



Prepared in cooperation with the
City of Tulsa, Oklahoma

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



Spavinaw Creek near Colcord, Oklahoma

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.

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By Robert L. Tortorelli

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

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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

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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).

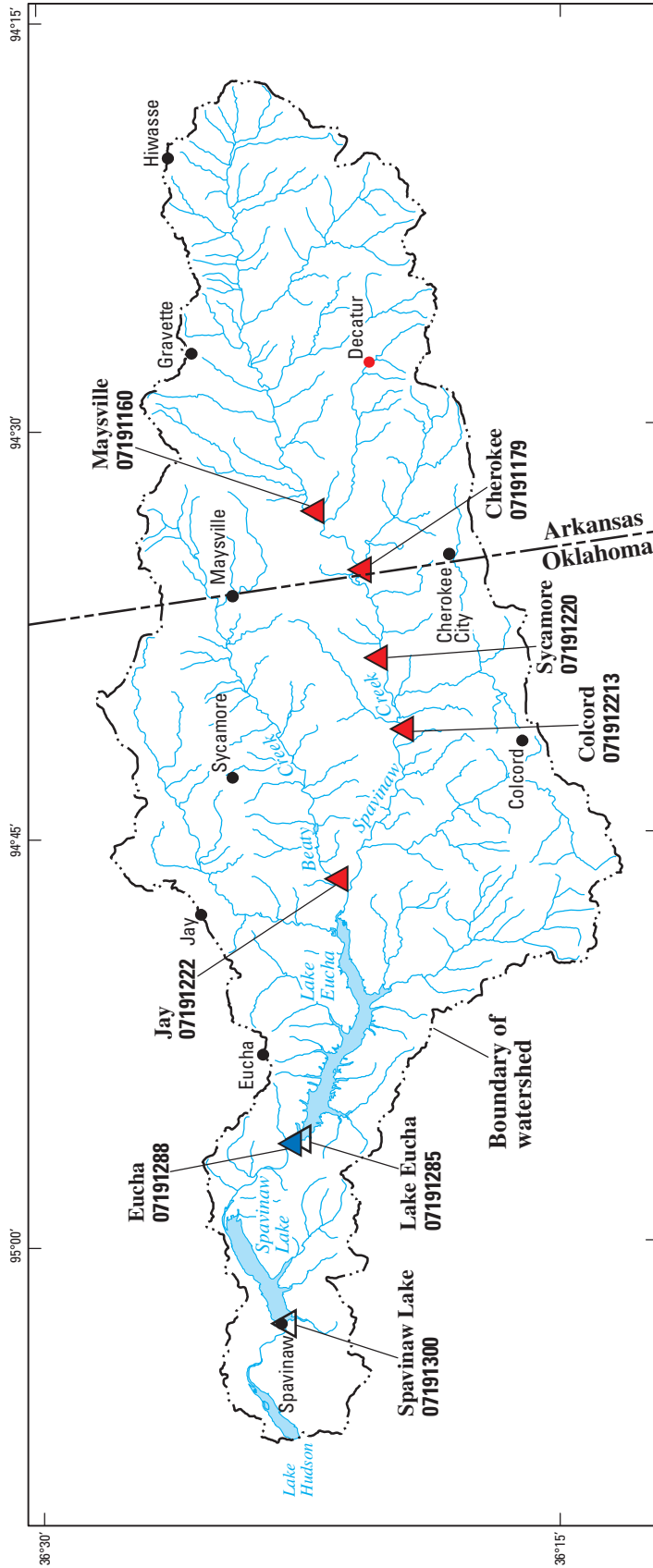
The Eucha-Spavinaw system continues to be designated as a system for public water supply along with recreation, fish and wildlife, and aesthetics. Eucha-Spavinaw provides a yield of 59 million gallons per day (mgd) to the Tulsa metropolitan area. Under drought conditions, the system can produce a maximum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



Base from U.S. Geological Survey digital data, 1:100,000, 1983, and U.S. Environmental Protection Agency enhanced River Reach File 3 Albers Equal-Area Conic projection, North American Datum of 1983

EXPLANATION

- 07191288 ▲ U.S. Geological Survey streamflow-gaging station and number
- 071912213 ▲ U.S. Geological Survey streamflow-gaging station and water-quality monitoring station and number (table 1)
- 07191285 △ U.S. Geological Survey lake-level station and number
- Town with water-treatment plant that discharges into streams in the Eucha-Spavinaw basin



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). Live-stock 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 phosphorus-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.

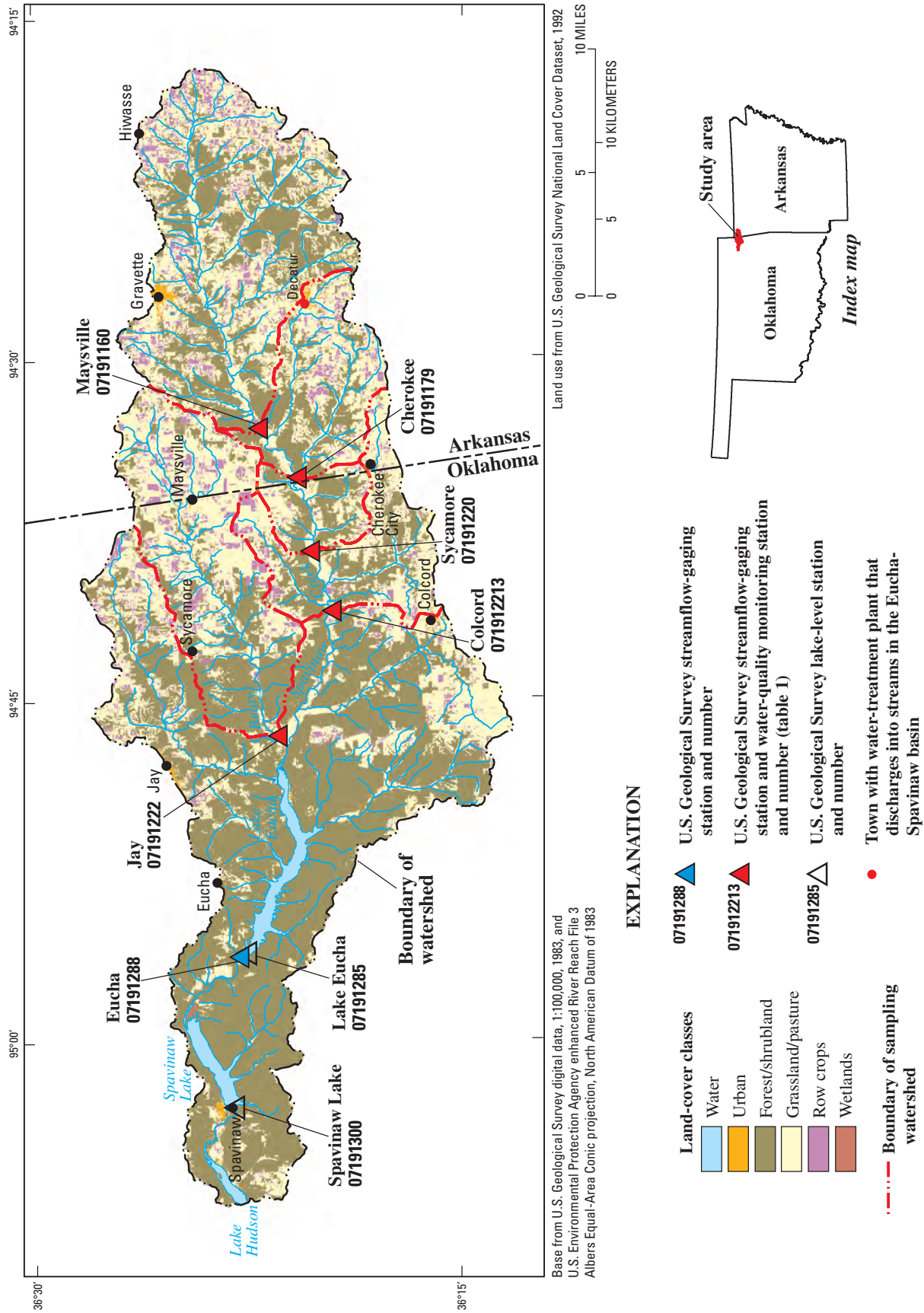


Figure 2. Land use in the Eucha-Spavinaw basin, Arkansas and Oklahoma.

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; ddmms, degrees, minutes, seconds; mi², square mile; ft³/s, cubic foot per second]

Station name (number)	Period of record for station (WY)	Latitude (ddmms)	Longitude (ddmms)	Drainage area (mi ²)	Mean annual streamflow (ft ³ /s)			Minimum and maximum daily mean streamflow for study period, 2002–2004 (ft ³ /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 Chero- kee, 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 Sycam- ore, 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.

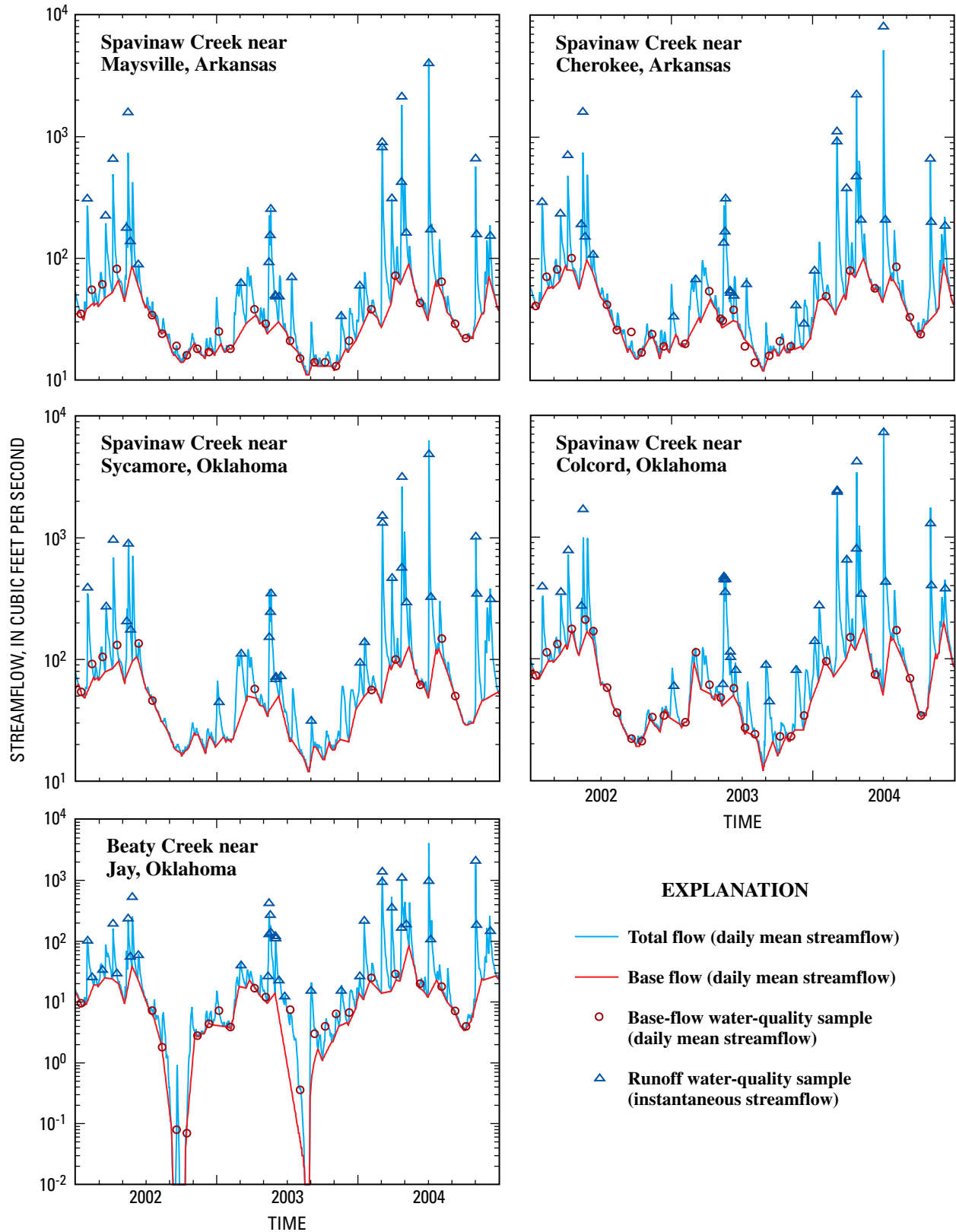


Figure 3. Streamflow divided into total flow and base flow, and base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

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 (ft³/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:

$$\ln(L) = b_0 + b_1 \ln Q + b_2 \ln Q^2 + b_3 T + b_4 T^2 + b_5 \sin SS + b_6 \cos SS \quad (1)$$

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 (ft³/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, decltime, time parameter in decimal years; SS, seasonality parameter, (2πdecltime); R², coefficient of determination]

Station name (number)	Nutrient	No. of obs.	Regression model	Estimated residual variance ¹	R ² (percent)
Spavinaw Creek near Maysville, Ark. (07191160)	Nitrogen	54	$\ln(L) = 7.92 + 1.06*\ln Q + 0.0091*\ln Q^2 + 0.0623*T + 0.108*\Gamma^2 + 0.156*\sin SS + 0.0014*\cos SS$	0.018	99
Spavinaw Creek near Cherokee, Ark. (07191179)	Phosphorus	53	$\ln(L) = 3.76 + 1.61*\ln Q + 0.128*\ln Q^2 - 0.0553*T - 0.195*\Gamma^2 - 0.208*\sin SS - 0.155*\cos SS$	0.240	96
Spavinaw Creek near Cherokee, Ark. (07191179)	Nitrogen	57	$\ln(L) = 8.28 + 1.00*\ln Q - 0.0129*\ln Q^2 + 0.0760*\Gamma + 0.0881*\Gamma^2 + 0.114*\sin SS + 0.0943*\cos SS$	0.025	99
Spavinaw Creek near Sycamore, Okla. (07191220)	Phosphorus	57	$\ln(L) = 5.05 + 1.13*\ln Q + 0.135*\ln Q^2 - 0.204*T - 0.0070*\Gamma^2 - 0.111*\sin SS - 0.0926*\cos SS$	0.177	94
Spavinaw Creek near Colcord, Okla. (07191221)	Nitrogen	40	$\ln(L) = 8.89 + 1.05*\ln Q + 0.0181*\ln Q^2 + 0.0554*T + 0.0485*\Gamma^2 + 0.0482*\sin SS + 0.0834*\cos SS$	0.022	99
Spavinaw Creek near Colcord, Okla. (07191221)	Phosphorus	39	$\ln(L) = 5.68 + 1.35*\ln Q + 0.162*\ln Q^2 - 0.171*T - 0.126*\Gamma^2 - 0.122*\sin SS - 0.0302*\cos SS$	0.055	98
Spavinaw Creek near Jay, Okla. (07191222)	Nitrogen	58	$\ln(L) = 8.47 + 1.02*\ln Q + 0.0027*\ln Q^2 + 0.0770*\Gamma + 0.105*\Gamma^2 + 0.155*\sin SS + 0.0651*\cos SS$	0.024	99
Spavinaw Creek near Jay, Okla. (07191222)	Phosphorus	58	$\ln(L) = 5.30 + 1.37*\ln Q + 0.0780*\ln Q^2 - 0.136*\Gamma - 0.192*\Gamma^2 - 0.0839*\sin SS - 0.0835*\cos SS$	0.116	97
Beauty Creek near Jay, Okla. (07191222)	Nitrogen	57	$\ln(L) = 5.19 + 1.07*\ln Q + 0.0074*\ln Q^2 + 0.0673*\Gamma + 0.244*\Gamma^2 + 0.295*\sin SS - 0.0035*\cos SS$	0.051	99
Beauty Creek near Jay, Okla. (07191222)	Phosphorus	57	$\ln(L) = 1.32 + 1.36*\ln Q + 0.0688*\ln Q^2 - 0.0967*\Gamma + 0.0636*\Gamma^2 - 0.317*\sin SS - 0.131*\cos SS$	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 (mg/L as N)					Obs	Runoff concentrations (mg/L as N)					Obs
		Minimum	Median	Mean	Maximum	Obs		Minimum	Median	Mean	Maximum	Obs	
Spavinaw Creek near Maysville, Ark. (07191160)	2002	2.80	3.31	3.60	4.80	10	3.40	3.97	4.35	7.40	7		
	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. (07191179)	2002	3.11	3.56	3.98	5.40	10	3.28	4.26	4.44	6.82	7		
	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. (07191220)	2002	3.65	4.60	4.60	5.50	6	3.20	4.35	4.65	7.10	6		
	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. (071912213)	2002	2.82	3.52	3.76	5.20	12	3.51	4.10	4.38	6.29	5		
	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. (07191222)	2002	1.15	1.34	1.71	3.20	7	2.57	2.90	3.23	4.68	9		
	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 (mg/L as P)					Obs	Runoff concentrations (mg/L as P)					Obs
		Minimum	Median	Mean	Maximum	Obs		Minimum	Median	Mean	Maximum	Obs	
Spavinaw Creek near Maysville, Ark. (07191160)	2002	0.022	0.026	0.027	0.033	10	0.028	0.042	0.120	0.500	7		
	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. (07191179)	2002	0.204	0.234	0.259	0.315	10	0.170	0.170	0.205	0.380	7		
	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. (07191220)	2002	0.143	0.146	0.147	0.153	6	0.140	0.165	0.186	0.310	6		
	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. (071912213)	2002	0.087	0.104	0.106	0.130	12	0.120	0.130	0.182	0.390	5		
	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. (07191222)	2002	0.029	0.041	0.039	0.048	7	0.031	0.053	0.155	0.810	9		
	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		

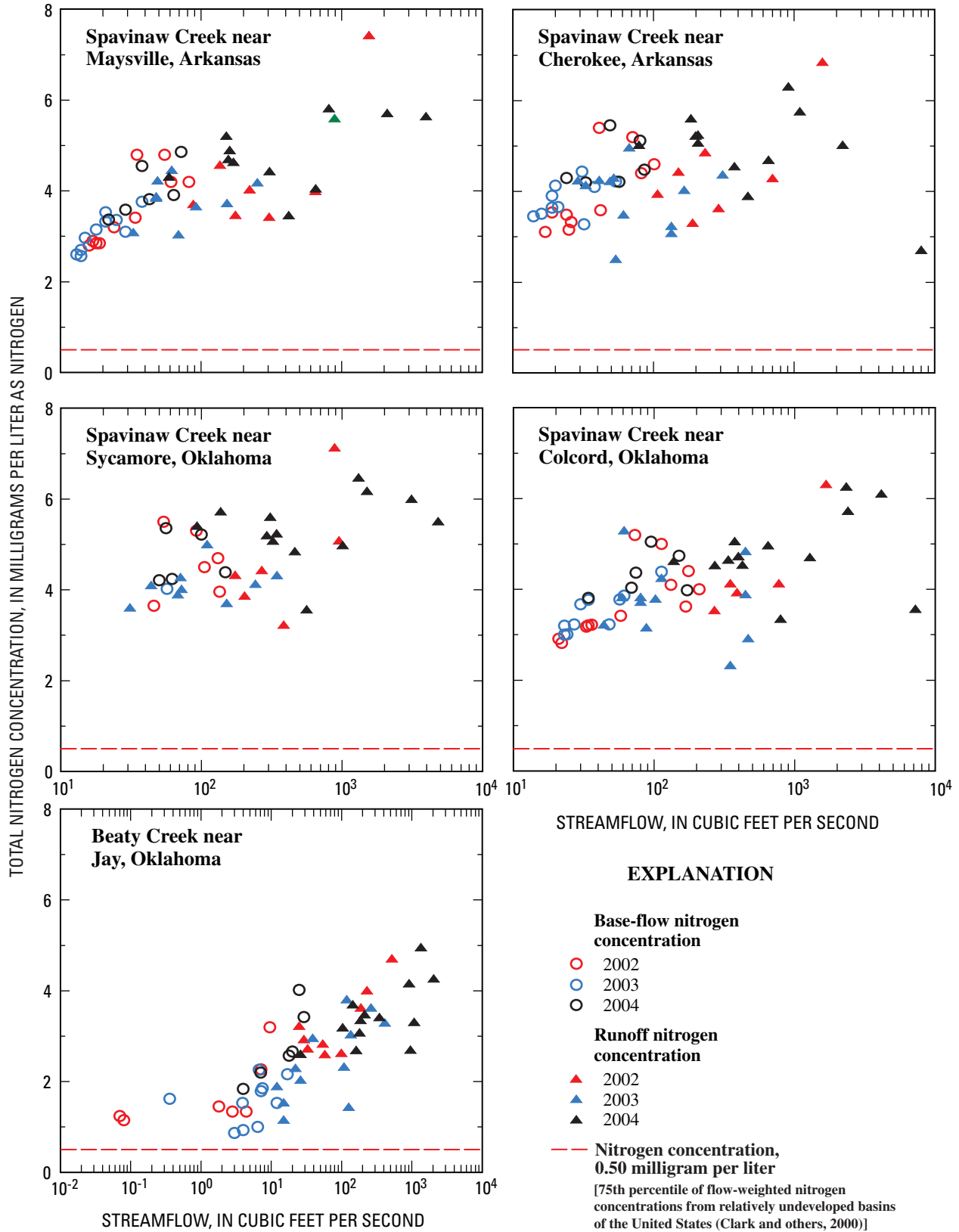


Figure 4. Total nitrogen concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

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 p = 0.0005	z = -4.383 p < 0.0001
Spavinaw Creek near Cherokee, Ark. (07191179)	z = -1.354 p = 0.1757	z = 1.835 p = 0.0665
Spavinaw Creek near Sycamore, Okla. (07191220)	z = -0.398 p = 0.6903	z = -1.583 p = 0.1133
Spavinaw Creek near Colcord, Okla. (071912213)	z = -2.070 p = 0.0385	z = -3.557 p = 0.0004
Beaty Creek near Jay, Okla. (07191222)	z = -4.140 p < 0.0001	z = -3.801 p = 0.0001

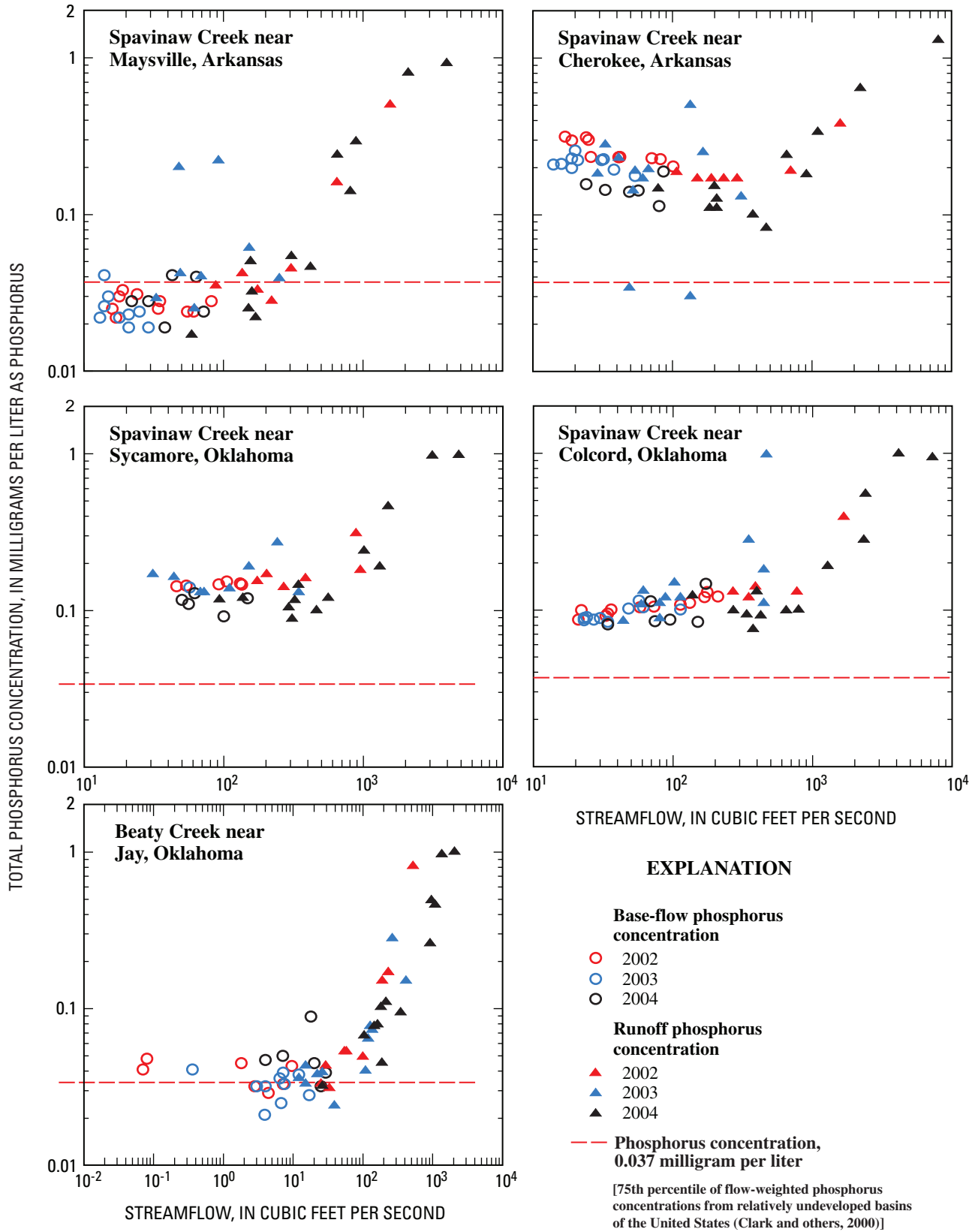
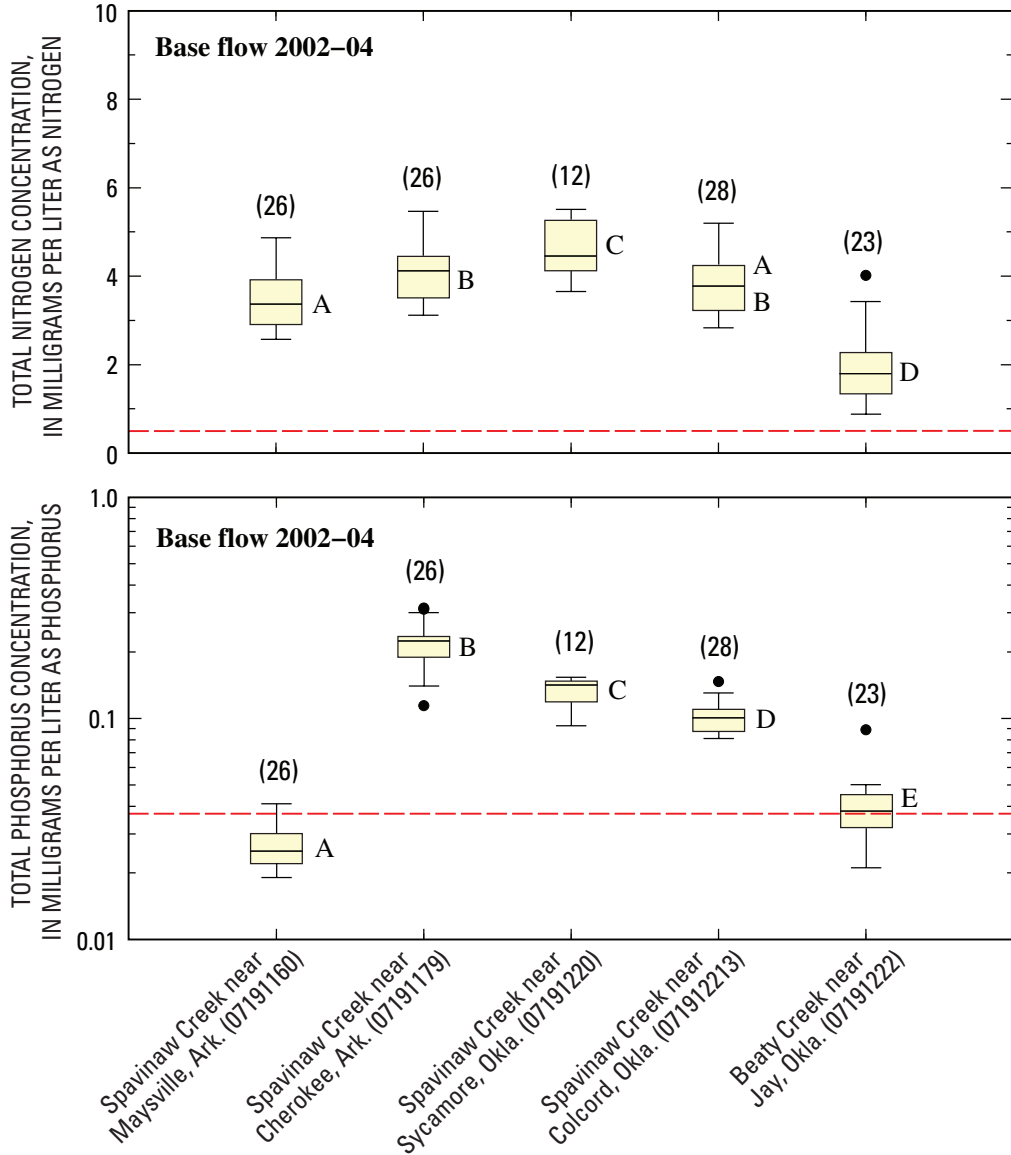


Figure 5. Total phosphorus concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.



EXPLANATION

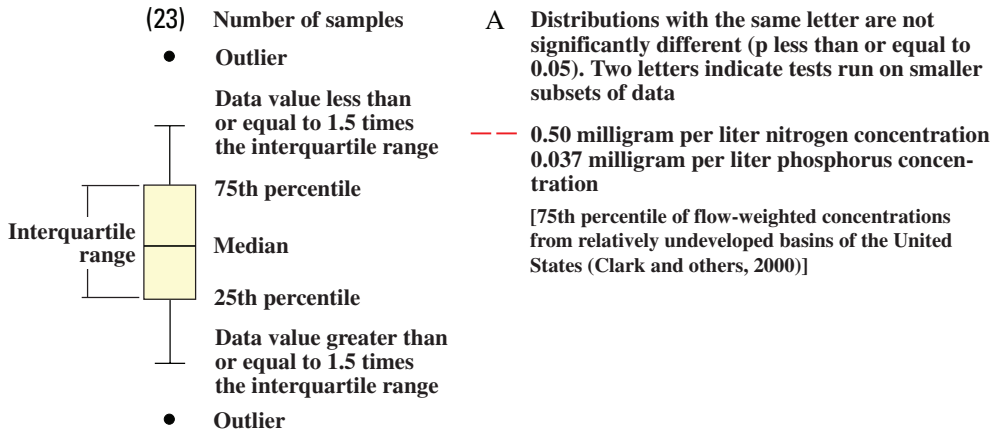
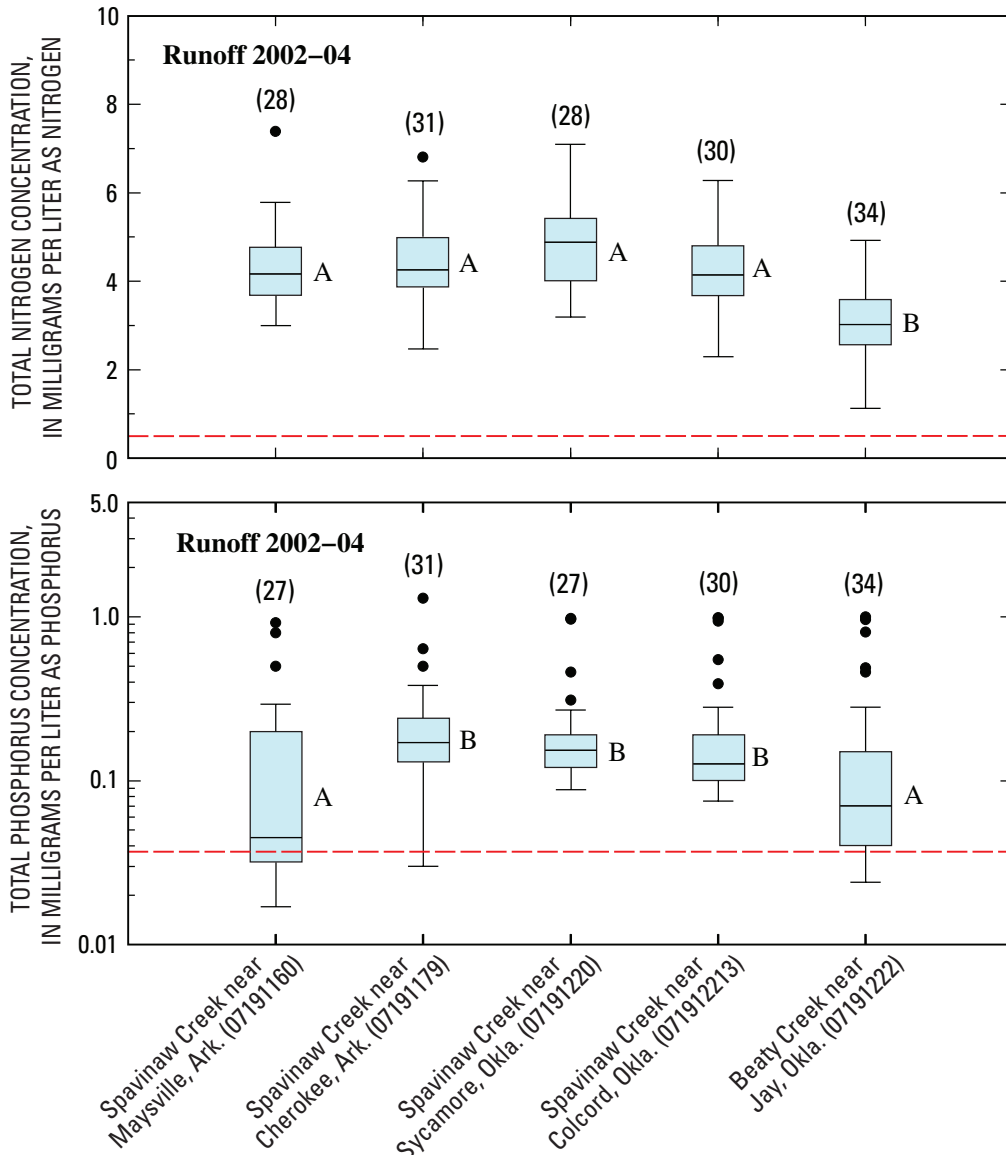


Figure 6. Distributions of **base-flow** total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.



EXPLANATION

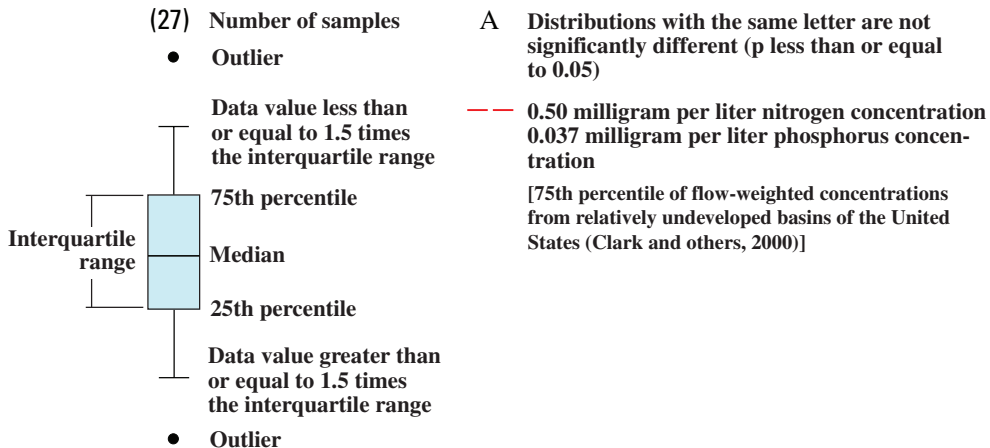


Figure 7. Distributions of runoff total nitrogen and total phosphorus concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2004.

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

