Prepared in cooperation with the
WICHITA AND AFFILIATED TRIBES TRIBAL COUNCIL AND BUREAU OF INDIAN AFFAIRS

Overview of Water Resources in and Near Wichita and Affiliated Tribes Treaty Lands in Western Oklahoma

Water-Resources Investigations Report 03–4024

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

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By M.M. Abbott, R.L. Tortorelli, M.F. Becker, and T.J. Trombley

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U.S. Geological Survey

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Contents

Figures

Tables

Conversion Factors and Datum

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (L)
Flow rate		
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
Transmissivity*		
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

°F = (1.8 × °C) + 32

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

°C = (°F - 32) / 1.8

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

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

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

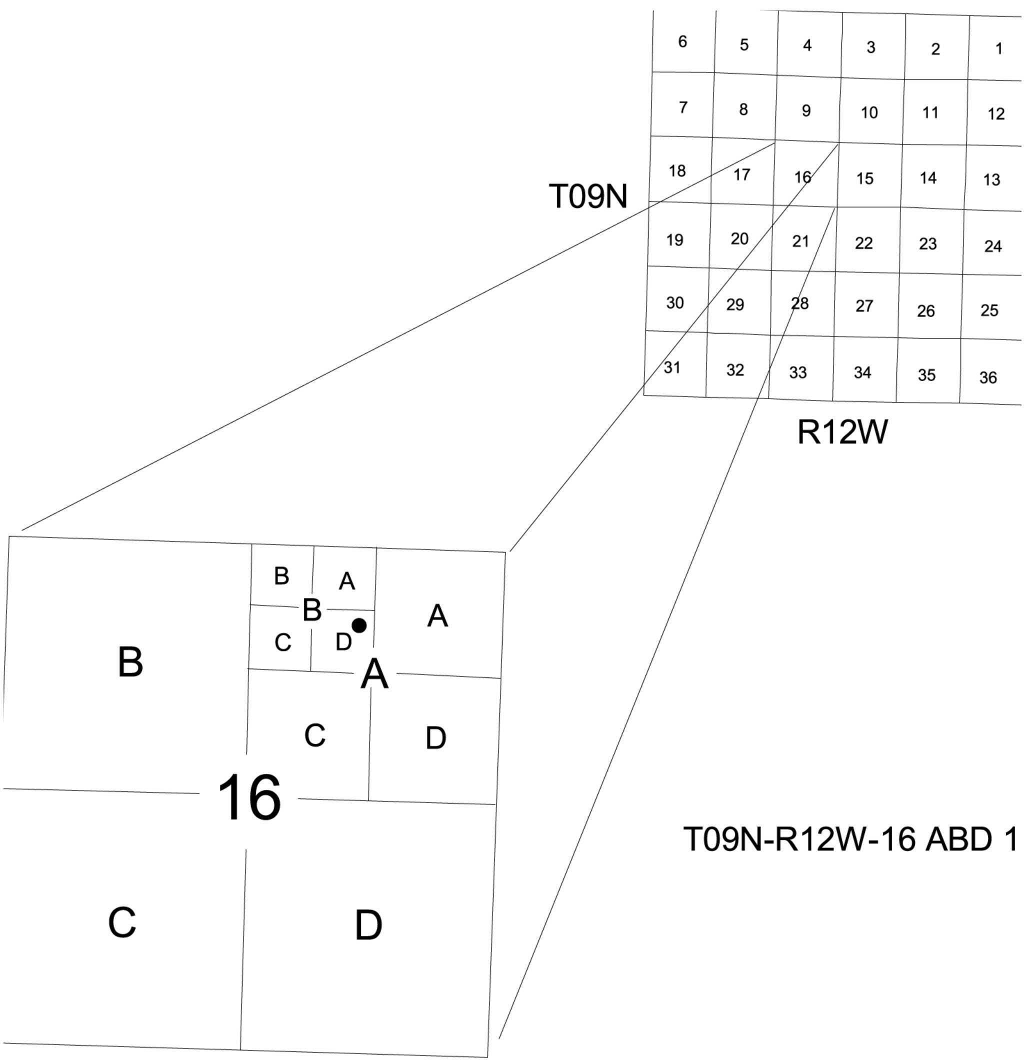
*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

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

Explanation of the Site-Numbering System

The locations of the sample-collection sites and the streamflow-gaging stations are identified by a station-identification number or a local-identification number. The station number is a downstream order number of 8 digits such as 07325800. The downstream ordering system is used to identify hydrologic data collection sites in U.S. Geological Survey reports. Station numbers are unique numbers assigned in a downstream sequence so that numbers become larger downstream. The number is unique in that it applies specifically to a given station and to no other. All stations on a tributary entering upstream from a main stream are listed before that station. A station on a tributary that enters between two mainstream stations is listed between them.

The local-identification number includes the township and range followed by the section and a series of letters that designate the quarter-section subdivisions, from the largest to the smallest. The order of the quarter-section subdivisions differs from that used by the Bureau of Land Management and the public land survey. As illustrated in the figure, the public land survey description of the site indicated by the dot as SE$^{1}/_{4}$ NW$^{1}/_{4}$ NE$^{1}/_{4}$ sec. 16, T. 09 N., R. 12W., is denoted by the local identifier number 09N–12W–16 ABD. If the sequence number is 1, the complete identifier number is 09N–12W–16 ABD 1. Sequence numbers are used when more than one site is located in the smallest subdivision.



Overview of Water Resources in and Near Wichita and Affiliated Tribes Treaty Lands in Western Oklahoma

By M.M. Abbott, R.L. Tortorelli, M.F. Becker, and T.J. Trombley

Abstract

This report is an overview of water resources in and near the Wichita and Affiliated Tribes treaty lands in western Oklahoma. The tribal treaty lands are about 1,140 square miles and are bordered by the Canadian River on the north, the Washita River on the south, 98° west longitude on the east, and 98° 40′ west longitude on the west. Seventy percent of the study area lies within the Washita River drainage basin and 30 percent of the area lies within the Canadian River drainage basin.

March through June are months of greatest average streamflow, with 49 to 57 percent of the annual streamflow occurring in these four months. November through February, July, and August have the least average streamflow with only 26 to 36 percent of the annual streamflow occurring in these six months.

Two streamflow-gaging stations, Canadian River at Bridgeport and Cobb Creek near Fort Cobb, indicated peak streamflows generally decrease with regulation. Two other streamflow-gaging stations, Washita River at Carnegie and Washita River at Anadarko, indicated a decrease in peak streamflows after regulation at less than the 100-year recurrence and an increase in peak streamflows greater than the 100-year recurrence. Canadian River at Bridgeport and Washita River at Carnegie had estimated annual low flows that generally increased with regulation. Cobb Creek near Fort Cobb had a decrease of estimated annual low flows after regulation.

There are greater than 900 ground-water wells in the tribal treaty lands. Eighty percent of the wells are in Caddo County. The major aquifers in the study area are the Rush Springs Aquifer and portions of the Canadian River and Washita River valley alluvial aquifers. The Rush Springs Aquifer is used extensively for irrigation as well as industrial and municipal purposes, especially near population centers. The Canadian River and Washita River valley alluvial aquifers are not used extensively in the study area. Well yields from the Rush Springs Aquifer ranged from 11 to greater than 850 gallons per minute. The Rush Springs Aquifer is recharged by the infiltration of precipitation. The estimated recharge is about 1.80 inches per year evenly distributed over the outcrop of the aquifer in the study area.

Principal factors affecting the water quality in the study area include geology, agricultural practices, and oil and gas production. Calcium, magnesium, sulfate, and bicarbonate are the dominant dissolved constituents in water in the study area.

Interquartile dissolved-solids concentrations in surface-water samples in the study area generally were greater than interquartile concentrations in ground-water samples. Median dissolved-solids concentrations for ground-water samples from Canadian River, Ionine Creek, Spring Creek, and Washita River Basins, which ranged from 535 to 1,195 milligrams per liter, exceeded the U.S. Environmental Protection Agency Secondary Drinking Water Standard of 500 milligrams per liter.

Interquartile sulfate concentrations in surface-water samples in the study area generally were greater than interquartile concentrations in ground-water samples. Median sulfate concentrations from ground-water samples in the Canadian River, Ionine Creek, and Spring Creek Basins, which ranged from 385 to 570 milligrams per liter, exceeded the U.S. Environmental Protection Agency Secondary Drinking Water Standard of 250 milligrams per liter.

Nitrite plus nitrate as nitrogen concentrations in surface-water samples in the study area generally were less than concentrations in ground-water samples. The median nitrite plus nitrate as nitrogen concentration in ground water was 9.8 milligrams per liter, suggesting almost one-half the ground-water samples exceeded the U.S. Environmental Protection Agency Primary Drinking Water Standard (10 milligrams per liter).

An estimated 100 million gallons of water per day were withdrawn from surface and ground water for all uses in counties of the study area during 1995. Fifty percent of water use was for irrigation, and about 83 percent of water withdrawn for irrigation was from ground water. Livestock use represented 14 percent of the total water withdrawn and was supplied by surface- and ground-water sources. Water-supply for domestic and commercial uses was 31 percent of the total withdrawn and was supplied by surface- and ground-water sources.

Introduction

Increased demand for water in west-central Oklahoma has led to concern about future water resources. As a result, the Wichita and Affiliated Tribes of Oklahoma are interested in prudent development of the water resources in and near their treaty lands (fig. 1). The Affiliated Tribes include the Waco, Keechi, and Tawakoni tribes. The U.S. Geological Survey, in cooperation with the tribes, conducted a reconnaissance study to provide an overview of the availability and quality of water resources in and near tribal treaty lands in western Oklahoma.

The study area is located in western Oklahoma and includes most of Caddo County, part of western Grady County, southwestern Blaine and Canadian Counties, and parts of eastern Custer and Washita Counties. The study-area boundaries (fig. 1) are the original treaty lands for the tribes encompassing 1,140 square-miles. These boundaries are based on hydrologic features on the north and south and are based on lines of longitude on the east and west. The area was described as: "Commencing at a point in the middle of the main channel of the Washita river where the ninety-eighth meridian of W. longitude crosses the same; thence up the middle of the main channel of said river to the line of 98° 40′ W. longitude; thence on said line of 98° 40′ due N. to the middle of the main channel of the main Canadian river; thence down the middle of said main Canadian river to where it crosses the ninety-eighth meridian; thence due S. to the place of beginning." (Library of Congress, 2002).

Purpose and Scope

This report is an overview of water resources in and near the Wichita and Affiliated Tribes treaty lands in western Oklahoma. The primary objectives of the report are to describe surface- and ground-water availability, water quality, and water use in the study area. The report also includes: (1) physical setting, such as soils, geology, climate, and land use; (2) surface-water characteristics; (3) water availability from major and minor aquifers; (4) comparison of water-quality data grouped by source and by surface-drainage basins; (5) comparison of water use grouped by source; and (6) presentation of maps of physical and hydrologic features, such as soils, geology, land use, surface-drainage basins, and aquifer boundaries. The study did not include the collection of any new water-resources data. Existing data were compiled from various agencies.

Acknowledgments

The authors express their appreciation to the Wichita and Affiliated Tribes for their assistance with this report. Ira French provided photographs and detailed information of the tribe's trust and allotment lands

Historical Overview of Wichita and Affiliated Tribes and Treaty Lands

This historical overview is from The Texas State Historical Association (2001). Additional information on the Wichita and Affiliated Tribes can be found in Bell and others (1974); Elam (1971); Hodge (1959); John (1975); and Newcomb (1976). A synopsis of the historical accounts follows.

The Wichita were one of several bands that composed the Wichita confederacy. The name Wichita is first found in the early 17th century in historical records of French traders, who used the word Ousitas to identify one band of Indians who lived near the Arkansas River in present-day Oklahoma. The Wichita called themselves Kitikiti'sh, meaning "raccoon eyes," because the designs of tattoos around the men's eyes resembled the eyes of the raccoon. The Coronado expedition in 1541 visited Indians in central Kansas whom Coronado called Quiviras and who have been identified by archeological and historical studies as Wichitas. The Wichitas had moved south by 1719 to Oklahoma and were called Ousitas by the French trader Jean Baptiste Bénard de La Harpe. From the 1750s to 1810, one band of the Wichita Indians lived along the Red River north of the site of present-day Nocona, Texas. The Wichitas, during this period, were prominent middlemen in the trade between the Comanches on the plains and Louisiana merchants and were at the zenith of their power and prestige.

The Wichita as a distinct band declined after about 1810, although until the 1850s villages of Wichita, sometimes called Towiach or Tawehash, were located on the Wichita and Brazos Rivers. A United States cavalry unit visited a Wichita village on the North Fork Red River west of the Wichita Mountains in Oklahoma in 1834. The Wichita had lived near the mountains for many years, including the site where Fort Sill was established and the present-day townsite of Rush Springs. Their village near the present-day townsite of Rush Springs was destroyed in 1858 by a United States military force pursuing Comanches who were camped nearby. Survivors joined remnants of other bands of the Wichita confederacy on the Washita River in 1859, and when the Civil War broke out fled with them to Kansas. The Wichita were relocated in 1872 with their kinsmen, the Wacoes, Tawakonis, and Kichais, and other associated tribes to the Wichita Reservation near present-day Anadarko, Oklahoma. The reservation was opened to allotment in an agreement with the Wichitas and affiliated bands in 1891. The Wichita and Affiliated Tribes trust and allotment lands are shown in figure 2 (Wichita and Affiliated Tribes, written commun, 2002). Headquarters of the Wichita and Affiliated Tribes is located near Anadarko, Oklahoma (figs. 1, 2).

Significant and continued use of the name Wichita is found in North Texas in the name of a river, the name of a county, and the name of a prominent city, Wichita Falls. Wichita, Kansas, owes its name to the early presence of the tribe in Kansas. Wichita Mountains, south of the tribal treaty lands (fig. 3) in Oklahoma, are named for the tribe.

The Wichitas were dependent on both agriculture and hunting for subsistence. They lived in villages of dome-shaped grass lodges (fig. 4) and farmed extensive fields of corn, tobacco, and melons along the streams where they made their homes. The Wichita left their villages for annual hunts during which time they cached their stores of agricultural goods in the ground along the banks of streams.

The Wichita were slightly darker in skin color than other native people of Texas and were distinguished by their elaborate tattoos and the scalp-lock worn by the men. They had little ritualistic religion, but were impressed by the natural forces around them and gave expression to them in an elaborate

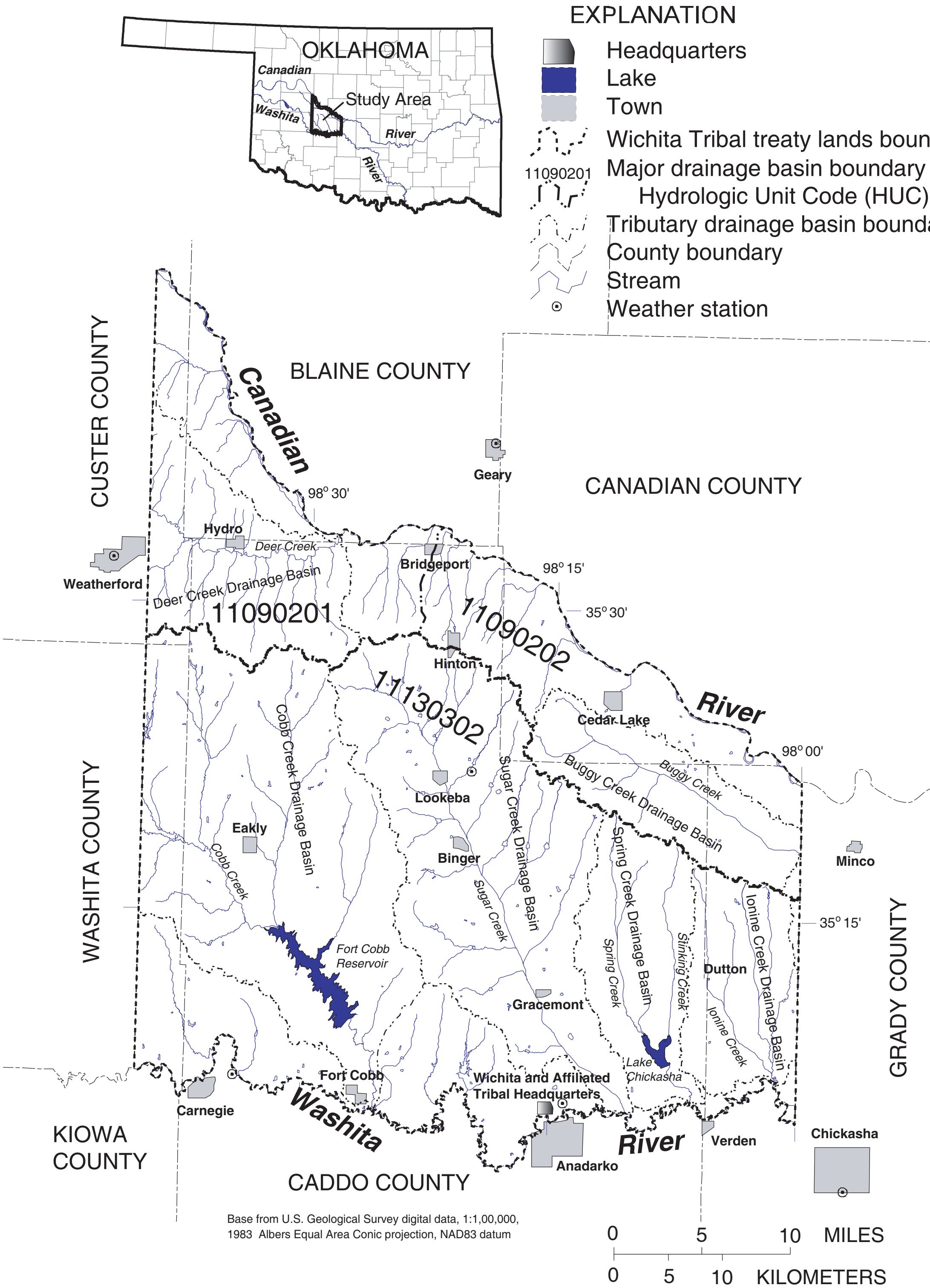


Figure 1. Location of study area, extent of Wichita and Affiliated Tribes treaty lands, and hydrologic unit boundaries in western Oklahoma.

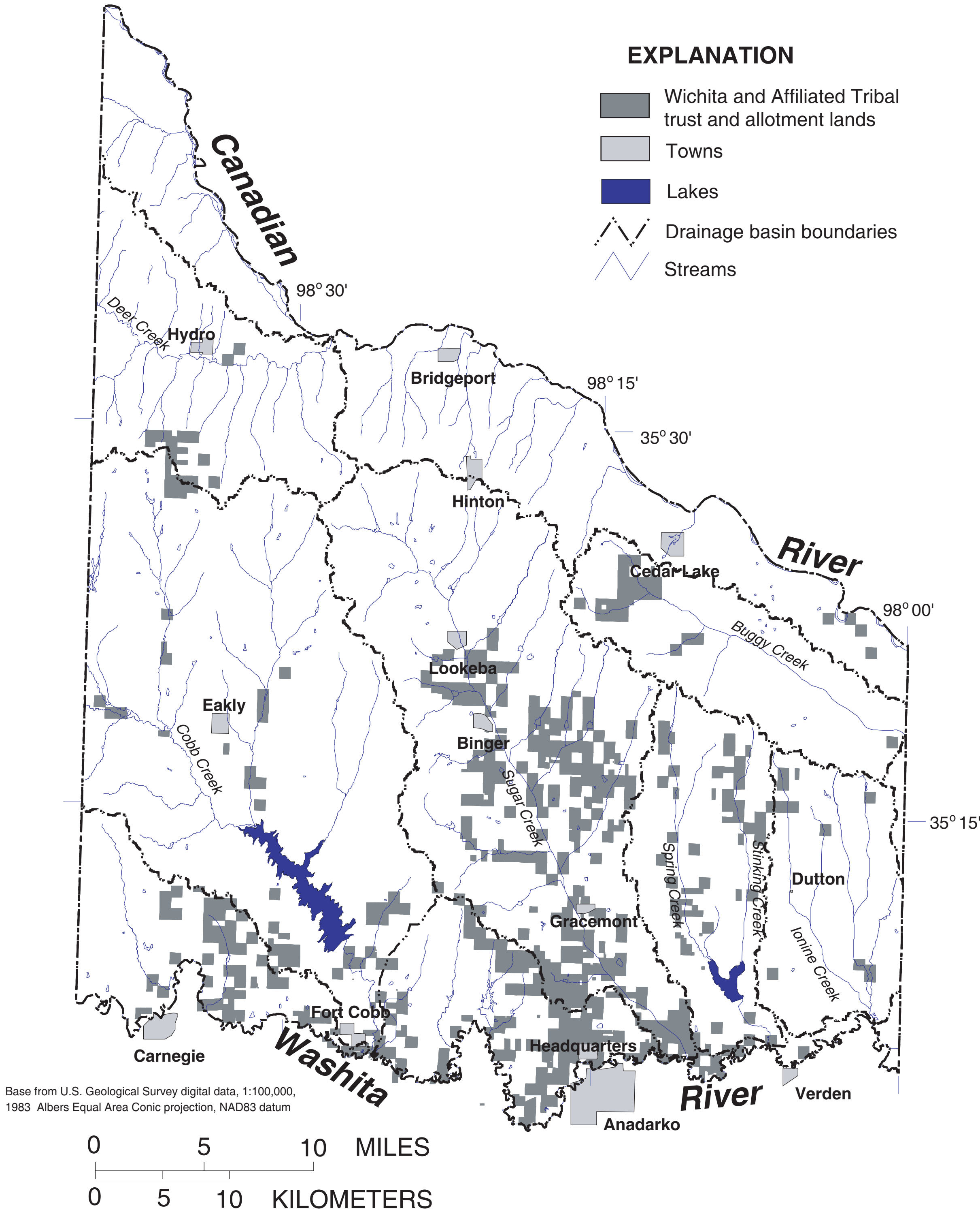


Figure 2. Wichita and Affiliated Tribal trust and allotments lands (Bureau of Indian Affairs, 2000).

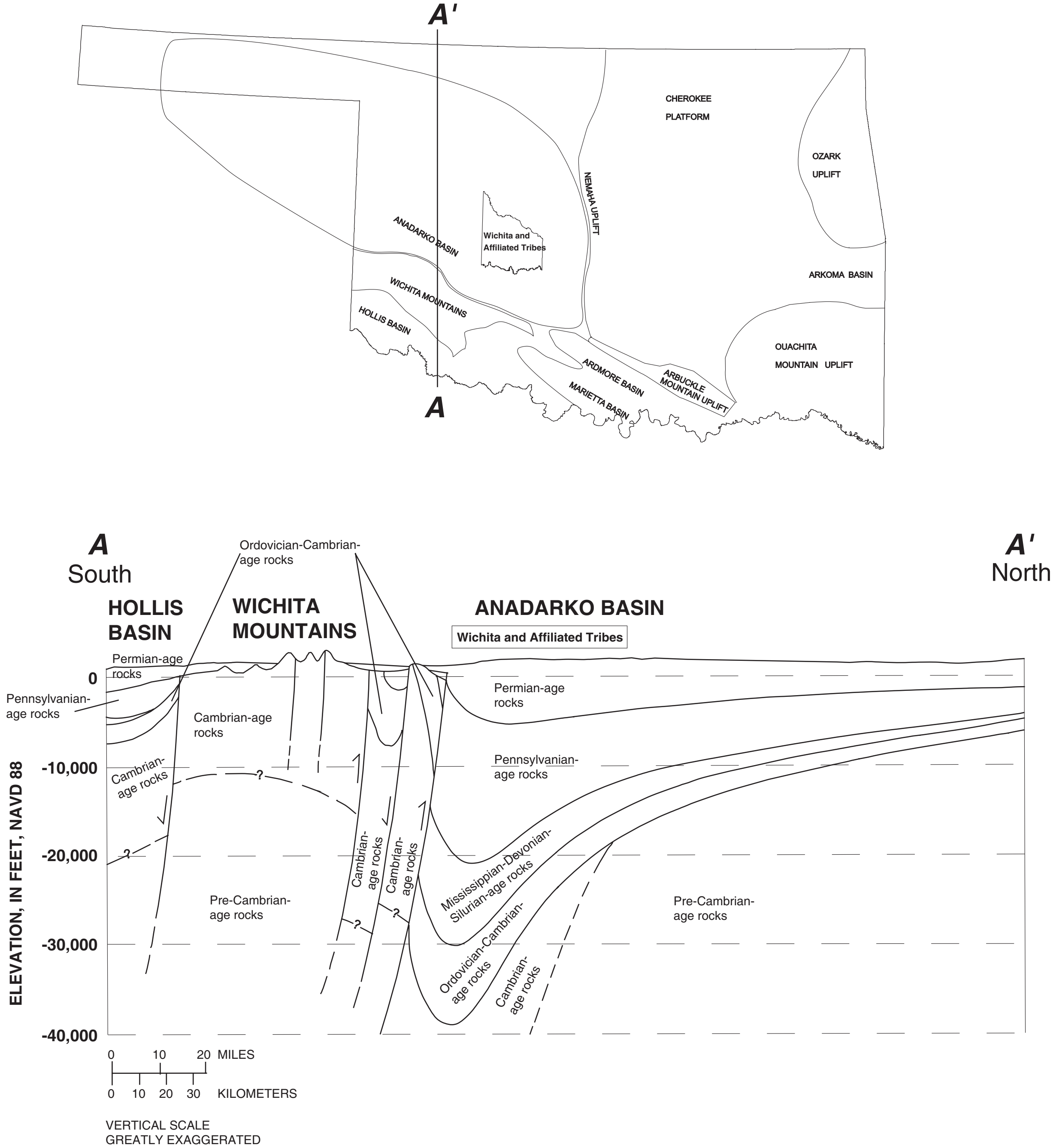


Figure 3. Regional geologic structural features and north-south geologic section across western Oklahoma (modified from Johnson and others, 1972).

Figure 4. Dome-shaped Wichita grass lodge.

mythology. Although warriors by tradition the Wichita tended to be friendly toward strangers, avoided confrontations unless provoked, and were noted for their hospitality. Their villages were landmarks on the southern plains; they were well laid out and clearly distinguishable by their grass lodges and nearby fields.

Methods of Investigation

Existing data compiled from the Oklahoma Geological Survey, Oklahoma Water Resources Board, Oklahoma Climatological Survey, U.S. Department of Agriculture, Natural Resources Conservation Service, National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and other agencies provided the basis for this overview of water-resources for the study area.

Streamflow characteristics for selected streamflow-gaging stations in the study area are presented. Seasonal distribution of streamflows are shown by the monthly mean streamflows. Magnitude and frequency of floods are shown by documented extreme peak discharges and peak-streamflow frequency estimates. Low-flow characteristics are shown by annual low-flow frequency estimates. Long-term trends are shown for the entire period of record and post-regulation periods of record for total annual precipitation and mean annual streamflow.

Ground-water availability was summarized by describing aquifer location, extent, geometry, geology, and potentiometric surfaces. Hydraulic properties of the aquifers were estimated using published results of aquifer tests. Where water-level data were available, hydrograph comparison and analysis afforded a method to evaluate long-term effects of withdrawals from the aquifers.

Data from 20 surface-water sites and 160 ground-water wells were used to describe water quality in the study area. This report characterizes water quality by drainage basin using summary statistics and graphical methods for dissolved-solids concentrations; dissolved concentrations of calcium, sodium, chloride, sulfate, and nitrite plus nitrate as nitrogen.

Boxplots were used to provide an overview of concentration distributions within each of eight drainage basins (six tributaries and two major drainage basins). Boxplots are a useful method to qualitatively compare the statistical characteristics of several data sets (Helsel and Hirsch, 1992). Median value, the center line on the boxplot, represents the central tendency of water quality within each basin. The length of the box, the distance between the 25th and 75th percentiles of the data, gives an indication of the variation in values. Relative skewness of the data is indicated by the difference between the sizes of the box parts and the lengths of the "whiskers" above and below the box. The presence or absence of outlying values is indicated by plotting those values individually. "Outside" values, which are plotted as "*", are present in less than 1 of 100 values that are normally distributed. The term "interquartile" is used in this report to indicate values between the 25th and 75th percentiles (interquartile range).

Areal distribution of water-quality constituents within the study area were calculated using one value for each site sampled within the drainage basin to eliminate biasing by sites with larger numbers of analyses. For sites with one analysis, the value for that analysis was used. For sites with multiple analyses, the median value for that site was used. Water-quality trends through time were not evaluated because the analysis requires a minimum of 10 years of incremental data. Very few sites in the study area met the requirements; therefore, water-quality time trends could not be determined.

Physical Setting

Physiography

Gould (1905) and Fenneman (1938) have described the physiography of the study area to be of the Gypsum Hills Province, a region west of the Red Bed Plains physiographic province. The Gypsum Hills Province is characterized by erosion-resistant strata composed of sandstone, dolomite, limestone, and gypsum interbedded with silts and clays. The interbeds of resistant and erodible material create topographic features such as escarpments and level plains. Discontinuous gypsum beds form caprocks that, where present, result in small cuestas, pronounced ledges overlooking river valleys, and small steep-sided canyons with 150 feet or more of relief incising the Rush Springs Aquifer (Becker, 1998). Land-surface altitudes range from approximately 1,115 feet where the Washita River leaves the tribal treaty lands east of Verden, to greater than 1,720 feet northwest of Hydro (fig. 1).

The study area lies within two major drainage basins — the Washita River drainage basin and the Canadian River drainage basin (fig. 1). Six tributary drainage basins lie within the major drainage basins (fig. 1). Tributaries of the Washita River in the tribal treaty lands, from west to east, include Cobb Creek, Sugar Creek, Spring Creek, and Ionine Creek. Cobb Creek and Sugar Creek are perennial streams that are maintained by discharge from the Rush Springs Aquifer (Tanaka and Davis, 1963). Principal tributaries of the Canadian River are Deer Creek and Buggy Creek. Deer Creek is a perennial stream maintained by discharge from the Rush Springs Aquifer. The percentages of the tribal trust and allotment lands within each of these surface drainage basins are as follows: Buggy Creek, 5 percent; Canadian River, 1 percent; Cobb Creek, 9 percent; Deer Creek, 3 percent; Ionine Creek, 2 percent; Spring Creek, 10 percent; Sugar Creek, 40 percent; and Washita River, 30 percent (fig. 2).

Soils

There are 12 general soil groups in the study area (fig. 5, table 1). The discussion of soils in this report is from the detailed soil information, published county soil-survey maps available from the U.S. Department of Agriculture Soil Conservation Service for counties in the study area (Bogard and others, 1978; Fisher, 1968; Fisher and Swafford, 1976; Henson, 1978; Moffatt, 1973; and Moffatt and Conradi, 1979).

Certain physical characteristics of soils affect the rate at which precipitation infiltrates or is transmitted through the soil, thereby affecting the water resources of an area. These physical characteristics help determine the rates of both ground-water recharge and surface-water runoff. Soil formation is a continuing process affected by environmental factors, including climate and biota, especially natural vegetation. Materials from which the soil is formed have a substantial effect on certain primary characteristics of the soil, such as texture; but climate, biotic factors, topographic position, and time determine the final character of the soil. The degree of weathering of the parent materials dictates the depth of soil development and the prevalence of clay and organic materials.

Six soil characteristics that indicate the relation between soil and water were used to describe the hydrologic responses of soil. Those six characteristics are:

(1) Average profile permeability is a measure of the rate at which water moves down through the saturated soil profile. It is affected by soil texture, structure, and porosity.

(2) Depth to bedrock is a measure of the depth to the parent material for the soil.

(3) Average profile of available water capacity is the difference between the field capacity, which is the quantity of water held by unsaturated soil against the pull of gravity; and the wilting point, which is the point at which the water content of the soil becomes too low to prevent the permanent wilting of plants.

(4) Average maximum soil slope is the difference in elevation of the soil surface within a given horizontal distance expressed as a percentage.

(5) Depth below land surface to the seasonal high water table is the normal annual minimum depth to the water table and does not include any perched water tables. Long periods of saturation can change the structure of soils, which in turn, can affect other hydrologic soil characteristics, such as available water capacity and permeability.

(6) Soil profile thickness is used to distinguish between relatively thin soils, less than 60 inches thick, forming a veneer over bedrock, and thicker soils, greater than 60 inches thick, overlying unconsolidated or weakly consolidated parent material that is easily weathered. This soil characteristic can indicate the potential volume of water stored within the soil profile and its rate of movement through this profile.

The rate of soil development is affected by the physical characteristics of the parent material. Typical parent materials for soils in the study area are loess, alluvium, colluvium, eolian sand, shale, and limestone. These physical characteristics include average profile permeability, depth to bedrock, and average profile of available water capacity. Consolidated sedimentary and crystalline bedrock usually weathers more slowly than unconsolidated materials, such as alluvium or loess, which already have certain characteristics similar to mature soils.

Climatic variations substantially affect soil development. The study area has a dry, subhumid, continental climate (U.S. Department of Agriculture, 1973, p. 60). Strong winds and high temperatures result in high evaporation rates. Therefore, little water moves through the soils, except in more permeable sandy soils, and results in less leaching of basic elements (U.S. Department of Agriculture, p. 60, 1973).

Natural vegetation in the study area is diverse and related to the amount of water available. The organic matter in the soil is largely dependent on the decay of root systems. Grasslands, particularly tall-grass prairie, add large amounts of organic matter to the soil. Short-grass prairie produces less organic matter, therefore soils are lighter in color. Woodland soils usually have only a thin surface layer of organic material, mostly from leaf decay. Under warm, moist conditions, leaching prevents the accumulation of organic material in the upper soil horizons.

Topographic position of a soil is an important but passive factor in soil-forming process. Steep slopes tend to promote rapid runoff of precipitation, decreasing the time available for infiltration, thus limiting the amount of water available to weather parent materials. Also, steep slopes tend to erode easily, thus resulting in thin, poorly developed soils. The degree to which topographic position affects soil development is inversely dependent on the angle of the slope. In the study area, topography ranges from nearly flat, relatively large, continuous areas along and near divides or in the valley bottoms to steep slopes along the highly dissected bluffs adjacent to the large river valleys.

The degree of soil development also depends on the length of time that geologic parent materials have been exposed to climatic elements and to the intensity of weathering. The age of soils in the study area ranges from very young for flood-plain soils to very mature for soils long exposed on relatively flat uplands. The more mature soils are the most deeply developed, with accumulations of clayey materials from leaching and redepositing. It is nearly impossible to quantify the time involved in soil-forming processes at any particular place because of continuous addition of wind- or water-transported organic material to the soil surface.

Geology in Relation to Ground Water

The ground-water hydrology of an area is dependent on the geology of that area. Knowledge of the geology, including the stratigraphy and geologic structure, leads to an improved understanding of the occurrence and availability of ground water. A brief description of the geology of the study area, as it relates to ground water, follows.

The study area lies within the stable interior of the North American continent. Since Precambrian time (about 600 mil-

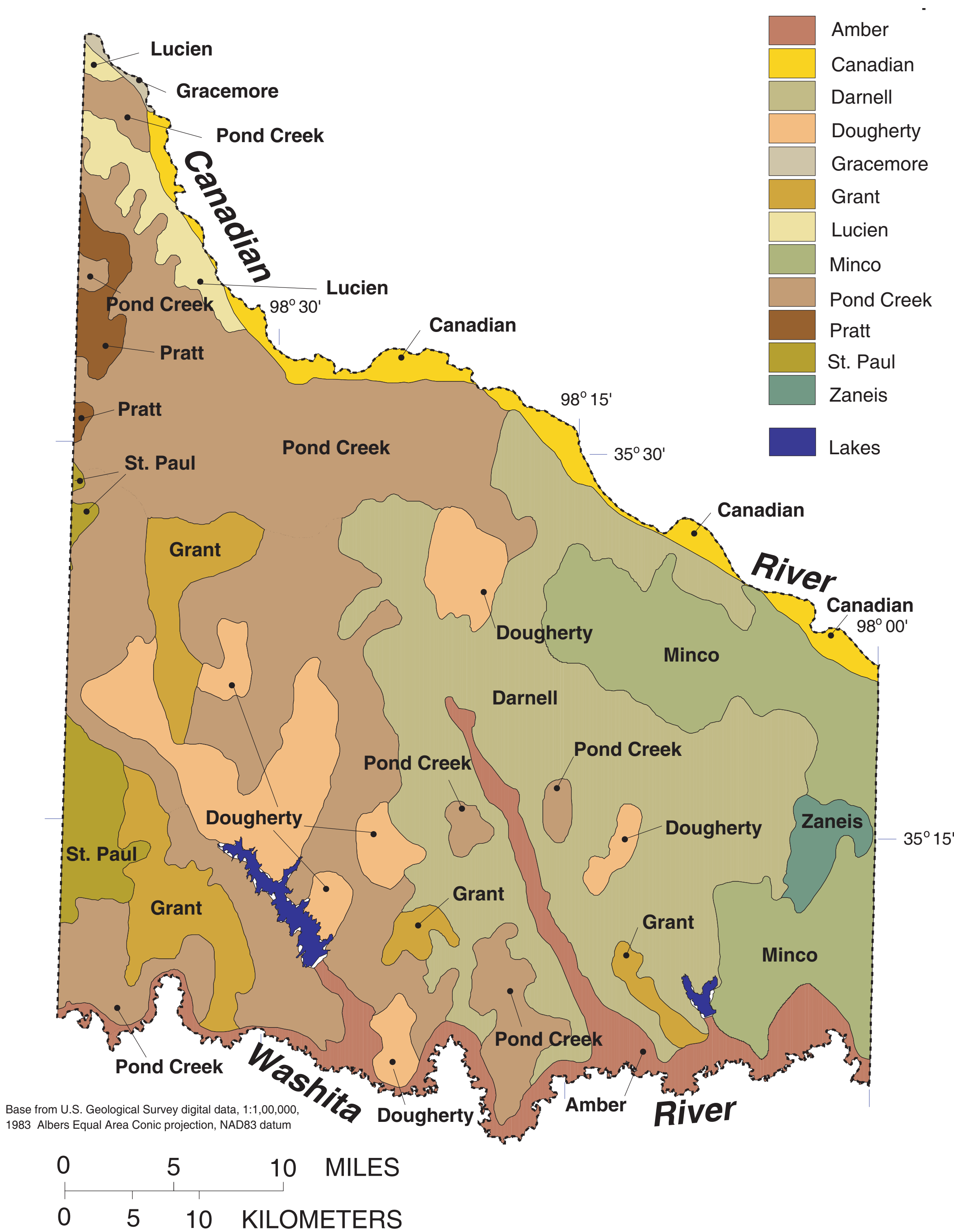


Figure 5. Hydrologic soil groups in the Wichita Affiliated Tribes treaty lands, Oklahoma (U.S. Department of Agriculture, Natural Resources Conservation Service, 1994).

Table 1. Hydrologic characteristics of soils in the Wichita and Affiliated Tribes treaty lands, Oklahoma

[<, less than; >, greater than]

Hydrologic soil group (numbers)	Average profile permeability (inch per hour)	Depth to bedrock (inches)	Average profile of available water capacity (inch per inch)	Average maximum soil slope (percent)	Depth below land surface to seasonal high water table (feet)	Soil profile thickness (inches)	Description
Amber OK124 OK031	0.6-2.0 moderate[1]	no data	0.07-0.20	1-3	>6.0	0-36	Very gently sloping soils on flood plains but is rarely flooded. These soils are well drained and water capacity is high.[2]
Canadian OK130	2.0-6.3 moderately rapid[3, 4]	no data	0.12	nearly level	>6.0	0-60	Nearly level soils on flood plains, formed from friable loamy alluvium. These soils are well drained and water capacity is moderate.[5, 6]
Darnell OK149	2.0-6.3 moderately rapid[1, 3, 7]	4-20	0.12	3-12	>6.0	0-14	Shallow, gently sloping to hilly soils on uplands, formed under mid grasses and oak forest in weathered sandstone. These soils are well drained and water capacity is low.[1, 3, 8]
Dougherty OK142	2.0-6.3 moderately rapid[1, 4]	<30->120	0.07	3-8	>6.0	0-27	Very gently sloping soils on uplands, formed under oak forests and mid and tall grasses. These soils are well drained and water capacity is low to medium.[1, 4]
Gracemore OK051	0.2-6.0 moderately rapid[1, 3]	10	0.05-0.13	nearly level	0.5-3.0	0-12	Nearly level soils on flood plains and are frequently flooded for brief periods of time. Water capacity is medium.[1, 3]
Grant OK088	0.63-2.0 moderate[1, 2, 3, 4]	>40	0.14	1-8	>6.0	0-20	Deep, very gently sloping soils on uplands, formed under mid and tall grasses. These soils are well drained and water capacity is high.[1, 2, 3, 4]
Lucien OK096	2.0-6.3 moderately rapid[1, 2, 4]	7-20	0.12	3-30	>6.0	0-17	Deep, gently sloping to steep soils on uplands, formed from fine-grained sandstones under short, mid, and tall grasses. These soils are well drained and water capacity is low.[1, 2, 4]
Minco OK100 OK10	0.63-2.0 moderate[1, 2, 3, 4]	70->120	0.14	0-30	>6.0	0-72	Deep, gently sloping soils on uplands, formed under mid and tall grasses in alkaline, calcareous, loamy sediments. These soils are well drained and water capacity is high.[1, 2, 3, 4]
Pond Creek OK107 OK109 OK110	0.63-2.0 moderate[1, 3, 4]	10->60	0.12	0-3	>6.0	0-9	Nearly level or very gently sloping soils on uplands, formed under mid and tall grasses on alkaline loamy sediments. These soils are well drained and water capacity is high.[1, 3, 4]

Table 1. Hydrologic characteristics of soils in the Wichita and Affiliated Tribes treaty lands, Oklahoma—Continued

[<, less than; >, greater than]

Hydrologic soil group (numbers)	Average profile permeability (inch per hour)	Depth to bedrock (inches)	Average profile of available water capacity (inch per inch)	Average maximum soil slope (percent)	Depth below land surface to seasonal high water table (feet)	Soil profile thickness (inches)	Description
Pratt OK057	2.5-5.0 moderately rapid[2]	no data	0.07	0-2	>6.0	0-8	Nearly level to very gently sloping soils on sandy uplands. These soils are very well drained and water capacity is very low.[2]
St. Paul OK063	0.2-0.8 moderately slow[2]	no data	0.14-0.17	0-3	>6.0	0-121	Nearly level to very gently sloping soils on uplands. These soils are well drained and water capacity is moderate.[2]
Zaneis OK103	0.2-2.0 moderate[1]	50	0.11-0.20	1-8	>6.0	50	Deep, very gently sloping soils on uplands. These soils are well drained and water capacity is high.[1]

[1]Moffatt (1973)
[2]Moffatt (1973)
[3]Bogard and others (1978)
[4]Fisher (1968)
[5]Bogard and others (1978)
[6]Fisher (1968)
[7]Fisher and Swafford (1976)
[8]Fisher and Swafford (1976)

lion years ago), most of this part of the continent has undergone deformation with downwarping of the Earth's crust over a large area known as the Anadarko Basin, a broad deep basin covering most of western Oklahoma (fig. 3). It is the deepest sedimentary and structural basin on the North American craton (Johnson, 1989).

Precambrian-age basement rocks are deeply buried in the study area (fig. 3). The Anadarko Basin is asymmetric in shape, with the deepest part near the southern boundary of the study area. The axis of the basin crosses the study area between Carnegie and Fort Cobb Reservoir (fig. 1) (Carr and Bergman, 1976). The basin contains approximately 40,000 feet of Paleozoic-age sedimentary rocks and 20,000 feet of Cambrian-age igneous rocks in this area (Johnson, 1989). As shown in the north-south schematic-geologic section (fig. 3), the Paleozoic-age sedimentary rock units in the basin are of Cambrian through Permian age (Johnson and others, 1972). Paleozoic-age rocks in the study area include limestone, dolomite, sandstone, shale, and gypsum beds (Carr and Bergman, 1976).

Unconsolidated alluvial and eolian terrace deposits of Quaternary age unconformably overlie the erosional surface of the Paleozoic-age sedimentary rocks (Carr and Bergman, 1976). The deposits include sediments of both Pleistocene and Holocene age. The deposits are present throughout much of the study area along and adjacent to rivers and streams (fig. 6). Alluvial and terrace deposits are generally thin along minor streams and upland areas (20 to 50 feet). Along the major rivers, the deposits may be as thick as 120 to 170 feet (Carr and Bergman, 1976). The lithology of the deposits varies horizontally and vertically and ranges from fine-grained silts and clays to coarse-grained sands and gravels (Carr and Bergman, 1976).

Climate

Western Oklahoma has a typical continental climate that is characterized by large variations in temperature and precipitation throughout the year and from year to year. The study area is classified as dry subhumid by Thornthwaite (1941), but can range from semiarid to humid in any given year. In a dry subhumid climate, there is a precipitation deficit and evapotranspiration exceeds precipitation. During intervals of high temperatures, evapotranspiration can remove large quantities of surface water and shallow soil water resulting in drought conditions.

Average annual precipitation in the tribal treaty lands ranged from 28 inches in the west to greater than 32 inches in the east, based upon records from 1961 to 1990 (Johnson and

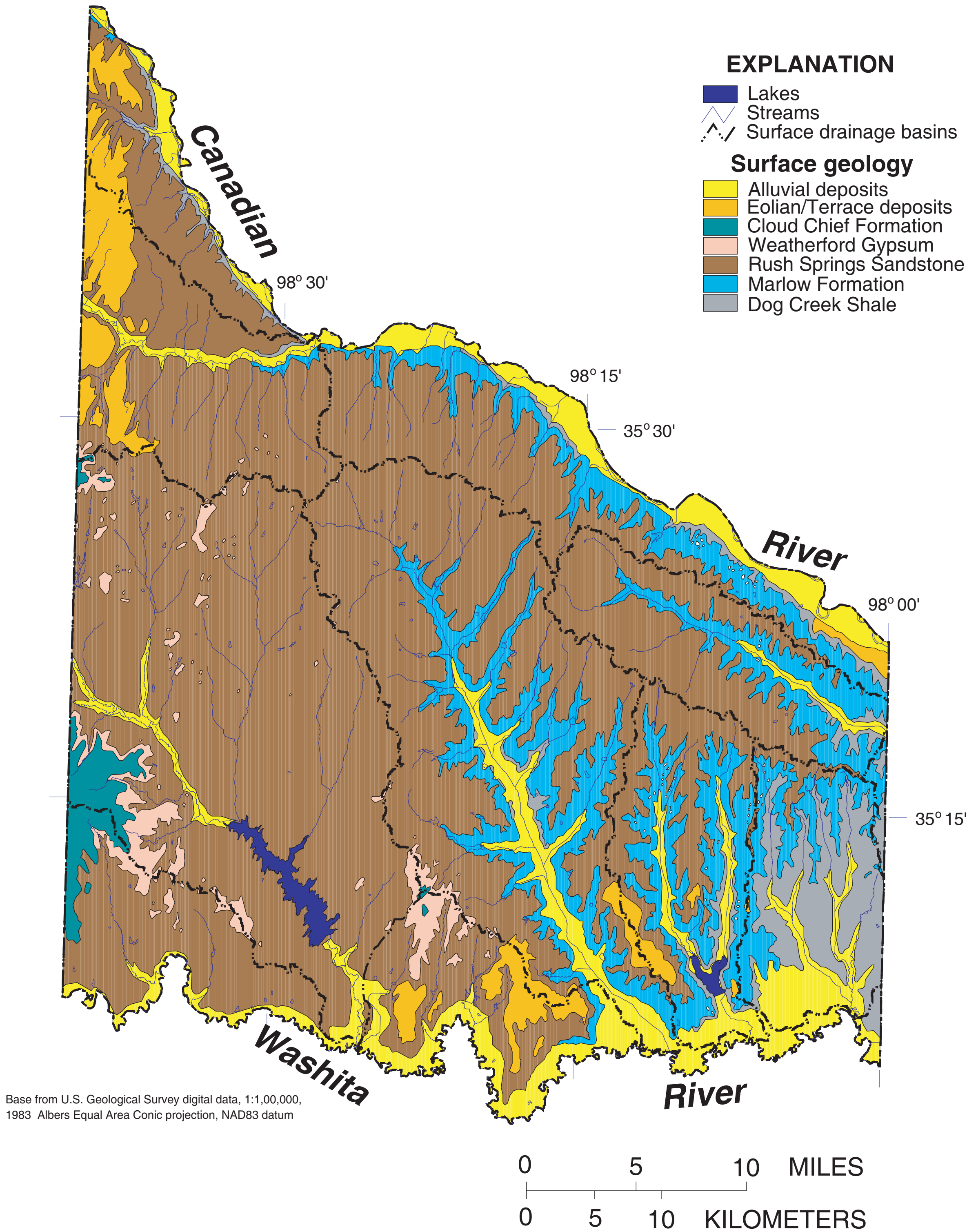


Figure 6. Surface geology in the Wichita and Affiliated Tribes treaty lands, Oklahoma (Cederstrand, 1996).

Duchon, 1995). The wettest month was May, with an average monthly rainfall of greater than 5 inches. The minimum mean monthly precipitation was in January with 1 inch. Greater than 80 percent of the annual precipitation fell from March through October. Most rainfall tends to be localized and intense, resulting in rapid runoff and local flash floods (Tanaka and Davis, 1963). Small amounts of snow fall in January and February and may remain for a brief period of time.

Climatological data are available for weather stations in or near Anadarko, Carnegie, Chickasha, Geary, Lookeba, and Weatherford near the tribal treaty lands (fig. 1). Averaging the 30-year statistical data from 1961 to 1990 for five of the stations, one year out of five will have less than 24 inches of precipitation, and one out of five will have more than 34 inches of precipitation (U.S. Department of Agriculture, 200a).

Long-term climatological data are available for weather stations in Carnegie and Lookeba. These data begin in 1941 and 1915, respectively. Thirty-five to 40 percent of the annual precipitation typically falls during the April-to-June growing season (fig. 7) (National Oceanic and Atmospheric Administration, National Climatic Data Center, 2001).

The statewide average precipitation for Oklahoma is 33.38 inches (Johnson and Duchon, 1995). The driest year on record was 1910 when the statewide average precipitation was only 18.95 inches, and the wettest year was 1957 with 48.21 inches of precipitation. Smoothed precipitation data using a 10-year moving average for annual precipitation for Oklahoma was least in 1918 and most 1950. The 10-year moving average for the state ranges from 30 inches to 37 inches for the period 1901 to 1990.

Monthly mean maximum temperature average for the five weather stations, ranged from 49°F in January to 95°F in July. Monthly mean minimum temperatures ranged from 24°F in January to 70°F in July (U.S. Department of Agriculture, 2000). The lowest temperature for the five weather stations for the years 1961-1990 was –17°F in Anadarko, and the highest temperature was 114°F in Geary (U.S. Department of Agriculture, 2000). An average of about 85 days have a minimum temperature of 32°F or less (Johnson and Duchon, 1995). There are an average of nine days annually with a maximum temperature of 32°F or less for the five weather stations. The average date of the earliest freeze for the five weather stations is between October 28 and November 4. The average date of the latest freeze is between April 1 and April 8. The average year has about 30 frost-free weeks (Johnson and Duchon, 1995). There are about 85 days annually with maximum temperatures 90°F or greater, and about 19 days with maximum temperatures 100°F or greater.

There is a negative relation between average summer (June-August) precipitation and average summer temperatures, and this relation is common to the central part of the United States (Trombley and others, 1996). This relation explains the likelihood of drought conditions developing during hot summers because warmer temperatures increase evapotranspiration. Total average-monthly-pan evaporation for the tribal treaty lands is about 59 inches for the period from May to October (Johnson and Duchon, 1995).

Land Cover and Land Use

Land cover in the study area is very different from the original vegetative cover that existed prior to the influx of native tribes in the early to middle 1800s followed by the influx of non-native settlers in the late 19th century. These changes in land cover were due to: (1) massive conversion of native vegetative cover to agricultural uses, (2) wildfire suppression, which favored woodland cover over prairie cover, and (3) introduction of non-native plant and animal species to the region. Land use in the study area (fig. 8) is dominantly agricultural (mostly cropland or pasture and rangeland, and confined feeding operations).

Tribal treaty lands occupy a portion of six counties in western Oklahoma (fig. 1). These include about 800 square miles of northern Caddo County or about 62 percent of the county; 100 square miles of northwestern Grady County, about 9 percent of the county; 84 square miles of southwestern Canadian County, about 9 percent of the county; 61 square miles in eastern Washita County, about 6 percent of the county; 55 square miles of southwestern Blaine County, about 6 percent of the county; and 43 square miles in eastern Custer County, about 4 percent of the county.

Land use in the tribal treaty lands are as follows: cropland (46 percent), pasture (38 percent), forest and shrub lands (11 percent), rangeland (3 percent), and lakes with wetlands (2 percent) (U.S. Geological Survey, 2000). Cropland is generally situated on land underlain by the Rush Springs Aquifer, where water is available for irrigation, or along creeks and rivers. Pasture, rangeland, and forest are more prevalent land uses where land slopes are steep. Small urban areas (towns), farm houses, ranches, and confined animal feeding operations are scattered throughout the tribal treaty lands. Two reservoirs, Fort Cobb Reservoir and Lake Chickasha are in the Washita River drainage basin within the study area (fig. 1). Most wetland areas within the study area have been drained by ditching and tilling to provide agriculture fields for crops.

Surface-Water Characteristics

The Wichita and Affiliated Tribes treaty lands are a part of two major drainage basins the Canadian River Basin (hydrologic units 11090201 and 11090202) and the Washita River Basin (hydrologic unit 11130302). The Canadian River Basin drains the area along the northern boundary with two major tributary creeks (Seaber and others, 1987). The Deer Creek Basin is in the west, flowing into the Canadian River just east of Hydro. The Buggy Creek Basin is in the east, flowing into the Canadian River just east of Minco. Flow in the Canadian River main stem is regulated by Lake Meredith in Texas. The Washita River Basin drains most of the tribal treaty lands and is along

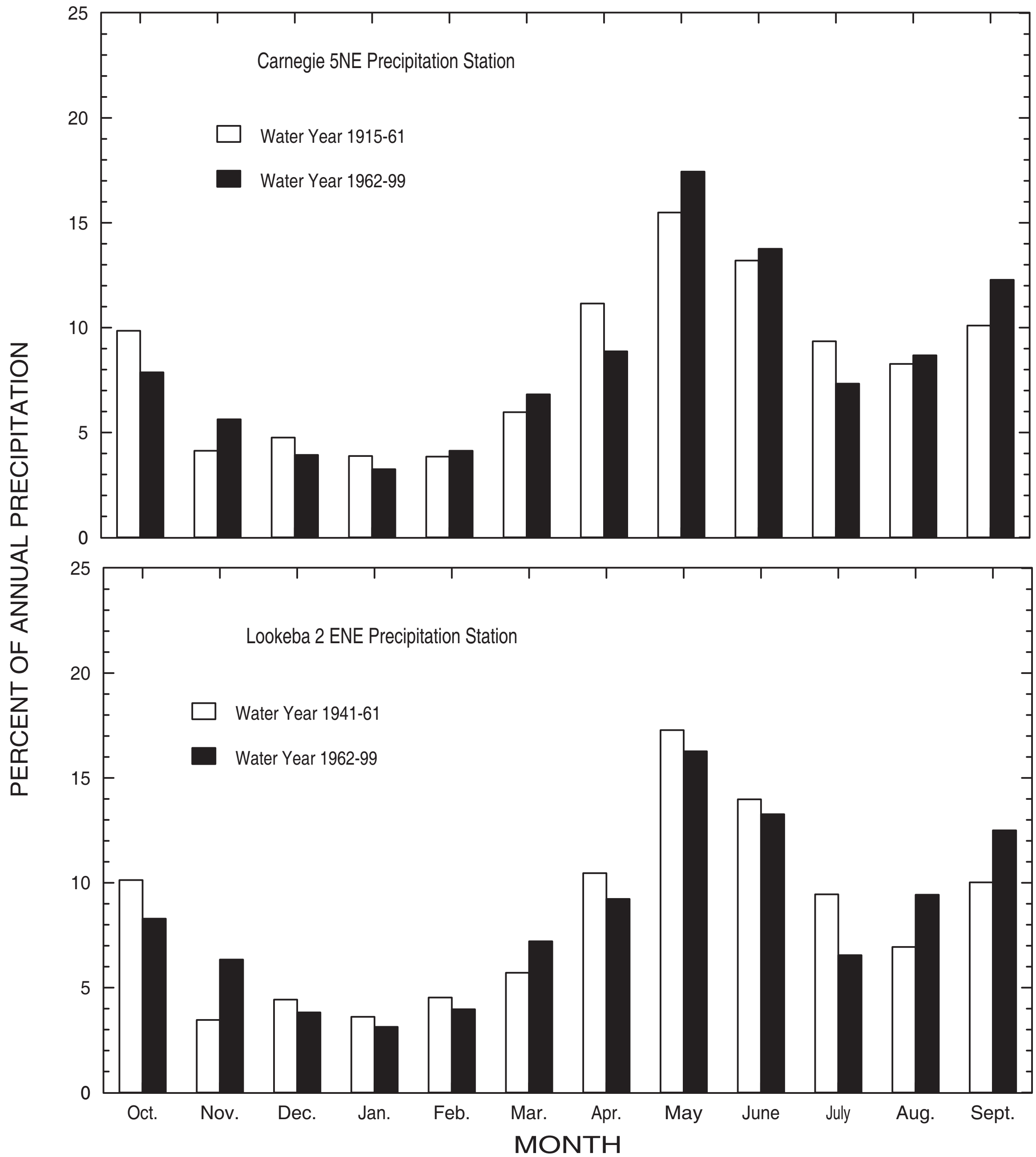


Figure 7. Seasonal distribution of monthly mean precipitation, based on water year (October 1–September 30), for two selected precipitation stations in and near the Wichita and Affiliated Tribes treaty lands, Oklahoma.

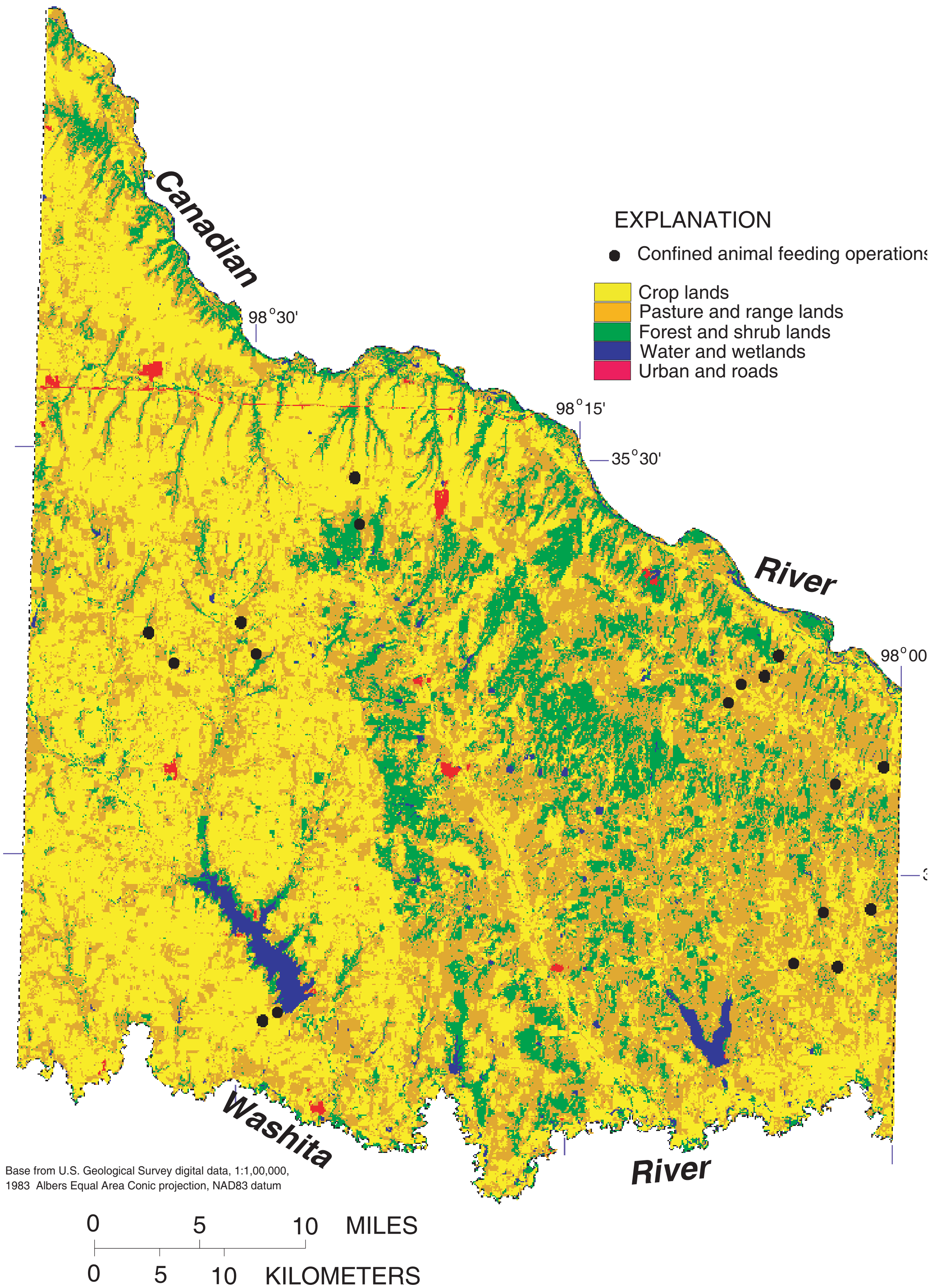


Figure 8. Land use in the Wichita and Affiliated Tribes treaty lands, Oklahoma (U.S. Geologic Survey, 2000)

the southern boundary with three major tributary creeks. The Cobb Creek Basin is in the west, flowing into the Washita River at Fort Cobb. Fort Cobb Reservoir, with a surface-area of 4,100 acres and a capacity of 80,010 acre-feet at normal pool (Oklahoma Water Resources Board, 1990) is the principal reservoir in the tribal treaty lands. The Sugar Creek Basin is in the center of the treaty lands, flowing into the Washita River just east of Anadarko. This basin is heavily regulated by Natural Resources Conservation Service floodwater retarding structures. The Spring Creek Basin is in the east, flowing into the Washita River just northwest of Verden. Lake Chickasha, having a surface area of 820 acres and a capacity of 41,080 acre-feet at normal pool (Oklahoma Water Resources Board, 1990), is located in this basin. Flow in the Washita River main stem is regulated by Foss Reservoir in western Custer County (not shown) and numerous floodwater retarding structures. The streamflow characteristics in the study area can be summarized by the seasonal distribution of streamflow, magnitude and frequency of floods, annual low-flow frequency estimates, and long-term trends.

Seasonal Distribution of Streamflow

Many of the streams in the study area do not flow during low rainfall periods in late summer, late fall, and winter in some years. Seasonal changes in streamflow reflect the quantity and frequency of rainfall and differences in evapotranspiration. Seasonal distribution of streamflow in the tribal treaty lands is shown by monthly mean streamflows, expressed as percent of annual flow, for six selected continuous record streamflow gaging stations (figs. 9, 10). Both unregulated and regulated periods of record are shown. A stream was considered regulated when 20 percent or more of the contributing drainage basin area is controlled by reservoirs (Heimann and Tortorelli, 1988). For the unregulated conditions, March through June are months of greatest average streamflow with 46 to 63 percent of the annual flow occurring in these four months (fig. 10). November through February, July, and August have the least average streamflow; with 25 to 37 percent of the annual flow occurring in these six months. For the present regulated conditions, March through June are months of greatest average streamflow with 49 to 57 percent of annual streamflow occurring in these four months. November through February, July, and August have the least average streamflow with 26 to 36 percent of the annual streamflow occurring in these six months.

Magnitude and Frequency of Floods

A knowledge of the magnitude and frequency of floods is required for the safe and economical design of highway bridges, culverts, dams, levees, and other structures on and near streams. Flood plain management programs and flood-insurance rates also are based on flood magnitude and frequency information. The documented extreme peak discharges and peak-streamflow frequency estimates for nine selected streamflow-gaging stations (fig. 9) are shown in table 2. Frequencies of those peak discharges are expressed as recurrence intervals in years. Both unregulated and regulated periods of record are shown. Canadian River at Bridgeport (07228500) and Cobb Creek near Fort Cobb (07326000), with both unregulated and regulated periods of record, indicated peak streamflows generally decrease with regulation. Washita River at Carnegie (07325500), and Washita River at Anadarko (07326500) indicated a decrease in peak streamflows after regulation at less than the 100-year recurrence and an increase in peak streamflows greater than the 100-year recurrence. Estimates of peak streamflows at Sugar Creek near Gracemont (07327000) were greater after regulation. This difference in the effects of regulation on peak streamflows may be due to analysis of different periods of record, different climatic conditions, the effects of reservoir operations of the major dams, and sites with small drainage basins that may have peak streamflows from very small, intense localized storms. The magnitude and frequency of peak flow may be estimated for streams where streamflow-gaging stations are not available by use of regression equations (Tortorelli, 1997).

Low-Flow Characteristics

Information on low-flow characteristics of streams is essential for water-management agencies charged with regulation of irrigation, municipal and industrial water supplies, fish and wildlife conservation, and assessment of stream capabilities to receive and assimilate treated wastewater. Annual low-flow frequency estimates for six selected continuous record streamflow-gaging stations (fig. 9) are shown in table 3. Frequency of annual low flow is expressed as recurrence interval in years. Both unregulated and regulated periods of record are shown in table 3. The small streams in the study area do not flow during periods in late summer, late fall, and in winter during drier years and, therefore, the unregulated annual low-flow frequency estimates are zero or near zero for a few days. Three sites had both unregulated and regulated periods of record, Canadian River at Bridgeport (07228500), Washita River at Carnegie (07325500), and Cobb Creek near Fort Cobb (07326000). Canadian River at Bridgeport (07228500) and Washita River at Carnegie (07325500) had estimated annual low flows that generally increased with regulation. Cobb Creek near Fort Cobb (07326000) had estimated annual low flows that decreased with regulation. This station is immediately downstream of Fort

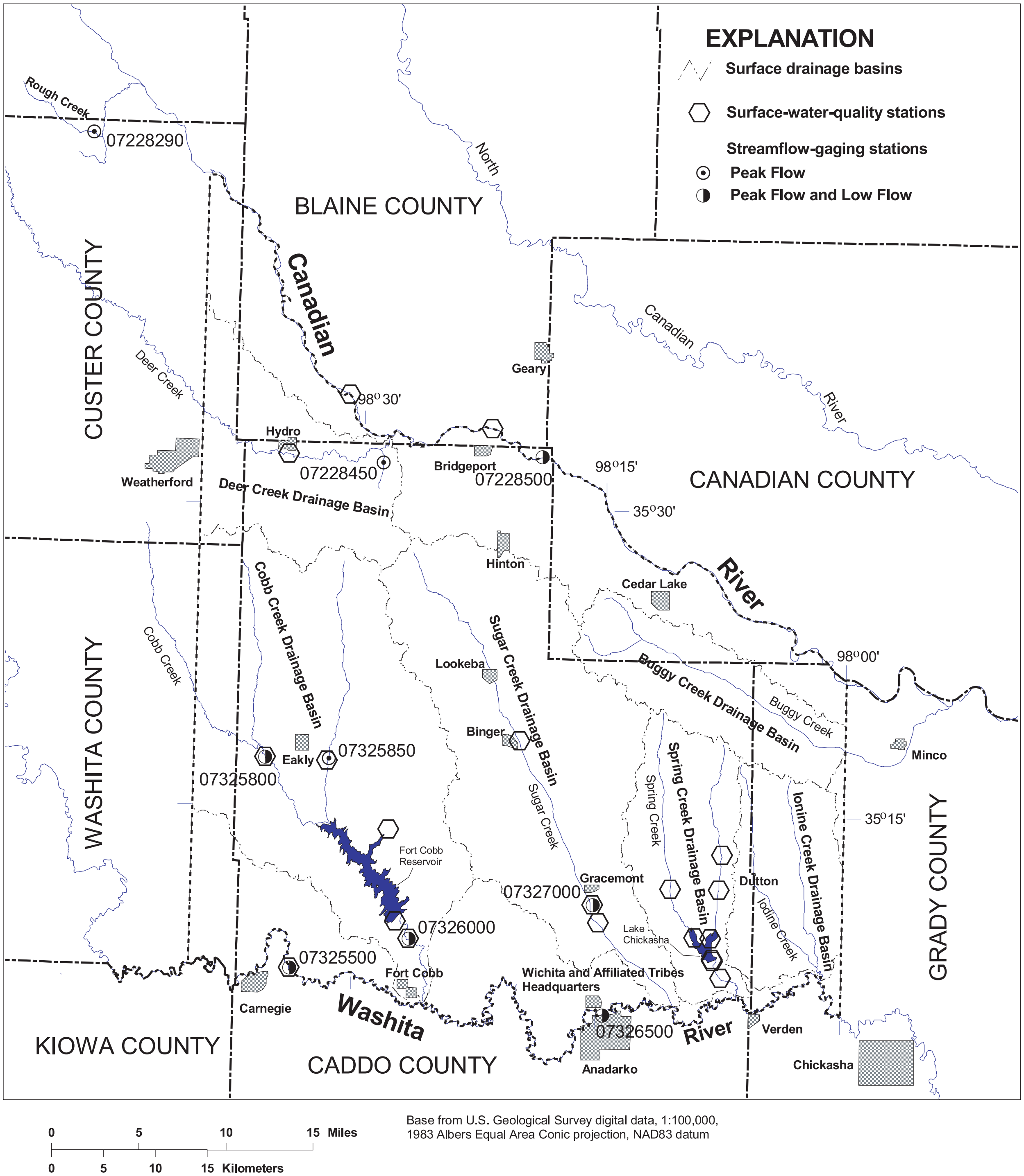


Figure 9. Location of streamflow-gaging stations and surface-water-quality stations in and near the Wichita Affiliated Tribes treaty lands, Oklahoma.

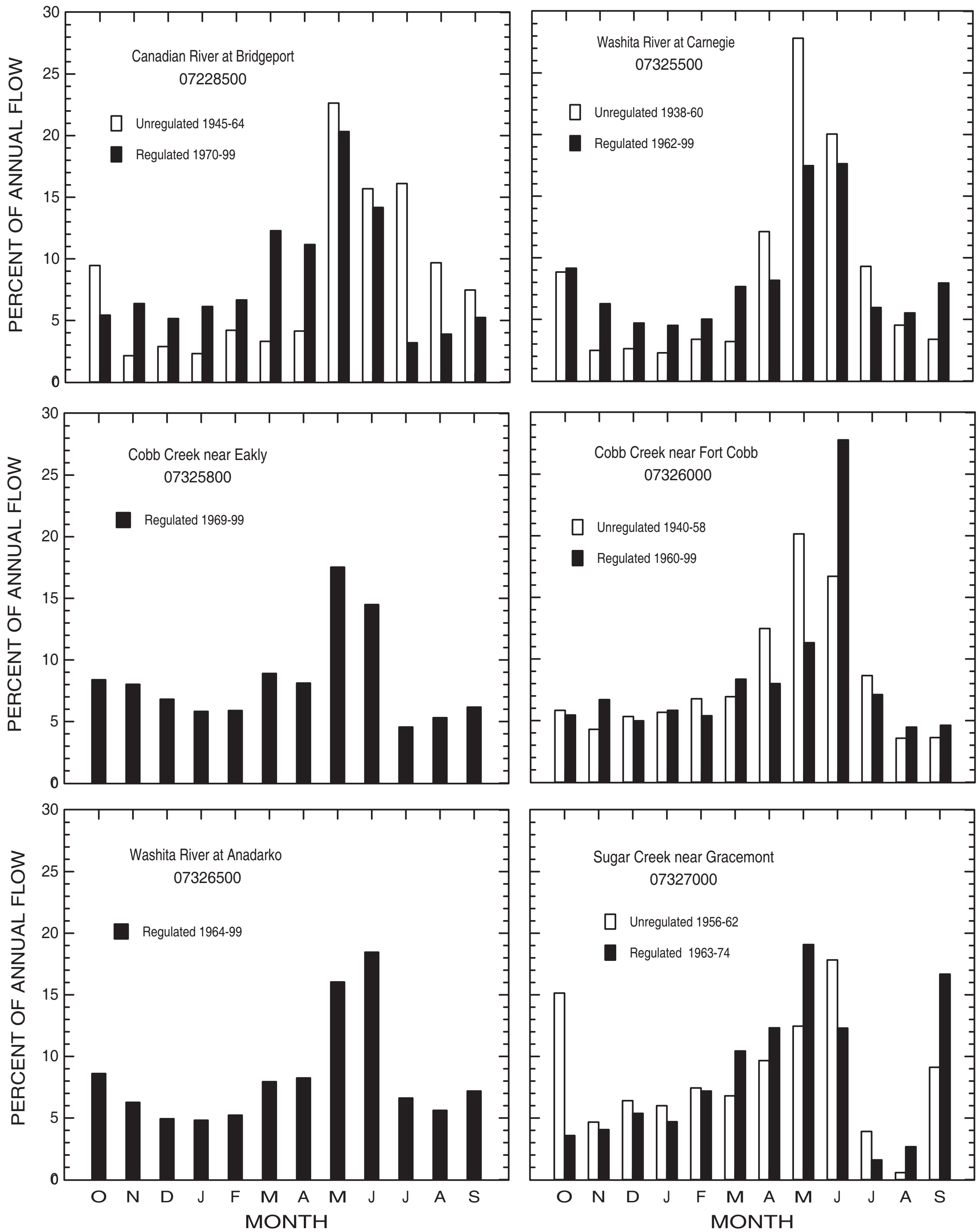


Figure 10. Seasonal distribution of monthly mean streamflows, based on water year (October 1-September 30), for selected continuous record streamflow-gaging stations in and near the Wichita Affiliated Tribes treaty lands, Oklahoma.

Cobb Reservoir dam, therefore streamflow is dependent upon reservoir operations.

Long-Term Trends

Available streamflow records in the study area are not adequate for a study of time trends for more than a few decades. Data from two precipitation stations in and near the study area enabled determination of long-term trends. The two National Weather Service precipitation stations are located near Carnegie (1915-1999) and Lookeba (1941-1999) (fig. 1). The seasonal distribution of precipitation at these stations (fig. 7) was plotted to approximate the unregulated and regulated periods of streamflow in figure 10. The seasonal distribution of precipitation generally matches that of regulated streamflow in the area. There has not been a change in the seasonal distribution of precipitation for the two periods in figure 7.

A common statistical exploratory technique is to look at trends of data smoothed with a LOWESS smooth or LOcally WEighted Scatterplot Smoothing (Helsel and Hirsch, 1992). A LOWESS smooth performed on the entire period of record of the precipitation shows a slight upward trend toward the end of the century (fig. 11). A LOWESS smooth performed on the regulated period of record of the precipitation shows a slight upward trend, with a dip downward coinciding with droughts in the 1990s (fig. 12). A LOWESS smooth of the regulated period of record for the streamflow at Canadian River at Bridgeport (07228500), Cobb Creek near Fort Cobb (07326000), and Washita River at Anadarko (07326500) shows general upward trends (fig. 13). This upward trend in streamflow may be due to the variability of large storm events, effects of reservoir operations of the major dams, and gradual sediment filling of the hundreds of Natural Resources Conservation Service floodwater retarding structures in the Washita River Basin (Kennon, 1966).

Ground-Water Availability

There are greater than 900 ground-water wells in the tribal treaty lands (fig. 14). Eighty percent of the wells are in Caddo County (fig. 1).

Availability of ground water can be considered in two categories on the basis of well capacities. Major aquifers, in this report, are those that are capable of sustaining pumping rates greater than 100 gallons per minute to individual wells, as typically required for irrigation, large industrial, or municipal uses. Conversely, minor aquifers are those with sustained pumping rates as much as, but not exceeding, 100 gallons per minute.

Major Aquifers

The major aquifers in the study area of the tribal treaty lands are the Rush Springs Aquifer and portions of the Canadian River and Washita River valley alluvial aquifers (fig. 15). The Rush Springs Aquifer is used extensively for irrigation as well as industrial and municipal purposes, especially near population centers. The Canadian River and Washita River valley alluvial aquifers are not used extensively in the study area because of the limited areal extent of the aquifers (fig. 15).

Rush Springs Aquifer

The term “Rush Springs Aquifer” as used in this report is composed of the Rush Springs Formation[1] of late Permian, Guadalupian age (fig. 15) (Fay and Hart, 1978). The Rush Springs Aquifer can be greater than 300 feet thick. However, it is truncated in most areas and generally is less than 250 feet thick through the central part of the study area (Becker and Runkle, 1998).

Observations of cores and outcrops within the study area indicate that the Rush Springs Aquifer generally is a homogeneous sandstone throughout most of the study area, with variable amounts and types of cementation. Cements in the Rush Springs Aquifer comprise either calcite or gypsum, with most of the cementation occurring in the upper and lower parts of the sandstone. Cores of the Rush Springs Aquifer taken within the study area comprise primarily very fine to fine-grained quartz that tend to be subround to subangular, moderately to poorly sorted, and frosted (Davis, 1955; Tanaka and Davis, 1963; O'Brien, 1963; and Allen, 1980).

The hydrologic boundaries of the Rush Springs Aquifer are the erosional extent and the Canadian River and the Washita River. The Rush Springs Aquifer over most of the tribal treaty land is a water-table aquifer. Water levels measured in wells from 1986 to 1991 and altitudes of perennial streams were used to prepare a potentiometric-surface map of the Rush Springs Aquifer (fig. 16). Perennial streams are streams that flow during periods of no surface runoff. Ground water flows perpendicular to the water-level contours from highest altitudes to lowest altitudes until the flow path intersects the land surface and discharges as base flow for streams, springs, and seeps. Locally, ground-water flows to streams that incise the Rush Springs Aquifer and intersect the water table.

Water-level measurements in wells indicate that climatic conditions such as droughts and periods of greater than normal precipitation affect the water levels in the Rush Springs Aquifer. Daily average water levels from 1947 through 1996 plotted with total annual precipitation (fig. 17) show the effects of daily changes in water levels in response to precipitation for a well in Caddo County. The hydrographs in figure 18 show the magnitude of annual water-level changes in selected wells in the Rush

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[1]Geologic names and stratigraphic ages in this report are accepted by the Oklahoma Geological Survey and not necessarily the same as those used by the U.S. Geological Survey.

Table 2. Documented extreme peak discharges and peak-streamflow frequency estimates for selected streamflow-gaging stations with lands, Oklahoma

[CONT, continuous record site; dms, degrees, minutes, seconds; CSG, crest-stage partial record site; mi^2, square miles; H, historic; N, unregulated; R, regulated;

Site-identification number (figure 9)	Station name	Type of station (CONT/CSG)	Latitude (dms)	Longitude (dms)	Contributing drainage area (mi^2)	Period of record[1]
07228290	Rough Creek near Thomas	CSG	354808	0984715	10.4	1964-85
07228450	Deer Creek Tributary near Hydro	CSG	353210	0982850	2.31	1964-75
07228500	Canadian River at Bridgeport	CONT	353237	0981903	20,475	1945-64[a]
						1970-99
07325500	Washita River at Carnegie	CONT	350702	0983349	3,129	1938-60[a]
						1962-99
07325800	Cobb Creek near Eakly	CONT	351726	0983538	132	1969-99
07325850	Lake Creek near Eakly	CONT	351727	0983144	52.0	1970-78
07326000	Cobb Creek near Fort Cobb	CONT	350837	0982633	307	
						1940-58[a]
						1960-99
07326500	Washita River at Anadarko	CONT	350503	0981435	3,656	1903-08, 36-37[a]
						1964-99
07327000	Sugar Creek near Gracemont	CONT	351030	0981520	208	
						1956-62[a]
						1963-74

[1]Based on water year starting October 1 and ending September 30

a Record according to operation of continuous record site, earlier historic peak dates not included at least eight years of annual peak-streamflow data from unregulated and regulated basins in and near the Wichita and Affiliated Tribes

ft^3/s, cubic feet per second; LPIII, Log-Pearson Type III; yr, year]

Site-identification number	Type of record (H,N,R)	Documented extreme peak discharge		Peak-streamflow LPIII frequency estimates: Peak discharge for indicated recurrence interval (ft^3/s)						
		Date	Discharge (ft^3/s)	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	500 yr
07228290	N	05/23/81	6,270	794	2,170	3,690	6,500	9,390	13,100	25,600
07228450	N	09/21/65	1,050	304	539	741	1,060	1,340	1,670	2,640
07228500	N	06/23/48	150,000	26,200	45,300	60,000	80,900	97,900	116,000	164,000
	R	05/17/82	86,100	16,200	31,400	43,800	61,700	76,600	92,700	135,000
07325500	N	05/19/49	50,000	9,210	17,000	23,600	33,700	42,600	52,700	81,500
	R	10/20/83	40,600	5,740	12,000	18,500	30,000	41,900	57,200	111,000
07325800	R	06/04/95	12,000	2,060	4,490	7,060	11,800	16,800	23,300	47,000
07325850	N	05/20/77	7,000	707	1,850	3,160	5,740	8,560	12,400	26,900
07326000	HN	06/15/37	51,000							
	N	05/17/49	35,000	4,420	10,500	16,900	28,700	40,800	56,500	112,000
	R	06/23/87	1,280	535	1,020	1,340	1,680	1,900	2,100	2,440
07326500	N	05/25/03	29,000	8,720	18,300	27,400	42,600	57,200	74,700	130,000
	HN	05/18/49	45,000							
	R	06/06/95	52,800	4,640	10,400	17,300	31,800	49,000	72,200	186,000
07327000	HN	05/17/49	32,000							
	N	10/04/59	1,260	1,260	2,930	4,690	7,910	11,200	15,400	30,200
	R	09/21/65	8,500	1,480	3,520	5,730	9,940	14,400	20,300	42,100

Table 3. Annual low-flow frequency estimates for selected continuous record streamflow-gaging stations with at least 10 years of streamflow data from unregulated and regulated basins in and near the Wichita and Affiliated Tribes treaty lands, Oklahoma

[1][mi^2, square miles; N, unregulated; R, regulated; ft^3/s, cubic feet per second; LPIII, Log-Pearson Type III; yr, year]

Site-identification number	Station name	Contributing drainage area (mi^2)	Period of record[1]	Type of record (N/R)	Consec-utive days	Annual low flow LPIII frequency estimates: Discharge for indicated recurrence interval (ft^3/s)			
						2 yr	5 yr	10 yr	20 yr
07228500	Canadian River at Bridgeport	20,475	1946-64	N	1	1.61	0.00	0.00	0.00
					3	2.27	0.00	0.00	0.00
					7	3.08	0.00	0.00	0.00
					10	3.64	0.00	0.00	0.00
			1971-99	R	1	6.37	1.41	0.00	0.00
					3	6.90	1.53	0.00	0.00
					7	7.76	1.81	0.00	0.00
					10	8.55	2.10	0.00	0.00
07325500	Washita River at Carnegie	3,129	1939-60	N	1	21.2	6.21	2.33	0.85
					3	21.5	6.60	2.91	1.31
					7	22.0	7.38	3.79	2.01
					10	23.0	7.84	4.04	2.15
			1963-99	R	1	33.6	7.51	2.49	0.70
					3	34.2	8.19	2.95	0.93
					7	36.5	9.73	3.87	1.39
					10	37.9	11.2	4.96	2.04
07325800	Cobb Creek near Eakly	132	1970-99	R	1	3.34	0.85	0.24	0.00
					3	3.72	0.96	0.36	0.09
					7	4.10	1.13	0.45	0.19
					10	4.13	1.35	0.65	0.33
07326000	Cobb Creek near Fort Cobb	307	1941-58	N	1	7.68	3.11	1.51	0.72
					3	7.97	3.23	1.56	0.74
					7	8.41	3.39	1.68	0.82
					10	8.74	3.52	1.75	0.86
			1961-99	R	1	1.59	0.92	0.63	0.44
					3	1.69	1.02	0.70	0.48
					7	1.82	1.13	0.78	0.54

Table 3. Annual low-flow frequency estimates for selected continuous record streamflow-gaging stations with at least 10 years of streamflow data from unregulated and regulated basins in and near the Wichita and Affiliated Tribes treaty lands, Oklahoma—Continued

[1][mi^2, square miles; N, unregulated; R, regulated; ft^3/s, cubic feet per second; LPIII, Log-Pearson Type III; yr, year]

Site-identification number	Station name	Contributing drainage area (mi^2)	Period of record[1]	Type of record (N/R)	Consecutive days	Annual low flow LPIII frequency estimates — Discharge for indicated recurrence interval (ft^3/s) 2 yr	5 yr	10 yr	20 yr
					10	1.90	1.19	0.94	0.76
07326500	Washita River at Anadarko	3,656	1965-99	R	1	57.2	11.7	3.42	0.76
					3	58.5	12.9	4.93	1.99
					7	59.0	15.3	6.56	2.99
					10	59.3	16.9	7.60	3.64
07327000	Sugar Creek near Gracemont	208	1964-74	R	1	0.00	0.00	0.00	0.00
					3	0.00	0.00	0.00	0.00
					7	0.00	0.00	0.00	0.00
					10	0.00	0.00	0.00	0.00

[1]Based on climatic year starting April 1 and ending March 31

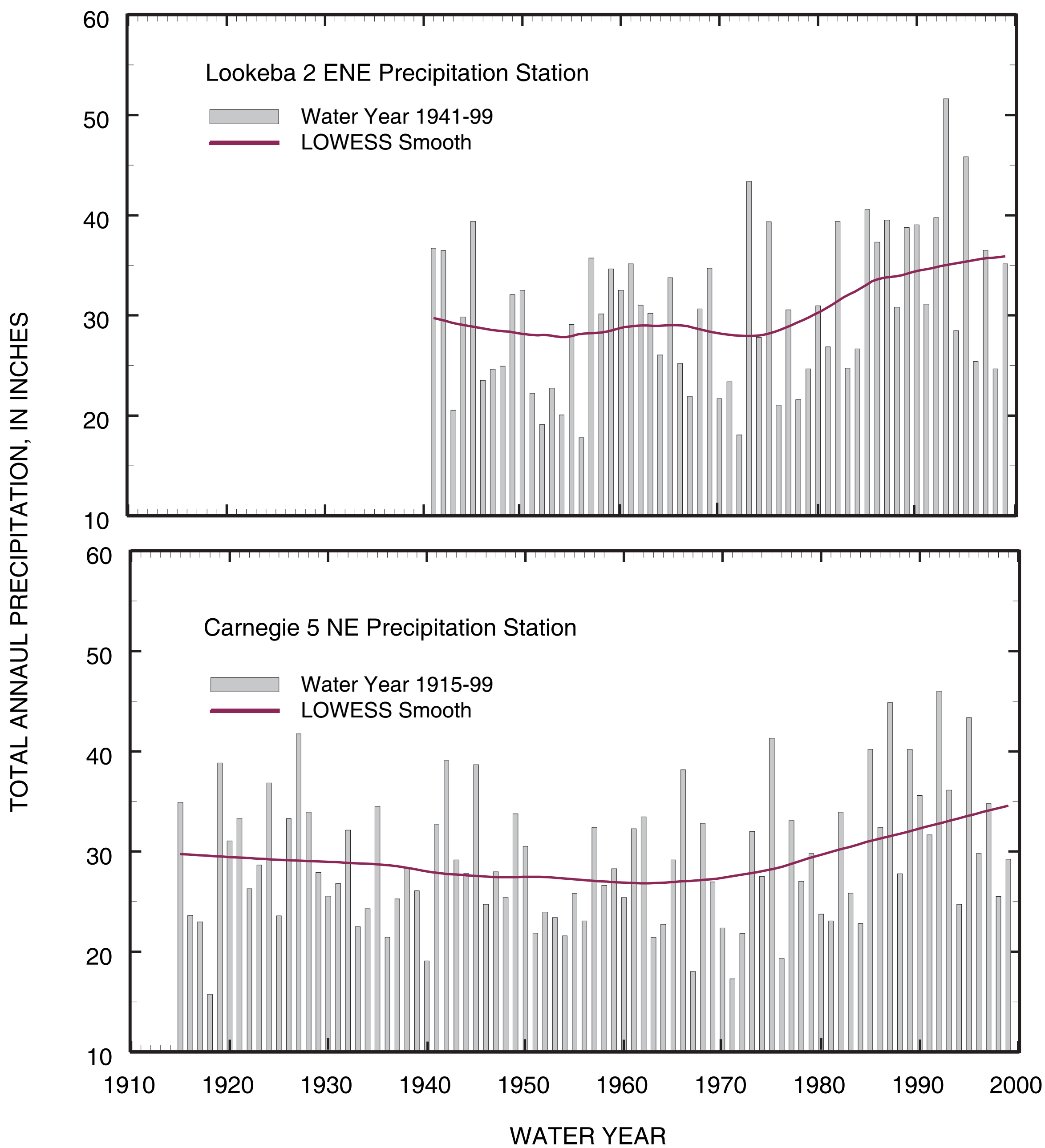


Figure 11. Total annual precipitation and LOWESS smooth for the entire period of record for two selected precipitation stations in and near the Wichita and Affiliated Tribes treaty lands, Oklahoma.

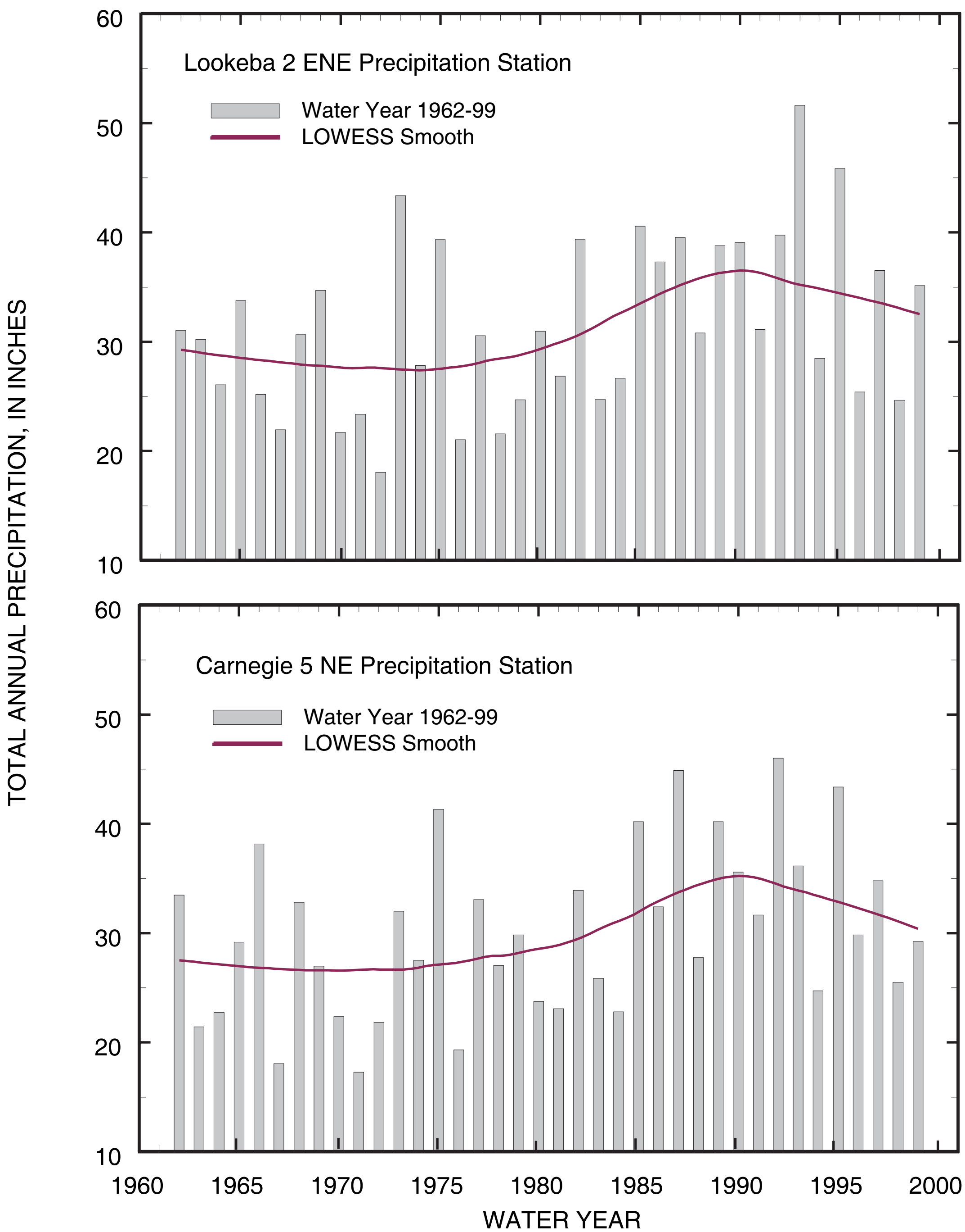


Figure 12. Total annual precipitation and LOWESS smooth for the regulated streamflow period of record at two selected precipitation stations in and near the Wichita Affiliated Tribes treaty lands, Oklahoma.

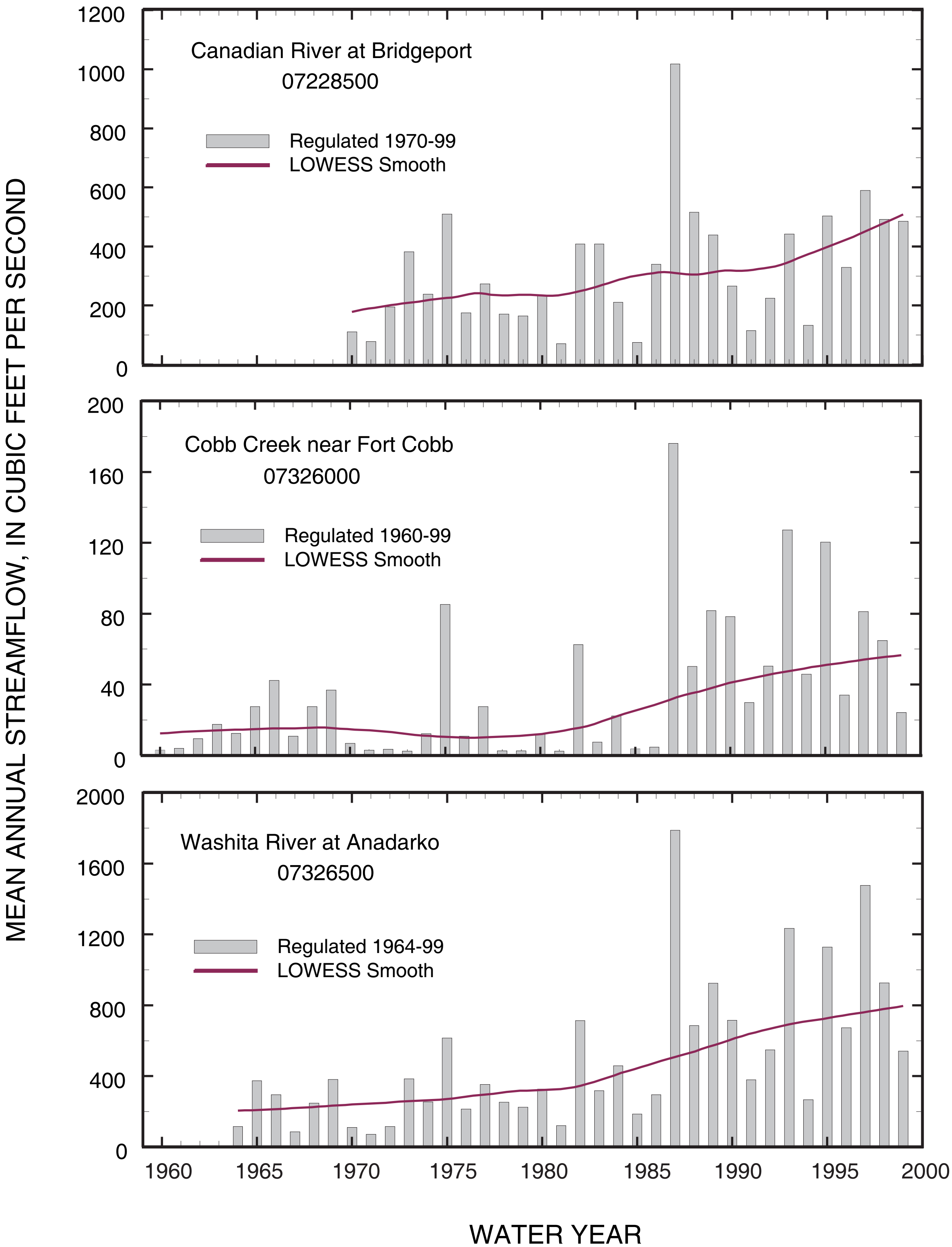


Figure 13. Mean annual streamflow and LOWESS smooth for the regulated period of record at three selected streamflow-gaging stations in and near the Wichita and Affiliated Tribes treaty lands, Oklahoma.

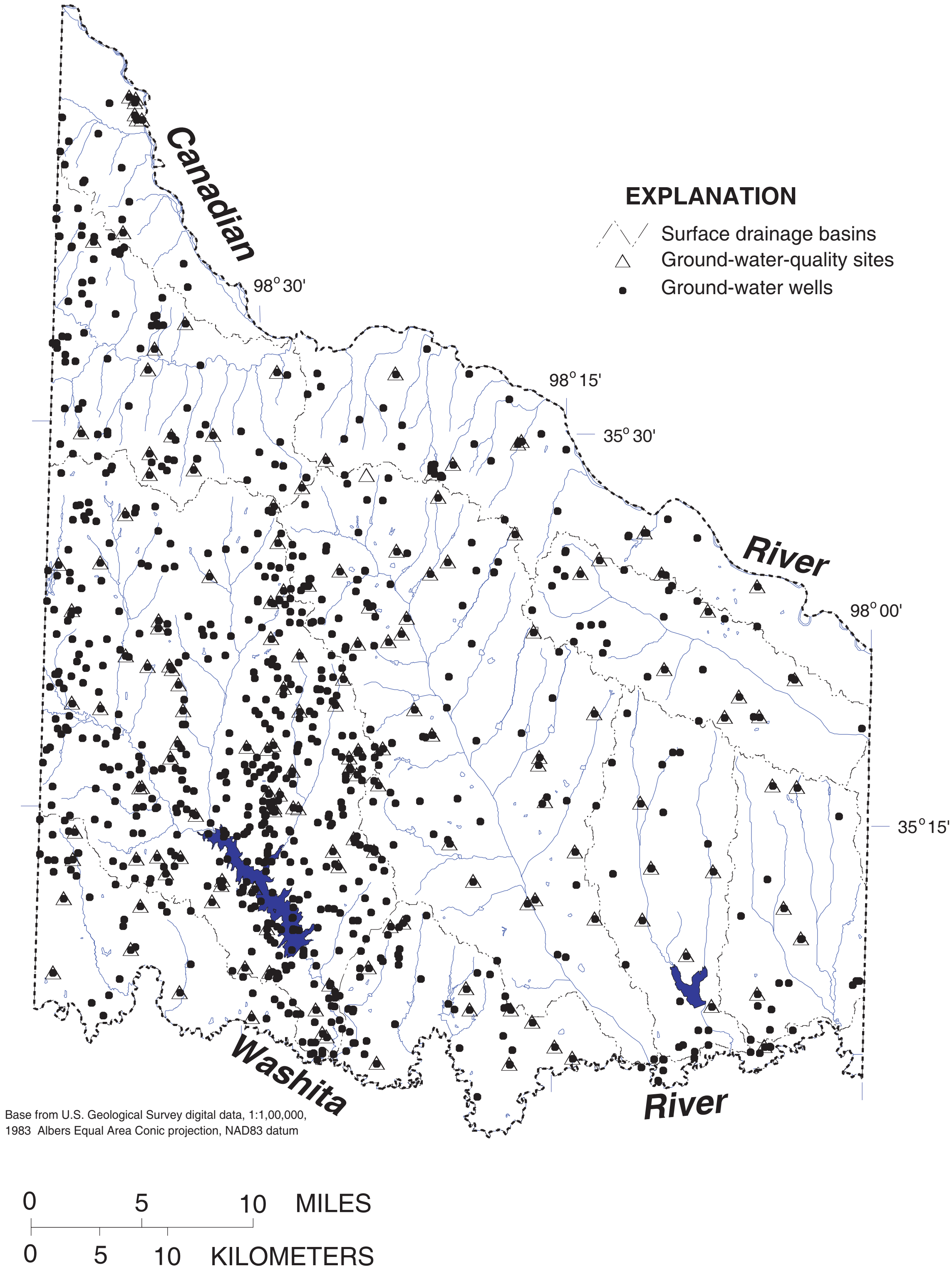


Figure 14. Location of wells and ground-water-quality sites in the Wichita and Affiliated Tribes treaty lands, Oklahoma.

Era (geologic time scale)[1]	Geologic system/ series		Stratigraphic unit	Geohydrologic unit[2]	Character and distribution[2]	Aquifer or confining unit and water-bearing characteristics
Cenozoic	QUATERNARY		Alluvial deposits	Alluvial aquifer system	Includes sand, gravel, silt, and clay. These deposits are most continuous and thickest beneath flood plains of major streams. Along the smaller stream valleys, alluvial deposits may be capable of yielding moderate water supplies. Thickness ranges from 0 to about 170 feet.	Canadian River Valley alluvial aquifer—well yields generally are 150 to 300 gallons per minute. Restricted to deposits underlying the flood plain along the Canadian River. Washita River Valley alluvial aquifer—well yields generally are 25 to 150 gallons per minute. Restricted to deposits underlying the flood plain along the Washita River. In smaller stream-valley alluvial aquifers well yields are generally less than 25 gallons per minute.
			Terrace deposits	Terrace aquifer system	Include sand, gravel, silt, clay, and volcanic ash deposits that make up the surficial materials in the upland areas and are thickest near the larger streams. Thickness ranges from 0 to about 120 feet.	Restricted to unconsolidated deposits out of the flood plain. Well yields generally are 25 to 150 gallons per minute.
Paleozoic	PERMIAN	OCHOAN	Cloud Chief Formation	Cloud Chief Confining Unit	Interbedded with siltsone and sandstone in the middle part and some dolomite and much gypsum in lower part. Thickness is about 400 feet, thinning northward to about 175 feet.	Confining unit
		GUADALUPIAN	Weatherford Bed Rush Springs Formation	Rush Springs Aquifer	Predominately massive to highly cross-bedded fine-grained sandstone with some dolomite and gypsum beds. Thickness ranges from 0 to more than 300 feet.	Well yields generally are greater than 300 gallons per minute, in areas where the aquifer is thickest. Well yields are 25 to 150 gallons per minute, near the eroded edge of the aquifer.
			Verden Sandstone Marlow Formation	Marlow Aquifer	Predominately fine-grained sandstone with much gypsum and shale beds. Thickness ranges from 0 to about 100 feet.	Well yields are 1 to 2 gallons per minute.

[1]Geologic time scale from Holmes (1959).
[2]Modified from Carr and Bergman, (1976).

Figure 15. Geohydrologic systems and associated water-bearing characteristics in and near the Wichita and Affiliated Tribes treaty lands, Oklahoma.

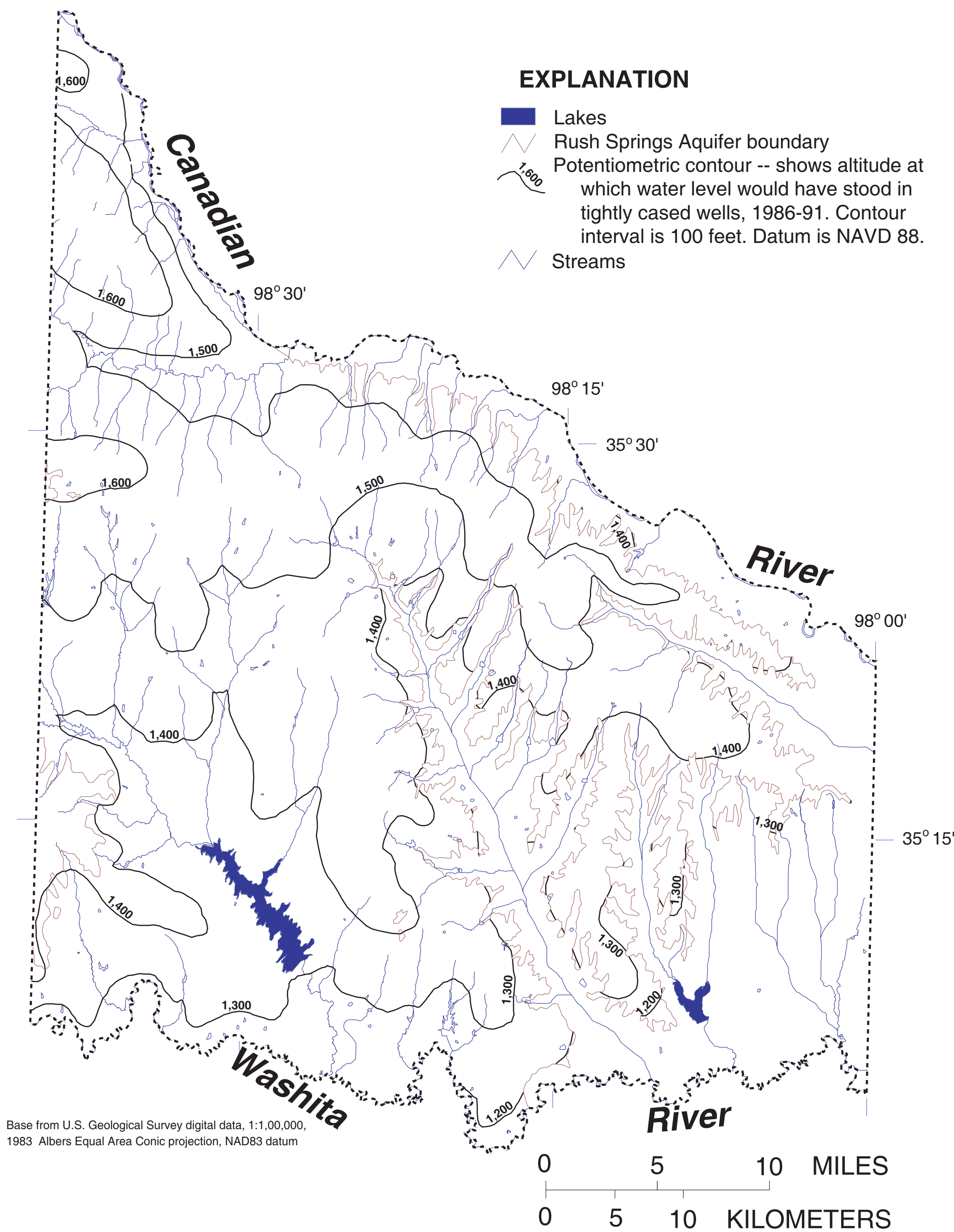


Figure 16. Altitude and configuration of the potentiometric surface in the Rush Springs Aquifer in the Wichita and Affiliated Tribes treaty lands, Oklahoma (Becker and others, 1998).

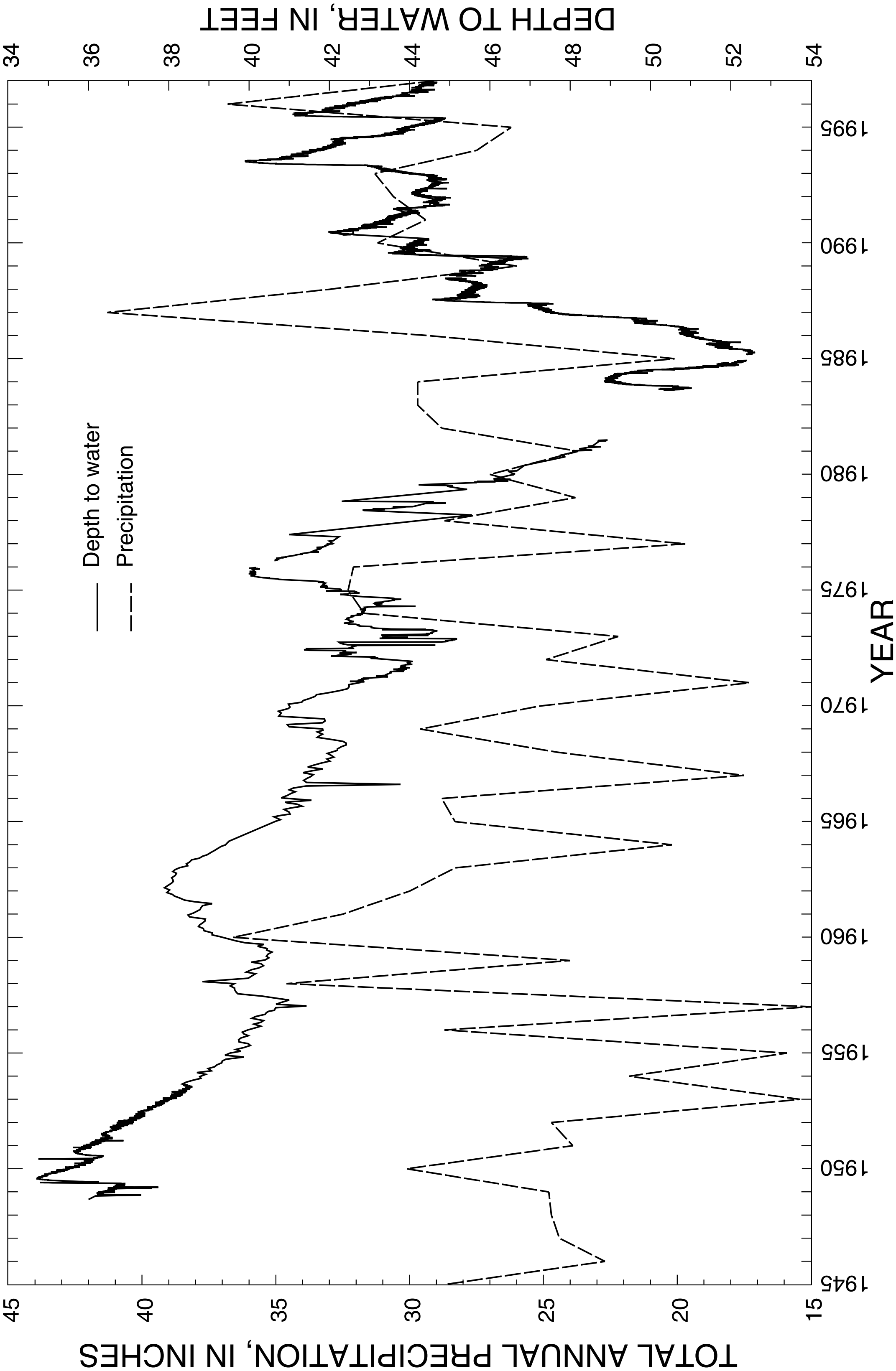


Figure 17. Depth to water recorded in well at 9N-13W-28 D in Caddo County and average annual precipitation in climatic division 4.

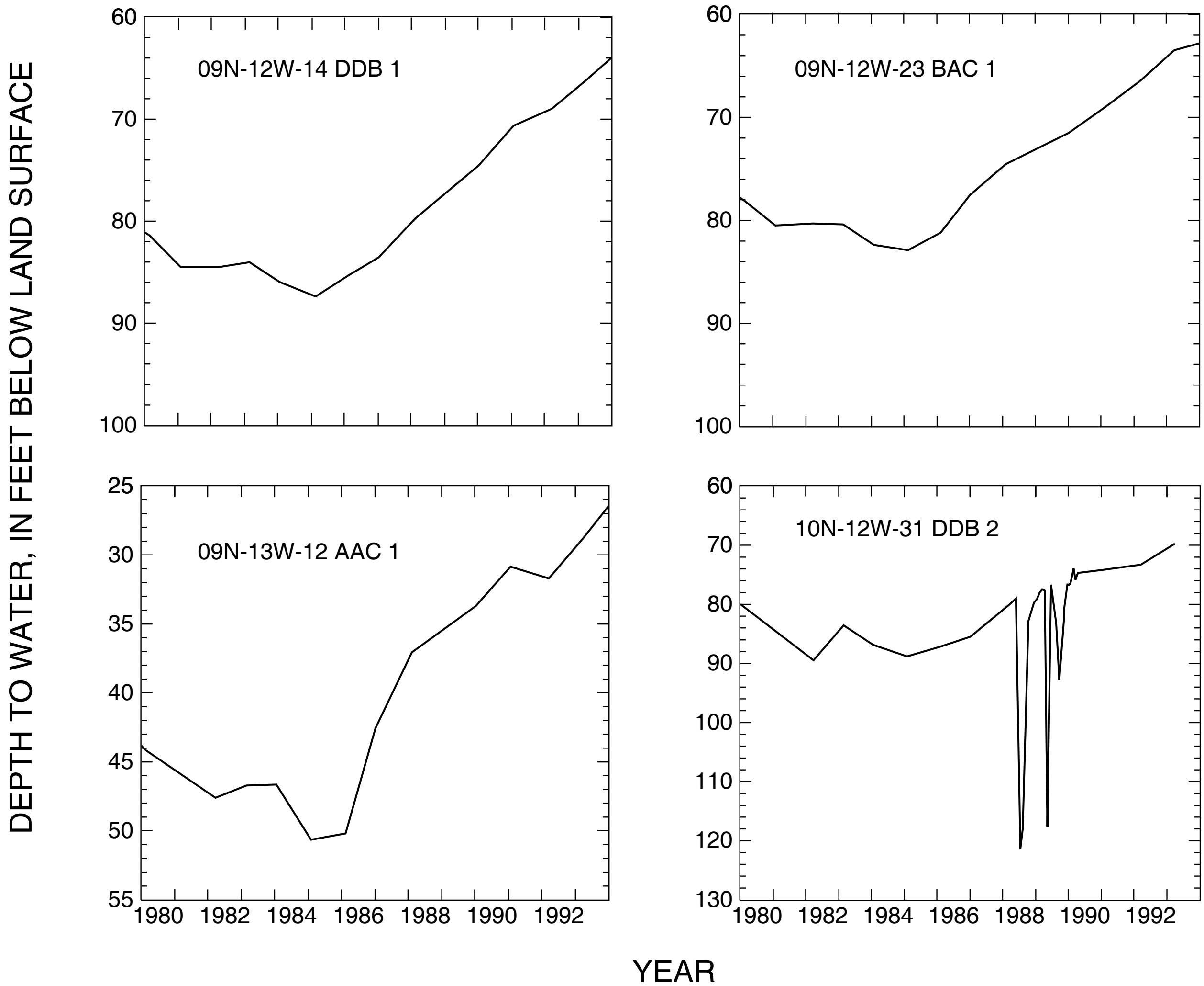


Figure 18. Annual water-level measurements in wells in the Rush Springs Aquifer in the Wichita and Affiliated Tribes treaty lands, Oklahoma.

Springs Aquifer. Water-level changes measured in well 10N-12W-31 DDB2 from 1979-1992 (fig. 18) are based on quarterly measurements, and the steep declines and recoveries are possibly the result of seasonal irrigation withdrawals (Becker and Runkle, 1998).

Well yields from the Rush Springs Aquifer vary, but the most productive irrigation wells produce more than 1,000 gallons per minute (Tanaka and Davis, 1963). Drillers' logs for 89 wells in the Rush Springs Aquifer report discharges that ranged from 11 to 850 gallons per minute, with a mean discharge of 209 gallons per minute.

Specific capacity is the pumping rate divided by the water-level drawdown within the well as a result of the pumping. Specific capacities calculated for the 89 wells ranged from 0.7 to 15 gallons per minute per foot of drawdown, with a mean of 2.3 gallons per minute per foot.

Transmissivity, defined by Lohman and others (1972), is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Transmissivities estimated from four aquifer tests conducted by Tanaka and Davis (1963) ranged from 670 to 1,740 feet squared per day. Davis (1955) reported transmissivities ranging from 670 to 1,870 feet squared per day.

The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman and others, 1972). Storage coefficient is a term usually used when describing storage in confined aquifers. Calculated storage coefficients ranged from 0.0035 to 0.02.

The specific yield of a rock or soil is the ratio of the volume of water that the rock or soil, after being saturated, will yield by gravity to its own volume (Lohman and others, 1972). Tanaka and Davis (1963) reported that specific yields, from core samples of the Rush Springs Aquifer, ranged from 0.13 to 0.34, with a mean of 0.25.

The 3M Company conducted a hydrologic investigation at a site in the town of Weatherford (U. S. Geological Survey files, Oklahoma City, OK, written commun., 1991). The investigation included slug and pumping tests in wells completed in the Rush Springs Aquifer. Hydraulic conductivity is a measure of how quickly water moves through an aquifer. Hydraulic conductivities estimated from slug tests ranged from 1.05 to 5.62 feet per day with a mean of 2.30 feet per day. Hydraulic conductivities estimated from pumping tests ranged from 3.84 to 4.41 feet per day.

Local variations of hydraulic conductivity are due to the degree of cementation present in the Rush Springs Aquifer. One example is the area south of the tribal treaty lands, where the Rush Springs Aquifer has been diagenetically altered. The Rush Springs Aquifer has a high degree of cementation resulting in lower estimated hydraulic conductivities. No aquifer tests for this area were available, but based on specific capacities calculated from drillers' logs, hydraulic conductivities in this area were estimated to be less than 1 foot per day in some cases.

An estimate of the saturated thickness (fig. 19) was generated, using the geographic information system software ARC/INFO, by subtracting the elevation of the base of the aquifer from the potentiometric surface. The map (fig. 19) illustrates general trends of saturated thickness and should not be used to derive the saturated thickness for a specific location.

The Rush Springs Aquifer is recharged by the infiltration of precipitation. The estimated recharge is about 1.80 inches per year evenly distributed over the outcrop of the aquifer in the study area (Becker and Runkle, 1998).

Canadian and Washita River Valley Alluvial Aquifers

The Canadian and Washita River valley alluvial aquifers, which are restricted to the flood plains and terraces along the rivers, also are potential water resources in the study area. Water availability from the aquifer is directly affected by variations in aquifer lithology, which consists of Quaternary-age sand, gravel, silt, and clay. Large-capacity wells are possible in these aquifers where thick sequences of coarse material are present. Coarse materials have greater hydraulic conductivity that increase the possibility of induced recharge from the surface water in the rivers to pumping wells. Thicknesses of the sediments range from zero at the valley walls to as much as 170 feet in the deepest part of the buried channel (fig. 15) (Carr and Bergman, 1976). Reported hydraulic conductivity, 10 miles north of the tribal treaty lands, for the North Canadian River alluvial aquifer was 38.9 feet per day (Christenson, 1983).

The Canadian River valley alluvial aquifer in the tribal treaty lands has 10 wells reported for irrigation usage (Mark Beldon, Oklahoma Water Resources Board, written commun., 2000). Some of these wells have reported yields greater than 300 gallons per minute. The Washita River valley alluvial aquifer has six wells in the tribal treaty lands and one was reported to yield greater than 300 gallons per minute.

The water supplies of the Canadian and Washita River valley alluvial aquifers in the tribal treaty lands are not used extensively because of potential problems from flooding. Much of these aquifers lie in flood-prone areas where well-head protection and water-supply facilities need to be elevated or otherwise protected from surface contamination during flooding.

Minor Aquifers

Minor aquifers that occur throughout the study area include the Marlow Aquifer and small stream-valley alluvial aquifers (fig. 15).

Marlow Aquifer

The Marlow Aquifer is part of the Marlow Formation of late Permian, Guadalupian age (fig. 15) (Fay and Hart, 1978). The Marlow Aquifer underlies the Rush Springs Aquifer and is composed of interbedded sandstone, siltstone, mudstone, gypsum-anhydrite, and dolomite. The Marlow Formation is about 90 to 100 feet thick, and has been interpreted as being deposited

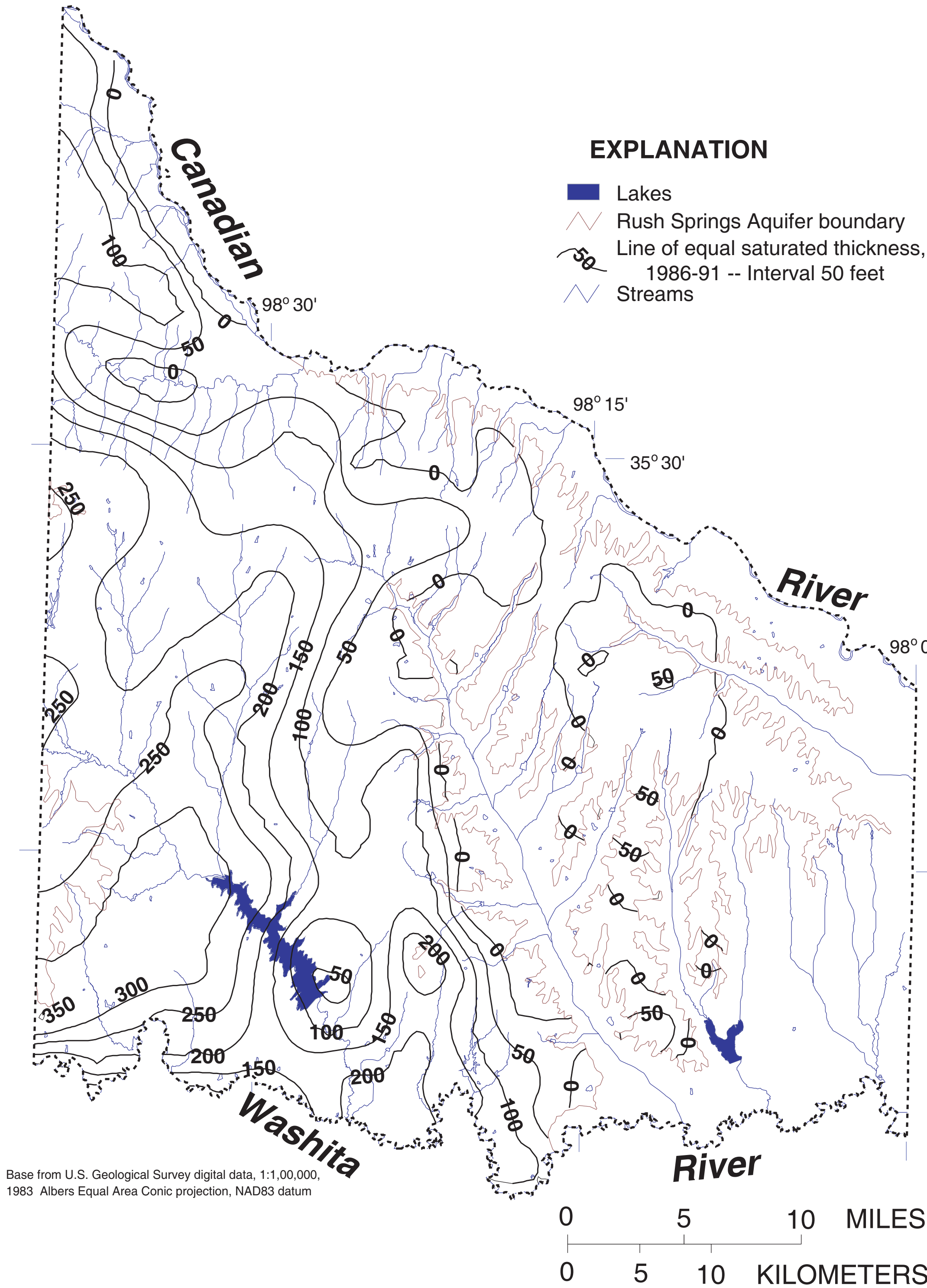


Figure 19. Saturated thickness of the Rush Springs Aquifer in the Wichita and Affiliated Tribes treaty lands, Oklahoma (Becker and others, 1998).

in a near-shore marine environment that includes (1) a brackish-water to near-shore-marine setting (Fay, 1962) and (2) a tidal flat bordering an open marine environment (MacLachlan, 1967). The Verden Sandstone within the Marlow Formation (fig. 15) has been interpreted as a near-shore strandline deposit (Bass, 1939), whereas Evans (1948) interpreted the Verden Sandstone as a channel deposit. Cores show that the primary cement in the Marlow Formation is gypsum with minor amounts of carbonate. The Marlow Formation is moderately to well-cemented, with extremely low primary permeability, generally retarding downward movement of water from the Rush Springs Aquifer to underlying units (Becker and Runkle, 1998). Selenite crystals in the mudstone and siltstone units, as well as bedded gypsum ranging in thickness from paper-thin to one foot indicate that waters in the Marlow Formation probably were saturated with gypsum.

Water from the Marlow Aquifer, where potable, is used primarily for domestic use. Well yields are much less than those from the Rush Springs Aquifer, ranging from 1 to 2 gallons per minute (Tanaka and Davis, 1963). Water from the Marlow Aquifer, where it is overlain by a thin section of the Rush Springs Aquifer or exposed at land surface, is generally potable. However, in areas where the Marlow Aquifer is deeply buried, it is not used for drinking water because of the large concentrations of dissolved sulfate from gypsum.

Small Stream-Valley Alluvial Aquifers

Small stream-valley alluvial aquifers in this report refer to all stream-valley alluvial aquifers except the Canadian River and Washita River valley alluvial aquifers. Although most of the small stream-valley alluvial aquifers in the study area contain clayey or silty alluvium, the alluvial deposits commonly have some coarser material near the deepest parts of the valleys capable of yielding small water supplies to wells. Test drilling is necessary to delineate the deepest parts of the valleys where the coarser materials are frequently found.

Water Quality

Principal factors affecting the water quality in the study area include geology, agricultural practices, and oil and gas production. Calcium, magnesium, sulfate, and bicarbonate are the dominant dissolved constituents in water in the study area due to dissolution of bedrock and sediment, which consist primarily of sandstone, shales, gypsum, and anhydrites. Agricultural practices may result in increased pesticide, fertilizer, and fecal bacteria concentrations in surface-water runoff and ground water.

There are 181 water-quality analyses available, during 1947-2000, for 160 ground-water wells in the area. There are 3,138 water-quality analyses available for 20 surface-water sites in the study area. Ninety-five percent of the analyses are from seven surface-water sites that were monitoring select constituents for 1942-1999. The ground-water data used in figures 20a through 25a also are used in figures 20b through 25b.

Water Properties

Acidity of water is measured by pH. According to Hem (1985), the pH of river water in areas not affected by contamination generally ranges from 6.5 to 8.5 standard units. In areas where photosynthesis by aquatic organisms take up carbon dioxide during daylight and releases carbon dioxide at night, pH fluctuations may occur, and the maximum pH value may be as great as 9.0. In contrast, other factors such as oxidation of dissolved ferrous iron, decrease the pH. The U.S. Environmental Protection Agency (2001) recommends a Secondary Drinking Water Standard for pH from 6.5 to 8.5 for drinking-water supplies. On the basis of available water-quality analyses, pH in surface-water samples in the study area ranged between 4.0 and 9.6 standard units. In ground-water samples, pH ranged from 6.5 to 8.4.

Alkalinity is the capacity of a solute to neutralize acid (Hem, 1985) and is expressed as milligrams per liter of calcium carbonate ($CaCO_3$). Bicarbonate is the dominate carbonate species for the pH range of 6.5 to 8.5 for surface water and ground water in the study area. Bicarbonate concentrations in water are calculated by dividing alkalinity, as calcium carbonate, by 0.8202 (Hem, 1985). Alkalinities in surface- and ground-water samples in the study area were similar. Alkalinities in surface water ranged from 25 to 388 milligrams per liter, with concentrations for the interquartile between 118 and 218 milligrams per liter. The interquartile represents half of the sampled values and is between the 25th and 75th percentiles (Ott, 1993, p. 82). Alkalinities in surface water generally were proportional to the concentrations of calcium and magnesium. Alkalinities in ground water ranged from 10 to 472 milligrams per liter, with concentrations for the interquartile between 132 and 232 milligrams per liter.

Dissolved Solids

Dissolved solids in water consist primarily of the cations calcium, magnesium, sodium, and potassium and the anions bicarbonate, chloride, and sulfate. According to the U.S. Environmental Protection Agency (2001), excess dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable mineral tastes, and greater costs because of corrosion or the necessity for additional treatment. The USEPA Secondary Drinking Water Standard for dissolved solids is 500 milligrams per liter (U.S. Environmental Protection Agency, 2001).

Interquartile dissolved-solids concentrations in surface-water samples in the study area were greater than interquartile concentrations in ground-water samples (fig. 20a). Dissolved-solids concentrations in surface water ranged from 15 to 2,460 milligrams per liter, with the interquartile between 579 and 1,620 milligrams per liter. Concentrations of dissolved solids in

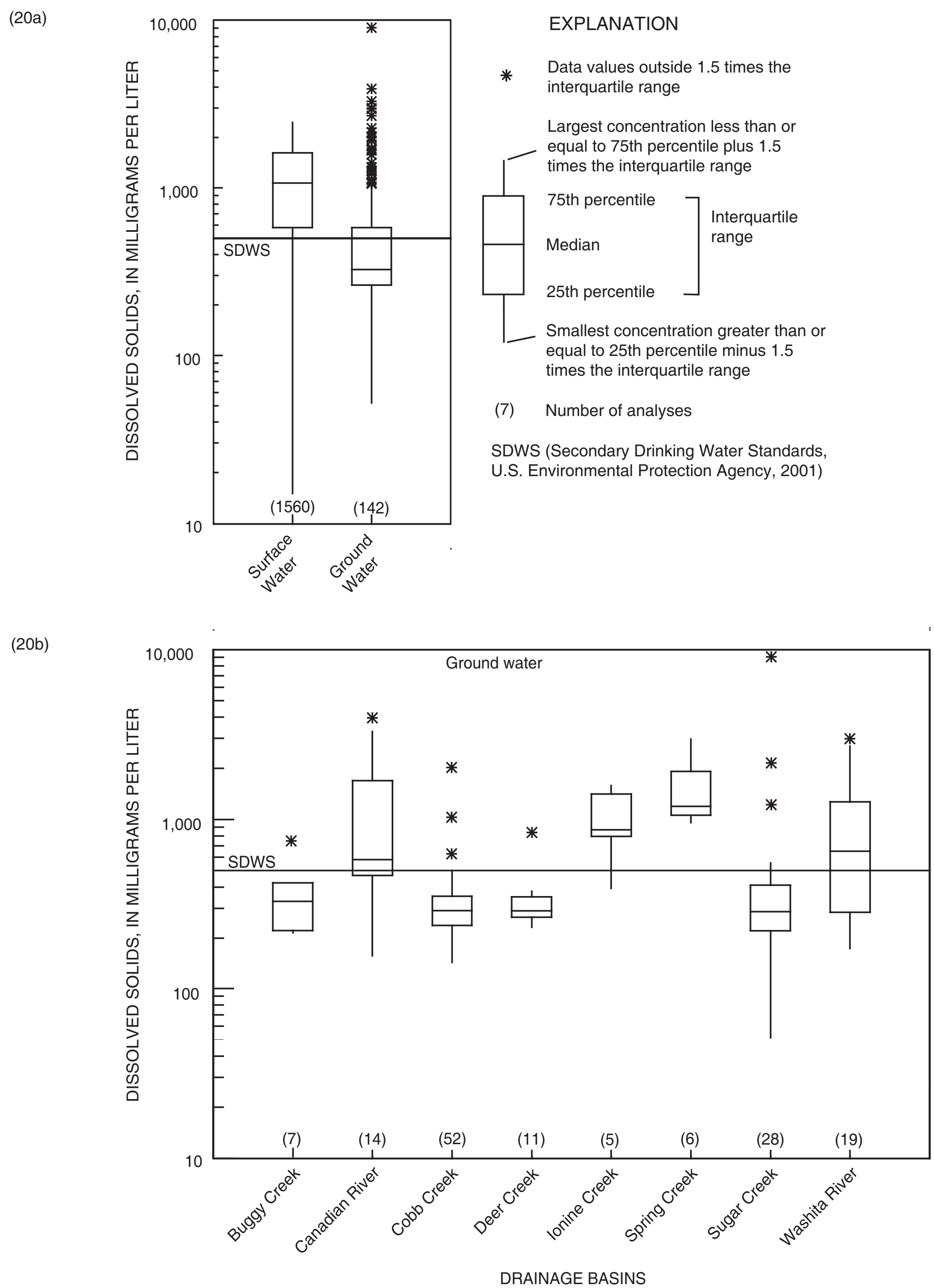


Figure 20. Dissolved-solids concentrations in surface water and ground water (20a) and by ground water in drainage basin (20b) in the Wichita Affiliated Tribes treaty lands, Oklahoma.

ground water ranged from 52 to 9,040 milligrams per liter, with the interquartile between 264 and 574 milligrams per liter (fig. 20a). Median dissolved-solids concentrations for ground-water samples from Canadian River, Ionine Creek, Spring Creek, and Washita River Basins exceeded the USEPA Secondary Drinking Water Standard of 500 milligrams per liter (fig. 20b).

Major Ions

Calcium is a major constituent of rocks (Hem, 1985) such as limestone, dolomite, gypsum, anhydrite and sandstones. It dissolves readily in water; therefore, the calcium concentrations in water from areas with these type of rocks and sediments tend to be greater than in other areas. Interquartile calcium concentrations in surface-water samples in the study area were greater than interquartile concentrations in ground-water samples (fig. 21a). Calcium concentrations in surface water in the study area ranged between about 27 and 440 milligrams per liter, with concentrations for the interquartile between 100 and 248 milligrams per liter. Calcium concentrations in ground water ranged between 7.0 and 600 milligrams per liter, with the interquartile between 46 and 110 milligrams per liter (fig. 21a). Greater median concentrations were detected in ground water from wells in the Canadian River, Ionine Creek, Spring Creek, and Washita River Basins (fig. 21b) than from the other basins.

Magnesium is a common alkaline-earth metal and is essential in plant and animal nutrition (Hem, 1985). The principal sources for magnesium in the study area are similar to those for calcium. As with calcium, interquartile magnesium concentrations in surface-water samples in the study area generally were greater than interquartile concentrations in ground-water samples. Magnesium concentrations in surface water area ranged between about 3.9 and 139 milligrams per liter, with concentrations for the interquartile between 25 and 82 milligrams per liter. Magnesium concentrations in ground water were similar to those in surface water. Magnesium concentrations in ground water ranged between 2.9 and 130 milligrams per liter, with concentrations for the interquartile between 9.5 and 26 milligrams per liter. Greater concentrations of magnesium were detected in ground water from wells in the Canadian River, Ionine Creek, and Spring Creek Basins than from the other basins.

Sodium is the most abundant member of the alkali-metal group of elements, and when dissolved, it tends to remain in solution (Hem, 1985). Natural sources of sodium include the weathering of plagioclase feldspar and the dissolution of sodium salts from sedimentary rocks. Human-related sources include septic systems and as a by-product of water treatment (it is discharged by water softeners and reverse-osmosis units). Water from oil and gas production in the study area is composed of sodium and chloride. The U.S. Environmental Protection Agency (2001) established a health advisory level of 20 milligrams per liter for people who are on very restricted sodium diets.

Interquartile sodium concentrations in surface-water samples in the study area were greater than interquartile concentrations in ground-water samples (fig. 22a). Sodium concentrations in surface water in the study area ranged from 1.6 to 215 milligrams per liter, with concentrations for the interquartile between 31 and 100 milligrams per liter (fig. 22a). The median concentration in surface-water samples was 57 milligrams per liter, which exceeds the USEPA health advisory level. Sodium concentrations in ground-water samples (fig. 22a) ranged from 4.2 to 1,500 milligrams per liter, with concentrations for the interquartile between 17 and 44 milligrams per liter. The greater concentrations in surface water than in ground water were probably from the dissolution of sodium salts from sedimentary rocks. The median values for ground water from Cobb Creek and Sugar Creek Basins were less than the health advisory level (fig. 22b).

Potassium concentrations generally were much less than sodium concentrations in most natural water (Hem, 1985). Although the sodium concentrations generally exceeded 10 milligrams per liter in water samples collected in the study area, the potassium concentrations commonly were one-half to one-tenth that of sodium concentrations. Potassium concentrations in surface-water samples in the study area ranged from 0.6 to 9.6 milligrams per liter, with concentrations for the interquartile between 4.2 and 6.2 milligrams per liter. Potassium concentrations in ground-water samples ranged from 0.1 to 11.0 milligrams per liter, with concentrations for the interquartile between 0.7 and 2.0 milligrams per liter. There is no USEPA Secondary Drinking Water Standard for potassium.

Natural sources of sulfate (Hem, 1985) in water include the weathering of sulfur-bearing minerals, such as pyrite and gypsum-anhydrite, volcanic discharges to the atmosphere, and biologic and biochemical processes. Human-related sources include industrial discharges to both streams and the atmosphere and combustion of fossil fuels, such as coal and gasoline. Gypsum, the most probable source of sulfate, is present in the Marlow Formation and Rush Springs Formation and in the overlying Cloud Chief Formation (Becker, 1998). The U.S. Environmental Protection Agency (2001) established a Secondary Drinking Water Standard of 250 milligrams per liter for sulfate to because of laxative effects. Interquartile sulfate concentrations in surface-water samples in the study area were greater than interquartile concentrations in ground-water samples (fig. 23a). Sulfate concentrations in surface water in the study area ranged from 1.0 to 1,700 milligrams per liter, with the interquartile between 270 and 825 milligrams per liter. Sulfate concentrations in ground water (fig. 23a) ranged from 4.1 to 4,600 milligrams per liter, with the interquartile concentrations between 12 and 190 milligrams per liter. Median sulfate concentrations from ground-water samples in the Canadian River, Ionine Creek, and Spring Creek Basins exceeded the USEPA Secondary Drinking Water Standard and ranged from 385 to 570 milligrams per liter (fig. 23b).

The most important natural source of chloride in the study area is dissolution of halite from sedimentary rocks. The USEPA Secondary Drinking Water Standard of 250 milligrams per liter was established for chloride on the basis of taste (U.S. Environmental Protection Agency, 2001). Interquartile chloride

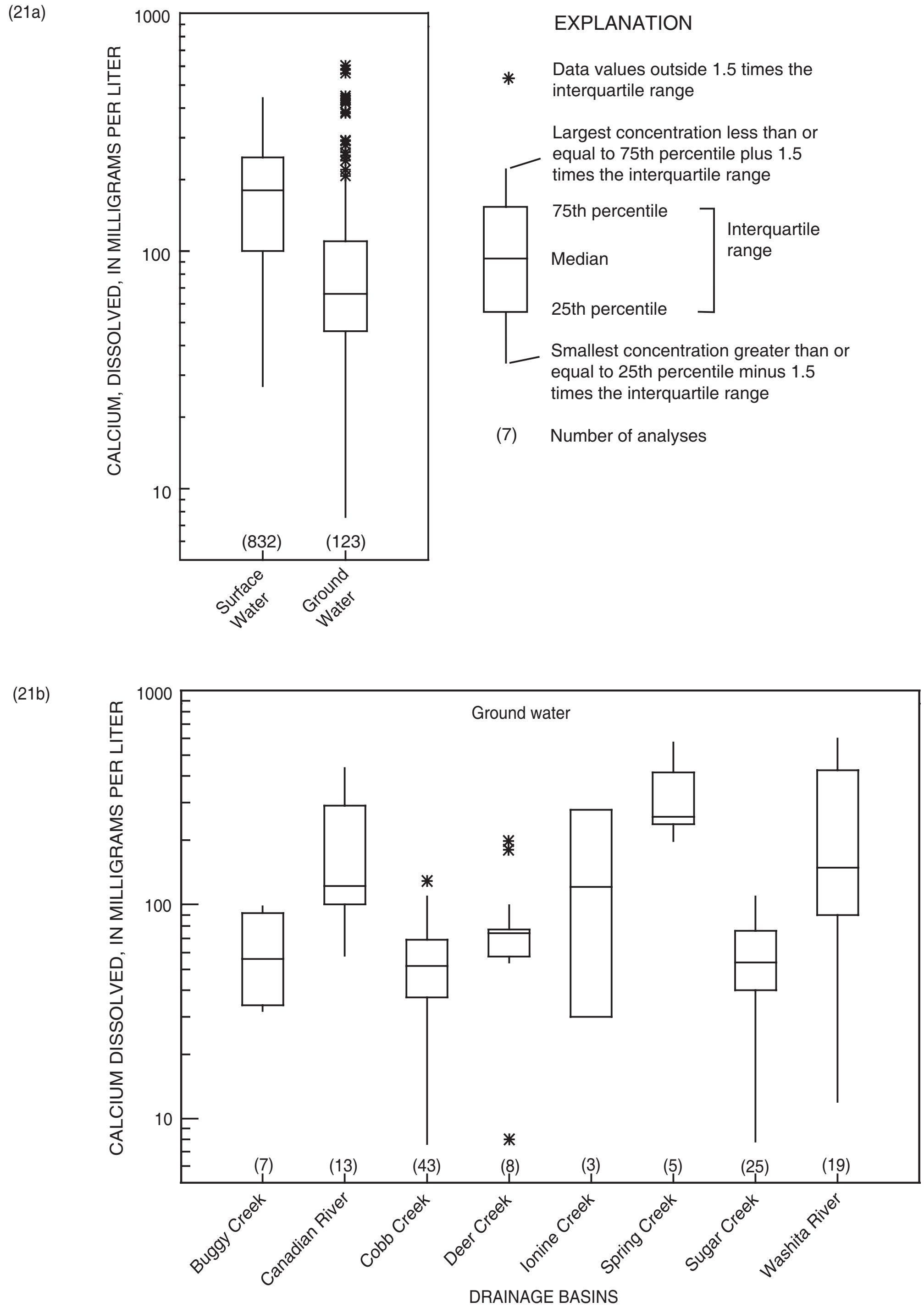
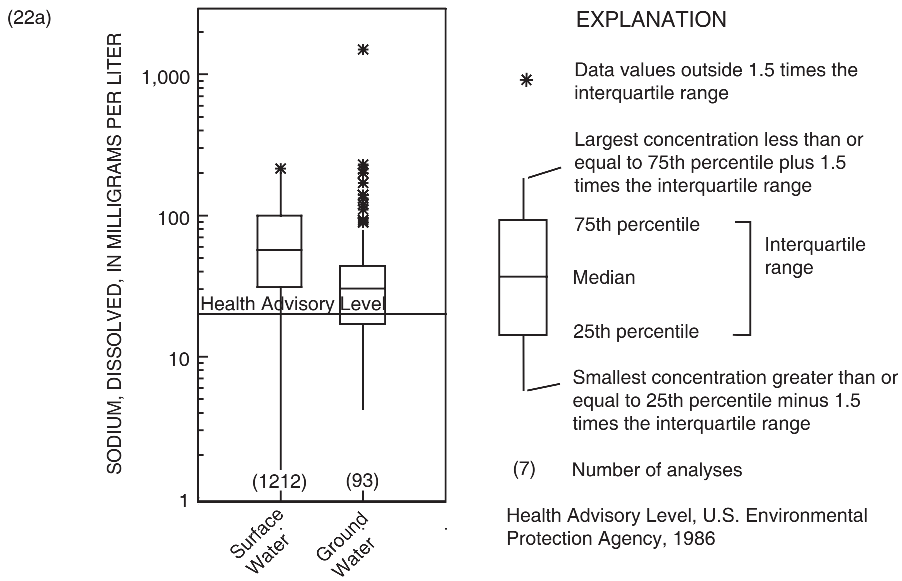


Figure 21. Calcium concentrations in surface water and ground water (21a) and by ground water in drainage basin (21b) in the Wichita Affiliated Tribes treaty lands, Oklahoma.



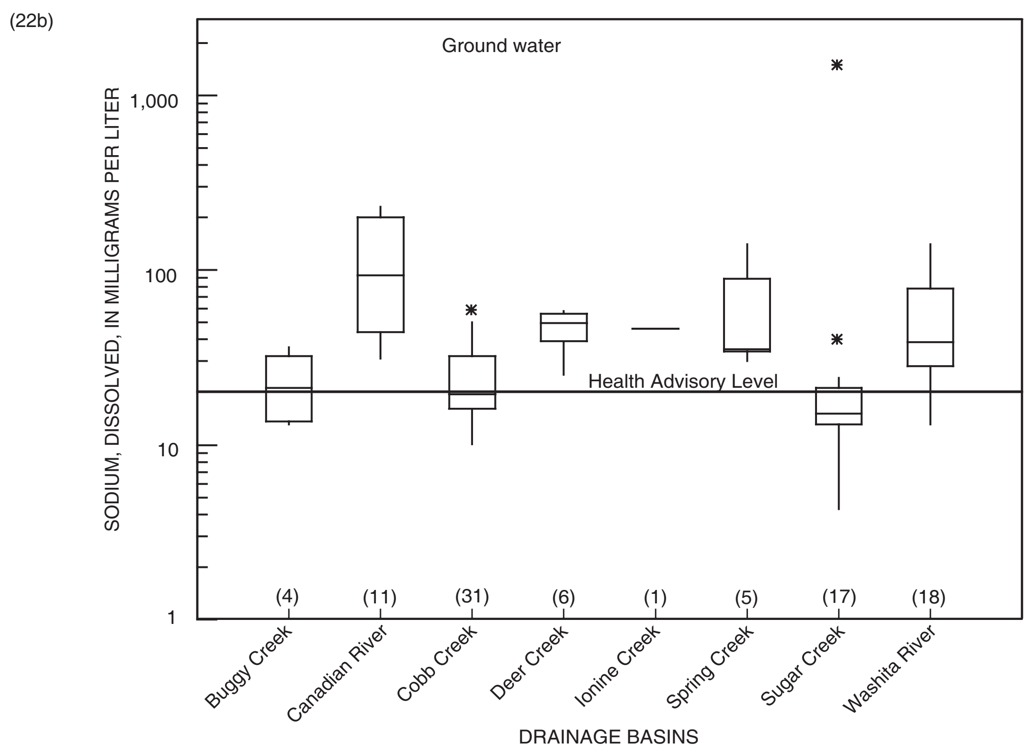


Figure 22. Sodium concentrations in surface water and ground water (22a) and by ground water in drainage basin (22b) in the Wichita and Affiliated Tribes treaty lands, Oklahoma.

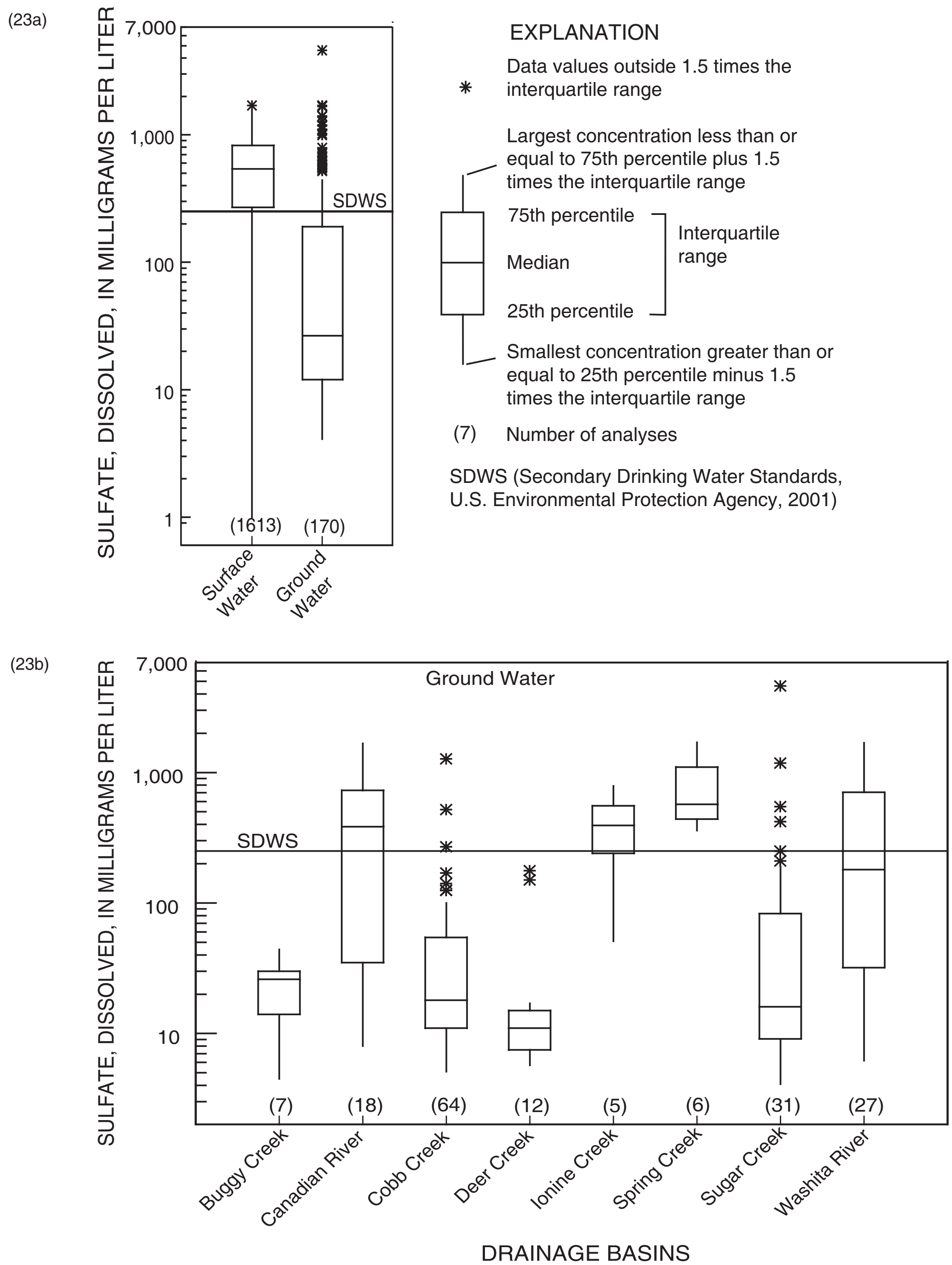


Figure 23. Sulfate concentrations in surface water and ground water (23a) and by ground water in drainage basin (23b) in the Wichita and Affiliated Tribes treaty lands, Oklahoma.

concentrations in surface-water samples in the study area generally were greater than interquartile concentrations in groundwater samples (fig. 24a). Chloride concentrations in surface water ranged from 0.3 to 400 milligrams per liter, with the interquartile between 22 and 100 milligrams per liter. Chloride concentrations in ground water (fig. 24) ranged from 0.49 to 900 milligrams per liter, with concentrations for the interquartile between 6.5 and 30 milligrams per liter. Greater interquartile concentrations were detected in water from wells in the Canadian River Basin (fig. 24b) than from the other basins.

Nutrients

Nitrogen and phosphorus are essential nutrients for plant growth. Dense algal growths or blooms occur in lakes and streams that receive increased concentrations of nitrogen or phosphorus. These growths cause problems for other aquatic life when the dissolved oxygen is removed from the water by decaying organic matter, resulting from sudden dieback of algae and plants (Hem, 1985).

Nitrate is formed by complete oxidation of ammonium ions by micro-organisms in soil or water, and nitrite is formed from the nitrate or ammonium ions by micro-organisms in soil, water, sewage, and the digestive tract (U.S. Environmental Protection Agency, 1986). Major point sources for nitrogen entry into water are municipal and industrial wastewater outfalls, septic tanks, feedlot discharges, and leachate from waste disposal in dumps or sanitary landfills. Diffuse or non-point sources include farm-site fertilizer and animal wastes, lawn fertilizer, and atmospheric deposition. A Primary Drinking Water Regulation of 10 milligrams per liter was established by the U.S. Environmental Protection Agency (2001) for nitrite plus nitrate as nitrogen because of possible toxic effects to infants.

Nitrite plus nitrate as nitrogen concentrations in surface-water samples in the study area generally were less than concentrations in ground-water samples (fig. 25a). Nitrite plus nitrate as nitrogen concentrations in surface water in the study area ranged from less than 0.10 to about 4.8 milligrams per liter, with concentrations for the interquartile between 0.78 and 1.5 milligrams per liter (fig. 25a). Nitrite plus nitrate as nitrogen concentrations in ground water in the study area ranged from 0.25 to 63 milligrams per liter, with concentrations for the interquartile between 5.9 and 19 milligrams per liter (fig. 25a). The median nitrite plus nitrate as nitrogen concentration in ground water was 9.8 milligrams per liter, indicating almost one-half the ground-water samples exceeded the USEPA Primary Drinking Water Regulation. The sparse existing data indicate that water from wells in the Canadian and Washita River Basins may have greater nitrite plus nitrate as nitrogen concentrations (fig. 25b) than water from wells in the other basins.

The USEPA Secondary Drinking Water Standard (1986) for total phosphorus as phosphate is 0.10 milligram per liter. Greater concentrations may interfere with coagulation in water-treatment plants. To prevent excessive algal growth, the concentration should not exceed 0.05 milligram per liter in any stream at the point where it enters a lake or reservoir nor should it exceed 0.025 milligram per liter within the lake or reservoir (U.S. Environmental Protection Agency, 1986). Phosphorous concentrations in streams in the study area ranged from less than 0.01 to about 3.0 milligrams per liter, with concentrations for the interquartile between 0.01 and 0.46 milligram per liter. No ground-water analyses were available for phosphorus.

Metals

The U.S. Environmental Protection Agency (2001) has established a Secondary Drinking Water Standard of 300 micrograms per liter for iron. These limits are for drinking water that has been treated. If source water contains iron concentrations that are greater than 300 micrograms per liter, the iron generally can be removed during the treatment process. High concentrations of iron in ground water generally are caused by reducing conditions, where there is little or no dissolved oxygen. If iron is present in water in excessive amounts, it forms a red iron-oxide precipitate that stains laundry and plumbing fixtures and, therefore, is an objectionable constituent in domestic and industrial water supplies (Hem 1985). Total iron concentrations in surface-water samples in the study area ranged from 5 to 170 micrograms per liter, with concentrations for the interquartile between 10 and 60 micrograms per liter. Total iron concentrations in ground-water samples within the study area ranged from 5 to 1,600 micrograms per liter, with concentrations for the interquartile between 5 and 20 micrograms per liter. Greater concentrations were detected in water from wells in the alluvial aquifer in the Canadian River Basin, with concentrations for the interquartile between 10 and 110 micrograms per liter and a median concentration of 30 micrograms per liter, than in water from wells in the other basins.

Water Use

The data presented here are for 1995, the most recent water-use compilation effort by the U.S. Geological Survey for Oklahoma (Solley and others, 1998; Tortorelli, 1998). Estimated freshwater withdrawals (in millions of gallons per day) for Blaine, Caddo, Canadian, Custer, Grady, and Washita Counties by use and source (surface or ground water) are listed in table 4. The tribal treaty lands include only portions of these counties (fig.1). The amount of water withdrawn and percentages for each category will be different for tribal treaty lands.

Annual amounts of surface- and ground-water withdrawals are reported for irrigation, water supply, livestock, thermoelectric-power generation, domestic and commercial, and industrial and mining. Withdrawal in this report is the amount of water withdrawn or diverted from a surface- or ground-water source. Use is the amount of water that is brought into a facility (or to an irrigation area) for use, and is equal to the withdrawal plus delivery from water suppliers minus any loss that occurred prior to use. Fresh water is defined as water containing less than

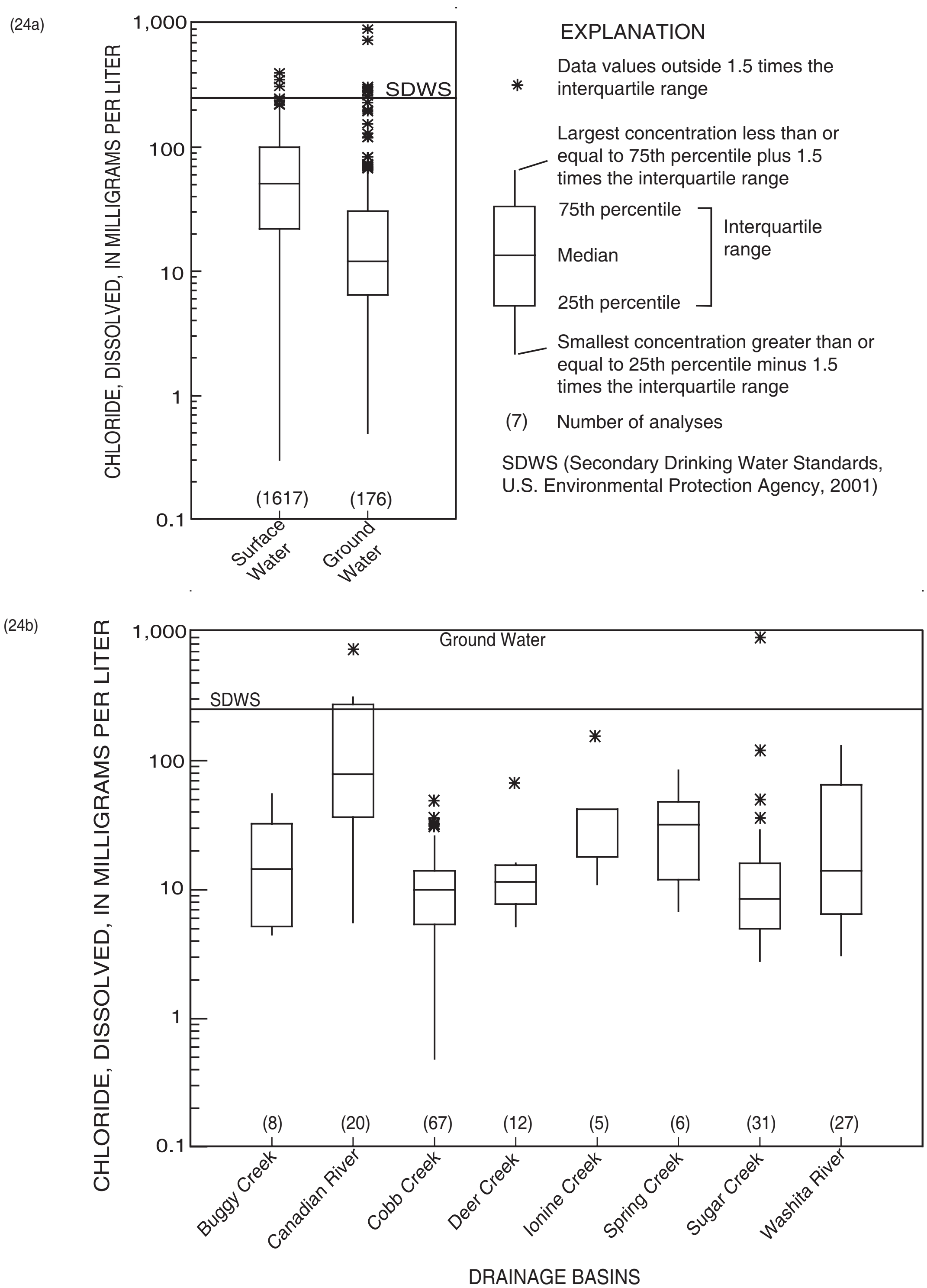


Figure 24. Chloride concentrations in surface water and ground water (24a) and by ground water in drainage basin (24b) in the Wichita and Affiliated Tribes treaty lands, Oklahoma.

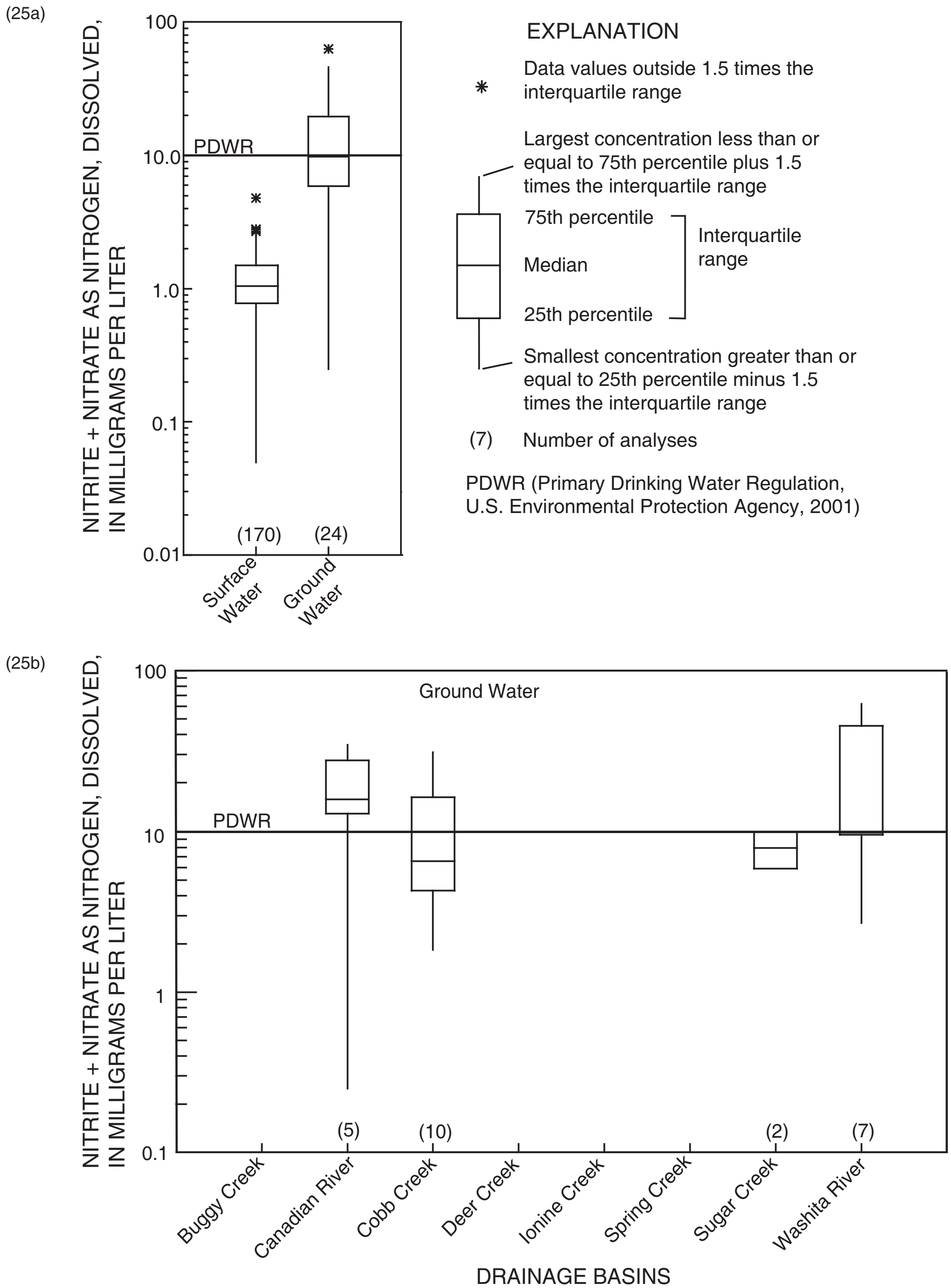


Figure 25. Nitrite plus nitrate as nitrogen concentrations in surface water and ground water (25a) and by ground water in drainage basin (25b) in the Wichita and Affiliated Tribes treaty lands, Oklahoma.

Table 4. Estimated freshwater withdrawals in 1995, by county, use, and source, in and near the Wichita and Affiliated Tribes treaty lands, Oklahoma

[Amounts in million gallons per day. Amounts may not add to total because of independent rounding]

County (tribes treaty lands approximate percent of total area)	Irrigation		Water-supply		Livestock		Thermoelectric-power generation	
	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water
Blaine (6)	0.44	1.23	0.00	1.15	1.20	0.66	0.00	0.00
Caddo (62)	1.32	29.27	8.35	1.15	2.70	0.90	2.88	0.00
Canadian (9)	0.25	2.14	0.00	3.16	1.91	0.24	0.00	1.42
Custer (4)	0.43	2.83	5.28	2.35	1.37	0.46	0.00	0.00
Grady (9)	5.69	2.92	0.00	3.63	2.93	0.27	0.00	0.00
Washita (6)	0.97	3.20	0.24	0.68	1.21	0.40	0.00	0.00

Table 4. Estimated freshwater withdrawals in Oklahoma, 1995, by county, use, and source, in and near the Wichita and Affiliated Tribes treaty lands, Oklahoma—Continued

County (tribes treaty lands approximate percent of total area)	Domestic and commercial		Industrial and mining		Total		
	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Total
Blaine (6)	0.00	0.51	0.00	0.04	1.64	3.59	5.3
Caddo (62)	0.25	0.77	0.00	0.00	15.5	32.0	47.6
Canadian (9)	0.11	0.23	0.00	0.43	2.27	7.61	9.9
Custer (4)	0.52	0.01	0.00	0.01	7.60	5.66	13.3
Grady (9)	0.70	1.38	0.00	0.00	9.32	8.20	17.5
Washita (6)	0.19	0.19	0.00	0.00	2.61	4.47	7.1

1,000 milligrams per liter of dissolved solids. The types of withdrawals are defined as (Lurry and Tortorelli, 1996):

- Irrigation withdrawal is water applied artificially on land to assist in the growing of crops and pastures or maintaining recreation lands such as parks and golf courses. The water is self supplied or purchased from an irrigation company, irrigation district, or other supplier for irrigation use. It is not obtained from a public-water supply system for irrigation.
- Water-supply withdrawal is water withdrawn by public and private water suppliers and delivered to users that do not have their own water supply.
- Livestock withdrawal is water supplied for livestock. Livestock includes cattle, sheep, goats, hogs, poultry, horses, rabbits, bees, and fur-bearing animals in captivity.
- Thermoelectric-power generation withdrawal is water for cooling purposes in the production of electrical power using fossil-fuel (coal, oil, or natural gas), geothermal, or nuclear energy.
- Domestic withdrawal is water for normal household purposes such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens; also referred to as residential use. The water is self supplied and is not obtained from a water-supply system.
- Commercial withdrawal is water for motels, hotels, restaurants, office buildings, commercial facilities, fish hatcheries, and civilian and military institutions. The water is self supplied and is not obtained from a water-supply system. Commercial withdrawal is combined with domestic withdrawal for this study.
- Industrial withdrawal is water for purposes such as fabrication, processing, washing, and cooling in the production of steel, chemical and allied products, paper and allied products, mineral processing not performed on mine site, and petroleum refining. The water is self supplied and is not obtained from a water-supply system.
- Mining withdrawal is water used in the extraction of naturally occurring minerals such as coal, ores, crude petroleum, and natural gas. It also includes quarrying, well operation (dewatering), milling (crushing, screening, washing, and flotation), and other preparations typically performed at the mine site or as part of a mining activity. Mining withdrawals are combined with the industrial withdrawals for this study.

An estimated 100 million gallons of water per day were withdrawn in the counties listed in table 4 during 1995. Of this amount, 61 percent was supplied by ground-water sources. The largest withdrawal of water in the counties, 50 percent, was for irrigation, and about 83 percent of irrigation withdrawals was ground water. Livestock use represented 14 percent of the total water withdrawn and was supplied by both surface- (79 percent) and ground-water (21 percent) sources. Water-supply and domestic and commercial uses combined for 31 percent of the total withdrawn and were supplied by surface- and ground-water sources. About 50 percent of water-supply use was surface water and about 50 percent was ground water. Self-supply domestic use was 100 percent ground water. About 79 percent of commercial use was surface water and about 21 percent was ground water (Tortorelli, 1998).

Summary

This report is an overview of water resources in and near the Wichita and Affiliated Tribes treaty lands in western Oklahoma. The primary objectives of the report are to describe surface- and ground-water availability, water quality, and water use in the study area.

Seventy percent of the study area lies within the Washita River drainage basin and 30 percent of the area is in the Canadian River drainage basin. Tributaries of the Washita River in the tribal treaty lands, from west to east, include Cobb Creek, Sugar Creek, Spring Creek, and Ionine Creek. Cobb Creek and Sugar Creek are perennial streams that are maintained by discharge from the Rush Springs Aquifer. Principal tributaries of the Canadian River are Deer Creek and Buggy Creek. Deer Creek is a perennial stream maintained by discharge from the Rush Springs Aquifer. The percentages of the tribal trust and allotment lands within each of these surface-water drainage basins are as follows: Buggy Creek, 5 percent; Canadian River, 1 percent; Cobb Creek, 9 percent; Deer Creek, 3 percent; Ionine Creek, 2 percent; Spring Creek, 10 percent; Sugar Creek, 40 percent; and Washita River, 30 percent.

Seasonal changes in streamflow reflect the quantity and frequency of rainfall and differences in evapotranspiration. March through June are months of greatest average streamflow, with 49 to 57percent of the annual flow occurring in these four months. November through February, July, and August have the least average streamflow, with 26 to 36 percent of the annual flow occurring in these six months.

Two streamflow-gaging stations with both unregulated and regulated periods of record indicated peak streamflows generally decrease with regulation, and two other stations indicated a decrease in peak streamflows after regulation at less than the 100-year recurrence and an increase in peak streamflows greater than the 100-year recurrence. Three stations with both unregulated and regulated periods of record had estimated annual low flows that generally increased with regulation. One station located immediately downstream from Fort Cobb Reservoir dam had a decrease of estimated annual low flows after regulation.

A LOWESS smooth performed on the regulated period of record of the precipitation shows a slight upward trend, with a dip downward coinciding with droughts in the 1990s. A LOWESS smooth of the regulated period of record for the streamflow at three stations shows general upward trends, which may be due to the variability of large storm events, effects of reservoir operations of the major dams, and gradual sediment filling of the hundreds of Natural Resources Conservation Service floodwater retarding structures in the Washita River Basin.

There are more than 900 ground-water wells in the tribal treaty lands. Eighty percent of the wells are in Caddo County. The major aquifers in the study area of the tribal treaty lands are the Rush Springs Aquifer and portions of the Canadian River and Washita River valley alluvial aquifers. The Rush Springs Aquifer is used extensively for irrigation as well as industrial and municipal purposes, especially near population centers. The Canadian River and Washita River valley alluvial aquifers are not used extensively in the study area because of the limited areal extent of the aquifers.

Water-level measurements indicate that climatic conditions such as droughts and periods of greater than normal precipitation affect the water levels in the Rush Springs Aquifer. The Rush Springs Aquifer is recharged by the infiltration of precipitation. The estimated recharge is about 1.80 inches per year evenly distributed over the outcrop of the aquifer in the study area. Well yields from the Rush Springs Aquifer vary, but the most productive irrigation wells produce more than 1,000 gallons per minute.

The Canadian and Washita River valley alluvial aquifers occur in the flood plains along the rivers. The Canadian River valley alluvial aquifer in the tribal treaty lands has 10 wells reported for irrigation usage. Some of these wells have reported yields greater than 300 gallons per minute. The Washita River valley alluvial aquifer has six wells in the tribal treaty lands and one was reported to yield greater than 300 gallons per minute. Much of these aquifers lie in flood-prone areas where well-head protection and water-supply facilities need to be elevated or otherwise protected from surface contamination during flooding.

Principal factors affecting the water quality in the study area include geology, agricultural practices, and oil and gas production. Agricultural practices may result in increased pesticide, fertilizer, and fecal bacteria concentrations in surface-water runoff and ground water. Calcium, magnesium, sulfate, and bicarbonate are the dominant dissolved constituents in water in the study area due to dissolution of bedrock and sediment, which consist primarily of sandstone, shales, gypsum, and anhydrites.

Interquartile dissolved-solids concentrations in surface-water samples in the study area were greater than interquartile concentrations in ground-water samples. Dissolved-solids concentrations in surface water ranged from 15 to 2,460 milligrams per liter, with the interquartile concentrations between 579 and 1,620 milligrams per liter. Concentrations of dissolved solids in ground water ranged from 52 to 9,040 milligrams per liter, with the interquartile between 264 and 574 milligrams per liter. Median dissolved-solids concentrations for ground-water samples from Canadian River, Ionine Creek, Spring Creek, and Washita River Basins exceeded the USEPA Secondary Drinking Water Standard of 500 milligrams per liter.

Interquartile calcium concentrations in surface-water samples in the study area were greater than interquartile concentrations in ground-water samples. Calcium concentrations in surface water in the study area ranged between about 27 and 440 milligrams per liter, with the interquartile concentrations between 100 and 248 milligrams per liter. Calcium concentrations in ground water ranged between 7.0 and 600 milligrams per liter, with the interquartile concentrations between 46 and 110 milligrams per liter. Greater median concentrations were detected in ground water from wells in the Canadian River, Ionine Creek, Spring Creek, and Washita River Basins than from the other basins.

Interquartile sodium concentrations in surface-water samples in the study area were greater than interquartile concentrations in ground-water samples. Sodium concentrations in surface water in the study area ranged from 1.6 to 215 milligrams per liter, with the interquartile concentrations between 31 and 100 milligrams per liter. The median concentration in surface-water samples was 57 milligrams per liter, which exceeds the USEPA health advisory level. Sodium concentrations in ground-water samples ranged from 4.2 to 1,500 milligrams per liter, with the interquartile concentrations between 17 and 44 milligrams per liter. The greater concentrations in surface water than in ground water were probably from the dissolution of sodium salts from sedimentary rocks.

Sulfate concentrations in surface water in the study area ranged from 1.0 to 1,700 milligrams per liter, with the interquartile between 270 and 825 milligrams per liter. Sulfate concentrations in ground water ranged from 4.1 to 4,600 milligrams per liter, with the interquartile concentrations between 12 and 190 milligrams per liter. Median sulfate concentrations from ground-water samples in the Canadian River, Ionine Creek, and Spring Creek Basins ranged from 385 to 570 milligrams per liter, which exceeded the USEPA Secondary Drinking Water Standard of 250 milligrams per liter.

Interquartile chloride concentrations in surface-water samples in the study area generally were greater than interquartile concentrations in ground-water samples. Chloride concentrations in surface water ranged from 0.3 to 400 milligrams per liter, with the interquartile concentrations between 22 and 100 milligrams per liter. Chloride concentrations in ground water ranged from 0.49 to 900 milligrams per liter, with the interquartile concentrations between 6.5 and 30 milligrams per liter.

Nitrite plus nitrate as nitrogen concentrations in surface-water samples in the study area generally were less than concentrations in ground-water samples. Nitrite plus nitrate as nitrogen concentrations in surface water in the study area ranged from less than 0.10 to about 4.8 milligrams per liter, with the interquartile concentrations between 0.78 and 1.5 milligrams per liter. Nitrite plus nitrate as nitrogen concentrations in ground water in the study area ranged from 0.25 to 63 milligrams per liter, with the interquartile concentrations between 5.9 and 19 milligrams per liter. The median nitrite plus nitrate as nitrogen concentration in ground water was 9.8 milligrams per liter, indicating almost one-half the ground-water samples exceeded the USEPA Primary Drinking Water Regulation of 10 milligrams per liter.

Phosphorous concentrations in streams in the study area ranged from less than 0.01 to about 3.0 milligrams per liter, with the interquartile concentrations between 0.01 and 0.46 milligram per liter. No ground-water analyses were available for phosphorus.

Total iron concentrations in surface-water samples in the study area ranged from 5 to 170 micrograms per liter, with the interquartile concentrations between 10 and 60 micrograms per liter. Total iron concentrations in ground-water samples within the study area ranged from 5 to 1,600 micrograms per liter, with the interquartile concentrations between 5 and 20 micrograms per liter. Greater concentrations were detected in water from wells in the alluvial aquifer in the Canadian River Basin than in water from wells in other basins, with most concentrations between 10 and 110 micrograms per liter and the median was 30 micrograms per liter.

An estimated 100 million gallons of water per day were withdrawn from surface and ground water for all uses in counties of the study area during 1995. Fifty percent of water use was for irrigation, and about 83 percent of water withdrawn for irrigation was from ground water. Livestock use represented 14 percent of the total water withdrawn and was supplied by surface- and ground-water sources. Water-supply for domestic and commercial uses was 31 percent of the total withdrawn and was supplied by surface- and ground-water sources.

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