Prepared in cooperation with the
City of Tulsa, Oklahoma

Nutrient Concentrations, Loads, and Yields in the Eucha-Spavinaw Basin, Arkansas and Oklahoma, 2002–2004

Scientific Investigations Report 2006–5250

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

Cover Photo Credit: Picture is Spavinaw Creek near Colcord, Delaware County, Oklahoma, downstream from County Road, taken October 2001. Photographer: Robert L. Blazs, U.S. Geological Survey.

Nutrient Concentrations, Loads, and Yields in the Eucha-Spavinaw Basin, Arkansas and Oklahoma, 2002–2004

By Robert L. Tortorelli

Prepared in cooperation with the City of Tulsa, Oklahoma

Scientific Investigations Report 2006–5250

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

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2006

For product and ordering information:
World Wide Web: *http://www.usgs.gov/pubprod*
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: *http://www.usgs.gov*
Telephone: 1-888-ASK-USGS

Suggested citation:
Tortorelli, R.L., 2006, Nutrient concentrations, loads, and yields in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004: U.S. Geological Survey Scientific Investigations Report 2006–5250, 44 p.
Copies of this report are available at the Oklahoma Water Science Center, 202 NW 66th St., Bldg. 7, Oklahoma City, OK 73116.

Contents

Abstract 1
Introduction 2
    Purpose and Scope 4
    Study Area Description 4
    Streamflow in the Eucha-Spavinaw Basin 4
    Nutrient Concentrations in Undeveloped Basins 4
    Acknowledgments 8
Methods 8
    Water-Quality Data Collection and Analysis 8
    Streamflow Separation 8
    Statistical Tests 9
    Load and Yield Estimation 9
Nutrient Concentrations, Loads, and Yields in the Eucha-Spavinaw Basin 11
    Concentrations 11
        Nitrogen 11
        Phosphorus 11
    Estimated Mean Annual Loads 19
        Nitrogen 19
        Phosphorus 19
    Estimated Mean Seasonal Loads 19
        Nitrogen 22
        Phosphorus 22
    Estimated Mean Annual Yields 22
        Nitrogen 22
        Phosphorus 22
    Estimated Mean Flow-Weighted Concentrations 24
        Nitrogen 24
        Phosphorus 24
    Estimated Mean Annual Nutrient Loads into Lake Eucha 24
Summary 24
Selected References 29
Appendixes 33
    1. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Maysville, Arkansas, 2002–2004 35
    2. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Cherokee, Arkansas, 2002–2004 37
    3. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Sycamore, Oklahoma, 2002–2004 39
    4. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Colcord, Oklahoma, 2002–2004 41
    5. Streamflows, and total nitrogen and total phosphorus concentrations for Beaty Creek near Jay, Oklahoma, 2002–2004 43

Figures

1–2. Maps showing:

1. The Eucha-Spavinaw basin, Arkansas and Oklahoma, with locations of selected streamflow and water-quality stations in the basin and towns with wastewater-treatment plants that discharge into streams in the basin 3
2. Land use in the Eucha-Spavinaw basin, Arkansas and Oklahoma 5

3–5. Graphs showing:

3. Streamflow divided into total flow and base flow, and base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004 7
4. Total nitrogen concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004 14
5. Total phosphorus concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004 16

6–8. Box plots showing:

6. Distributions of **base-flow** total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004 17
7. Distributions of **runoff** total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004 18
8. Instantaneous total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Sapvinaw basin, Arkansas and Oklahoma, 2002–2004 25

Tables

1. Station information and streamflow statistics for surface-water and water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma......6
2. Regression models for estimating total nitrogen and total phosphorus loads at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, developed using data collected during 2002–2004. 10
3. Summary statistics of total nitrogen concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004. 12
4. Summary statistics of total phosphorus concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004. 13
5. Wilcoxon rank-sum test results comparing base-flow total nitrogen and total phosphorus concentrations to runoff total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004 15
6. Estimated mean annual total nitrogen and total phosphorus loads and yields using regression methods from concentrations in water-quality samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004......20

7. Number of days of base flow and runoff designated by Base-Flow Index program at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004 21
8. Estimated mean seasonal total nitrogen and total phosphorus loads estimated using regression methods from concentrations in water-quality samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.....23
9. Estimated mean annual total nitrogen and total phosphorus loads, mean annual streamflows, and estimated mean flow-weighted total nitrogen and total phosphorus concentrations at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004 26
10. Summary of estimated mean annual total nitrogen and total phosphorus loads to Lake Eucha, Oklahoma, 2002–2004.....27

Conversion Factors and Definitions

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
pound per day (lb/d)	0.4536	kilogram per day (kg/d)
pound per day per square mile [(lb/d)/mi^2]	0.1751	kilogram per day per square kilometer [(kg/d)/km^2]
pound per year (lb/yr)	0.4536	kilogram per year (kg/yr)

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

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

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

Method detection limit (MDL)—Minimum concentration of a substance that can be measured and reported with 99-percent confidence that the analyte concentration is greater than zero. It is determined from the analysis of a sample in a given matrix containing the analyte (U.S. Environmental Protection Agency, 1997). At the MDL concentration, the risk of a false positive is predicted to be less than or equal to 1 percent (Childress and others, 1999).

Long-term method detection level (LT–MDL)—A detection level derived by determining the standard deviation of a minimum of 24 MDL spike sample measurements over an extended period of time. LT–MDL data are collected on a continuous basis to assess year-to-year variations in the LT–MDL.

The LT–MDL controls false positive error. The chance of falsely reporting a concentration at or greater than the LT–MDL for a sample that did not contain the analyte is predicted to be less than or equal to 1 percent (Childress and others, 1999).

Laboratory reporting level (LRL)—Generally equal to twice the yearly determined LT–MDL. The LRL controls false negative error. The probability of falsely reporting a non-detection for a sample that contained an analyte at a concentration equal to or greater than the LRL is predicted to be less than or equal to 1 percent. The value of the LRL will be reported with a “less than” remark code for samples in which the analyte was not detected. The National Water Quality Laboratory collects quality-control data from selected analytical methods on a continuing basis to determine long-term method detection levels (LT–MDL’s) and establish laboratory reporting levels (LRL’s). These values are re-evaluated annually based on the most current quality-control data and may, therefore, change (Childress and others, 1999).

Estimated concentration (“E” remark code)—Positive detections below the LRL are not censored. Detected analytes with concentrations between the LT–MDL and the LRL are reported as estimated (“E” remark code). This is because a detection in this region should have a less than or equal to 1-percent probability of being a false positive (Childress and others, 1999). There are several circumstances that dictate this code; this is one of the most common.

Minimum reporting level (MRL)—Smallest measured concentration of a constituent that may be reliably reported by using a given analytical method (Timme, 1995).

Water year (WY) —The 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends.

Nutrient Concentrations, Loads, and Yields in the Eucha-Spavinaw Basin, Arkansas and Oklahoma, 2002–2004

By Robert L. Tortorelli

Abstract

The City of Tulsa, Oklahoma, uses Lake Eucha and Spavinaw Lake in the Eucha-Spavinaw basin in northwestern Arkansas and northeastern Oklahoma for public water supply. Taste and odor problems in the water attributable to blue-green algae have increased in frequency over time. Changes in the algae community in the lakes may be attributable to increases in nutrient levels in the lakes, and in the waters feeding the lakes. The U.S. Geological Survey, in cooperation with the City of Tulsa, conducted an investigation to summarize nitrogen and phosphorus concentrations and provide estimates of nitrogen and phosphorus loads, yields, and flow-weighted concentrations in the Eucha-Spavinaw basin for a 3-year period from January 2002 through December 2004. This report provides information needed to advance knowledge of the regional hydrologic system and understanding of hydrologic processes, and provides hydrologic data and results useful to multiple parties for interstate compacts.

Nitrogen and phosphorus concentrations were significantly greater in runoff samples than in base-flow samples at Spavinaw Creek near Maysville, Arkansas; Spavinaw Creek near Colcord, Oklahoma, and Beaty Creek near Jay, Oklahoma. Runoff concentrations were not significantly greater than in base-flow samples at Spavinaw Creek near Cherokee, Arkansas; and Spavinaw Creek near Sycamore, Oklahoma.

Nitrogen concentrations in base-flow samples significantly increased in the downstream direction in Spavinaw Creek from the Maysville to Sycamore stations then significantly decreased from the Sycamore to the Colcord stations. Nitrogen in base-flow samples from Beaty Creek was significantly less than in those from Spavinaw Creek. Phosphorus concentrations in base-flow samples significantly increased from the Maysville to Cherokee stations in Spavinaw Creek, probably due to a point source between those stations, then significantly decreased downstream from the Cherokee to Colcord stations. Phosphorus in base-flow samples from Beaty Creek was significantly less than phosphorus in base-flow samples from Spavinaw Creek downstream from the Maysville station.

Nitrogen concentrations in runoff samples were not significantly different among the stations on Spavinaw Creek; however, the concentrations at Beaty Creek were significantly less than at all other stations. Phosphorus concentrations in runoff samples were not significantly different among the three downstream stations on Spavinaw Creek, and not significantly different at the Maysville station on Spavinaw Creek and the Beaty Creek station. Phosphorus and nitrogen concentrations in runoff samples from all stations generally increased with increasing streamflow.

Estimated mean annual nitrogen total loads from 2002–2004 were substantially greater at the Spavinaw Creek stations than at Beaty Creek and increased in a downstream direction from Maysville to Colcord in Spavinaw Creek, with the load at the Colcord station about 2 times that of Maysville station. Estimated mean annual nitrogen base-flow loads at the Spavinaw Creek stations were about 5 to 11 times greater than base-flow loads at Beaty Creek. The runoff component of the annual nitrogen total load for Beaty Creek was 85 percent, whereas, at the Spavinaw Creek stations, the range in the runoff component was 60 to 66 percent.

Estimated mean annual phosphorus total loads from 2002–2004 were greater at the Spavinaw Creek stations from Cherokee to Colcord than at Beaty Creek and increased in a downstream direction from Maysville to Colcord in Spavinaw Creek, with the load at the Colcord station about 2.5 times that of Maysville station. Estimated mean annual phosphorus base-flow loads at the Spavinaw Creek stations were about 2.5 to 19 times greater than at Beaty Creek. Phosphorus base-flow loads increased about 8 times from Maysville to Cherokee in Spavinaw Creek; the base-flow loads were about the same at the three downstream stations. The runoff component of the annual phosphorus total load for the Spavinaw Creek stations ranged from 66 to 93 percent, whereas the runoff component at Beaty Creek was 98 percent.

Estimated mean seasonal nitrogen base-flow and runoff loads generally were least in fall and greatest in spring at all stations in the Eucha-Spavinaw basin. Seasonal base-flow loads at stations on Spavinaw Creek were about 3 to 18 times greater than at the station on Beaty Creek and increased in a downstream direction from Maysville to Colcord in Spavinaw

Creek, with the seasonal base-flow load at the Colcord station about 2 times that of Maysville station. Estimated mean seasonal phosphorus base-flow and runoff loads generally were least in fall and winter, and greatest in spring and summer at all stations in the Eucha-Spavinaw basin. Seasonal phosphorus base-flow loads at Spavinaw Creek stations were about 2 to 30 times greater than at the station on Beaty Creek.

Estimated mean annual nitrogen total yields ranged from 4,340 to 6,870 pounds per year per square mile, with greatest yield at Spavinaw Creek near Sycamore, and the least yield at Beaty Creek near Jay. Estimated mean annual nitrogen base-flow yields ranged from 664 to 2,640 pounds per year per square mile, and estimated mean annual nitrogen runoff yields ranged from 3,680 to 4,530 pounds per year per square mile. Estimated mean annual phosphorus total yields ranged from 227 to 456 pounds per year per square mile, with greatest the yield at Beaty Creek, and the least yield at Spavinaw Creek near Maysville. Most of the yield was delivered during runoff events. Estimated mean annual phosphorus base-flow yields at the three downstream Spavinaw Creek stations ranged from 62.5 to 112 pounds per year per square mile and were about 6 to 11 times greater than at Beaty Creek.

Estimated mean flow-weighted nitrogen concentrations at all stations in the basin for 2002–2004 were about 7–10 times greater than the 75th percentile of flow-weighted nitrogen concentrations (0.50 milligram per liter) in relatively undeveloped basins of the United States. Estimated mean flow-weighted phosphorus concentrations at all stations in the basin for 2002–2004 were about 4–10 times greater than the 75th percentile of flow-weighted phosphorus concentrations (0.037 milligram per liter) in relatively undeveloped basins of the United States.

Spavinaw Creek and Beaty Creek contributed an estimated mean annual nitrogen total load of about 1,350,000 pounds per year and about 65 percent of the annual nitrogen total load was transported to Lake Eucha by runoff. Spavinaw Creek and Beaty Creek contributed an estimated mean annual phosphorus total load of about 77,700 pounds per year with about 86 percent of the annual phosphorus total load being transported to Lake Eucha by runoff.

Introduction

The City of Tulsa, Oklahoma, uses Lake Eucha and Spavinaw Lake in the Eucha-Spavinaw basin in northwestern Arkansas and northeastern Oklahoma for public water supply (fig. 1). Construction on Spavinaw Lake Dam on Spavinaw Creek began in 1922 and was completed in 1924. A series of pipelines 60-miles long, from the base of Spavinaw Lake Dam to the City of Tulsa, were constructed to transfer water to a treatment plant in Tulsa. Spavinaw Lake supplied Tulsans with a safe, reliable water supply until 1950 (Oklahoma Water Resources Board, 2002). During that year, city officials decided to create an impoundment of Spavinaw Creek 4 miles upstream from Spavinaw Lake to serve as "an environmental and hydrologic barrier" (Tulsa Metropolitan Utility Authority, 2001a) for Spavinaw Lake to ensure a constant supply of clean water. This second dam came to be known as Lake Eucha Dam and was finished in 1954 (fig. 1).

The Eucha-Spavinaw system continues to be designated as a system for public water supply along with recreation, fish and wildlife, and aesthetics. Eucha-Spavinaw provides a yield of 59 million gallons per day (mgd) to the Tulsa metropolitan area. Under drought conditions, the system can produce a maximum of 100 mgd (Tulsa Metropolitan Utility Authority, 2001a).

Recently, the Tulsa Metropolitan Utility Authority (TMUA) has increased expenditures treating Spavinaw Lake raw water for human consumption. Consumer complaints of taste and odor in the finished water also have been reported. City staff has determined that taste and odor problems attributable to blue-green algae have increased in frequency over time. Changes in the algae community in the lakes may be attributable to increases in nutrient levels in the lakes, and in the waters feeding the lakes (Tulsa Metropolitan Utility Authority, 2001b). Studies of phosphorous loading began with a 1997 Oklahoma Conservation Commission report indicating increasing phosphate content of Spavinaw Creek (Wagner and Woodruff, 1997). Other studies were conducted in 2001–2002 (Oklahoma Water Resources Board, 2002; Storm and others, 2001 and 2002).

Phosphorus enters streams in discharges from wastewater-treatment plants (point-source components) and in agricultural and urban runoff (nonpoint-source components) (Oklahoma Water Resources Board, 2002). Streams in the Eucha-Spavinaw basin are susceptible to contamination from point and nonpoint sources. Elevated phosphorus concentrations promote algae growth in streams (Sharpley, 1995; U.S. Geological Survey, 1999), and accelerate eutrophication of lakes (Daniel and others, 1998; U.S. Geological Survey, 1999).

One possible major contributor of nutrients to the creeks feeding Lake Eucha and Spavinaw Lake is the phosphorous-rich waste produced by commercial poultry growing operations in the watershed (Tulsa Metropolitan Utility Authority, 2001b). This waste is routinely spread onto fields as fertilizer, and can be a source of phosphorous washed into streams as nonpoint-source pollution, which ultimately reaches the water-supply lakes and promotes growth of unwanted algae. Today, the poultry operations in the Eucha-Spavinaw basin have the capacity to produce over 84 million birds, along with some 1,500 tons of phosphorous-rich waste per year (Tulsa Metropolitan Utility Authority, 2001b).

Historical water-quality data collection in the Eucha-Spavinaw basin has been biased towards sampling during base-flow (non-runoff) conditions. Because of insufficient historic sampling during runoff events, calculations using historic data may have underestimated true nutrient concentrations, loads, and yields. In July 2001, the U.S. Geological Survey (USGS), in cooperation with the TMUA, supplemented fixed period, monthly water-quality sampling with six runoff-event

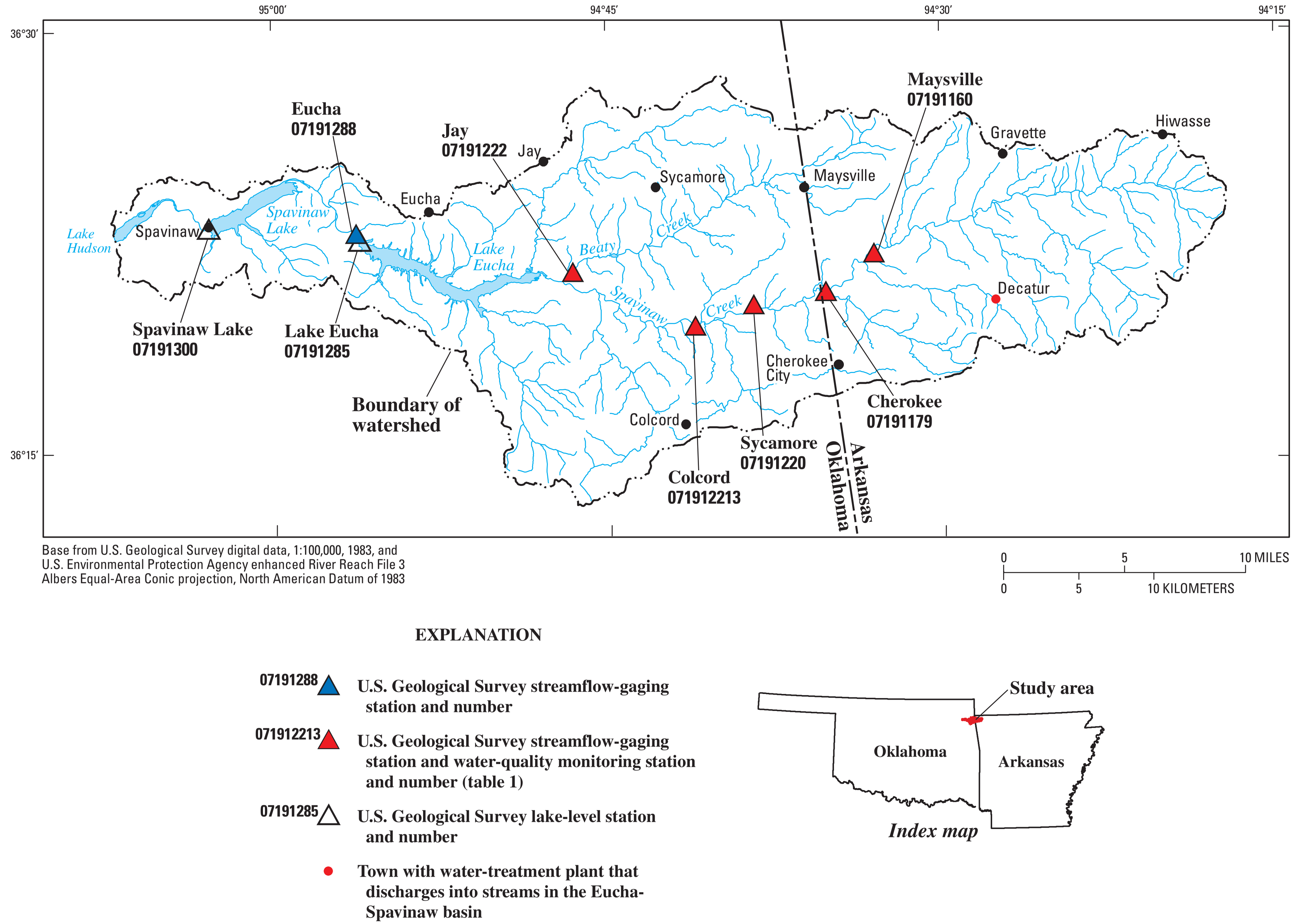

Figure 1. The Eucha-Spavinaw basin, Arkansas and Oklahoma, with locations of selected streamflow and water-quality stations in the basin and towns with wastewater-treatment plants that discharge into streams in the basin.

samplings per year to better determine water quality over a broader range of streamflows in the basin. The period 2002–2004 encompasses a period where the runoff-event sampling protocol was in effect during the entire period. The USGS, in cooperation with the City of Tulsa, Oklahoma, conducted an investigation to summarize nitrogen and phosphorus concentrations and provide estimates of nitrogen and phosphorus loads, yields, and flow-weighted concentrations in the Eucha-Spavinaw basin for a 3-year period from January 2002 through December 2004.

Purpose and Scope

The purpose of this report is to summarize nitrogen and phosphorus concentrations and provide estimates of nitrogen and phosphorus loads, yields, and flow-weighted concentrations in the Eucha-Spavinaw basin, Spavinaw Creek and Beaty Creek tributary, for a 3-year period—2002–2004. This report comprises a preliminary analysis of data collected for a multi-year monitoring program.

Nitrogen and phosphorus concentrations are compared among stations in the Eucha-Spavinaw basin, and to those measured at relatively undeveloped basins of the United States. Nitrogen and phosphorus loads are computed using S-LOADEST, a program to compute mean constituent loads in rivers using the rating-curve method (Dave Lorenz, USGS, written commun., 2006). S-LOADEST, based on LOADEST (LOAD ESTimator), uses instantaneous nutrient concentrations and daily mean streamflows to estimate annual and seasonal (spring, summer, fall, and winter) average nutrient loads for the study period (Crawford, 1999; Runkel and others, 2004). The report provides information needed to advance knowledge of the regional hydrologic system and understanding of hydrologic processes, and provides hydrologic data and results useful to multiple parties for interstate compacts.

Study Area Description

The Eucha-Spavinaw basin is a 415-square-mile drainage basin divided between northeastern Oklahoma (70 percent), and northwestern Arkansas (30 percent) (fig. 1). Lake Eucha and Spavinaw Lake collect and store water from Spavinaw Creek (the main drainage channel for the basin) to supply the Tulsa metropolitan area and other local water users (Oklahoma Water Resources Board, 2002).

The basin is in the southwestern part of the Ozark Plateaus physiographic province (Fenneman, 1938), and is underlain by the cherty limestone of the Springfield Plateau aquifer (Adamski and others, 1995; Renken, 1998).

The basin is dominated by about equal proportions of agricultural (pasture and row crops) and forest land uses and is interspersed with minor amounts of urban land uses (Storm and others, 2002; DeLaune and others, 2006) (fig. 2). Livestock production on pasture is the primary form of agriculture in the basin; the drainage area is densely populated with poultry/beef cattle operations that use poultry litter as a fertilizer source for pastures (DeLaune and others, 2006). Poultry operations in the Eucha-Spavinaw basin have the capacity to produce over 84 million birds, along with some 1,500 tons of phosphorous-rich waste per year (Tulsa Metropolitan Utility Authority, 2001b).

There also is a municipal wastewater-treatment plant, operated by the city of Decatur, Arkansas, that discharges phosphorus containing wastewater to the Eucha-Spavinaw basin (Storm and others, 2002; DeLaune and others, 2006).

Streams in the basin receive potentially large concentrations of nitrogen and phosphorus from point sources (such as wastewater-treatment plants) and nonpoint sources (such as runoff from fertilized pastures and row crops). Nitrogen and phosphorus concentrations in Ozark streams are typically greater in streams draining agricultural lands than in those draining forested lands (Petersen and others, 1998; 1999) because runoff from pastures fertilized with animal manure probably are substantial sources of phosphorus to the streams in this basin (Storm and others, 2002). Streams receiving municipal wastewater from treatment plants can have nitrogen and phosphorus concentrations substantially greater than those in streams draining agricultural areas (Petersen and others, 1998; 1999). Spavinaw Creek (fig. 1) receives discharges from a wastewater-treatment plant, whereas, Beaty Creek does not.

Streamflow in the Eucha-Spavinaw Basin

Streamflow in the Eucha-Spavinaw basin was highly variable from 2002 to 2004, and generally increased with basin drainage area (table 1, fig. 3). The maximum daily mean streamflow during the study period occurred in July 2004 at all stations, and the minimum daily mean streamflow during the study period occurred in August 2003 at all stations; there was zero flow at Beaty Creek near Jay at various times in September–October 2002, August 2003 (table 1, fig. 3). Greatest monthly mean streamflows generally occurred from March through June and least monthly mean streamflows generally occurred from August through December at all stations (Blazs and others, 2003-2006).

Nutrient Concentrations in Undeveloped Basins

Nitrogen and phosphorus concentrations were compared among stations in the Eucha-Spavinaw basin, and to those measured at relatively undeveloped basins of the United States. The nutrient concentrations were compared with the 75th percentile of flow-weighted total phosphorus concentrations from streams draining 85 relatively undeveloped basins from across the United States selected from three programs of the USGS the Hydrologic Benchmark Network, the National Water-Quality Assessment program, and the USGS Research Program (Clark and others, 2000). Total phosphorus is the concentration of dissolved phosphorus and particulate phosphorus in the sample.

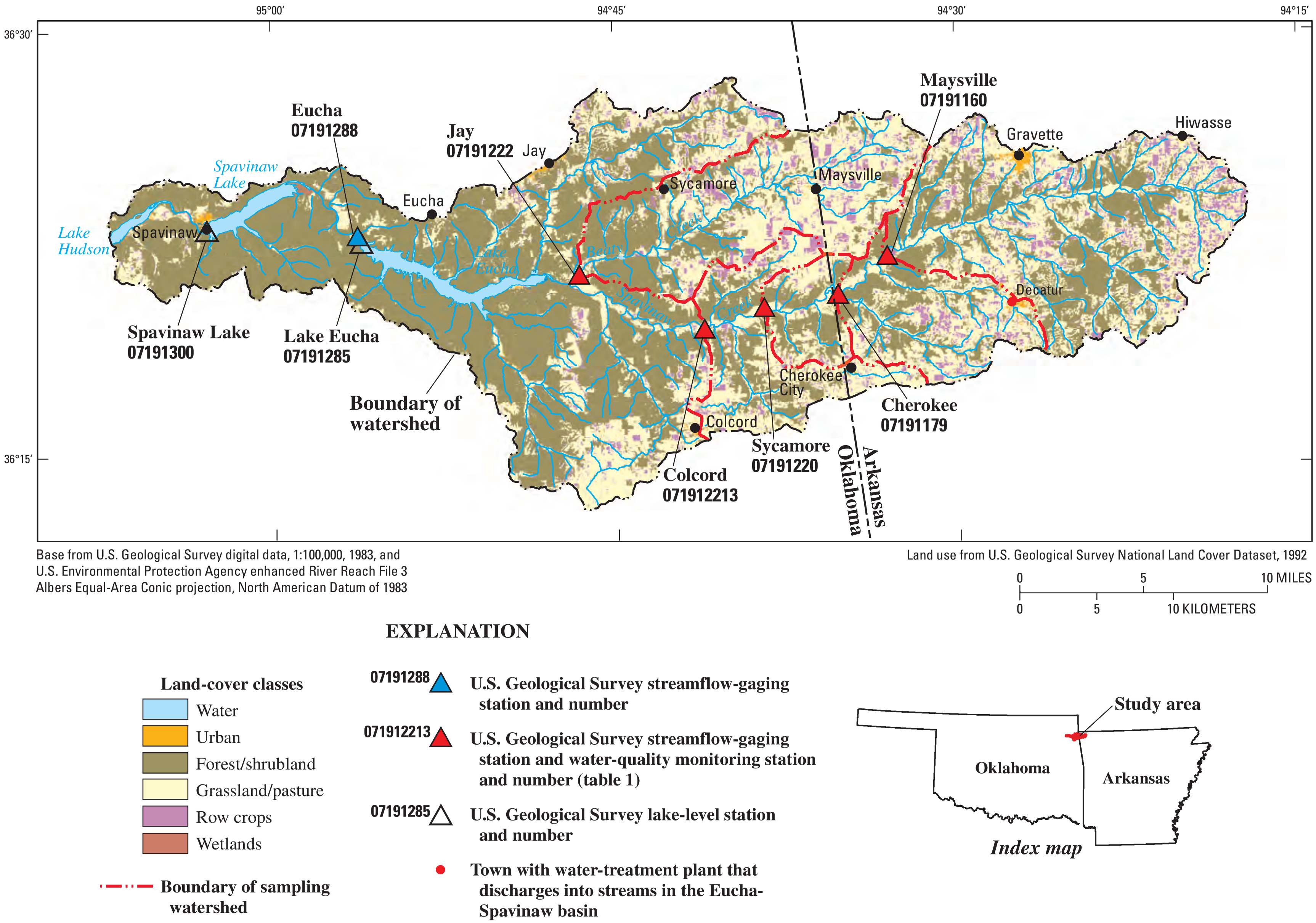

Figure 2. Land use in the Eucha-Spavinaw basin, Arkansas and Oklahoma.

Table 1. Station information and streamflow statistics for surface-water and water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma.

[WY, water year; ddmmss, degrees, minutes, seconds; mi², square mile; ft³/s, cubic foot per second]

Station name (number)	Period of record for station (WY)	Latitude (ddmmss)	Longitude (ddmmss)	Drainage area (mi²)	Mean annual streamflow (ft³/s)					Minimum and maximum daily mean streamflow for study period, 2002–2004 (ft³/s)	
					2002	2003	2004	2002–2004	Period of record[1]	Minimum (date)	Maximum (date)
Spavinaw Creek near Maysville, Ark. (07191160)	2002–present	362152	943304	88.2	57.9	32.0	95.8	61.9	64.9	11 (08/21/2003)[2]	4,150 (07/03/2004)
Spavinaw Creek near Cherokee, Ark. (07191179)	2002–present	362031	943515	104	68.7	36.4	118	74.4	78.7	12 (08/25/2003)[3]	5,180 (07/03/2004)
Spavinaw Creek near Sycamore, Okla. (07191220)	1962–present	362005	943829	133	83.4	45.4	161	96.6	114	12 (08/25/2003)[3]	6,300 (07/03/2004)
Spavinaw Creek near Colcord, Okla. (071912213)	2002–present	361921	944106	163	105	56.9	218	127	129	12 (08/26/2003)	7,720 (07/03/2004)
Beaty Creek near Jay, Okla. (07191222)	1998–present	362119	944634	59.2	20.8	14.9	80.4	38.7	45.2	0 at times 2002, 2003	4,080 (07/03/2004)

[1] Based on streamflow statistics through Water Year 2005.

[2] Also occurred 08/23–08/28/2003.

[3] Also occurred 08/26–08/28/2003.

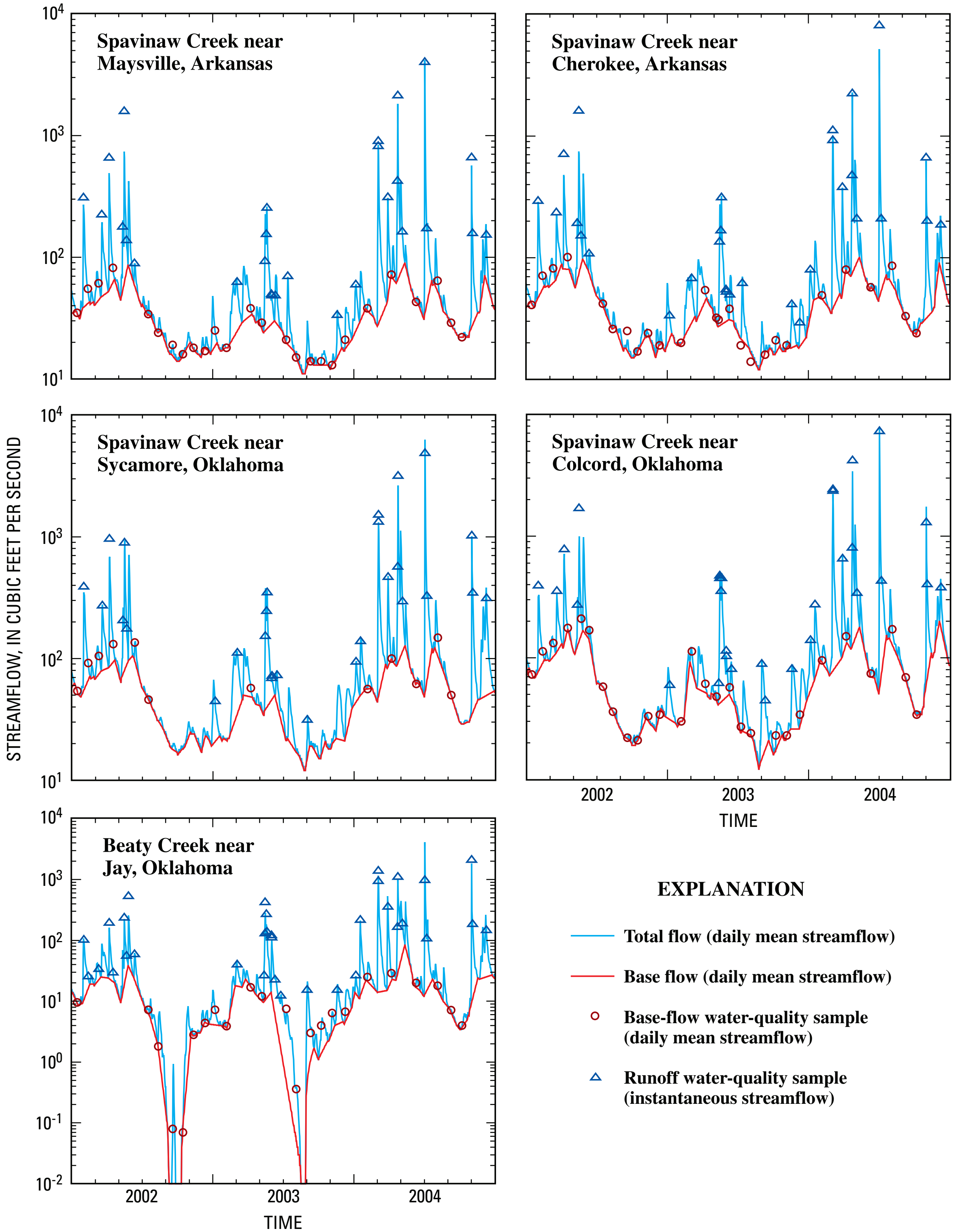

Figure 3. Streamflow divided into total flow and base flow, and base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

The Hydrologic Benchmark Network program, initiated by the USGS in 1958, was established to track water-quality trends in streams draining basins free from anthropogenic influence and to study cause and effect relation between various physiologic, meteorologic, and hydrologic variables (Cobb and Biesecker, 1971). The Hydrologic Benchmark Network is primarily composed of relatively undeveloped basins encompassing a wide variety of natural environments nationwide (Mast and Turk, 1999).

The National Water-Quality Assessment program, initiated by the USGS in 1991, is a primary source for long-term, nationwide information on the quality of streams, ground water, and aquatic ecosystems. The information gathered through the program supports national, regional, state, and local decision making and policy formation for water-quality management (Gilliom and others, 2001). Long-term goals of the program are to describe the status and trends in the quality of the Nation's surface- and ground-water resources and determine the natural and anthropogenic factors affecting water quality (Gilliom and others, 1995).

The USGS Research Program provided research data for the assessment in Clark and others (2000) from 20 USGS research basins nationwide. These were small basins, ranging in size from about 0.04 to 8.5 square miles, that were located predominately in the Appalachian and Rocky Mountains (Clark and others, 2000).

Acknowledgments

The author thanks many people for their contributions to the data collection and data analysis presented in this report. There were numerous City of Tulsa personnel that participated in monthly water-quality sampling. There were numerous USGS personnel that participated in the runoff-event water-quality sampling, the entire Oklahoma Water Science Center Data Section at all three field offices added to the effort, but special thanks goes to the Tulsa Field Office for their contribution to the data collection. Additional special thanks go to Dave Lorenz for his help using the load estimation program, S-LOADEST; and Dave Mueller for his insight into load estimation equations.

Methods

This section describes the water-quality data-collection and analysis protocols, method of streamflow separation into base flow and runoff, statistical tests used to compare groups of data, and methods used to estimate total nitrogen and phosphorus loads, yields, and flow-weighted concentrations.

Water-Quality Data Collection and Analysis

The USGS operates several continuous streamflow-gaging stations and collects water-quality data in the Eucha-Spavinaw basin in Arkansas and Oklahoma. Five continuous streamflow-gaging stations were selected for use in this report: Spavinaw Creek near Maysville, Arkansas; Spavinaw Creek near Cherokee, Arkansas; Spavinaw Creek near Sycamore, Oklahoma; Spavinaw Creek near Colcord, Oklahoma; and Beaty Creek near Jay, Oklahoma (table 1, fig. 1). Stream gages were operated and streamflows were measured according to methods described in Rantz and others (1982).

Surface-water quality data used for load and yield estimation should represent different flow conditions (from low to high) and be reasonably balanced among seasons (A.V. Vecchia, USGS, written commun., 2005). Prior to July 2001, only fixed period, monthly water-quality samples were collected at these stations by staff from the City of Tulsa, Oklahoma. Starting in July 2001 at the Cherokee, Colcord, and Jay streamflow gages and December 2001 at the Maysville and Sycamore streamflow gages, six water-quality samples were collected annually during runoff events at these stations by the USGS (fig. 3). Representative water-quality samples were collected by USGS during runoff events using equal-width increment methods (Edwards and Glysson, 1999).

The City of Tulsa Water Quality Laboratory analyzed the water-quality samples (U.S. Environmental Protection Agency, 1983 and 1993). Total nitrogen concentrations are calculated by adding Kjeldahl-Nitrogen and nitrite plus nitrate analyses. Nitrogen and total phosphorus concentrations are reported as values if above the laboratory reporting level (LRL). The LRL is set to reduce false positive error, and is equal to twice the yearly determined long-term method detection level (Childress and others, 1999).

Streamflow data and nitrogen and phosphorus concentration data collected from 2002 through 2004 are analyzed in this report. All streamflow and water-quality data from samples are available through the world wide web at *http://water.usgs.gov/ok/nwis*.

Streamflow Separation

Streamflow was separated into base-flow and runoff components using a hydrograph separation program, Base-Flow Index (Institute of Hydrology, 1980a, 1980b; Wahl and Wahl, 1995) (fig. 3). Base flow is the sustained runoff or fair-weather flow of the stream and is largely composed of ground-water seepage (Langbein and Iseri, 1960). The minimum daily mean flow was identified in consecutive 5-day increments, and minimums less than 90 percent of adjacent minimums were defined as turning points (Wahl and Wahl, 1988; Wahl and Tortorelli, 1997). The Base-Flow Index program estimated the base-flow hydrograph by drawing straight lines through successive turning points. Runoff components were calculated as the difference between total streamflow and base-flow components.

Each day was designated to be either base flow or runoff. Base-flow days in this report were defined as days when base flow contributed greater than or equal to 70 percent of total flow; runoff days were defined as days when runoff contributed greater than 30 percent of total flow (Pickup and others, 2003; Tortorelli and Pickup, 2006).

Statistical Tests

Streamflow data and water-quality data were analyzed in the three-year period 2002–2004, based on calendar year. The three-year period was used to average annual climate variation.

The Mann-Whitney rank-sum test (Helsel and Hirsch, 1992), used to compare two groups of data, was used to determine the statistical significance of differences between base-flow and runoff nitrogen and phosphorus concentrations at each station within the study period. The Kruskal-Wallis test (Helsel and Hirsch, 1992), used to compare multiple data sets at one time, was used to determine the statistical significance of differences in nitrogen and phosphorus concentrations among stations in the Eucha-Spavinaw basin within base-flow and runoff groups of data.

The tests were selected because neither test requires normally distributed data. The null hypotheses of both tests are that there are no differences in median concentrations between the data sets being compared. The null hypothesis was rejected and medians were described as being significantly different if the two-sided p-value of the test was less than or equal to 0.05 (Helsel and Hirsch, 1992). If the null hypothesis of the Kruskal-Wallis test was rejected and the medians were described as significantly different, the multiple-stage Kruskal-Wallis test (that is individual Kruskal-Wallis tests on smaller subsets of data) was applied to determine which sites were different and which were not (Helsel and Hirsch, 1992).

Load and Yield Estimation

Linear regression was used to evaluate relations between nitrogen and phosphorus loads (dependent variables) and streamflow and time variables (explanatory variables). Daily nitrogen and phosphorus loads could not be calculated directly because water-quality data were collected intermittently. Regression methods allow estimation of daily water-quality constituent loads based on continuous streamflow records. Regression methods require daily mean streamflow data and discrete water-quality samples collected over several years. Sample dates, times, streamflows, and nitrogen and phosphorus concentrations used in this analysis are provided in Appendixes 1–5; and are available through the world wide web at *http://water.usgs.gov/ok/nwis*.

Linear regression models developed by S-LOADEST for the estimation of nitrogen and phosphorus loads for the study period at each station are listed in table 2. Constituent load (*L*) is the product of streamflow (*Q*) and the constituent concentration in the water (*C*) multiplied by a conversion factor to convert cubic feet per second (ft^3/s) and milligrams per liter (mg/L) to pounds per day (lb/d). Load is the amount of a constituent transported past a selected point in a stream in a given amount of time, usually one year. The S-LOADEST program (Dave Lorenz, USGS, written commun., 2006) was used to estimate constituent loads by the rating-curve method (Cohn and others, 1989; Crawford, 1991) in the Eucha-Spavinaw basin. S-LOADEST is based on LOADEST (Crawford, 1999; Runkel and others, 2004) and is incorporated in the computer program S-Plus (Insightful Corporation, 2005) to facilitate graphical analysis and tabular results. S-LOADEST estimates rating-curve parameters and mean daily loads using several regression methods and a ratio estimator. If some of the constituent concentrations included in this analysis were censored, parameters would be estimated by the adjusted maximum likelihood estimation method (Cohn, 1988; Cohn and others, 1992); none were present. In the absence of censored data, the method converts to the maximum likelihood estimation method (Dempster and others, 1977; Wolynetz, 1979). An estimate of the uncertainty in the estimated load was obtained using the method described by Likes (1980) and Gilroy and others (1990). S-LOADEST contains nine predefined rating-curve models that can test the relation between constituent load and streamflow. The model used for this report (equation 1) includes time variables and seasonality variables to model the relation between the natural logarithms of *L*, *Q* and Q^2:

$$ln(L) = b_o + b_1\, lnQ + b_2\, lnQ^2 + b_3T + b_4T^2 + b_5 \sin SS + b_6 \cos SS \quad (1)$$

where

ln = natural logarithm

L = constituent load, in pounds per day (lb/d);

b_0 = regression constant, dimensionless;

$b_1, b_2, b_3, b_4, b_5, b_6$ = regression coefficients, dimensionless;

Q = daily mean streamflow, in cubic feet per second (ft^3/s);

T = dectime, time parameter in decimal years;

sin = sine;

cos = cosine;

and

SS = seasonality parameter (2πdectime).

Data from all stations generally fit the model well for nitrogen. Data from all stations in Oklahoma generally fit the model for phosphorus better than data from the stations in Arkansas. Other S-LOADEST predefined regression models using various combinations of streamflow, time, and seasonal coefficients had lesser residuals than the model used for this report; however, the “best” model indicated in S-LOADEST was different for each nutrient and station. The one general model (equation 1) was chosen for all stations and nutrients:

Table 2. Regression models for estimating total nitrogen and total phosphorus loads at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, developed using data collected during 2002–2004.

[no., number; obs., observations; ln, natural logarithm; L, daily load in pound per day; Q, mean daily streamflow in cubic foot per second; T, dectime, time parameter in decimal years; SS, seasonality parameter, (2πdectime); R^2, coefficient of determination]

Station name (number)	Nutrient	No. of obs.	Regression model	Estimated residual variance [1]	R^2 (percent)
Spavinaw Creek near Maysville, Ark.	Nitrogen	54	$\ln(L) = 7.92 + 1.06*\ln Q + 0.0091*\ln Q^2 + 0.0623*T + 0.108*T^2 + 0.156*\sin SS + 0.0014*\cos SS$	0.018	99
(07191160)	Phosphorus	53	$\ln(L) = 3.76 + 1.61*\ln Q + 0.128*\ln Q^2 - 0.0553*T - 0.195*T^2 - 0.208*\sin SS - 0.155*\cos SS$	0.240	96
Spavinaw Creek near Cherokee, Ark.	Nitrogen	57	$\ln(L) = 8.28 + 1.00*\ln Q - 0.0129*\ln Q^2 + 0.0760*T + 0.0881*T^2 + 0.114*\sin SS + 0.0943*\cos SS$	0.025	99
(07191179)	Phosphorus	57	$\ln(L) = 5.05 + 1.13*\ln Q + 0.135*\ln Q^2 - 0.204*T - 0.0070*T^2 - 0.111*\sin SS - 0.0926*\cos SS$	0.177	94
Spavinaw Creek near Sycamore, Okla.	Nitrogen	40	$\ln(L) = 8.89 + 1.05*\ln Q + 0.0181*\ln Q^2 + 0.0554*T + 0.0485*T^2 + 0.0482*\sin SS + 0.0834*\cos SS$	0.022	99
(07191220)	Phosphorus	39	$\ln(L) = 5.68 + 1.35*\ln Q + 0.162*\ln Q^2 - 0.171*T - 0.126*T^2 - 0.122*\sin SS - 0.0302*\cos SS$	0.055	98
Spavinaw Creek near Colcord, Okla.	Nitrogen	58	$\ln(L) = 8.47 + 1.02*\ln Q + 0.0027*\ln Q^2 + 0.0770*T + 0.105*T^2 + 0.155*\sin SS + 0.0651*\cos SS$	0.024	99
(071912213)	Phosphorus	58	$\ln(L) = 5.30 + 1.37*\ln Q + 0.0780*\ln Q^2 - 0.136*T - 0.192*T^2 - 0.0839*\sin SS - 0.0835*\cos SS$	0.116	97
Beaty Creek near Jay, Okla.	Nitrogen	57	$\ln(L) = 5.19 + 1.07*\ln Q + 0.0074*\ln Q^2 + 0.0673*T + 0.244*T^2 + 0.295*\sin SS - 0.0035*\cos SS$	0.051	99
(07191222)	Phosphorus	57	$\ln(L) = 1.32 + 1.36*\ln Q + 0.0688*\ln Q^2 - 0.0967*T + 0.0636*T^2 - 0.317*\sin SS - 0.131*\cos SS$	0.128	99

[1] Estimated residual variance is the maximum likelihood estimation variance corrected for the number of observations, number of censored observations, and number of parameters in the regression model.

(1) to use a consistent general model to estimate loads for all stations in a basin for each nutrient, (2) because an analysis of the "best" models compared with this general model indicated a very small improvement in reduction in variance for each nutrient, and (3) because seasonality parameters were present in the majority of the "best" models for each nutrient.

Estimated mean annual nitrogen and phosphorus loads and estimates of the standard deviations of the mean loads were calculated by S-LOADEST using all base-flow and runoff data. The daily load values generated by S-LOADEST were separated into base-flow and runoff sample sets according to the number of base-flow days and the number of runoff days in the study period. Estimated mean annual base-flow loads were calculated as the mean of the base-flow day sample set. Estimated mean annual runoff loads were calculated as the mean of the runoff day sample set. Estimated seasonal base-flow and runoff loads were calculated in the same way based on the number of base-flow and runoff days in each season. In this report, spring is March through May, summer is June through August, fall is September through November, and winter is December through February.

Nitrogen and phosphorus yields for the study period at each station were calculated by dividing mean annual nitrogen and phosphorus loads by drainage area (table 1).

Flow-weighted concentrations for the study period at each station were calculated by dividing mean annual nitrogen and phosphorus loads by mean annual streamflow and multiplying by a conversion factor to adjust the units.

Nutrient Concentrations, Loads, and Yields in the Eucha-Spavinaw Basin

Nitrogen and phosphorus in the Eucha-Spavinaw basin for 2002–2004 are described in terms of mean concentrations, loads, and yields in base-flow and runoff samples, and in terms of mean flow-weighted concentrations. All annual and seasonal loads, yields, and flow-weighted concentrations are estimated mean values that were calculated by S-LOADEST. All total nitrogen values are referred to as nitrogen and total phosphorus values are referred to as phosphorus in this report.

Concentrations

The summary statistics of nitrogen and phosphorus concentrations divided into base-flow and runoff samples are presented in tables 3 and 4. Graphs showing the nitrogen and phosphorus concentrations from base-flow and runoff water samples are presented in figures 4 and 5.

Nitrogen

Nitrogen concentrations were significantly greater ($p \leq 0.05$) in runoff samples than in base-flow samples for 2002–2004 at Spavinaw Creek near Maysville, Arkansas; Spavinaw Creek near Colcord, Oklahoma, and Beaty Creek near Jay, Oklahoma (tables 3 and 5, fig. 4). Nitrogen concentrations in runoff samples were not significantly greater than in base-flow samples at Spavinaw Creek near Cherokee, Arkansas, and Spavinaw Creek near Sycamore, Oklahoma.

Nitrogen concentrations in base-flow samples during the study period significantly increased ($p \leq 0.05$) in the downstream direction in Spavinaw Creek from the Maysville to Sycamore stations (fig. 6). Nitrogen concentrations in base-flow samples during the study period significantly decreased ($p \leq 0.05$) in the downstream direction in Spavinaw Creek from the Sycamore to Colcord stations (fig. 6). Nitrogen concentrations in base-flow samples from the Eucha-Spavinaw basin generally increased with increasing streamflow (fig. 4, table 3). As base flow increased by addition of ground water, additional nitrate in the ground water could increase the concentration of nitrogen (U.S. Geological Survey, 1999). Spavinaw Creek probably received nitrogen concentrations from a point source (the City of Decatur, Arkansas, municipal wastewater treatment plant), but Beaty Creek did not. Nitrogen in base-flow samples from Beaty Creek was significantly less than those in base-flow samples from Spavinaw Creek during the study period (fig. 6).

Nitrogen concentrations in runoff samples for the study period were not significantly different among the stations on Spavinaw Creek (fig. 7). However, the concentrations at Beaty Creek were significantly less than at all other stations (fig. 7). Nitrogen concentrations in runoff samples from all stations generally increased with increasing streamflow (fig. 4). The larger concentrations of nitrogen during runoff events indicates addition of nitrogen from nonpoint sources.

Phosphorus

Phosphorus concentrations were significantly greater ($p \leq 0.05$) in runoff samples than in base-flow samples for 2002–2004 at Spavinaw Creek near Maysville, Arkansas; Spavinaw Creek near Colcord, Oklahoma, and Beaty Creek near Jay, Oklahoma (tables 4 and 5, fig. 5). Phosphorus concentrations in runoff samples were not significantly greater than in base-flow samples at Spavinaw Creek near Cherokee, Arkansas, and Spavinaw Creek near Sycamore, Oklahoma.

Phosphorus concentrations in base-flow samples during the study period significantly increased ($p \leq 0.05$) from the Maysville to Cherokee stations in Spavinaw Creek probably from a point source between those stations (the City of Decatur, Arkansas, municipal wastewater treatment plant) (fig. 6). Phosphorus concentrations in base-flow samples significantly decreased ($p \leq 0.05$) in the downstream direction in the Spavinaw Creek from the Cherokee to Colcord stations (fig. 6), as has been reported for other point-source affected streams in the region (Haggard, 2000; Haggard and others, 2001; Pickup and others, 2003; Tortorelli and Pickup, 2006). As base flow increased by addition of ground water, dilution may have reduced the concentration of phosphorus from point

Table 3. Summary statistics of total nitrogen concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

[Obs, number of observations; mg/L, milligram per liter; N, nitrogen]

Station name (number)	Period	Base-flow concentrations					Runoff concentrations				
		Minimum	Median	Mean	Maximum	Obs	Minimum	Median	Mean	Maximum	Obs
		(mg/L as N)					(mg/L as N)				
Spavinaw Creek near Maysville, Ark.	2002	2.80	3.31	3.60	4.80	10	3.40	3.97	4.35	7.40	7
(07191160)	2003	2.57	3.12	3.11	3.76	10	3.01	3.82	3.76	4.43	9
	2004	3.37	3.86	4.02	4.86	6	3.43	4.77	4.84	5.79	12
	2002–2004	**2.57**	**3.36**	**3.51**	**4.86**	**26**	**3.01**	**4.18**	**4.37**	**7.40**	**28**
Spavinaw Creek near Cherokee, Ark.	2002	3.11	3.56	3.98	5.40	10	3.28	4.26	4.44	6.82	7
(07191179)	2003	3.28	3.78	3.83	4.44	10	2.48	4.16	3.87	4.94	12
	2004	4.20	4.39	4.63	5.46	6	2.68	5.02	4.90	6.28	12
	2002–2004	**3.11**	**4.12**	**4.07**	**5.46**	**26**	**2.48**	**4.27**	**4.40**	**6.82**	**31**
Spavinaw Creek near Sycamore, Okla.	2002	3.65	4.60	4.60	5.50	6	3.20	4.35	4.65	7.10	6
(07191220)	2003	4.02	4.02	4.02	4.02	1	3.58	4.07	4.09	4.97	9
	2004	4.21	4.39	4.68	5.36	5	3.54	5.38	5.34	6.44	13
	2002–2004	**3.65**	**4.44**	**4.59**	**5.50**	**12**	**3.20**	**4.88**	**4.79**	**7.10**	**28**
Spavinaw Creek near Colcord, Okla.	2002	2.82	3.52	3.76	5.20	12	3.51	4.10	4.38	6.29	5
(071912213)	2003	3.00	3.45	3.51	4.39	10	2.30	3.78	3.73	5.27	12
	2004	3.81	4.20	4.33	5.05	6	3.32	4.68	4.80	6.23	13
	2002–2004	**2.82**	**3.78**	**3.79**	**5.20**	**28**	**2.30**	**4.16**	**4.30**	**6.29**	**30**
Beaty Creek near Jay, Okla.	2002	1.15	1.34	1.71	3.20	7	2.57	2.90	3.23	4.68	9
(07191222)	2003	0.87	1.58	1.55	2.26	10	1.13	2.28	2.42	3.78	12
	2004	1.84	2.62	2.78	4.02	6	2.58	3.32	3.42	4.93	13
	2002–2004	**0.87**	**1.79**	**1.92**	**4.02**	**23**	**1.13**	**3.03**	**3.02**	**4.93**	**34**

Table 4. Summary statistics of total phosphorus concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

[Obs, number of observations; mg/L, milligram per liter; P, phosphorus]

Station name (number)	Period	Base-flow concentrations					Runoff concentrations				
		Minimum	Median	Mean	Maximum	Obs	Minimum	Median	Mean	Maximum	Obs
		(mg/L as P)					(mg/L as P)				
Spavinaw Creek near Maysville, Ark.	2002	0.022	0.026	0.027	0.033	10	0.028	0.042	0.120	0.500	7
(07191160)	2003	0.019	0.022	0.024	0.041	10	0.025	0.041	0.082	0.220	8
	2004	0.019	0.028	0.030	0.041	6	0.017	0.052	0.220	0.920	12
	2002–2004	**0.019**	**0.025**	**0.027**	**0.041**	**26**	**0.017**	**0.045**	**0.153**	**0.920**	**27**
Spavinaw Creek near Cherokee, Ark.	2002	0.204	0.234	0.259	0.315	10	0.170	0.170	0.205	0.380	7
(07191179)	2003	0.177	0.217	0.215	0.257	10	0.030	0.186	0.194	0.500	12
	2004	0.114	0.144	0.148	0.189	6	0.082	0.149	0.294	1.300	12
	2002–2004	**0.114**	**0.223**	**0.216**	**0.315**	**26**	**0.030**	**0.170**	**0.235**	**1.300**	**31**
Spavinaw Creek near Sycamore, Okla.	2002	0.143	0.146	0.147	0.153	6	0.140	0.165	0.186	0.310	6
(07191220)	2003	0.140	0.140	0.140	0.140	1	0.130	0.150	0.165	0.270	8
	2004	0.092	0.117	0.114	0.129	5	0.088	0.120	0.288	0.980	13
	2002–2004	**0.092**	**0.142**	**0.132**	**0.153**	**12**	**0.088**	**0.153**	**0.229**	**0.980**	**27**
Spavinaw Creek near Colcord, Okla.	2002	0.087	0.104	0.106	0.130	12	0.120	0.130	0.182	0.390	5
(071912213)	2003	0.084	0.090	0.095	0.115	10	0.085	0.120	0.205	0.980	12
	2004	0.081	0.086	0.100	0.147	6	0.075	0.123	0.289	0.990	13
	2002–2004	**0.081**	**0.100**	**0.101**	**0.147**	**28**	**0.075**	**0.126**	**0.238**	**0.990**	**30**
Beaty Creek near Jay, Okla.	2002	0.029	0.041	0.039	0.048	7	0.031	0.053	0.155	0.810	9
(07191222)	2003	0.021	0.032	0.032	0.041	10	0.024	0.042	0.075	0.280	12
	2004	0.032	0.046	0.050	0.089	6	0.032	0.102	0.291	1.000	13
	2002–2004	**0.021**	**0.038**	**0.039**	**0.089**	**23**	**0.024**	**0.070**	**0.178**	**1.000**	**34**

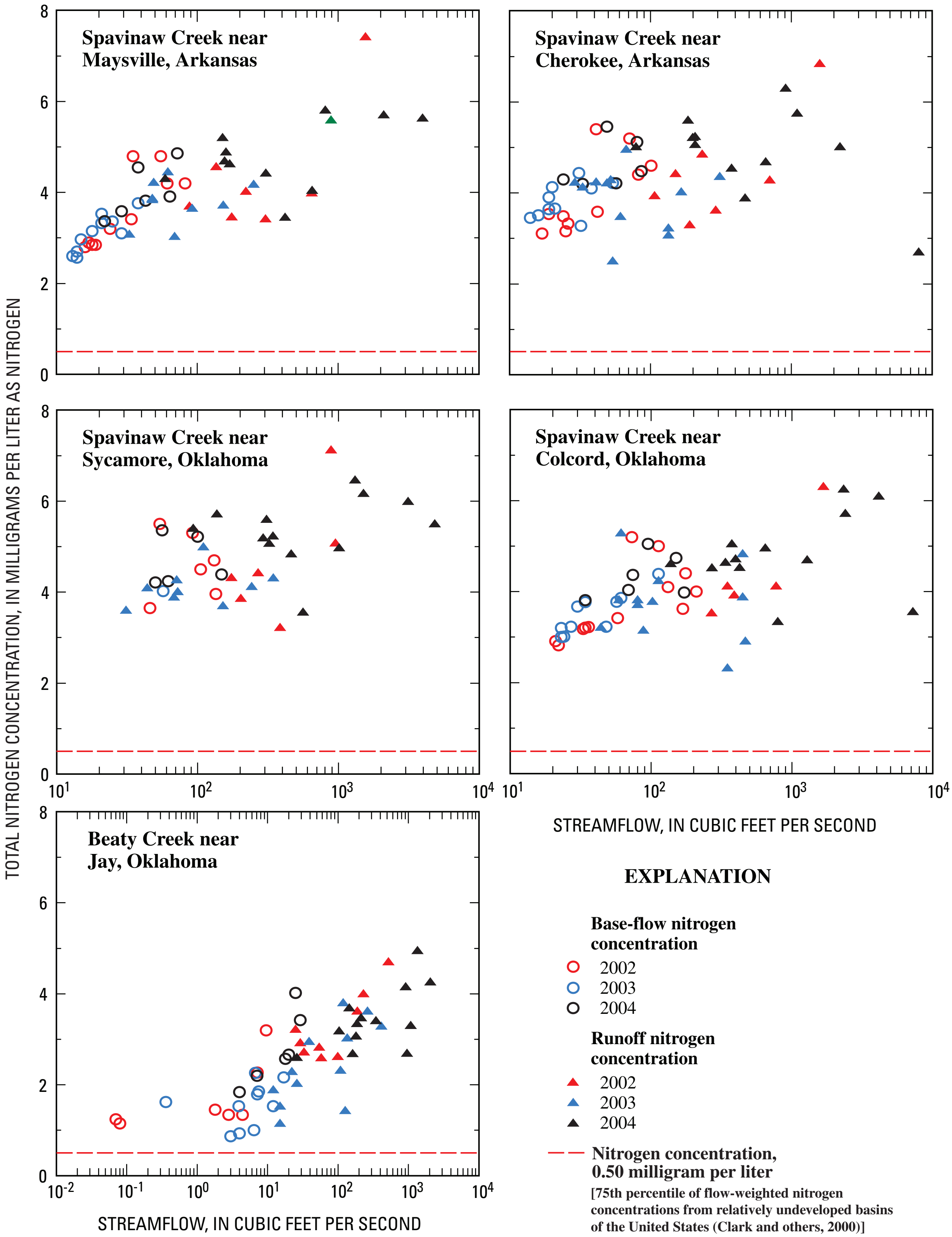

Figure 4. Total nitrogen concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

Table 5. Wilcoxon rank-sum test results comparing base-flow total nitrogen and total phosphorus concentrations to runoff total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

[z, normal test statistic with correction for ties; p, probability value; p-values in bold indicate statistically significant differences between groups of data at 95-percent confidence level (probability value less than or equal to 0.05)]

Station name (number)	2002–2004	
	Nitrogen	Phosphorus
Spavinaw Creek near Maysville, Ark. (07191160)	z = -3.480	z = -4.383
	p = 0.0005	**p < 0.0001**
Spavinaw Creek near Cherokee, Ark. (07191179)	z = -1.354	z = 1.835
	p = 0.1757	p = 0.0665
Spavinaw Creek near Sycamore, Okla. (07191220)	z = -0.398	z = -1.583
	p = 0.6903	p = 0.1133
Spavinaw Creek near Colcord, Okla. (071912213)	z = -2.070	z = -3.557
	p = 0.0385	**p = 0.0004**
Beaty Creek near Jay, Okla. (07191222)	z = -4.140	z = -3.801
	p < 0.0001	**p = 0.0001**

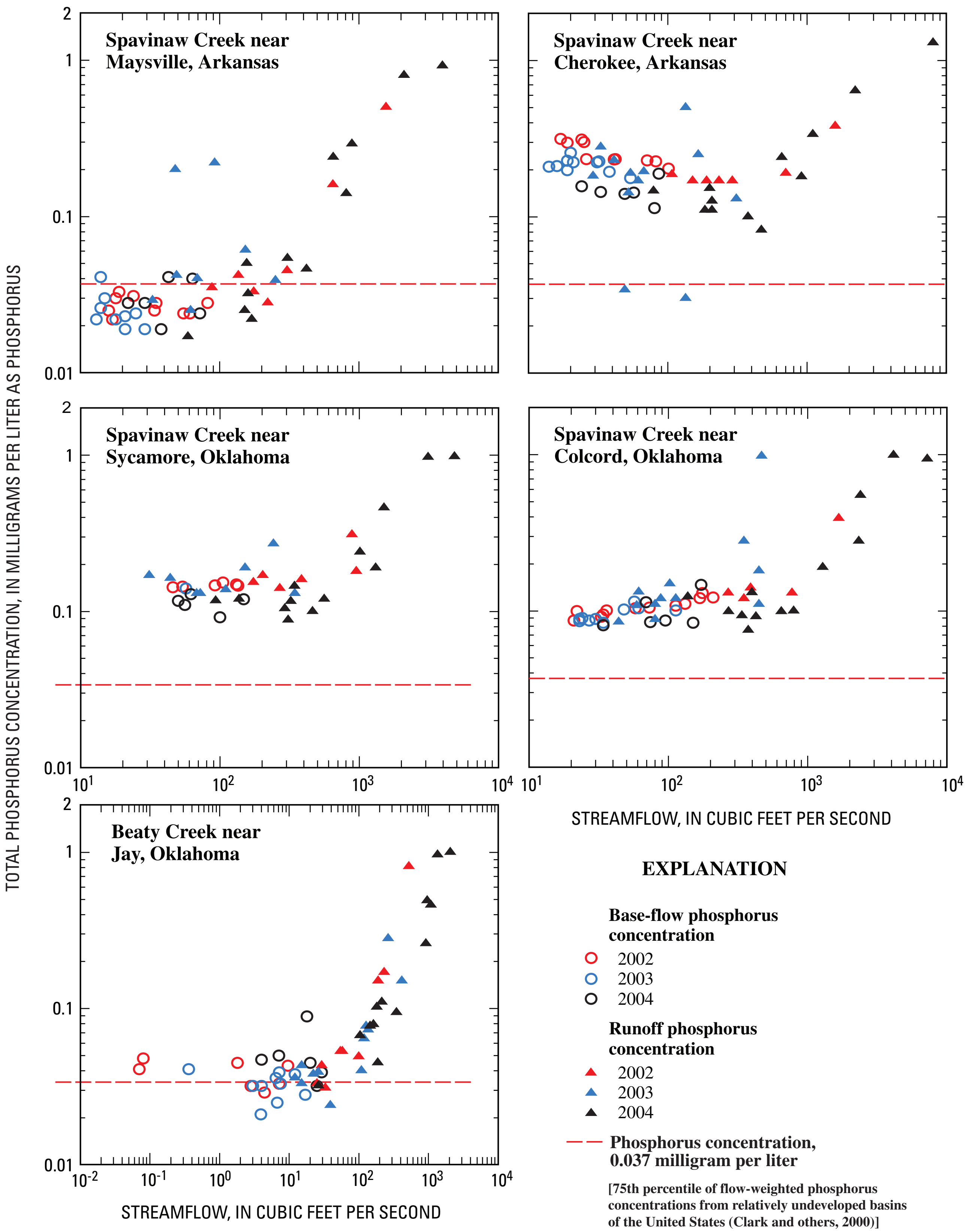

Figure 5. Total phosphorus concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

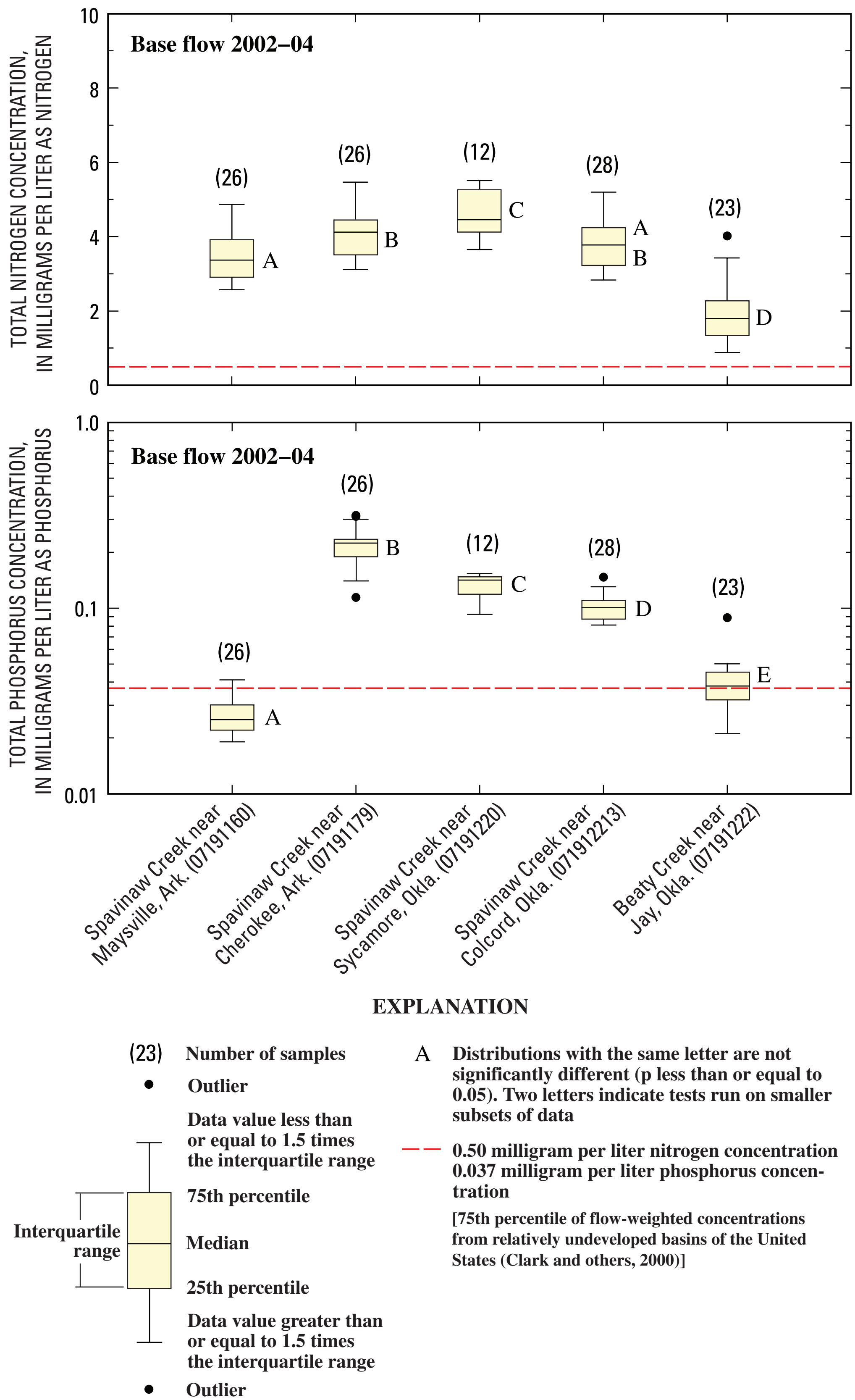

Figure 6. Distributions of **base-flow** total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

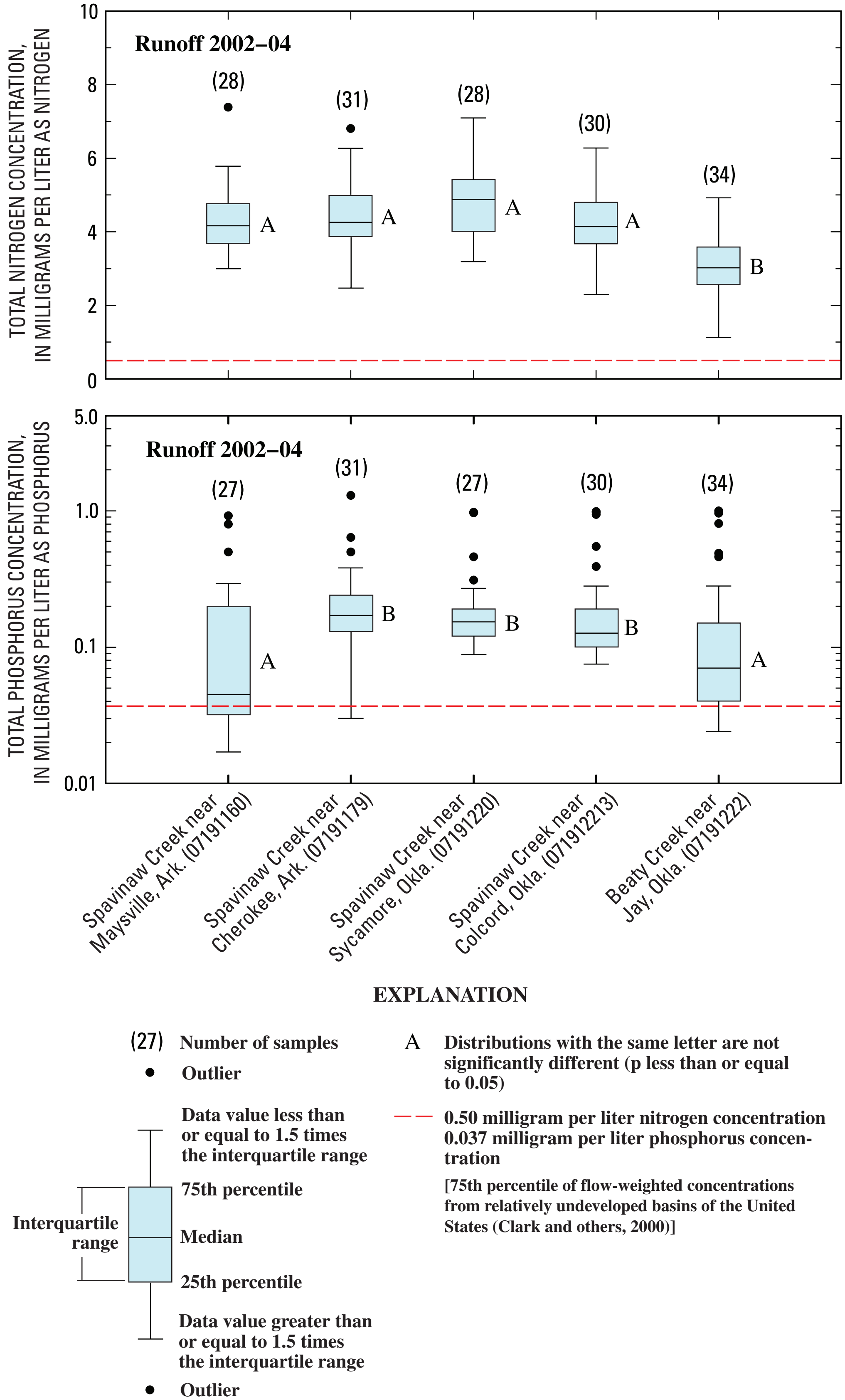

Figure 7. Distributions of **runoff** total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

sources. Phosphorus concentrations in base-flow samples within each station generally had no change with increasing streamflow (fig. 5, table 4). Spavinaw Creek probably received phosphorus concentrations from a point source, but Beaty Creek did not. Phosphorus concentrations in base-flow samples from Beaty Creek were significantly less than phosphorus in base-flow samples from the Spavinaw Creek stations downstream from Maysville station during the study period (fig. 6).

Phosphorus concentrations in runoff samples for the study period were not significantly different among the three downstream stations on Spavinaw; and not significantly different among the Maysville station on Spavinaw Creek and the Beaty Creek station (fig. 7). Phosphorus concentrations in runoff samples from all stations generally increased with increasing streamflow (fig. 5). Possible causes of larger concentrations of phosphorus during runoff events than in base flow are the addition of phosphorus from nonpoint sources, resuspension of phosphorus from the streambed sediment, and stream bank erosion. Wagner and Woodruff (1997) and Storm and others (2001) attribute the majority of phosphorus transported in the basin to nonpoint sources during runoff events.

Estimated Mean Annual Loads

Estimated mean annual nitrogen and phosphorus loads are discussed in this section. The total annual loads also are divided into base-flow and runoff components.

Nitrogen

Estimated mean annual nitrogen total loads were substantially greater at Spavinaw Creek stations than at Beaty Creek, primarily because of greater streamflow at the stations on the Spavinaw Creek (tables 1 and 6). Annual total loads increased in a downstream direction for 2002–2004 (table 6) from Maysville to Colcord in Spavinaw Creek, with the annual total load at the Colcord station about 2 times that of Maysville station (table 6).

Estimated mean annual nitrogen base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations (table 6). Annual base-flow loads at stations on Spavinaw Creek were about 5 to 11 times greater than base-flow loads at the station on Beaty Creek. Annual nitrogen base-flow loads increased in a downstream direction for the study period (table 6) from Maysville to Colcord in Spavinaw Creek, with the annual base-flow load at the Colcord station about 2 times that of Maysville station (table 6).

Estimated mean annual nitrogen runoff loads in the basin increased with increasing drainage area and with increasing streamflow (tables 1 and 6). The runoff component of the annual nitrogen total load for Beaty Creek was 85 percent for the study period (table 6). At the Spavinaw Creek stations, the range in the runoff component of the annual nitrogen runoff load was 60 to 66 percent for 2002–2004 (table 6). Runoff conditions averaged no more than 30 percent of the time for any station for the study period (table 7), but accounted for most of the annual nitrogen total load for every station.

Phosphorus

Estimated mean annual phosphorus total loads were greater at the Spavinaw Creek stations from Cherokee to Colcord than at Beaty Creek, primarily because of greater streamflow at those stations (tables 1 and 6). Annual total loads increased in a downstream direction for 2002–2004 (table 6) from Maysville to Colcord in Spavinaw Creek, with the annual total load at the Colcord station about 2.5 times that of Maysville station (table 6).

Estimated mean annual phosphorus base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations (table 6). Annual base-flow loads at stations on Spavinaw Creek were about 2.5 to 19 times greater than base-flow loads at the station on Beaty Creek. Annual phosphorus base-flow loads increased substantially in a downstream direction for the study period (table 6) from Maysville to Cherokee in Spavinaw Creek, probably due to the inflow of wastewater discharges from the City of Decatur, with the annual base-flow load at the Cherokee station about 8 times that of Maysville station (table 6). The annual base-flow loads at the three downstream stations on Spavinaw Creek from Cherokee to Colcord were about the same (table 6).

Estimated mean annual phosphorus runoff loads in the basin increased with increasing drainage area and with increasing streamflow (tables 1 and 6). The portion of annual phosphorus load contributed by runoff at the three downstream Spavinaw Creek stations increased in the downstream direction (Cherokee to Colcord) (table 6). The runoff component of the annual phosphorus total load for Beaty Creek was 98 percent for the study period (table 6). At the Spavinaw Creek stations, the range in the runoff component of the annual phosphorus total load was 66 to 93 percent for the study period (table 6). Because almost all of the phosphorus loads for Beaty Creek are delivered during runoff events, the annual runoff load for Beaty Creek was larger than those of the two upper Spavinaw Creek stations (table 6). Runoff conditions averaged no more than 30 percent of the time for any station for the study period (table 7), but accounted for most of the annual phosphorus total load for every station.

Estimated Mean Seasonal Loads

Nutrient concentrations vary throughout the year, mainly in response to variation in precipitation and streamflow, and differences in time since fertilizer or manure applications (U.S. Geological Survey, 1999). Nutrient concentrations in streams usually are higher during high streamflow during spring and summer following fertilizer application. High nutrient concentrations also can be present in streams during seasonal low flows. Nitrogen and phosphorus concentrations

Table 6. Estimated mean annual total nitrogen and total phosphorus loads and yields using regression methods from concentrations in water-quality samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

[mi^2, square mile; lb/yr, pound per year; lb/yr/mi^2, pound per year per square mile; SEP, standard error of prediction; N, nitrogen; P, phosphorus. Differences between total load and the sum of the base-flow load plus runoff loads are due to rounding.]

Station name (number)	Drainage area (mi^2)	Nutrient	Mean annual						Load delivered during runoff (percent)
			Total load [1] (+/- SEP[1]) (lb/yr as N) (lb/yr as P)	Total yield (lb/yr/mi^2 as N) (lb/yr/mi^2 as P)	Base-flow load [2] (lb/yr as N) (lb/yr as P)	Base-flow yield (lb/yr/mi^2 as N) (lb/yr/mi^2 as P)	Runoff load [3] (lb/yr as N) (lb/yr as P)	Runoff yield (lb/yr/mi^2 as N) (lb/yr/mi^2 as P)	
Spavinaw Creek near Maysville, Ark. (07191160)	88.2	Nitrogen	521,000 (13,700)	5,910	187,000	2,120	335,000	3,800	64
		Phosphorus	20,000 (8,430)	227	1,480	16.8	18,600	211	93
Spavinaw Creek near Cherokee, Ark. (07191179)	104	Nitrogen	656,000 (18,400)	6,310	262,000	2,520	394,000	3,790	60
		Phosphorus	34,500 (4,800)	332	11,600	112	22,900	220	66
Spavinaw Creek near Sycamore, Okla. (07191220)	133	Nitrogen	914,000 (28,300)	6,870	312,000	2,350	602,000	4,530	66
		Phosphorus	47,800 (6,110)	359	10,400	77.9	37,400	281	78
Spavinaw Creek near Colcord, Okla. (071912213)	163	Nitrogen	1,090,000 (31,000)	6,690	430,000	2,640	659,000	4,040	61
		Phosphorus	50,700 (7,340)	311	10,200	62.5	40,500	249	80
Beaty Creek near Jay, Okla. (07191222)	59.2	Nitrogen	257,000 (15,300)	4,340	39,300	664	218,000	3,680	85
		Phosphorus	27,000 (7,630)	456	600	10.1	26,400	446	98

[1] Calculated by S-LOADEST and are sstatistics of all data in the 3-year period.

[2] Means of the base-flow loads are calculated from base-flow days data only.

[3] Means of the runoff loads are calculated from runoff days data only.

Table 7. Number of days of base flow and runoff designated by Base-Flow Index (BFI) program at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

[Spring is March through May, Summer is June through August, Fall is September through November, and Winter is December through February]

Station name (number)	Period	Spring		Summer		Fall		Winter		Total		Percent of runoff days in period
		Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	
Spavinaw Creek near	2002	48	44	87	5	91	0	76	14	302	63	17
Maysville, Ark.	2003	47	45	73	19	78	13	61	29	259	106	29
(07191160)	2004	44	48	72	20	76	15	68	23	260	106	29
	2002–2004	**139**	**137**	**232**	**44**	**245**	**28**	**205**	**66**	**821**	**275**	**25**
Spavinaw Creek near	2002	54	38	87	5	91	0	72	18	304	61	17
Cherokee, Ark.	2003	48	44	74	18	77	14	59	31	258	107	29
(07191179)	2004	48	44	70	22	71	20	68	23	257	109	30
	2002–2004	**150**	**126**	**231**	**45**	**239**	**34**	**199**	**72**	**819**	**277**	**25**
Spavinaw Creek near	2002	49	43	87	5	91	0	77	13	304	61	17
Sycamore, Okla.	2003	48	44	71	21	72	19	55	35	246	119	33
(07191220)	2004	46	46	70	22	73	18	56	35	245	121	33
	2002–2004	**143**	**133**	**228**	**48**	**236**	**37**	**188**	**83**	**795**	**301**	**27**
Spavinaw Creek near	2002	60	32	87	5	91	0	80	10	318	47	13
Colcord, Okla.	2003	59	33	71	21	56	35	61	29	247	118	32
(071912213)	2004	42	50	70	22	79	12	61	30	252	114	31
	2002–2004	**161**	**115**	**228**	**48**	**226**	**47**	**202**	**69**	**817**	**279**	**25**
Beaty Creek near	2002	44	48	80	12	91	0	77	13	292	73	20
Jay, Okla.	2003	52	40	66	26	78	13	65	25	261	104	28
(07191222)	2004	37	55	58	34	70	21	48	43	212	154	42
	2002–2004	**133**	**143**	**204**	**72**	**239**	**34**	**190**	**81**	**765**	**331**	**30**

in streams downstream from urban areas may be high during seasonal low flows, when contributions from point sources (such as wastewater treatment plants) are greater relative to streamflow, and dilution is less (U.S. Geological Survey, 1999).

Nitrogen

Estimated mean seasonal nitrogen base-flow loads generally were least in fall (September through November) and greatest in spring (March through May) at all stations in the Eucha-Spavinaw basin for 2002–2004 (table 8). The seasonal base-flow loads followed the same pattern as the annual base-flow loads (table 6) in terms of variability between stations. Seasonal nitrogen base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations (table 8). Seasonal base-flow loads at stations on Spavinaw Creek were about 3 to 18 times greater than base-flow loads at the station on Beaty Creek. Seasonal nitrogen base-flow loads increased in a downstream direction for the study period from Maysville to Colcord in Spavinaw Creek, with the seasonal base-flow load at the Colcord station about 2 times that of Maysville station (table 8).

Estimated mean seasonal nitrogen runoff loads were generally least in fall at all stations for the study period (table 8). Runoff loads were greatest in spring at all stations. Estimated mean seasonal nitrogen runoff loads in the basin increased with increasing drainage area and with increasing streamflow (tables 1 and 8).

Phosphorus

Estimated mean seasonal phosphorus base-flow loads generally were least in fall (September through November) and winter (December through February); and greatest in spring (March through May) and summer (June through August) at all stations in the Eucha-Spavinaw basin for 2002–2004 (table 8). The seasonal base-flow loads followed the same pattern as the annual base-flow loads (table 6) in terms of variability between stations. Seasonal phosphorus base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations (table 8). Seasonal base-flow loads at stations on Spavinaw Creek were about 2 to 30 times greater than base-flow loads at the station on Beaty Creek. Seasonal phosphorus base-flow loads increased substantially in a downstream direction for the study period from Maysville to Cherokee in Spavinaw Creek, probably due to the inflow of wastewater discharges from the City of Decatur, with the seasonal loads at the Cherokee station about 8 times that of Maysville station (table 8). The seasonal base-flow loads at the three downstream stations on Spavinaw Creek from Cherokee to Colcord were about the same (table 8).

Estimated mean seasonal phosphorus runoff loads generally were least in fall (September through November) and winter (December through February); and greatest in spring (March through May) and summer (June through August) at all stations in the Eucha-Spavinaw basin for the study period 2002–2004 (table 8). Estimated mean seasonal phosphorus runoff loads in the basin generally increased with increasing drainage area and with increasing streamflow at the Spavinaw Creek stations (tables 1 and 8). Most of the phosphorus loads at Beaty Creek were delivered during runoff events and seasonal loads at Beaty Creek often were larger than the Spavinaw Creek stations, especially during the summer and fall (table 8).

Estimated Mean Annual Yields

Estimated mean annual nitrogen and phosphorus yields are discussed in this section. The total annual yields also are divided into base-flow and runoff components.

Nitrogen

Estimated mean annual nitrogen total yields generally increased slightly in a downstream direction for 2002–2004 in Spavinaw Creek. The total yields ranged from 5,910 to 6,870 pounds per year per square mile (lbs/yr/mi^2), with greatest yield being reported for Spavinaw Creek near Sycamore (6,870 lbs/yr/mi^2), and the least yield being reported for Spavinaw Creek near Maysville (5,910 lbs/yr/mi^2) (table 6). Beaty Creek near Jay had a slightly lower yield than Maysville (4,340 lbs/yr/mi^2)

Estimated mean annual nitrogen base-flow yields also generally increased slightly in a downstream direction at the Spavinaw Creek stations, ranging from 2,120 to 2,640 lbs/yr/mi^2. However, the base-flow yield at Beaty Creek (664 lbs/yr/mi^2) was substantially less than those of the Spavinaw Creek stations, which were about 3 to 4 times greater (table 6).

Estimated mean annual nitrogen runoff yields were about the same at all stations in the basin, ranging from 3,790 to 4,530 lbs/yr/mi^2 on Spavinaw Creek and slightly less on Beaty Creek (3,680 lbs/yr/mi^2) (table 6).

Phosphorus

Estimated mean annual phosphorus total yields for 2002–2004 in Spavinaw Creek generally increased in a downstream direction, ranging from 227 to 359 lbs/yr/mi^2, with greatest yield being reported for Spavinaw Creek near Sycamore (359 lbs/yr/mi^2), and the least yield being reported for Spavinaw Creek near Maysville (227 lbs/yr/mi^2) (table 6). The total yield for Beaty Creek (456 lbs/yr/mi^2), was greater than any Spavinaw Creek station. The greater yield in Beaty Creek may be caused by the addition of phosphorus from nonpoint sources, resuspension of phosphorus from the streambed, and stream bank erosion.

Estimated mean annual phosphorus base-flow yield was substantially less in Beaty Creek (10.1 lbs/yr/mi^2) than in the three downstream Spavinaw Creek stations (62.5 to

Table 8. Estimated mean seasonal total nitrogen and total phosphorus loads estimated using regression methods from concentrations in water-quality samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

[Values are loads in pound per season as nitrogen and phosphorus; Spring is March through May, Summer is June through August, Fall is September through November, and Winter is December through February]

Flow type	Station name (number)	2002–2004							
		Mean seasonal total nitrogen load				Mean seasonal total phosphorus load			
		Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
Base flow	Spavinaw Creek near Maysville, Ark. (07191160)	56,800	54,600	28,700	46,500	404	544	257	270
	Spavinaw Creek near Cherokee, Ark. (07191179)	82,200	70,100	40,300	69,600	2,930	3,230	2,480	2,960
	Spavinaw Creek near Sycamore, Okla. (07191220)	94,000	94,400	49,300	74,700	2,570	3,440	2,140	2,210
	Spavinaw Creek near Colcord, Okla. (071912213)	140,000	105,000	63,000	122,000	3,430	3,060	1,380	2,310
	Beaty Creek near Jay, Okla. (07191222)	16,700	8,160	3,580	10,800	231	162	72	135
Runoff	Spavinaw Creek near Maysville, Ark. (07191160)	203,000	80,600	16,800	33,900	4,690	13,400	234	270
	Spavinaw Creek near Cherokee, Ark. (07191179)	234,000	82,200	26,100	52,000	10,200	9,770	904	1,980
	Spavinaw Creek near Sycamore, Okla. (07191220)	337,000	139,000	42,300	84,000	13,800	20,400	1,190	2,040
	Spavinaw Creek near Colcord, Okla. (071912213)	380,000	150,000	51,400	78,100	18,200	18,800	1,750	1,800
	Beaty Creek near Jay, Okla. (07191222)	120,000	52,800	22,600	22,300	4,990	17,100	3,820	540

112 lbs/yr/mi^2) (table 6). Annual base-flow yields at those stations on Spavinaw Creek were about 6 to 11 times greater than base-flow yields at the station on Beaty Creek. Annual phosphorus base-flow yield increased substantially in a downstream direction for the study period (table 6) from Maysville to Cherokee in Spavinaw Creek, probably due to the inflow of wastewater discharges from the City of Decatur, with the annual base-flow yield at the Cherokee station about 7 times that of Maysville station (table 6).

Estimated mean annual phosphorus runoff yields were about the same at all Spavinaw Creek stations in the basin, ranging from 211 to 281 lbs/yr/mi^2. The runoff yield for Beaty Creek (446 lbs/yr/mi^2), was greater than those of any Spavinaw Creek station (table 6); about 98 percent of the phosphorus loads at Beaty Creek were delivered during runoff events.

Estimated Mean Flow-Weighted Concentrations

Nitrogen

Estimated mean flow-weighted nitrogen concentrations at all stations in the basin for 2002–2004 were more than the median flow-weighted concentrations in relatively undeveloped basins of the United States and were about 7–10 times greater than the 75th percentile of flow-weighted nitrogen concentrations in relatively undeveloped basins of the United States (0.50 mg/L, Clark and others, 2000) (fig. 8, table 9).

Estimated mean flow-weighted nitrogen concentrations were consistently greater than the median nitrogen concentrations shown in figure 8. The collected water-quality data have a wide range (table 3) and high outliers can greatly effect the computation of the mean flow-weighted concentrations. For example, the maximum concentration during 2004 at Spavinaw Creek near Colcord (6.23 mg/L, table 3) was collected during a high runoff event in March 2004 and contributed to a large nitrogen load. There were similar events in April and July 2004. Because mean flow-weighted concentration (mean load divided by mean streamflow times a conversion factor) is proportional to load, this resulted in a large estimated mean flow-weighted nitrogen concentration.

Phosphorus

Estimated mean flow-weighted phosphorus concentrations at all stations in the basin for 2002–2004 were greater than the median flow-weighted concentrations in relatively undeveloped basins of the United States and were about 4–10 times greater than the 75th percentile of flow-weighted phosphorus concentrations in relatively undeveloped basins of the United States (0.037 mg/L, Clark and others, 2000; fig. 8, table 9).

Estimated mean flow-weighted phosphorus concentrations were consistently greater than the median phosphorus concentrations shown in figure 8. The collected water-quality data have a wide range (table 4) and high outliers can greatly effect the computation of the mean flow-weighted concentrations. For example, the maximum concentration during 2004 at Beaty Creek near Jay (1 mg/L, table 4) was collected during a high runoff event in November 2004 and contributed to a large phosphorus load. There was a similar event in July 2004 that was the highest streamflow event in the study period and was responsible for the majority of the study period load at Beaty Creek. Because mean flow-weighted concentration (mean load divided by mean streamflow times a conversion factor) is proportional to load, this resulted in a large estimated mean flow-weighted nitrogen concentration.

Estimated Mean Annual Nutrient Loads into Lake Eucha

Most of mean annual nutrient loads entering Lake Eucha can be estimated by adding the loads of Beaty Creek near Jay and the Spavinaw Creek near Colcord. Nutrient loads at these stations do not represent the entire nutrient load into Lake Eucha, but the drainage area of these stations accounts for about 62 percent of the drainage basin of the lake.

Spavinaw Creek and Beaty Creek contributed a mean annual nitrogen total load of about 1,350,000 pounds per year (lbs/yr) (table 10) and about 65 percent of the annual nitrogen total load was transported to Lake Eucha by runoff. Spavinaw Creek transported about 11 times more nitrogen load during base flow and about 3 times more nitrogen load during runoff to the lake than Beaty Creek (table 10).

Spavinaw Creek and Beaty Creek contributed a mean annual phosphorus total load of about 77,700 lbs/yr (table 10) with about 86 percent of the annual phosphorus total load being transported to Lake Eucha by runoff. Spavinaw Creek transported about 16 times more phosphorus load during base flow and about 1.5 times more phosphorus load during runoff to the lake than Beaty Creek (table 10).

Summary

The City of Tulsa, Oklahoma, uses Lake Eucha and Spavinaw Lake in the Eucha-Spavinaw basin in northwestern Arkansas and northeastern Oklahoma for public water supply. Recently, the Tulsa Metropolitan Utility Authority has increased expenditures treating Spavinaw Lake raw water for human consumption. Consumer complaints of taste and odor in the finished water also have been reported. City staff has determined that taste and odor problems attributable to blue-green algae have increased in frequency over time. Changes in the algae community in the lakes may be attributable to increases in nutrient levels in the lakes, and in the waters feeding the lakes.

In July 2001, the USGS, in cooperation with the City of Tulsa, Oklahoma, supplemented fixed period, monthly water-quality sampling with six runoff-event samplings per year to better determine water quality over the range of streamflows in

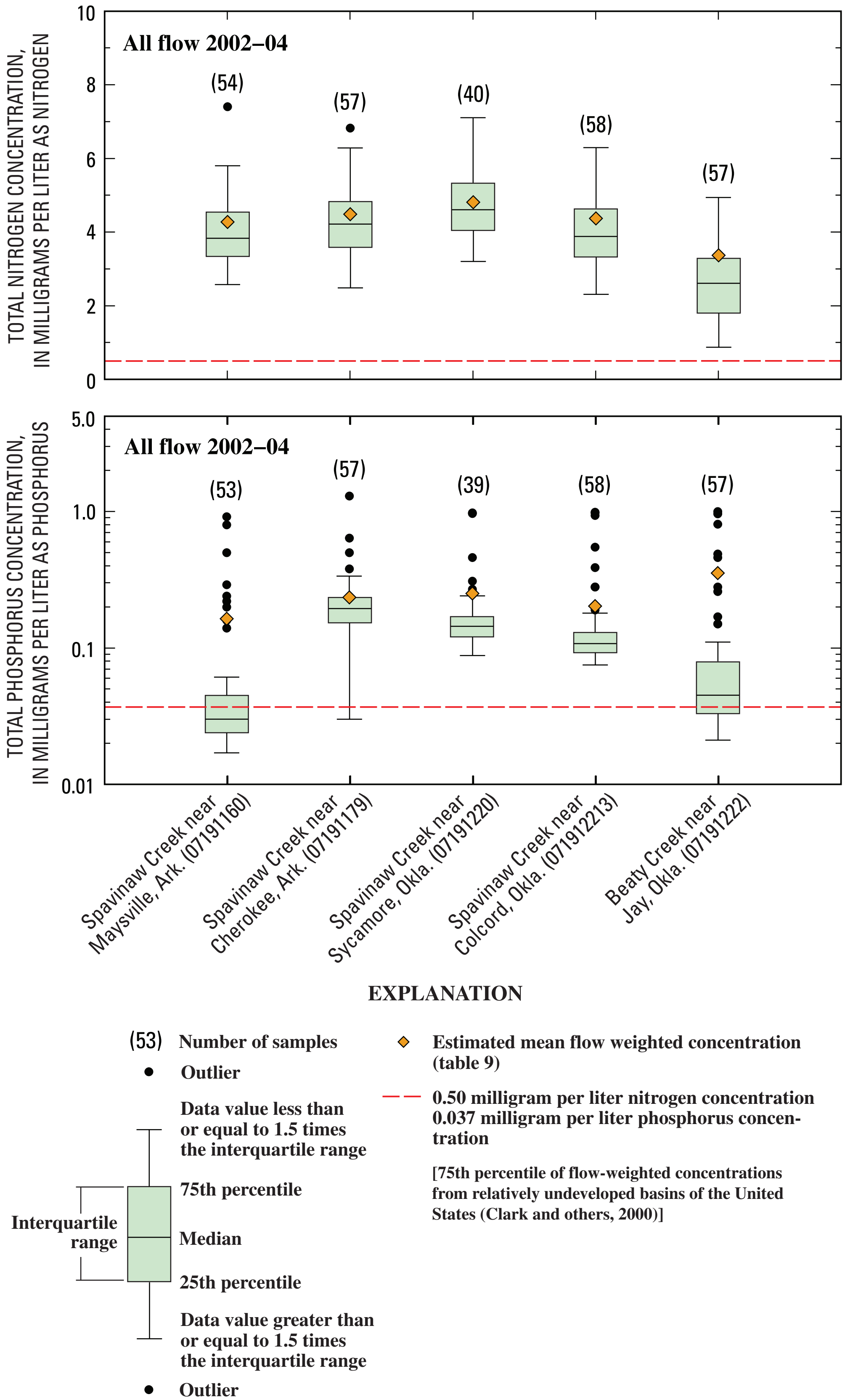

Figure 8. Instantaneous total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Sapvinaw basin, Arkansas and Oklahoma, 2002–2004.

Table 9. Estimated mean annual total nitrogen and total phosphorus loads, mean annual streamflows, and estimated mean flow-weighted total nitrogen and total phosphorus concentrations at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

[lb/yr, pound per year; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus]

Station name (number)	2002–2004				
	Mean annual total nitrogen load (lb/yr as N)	Mean annual total phosphorus load (lb/yr as P)	Mean annual streamflow (ft^3/s)	Mean flow-weighted total nitrogen concentration (mg/L as N)	Mean flow-weighted total phosphorus concentration (mg/L as P)
Spavinaw Creek near Maysville, Ark. (07191160)	521,000	20,000	61.9	4.27	0.164
Spavinaw Creek near Cherokee, Ark. (07191179)	656,000	34,500	74.4	4.48	0.236
Spavinaw Creek near Sycamore, Okla. (07191220)	914,000	47,800	96.6	4.81	0.251
Spavinaw Creek near Colcord, Okla. (071912213)	1,090,000	50,700	127	4.37	0.203
Beaty Creek near Jay, Okla. (07191222)	257,000	27,000	38.7	3.37	0.354

Table 10. Summary of estimated mean annual total nitrogen and total phosphorus loads to Lake Eucha, Oklahoma, 2002–2004.

[lb/yr, pound per year; N, nitrogen; P, phosphorus]

Flow type	2002–2004					
	Lake Eucha	Spavinaw Creek near Colcord, Okla.	Beaty Creek near Jay, Okla.	Lake Eucha	Spavinaw Creek near Colcord, Okla.	Beaty Creek near Jay, Okla.
	Mean annual total nitrogen load [1] (lb/yr as N)	Component of mean annual total nitrogen load (percent)	Component of mean annual total nitrogen load (percent)	Mean annual total phosphorus load [1] (lb/yr as P)	Component of mean annual total phosphorus load (percent)	Component of mean annual total phosphorus load (percent)
Base Flow [2]	469,000	92	8	10,800	94	6
Runoff [3]	877,000	75	25	66,900	61	39
Total [4]	1,350,000	81	19	77,700	65	35

[1] Loads to Lake Eucha are calculated by adding loads from Spavinaw Creek near Colcord, Okla. to loads from Beaty Creek near Jay, Okla. (table 6). These two locations account for 62 percent of drainage area that contributes inflows to Lake Eucha.

[2] Means of the base-flow loads are calculated from base-flow day data only by S-LOADEST and are statistics of all data in the 3-year period.

[3] Means of the runoff loads are calculated from runoff day data only by S-LOADEST and are statistics of all data in the 3-year period.

[4] Differences between total load and the sum of the base-flow load plus runoff loads are due to rounding.

the basin. Nitrogen and phosphorus concentrations, loads, and yields were determined for a 3-year period from January 2002 through December 2004.

Nitrogen and phosphorus concentrations were significantly greater in runoff samples than in base-flow samples at Spavinaw Creek near Maysville, Arkansas; Spavinaw Creek near Colcord, Oklahoma, and Beaty Creek near Jay, Oklahoma. Runoff concentrations were not significantly greater than in base-flow samples at Spavinaw Creek near Cherokee, Arkansas, and Spavinaw Creek near Sycamore, Oklahoma.

Nitrogen concentrations in base-flow samples significantly increased in the downstream direction in Spavinaw Creek from the Maysville to Sycamore stations then significantly decreased from the Sycamore to Colcord stations. Nitrogen concentrations in base-flow samples generally increased with increasing streamflow. Nitrogen in base-flow samples from Beaty Creek was significantly less than nitrogen in base-flow samples from Spavinaw Creek. Phosphorus concentrations in base-flow samples significantly increased from the Maysville to Cherokee stations in Spavinaw Creek, probably due to a point source between those stations. Phosphorus concentrations in base-flow samples significantly decreased in the downstream direction in the Spavinaw Creek from the Cherokee to Colcord stations. Phosphorus in base-flow samples from Beaty Creek was significantly less than phosphorus in base-flow samples from Spavinaw Creek downstream from the Maysville station from 2002–2004.

Nitrogen concentrations in runoff samples were not significantly different among the stations on Spavinaw Creek; however, the concentrations at Beaty Creek were significantly less than all other stations from 2002–2004. Phosphorus concentrations in runoff samples were not significantly different among the three downstream stations on Spavinaw Creek, and not significantly different among the Maysville station on Spavinaw Creek and the Beaty Creek station. Phosphorus and nitrogen concentrations in runoff samples from all stations generally increased with increasing streamflow. The larger concentrations of nitrogen during runoff events indicates addition of nitrogen from nonpoint sources and the larger concentrations of phosphorus during runoff events indicates phosphorus resuspension, stream bank erosion, and addition of phosphorus from nonpoint sources.

Estimated mean annual nitrogen total loads were substantially greater at the Spavinaw Creek stations than at Beaty Creek and increased in a downstream direction from Maysville to Colcord in Spavinaw Creek, with the annual total load at the Colcord station about 2 times that of Maysville station. Estimated mean annual nitrogen base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations with about 5 to 11 times greater than base-flow loads at Beaty Creek. Estimated mean annual nitrogen runoff loads in the basin increased with increasing drainage area and with increasing streamflow. The runoff component of the annual nitrogen total load for Beaty Creek was 85 percent, whereas at the Spavinaw Creek stations, the range in the runoff component was 60 to 66 percent from 2002–2004.

Estimated mean annual phosphorus total loads were greater at the Spavinaw Creek stations from Cherokee to Colcord than at Beaty Creek, primarily because of greater streamflow at those stations. Annual total loads increased in a downstream direction from Maysville to Colcord in Spavinaw Creek, with the annual total load at the Colcord station about 2.5 times that of Maysville station. Estimated mean annual phosphorus base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations with about 2.5 to 19 times greater than base-flow loads at the station on Beaty Creek. Phosphorus base-flow loads increased substantially in a downstream direction from Maysville to Cherokee in Spavinaw Creek, probably due to the inflow of wastewater discharges from the City of Decatur, with the annual base-flow load at the Cherokee station about 8 times that of Maysville station. The annual base-flow loads were about the same at the three downstream stations on Spavinaw Creek from Cherokee to Colcord. Estimated mean annual phosphorus runoff loads in the basin increased with increasing drainage area and with increasing streamflow. The portion of annual phosphorus load contributed by runoff at the three downstream Spavinaw Creek stations increased in the downstream direction (Cherokee to Colcord). The runoff component of the annual phosphorus total load for Beaty Creek was 98 percent, whereas at the Spavinaw Creek stations the range in the runoff component was 66 to 93 percent from 2002–2004. Because almost all of the phosphorus loads at Beaty Creek are delivered during runoff events, the annual runoff load at Beaty Creek was larger than the two upper Spavinaw Creek stations.

Estimated mean seasonal nitrogen base-flow loads generally were least in fall and greatest in spring for 2002–2004 at all stations in the Eucha-Spavinaw basin and followed the same pattern as the annual base-flow loads in terms of variability between stations. Seasonal nitrogen base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations. Seasonal base-flow loads at stations on Spavinaw Creek were about 3 to 18 times greater than base-flow loads at the station on Beaty Creek and increased in a downstream direction from Maysville to Colcord in Spavinaw Creek, with the seasonal base-flow load at the Colcord station about 2 times that of Maysville station. Estimated mean seasonal nitrogen runoff loads were generally least in fall and were greatest in spring at all stations. Estimated mean seasonal nitrogen runoff loads in the basin increased with increasing drainage area and with increasing streamflow.

Estimated mean seasonal phosphorus base-flow loads generally were least in fall and winter, and greatest in spring and summer for 2002–2004 at all stations in the Eucha-Spavinaw basin and followed the same pattern as the annual base-flow loads in terms of variability between stations. Seasonal phosphorus base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations. Seasonal base-flow loads at stations on Spavinaw Creek were about 2 to 30 times greater than base-flow loads at the station on Beaty Creek and increased substantially in a downstream direction from Maysville to Cherokee in Spavinaw Creek, probably due to the inflow of wastewater discharges from the City of Decatur. The seasonal loads at the Cherokee station about 8 times that of Maysville station and then the seasonal base-flow loads at the three downstream stations on Spavinaw Creek from Cherokee to Colcord were about the same.

Estimated mean seasonal phosphorus runoff loads generally were least in fall and winter, and greatest in spring and summer at all stations for 2002-2004. Estimated mean seasonal phosphorus runoff loads in the basin generally increased with increasing drainage area and with increasing streamflow at the Spavinaw Creek stations. Because almost all of the phosphorus loads at Beaty Creek are delivered during runoff events, many of the seasonal loads at Beaty Creek were larger than the Spavinaw Creek stations, especially during the summer and fall.

Estimated mean annual nitrogen total yields generally increased slightly in a downstream direction in Spavinaw Creek for 2002-2004. The total yields ranged from 5,910 to 6,870 pounds per year per square mile, with greatest yield being reported for Spavinaw Creek near Sycamore, and the least yield being reported for Spavinaw Creek near Maysville. Beaty Creek near Jay had a slightly lower yield than Maysville (4,340 pounds per year per square mile). Estimated mean annual nitrogen base-flow yields also generally increased slightly in a downstream direction at the Spavinaw Creek stations, ranging from 2,120 to 2,640 pounds per year per square mile. However, the base-flow yield at Beaty Creek (664 pounds per year per square mile) was substantially less than those of the Spavinaw Creek stations, which were about 3 to 4 times greater. Estimated mean annual nitrogen runoff yields were about the same at all stations in the basin, ranging from 3,790 to 4,530 pounds per year per square mile on Spavinaw Creek and slightly lower on Beaty Creek (3,680 pounds per year per square mile).

Estimated mean annual phosphorus total yields for the 3-year period 2002-2004 in Spavinaw Creek generally increased in a downstream direction, ranging from 227 to 359 pounds per year per square mile, with greatest yield being reported for Spavinaw Creek near Sycamore, and the least yield being reported for Spavinaw Creek near Maysville. However, the total yield for Beaty Creek (456 pounds per year per square mile), was greater than any Spavinaw Creek station. The greater yield in Beaty Creek may be caused by the addition of phosphorus from nonpoint sources, resuspension of phosphorus from the streambed, and stream bank erosion. Estimated mean annual phosphorus base-flow yield was substantially less in Beaty Creek (10.1 pounds per year per square mile) than in the three downstream Spavinaw Creek stations (62.5 to 112 pounds per year per square mile) for 2002-2004. Annual base-flow yields at those stations on Spavinaw Creek were about 6 to 11 times greater than those at Beaty Creek. Annual phosphorus base-flow yield increased substantially in a downstream direction from Maysville to Cherokee in Spavinaw Creek, probably due to the inflow of wastewater discharges from the City of Decatur, with the annual base-flow yield at the Cherokee station about 7 times that of Maysville station.

Estimated mean annual phosphorus runoff yields were about the same at all Spavinaw Creek stations in the basin, ranging from 211 to 281 pounds per year per square mile. The runoff yield for Beaty Creek (446 pounds per year per square mile), was greater than any Spavinaw Creek station; about 98 percent of the phosphorus loads at Beaty Creek are delivered during runoff events.

Estimated mean flow-weighted nitrogen concentrations at all stations in the basin for 2002-2004 were about 7-10 times greater than the 75th percentile of flow-weighted nitrogen concentrations (0.50 milligram per liter) in relatively undeveloped basins of the United States. Estimated mean flow-weighted phosphorus concentrations at all stations in the basin for 2002-2004 were about 4-10 times greater than the 75th percentile of flow-weighted phosphorus concentrations (0.037 milligram per liter) in relatively undeveloped basins of the United States.

Spavinaw Creek and Beaty Creek contributed a mean annual nitrogen total load of about 1,350,000 pounds per year and about 65 percent of the annual nitrogen total load was transported to Lake Eucha by runoff. Spavinaw Creek transported about 11 times more nitrogen load during base flow and about 3 times more nitrogen load during runoff to the lake than Beaty Creek. Spavinaw Creek and Beaty Creek contributed a mean annual phosphorus total load that of about 77,700 pounds per year with about 86 percent of the annual phosphorus total load being transported to Lake Eucha by runoff. Spavinaw Creek transported about 16 times more phosphorus load during base flow and about 1.5 times more phosphorus load during runoff to the lake than Beaty Creek.

Selected References

Adamski, J.C., Petersen, J.C., Freiwald, D.A., and Davis, J.V., 1995, Environmental and hydrologic setting of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma: U.S. Geological Survey Water-Resources Investigations Report 94–4022, 69 p.

Blazs, R.L., Walters, D.M., Coffey, T.E., Boyle, D.L., and Wellman, J.J., 2003, Water resources data, Oklahoma, water year 2002: U.S. Geological Survey Water-Data Report OK–02–1, 375 p.

Blazs, R.L., Walters, D.M., Coffey, T.E., Boyle, D.L., and Wellman, J.J., 2004, Water resources data, Oklahoma, water year 2003: U.S. Geological Survey Water-Data Report OK–03–1, 394 p.

Blazs, R.L., Walters, D.M., Coffey, T.E., Boyle, D.L., and Wellman, J.J., 2005, Water resources data, Oklahoma, water year 2004: U.S. Geological Survey Water-Data Report OK–04–1, 408 p.

Blazs, R.L., Walters, D.M., Coffey, T.E., Boyle, D.L., and Wellman, J.J., 2006, Water resources data, Oklahoma, water year 2005: U.S. Geological Survey Water-Data Report OK–05–1, 473 p.

Childress, C.J.O., Foreman, W.T., Connor, B.F., and Maloney, T.J., 1999, New reporting procedures based on long-term method detection levels and some considerations for interpretations of water-quality data provided by the U.S. Geological Survey National Water Quality Laboratory: U.S. Geological Survey Open-File Report 99–193, 19 p.

Clark, G.M., Mueller, D.K., and Mast, M.A., 2000, Nutrient concentrations and yields in undeveloped stream basins of the United States: Journal of the American Water Resources Association, v. 36, no. 4, p. 849–860.

Cobb, E.D., and Biesecker, J.E., 1971, The National Hydrologic Benchmark Network: U.S. Geological Survey Circular 460–D, 38 p.

Cohn, T.A., 1988, Adjusted maximum likelihood estimation of the moments of lognormal populations from type I censored samples: U.S. Geological Survey Open-File Report 88–350, 34 p.

Cohn, T.A., 1995, Recent advances in statistical methods for the estimation of sediment and nutrient transport in rivers: Reviews of Geophysics, v. 33 (Supplement), p. 1117–1124.

Cohn, T.A., DeLong, L.L., Gilroy, E.J., Hirsch, R.M., and Wells, D.K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 937–942.

Cohn, T.A., Gilroy, E.J., and Baier, W.G., 1992, Estimating fluvial transport of trace constituents using a regression model with data subject to censoring: Proceedings of the Joint Statistical Meeting, Boston, August 9–13, 1992, p. 142–151.

Crawford, C.G., 1991, Estimation of suspended-sediment rating curves and mean suspended-sediment loads: Journal of Hydrology, v. 129, p. 331–348.

Crawford, C.G., 1996, Estimating mean constituent loads in rivers by the rating-curve and flow-duration, rating-curve methods: Bloomington, Indiana University, Ph.D. dissertation, 245 p.

Crawford, C.G., 1999, Read.me file, LOADEST2, v 2.0: accessed April 9, 2001, at *http://srv1dinind.er.usgs.gov*

Daniel, T.C., Sharpley, A.N., and Lemunyon, J.L., 1998, Agricultural phosphorus and eutrophication—A symposium overview: Journal of Environmental Quality, v. 27, no. 2, p. 251–257.

DeLaune, P.B., Haggard, B.E., Daniel, T.C., Chaubey, Indrajeet, and Cochran, M.J. 2006, The Eucha/Spavinaw phosphorus index: A court mandated index for litter management: Journal of Soil and Water Conservation, v. 61, no. 2, p. 1–10.

Dempster, A.P., Laird, N.M., and Rubin, D.B., 1977, Maximum likelihood from incomplete data via the EM algorithm: Journal of the Royal Statistical Society, Series B, v. 39, no. 1, p. 1–38.

Edwards, T.K, and Glysson, G.D., 1999, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 89 p.

Fenneman, N.M., 1938, Physiography of eastern United States: New York, McGraw-Hill, p. 631–662.

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program—Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1112, 33 p.

Gilliom, R.J., Hamilton, P.A., and Miller, T.L., 2001, The National Water-Quality Assessment Program—Entering a new decade of investigation: U.S. Geological Survey Fact Sheet 071–01, 6 p.

Gilroy, E.J., Hirsch, R.M., and Cohn, T.A., 1990, Mean square error of regression-based constituent transport estimates: Water Resources Research, v. 26, no. 9, p. 2069–2077.

Haggard, B.E., 2000, Stream nutrient retention in the Lake Eucha-Spavinaw Basin: Stillwater, Oklahoma State University, Ph.D. dissertation, 165 p.

Haggard, B.E., Moore, P.A., Jr., Chaubey, Indrajeet, and Stanley, E.H., 2003. Nitrogen and phosphorus concentrations and export from an Ozark plateau catchment in the United States: Biosystems Engineering, v. 86, no. 1, p. 75–85.

Haggard, B.E., Storm, D.E., and Stanley, E.H., 2001, Effect of a point source input on stream nutrient retention: Journal of the American Water Resources Association, v. 37, no. 5, p. 1291–1299.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Amsterdam, Netherlands, Elsevier, 522 p.

Insightful Corporation, 2005, S-Plus 7.0 for Windows Professional Developer Edition with Release 3.0 of the U.S. Geological Survey S-PLUS library: Seattle, Washington.

Institute of Hydrology, 1980a, Low flow studies: Wallingford, Oxon, United Kingdom, Report No. 1, 41 p.

Institute of Hydrology, 1980b, Low flow studies: Wallingford, Oxon, United Kingdom, Report No. 3, p. 12–19.

Langbein, W.B., and Iseri, K.T., 1960, General introductions and hydrologic definitions—Manual of Hydrology—Part 1. General surface-water techniques: U.S. Geological Survey Water-Supply Paper 1541–A, 29 p.

Likes, Jiri, 1980, Variance of the MVUE for lognormal variance: Technometrics, v. 22, no. 2, p. 253–258.

Mast, M.A., and Turk, J.T., 1999, Environmental characteristics and water quality of Hydrologic Benchmark Network Stations in the Midwestern United States, 1963–95: U.S. Geological Survey Circular 1173–B, 130 p.

Oklahoma Water Resources Board, 2002, Water quality evaluation of the Eucha/Spavinaw Lake System: Oklahoma Water Resources Board, 145 p.

Patton, C.J., and Truitt, E.P., 1992, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—Determination of total phosphorus by a Kjeldahl digestion method and an automated colorimetric finish that includes dialysis: U.S. Geological Survey Open-File Report 92–146, 39 p.

Peterson, J.C., Adamski, J.C., Bell, R.W., Davis, J.V., Femmer, S.R., Freiwald, D.A., and Joseph, R.L., 1998, Water quality in the Ozark Plateaus, Arkansas, Kansas, Missouri, and Oklahoma, 1992–1995: U.S. Geological Survey Circular 1158, accessed July 11, 2003, at *http://water.usgs.gov/pubs/circ/circ1158*

Peterson, J.C., Adamski, J.C., Bell, R.W., Davis, J.V., Femmer, S.R., Freiwald, D.A., and Joseph, R.L., 1999, Quality of Ozark streams and ground water, 1992–95: U.S. Geological Survey Fact Sheet FS–092–99, 4 p.

Pickup, B.E., Andrews, W.J., Haggard, B.E., and Green, W.R., 2003, Phosphorus concentrations, loads, and yields in the Illinois River basin, Arkansas and Oklahoma, 1997–2001: U.S. Geological Survey Water-Resources Investigations Report 03–4168, 39 p.

Rantz, S.E. and others, 1982, Measurement and computation of streamflow—Volume 2. Computation of discharge: U.S Geological Survey Water-Supply Paper 2175, v. 2, 285–631 p.

Renken, R.A., 1998, Ground water atlas of the United States—Segment 5, Arkansas, Louisiana, Mississippi: U.S. Geological Survey Hydrologic Atlas 730–F, 28 p.

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load Estimator (LOADEST)—A FORTRAN program for estimating constituent loads in streams and rivers: U.S. Geological Survey Techniques and Methods Book 4, Chapter A5, 69 p. (online only), accessed October 12, 2005, at *http://pubs.usgs.gov/tm/2005/tm4A5/*

Sharpley, A.N., 1995, Fate and transport of nutrients—Phosphorus: U.S. Department of Agriculture, Agricultural Research Service Working Paper No. 8, 28 p.

Sims, J.T. and Wolf, D.C., 1994, Poultry waste management—Agricultural and environmental issues: Advances in Agronomy, v. 52, p. 1–83.

Storm, D.E., White, Michael, Smolen, M.D., and Zhang, Hailin, 2001, Modeling phosphorus loading for the Lake Eucha basin: Oklahoma State University, Biosystems and Agricultural Engineering Department, 14 p.

Storm, D.E., White, M.J., and Smolen, M.D., 2002, Modeling the Lake Eucha basin using SWAT 2000: Oklahoma State University, Biosystems and Agricultural Engineering Department, 60 p.

Svendsen, L.M., Kronvang, Brian, Kristensen, P., and Graesbol, P., 1995, Dynamics of phosphorus compounds in a lowland river system—Importance of retention and nonpoint sources: Hydrological Processes, v. 9, p. 119–142.

Timme, P.J., 1995, National Water Quality Laboratory 1995 services catalog: U.S. Geological Survey Open-File Report 95–352, p. 92.

Tortorelli, R.L., and Pickup, B.E., 2006, Phosphorus concentrations, loads, and yields in the Illinois River basin, Arkansas and Oklahoma, 2000–2004: U.S. Geological Survey Scientific Investigations Report 2006–5175, 38 p.

Tulsa Metropolitan Utility Authority, 2001a, A history of Tulsa's water: (online only), accessed August 10, 2006, at *http://www.tulsawater.com/watrhist.html*

Tulsa Metropolitan Utility Authority, 2001b, Eucha/Spavinaw Watershed Project: (online only), accessed August 10, 2006, at *http:www.tulsawater.com/eucha.html*

U.S. Environmental Protection Agency, 1983, Methods for chemical analysis of water and wastes, Method 365.2 (2nd ed.): EPA–600/4–79–020 Revised March 1983 [variously paged]

U.S. Environmental Protection Agency, 1993, Methods for the determination of inorganic substances in environmental samples: EPA–600/R–93–100 [variously paged]

U.S. Environmental Protection Agency, 1997, Guidelines establishing test procedures for the analysis of pollutants (App. B, Part 136, Definition and procedures for the determination of the method detection limit): U.S. Code of Federal Regulations, Title 40, revised July 1, 1997, p. 265–267.

U.S. Geological Survey, 1999, The quality of our nation's waters—Nutrients and Pesticides: U.S. Geological Survey Circular 1225, 82 p.

Wagner, Kevin, and Woodruff, Scott, 1997, Phase I Clean Lakes Project, Diagnostic and Feasibility Study of Lake Eucha: Oklahoma Conservation Commission, Final Report.

Wahl, K.L., and Tortorelli, R.L., 1997, Changes in flow in the Beaver-North Canadian River basin upstream from Canton Lake, western Oklahoma: U.S. Geological Survey Water-Resources Investigations Report 96–4304, 58 p.

Wahl, K.L., and Wahl, T.L., 1988, Effects of regional ground-water level declines on streamflow in the Oklahoma Panhandle, *in* Proceedings of Symposium on Water-Use Data for Water Resources Management, Tucson, Ariz., August 1988: American Water Resources Association, p. 239–249.

Wahl, K.L., and Wahl, T.L., 1995, Determining the flow of Comal Springs at New Braunfels, Texas, *in* Proceedings of Texas Water, ‘95, A Component Conference of the First International Conference on Water Resources Engineering, American Society of Civil Engineers Symposium, San Antonio, Texas, August 16–17, 1995: American Society of Civil Engineers, p. 77–86.

Wolynetz, M.S., 1979, Algorithm 139—Maximum likelihood estimation in a linear model with confined and censored data: Applied Statistics, v. 28, p. 195–206.

Appendixes

Appendix 1. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Maysville, Arkansas, 2002-2004.

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; —, not reported; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
01/15/2002	0820	COT	35	4.80	0.028	Base flow
02/01/2002	1010	USGS	305	3.40	0.045	Runoff
02/12/2002	0815	COT	55	4.80	0.024	Base flow
03/12/2002	0845	COT	61	4.20	0.024	Base flow
03/20/2002	1445	USGS	221	4.00	0.028	Runoff
04/08/2002	1205	USGS	648	3.97	0.160	Runoff
04/18/2002	0817	COT	82	4.20	0.028	Base flow
05/13/2002	1320	USGS	176	3.44	0.033	Runoff
05/17/2002	1300	USGS	1,560	7.40	0.500	Runoff
05/23/2002	0808	COT	136	4.54	0.042	Runoff
06/13/2002	0838	COT	88	3.68	0.035	Runoff
07/18/2002	0832	COT	34	3.41	0.025	Base flow
08/13/2002	0820	COT	24	3.20	0.031	Base flow
09/19/2002	0810	COT	19	2.85	0.033	Base flow
10/16/2002	0735	COT	16	2.80	0.025	Base flow
11/12/2002	0753	COT	18	2.85	0.030	Base flow
12/12/2002	0818	COT	17	2.90	0.022	Base flow
01/07/2003	0845	COT	25	3.36	0.024	Base flow
02/06/2003	0817	COT	18	3.15	0.022	Base flow
03/05/2003	0818	COT	62	4.43	0.025	Runoff
04/09/2003	0822	COT	38	3.76	0.019	Base flow
05/08/2003	0825	COT	29	3.10	0.019	Base flow
05/16/2003	1100	USGS	92	3.63	0.220	Runoff
05/20/2003	1102	USGS	153	3.70	0.061	Runoff
05/21/2003	1115	USGS	251	4.16	0.039	Runoff
06/02/2003	1258	USGS	49	4.20	0.042	Runoff
06/03/2003	0830	COT	48	3.85	—	Runoff
06/12/2003	1102	USGS	48	3.82	0.200	Runoff
07/10/2003	0800	COT	21	3.33	0.023	Base flow
07/14/2003	1235	USGS	69	3.01	0.040	Runoff
08/05/2003	0800	COT	15	2.97	0.030	Base flow
09/11/2003	0759	COT	14	2.70	0.026	Base flow
10/09/2003	0755	COT	14	2.57	0.041	Base flow
11/06/2003	0755	COT	13	2.60	0.022	Base flow
11/19/2003	1111	USGS	33	3.06	0.029	Runoff
12/10/2003	0820	COT	21	3.53	0.019	Base flow

Appendix 1. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Maysville, Arkansas, 2002-2004. — Continued

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; —, not reported; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
01/06/2004	0840	COT	59	4.28	0.017	Runoff
02/05/2004	0815	COT	38	4.55	0.019	Base flow
03/04/2004	0825	COT	890	5.57	0.291	Runoff
03/04/2004	1125	USGS	809	5.79	0.140	Runoff
03/29/2004	1110	USGS	307	4.40	0.054	Runoff
04/07/2004	0845	COT	72	4.86	0.024	Base flow
04/23/2004	1040	USGS	419	3.43	0.046	Runoff
04/24/2004	1435	USGS	2,110	5.68	0.800	Runoff
05/06/2004	0817	COT	160	4.87	0.032	Runoff
06/10/2004	0815	COT	43	3.82	0.041	Base flow
07/03/2004	1100	USGS	3,970	5.61	0.920	Runoff
07/08/2004	0830	COT	170	4.61	0.022	Runoff
08/05/2004	0825	COT	64	3.91	0.040	Base flow
09/09/2004	0830	COT	29	3.59	0.028	Base flow
10/07/2004	0806	COT	22	3.37	0.028	Base flow
11/01/2004	1200	USGS	654	4.02	0.240	Runoff
11/03/2004	0848	COT	156	4.67	0.050	Runoff
12/09/2004	0840	COT	151	5.18	0.025	Runoff

[1] Streamflow for data collected by USGS is measured instantaneous streamflow; streamflow for data collected by COT is daily mean streamflow unless streamflow changing during the day, then it is 15-minute unit value.

[2] Total nitrogen is calculated by adding Kjeldahl-N and nitrite plus nitrate analyses.

[3] Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b).

Appendix 2. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Cherokee, Arkansas, 2002–2004.

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
01/15/2002	0835	COT	41	5.40	0.233	Base flow
02/01/2002	1236	USGS	290	3.60	0.170	Runoff
02/12/2002	0835	COT	71	5.20	0.230	Base flow
03/12/2002	0900	COT	82	4.40	0.227	Base flow
03/20/2002	1641	USGS	233	4.83	0.170	Runoff
04/08/2002	1410	USGS	700	4.26	0.190	Runoff
04/18/2002	0835	COT	101	4.60	0.204	Base flow
05/13/2002	1510	USGS	190	3.28	0.170	Runoff
05/17/2002	1630	USGS	1,590	6.82	0.380	Runoff
05/23/2002	0823	COT	150	4.40	0.170	Runoff
06/13/2002	0850	COT	107	3.92	0.186	Runoff
07/18/2002	0847	COT	42	3.59	0.234	Base flow
08/13/2002	0835	COT	26	3.33	0.234	Base flow
09/19/2002	0825	COT	25	3.16	0.301	Base flow
10/16/2002	0755	COT	17	3.11	0.315	Base flow
11/12/2002	0808	COT	24	3.49	0.312	Base flow
12/12/2002	0833	COT	19	3.54	0.299	Base flow
01/07/2003	0900	COT	33	4.11	0.279	Runoff
02/06/2003	0834	COT	20	4.13	0.257	Base flow
03/05/2003	0900	COT	67	4.94	0.194	Runoff
04/09/2003	0836	COT	54	4.22	0.177	Base flow
05/08/2003	0840	COT	32	3.28	0.227	Base flow
05/14/2003	0800	COT	31	[4] 4.44	0.223	Base flow
05/16/2003	0945	COT	134	3.05	0.500	Runoff
05/16/2003	1211	USGS	134	3.21	0.030	Runoff
05/20/2003	1258	USGS	165	4.00	0.250	Runoff
05/21/2003	1247	USGS	310	4.34	0.130	Runoff
06/02/2003	1405	USGS	54	2.48	0.190	Runoff
06/03/2003	0850	COT	52	4.27	0.142	Runoff
06/11/2003	0910	COT	38	4.10	0.194	Base flow
06/12/2003	1218	USGS	49	4.20	0.034	Runoff
07/10/2003	0815	COT	19	3.64	0.199	Base flow
07/14/2003	1054	USGS	61	3.46	0.170	Runoff
08/05/2003	0820	COT	14	3.45	0.209	Base flow
09/11/2003	0826	COT	16	3.51	0.211	Base flow
10/09/2003	0815	COT	21	3.66	0.223	Base flow

Appendix 2. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Cherokee, Arkansas, 2002–2004. — Continued

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
11/06/2003	0811	COT	19	3.90	0.229	Base flow
11/19/2003	1236	USGS	41	4.22	0.230	Runoff
12/10/2003	0845	COT	29	4.21	0.182	Runoff
01/06/2004	0855	COT	79	4.99	0.146	Runoff
02/05/2004	0835	COT	49	5.46	0.140	Base flow
03/04/2004	0840	COT	1,100	5.73	0.336	Runoff
03/04/2004	1510	USGS	912	6.28	0.180	Runoff
03/29/2004	1235	USGS	375	4.52	0.100	Runoff
04/07/2004	0900	COT	80	5.12	0.114	Base flow
04/23/2004	1259	USGS	470	3.87	0.082	Runoff
04/24/2004	1735	USGS	2,210	4.99	0.640	Runoff
05/06/2004	0837	COT	207	5.22	0.110	Runoff
06/10/2004	0830	COT	57	4.21	0.143	Base flow
07/03/2004	0926	USGS	8,000	2.68	1.300	Runoff
07/08/2004	0845	COT	207	5.04	0.126	Runoff
08/05/2004	0840	COT	86	4.48	0.189	Base flow
09/09/2004	0845	COT	33	4.20	0.144	Base flow
10/07/2004	0820	COT	24	4.30	0.157	Base flow
11/01/2004	1400	USGS	657	4.66	0.240	Runoff
11/03/2004	0905	COT	199	5.20	0.152	Runoff
12/09/2004	0855	COT	184	5.58	0.110	Runoff

[1] Streamflow for data collected by USGS is measured instantaneous streamflow; streamflow for data collected by COT is daily mean streamflow unless streamflow changing rapidly during the day, then it is 15-minute unit value.

[2] Total nitrogen is calculated by adding Kjeldahl-N and nitrite plus nitrate analyses.

[3] Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b).

[4] Nitrite plus nitrate analyses not reported, nitrate analyses was substitued in the total nitrogen calculation for this sample.

Appendix 3. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Sycamore, Oklahoma, 2002–2004.

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; —, not reported; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
01/15/2002	0755	COT	54	5.50	0.144	Base flow
02/01/2002	1506	USGS	384	3.20	0.160	Runoff
02/12/2002	0750	COT	92	5.30	0.147	Base flow
03/12/2002	0815	COT	105	4.50	0.153	Base flow
03/21/2002	1123	USGS	268	4.40	0.140	Runoff
04/08/2002	1708	USGS	952	5.06	0.180	Runoff
04/18/2002	0817	COT	131	4.70	0.149	Base flow
05/13/2002	1205	USGS	203	3.84	0.170	Runoff
05/17/2002	1428	USGS	885	7.10	0.310	Runoff
05/23/2002	0740	COT	174	4.30	0.153	Runoff
06/13/2002	0803	COT	135	3.96	0.146	Base flow
07/18/2002	0800	COT	46	3.65	0.143	Base flow
01/07/2003	0818	COT	44	4.07	0.163	Runoff
03/05/2003	0700	COT	110	4.97	0.138	Runoff
04/09/2003	0757	COT	57	4.02	0.140	Base flow
05/16/2003	1335	USGS	151	3.68	0.190	Runoff
05/20/2003	1705	USGS	242	4.10	0.270	Runoff
05/21/2003	1437	USGS	345	4.29	0.130	Runoff
06/02/2003	1519	USGS	68	3.87	0.130	Runoff
06/03/2003	0800	COT	71	4.25	—	Runoff
06/16/2003	1312	USGS	72	3.99	0.130	Runoff
09/02/2003	1220	COT	31	3.58	0.170	Runoff

Appendix 3. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Sycamore, Oklahoma, 2002–2004. — Continued

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; —, not reported; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
01/06/2004	0815	COT	93	5.38	0.117	Runoff
01/18/2004	1540	USGS	137	5.70	0.120	Runoff
02/05/2004	0740	COT	56	5.36	0.110	Base flow
03/04/2004	0754	COT	1,500	6.15	0.461	Runoff
03/04/2004	1135	USGS	1,310	6.44	0.190	Runoff
03/29/2004	1430	USGS	462	4.82	0.100	Runoff
04/07/2004	0817	COT	100	5.22	0.092	Base flow
04/23/2004	1445	USGS	561	3.54	0.120	Runoff
04/24/2004	1445	USGS	3,120	5.97	0.970	Runoff
05/06/2004	0750	COT	291	5.17	0.104	Runoff
06/10/2004	0750	COT	62	4.24	0.129	Base flow
07/03/2004	1327	USGS	4,810	5.48	0.980	Runoff
07/08/2004	0800	COT	323	5.05	0.116	Runoff
08/05/2004	0755	COT	148	4.39	0.120	Base flow
09/09/2004	0800	COT	50	4.21	0.117	Base flow
11/01/2004	1600	USGS	1,010	4.95	0.240	Runoff
11/03/2004	0818	COT	343	5.21	0.145	Runoff
12/09/2004	0812	COT	309	5.58	0.088	Runoff

[1] Streamflow for data collected by USGS is measured instantaneous streamflow; streamflow for data collected by COT is daily mean streamflow unless streamflow changing during the day, then it is 15-minute unit value.

[2] Total nitrogen is calculated by adding Kjeldahl-N and nitrite plus nitrate analyses.

[3] Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b).

Appendix 4. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Colcord, Oklahoma, 2002–2004.

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
01/15/2002	0905	COT	73	5.20	0.105	Base flow
02/01/2002	1706	USGS	388	3.90	0.140	Runoff
02/12/2002	0900	COT	113	5.00	0.108	Base flow
03/12/2002	0927	COT	132	4.10	0.111	Base flow
03/21/2002	1445	USGS	349	4.10	0.120	Runoff
04/09/2002	1026	USGS	769	4.10	0.130	Runoff
04/18/2002	0902	COT	176	4.40	0.130	Base flow
05/13/2002	1342	USGS	269	3.51	0.130	Runoff
05/17/2002	1850	USGS	1,670	6.29	0.390	Runoff
05/23/2002	0852	COT	210	4.00	0.122	Base flow
06/13/2002	0917	COT	168	3.62	0.121	Base flow
07/18/2002	0914	COT	58	3.42	0.104	Base flow
08/13/2002	0902	COT	36	3.22	0.101	Base flow
09/19/2002	0805	COT	22	2.82	0.100	Base flow
10/16/2002	0820	COT	21	2.91	0.087	Base flow
11/12/2002	0837	COT	33	3.18	0.092	Base flow
12/12/2002	0900	COT	34	3.21	0.095	Base flow
01/07/2003	0925	COT	59	3.80	0.108	Runoff
02/06/2003	0900	COT	30	3.67	0.089	Base flow
03/05/2003	0930	COT	113	4.39	0.101	Base flow
04/09/2003	0902	COT	61	3.86	0.104	Base flow
05/08/2003	0907	COT	48	3.23	0.102	Base flow
05/14/2003	0830	COT	61	[4] 5.27	0.132	Runoff
05/16/2003	1010	COT	467	2.89	0.980	Runoff
05/16/2003	1504	USGS	446	3.86	0.180	Runoff
05/20/2003	1435	USGS	349	2.30	0.280	Runoff
05/21/2003	1607	USGS	446	4.81	0.110	Runoff
06/02/2003	1639	USGS	113	4.22	0.120	Runoff
06/03/2003	0920	COT	102	3.76	0.149	Runoff
06/11/2003	0945	COT	57	3.78	0.115	Base flow
06/16/2003	1452	USGS	80	3.69	0.110	Runoff
07/10/2003	0841	COT	27	3.23	0.087	Base flow
08/05/2003	0845	COT	24	3.01	0.090	Base flow
09/02/2003	1418	USGS	88	3.13	0.120	Runoff
09/11/2003	0901	COT	44	3.19	0.085	Runoff
10/09/2003	0840	COT	23	3.00	0.089	Base flow

Appendix 4. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Colcord, Oklahoma, 2002–2004. — Continued

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
11/06/2003	0840	COT	23	3.20	0.086	Base flow
11/19/2003	1545	USGS	80	3.80	0.088	Runoff
12/10/2003	0925	COT	34	3.77	0.084	Base flow
01/06/2004	0922	COT	138	4.59	0.123	Runoff
01/18/2004	1350	USGS	270	4.50	0.099	Runoff
02/05/2004	0850	COT	95	5.05	0.087	Base flow
03/04/2004	0909	COT	2,390	5.70	0.550	Runoff
03/04/2004	0945	USGS	2,320	6.23	0.280	Runoff
03/29/2004	1600	USGS	646	4.94	0.099	Runoff
04/07/2004	0931	COT	150	4.74	0.084	Base flow
04/23/2004	1315	USGS	792	3.32	0.100	Runoff
04/24/2004	1235	USGS	4,130	6.08	0.990	Runoff
05/06/2004	0904	COT	337	4.62	0.093	Runoff
06/10/2004	0900	COT	74	4.37	0.085	Base flow
07/03/2004	1405	USGS	7,200	3.54	0.940	Runoff
07/08/2004	0910	COT	424	4.51	0.092	Runoff
08/05/2004	0910	COT	172	3.98	0.147	Base flow
09/09/2004	0910	COT	69	4.04	0.114	Base flow
10/07/2004	0845	COT	34	3.81	0.081	Base flow
11/01/2004	1730	USGS	1,280	4.68	0.190	Runoff
11/03/2004	0935	COT	397	4.70	0.131	Runoff
12/09/2004	0927	COT	374	5.03	0.075	Runoff

[1] Streamflow for data collected by USGS is measured instantaneous streamflow; streamflow for data collected by COT is daily mean streamflow unless streamflow changing during the day, then it is 15-minute unit value.

[2] Total nitrogen is calculated by adding Kjeldahl-N and nitrite plus nitrate analyses.

[3] Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b).

[4] Nitrite plus nitrate analyses not reported, nitrate analyses was substitued in the total nitrogen calculation for this sample.

Appendix 5. Streamflows, and total nitrogen and total phosphorus concentrations for Beaty Creek near Jay, Oklahoma, 2002–2004.

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
01/15/2002	0940	COT	9.6	3.20	0.043	Base flow
02/01/2002	1911	USGS	99	2.60	0.049	Runoff
02/12/2002	0755	COT	25	3.20	0.033	Runoff
03/12/2002	0750	COT	33	2.70	0.031	Runoff
04/08/2002	1837	USGS	189	3.60	0.150	Runoff
04/18/2002	0752	COT	29	2.90	0.043	Runoff
05/17/2002	1220	USGS	231	3.98	0.170	Runoff
05/23/2002	0805	COT	54	2.80	0.053	Runoff
05/28/2002	1542	USGS	519	4.68	0.810	Runoff
06/13/2002	0735	COT	58	2.57	0.053	Runoff
07/18/2002	0742	COT	7.2	2.27	0.033	Base flow
08/13/2002	0820	COT	1.8	1.45	0.045	Base flow
09/19/2002	0755	COT	0.08	1.15	0.048	Base flow
10/16/2002	0800	COT	0.07	1.24	0.041	Base flow
11/12/2002	0920	COT	2.8	1.34	0.032	Base flow
12/12/2002	0755	COT	4.4	1.34	0.029	Base flow
01/07/2003	0750	COT	7.2	1.79	0.039	Base flow
02/06/2003	0755	COT	3.9	1.53	0.021	Base flow
03/05/2003	0735	COT	39	2.93	0.024	Runoff
04/09/2003	0720	COT	17	2.16	0.028	Base flow
05/08/2003	0725	COT	12	1.53	0.038	Base flow
05/14/2003	0850	COT	26	[4] 2.01	0.039	Runoff
05/16/2003	1048	COT	127	1.41	0.077	Runoff
05/16/2003	1741	USGS	414	3.27	0.150	Runoff
05/20/2003	1929	USGS	263	3.60	0.280	Runoff
05/21/2003	1743	USGS	135	3.01	0.073	Runoff
06/02/2003	1755	USGS	118	3.78	0.064	Runoff
06/03/2003	0730	COT	108	2.30	0.040	Runoff
06/11/2003	1000	COT	22	2.27	0.038	Runoff
06/26/2003	1044	USGS	12	1.87	0.036	Runoff
07/10/2003	0750	COT	7.5	1.85	0.033	Base flow
08/05/2003	0730	COT	0.36	1.62	0.041	Base flow
09/02/2003	1549	USGS	15	1.13	0.043	Runoff
09/11/2003	0727	COT	3	0.87	0.032	Base flow
10/09/2003	0705	COT	4	0.93	0.032	Base flow
11/06/2003	0730	COT	6.4	1.00	0.036	Base flow

Appendix 5. Streamflows, and total nitrogen and total phosphorus concentrations for Beaty Creek near Jay, Oklahoma, 2002–2004. — Continued

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; mg/L, milligram per liter; N, nitrogen; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Agency collecting sample	Streamflow [1] (ft^3/s)	Total nitrogen concentration (mg/L as N) [2]	Total phosphorus concentration (mg/L as P)	Flow category [3]
11/19/2003	1722	USGS	15	1.51	0.033	Runoff
12/10/2003	0750	COT	6.7	2.26	0.025	Base flow
01/06/2004	0735	COT	26	2.58	0.032	Runoff
01/18/2004	1205	USGS	212	3.45	0.110	Runoff
02/05/2004	0725	COT	25	4.02	0.032	Base flow
03/04/2004	0744	COT	1,350	4.93	0.964	Runoff
03/04/2004	1345	USGS	916	4.13	0.260	Runoff
03/29/2004	1720	USGS	346	3.39	0.094	Runoff
04/07/2004	0729	COT	29	3.42	0.039	Base flow
04/23/2004	1115	USGS	162	2.66	0.079	Runoff
04/24/2004	1030	USGS	1,080	3.28	0.460	Runoff
05/06/2004	0724	COT	186	3.32	0.045	Runoff
06/10/2004	0720	COT	20	2.66	0.045	Base flow
07/03/2004	1635	USGS	953	2.67	0.490	Runoff
07/08/2004	0720	COT	104	3.16	0.067	Runoff
08/05/2004	0729	COT	18	2.57	0.089	Base flow
09/09/2004	0718	COT	7.1	2.20	0.050	Base flow
10/07/2004	0720	COT	4	1.84	0.047	Base flow
11/01/2004	1120	USGS	2,050	4.24	1.000	Runoff
11/03/2004	0738	COT	181	3.05	0.102	Runoff
12/09/2004	0740	COT	144	3.67	0.077	Runoff

[1] Streamflow for data collected by USGS is measured instantaneous streamflow; streamflow for data collected by COT is daily mean streamflow unless streamflow changing during the day, then it is 15-minute unit value.

[2] Total nitrogen is calculated by adding Kjeldahl-N and nitrite plus nitrate analyses.

[3] Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b); with the additional qualifier that any discharge less than 10 ft^3/s was designated baseflow.

[4] Nitrite plus nitrate analyses not reported, nitrate analyses was substitued in the total nitrogen calculation for this sample.