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Summary of Climatic, Geographic, Geologic, and Available Hydrologic Data and Identification of Data Gaps for the Black Bear Creek Watershed of the Pawnee Nation Tribal Jurisdictional Area, Oklahoma

Scientific Investigations Report 2019–5043

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

Front cover, Black Bear Creek upstream from the 4th Street bridge in Pawnee, Oklahoma, 2012.

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2019

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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	
section (640 acres or 1 square mile)	259.0	square hectometer (hm^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as
°F = (1.8 × °C) + 32.

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

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

ALC	Aquatic Life Criteria
BUMP	Beneficial Use Monitoring Program
EPA	U.S. Environmental Protection Agency
GMAP	Groundwater Monitoring & Assessment Program
LOESS	locally weighted estimated scatterplot smoothing
MCL	maximum contaminant level
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
NWS	National Weather Service
OCS	Oklahoma Climatological Survey
ODAFF	Oklahoma Department of Agriculture, Food and Forestry
OWRB	Oklahoma Water Resources Board
PD	percent difference
PNTJA	Pawnee Nation Tribal Jurisdictional Area
RPD	relative percent difference
RWD	rural water district
SC	specific conductance
STORET	STOrage and RETrieval
SWSTAT	Surface-Water Statistics
TDS	total dissolved solids
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WHO	World Health Organization

Summary of Climatic, Geographic, Geologic, and Available Hydrologic Data and Identification of Data Gaps for the Black Bear Creek Watershed of the Pawnee Nation Tribal Jurisdictional Area, Oklahoma

By Matthew S. Varonka

Abstract

The Pawnee Nation is compiling a comprehensive water-management plan for the Pawnee Nation Tribal Jurisdictional Area in north-central Oklahoma. One of the first steps needed in preparing such a plan is a summary and analysis of available hydrologic data and reports that have been published for the area. In phase I of a three-phase, watershed-based approach to summary and analysis of water resources of the Pawnee Nation, the U.S. Geological Survey, in cooperation with the Pawnee Nation and Bureau of Indian Affairs, conducted a literature search and data analysis for the Black Bear Creek watershed within the Pawnee Nation Tribal Jurisdictional Area, referred to herein as the "Black Bear Creek study area." This report summarizes the available data for the Black Bear Creek study area.

Climatic, geographic, geologic, water-use, and hydrologic data from previously published reports or databases were collected and analyzed for this report. Because of the limited amount of groundwater-quality data for the study area, a field collection of groundwater levels and water samples was conducted. Sixteen wells were identified, and groundwater levels were measured at each well. Eight wells were sampled, and water properties, major ions, and nutrients were measured.

Overall, there are few long-term monitoring stations to help determine trends of surface-water quality, groundwater quality, and groundwater levels across the study area. Establishing and maintaining long-term streamflow, surface-water-quality, groundwater-level, and groundwater-quality monitoring sites would greatly increase the understanding of the water resources in the Black Bear Creek study area. Additionally, water-use estimates would be greatly improved by metering groundwater withdrawals. Establishing hydrologic and water-quality trends and having improved estimates of water use can aid decision makers in the stewardship of the water resources in this area.

This report can aid the Pawnee Nation in prioritization of future projects and serve as a background document for the development of a jurisdiction-wide comprehensive water-management plan.

Introduction

The Pawnee Nation is compiling a comprehensive water-management plan for the Pawnee Nation Tribal Jurisdictional Area in north-central Oklahoma. One of the first steps needed in preparing such a plan is a summary and analysis of available hydrologic data and reports that have been published for the area and gaps in those data. When gaps in available data have been identified, such data needs can be more effectively and efficiently addressed in future data-collection efforts.

In phase 1 of a three-phase, watershed-based approach to summary and analysis of water resources of the Pawnee Nation, the U.S. Geological Survey (USGS), in cooperation with the Pawnee Nation and Bureau of Indian Affairs, conducted a literature search and data analysis for the Black Bear Creek watershed in the Pawnee Nation Tribal Jurisdictional Area. This report can serve as a comprehensive background document summarizing climatic, geographic, geologic, water-use, and hydrologic data. Knowledge of data gaps can be used to guide future data-collection efforts for the Pawnee Nation to produce a comprehensive Tribal water-management plan.

Purpose and Scope

The purpose of this report is to summarize and analyze available climatic, geographic, geologic, water-use, and hydrologic data and to identify data gaps for the Black Bear Creek watershed in the Pawnee Nation Tribal Jurisdictional Area. This report can aid the Pawnee Nation in prioritization of future projects and serve as a background document for the development of a jurisdiction-wide comprehensive water-management plan.

Location of Study Area

The Pawnee Nation Tribal Jurisdictional Area consists of approximately 450 square miles (mi^2) in Pawnee County and

Payne County in north-central Oklahoma (fig. 1). The area is bounded by two major rivers (Arkansas and Cimarron) and is drained by several smaller streams (fig. 1). The largest of these streams is Black Bear Creek, which bisects the jurisdictional area before joining the Arkansas River.

The study area described in this report is the extent of the Black Bear Creek watershed that lies within the Pawnee Nation Tribal Jurisdictional Area, also referred to as the "Black Bear Creek study area" (fig. 1). The Black Bear Creek study area lies entirely within Pawnee County and consists of approximately 176 mi^2, or about 39 percent of the area of the jurisdictional area. The second largest community in Pawnee County, the City of Pawnee, lies within the Black Bear Creek study area and is both the county seat and center of government for the Pawnee Nation.

In anticipation of future studies, much of the climatic, geographic, geologic, and water-use data in this report are summarized for the entire Pawnee Nation Tribal Jurisdictional Area and, when possible, the Black Bear Creek study area. Streamflow, surface-water-quality, groundwater-availability, and groundwater-quality data are summarized only for the Black Bear Creek study area.

Methods of Analysis

Climatic, geographic, geologic, water-use, and hydrologic data from previously published reports or databases were collected and analyzed for this report. Additionally, a limited field effort was completed to provide additional groundwater-quality information. Data gaps were also identified and summarized in this report.

Selection and Analysis of Climatic, Geographic, and Geologic Data

Climatic data were obtained for two weather stations in the Pawnee Nation Tribal Jurisdictional Area. Daily and annual data from the National Weather Service (NWS) weather station at Ralston, Okla. (station identifier USC00347390), were downloaded from the National Oceanic and Atmospheric Administration (NOAA; 2017). Daily data from the Oklahoma Climatological Survey (OCS) Mesonet weather station at Pawnee, Okla. (station identifier PAWN), were downloaded from the Mesonet website (OCS, 2017a). Annual values were not reported for years with missing data. Climatic trends are shown by using locally weighted estimated scatterplot smoothing (LOESS) curves (Cleveland, 1979) calculated by using R (R Core Team, 2016).

Physiographic data were collected from a number of sources. A digital elevation model for the Pawnee Nation Tribal Jurisdictional Area was obtained from the USGS National Elevation Dataset (USGS, 2016a). Soil data were obtained from the Natural Resources Conservation Service "Digital General Soil Map of U.S." (U.S. Department of Agriculture [USDA], Natural Resources Conservation Service [NRCS], 2016) and mapped with the Soil Data Viewer 6.2 ArcGIS plug-in (USDA NRCS, 2015). National Land Cover Database 2011 (NLCD) raster data were used to estimate land use in the study area (Multi-Resolution Land Characteristics Consortium, 2014; Homer and others, 2015). Crop information was obtained from the National Agricultural Statistics Service CropScape Cropland Data Layer (USDA National Agricultural Statistics Service, 2018).

Descriptions of the geologic and hydrogeologic settings were obtained from previously published reports in or around the study area including Pawnee, Payne, and Osage Counties. Geologic reports reviewed include Greene (1928), Greig (1959), Clare (1963), Fay and others (1979), Bingham and Bergman (1980), and Shelton and others (1985). Surficial geology and fault lines were obtained from Heran and others (2003). Hydrogeologic reports reviewed include Bingham and Bergman (1980), D'Lugosz and others (1986), and Andrews and Smith (2014).

Selection and Analysis of Water-Use Data

Water-use information was sourced from the 2010 compilation of the USGS National Water Use Information Program, which estimates and characterizes water use by analyzing surface-water and groundwater withdrawals (Maupin and others, 2014). In this compilation, water-use data are aggregated by county, so specific water-use data are not available for the Pawnee Nation Tribal Jurisdictional Area. Domestic, industrial, and commercial distributions of the public water supply withdrawals were not provided for Pawnee and Payne Counties in the 2010 water-use compilation, so data are reported as the aggregate public water supply for all uses. Self-supplied water is reported by domestic, industrial, commercial, mining and petroleum production, irrigation, livestock, aquaculture, and thermoelectric power generation uses.

A scaling procedure described by Andrews and others (2013) was used to estimate water use for the Pawnee Nation Tribal Jurisdictional Area from water-use data for Pawnee and Payne Counties from the USGS National Water Information System (NWIS) (USGS, 2017a). The water-use scaling procedure relies on calculations of land area, impervious land area (Xian and others, 2011; Multi-Resolution Land Characteristics Consortium, 2014), tree canopy (Coulston and others, 2012; Multi-Resolution Land Characteristics Consortium, 2014), and population (U.S. Census Bureau, 2017) for the counties and the jurisdictional area (table 1). Percentages of impervious area and tree canopy area were generated by using the ArcMap Zonal Statistics as Table tool (Environmental Systems Research Institute, 2017). In addition to the scaling procedures described in Andrews and others (2013), the percentage of the county population living in the Black Bear Creek study area was applied to the public water supply withdrawals, and the scaling procedure used in Andrews and others (2013) for livestock and irrigation was applied to aquaculture as well.

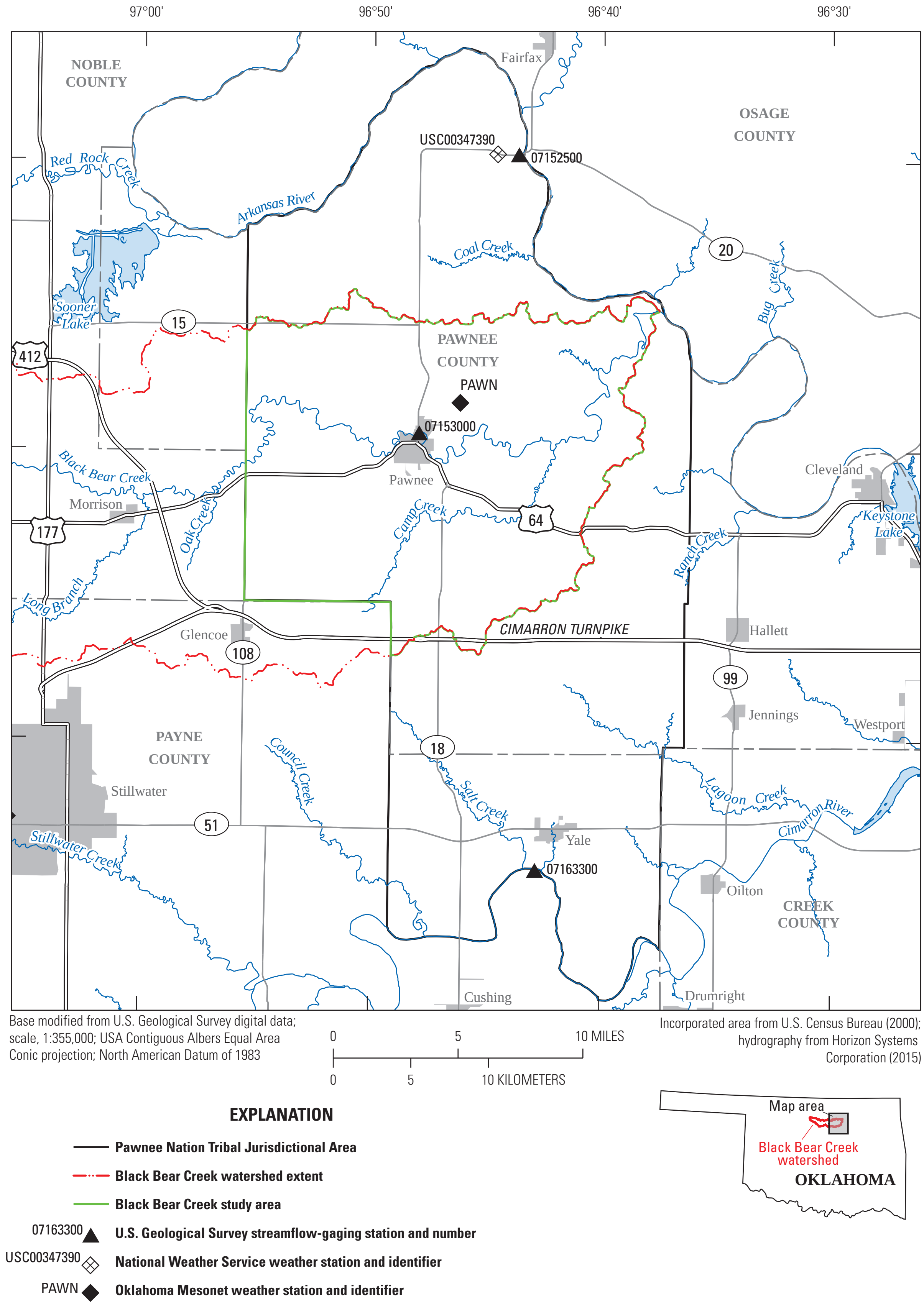

Figure 1. Locations of the Pawnee Nation Tribal Jurisdictional Area and the Black Bear Creek watershed, Oklahoma.

Table 1. Data used to estimate water use for the Pawnee Nation Tribal Jurisdictional Area from water-use data for Pawnee and Payne Counties, Oklahoma (Multi-Resolution Land Characteristics Consortium, 2014; U.S. Census Bureau, 2017).

[PNTJA, Pawnee Nation Tribal Jurisdictional Area]

Data type	County	
	Pawnee	Payne
County land area in PNTJA, in percent	61.5	11.5
Impervious area in PNTJA, in percent	0.463	0.677
Impervious area in counties, in percent	0.650	1.79
Tree canopy cover in PNTJA, in percent	20.0	26.0
Tree canopy cover in counties, in percent	24.4	21.4
Total county population	16,577	77,350
PNTJA population	5,198	2,453
PNTJA population, in percent of county population	31.4	3.2
PNTJA population density, in people per square mile	14.2	30.7

Selection and Analysis of Streamflow and Surface-Water-Quality Data

Streamflow data in the study area were limited to one long-term streamflow-gaging station operated by the USGS in cooperation with the U.S. Army Corps of Engineers (USACE) and the Oklahoma Water Resources Board (OWRB). Data from the Black Bear Creek at Pawnee, Okla., streamflow-gaging station (station number 07153000) were downloaded from NWIS (USGS, 2016b). Monthly mean, annual mean, and annual peak flows and associated statistical calculations, including base flow, are reported for the regulated-streamflow period from water years (October 1 to September 30, designated by the calendar year in which the water year ends) 1968 through 2015. Daily mean flows for water years 1968–2015 were used to compute flow-duration data. Low-flow recurrence intervals were calculated by using flow data from climate years (April 1 to March 31, designated by the calendar year in which the climate year ends) 1969 through 2015.

Several software programs were used to calculate statistics related to flow data. Base flows were calculated by hydrograph separation by using the Base-Flow Index Standard method (Wahl and Wahl, 1995) implemented through the USGS Groundwater Toolbox software program (Barlow and others, 2016). Flood magnitude and frequency were computed according to methods described in Bulletin 17C (England and others, 2018) using the PeakFQ software program (USGS, 2018a). Station-record skew was used in flood frequency and magnitude calculations because of the regulation of the stream by floodwater-retarding structures, as in Lewis and Esralew (2009). Flow-duration data and recurrence intervals of low-flow periods were calculated by using the Surface-Water Statistics (SWSTAT) software program (Lumb and others, 1990; USGS, 2002) implemented through the USGS Groundwater Toolbox software program (Barlow and others, 2016). LOESS curves, Wilcoxon rank-sum tests (Wilcoxon, 1945), Kendall rank-correlation coefficients (Kendall, 1938), and Mann-Kendall trend tests (Mann, 1945) were calculated by using R (R Core Team, 2016) and the Kendall R package (McLeod, 2011). Linear regressions were calculated using the SigmaPlot software package (Systat Software, Inc., 2011).

Surface-water-quality data for the study area were collected by several agencies including the USGS, the OWRB, the Oklahoma Conservation Commission, the Oklahoma Corporation Commission, and the Pawnee Nation Department of Environmental Conservation and Safety. Data from 1985 through 2015 were summarized in this report. Data were retrieved from the USGS NWIS database and the U.S. Environmental Protection Agency (EPA) STOrage and RETrieval (STORET) database through the National Water Quality Monitoring Council's Water Quality Portal website (EPA, 2017; National Water Quality Monitoring Council, 2017; USGS, 2017b). Additional surface-water-quality data were obtained from the OWRB's Beneficial Use Monitoring Program (BUMP) (OWRB, 2017a). Eighteen water-quality sites were identified in the study area, though many of the sites have only 1–2 years of water properties measured. Distributions of water-quality data are presented graphically as boxplots made by using the SigmaPlot software package (Systat Software, Inc., 2011). Pearson correlation coefficients for linear regression to relate selected water-quality variables were calculated by using R (R Core Team, 2016).

Selection and Analysis of Groundwater-Level and Groundwater-Quality Data

Groundwater-level data were obtained from the USGS NWIS and the OWRB (USGS, 2017b; OWRB, 2018a). Groundwater-quality data were obtained from queries of the NWIS and STORET databases through the National Water Quality Monitoring Council's Water Quality Portal website (EPA, 2017; National Water Quality Monitoring Council, 2017; USGS, 2017b). Additional groundwater-quality data were obtained from the OWRB's Groundwater Monitoring & Assessment Program (GMAP) (OWRB, 2018a). Because of the limited availability of groundwater-level and groundwater-quality data, a small field effort was conducted during June and December 2017 and March–May 2018 to start to fill this known data gap. Groundwater levels were measured at 16 wells across the study area, and 8 wells were sampled for water properties (pH, temperature, and specific conductance), major ions, and nutrients. Groundwater wells were sampled according to USGS protocols (USGS, variously dated) and analyzed at the USGS National Water Quality Laboratory in Denver, Colo. (Fishman, 1993; Clesceri and others, 1998; Patton and Kryskalla, 2011). The groundwater levels and groundwater-quality data for these wells are available from NWIS (USGS, 2018b). Stiff diagrams of major-ion concentrations (Stiff, 1951) were made by using R (R Core Team, 2016) and the smwrGraphs package (Lorenz and Diekoff, 2017) to compare and interpret the data.

Quality Assurance

Quality assurance is the process of analyzing quality-control data to assess the reproducibility and accuracy of processes such as equipment cleaning, sample collection, and sample analysis. Quality-control data relating to water-quality sampling are described in this report and include blank samples and replicate samples. Water-quality data obtained from blank samples are used to evaluate potential positive bias introduced by equipment-cleaning, sample-collection, and sample-analysis methods on water-quality results. Replicate samples, which are samples that are collected from the same source at approximately the same time, provide an indication of variability of results due to sample collection and analysis, as well as the variability inherent in the aqueous system being analyzed over a short time period. This variability is assessed by calculating the relative percent difference (RPD) in replicate data, with smaller RPD indicating less variability and larger RPD indicating more variability. RPD is calculated according to

$$\text{RPD} = |a-b| / \left((a+b) / 2 \right) \times 100$$

where

a is the constituent concentration of the field sample, and

b is the constituent concentration of the field-replicate sample.

Surface-Water-Quality Data

Surface-water-quality data were obtained by several different agencies with varying sampling and analytical procedures. Quality-control information was not available for data sourced from the STORET or OWRB databases. Surface-water-quality data retrieved from the NWIS database were collected and analyzed according to the USGS "National Field Manual for the Collection of Water-Quality Data" (USGS, variously dated). One field-blank sample collected at the Black Bear Creek at Pawnee, Okla., streamflow-gaging station was identified in the NWIS database (USGS, 2018b). Major-ion concentrations in the field-blank sample were below detection limits, with the exceptions of calcium, chloride, and sulfate. Concentrations of these ions in the field-blank sample were less than 3 percent of the concentrations in the related environmental sample.

Groundwater-Quality Data

In the study area, only one well with groundwater-quality data was identified through the NWIS and STORET databases. No quality-control information was available for these data. Data provided by the OWRB did not include quality-control information.

Data collected by the USGS during the limited field sampling during March–May 2018 involved several quality-control measures. Equipment cleaning was performed by using USGS standard methods (USGS, variously dated). Groundwater levels and groundwater-quality data were collected according to the USGS "National Field Manual for the Collection of Water-Quality Data" (USGS, variously dated). Quality-control samples included an equipment blank and a replicate sample. The equipment blank was collected at the USGS Oklahoma Water Science Center by using reagent-grade water and analyzed for major ions and nutrients to ensure the quality of equipment-cleaning and sampling methods. Analytical results for the equipment blank for major-ion and nutrient concentrations were below the detection limits set by the USGS National Water Quality Laboratory, with the exception of ammonia nitrogen, which was above the detection limit but below the set reporting limit. Replicate data for major-ion and nutrient concentrations were generally in agreement. RPD values for individual analytes ranged from 0 to 22 percent. Percent difference (PD) of cation/anion balance was calculated by using the sum of major anions and the sum of major cations in milliequivalents per liter according to

$$\text{PD} = \left| \sum cations - \sum anions \right| / (\sum cations + \sum anions) \times 100$$

where

$\sum cations$ is the sum of calcium, magnesium, sodium, potassium, iron, manganese, and hydrogen ion concentrations, and

$\sum anions$ is the sum of chloride, sulfate, fluoride, and alkalinity concentrations.

In all but one sample, PD of cation/anion balance was less than 3 percent. PD of cation/anion balance for the sample collected at USGS station number 361748096512201 was 19.71 percent. The water from this well was gray and turbid, and on the basis of the appearance and odor of the sample, some form of well contamination is suspected. Nutrient results for this sample were not completed. Because of these issues, water-quality results from this well are to be considered estimated.

Summary of Climatic, Geographic, and Geologic Data

Climatic, geographic, and geologic data from previously published reports or databases are summarized in this section. Because of the small size of the study area and possibility for future studies of adjacent watersheds, these data are summarized for the entire Pawnee Nation Tribal Jurisdictional Area. Climatic data include air temperature and precipitation at two stations in the jurisdictional area, and the geographic-data summary includes a description of the physiography, land cover, and soil types. Surficial and subsurface geology are described, and the water-bearing formations in the area are discussed. An understanding of the climatic, geographic, and geologic setting of the jurisdictional area and the study area can aid the Pawnee Nation in the development of a Tribal water-management plan.

Climate

The majority of the Pawnee Nation Tribal Jurisdictional Area is in the Northeastern Oklahoma climate division (Guttman and Quayle, 1996), which is classified in the Köppen Climate Classification System as having a temperate humid subtropical (Cfa) climate (Kottek and others, 2006). Average air temperatures in the jurisdictional area can range from approximately 94 degrees Fahrenheit (°F) in July to approximately 24 °F in January (OCS, 2017b). Annual average air temperatures are approximately 60 °F (OCS, 2017b). The area receives an average of approximately 39 inches of precipitation annually, with the majority of precipitation occurring in spring and fall (OCS, 2017b). Snowfall varies, with approximately half of all years with 10 or more inches of snow (OCS, 2017b). Winds are typically out of the south or southeast and average approximately 9 miles per hour, bringing humidity north from the Gulf of Mexico, especially in late spring, when significant thunderstorms and tornados can develop (OCS, 2017b). From 1950 through 2015, the NWS recorded 29 tornados in Pawnee County, including three F4 tornados, two of which were in late April 1984 and the other in late April 1991 (NWS, 2018b).

The NWS station at Ralston, Okla., is the only long-term weather station in the area. Precipitation data have been collected since 1925, and temperature data have been collected since 1960 at this station (fig. 2*A*). LOESS curves show mostly flat trends for temperature and precipitation from 1960 to 1980 at the Ralston, Okla., station. Temperatures and precipitation trended higher from 1980 through the early 1990s and then decreased to pre-1980 conditions in the late 1990s. From 2000 onward, temperature has trended slightly higher, and precipitation has trended slightly lower. These trends are influenced by the historic drought of 2011, when less than 20 inches of precipitation and an average temperature of about 64 °F were measured at the Ralston station.

In 1994, the OCS Mesonet station at Pawnee, Okla., was established, adding a second continuous weather station in the jurisdictional area, though precipitation and temperature data are only available from 1998 onward (fig. 2*B*). Because of the relatively short period of climate record at this station, trends for this dataset are unclear, though the data do agree well with measurements at the NWS Ralston station within the period of data overlap of those two stations.

Physiography

The topography of the Pawnee Nation Tribal Jurisdictional Area is dominated by shallow east-facing ridges or cuestas, with relief generally less than 150 feet (ft) (fig. 3) (Greig, 1959). The highest point in the jurisdictional area (1,138 ft) is near the Cimarron Turnpike (NW¼SW¼ sec.11, T. 20 N., R. 05 E.), and the highest point in the Black Bear Creek study area (1,135 ft) is approximately 1 mile north, in SE¼NW¼ sec.03, T. 20 N., R. 05 E. (fig. 3). The lowest point in the jurisdictional area (728 ft) is on the eastern boundary of the jurisdictional area, in NE¼SE¼ sec.01, T. 21 N., R. 06 E. The lowest point in the Black Bear Creek watershed (751 ft) is the confluence of Black Bear Creek and the Arkansas River. The jurisdictional area is drained by the Arkansas River to the north and northeast and by the Cimarron River to the south and southwest. Black Bear Creek bisects the jurisdictional area, meandering from the western border of the jurisdictional area approximately 43 miles through the City of Pawnee to the Arkansas River in the east. The Arkansas River and Black Bear Creek drain approximately 75 percent of the county, with the Cimarron River and a number of smaller tributaries draining the remaining area (USDA Soil Conservation Service, 1959).

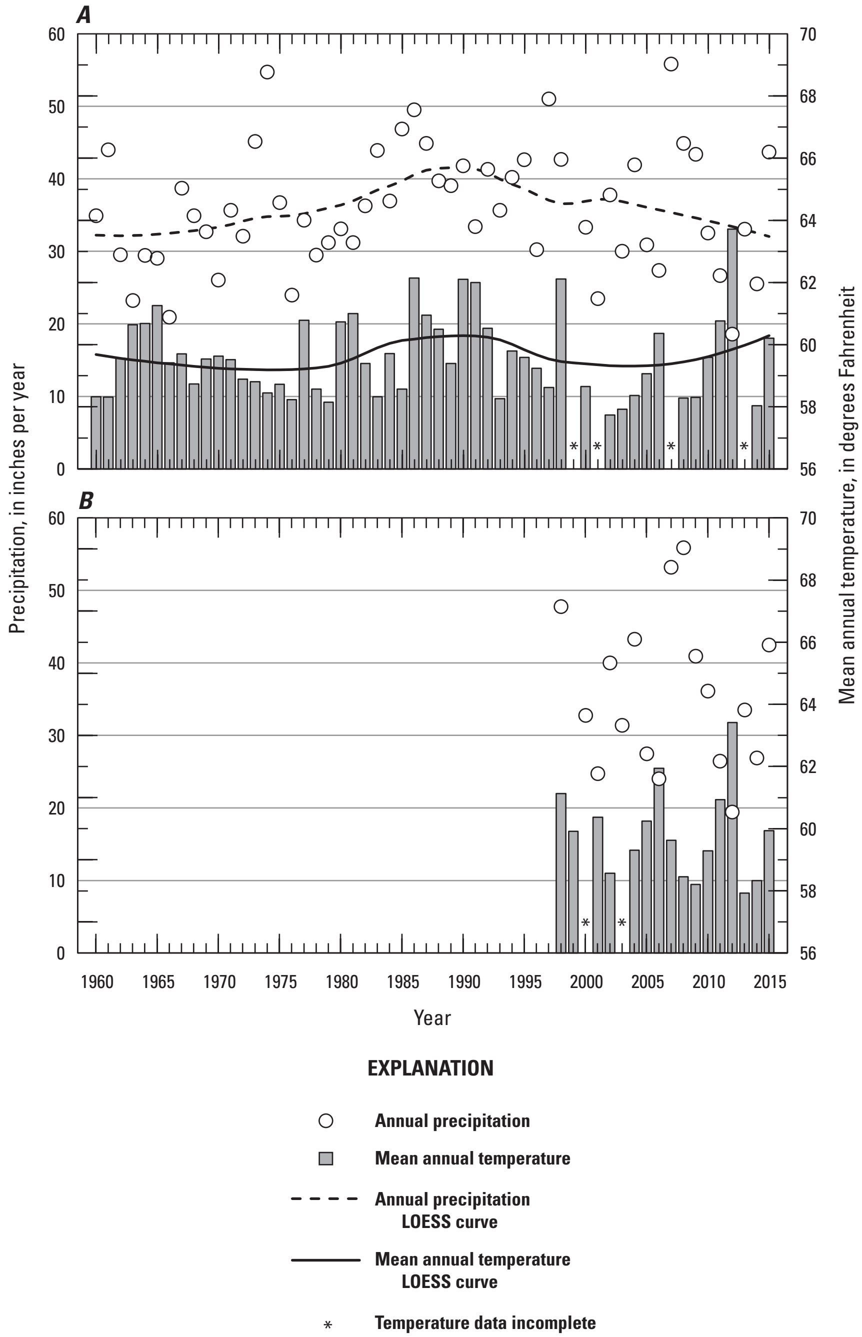

Figure 2. Climate data including annual precipitation and mean annual temperature, 1960 through 2015, within the Pawnee Nation Tribal Jurisdictional Area, Oklahoma. *A*, National Weather Service station at Ralston, Okla. (station identifier USC00347390). *B*, Oklahoma Climatological Survey Mesonet station at Pawnee, Okla. (station identifier PAWN) (National Oceanic and Atmospheric Administration, 2017; Oklahoma Climatological Survey, 2017a). Trends are shown by using locally weighted estimated scatterplot smoothing (LOESS) curves.

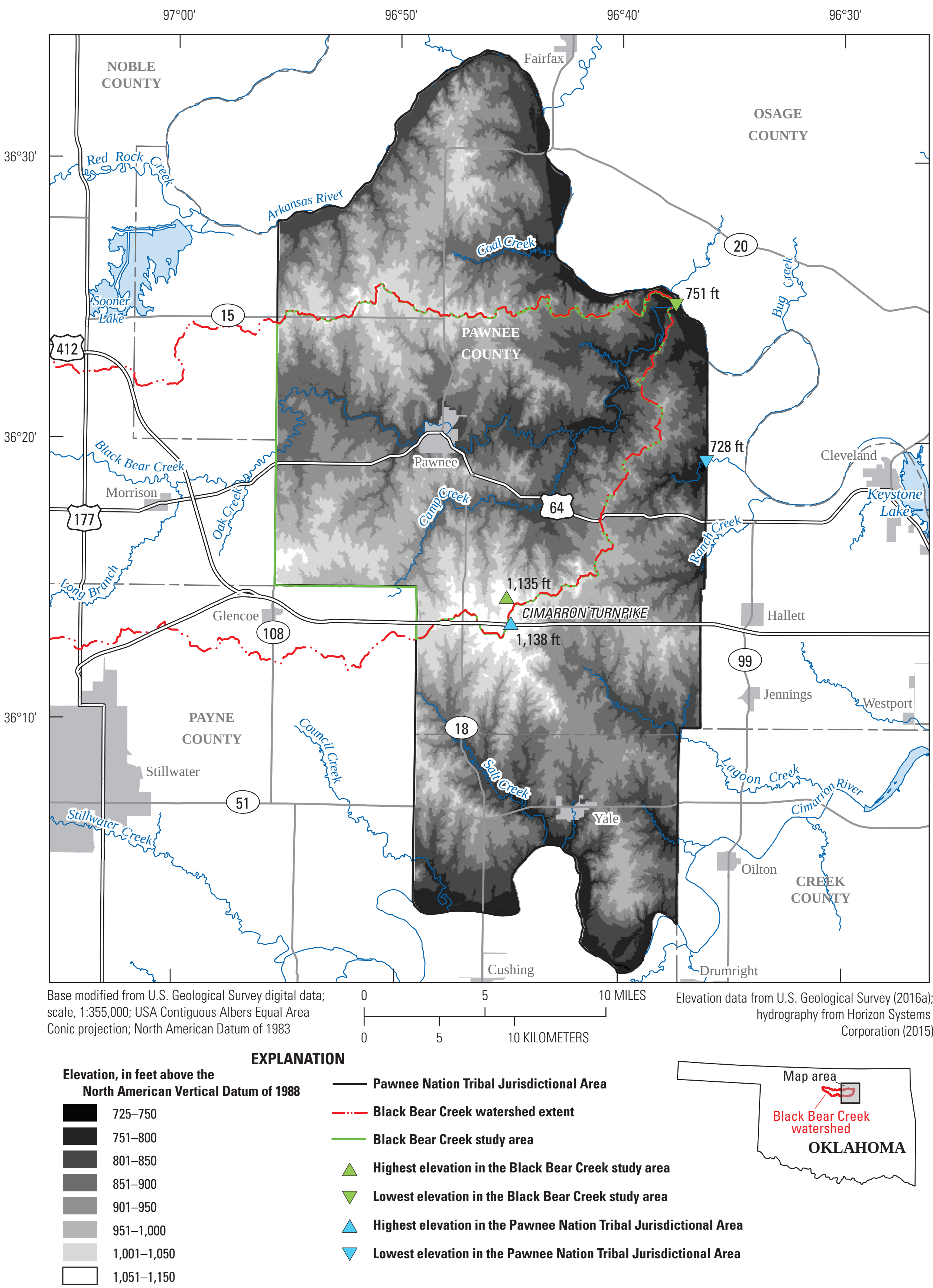

Figure 3. Land surface relief of the Pawnee Nation Tribal Jurisdictional Area, Oklahoma.

Land Cover

The Pawnee Nation Tribal Jurisdictional Area lies within the Central Great Plains Level III ecoregion and the Cross Timbers Transition Level IV ecoregion, with the Northern Cross Timbers ecoregion bordering to the east and the Prairie Tableland ecoregion bordering to the west (Woods and others, 2005). Approximately 60 percent of the land in both the jurisdictional area and the Black Bear Creek study area is grassland or scrub (figs. 4 and 5), much of which is used for ranching (Homer and others, 2015). Approximately 20 percent of both areas are covered by forest consisting of *Juniperus virginiana* (eastern redcedar), *Quercus* spp. (oak), and *Ulmus* spp. (elm) trees, mostly concentrated along riparian zones (Woods and others, 2005). Cultivated crops including winter wheat, soybeans, sorghum, alfalfa, and corn (USDA National Agricultural Statistics Service, 2018) cover approximately 15 percent of the land area, utilizing an average growing season of 197 days (OCS, 2017b). Approximately 5 percent of both areas are developed or barren, and approximately 1 percent is water or wetlands.

Soils

The soils underlying the Pawnee Nation Tribal Jurisdictional Area are ustic to udic alfisols and mollisols ranging from silty clays to sandy loams (USDA NRCS, 2016). Silty clay loams of the Zaneis-Renfrow-Grainola-Coyle, Summit-Shidler, and Steedman-Coyle-Agra soil associations underlie most of the jurisdictional area (fig. 6). These soils were formed from weathered sandstone and shales of the Permian and Pennsylvanian ages and are typically well drained, with moderate permeability and runoff potential depending on the slope of the soil (USDA NRCS, 2016). Along the Arkansas River, Cimarron River, Black Bear Creek, and Camp Creek, soils of coarse sandy loams of the Yahola-Gaddy-Dale, Yahola-Gracemore-Goodnight-Gaddy, and Yahola-Pulaski-Port-Ashport associations predominate (fig. 6). These associations are characterized by well-drained, rapidly permeable alluvial soils (USDA NRCS, 2016). Typically adjacent to the Yahola series soils are loamy sands or sandy loams of the Konawa-Eufaula-Dougherty, Stephenville-Niotaze-Darnell, and Vanoss-Norge associations (USDA NRCS, 2016). These soils occur on the stream terraces and are generally well drained and moderately permeable (USDA NRCS, 2016).

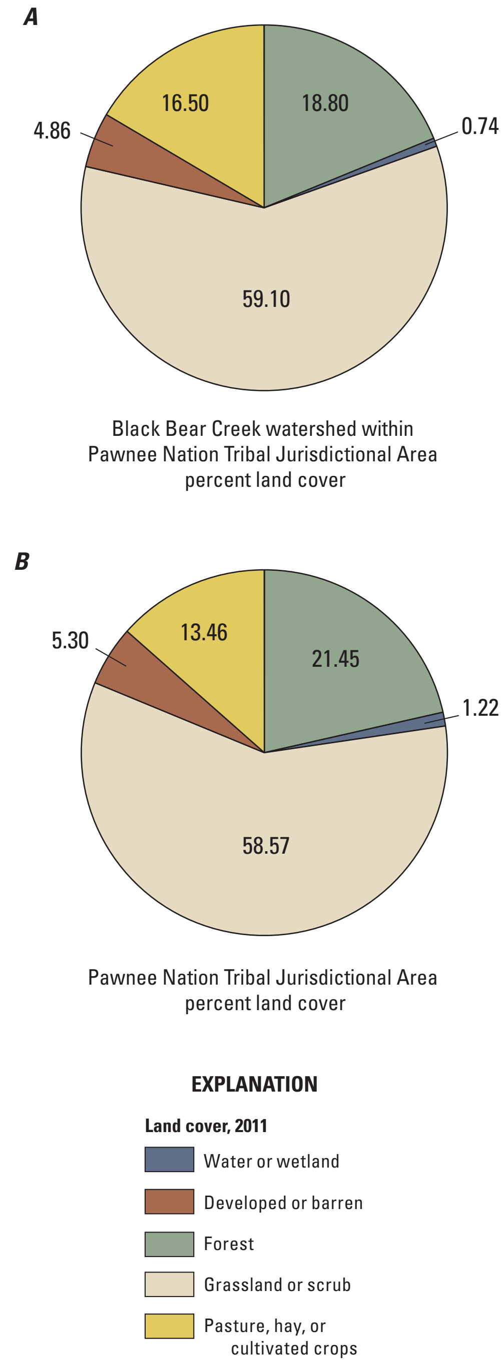

Figure 4. Percentage land cover by type for *A*, the Black Bear Creek watershed within the Pawnee Nation Tribal Jurisdictional Area and *B*, the Pawnee Nation Tribal Jurisdictional Area, Oklahoma.

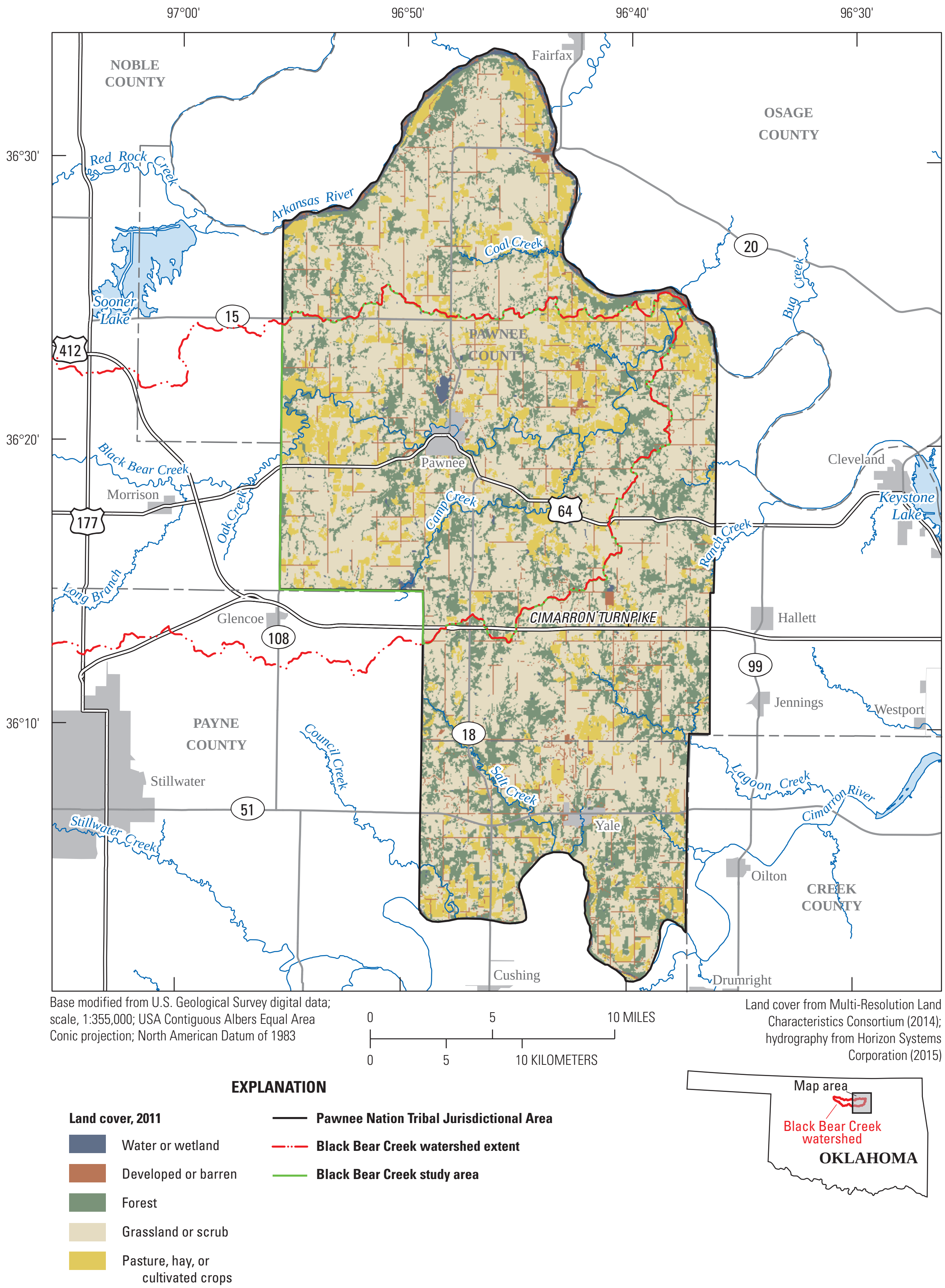

Figure 5. Land cover in the Pawnee Nation Tribal Jurisdictional Area, Oklahoma, 2011.

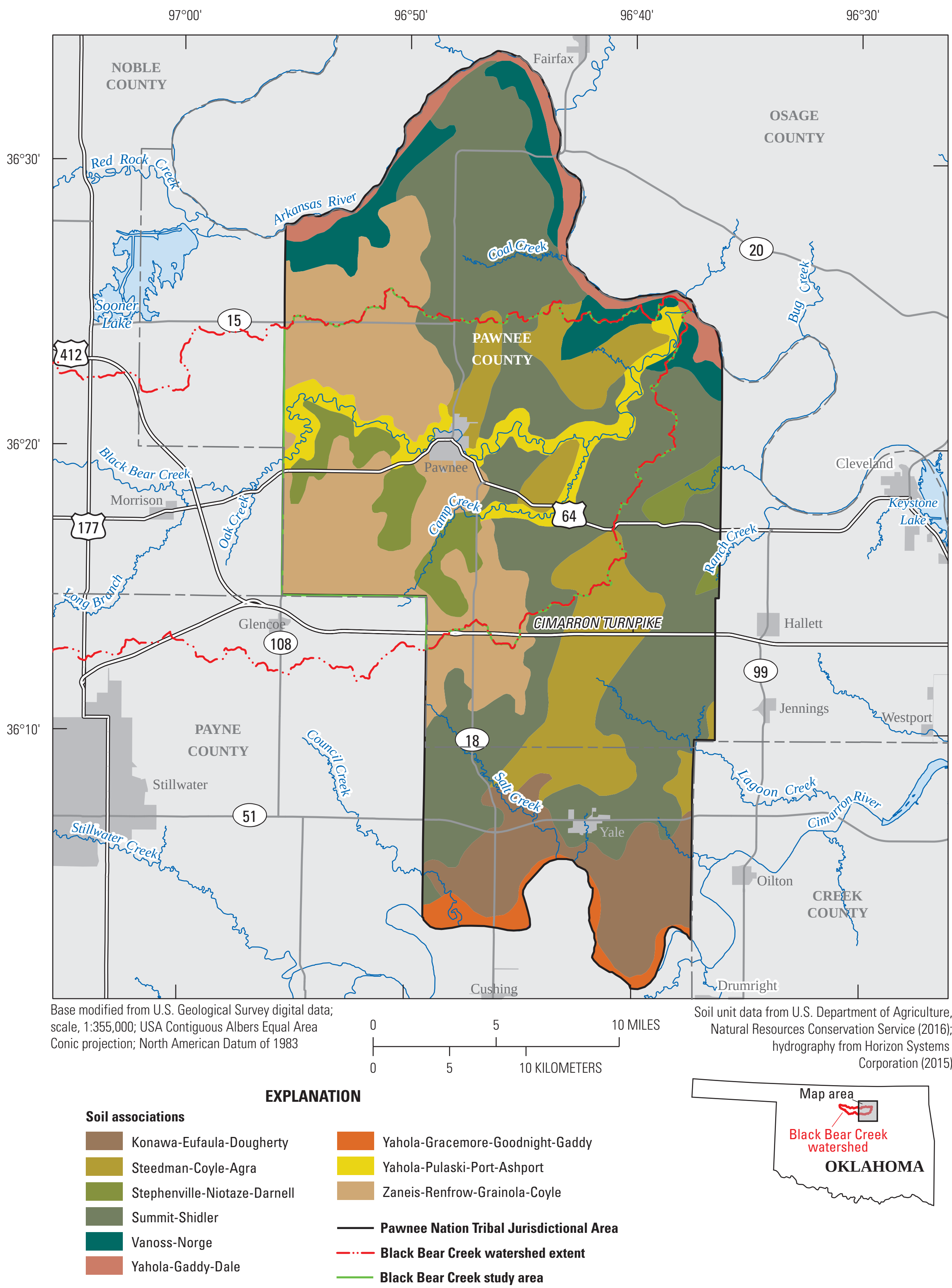

Figure 6. Soil associations in the Pawnee Nation Tribal Jurisdictional Area, Oklahoma.

Geology

The surficial geology of the Pawnee Nation Tribal Jurisdictional Area is dominated by shelf deposits of Pennsylvanian-age sediments laid down on the cratonic Central Oklahoma platform and overlain with Quaternary deposits in some areas, principally near rivers and streams (fig. 7) (Heran and others, 2003). The Pennsylvanian beds, along with exposed Permian deposits to the west and Mississippian deposits to the east, form the Prairie Plains homocline, which is the result of westward tilting during the late Permian and subsequent erosion (Greig, 1959). In the jurisdictional area, strata dip gently to the west at approximately 50 ft per mile, exposing from west to east the Late Pennsylvanian Oscar, Vanoss, and Ada Groups, which are composed of alternating beds of limestone, shale, and sandstone (fig. 7) (Clare, 1963).

Pennsylvanian-age beds extend deep into the subsurface, with an aggregate thickness ranging from 3,900 ft in the western extent of the study area to 2,200 ft in the eastern extent (Greig, 1959; Clare, 1963). Beneath the Pennsylvanian-age sedimentary rocks lies a thick layer (100–300 ft) of Mississippian limestone known as the Keokuk Limestone and the Reeds Spring Formation, the Late Devonian Woodford (Chattanooga) shale and Misener Sandstone, older members of the Ordovician Simpson Group, and finally younger members of the Cambro-Ordovician Arbuckle group (fig. 8). Basement rock is thought to be the equivalent of the Precambrian Spavinaw granite (Greig, 1959).

Freshwater aquifers in the Pawnee Nation Tribal Jurisdictional Area include Quaternary-age alluvium and terrace deposits, the minor bedrock aquifers of the Oscar and Vanoss Groups, and the Ada Group of the Ada-Vamoosa aquifer. Alluvium and terrace deposits consist of unconsolidated silt, sand, and gravel (fig. 8) and occur along the Arkansas River, Cimarron River, Salt Creek, and Black Bear Creek (fig. 7) (Bingham and Bergman, 1980). Alluvium and terrace deposits along the major streams range in thickness between 15 and 50 ft and between 0 and 50 ft along the minor streams (Bingham and Bergman, 1980). The Late Pennsylvanian-age Oscar and Vanoss Groups underlie the majority of the jurisdictional area and the Black Bear Creek study area and consist of layers of limestone, shale, and fine-grained arkosic sandstone hundreds of feet thick (Bingham and Bergman, 1980). The Ada Group, part of the Ada-Vamoosa aquifer, consists of layers of limestone, shale, and fine-grained sandstones and is accessible along the extreme eastern border of the jurisdictional area (Bingham and Bergman, 1980). Recharge to the Ada group is primarily due to infiltration of precipitation in outcrop areas (D’Lugosz and others, 1986). With increasing distance and depth from the recharge areas, salinity increases, and the Ada Group is not a source of freshwater in the Black Bear Creek study area. The most productive sources of freshwater in the jurisdictional area are the alluvium and terrace deposits along the larger streams like the Arkansas River, Cimarron River, and Black Bear Creek (Bingham and Bergman, 1980). The Pennsylvanian-age formations produce moderate amounts of freshwater but can also produce saline water if penetrated too far from the outcrop (Greig, 1959).

Summary of Available Hydrologic Data

Available hydrologic data include several components. Estimated water use and streamflow, surface-water quality, groundwater availability, and groundwater quality are described in this section.

Estimated Water Use

As described in the “Methods of Analysis” section of this report, water-use data for Pawnee and Payne Counties were obtained from the 2010 compilation of the USGS National Water Use Information Program, and a scaling procedure was used to estimate water use for the Pawnee Nation Tribal Jurisdictional Area from the county data (table 1) (USGS, 2017a). Because of the small size of the Black Bear Creek study area and the small amount of water use for the entire jurisdictional area, estimates of water use were not calculated for the Black Bear Creek study area.

The Pawnee Nation Tribal Jurisdictional Area is primarily pasture with little water use (Maupin and others, 2014). The population of the jurisdictional area, calculated from county population data (U.S. Census Bureau, 2017), was approximately 7,700 people (table 1). Primary economic activities of the area are ranching, oil production, and mining. Urban centers include the city of Pawnee central to the jurisdictional area, the city of Yale in the southern portion of the jurisdictional area, and the town of Ralston in the northern portion of the jurisdictional area.

Total water withdrawals for the Pawnee Nation Tribal Jurisdictional Area were estimated to be 8.01 million gallons per day (Mgal/d) (table 2), consisting of about 84 percent groundwater withdrawals and 16 percent surface-water withdrawals. The dominant water-withdrawal types for the area were public water supply for domestic, industrial, and commercial use, self-supplied water for agriculture (livestock and irrigation), and self-supplied water for mining and petroleum production.

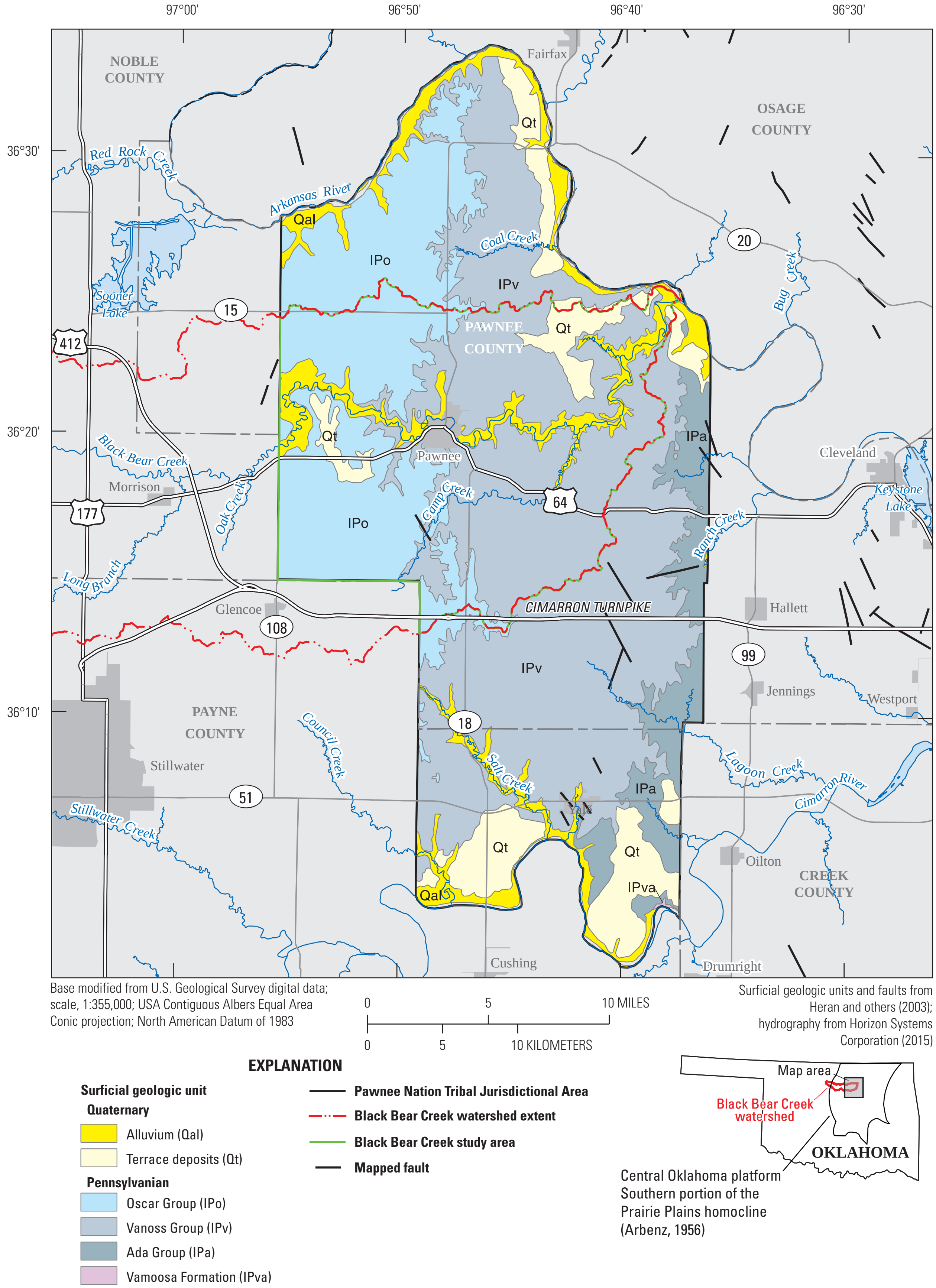

Figure 7. Surficial geology in the Pawnee Nation Tribal Jurisdictional Area, Oklahoma.

Figure 8. Major stratigraphic units in the Pawnee Nation Tribal Jurisdictional Area, Oklahoma.

[ft, feet; Fm., Formation; Sh., shale; Ss., sandstone; Ls., limestone; Dol., dolomite; Cht., chert; lithology listed in order of prominence in formation. Modified from Greig, 1959; Heran and others, 2003; Clare, 1963; Andrews and Smith, 2014; Shelton and others, 1985; Fay and others, 1979; Greene, 1928]

Time-stratigraphic unit	Group	Surficial deposits and formations	Lithology	Thickness, in feet
Quaternary		Alluvium	Gravel to clay	0–20
		Terrace deposits	Gravel to clay	0–30
Pennsylvanian	Oscar	Numerous	Sh., Ss., Ls.	0–400
	Vanoss	Numerous	Sh., Ls., Ss.	0–500
	Ada	Numerous	Sh., Ss., Ls.	0–400
		Vamoosa Fm.	Sh., Ss., Ls.	≤ 630
	Ochelata	Tallant Fm.	Ss., Sh.	80–220
		Barnsdall Fm.	Ss., Sh.	45–165
		Wann Fm.	Sh., Ss., Ls.	360–565
		Iola Ls.	Ls., Ss., Sh.	20–130
		Chanute Fm.	Ss., Sh.	80–220
	Skiatook	Dewey Ls.	Ls., Ss., Sh.	5–35
		Nellie Bly Fm.	Sh., Ss.	30–110
		Hogshooter Ls.	Ls., Sh.	5–25
		Coffeyville Fm.	Sh., Ss.	250–330
		Checkerboard Ls.	Ls.	2–15
		Seminole Fm.	Sh., Ss., Coal	70–240
	Marmaton	Numerous	Sh., Ls., Sh.	150–310
	Cabaniss	Numerous	Ss., Ls., Sh.	180–275
	Krebs	Numerous	Ss., Ls., Sh.	155–375
Mississippian		Keokuk Ls.	Ls., Cht.	100–300
		Reeds Spring Fm.	Cht., Ls.	
Mississippian/Devonian		Woodford Sh.	Sh.	10–45
		Misener Ss.	Ss.	0–25
Ordovician		Viola Ls.	Ls.	0–60
	Simpson	Bromide Fm.	Ss.	70–310
		Tulip Creek Fm.	Sh.	
		McLish Fm.	Ss.	
		Oil Creek Fm.	Ss.	
Cambro-Ordovician	Arbuckle	Numerous	Dol., Ss.	60–780

Table 2. Estimated water withdrawals during 2010 for Pawnee and Payne Counties and the Pawnee Nation Tribal Jurisdictional Area, Oklahoma (U.S. Geological Survey, 2017a).

[Mgal/d, million gallons per day; PNTJA, Pawnee Nation Tribal Jurisdictional Area]

Water-withdrawal type	County/area	Estimated water withdrawals, in Mgal/d		
		Groundwater	Surface water	Total
Public water supply for domestic, industrial, and commercial use	Pawnee	0.45	2.64	3.09
	Payne	1.71	2.52	4.23
	PNTJA	0.20	0.91	1.11
Industrial, self-supplied	Pawnee	0.00	0.00	0.00
	Payne	0.00	0.00	0.00
	PNTJA	0.00	0.00	0.00
Commercial, self-supplied	Pawnee	0.00	0.00	0.00
	Payne	0.00	0.00	0.00
	PNTJA	0.00	0.00	0.00
Domestic, self-supplied	Pawnee	0.39	0.00	0.39
	Payne	0.83	0.00	0.83
	PNTJA	0.15	0.00	0.15
Livestock, self-supplied	Pawnee	0.06	0.49	0.55
	Payne	0.07	0.68	0.75
	PNTJA	0.04	0.34	0.38
Irrigation, self-supplied	Pawnee	0.00	0.01	0.01
	Payne	0.33	0.05	0.38
	PNTJA	0.05	0.01	0.06
Mining/petroleum production, self-supplied, saline groundwater, fresh surface water	Pawnee	9.12	0.10	9.22
	Payne	5.44	0.00	5.44
	PNTJA	6.23	0.06	6.29
Thermoelectric power generation, self-supplied	Pawnee	0.00	0.00	0.00
	Payne	0.00	0.00	0.00
	PNTJA	0.00	0.00	0.00
Aquaculture, self-supplied	Pawnee	0.00	0.00	0.00
	Payne	0.23	0.01	0.24
	PNTJA	0.03	0.00	0.03
Total withdrawals	Pawnee	10.02	3.24	13.26
	Payne	8.61	3.26	11.87
	PNTJA	6.69	1.32	8.01

Water supplied for public distribution systems to domestic, industrial, and commercial users in the Pawnee Nation Tribal Jurisdictional Area accounted for 1.11 Mgal/d, or about 14 percent of the total water use for the jurisdictional area. Surface-water withdrawals made up about 82 percent of the total public-supplied water in the jurisdictional area with groundwater withdrawals making up the balance. This water was supplied by several water systems, including the Lone Chimney Water Association, Pawnee County Rural Water District (RWD) 3, Pawnee County RWD 4, Payne County RWD 4, and the Yale Water and Sewer Trust Authority (OWRB, 2018b). Though a breakdown of water use by sector is not available, most of the public-supplied water was likely delivered to domestic customers, as there is relatively little commercial and industrial development within the jurisdictional area. Industrial and commercial self-supplied (not supplied by a public distribution system) water use was estimated to be 0 Mgal/day for both Pawnee and Payne Counties and the jurisdictional area (table 2) (USGS, 2017a).

Self-supplied water for livestock and irrigation totaled 0.44 Mgal/d (table 2) (USGS, 2017a). Grassland or scrub cover approximately 60 percent of the Pawnee Nation Tribal Jurisdictional Area (fig. 4), and the majority (86 percent) of the water use is for livestock, provided primarily (89 percent) by surface-water withdrawals. Self-supplied water for irrigation was primarily withdrawn from groundwater sources and totaled 0.06 Mgal/d, or about 14 percent of the total agricultural water use.

Self-supplied water for mining and petroleum production totaled 6.29 Mgal/d, or about 79 percent of the total water use, for the Pawnee Nation Tribal Jurisdictional Area (table 2) (USGS, 2017a). More than 99 percent of this water was derived from saline groundwater sources and used for hydraulic fracturing and secondary oil recovery in petroleum production and dust control in aggregate mining (Maupin and others, 2014). Marginally saline waters will likely continue to be a target of exploration because of the continued development of petroleum resources but also potentially for public water supply and agricultural uses as treatment technologies advance.

Future water use will likely be driven by population change or changes in oil and gas production. The cities of Pawnee and Yale underwent population declines of 1.5 and 8.6 percent, respectively, between the 2000 and 2010 decennial censuses (U.S. Census Bureau, 2017). Further decreases in population could reduce withdrawal amounts for public distribution systems serving primarily domestic users. Demand for oil and gas, the viability of current oil fields, the discovery of new petroleum sources, and advances in oil-field technologies could also drive changes in water use in the Pawnee Nation Tribal Jurisdictional Area.

Streamflow and Surface-Water Quality

Streamflow statistics and long-term trends are described in this section of the report for the Black Bear Creek at Pawnee, Okla., streamflow-gaging station (station number 07153000). Surface-water-quality data for 18 sites in the study area are also summarized.

Streamflow Statistics and Long-Term Trends

The Black Bear Creek at Pawnee, Okla., streamflow-gaging station (station number 07153000) is the only streamflow-gaging station in the Black Bear Creek study area. This station is located at latitude 36°20′37″N, longitude 96°47′57″W, where State Highway 18 crosses Black Bear Creek (fig. 1). The station upstream drainage area is 576 mi^2 (USGS, 2016b). The period of record for this station is from July 1944 to the present, but the flow has been regulated by upstream floodwater-retarding structures since 1968 (Lewis and Esralew, 2009). To more accurately describe current streamflow conditions, statistics reported in this section summarize only the regulated streamflow period from water years 1968–2015.

Monthly mean streamflow at the Black Bear Creek at Pawnee, Okla., streamflow-gaging station increased from about 145 cubic feet per second (ft^3/s) in the late 1960s to a peak of about 330 ft^3/s in 1994 (fig. 9). Monthly mean

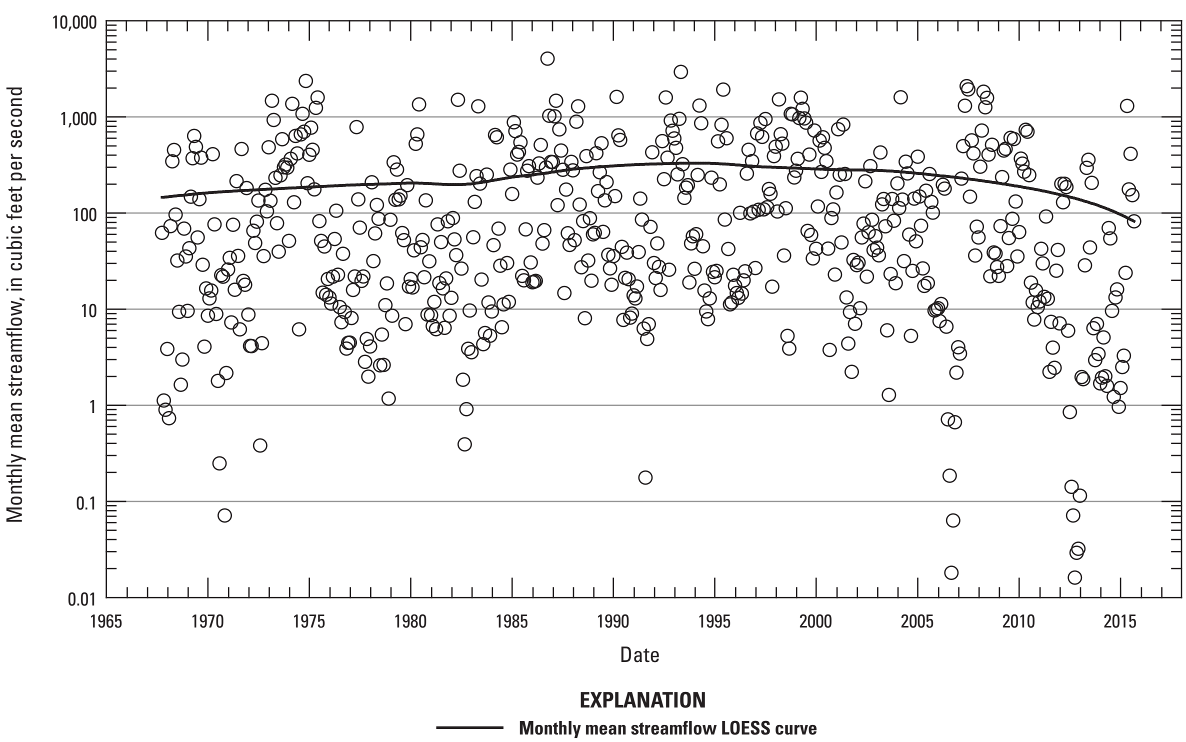

Figure 9. Monthly mean streamflow at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000), water years 1968–2015 (U.S. Geological Survey, 2016b). Trends are shown by using locally weighted estimated scatterplot smoothing (LOESS) curves.

streamflow then decreased to about 82 ft^3/s by 2015. Over the regulated streamflow period, monthly mean streamflow was trending lower (τ=−0.178, p=0.028), probably influenced by the severe drought periods of 2002–6 and 2010–14. Monthly mean streamflow was greatest in May and lowest in January, with streamflows of 529 ft^3/s and 97.4 ft^3/s, respectively (fig. 10, table 3). October was the most variable month, with the largest maximum streamflow of 4,025 ft^3/s in 1986 and smallest minimum streamflow of 0.02 ft^3/s in 2012 (USGS, 2016b).

Seasonally, spring (March–May) was the period of greatest streamflow with an average monthly mean streamflow of about 420 ft^3/s, and winter (December–February) was the period of least monthly mean streamflow with an average of about 122 ft^3/s (fig. 11, table 3). Monthly mean streamflow of summer (June–August) and fall (September–November) averaged about 218 ft^3/s and 171 ft^3/s, respectively. The fall and winter distributions of monthly mean streamflow were not significantly different from each other, whereas the spring and summer distributions of monthly mean streamflow were significantly different from each other and from the fall and winter seasons (fig. 11).

Annual mean streamflow varied from a maximum of 835 ft^3/s (water year 1987) to a minimum of 13.4 ft^3/s (water year 2014), with a mean for the regulated flow period of 233 ft^3/s (fig. 12, table 3). Annual mean base flow, or the portion of streamflow sourced from groundwater or the underlying aquifer and not from surface-water runoff from precipitation, ranged between 2.2 (water year 1971) and 33 percent (water year 2011) of the annual mean streamflow. Annual mean base flow as a percentage of annual mean streamflow was generally highest the year before a drought period, as seen in 1976 and 2010–11, prior to decreases in groundwater levels due to drought. Annual mean base flow as a percentage of annual mean streamflow appears to be trending upward from 1968 to 2015, but this trend is not statistically significant (τ=0.149, p=0.138).

Flow-duration statistics, derived from daily mean streamflow, indicate the percentage of time in which the streamflow was equaled or exceeded for the analysis period (table 4). For the Black Bear Creek at Pawnee, Okla., streamflow-gaging station during water years 1968–2015, 10 percent of daily mean streamflows were greater than or equal to 488 ft^3/s, and 90 percent of daily mean streamflows were greater than or equal to 1.6 ft^3/s.

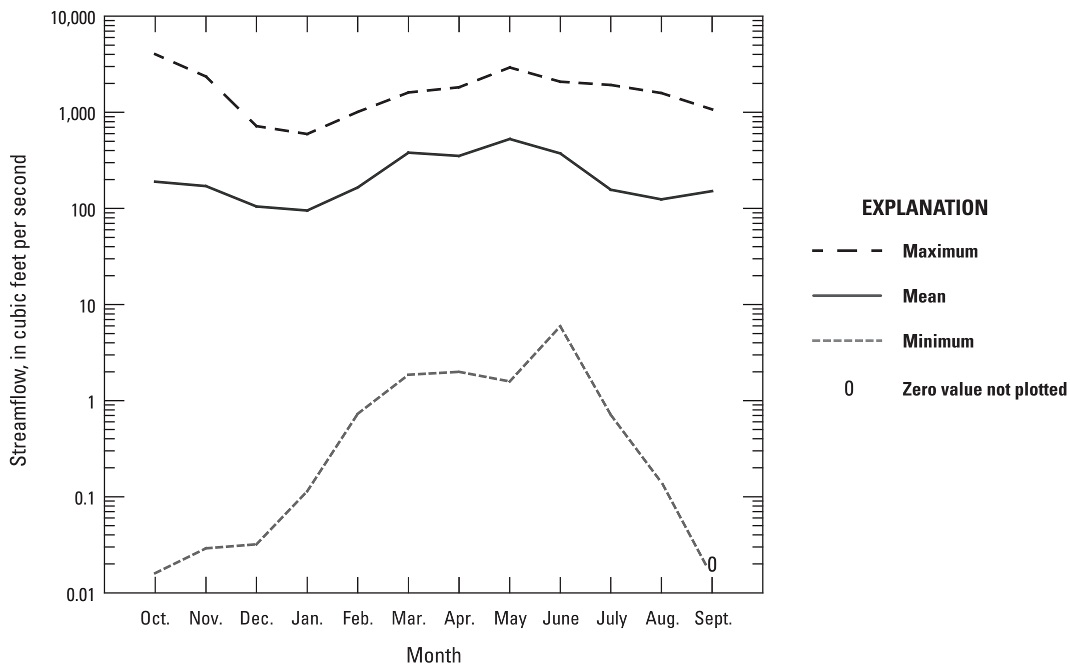

Figure 10. Monthly maximum, mean, and minimum streamflow at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000), water years 1968–2015 (U.S. Geological Survey, 2016b).

Table 3. Monthly and annual maximum, minimum, mean, and median streamflow at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000), calculated for the regulated streamflow period, water years 1968–2015 (U.S. Geological Survey, 2016b).

[ft^3/s, cubic foot per second]

Month	Maximum streamflow, in ft^3/s	Minimum streamflow, in ft^3/s	Mean streamflow, in ft^3/s	Median streamflow, in ft^3/s
October	4,025	0.02	192	28.9
November	2,359	0.03	175	33.6
December	720	0.03	107	24.4
January	595	0.11	97.4	25.8
February	1,013	1.95	169	52.1
March	1,607	1.88	387	147
April	1,821	2.00	353	176
May	2,933	1.59	529	328
June	2,082	5.96	379	176
July	1,927	0.71	159	48.0
August	1,592	0.14	127	21.1
September	1,076	0.00	155	37.6
Annual	835	13.4	233	178

Annual instantaneous peak streamflow at the Black Bear Creek at Pawnee, Okla., streamflow-gaging station ranged from 19,200 ft^3/s (water year 1987) to 717 ft^3/s (water year 2014) (fig. 13). Annual instantaneous peak streamflow increased from the late 1960s through the early 1990s and then decreased through 2015. Annual instantaneous peak streamflow did not increase or decrease significantly (τ=0.082, p=0.419) for water years 1968–2015.

Peak-flow frequency statistics provide recurrence intervals and exceedance probabilities for annual instantaneous peak streamflow. Based on annual instantaneous peak streamflow for water years 1968–2015 at the Black Bear Creek at Pawnee, Okla., streamflow-gaging station, the 50-year flood (2-percent exceedance probability), the 100-year flood (1-percent exceedance probability), and the 500-year flood (0.20-percent exceedance probability) are expected to have peak streamflows of 16,800, 18,800, and 23,200 ft^3/s, respectively (table 5). Based on the peak-flow frequency statistics, Black Bear Creek at Pawnee, Okla., exceeded flood stage at 17 ft (NWS, 2018a) approximately every 6 years (fig. 14).

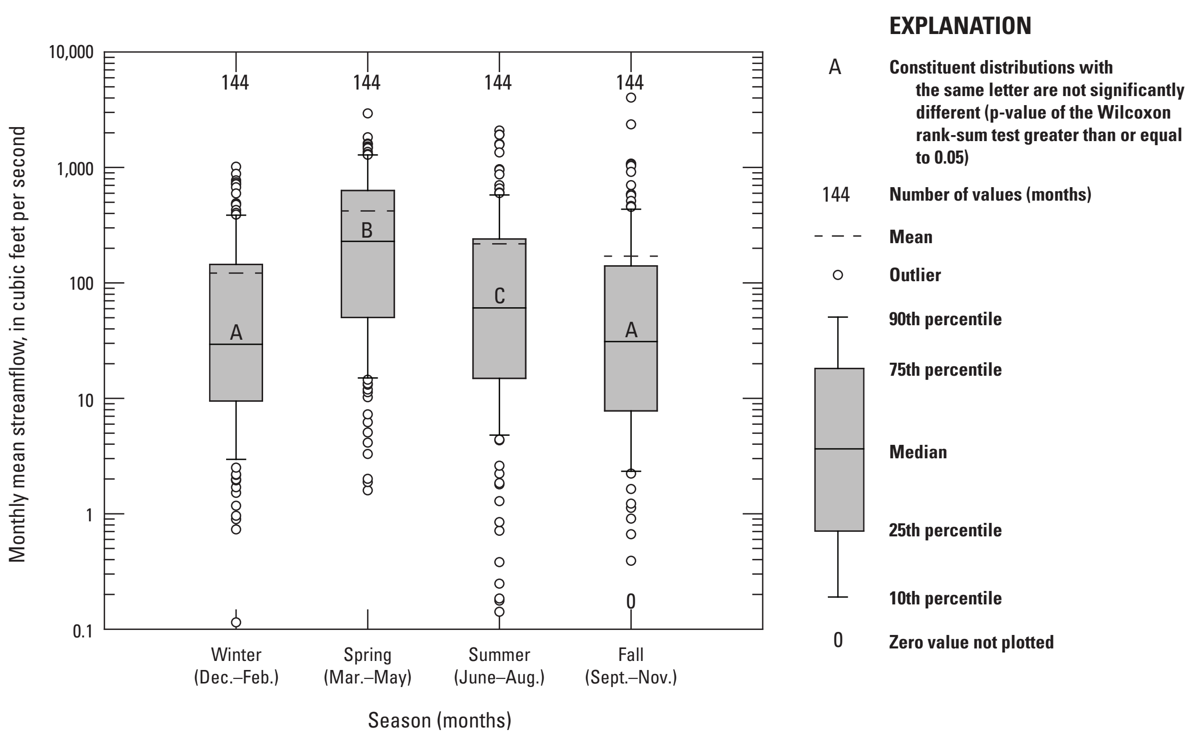

Figure 11. Seasonal distributions of monthly mean streamflow at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000), water years 1968–2015 (U.S. Geological Survey, 2016b).

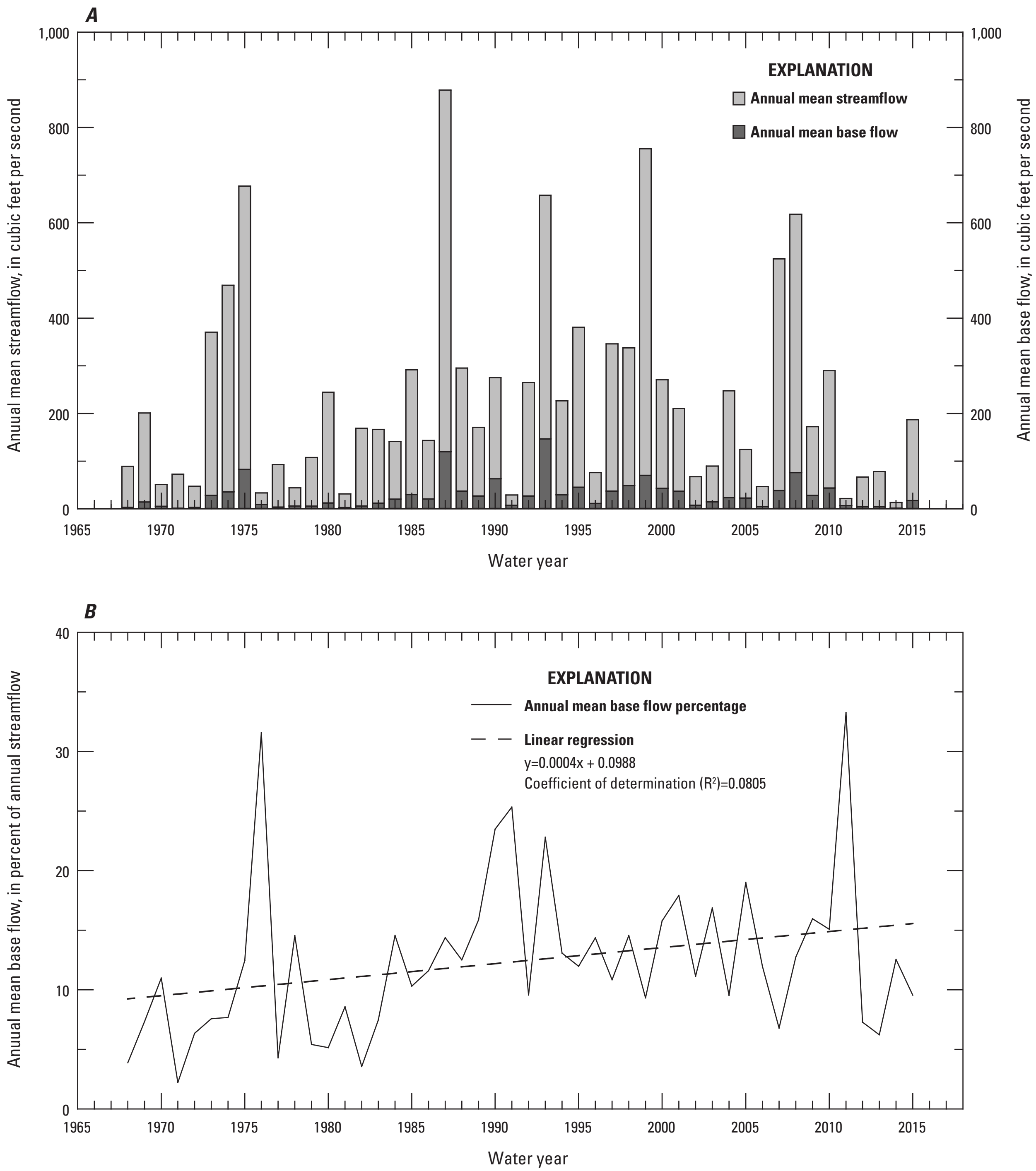

Figure 12. *A*, Annual mean streamflow and annual mean base flow and *B*, annual mean base flow as a percentage of annual mean streamflow at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000), water years 1968–2015 (U.S. Geological Survey, 2016b).

Table 4. Duration table of daily mean streamflow at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000), calculated for the regulated streamflow period, water years 1968–2015 (U.S. Geological Survey, 2016b).

[ft³/s, cubic foot per second; %, percent]

Streamflow, in ft³/s, which was equaled or exceeded for indicated percentage of time															
1%	2%	5%	10%	15%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	99%
3,790	2,540	1,190	488	261	158	68	35	21	14	8.3	4.4	1.6	0.44	0.03	0.00

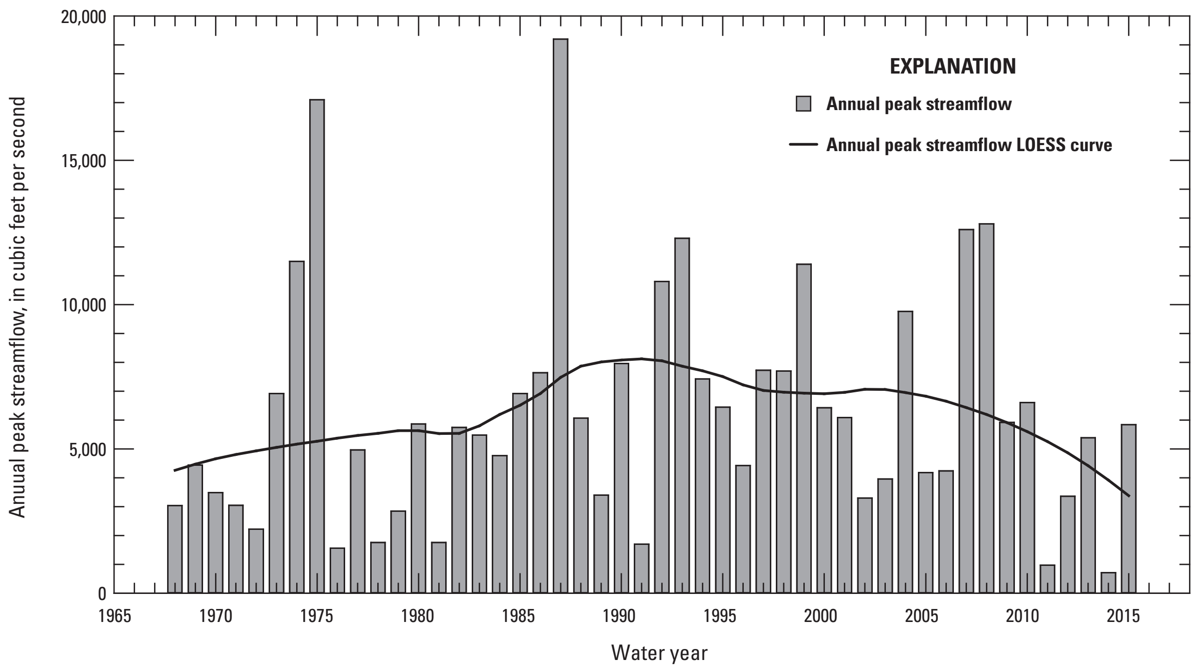

Figure 13. Annual peak streamflow at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000), water years 1968–2015 (U.S. Geological Survey, 2016b). Trends are shown by using locally weighted estimated scatterplot smoothing (LOESS) curves.

Table 5. Recurrence intervals and exceedance probabilities of annual instantaneous peak streamflow at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000), calculated for the regulated streamflow period, water years 1968–2015 (U.S. Geological Survey, 2016b).

[ft³/s, cubic foot per second; %, percent]

Streamflow, in ft³/s, for indicated recurrence interval, in years, and exceedance probability, in percent*							
2	5	10	25	50	100	200	500
50%	20%	10%	4%	2%	1%	0.50%	0.20%
5,440	9,180	11,700	14,700	16,800	18,800	20,800	23,200

*Station-record skew = −0.571.

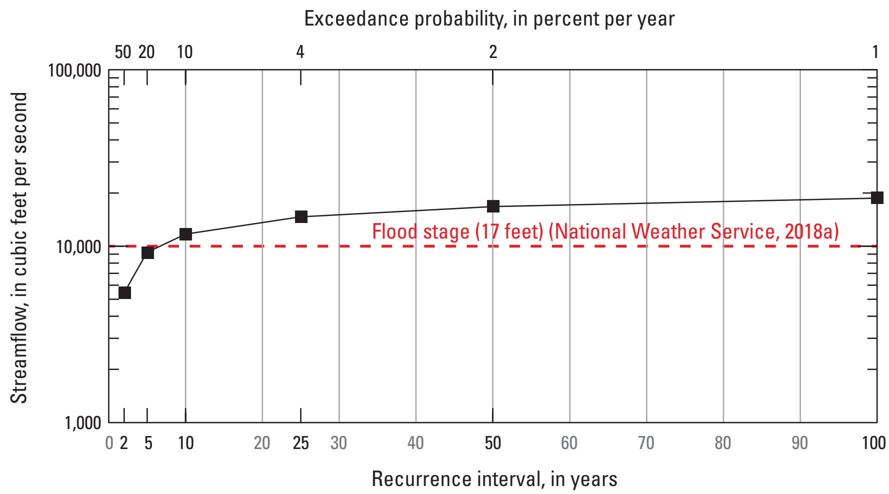

Figure 14. Flood recurrence intervals and exceedance probability at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000) calculated for the regulated streamflow period, water years 1968–2015.

Recurrence intervals and non-exceedance probabilities of low-flow streamflow were calculated from annual series of the lowest daily mean flows for 1-, 3-, 7-, 10-, 30-, and 60-day periods (table 6). For example, on the basis of the data for climate years 1969–2015 at the Black Bear Creek at Pawnee, Okla., streamflow-gaging station, every 20 years the streamflow can be expected to be 0.10 ft^3/s or less for a 60-day consecutive period. Normally the streamflow would increase with increasing period for each recurrence interval; for example, the streamflow for the 60-day period would be greater than the streamflow for the 30-day period. However, zero-flow days can cause anomalies in the calculations where streamflow does not increase with period for a given recurrence interval (Lewis and Esralew, 2009), as is the case for the 2-year recurrence interval with 1-day and 3-day period low flows of 0.93 and 0.82 ft^3/s, respectively (table 6).

Table 6. Recurrence intervals of low-flow streamflow by duration period at the Black Bear Creek at Pawnee, Oklahoma, streamflow-gaging station (station number 07153000), calculated for the regulated streamflow period, climate years 1969–2015 (U.S. Geological Survey, 2016b).

[ft^3/s, cubic foot per second; %, percent]

Period (consecutive days)	Streamflow, in ft^3/s, for indicated recurrence interval, in years, and nonexceedance probability, in percent			
	2	5	10	20
	50%	20%	10%	5%
1	0.93	0.00	0.00	0.00
3	0.82	0.01	0.00	0.00
7	1.19	0.07	0.00	0.00
10	1.51	0.13	0.01	0.00
30	3.79	0.58	0.12	0.01
60	8.10	1.28	0.35	0.10

Surface-Water Quality

Surface-water-quality data for 18 sites in the Black Bear Creek study area were summarized (fig. 15, table 7). Seven of the 18 sites were along Black Bear Creek itself, with the remaining sites on lakes or tributaries that discharge to Black Bear Creek in the study area. Many of the sites have relatively short periods of record (generally 1–2 years) with limited water-quality parameters measured. Data were collected by the USGS, the OWRB, the Oklahoma Conservation Commission, the Oklahoma Corporation Commission, and the Pawnee Nation Department of Environmental Conservation and Safety. The most extensive water-quality dataset was collected at the OWRB Black Bear Creek at Pawnee, Okla., BUMP station (OWRB station identifier 621200030010-001AT). The USGS also periodically collects water-quality data at this site, as well as water-property measurements at Pawnee Lake and Lone Chimney Lake. Boxplots of water properties for the sites along Black Bear Creek are presented in figure 16. Water properties were collected along Black Bear Creek and several tributaries as part of a water-quality monitoring program by the Pawnee Nation Department of Environmental Conservation and Safety (table 7).

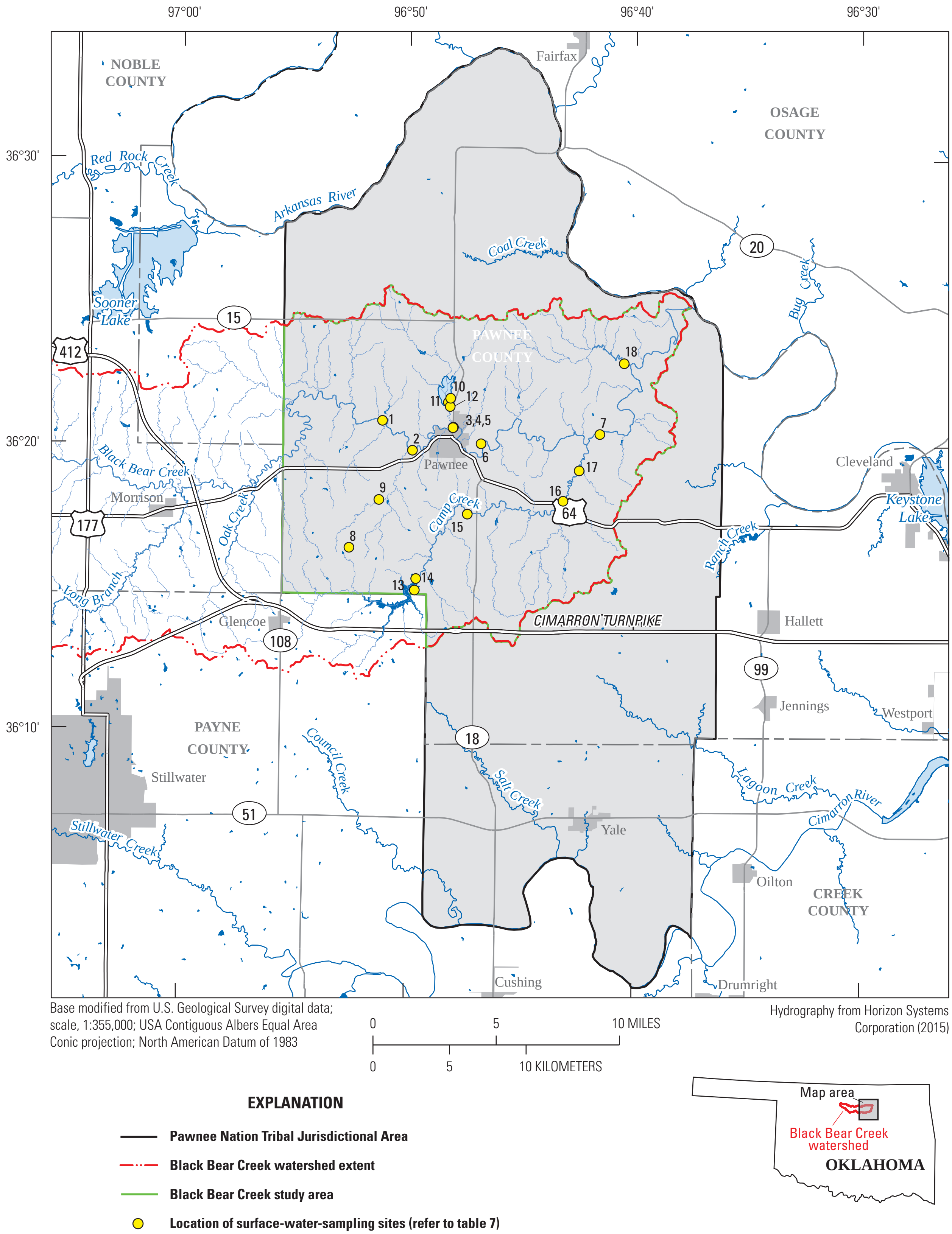

Figure 15. Locations of selected surface-water-quality sampling sites within the Black Bear Creek study area, Oklahoma.

Table 7. Names, locations, and water-property measurements of selected surface-water-quality sites sampled in the Black Bear Creek study area, Oklahoma, 1985 through 2015 (U.S. Geological Survey, 2016b; National Water Quality Monitoring Council, 2017; Oklahoma Water Resources Board, 2017a).

[Map numbers from fig. 15 for this report; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; --, not measured or calculated; the number of samples are in parentheses for water-property measurements]

Site (map) number (fig. 15)	Agency	Site name (station number or identifier, if available)	North decimal latitude	Decimal longitude	Median pH, in standard units	Median specific conductance, in µS/cm	Median total dissolved solids, in mg/L	Median dissolved oxygen, in mg/L
1	Oklahoma Conservation Commission	Black Bear Creek (CCA12-074)	36.347	−96.852	7.97 (2)	1,536 (2)	1,028 (1)	8.89 (2)
2	Oklahoma Conservation Commission	Black Bear Creek: Lower (OK621200-03-0010G)	36.330	−96.830	7.94 (14)	607 (15)	--	5.69 (15)
3	U.S. Geological Survey	Black Bear Creek at Pawnee, Okla. (07153000)	36.344	−96.799	7.90 (41)	1,015 (42)	618 (8)	7.45 (4)
4	Oklahoma Corporation Commission	Black Bear Creek (310810040030E)	36.343	−96.800	7.75 (9)	--	291 (7)	--
5	Oklahoma Water Resources Board	Black Bear Creek at Pawnee, Okla., BUMP (621200030010-001AT)	36.343	−96.800	7.96 (145)	732 (143)	475 (144)	8.17 (144)
6	Pawnee Nation Department of Environmental Conservation and Safety	Black Bear Creek	36.334	−96.779	8.06 (37)	725 (50)	--	8.48 (46)
7	Oklahoma Conservation Commission	Black Bear Creek: Lower (OK621200-03-0010D)	36.340	−96.692	7.99 (39)	670 (41)	326 (20)	8.38 (41)
8	Pawnee Nation Department of Environmental Conservation and Safety	Peters Creek	36.273	−96.876	8.25 (4)	271 (3)	--	6.05 (4)
9	Pawnee Nation Department of Environmental Conservation and Safety	Pepper Creek	36.301	−96.854	8.24 (10)	485 (10)	--	6.63 (10)
10	Pawnee Nation Department of Environmental Conservation and Safety	Pawnee Lake	36.361	−96.802	8.72 (17)	384 (17)	--	9.13 (17)
11	U.S. Geological Survey	Pawnee Lake at Dam (362129096481101)	36.358	−96.803	--	382 (6)	--	--
12	Pawnee Nation Department of Environmental Conservation and Safety	Black Bear Creek (OK621200030010) (coordinates locate north of Black Bear Creek)	36.356	−96.802	8.15 (7)	555 (8)	--	8.79 (11)
13	Pawnee Nation Department of Environmental Conservation and Safety	Lone Chimney Lake	36.248	−96.827	8.50 (17)	320 (17)	--	9.04 (17)
14	U.S. Geological Survey	Lone Chimney Lake at Dam (361518096493301)	36.255	−96.826	--	212 (6)	--	--
15	Oklahoma Conservation Commission	Camp Creek (CCA12-068)	36.293	−96.789	7.63 (2)	530 (2)	337 (1)	8.96 (19)
16	Oklahoma Conservation Commission	Camp Creek (OK621200-03-0040F)	36.301	−96.719	7.83 (19)	427 (21)	--	7.88 (22)
17	Pawnee Nation Department of Environmental Conservation and Safety	Camp Creek (OK621200030040)	36.319	−96.707	7.26 (8)	395 (8)	--	5.03 (8)
18	Pawnee Nation Department of Environmental Conservation and Safety	Crystal Creek	36.381	−96.674	7.27 (18)	389 (18)	--	6.85 (17)

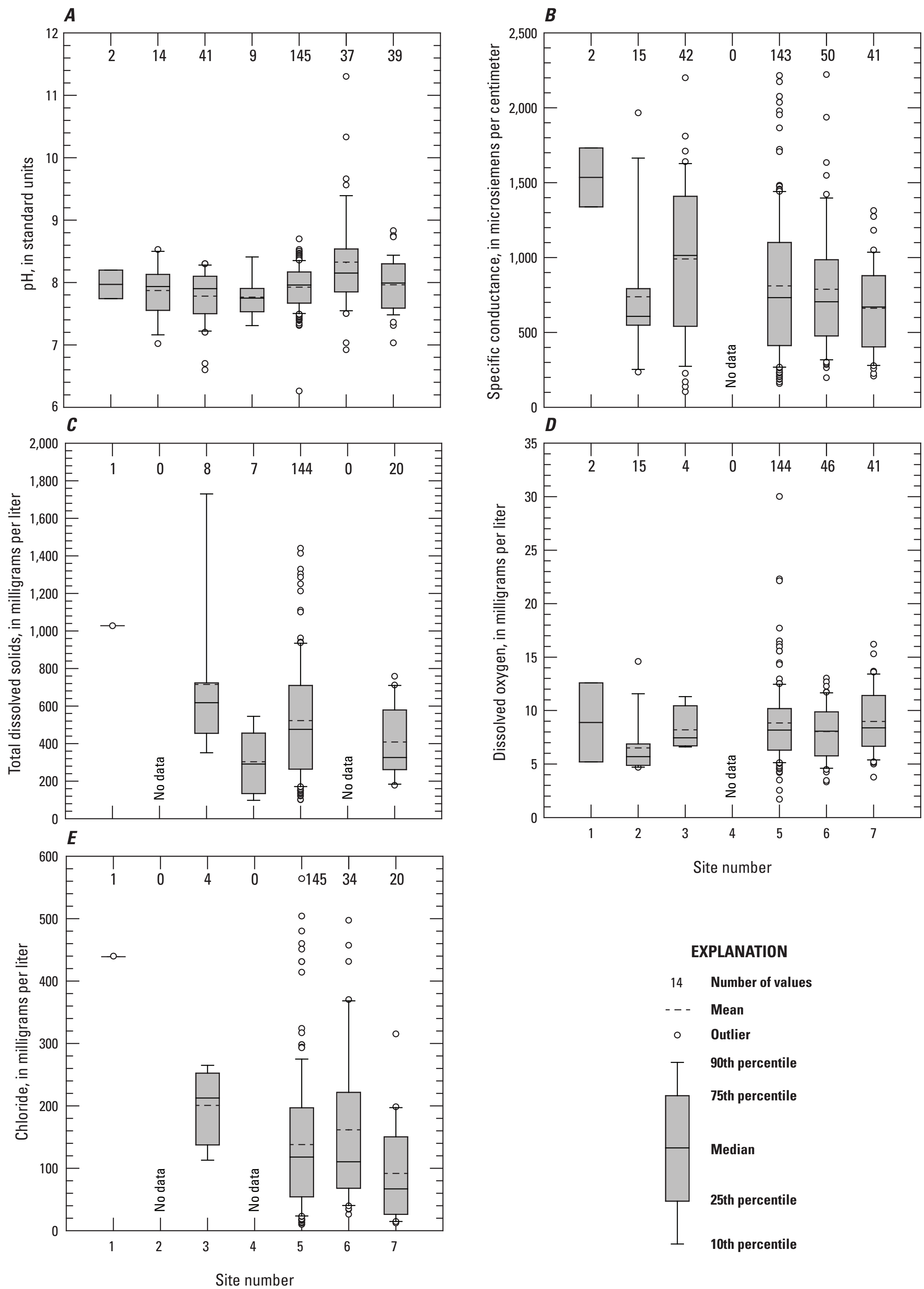

Figure 16. Distributions of *A*, pH, *B*, specific conductance, *C*, total dissolved solids, *D*, dissolved oxygen, and *E*, chloride concentration for seven sites along Black Bear Creek, north-central Oklahoma.

Surface-water samples in the Black Bear Creek study area were slightly basic, with a median pH per site ranging from 8.72 to 7.26 standard units (table 7). Flow across Pennsylvanian limestone units to the west is likely responsible for the slight basicity. High or low pH can affect the taste of drinking water and the viability of wildlife. One site, map number 10 (fig. 15, tables 6, 7), had a median pH value greater than the EPA secondary drinking-water standard of between 6.5 and 8.5, though no sites had median pH values greater than the EPA's National Recommended Aquatic Life Criteria (ALC) table of between 6.5 and 9.0 (EPA, 2018a; EPA 2018b). The median pH at site (map number) 10, Pawnee Lake, was 8.72 (n=17) and measured over pH 10 three times in late 2014 and early 2015: December 2014 (10.99), January 2015 (10.32), and April 2015 (10.01) (National Water Quality Monitoring Council, 2017). Values of pH greater than 10 are high for natural waters and are typically only seen in saline-alkaline lakes. The source of basicity to Pawnee Lake is not apparent. Values of pH above 11 have been associated with eye and skin irritation (World Health Organization [WHO], 1996).

Specific conductance (SC) is a measurement of the ability of water to conduct electricity and is tied to the concentration of total dissolved solids (TDS). TDS is typically composed of major ions and can be influenced by natural sources, such as the inflow of brackish groundwater (base flow) or flow over evaporites or carbonates, or anthropogenic sources, such as fertilizer runoff or leaks of oil-field-produced water. High SC and concentrations of TDS can result in poor water taste and inhibit growth of aquatic life (EPA, 2018a; EPA 2018b). Median SC measured along Black Bear Creek ranged between 607 and 1,536 microsiemens per centimeter (µS/cm) (fig. 16*B*, table 7), which is high for a natural stream but not unusual in northern Oklahoma. Median specific conductance measured in tributaries to Black Bear Creek in the study area were generally less than 500 µS/cm (table 7). Median TDS along Black Bear Creek ranged from 291 to 1,028 milligrams per liter (mg/L) but at sites across the study area were generally less than 500 mg/L (fig. 16*C*, table 7), which is the EPA secondary drinking-water standard for TDS (EPA, 2018a). Concentrations of chloride, one of the constituents accounted for in TDS, ranged between 10 and 564 mg/L along Black Bear Creek (fig. 16*E*). The median chloride concentration at the OWRB Black Bear Creek at Pawnee, Okla., BUMP station (site number 5) was 118 mg/L (fig. 16*E*), less than the EPA secondary drinking-water standard of 250 mg/L and the EPA ALC of 230 mg/L for chloride (EPA, 2018a; EPA, 2018b). Chloride concentrations negatively correlate with increased streamflow (Pearson's r=−0.266, p-value=0.001), indicating that chloride concentrations may be related to brackish groundwater discharging into streams or by point-source contamination rather than runoff processes (fig. 17*A*).

Nutrients, primarily compounds of nitrogen and phosphorus, can enter a waterway through natural processes or as a result of anthropogenic sources such as fertilizer runoff or wastewater discharge (Dubrovsky and others, 2010). These compounds are vital for aquatic plant growth, but large concentrations can lead to eutrophication of streams and lakes, reducing dissolved oxygen concentrations and leading to wildlife die off (Dubrovsky and others, 2010). The EPA has set total nitrogen and total phosphorus criteria for streams in Aggregate Nutrient Ecoregion V of 0.88 and 0.067 mg/L, respectively (EPA, 2001). Additionally, the State of Oklahoma has set a total phosphorus limit of 0.037 mg/L for Scenic River designation (State of Oklahoma, 2014). Total nitrogen concentration at the OWRB Black Bear Creek at Pawnee, Okla., BUMP station exceeded the EPA criterion of 0.88 mg/L in less than 10 percent of samples (n=37) (OWRB, 2017a). However, total phosphorus at the same site exceeded the EPA criterion of 0.067 mg/L in 91 percent of samples (n=145) and exceeded the State of Oklahoma Scenic River limit of 0.037 mg/L in 97 percent of samples (fig. 17*B*). Median total phosphorus at this site was 0.187 mg/L, nearly three times greater than the EPA criteria (OWRB, 2017a). Phosphorus concentrations are strongly correlated with increased streamflow (fig. 17*B*) (Pearson's r=0.542, p-value <0.001), indicating that phosphorus loading is likely attributable to surface-water runoff associated with precipitation.

Dissolved oxygen is necessary for respiration of aquatic life and can vary seasonally and diurnally with changes in photosynthetic production and temperature, or as a result of changes in surface-water contact with the atmosphere with changing flow and turbulence. Median dissolved oxygen concentrations at sites across the study area ranged from 5.03 to 9.13 mg/L, with minimum measured values greater than 3.4 mg/L for all sites (fig. 16*D*). All seven of the sites along Black Bear Creek had median dissolved oxygen concentrations greater than the minimum EPA cold water standard of 5.5 mg/L (fig. 16*D*, table 7) (EPA, 1986). Only one site in the study area, Camp Creek (Pawnee Nation Department of Environmental Conservation and Safety station identifier OK621200030040, map number 17), near the confluence with Black Bear Creek, had a median dissolved oxygen concentration (5.03 mg/L; table 7) less than the recommended concentrations, but this result could be due to the small sample size (n=8) being collected in just one water year (2007).

Trace-metals data were only available for samples collected at the OWRB Black Bear Creek at Pawnee, Okla., BUMP station (OWRB, 2017a). Of the metals listed as priority contaminants by the EPA ALC table (EPA, 2018b), cadmium (n=14), mercury (n=14), selenium (n=14), and silver (n=14) concentrations for all samples were below the laboratory reporting limit, and chromium (n=14), lead (n=22), nickel (n=14), and zinc (n=14) concentrations were reported for 4, 6, 3, and 11 samples, respectively. The reported values were below the EPA ALC chronic freshwater limits set for each contaminant, with the exception of lead (EPA, 2018b). Dissolved lead concentrations ranged from below the reporting limit to 5.3 µg/L and exceeded the EPA ALC chronic freshwater limit of 2.5 µg/L in four samples. All samples were below the EPA maximum contaminant level (MCL) of 15 µg/L for public water supply, however (EPA, 2018c).

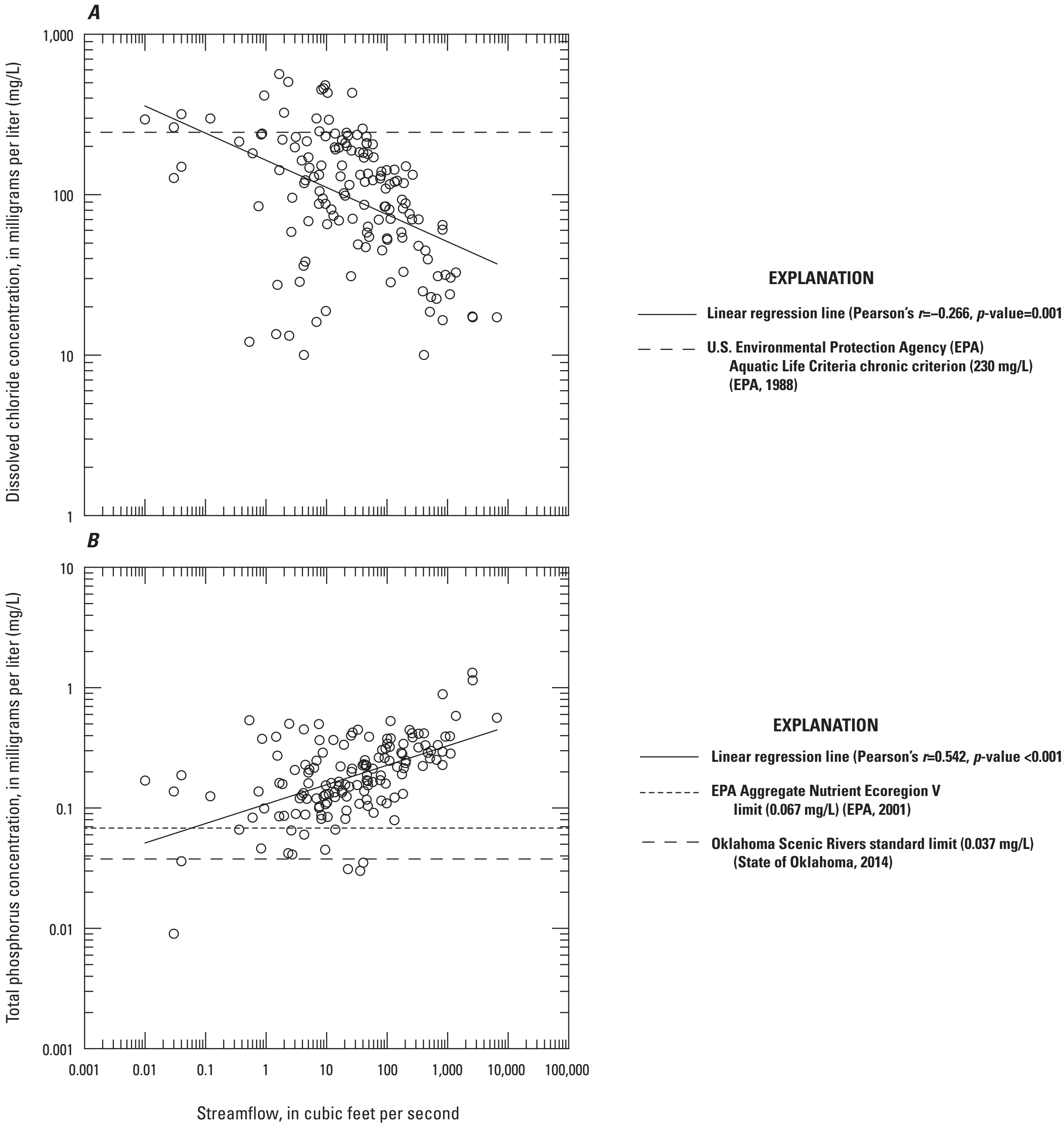

Figure 17. *A*, Concentrations of dissolved chloride and *B*, total phosphorus with streamflow collected at the Oklahoma Water Resources Board (OWRB) Black Bear Creek at Pawnee, Okla., Beneficial Use Monitoring Program (BUMP) station (OWRB station identifier 621200030010-001AT, map number 5 on fig. 15) on Black Bear Creek, Okla. (OWRB, 2018a).

Although most forms of *Escherichia coli* (*E. coli*) and enterococci bacteria are not inherently pathogenic, they can be indicators of potentially harmful bacterial contamination from animal feces. The EPA MCL for public water supply for all coliforms, including *E. coli*, is zero detected colonies per 100 milliliters (mL) (EPA, 2018c). The State of Oklahoma primary body contact recreation support limits for *E. coli* and enterococci are 126 and 33 colonies per 100 mL, respectively (State of Oklahoma, 2014). Based on 36 samples collected from May through September of 2001–15, the median numbers of colonies per 100 mL at the OWRB Black Bear Creek at Pawnee, Okla., BUMP station for *E. coli* and enterococci were 66 and 287, respectively (OWRB, 2017a). Because of the high levels of enterococci bacteria, drinking from or bathing in Black Bear Creek during summer could pose a health risk.

Groundwater Availability and Quality

Groundwater-availability and -quality data for the Black Bear Creek study area are sparse. Groundwater levels or water-quality data were identified for 28 wells (fig. 18). Groundwater levels were measured at 10 wells in the study area in 1972, and the OWRB recently established a groundwater monitoring site near the confluence of Black Bear Creek and the Arkansas River. The only water-quality data found were from the Oklahoma Department of Agriculture, Food and Forestry (ODAFF), which sampled an irrigation well periodically in the early 2000s for a small suite of herbicides. Because of the extremely limited amount of data available, a field campaign was conducted that measured groundwater levels at 16 additional wells and sampled 8 wells for a suite of inorganic constituents. Historical data and the results from the field campaign conducted for this report are described in this section.

Groundwater Availability

Important hydrogeologic formations of the Pawnee Nation Tribal Jurisdictional Area include the Quaternary-age alluvium and terrace deposits (including the Arkansas River alluvial aquifer), the minor bedrock aquifers of the Oscar and Vanoss Groups, and the Ada Group of the Ada-Vamoosa aquifer.

Quaternary-age alluvium and terrace deposits are composed of unconsolidated silt, sand, and gravel and cover approximately 20 percent of the Pawnee Nation Tribal Jurisdictional Area and approximately 15 percent of the Black Bear Creek study area (table 8). Alluvium are sediments that are actively moving in a stream valley. In the jurisdictional area, alluvium adjoins rivers and streams and occurs mainly along the Arkansas River, Cimarron River, Salt Creek, and Black Bear Creek (fig. 18). Terrace deposits are located adjacent to alluvium at higher elevations and represent alluvium deposited during floods or other periods of high water. Terrace deposits occur along the Arkansas River and Cimarron River, though a small section occurs along the western edge of the jurisdictional area along Black Bear Creek (fig. 7). Thicknesses of alluvial deposits along the Arkansas River and Cimarron River vary between 15 and 60 ft, and wells completed in these deposits can produce between 50 and 600 gallons per minute (gal/min), depending on the thickness of the saturated basal sand and gravel zone (Bingham and Bergman, 1980).

The Oscar and Vanoss Groups underlie the majority of Pawnee Nation Tribal Jurisdictional Area and almost 85 percent of the Black Bear Creek study area (fig. 7, table 8). These units serve as minor bedrock aquifers and generally produce less than 25 gal/min (Bingham and Bergman, 1980).

The Ada Group along the eastern border of the Pawnee Nation Tribal Jurisdictional Area (fig. 18) is part of the sandstone Ada-Vamoosa aquifer. The Ada Group surficial exposure is approximately 7 percent of the jurisdictional area (table 8) and is only accessible along the extreme eastern border of the jurisdictional area. The Ada Group generally yields between 25 and 35 gal/min (Bingham and Bergman, 1980); however, brine contamination of the aquifer from historical oil-field development is an issue in some localities (Runkle and others, 2000). Though the Ada Group underlies the Oscar and Vanoss Groups in central and western areas of the jurisdictional area, the increasing depth and salinity with western downdip make the formation unsuitable as a source of freshwater in most of the jurisdictional area and the Black Bear Creek study area (Urban Planners, 1968).

Historical groundwater-level measurements for the area are limited. Only 10 wells in the study area were identified in the USGS NWIS database; all were measured on one occasion in 1972 (USGS, 2018b) (fig. 18, table 9). Because of the limited amount of data, a field campaign to identify additional wells was conducted for this study. Sixteen additional wells were identified, and groundwater levels were measured at each well during 2017 (fig. 18, table 9). Most of the wells in the database and those that were measured for this study were completed in the minor bedrock aquifers associated with the Oscar and Vanoss Groups. One well, map number 4, is completed in terrace deposits along Black Bear Creek, and three wells, map numbers 14, 15, and 16, are completed in the Arkansas River alluvial aquifer (fig. 18, table 9).

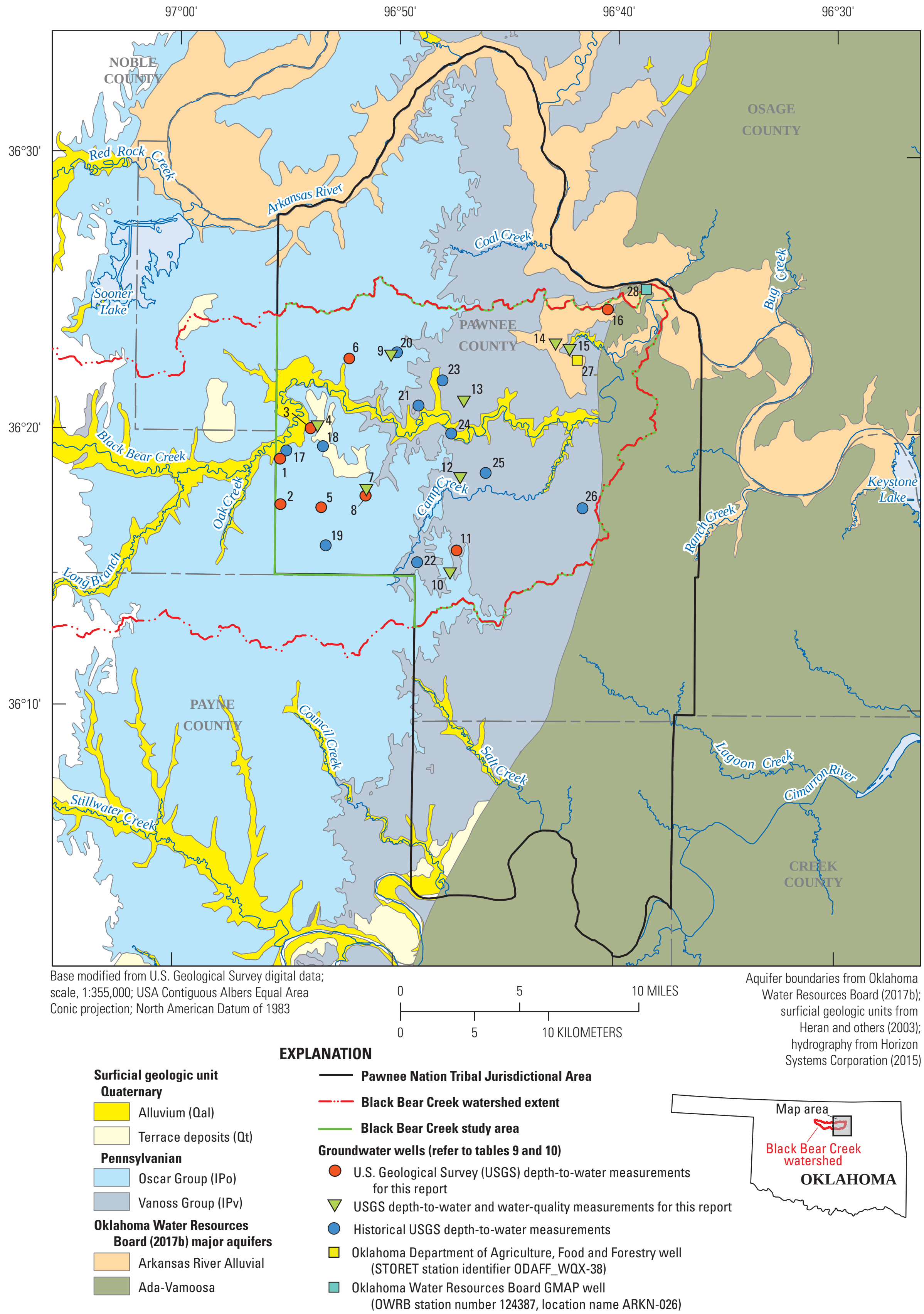

Figure 18. Locations of wells with groundwater-level and water-quality measurements in the Black Bear Creek study area, Oklahoma.

Table 8. Coverage of surficial geologic units as a percent of the Pawnee Nation Tribal Jurisdictional Area and the Black Bear Creek study area, Oklahoma.

[PNTJA, Pawnee Nation Tribal Jurisdictional Area; BBCSA, Black Bear Creek study area; area may not sum to 100 percent because of rounding]

Geologic formation	Area, in percent	
	PNTJA	BBCSA
Alluvium	9.71	9.51
Terrace deposits	9.49	5.58
Oscar Group	23.8	36.1
Vanoss Group	50.0	48.8
Ada Group	6.89	0.00
Vamoosa Formation	0.03	0.00

Although coverage of the study area with individual groundwater-level measurements is important, a long-term record of groundwater levels at the same well can be a valuable indicator of changes within the groundwater system. No such site existed in the study area until 2014, when the OWRB established a monitoring site near the confluence of Black Bear Creek and the Arkansas River as part of the GMAP (fig. 18). The site (OWRB station number 124387, location name ARKN-026, map number 28) is a shallow irrigation well in the Arkansas River alluvial aquifer with a total depth of 31.5 ft (fig. 18). Three water-level measurements are available through the end of 2015: 22.57 ft (7/28/2014), 23.44 ft (9/22/2014), and 23.75 ft (1/8/2015) (OWRB, 2018a) below land surface. Though little data are available for this site now, continued data collection at this site could serve as an important indicator of water-level trends in the aquifer.

Groundwater Quality

Groundwater-quality data for the study area also are extremely limited. A search of both the USGS NWIS and EPA STORET databases yielded water-quality data from just one well in the Black Bear Creek study area. The ODAFF collected samples from a well near the center of the study area (fig. 18, table 10, STORET station identifier ODAFF_WQX-38, map number 27) and analyzed for a suite of four herbicides on 19 occasions between 2000 and 2009. Atrazine, alachlor, simazine, and metolachlor were below detection levels in all samples. Water-quality data also were collected by the OWRB as part of GMAP (fig. 18, table 10, OWRB station number 124387, map number 28), though data were only available for 1 year during the study period. Because of the limited amount of groundwater-quality data in the study area, a field collection of water samples was conducted. Eight wells were sampled during 2018, and water properties, major ions, and nutrients were measured (figs. 18–19, table 10).

Groundwater pH in samples collected in the study area was about neutral, varying from 6.3 to 7.6 standard units, with a mean pH of all sampled wells of 6.9 standard units (table 10). Only one sample did not meet the EPA secondary drinking-water standard for pH of between 6.5 and 8.5 standard units. That groundwater sample had a pH value of 6.3 standard units. Water with a pH less than 6.5 can have a bitter taste and can cause corrosion of metal pipes (EPA, 2018a).

The mean concentration of TDS for sampled wells was 446 mg/L, which is less than the EPA's secondary drinking-water standard of 500 mg/L. Approximately 33 percent of samples had concentrations of TDS exceeding 500 mg/L, however. Water with a concentration of TDS greater than 500 mg/L can taste salty and cause deposits and stains to form on plumbing fixtures (EPA, 2018a).

Concentrations of individual major ions are presented in table 10. Groundwater in the study area is dominated primarily by bicarbonate (table 10), likely from the dissolution of carbonate rocks in the area. Stiff diagrams (Stiff, 1951) are visual representations of major-ion concentrations and show that the dominant water type in most of the Black Bear Creek study area is calcium bicarbonate followed by sodium bicarbonate (fig. 19). Calcium and magnesium ions in water contribute to the measure of water hardness. Hard water can contribute to scale buildup in pipes, eventually reducing flow and potentially causing failure of appliances like water heaters (EPA, 2018a). Water across the area was generally hard (defined as between 121 and 180 mg/L) to very hard (defined as greater than 180 mg/L), with an average of 223 mg/L as calcium carbonate (EPA, 2018a). For all samples, concentrations of major anions including chloride, fluoride, and sulfate were less than the EPA secondary drinking-water standards of 250, 2, and 250 mg/L, respectively (EPA, 2018a).

Nutrients applied at the land surface, mainly for agricultural purposes or due to sewage leakage, can infiltrate groundwater basins and contaminate sources of drinking water. For the two common, nitrogen-derived nutrients, nitrate and nitrite, the EPA has set the MCLs for nitrate at 10 mg/L and nitrite at 1 mg/L (EPA, 2018c). Long-term exposure to water containing concentrations of these compounds above these MCLs in infants under 6 months old can lead to methemoglobinemia, or blue-baby syndrome (EPA, 2018c). Ingestion of nitrate is also "probably carcinogenic to humans" according to the WHO International Agency for Research on Cancer (WHO, 2010). The sum of nitrate plus nitrite, in milligrams per liter as nitrogen, is presented in table 10 for the sampled wells. Concentrations measured in the collected groundwater samples ranged from below the detection limit of 0.04 mg/L to 42.4 mg/L, and three samples had nitrate plus nitrite concentrations greater than 10 mg/L. The water sample taken from USGS station number 362003096533801 (map number 4, fig. 18, table 10) had a nitrate plus nitrite concentration of more than four times the EPA MCL. This well was unused, and the source of contamination is unknown.

Table 9. Names, locations, and water-level measurements of groundwater wells in the Black Bear Creek study area, Oklahoma, 1972 through 2017 (National Water Quality Monitoring Council, 2017; Oklahoma Water Resources Board, 2018a; U.S. Geological Survey, 2018b).

[Map numbers from fig. 18 for this report; altitudes are in feet above North American Vertical Datum of 1988 (NAVD 88); ft, foot; LSD, land-surface datum; >, greater than; --, data not available; USGS, U.S. Geological Survey; ODAFF, Oklahoma Department of Agriculture, Food and Forestry; OWRB, Oklahoma Water Resources Board]

Map number (fig. 18)	Agency	Station number or identifier	North decimal latitude	Decimal longitude	Well depth, in ft	Altitude of land surface, in ft above NAVD 88	Water level referenced to vertical datum, in ft above NAVD 88	Water level below LSD, in ft	Water-level measure-ment date	Completion unit
1	USGS	361856096551801	36.3157	−96.9218	80	930	909	21	6/14/2017	Oscar Group
2	USGS	361718096551701	36.2882	−96.9213	350	951	934	17	6/14/2017	Oscar Group
3	USGS	362004096535601	36.3344	−96.8989	127	899	871	28	12/7/2017	Oscar Group
4	USGS	362003096533801	36.3341	−96.8938	44.22	922	899	23	12/7/2017	Alluvium
5	USGS	361712096532501	36.2866	−96.8902	>150	1,023	926	97	6/28/2017	Oscar Group
6	USGS	362235096521101	36.3764	−96.8698	140	912	885	27	6/28/2017	Vanoss Group
7	USGS	361748096512201	36.2966	−96.8561	130	948	903	45	12/6/2017	Vanoss Group
8	USGS	361738096512501	36.2940	−96.8569	130	947	907	40	12/6/2017	Vanoss Group
9	USGS	362242096501801	36.3783	−96.8384	110	1,006	993	13	6/28/2017	Vanoss Group
10	USGS	361446096473201	36.2462	−96.7921	130	1,062	1008	54	6/14/2017	Vanoss Group
11	USGS	361540096471401	36.2612	−96.7873	80	1,001	987	14	6/14/2017	Vanoss Group
12	USGS	361814096470601	36.3038	−96.7851	185	954	854	100	12/6/2017	Vanoss Group
13	USGS	362101096465701	36.3502	−96.7826	67	861	829	32	6/23/2017	Vanoss Group
14	USGS	362306096424901	36.3850	−96.7136	32.52	846	823	23	12/7/2017	Alluvium
15	USGS	362258096421101	36.3827	−96.7031	26.53	822	805	17	12/7/2017	Alluvium
16	USGS	362426096402601	36.4071	−96.6740	76	935	918	17	6/23/2017	Alluvium
17	USGS	361915096550001	36.3208	−96.9170	192	913	761	152	3/21/1972	Oscar Group
18	USGS	361925096532001	36.3236	−96.8892	118	922	912	10	3/21/1972	Oscar Group
19	USGS	361550096531001	36.2639	−96.8864	59	1,042	1,023	19	5/1/1972	Oscar Group
20	USGS	362250096500001	36.3806	−96.8336	125	1,013	995	18	5/23/1972	Oscar Group
21	USGS	362055096490001	36.3486	−96.8170	115	879	863	16	3/21/1972	Vanoss Group
22	USGS	361515096490001	36.2543	−96.8170	120	914	809	105	3/21/1972	Vanoss Group
23	USGS	362150096475501	36.3639	−96.7989	202	924	844	80	3/21/1972	Vanoss Group
24	USGS	361955096473001	36.3319	−96.7920	65	817	784	33	3/1/1972	Vanoss Group
25	USGS	361830096455501	36.3084	−96.7656	150	918	907	11	3/21/1972	Vanoss Group
26	USGS	361715096413001	36.2875	−96.6917	68	935	875	60	5/1/1972	Vanoss Group
27	ODAFF	ODAFF_WQX-38	36.3770	−96.6992	--	838	--	--	--	--
28	OWRB	124387	36.4198	−96.6447	35	784	761	23	7/28/2014	Alluvium
							761	23	9/22/2014	
							760	24	1/8/2015	

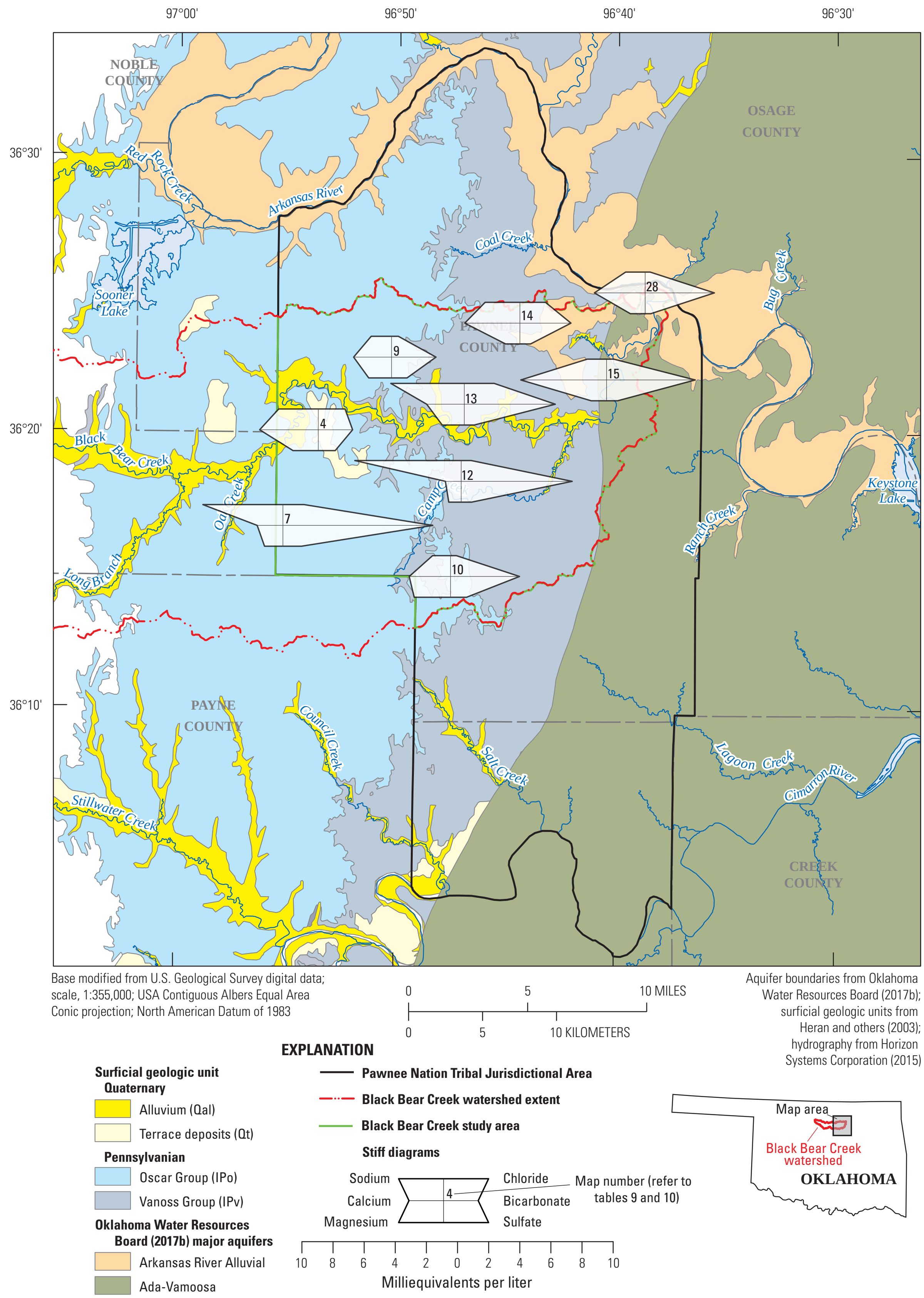

Figure 19. Major-ion chemistry in groundwater collected from wells in the Black Bear Creek study area, Oklahoma, 2014 through 2018.

Table 10. Water-property measurements and concentrations of major ions and nutrients measured in groundwater samples collected from wells in the Black Bear Creek study area, Oklahoma, 2014 through 2018 (National Water Quality Monitoring Council, 2017; Oklahoma Water Resources Board, 2018a; U.S. Geological Survey, 2018b).

[Map numbers from fig. 18 for this report; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; $CaCO_3$, calcium carbonate; SiO_2, silicone dioxide; N, nitrogen; P, phosphorus; USGS, U.S. Geological Survey; REP, replicate sample; ODAFF, Oklahoma Department of Agriculture, Food and Forestry; OWRB, Oklahoma Water Resources Board; --, not measured or calculated; <, less than; BLANK, blank sample]

Map number (fig. 18)	Agency	Station number or identifier	Sample date	pH, in standard units	Specific conductance, in µS/cm	Total dissolved solids, in mg/L	Hardness, in mg/L as $CaCO_3$	Calcium, in mg/L	Magnesium, in mg/L	Potassium, in mg/L	Sodium, in mg/L	Alkalinity, in mg/L as $CaCO_3$
1	USGS	361856096551801	--	--	--	--	--	--	--	--	--	--
2	USGS	361718096551701	--	--	--	--	--	--	--	--	--	--
3	USGS	362004096535601	--	--	--	--	--	--	--	--	--	--
4	USGS	362003096533801	5/11/2018	6.7	879	564	284	79.4	20.7	1.63	61.5	116
5	USGS	361712096532501	--	--	--	--	--	--	--	--	--	--
6	USGS	362235096521101	--	--	--	--	--	--	--	--	--	--
7	USGS	361748096512201*	4/27/2018	7.0	1,150	616	149	34.9	15.1	8.65	125	508
8	USGS	361738096512501	--	--	--	--	--	--	--	--	--	--
9	USGS	362242096501801	5/11/2018	6.6	526	332	206	51.4	18.8	1.11	31.6	151
10	USGS	361446096473201	3/28/2018	7.0	578	340	261	55.8	29.5	0.66	27.6	234
REP	USGS	361446096473201	3/28/2018	--	--	--	263	56.1	29.9	0.70	27.9	234
11	USGS	361540096471401	--	--	--	--	--	--	--	--	--	--
12	USGS	361814096470601	3/29/2018	7.6	821	501	95	21.4	10.2	1.67	165	376
13	USGS	362101096465701	3/30/2018	7.2	854	498	202	50.9	18.1	2.09	114	308
14	USGS	362306096424901	3/15/2018	6.3	676	424	235	74.8	11.8	0.73	54.1	173
15	USGS	362258096421101	5/22/2018	6.8	721	448	343	116.3	12.7	0.20	30.0	300
16	USGS	362426096402601	--	--	--	--	--	--	--	--	--	--
17	USGS	361915096550001	--	--	--	--	--	--	--	--	--	--
18	USGS	361925096532001	--	--	--	--	--	--	--	--	--	--
19	USGS	361550096531001	--	--	--	--	--	--	--	--	--	--
20	USGS	362250096500001	--	--	--	--	--	--	--	--	--	--
21	USGS	362055096490001	--	--	--	--	--	--	--	--	--	--
22	USGS	361515096490001	--	--	--	--	--	--	--	--	--	--
23	USGS	362150096475501	--	--	--	--	--	--	--	--	--	--
24	USGS	361955096473001	--	--	--	--	--	--	--	--	--	--
25	USGS	361830096455501	--	--	--	--	--	--	--	--	--	--
26	USGS	361715096413001	--	--	--	--	--	--	--	--	--	--
27	ODAFF	ODAFF_WQX-38	--	--	--	--	--	--	--	--	--	--
28	OWRB	124387	9/23/2014	6.9	479	295	193	57.7	10.1	0.5	25.5	195
BLANK	USGS	353000097300001	3/29/2018	--	--	--	<0.1	<0.022	<0.011	<0.1	<0.1	--
		Mean excluding BLANK		6.9	743	446	223	59.9	17.7	1.8	66.2	259.4

Table 10. Water-property measurements and concentrations of major ions and nutrients measured in groundwater samples collected from wells in the Black Bear Creek study area, Oklahoma, 2014 through 2018 (National Water Quality Monitoring Council, 2017; Oklahoma Water Resources Board, 2018a; U.S. Geological Survey, 2018b).—Continued

[Map numbers from fig. 18 for this report; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; $CaCO_3$, calcium carbonate; SiO_2, silicone dioxide; N, nitrogen; P, phosphorus; USGS, U.S. Geological Survey; REP, replicate sample; ODAFF, Oklahoma Department of Agriculture, Food and Forestry; OWRB, Oklahoma Water Resources Board; --, not measured or calculated; <, less than; BLANK, blank sample]

Map number (fig. 18)	Agency	Station number or identifier	Sample date	Bicar-bonate, in mg/L	Bromide, in mg/L	Carbonate, in mg/L	Chloride, in mg/L	Fluoride, in mg/L	Silica, in mg/L as SiO_2	Sulfate, in mg/L	Nitrate plus nitrite, in mg/L as N	Orthophosphate, in mg/L as P
1	USGS	361856096551801	--	--	--	--	--	--	--	--	--	--
2	USGS	361718096551701	--	--	--	--	--	--	--	--	--	--
3	USGS	362004096535601	--	--	--	--	--	--	--	--	--	--
4	USGS	362003096533801	5/11/2018	142	0.391	0	64.4	0.20	23.4	55.2	42.4	0.07
5	USGS	361712096532501	--	--	--	--	--	--	--	--	--	--
6	USGS	362235096521101	--	--	--	--	--	--	--	--	--	--
7	USGS	361748096512201*	4/27/2018	618	0.276	0.3	50.9	0.55	16.6	60.2	--	--
8	USGS	361738096512501	--	--	--	--	--	--	--	--	--	--
9	USGS	362242096501801	5/11/2018	184	0.233	0	16.4	0.50	18.3	50.4	11.9	0.086
10	USGS	361446096473201	3/28/2018	285	0.192	0.1	13.9	0.25	13.4	52.0	1.15	0.005
REP	USGS	361446096473201	3/28/2018	284.6	0.164	0.1	11.2	0.25	13.8	43.1	1.12	0.005
11	USGS	361540096471401	--	--	--	--	--	--	--	--	--	--
12	USGS	361814096470601	3/29/2018	458	0.094	0.3	23.9	0.24	17.6	33.7	0.14	0.017
13	USGS	362101096465701	3/30/2018	376	0.306	0.2	71.7	0.27	22.6	32.2	<0.04	0.008
14	USGS	362306096424901	3/15/2018	211	0.390	0	61.3	0.22	27.7	34.5	12.3	0.135
15	USGS	362258096421101	5/22/2018	366	0.107	0.1	17.4	0.16	22.6	36.0	7.2	0.034
16	USGS	362426096402601	--	--	--	--	--	--	--	--	--	--
17	USGS	361915096550001	--	--	--	--	--	--	--	--	--	--
18	USGS	361925096532001	--	--	--	--	--	--	--	--	--	--
19	USGS	361550096531001	--	--	--	--	--	--	--	--	--	--
20	USGS	362250096500001	--	--	--	--	--	--	--	--	--	--
21	USGS	362055096490001	--	--	--	--	--	--	--	--	--	--
22	USGS	361515096490001	--	--	--	--	--	--	--	--	--	--
23	USGS	362150096475501	--	--	--	--	--	--	--	--	--	--
24	USGS	361955096473001	--	--	--	--	--	--	--	--	--	--
25	USGS	361830096455501	--	--	--	--	--	--	--	--	--	--
26	USGS	361715096413001	--	--	--	--	--	--	--	--	--	--
27	ODAFF	ODAFF_WQX-38	--	--	--	--	--	--	--	--	--	--
28	OWRB	124387	9/23/2014	240	0.251	<6	<10	0.25	24.3	15.4	7.65	0.061
BLANK	USGS	353000097300001	3/29/2018	--	<0.01	--	<0.02	<0.01	<0.018	<0.02	<0.04	<0.004
		Mean excluding BLANK		316.5	0.2	0.1	36.8	0.3	20.0	41.3	10.5	0.0

*Due to suspected well contamination, water-quality results from this sample are considered estimated.

Phosphate nutrients ingested via drinking water are not generally considered a health risk. In fact, phosphates are added to some public water systems to inhibit heavy-metal leaching from pipes and fixtures into drinking water. Orthophosphate concentrations, in milligrams per liter as phosphorus, measured in the collected groundwater samples ranged from 0.005 to 0.135 mg/L (table 10). Wells yielding water from alluvial aquifers, including USGS station numbers 362306096424901 and 362258096421101 (map numbers 14 and 15) and OWRB station number 124387 (map number 28), had relatively high orthophosphate concentrations. These wells are relatively shallow at less than or equal to 35 ft (table 9), so contamination from surficial sources of phosphorus is possible.

Trace-metals data were only available for the well sampled by the OWRB (OWRB station number 124387, map number 28) near the northeastern edge of the Black Bear Creek study area (fig. 18). Metals with established EPA MCL drinking-water standards, including antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, and selenium, were measured at concentrations either below detection limit or below the recommended MCL for the only sample within the study area (EPA, 2018c; OWRB, 2018a). Thallium concentrations were not available. Concentrations of metals included on the EPA secondary drinking-water standard list, including aluminum, iron, manganese, silver, and zinc, were either below detection or less than the recommended MCL (EPA, 2018a; OWRB, 2018a).

Generally, groundwater in this area contains slightly elevated concentrations of TDS and is considered to be hard to very hard. Localized contamination of nutrients is probably due to surface-water infiltration into shallow groundwater sources. The limited number of samples makes it difficult to statistically correlate water properties and concentrations of major ions and nutrients with factors such as well depth and completion unit. In general, however, water sampled from deeper wells had less nutrient contamination but also had higher concentrations of chloride, possibly due to proximity to deeper saline groundwater sources.

Identification of Data Gaps

Hydrologic, water-quality, and water-use data for the Black Bear Creek study area are sparse. Though a few datasets of discrete measurements are available, there is a lack of long-term monitoring stations to help determine trends of surface-water quality, groundwater quality, and groundwater levels across the area. Based on the available data, the following data gaps were identified for the Black Bear Creek study area:

1. There is a lack of streamflow-gaging stations. As the only measurement of streamflow in the study area, it is vital to continue data collection at the Black Bear Creek streamflow-gaging station. Additional streamflow-gaging stations where Black Bear Creek enters the jurisdictional area and near the confluence with the Arkansas River could provide a comprehensive measurement of streamflow changes (long-term trends in availability and streamflow losses or gains) in the Black Bear Creek study area.

2. There is a lack of surface-water-quality data collected at long-term monitoring sites. Though the USGS and OWRB conduct discrete water-quality monitoring at the Black Bear Creek streamflow-gaging station, continuous monitoring of water-quality parameters and constituents such as chloride, nitrate, and phosphorus could provide valuable data for future trend analysis and help identify possible contamination events. Recently, the Pawnee Nation has started collecting water-quality parameters at surface-water sites along Black Bear Creek and tributaries. Continuing to monitor water-quality parameters at these sites, along with sampling for major ions, nutrients, and bacteria on a reoccurring basis, could allow for a better understanding of surface-water-quality trends across the Black Bear Creek study area.

3. There is a lack of recent groundwater-level measurements at long-term monitoring sites. Establishing a set of sites across the jurisdictional area to measure groundwater levels on at least an annual basis under similar hydrologic conditions, such as during the winter months when groundwater levels are likely to be at the highest level, and installing continuous groundwater-level monitors in the minor bedrock aquifers and the alluvial aquifers could allow for evaluation of trends in groundwater storage and provide information to water-resource managers, especially during drought conditions.

4. There is a lack of recent groundwater-quality data. Prior to the analyses conducted for this study, there was very little groundwater-quality data for the Black Bear Creek study area. Establishing several long-term monitoring sites for periodic sampling could provide an indication of groundwater-quality changes in the groundwater system. When possible, additional sampling, by both increasing the number of sites and analyzing for additional constituents (such as trace metals), across the area could provide a clearer picture of groundwater quality in the study area.

5. There is a lack of local-scale water-use data. The State of Oklahoma does not require metering on permitted wells and does not require a permit for domestic users. Estimates of water use can be made on the county scale by using State water permits, but there is no actual measurement of water withdrawals. Metering withdrawals would allow for more accurate estimates of water use.

Summary

The Pawnee Nation is compiling a comprehensive water-management plan for the Pawnee Nation Tribal Jurisdictional Area in north-central Oklahoma. One of the first steps needed in preparing such a plan is a summary and analysis of available hydrologic data and reports that have been published for the area. In phase 1 of a three-phase, watershed-based approach to summary and analysis of water resources of the Pawnee Nation, the U.S. Geological Survey (USGS), in cooperation with the Pawnee Nation and Bureau of Indian Affairs, conducted a literature search and data analysis for the Black Bear Creek watershed within the Pawnee Nation Tribal Jurisdictional Area, referred to herein as the “Black Bear Creek study area.” This report summarizes the available data for the Black Bear Creek study area.

The Pawnee Nation Tribal Jurisdictional Area consists of approximately 450 square miles (mi^2) in Pawnee County and Payne County in north-central Oklahoma. The Black Bear Creek study area described in this report lies entirely in Pawnee County and consists of approximately 176 mi^2, or about 39 percent of the area of the jurisdictional area. The topography of the area is dominated by shallow east-facing ridges or cuestas, with relief generally less than 150 feet. Approximately 60 percent of the land in both the jurisdictional area and the Black Bear Creek study area is grassland or scrub, much of which is used for ranching, and approximately 20 percent of both areas are covered by forests consisting of eastern redcedar, oak, and elm trees. The surficial geology of the jurisdictional area is dominated by shelf deposits of Pennsylvanian-age sedimentary rocks laid down on the cratonic Central Oklahoma platform, overlain with Quaternary-age deposits in some areas, principally near rivers and streams.

The jurisdictional area is primarily pasture with little water use. The population of the jurisdictional area, as calculated from county population data, is approximately 7,700 people. Primary economic activities of the area are ranching, oil production, and mining. Total water withdrawals for the jurisdictional area were estimated to be 8.01 million gallons per day, consisting of about 84 percent groundwater withdrawals and 16 percent surface-water withdrawals.

The USGS Black Bear Creek at Pawnee, Okla., streamflow-gaging station (station number 07153000) is the only streamflow-gaging station in the Black Bear Creek study area. Monthly mean streamflow at the Black Bear Creek at Pawnee, Okla., streamflow-gaging station increased from about 145 cubic feet per second (ft^3/s) in the late 1960s to a peak of about 330 ft^3/s in 1994 and then decreased to about 82 ft^3/s by 2015. Over the regulated streamflow period (water years 1968–2015), monthly mean streamflow was trending lower. No statistically significant trends in annual mean base flow or annual instantaneous peak streamflow were observed for the regulated streamflow period. Based on the peak-flow frequency statistics, Black Bear Creek at Pawnee, Okla., exceeded flood stage approximately every 6 years. The 50-year flood (2-percent exceedance probability), the 100-year flood (1-percent exceedance probability), and the 500-year flood (0.20-percent exceedance probability) are expected to have peak streamflows of 16,800, 18,800, and 23,200 ft^3/s, respectively.

Surface-water-quality data for 18 sites in the Black Bear Creek study area were summarized. Surface-water-quality samples collected in the Black Bear Creek study area were slightly basic, with a median pH per site ranging from 8.72 to 7.26 standard units. Median specific conductance measured along Black Bear Creek ranged between 607 and 1,536 microsiemens per centimeter (µS/cm), and the median chloride concentration at the OWRB Black Bear Creek at Pawnee, Okla., BUMP station was 118 milligrams per liter (mg/L). Total nitrogen concentration at the OWRB Black Bear Creek at Pawnee, Okla., BUMP station exceeded the U.S. Environmental Protection Agency (EPA) criterion of 0.88 mg/L in less than 10 percent of samples (n=37); however, total phosphorus at the same site exceeded the EPA criterion of 0.067 mg/L in 91 percent of samples (n=145). Concentrations of dissolved oxygen and trace metals measured at the Black Bear Creek at Pawnee, Okla., streamflow-gaging station were generally not of concern; however, high levels of enterococci bacteria could pose a health risk to people drinking or bathing in the creek.

Important hydrogeologic formations in the area include the Quaternary-age alluvium and terrace deposits, the minor bedrock aquifers of the Oscar and Vanoss Groups, and the Ada Group of the principal Ada-Vamoosa aquifer. Wells completed in the alluvium and terrace deposits generally produce up to 600 gallons per minute (gal/min) in areas with thick, granular deposits. Wells in the Oscar and Vanoss Groups, which underlie approximately 85 percent of the Black Bear Creek study area, generally produce less than 25 gal/min. Where accessible, the Ada Group generally yields between 25 and 35 gal/min.

Groundwater-quality data for the study area are extremely limited. To supplement available data, a field collection of samples from eight wells was conducted, and water properties, major ions, and nutrients were measured. Groundwater pH was about neutral with a mean pH of all sampled wells of 6.9 standard units. The average concentration of total dissolved solids for sampled wells was 446 mg/L, just under the EPA’s secondary drinking-water standard of 500 mg/L. Concentrations of major anions including chloride, fluoride, and sulfate were well below the EPA secondary drinking-water maximum contaminant levels. Generally, the groundwater in the area is hard to very hard, and localized contamination by nutrients is probably due to surficial sources infiltrating into shallow groundwater.

Hydrologic, water-quality, and water-use data for the Black Bear Creek study area are sparse. Establishing and maintaining long-term streamflow, surface-water-quality, groundwater-level, and groundwater-quality monitoring sites could greatly increase the understanding of the water resources in the Black Bear Creek study area. Additionally, water-use

estimates could be greatly improved by metering groundwater withdrawals. Establishing hydrologic and water-quality trends and having improved estimates of water use could aid decision makers in the stewardship of the area's water resources.

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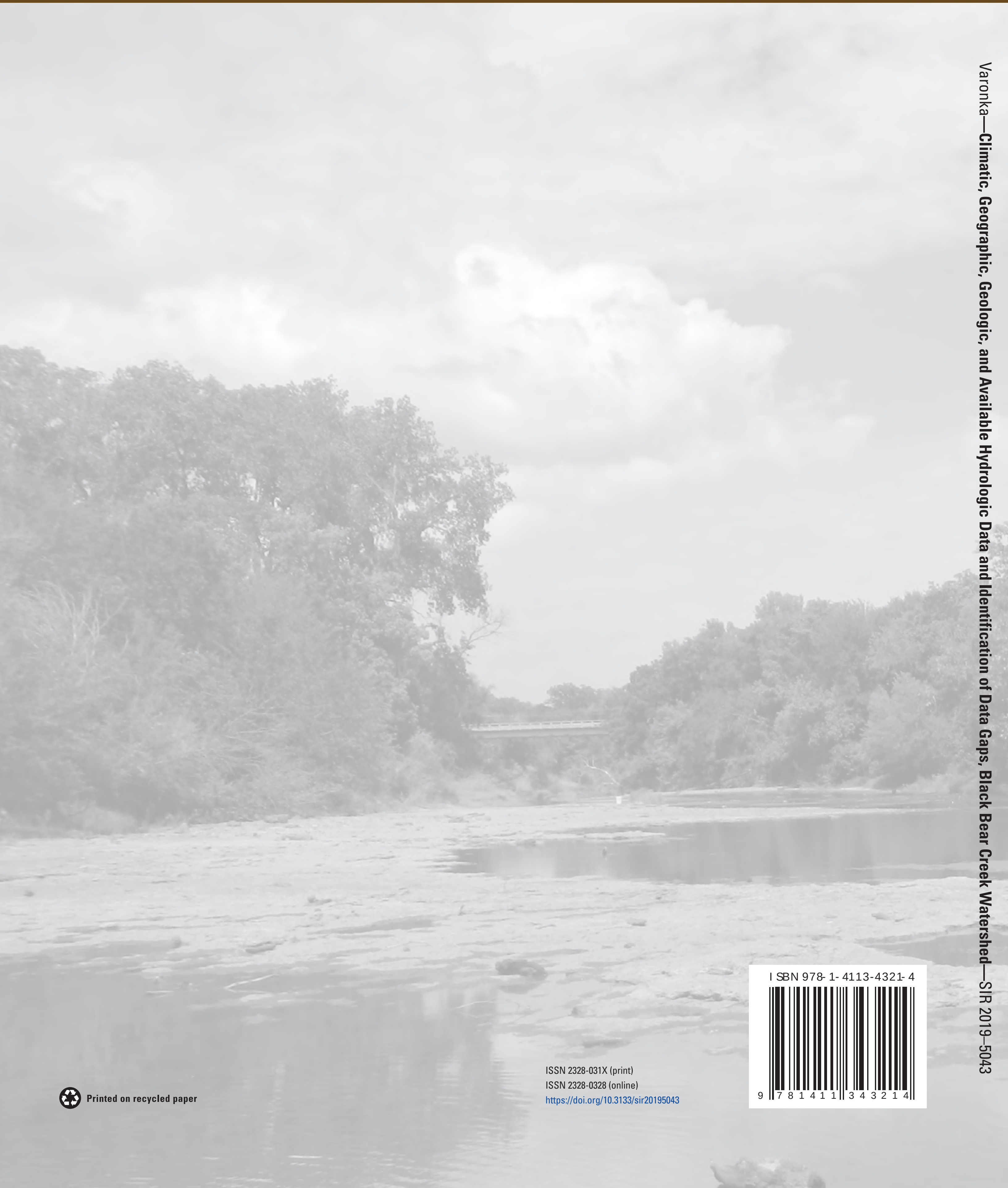

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