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Nutrient Concentrations, Loads, and Yields in the Eucha-Spavinaw Basin, Arkansas and Oklahoma, 2002–2006

Scientific Investigations Report 2008–5174

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

Cover Photograph Credits:

Top Left Picture is Beaty Creek near Jay, Delaware County, Oklahoma, downstream from the streamflow-gaging station, taken November 6, 2006. Photographer: Monica Allen, U.S. Geological Survey.

Top Right Picture is Spavinaw Creek near Colcord, Delaware County, Oklahoma, downstream from the stream-flow-gaging station, taken November 6, 2006. Photographer: Monica Allen, U.S. Geological Survey.

Bottom Picture is Lake Eucha, Delaware County, Oklahoma, at dam site, taken July 2001. Photographer: Robert L. Blazs, 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 (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 year (lb/yr)	0.4536	kilogram per year (kg/yr)
	Yield	
pound per year per square mile [(lb/yr)/mi^2]	0.1751	kilogram per year per kilometer [(kg/yr)/km^2]

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–MDLs) and establish laboratory reporting levels (LRLs). 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 ≤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).

Nutrient Concentrations, Loads, and Yields in the Eucha-Spavinaw Basin, Arkansas and Oklahoma, 2002-2006

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. 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, investigated and summarized nitrogen and phosphorus concentrations and provided estimates of nitrogen and phosphorus loads, yields, and flow-weighted concentrations in the Eucha-Spavinaw basin for three 3-year periods—2002–2004, 2003–2005, and 2004–2006, to update a previous report that used data from water-quality samples 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 agencies for interstate agreements.

Nitrogen and phosphorus concentrations were significantly greater in runoff samples than in base-flow samples for all three periods at Spavinaw Creek near Maysville, Arkansas; Spavinaw Creek near Colcord, Oklahoma, and Beaty Creek near Jay, Oklahoma. Runoff concentrations were not significantly greater than base-flow concentrations at Spavinaw Creek near Cherokee, Arkansas; and Spavinaw Creek near Sycamore, Oklahoma except for phosphorus during 2003–2005.

Nitrogen concentrations in base-flow samples significantly increased downstream in Spavinaw Creek from the Maysville to Sycamore stations then significantly decreased from the Sycamore to the Colcord stations for all three periods. Nitrogen in base-flow samples from Beaty Creek was significantly less than in samples from Spavinaw Creek. Phosphorus concentrations in base-flow samples significantly increased from the Maysville to Cherokee stations in Spavinaw Creek for all three periods, probably because of a wastewater-treatment plant point source between those stations, and 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 for most of the three periods, except during 2003–2005 when runoff samples at the Colcord station were less than at the Sycamore station; 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 were significantly different at the Maysville station on Spavinaw Creek and the Beaty Creek station, only during 2004–2006. Phosphorus and nitrogen concentrations in runoff samples from all stations generally increased with increasing streamflow.

Estimated mean annual nitrogen total loads for the three 3-year periods were substantially greater at the Spavinaw Creek stations than at Beaty Creek and increased downstream from Maysville to Colcord in Spavinaw Creek, with the load at the Colcord station about 2 times that at 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 to 89 percent; whereas, the range in the runoff component at the Spavinaw Creek stations was 60 to 71 percent.

Estimated mean annual phosphorus total loads for the three 3-year periods were greater at the Spavinaw Creek stations from Cherokee to Colcord than at Beaty Creek and increased downstream from Maysville to Colcord in Spavinaw Creek, with the load at the Colcord station about 2.5 times that at 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 4 to 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 Beaty Creek was 98 percent; whereas, the range in the runoff component at the Spavinaw Creek stations was 66 to 93 percent.

Estimated mean seasonal nitrogen base-flow and runoff loads generally were least in autumn for all three periods and greatest in spring at all stations in the Eucha-Spavinaw basin for 2002–2004 and 2003–2005; and greatest in spring and winter for 2004–2006. Seasonal base-flow loads at stations on Spavinaw Creek were about 3 to 20 times greater than at

the station on Beaty Creek and increased downstream from Maysville to Colcord in Spavinaw Creek, with the seasonal base-flow load at the Colcord station about 2 times that at Maysville station. Estimated mean seasonal phosphorus base-flow and runoff loads generally were least in autumn and greatest in spring for base-flow loads and greatest in the summer for runoff loads 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; with the seasonal base-flow load at the Cherokee station about 4 to 10 times that at Maysville station.

Estimated mean annual nitrogen total yields ranged from 4,340 to 7,490 pounds per year per square mile, with greatest yield at the Sycamore station in 2003–2005, and the least yield at Beaty Creek near Jay for all three periods. Estimated mean annual nitrogen base-flow yields ranged from 549 to 2,640 pounds per year per square mile, and estimated mean annual nitrogen runoff yields ranged from 3,680 to 5,150 pounds per year per square mile. Estimated mean annual phosphorus total yields ranged from 227 to 478 pounds per year per square mile, with the greatest yield at Beaty Creek, and the least yield at Spavinaw Creek near Maysville. Most of the yield at Beaty Creek was delivered during runoff. Estimated mean annual phosphorus base-flow yields at the three downstream Spavinaw Creek stations ranged from 46.1 to 112 pounds per year per square mile and were about 5 to 11 times greater than at Beaty Creek.

Estimated mean flow-weighted nitrogen concentrations at all stations in the basin for three 3-year periods were about 7 to 10 times greater than the 75th percentile of flow-weighted nitrogen concentrations (0.50 milligram per liter) in mostly undeveloped basins of the United States. Estimated mean flow-weighted phosphorus concentrations at all stations in the basin for all three periods were about 4 to 10 times greater than the 75th percentile of flow-weighted phosphorus concentrations (0.037 milligram per liter) in mostly undeveloped basins of the United States.

Spavinaw Creek and Beaty Creek contributed an estimated mean annual nitrogen total load of about 1,350,000 to 1,490,000 pounds per year, and about 65 to 72 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 to 88,700 pounds per year with about 86 to 89 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 of Spavinaw Dam on Spavinaw Creek began in 1922 and was completed in 1924. A series of pipelines 60-miles long, from the base of Spavinaw Dam to the City of Tulsa, were constructed to transfer water from Spavinaw Lake 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" (City of Tulsa City Services, 2008a) for Spavinaw Lake to ensure a constant supply of clean water. This second dam came to be known as Eucha Dam and was finished in 1954 to impound Lake Eucha (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. In a drought, the system can produce a maximum of 100 mgd (City of Tulsa City Services, 2008b).

Consumer complaints of taste and odor in the finished water have been reported. The Tulsa Metropolitan Utility Authority (TMUA) has spent millions of dollars from 1998–2005 to eliminate taste and odor problems in the drinking water from the Eucha-Spavinaw system. City staff has determined that taste and odor problems attributable to blue-green algae have increased in frequency. 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 (City of Tulsa City Services, 2008c). 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 made in 2001–2002 (Oklahoma Water Resources Board, 2002; Storm and others, 2001 and 2002).

Nitrogen and 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 nitrogen and 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. This waste is routinely spread onto fields as fertilizer, and can be a source of nitrogen and 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 more than 84 million birds, along with some 1,500 tons of nitrogen and phosphorous-rich waste per year (Tulsa Metropolitan Utility Authority, 2001).

Historical water-quality data collection in the Eucha-Spavinaw basin has been biased toward sampling during base

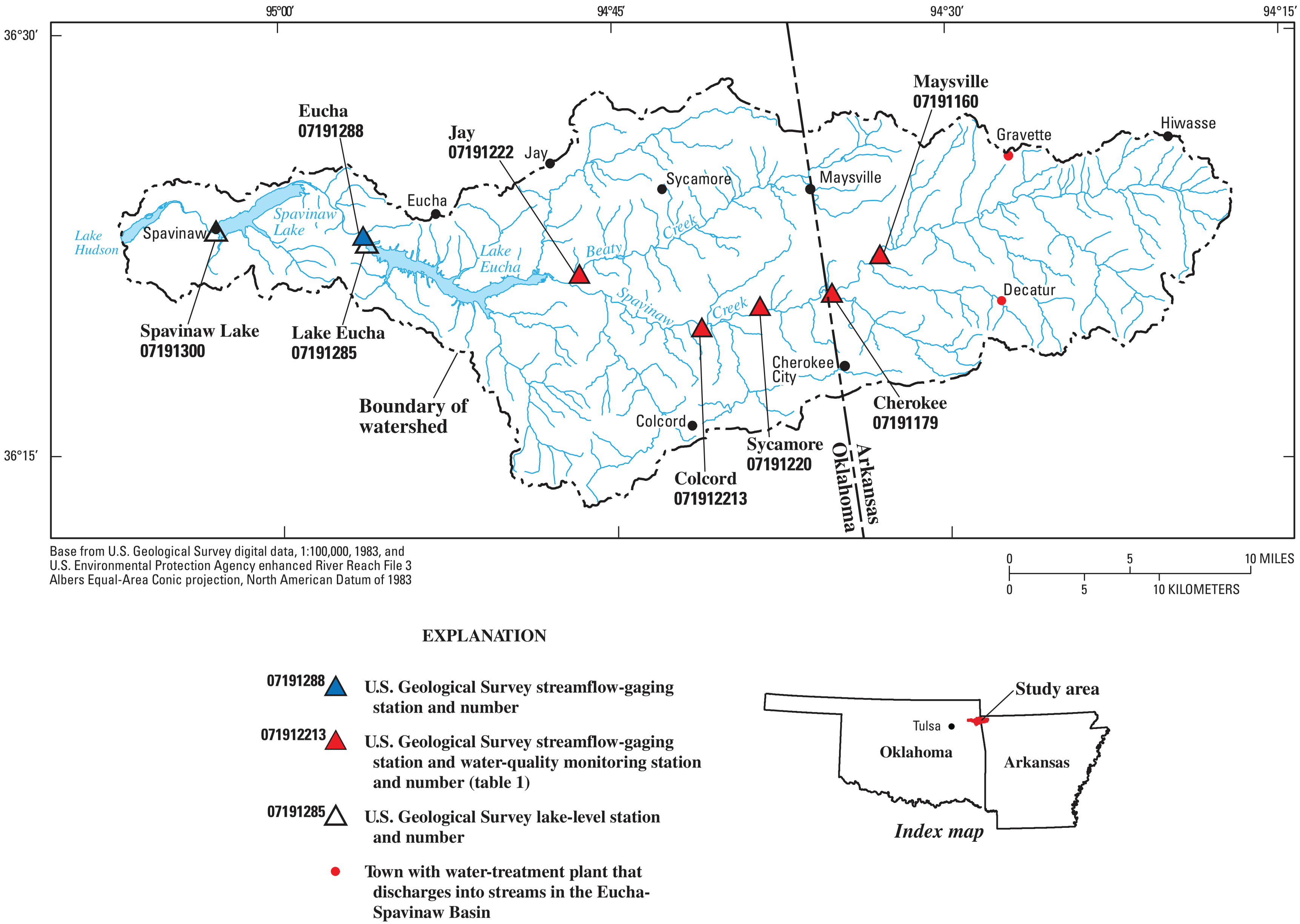

Figure 1. The Eucha-Spavinaw basin, Arkansas and Oklahoma, with locations of selected streamflow and water-quality stations in the basin and the towns with wastewater-treatment plants that discharge into streams in the basin.

flow (nonrunoff). Because of insufficient historic sampling during runoff, 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 samplings per year to better determine water quality over a broader range of streamflows in the basin. The period 2002–2006 encompasses a period where the runoff sampling protocol was in effect. The USGS, in cooperation with the City of Tulsa, Oklahoma, investigated and summarized nitrogen and phosphorus concentrations and provided estimates of nitrogen and phosphorus loads, yields, and flow-weighted concentrations in the Eucha-Spavinaw basin for three 3-year periods from January 2002 through December 2006.

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, from January 2002 through December 2006 for three 3-year periods—2002–2004, 2003–2005, and 2004–2006. This report updates the work of Tortorelli (2006), which used water-quality and streamflow data from 2002 to 2004, and 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 concentrations measured at mostly undeveloped basins of the United States. Nitrogen and phosphorus loads are computed by using S-LOADEST, a program to compute mean constituent loads in rivers by 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, autumn, and winter) average nutrient loads for the study period (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 agencies for interstate agreements.

Study Area Description

The Eucha-Spavinaw basin is a 388-square-mile drainage basin divided between northeastern Oklahoma (63 percent), and northwestern Arkansas (37 percent) (fig. 1) (R. Esralew, U.S. Geological Survey, written commun., 2008). 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.

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).

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 more than 84 million birds, along with some 1,500 tons of nitrogen and phosphorous-rich waste per year (Tulsa Metropolitan Utility Authority, 2001). There also is a municipal wastewater-treatment plant, operated by the city of Decatur, Arkansas, that discharges nitrogen and 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 septic tanks and 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 streams draining forested lands (Petersen and others, 1998), because runoff from pastures fertilized with animal manure probably are substantial sources of nitrogen and phosphorus to the streams in this basin (Storm and others, 2002). Streams receiving municipal wastewater from a treatment plant can have nitrogen and phosphorus concentrations substantially greater than concentrations in streams draining agricultural areas (Petersen and others, 1998). Spavinaw Creek (fig. 1) receives discharges from wastewater-treatment plants, whereas, Beaty Creek does not.

Streamflow in the Eucha-Spavinaw Basin

Streamflow in the Eucha-Spavinaw basin was highly varied from 2002 to 2006, and generally increased with basin drainage area (table 1, fig. 3). The maximum daily mean streamflow during the study period was in July 2004 at all stations, and the minimum daily mean streamflow during the study period was in August 2006 at the three upstream Spavinaw Creek stations, July 2006 at Spavinaw Creek near Colcord; and zero flow was at Beaty Creek near Jay at several times in September–October 2002, August 2003, October 2005, and July–October 2006 (table 1, fig. 3). Greatest monthly mean streamflows generally were from March through June and least monthly mean streamflows generally were from August through December at all stations (Blazs and others, 2003–2006, U.S. Geological Survey, 2007 and 2008).

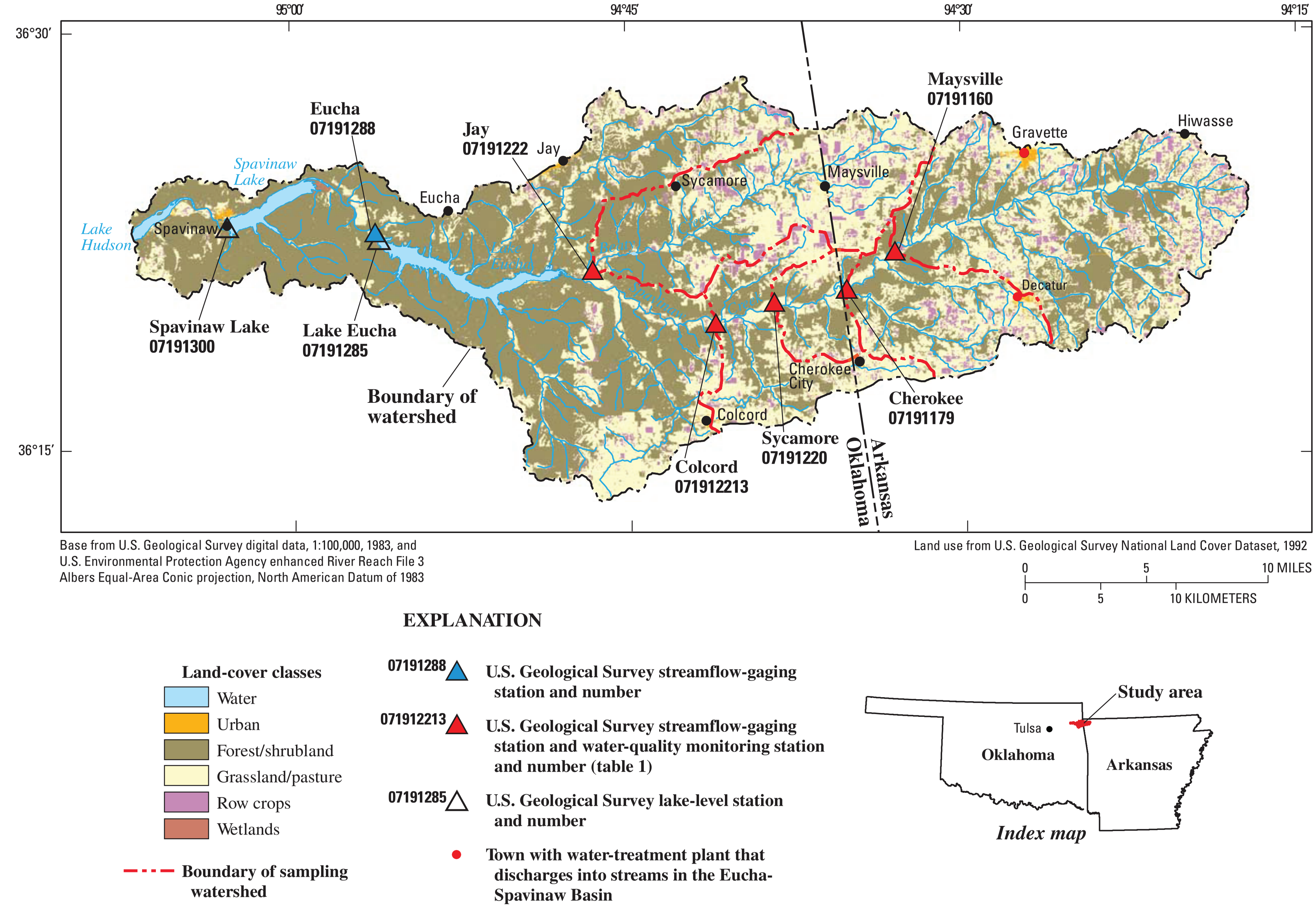

Figure 2. Land use in the Eucha-Spavinaw basin, Arkansas and Oklahoma.

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 (October 1 through September 30); 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, 2002–2006 (ft³/s)	
					2002–2004 (calendar year)	2003–2005 (calendar year)	2004–2006 (calendar year)	Period of record [1]	Minimum (date)	Maximum (date)
Spavinaw Creek near Maysville, Ark. (07191160)	2002–present	362152	943304	88.2	61.9	63.0	59.9	52.7	4.2 (08/04/2006)	4,150 (07/03/2004)
Spavinaw Creek near Cherokee, Ark. (07191179)	2002–present	362031	943515	104	74.4	77.8	74.8	64.5	7.0 (08/01/2006)	5,180 (07/03/2004)
Spavinaw Creek near Sycamore, Okla. (07191220)	1962–present	362005	943829	133	96.6	99.1	92.5	110	7.7 (08/18/2006)	6,300 (07/03/2004)
Spavinaw Creek near Colcord, Okla. (071912213)	2002–present	361921	944106	163	127	132	125	106	8.7 (07/29/2006)	7,720 (07/03/2004)
Beaty Creek near Jay, Okla. (07191222)	1998–present	362119	944634	59.2	38.7	44.1	42.4	39.6	0 at times 2002, 2003 2005, 2006	4,080 (07/03/2004)

[1] Based on streamflow statistics through Water Year 2007.

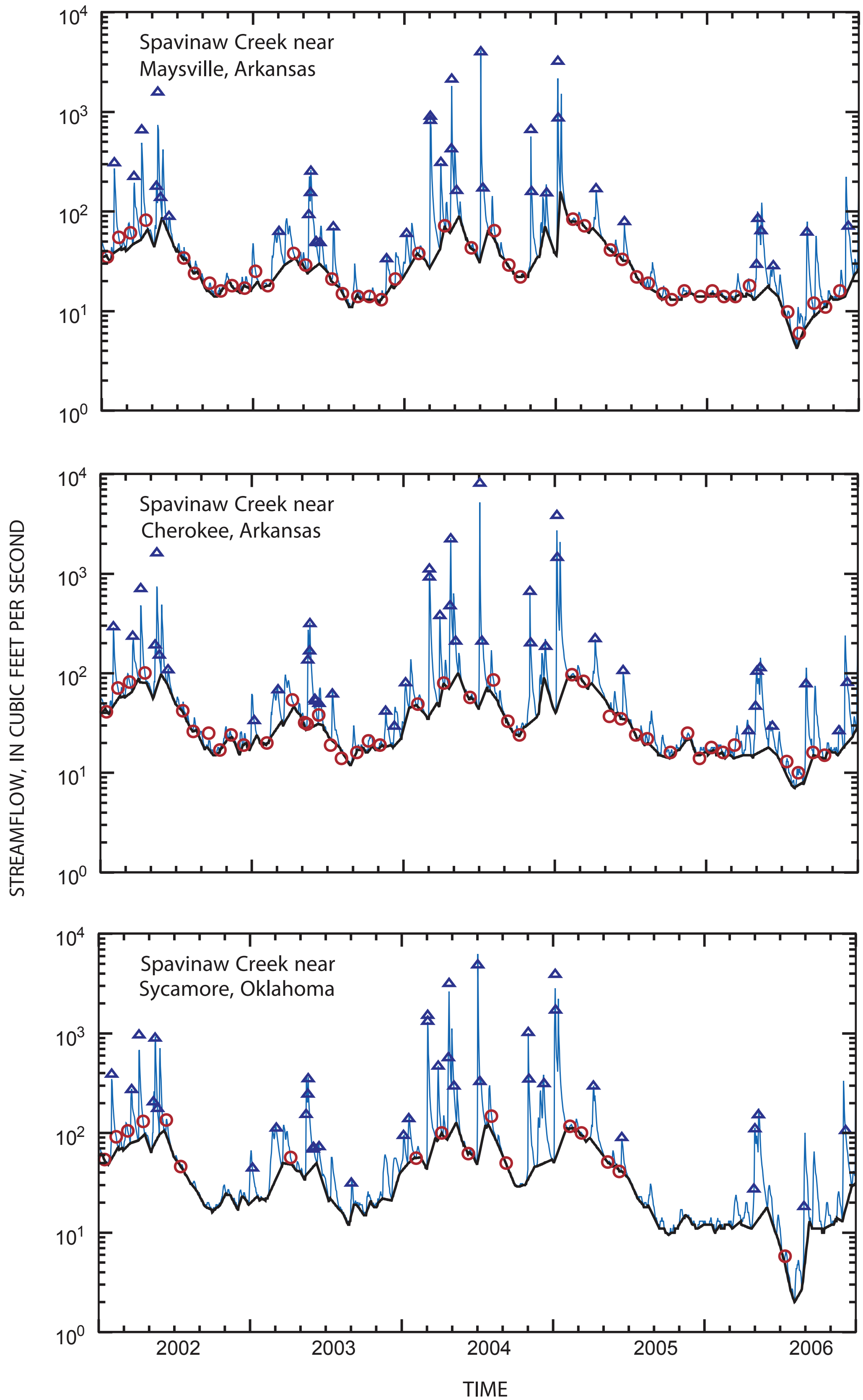

Figure 3. Streamflow divided into total flow and base flow, and base-flow and runoff water samples collected at water-quality stations in Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2006.—Continued

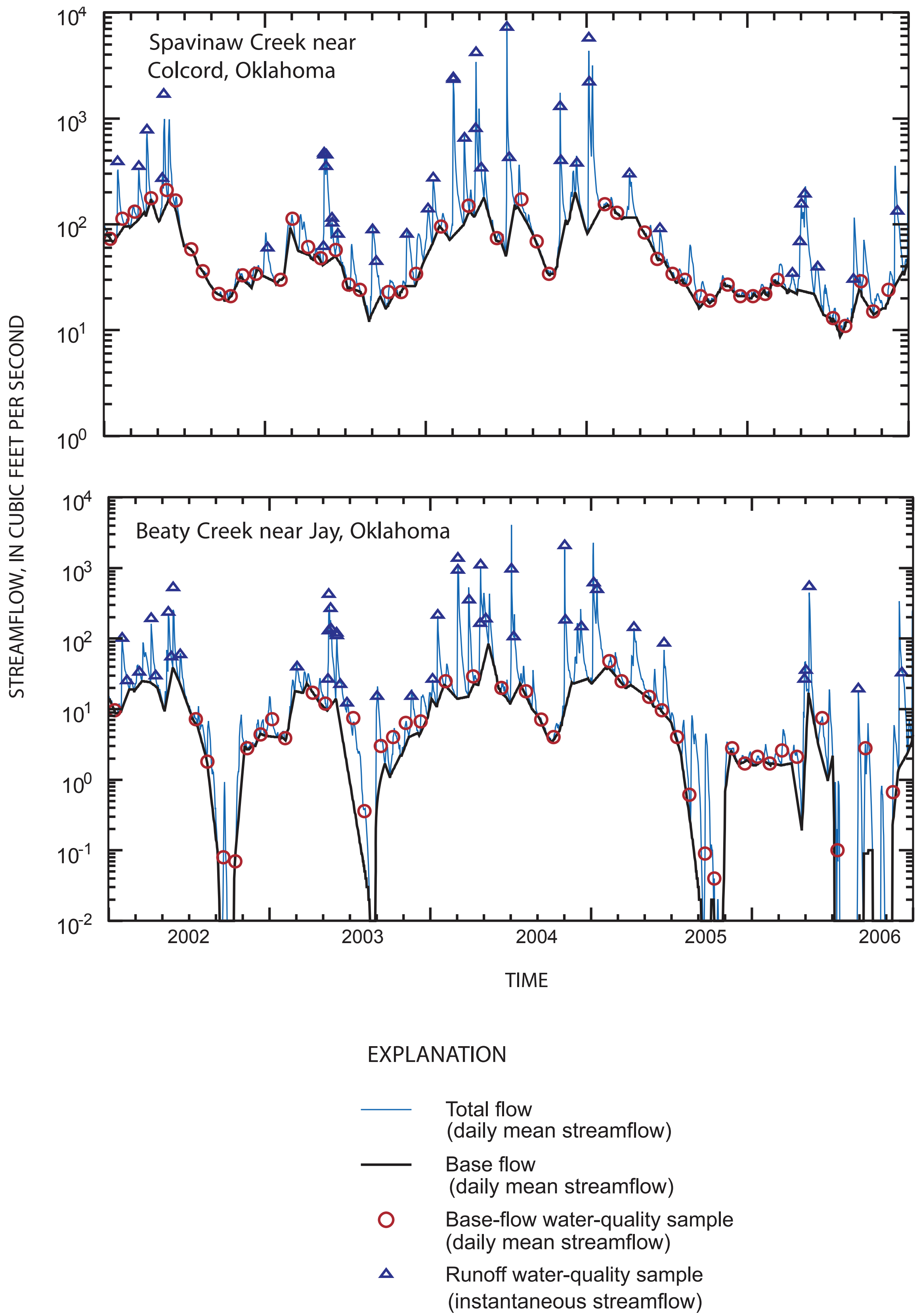

Figure 3. Streamflow divided into total flow and base flow, and base-flow and runoff water samples collected at water-quality stations in Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2006.

Acknowledgments

The author thanks several people for their contributions to the data collection and data analysis presented in this report. Numerous City of Tulsa personnel participated in monthly water-quality sampling, and numerous USGS personnel participated in the runoff water-quality sampling. The 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. Thanks to Rachel Esralew of the Oklahoma City Office for her assistance in the compilation of the nitrogen and phosphorus data set. Additional special thanks go to Dave Lorenz for his help in the use of 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, statistics of nutrient concentrations of undeveloped basins used to compare the basin data, and methods used to estimate total nitrogen and phosphorus loads and yields.

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, and included few runoff events. 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 targeted to be collected annually during runoff at these stations by the USGS. Because of climate variability, more than six samples were collected in some wet years and fewer than six samples were collected in some dry years (fig. 3). Representative water-quality samples were collected by USGS during runoff by using equal-width increment methods (Edwards and Glysson, 1999). Samples for total nitrogen and phosphorus were whole-water samples and were not filtered in the field. Total nitrogen and phosphorus concentrations represent dissolved and particulate components.

The City of Tulsa Water Quality Laboratory analyzed the water-quality samples (U.S. Environmental Protection Agency, 1983 and 1993). Total nitrogen concentrations were calculated by adding Kjeldahl-Nitrogen (measure of ammonia plus organic nitrogen) and nitrite plus nitrate analyses. Nitrogen and total phosphorus concentrations were reported if values were greater than 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 2006 were analyzed for this report. All streamflow and water-quality data from samples are available through the internet at *http://water.usgs.gov/ok/nwis*.

Quality assurance was achieved mainly through following a prescribed method of protocols and procedures as described in the National Field Manual (U.S. Geological Survey, 2006). Additionally, the collection and analysis of quality-control (QC) samples are mandated components of USGS water-quality field studies (U.S. Geological Survey, 2006) and compose an important part of the overall quality assurance of the project. The goal of QC sampling is to identify, quantify, and document bias and variability in data that result from the collection, processing, shipping, and handling of samples. Field blanks and field sequential replicates were collected by the USGS at the rate of about 20 percent of the number of environmental samples. The City of Tulsa collected QC samples at the rate of about 11 percent.

The two blank samples collected were from the Beaty Creek site in 2006. Total nitrogen components analyses were nondetectable. Total phosphorus analyses had values of 0.011mg/L (USGS) and 0.006 mg/L (City of Tulsa). Those results indicate that some contamination occurred as a result of sample collection or sample processing and the potential contamination should be considered when evaluating the phosphorus data in this report. Concentrations for this report ranged from 0.019 to 1.30 mg/L. The median relative percent difference between sequential replicate analyses for the main component of total nitrogen (nitrite plus nitrate) was acceptable at less than one percent. The median relative percent difference between sequential replicate total phosphorus analyses was acceptable at 2.7 percent.

Streamflow Separation

Streamflow was separated into base-flow and runoff components by 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). Base-flow and runoff components were separated because base-flow concentrations are more indicative of point sources and runoff concentrations are more indicative of nonpoint sources. 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 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 (Tortorelli and Pickup, 2006; Tortorelli, 2006).

Statistical Tests

Streamflow data and water-quality data were divided into three 3-year periods: 2002–2004, 2003–2005, and 2004–2006, on the basis of calendar year. Three-year periods were used to average annual climate variation and emulate a 3-year moving average. Three-year periods and a 3-year moving average were done to determine if there are any indications of major changes in concentrations and loads with time, because more data are needed for true trend analysis.

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 in the study period. The Kruskal-Wallis test (Helsel and Hirsch, 1992), used to compare multiple datasets at one time, was used to determine the statistical significance of differences in nitrogen and phosphorus concentrations among stations in the Eucha-Spavinaw basin in base-flow and runoff data groups.

The tests were selected because neither test requires normally distributed data. The null hypotheses of the tests are that there are no differences in median concentrations among the datasets 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 being 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).

Nutrient Concentrations in Undeveloped Basins

Nitrogen and phosphorus concentrations were compared among stations in the Eucha-Spavinaw basin and compared with the median and 75th percentile of flow-weighted total nitrogen and phosphorus concentrations of mostly undeveloped basins. These comparisons were from streams draining 85 mostly 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).

The Hydrologic Benchmark Network program, started 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 several physiologic, meteorologic, and hydrologic variables (Cobb and Biesecker, 1971). The Hydrologic Benchmark Network is primarily composed of mostly undeveloped basins encompassing a wide variety of natural environments nationwide (Mast and Turk, 1999).

The National Water-Quality Assessment program, started 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 small basins ranged in size from about 0.04 to 8.5 square miles, and were predominately in the Appalachian and Rocky Mountains (Clark and others, 2000).

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 during 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 internet at *http://water.usgs.gov/ok/nwis.*

Load is the amount of a constituent transported past a selected point in a stream in a given amount of time, usually one year. 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). 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 (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 by 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); however, none were present (censored values are the value of the LRL reported with a "less than" remark code for samples in which the concentration was not detected). 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 by 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 simulate the relation between the natural logarithms of L, Q and Q^2:

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

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).

Linear regression models developed by S-LOADEST for the estimation of nitrogen and phosphorus loads for all 3-year periods at each station are listed in tables 2 and 3. 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 that used 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. Therefore, one general model (equation 1) was selected for all stations and nutrients: (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 in most of the "best" models for each nutrient.

Three-year periods were used to average annual climate variation and to emulate a 3-year moving average. Different model coefficients for each 3-year period were used (1) to allow the slope between L and Q to vary with time instead of having one slope for the 5-year period, and (2) because most of the model variances were lower by using different 3-year models instead of a single 5-year model, indicating a better model fit.

Estimated mean annual nitrogen and phosphorus loads and estimates of the standard deviations of the mean loads were calculated by S-LOADEST by 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 each 3-year 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 on the basis of the number of base-flow and runoff days in each season. In this report, spring is March through May, summer is June through August, autumn 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 are described in terms of three 3-year periods (2002–2004, 2003–2005, and 2004–2006) 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 4 and 5. Graphs showing the nitrogen and phosphorus concentrations from base-flow and runoff water samples are presented in figures 4 and 5.

Table 2. Regression models for estimating total **nitrogen** loads at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, developed by using data collected during 2002–2006.

[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, (2*pi*dectime); R^2, coefficient of determination; +, Indicates >99.5% but <100%]

Station name (number)	3-year period	No. of obs.	Total nitrogen load regression model	Estimated residual variance [1]	R^2 (percent)
Spavinaw Creek near	2002–2004	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
Maysville, Ark.	2003–2005	51	$\ln(L) = 8.21 + 1.11*\ln Q – 0.0009*\ln Q^2 + 0.0115*T – 0.0754*T^2 + 0.0914*\sin SS + 0.0665*\cos SS$	0.017	99+
(07191160)	2004–2006	47	$\ln(L) = 7.91 + 1.10*\ln Q + 0.0062*\ln Q^2 – 0.186*T – 0.0120*T^2 – 0.0362*\sin SS + 0.139*\cos SS$	0.072	98
Spavinaw Creek near	2002–2004	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
Cherokee, Ark.	2003–2005	53	$\ln(L) = 8.58 + 1.03*\ln Q – 0.0092*\ln Q^2 + 0.0360*T – 0.0963*T^2 + 0.0572*\sin SS + 0.167*\cos SS$	0.028	99
(07191179)	2004–2006	46	$\ln(L) = 8.48 + 1.06*\ln Q – 0.0203*\ln Q^2 – 0.0743*T – 0.0144*T^2 – 0.0345*\sin SS + 0.188*\cos SS$	0.026	99
Spavinaw Creek near	2002–2004	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
Sycamore, Okla.	2003–2005	36	$\ln(L) = 9.15 + 1.06*\ln Q + 0.0180*\ln Q^2 + 0.0534*T – 0.0794*T^2 + 0.0465*\sin SS + 0.139*\cos SS$	0.012	99+
(07191220)	2004–2006	33	$\ln(L) = 8.73 + 1.07*\ln Q + 0.0079*\ln Q^2 – 0.0641*T – 0.0187*T^2 + 0.0048*\sin SS + 0.165*\cos SS$	0.016	99+
Spavinaw Creek near	2002–2004	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
Colcord, Okla.	2003–2005	55	$\ln(L) = 8.77 + 1.05*\ln Q + 0.0047*\ln Q^2 + 0.0319*T – 0.101*T^2 + 0.114*\sin SS + 0.125*\cos SS$	0.028	99
(071912213)	2004–2006	48	$\ln(L) = 8.58 + 1.08*\ln Q – 0.0052*\ln Q^2 – 0.0881*T – 0.0383*T^2 + 0.0232*\sin SS + 0.166*\cos SS$	0.021	99+
Beaty Creek near	2002–2004	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
Jay, Okla.	2003–2005	55	$\ln(L) = 5.38 + 1.10*\ln Q + 0.0034*\ln Q^2 + 0.0508*T - 0.201*T^2 + 0.268*\sin SS + 0.0780*\cos SS$	0.060	99
(07191222)	2004–2006	45	$\ln(L) = 5.28 + 1.14*\ln Q – 0.0050*\ln Q^2 – 0.199*T - 0.0342*T^2 + 0.0244*\sin SS + 0.126*\cos SS$	0.058	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.

Table 3. Regression models for estimating total **phosphorus** loads at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, developed by using data collected during 2002–2006.

[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, (2*pi*dectime); R^2, coefficient of determination]

Station name (number)	3-year period	No. of obs.	Total phosphorus load regression model	Estimated residual variance [1]	R^2 (percent)
Spavinaw Creek near	2002–2004	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
Maysville, Ark.	2003–2005	50	$\ln(L) = 3.64 + 1.65*\ln Q + 0.120*\ln Q^2 + 0.0134*T + 0.299*T^2 - 0.211*\sin SS - 0.248*\cos SS$	0.277	96
(07191160)	2004–2006	43	$\ln(L) = 3.83 + 1.60*\ln Q + 0.151*\ln Q^2 + 0.236*T - 0.141*T^2 - 0.100*\sin SS - 0.0556*\cos SS$	0.207	97
Spavinaw Creek near	2002–2004	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
Cherokee, Ark.	2003–2005	53	$\ln(L) = 4.99 + 1.21*\ln Q + 0.131*\ln Q^2 - 0.180*T + 0.0760*T^2 - 0.115*\sin SS + 0.0466*\cos SS$	0.210	95
(07191179)	2004–2006	42	$\ln(L) = 5.06 + 1.26*\ln Q + 0.104*\ln Q^2 + 0.0579*T + 0.0244*T^2 - 0.139*\sin SS - 0.0463*\cos SS$	0.074	98
Spavinaw Creek near	2002–2004	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
Sycamore, Okla.	2003–2005	35	$\ln(L) = 5.49 + 1.41*\ln Q + 0.186*\ln Q^2 - 0.215*T + 0.149*T^2 - 0.0654*\sin SS - 0.0466*\cos SS$	0.064	99
(07191220)	2004–2006	33	$\ln(L) = 4.77 + 1.31*\ln Q + 0.109*\ln Q^2 - 0.0153*T + 0.0011*T^2 - 0.0280*\sin SS - 0.0400*\cos SS$	0.100	98
Spavinaw Creek near	2002–2004	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
Colcord, Okla.	2003–2005	55	$\ln(L) = 5.07 + 1.40*\ln Q + 0.0877*\ln Q^2 - 0.175*T + 0.189*T^2 - 0.0628*\sin SS - 0.142*\cos SS$	0.125	98
(071912213)	2004–2006	44	$\ln(L) = 4.93 + 1.32*\ln Q + 0.107*\ln Q^2 + 0.0023*T - 0.0386*T^2 + 0.0553*\sin SS - 0.0109*\cos SS$	0.121	98
Beaty Creek near	2002–2004	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
Jay, Okla.	2003–2005	55	$\ln(L) = 1.26 + 1.32*\ln Q + 0.0633*\ln Q^2 + 0.104*T + 0.0380*T^2 - 0.256*\sin SS - 0.121*\cos SS$	0.107	99
(07191222)	2004–2006	43	$\ln(L) = 1.25 + 1.27*\ln Q + 0.0624*\ln Q^2 + 0.0784*T - 0.0825*T^2 - 0.211*\sin SS - 0.0337*\cos SS$	0.145	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

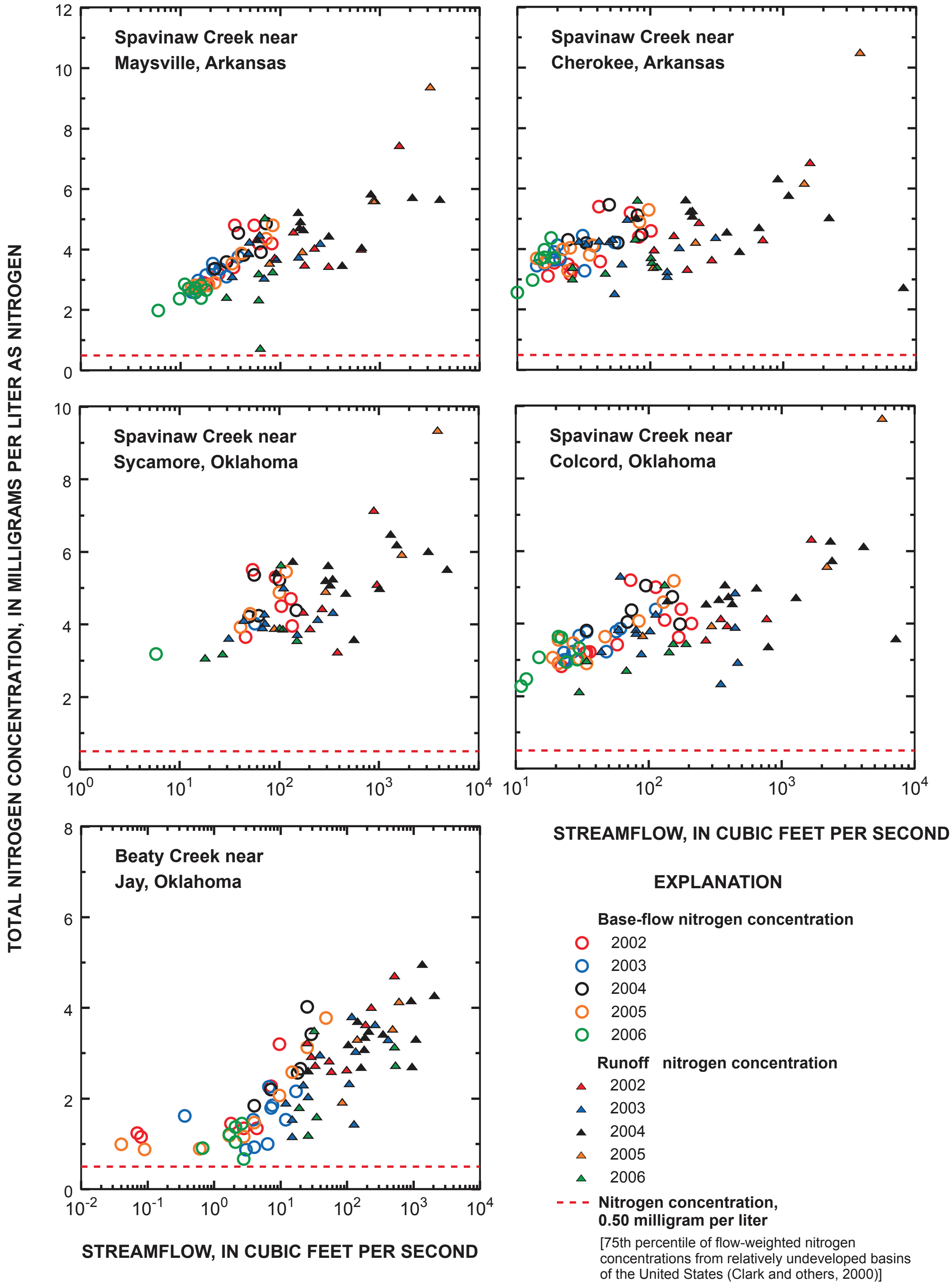

Figure 4. Total **nitrogen** concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2006.

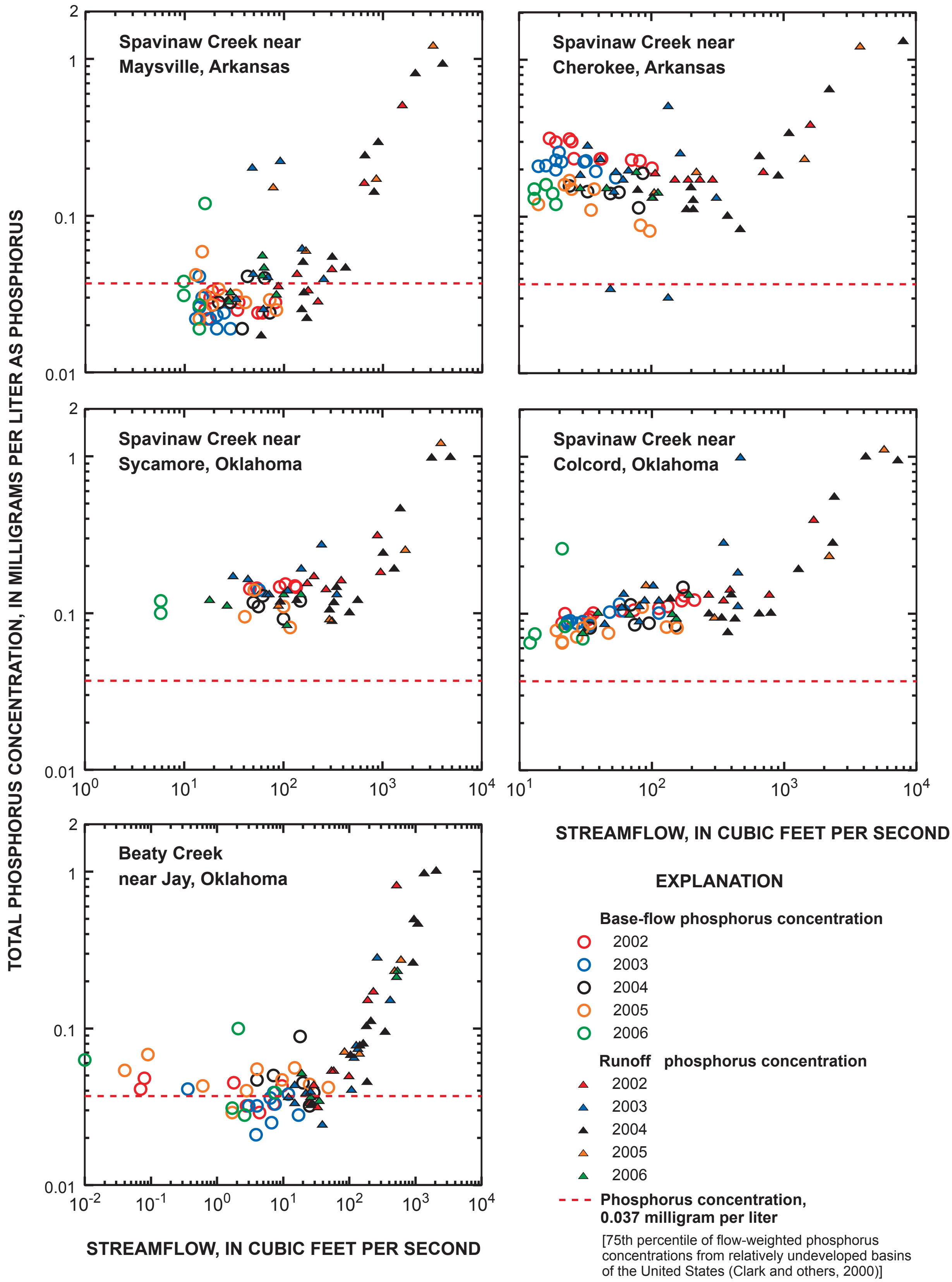

Figure 5. Total **phosphorus** concentrations in base-flow and runoff water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, 2002–2006.

Table 4. 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, periods 2002–2004, 2003–2005, and 2004–2006.

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

Station name (number)	3-year 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	2002–2004	2.57	3.36	3.51	4.86	26	3.01	4.18	4.37	7.40	28
Maysville, Ark.	2003–2005	2.57	3.34	3.40	4.86	26	3.01	4.28	4.57	9.34	25
(07191160)	2004–2006	1.98	2.82	3.22	4.86	25	0.69	4.50	4.41	9.34	22
Spavinaw Creek near	2002–2004	3.11	4.12	4.07	5.46	26	2.48	4.27	4.40	6.82	31
Cherokee, Ark.	2003–2005	3.28	4.10	4.11	5.46	25	2.48	4.30	4.62	10.45	28
(07191179)	2004–2006	2.56	4.02	4.06	5.46	22	2.68	4.59	4.70	10.45	24
Spavinaw Creek near	2002–2004	3.65	4.44	4.59	5.50	12	3.20	4.88	4.79	7.10	28
Sycamore, Okla.	2003–2005	3.92	4.34	4.60	5.45	10	3.54	4.96	5.01	9.31	26
(07191220)	2004–2006	3.18	4.34	4.51	5.45	10	3.03	5.17	5.06	9.31	23
Spavinaw Creek near	2002–2004	2.82	3.78	3.79	5.20	28	2.30	4.16	4.30	6.29	30
Colcord, Okla.	2003–2005	2.90	3.72	3.75	5.18	26	2.30	4.50	4.48	9.62	29
(071912213)	2004–2006	2.28	3.58	3.61	5.18	24	2.08	4.55	4.49	9.62	24
Beaty Creek near	2002–2004	0.87	1.79	1.92	4.02	23	1.13	3.03	3.02	4.93	34
Jay, Okla.	2003–2005	0.87	1.82	1.94	4.02	26	1.13	3.16	2.98	4.93	29
(07191222)	2004–2006	0.67	1.46	1.89	4.02	22	1.16	3.28	3.09	4.93	23

Table 5. 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, periods 2002–2004, 2003–2005, and 2004–2006.

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

Station name (number)	3-year period	Base-flow concentrations					Runoff concentrations				
		Minimum (mg/L as P)	Median (mg/L as P)	Mean (mg/L as P)	Maximum (mg/L as P)	Obs.	Minimum (mg/L as P)	Median (mg/L as P)	Mean (mg/L as P)	Maximum (mg/L as P)	Obs.
Spavinaw Creek near	2002–2004	0.019	0.025	0.027	0.041	26	0.017	0.045	0.153	0.920	27
Maysville, Ark.	2003–2005	0.019	0.028	0.029	0.059	26	0.017	0.056	0.203	1.200	24
(07191160)	2004–2006	0.019	0.029	0.035	0.120	21	0.017	0.052	0.202	1.200	22
Spavinaw Creek near	2002–2004	0.114	0.223	0.216	0.315	26	0.030	0.170	0.235	1.300	31
Cherokee, Ark.	2003–2005	0.081	0.160	0.169	0.257	25	0.030	0.181	0.272	1.300	28
(07191179)	2004–2006	0.081	0.143	0.139	0.189	20	0.082	0.150	0.281	1.300	22
Spavinaw Creek near	2002–2004	0.092	0.142	0.132	0.153	12	0.088	0.153	0.229	0.980	27
Sycamore, Okla.	2003–2005	0.081	0.114	0.113	0.140	10	0.088	0.138	0.269	1.200	25
(07191220)	2004–2006	0.081	0.110	0.110	0.140	11	0.083	0.120	0.272	1.200	22
Spavinaw Creek near	2002–2004	0.081	0.100	0.101	0.147	28	0.075	0.126	0.238	0.990	30
Colcord, Okla.	2003–2005	0.065	0.086	0.090	0.147	26	0.075	0.123	0.269	1.100	29
(071912213)	2004–2006	0.065	0.081	0.093	0.260	21	0.074	0.100	0.258	1.100	23
Beaty Creek near	2002–2004	0.021	0.038	0.039	0.089	23	0.024	0.070	0.178	1.000	34
Jay, Okla.	2003–2005	0.021	0.040	0.042	0.089	26	0.024	0.077	0.183	1.000	29
(07191222)	2004–2006	0.028	0.045	0.050	0.100	21	0.032	0.098	0.226	1.000	22

Nitrogen

Nitrogen concentrations were significantly greater ($p \leq 0.05$) in runoff samples than in base-flow samples for all three periods, 2002–2004, 2003–2005, and 2004–2006, at Spavinaw Creek near Maysville, Arkansas; Spavinaw Creek near Colcord, Oklahoma, and Beaty Creek near Jay, Oklahoma (tables 4 and 6, 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 all 3-year periods significantly increased ($p \leq 0.05$) downstream in Spavinaw Creek from the Maysville to Sycamore stations, except 2004–2006 (fig. 6). Nitrogen concentrations in base-flow samples during all 3-year periods significantly decreased ($p \leq 0.05$) downstream 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 4). As base flow increased by addition of ground water, additional nitrate in the ground water may increase the concentration of nitrogen as nitrogen is more prone to leach than phosphorus. Spavinaw Creek received nitrogen concentrations from a point source (the City of Decatur, Arkansas, municipal wastewater treatment plant), but Beaty Creek did not. Nitrogen concentrations in base-flow samples from Beaty Creek were significantly less than nitrogen concentrations in base-flow samples from Spavinaw Creek during all 3-year periods (fig. 6).

Nitrogen concentrations in runoff samples during 2002–2004 and 2004–2006 were not significantly different among the stations on Spavinaw Creek; but during 2003–2005, the concentrations at the Colcord station were significantly less than concentrations at the Sycamore station (fig. 7). However, the concentrations at Beaty Creek were significantly less than at all other stations during all 3-year periods (fig. 7). Nitrogen concentrations in runoff samples from all stations generally increased with increasing streamflow (fig. 4). The larger concentrations of nitrogen during runoff 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 during all 3-year periods at Spavinaw Creek near Maysville, Arkansas; Spavinaw Creek near Colcord, Oklahoma, and Beaty Creek near Jay, Oklahoma (tables 5 and 6, 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, except during 2003–2005.

Phosphorus concentrations in base-flow samples during all 3-year periods significantly increased ($p \leq 0.05$) from the Maysville to Cherokee stations in Spavinaw Creek probably because of a point source between those stations (the City of Decatur, Arkansas, municipal wastewater treatment plant) (fig. 8). Phosphorus concentrations in base-flow samples significantly decreased ($p \leq 0.05$) downstream in Spavinaw Creek from the Cherokee to Colcord stations (fig. 8), as has been reported for other point-source affected streams in the region (Haggard, 2000; Haggard and others, 2001; Tortorelli and Pickup, 2006). Phosphorus concentrations in base-flow samples from Spavinaw Creek generally decreased with increasing streamflow (fig. 5, table 5). As base flow increased by addition of ground water, dilution reduced the concentration of phosphorus from point sources. Spavinaw Creek 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 all 3-year periods (fig. 8).

Phosphorus concentrations in runoff samples during all 3-year periods were not significantly different among the three downstream stations on Spavinaw Creek; and were significantly different at the Maysville station on Spavinaw Creek and the Beaty Creek station, only during 2004–2006 (fig. 9). Phosphorus concentrations in runoff samples from all stations generally increased with increasing streamflow (fig. 5). Possible causes of larger concentrations of phosphorus during runoff than in base flow are the addition of phosphorus from nonpoint sources, resuspension of phosphorus from the streambed sediment, and streambank erosion. Wagner and Woodruff (1997) and Storm and others (2001) attribute most of the phosphorus transported in the basin to nonpoint sources during runoff.

Estimated Mean Annual Loads

Estimated mean annual nitrogen and phosphorus loads are discussed in this section. Total annual loads are divided into base-flow and runoff components as presented in tables 7 and 8.

Nitrogen

Estimated mean annual nitrogen total loads were substantially greater at Spavinaw Creek stations than at Beaty Creek (about 2 to 5 times), primarily because of greater streamflow at the stations on the Spavinaw Creek (tables 1 and 7). Annual total loads increased downstream (table 7) from Maysville to Colcord in Spavinaw Creek, with the annual total load at the Colcord station about 2 times that of Maysville station during all 3-year periods (table 7).

Estimated mean annual nitrogen base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations (table 7). 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 during all 3-year

Table 6. Wilcoxon rank-sum test results comparing base-flow total nitrogen and total phosphorus concentrations to runoff total nitrogen and total phosphorus concentrations from water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

[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)	3-year period					
	2002-2004		2003-2005		2004-2006	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Spavinaw Creek near Maysville, Ark. (07191160)	z = -3.480 **p = 0.0005**	z = -4.383 **p < 0.0001**	z = -3.976 **p = 0.0001**	z = -3.965 **p = 0.0001**	z = -3.071 **p = 0.0021**	z = -3.028 **p < 0.0025**
Spavinaw Creek near Cherokee, Ark. (07191179)	z = -1.354 p = 0.1757	z = 1.835 p = 0.0665	z = -1.604 p = 0.1088	z = -0.624 p = 0.5328	z = -1.264 p = 0.2061	z = -1.299 p = 0.1938
Spavinaw Creek near Sycamore, Okla. (07191220)	z = -0.398 p = 0.6903	z = -1.583 p = 0.1133	z = -0.671 p = 0.5022	z = -2.266 **p = 0.0234**	z = -1.116 p = 0.2642	z = -1.666 p = 0.0957
Spavinaw Creek near Colcord, Okla. (071912213)	z = -2.070 **p = 0.0385**	z = -3.557 **p = 0.0004**	z = -2.318 **p = 0.0204**	z = -4.579 **p < 0.0001**	z = -2.186 **p = 0.0288**	z = -3.808 **p = 0.0001**
Beaty Creek near Jay, Okla. (07191222)	z = -4.140 **p < 0.0001**	z = -3.801 **p = 0.0001**	z = -3.717 **p = 0.0002**	z = -3.685 **p = 0.0002**	z = -3.611 **p = 0.0003**	z = -3.621 **p = 0.0003**

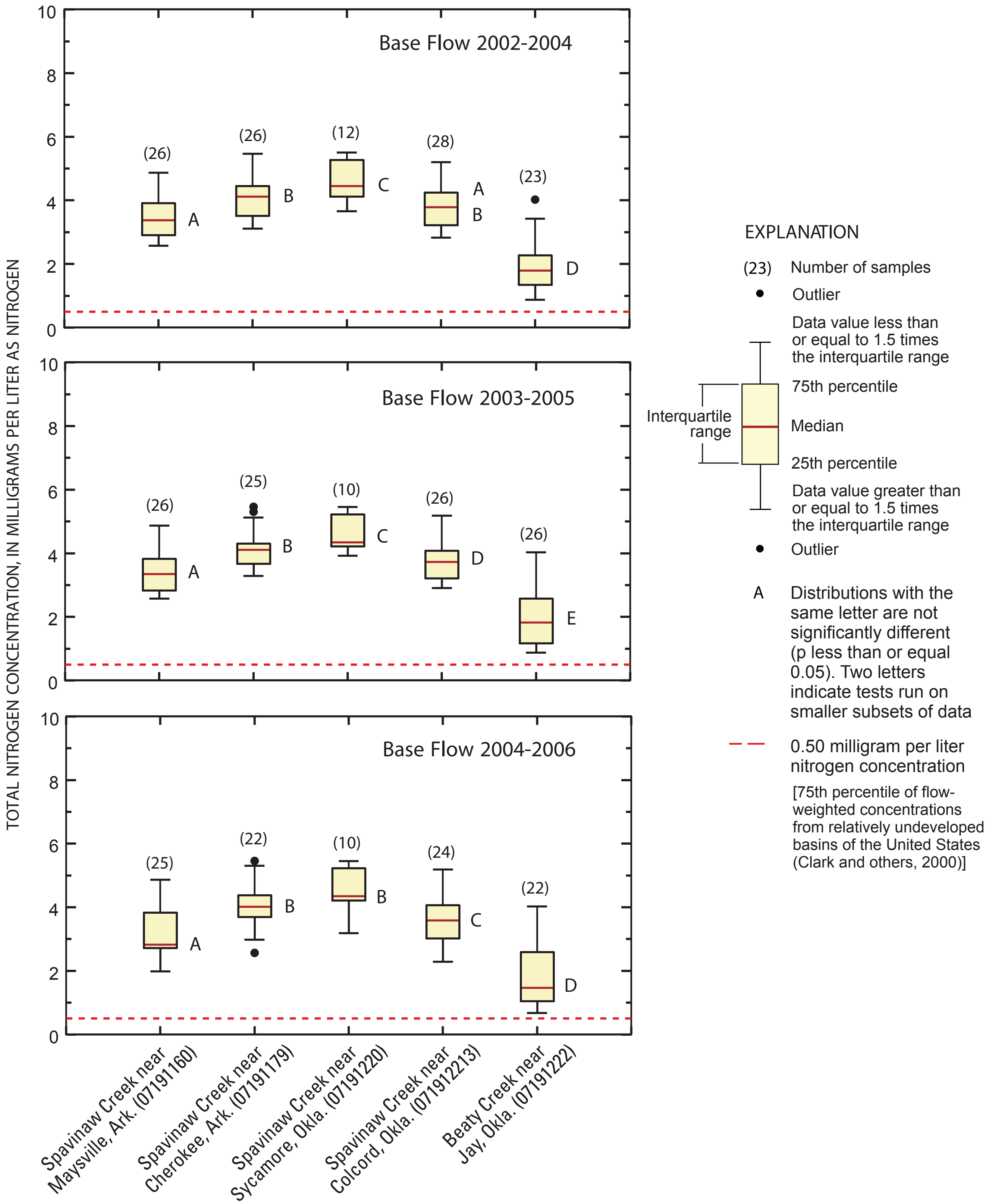

Figure 6. Distributions of **base-flow** total **nitrogen** concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

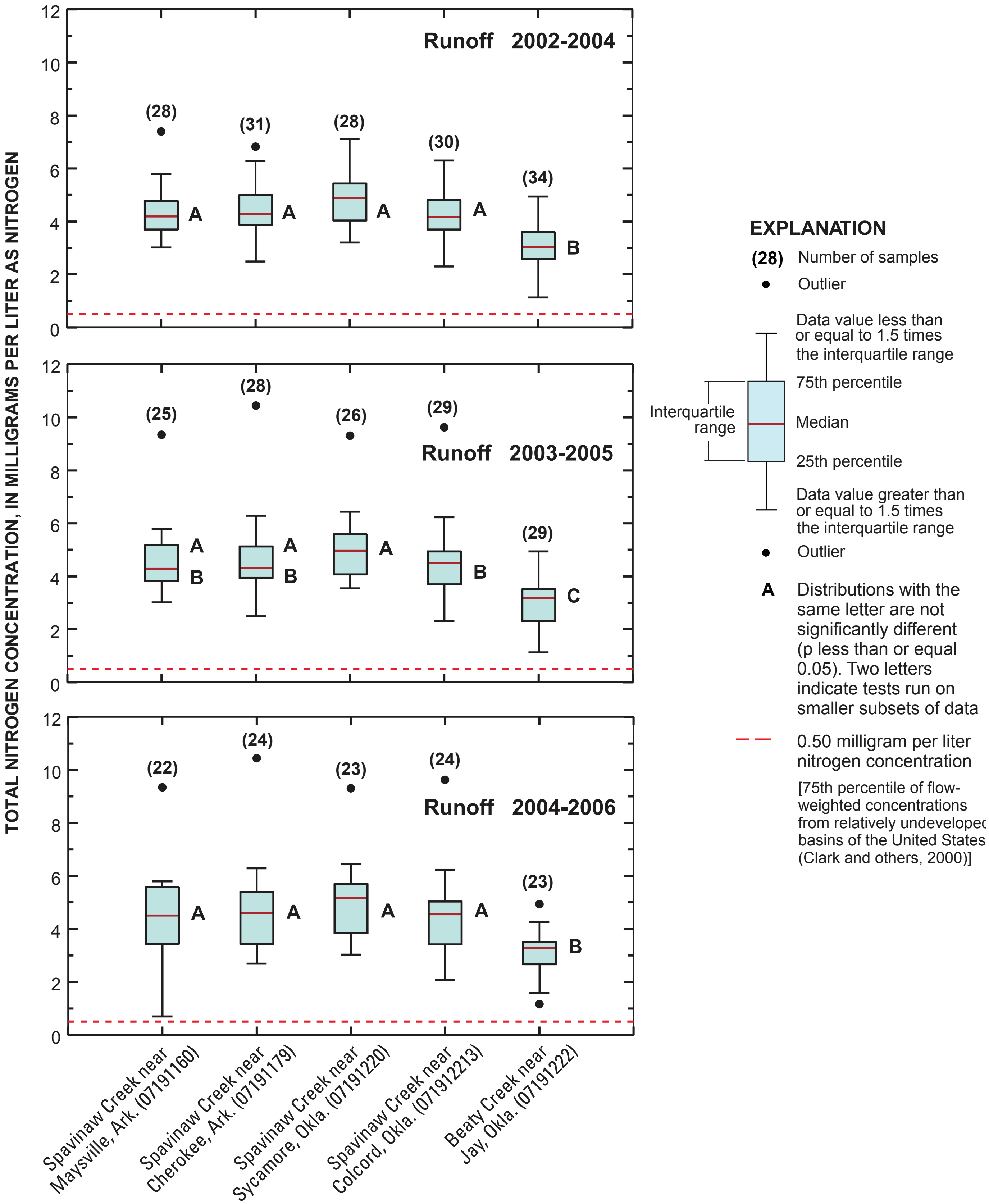

Figure 7. Distributions of **runoff** total **nitrogen** concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

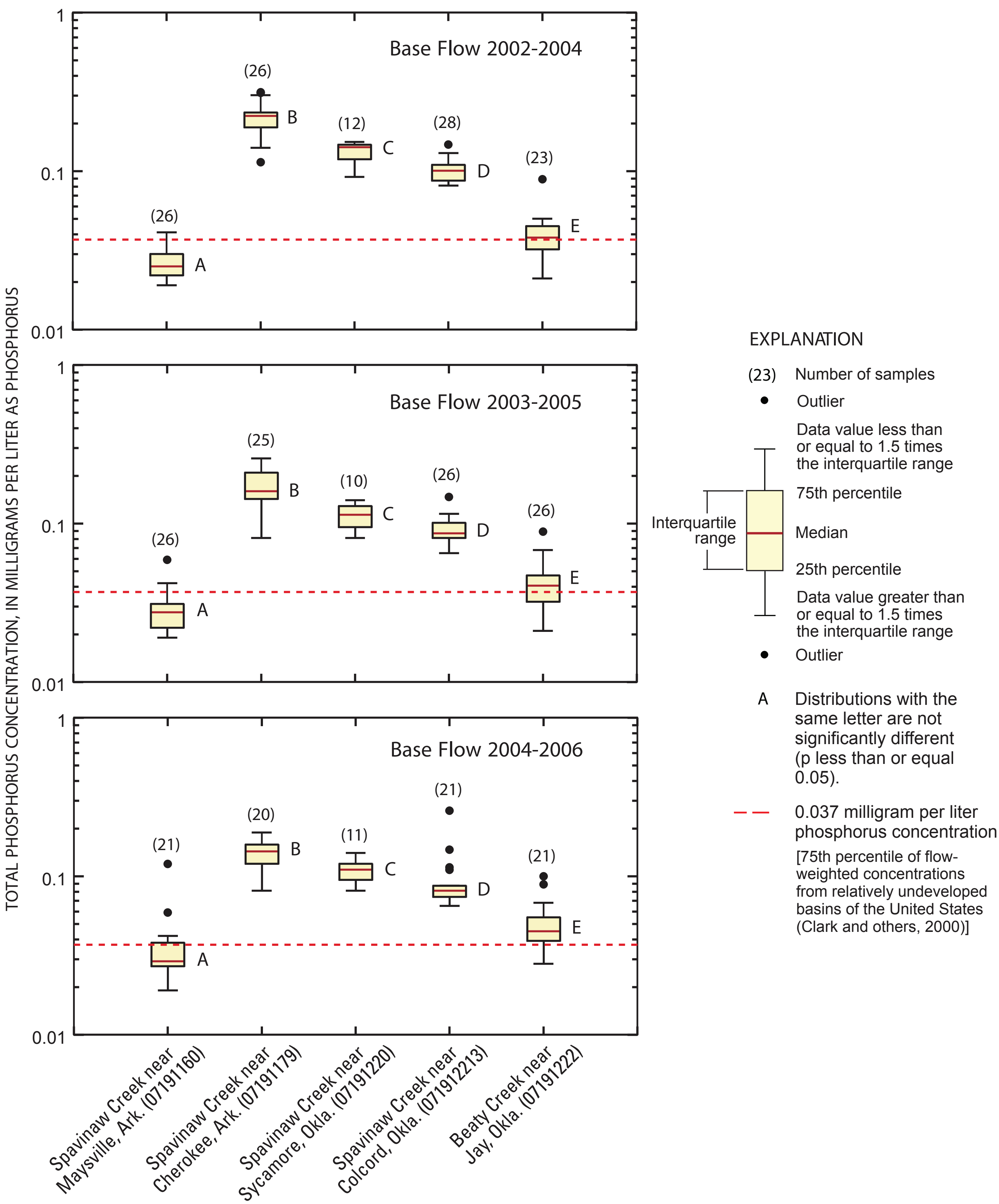

Figure 8. Distribution of **base-flow** total **phosphorus** concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

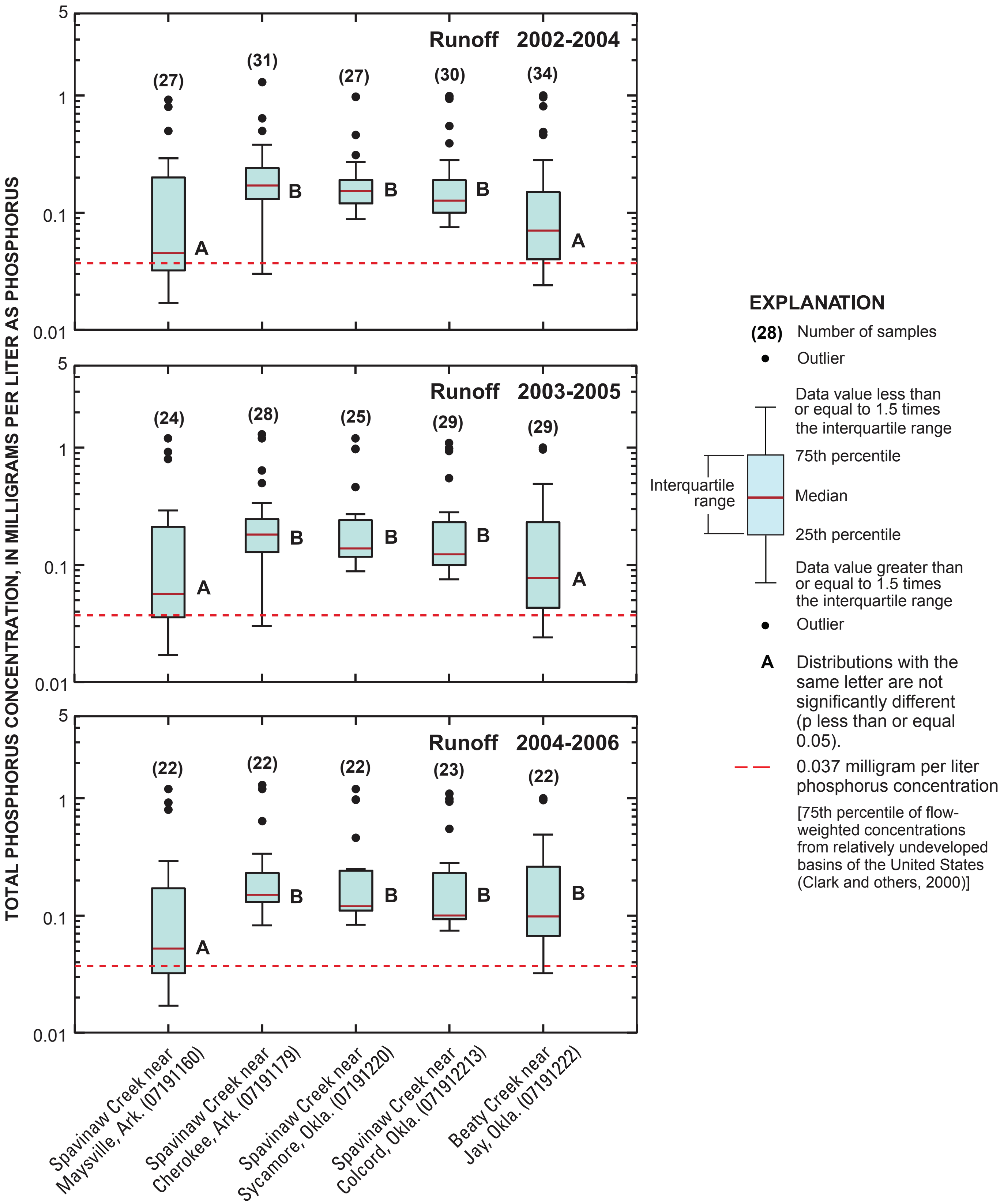

Figure 9. Distributions of **runoff** total **phosphorus** concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

Table 7. Estimated mean annual total **nitrogen** loads and yields by using regression methods from concentrations in water-quality samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

[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; 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)	3-year period	Estimated mean annual						Load delivered during runoff (percent)
			Total load [1] (+/– SEP[1]) (lb/yr as N)	Total yield (lb/yr/mi^2 as N)	Base-flow load [2] (lb/yr as N)	Base-flow yield (lb/yr/mi^2 as N)	Runoff load [3] (lb/yr as N)	Runoff yield (lb/yr/mi^2 as N)	
Spavinaw Creek near	88.2	2002–2004	521,000 (13,700)	5,910	187,000	2,120	335,000	3,800	64
Maysville, Ark.		2003–2005	552,000 (15,100)	6,260	202,000	2,290	350,000	3,970	63
(07191160)		2004–2006	520,000 (31,600)	5,900	186,000	2,120	334,000	3,790	64
Spavinaw Creek near	104	2002–2004	656,000 (18,400)	6,310	262,000	2,520	394,000	3,790	60
Cherokee, Ark.		2003–2005	737,000 (24,600)	7,090	267,000	2,570	469,000	4,510	64
(07191179)		2004–2006	709,000 (23,500)	6,820	243,000	2,250	466,000	4,480	66
Spavinaw Creek near	133	2002–2004	914,000 (28,300)	6,870	312,000	2,350	602,000	4,530	66
Sycamore, Okla.		2003–2005	996,000 (23,100)	7,490	311,000	2,340	685,000	5,150	69
(07191220)		2004–2006	932,000 (26,000)	7,010	271,000	2,040	661,000	4,970	71
Spavinaw Creek near	163	2002–2004	1,090,000 (31,000)	6,690	430,000	2,640	659,000	4,040	61
Colcord, Okla.		2003–2005	1,190,000 (39,800)	7,300	413,000	2,530	781,000	4,790	65
(071912213)		2004–2006	1,140,000 (34,800)	6,990	370,000	2,270	767,000	4,710	67
Beaty Creek near	59.2	2002–2004	257,000 (15,300)	4,340	39,300	664	218,000	3,680	85
Jay, Okla.		2003–2005	296,000 (19,400)	5,000	38,700	654	257,000	4,340	87
(07191222)		2004–2006	285,000 (19,200)	4,810	32,500	549	253,000	4,270	89

[1] Calculated by S-LOADEST and are statistics 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 8. Estimated mean annual total **phosphorus** loads and yields by using regression methods from concentrations in water-quality samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

[mi², square mile; lb/yr, pound per year; lb/yr/mi², pound per year per square mile; SEP, standard error of prediction; 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 (mi²)	3-year period	Estimated mean annual						Load delivered during runoff (percent)
			Total load [1] (+/– SEP[1]) (lb/yr as P)	Total yield (lb/yr/mi² as P)	Base-flow load [2] (lb/yr as P)	Base-flow yield (lb/yr/mi² as P)	Runoff load [3] (lb/yr as P)	Runoff yield (lb/yr/mi² as P)	
Spavinaw Creek near	88.2	2002–2004	20,000 (8,430)	227	1,480	16.8	18,600	211	93
Maysville, Ark.		2003–2005	25,800 (10,900)	292	1,770	20.1	24,000	272	93
(07191160)		2004–2006	24,200 (8,280)	274	1,750	19.8	22,500	255	93
Spavinaw Creek near	104	2002–2004	34,500 (4,800)	332	11,600	112	22,900	220	66
Cherokee, Ark.		2003–2005	38,400 (6,900)	369	9,020	86.7	29,500	284	77
(07191179)		2004–2006	35,600 (3,920)	342	7,210	69.3	28,400	273	80
Spavinaw Creek near	133	2002–2004	47,800 (6,110)	359	10,400	77.9	37,400	281	78
Sycamore, Okla.		2003–2005	55,000 (7,920)	414	8,990	67.6	46,000	346	84
(07191220)		2004–2006	45,600 (7,040)	343	6,130	46.1	39,500	297	87
Spavinaw Creek near	163	2002–2004	50,700 (7,340)	311	10,200	62.5	40,500	249	80
Colcord, Okla.		2003–2005	60,400 (9,610)	371	8,960	55.0	51,400	315	85
(071912213)		2004–2006	55,000 (8,330)	337	8,370	51.3	46,700	287	85
Beaty Creek near	59.2	2002–2004	27,000 (7,630)	456	600	10.1	26,400	446	98
Jay, Okla.		2003–2005	28,300 (6,010)	478	644	10.7	27,700	468	98
(07191222)		2004–2006	26,700 (6,200)	451	637	10.8	26,000	439	98

[1] Calculated by S-LOADEST and are statistics 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.

periods (table 7) 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 7).

Estimated mean annual nitrogen runoff loads in the basin increased with increasing drainage area and with increasing streamflow during all 3-year periods (tables 1 and 7). The runoff component of the annual nitrogen total load for Beaty Creek was 85 to 89 percent (table 7). At the Spavinaw Creek stations, the range in the runoff component of the annual nitrogen runoff load was 60 to 71 percent and increased in the three downstream stations even with the drier years of 2005 and 2006 included in the 3-year periods (tables 1 and 7). Runoff occurred no more than 31 percent of the time for any station (table 9), but accounted for most of the annual nitrogen total load for every station.

Annual nitrogen runoff loads seemed to be greater in the 2003–2005 period compared to the other two time periods at all stations in the basin (table 7). The most significant increase was between the 2002–2004 period and the 2003–2005 period, which coincides with the increase in mean annual streamflow (table 1).

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 8). Annual total loads increased downstream during all 3-year periods (table 8) 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 8).

Estimated mean annual phosphorus base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations during all 3-year periods (table 8). 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 downstream from Maysville to Cherokee in Spavinaw Creek (table 8), probably because of the inflow of discharges from a wastewater-treatment plant, with the annual base-flow load at the Cherokee station about 4 to 8 times that of Maysville station (table 8). The annual base-flow loads at the three downstream stations on Spavinaw Creek from Cherokee to Colcord were about the same during all 3-year periods (table 8).

Estimated mean annual phosphorus runoff loads in the basin increased with increasing drainage area and with increasing streamflow during all 3-year periods (tables 1 and 8). The portion of annual phosphorus load contributed by runoff at the three downstream Spavinaw Creek stations generally increased downstream (Cherokee to Colcord) (table 8). The runoff component of the annual phosphorus total load for Beaty Creek was 98 percent during all 3-year periods (table 8). At the Spavinaw Creek stations, the range in the runoff component of the annual phosphorus total load was 66 to 93 percent and increased in the three downstream stations even with the drier years of 2005 and 2006 included in the 3-year periods (tables 1 and 8). Almost all the phosphorus loads for Beaty Creek are delivered during runoff, and the annual runoff load for Beaty Creek was larger than runoff loads of the two upper Spavinaw Creek stations (table 8). Runoff occurred no more than 31 percent of the time for any station (table 9), but accounted for most of the annual phosphorus total load for every station during all 3-year periods.

Annual runoff loads seemed to be greater in the 2003–2005 period compared to the other two time periods at all stations in the basin. The most significant increase was between the 2002–2004 period and the 2003–2005 period, which coincides with the increase in mean annual streamflow (table 1).

Estimated Mean Seasonal Loads

Nutrient concentrations in streams vary throughout the year, mainly in response to variation in precipitation and streamflow, and differences in time because of fertilizer or manure applications (U.S. Geological Survey, 1999). Nutrient concentrations in streams generally are higher during high streamflow during spring and summer after fertilizer application. High nutrient concentrations also can be in streams during seasonal low flows. Nitrogen and phosphorus concentrations 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). Estimated mean seasonal nitrogen and phosphorus loads are discussed in this section and are divided into base-flow and runoff components (tables 10 and 11).

Nitrogen

Estimated mean seasonal nitrogen base-flow loads generally were least in autumn (September through November) and greatest in spring (March through May) at all stations in the Eucha-Spavinaw basin for 2002–2004 and 2003–2005, and greatest in spring and winter for 2004–2006 (table 10). The seasonal base-flow loads showed the same pattern as the annual base-flow loads (tables 7 and 10) in terms of variability among stations. Seasonal nitrogen base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations (table 10). Seasonal base-flow loads at stations on Spavinaw Creek were about 3 to 20 times greater than base-flow loads at the station on Beaty Creek. Seasonal nitrogen base-flow loads increased downstream from Maysville to Colcord in Spavinaw Creek, with the seasonal base-flow load at the Colcord station about 2 times that at Maysville station (table 10).

Estimated mean seasonal nitrogen runoff loads were generally least in autumn at all stations for the study period (table 10). Runoff loads were greatest in spring at all stations

Table 9. 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, periods 2002–2004, 2003–2005, and 2004–2006.

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

Station name (number)	3-year period	Seasons								Total		Percent of runoff days in period
		Spring		Summer		Autumn		Winter				
		Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	
Spavinaw Creek near	2002–2004	139	137	232	44	245	28	205	66	821	275	25
Maysville, Ark.	2003–2005	174	102	221	55	245	28	207	64	847	249	23
(07191160)	2004–2006	188	88	218	58	229	44	219	52	854	242	22
Spavinaw Creek near	2002–2004	150	126	231	45	239	34	199	72	819	277	25
Cherokee, Ark.	2003–2005	175	101	217	59	234	39	194	77	820	276	25
(07191179)	2004–2006	172	104	209	67	214	59	207	64	802	294	27
Spavinaw Creek near	2002–2004	143	133	228	48	236	37	188	83	795	301	27
Sycamore, Okla.	2003–2005	172	104	220	56	236	37	177	94	805	291	27
(07191220)	2004–2006	172	104	220	56	219	54	193	78	804	292	27
Spavinaw Creek near	2002–2004	161	115	228	48	226	47	202	69	817	279	25
Colcord, Okla.	2003–2005	182	94	214	62	219	54	190	81	805	291	27
(071912213)	2004–2006	175	101	212	64	219	54	201	70	807	289	26
Beaty Creek near	2002–2004	133	143	204	72	238	35	190	81	765	331	30
Jay, Okla.	2003–2005	145	131	204	72	238	35	172	99	759	337	31
(07191222)	2004–2006	166	110	225	51	250	23	181	90	822	274	25

Table 10. Estimated mean seasonal total **nitrogen** base-flow and runoff loads estimated by using regression methods from concentrations in water-quality samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

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

Flow type	Station name (number)	Estimated mean seasonal total nitrogen load			
		Spring	Summer	Autumn	Winter
	2002–2004				
Base flow	Spavinaw Creek near Maysville, Ark. (07191160)	56,800	54,600	28,700	46,500
	Spavinaw Creek near Cherokee, Ark. (07191179)	82,200	70,100	40,300	69,600
	Spavinaw Creek near Sycamore, Okla. (07191220)	94,000	94,400	49,300	74,700
	Spavinaw Creek near Colcord, Okla. (071912213)	140,000	105,000	63,000	122,000
	Beaty Creek near Jay, Okla. (07191222)	16,700	8,160	3,580	10,800
Runoff	Spavinaw Creek near Maysville, Ark. (07191160)	203,000	80,600	16,800	33,900
	Spavinaw Creek near Cherokee, Ark. (07191179)	234,000	82,200	26,100	52,000
	Spavinaw Creek near Sycamore, Okla. (07191220)	337,000	139,000	42,300	84,000
	Spavinaw Creek near Colcord, Okla. (071912213)	380,000	150,000	51,400	78,100
	Beaty Creek near Jay, Okla. (07191222)	120,000	52,800	22,600	22,300
	2003–2005				
Base flow	Spavinaw Creek near Maysville, Ark. (07191160)	68,300	41,400	26,300	66,300
	Spavinaw Creek near Cherokee, Ark. (07191179)	90,300	53,700	40,500	82,800
	Spavinaw Creek near Sycamore, Okla. (07191220)	106,000	75,300	44,700	85,300
	Spavinaw Creek near Colcord, Okla. (071912213)	144,000	79,800	58,400	131,000
	Beaty Creek near Jay, Okla. (07191222)	16,900	5,960	3,090	12,700
Runoff	Spavinaw Creek near Maysville, Ark. (07191160)	149,000	80,900	16,600	104,000
	Spavinaw Creek near Cherokee, Ark. (07191179)	180,000	84,900	27,300	177,000
	Spavinaw Creek near Sycamore, Okla. (07191220)	256,000	135,000	43,800	250,000
	Spavinaw Creek near Colcord, Okla. (071912213)	312,000	148,000	52,600	268,000
	Beaty Creek near Jay, Okla. (07191222)	114,000	47,100	19,100	77,400
	2004–2006				
Base flow	Spavinaw Creek near Maysville, Ark. (07191160)	56,600	35,500	26,800	67,000
	Spavinaw Creek near Cherokee, Ark. (07191179)	76,300	46,900	37,600	82,000
	Spavinaw Creek near Sycamore, Okla. (07191220)	90,100	62,100	37,600	81,000
	Spavinaw Creek near Colcord, Okla. (071912213)	117,000	68,700	58,700	126,000
	Beaty Creek near Jay, Okla. (07191222)	11,900	5,850	2,980	11,800
Runoff	Spavinaw Creek near Maysville, Ark. (07191160)	125,000	78,500	20,900	110,000
	Spavinaw Creek near Cherokee, Ark. (07191179)	161,000	84,700	35,000	186,000
	Spavinaw Creek near Sycamore, Okla. (07191220)	228,000	127,000	46,800	259,000
	Spavinaw Creek near Colcord, Okla. (071912213)	282,000	143,000	53,700	289,000
	Beaty Creek near Jay, Okla. (07191222)	98,300	44,400	25,100	85,000

Table 11. Estimated mean seasonal total **phosphorus** base-flow and runoff loads estimated by using regression methods from concentrations in water-quality samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

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

Flow type	Station name (number)	Estimated mean seasonal total phosphorus load			
		Spring	Summer	Autumn	Winter
	2002–2004				
Base flow	Spavinaw Creek near Maysville, Ark. (07191160)	404	544	257	270
	Spavinaw Creek near Cherokee, Ark. (07191179)	2,930	3,230	2,480	2,960
	Spavinaw Creek near Sycamore, Okla. (07191220)	2,570	3,440	2,140	2,210
	Spavinaw Creek near Colcord, Okla. (071912213)	3,430	3,060	1,380	2,310
	Beaty Creek near Jay, Okla. (07191222)	231	162	71.9	135
Runoff	Spavinaw Creek near Maysville, Ark. (07191160)	4,690	13,400	234	270
	Spavinaw Creek near Cherokee, Ark. (07191179)	10,200	9,770	904	1,980
	Spavinaw Creek near Sycamore, Okla. (07191220)	13,800	20,400	1,190	2,040
	Spavinaw Creek near Colcord, Okla. (071912213)	18,200	18,800	1,750	1,800
	Beaty Creek near Jay, Okla. (07191222)	4,990	17,100	3,820	540
	2003–2005				
Base flow	Spavinaw Creek near Maysville, Ark. (07191160)	552	489	272	460
	Spavinaw Creek near Cherokee, Ark. (07191179)	2,540	2,190	1,870	2,420
	Spavinaw Creek near Sycamore, Okla. (07191220)	2,550	2,570	1,830	2,030
	Spavinaw Creek near Colcord, Okla. (071912213)	3,120	2,240	1,270	2,330
	Beaty Creek near Jay, Okla. (07191222)	251	134	75.1	184
Runoff	Spavinaw Creek near Maysville, Ark. (07191160)	3,640	15,800	291	4,320
	Spavinaw Creek near Cherokee, Ark. (07191179)	7,660	11,800	961	9,070
	Spavinaw Creek near Sycamore, Okla. (07191220)	10,200	24,600	1,230	10,000
	Spavinaw Creek near Colcord, Okla. (071912213)	14,400	22,400	1,980	12,700
	Beaty Creek near Jay, Okla. (07191222)	4,420	13,500	3,220	6,530
	2004–2006				
Base flow	Spavinaw Creek near Maysville, Ark. (07191160)	529	380	275	564
	Spavinaw Creek near Cherokee, Ark. (07191179)	2,050	1,800	1,400	1,950
	Spavinaw Creek near Sycamore, Okla. (07191220)	2,010	1,690	894	1,530
	Spavinaw Creek near Colcord, Okla. (071912213)	2,770	1,800	1,300	2,500
	Beaty Creek near Jay, Okla. (07191222)	227	134	70.1	206
Runoff	Spavinaw Creek near Maysville, Ark. (07191160)	2,950	13,600	340	5,540
	Spavinaw Creek near Cherokee, Ark. (07191179)	6,600	11,900	1,180	8,690
	Spavinaw Creek near Sycamore, Okla. (07191220)	9,790	17,800	1,350	10,500
	Spavinaw Creek near Colcord, Okla. (071912213)	12,400	18,500	1,750	14,100
	Beaty Creek near Jay, Okla. (07191222)	4,380	11,300	3,250	7,150

in the Eucha-Spavinaw basin for 2002–2004 and 2003–2005; and greatest in spring and winter for 2004–2006. Estimated mean seasonal nitrogen runoff loads increased with increasing drainage area and with increasing streamflow showing the same pattern as annual runoff loads (tables 7 and 10).

Phosphorus

Estimated mean seasonal phosphorus base-flow loads generally were least in autumn (September through November) and greatest in spring (March through May) at all stations in the Eucha-Spavinaw basin during all 3-year periods (table 11). The seasonal base-flow loads showed the same pattern as the annual base-flow loads (tables 8 and 11) in terms of variability among stations. Seasonal phosphorus base-flow loads were substantially less in Beaty Creek than in the Spavinaw Creek stations (table 11). 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 downstream from Maysville to Cherokee in Spavinaw Creek, probably because of the inflow of wastewater discharges from the City of Decatur, with the seasonal loads at the Cherokee station about 4 to 10 times that at Maysville station (table 11). The seasonal base-flow loads at the three downstream stations on Spavinaw Creek from Cherokee to Colcord were about the same (table 11).

Estimated mean seasonal phosphorus runoff loads generally were least in autumn (September through November); and greatest in summer (June through August) at all stations in the Eucha-Spavinaw basin during all 3-year periods (table 11). 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 11). Almost all the phosphorus loads at Beaty Creek were delivered during runoff events, and seasonal runoff loads at Beaty Creek generally were larger than some of the Spavinaw Creek stations, especially during the autumn (table 11).

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; in 2003–2005 and 2004–2006 yields generally increased slightly downstream, but remained about the same at Sycamore and Colcord sites (table 7). The total yields ranged from 5,900 to 7,490 pounds per year per square mile (lbs/yr/mi^2), with the greatest yield being reported for Spavinaw Creek near Sycamore in 2003–2005 (7,490 lbs/yr/mi^2), and the least yield being reported for Spavinaw Creek near Maysville in 2004–2006 (5,900 lbs/yr/mi^2) (table 7). Beaty Creek near Jay had a slightly lower yield than Maysville during all 3-year periods (4,340 to 5,000 lbs/yr/mi^2).

Estimated mean annual nitrogen base-flow yields also generally increased slightly from the Maysville to the Cherokee station and then remained about the same in a downstream direction at the Spavinaw Creek stations, ranging from 2,040 to 2,640 lbs/yr/mi^2. However, the base-flow yield at Beaty Creek (549 to 664 lbs/yr/mi^2) was substantially less than base-flow yield of the Spavinaw Creek stations, which were about 3 to 4 times greater (table 7).

Estimated mean annual nitrogen runoff yields also generally increased slightly from the Maysville to the Cherokee station and then remained about the same in a downstream direction at the Spavinaw Creek stations, ranging from 3,790 to 5,150 lbs/yr/mi^2 and slightly less on Beaty Creek (3,680 to 4,340 lbs/yr/mi^2) (table 7).

Phosphorus

Estimated mean annual phosphorus total yields during all 3-year periods in Spavinaw Creek generally increased in a downstream direction, ranging from 227 to 414 lbs/yr/mi^2, with greatest yields being reported for Spavinaw Creek near Sycamore (359 to 414 lbs/yr/mi^2), and the least yield being reported for Spavinaw Creek near Maysville (227 to 292 lbs/yr/mi^2) (table 8). The total yield for Beaty Creek (451 to 478 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 streambank erosion.

Estimated mean annual phosphorus base-flow yield was substantially less in Beaty Creek (10.1 to 10.8 lbs/yr/mi^2) than in the three downstream Spavinaw Creek stations (46.1 to 112 lbs/yr/mi^2) (table 8). Annual base-flow yields at stations on Spavinaw Creek were about 5 to 11 times greater than base-flow yields at the station on Beaty Creek. Annual phosphorus base-flow yield increased substantially downstream from Maysville to Cherokee in Spavinaw Creek (table 8), probably because of the inflow of wastewater discharges from the City of Decatur, with the annual base-flow yield at the Cherokee station about 4 to 7 times that of Maysville station (table 8).

Estimated mean annual phosphorus runoff yields were about the same at all Spavinaw Creek stations in the basin in all 3-year periods, ranging from 211 to 346 lbs/yr/mi^2. The runoff yield for Beaty Creek (439 to 468 lbs/yr/mi^2), was greater than runoff yields of any Spavinaw Creek station (table 8); about 98 percent of the phosphorus loads at Beaty Creek were delivered during runoff.

Estimated Mean Flow-Weighted Concentrations

Nitrogen

Estimated mean flow-weighted nitrogen concentrations at all stations in the basin during all 3-year periods were more than the median flow-weighted concentration (0.26 mg/L) in mostly undeveloped basins of the United States and were about 7 to 10 times greater than the 75th percentile of flow-weighted nitrogen concentrations in those basins (0.50 mg/L, Clark and others, 2000) (fig. 10, table 12).

Estimated mean flow-weighted nitrogen concentrations at each station in the basin during all 3-year periods were consistently greater than the median instantaneous nitrogen concentrations at each station shown in figure 10. The collected water-quality data have a wide range (table 4, appendixes 1-5) and high values during runoff events can greatly affect the computation of the mean flow-weighted concentrations. For example, the maximum concentration during 2005 at Spavinaw Creek near Colcord (9.62 mg/L, table 4, appendix 4) was collected during high runoff in January 2005 and contributed to a large nitrogen load, and similar runoffs were in April and July 2004 (appendix 4). Because mean flow-weighted concentration (mean load divided by mean streamflow times a conversion factor) is proportional to load, the result was a large estimated mean flow-weighted nitrogen concentration.

Phosphorus

Estimated mean flow-weighted phosphorus concentrations at all stations in the basin during all 3-year periods were greater than the median flow-weighted concentration (0.022 mg/L) in mostly undeveloped basins of the United States and were about 4 to 10 times greater than the 75th percentile of flow-weighted phosphorus concentrations in those basins (0.037 mg/L, Clark and others, 2000; fig. 11, table 13).

Estimated mean flow-weighted phosphorus concentrations at each station were consistently greater than the median instantaneous phosphorus concentrations shown in figure 11. The collected water-quality data have a wide range (table 5, appendixes 1-5) and high values during runoff events 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 5, appendix 5) was collected during high runoff in November 2004 and contributed to a large phosphorus load. However, the highest daily mean streamflow and load occurred during a July 2004 event and was responsible for a large portion of the load during all 3-year periods at Beaty Creek. Because mean flow-weighted concentration (mean load divided by mean streamflow times a conversion factor) is proportional to load, the result was a large estimated mean flow-weighted phosphorus concentration.

Estimated Mean Annual Nutrient Loads into Lake Eucha

Most of the 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 upstream from these stations accounts for about 62 percent of the drainage basin upstream from the lake.

Spavinaw Creek and Beaty Creek contributed a mean annual nitrogen total load of about 1,350,000 to 1,490,000 pounds per year (lbs/yr) (table 14) and about 65 to 72 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 14).

Spavinaw Creek and Beaty Creek contributed a mean annual phosphorus total load of about 77,700 to 88,700 lbs/yr (table 14) with about 86 to 89 percent of the annual phosphorus total load being transported to Lake Eucha by runoff. Spavinaw Creek transported about 13 to 16 times more phosphorus load during base flow and about 1.5-2 times more phosphorus load during runoff to the lake than Beaty Creek (table 14).

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. Consumer complaints of taste and odor in the finished water have been reported. The Tulsa Metropolitan Utility Authority (TMUA) has spent millions of dollars from 1998–2005 to eliminate taste and odor problems in the drinking water from the Eucha-Spavinaw system. 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 TMUA, supplemented fixed period, monthly water-quality sampling with six runoff samplings per year to better determine water quality over the range of streamflows in the basin. Nitrogen and phosphorus concentrations, loads, and yields were determined for three 3-year periods—2002–2004, 2003–2005, and 2004–2006, to update a previous report that used data from water-quality samples collected during 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 for all three periods collected at Spavinaw Creek near Maysville, Arkansas; Spavinaw Creek near Colcord, Oklahoma, and Beaty Creek near Jay, Oklahoma. Runoff concentrations were

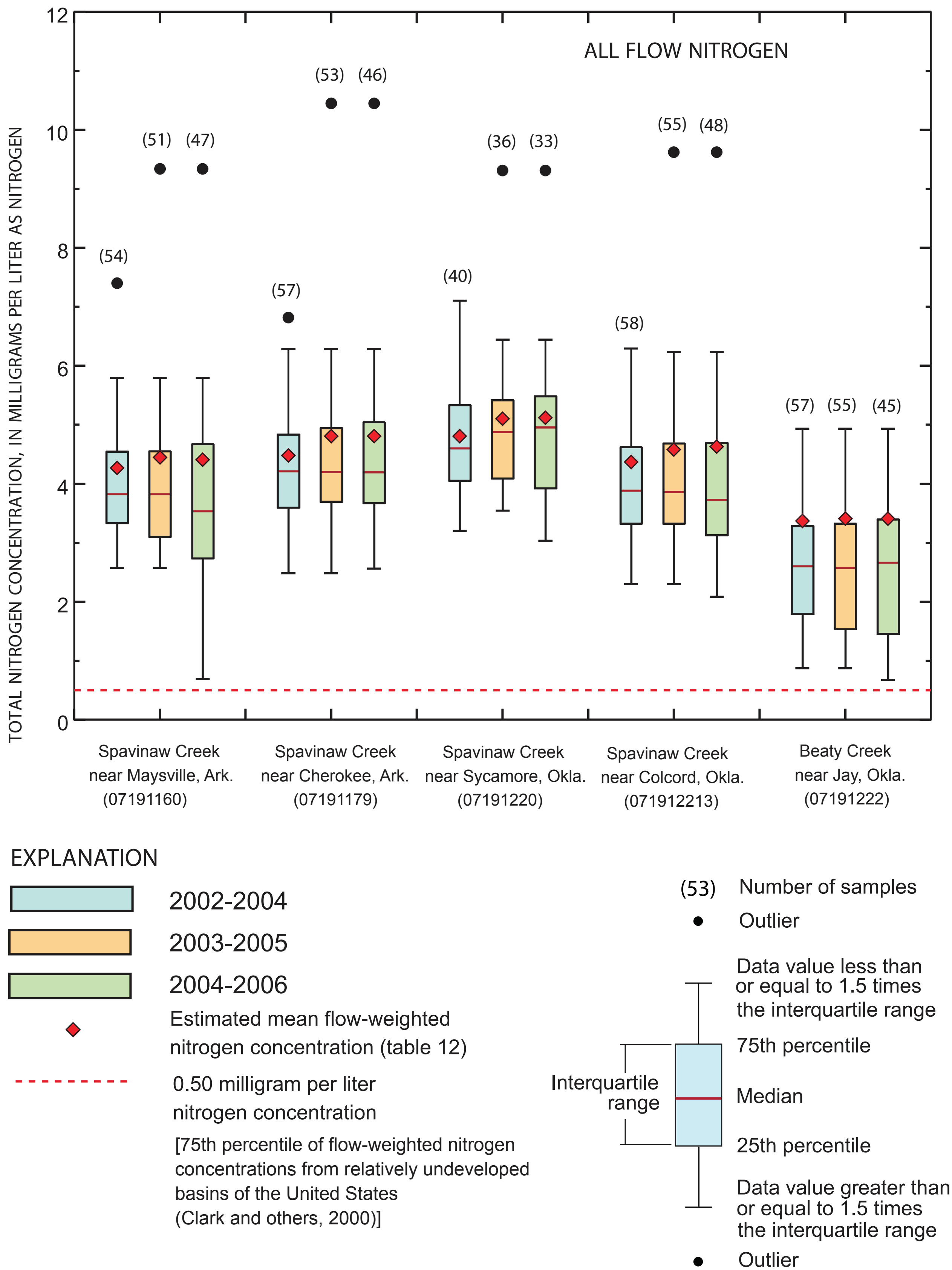

Figure 10. Instantaneous total **nitrogen** concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

Table 12. Estimated mean annual total **nitrogen** loads, mean annual streamflows, and estimated mean flow-weighted total nitrogen concentrations at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

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

Station name (number)	3-year period	Estimated mean annual total nitrogen load (lb/yr as N)	Mean annual streamflow (ft^3/s)	Estimated mean flow-weighted total nitrogen concentration (mg/L as N)
Spavinaw Creek near	2002–2004	521,000	61.9	4.27
Maysville, Ark. (07191160)	2003–2005	552,000	63.0	4.45
	2004–2006	520,000	59.9	4.41
Spavinaw Creek near	2002–2004	656,000	74.4	4.48
Cherokee, Ark. (07191179)	2003–2005	737,000	77.8	4.81
	2004–2006	709,000	74.8	4.81
Spavinaw Creek near	2002–2004	914,000	96.6	4.81
Sycamore, Okla. (07191220)	2003–2005	996,000	99.1	5.10
	2004–2006	932,000	92.5	5.12
Spavinaw Creek near	2002–2004	1,090,000	127	4.37
Colcord, Okla. (071912213)	2003–2005	1,190,000	132	4.58
	2004–2006	1,140,000	125	4.63
Beaty Creek near	2002–2004	257,000	38.7	3.37
Jay, Okla. (07191222)	2003–2005	296,000	44.1	3.41
	2004–2006	285,000	42.4	3.41

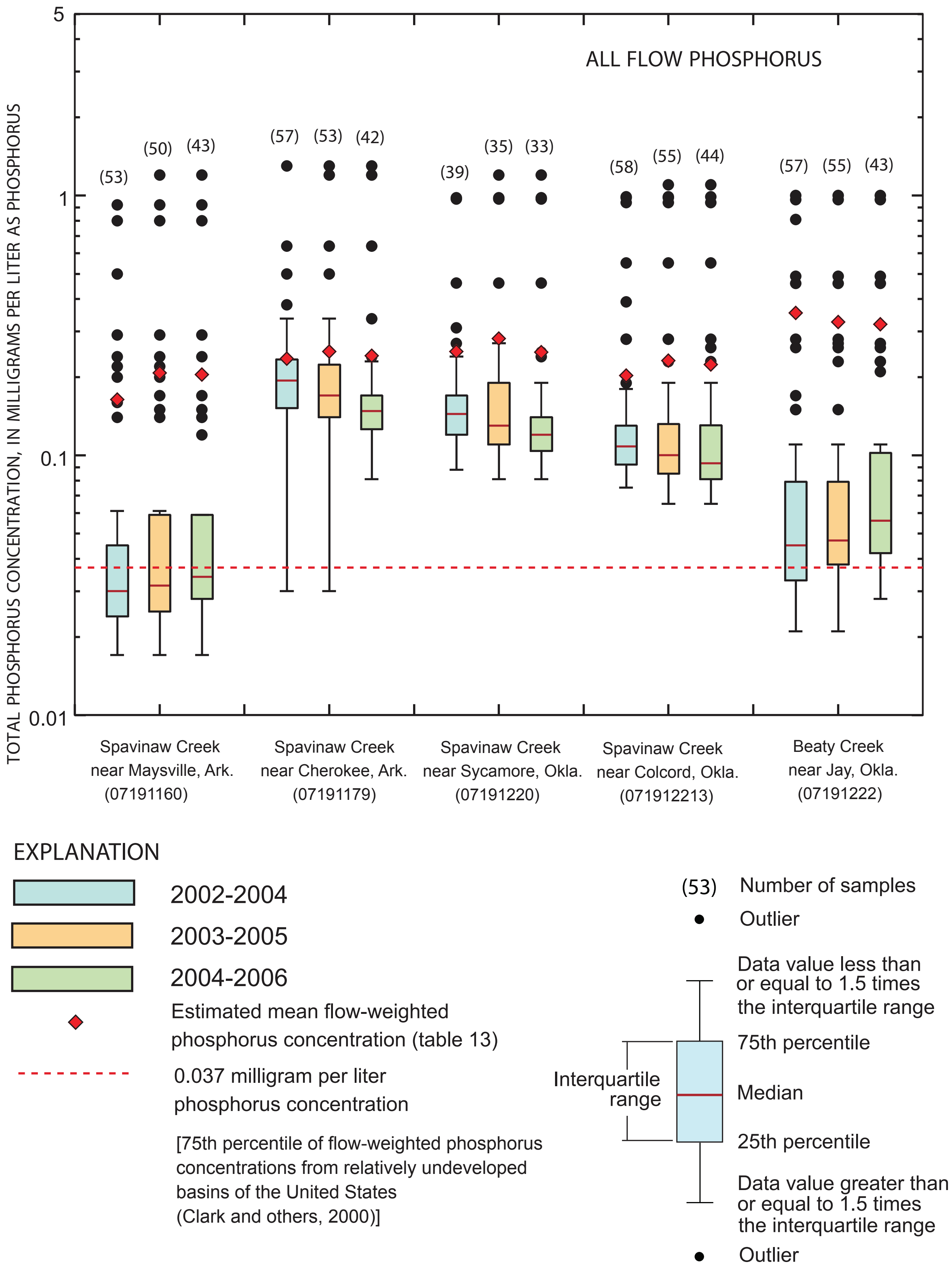

Figure 11. Instantaneous total **phosphorus** concentrations in water samples collected at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

Table 13. Estimated mean annual total **phosphorus** loads, mean annual streamflows, and estimated mean flow-weighted total nitrogen concentrations at water-quality stations in the Eucha-Spavinaw basin, Arkansas and Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

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

Station name (number)	3-year period	Estimated mean annual total phosphorus load (lb/yr as P)	Mean annual streamflow (ft^3/s)	Estimated mean flow-weighted total phosphorus concentration (mg/L as P)
Spavinaw Creek near	2002–2004	20,000	61.9	0.164
Maysville, Ark. (07191160)	2003–2005	25,800	63.0	0.208
	2004–2006	24,200	59.9	0.205
Spavinaw Creek near	2002–2004	34,500	74.4	0.236
Cherokee, Ark. (07191179)	2003–2005	38,400	77.8	0.251
	2004–2006	35,600	74.8	0.242
Spavinaw Creek near	2002–2004	47,800	96.6	0.251
Sycamore, Okla. (07191220)	2003–2005	55,000	99.1	0.282
	2004–2006	45,600	92.5	0.250
Spavinaw Creek near	2002–2004	50,700	127	0.203
Colcord, Okla. (071912213)	2003–2005	60,400	132	0.232
	2004–2006	55,000	125	0.224
Beaty Creek near	2002–2004	27,000	38.7	0.354
Jay, Okla. (07191222)	2003–2005	28,300	44.1	0.326
	2004–2006	26,700	42.4	0.320

Table 14. Summary of estimated mean annual total nitrogen and total phosphorus loads to Lake Eucha, Oklahoma, periods 2002–2004, 2003–2005, and 2004–2006.

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

Flow type	Lake Eucha: Mean annual nitrogen load [1] (lb/yr as N)	Lake Eucha: Mean annual nitrogen load [1] (percent)	Spavinaw Creek near Colcord, Okla.: Component of mean annual nitrogen load (percent)	Beaty Creek near Jay, Okla.: Component of mean annual nitrogen load (percent)	Lake Eucha: Mean annual phosphorus load [1] (lb/yr as P)	Lake Eucha: Mean annual phosphorus load [1] (percent)	Spavinaw Creek near Colcord, Okla.: Component of mean annual phosphorus load (percent)	Beaty Creek near Jay, Okla.: Component of mean annual phosphorus load (percent)
2002–2004								
Base Flow [2]	469,000	35	92	8	10,800	14	94	6
Runoff [3]	877,000	65	75	25	66,900	86	61	39
Total [4]	1,350,000	100	81	19	77,700	100	65	35
2003–2005								
Base Flow [2]	452,000	30	91	9	9,630	11	93	7
Runoff [3]	1,040,000	70	75	25	79,100	89	65	35
Total [4]	1,490,000	100	80	20	88,700	100	68	32
2004–2006								
Base Flow [2]	402,000	28	92	8	9,010	11	93	7
Runoff [3]	1,020,000	72	75	25	72,700	89	64	36
Total [4]	1,420,000	100	80	20	81,700	100	67	33

[1] Loads to Lake Eucha are calculated by adding loads from Spavinaw Creek near Colcord, Okla. to loads from Beaty Creek near Jay, Okla. (tables 7 and 8). These two locations account for 62 percent of drainage area that 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.

not significantly greater than base-flow concentrations in samples collected at Spavinaw Creek near Cherokee, Arkansas; and Spavinaw Creek near Sycamore, Oklahoma except for phosphorus during 2003–2005.

Nitrogen concentrations in base-flow samples significantly increased downstream in Spavinaw Creek from the Maysville to Sycamore stations then significantly decreased from the Sycamore to the Colcord stations for all three periods. Nitrogen in base-flow samples collected from Beaty Creek was significantly less than base-flow samples from Spavinaw Creek. Phosphorus concentrations in base-flow samples significantly increased from the Maysville to Cherokee stations in Spavinaw Creek for all three periods, probably because of a point source between those stations, and then significantly decreased downstream from the Cherokee to Colcord stations. Phosphorus in base-flow samples collected from Beaty Creek was significantly less than phosphorus in base-flow samples collected from Spavinaw Creek downstream from the Maysville station during all 3-year periods.

Nitrogen concentrations in runoff samples were not significantly different among the stations on Spavinaw Creek for most of the three periods, except during 2003–2005 when runoff samples at the Colcord station were less than at the Sycamore station; 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; and were significantly different at the Maysville station on Spavinaw Creek and the Beaty Creek station, only during 2004–2006. Nitrogen and phosphorus concentrations in runoff samples collected from all stations generally increased with increasing streamflow. The larger concentrations of nitrogen during runoff indicates addition of nitrogen from nonpoint sources and the larger concentrations of phosphorus during runoff indicates phosphorus resuspension, stream bank erosion, or addition of phosphorus from nonpoint sources.

Estimated mean annual nitrogen total loads for the three 3-year periods were substantially greater at the Spavinaw Creek stations than at Beaty Creek and increased downstream 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 to 89 percent; whereas, at the Spavinaw Creek stations, the range in the runoff component was 60 to 71 percent. Annual runoff loads seemed to be greater in the 2003–2005 period compared to the other two time periods at all stations in the basin. The most significant increase was between the 2002–2004 period and the 2003–2005 period, which coincides with the increase in mean annual streamflow.

Estimated mean annual phosphorus total loads for the three 3-year periods were greater at the Spavinaw Creek stations from Cherokee to Colcord than at Beaty Creek and increased downstream 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 substantially downstream from Maysville to Cherokee in Spavinaw Creek, probably because of the inflow of discharges from a wastewater-treatment plant. Phosphorus base-flow loads increased about 4 to 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 Beaty Creek was 98 percent; whereas, at the Spavinaw Creek stations, the range in the runoff component was 66 to 93 percent. Almost all the phosphorus loads at Beaty Creek are delivered during runoff, and the annual runoff load at Beaty Creek was larger than the two upper Spavinaw Creek stations.

Estimated mean seasonal nitrogen base-flow and runoff loads generally were least in autumn for all three periods and greatest in spring at all stations in the Eucha-Spavinaw basin for 2002–2004 and 2003–2005 and greatest in spring and winter for 2004–2006. Seasonal nitrogen base-flow loads at stations on Spavinaw Creek were about 3 to 20 times greater than at the station on Beaty Creek and increased downstream from Maysville to Colcord in Spavinaw Creek, with the seasonal base-flow load at the Colcord station about 2 times that at Maysville station. Estimated mean seasonal nitrogen runoff loads in the basin increased with increasing drainage area and with increasing streamflow.

Estimated mean seasonal phosphorus base-flow and runoff loads generally were least in autumn and greatest in spring for base-flow loads and greatest in the summer for runoff loads during all 3-year periods 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 and increased substantially downstream from Maysville to Cherokee in Spavinaw Creek, probably because of the inflow of discharges from a wastewater-treatment plant. The seasonal base-flow loads at the Cherokee station were about 4 to 10 times that at Maysville station and 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 in the basin generally increased with increasing drainage area and with increasing streamflow at the Spavinaw Creek stations. Almost all the phosphorus loads at Beaty Creek are delivered during runoff, and several of the seasonal loads at Beaty Creek were generally larger than the Spavinaw Creek stations, especially during the autumn.

Estimated mean annual nitrogen total yields generally increased slightly in a downstream direction for 2002–2004 in Spavinaw Creek; in 2003–2005 and 2004–2006 yields generally increased slightly downstream, but remained about the same at Sycamore and Colcord sites. Estimated mean annual nitrogen total yields ranged from 4,340 to 7,490 pounds per year per square mile, with greatest yield at the Sycamore station in 2003–2005, and the least yield at Beaty Creek near Jay for all three periods. Estimated mean annual nitrogen base-flow yields ranged from 549 to 2,640 pounds per year per square mile, and also generally increased slightly downstream at the Spavinaw Creek stations. However, the base-flow yield at Beaty Creek was substantially less than base-flow yields of the Spavinaw Creek stations, which were about 3 to 4 times greater. The estimated mean annual nitrogen runoff yields ranged from 3,680 to 5,150 pounds per year per square mile.

Estimated mean annual phosphorus total yields ranged from 227 to 478 pounds per year per square mile, with greatest yield at Beaty Creek, and the least yield at Spavinaw Creek near Maysville. Most of the yield was delivered during runoff; about 98 percent of the phosphorus loads at Beaty Creek are delivered during runoff. 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 yields at the three downstream Spavinaw Creek stations ranged from 46.1 to 112 pounds per year per square mile and were about 5 to 11 times greater than at Beaty Creek, probably because of the inflow of discharges from a wastewater-treatment plant, with the annual base-flow yield at the Cherokee station about 4 to 7 times that of Maysville station.

Estimated mean flow-weighted nitrogen concentrations at all stations in the basin for three 3-year periods were about 7 to 10 times greater than the 75th percentile of flow-weighted nitrogen concentrations (0.50 milligram per liter) in mostly undeveloped basins of the United States. Estimated mean flow-weighted phosphorus concentrations at all stations in the basin for all three periods were about 4 to 10 times greater than the 75th percentile of flow-weighted phosphorus concentrations (0.037 milligram per liter) in mostly undeveloped basins of the United States.

Spavinaw Creek and Beaty Creek contributed an estimated mean annual nitrogen total load of about 1,350,000 to 1,490,000 pounds per year and about 65 to 72 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 an estimated mean annual phosphorus total load of about 77,700 to 88,700 pounds per year with about 86 to 89 percent of the annual phosphorus total load being transported to Lake Eucha by runoff. Spavinaw Creek transported about 13 to 16 times more phosphorus load during base flow and about 1.5 to 2 times more phosphorus load during runoff to the lake than Beaty Creek.

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Appendixes

Appendix 1. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Maysville, Arkansas, 2002-2006.

[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

Appendix 1. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Maysville, Arkansas, 2002-2006. —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]
12/10/2003	0820	COT	21	3.53	0.019	Base flow
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
01/05/2005	1215	USGS	3,190	9.34	1.200	Runoff
01/06/2005	0858	COT	855	5.57	0.170	Runoff
02/10/2005	0832	COT	84	4.80	0.025	Base flow
03/10/2005	0837	COT	72	4.36	0.029	Base flow
04/07/2005	0845	COT	167	3.88	0.059	Runoff
05/12/2005	0825	COT	41	3.87	0.028	Base flow
06/09/2005	0902	COT	33	3.53	0.031	Base flow
06/14/2005	1145	USGS	78	3.50	0.150	Runoff
07/14/2005	0827	COT	22	2.90	0.034	Base flow
08/11/2005	0757	COT	19	2.82	0.027	Base flow
09/15/2005	0835	COT	15	2.70	0.059	Base flow
10/06/2005	0815	COT	13	2.75	0.042	Base flow
11/16/2005	0752	COT	16	2.73	0.031	Base flow
12/15/2005	0812	COT	14	2.82	0.022	Base flow

Appendix 1. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Maysville, Arkansas, 2002-2006. —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]
01/12/2006	0812	COT	16	2.82	0.120	Base flow
02/09/2006	0823	COT	14	2.73	0.027	Base flow
03/09/2006	0805	COT	14	2.60	0.019	Base flow
04/12/2006	0802	COT	18	2.66	--	Base flow
04/29/2006	1330	USGS	29	2.37	0.032	Runoff
05/02/2006	1335	USGS	84	3.22	0.031	Runoff
05/10/2006	0830	COT	63	0.69	0.046	Runoff
05/10/2006	1135	USGS	61	3.15	0.041	Runoff
06/08/2006	0837	COT	28	--	0.028	Runoff
07/13/2006	0856	COT	9.8	--	0.038	Base flow
07/13/2006	1100	USGS	9.8	2.37	0.031	Base flow
08/10/2006	0755	COT	6	1.98	--	Base flow
08/28/2006	1135	USGS	61	2.29	0.055	Runoff
09/14/2006	0837	COT	12	2.71	--	Base flow
10/12/2006	0837	COT	11	2.85	--	Base flow
11/16/2006	0730	COT	16	2.39	--	Base flow
12/06/2006	0847	COT	70	5.00	--	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).

Appendix 2. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Cherokee, Arkansas, 2002–2006.

[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	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

Appendix 2. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Cherokee, Arkansas, 2002–2006.—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]
10/09/2003	0815	COT	21	3.66	0.223	Base flow
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
01/05/2005	1325	USGS	3,780	10.45	1.200	Runoff
01/06/2005	0915	COT	1,440	6.13	0.230	Runoff
02/10/2005	0848	COT	97	5.30	0.081	Base flow
03/10/2005	0852	COT	83	4.89	0.088	Base flow
04/07/2005	0900	COT	219	4.18	0.190	Runoff
05/12/2005	0840	COT	37	4.13	0.150	Base flow
06/09/2005	0919	COT	35	3.81	0.110	Base flow
06/14/2005	1440	USGS	105	3.34	0.140	Runoff
07/14/2005	0844	COT	24	3.28	0.170	Base flow
08/11/2005	0815	COT	22	3.99	0.160	Base flow
10/06/2005	0825	COT	16	3.55	0.160	Base flow
11/16/2005	0815	COT	25	4.04	0.150	Base flow
12/15/2005	0828	COT	14	3.69	0.120	Base flow

Appendix 2. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Cherokee, Arkansas, 2002–2006. —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]
01/12/2006	0825	COT	18	4.37	0.140	Base flow
02/09/2006	0840	COT	16	3.98	0.160	Base flow
03/09/2006	0820	COT	19	3.71	0.120	Base flow
04/12/2006	0818	COT	26	2.96	--	Runoff
04/29/2006	1645	USGS	46	3.15	0.150	Runoff
05/02/2006	1455	USGS	103	3.51	0.130	Runoff
05/10/2006	0845	COT	112	3.37	0.140	Runoff
05/10/2006	1245	USGS	101	3.67	0.130	Runoff
06/08/2006	0853	COT	29	--	0.150	Runoff
07/13/2006	0920	COT	13	--	0.150	Base flow
07/13/2006	1245	USGS	13	2.97	0.130	Base flow
08/10/2006	0810	COT	10	2.56	--	Base flow
08/28/2006	1315	USGS	77	4.28	0.190	Runoff
09/14/2006	0855	COT	16	3.72	--	Base flow
10/12/2006	0857	COT	15	3.68	--	Base flow
11/16/2006	0745	COT	26	3.34	--	Runoff
12/06/2006	0905	COT	80	5.57	--	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 substituted in the total nitrogen calculation for this sample.

Appendix 3. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Sycamore, Oklahoma, 2002–2006.

[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
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

Appendix 3. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Sycamore, Oklahoma, 2002–2006. —Continued

[COT, City of Tulsa; USGS, U.S. Geological Survey; ft³/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]
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
01/05/2005	1440	USGS	3,860	9.31	1.200	Runoff
01/06/2005	0827	COT	1,690	5.89	0.250	Runoff
02/10/2005	0805	COT	117	5.45	0.081	Base flow
03/10/2005	0811	COT	100	4.88	0.110	Base flow
04/07/2005	0815	COT	292	4.87	0.090	Runoff
05/12/2005	0755	COT	51	4.29	0.140	Base flow
06/09/2005	0836	COT	41	3.92	0.095	Base flow
06/15/2005	1115	USGS	89	3.85	0.110	Runoff
04/29/2006	1845	USGS	27	3.15	0.110	Runoff
05/02/2006	1515	USGS	109	3.83	0.083	Runoff
05/10/2006	0803	COT	101	3.86	0.130	Runoff
05/10/2006	1330	USGS	150	3.52	0.130	Runoff
07/13/2006	0825	COT	5.8	--	0.120	Base flow
07/13/2006	0900	USGS	5.8	3.18	0.100	Base flow
08/28/2006	1145	USGS	18	3.03	0.120	Runoff
12/06/2006	0814	COT	104	5.60	--	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 30-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, 2002–2006.

[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	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

Appendix 4. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Colcord, Oklahoma, 2002–2006. —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]
10/09/2003	0840	COT	23	3.00	0.089	Base flow
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
01/05/2005	1430	USGS	5,700	9.62	1.100	Runoff
01/06/2005	0945	COT	2,190	5.54	0.230	Runoff
02/10/2005	0917	COT	155	5.18	0.081	Base flow
03/10/2005	0920	COT	129	4.59	0.082	Base flow
04/07/2005	0928	COT	296	3.90	0.093	Runoff
05/12/2005	0907	COT	84	4.07	0.110	Base flow
06/09/2005	0950	COT	47	3.64	0.075	Base flow
06/15/2005	1350	USGS	90	3.63	0.150	Runoff
07/14/2005	0915	COT	34	2.90	0.087	Base flow
08/11/2005	0850	COT	30	3.02	0.081	Base flow
09/15/2005	0925	COT	21	2.90	0.066	Base flow
10/06/2005	0900	COT	19	3.06	0.078	Base flow

Appendix 4. Streamflows, and total nitrogen and total phosphorus concentrations for Spavinaw Creek near Colcord, Oklahoma, 2002–2006. —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]
11/16/2005	0845	COT	27	3.46	0.071	Base flow
12/15/2005	0857	COT	21	3.55	0.065	Base flow
01/12/2006	0855	COT	21	3.64	0.260	Base flow
02/09/2006	0913	COT	22	3.61	0.083	Base flow
03/09/2006	0850	COT	30	3.32	0.069	Base flow
04/12/2006	0850	COT	34	2.94	--	Runoff
04/29/2006	1355	USGS	68	2.67	0.097	Runoff
05/02/2006	1410	USGS	153	3.41	0.092	Runoff
05/10/2006	0917	COT	142	3.18	0.098	Runoff
05/10/2006	1150	USGS	191	3.41	0.130	Runoff
06/08/2006	0925	COT	39	--	0.100	Runoff
07/13/2006	0947	COT	13	--	0.074	Base flow
07/13/2006	1300	USGS	12	2.47	0.065	Base flow
08/10/2006	0842	COT	11	2.28	--	Base flow
08/28/2006	1345	USGS	30	2.08	0.074	Runoff
09/14/2006	0927	COT	29	3.01	--	Base flow
10/12/2006	0926	COT	15	3.07	--	Base flow
11/16/2006	0815	COT	24	2.94	--	Base flow
12/06/2006	0940	COT	132	5.03	--	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 substituted in the total nitrogen calculation for this sample.

Appendix 5. Streamflows, and total nitrogen and total phosphorus concentrations for Beaty Creek near Jay, Oklahoma, 2002–2006.

[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	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

Appendix 5. Streamflows, and total nitrogen and total phosphorus concentrations for Beaty Creek near Jay, Oklahoma, 2002–2006. —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]
11/06/2003	0730	COT	6.4	1.00	0.036	Base flow
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
01/06/2005	0720	COT	603	4.11	0.270	Runoff
01/13/2005	1325	USGS	486	3.50	0.230	Runoff
02/10/2005	0730	COT	48	3.78	0.042	Base flow
03/10/2005	0730	COT	25	3.13	0.044	Base flow
04/07/2005	0735	COT	142	3.28	0.068	Runoff
05/12/2005	0625	COT	15	2.58	0.056	Base flow
06/09/2005	0755	COT	9.6	2.07	0.047	Base flow
06/14/2005	1030	USGS	85	1.89	0.070	Runoff
07/14/2005	0725	COT	4.0	1.47	0.055	Base flow
08/11/2005	0735	COT	0.61	0.89	0.043	Base flow
09/15/2005	0755	COT	0.09	0.88	0.068	Base flow
10/06/2005	0745	COT	0.04	0.99	0.054	Base flow
11/16/2005	0734	COT	2.8	1.16	0.040	Base flow

Appendix 5. Streamflows, and total nitrogen and total phosphorus concentrations for Beaty Creek near Jay, Oklahoma, 2002–2006. —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]
12/15/2005	0750	COT	1.7	1.18	0.029	Base flow
01/12/2006	0740	COT	2.1	1.37	0.100	Base flow
02/09/2006	0905	COT	1.7	1.21	0.031	Base flow
03/09/2006	0806	COT	2.6	1.45	0.028	Base flow
04/12/2006	0738	COT	2.1	1.04	--	Base flow
04/29/2006	1210	USGS	26	1.16	0.036	Runoff
05/02/2006	1125	USGS	35	1.57	0.034	Runoff
05/10/2006	0810	COT	535	2.70	0.230	Runoff
05/10/2006	1030	USGS	519	3.11	0.210	Runoff
06/08/2006	0745	COT	7.5	--	0.039	Base flow
07/13/2006	0735	COT	[5] 0.1	--	0.063	Base flow
08/29/2006	1125	USGS	19	1.77	0.051	Runoff
09/14/2006	0745	COT	2.8	0.67	--	Base flow
11/16/2006	0835	COT	0.67	0.91	--	Base flow
12/06/2006	0745	COT	32	3.47	--	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 30-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 ft3/s was designated base flow.

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

[5] Instantaneous streamflow estimated by author for this sample from recorded 30-minute streamflow data.

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