Prepared in cooperation with the
BUREAU OF RECLAMATION

Surface-Water Quality Assessment of the North Fork Red River Basin Upstream from Lake Altus, Oklahoma, 2002

Open-File Report 03–362

Panoramic photograph of Lake Altus and Wichita Mountains taken from Twin Mountain West, looking southeast. Photograph taken by S. Jerrod Smith, April 30, 2003, U.S. Geological Survey.

U.S. Department of the Interior
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Conversion Factors and Datum

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

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

$°F = (1.8 \times °C) + 32$

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

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

Surface-Water Quality Assessment of the North Fork Red River Basin Upstream from Lake Altus, Oklahoma, 2002

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Abstract

Elevated salinity in the North Fork Red River is a major concern of the Bureau of Reclamation W. C. Austin Project at Lake Altus. Understanding the relation between surface-water runoff, ground-water discharge, and surface-water quality is important for maintaining the beneficial use of water in the North Fork Red River basin. Agricultural practices, petroleum production, and natural dissolution of salt-bearing bedrock have the potential to influence the quality of nearby surface water.

The U.S. Geological Survey, in cooperation with the Bureau of Reclamation, sampled stream discharge and water chemistry at 19 stations on the North Fork Red River and tributaries. To characterize surface-water resources of the basin in a systematic manner, samples were collected synoptically during receding streamflow conditions during July 8-11, 2002.

Together, sulfate and chloride usually constitute greater than half of the dissolved solids. Concentrations of sulfate ranged from 87.1 to 3,450 milligrams per liter. The minimum value was measured at McClellan Creek near Back (07301220), and the maximum value was measured at Bronco Creek near Twitty (07301303). Concentrations of chloride ranged from 33.2 to 786 milligrams per liter. The minimum value was measured at a North Fork Red River tributary (unnamed) near Twitty (07301310), and the maximum value was measured at the North Fork Red River near Back (07301190), the most upstream sample station.

Introduction

Elevated salinity in the North Fork Red River is a major concern of the Bureau of Reclamation W. C. Austin Project at Lake Altus. The concentration of dissolved solids, especially sulfate and chloride, generally increases downstream as the river passes over salt-bearing rocks of Permian age (Smith and Wahl, 2003). Ongoing studies in the North Fork Red River basin (fig. 1) indicate changes in water sources that could contribute to impaired surface-water quality. Some streamflow-gaging stations in the basin show an increased proportion of base flow as well as substantial decreases in annual peak discharges over the past few decades (Smith and Wahl, 2003). Understanding the relation between surface-water runoff, ground-water discharge, and surface-water quality is important for maintaining the beneficial use of water in the North Fork Red River basin.

The Bureau of Reclamation began construction of the Lake Altus dam in 1941 as part of the W.C. Austin Project. Storage operations began in 1946, and the project was completed in 1948 (Oklahoma Water Resources Board, 1990). The purposes of the project were flood control, water supply for the city of Altus, and irrigation (Blazs and others, 2003). In 2002, the Lugert-Altus Irrigation District withdrew about 57,700 acre-feet (L. Hall, Bureau of Reclamation, written commun., 2002) from the lake to sustain about 46,000 acres of agricultural land south of Lake Altus (A. Ensley, Lugert-Altus Irrigation District, oral commun., 2002; fig. 2).

As water-use requirements increased in the basin, concerns were expressed about the effects of runoff retention structures and ground-water withdrawals on the quantity and quality of water flowing into Lake Altus. Determination of both stream discharge and chemistry was necessary to evaluate water resources in the basin. The U.S. Geological Survey, in cooperation with the Bureau of Reclamation, sampled stream discharge and water chemistry at 19 stations on the North Fork Red River and tributaries.

Purpose and Scope

The purpose of this report is to present data from a surface-water quality assessment that will be used to assess the ground-water and surface-water interaction in the North Fork Red River upstream from Lake Altus. To characterize surface-water resources of the basin in a systematic manner, samples were collected synoptically during receding streamflow conditions during July 8-11, 2002. These data can be used to support modeling of ground-water and surface-water interaction for the purpose of identifying areas where ground-water contribution has a substantial effect on surface-water quality. The data presented

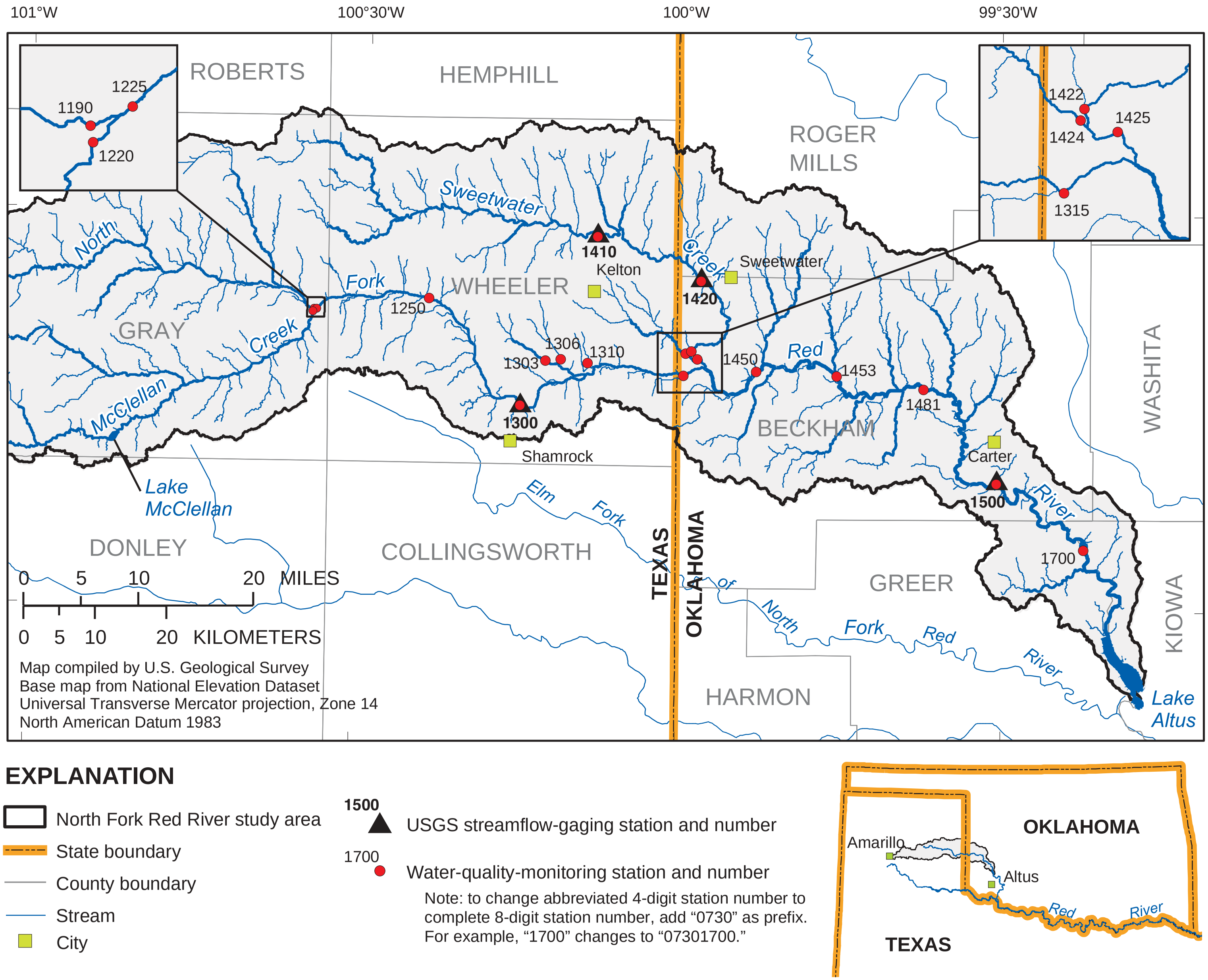


Figure 1. North Fork Red River basin upstream from Lake Altus with locations of streamflow-gaging stations and water-quality-monitoring stations.

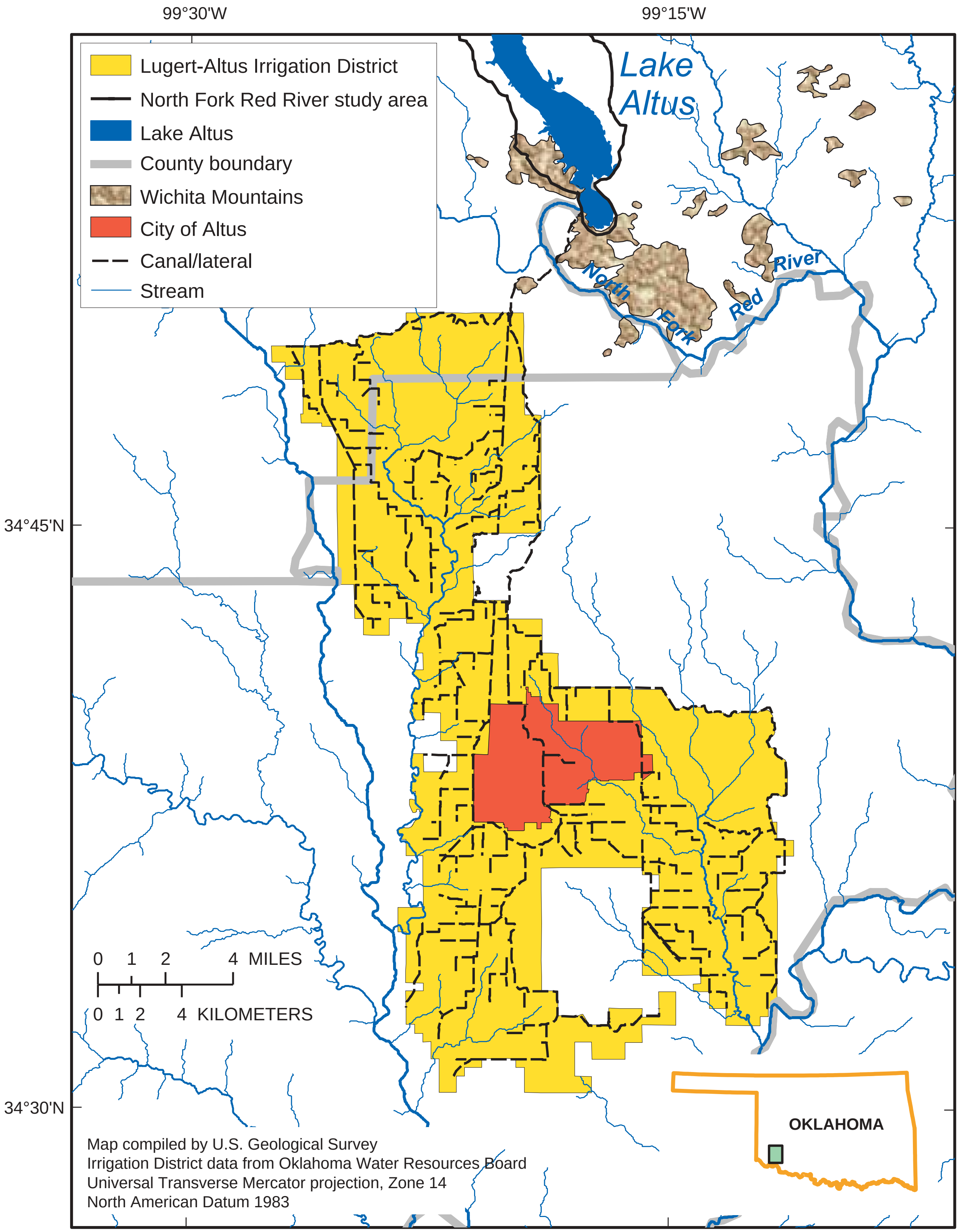


Figure 2. Lugert-Altus Irrigation District with locations of canals and laterals.

in this report will provide information that can be used to determine the need for a ground-water-quality model and can be used for placement of streamflow-gaging stations and water-quality stations.

Acknowledgments

The authors thank Martyn McMurphy, U.S. Geological Survey, who assisted in field data collection.

Description of the Study Area

The study area was the portion of the North Fork Red River basin that is upstream from the dam at Lake Altus (fig. 1). The study area extended 147 miles from the headwaters in the High Plains near Amarillo, Texas, to the Wichita Mountains north of Altus, Oklahoma (figs. 1-2). The study area included five counties in Texas (Carson, Donley, Gray, Potter, and Wheeler) and five counties in Oklahoma (Beckham, Greer, Kiowa, Roger Mills, and Washita) (figs. 3-4). The study area included 2,515 square miles, of which 399 square miles were non-contributing (Blazs and others, 2003). At the time of this study, the U.S. Geological Survey maintained four continuous-streamflow-gaging stations in the study area (fig. 1, table 1).

Sweetwater Creek and McClellan Creek are the two major tributaries of the North Fork Red River upstream from Lake Altus (fig. 1), with drainage areas of 540 square miles and 768 square miles, respectively. However, much of the headwaters area of McClellan Creek does not contribute runoff to the stream. Instead, runoff is stored in numerous small playa lakes, from which it percolates into ground water or evaporates (Wood, 2000) (fig. 3).

The semiarid climate in the North Fork Red River study area is due to the position of the basin on the leeward side of the Rocky Mountains. Mean-annual precipitation increases steadily to the east as the effect of the mountains decreases. The basin headwaters receive about 17 inches of mean-annual precipitation, whereas the basin outlet receives about 26 inches (Daly and others, 1994). Most rainfall occurs from spring and early summer storms, usually peaking in May. Warm and humid conditions are typical of Oklahoma and Texas in summer, but most thunderstorms that occur in summer are too localized to produce substantial runoff (Cooter, 1991). Mean-annual runoff is usually less than 2.5 percent of the annual precipitation, ranging from 0.2 to 1 inch per year (Gebert and others, 1987).

Hydrogeologic Setting

The bedrock in the western third of the study area is the Ogallala Formation of Tertiary age, a poorly sorted, loosely consolidated assemblage of clay to gravel-sized sediment with extensive zones of calcium carbonate caliche (fig. 4). In northwestern Texas, the Ogallala Formation is usually overlain by a thin layer of Pleistocene sediment named the Blackwater Draw Formation (Texas Bureau of Economic Geology, 1992). A large number of small playa lakes are scattered throughout the extent of the Blackwater Draw Formation due to the

Table 1. Active streamflow-gaging stations in the North Fork Red River basin upstream from Lake Altus, Oklahoma

Station number	Station name	Period of record (complete water year)	Length of record (water years)	Drainage area (square miles)	Mean annual streamflow (acre-feet)
07301300	North Fork Red River near Shamrock, Tex.	2001-2002	2	1,082	10,018
07301410	Sweetwater Creek near Kelton, Tex.	1963-2002	40	287	9,701
07301420	Sweetwater Creek near Sweetwater, Okla.	1987-2002	16	424	17,349
07301500	North Fork Red River near Carter, Okla.	1945-1962, 1965-2002	56	2,337	90,701

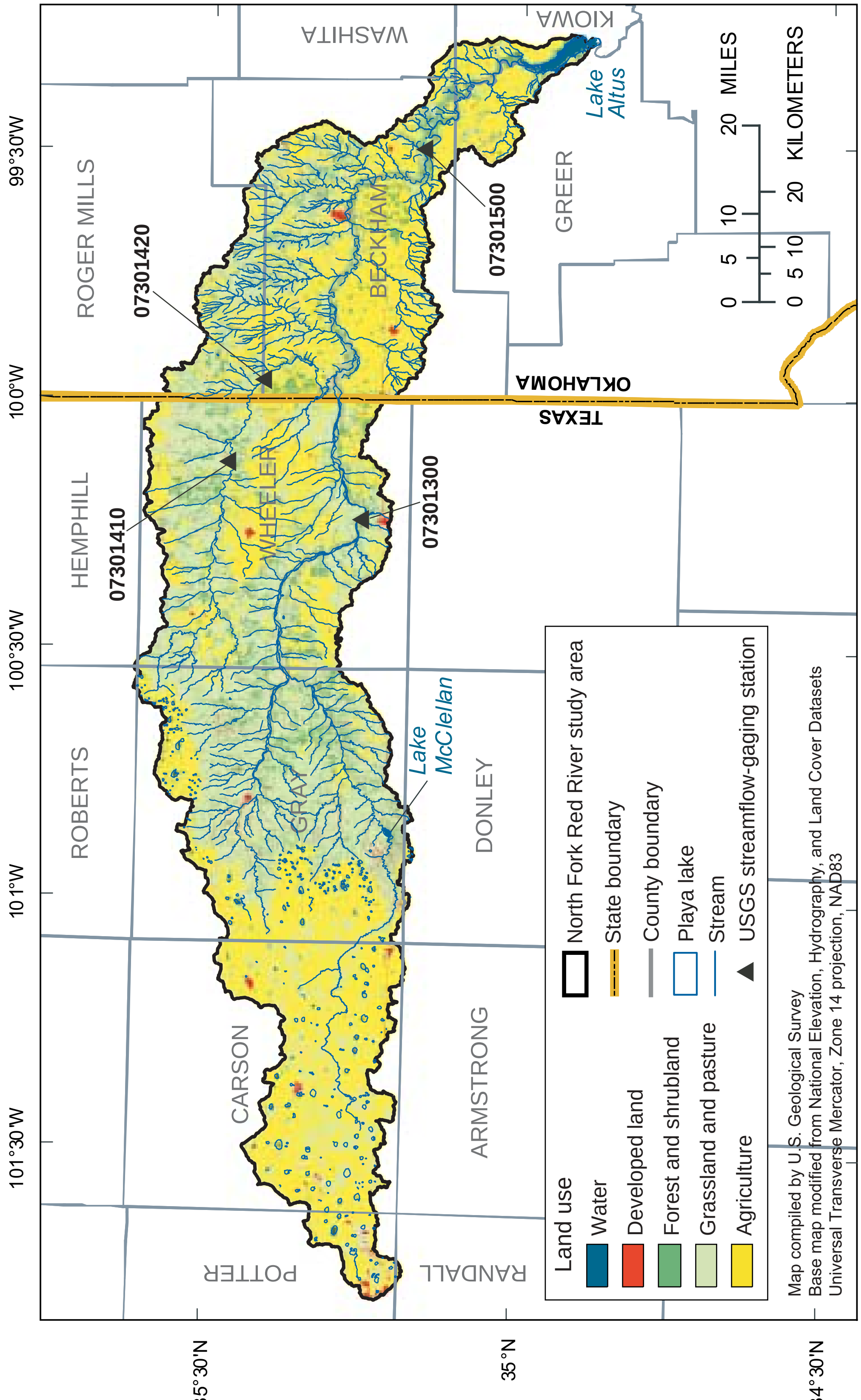


Figure 3. Land use in the North Fork Red River study area, with locations of streamflow-gaging stations.

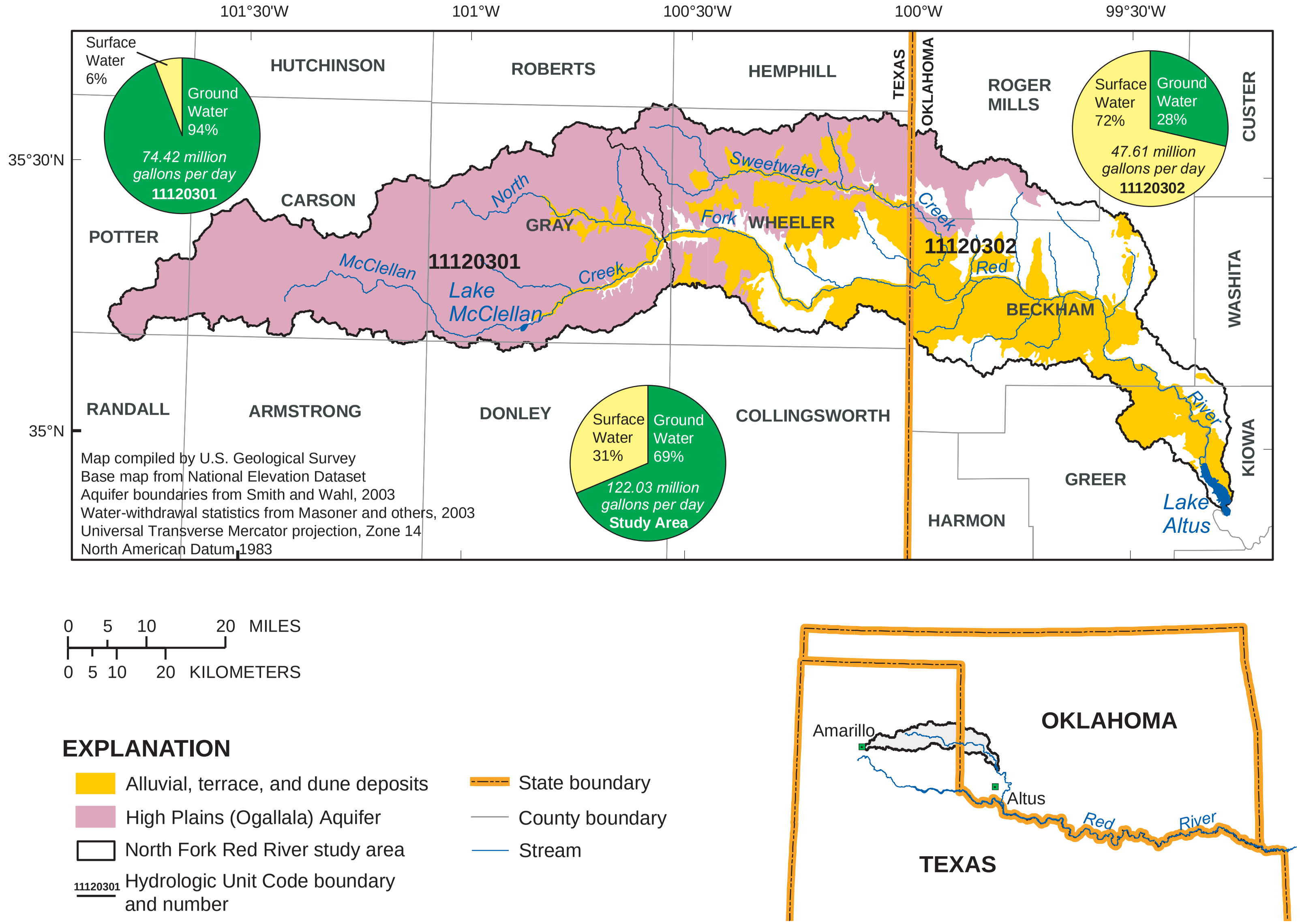


Figure 4. Major aquifers and 1995 water-withdrawal statistics in the North Fork Red River study area.

scouring action of wind and dissolution of underlying bedrock (Oklahoma Water Resources Board, 1990, p. 52). High rates of evaporation in the Texas Panhandle concentrate salts in these lakes, which eventually leach to ground water (Wood, 2000). Natural springs and seeps are common at the base of the Ogallala Formation (Wood, 2000; Marine, 1963, p. 4). In northwestern Texas, the Ogallala Formation, Blackwater Draw Formation, and overlying alluvial deposits comprise the High Plains (Ogallala) Aquifer.

The bedrock in the eastern two-thirds of the basin consists of Permian-age, gypsiferous shale and sandstone. Beds of gypsum, anhydrite, and dolomite are common among the Permian-age shales (Scott and Ham, 1957). In the Blaine Formation of Permian age, individual beds of gypsum reach thicknesses of 25 feet in outcrops (Scott and Ham, 1957, p. 28). Terrace and dune deposits of Quaternary age overlie a substantial portion of the lower study area. Together with recent river deposits, these sediments form a large aquifer in the Oklahoma portion of the study area.

A generalized geologic map and stratigraphic column of the North Fork Red River study area can be found in Smith and Wahl (2003, p. 7). Smith and Wahl (2003) also discussed the relation between surface-water quality and bedrock mineralogy in the study area.

Water Use

For the portion of the North Fork Red River basin upstream from Lake Altus, consumptive water use in 1995 was estimated to be 108 million gallons per day (Smith and Wahl, 2003). Ground water supplied the majority of that amount. The western hydrologic unit of the basin (11120301, fig. 4), due to greater irrigation requirements, withdrew more than twice as much water as the eastern hydrologic unit (11120302, fig. 4) (Masoner and others, 2003). Withdrawals in the western unit were predominantly supplied by ground water (94 percent) from the High Plains (Ogallala) Aquifer (fig. 4). Well yields in the High Plains Aquifer (fig. 4) typically range from 100 to 1,000 gallons per minute; yields of some wells may exceed 1,500 gallons per minute (Havens and others, 1985). The eastern unit relied primarily on surface water (72 percent), but also withdrew a substantial portion of water from unconsolidated aquifers consisting of alluvial, terrace, and dune deposits (fig. 4). Well yields in these unconsolidated aquifers range from 100 to 200 gallons per minute in the alluvial deposits and 200 to 500 gallons per minute in the terrace deposits (Havens and others, 1985). Irrigated agriculture was the greatest consumer of water in the basin in 1995, accounting for 82 percent of total withdrawals, 79 percent of ground-water withdrawals, and 89 percent of surface-water withdrawals (Masoner and others, 2003).

Land Use

Agriculture is the predominant land use in the study area (National Land Cover Dataset, 2000) (fig. 3). Agriculture is widespread in the headwater plains, where irrigation is sustained by ground-water withdrawals from the High Plains (Ogallala) Aquifer (figs. 3-4). Elsewhere, water for irrigation is usually supplied from unconsolidated aquifers consisting of alluvial and terrace deposits along the North Fork Red River (fig. 4) and from surface-water diversions. The most common crops in the North Fork Red River study area are wheat and alfalfa (Masoner and others, 2003). However, most of the storage in Lake Altus is used to support cotton crops in the Lugert-Altus Irrigation District outside the study area (fig. 2). In addition to agriculture, petroleum production is a major industry within the basin. Petroleum production wells are present throughout the study area, but they are most abundant in Gray and Wheeler Counties of Texas. Agricultural practices, petroleum production, and natural dissolution of salt-bearing bedrock have the potential to influence the quality of nearby surface water.

Methods

The U.S. Geological Survey selected 19 surface-water and water-quality stations within the North Fork Red River basin to be sampled synoptically during base-flow conditions (fig. 1). However, throughout the summer months, streamflow and therefore base-flow discharge are 0 cubic feet per second in most stream channels in the study area. These streams contain flowing water only after substantial summer precipitation events. Therefore, streams were sampled when there was low flow in all channels, and thus, as close to base flow as possible.

On June 19, 2002, a reconnaissance visit was made to each of the 19 proposed sampling stations to investigate streamflow conditions. Streamflow was observed at most stations except 07301303 (Bronco Creek near Twitty) and 07301306 (East Branch Creek near Twitty). Specific conductance was measured at 10 of these stations (table 2). The North Fork Red River subsequently ceased flowing for 14 days. The no-flow period ended on July 4, 2002, when the upper reaches of the basin received 3-4 inches of precipitation. All 19 prospective stations were flowing on July 8 when sampling began. Streamflow hydrographs for the four active streamflow-gaging stations in the study area show when these stations were sampled (figs. 5-6). Base-flow hydrographs were estimated from 5-day-interval minimum discharges, starting on July 1 (figs. 5-6). This method of base-flow estimation was modified from Wahl and Wahl (1988, 1995).

Sampling began at the stations in the upstream reaches of both the North Fork Red River and Sweetwater Creek and progressed to the downstream stations. The environmental samples were filtered, bottled, packed in ice, and shipped to the U.S. Geological Survey National Water Quality Laboratory in Lakewood, Colorado. The samples were analyzed for the following properties and constituents using U.S. Geological Survey schedule 2750: pH, dissolved solids (residue on evaporation), calcium, magnesium, sodium, potassium, sulfate, chloride, flu-

Table 2. Reconnaissance measurements of specific conductance in the North Fork Red River study area, June 2002

Station number (see fig. 1 for location)	Date	Time	Specific conductance (microSiemens per centimeter at 25 degrees Celsius)
07301190	06-19-02	0930	3,970
07301225	06-19-02	1600	1,900
07301250	06-19-02	1015	2,590
07301300	06-19-02	1045	3,240
07301315	06-19-02	1200	5,440
07301422	06-19-02	1115	1,200
07301425	06-19-02	1130	1,630
07301450	06-19-02	1230	2,420
07301453	06-19-02	1300	2,660
07301481	06-19-02	1400	2,660

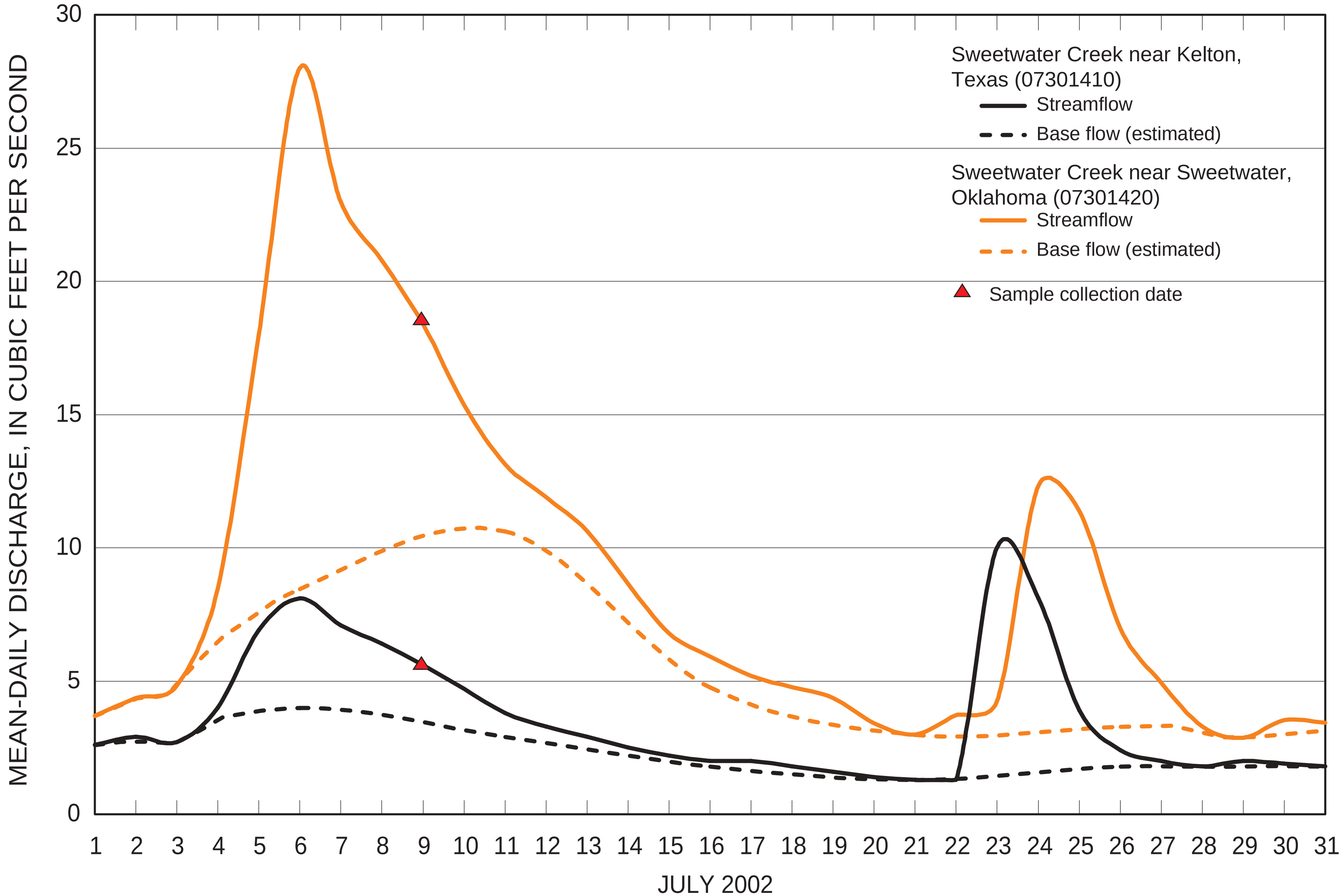


Figure 5. Streamflow and estimated base-flow hydrographs for streamflow-gaging stations on Sweetwater Creek, July 2002 (station numbers 07301410 and 07301420).

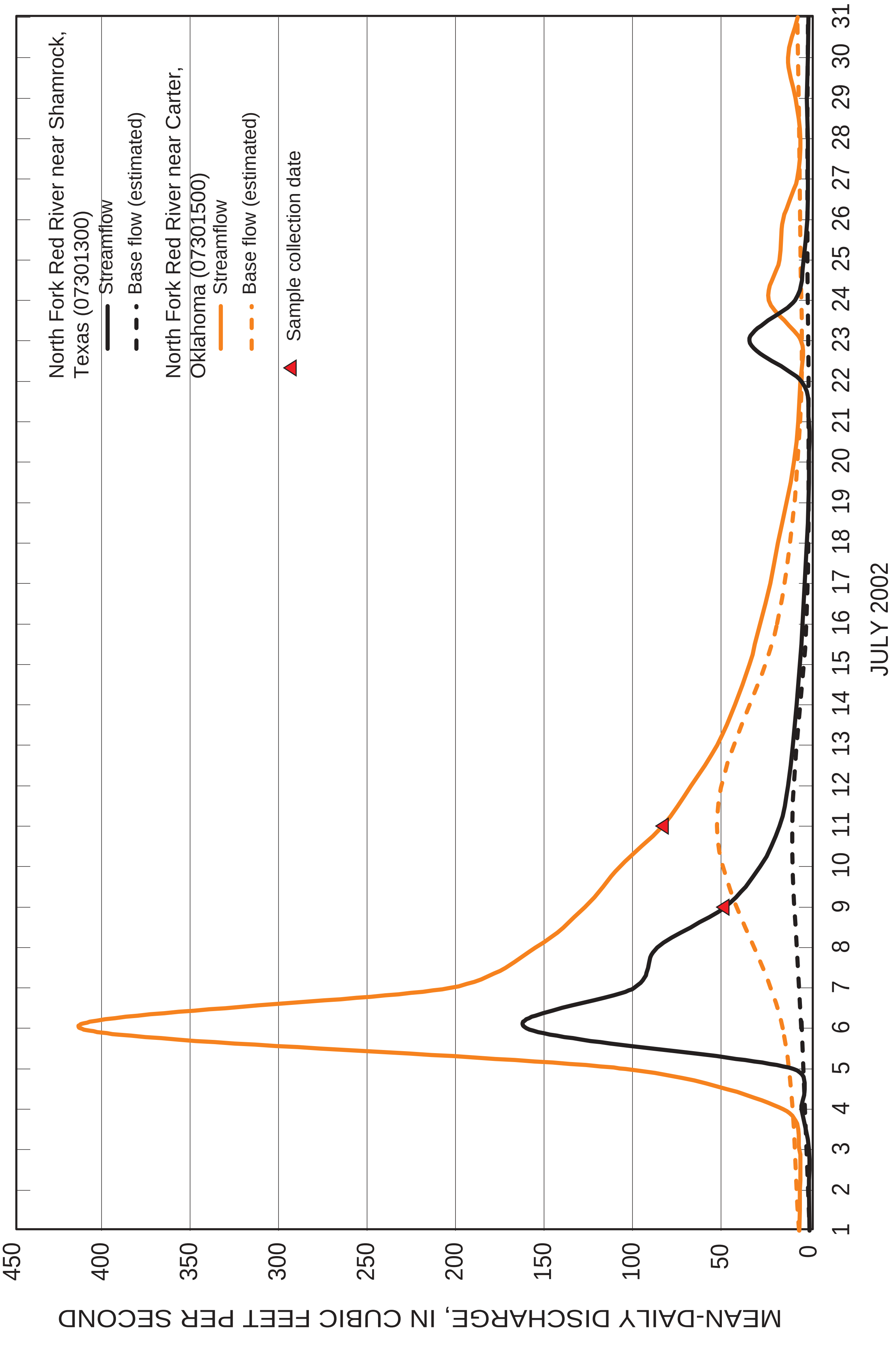


Figure 6. Streamflow and estimated base-flow hydrographs for streamflow-gaging stations on the North Fork Red River, July 2002 (station numbers 07301300 and 07301500).

Table 3. Laboratory analysis methods for measured water-quality constituents in U.S. Geological Survey schedule 2750

[MRL, minimum reporting level; ˚C, degree Celsius; µg/L, microgram per liter; mg/L, milligram per liter; ICP, inductively coupled plasma; AA, atomic adsorption; IC, ion chromatography; ISE, ion-specific electrode; ASF, automated, segmented flow]

Property or constituent	Unit	Method	MRL	Reference
Specific conductance at 25˚C, laboratory	µg/L	Wheatstone bridge	2.6	Fishman and Friedman, 1989
pH, laboratory	standard unit	electrometric, electrode	0.1	Fishman and Friedman, 1989
Solids, residue at 180˚C	mg/L	gravimetric	10	Fishman and Friedman, 1989
Calcium	mg/L	ICP	0.012	Fishman, 1993
Magnesium	mg/L	ICP	0.008	Fishman, 1993
Sodium	mg/L	ICP	0.09	Fishman, 1993
Potassium	mg/L	AA, flame	0.11	Fishman and Friedman, 1989
Sulfate	mg/L	IC	0.18	Fishman and Friedman, 1989
Chloride	mg/L	IC	0.20	Fishman and Friedman, 1989
Fluoride	mg/L	electrometric, ISE	0.17	Fishman and Friedman, 1989
Bromide	mg/L	colorimetry, ASF	0.016	Fishman and Friedman, 1989
Silica	mg/L	ICP	0.13	Fishman, 1993
Iron	µg/L	ICP	10	Fishman, 1993
Manganese	µg/L	ICP	1.6	Fishman, 1993

oride, bromide, silica, iron, and manganese (table 3). Measurements of instantaneous discharge, specific conductance, pH, water temperature, dissolved oxygen, and alkalinity also were conducted in the field according to procedures specified in Rantz and others (1982) and Wilde and Radtke (1998).

Two quality-control samples were collected for comparison with environmental samples (table 4). A replicate sample was collected at station 07301420, and a field blank sample was collected at station 07301700.

Surface-Water Quality

Field measurements of specific conductance ranged from 780 to 5,780 microSiemens per centimeter (table 4). Dissolved solids (residue at 180 degrees Celsius) concentrations ranged from 501 to 6,040 milligrams per liter (figs. 7-10, table 4). The minimum dissolved solids value was measured at Sweetwater Creek near Sweetwater (07301420), and the maximum dissolved solids value was measured at Bronco Creek near Twitty (07301303) (figs. 7-10, table 4).

Together, sulfate and chloride usually constitute greater than half of the dissolved solids (figs. 7-9, table 4). Concentrations of sulfate ranged from 87.1 to 3,450 milligrams per liter (figs. 7-9, 11, table 4). The minimum value was measured at McClellan Creek near Back (07301220), and the maximum value was measured at Bronco Creek near Twitty (07301303) (figs. 7-9, 11, table 4). Concentrations of chloride ranged from 33.2 to 786 milligrams per liter (figs. 7-9, 12, table 4). The minimum value was measured at a North Fork Red River tributary (unnamed) near Twitty (07301310), and the maximum value was measured at the North Fork Red River near Back (07301190), the most upstream sample station (figs. 7-9, 12, table 4).

To visualize major-ion composition at each water-quality station, major-anion and cation concentrations were converted to milliequivalent proportions and graphed on a ternary Piper (1944) diagram (fig. 13). Refer to Smith and Wahl (2003, p. 27) for explanation of Piper diagrams.

Table 4. Water properties and major-ion concentrations of surface-water samples in the North Fork Red River study area

[ft^3/s, cubic feet per second; mm of Hg, millimeters of mercury; ˚C, degrees Celsius; µS/cm, microSiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; E, estimated value; --, no data; shaded samples are quality-control samples]

Station number (see fig. 1 for location)	Station name	Date	Time	Sample type	Discharge, instantaneous (ft^3/s)	Barometric pressure (mm of Hg)	Specific conductance at 25˚C, (µS/cm)		pH (standard unit)		Temperature, (˚C)	
							field	lab	field	lab	air	water
07301190	North Fork Red River near Back, Tex.	07/08/2002	1400	regular	20	708	3,040	2,830	8.0	7.9	33.0	32.5
07301220	McClellan Creek near Back, Tex.	07/08/2002	1700	regular	29	708	1,040	941	8.1	8.1	32.5	29.0
07301225	North Fork Red River near Kellerville, Tex.	07/08/2002	1530	regular	50	708	1,830	1,790	8.1	8.1	33.0	31.0
07301250	North Fork Red River near Magic City, Tex.	07/08/2002	1900	regular	54	708	1,950	1,820	8.1	8.1	30.5	33.0
07301300	North Fork Red River near Shamrock, Tex.	07/09/2002	0800	regular	51	711	2,100	2,010	8.0	8.0	27.5	23.5
07301303	Bronco Creek near Twitty, Tex.	07/09/2002	0930	regular	0.02	711	5,780	5,310	7.7	7.9	27.5	23.5
07301306	East Branch Creek near Twitty, Tex.	07/09/2002	1000	regular	0.14	711	4,190	3,890	7.8	7.8	32.0	25.5
07301310	North Fork Red River tributary (unnamed) near Twitty, Tex.	07/09/2002	1100	regular	1.6	711	2,330	2,190	7.3	7.6	32.0	26.0
07301315	North Fork Red River near Texola, Okla.	07/10/2002	0800	regular	46	717	2,770	2,610	8.0	8.1	27.0	24.5
07301410	Sweetwater Creek near Kelton, Tex.	07/09/2002	1630	regular	5.3	711	828	747	8.2	8.2	34.5	32.5
07301420	Sweetwater Creek near Sweetwater, Okla.	07/09/2002	1800	regular	18	711	780	715	8.4	8.4	34.5	32.5

Table 4. Water properties and major-ion concentrations of surface-water samples in the North Fork Red River study area—Continued.

[ft^3/s, cubic feet per second; mm of Hg, millimeters of mercury; ˚C, degrees Celsius; µS/cm, microSiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; E, estimated value; --, no data; shaded samples are quality-control samples]

Station number (see fig. 1 for location)	Station name	Date	Time	Sample type	Discharge, instantaneous (ft^3/s)	Barometric pressure (mm of Hg)	Specific conductance at 25˚C, (µS/cm)		pH (standard unit)		Temperature, (˚C)	
							field	lab	field	lab	air	water
07301420	Sweetwater Creek near Sweetwater, Okla.	07/09/2002	1801	replicate	--	--	--	723	--	8.3	--	--
07301422	Sweetwater Creek near May-field, Okla.	07/10/2002	0930	regular	14	717	1,100	995	8.1	8.2	28.0	26.0
07301424	Salt Creek near Texola, Okla.	07/10/2002	1100	regular	2.5	717	3,790	3,510	8.0	7.7	32.0	26.5
07301425	Sweetwater Creek near Texas Line, Okla.	07/10/2002	1200	regular	18	717	1,600	1,520	8.2	8.2	33.0	28.0
07301450	North Fork Red River near Erick, Okla.	07/10/2002	1400	regular	62	717	2,500	2,330	8.1	8.1	36.5	34.0
07301453	North Fork Red River near Hext, Okla.	07/10/2002	1530	regular	78	717	2,460	2,280	8.2	7.9	37.0	34.5
07301481	North Fork Red River near Sayre, Okla.	07/10/2002	1700	regular	96	717	2,270	2,120	8.2	7.8	39.0	36.0
07301500	North Fork Red River near Carter, Okla.	07/11/2002	0800	regular	86	725	2,200	2,080	8.1	7.8	25.0	26.5
07301700	North Fork Red River near Retrop, Okla.	07/11/2002	1000	regular	94	725	2,210	2,090	8.2	7.7	25.0	27.5
07301700	North Fork Red River near Retrop, Okla.	07/11/2002	1006	field blank	--	--	--	12		8.4	--	--

Table 4. Water properties and major-ion concentrations of surface-water samples in the North Fork Red River study area—Continued

[ft^3/s, cubic feet per second; mm of Hg, millimeters of mercury; °C, degrees Celsius; µS/cm, microSiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; E, estimated value; --, no data; shaded samples are quality-control samples]

Station number (see fig. 1 for location)	Date	Sample type	Oxygen, dissolved (mg/L)	Alkalinity, dissolved, field (mg/L as $CaCO_3$)	Solids, sum of constituents, dissolved (mg/L)	Solids, residue at 180°C, dissolved (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Carbonate, dissolved, field (mg/L)	Bicarbonate, dissolved, field (mg/L)
07301190	07/08/2002	regular	6.6	130	1,560	1,750	174	41.0	340	6.16	0	158
07301220	07/08/2002	regular	6.8	203	580	645	77.3	17.2	111	3.84	0	248
07301225	07/08/2002	regular	6.9	180	1,040	1,130	118	26.9	210	4.73	0	220
07301250	07/08/2002	regular	6.3	151	1,010	1,130	114	26.5	198	4.80	0	184
07301300	07/09/2002	regular	7.8	114	1,150	1,300	137	32.3	209	4.84	0	139
07301303	07/09/2002	regular	5.7	260	5,200	6,040	509	468	325	4.38	0	317
07301306	07/09/2002	regular	7.2	189	3,620	4,120	461	239	248	7.00	0	230
07301310	07/09/2002	regular	5.5	116	1,970	2,210	408	93.6	48.4	4.90	0	141
07301315	07/10/2002	regular	7.8	114	1,630	1,750	200	49.3	291	5.23	0	139
07301410	07/09/2002	regular	8.9	179	496	537	75.5	20.1	59.1	2.67	0	218
07301420	07/09/2002	regular	7.8	180	465	501	64.4	22.6	68.0	2.56	0	220
07301420	07/09/2002	replicate	--	--	--	503	62.6	22.0	66.2	2.43	--	--
07301422	07/10/2002	regular	7.3	189	654	704	77.3	28.4	110	2.91	0	230
07301424	07/10/2002	regular	8.0	187	2,770	3,110	421	102	270	2.89	0	228
07301425	07/10/2002	regular	8.1	193	996	1,090	129	39.8	147	2.89	0	235
07301450	07/10/2002	regular	7.1	129	1,470	1,600	177	46.5	242	5.12	0	157
07301453	07/10/2002	regular	7.9	124	1,460	1,600	185	51.1	233	4.75	0	151
07301481	07/10/2002	regular	8.0	121	1,360	1,500	172	48.7	202	4.60	0	148
07301500	07/11/2002	regular	7.8	106	1,370	1,490	177	52.6	202	5.07	0	129
07301700	07/11/2002	regular	8.2	91	1,330	1,460	162	47.8	202	5.04	0	111
07301700	07/11/2002	field blank	--	--	--	< 10	E 0.01	< 0.008	< 0.09	< 0.10	--	--

Table 4. Water properties and major-ion concentrations of surface-water samples in the North Fork Red River study area—Continued

[ft^3/s, cubic feet per second; mm of Hg, millimeters of mercury; ˚C, degrees Celcius; µS/cm, microSiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; E, estimated value; --, no data; shaded samples are quality-control samples]

Station number (see fig. 1 for location)	Date	Sample type	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Silica, dissolved (mg/L)	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)
07301190	07/08/2002	regular	105	786	0.7	2.02	26.6	< 30	E 2.4
07301220	07/08/2002	regular	87.1	124	0.8	< 0.03	37.3	47	8.1
07301225	07/08/2002	regular	96.6	440	0.7	0.76	30.7	14	8.1
07301250	07/08/2002	regular	128	416	0.7	0.70	30.5	< 10	E 3.2
07301300	07/09/2002	regular	233	435	0.8	0.82	27.5	< 30	12.4
07301303	07/09/2002	regular	3,450	256	0.7	0.25	31.7	< 50	565
07301306	07/09/2002	regular	2,370	158	0.5	0.04	24.3	< 30	245
07301310	07/09/2002	regular	1,290	33.2	0.5	< 0.03	25.8	E 18	192
07301315	07/10/2002	regular	448	539	0.7	0.94	27.6	< 30	18.6
07301410	07/09/2002	regular	167	41.5	0.6	0.06	22.1	< 10	12.1
07301420	07/09/2002	regular	138	40.7	0.7	0.03	19.9	< 10	E 2.9
07301420	07/09/2002	replicate	139	40.1	0.7	E 0.03	19.4	< 10	E 2.9
07301422	07/10/2002	regular	203	99.1	0.8	0.05	19.7	< 10	E 3.1
07301424	07/10/2002	regular	1,420	402	0.5	0.18	41.8	< 30	13.1
07301425	07/10/2002	regular	376	162	0.7	0.06	22.7	< 10	3.6
07301450	07/10/2002	regular	445	447	0.8	0.69	24.4	< 30	5.6
07301453	07/10/2002	regular	496	389	0.7	0.52	23.5	< 30	10.5
07301481	07/10/2002	regular	503	336	0.7	0.37	21.5	< 30	5.7
07301500	07/11/2002	regular	520	328	0.7	0.37	20.2	< 30	< 5.0
07301700	07/11/2002	regular	491	350	0.6	0.48	17.2	< 30	E 2.4
07301700	07/11/2002	field blank	< 0.1	< 0.30	< 0.10	< 0.03	< 0.13	< 10	E 2.0

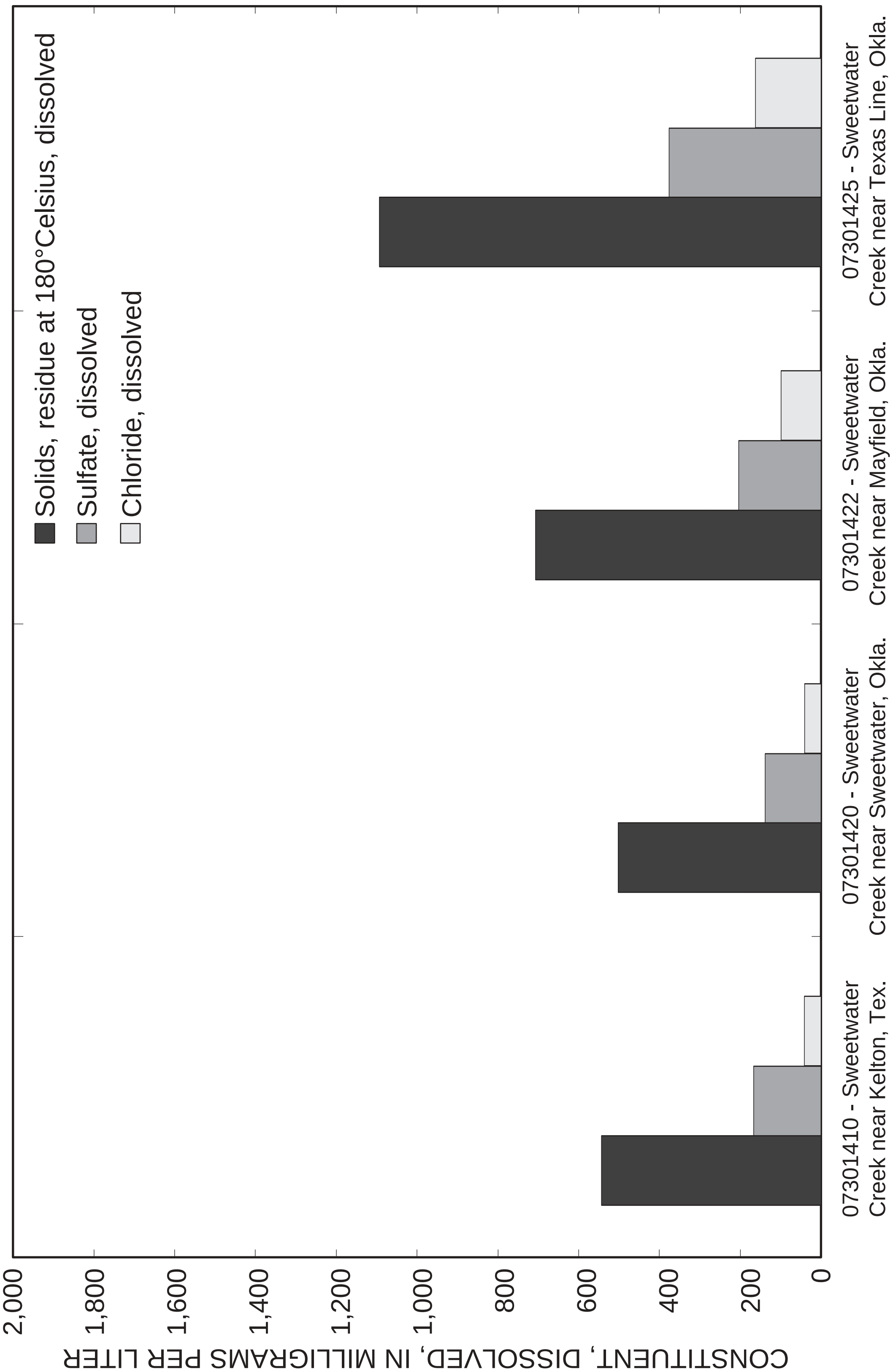


Figure 7. Concentrations of dissolved solids, sulfate, and chloride for stations on Sweetwater Creek, July 9–10, 2002.

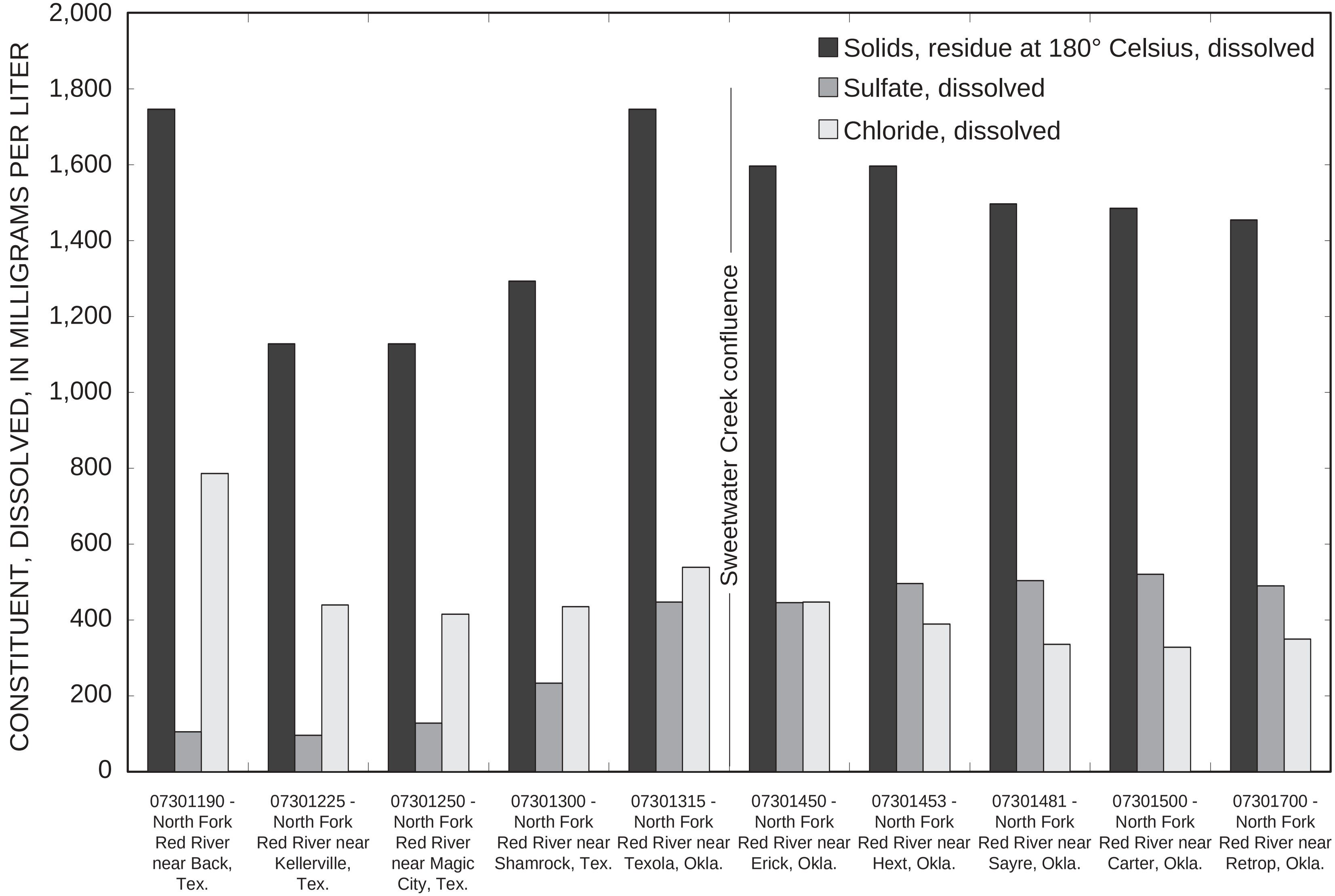


Figure 8. Concentrations of dissolved solids, sulfate, and chloride for stations on North Fork Red River, July 8–11, 2002.

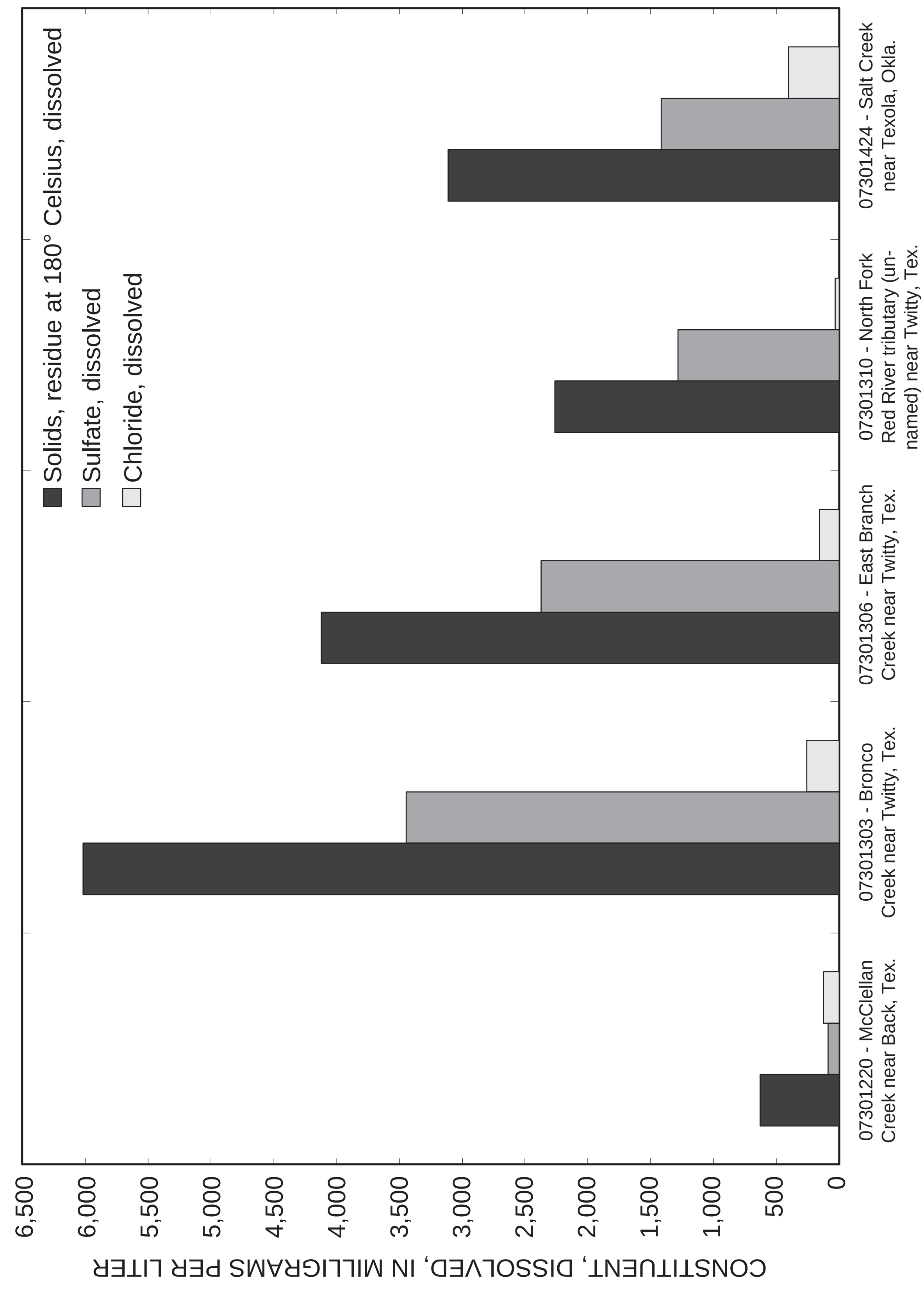
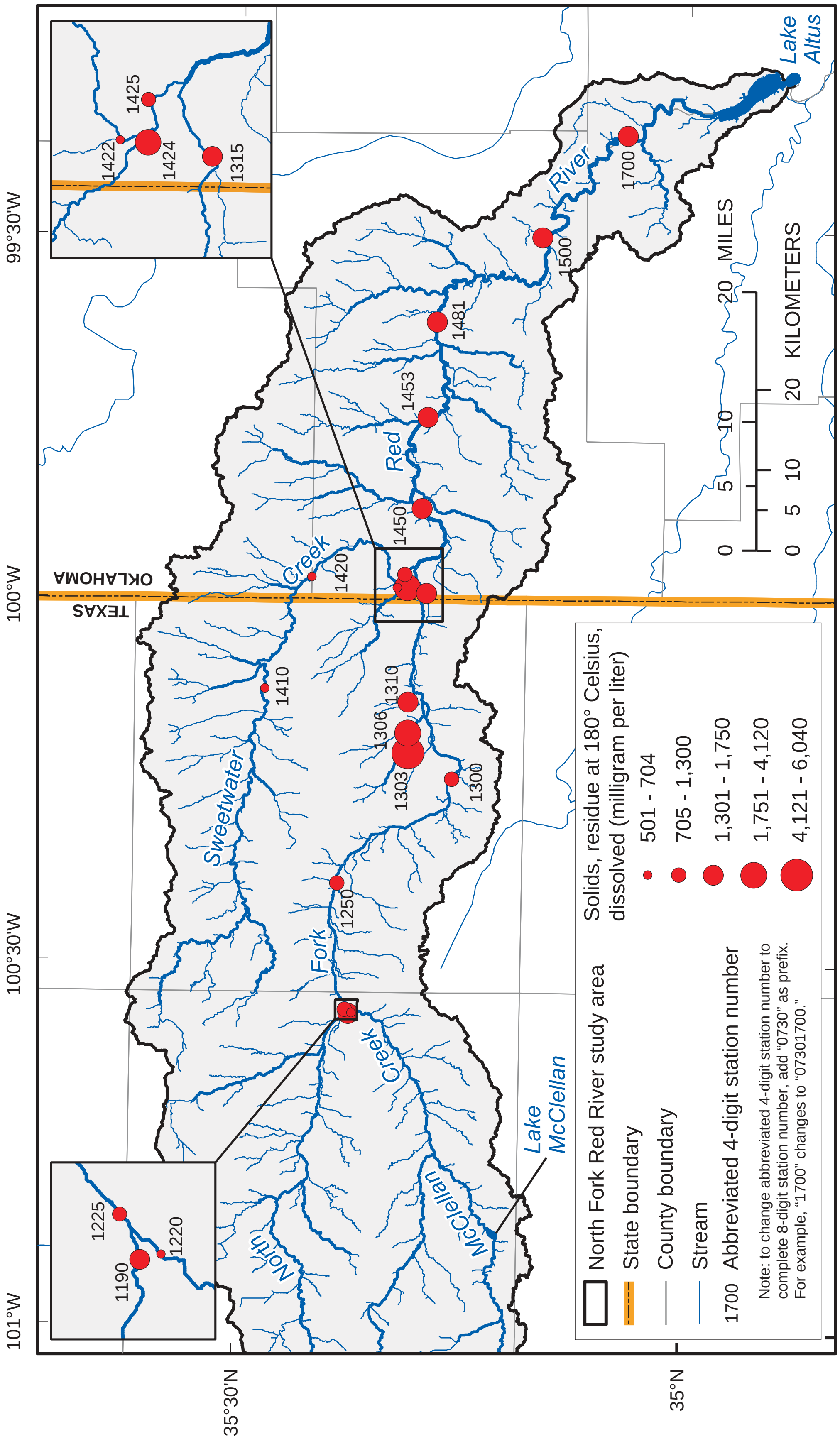
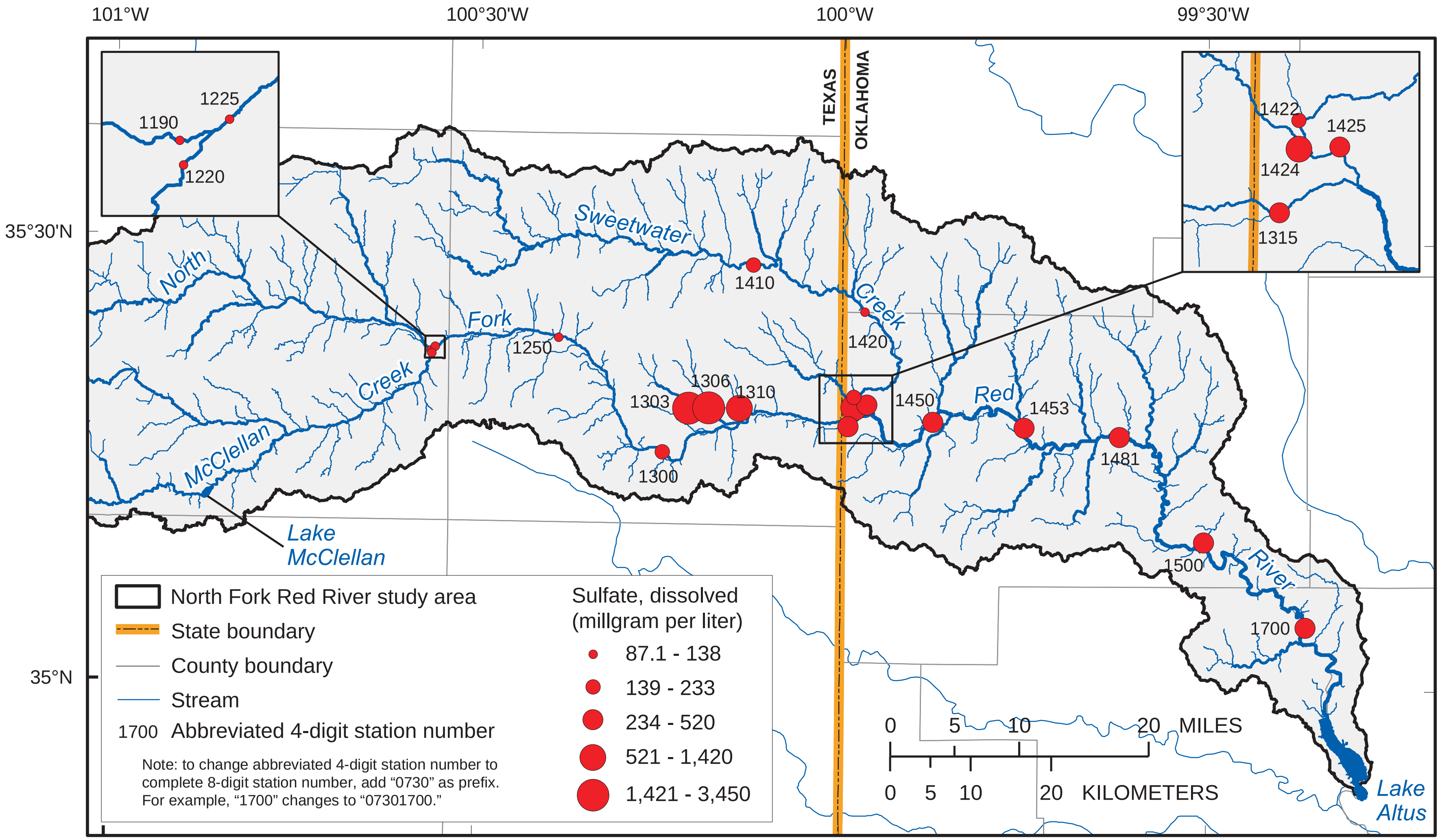


Figure 9. Concentrations of dissolved solids, sulfate, and chloride for stations on tributaries of North Fork Red River and Sweetwater Creek, July 8–10, 2002.



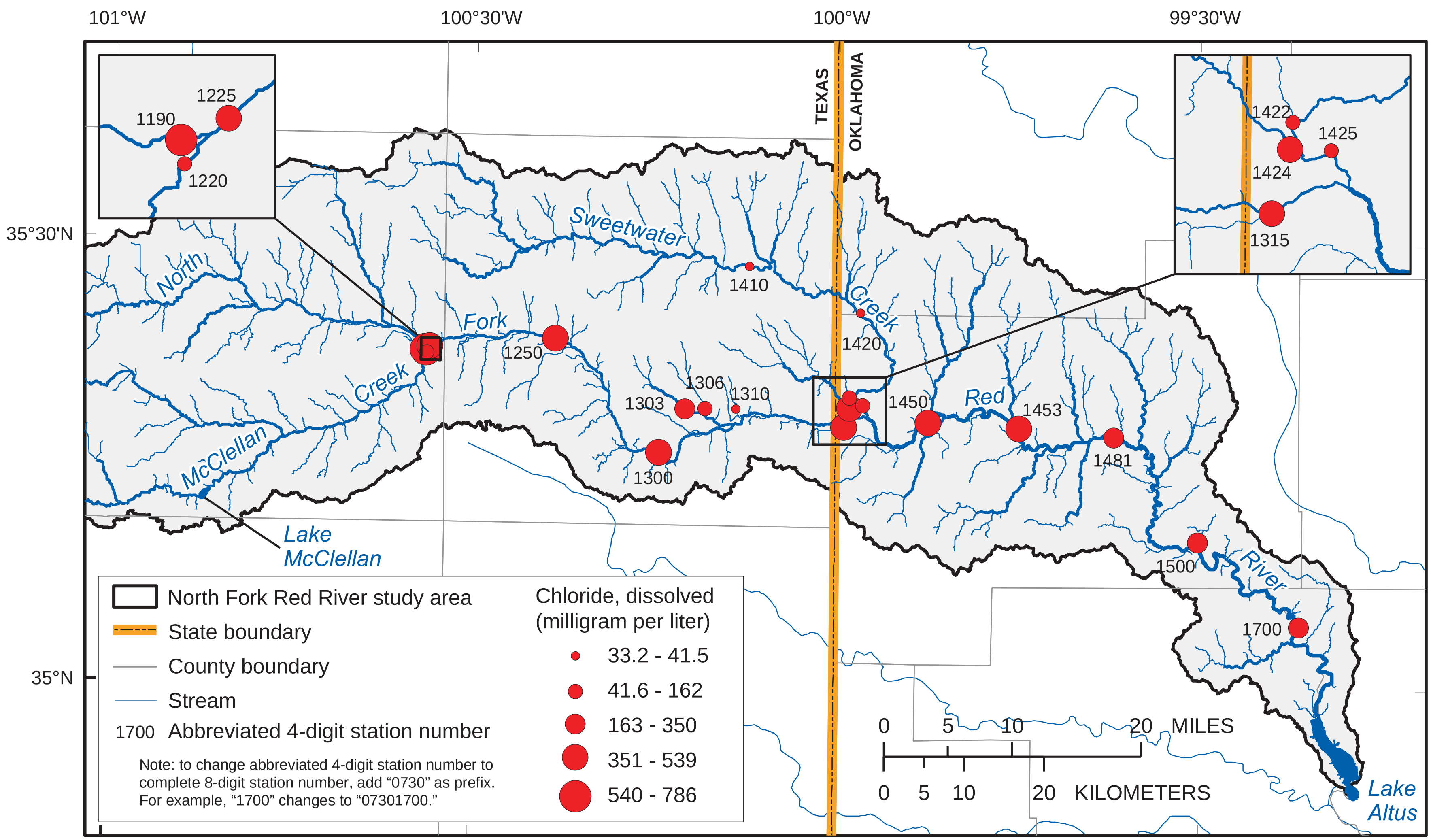
Map compiled by U.S. Geological Survey
Base map from National Elevation Dataset
Universal Transverse Mercator projection, Zone 14
North American Datum 1983

Figure 10. North Fork Red River study area with graduated symbols representing dissolved solids concentrations, July 8–11, 2002.



Map compiled by U.S. Geological Survey
Base map from National Elevation Dataset
Universal Transverse Mercator projection, Zone 14
North American Datum 1983

Figure 11. North Fork Red River study area with graduated symbols representing sulfate concentrations, July 8–11, 2002.



Map compiled by U.S. Geological Survey
Base map from National Elevation Dataset
Universal Transverse Mercator projection, Zone 14
North American Datum 1983

Figure 12. North Fork Red River study area with graduated symbols representing chloride concentrations, July 8–11, 2002.

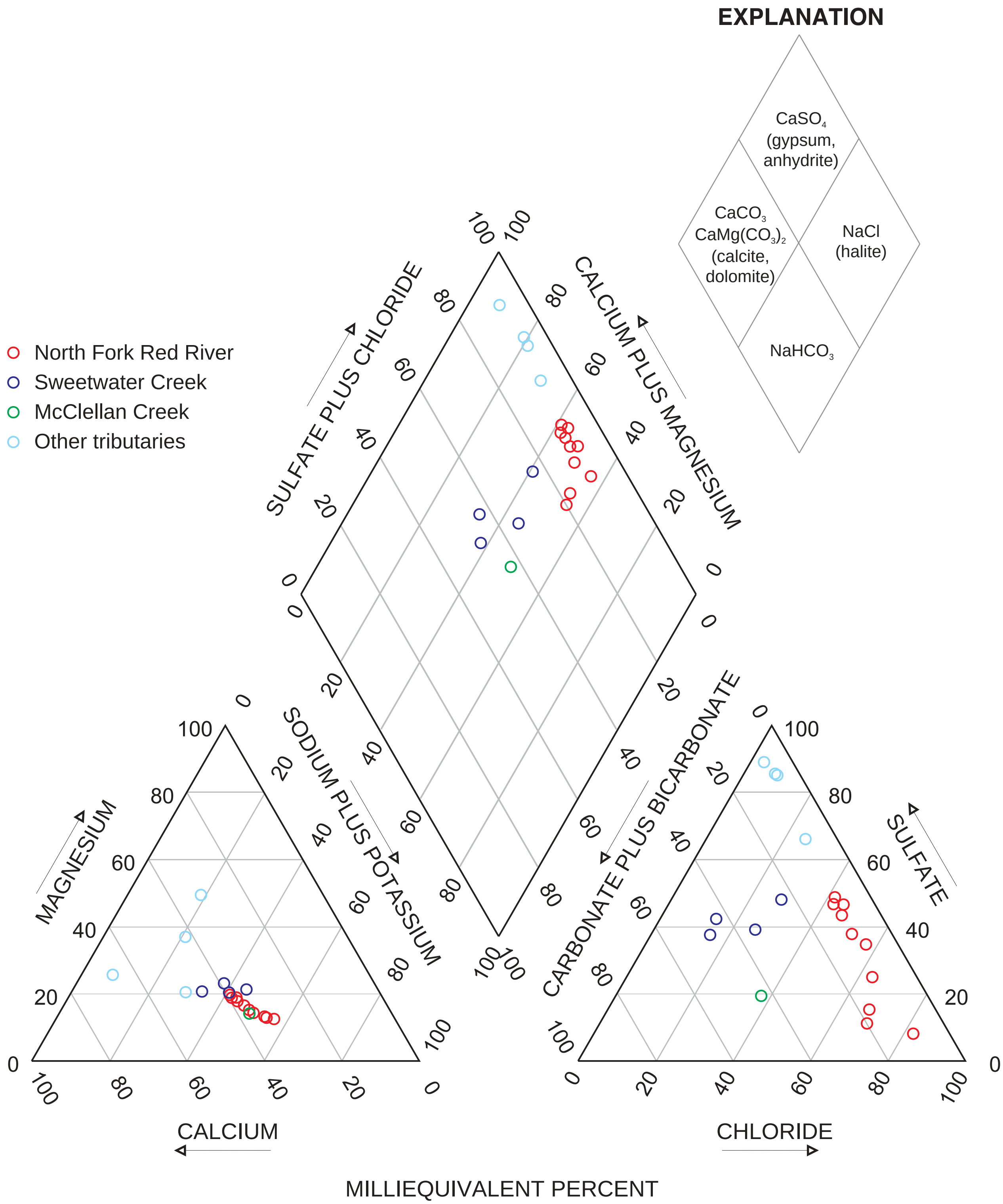


Figure 13. Major-ion composition in the North Fork Red River, Sweetwater Creek, McClellan Creek, and other tributaries, July 8–11, 2002.

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