

Prepared in cooperation with the Poteau Valley Improvement Authority

# **Concentrations, Loads, and Yields of Total Phosphorus, Total Nitrogen, and Suspended Sediment and Bacteria Concentrations in the Wister Lake Basin, Oklahoma and Arkansas, 2011–13**



Scientific Investigations Report 2014–5170

**Front cover:**

**Background,** Wister Lake dam, Oklahoma, 2012.

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By Stephanie D. Buck

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Scientific Investigations Report 2014–5170

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

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

**U.S. Geological Survey**  
Suzette M. Kimball, Acting Director

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## Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
<b>Length</b>		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
<b>Area</b>		
acre	4,047	square meter (m <sup>2</sup> )
acre	0.4047	hectare (ha)
square mile (mi <sup>2</sup> )	259.0	hectare (ha)
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
<b>Volume</b>		
acre-foot (acre-ft)	1,233	cubic meter (m <sup>3</sup> )
<b>Flow rate</b>		
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m <sup>3</sup> /s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m <sup>3</sup> /yr)
cubic foot per second per square mile [(ft <sup>3</sup> /s)/mi <sup>2</sup> ]	0.01093	cubic meter per second per square kilometer [(m <sup>3</sup> /s)/km <sup>2</sup> ]
cubic foot per day (ft <sup>3</sup> /d)	0.02832	cubic meter per day (m <sup>3</sup> /d)
<b>Mass</b>		
ton, long (2,240 lb)	1.016	megagram (Mg)
ton per day per square mile [(ton/d)/mi <sup>2</sup> ]	0.3503	megagram per day per square kilometer [(Mg/d)/km <sup>2</sup> ]
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per year (ton/yr)	0.9072	metric ton per year

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

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

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). The NAVD 88 replaced the National Geodetic Vertical Datum of 1929 (NGVD 29), previously known as the Sea Level Datum of 1929.

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

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

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

# Concentrations, Loads, and Yields of Total Phosphorus, Total Nitrogen, and Suspended Sediment and Bacteria Concentrations in the Wister Lake Basin, Oklahoma and Arkansas, 2011–13

By Stephanie D. Buck

## Abstract

The Poteau Valley Improvement Authority uses Wister Lake in southeastern Oklahoma as a public water supply. Total phosphorus, total nitrogen, and suspended sediments from agricultural runoff and discharges from wastewater treatment plants and other sources have degraded water quality in the lake. As lake-water quality has degraded, water-treatment cost, chemical usage, and sludge production have increased for the Poteau Valley Improvement Authority.

The U.S. Geological Survey (USGS), in cooperation with the Poteau Valley Improvement Authority, investigated and summarized concentrations of total phosphorus, total nitrogen, suspended sediment, and bacteria (*Escherichia coli* and *Enterococcus* sp.) in surface water flowing to Wister Lake. Estimates of total phosphorus, total nitrogen, and suspended sediment loads, yields, and flow-weighted mean concentrations of total phosphorus and total nitrogen concentrations were made for the Wister Lake Basin for a 3-year period from October 2010 through September 2013. Data from water samples collected at fixed time increments during base-flow conditions and during runoff conditions at the Poteau River at Loving, Okla. (USGS station 07247015), the Poteau River near Heavener, Okla. (USGS station 07247350), and the Fourche Maline near Leflore, Okla. (USGS station 07247650) water-quality stations were used to evaluate water quality over the range of streamflows in the basin. These data also were collected to estimate annual constituent loads and yields by using regression models.

At the Poteau River stations, total phosphorus, total nitrogen, and suspended sediment concentrations in surface-water samples were significantly larger in samples collected during runoff conditions than in samples collected during base-flow conditions. At the Fourche Maline station, in contrast, concentrations of these constituents in water samples collected during runoff conditions were not significantly larger than concentrations during base-flow conditions. Flow-weighted mean total phosphorus concentrations at all three

stations from 2011 to 2013 were several times larger than the Oklahoma State Standard for Scenic Rivers (0.037 milligrams per liter [mg/L]), with the largest flow-weighted phosphorus concentrations typically being measured at the Poteau River at Loving, Okla., station. Flow-weighted mean total nitrogen concentrations did not vary substantially between the Poteau River stations and the Fourche Maline near Leflore, Okla., station. At all of the sampled water-quality stations, bacteria (*Escherichia coli* and *Enterococcus* sp.) concentrations were substantially larger in water samples collected during runoff conditions than in water samples collected during base-flow conditions from 2011 to 2013.

Estimated annual loads of total phosphorus, total nitrogen, and suspended sediment in the Poteau River stations during runoff conditions ranged from 82 to 98 percent of the total annual loads of those constituents. Estimated annual loads of total phosphorus, total nitrogen, and suspended sediment in the Fourche Maline during runoff conditions ranged from 86 to nearly 100 percent of the total annual loads.

Estimated seasonal total phosphorus loads generally were smallest during base-flow and runoff conditions in autumn. Estimated seasonal total phosphorus loads during base-flow conditions tended to be largest in winter and during runoff conditions tended to be largest in the spring. Estimated seasonal total nitrogen loads tended to be smallest in autumn during base-flow and runoff conditions and largest in winter during runoff conditions. Estimated seasonal suspended sediment loads tended to be smallest during base-flow conditions in the summer and smallest during runoff conditions in the autumn. The largest estimated seasonal suspended sediment loads during runoff conditions typically were in the spring.

The estimated mean annual total phosphorus yield was largest at the Poteau River at Loving, Okla., water-quality station. The estimated mean annual total phosphorus yield was largest during base flow at the Poteau River at Loving, Okla., water-quality station and at both of the Poteau River water-quality stations during runoff conditions. The estimated mean annual total nitrogen yields were largest at the Poteau River

water-quality stations. Estimated mean annual total nitrogen yields were largest during base-flow and runoff conditions at the Poteau River at Loving, Okla., water-quality station. The estimated mean annual suspended sediment yield was largest at the Poteau River near Heavener, Okla., water-quality station during base-flow and runoff conditions.

Flow-weighted mean concentrations indicated that total phosphorus inputs from the Poteau River Basin in the Wister Lake Basin were larger than from the Fourche Maline Basin. Flow-weighted mean concentrations of total nitrogen did not vary spatially in a consistent manner.

The Poteau River and the Fourche Maline contributed estimated annual total phosphorus loads of 137 to 278 tons per year (tons/yr) to Wister Lake. Between 89 and 95 percent of the annual total phosphorus loads were transported to Wister Lake during runoff conditions. The Poteau River and the Fourche Maline contributed estimated annual total nitrogen loads of 657 to 1,294 tons/yr, with 86 to 94 percent of the annual total nitrogen loads being transported to Wister Lake during runoff conditions. The Poteau River and the Fourche Maline contributed estimated annual total suspended sediment loads of 110,919 to 234,637 tons/yr, with 94 to 99 percent of the annual suspended sediment loads being transported to Wister Lake during runoff conditions. Most of the total phosphorus and suspended sediment were delivered to Wister Lake during runoff conditions in the spring. The majority of the total nitrogen was delivered to Wister Lake during runoff conditions in winter.

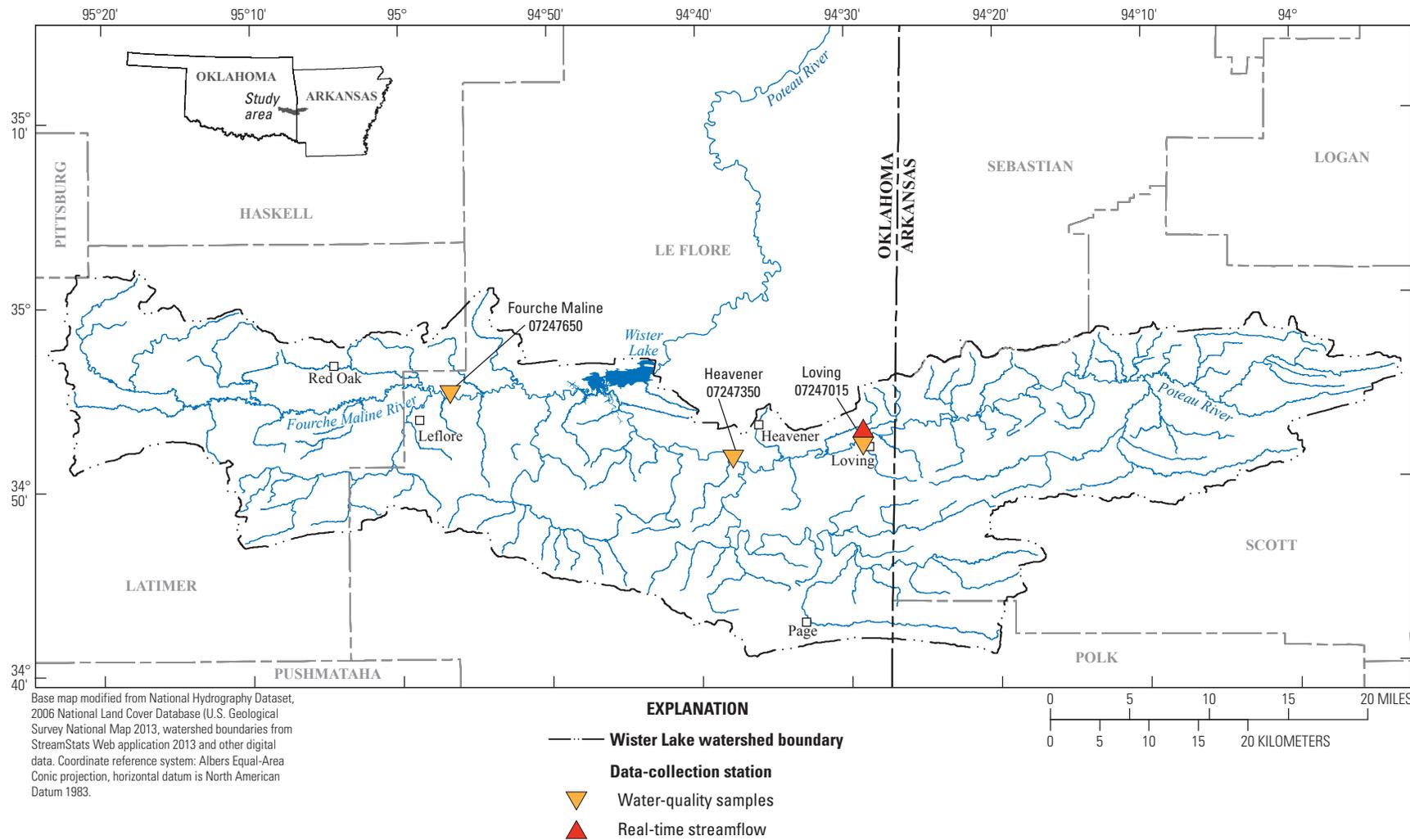
## Introduction

Wister Lake is the sole source of public water supplies for many residents and provides the water supply for all businesses in Le Flore County, Oklahoma (fig. 1) (Poteau Valley Improvement Authority, 2009). Wister Lake was constructed in 1949, and the Poteau Valley Improvement Authority (PVIA) began using the lake as a drinking water supply in 1969 (Poteau Valley Improvement Authority, 2009). Estimated total daily water use for Le Flore County in 2005 was about 20 million gallons per day, with most of the withdrawal of water in that county being for public supply (Tortorelli, 2009). Relatively large concentrations of total phosphorus, total nitrogen, and suspended sediment in the lake have caused it to become very turbid and eutrophic (containing increased amounts of algae and other aquatic plants caused by elevated concentrations of total phosphorus and total nitrogen) since a U.S. Environmental Protection Agency (EPA) survey was conducted in 1974 (Hession and others, 1996; Oklahoma Department of Environmental Quality, 2008). Wister Lake is cited in the Oklahoma Department of Environmental Quality (ODEQ) 2008 Section 303(d) of the Clean Water Act list of impaired water bodies because of relatively large concentrations of total phosphorus, total nitrogen, and suspended sediment. Such a listing requires that a Total

Maximum Daily Load (TMDL) estimate be prepared for the lake (Oklahoma Department of Environmental Quality, 2008; Poteau Valley Improvement Authority, 2009). A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water-quality standards (U.S. Environmental Protection Agency, 2013).

The mission of the PVIA is to produce and distribute potable water supplies to more than 40,000 customers through 16 member municipalities and rural water districts (Poteau Valley Improvement Authority, 2009; U.S. Census Bureau, 2012). The PVIA service region includes about 80 percent of Le Flore County, Okla. Deterioration of water quality in the lake has been caused by inflows of total phosphorus, total nitrogen, and suspended sediment from point and nonpoint sources surrounding and upstream of the lake (Oklahoma Department of Environmental Quality, 2008). Nonpoint sources can include runoff from agricultural areas, forests, dirt roads, and construction sites. Additionally, discharges from point sources such as wastewater-treatment (WWT) facilities and improperly functioning onsite wastewater treatment systems also may contribute total phosphorus and total nitrogen to the lake (Busteed and others, 2009; Poteau Valley Improvement Authority, 2009; U.S. Geological Survey, 1999). Deteriorating water quality in this lake has increased water-treatment costs, the amounts of treatment chemicals used, and production of sludge from water-treatment processes (Poteau Valley Improvement Authority, 2009).

Elevated concentrations of total phosphorus, total nitrogen, suspended sediment, and bacteria are the most common sources of impairment of surface-water quality in the United States (U.S. Environmental Protection Agency, 2009). Determination of a TMDL requires estimation of the total load of a substance in a lake and contributions of those substances to a lake from nonpoint and point sources. To account for nonpoint sources contributing to the lake, water samples need to be collected during runoff conditions (Petersen and others, 2005). Other studies in basins in Oklahoma with similar land uses have shown that about 75 to 95 percent of total phosphorus and total nitrogen loads flow downstream during runoff conditions (Tortorelli, 2008; Andrews and others, 2009; Esralew and others, 2011). Fecal-indicator bacteria such as *Escherichia coli* and *Enterococcus* sp. also can seep in groundwater or be washed by runoff to streams from nonpoint and point sources. Mott and Steele (1991) reported that at the Buffalo River Basin in Arkansas, a single rain event can transport larger numbers of such bacteria from pastures into that river compared to base-flow conditions. Busteed and others (2009) described a study to identify critical source areas (CSAs) that contribute disproportionate pollutant loads to the lake, but the model used for that study was calibrated on the basis of nutrient concentrations from water samples that typically were collected during base-flow conditions (streamflow that occurs during relatively dry periods that is composed largely of groundwater seepage and treated wastewater from point-source discharges). Underrepresentation of samples collected during runoff



**Figure 1.** The Wister Lake Basin, Oklahoma and Arkansas, with locations of selected real-time streamflow and water-quality data-collection stations and towns with wastewater treatment plants that discharge into streams in the basin, 2011–13.

(also known as high-flow) conditions reduces the ability to reliably estimate concentrations and loads of constituents flowing down a stream during those conditions. Water-quality sampling conducted in this basin prior to the study described in this report did not include collection of notable numbers of surface-water samples at runoff conditions or analysis of suspended sediment and bacteria concentrations in water samples (Busteed and others, 2009).

## Purpose and Scope

The purpose of this report is to describe concentrations, loads, and yields of total phosphorus, total nitrogen, and suspended sediment and concentrations of bacteria in the two principal tributaries of Wister Lake. This report provides annual estimates of total phosphorus, total nitrogen, and suspended sediment loads, yields, and flow-weighted mean (FWM) concentrations in the Poteau River and Fourche Maline from October 2010 through September 2013 (also known as water years 2011–13; a water year is the 12-month period October 1 through September 30 designated by the calendar year in which it ends). Load estimates by season and flow (base-flow versus runoff components) for the 3-year period also are presented for these constituents.

Total phosphorus, total nitrogen, suspended sediment, and bacteria (*Escherichia coli* and *Enterococcus* sp.) concentrations were compared for water samples collected by the U.S. Geological Survey (USGS) at three stations in the Wister Lake Basin. Those concentrations also were compared to Oklahoma State Standards for Scenic Rivers (State of Oklahoma, 2006) to flow-weighted concentrations measured mostly at undeveloped basins of the United States (Clark and others, 2000) and to Oklahoma State Standards for Primary Body Contact Recreation (State of Oklahoma, 2006). This report provides information needed to increase understanding of hydrology and water quality in the Wister Lake Basin and provides hydrologic data and interpretations that can be used to implement and enhance land-use and water-management policies for the Wister Lake Basin.

## Study Area Description

Wister Lake in southeastern Oklahoma (fig. 1) receives inflows of water primarily from the Poteau River to the east and the Fourche Maline to the west. The Wister Lake Basin consists of approximately 930 square miles (mi<sup>2</sup>) in southeastern Oklahoma and southwestern Arkansas. Wister Lake was constructed in 1949 by the U.S. Army Corps of Engineers (USACE) to provide flood control, water supply, flow regulation, and conservation (Poteau Valley Improvement Authority, 2009). The recreation opportunities Wister Lake provides are economically important for the surrounding area (Hession and others, 1996).

The study area surrounding Wister Lake Basin is about 65 percent forest, 34 percent pasture and cropland, and

1 percent urban (fig. 2; Multi-Resolution Land Characteristics Consortium, 2013). There were 1,428 cattle farms and 316 poultry farms in this basin as of 2007 (U.S. Department of Agriculture, 2007). There are 2 municipal WWT facilities in Heavener that discharge into the Poteau River and 1 WWT facility that discharges into the Fourche Maline at Red Oak (fig. 1). Streams receiving discharges of effluent from WWT facilities can have relatively large phosphorus and nitrogen concentrations during base-flow conditions in the Poteau River, whereas bacteria concentrations typically have been largest in nonpoint source runoff in this region (Petersen and others, 2005).

## Streamflow in the Wister Lake Basin

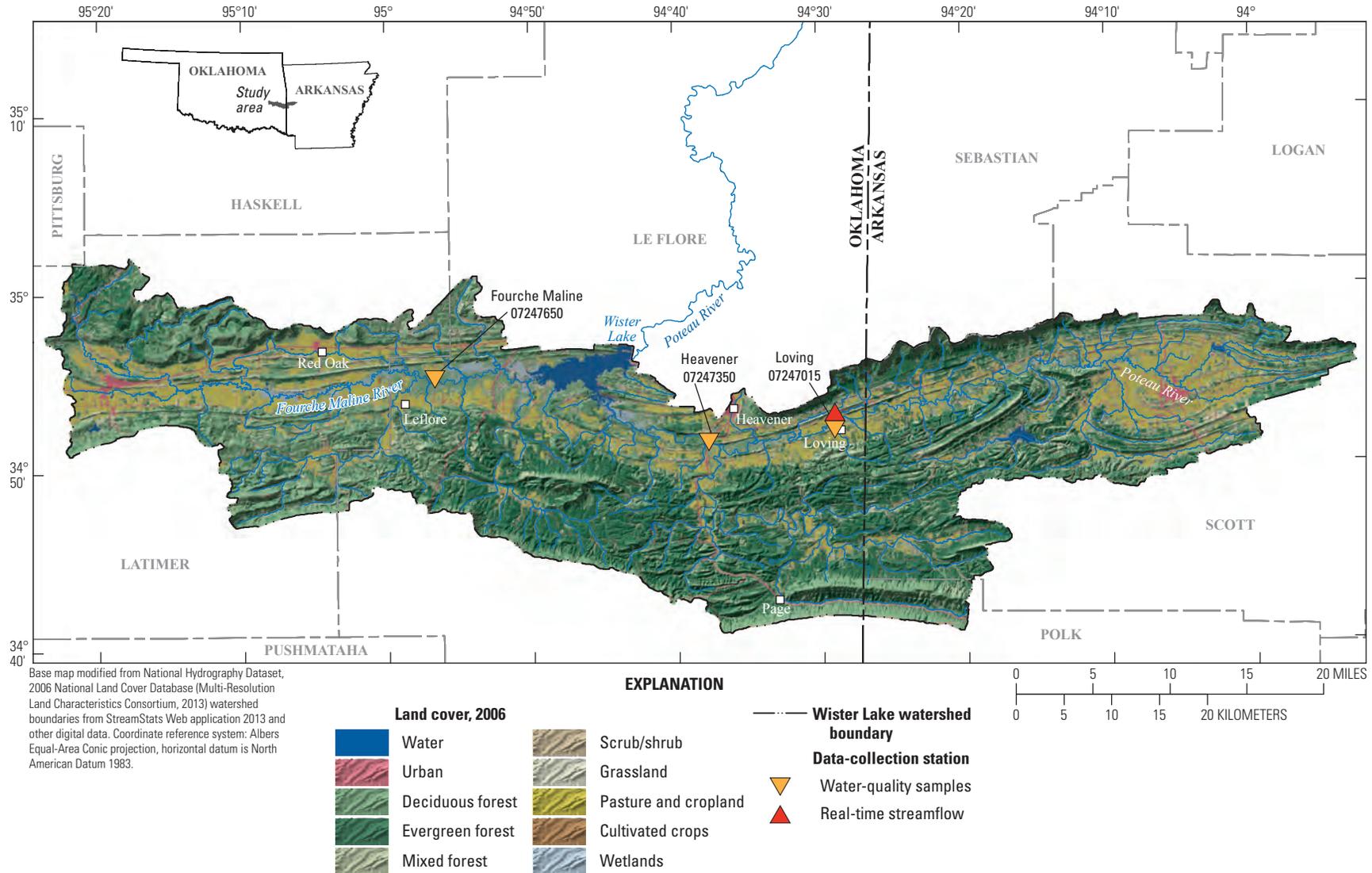
Streamflow in the Wister Lake Basin varied considerably during water years 2011–13 (table 1). The Poteau River, the primary stream that discharges to Wister Lake from the east, contributed the majority of the water flowing into the lake, with streamflow at particular sites increasing with upstream drainage area (table 1). Maximum daily streamflows for the study period were recorded in November 2011 at the Poteau River at Loving, Okla., water-quality station; in May 2013 at the Poteau River near Heavener, Okla., water-quality station; and in April 2011 at the Fourche Maline near Leflore, Okla., water-quality station (see Estimation of Daily Streamflow for Ungaged Water-Quality Stations section of this report) (fig. 3). Minimum recorded streamflows were zero flow, which were recorded at each of these three stations periodically during the 2011 and 2012 water years. At these stations, the largest monthly streamflows generally were measured from March to June, whereas the smallest monthly streamflows generally were measured from July through October (fig. 4).

## Methods

Methods used for water-quality data collection and analysis, estimation of streamflow at ungaged stations, streamflow separation into base flow and runoff, statistical tests used to compare groups of data, and computation of statistics of phosphorus and nitrogen concentrations in the Wister Lake Basin from 2011 to 2013 are described in this section. Regression methods used to estimate phosphorus, nitrogen, and sediment loads and yields at selected stations in this basin also are described.

## Water-Quality Data Collection and Analysis

Water-quality data were collected at three stations: the USGS streamflow-gaging station Poteau River at Loving, Okla., (USGS station 07247015) and two ungaged water-quality stations, Poteau River near Heavener, Okla., (USGS



**Figure 2.** The Wister Lake Basin, Oklahoma and Arkansas, with 2006 land cover and data-collection stations.

**Table 1.** Streamflow-gaging station information and streamflow statistics for the water-quality stations sampled in the Wister Lake Basin, Oklahoma and Arkansas, 2011–13.[ddmss, degrees, minutes, seconds; mi<sup>2</sup>, square mile; ft<sup>3</sup>/s, cubic feet per second]

U.S. Geological Survey station name (number)	Latitude (ddmss)	Longitude (ddmss)	Upstream drainage area (mi <sup>2</sup> )	Mean annual streamflow (ft <sup>3</sup> /s)			Minimum and maximum daily mean streamflow for study period October 2010–September 2013 (ft <sup>3</sup> /s)	
				2011	2012	2013	Minimum (date)	Maximum (date)
Poteau River at Loving, Okla. (07247015)	345247	942902	268	192.6	405.8	379.9	5 zero-flow days in 2011, 11 zero-flow days in 2012	17,900 (11/22/2011)
Poteau River near Heavener, Okla. (07247350)	345130	943745	515	415.0	846.7	911.0	5 zero-flow days in 2011, 6 zero-flow days 2012	64,819 (5/31/2013)
Fourche Maline near Leflore, Okla. (07247650)	345511	945643	267	265.9	232.9	281.7	3 zero-flow days in 2011, 8 zero-flow days 2012	10,418 (04/25/2011)

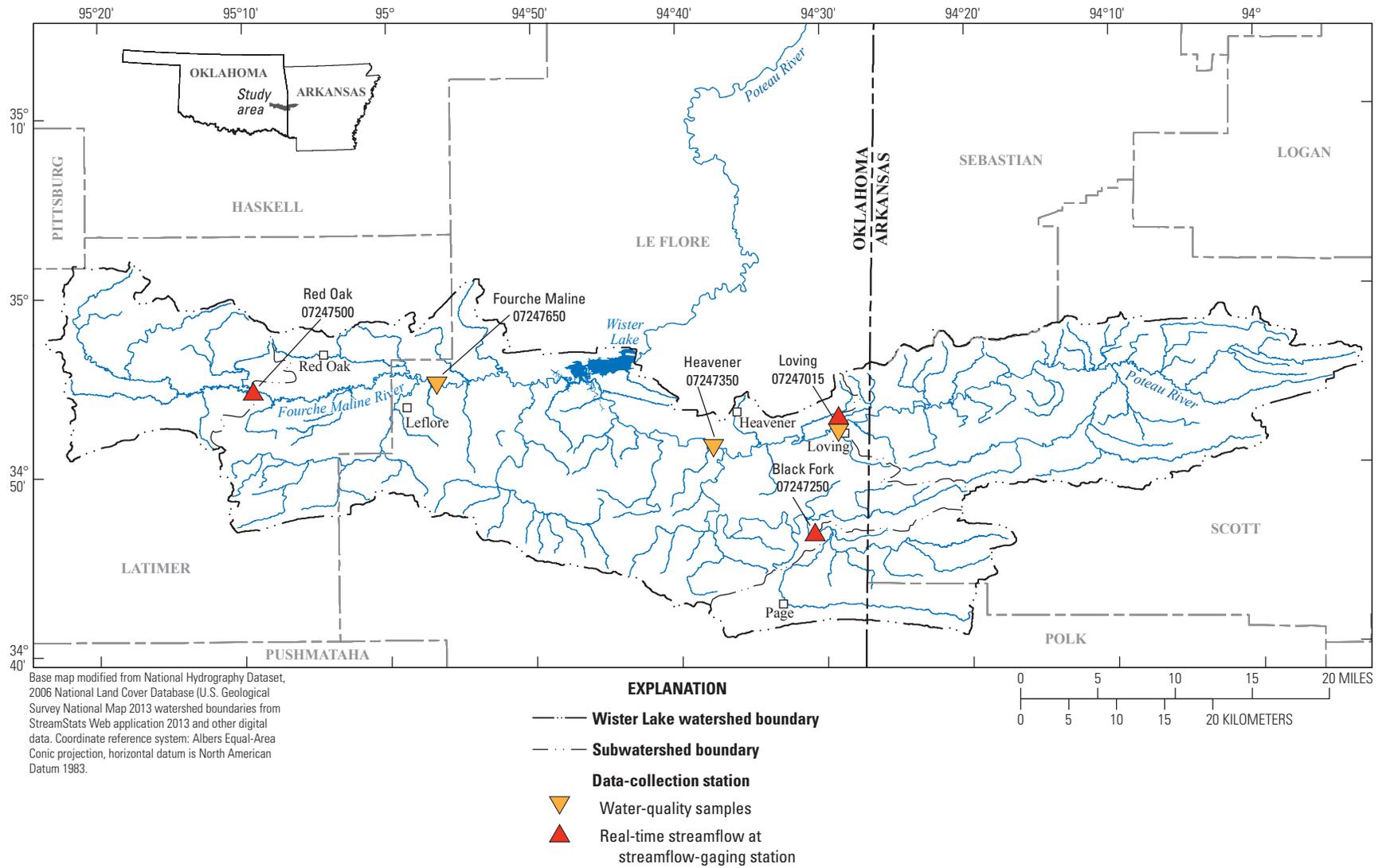
station 07247350) and Fourche Maline near Leflore, Okla., (USGS station 07247650), all of which are referred to in the remainder of this text as “stations” (fig. 1, table 1). The station on the Poteau River at Loving, Okla., was operated, and streamflows were measured according to methods described by Rantz and others (1982). At the ungaged stations on the Poteau River near Heavener, Okla., and the Fourche Maline near Leflore, Okla., streamflow measurements were made on the same dates as water-quality-sample collection in accordance with methods described by Rantz and others (1982).

Surface-water-quality data used for determining concentrations and estimating loads should be collected at a range of flow conditions (from low to high) in approximately equal numbers in all seasons (Tortorelli, 2008). Thirty-six water samples were collected from October 2010 to September 2013 at each of these three stations. Those samples were collected over wide ranges of streamflows and seasonal conditions (fig. 4). During each of the 3 years at each of these stations, 6 fixed-frequency water-quality samples per year were collected during low- to median-flow conditions, and 6 water-quality samples were sampled during higher flow (runoff) conditions. All of those samples were collected by using isokinetic equal-width incremental methods (Edwards and Glysson, 1999) which are designed to weight the amount of water collected across the width of a stream channel to include greater amounts from the faster flowing parts of stream cross sections. The water samples were sent to the USGS National Water-Quality Laboratory in Denver, Colorado, for analysis of concentrations of

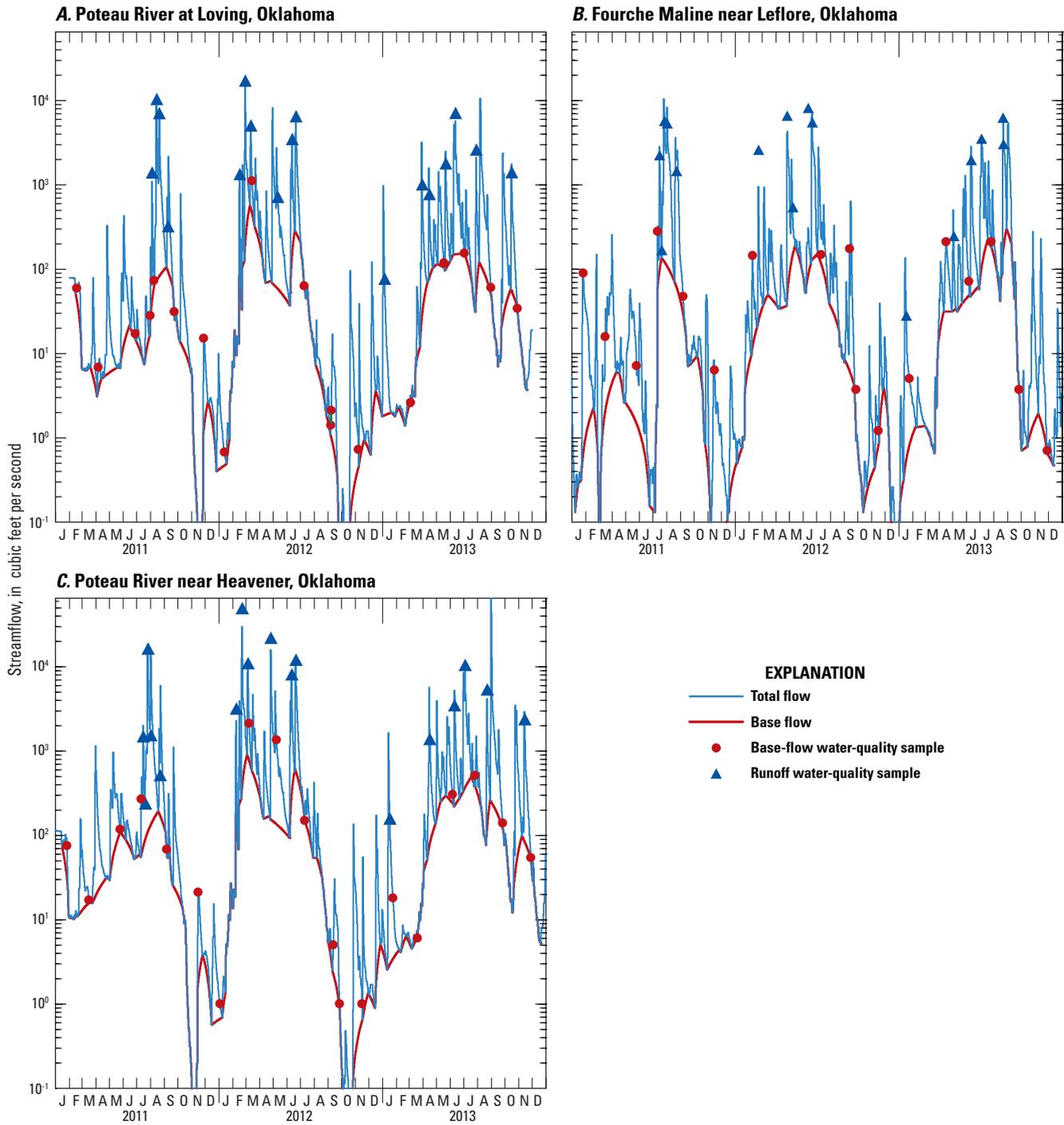
total phosphorus and total nitrogen. Water samples to be analyzed for suspended sediment concentration were sent to the USGS Iowa Sediment Laboratory in Iowa City, Iowa, at the beginning of water year 2011 and the USGS Missouri Sediment Laboratory in Rolla, Missouri, for the remainder of the study period. Bacteria concentrations were analyzed by USGS Tulsa (Okla.) Field Office personnel by using IDEXX® Colilert® for *Escherichia coli* concentrations and IDEXX® Enterolert® for *Enterococcus* sp. concentrations, by following methods described in U.S. Geological Survey (2006), Harwell and Mobley (2009), and IDEXX Laboratories (2009).

U.S. Geological Survey protocols and procedures were followed for quality assurance (QA), as described in U.S. Geological Survey (2006). Collection of quality-control (QC) samples is a mandated USGS practice for water-quality field studies (U.S. Geological Survey, 2006) and is an important component of the quality assurance of this project. The goal of quality-assurance sampling is to identify, quantify, and document bias and variability in data that result from the collection, processing, shipping, and handling of samples. Field blanks and field sequential replicates were collected by the USGS at rates of 3 to 7 percent of the number of environmental samples collected.

Three blank samples were collected at the Poteau River near Heavener station, with concentrations of all of the analyzed constituents in those samples being less than laboratory reporting levels. Additionally, numerous blank samples were analyzed for bacterial concentrations. Results of those analyses indicated little to no contamination during sampling or sample processing.



**Figure 3.** The Wister Lake Basin, Oklahoma and Arkansas, and water-quality stations and streamflow-gaging stations that produced data used to compute streamflow for ungaged water-quality stations, 2011–13.



**Figure 4.** Streamflow separated into total flow, base flow, and the times and flows at which water-quality samples were collected at the (A) Poteau River at Loving, Oklahoma; (B) Fourche Maline near Leflore, Okla.; and (C) Poteau River near Heavener, Okla., water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, 2010–13.

Relative percent difference (RPD) was computed for analyzed concentrations between seven pairs of environmental and field sequential replicate samples (equation 1).

$$RPD = \text{abs}(D1-D2) / \text{avg}(D1+D2) \times 100 \quad (1)$$

where

- $RPD$  = relative percent difference,
- $D1$  = measured value of the first duplicate,
- $D2$  = measured value of the second duplicate,
- $\text{abs}$  = absolute value of  $D1-D2$ , and
- $\text{avg}$  = mean value of  $D1$  and  $D2$ .

The median RPDs between sequential replicates analyzed for phosphorus and nitrogen concentrations were 3.5 and 1.9, respectively. The median RPD in the sediment concentration was 11.8. Bacterial quantification was more variable, with the median RPD for analyses of *Escherichia coli* being 21.1 and the median RPD for *Enterococcus* sp. being 28.6.

## Estimation of Daily Streamflow for Ungaged Water-Quality Stations

Streamflow data at times other than sampling were not collected at two of the water-quality stations—Poteau River near Heavener, Okla., and Fourche Maline near Leflore, Okla.; however, streamflow data are required for computing annual and seasonal water-quality constituent loads with the S-LOADEST program (Cohn and others, 1989; Crawford, 1991). Streamflow data were therefore estimated for these two stations by using data collected at nearby streamflow-gaging stations operated by the USGS (fig. 3). The Drainage-Area Ratio Method, which can be used to estimate flow at ungaged stations with upstream or downstream gages (Ries and Friesz, 2000), was used to estimate daily flow data for the ungaged stations, as follows:

$$Q_s = [DA_s / DA_g] * Q_g \quad (2)$$

where

- $Q_s$  = the daily mean streamflow at the ungaged station, in cubic feet per second;
- $DA_s$  = the drainage area of the ungaged station, in square miles;
- $DA_g$  = the drainage area of the gaging station (upstream or downstream), in square miles; and
- $Q_g$  = the daily mean streamflow at the gaging station (upstream or downstream) in cubic feet per second.

Daily mean streamflow at the Poteau River near Heavener, Okla., (fig. 3) was estimated by using the sum of daily streamflow at two upstream real-time streamflow-gaging stations: Poteau River at Loving, Okla., (USGS station 07247015) and Black Fork below Big Creek near Page, Okla.

(USGS station 07247250). Daily mean streamflow for the Fourche Maline near Leflore, Okla., station was estimated by using the daily streamflow at the upstream station Fourche Maline near Red Oak, Okla. (USGS station 07247500) (fig. 3).

## Streamflow Separation

Streamflow data were separated into base-flow and runoff components by using a hydrograph-separation program, Base-Flow Index (Institute of Hydrology, 1980a, 1980b; Wahl and Wahl, 1988). Base flow is streamflow that occurs during dry periods and is largely composed of groundwater seepage (Langbein and Iseri, 1960). Base-flow and runoff components were separated because water-quality-constituent concentrations collected during base-flow conditions are more indicative of the effects of point-source discharges, and constituent concentrations collected during runoff conditions are more indicative of discharges from nonpoint sources, with separation being useful for developing understanding of potential sources of these constituents (Tortorelli, 2008). By using the Base-Flow Index program, the minimum daily flow was identified in consecutive 5-day increments, and minimums smaller than 90 percent of adjacent minimums were defined as turning points (Wahl and Tortorelli, 1997). The Base-Flow Index program computes estimates of the base-flow hydrograph by connecting straight lines through consecutive turning points. Runoff components were calculated as the difference between total streamflow and the base-flow component.

## Load and Yield Estimation

Load is the amount of a constituent transported past a given point of a stream per period of time, expressed in units of mass per unit of time. Instantaneous load can be computed as the product of instantaneous streamflow ( $Q$ ) and an instantaneous constituent concentration in water ( $C$ ) multiplied by a conversion factor to convert cubic feet per second ( $\text{ft}^3/\text{s}$ ) and milligrams per liter ( $\text{mg}/\text{L}$ ) into mass per unit of time. Similarly, seasonal or annual load can be computed as the product of seasonal or annual mean  $Q$  and seasonal or annual mean  $C$  if measured, but seasonal and annual mean  $C$  were not measured in this study because water-quality samples were only collected periodically. Linear regression was used, therefore, to estimate daily, seasonal, and annual mean constituent loads (total phosphorus, total nitrogen, and suspended sediment) from the periodically collected water-quality data and daily mean streamflow data. Constituent load is the dependent variable, and streamflow and time are the independent variables in such regressions. Regression methods require that daily mean streamflow and data from discrete water-quality samples be collected for several years (Runkel and others, 2004). Sample dates, times, continuous streamflow data, and total phosphorus, total nitrogen, and suspended sediment concentrations used in the regression analyses are provided in appendixes 1–3.

The S-LOADEST program was used to fit parameters for linear regressions between constituent load and independent variables and then to estimate constituent loads at the sampled stations (Cohn and others, 1989; Crawford, 1991). S-LOADEST is based on the LOADEST program (Runkel and others, 2004) and has been incorporated in the statistical computer program S-Plus (Insightful Corporation, 2005) by the USGS to aid in graphical analysis and production of tabular results. S-LOADEST provides several options (for example, adjusted maximum likelihood method, least absolute deviation, Beale's ratio estimator) for applying regressions. Because the sample dataset for each constituent contained censored data (censored values are the values of the lower reporting level, reported with a "less than" remark code for samples in which the concentration was not detected), the adjusted maximum likelihood method was selected to estimate values of censored data for model computation (Dempster and others, 1977).

S-LOADEST contains nine predefined rating-curve models that can be used to test relations between constituent load and streamflow. For this study, two of the model equations were used. The first model (equation 3) was used to estimate loads of total phosphorus and total nitrogen and includes seasonality variables to simulate the relation between the natural logarithms of L and Q:

$$\ln(L) = a_0 + a_1 * \ln Q + a_2 * \sin SS + a_3 * \cos SS \quad (3)$$

where

- ln = natural logarithm;
- L = constituent load, in tons per day;
- $a_0, a_1, a_2, a_3$  = regression coefficients, dimensionless;
- Q = daily streamflow, in cubic feet per second;
- sin = sine;
- cos = cosine; and
- SS = seasonality parameter ( $2 * \pi * \text{dectime}$ , the time parameter in decimal years).

The second model (equation 4) was used to estimate loads of suspended sediment and simulates the relation between the natural logarithms of L, Q, and  $Q^2$ :

$$\ln(L) = a_0 + a_1 * \ln Q + a_2 * \ln Q^2 \quad (4)$$

where

- ln = natural logarithm;
- L = constituent load, in tons per day;
- $a_0, a_1, a_2$  = regression coefficients, dimensionless; and
- Q = daily streamflow, in cubic feet per second.

Estimated annual total phosphorus, total nitrogen, and suspended sediment loads and estimates of the standard deviations of the loads were calculated with S-LOADEST by using all data from water samples collected during base-flow and runoff conditions. The daily load values generated by S-LOADEST were separated into base-flow and runoff

component sample sets according to the number of base-flow and runoff days for each water year (October 1 through September 30). Estimated annual base-flow loads were calculated as the sum of the values of the base-flow days sample sets. Estimated annual runoff loads were calculated as the sum of the values of the runoff days sample sets. The estimates of annual runoff load were biased slightly high, and the corresponding estimates of base-flow load were biased slightly low because a small fraction of the load on runoff days is from base flow, but because that fraction is small, the bias can be considered negligible. Estimated seasonal base-flow and runoff loads were calculated in the same manner, on the basis of the number of base-flow and runoff days in each season. In this report, the seasons are described as follows: (1) spring is March through May, (2) summer is June through August, (3) autumn is September through November, and (4) winter is December through February. Yields of total phosphorus, total nitrogen, and suspended sediment for the study period at each station were calculated by dividing annual loads of total phosphorus, total nitrogen, and suspended sediment by upstream drainage-basin area.

## Assessment of Concentrations, Loads, and Yields of Total Phosphorus, Total Nitrogen, and Suspended Sediment and Bacteria Concentrations in the Wister Lake Basin

In this section, concentrations, loads, and yields of total phosphorus, total nitrogen, and suspended sediment are described for the three sampled stations in the Wister Lake Basin for water years 2011–13. Bacteria (*Escherichia coli* and *Enterococcus* sp.) concentrations collected during base-flow and runoff conditions also are described. All annual and seasonal loads, yields, and concentrations are based on estimated daily values of those statistics calculated by using the S-LOADEST program.

### Concentrations

This section describes total phosphorus, total nitrogen, suspended sediment, and bacteria (*Escherichia coli* and *Enterococcus* sp.) concentrations in water-quality samples collected during base-flow and runoff conditions. Summary statistics of those data were computed for all samples collected from water years 2011 through 2013 and were divided into samples collected during base-flow and runoff conditions (table 2). For constituent results with censored data (marked with a less than symbol [ $<$ ]), a distributional method called the maximum likelihood method (MLE) was used to estimate summary statistics (Helsel and Hirsch, 1992). Total nitrogen concentration and bacteria concentrations were the only

**Table 2.** Summary statistics of total phosphorus, total nitrogen, suspended sediment, *Escherichia coli*, and *Enterococcus* sp. concentrations in water-quality samples collected during base-flow and runoff conditions at water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

[obs., number of observations; mg/L, milligrams per liter; mL, milliliters; <, less than; >, greater than]

Station name (number)	Base-flow concentrations				obs.	Runoff concentrations				obs.
	Minimum	Median	Mean	Maximum		Minimum	Median	Mean	Maximum	
	Total phosphorus (mg/L as P)					Total phosphorus (mg/L as P)				
Poteau River at Loving, Okla. (07247015)	0.043	0.055	0.065	0.152	17	0.06	0.279	0.273	0.461	18
Poteau River near Heavener, Okla. (07247350)	0.023	0.05	0.056	0.114	15	0.051	0.205	0.196	0.378	22
Fourche Maline near Leflore, Okla. (07247650)	0.04	0.069	0.069	0.096	11	0.034	0.142	0.176	0.717	24

Station name (number)	Base-flow concentrations				obs.	Runoff concentrations				obs.
	Minimum	Median	Mean	Maximum		Minimum	Median	Mean	Maximum	
	Total nitrogen (mg/L as N)					Total nitrogen (mg/L as N)				
Poteau River at Loving, Okla. (07247015)	0.43	0.59	0.65	1.1	17	0.53	1.3	1.1	2.4	18
Poteau River near Heavener, Okla. (07247350)	0.36	0.57	0.65	1.2	15	0.5	1.1	1.1	1.7	22
Fourche Maline near Leflore, Okla. (07247650)	0.52	0.71	0.82	1.7	11	0.45	1.0	1.1	2.5	24

Station name (number)	Base-flow concentrations				obs.	Runoff concentrations				obs.
	Minimum	Median	Mean	Maximum		Minimum	Median	Mean	Maximum	
	Suspended sediment (mg/L)					Suspended sediment (mg/L)				
Poteau River at Loving, Okla. (07247015)	3	11	11	28	16	10	84	134	554	16
Poteau River near Heavener, Okla. (07247350)	3	14	14	28	14	11	86	148	658	20
Fourche Maline near Leflore, Okla. (07247650)	9	27	33	71	10	10	74	146	820	20

Station name (number)	Base-flow concentrations				obs.	Runoff concentrations				obs.
	Minimum	Median	Mean	Maximum		Minimum	Median	Mean	Maximum	
	<i>Escherichia coli</i> per 100 mL of water					<i>Escherichia coli</i> per 100 mL of water				
Poteau River at Loving, Okla. (07247015)	<10	52	69	310	13	120	3,100	4,253	14,000	18
Poteau River near Heavener, Okla. (07247350)	<10	26	54	250	14	41	2,050	2,443	9,900	22
Fourche Maline near Leflore, Okla. (07247650)	<10	52	120	490	10	10	1,085	3,179	24,000	24

**Table 2.** Summary statistics of total phosphorus, total nitrogen, suspended sediment, *Escherichia coli*, and *Enterococcus* sp. concentrations in water-quality samples collected during base-flow and runoff conditions at water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.—Continued

[obs., number of observations; mg/L, milligrams per liter; mL, milliliters; &lt;, less than; &gt;, greater than]

Station name (number)	Base-flow concentrations				obs.	Runoff concentrations				obs.
	Minimum	Median	Mean	Maximum		Minimum	Median	Mean	Maximum	
	<i>Enterococcus</i> sp. colonies per 100 mL of water					<i>Enterococcus</i> sp. colonies per 100 mL of water				
Poteau River at Loving, Okla. (07247015)	13	260	978	>4,800	13	40	4,800	3,424	>4,800	18
Poteau River near Heavener, Okla. (07247350)	4	18	72	500	14	<2	3,200	2,706	>4,800	22
Fourche Maline near Leflore, Okla. (07247650)	32	74	153	820	10	27	1,750	2,170	>4,800	24

constituents with censored data. The Wilcoxon rank-sum test was used to determine statistical significance of differences between samples collected during base-flow conditions and samples collected during runoff conditions, with significant differences in locations of distribution of datasets in this report being indicated by  $p$ -values <0.05 (Helsel and Hirsch, 1992).

## Total Phosphorus

Total phosphorus concentrations in water samples collected during runoff conditions (fig. 5, table 2) were significantly larger ( $p \leq 0.05$ ) than concentrations in samples collected during base-flow conditions at all stations except Fourche Maline for the 3-year study period. The smallest base-flow concentration of total phosphorus of 0.023 mg/L was measured in a water sample collected at the Poteau River near Heavener, Okla., station (table 2). The smallest total phosphorus concentration of 0.034 mg/L during runoff conditions was measured in a water sample collected at the Fourche Maline near Leflore, Okla., station. The largest total phosphorus concentration collected during base-flow conditions of 0.152 mg/L was measured in a water sample collected at the Poteau River at Loving, Okla., station, and the largest total phosphorus concentration of 0.717 mg/L collected during runoff conditions was measured in a water sample collected at the Fourche Maline near Leflore, Okla., station (table 2).

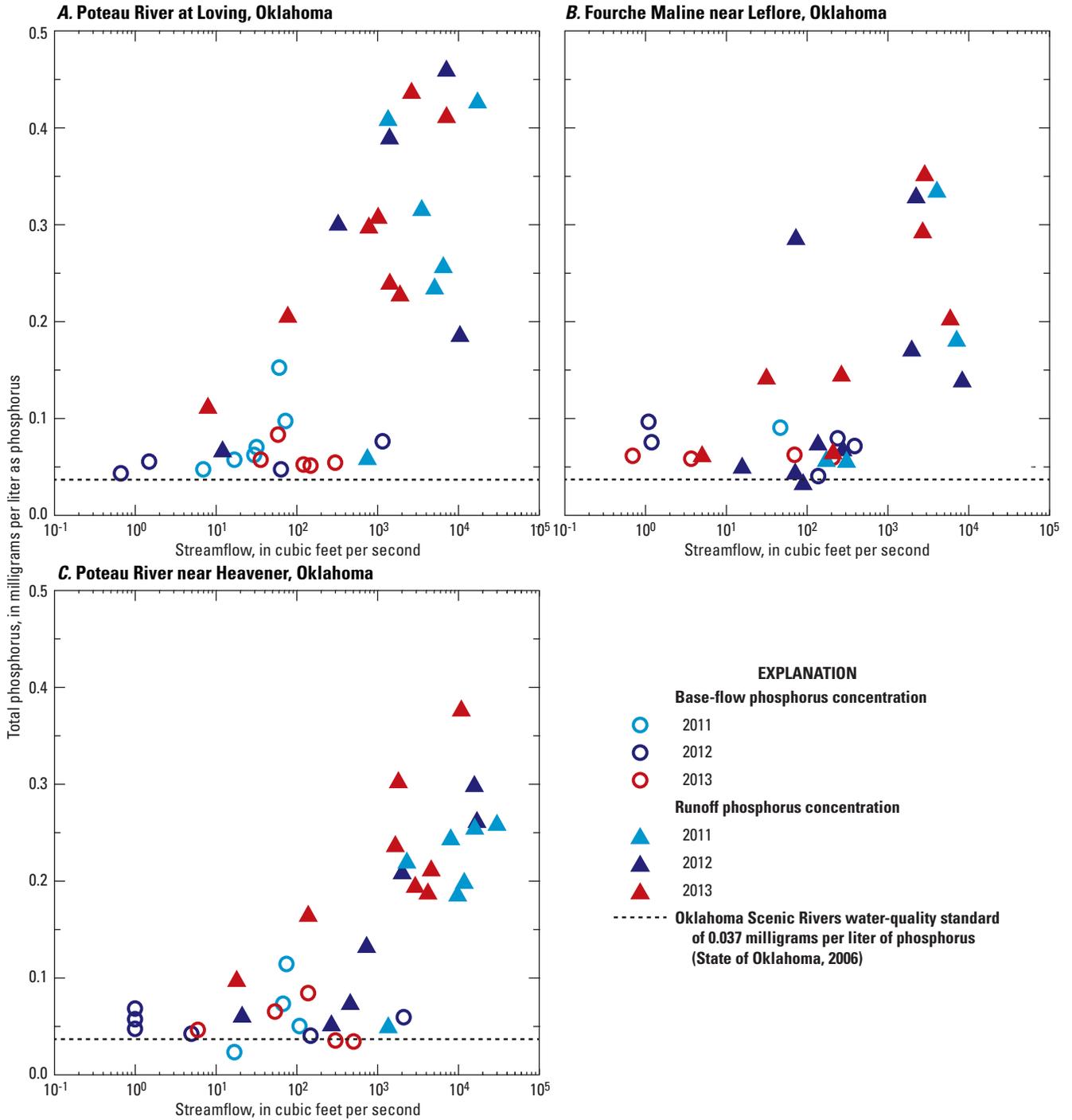
## Total Nitrogen

Total nitrogen concentrations measured in water samples collected during runoff conditions (fig. 6, table 2) were significantly larger ( $p \leq 0.05$ ) than total nitrogen concentrations in water samples collected during base-flow conditions at all stations except at the Fourche Maline near Leflore, Okla., station during the 3-year study period. Total nitrogen concentrations in water samples collected during base-flow

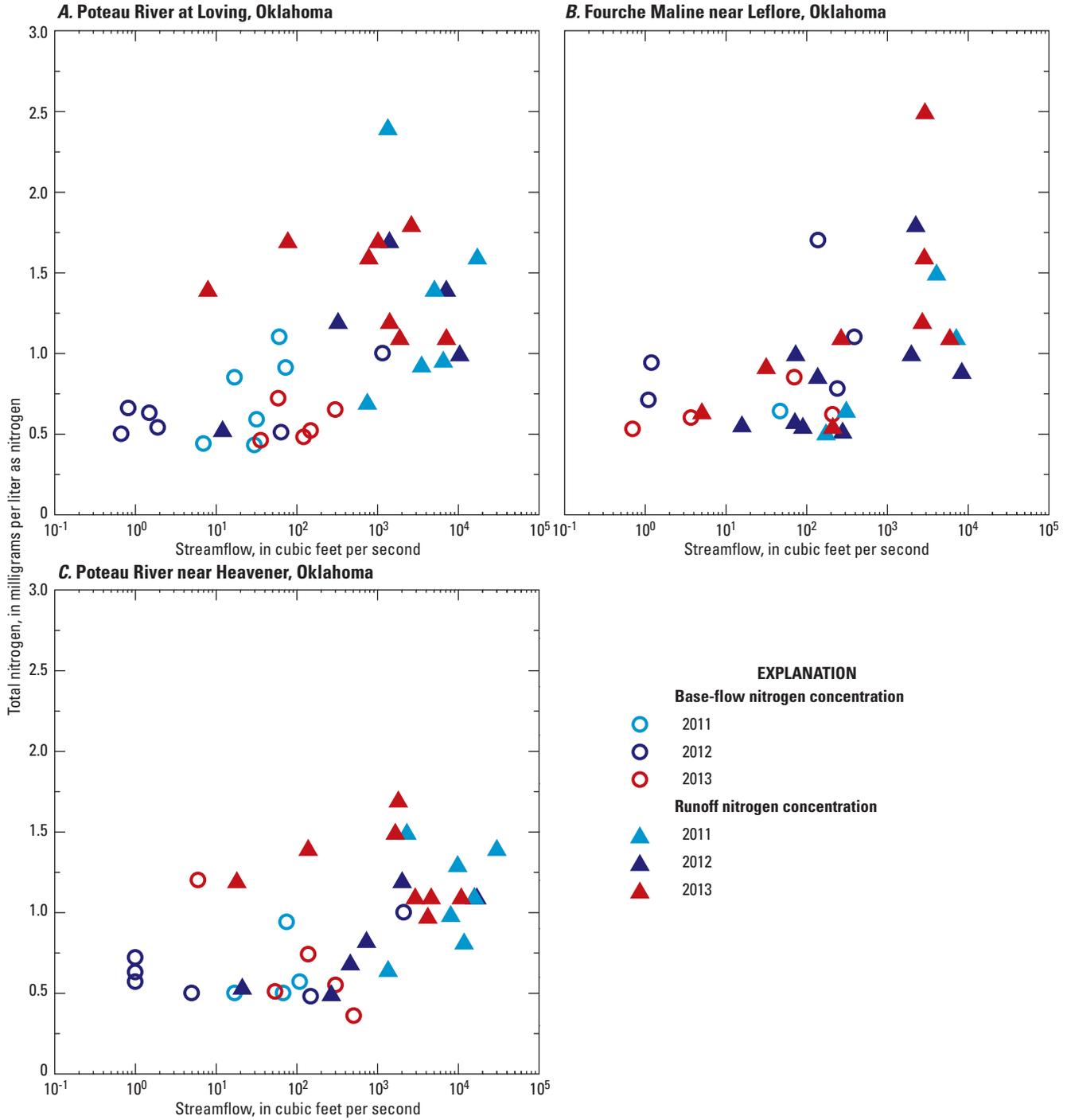
conditions at the Fourche Maline near Leflore, Okla., station generally were larger than concentrations in the water samples collected at the Poteau River stations during base-flow conditions. The smallest total nitrogen concentration of 0.36 mg/L measured at base-flow conditions was measured in a water sample collected at the Poteau River near Heavener, Okla., station, and the smallest total nitrogen concentration of 0.45 mg/L was measured at runoff conditions in a water sample collected at the Fourche Maline near Leflore, Okla., station (table 2). The largest total nitrogen concentration at base-flow conditions (1.7 mg/L) and the largest total nitrogen concentration at runoff conditions (2.5 mg/L) were measured in water samples collected at the Fourche Maline near Leflore, Okla., station (table 2).

## Suspended Sediment

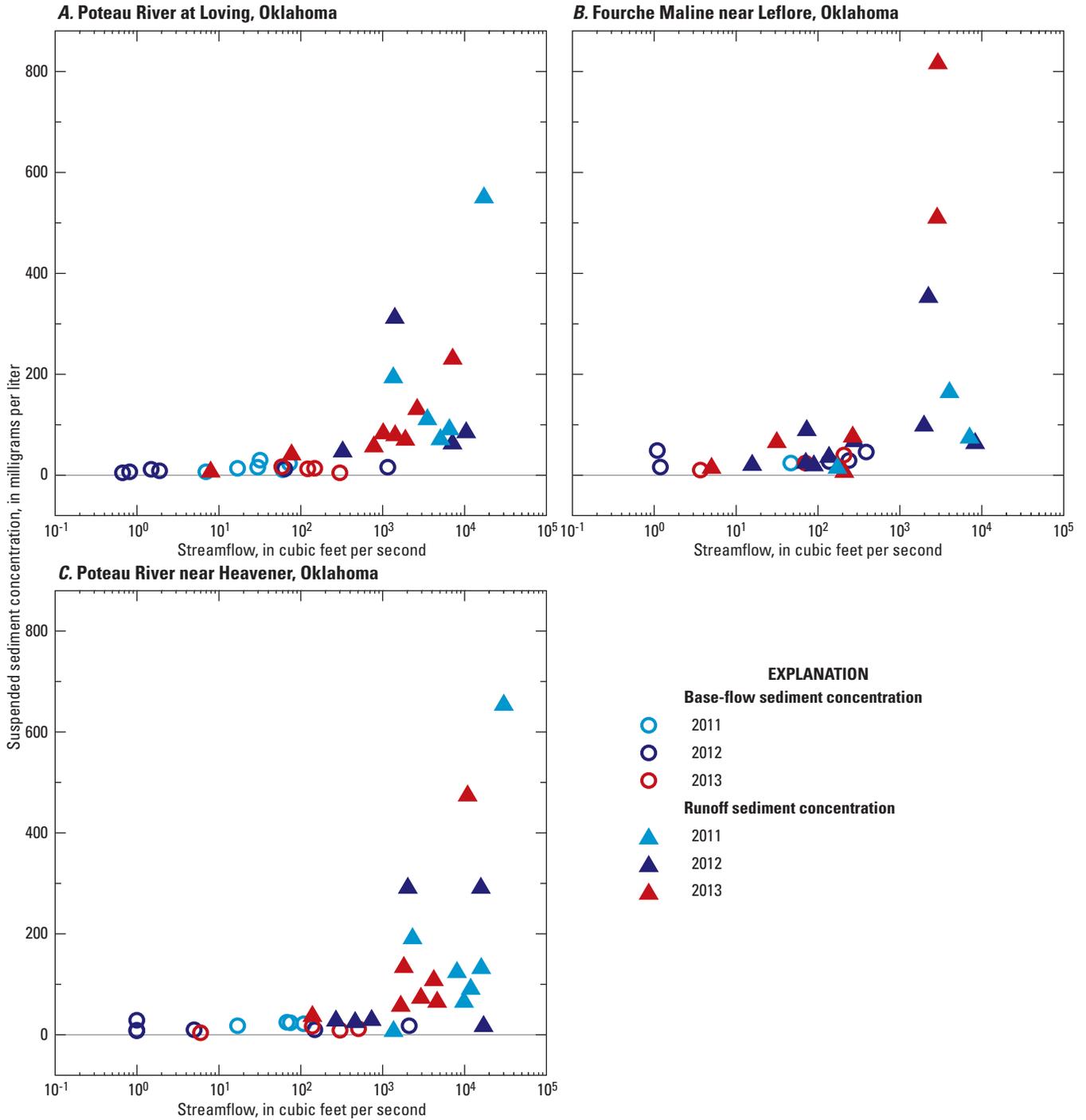
Suspended sediment concentrations (fig. 7, table 2) were significantly larger ( $p \leq 0.05$ ) in water samples collected during runoff conditions than in water samples collected at base-flow conditions at all stations except at the Fourche Maline station during the 3-year study period. Suspended sediment concentrations in water samples collected at base-flow conditions at the Fourche Maline near Leflore, Okla., station generally were larger than in water samples collected during base-flow conditions at the Poteau River stations. The smallest suspended sediment concentration in water samples collected during base-flow conditions (3 mg/L) was measured in water samples collected at the Poteau River stations (table 2). The smallest suspended sediment concentration in water samples collected during runoff conditions (10 mg/L) was measured in a water sample collected at the Poteau River at Loving, Okla., and the Fourche Maline near Leflore, Okla., stations. The smallest suspended sediment concentration in water samples collected during runoff conditions was only slightly larger at the Poteau River near Heavener, Okla., station (11 mg/L). The largest



**Figure 5.** Total phosphorus concentrations in water-quality samples collected during base-flow and runoff conditions at the (A) Poteau River at Loving, Oklahoma; (B) Fourche Maline near Leflore, Okla.; and (C) Poteau River near Heavener, Okla., water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.



**Figure 6.** Total nitrogen concentrations in water-quality samples collected during base-flow and runoff conditions at the (A) Poteau River at Loving, Oklahoma; (B) Fourche Maline near Leflore, Okla.; and (C) Poteau River near Heavener, Okla., water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.



**Figure 7.** Suspended sediment concentrations in water-quality samples collected during base-flow and runoff conditions at the (A) Poteau River at Loving, Oklahoma; (B) Fourche Maline near Leflore, Okla.; and (C) Poteau River near Heavener, Okla., water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

suspended sediment concentration measured in water samples collected at base-flow conditions (71 mg/L) and the largest suspended sediment concentration in water samples collected during runoff conditions (820 mg/L) were in samples collected at the Fourche Maline near Leflore, Okla., station (table 2).

## Bacteria

Concentrations of *Escherichia coli* (fig. 8, table 2) were significantly larger ( $p \leq 0.05$ ) in water samples collected during runoff conditions than during base-flow conditions at these three stations. In water samples collected during base-flow conditions, *Escherichia coli* bacteria concentrations decreased in the downstream direction (Loving to Heavener, Okla.) at the two Poteau River stations. At the Fourche Maline near Leflore, Okla., station, bacteria concentrations collected during base-flow conditions were not significantly larger ( $p$  is greater than  $>$ ) 0.05) than concentrations measured in water samples collected in base-flow conditions at the Poteau River stations. In water samples collected during runoff conditions, *Escherichia coli* concentrations decreased in the downstream direction (Loving to Heavener) in water samples collected at the Poteau River stations. During runoff conditions, *Escherichia coli* bacteria concentrations generally were larger in water samples collected at the Poteau River stations than at the Fourche Maline near Leflore, Okla., station. The smallest *Escherichia coli* bacteria concentration in water samples collected at all stations during base-flow conditions was smaller than the detection limit ( $< 10$  colonies per 100 milliliters [mL], table 2). During base-flow conditions, the largest *Escherichia coli* bacteria concentration (490 colonies per 100 mL) was measured in a water sample collected at the Fourche Maline near Leflore, Okla., station. That concentration of *Escherichia coli* bacteria was larger than the Oklahoma State Standard for Primary Body Contact Recreation of 126 colonies per 100 mL (geometric mean of no less than five samples per 30 days) (State of Oklahoma, 2006). The largest measured *Escherichia coli* bacteria concentration (24,000 colonies per 100 mL) was measured in a water sample collected during runoff conditions at the Fourche Maline near Leflore, Okla., station (table 2).

Concentrations of *Enterococcus* sp. bacteria (fig. 9, table 2) were significantly larger ( $p \leq 0.05$ ) in water samples collected during runoff conditions than in water samples collected during base-flow conditions at the three sampled stations. Concentrations of *Enterococcus* sp. bacteria in water samples collected at base-flow conditions were largest at the Poteau River at Loving, Okla., station. Concentrations of *Enterococcus* sp. bacteria concentrations in water samples collected during runoff conditions at the two Poteau River stations generally were larger than in water samples collected during runoff conditions at the Fourche Maline near Leflore, Okla., station. The smallest measured concentration of *Enterococcus* sp. bacteria (4 colonies per

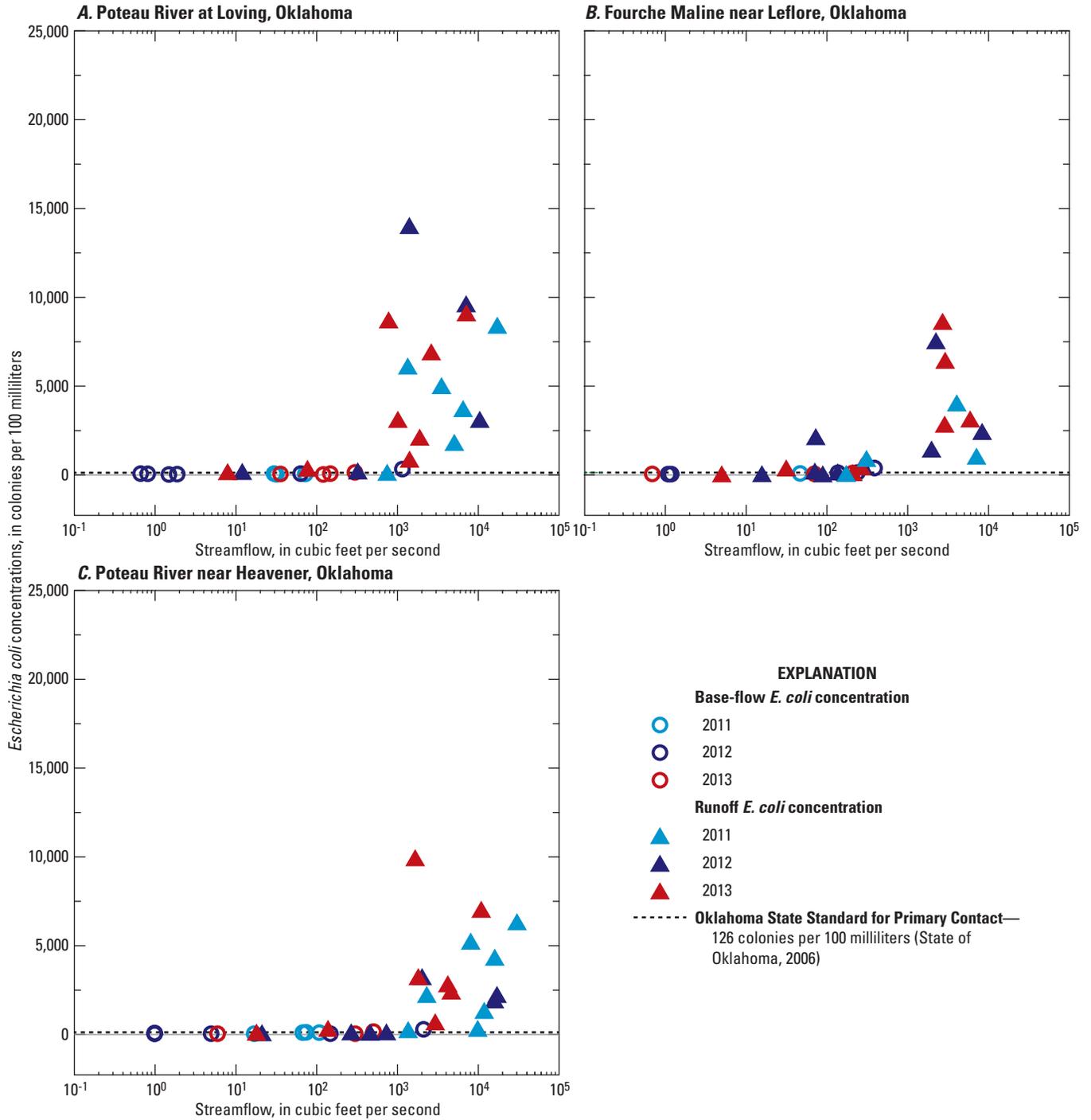
100 mL) was measured in a water sample collected during base-flow conditions at the Poteau River near Heavener, Okla., station (table 2). The largest concentration of *Enterococcus* sp. bacteria in water samples collected during base-flow conditions ( $> 4,800$  colonies per 100 mL) was measured at the Poteau River at Loving, Okla., station. Some water samples collected at baseflow conditions and most water samples collected at runoff conditions contained *Enterococcus* sp. bacteria concentrations exceeding the Oklahoma State Primary Body Contact Recreation of 33 colonies per 100 mL (which is based on a geographic mean of samples) (fig. 9; State of Oklahoma, 2006). The smallest *Enterococcus* sp. bacteria concentration measured during runoff conditions was less than the detection limit ( $< 2$  colonies per 100 mL) in a water sample collected at the Poteau River near Heavener, Okla., station (table 2). The largest *Enterococcus* sp. bacteria concentration measured in water samples collected during runoff conditions exceeded the maximum detection limit of 4,800 colonies per 100 mL at each of these stations.

## Seasonal Variation of Concentration

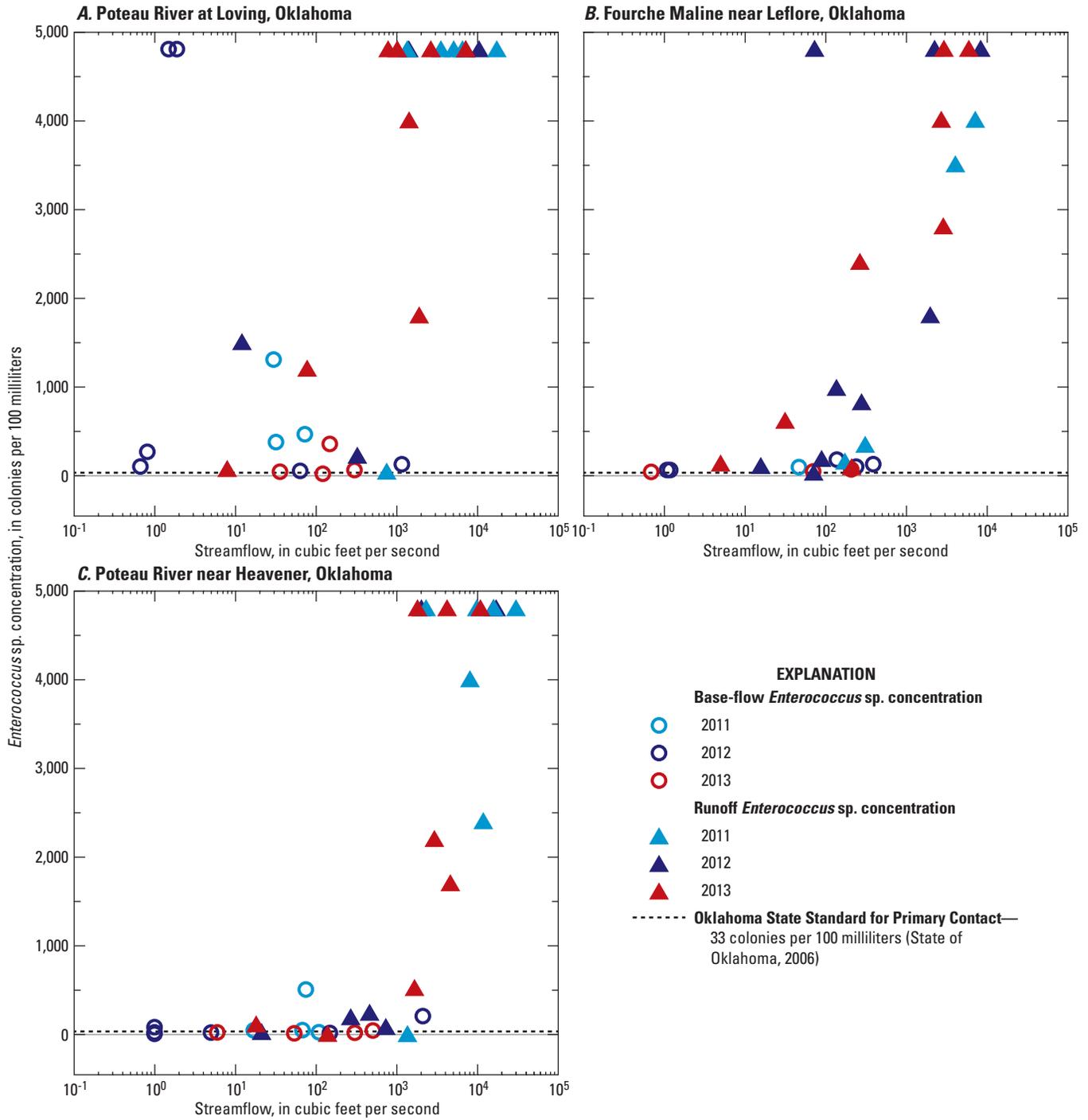
Total phosphorus, total nitrogen, and suspended sediment concentrations in these streams varied throughout the year, probably affected by a combination of factors such as precipitation amounts, land use in the upstream basins, ground cover in pastures, and streamflow. Total phosphorus and nitrogen concentrations can vary seasonally on the basis of timing of fertilizer and manure applications in addition to variable precipitation amounts (Storm and others, 2001). These factors increase the probability of larger phosphorus and nitrogen concentrations in streams during runoff conditions during the growing season (spring and summer); however, relatively large total phosphorus and nitrogen concentrations also were measured in these streams during base-flow conditions. Total phosphorus and nitrogen concentrations in streams downstream from urban areas may be larger during seasonal base flow when effluents from point sources such as WWT plants compose a substantial part of streamflow and dilution of those discharges is relatively small (U.S. Geological Survey, 1999). Suspended sediment concentration can vary seasonally, partly on the basis of the amount of ground cover in pastures during the nongrowing seasons (autumn and winter), when increased sediment runoff can occur (Wilson, 1972).

## Estimated Annual Loads

Estimated annual loads of total phosphorus, total nitrogen, and suspended sediment for the three stations sampled for this report from 2011 to 2013 are described in this section. Total annual loads were divided into base-flow and runoff components. Linear regression models developed



**Figure 8.** Total *Escherichia coli* bacteria concentrations in water-quality samples collected during base-flow and runoff conditions at the (A) Poteau River at Loving, Oklahoma; (B) Fourche Maline near Leflore, Okla.; and (C) Poteau River near Heavener, Okla., water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.



**Figure 9.** *Enterococcus* sp. bacteria concentrations in water-quality samples collected during base-flow and runoff conditions at the (A) Poteau River at Loving, Oklahoma; (B) Fourche Maline near Leflore, Okla.; and (C) Poteau River near Heavener, Okla., water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

by S-LOADEST for the estimation of loads of phosphorus, nitrogen, and sediment at each station for water years 2011–13 are listed on table 3. In some cases, other S-LOADEST predefined regressions that used various combinations of streamflow, time, and seasonal coefficients had smaller residuals than the models used for this report; however, the “best-fit” model varied substantially among constituents and stations. Therefore, one general model was used to estimate loads of phosphorus and nitrogen (equation 3, shown earlier in this report) and sediment (equation 4, shown earlier in this report). The standard error of estimate (SEE) is the square root of residual variance. These log-transformed values, when multiplied by 100, can be interpreted as average percent error. The actual percent error for the Poteau River near Heavener, Okla., and the Fourche Maline near Leflore, Okla., stations may be slightly higher because of the greater uncertainty of the streamflow values. LOADEST can produce biased results, and the load bias can be identified by analyzing the model residuals. The standard error of prediction (SEP) is the standard deviation of the estimated value from the observed value and measures the amount of variance among the distribution of the estimates (Runkel and others, 2004).

## Total Phosphorus

Total phosphorus loads during runoff conditions composed 86 to 96 percent of the total annual phosphorus load at the Poteau River stations (table 4). Total phosphorus loads during runoff conditions composed 87 to 98 percent of the total estimated annual phosphorus loads at the Fourche Maline near Leflore, Okla., station (table 4). Annual total phosphorus runoff loads were smaller in water year 2011 than in the subsequent 2 years at the Poteau River stations but were slightly larger than in the subsequent 2 years at the Fourche Maline near Leflore, Okla., station (table 4).

## Total Nitrogen

The runoff component of estimated total nitrogen loads at the Poteau River stations composed 82 to 91 percent of the total annual estimated total nitrogen load (table 5). Estimated runoff loads of total nitrogen at the Fourche Maline near Leflore, Okla., station composed 86 to 99 percent of the estimated total annual loads. The largest percentage of total nitrogen in runoff was estimated in 2011 at the three sampled stations during the 2011–13 study period (table 5).

**Table 3.** Regression models used for estimating total phosphorus, total nitrogen, and suspended sediment loads at water-quality stations sampled in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 to September 2013.

[ln, natural logarithm; L, daily load in tons per day; Q, mean daily streamflow in cubic feet per second; sin, sine; cos, cosine; SS, seasonality parameter ( $2\pi \times \text{decime}$ ). The standard error of the estimate is reported in natural logarithm units; therefore, this value, multiplied by 100, can be interpreted roughly as the average percent error]

Station name (number)	Number of observations	Total phosphorus load regression model	Standard error of the estimate (ln of tons)
Poteau River at Loving, Okla. (07247015)	36	$\ln(L) = -3.24 + 1.26 \ln Q - 0.23 \sin SS - 0.16 \cos SS$	0.495
Poteau River near Heavener, Okla. (07247350)	37	$\ln(L) = -3.41 + 1.22 \ln Q - 0.310 \sin SS - 0.244 \cos SS$	0.511
Fourche Maline near Leflore, Okla. (07247650)	38	$\ln(L) = -4.96 + 1.18 \ln Q - 0.23 \sin SS - 0.18 \cos SS$	0.536
Station name (number)	Number of observations	Total nitrogen load regression model	Standard error of the estimate (ln of tons)
Poteau River at Loving, Okla. (07247015)	36	$\ln(L) = -1.26 + 1.12 \ln Q - 0.21 \sin SS + 0.04 \cos SS$	0.358
Poteau River near Heavener, Okla. (07247350)	37	$\ln(L) = -1.26 + 1.09 \ln Q - 0.26 \sin SS + 0.12 \cos SS$	0.313
Fourche Maline near Leflore, Okla. (07247650)	34	$\ln(L) = -3.17 + 1.11 \ln Q - 0.30 \sin SS + 0.08 \cos SS$	0.327
Station name (number)	Number of observations	Suspended sediment load regression model	Standard error of the estimate (ln of tons)
Poteau River at Loving, Okla. (07247015)	33	$\ln(L) = 1.95 + 1.41 \ln Q + 0.014 \ln Q^2$	0.666
Poteau River near Heavener, Okla. (07247350)	33	$\ln(L) = 2.12 + 1.32 \ln Q + 0.23 \ln Q^2$	0.876
Fourche Maline near Leflore, Okla. (07247650)	30	$\ln(L) = -0.03 + 1.21 \ln Q + 0.026 \ln Q^2$	0.722

## Suspended Sediment

Estimated suspended sediment loads at the Poteau River stations during runoff conditions composed 91 to 98 percent of the estimated total annual loads (table 6). At the Fourche Maline near Leflore, Okla., station, estimated suspended sediment loads during runoff conditions composed 91 to more than 99 percent of the total estimated annual suspended sediment loads (table 6). Annual runoff suspended sediment loads were largest in 2011–13 at the Poteau River near Heavener, Okla., station (table 6).

## Estimated Seasonal Loads

Estimated seasonal total phosphorus, total nitrogen, and suspended sediment loads are described in this section. Those loads are divided into base-flow and runoff components (tables 7–9).

## Total Phosphorus

Estimated seasonal loads of total phosphorus during base-flow conditions varied between the Poteau River stations and the Fourche Maline station in 2011–13 (table 7). At the Poteau River at Loving, Okla., station, the smallest estimated total phosphorus loads during base-flow conditions occurred in autumn (September through November). At the Poteau River at Heavener, Okla., station, the smallest estimated total phosphorus loads during base flow generally occurred during summer (June through August). At the Fourche Maline near LeFlore, Okla., station, the smallest estimated total phosphorus loads during base flow occurred in autumn (September through November). At the Poteau River stations, estimated total phosphorus loads at base-flow conditions typically were several times larger than at the Fourche Maline near Leflore, Okla., station (table 7). Estimated seasonal total phosphorus loads generally were largest in the winter during base-flow conditions.

**Table 4.** Estimated annual total phosphorus loads and yields in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

[mi<sup>2</sup>, square mile; ton/yr, tons per year; ton·yr<sup>-1</sup>·mi<sup>-2</sup>, tons per year per square mile; SEP, standard error of prediction; P, phosphorus. Differences between base-flow loads plus runoff loads are due to rounding]

Station name (number)	Drainage area (mi <sup>2</sup> )	Water year	Estimated annual mean							Portion of annual load delivered during runoff (percent)
			Annual load (ton/yr)	SEP (ton/yr as P)	Annual yield (ton·yr <sup>-1</sup> · mi <sup>-2</sup> as P)	Base- flow load (ton/yr)	Base-flow yield (ton·yr <sup>-1</sup> · mi <sup>-2</sup> as P)	Runoff load (ton/yr)	Runoff yield (ton·yr <sup>-1</sup> · mi <sup>-2</sup> as P)	
Poteau River at Loving, Okla. (07247015)	268	2011	51	0.03	0.190	2	0.008	49	0.183	96
		2012	113	0.06	0.422	16	0.060	97	0.362	86
		2013	92	0.05	0.343	13	0.048	79	0.295	86
		3-year average			0.318		0.039		0.280	
Poteau River near Heavener, Okla. (07247350)	515	2011	81	0.05	0.157	6	0.012	75	0.146	93
		2012	164	0.09	0.318	17	0.033	147	0.285	90
		2013	225	0.17	0.437	16	0.031	209	0.406	93
		3-year average			0.304		0.025		0.279	
Fourche Maline near Leflore, Okla. (07247650)	267	2011	56	0.03	0.208	1	0.002	55	0.206	98
		2012	38	0.02	0.142	5	0.017	33	0.125	87
		2013	53	0.02	0.198	5	0.017	48	0.181	91
		3-year average			0.183		0.012		0.171	

**Table 5.** Estimated annual total nitrogen loads and yields in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

[mi<sup>2</sup>, square mile; ton/yr, tons per year; ton·yr<sup>-1</sup>·mi<sup>-2</sup>, tons per year per square mile; SEP, standard error of prediction; P, phosphorus. Differences between base-flow loads plus runoff loads are due to rounding]

Station name (number)	Drainage area (mi <sup>2</sup> )	Water year	Estimated annual mean							Portion of annual load delivered during runoff (percent)
			Annual load (ton/yr)	SEP (ton/yr as P)	Annual yield (ton·yr <sup>-1</sup> . mi <sup>-2</sup> as P)	Base-flow load (ton/yr)	Base-flow yield (ton·yr <sup>-1</sup> . mi <sup>-2</sup> as P)	Runoff load (ton/yr)	Runoff yield (ton·yr <sup>-1</sup> . mi <sup>-2</sup> as P)	
Poteau River at Loving, Okla. (07247015)	268	2011	217	0.1	0.81	20	0.075	197	0.74	91
		2012	565	0.2	2.11	102	0.381	463	1.73	82
		2013	436	0.1	1.63	45	0.168	391	1.46	90
		3-year average			1.51		0.208		1.31	
Poteau River near Heavener, Okla. (07247350)	515	2011	360	0.1	0.70	37	0.072	323	0.63	90
		2012	1,023	0.3	1.99	140	0.272	883	1.71	86
		2013	879	0.3	1.71	109	0.212	770	1.50	88
		3-year average			1.46		0.185		1.28	
Fourche Maline near Leflore, Okla. (07247650)	267	2011	296	0.1	1.11	5	0.018	292	1.09	99
		2012	271	0.1	1.01	39	0.145	232	0.87	86
		2013	306	0.1	1.15	32	0.120	274	1.02	90
		3-year average			1.09		0.094		1.00	

Estimated seasonal total phosphorus loads during runoff conditions typically were largest in spring (March through May) and smallest in autumn (September through November) at these three stations. Annual estimated total phosphorus seasonal loads typically were several times larger at the Poteau River stations than at the Fourche Maline near Leflore, Okla., station (table 7).

## Total Nitrogen

Estimated seasonal loads of total nitrogen generally were largest at the Poteau River near Heavener, Okla., station for all seasons (table 8). Estimated seasonal total nitrogen loads during base-flow conditions generally were smallest during the autumn for all stations (table 8). The smallest total nitrogen loads during base-flow conditions were estimated at the Fourche Maline near Leflore, Okla., station in autumn. The majority of the total nitrogen was delivered to Wister Lake during runoff conditions in winter. At the Poteau River stations, estimated total nitrogen seasonal loads at base-flow conditions were several times larger than at the Fourche Maline near Leflore, Okla., station (table 8). Estimated total nitrogen seasonal loads during runoff conditions generally

were largest in winter and spring for the Poteau River Stations and were largest during the spring at the Fourche Maline near Leflore, Okla., station (table 8).

## Suspended Sediment

Estimated seasonal suspended sediment loads during base-flow conditions generally were smallest in the summer at the Poteau River stations and smallest in the autumn at the Fourche Maline near Leflore, Okla., station (table 9). The estimated seasonal suspended sediment loads at base-flow conditions generally were smallest at the Poteau River at Loving, Okla., station during summer. Estimated seasonal base-flow suspended sediment loads at the Poteau River stations typically were several times larger than at the Fourche Maline near Leflore, Okla., station (table 9).

Estimated seasonal suspended sediment loads during runoff conditions typically were largest in the spring and smallest during the autumn (table 9). Seasonal runoff suspended sediment loads at the Poteau River stations generally were larger than those estimated at the Fourche Maline near Leflore, Okla., station (table 9).

**Table 6.** Estimated annual suspended sediment loads and yields in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

[mi<sup>2</sup>, square mile; ton/yr, tons per year; ton·yr<sup>-1</sup>·mi<sup>-2</sup>, tons per year per square mile; SEP, standard error of prediction. Differences between base-flow loads and runoff loads are due to rounding; 99+, less than 100 percent]

Station name (number)	Drainage area (mi <sup>2</sup> )	Water year	Estimated annual mean							Portion of annual load delivered during runoff (percent)
			Annual load (ton/yr)	SEP (ton/yr)	Annual yield (ton·yr <sup>-1</sup> ·mi <sup>-2</sup> )	Base-flow load (ton/yr)	Base-flow yield (ton·yr <sup>-1</sup> ·mi <sup>-2</sup> )	Runoff load (ton/yr)	Runoff yield (ton·yr <sup>-1</sup> ·mi <sup>-2</sup> )	
Poteau River at Loving, Okla. (07247015)	268	2011	23,787	22	89	450	2	23,337	87	98
		2012	52,351	46	195	4,822	18	47,530	177	91
		2013	41,496	31	155	1,719	6	39,777	148	96
		3-year average			146		9		138	
Poteau River near Heavener, Okla. (07247350)	515	2011	56,588	73	110	1,377	3	55,211	107	98
		2012	121,911	132	237	7,274	14	114,637	223	94
		2013	191,589	361	372	6,261	12	185,327	360	97
		3-year average			240		10		230	
Fourche Maline near Leflore, Okla. (07247650)	267	2011	54,321	52	203	252	1	54,069	202	99+
		2012	35,926	30	135	2,415	9	33,511	126	93
		2013	43,229	32	162	3,692	14	39,537	148	91
		3-year average			167		8		159	

## Comparison of Estimated Annual Yields Among Stations

Estimated annual yields for total phosphorus, total nitrogen, and suspended sediment for the three sampled stations in the Wister Lake Basin for the period 2011–13 are described in this section. The annual yields also are divided into base-flow and runoff components.

### Total Phosphorus

Estimated annual total phosphorus yield slightly decreased in the downstream direction in 2011 and 2012 and increased slightly in the downstream direction (Loving to Heavener, Okla.) in 2013 at the Poteau River stations (table 4). Annual total phosphorus yield at the Fourche Maline near Leflore, Okla., station decreased from 2011 to 2012 and increased from 2012 to 2013 (table 4). Annual yields of total phosphorus ranged from 0.142 to 0.437 tons per year per square mile (ton·yr<sup>-1</sup>·mi<sup>-2</sup>) at these stations, with

the largest mean annual yield estimated at the Poteau River near Heavener, Okla., station in 2013 and the smallest yield estimated at the Fourche Maline near Leflore, Okla., station in 2012 (table 4).

Estimated mean annual total phosphorus yields during base-flow conditions were largest at the Poteau River at Loving, Okla., station (table 4). The smallest mean annual yield during base-flow conditions was at the Fourche Maline near Leflore, Okla., station (table 4). Annual estimated total phosphorus yields during base-flow conditions at these stations ranged from 0.002 to 0.060 ton·yr<sup>-1</sup>·mi<sup>-2</sup> (table 4).

Mean estimated yields during runoff conditions were largest at the Poteau River stations (table 4). Annual estimated total phosphorus yields during runoff conditions at the three sampled stations ranged from 0.125 to 0.406 ton·yr<sup>-1</sup>·mi<sup>-2</sup> (table 4). The largest estimated total phosphorus yield during runoff conditions was at the Poteau River near Heavener, Okla., station in 2013, whereas the smallest estimated total phosphorus yield during runoff conditions was at the Fourche Maline near Leflore, Okla., station in 2012 (table 4).

**Table 7.** Estimates of seasonal total phosphorus loads during base-flow and runoff conditions in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

[Values are loads in tons per season as phosphorus; spring is March through May, summer is June through August, autumn is September through November, and winter is December through February]

Flow type	Station name (number)	Estimated seasonal total phosphorus loads					
		Water year	Spring	Summer	Autumn	Winter	
Base flow	Poteau River at Loving, Okla. (07247015)	2011	1.06	0.30	0.79	0.15	
		2012	2.50	0.01	1.76	11.50	
		2013	3.95	7.76	0.03	1.55	
Runoff		2011	46.58	1.07	0.06	0.85	
		2012	19.85	0.13	44.89	32.17	
		2013	29.35	41.19	1.35	7.75	
Base flow		Poteau River near Heavener, Okla. (07247350)	2011	1.92	0.81	0.99	0.77
			2012	4.45	0.01	2.74	9.90
			2013	9.51	2.85	0.06	3.18
Runoff	2011		70.55	1.22	0.13	2.74	
	2012		31.73	0.18	61.63	53.59	
	2013		110.60	85.64	1.86	10.97	
Base flow	Fourche Maline near Leflore, Okla. (07247650)		2011	0.24	0.36	0.01	0.03
			2012	2.18	0.04	0.24	2.06
			2013	3.62	0.49	0.03	0.45
Runoff		2011	54.08	0.08	0.30	54.90	
		2012	20.03	0.98	0.96	33.45	
		2013	30.70	14.68	0.14	48.37	

## Total Nitrogen

Estimated mean annual total nitrogen yields were largest at the Poteau River stations (table 5). Total nitrogen yields ranged from 0.70 to 2.11  $\text{ton}\cdot\text{yr}^{-1}\cdot\text{mi}^{-2}$ , with the largest annual total nitrogen yield being estimated at the Poteau River at Loving, Okla., station in 2012 and the smallest total nitrogen yield being estimated at the Poteau River near Heavener, Okla., station in 2011 (table 5).

Estimated mean annual total nitrogen yields at base-flow conditions were largest at the Poteau River at Loving, Okla., station (table 5). Estimated mean annual total nitrogen yields at base-flow conditions were smallest at the Fourche Maline near Leflore, Okla., station (table 5). Estimated total nitrogen yields at base-flow conditions at these three stations ranged from 0.018 to 0.381  $\text{ton}\cdot\text{yr}^{-1}\cdot\text{mi}^{-2}$ . The largest total nitrogen

yield during base-flow conditions was estimated at the Poteau River at Loving, Okla., station in 2012, and the smallest yield was estimated at the Fourche Maline station in 2011 during the 3-year study period.

Estimated mean annual total nitrogen yields during runoff conditions were largest at the Poteau River at Loving, Okla., station (table 5). At the Fourche Maline near Leflore, Okla., station, estimated total nitrogen yields during runoff conditions typically were the smallest of the three sampled stations (table 5). Estimated total nitrogen yields during runoff conditions at these stations ranged from 0.63 to 1.73  $\text{ton}\cdot\text{yr}^{-1}\cdot\text{mi}^{-2}$ . The largest total nitrogen yield during runoff conditions was estimated at the Poteau River at Loving, Okla., station in 2012, and the smallest total nitrogen yield during runoff conditions was estimated at the Poteau River near Heavener, Okla., station in 2011 (table 5).

**Table 8.** Estimates of seasonal total nitrogen loads during base-flow and runoff conditions in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

[Values are loads in tons per season as nitrogen; spring is March through May, summer is June through August, autumn is September through November, and winter is December through February]

Flow type	Station name (number)	Estimated seasonal total nitrogen loads				
		Water year	Spring	Summer	Autumn	Winter
Base flow	Poteau River at Loving, Okla. (07247015)	2011	7.2	16.2	6.6	3.8
		2012	15.0	0.1	11.0	67.0
		2013	23.0	6.0	0.3	11.0
Runoff	Poteau River at Loving, Okla. (07247015)	2011	184.6	5.0	0.5	6.0
		2012	85.0	1.0	179.0	153.0
		2013	163.0	144.0	7.0	42.0
Base flow	Poteau River near Heavener, Okla. (7247350)	2011	15.0	5.0	9.0	9.0
		2012	32.0	0.1	22.0	86.0
		2013	62.0	15.0	1.0	30.0
Runoff	Poteau River near Heavener, Okla. (7247350)	2011	290.0	6.0	1.0	323.0
		2012	174.0	1.0	345.0	882.0
		2013	390.0	286.0	12.0	771.0
Base flow	Fourche Maline near Leflore, Okla. (07247650)	2011	1.6	2.5	0.2	0.4
		2012	15.9	0.4	2.7	19.7
		2013	23.8	3.0	0.3	4.8
Runoff	Fourche Maline near Leflore, Okla. (07247650)	2011	283.2	0.6	3.2	4.7
		2012	122.9	5.8	9.2	94.5
		2013	174.7	73.5	1.4	24.0

**Table 9.** Estimates of seasonal suspended sediment loads during base-flow and runoff conditions in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

[Values are loads in tons per season as sediment; spring is March through May, summer is June through August, autumn is September through November, and winter is December through February]

Flow type	Station name (number)	Estimated seasonal suspended sediment load				
		Water year	Spring	Summer	Autumn	Winter
Base flow	Poteau River at Loving, Okla. (07247015)	2011	246	50	122	32
		2012	778	1	464	3,579
		2013	1,090	173	4	446
Runoff	Poteau River at Loving, Okla. (07247015)	2011	22,846	242	10	238
		2012	10,038	18	22,047	15,411
		2013	13,560	16,055	297	3,134
Base flow	Poteau River near Heavener, Okla. (07247350)	2011	665	198	207	305
		2012	1,988	3	1,037	4,244
		2013	4,083	674	13	1,471
Runoff	Poteau River near Heavener, Okla. (07247350)	2011	53,576	342	36	1,251
		2012	26,986	34	46,495	41,097
		2013	114,044	63,756	529	7,026
Base flow	Fourche Maline near Leflore, Okla. (07247650)	2011	107	125	4	15
		2012	1,171	14	89	1,139
		2013	3,075	379	9	221
Runoff	Fourche Maline near Leflore, Okla. (07247650)	2011	53,728	23	108	208
		2012	21,641	433	501	10,937
		2013	25,821	11,664	48	2,005

## Suspended Sediment

Estimated mean annual sediment yields were largest at the Poteau River near Heavener, Okla., station (table 6). The estimated mean annual suspended sediment yield was smallest at the Poteau River at Loving, Okla., station. Suspended sediment yields at the three stations during this period ranged from 89 to 372 ton·yr<sup>-1</sup>·mi<sup>-2</sup>, with the largest yield being estimated at the Poteau River near Heavener, Okla., station in 2013 and the smallest yield being estimated at Poteau River at Loving, Okla., station in 2011 (table 6).

The estimated mean annual suspended sediment yield at base-flow conditions was largest at the Poteau River near Heavener, Okla., station (table 6). Estimated mean annual suspended sediment yields at base-flow conditions were smallest at the Fourche Maline near Leflore, Okla., station. Suspended sediment yields at base-flow conditions ranged from 1 to 18 ton·yr<sup>-1</sup>·mi<sup>-2</sup> (table 6). The largest annual suspended sediment yield at base-flow conditions was estimated at the Poteau River at Loving, Okla., station in 2012, whereas the smallest suspended sediment yield at base-flow conditions was estimated at the Fourche Maline near Leflore, Okla., station in 2011 (table 6).

The estimated mean annual suspended sediment yield at runoff conditions was largest at the Poteau River near Heavener, Okla., station (table 6). Estimated annual suspended sediment yields during runoff conditions ranged from 87 to 360 ton·yr<sup>-1</sup>·mi<sup>-2</sup> (table 6). The largest suspended sediment yield during runoff conditions was estimated at the Poteau River near Heavener, Okla., station in 2013, and the smallest

suspended sediment yield at runoff conditions was estimated at the Poteau River at Loving, Okla., station in 2011 (table 6).

## Estimated Annual Flow-Weighted Mean Concentrations of Total Phosphorus and Total Nitrogen

Flow-weighted mean (FWM) concentrations, determined by dividing total annual constituent loads by mean annual streamflow, are useful for investigating trends in constituent concentrations by reducing the effects of wet and dry years on constituent concentrations. The following sections describe annual FWM concentrations of total phosphorus and total nitrogen at three sampled stations in the Wister Lake Basin from October 2011 through September 2013.

### Total Phosphorus

Estimated annual FWM concentrations of total phosphorus were substantially larger than the Oklahoma State Standard for Scenic Rivers of 0.037 mg/L at the three sampled stations (State of Oklahoma, 2006; table 10). This standard is useful as a point of reference because phosphorus concentrations exceeding that standard may be associated with greater eutrophication in rivers and downstream lakes receiving inflows from rivers. The FWM concentration of total phosphorus was much more stable over the 3-year period at the Poteau River at Loving, Okla., station than at the other two stations (table 10). The FWM concentration of total

**Table 10.** Estimated annual total phosphorus loads, mean annual streamflows, and flow-weighted mean total phosphorus concentrations at water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

[ton/yr, tons per year; ft<sup>3</sup>/s, cubic feet per second; mg/L, milligrams per liter]

Station name (number)	Water year	Estimated mean annual total phosphorus load (ton/yr as P)	Mean annual streamflow (ft <sup>3</sup> /s)	Estimated flow-weighted mean total phosphorus concentration (mg/L as P)
Poteau River at Loving, Okla. (07247015)	2011	51	192.6	0.270
	2012	112	405.8	0.281
	2013	100	379.9	0.268
Poteau River near Heavener, Okla. (07247350)	2011	79	415.0	0.194
	2012	164	846.7	0.197
	2013	225	911.0	0.251
Fourche Maline near Leflore, Okla. (07247650)	2011	56	265.9	0.212
	2012	38	232.9	0.165
	2013	53	281.7	0.191

phosphorus typically was lower at the Fourche Maline near Leflore, Okla., station than at the Poteau River stations.

## Total Nitrogen

Estimated FWM concentrations of total nitrogen at these three stations were substantially larger than the median flow-weighted concentration (0.26 mg/L) described for mostly undeveloped basins of the United States by Clark and others (2000) (table 11). Such nitrogen concentrations, along with relatively large phosphorus concentrations in these samples, are likely to be contributing to the eutrophication in Wister Lake. Flow-weighted mean concentrations of total nitrogen did not vary spatially in a consistent manner.

## Estimated Annual Total Phosphorus, Total Nitrogen, and Suspended Sediment Loads Discharged into Wister Lake

Most of the annual total phosphorus, total nitrogen, and suspended sediment loads discharged to Wister Lake can be estimated by adding the loads of the Poteau River near Heavener, Okla., station and the Fourche Maline near Leflore, Okla., station. The estimated loads of total phosphorus, total nitrogen, and suspended sediment at those stations do not represent the entire drainage area for Wister Lake but account for about 84 percent of the drainage basin of the lake.

The Poteau River and the Fourche Maline contributed estimated annual total phosphorus loads of 137 to 278 tons/yr,

with 89 to 95 percent of those annual total phosphorus loads being transported to Wister Lake during runoff conditions (table 12). The Poteau River transported several times more total phosphorus to the lake during base-flow and runoff conditions than the Fourche Maline (table 12). The estimated seasonal total phosphorus loads into Wister Lake typically were largest during runoff conditions in the spring at the Poteau River stations and during runoff conditions in the winter at the Fourche Maline near Leflore, Okla., station (table 7).

The Poteau River and the Fourche Maline contributed estimated annual total nitrogen loads of 657 to 1,294 tons/yr, with 86 to 94 percent of the estimated annual total nitrogen loads being transported to Wister Lake during runoff conditions (table 13). The Poteau River typically transported several times more nitrogen during base-flow and runoff conditions to the lake than the Fourche Maline (table 13). The estimated seasonal total nitrogen loads transported into Wister Lake typically were largest during runoff conditions in the spring at these sampled stations (table 8).

The Poteau River and the Fourche Maline contributed annual estimated suspended sediment loads of 110,919 to 234,637 tons/yr, with 94 to 99 percent of the annual suspended sediment loads being transported to Wister Lake during runoff conditions (table 14). The Poteau River typically transported several times more sediment during base-flow and runoff conditions to the lake than the Fourche Maline (table 14). The estimated seasonal suspended sediment loads into Wister Lake generally were largest during runoff conditions in the spring for all stations (table 9).

**Table 11.** Estimated annual total nitrogen loads, mean annual streamflows, and flow-weighted mean total nitrogen concentrations at water-quality stations in the Wister Lake Basin, Oklahoma and Arkansas, October 2010 through September 2013.

[ton/yr, tons per year; ft<sup>3</sup>/s, cubic feet per second; mg/L, milligrams per liter]

Station name (number)	Water year	Estimated mean annual total nitrogen load (ton/yr as N)	Mean annual streamflow (ft <sup>3</sup> /s)	Estimated flow-weighted mean total nitrogen concentration (mg/L as N)
Poteau River at Loving, Okla. (07247015)	2011	214	192.6	1.129
	2012	564	405.8	1.408
	2013	435	379.9	1.166
Poteau River near Heavener, Okla. (07247350)	2011	360	415.0	0.882
	2012	1,023	846.7	1.225
	2013	879	911.0	0.981
Fourche Maline near Leflore, Okla. (07247650)	2011	296	265.9	1.133
	2012	271	232.9	1.179
	2013	306	281.7	1.103

**Table 12.** Estimated annual total phosphorus loads discharged to Wister Lake, Oklahoma and Arkansas, October 2010 through September 2013.

[% , percent; ton/yr, tons per year]

Flow type (water year)	Discharged to Wister Lake from 84% of its drainage area		Poteau River near Heavener, Okla.	Fourche Maline near Leflore, Okla.
	Annual phosphorus load <sup>1</sup>		Component of mean annual phosphorus load (ton/yr)	
	ton/yr as P	%		
2011				
Base flow <sup>2</sup>	7	5	6	1
Runoff <sup>3</sup>	130	95	75	55
Total <sup>4</sup>	137	100	81	56
2012				
Base flow <sup>2</sup>	22	11	17	5
Runoff <sup>3</sup>	180	89	147	33
Total <sup>4</sup>	202	100	164	38
2013				
Base flow <sup>2</sup>	21	8	16	5
Runoff <sup>3</sup>	257	92	209	48
Total <sup>4</sup>	278	100	225	53
Average of 3 years, 2011–13				
Base flow <sup>2</sup>	17		13	4
Runoff <sup>3</sup>	189		144	45
Total <sup>4</sup>	206		157	49

<sup>1</sup>Loads to Wister Lake are calculated by adding loads from Poteau River near Heavener, Okla., to loads from Fourche Maline near Leflore, Okla. (table 4). These two stations account for 84 percent of drainage that flows into Wister Lake.

<sup>2</sup>Means of the base-flow loads are calculated from base-flow day data only by using S-LOADEST.

<sup>3</sup>Means of the runoff loads are calculated from runoff day data only by using S-LOADEST.

<sup>4</sup>Differences between total loads and the sum of base flow plus runoff are due to rounding.

**Table 13.** Estimated annual total nitrogen loads discharged to Wister Lake, Oklahoma and Arkansas, October 2010 through September 2013.

[%, percent; ton/yr, tons per year]

Flow type (water year)	Discharged to Wister Lake from 84% of its drainage area		Poteau River near Heavener, Okla.	Fourche Maline near Leflore, Okla.
	Annual nitrogen load <sup>1</sup>		Component of mean annual nitrogen load (ton/yr)	
	ton/yr as N	%		
2011				
Base flow <sup>2</sup>	42	6	37	5
Runoff <sup>3</sup>	615	94	323	292
Total <sup>4</sup>	657	100	360	297
2012				
Base flow <sup>2</sup>	179	14	140	39
Runoff <sup>3</sup>	1,115	86	883	232
Total <sup>4</sup>	1,294	100	1,023	271
2013				
Base flow <sup>2</sup>	141	12	109	32
Runoff <sup>3</sup>	1,044	88	770	274
Total <sup>4</sup>	1,185	100	879	306
Average of 3 years, 2011–13				
Base flow <sup>2</sup>	120		95	25
Runoff <sup>3</sup>	925		659	266
Total <sup>4</sup>	1,045		754	291

<sup>1</sup>Loads to Wister Lake are calculated by adding loads from Poteau River near Heavener, Okla., to loads from Fourche Maline near Leflore, Okla. (table 5). These two stations account for 84 percent of drainage that flows into Wister Lake.

<sup>2</sup>Means of the base-flow loads are calculated from base-flow day data only by using S-LOADEST.

<sup>3</sup>Means of the runoff loads are calculated from runoff day data only by using S-LOADEST.

<sup>4</sup>Differences between total loads and the sum of base flow plus runoff are due to rounding.

**30 Concentrations, Loads, and Yields and Bacteria Concentrations in the Wister Lake Basin, Oklahoma and Arkansas, 2011–13**

**Table 14.** Estimated annual total suspended sediment loads discharged to Wister Lake, Oklahoma and Arkansas, October 2010 through September 2013.

[%, percent; ton/yr, tons per year]

Flow type (water year)	Discharged to Wister Lake from 84% of its drainage area		Poteau River near Heavener, Okla.	Fourche Maline near Leflore, Okla.
	Annual sediment load <sup>1</sup>		Component of mean annual sediment load (ton/yr)	
	ton/yr	%		
2011				
Base flow <sup>2</sup>	1,629	1	1,377	252
Runoff <sup>3</sup>	109,290	99	55,221	54,069
Total <sup>4</sup>	110,919	100	56,598	54,321
2012				
Base flow <sup>2</sup>	9,689	6	7,274	2,415
Runoff <sup>3</sup>	148,148	94	114,637	33,511
Total <sup>4</sup>	157,837	100	121,911	35,926
2013				
Base flow <sup>2</sup>	9,953	4	6,261	3,692
Runoff <sup>3</sup>	224,684	96	185,327	39,357
Total <sup>4</sup>	234,637	100	191,588	43,049
Average of 3 years, 2011–13				
Base flow <sup>2</sup>	7,090		4,971	1,389
Runoff <sup>3</sup>	160,707		118,395	42,312
Total <sup>4</sup>	167,797		123,366	43,701

<sup>1</sup>Loads to Wister Lake are calculated by adding loads from Poteau River near Heavener, Okla., to loads from Fourche Maline near Leflore, Okla. (table 6). These two stations account for 84 percent of drainage that flows into Wister Lake.

<sup>2</sup>Means of the base-flow loads are calculated from base-flow day data only by using S-LOADEST.

<sup>3</sup>Means of the runoff loads are calculated from runoff day data only by using S-LOADEST.

<sup>4</sup>Differences between total loads and the sum of base flow plus runoff are due to rounding.

## Summary

The Poteau Valley Improvement Authority uses Wister Lake in southeastern Oklahoma as a sole source of public water supply. Total phosphorus, total nitrogen, and suspended sediments from agricultural runoff and discharges from wastewater treatment plants and other sources have caused impairment of water quality in the lake. Lake-water quality has degraded, causing water-treatment cost, chemical usage, and sludge production to increase for the Poteau Valley Improvement Authority.

The U.S. Geological Survey, in cooperation with the Poteau Valley Improvement Authority, investigated and summarized concentrations of total phosphorus, total nitrogen, suspended sediment, and bacteria (*Escherichia coli* and *Enterococcus* sp.) in surface water flowing to Wister Lake. Estimates of total phosphorus, total nitrogen, and suspended sediment loads and yields, and flow-weighted mean concentrations of total phosphorus and total nitrogen were made for the Wister Lake Basin for a 3-year period, October 2010 through September 2013. Samples collected at fixed time increments during base-flow conditions at the Poteau River at Loving, Okla.; the Poteau River near Heavener, Okla.; and the Fourche Maline near Leflore, Okla., water-quality stations were supplemented with samples collected during runoff conditions to determine water quality over the range of streamflows in the basin. These data also were collected to estimate annual constituent loads by using regression models.

Total phosphorus, total nitrogen, and suspended sediment concentrations were significantly larger in water samples collected during runoff conditions than in samples collected during base-flow conditions at the Poteau River stations. Bacteria (*Escherichia coli* and *Enterococcus* sp.) concentrations also were significantly larger in water samples collected during runoff conditions than in water samples collected during base-flow conditions from 2011 to 2013 at the three sampled stations.

Concentrations of total phosphorus, total nitrogen, suspended sediment, and bacteria (*Escherichia coli* and *Enterococcus* sp.) in water samples collected during base-flow conditions generally were larger at the Fourche Maline station than at the Poteau River stations. Total phosphorus, total nitrogen, and suspended sediment concentrations in water samples collected during runoff conditions were larger at the Poteau River stations than at the Fourche Maline near Leflore, Okla., station.

Estimated annual total phosphorus and total nitrogen loads generally were larger at the Poteau River stations than at the Fourche Maline near Leflore, Okla., station. Estimated annual suspended sediment loads were largest at the Poteau River near Heavener, Okla., station and generally were smallest at the Poteau River at Loving, Okla., station. Estimated annual total phosphorus, total nitrogen, and

suspended sediment loads at the Poteau River stations at base-flow conditions generally were larger than at the Fourche Maline near Leflore, Okla., station. The estimated annual loads of total phosphorus, total nitrogen, and suspended sediment in the Poteau River stations during runoff conditions ranged from 82 to 98 percent of the total annual loads of those constituents. The estimated annual loads of total phosphorus, total nitrogen, and suspended sediment in the Fourche Maline during runoff conditions ranged from 86 to nearly 100 percent of the total annual loads.

Estimated seasonal total phosphorus loads generally were smallest during base-flow and runoff conditions in autumn. Estimated seasonal total phosphorus loads during base-flow conditions generally were largest in winter and during runoff conditions generally were largest in the spring. Estimated seasonal total nitrogen loads generally were smallest in autumn during base-flow conditions and largest in winter during runoff conditions. Estimated seasonal suspended sediment loads generally were smallest during base-flow conditions in the summer and during runoff conditions in the autumn. The largest estimated seasonal suspended sediment loads typically were in the spring during runoff conditions.

Estimated mean annual total phosphorus yields were largest at the Poteau River at Loving, Okla., station. The estimated mean total phosphorus yields were largest during base-flow at the Poteau River at Loving, Okla., station. Estimated mean annual total nitrogen yields were largest at the Poteau River stations. The estimated mean total nitrogen yields during base-flow and runoff conditions were largest at the Poteau River at Loving, Okla., station. Estimated mean annual, base-flow, and runoff yields of suspended sediment were largest at the Poteau River near Heavener, Okla., station.

Flow-weighted mean total phosphorus concentrations at all three stations from 2011 to 2013 were several times larger than Oklahoma State Standard for Scenic Rivers (0.037 milligrams per liter), with the largest flow-weighted phosphorus concentrations typically being measured at the Poteau River at Loving, Okla., station. Flow-weighted mean concentrations indicated that total phosphorus inputs from the Poteau River Basin in the Wister Lake Basin were larger than from the Fourche Maline Basin. Flow-weighted mean concentrations of total nitrogen did not vary spatially in a consistent manner. Flow-weighted mean total nitrogen concentrations did not vary substantially between the Poteau River stations and the Fourche Maline near Leflore, Okla., station.

The Poteau River and the Fourche Maline contributed estimated annual total phosphorus loads of 137 to 278 tons per year to Wister Lake. Between 89 and 95 percent of the annual total phosphorus loads were transported to Wister Lake during runoff conditions. The Poteau River typically transported several times larger total phosphorus loads during base-flow conditions and runoff conditions than the Fourche Maline. The Poteau River and the Fourche Maline contributed estimated

annual total nitrogen loads of 657 to 1,294 tons per year, with 86 to 94 percent of the annual total nitrogen loads being transported to Wister Lake during runoff conditions. Several times larger total nitrogen loads typically were delivered to the lake during base-flow and runoff conditions from the Poteau River than the Fourche Maline. The Poteau River and the Fourche Maline contributed estimated annual total suspended sediment loads of 110,919 to 234,637 tons per year, with 94 to 99 percent of the annual suspended sediment loads being transported to Wister Lake during runoff conditions. Several times more suspended sediment loads typically were transported to the lake by the Poteau River than the Fourche Maline. Most of the total phosphorus, total nitrogen, and suspended sediment were discharged to Wister Lake during runoff conditions in the spring.

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## Appendixes 1–3

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**Appendix 1.** Instantaneous streamflows, total phosphorus concentrations, total nitrogen concentrations, suspended sediment concentrations, bacteria concentrations, and flow category for Poteau River at Loving, Oklahoma, from 2010 to 2013.

[ft<sup>3</sup>/s, cubic feet per second; mg/L, milligrams per liter; mL, milliliter; <, less than; >, greater than. All water-quality data available at <http://water.usgs.gov/ok/mwis/>]

Date	Sample time	Streamflow (ft <sup>3</sup> /s)	Total phosphorus concentration (mg/L as P)	Total nitrogen concentration (mg/L as N)	<i>Enterococcus</i> sp. concentration (colonies per 100 mL)	<i>Escherichia coli</i> (colonies per 100 mL)	Suspended sediment (mg/L)	Flow type
10/19/2010	1600	61	0.152	1.1			9	Base flow
12/9/2010	1600	7	0.047	<0.50			5	Base flow
3/7/2011	1455	17	0.057	0.85			12	Base flow
4/11/2011	1530	32	0.07	0.59	370	20	28	Base flow
4/15/2011	1330	1,400	0.391	1.7	>4,800	14,000	315	Runoff
4/20/2011	1430	73	0.097	0.91	460	40	22	Base flow
4/26/2011	1200	10,400	0.187	1	>4,800	3,100	88	Runoff
5/2/2011	1330	7,070	0.461	1.4	>4,800	9,600	66	Runoff
5/23/2011	1430	323	0.302	1.2	220	200	50	Runoff
6/7/2011	1200	30	0.062	<0.50	1,300	63	14	Base flow
8/16/2011	900	12	0.068	0.53	1,500	170		Runoff
10/4/2011	930	0.67	0.043	0.5	96	63	3	Base flow
11/9/2011	1330	1,340	0.401	2.4	>4,800	6,100	197	Runoff
11/22/2011	1430	17,200	0.428	1.6	>4,800	8,400	554	Runoff
12/5/2011	1345	5,050	0.236	1.4	>4,800	1,800	74	Runoff
12/8/2011	915	1,160	0.076	1	120	310	14	Base flow
2/7/2012	930	745	0.06	0.7	40	120		Runoff
3/12/2012	1130	3,500	0.317	0.93	>4,800	5,000	114	Runoff
3/21/2012	1145	6,490	0.258	0.96	>4,800	3,700	94	Runoff
4/10/2012	930	64	0.047	0.51	46	63	11	Base flow
6/12/2012	1530	1.5	0.055	0.63	>4,800	<10	10	Base flow
6/13/2012	1030	1.9	0.051	0.54	>4,800	31	7	Base flow
8/16/2012	830	0.82	0.052	0.66	260	52	5	Base flow
10/17/2012	1100	77	0.204	1.7	1,200	340	44	Runoff
10/24/2012	1200	7.9	0.113	1.4	69	160	10	Runoff
12/18/2012	930	3.1	0.054	0.65	56	130	3	Base flow
1/14/2013	1000	1,010	0.309	1.7	>4,800	3,100	86	Runoff
1/31/2013	1100	777	0.299	1.6	>4,800	8,700	60	Runoff
3/7/2013	1000	122	0.052	<0.50	13	<10	11	Base flow
3/11/2013	1400	1,880	0.229	1.1	1,800	2,100	73	Runoff
4/3/2013	1315	7,110	0.413	1.1	>4800	9,100	234	Runoff
4/24/2013	1530	149	0.051	0.52	350	63	12	Base flow
5/22/2013	1045	2,620	0.438	1.8	>4,800	6,900	134	Runoff
6/26/2013	1330	59	0.083	0.72			15	Base flow
8/14/2013	1200	1,410	0.241	1.2	4,000	860	82	Runoff
8/28/2013	900	36	0.057	<0.50	37	41	15	Base flow

**Appendix 2.** Instantaneous streamflows, total phosphorus concentrations, total nitrogen concentrations, suspended sediment concentrations, bacteria concentrations, and flow category for Poteau River near Heavener Oklahoma from 2010 to 2013.

[ft<sup>3</sup>/s, cubic feet per second; mg/L, milligrams per liter; mL, milliliter; <, less than; >, greater than. All water-quality data available at <http://water.usgs.gov/ok/mwis>]

Date	Sample time	Streamflow (ft <sup>3</sup> /s)	Total phosphorus concentration (mg/L as P)	Total nitrogen concentration (mg/L as N)	<i>Enterococcus</i> sp. concentration (colonies per 100 mL)	<i>Escherichia coli</i> (colonies per 100 mL)	Suspended sediment (mg/L)	Flow type
10/27/2010	1300	56	0.114	0.94	500	82	23	Base flow
12/15/2010	1230	12	0.023	<0.50	40	10	17	Base flow
2/23/2011	1300	117	0.05	0.57	19	63	21	Base flow
4/11/2011	1330	93	0.053	0.5	190	97	23	Runoff
4/15/2011	1200	1,490	0.21	1.2	>4,800	3,200	295	Runoff
4/20/2011	1230	239	0.075	0.69	240	73	29	Runoff
4/26/2011	1500	16,400	0.263	1.1	>4,800	2,200	21	Runoff
5/2/2011	1445	15,400	0.3	1.1	>4,800	1,900	295	Runoff
5/23/2011	1245	517	0.134	0.83	80	97	33	Runoff
6/7/2011	1045	75	0.073	<0.50	43	63	24	Base flow
8/16/2011	1115	0.64	0.062	0.54	24	41		Runoff
10/4/2011	1045	1	0.047	0.57	17	41	8	Base flow
11/9/2011	1215	3,190	0.221	1.5	>4,800	2,200	195	Runoff
11/22/2011	1045	49,400	0.26	1.4	>4,800	6,300	658	Runoff
12/5/2011	1130	11,000	0.187	1.3	>4,800	290	69	Runoff
12/8/2011	1100	1,970	0.059	1	200	250	17	Base flow
1/25/2012	1700	22,000	0.256	1.1	>4,800	4,300	136	Runoff
2/7/2012	1115	1,090	0.051	0.65	63	220	11	Runoff
3/12/2012	1300	8,130	0.245	0.99	>4,000	5,200	128	Runoff
3/21/2012	1445	12,100	0.2	0.82	2,400	1,300	95	Runoff
4/10/2012	1100	147	0.04	<0.50	10	10	9	Base flow
6/13/2012	1200	3.3	0.042	<0.50	15	10	9	Base flow
6/27/2012	1215	3.4	0.068	0.63	4	10	28	Base flow
8/16/2012	1000	0.13	0.057	0.72	76	10	7	Base flow
10/17/2012	1300	158	0.166	1.4	2	290	41	Runoff
10/24/2012	1300	24	0.099	1.2	110	74	16	Runoff
12/18/2012	1100	6.3	0.046	1.2	17	10	3	Base flow
1/14/2013	1145	1,390	0.304	1.7	>4,800	3,200	138	Runoff
1/31/2013	1330	1,500	0.238	1.5	520	9,900	61	Runoff
3/6/2013	1330	235	0.035	0.55	13	10	8	Base flow
3/11/2013	1630	3,480	0.213	1.1	1,700	2,400	69	Runoff
4/3/2013	1700	10,500	0.378	1.1	>4,800	7,000	478	Runoff
4/25/2013	1030	451	0.034	<0.50	37	120	11	Base flow
5/22/2013	1230	5,380	0.189	0.98	>4,800	2,800	112	Runoff
6/26/2013	1200	117	0.084	0.74			16	Base flow
8/14/2013	1430	2,390	0.196	1.1	2,200	660	77	Runoff
8/28/2013	1130	82	0.065	0.51	6	73	23	Base flow

**Appendix 3.** Instantaneous streamflows, total phosphorus concentrations, total nitrogen concentrations, suspended sediment concentrations, bacteria concentrations, and flow category for Fourche Maline near Leflore, Oklahoma, from 2010 to 2013.

[ft<sup>3</sup>/s, cubic feet per second; mg/L, milligrams per liter; mL, milliliter; <, less than; >, greater than. All water-quality data available at <http://water.usgs.gov/ok/nwis>]

Date	Sam- ple time	Streamflow (ft <sup>3</sup> /s)	Total phosphorus concentration (mg/L as P)	Total nitrogen concentration (mg/L as N)	<i>Enterococcus</i> sp. concentration (colonies per 100 mL)	<i>Escherichia coli</i> (colonies per 100 mL)	Suspended sediment (mg/L)	Flow type
10/27/2010	945	0.01	0.034	0.55	180	<10	23	Runoff
12/15/2010	1030	0.17	0.051	0.56	100	20	24	Runoff
2/23/2011	1030	12	0.045	0.58	27	160	28	Runoff
4/11/2011	1130	44	0.069	0.52	820	490	71	Base flow
4/15/2011	1030	2,230	0.33	1.8	>4,800	7,500	357	Runoff
4/20/2011	930	167	0.075	0.86	980	110	40	Runoff
4/26/2011	1730	5,690	0.287	1	>4,800	2,100	93	Runoff
5/2/2011	1400	5,310	0.14	0.89	>4,800	2,400	67	Runoff
5/23/2011	1000	1,450	0.172	1	1,800	1,400	102	Runoff
6/7/2011	830	37	0.09	0.64	87	41	23	Base flow
8/16/2011	1300	0.34	0.039	<0.50	60	<10		Runoff
11/9/2011	945	35	0.056		1,700	660	31	Runoff
11/22/2011	800	2,590	0.248	2.3	>4,800	24,000	281	Runoff
12/5/2011	930	948	0.137	1.7	410	1,300	104	Runoff
12/8/2011	1400	221	0.04	1.7	170	84	26	Base flow
1/25/2012	1400	6,540	0.336	1.5	3,500	4,000	168	Runoff
2/7/2012	1300	541	0.071	1.1	120	350	45	Base flow
3/12/2012	1000	8,130	0.057	0.65	340	870		Runoff
3/21/2012	900	5,480	0.182	1.1	4,000	10,000	78	Runoff
4/10/2012	1330	147	0.079	0.78	92	98	28	Base flow
6/13/2012	1400	15	0.058	0.51	150	30	18	Runoff
6/27/2012	1030	3.7	0.096	0.71	54	<10	48	Base flow
8/16/2012	1200	0.01	0.075	0.94	54	<10	15	Base flow
10/17/2012	1500	28	0.143	0.92	610	340	69	Runoff
10/24/2012	1015	0.27	0.063	0.64	130	<10	18	Runoff
1/14/2013	1430	13	0.066	0.55	88	74	10	Runoff
1/31/2013	1530	246	0.146	1.1	2,400	410	80	Runoff
3/6/2013	1300	61	0.062	0.85	37	31	23	Base flow
3/11/2013	1130	1,950	0.353	1.6	2,800	2,800	514	Runoff
4/3/2013	1030	3,500	0.294	1.2	4,000	8,600		Runoff
4/25/2013	1230	142	0.059	0.62	61	63	39	Base flow
5/21/2013	1430	6,230	0.717	2.5	>4,800	6,400	820	Runoff
5/22/2013	1330	3,020	0.204	1.1	>4,800	3,100	157	Runoff
6/26/2013	1530	20	0.058	0.6			9	Base flow
8/28/2013	1345	5	0.061	0.53	32	20	14	Base flow



