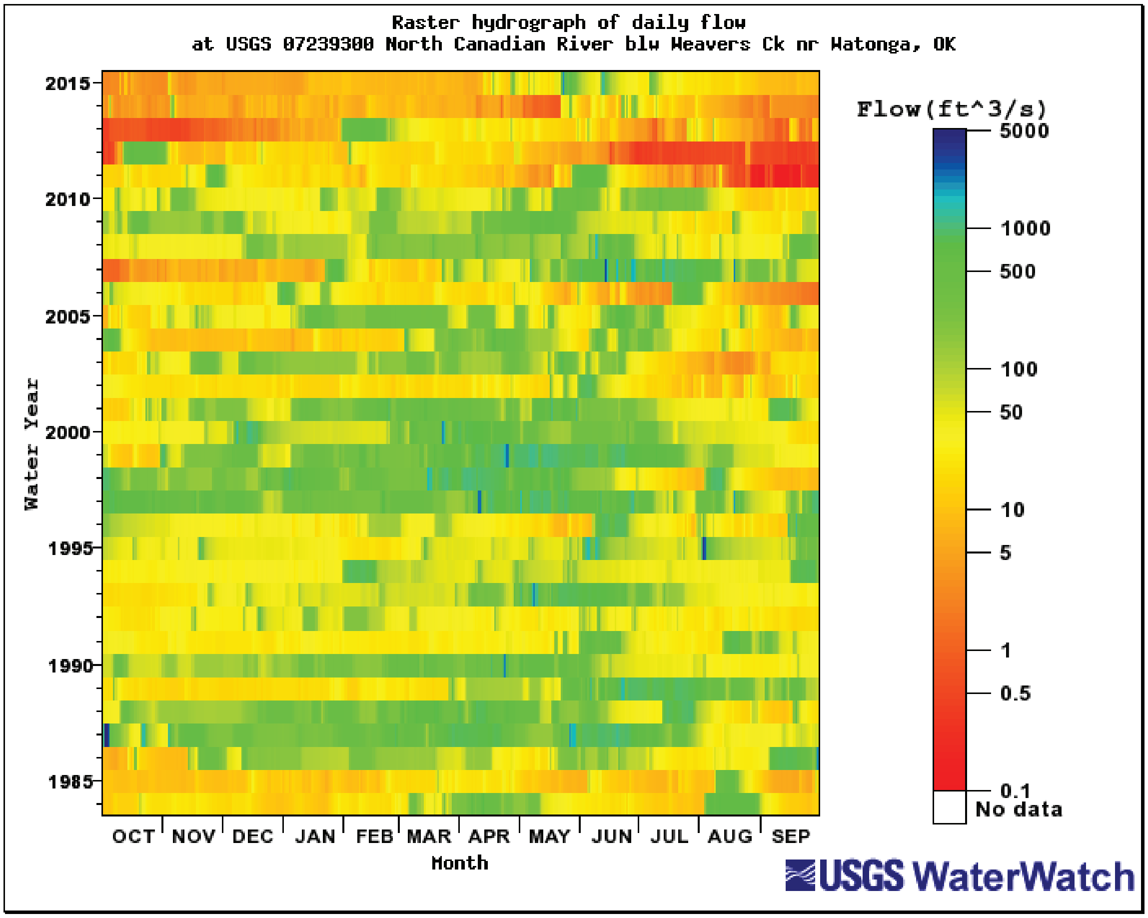
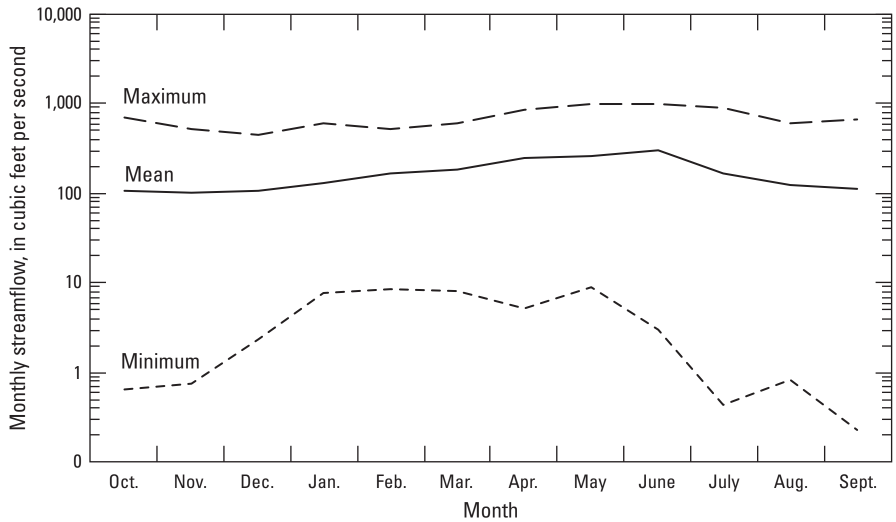


Figure 1.11. Daily streamflows measured at U.S. Geological Survey streamgage 07239300 North Canadian River below Weavers Creek near Watonga, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1984–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07239300&ds=dv01d&yt=wy&bdt=1984&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	708	0.67	108	30.6
November	532	0.74	101	39.7
December	452	2.40	109	44.6
January	620	7.63	131	61.8
February	532	8.60	167	111
March	597	8.07	188	76.7
April	863	5.18	247	106
May	1,004	9.11	265	157
June	977	2.98	308	240
July	895	0.43	171	48.5
August	610	0.83	125	40.2
September	667	0.23	111	32.0
Annual	476	13.5	169	136

Figure 1.12. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07239300 North Canadian River below Weavers Creek near Watonga, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

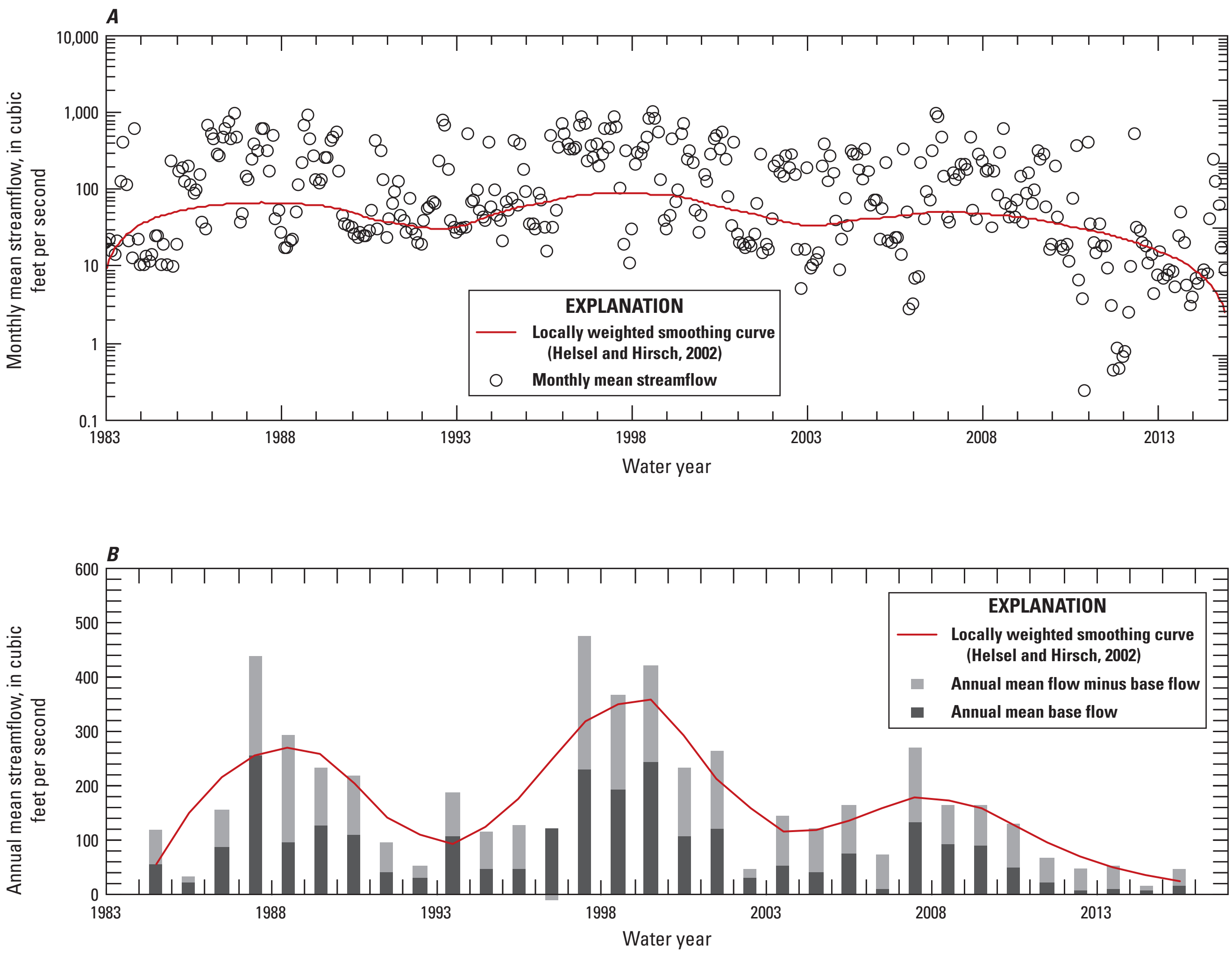


Figure 1.13. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07239300 North Canadian River below Weavers Creek near Watonga, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1984 to 2015.

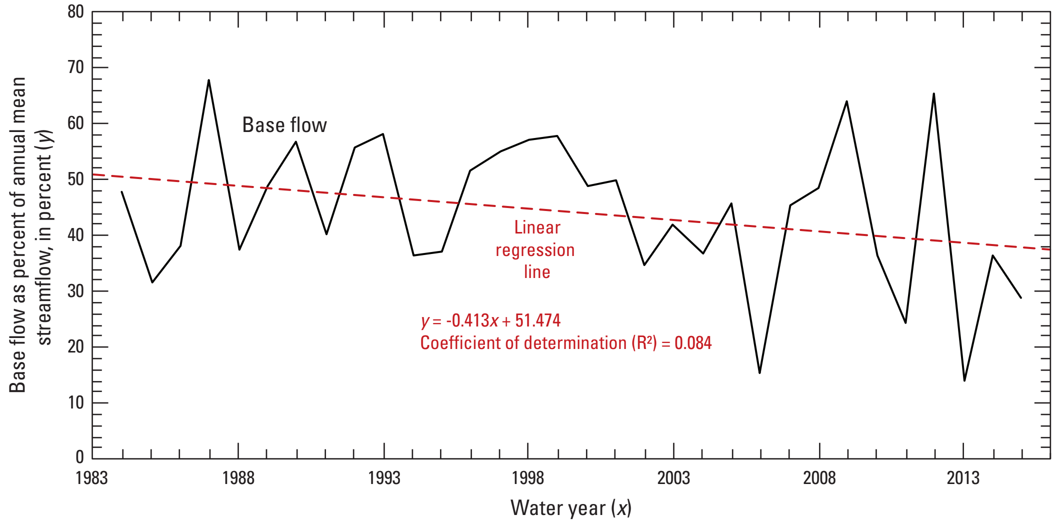


Figure 1.14. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1984–2015) at U.S. Geological Survey streamgage 07239300 North Canadian River below Weavers Creek near Watonga, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

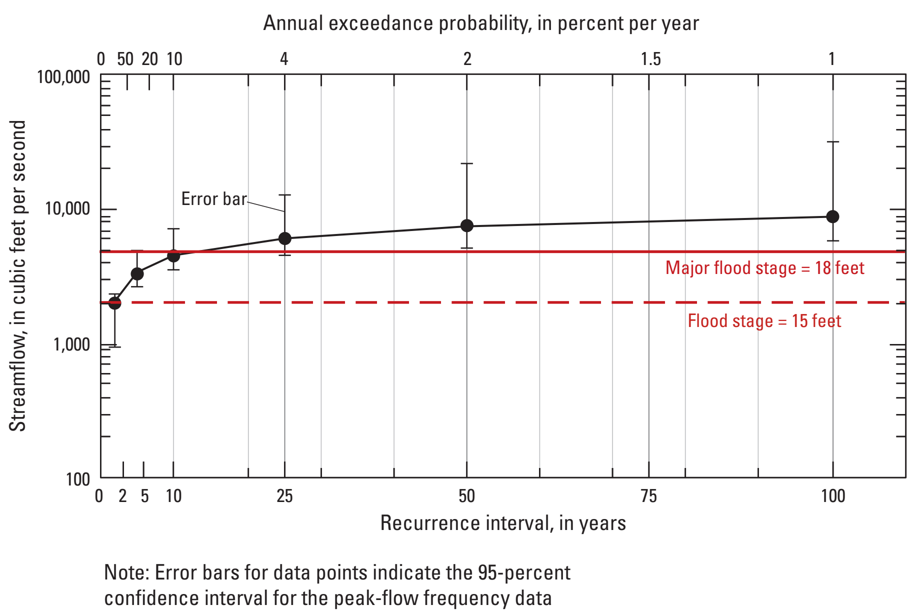


Figure 1.15. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07239300 North Canadian River below Weavers Creek near Watonga, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07239450 North Canadian River near Calumet, Oklahoma

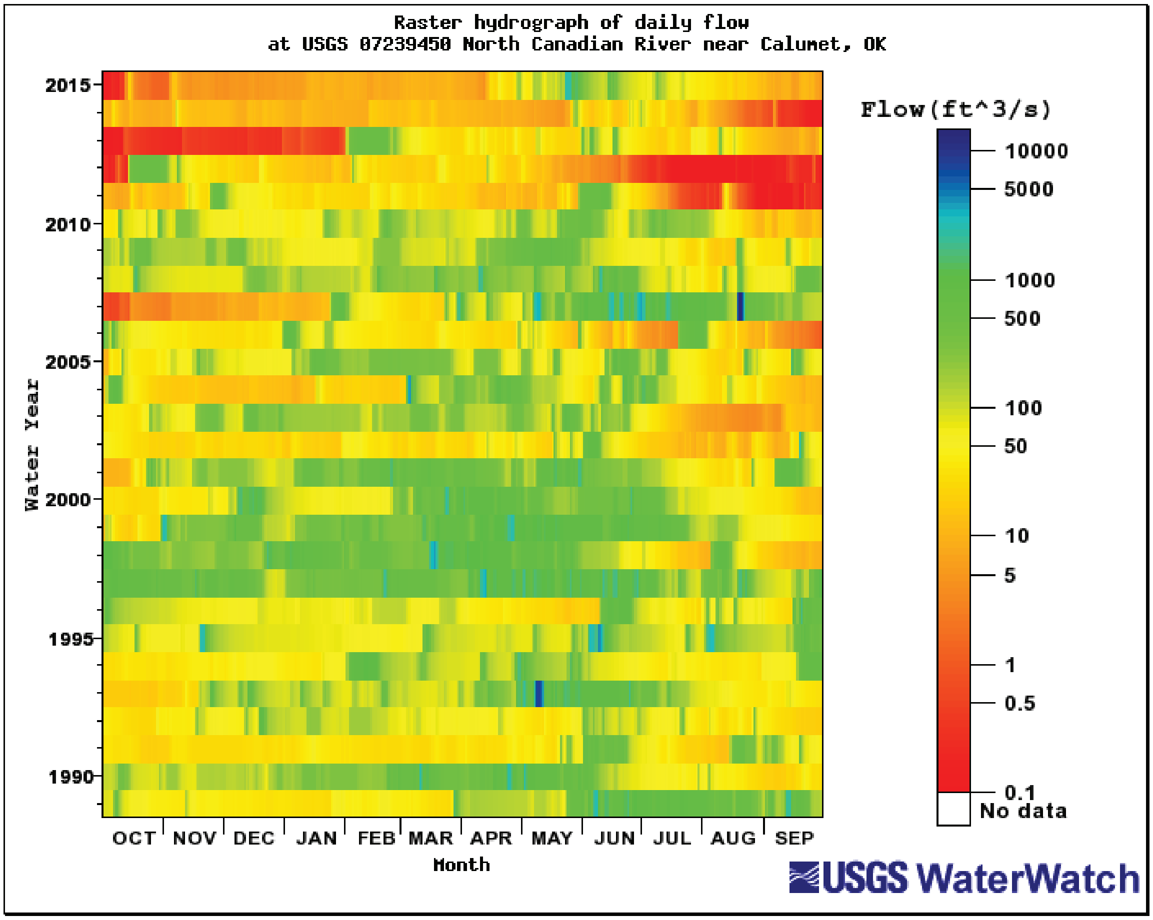
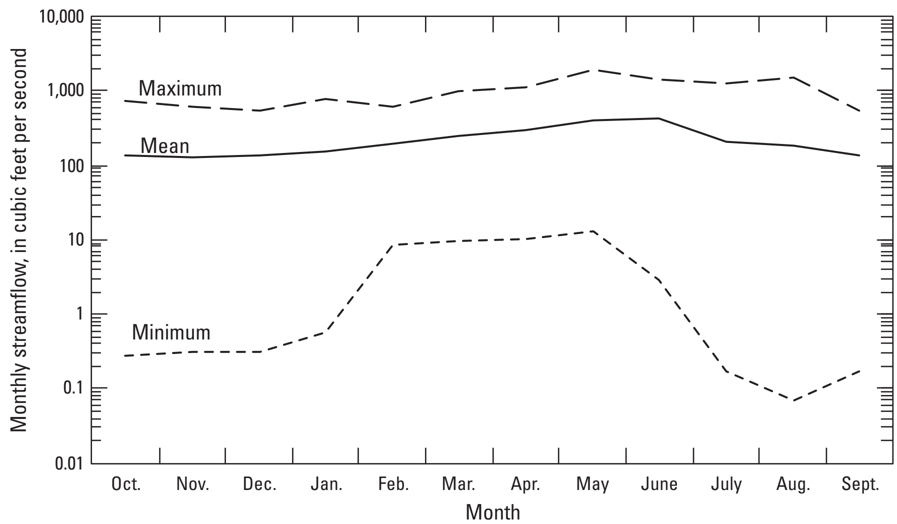


Figure 1.16. Daily streamflows measured at U.S. Geological Survey streamgage 07239450 North Canadian River near Calumet, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1989–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07239450&ds=dv01d&yt=wy&bdt=1989&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	745	0.28	134	70.2
November	603	0.31	128	79.4
December	547	0.32	139	68.8
January	777	0.58	151	74.6
February	600	8.33	197	132
March	977	9.8	251	131
April	1,110	10.2	297	177
May	1,878	13.3	401	269
June	1,435	2.84	432	309
July	1,260	0.17	201	79.1
August	1,533	0.07	178	54.8
September	535	0.17	134	41.0
Annual	635	14.9	220	166

Figure 1.17. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07239450 North Canadian River near Calumet, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

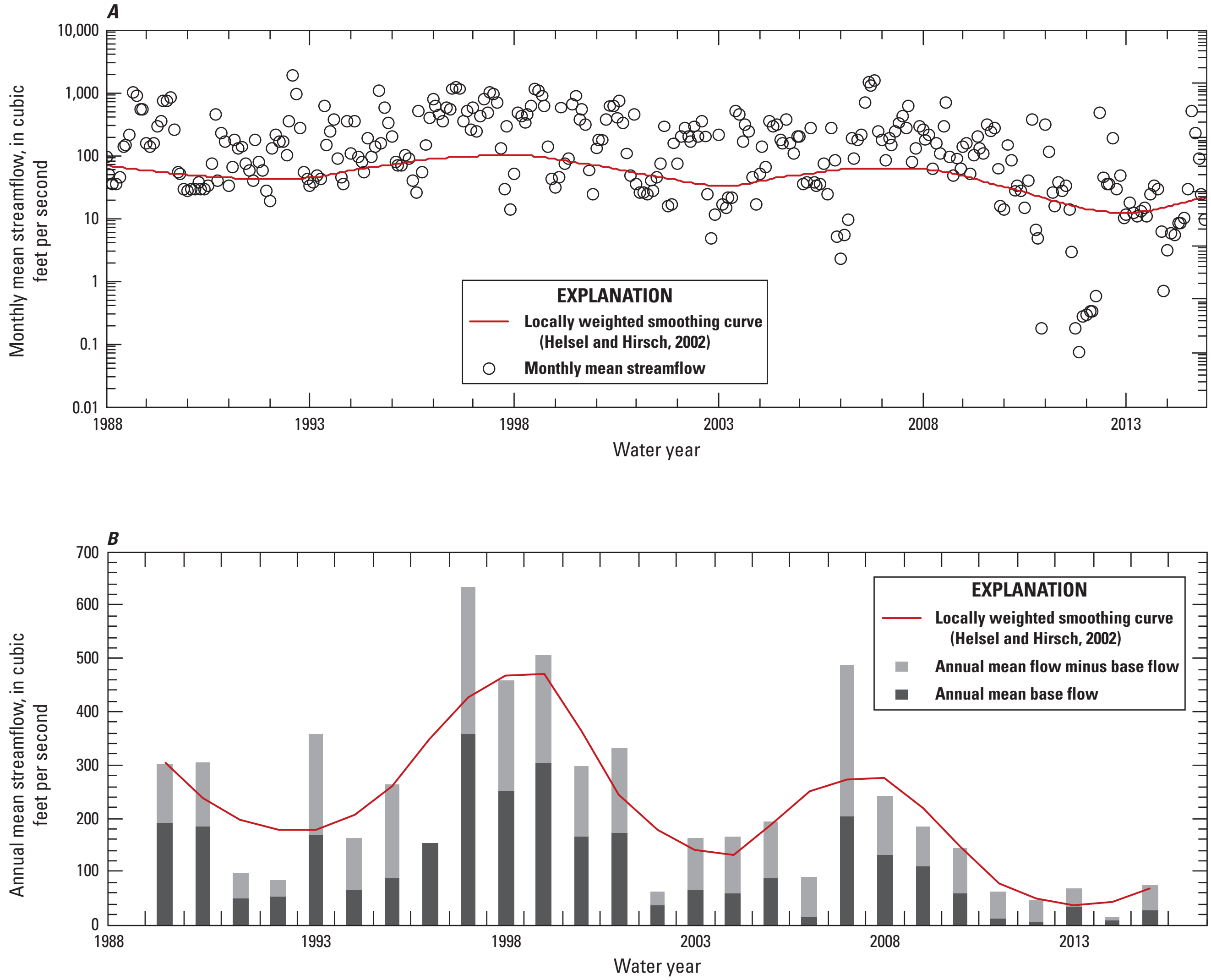


Figure 1.18. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07239450 North Canadian River near Calumet, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1989 to 2015.

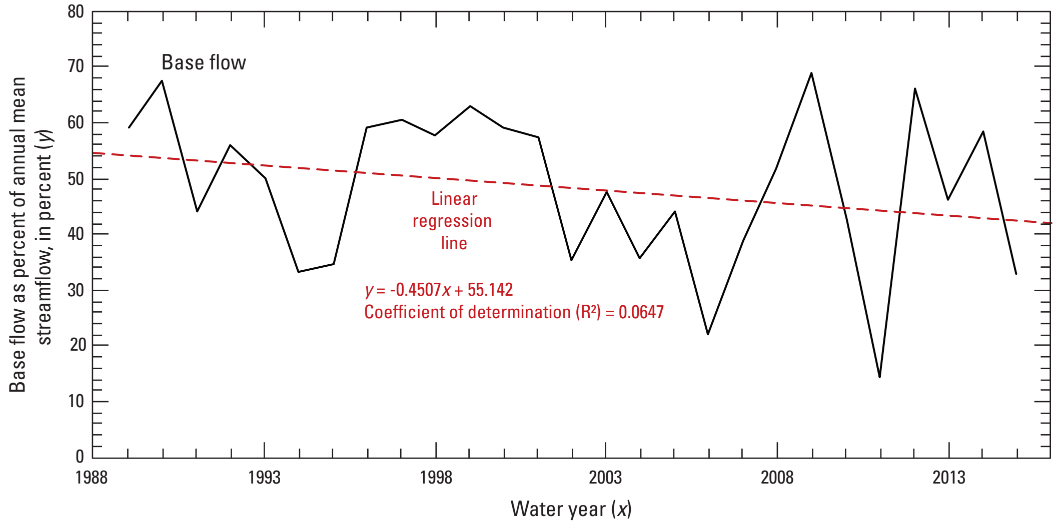


Figure 1.19. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1989–2015) at U.S. Geological Survey streamgage 07239450 North Canadian River near Calumet, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

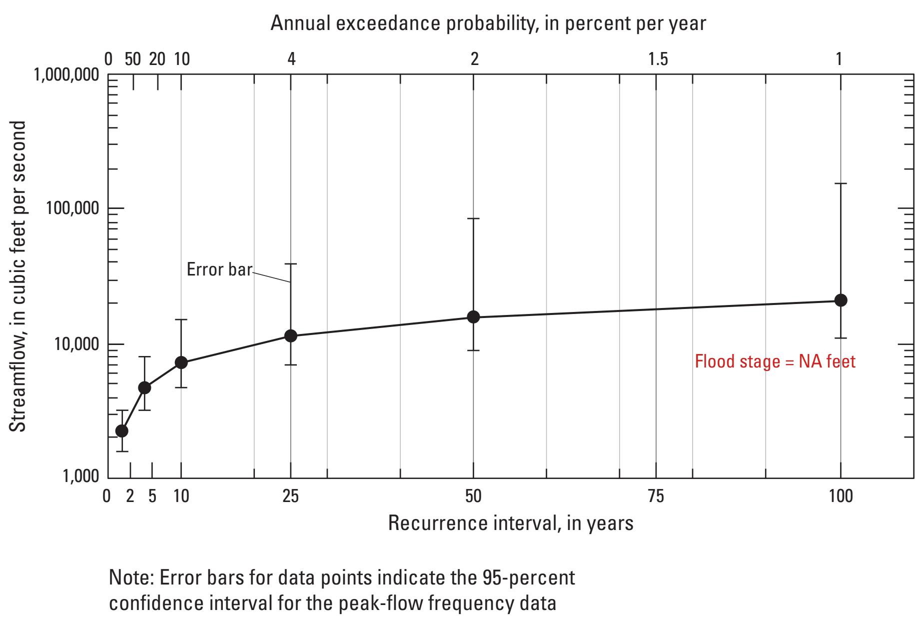


Figure 1.20. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07239450 North Canadian River near Calumet, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07239500 North Canadian River near El Reno, Oklahoma

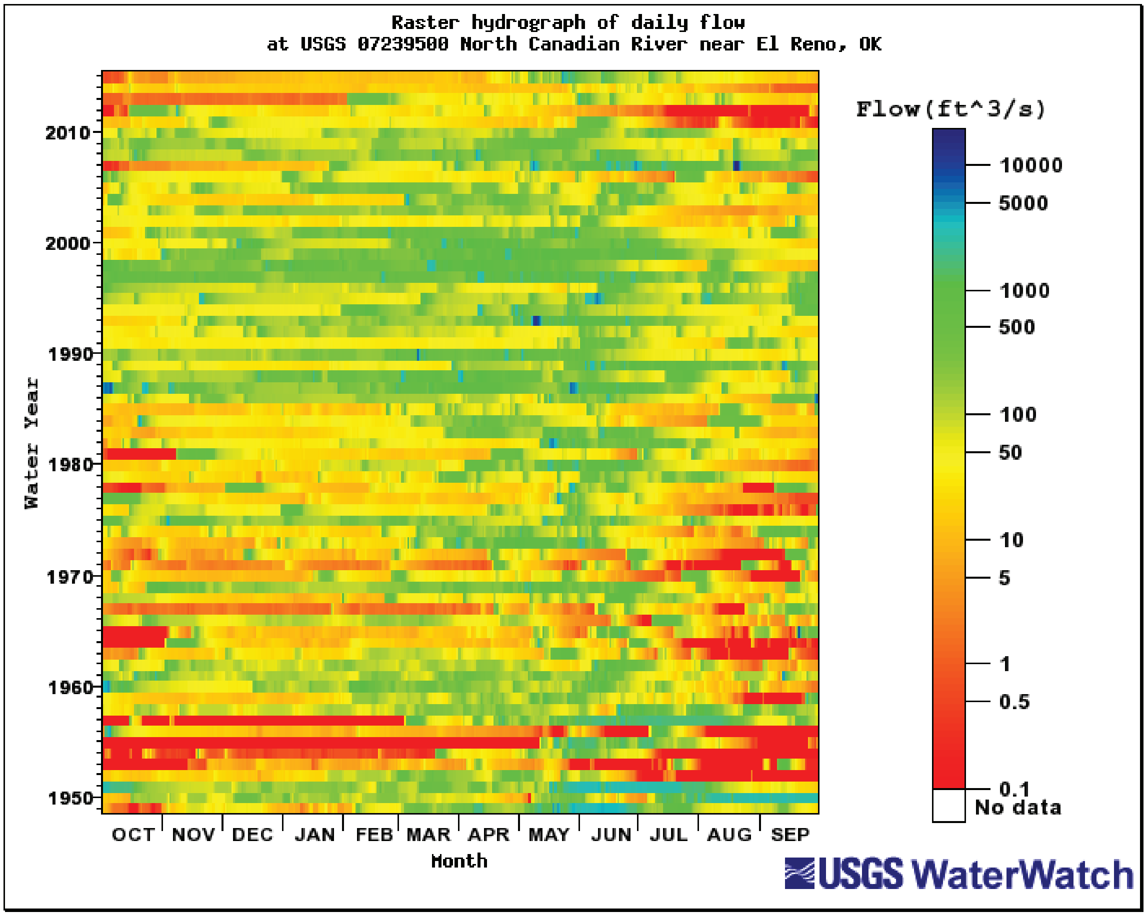
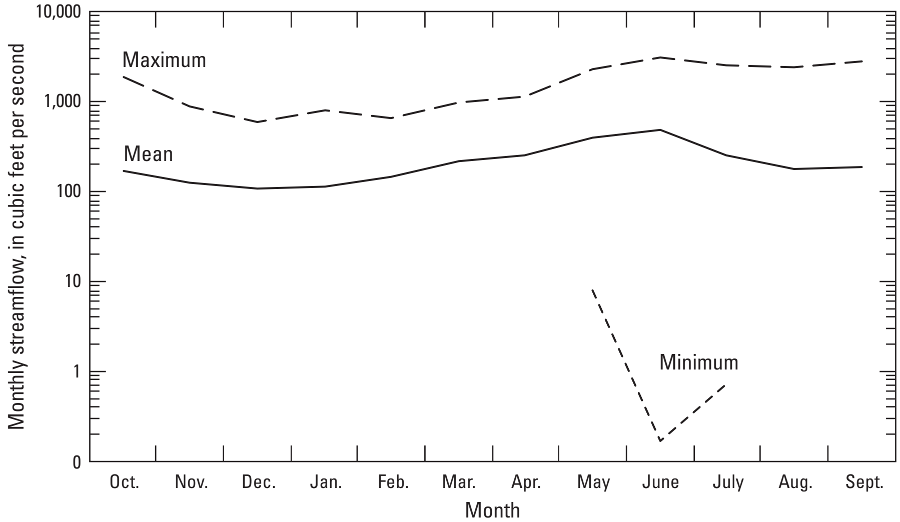


Figure 1.21. Daily streamflows measured at U.S. Geological Survey streamgage 07239500 North Canadian River near El Reno, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1949–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07239500&ds=dv01d&yt=wy&bdt=1949&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	1904	0.00	172	68.7
November	884	0.00	124	51.3
December	592	0.00	106	46.1
January	826	0.00	112	49.1
February	673	0.00	149	83.3
March	971	0.00	214	136
April	1129	0.00	260	141
May	2354	8.00	397	269
June	3121	0.17	484	340
July	2597	0.73	258	125
August	2460	0.00	182	59.1
September	2786	0.00	185	42.5
Annual	807	18.7	220	162

Figure 1.22. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07239500 North Canadian River near El Reno, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

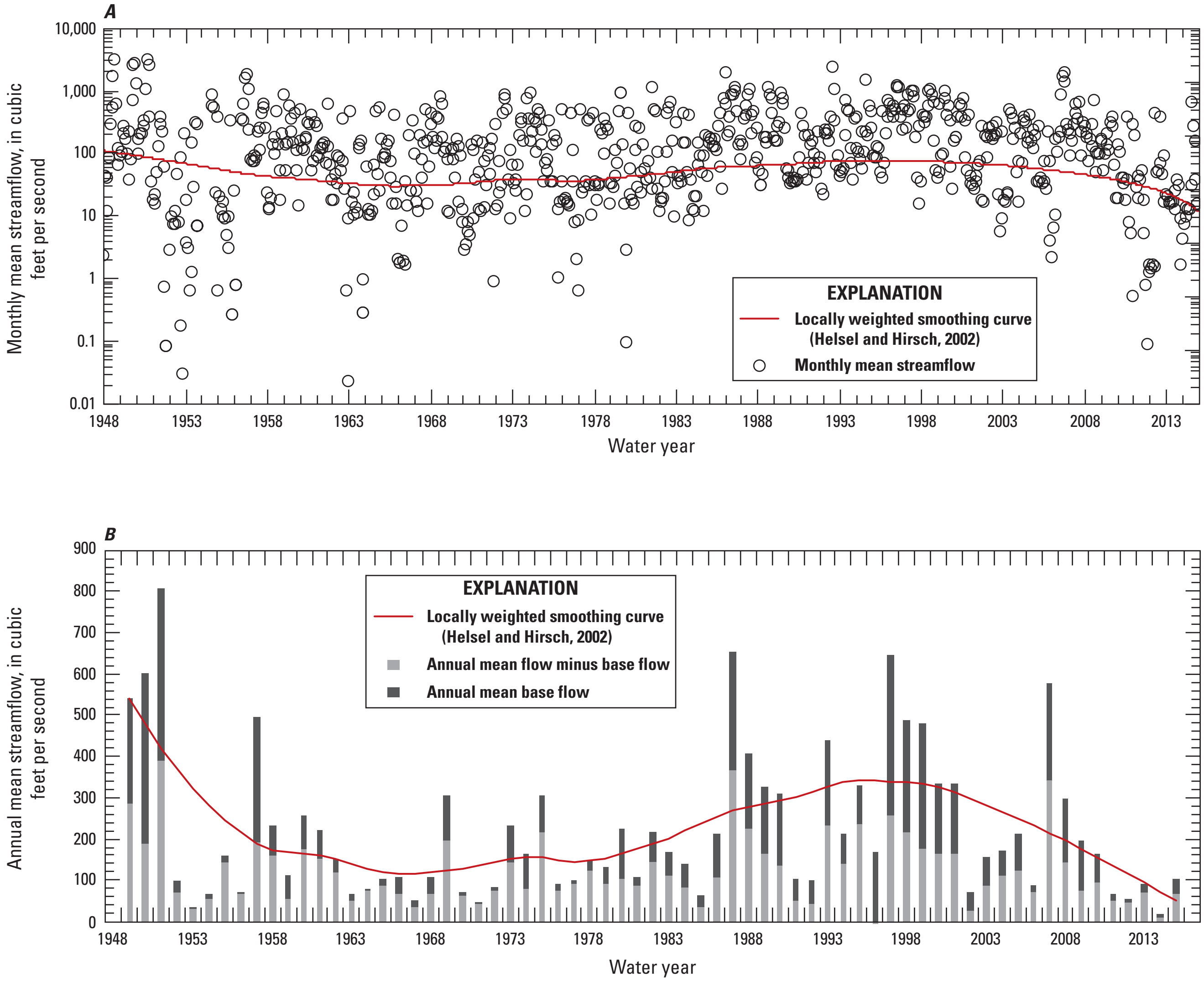


Figure 1.23. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07239500 North Canadian River near El Reno, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1949 to 2015.

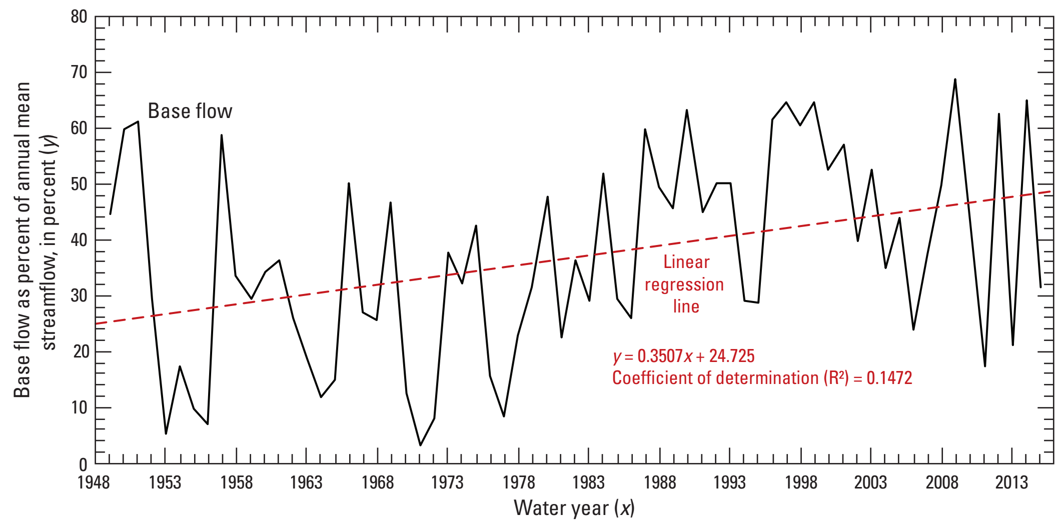


Figure 1.24. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1949–2015) at U.S. Geological Survey streamgage 07239500 North Canadian River near El Reno, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

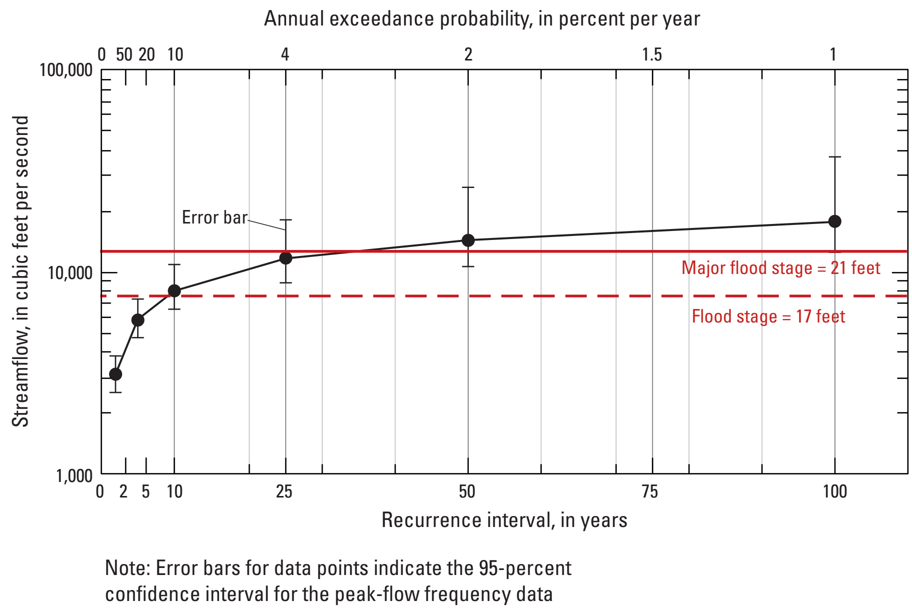


Figure 1.25. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07239500 North Canadian River near El Reno, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07239700 North Canadian River near Yukon, Oklahoma

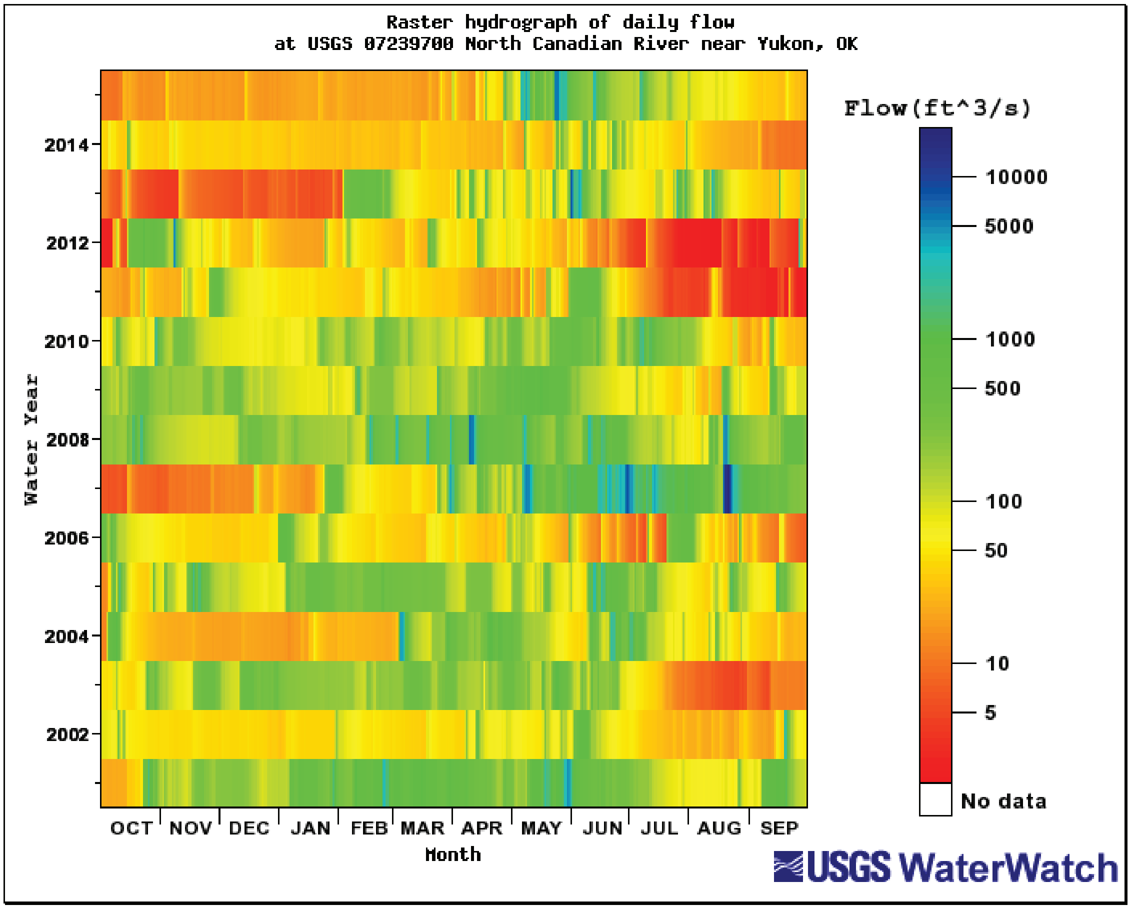
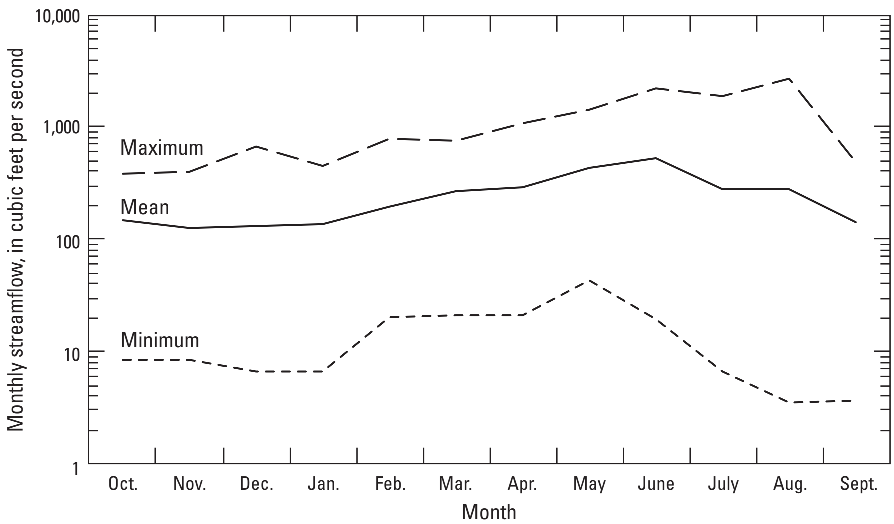


Figure 1.26. Daily streamflows measured at U.S. Geological Survey streamgage 07239700 North Canadian River near Yukon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 2001–15 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07239700&ds=dv01d&yt=wy&bdt=2001&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	379	8.46	148	165
November	393	8.40	128	80.4
December	673	6.77	133	57.3
January	455	6.56	136	85.8
February	778	19.9	193	103
March	755	21.3	269	173
April	1,093	21.4	293	194
May	1,438	42.4	440	246
June	2,178	19.3	524	388
July	1,861	6.55	276	170
August	2,645	3.48	276	76.8
September	479	3.67	139	58.3
Annual	771	57.8	246	204

Figure 1.27. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07239700 North Canadian River near Yukon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

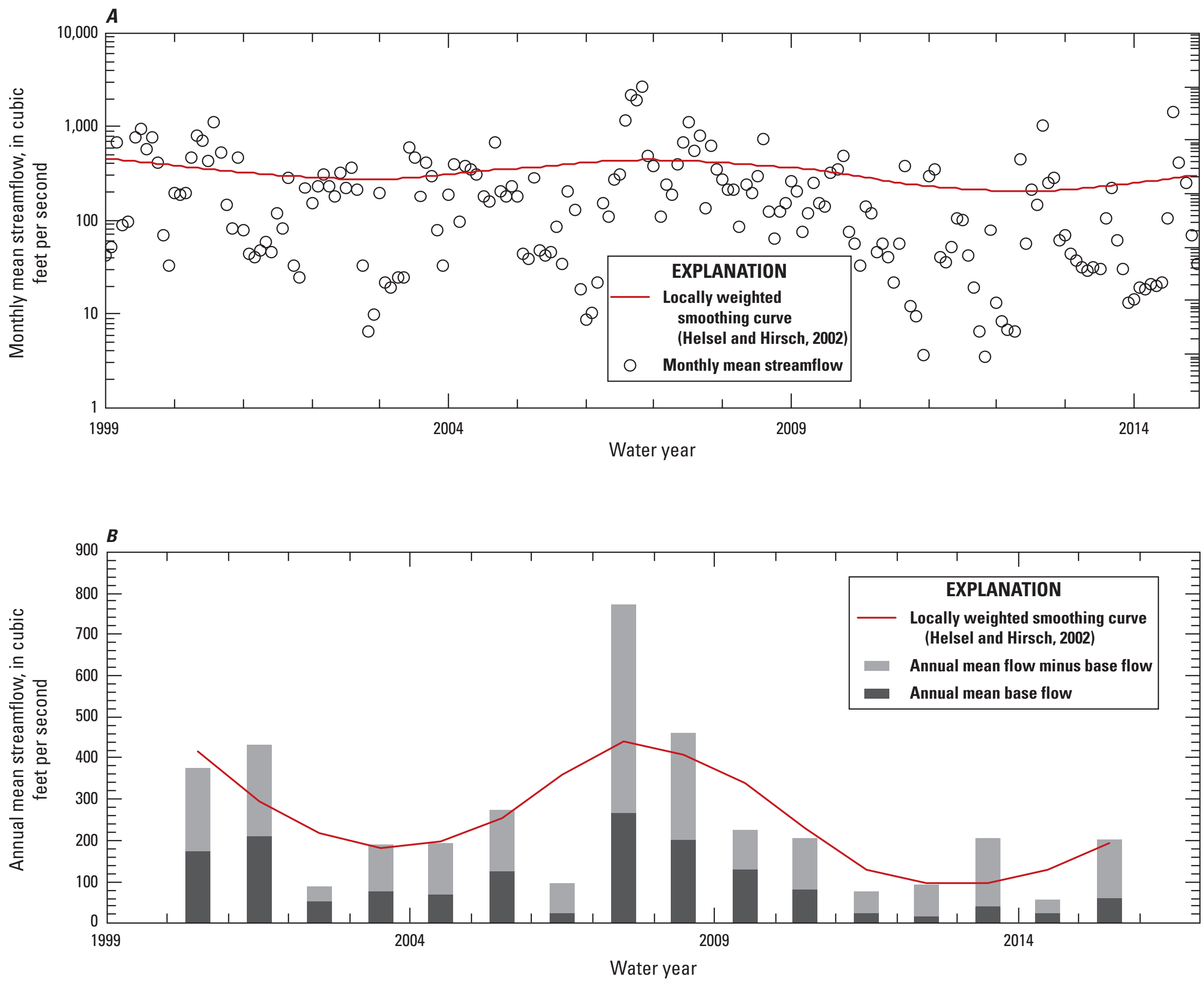


Figure 1.28. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07239700 North Canadian River near Yukon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 2001 to 2015.

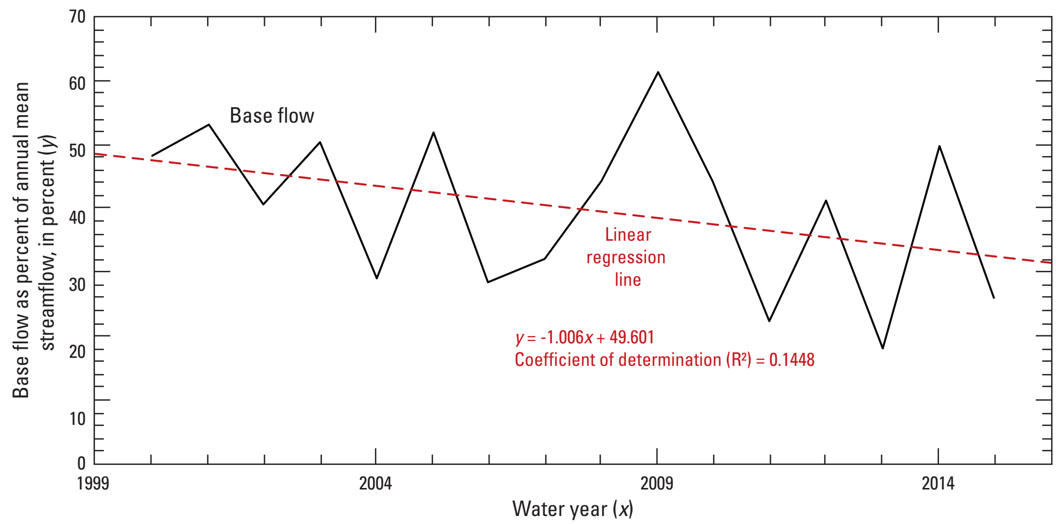


Figure 1.29. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 2001–15) at U.S. Geological Survey streamgage 07239700 North Canadian River near Yukon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

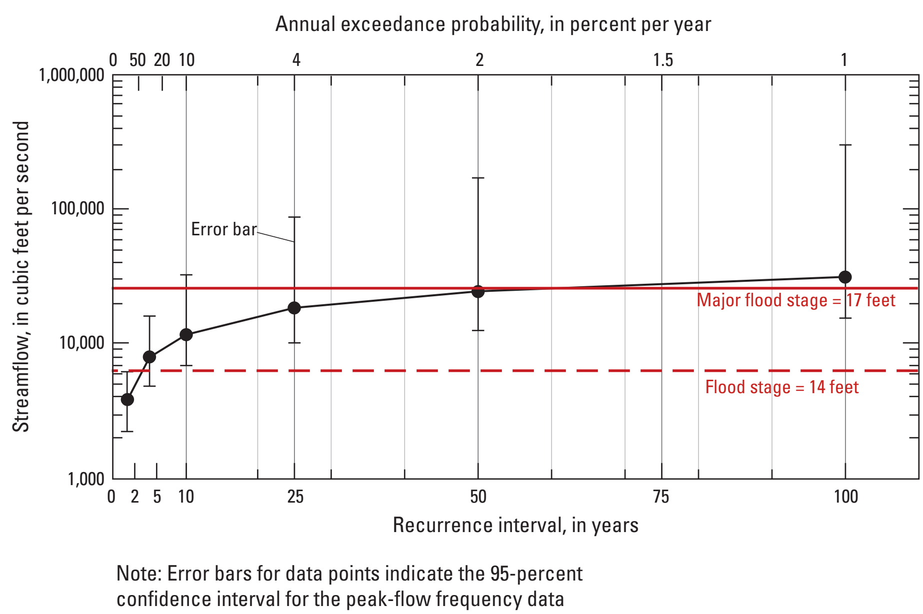


Figure 1.30. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07239700 North Canadian River near Yukon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07301420 Sweetwater Creek near Sweetwater, Oklahoma

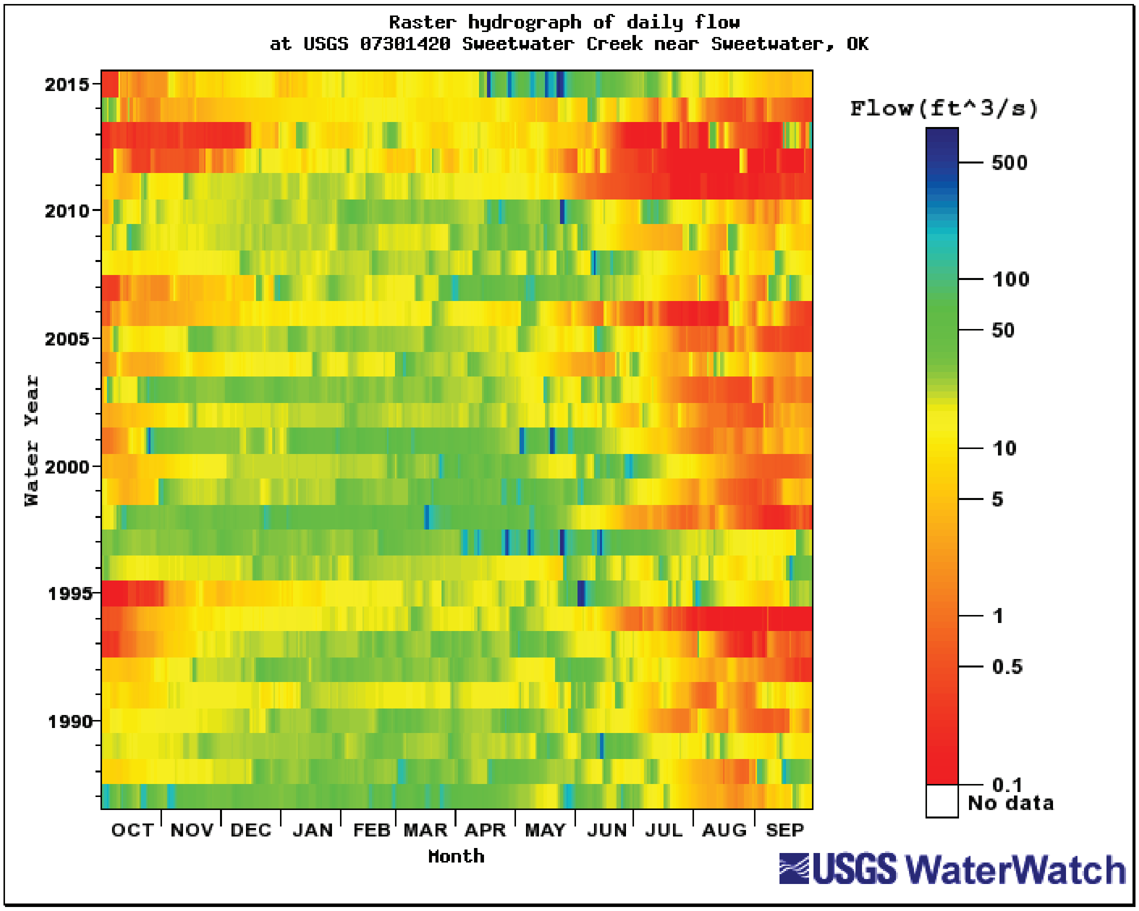
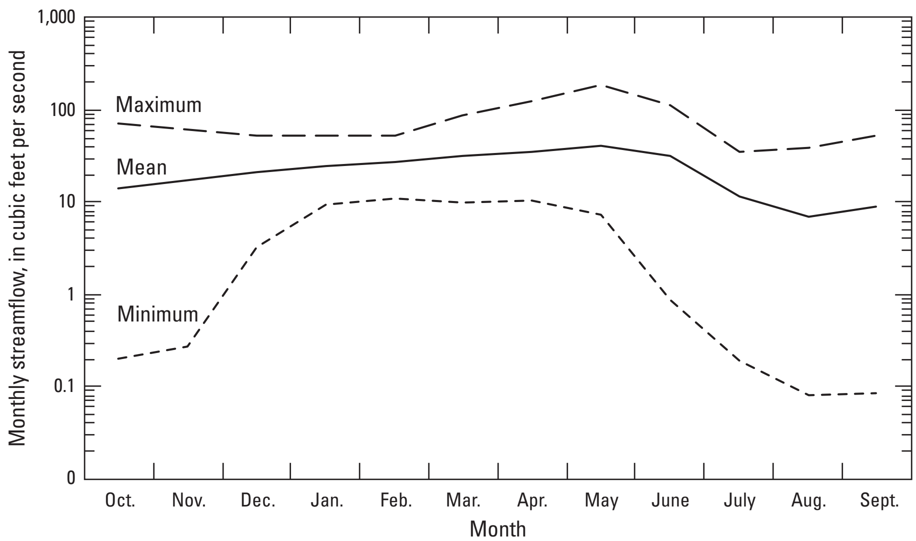


Figure 1.31. Daily streamflows measured at U.S. Geological Survey streamgage 07301420 Sweetwater Creek near Sweetwater, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1987–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07301420&ds=dv01d&yt=wy&bdt=1987&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	72.2	0.20	14.4	9.37
November	61.1	0.27	17.5	16.1
December	51.5	3.22	21.4	22.3
January	53.7	9.20	24.5	23.3
February	53.6	10.9	26.7	24.9
March	85.6	9.66	31.2	28.6
April	126	10.5	34.7	26.4
May	184	7.40	41.2	29.3
June	115	0.89	31.2	24.5
July	35.4	0.19	11.3	9.01
August	38.7	0.08	6.78	3.62
September	51.6	0.08	9.05	3.72
Annual	53.0	6.07	22.5	22.9

Figure 1.32. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07301420 Sweetwater Creek near Sweetwater, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

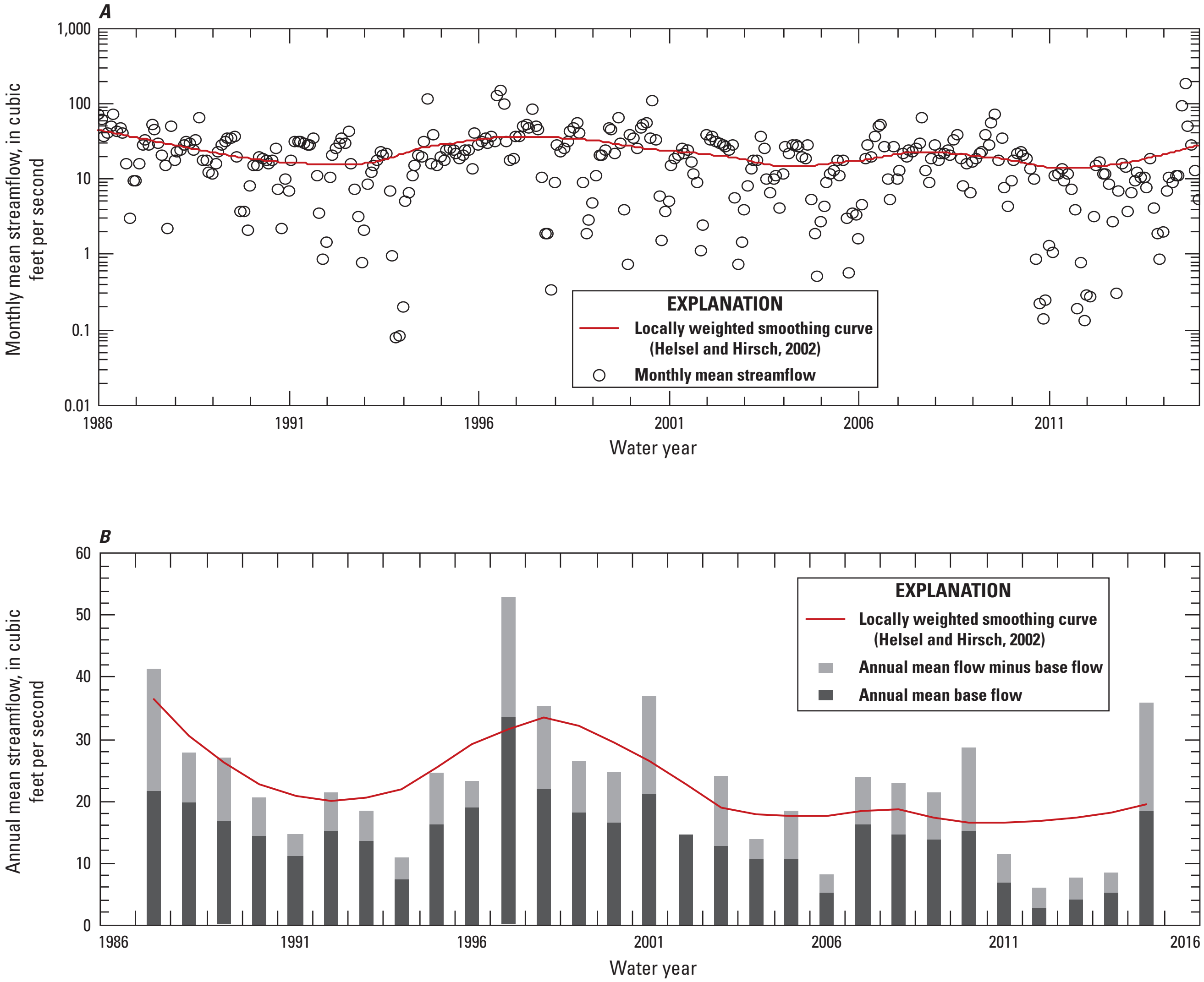


Figure 1.33. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07301420 Sweetwater Creek near Sweetwater, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1987 to 2015.

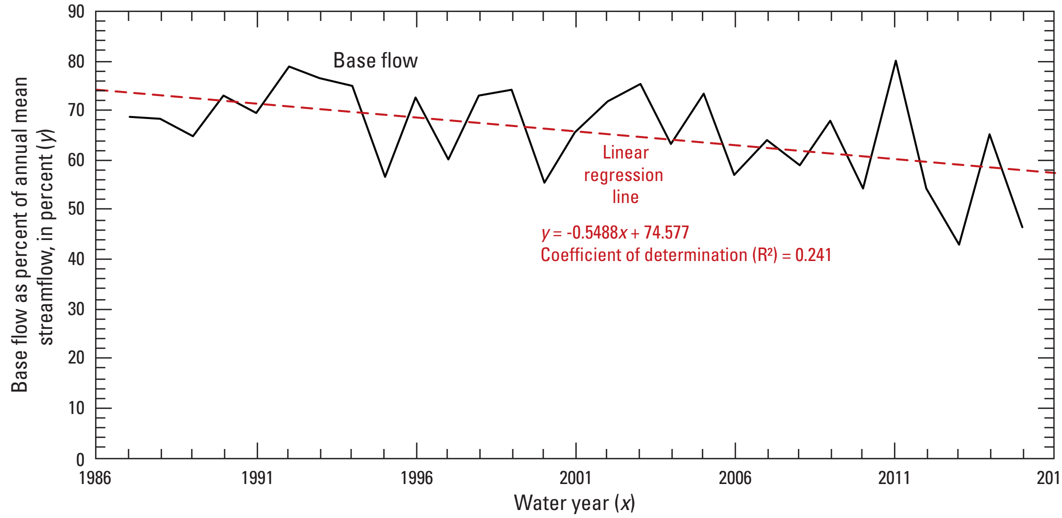


Figure 1.34. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1987–2015) at U.S. Geological Survey streamgage 07301420 Sweetwater Creek near Sweetwater, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

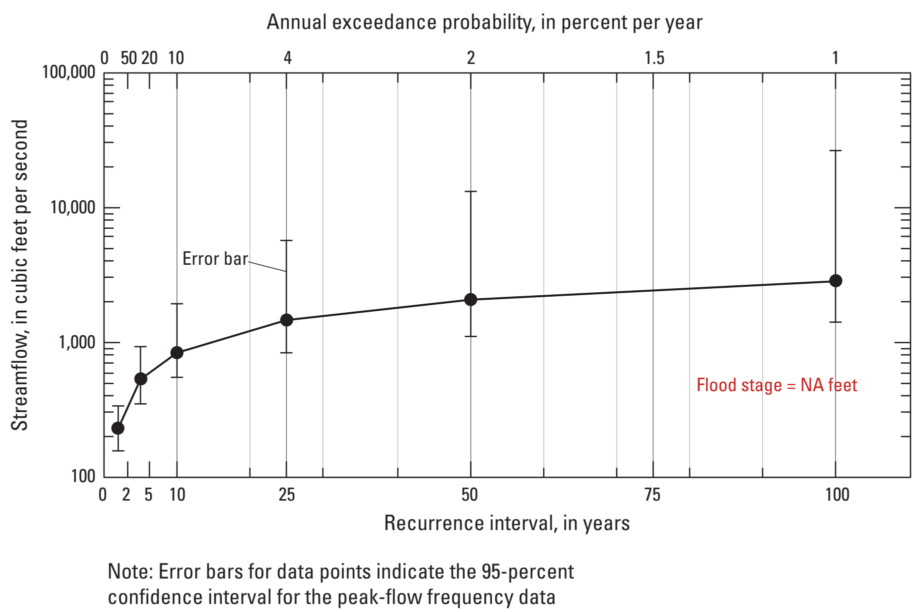


Figure 1.35. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07301420 Sweetwater Creek near Sweetwater, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07301500 North Fork Red River near Carter, Oklahoma

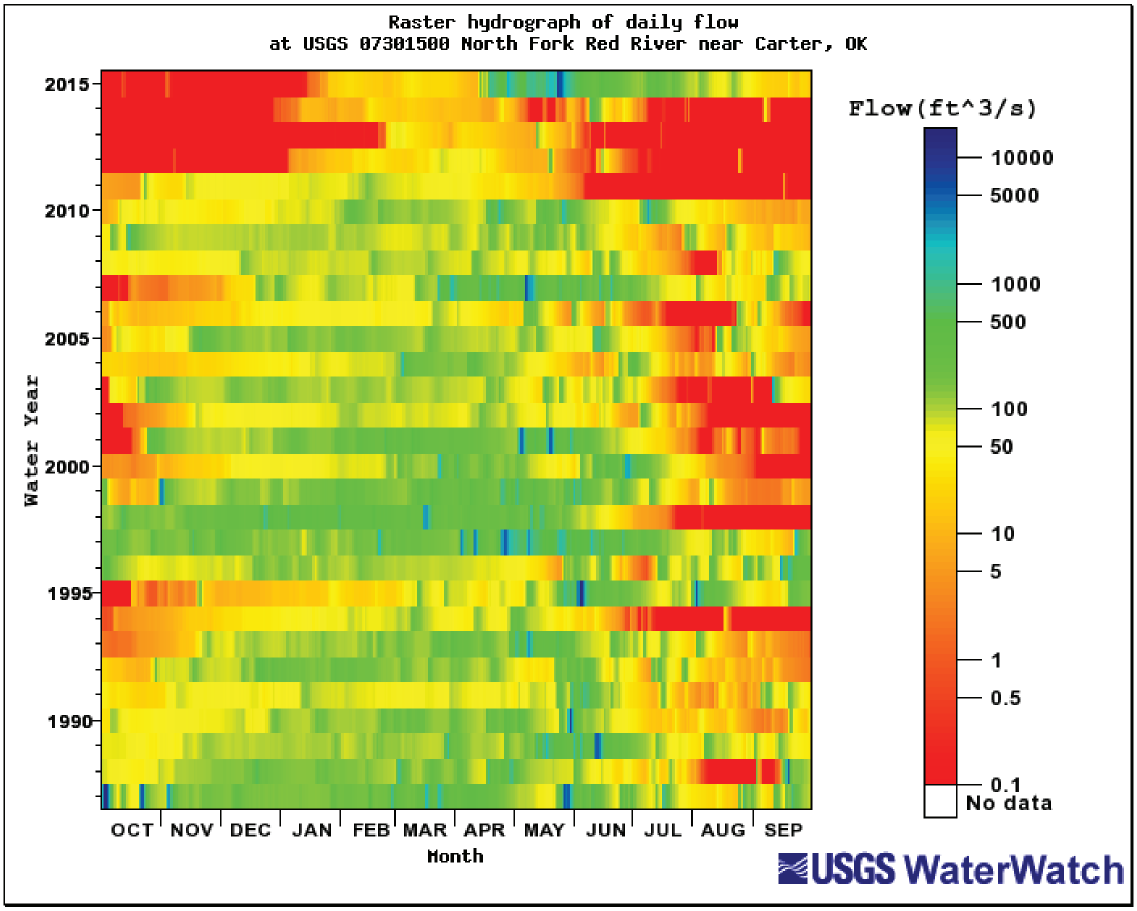
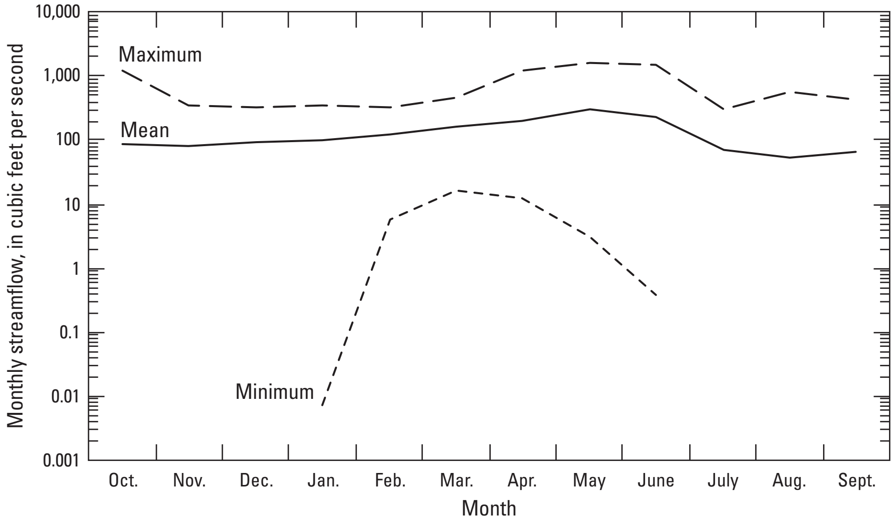


Figure 1.36. Daily streamflows measured at U.S. Geological Survey streamgage 07301500 North Fork Red River near Carter, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1987–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07301500&ds=dv01d&yt=wy&bdt=1987&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	1,195	0.00	87.3	28.5
November	360	0.00	78.8	47.8
December	333	0.00	90.0	86.5
January	362	0.01	102	102
February	331	5.71	120	102
March	466	16.0	158	126
April	1,253	12.6	194	128
May	1,588	2.97	312	127
June	1,560	0.38	228	121
July	313	0.00	68.6	39.8
August	560	0.00	53.9	21.7
September	432	0.00	66.1	18.9
Annual	356	6.61	130	116

Figure 1.37. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07301500 North Fork Red River near Carter, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

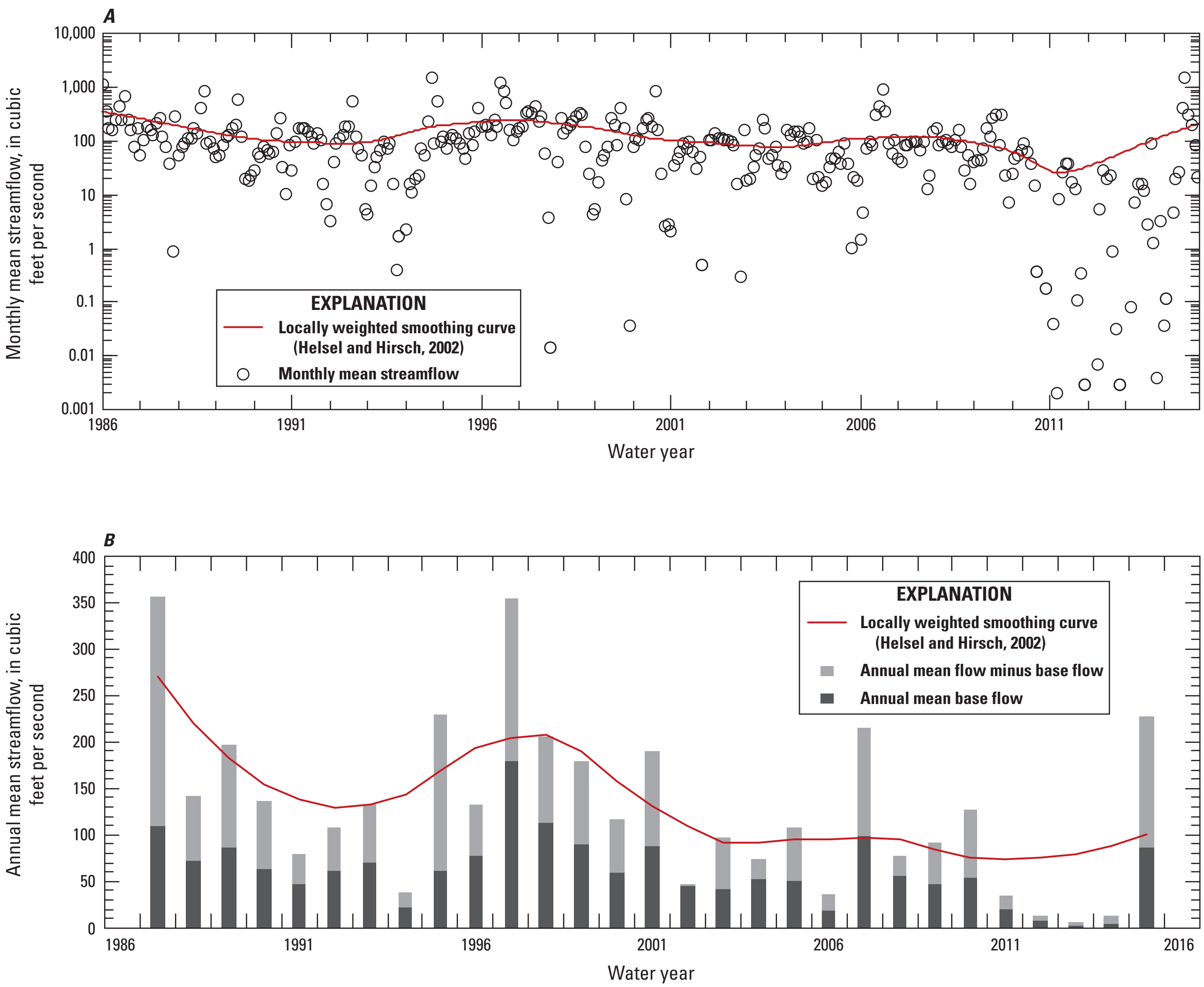


Figure 1.38. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07301500 North Fork Red River near Carter, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1987 to 2015.

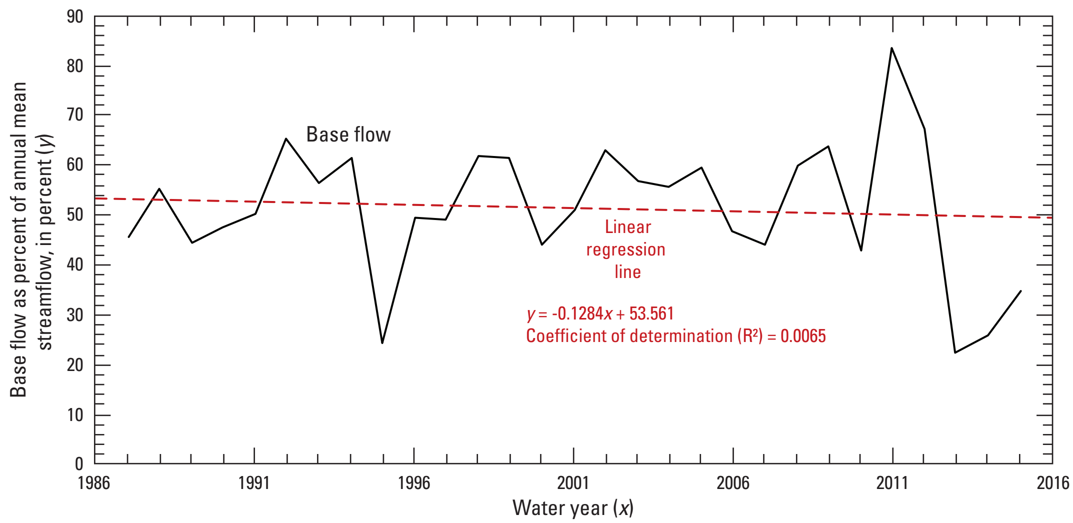
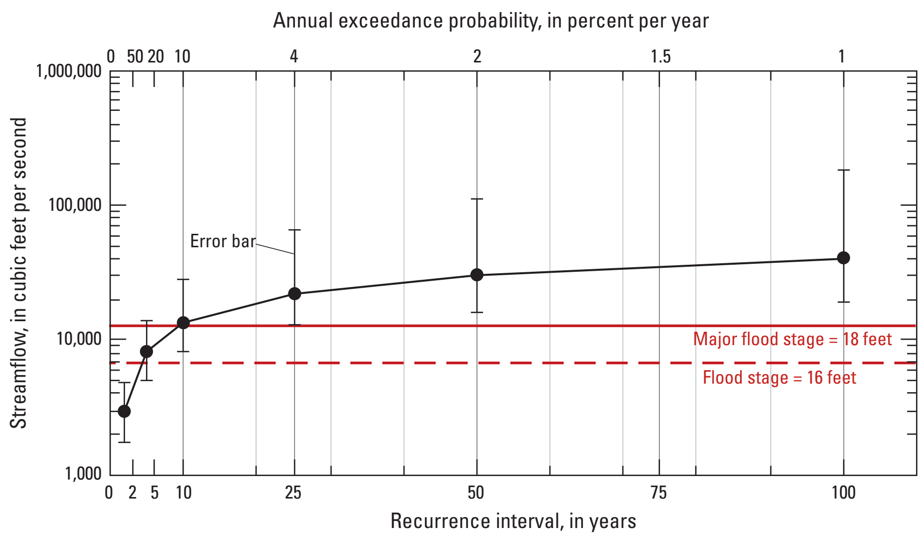


Figure 1.39. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1987–2015) at U.S. Geological Survey streamgage 07301500 North Fork Red River near Carter, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).



Note: Error bars for data points indicate the 95-percent confidence interval for the peak-flow frequency data

Figure 1.40. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07301500 North Fork Red River near Carter, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07316500 Washita River near Cheyenne, Oklahoma

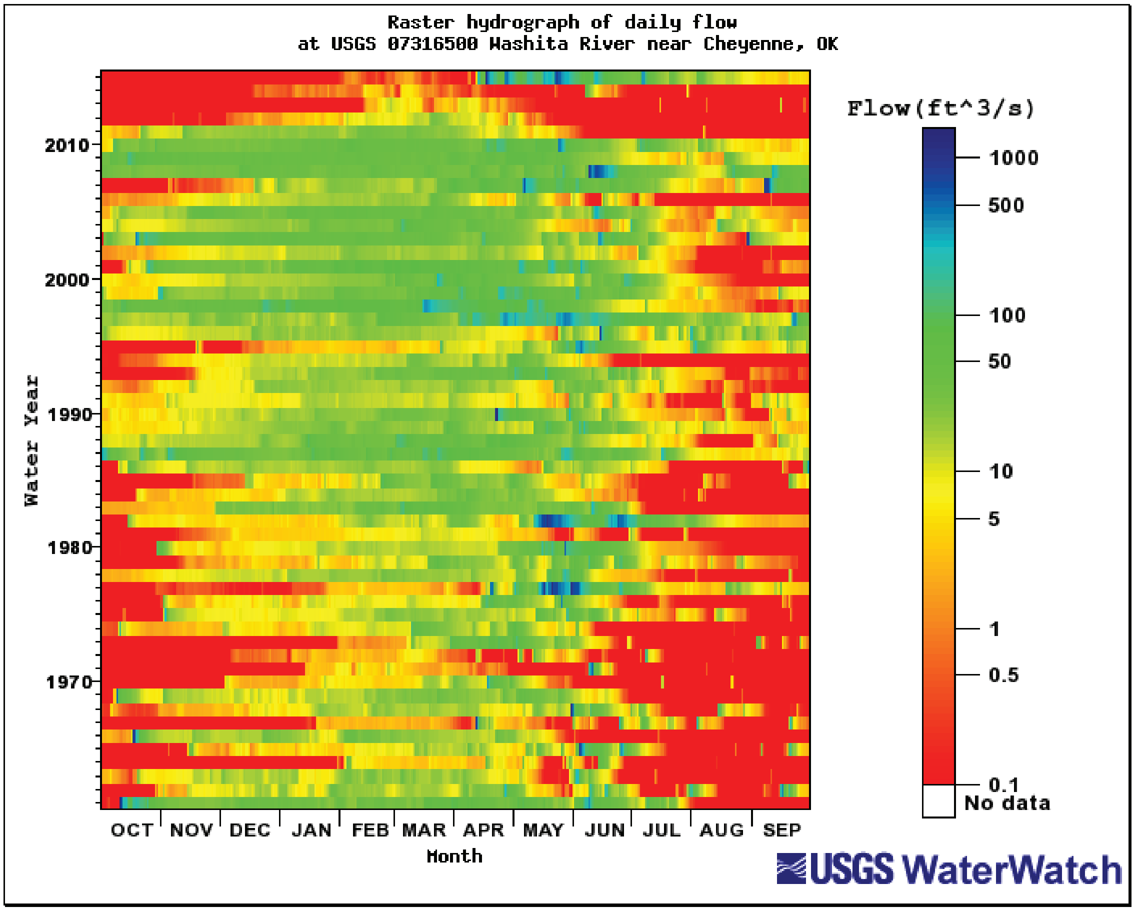
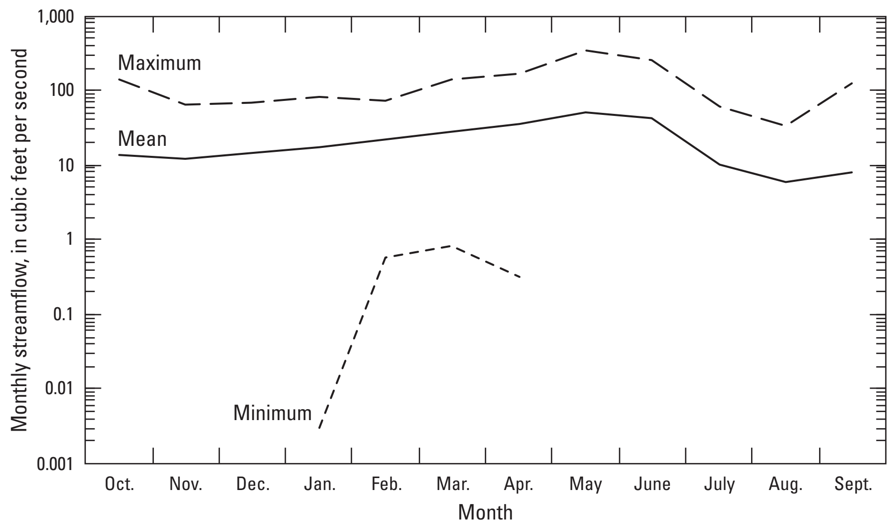


Figure 1.41. Daily streamflows measured at U.S. Geological Survey streamgage 07316500 Washita River near Cheyenne, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1961–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07316500&ds=dv01d&yt=wy&bdt=1961&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	144	0.00	13.4	2.21
November	64.3	0.00	12.2	6.43
December	67.7	0.00	14.6	11.2
January	80.7	0.00	17.8	15.5
February	71.0	0.59	21.9	18.9
March	138	0.80	27.8	21.1
April	171	0.32	35.4	23.0
May	348	0.00	49.8	27.1
June	251	0.00	42.4	24.4
July	61.7	0.00	10.4	5.66
August	33.5	0.00	5.95	0.98
September	122	0.00	8.18	0.89
Annual	64.0	0.93	21.6	15.3

Figure 1.42. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07316500 Washita River near Cheyenne, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

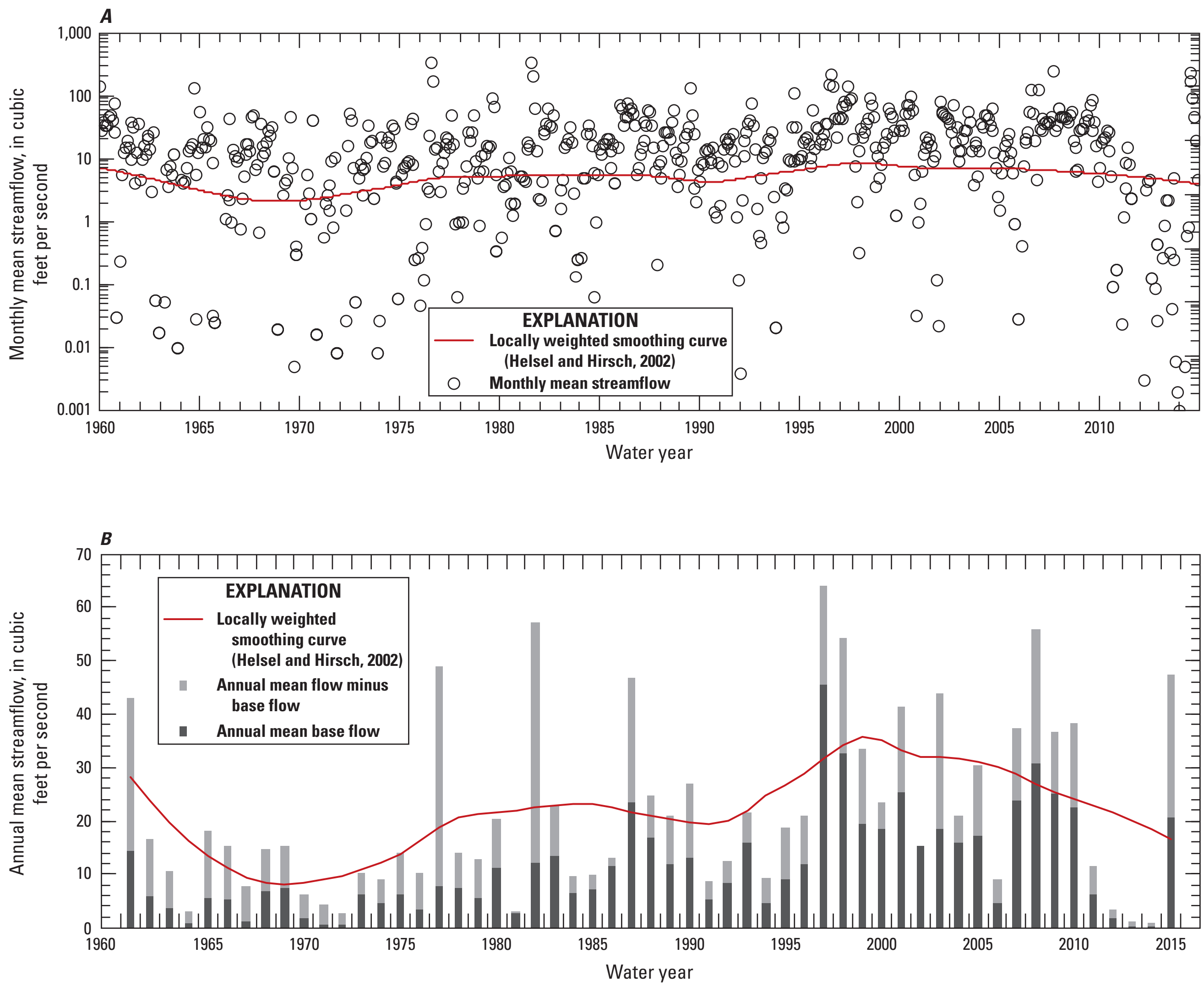


Figure 1.43. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07316500 Washita River near Cheyenne, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1961 to 2015.

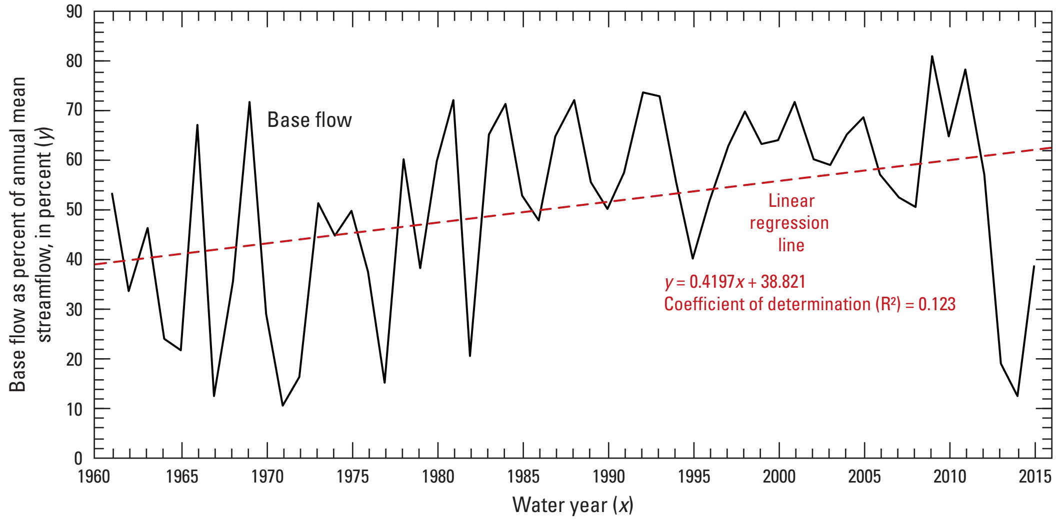


Figure 1.44. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1961–2015) at U.S. Geological Survey streamgage 07316500 Washita River near Cheyenne, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

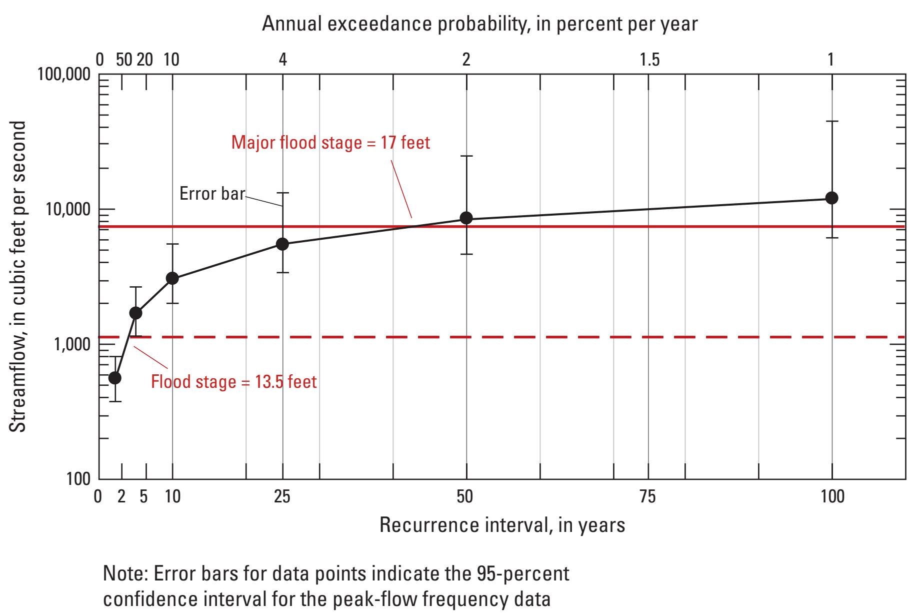


Figure 1.45. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07316500 Washita River near Cheyenne, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07324200 Washita River near Hammon, Oklahoma

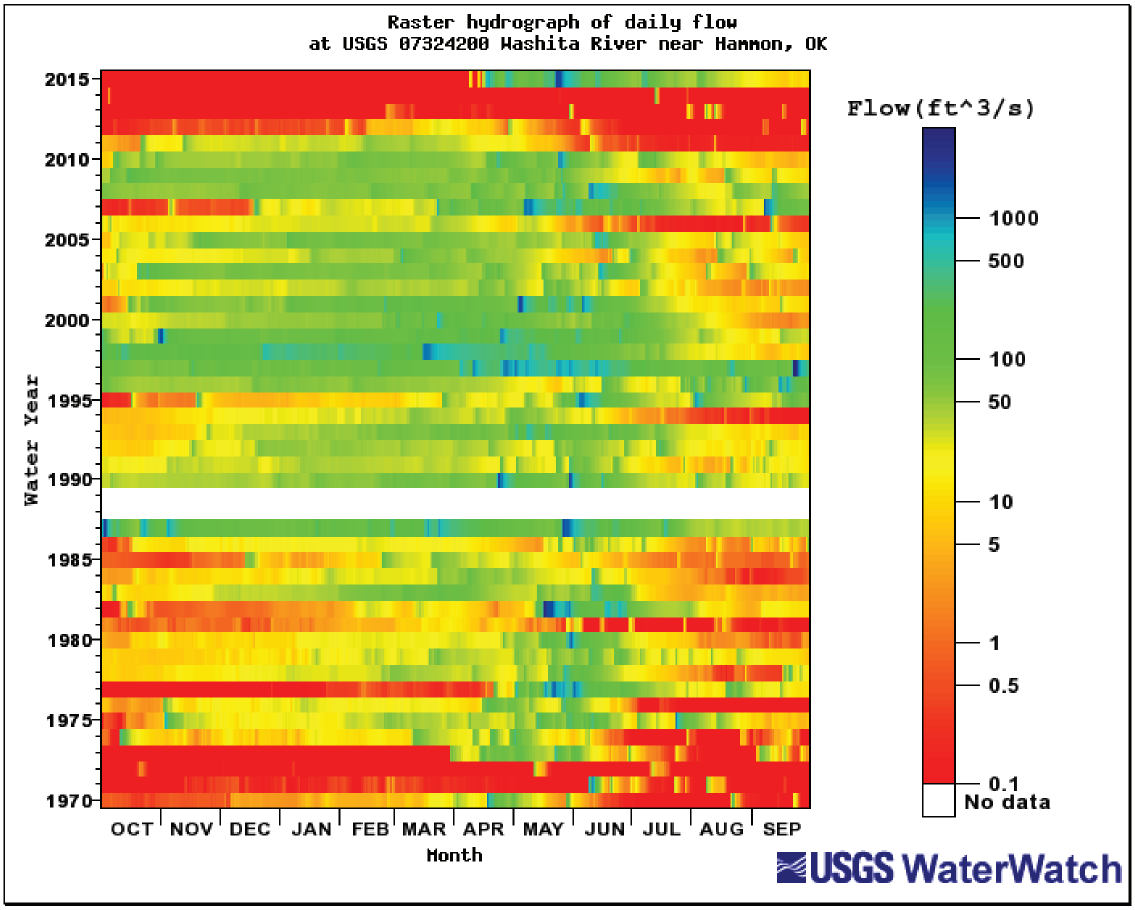
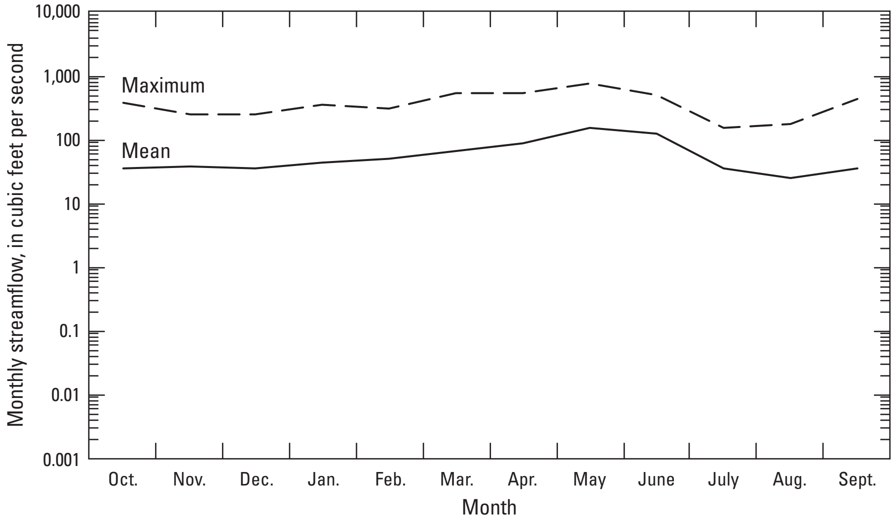


Figure 1.46. Daily streamflows measured at U.S. Geological Survey streamgage 07324200 Washita River near Hammon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1970–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07324200&ds=dv01d&yt=wy&bdt=1970&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	384	0.00	35.3	8.23
November	254	0.00	38.2	14.7
December	258	0.00	35.4	19.4
January	342	0.00	42.3	24.0
February	299	0.00	49.5	28.7
March	548	0.00	68.7	42.0
April	528	0.00	86.6	46.3
May	755	0.01	150	58.4
June	503	0.00	121	62.5
July	158	0.00	36.4	19.7
August	170	0.00	25.5	12.9
September	450	0.00	35.6	10.5
Annual	262	0.00	60.3	38.2

Figure 1.47. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07324200 Washita River near Hammon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

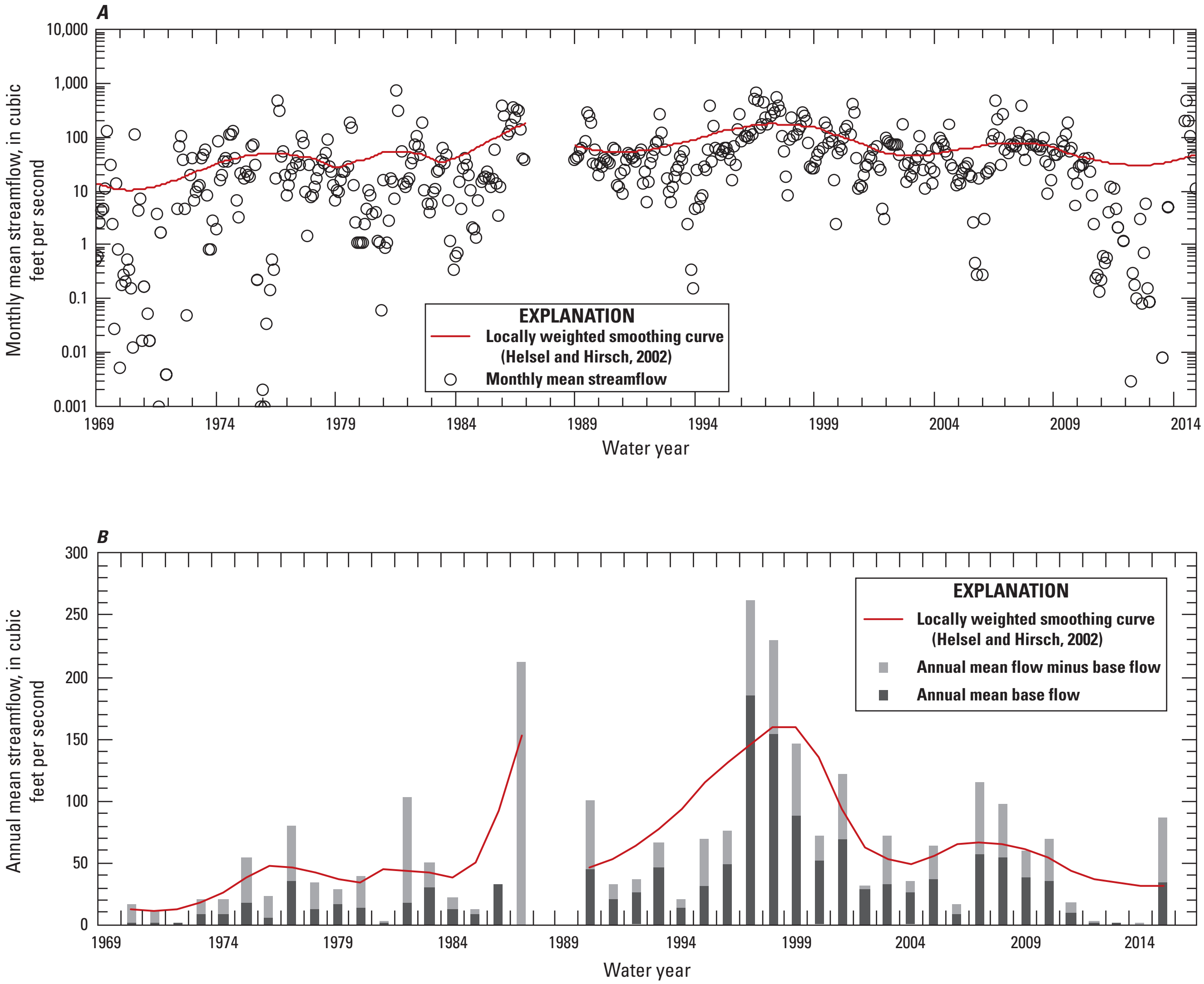


Figure 1.48. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07324200 Washita River near Hammon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1970 to 2015.

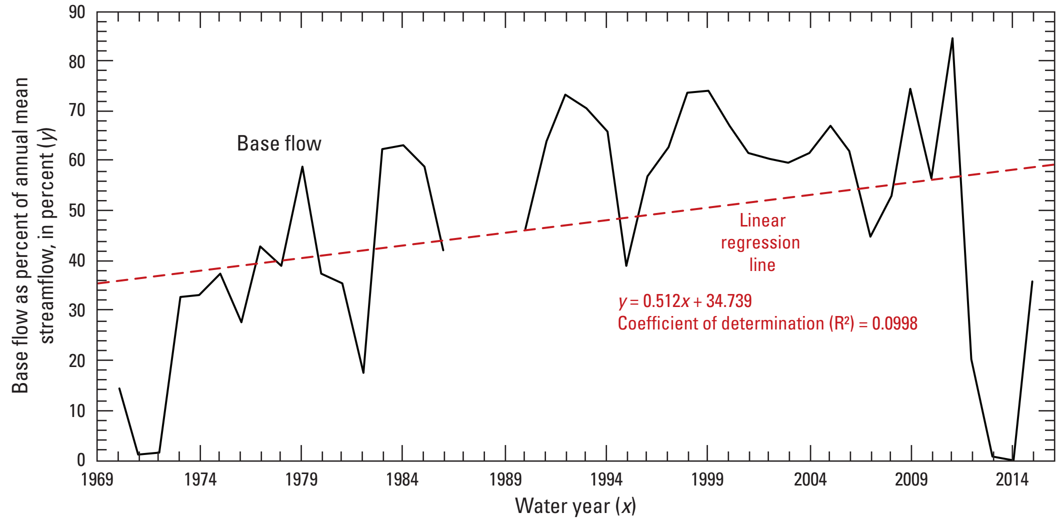


Figure 1.49. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1970–2015) at U.S. Geological Survey streamgage 07324200 Washita River near Hammon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

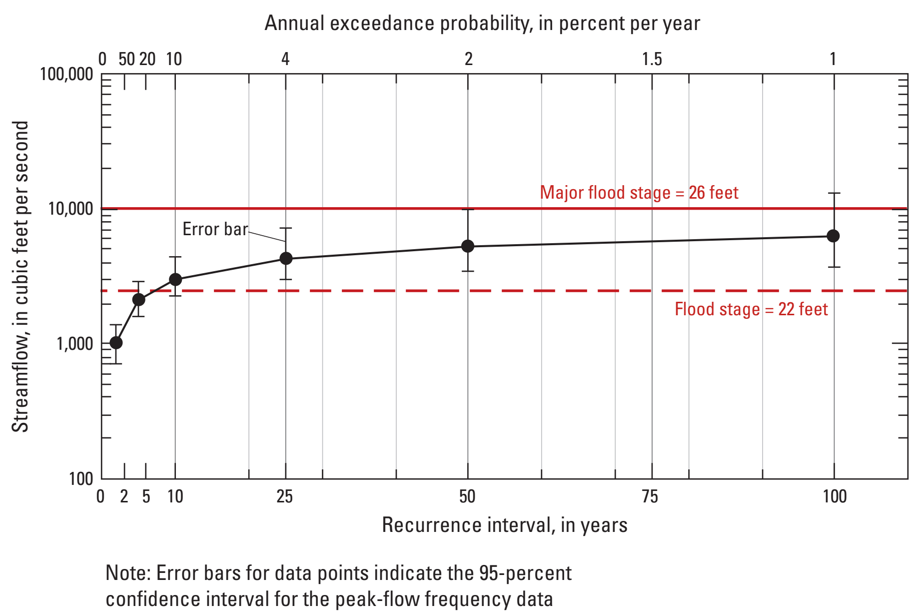


Figure 1.50. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07324200 Washita River near Hammon, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07324400 Washita River near Foss, Oklahoma

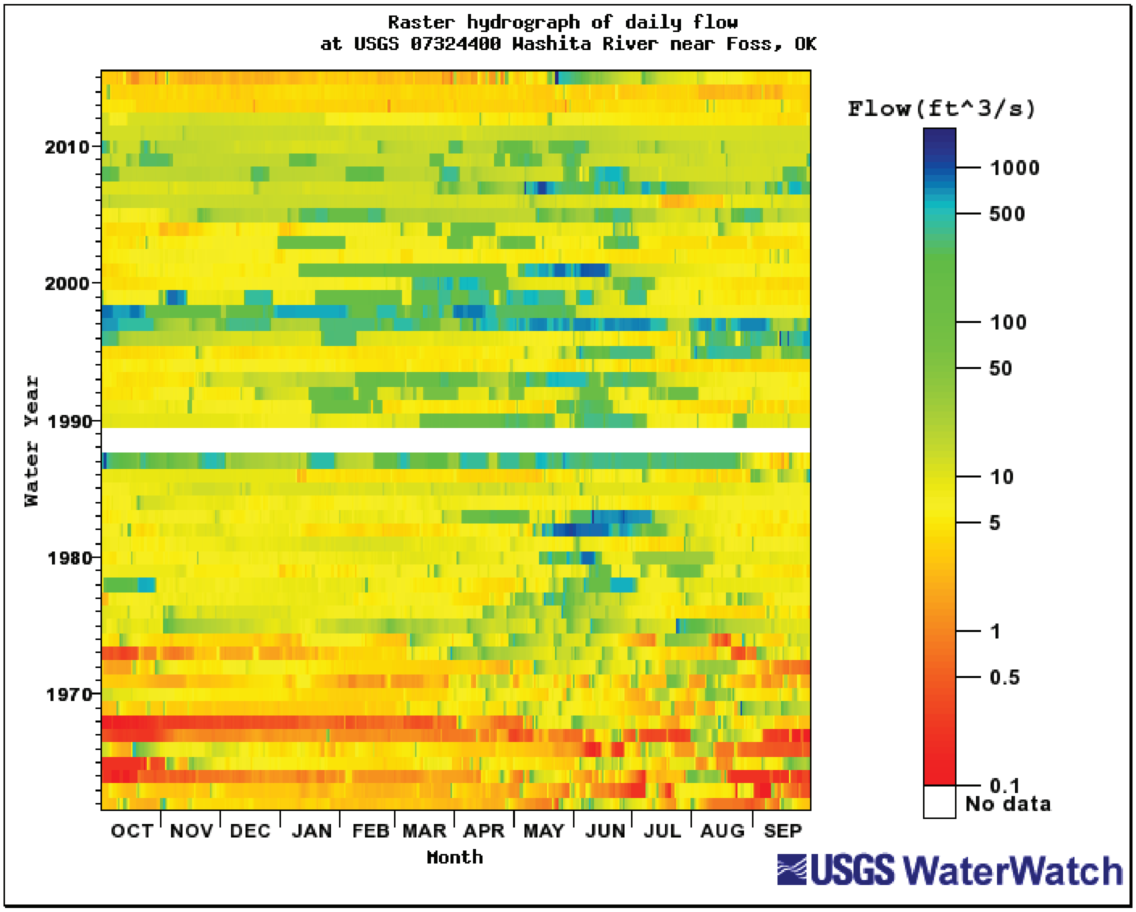
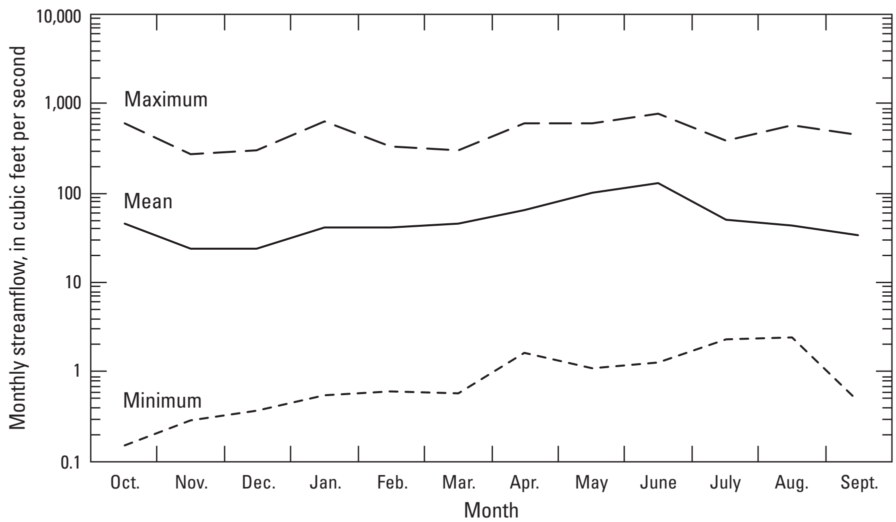


Figure 1.51. Daily streamflows measured at U.S. Geological Survey streamgage 07324400 Washita River near Foss, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1962–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07324400&ds=dv01d&yt=wy&bdt=1962&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	598	0.15	46.8	7.05
November	278	0.28	24.3	7.87
December	299	0.36	24.3	7.29
January	633	0.56	42.0	7.08
February	342	0.60	42.2	6.48
March	297	0.57	46.1	8.39
April	607	1.62	64.1	10.1
May	622	1.08	103	17.7
June	763	1.28	131	24.0
July	385	2.27	51.0	11.8
August	579	2.47	43.3	9.09
September	444	0.46	33.8	6.48
Annual	373	3.87	54.3	20.9

Figure 1.52. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07324400 Washita River near Foss, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

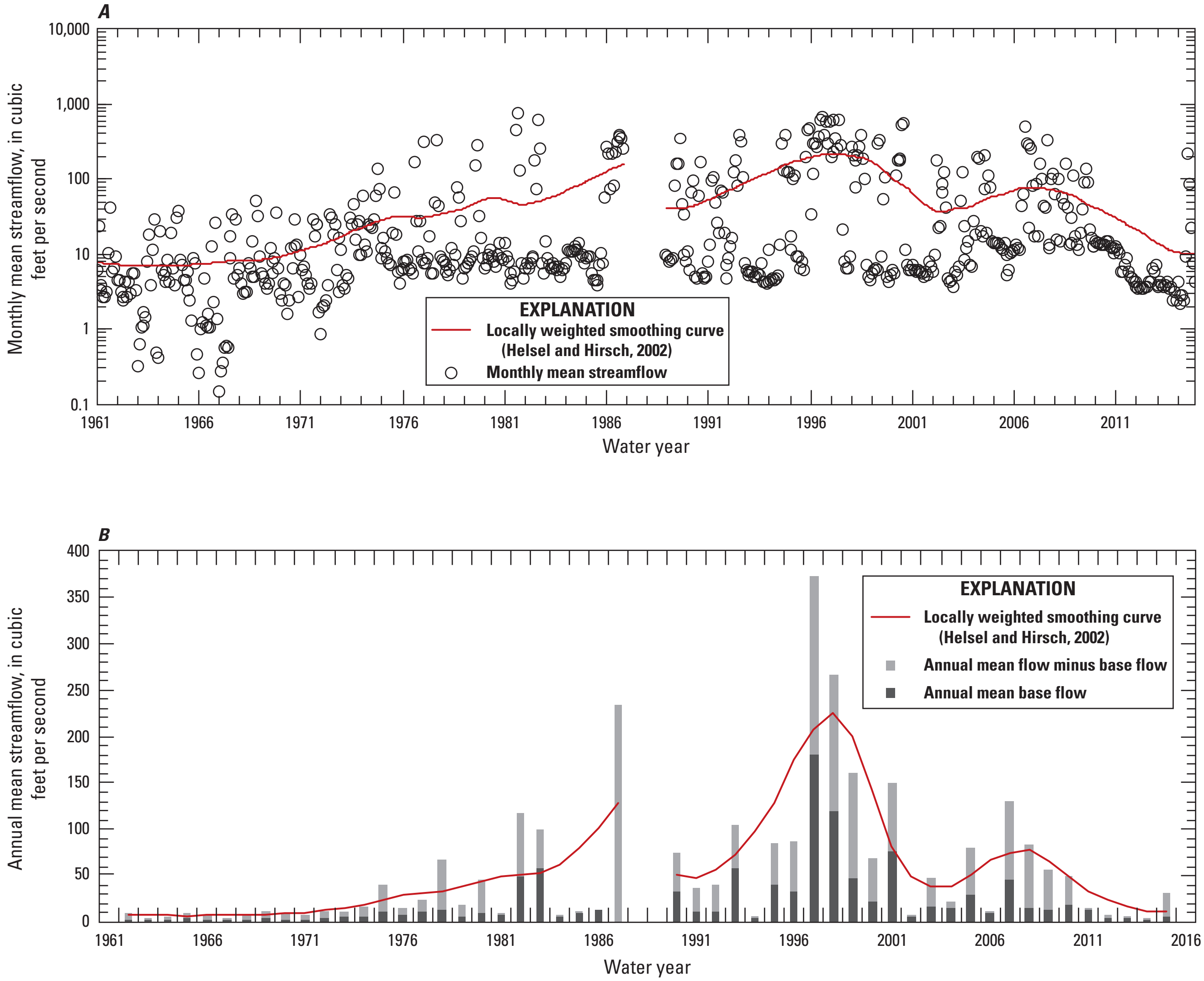


Figure 1.53. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07324400 Washita River near Foss, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1962 to 2015.

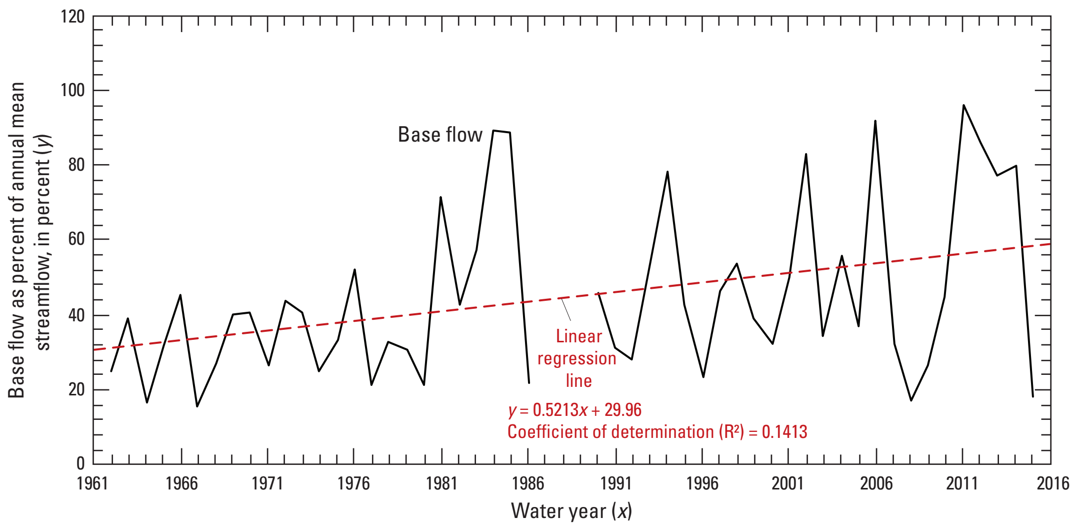


Figure 1.54. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1962–2015) at U.S. Geological Survey streamgage 07324400 Washita River near Foss, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

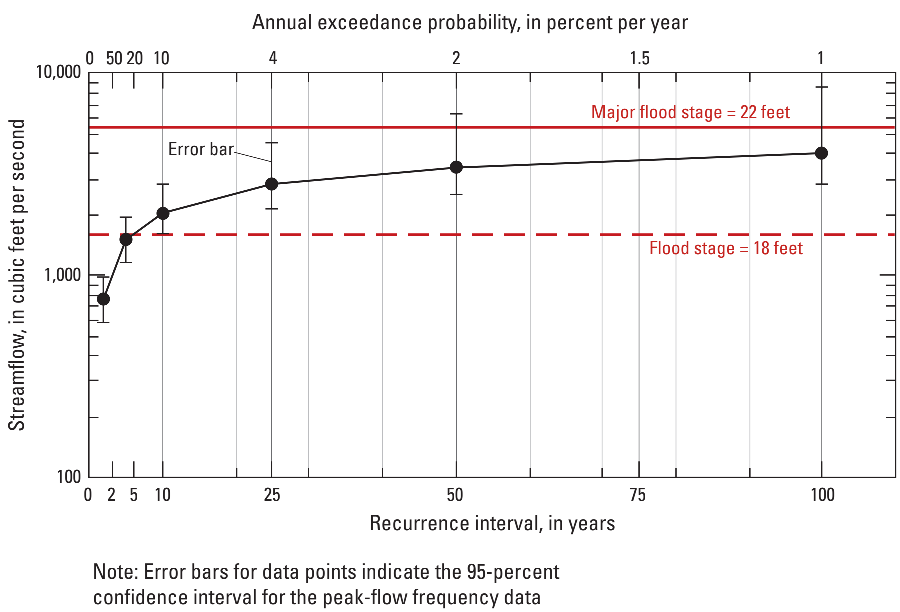


Figure 1.55. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07324400 Washita River near Foss, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

07325000 Washita River near Clinton, Oklahoma

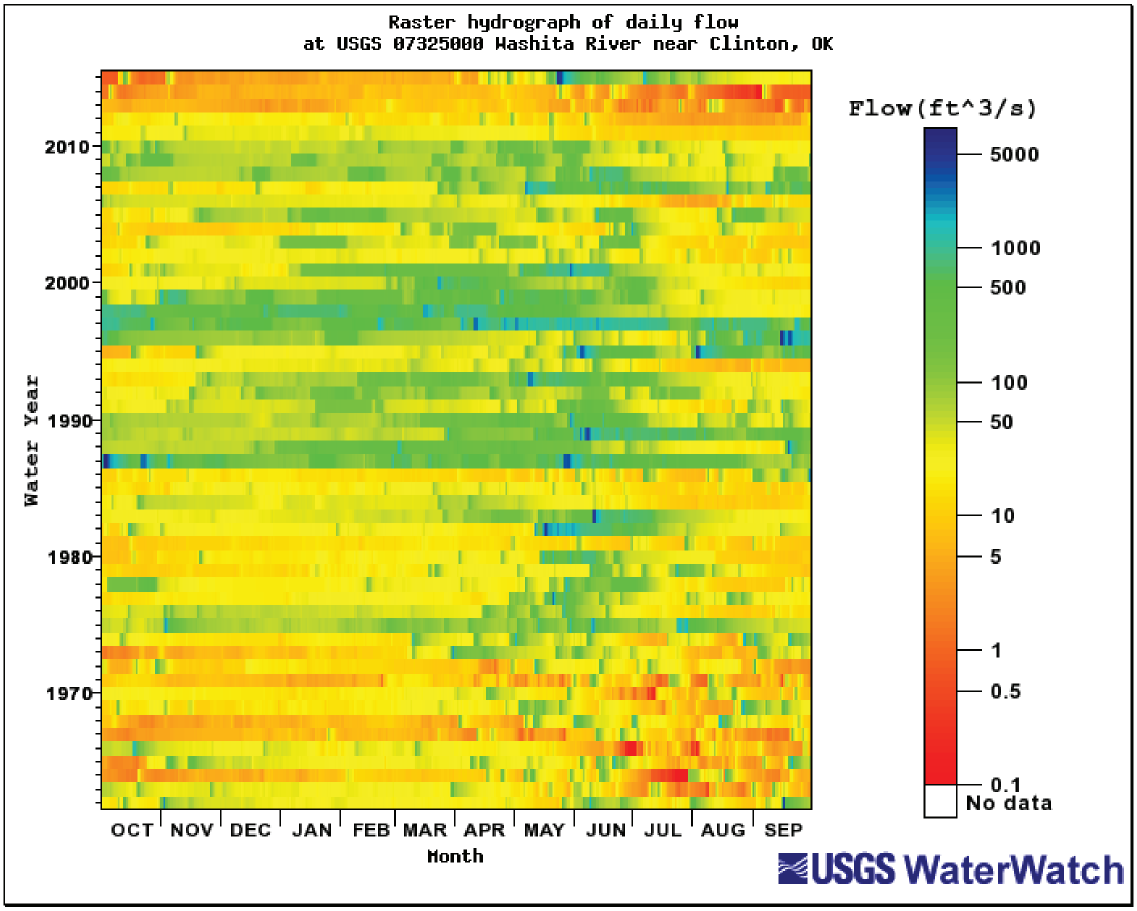
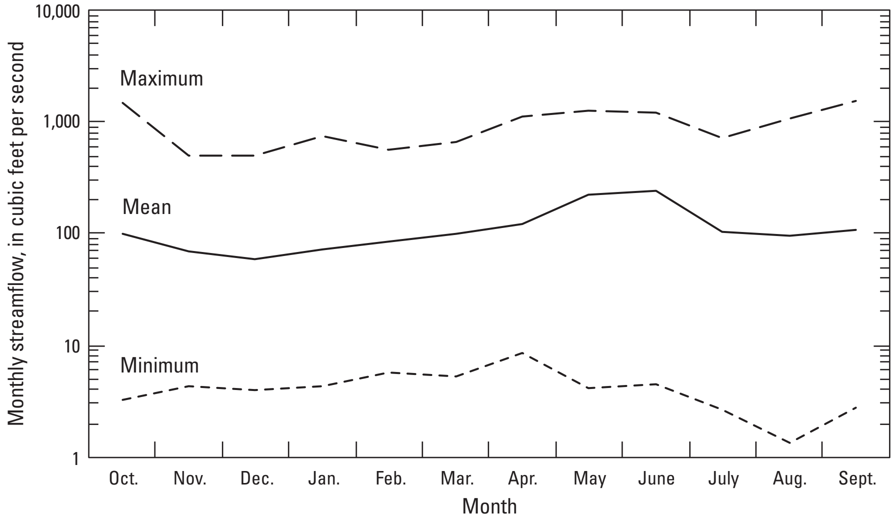


Figure 1.56. Daily streamflows measured at U.S. Geological Survey streamgage 07325000 Washita River near Clinton, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). The hydrograph shows monthly and annual variability of daily streamflows for 1962–2015 as a color ranging from red (low flow) to blue (high flow), allowing for visual identification of flood and drought periods. The raster hydrograph was generated by using the raster hydrograph toolkit available on the U.S. Geological Survey WaterWatch website (https://waterwatch.usgs.gov/index.php?sno=07325000&ds=dv01d&yt=wy&bdt=1962&edt=2015&ut=cfs&id=wwchart_rastergraph&ct=wwrg&mk=0; U.S. Geological Survey, 2019).



Month	Maximum	Minimum	Mean	Median
	(Cubic feet per second)			
October	1,477	3.30	101	27.8
November	494	4.23	69.0	31.5
December	504	4.03	58.4	31.0
January	742	4.39	73.6	30.1
February	574	5.61	85.5	32.0
March	654	5.35	100	43.2
April	1,112	8.54	125	43.8
May	1,256	4.10	221	87.6
June	1,190	4.44	238	109
July	705	2.65	104	39.7
August	1,061	1.33	96.0	32.0
September	1,519	2.81	107	24.8
Annual	696	6.70	115	71.0

Figure 1.57. Monthly maximum, mean, and minimum streamflows at U.S. Geological Survey streamgage 07325000 Washita River near Clinton, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

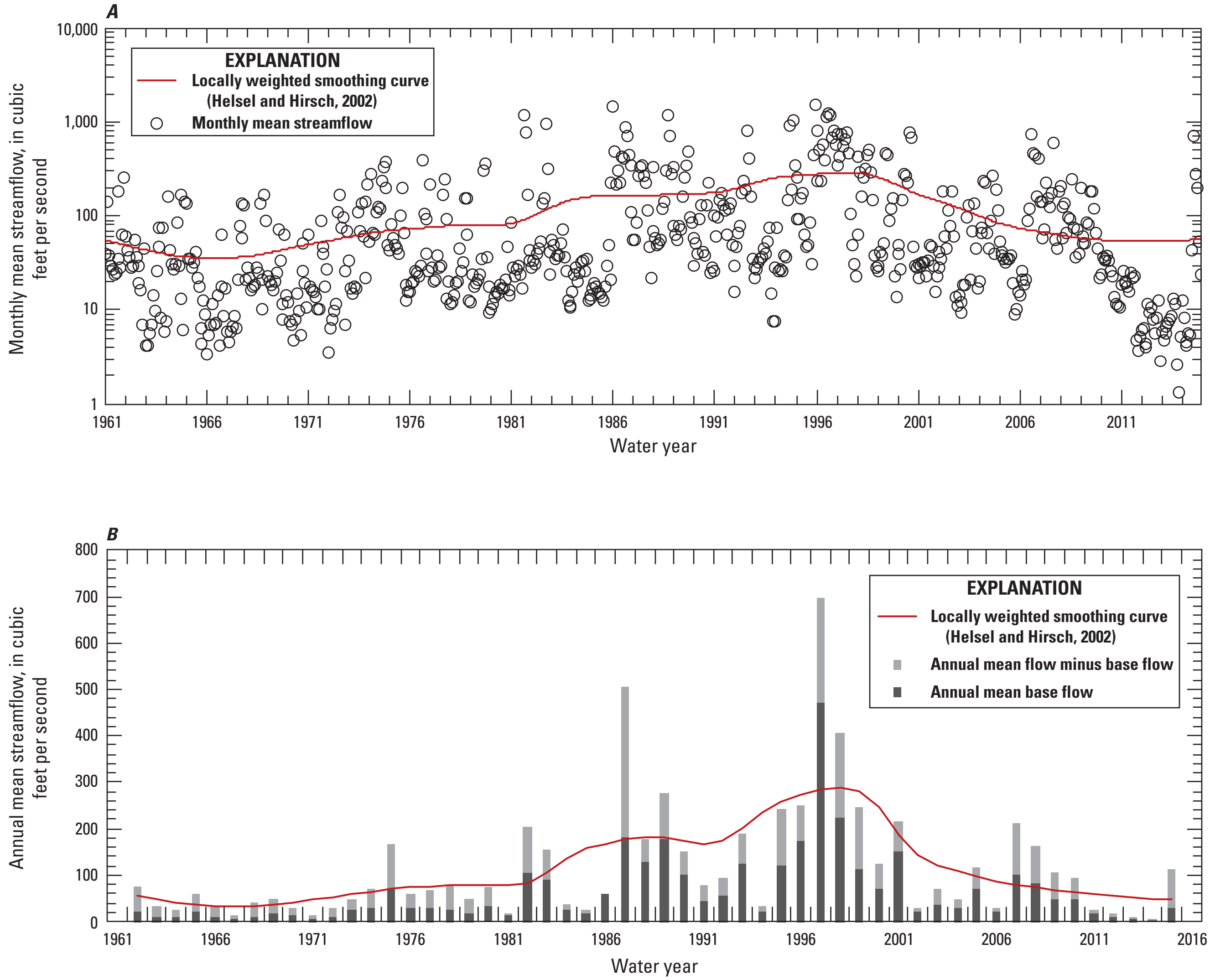


Figure 1.58. *A*, Monthly mean streamflow and *B*, annual mean streamflow by water year at U.S. Geological Survey streamgage 07325000 Washita River near Clinton, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018). Locally weighted scatterplot smoothing curves on each graph show the general streamflow trends over the period of record from water years 1962 to 2015.

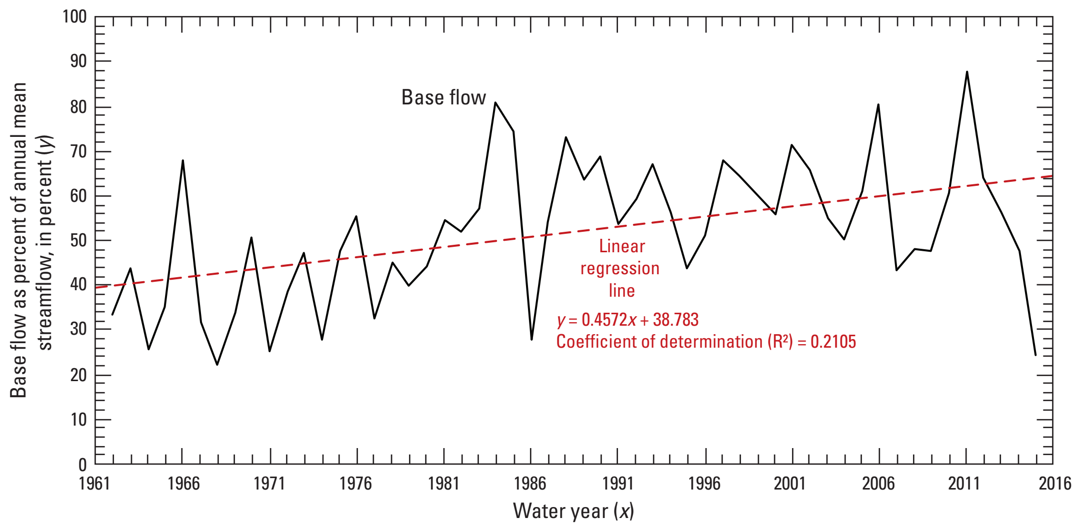


Figure 1.59. Percent of contribution of groundwater base flow to the annual mean streamflow over the period of record (water years 1962–2015) at U.S. Geological Survey streamgage 07325000 Washita River near Clinton, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

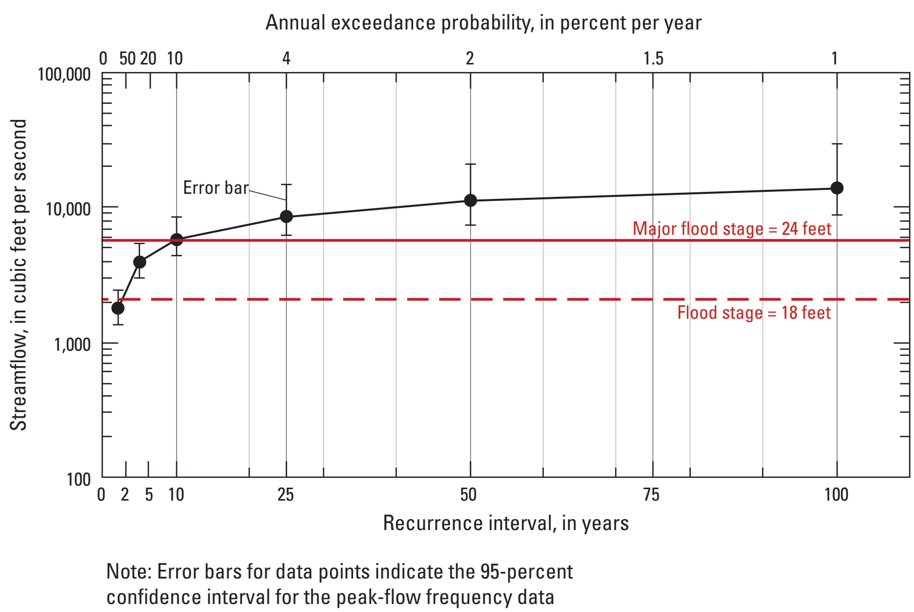


Figure 1.60. Annual exceedance probability of streamflow exceeding peak flows and reaching flood stage and major flood stage at U.S. Geological Survey streamgage 07325000 Washita River near Clinton, Oklahoma, Cheyenne and Arapaho Tribal jurisdictional area, west-central Oklahoma (U.S. Geological Survey, 2018).

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