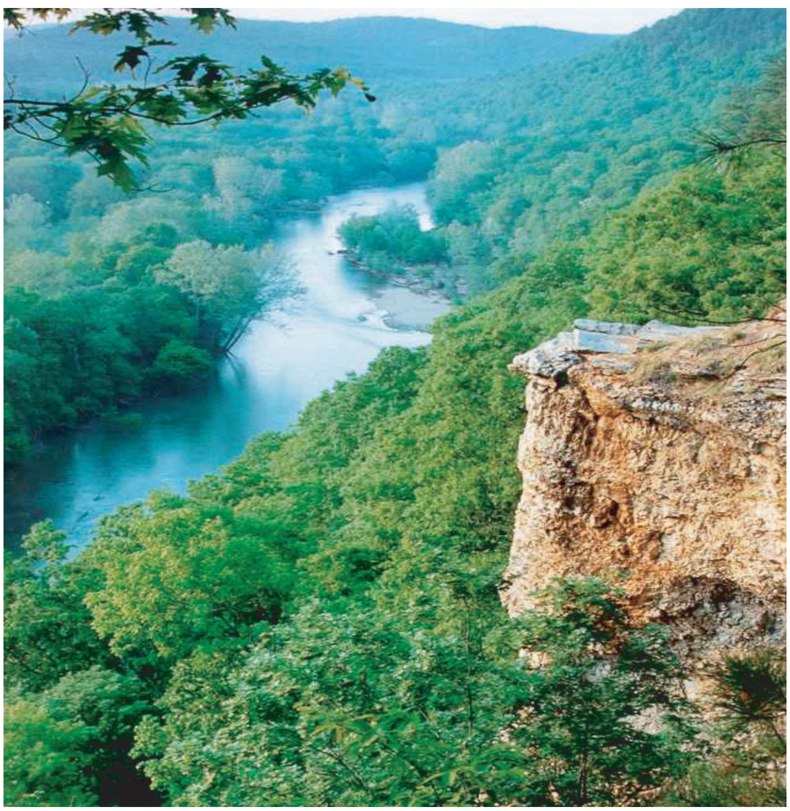
Prepared in cooperation with the
OKLAHOMA SCENIC RIVERS COMMISSION
OKLAHOMA WATER RESOURCES BOARD

Phosphorus Concentrations, Loads, and Yields in the Illinois River Basin, Arkansas and Oklahoma, 1997-2001

Water-Resources Investigations Report 03-4168



Photograph by Edward H. Fite, III, Oklahoma Scenic Rivers Commission

U.S. Department of the Interior
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Phosphorus Concentrations, Loads, and Yields in the Illinois River Basin, Arkansas and Oklahoma, 1997-2001

By Barbara E. Pickup[1], William J. Andrews[1], Brian E. Haggard[2], and W. Reed Green[1]

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[1]U.S. Geological Survey
[2]U.S. Department of Agriculture

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Conversion Factors and Datum

Multiply	By	To obtain
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
pound (lb)	0.4536	kilogram (kg)
pound per day (lb/d)	0.4536	kilogram per day (kg/d)
pound per year (lb/yr)	0.4536	kilogram per year (kg/yr)
pound per year per square mile ($lb/yr/mi^2$)	0.17514	kilogram per year per square kilometer ($kg/yr/(km^2)$)

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

$$°F = (1.8 \times °C) + 32$$

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

$$°C = (°F - 32) / 1.8$$

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).

Elevation, as used in this report, refers to distance above or below NAVD 88.

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

Phosphorus Concentrations, Loads, and Yields in the Illinois River Basin, Arkansas and Oklahoma, 1997-2001

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Abstract

The Illinois River and tributaries, Flint Creek and the Baron Fork, are designated scenic rivers in Oklahoma. Recent phosphorus increases in streams in the basin have resulted in the growth of excess algae, which have limited the aesthetic benefits of water bodies in the basin, especially the Illinois River and Lake Tenkiller. The Oklahoma Water Resources Board has established a standard for total phosphorus not to exceed the 30-day geometric mean concentration of 0.037 milligram per liter in Oklahoma Scenic Rivers. Data from water-quality samples from 1997 to 2001 were used to summarize phosphorus concentrations and estimate phosphorus loads, yields, and flow-weighted concentrations in the Illinois River basin.

Phosphorus concentrations in the Illinois River basin generally were significantly greater in runoff-event samples than in base-flow samples. Phosphorus concentrations generally decreased with increasing base flow, from dilution, and increased with runoff, possibly because of phosphorus resuspension, stream bank erosion, and the addition of phosphorus from nonpoint sources.

Estimated mean annual phosphorus loads were greater at the Illinois River stations than at Flint Creek and the Baron Fork. Loads appeared to generally increase with time during 1997-2001 at all stations, but this increase might be partly attributable to the beginning of runoff-event sampling in the basin in July 1999. Base-flow loads at stations on the Illinois River were about 10 times greater than those on the Baron Fork and 5 times greater than those on Flint Creek. Runoff components of the annual total phosphorus load ranged from 58.7 to 96.8 percent from 1997-2001. Base-flow and runoff loads were generally greatest in spring (March through May) or summer (June through August), and were least in fall (September through November).

Total yields of phosphorus ranged from 107 to 797 pounds per year per square mile. Greatest yields were at Flint Creek near Kansas (365 to 797 pounds per year per square mile) and the least yields were at Baron Fork at Eldon (107 to 440 pounds per year per square mile).

Estimated mean flow-weighted concentrations were more than 10 times greater than the median and were consistently greater than the 75th percentile of flow-weighted phosphorus concentrations in samples collected at relatively undeveloped basins of the United States (0.022 milligram per liter and 0.037 milligram per liter, respectively). In addition, flow-weighted phosphorus concentrations in 1999-2001 at all Illinois River stations and at Flint Creek near Kansas were equal to or greater than the 75th percentile of all National Water-Quality Assessment program stations in the United States (0.29 milligram per liter).

The annual average phosphorus load entering Lake Tenkiller was about 577,000 pounds per year, and more than 86 percent of the load was transported to the lake by runoff.

Introduction

The Oklahoma Scenic Rivers Act of 1969 designated the Illinois River in northeastern Oklahoma (fig. 1) a ‘Scenic River’ to protect water quality and preserve fish, wildlife, and outdoor recreational values for the benefit of the people of Oklahoma and visitors to the state. The Oklahoma Scenic Rivers Commission (OSRC) was created in 1977 to enforce the stipulations of this Act. A 1981 supplement to the Oklahoma Scenic Rivers Act designated Flint Creek and Baron Fork, two Illinois River tributaries, as scenic rivers (Oklahoma Statutes, Title O.S. Supp. 1981, Sec. 1451).

Streams in the Illinois River basin are used for primary body contact recreation (in which there is a possibility of human ingestion of water) and fisheries. Water from these streams also is used for public and private water supply and non-irrigation agriculture (Oklahoma Water Resources Board, 2000). About 350,000 tourists spend an estimated $9 million per year in the basin (Linda Loucks, Oklahoma Water Resources Board, written commun., 2001). The Illinois River flows into Tenkiller Ferry Lake (referred to as Lake Tenkiller). An estimated $16.5 million is generated annually by about 1,500,000 visitors per year to the area around this lake (John Marnell, U.S. Army Corps of Engineers, written commun., 2001).

Phosphorus can enter streams in discharges from wastewater-treatment plants (point-source components) and in agricultural and urban runoff (nonpoint-source components) (Oklahoma Water Resources Board, 2002b). Streams in the Illinois River basin are susceptible to potentially large concentrations of phosphorus from both types of sources. Total phosphorus (referred to as phosphorus) is the concentration of dissolved phosphorus and particulate phosphorus in the sample. Elevated phosphorus concentrations may promote algae growth in streams (Sharpley, 1995), and are associated with accelerated eutrophication of lakes (Daniel and others, 1998). Recent phosphorus increases in streams in the basin have resulted in the growth of excess algae, which have reduced the aesthetic benefits of water bodies in the basin, especially the Illinois River and Lake Tenkiller (Oklahoma Water Resources Board, 2002a). The recreation-based economy of the area relies on maintenance of aesthetically pleasing water quality in the Illinois River basin.

The 1998 Federal Clean Water Action Plan directs the states, in conjunction with the U.S. Environmental Protection Agency (USEPA), to develop numeric criteria for nutrients, including phosphorus. Oklahoma Water Resources Board (OWRB) has established a standard, which will be fully implemented by the year 2012, for total phosphorus concentration not to exceed the 30-day geometric mean concentration of 0.037 milligram per liter (mg/L) in Oklahoma Scenic Rivers. That standard is based on the 75th percentile of flow-weighted total phosphorus concentrations from streams draining 85 relatively undeveloped basins from across the United States (referred to as relatively undeveloped basins of the United States) selected from three programs of the USGS — the Hydrologic Benchmark Network, the National Water-Quality Assessment program (NAWQA), and the Research Program (Clark and others, 2000).

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

Historical water-quality data collection in the Illinois River basin has been biased towards sampling during base-flow (non-runoff) conditions. Because of insufficient historic sampling during runoff events, calculations using historic data may have underestimated true phosphorus concentrations, loads, and yields. In July 1999, the U.S. Geological Survey (USGS), in cooperation with the OSRC and the OWRB, supplemented fixed period, bimonthly water-quality sampling with six runoff-event samplings per year to better determine water quality over the range of streamflows in the basin.

Purpose and Scope

The purpose of this report is to summarize phosphorus concentrations and provide estimates of phosphorus loads, yields, and flow-weighted concentrations in the Illinois River and tributaries, Flint Creek and the Baron Fork, from January 1997 through December 2001. Phosphorus concentrations are compared among stations in the Illinois River basin, to those measured at relatively undeveloped basins of the United States, and to those measured at all USGS NAWQA program stations. Phosphorus loads are computed using LOADEST2, a program to compute mean constituent loads in rivers using the rating-curve method. LOADEST2 uses instantaneous phosphorus concentrations and mean daily streamflows to estimate annual and seasonal (spring, summer, fall, and winter) average phosphorus loads for the study period (Crawford, 1999). This report comprises a preliminary analysis of data collected for a multi-year monitoring program.

Study Area Description

The Illinois River basin is about equally divided between northeastern Oklahoma and northwestern Arkansas (fig. 1). The basin is in the southwestern portion of the Ozark Plateaus physiographic province (Fenneman, 1938), and is underlain by the cherty limestone of the Springfield Plateau aquifer (Adamski and others, 1995; Renken, 1998).

The basin is dominated by about equal proportions of agricultural and forested land uses and is interspersed with minor amounts of industrial, mining, and urban land uses (fig. 2). Livestock production is the primary form of agriculture in the basin. About 48 percent of agricultural land use in the basin is pasture for cattle and horses. Numerous large-scale poultry and swine production facilities are in the basin and poultry and swine manures are used to fertilize pastures (Sims and Wolf, 1994). There also are several municipal wastewater-treatment plants that discharge phosphorus-containing wastewater to the river or tributaries (Oklahoma Water Resources Board, 2002b; figs. 1 and 2).

Streams in the Illinois River basin are susceptible to potentially large concentrations of phosphorus from point sources (such as wastewater-treatment plants) and nonpoint sources (such as runoff from fertilized pastures). Phosphorus concentrations in Ozark streams typically are greater in streams draining agricultural lands than in those draining forested lands (Petersen and others, 1998, 1999), because runoff from pastures fertilized with animal manure probably are substantial sources of phosphorus to the rivers in this basin (Arkansas Department of Environmental Quality, 2000). Streams receiving municipal wastewater from treatment plants can have phosphorus concentrations substantially greater than those in streams draining agricultural areas (Petersen and others, 1998, 1999). The Illinois River and Flint Creek (fig. 2) receive discharges from wastewater treatment plants, whereas the Baron Fork does not.

Streamflow in the Illinois River Basin

Streamflow in the Illinois River basin was highly variable and generally increased with basin drainage area (table 1, fig.

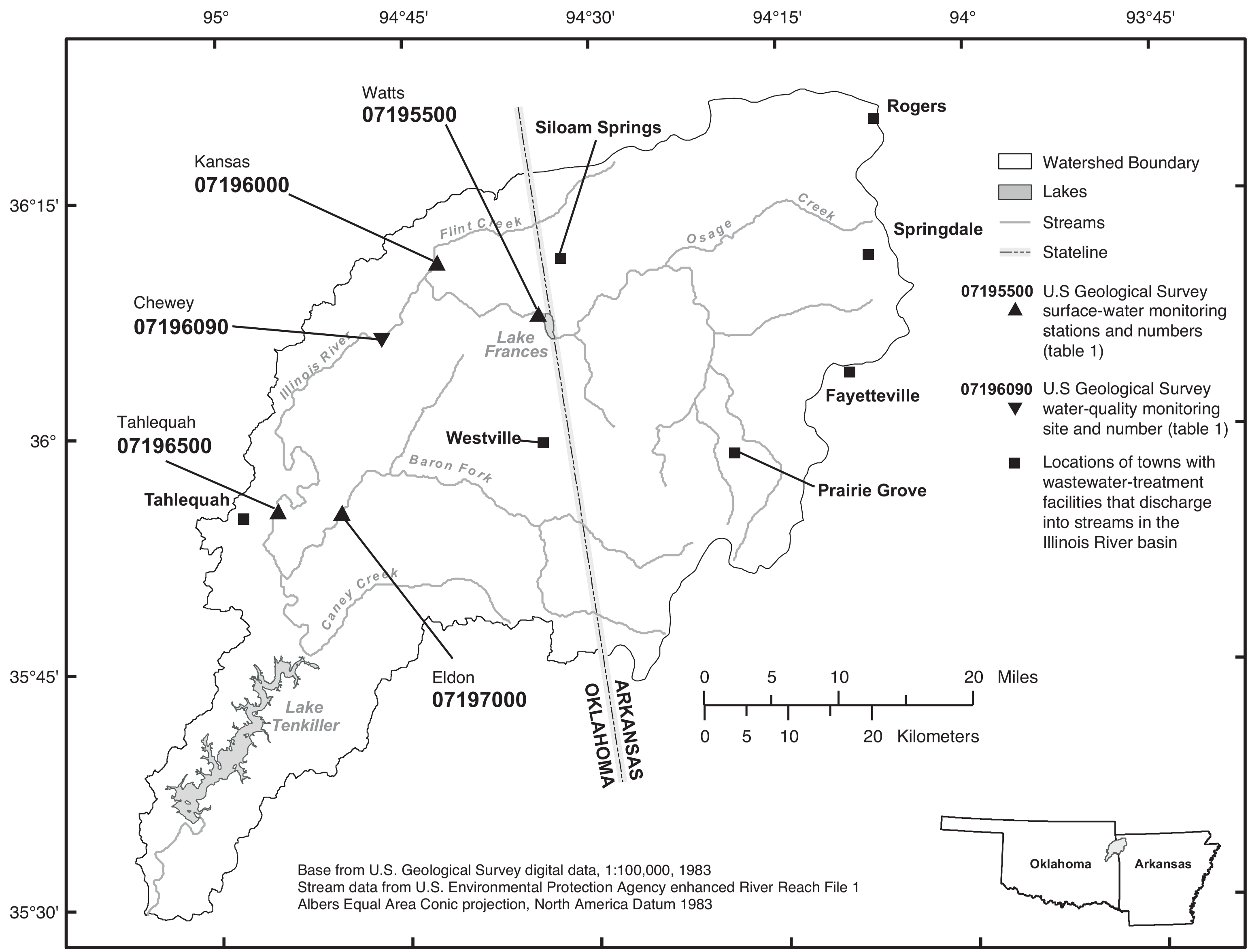

Figure 1. The Illinois River basin, Oklahoma, with locations of surface-water and water-quality stations in the basin and of towns with wastewater-treatment facilities that discharge into streams in the basin. [07195500, Illinois River near Watts; 07196000, Flint Creek near Kansas; 07196090, Illinois River at Chewey; 07196500, Illinois River near Tahlequah; 07197000, Baron Fork at Eldon]

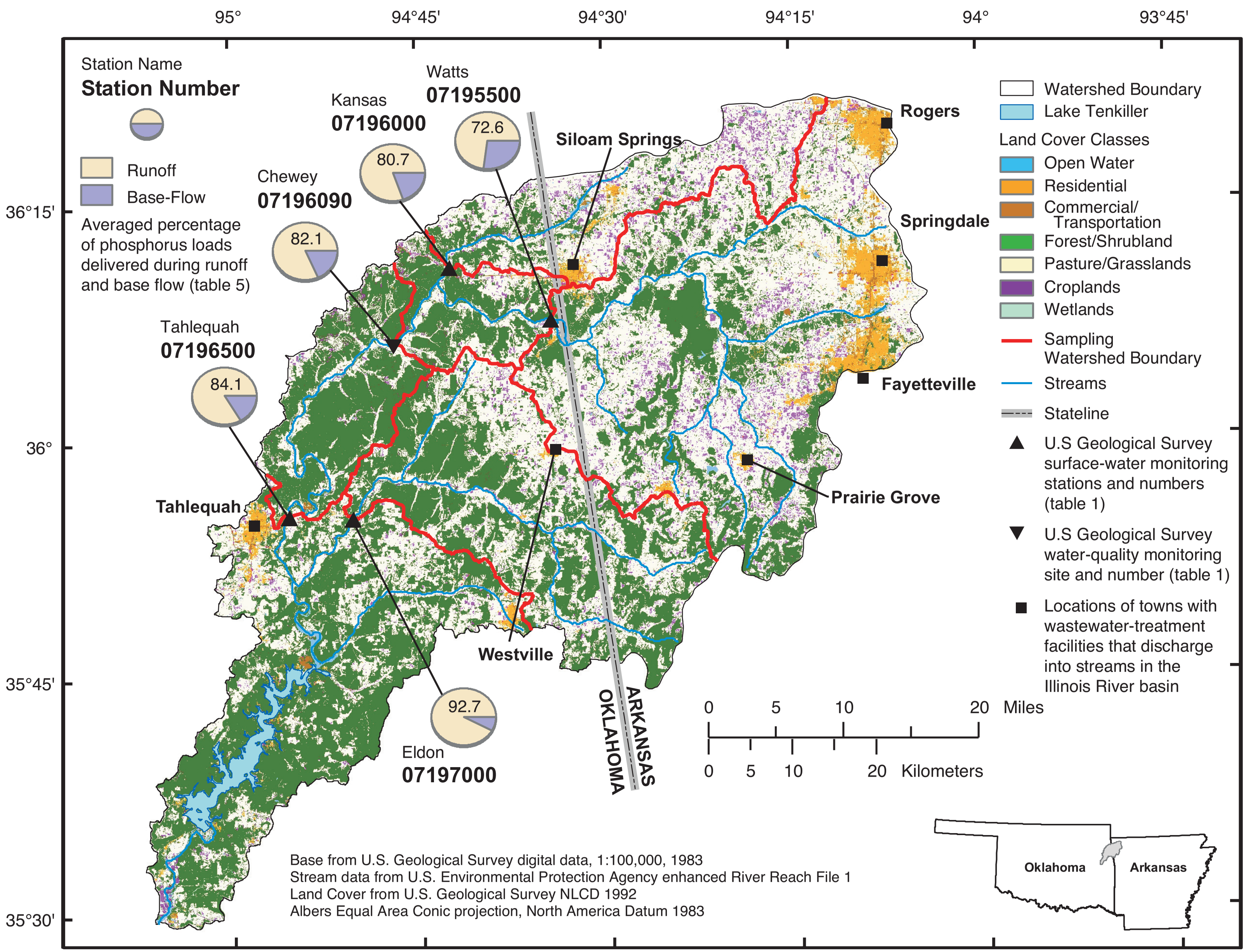

Figure 2. Land use and averaged percentage of phosphorus loads in the Illinois River basin, Oklahoma. [07195500, Illinois River near Watts; 07196000, Flint Creek near Kansas; 07196090, Illinois River at Chewey; 07196500, Illinois River near Tahlequah; 07197000, Baron Fork at Eldon]

Table 1. Station information and streamflow statistics for surface-water and water-quality stations in the Illinois River basin, Oklahoma

[The Illinois River at Chewey is ungaged; streamflow is estimated by adding streamflow from Illinois River near Watts to streamflow from Flint Creek near Kansas. ft^3/s, cubic foot per second; ddmmss, degrees, minutes, seconds; mi^2, square mile; N/A, not applicable]

Station name (number)	Period of record for station	Latitude (ddmmss)	Longitude (ddmmss)	Drainage area (mi^2)	Mean annual streamflow (ft^3/s)				Minimum and maximum mean daily streamflow for study period (1997-2001) (ft^3/s)	
					1997-1999	1998-2000	1999-2001	Period of record	Minimum (date)	Maximum (date)
Illinois River near Watts (07195500)	1955-	360748	943419	635	692	718	696	638	88 (Sept. 10, 1998)	18,200 (June 21, 2000)
Flint Creek near Kansas (07196000)	1955-1976; 1979-1990; 1992-	361111	944224	110	110	122	123	120	8.3 (Sept. 9, 1998)	7,820 (June 21, 2000)
Illinois River at Chewey (07196090)	N/A	360615	944657	820	802	840	819	N/A	97 (Sept. 10, 1998)	26,000 (June 21, 2000)
Illinois River near Tahlequah (07196500)	1935-	355522	945524	959	1,000	1,090	1,090	946	82 (Sept. 9-10, 1998)	32,800 (June 22, 2000)
Baron Fork at Eldon (07197000)	1948-	355516	945018	307	369	382	360	333	13 (Sept. 9-12, 1998)	22,300 (June 21, 2000)

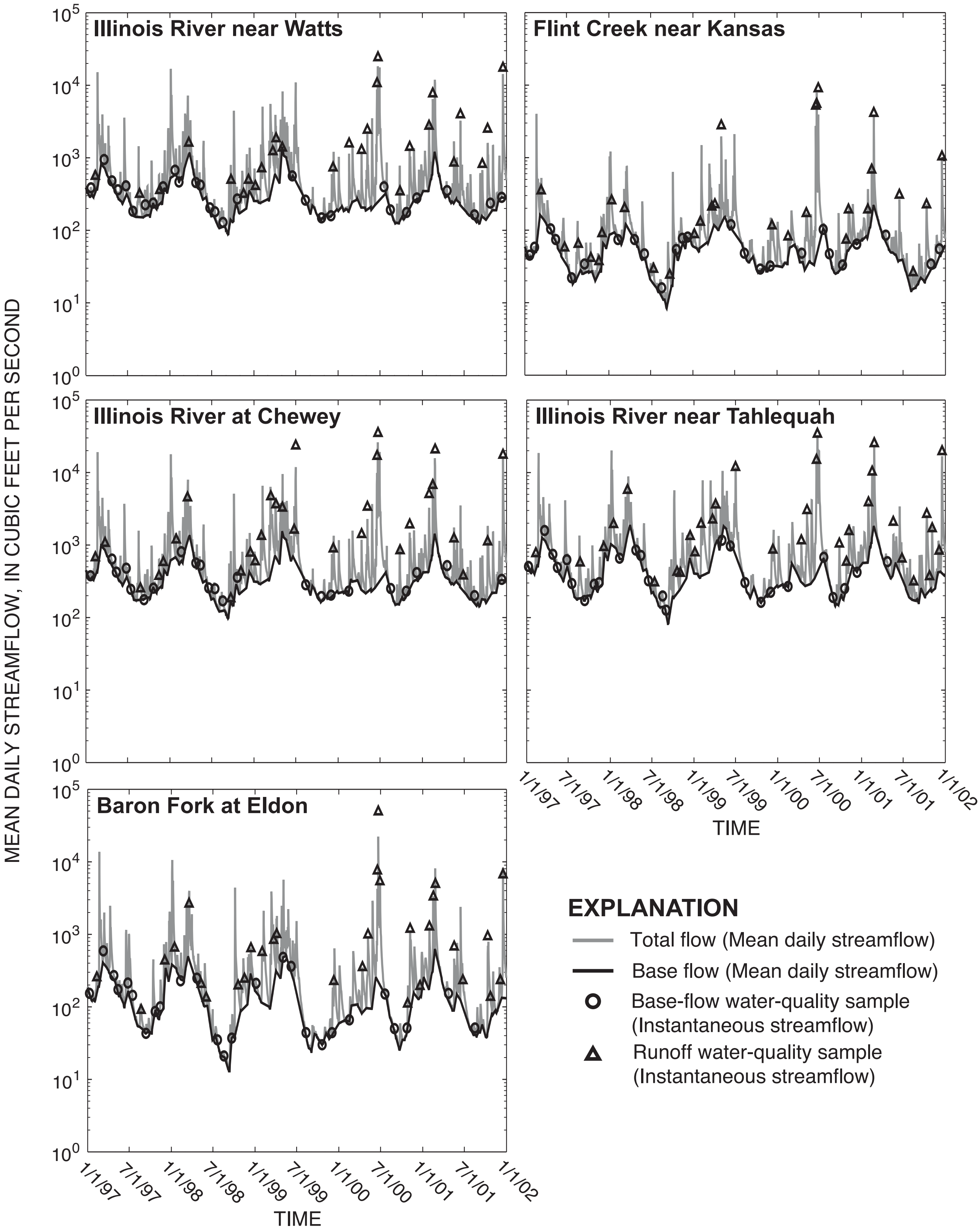

Figure 3. Streamflow divided into total flow and base flow, and base-flow and runoff water samples collected at water-quality stations in the Illinois River basin, Oklahoma, 1997-2001.

3). The maximum mean daily streamflow during the study period occurred in June 2000 and the minimum mean daily streamflow during the study period occurred in September 1998 at all stations (table 1, fig. 3). Greatest mean monthly streamflows occurred from January through June and least mean monthly streamflows occurred from mid-summer through October at all of the stations (Blazs and others, 1998, 1999, 2000, 2001, 2002, 2003). Continuous streamflow was not measured at the Illinois River near Chewey, so estimated mean daily streamflows for that station were computed by adding streamflow from Illinois River near Watts to streamflow from Flint Creek near Kansas (table 1, Appendix 1).

Acknowledgments

The authors thank many people for their contributions to the data collection and data analysis presented in this report. There were numerous USGS personnel that participated in the bimonthly and runoff-event water-quality sampling, but a special thanks goes to Royce Johnson for his leadership and contribution to the data collection. Additional special thanks go to Charlie Crawford for his help with load estimations and the LOADEST2 program and to Dave Mueller for his statistical guidance.

Methods

The USGS collects water-quality data and operates several continuous streamflow gaging stations and ungaged stations in the Illinois River basin in Oklahoma. Four continuous streamflow gaging stations were selected for use in this report: Illinois River near Watts, Flint Creek near Kansas, Illinois River near Tahlequah, and Baron Fork at Eldon (table 1, fig. 1). The Illinois River at Chewey is an ungaged station at which streamflow is only measured when water-quality samples are collected (table 1, fig. 1). Stream gages were operated and streamflows were measured according to methods described in Rantz and others (1982). Prior to July 1999, bimonthly water-quality samples were collected at these stations. Starting in July 1999, six additional water-quality samples were collected annually during runoff events at these stations (fig. 3). Representative water-quality samples were collected using equal-width increment methods (Edwards and Glysson, 1999).

The USGS National Water-Quality Laboratory in Lakewood, Colorado, analyzed the water-quality samples for total phosphorus using methods described in Patton and Truitt (1992).

Streamflow data and phosphorus concentrations measured from 1997 through 2001 are analyzed in this report. All streamflow and water-quality data are available through the world wide web at http://water.usgs.gov/ok/nwis.

Streamflow was separated into base-flow and runoff components using a hydrograph separation program, Base Flow Index (BFI) (Institute of Hydrology, 1980a, 1980b; Wahl and Wahl, 1995) (fig. 3). Base flow is the sustained runoff or natural flow of the stream and is largely composed of ground-water seepage (Langbein and Iseri, 1960). Base-flow contributions were estimated by BFI using a method proposed by the Institute of Hydrology (1980a, 1980b). The minimum daily mean flow was identified in consecutive 5-day increments, and minimums less than 90 percent of adjacent minimums were defined as turning points (Wahl and Wahl, 1988; Wahl and Tortorelli, 1997). The BFI 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 were defined as days when base flow was greater than or equal to 70 percent of total flow; runoff days were defined as days when runoff contributed more than 30 percent of total flow.

Water-quality data and streamflow data were divided into three 3-year periods: 1997-1999, 1998-2000, and 1999-2001. The Mann-Whitney rank-sum test (Helsel and Hirsch, 1992), used to compare pairs of data sets, was used to determine the statistical significance of differences between base-flow and runoff phosphorus concentrations at each station within each period. The Kruskal-Wallis test (Helsel and Hirsch, 1992, p. 159, 355), used to compare multiple data sets at one time, was used to determine the statistical significance of differences in phosphorus concentrations between stations in the Illinois River basin. The tests were selected because neither test requires normally distributed data. The null hypotheses of both tests state that there are no differences in median concentrations between the data sets being compared. The null hypothesis was rejected and medians were described as being significantly different if the two-sided p-value of the test was less than or equal to 0.05 (Helsel and Hirsch, 1992). If the null hypothesis of the Kruskal-Wallis test was rejected and the medians were described as significantly different, the Tukey (Helsel and Hirsch, 1992, p. 196) multiple comparison test was applied to determine which sites were different and which were not.

Linear regression was used to evaluate relations between phosphorus concentrations and total streamflow for each of the periods. Regression methods have been developed to estimate continuous constituent loads, because water-quality data are collected intermittently. The regression method requires discrete water-quality samples and mean daily streamflow data collected over several years. Sample dates, times, instantaneous streamflows, and phosphorus concentrations used in this analysis are provided in Appendix 1 or through the world wide web at http://water.usgs.gov/ok/nwis.

Constituent load (L) is the product of streamflow (Q) and the constituent concentration in the water (C) multiplied by a conversion factor for consistent units. Load is the amount of a constituent transported past a selected point in a stream in a given amount of time, usually one year. The LOADEST2 program (Crawford, 1991, 1996) was used to estimate constituent loads by the rating-curve method (Cohn and others, 1989; Crawford, 1991) in the Illinois River, Flint Creek, and Baron Fork. LOADEST2 estimates rating-curve parameters and mean load using several regression methods and a ratio estimator. Because some of the constituent concentrations included in this analysis were censored (values less than the laboratory method detection limit), parameters were estimated by maximum likelihood estimation (MLE) methods (Dempster and others, 1977; Wolynetz, 1979). In the absence of censored data, the MLE method is equivalent to ordinary least squares regression. An estimate of the uncertainty in the estimated load was obtained using the method described by Likes (1980) and Gilroy and others (1990). LOADEST2 contains 10 rating-curve models that can test the relation between constituent load and streamflow. The model used for this report (equation 1) includes a time variable to model the relation between the natural logarithms of L and Q:

$$\ln(L) = b_0 + b_1 \ln(Q) + b_2 dectime \qquad (1)$$

where

L = constituent load, in pounds per day (lb/d);
b_0 = regression constant, dimensionless;
b_1 and b_2 = regression coefficients, dimensionless;
Q = daily mean streamflow, in cubic feet per second (ft^3/s); and
dectime = time, in fractional years.

Plots of residuals (ln(instantaneous load) - In(estimated load)) with LOWESS curves are shown in Appendix 2. The LOWESS curve is a central line that represents the moving average or middle smooth through the data (Helsel and Hirsch, 1992). The shape of the curve indicates fluctuations in the data. The plots indicate the goodness of fit of this model, with a perfect fit indicated by the curve fluctuating around a value of zero. Data from stations on the Illinois river generally appeared to fit the model better than data from Flint Creek and Baron Fork. The goodness of fit also generally appeared to increase with time at most stations in the basin. Other LOADEST2 predefined regression models using various combinations of streamflow, time, and seasonal coefficients did not have lesser residuals than the model used for this report.

Estimated mean annual phosphorus loads and estimates of the standard deviations of the mean loads were calculated by LOADEST2 using all base-flow and runoff data. The daily load values generated by LOADEST2 were then 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. Mean annual base-flow loads were calculated as the mean of the base-flow sample set. Mean annual runoff loads were calculated as the mean of the runoff sample set. Seasonal base-flow and runoff loads were calculated in the same way based on the number of base-flow and runoff days in each season of each period.

Phosphorus yields for each of the three periods at each station were calculated by dividing mean annual phosphorus loads by drainage area. Flow-weighted concentrations for each of the three periods at each station were calculated by dividing mean annual phosphorus loads by mean annual streamflow.

Phosphorus Concentrations, Loads, and Yields in the Illinois River basin

Phosphorus in the Illinois River basin is described in terms of three 3-year periods (1997-1999, 1998-2000, and 1999-2001) of mean concentrations, loads, and yields in base-flow and runoff samples, and in terms of mean flow-weighted concentrations.

Concentrations

Phosphorus concentrations were significantly greater ($p < 0.05$) in runoff-event samples than in base-flow samples for the 1998-2000 and 1999-2001 periods at Flint Creek near Kansas, Illinois River at Chewey, Illinois River near Tahlequah, and Baron Fork at Eldon, but this difference was not significant at Illinois River near Watts (tables 2 and 3, fig. 4). The similarity of phosphorus concentrations during base flow and runoff at the Watts station may be caused by phosphorus cycling in Lake Frances, immediately upstream from that station. Phosphorus may precipitate with sediments to the lake bed during runoff, to be gradually released from those sediments into the water column during base flow. Phosphorus concentrations were not significantly greater in runoff-event samples than in base-flow samples for the period 1997-1999 at Illinois River near Watts, Flint Creek near Kansas, Illinois River at Chewey, and Baron Fork at Eldon. This lack of difference may be attributed to the lack of water-quality samples collected during runoff events during this period.

Phosphorus concentrations in base-flow samples during all 3-year periods significantly ($p < 0.05$) decreased in the downstream direction in the Illinois River from the Chewey to Tahlequah stations (fig. 5), as has been reported for other point-source affected streams in the region (Haggard, 2000; Haggard and others, 2001). Phosphorus concentrations in base-flow samples from the Illinois River generally decreased with increasing streamflow (fig. 4). As base flow increases by addition of ground water, dilution reduces the concentration of phosphorus from point sources such as municipal wastewater-treatment plants. The Illinois River and Flint Creek receive phosphorus concentrations from point sources. The Baron Fork receives treated wastewater from the relatively small community of Lincoln, Arkansas. Consequently, phosphorus concentrations in base-flow samples from the Baron Fork were significantly less than those in base-flow samples from the Illinois River and Flint Creek during all 3-year periods (fig. 5).

Phosphorus concentrations in runoff samples for all 3-year periods were not significantly different among the four stations on Flint Creek and the Illinois River, but concentrations at the Baron Fork were significantly less than at all other stations (fig. 6). Phosphorus concentrations in runoff samples from the Illinois River, Flint Creek, and the Baron Fork generally increased with increasing streamflow (fig. 4). Possible causes of larger concentrations of phosphorus during runoff events than in base flow are resuspension of phosphorus from the streambed,

Table 2. Summary statistics of phosphorus concentrations from base-flow and runoff water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001

[Min, minimum concentration; Med, median concentration; Mean, mean concentration; Max, maximum concentration; Obs, number of observations; mg/L, milligram per liter; all concentration data, including censored data, were used to calculate statistics. Censored data (concentrations less than minimum reporting limit) were entered in the statistics calculations as one-half the minimum reporting limit.]

Station name (number)	3-year period	Base Flow					Runoff				
		Min (mg/L)	Med (mg/L)	Mean (mg/L)	Max (mg/L)	Obs	Min (mg/L)	Med (mg/L)	Mean (mg/l)	Max (mg/L)	Obs
Illinois River near Watts, Oklahoma (07195500)	1997-1999	0.06	0.17	0.17	0.28	21	0.07	0.13	0.14	0.28	13
	1998-2000	0.06	0.21	0.19	0.38	16	0.07	0.18	0.26	0.65	17
	1999-2001	0.16	0.25	0.26	0.38	12	<0.06	0.30	0.37	0.88	20
Flint Creek near Kansas, Oklahoma (07196000)	1997-1999	0.09	0.12	0.15	0.66	17	0.09	0.13	0.18	0.88	16
	1998-2000	0.10	0.13	0.16	0.66	16	0.10	0.17	0.39	1.66	17
	1999-2001	0.10	0.12	0.17	0.66	12	0.10	0.21	0.41	1.66	20
Illinois River at Chewey, Oklahoma (07196090)	1997-1999	0.05	0.13	0.12	0.17	17	0.07	0.15	0.20	0.93	18
	1998-2000	0.05	0.14	0.14	0.22	14	0.07	0.21	0.33	0.96	19
	1999-2001	0.12	0.16	0.18	0.26	10	0.07	0.27	0.42	0.96	21
Illinois River near Tahlequah, Oklahoma (07196500)	1997-1999	0.02	0.07	0.06	0.11	20	0.07	0.10	0.19	1.14	15
	1998-2000	0.03	0.08	0.08	0.12	16	0.07	0.15	0.26	1.14	19
	1999-2001	0.04	0.09	0.09	0.12	11	<0.06	0.22	0.31	1.14	24
Baron Fork at Eldon, Oklahoma (07197000)	1997-1999	<0.01	0.02	0.02	0.05	20	<0.01	0.03	0.04	0.09	14
	1998-2000	<0.01	0.03	0.03	0.06	15	<0.01	0.04	0.24	1.65	19
	1999-2001	0.03	0.03	0.03	0.05	12	0.04	0.09	0.26	1.65	21

Table 3. Mann-Whitney rank-sum test (Helsel and Hirsch, 1992) results comparing base-flow phosphorus concentrations to runoff phosphorus concentrations from water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001

[p-values in bold indicate statistically significant ($p < 0.05$) differences between groups of data]

Station name (number)	3-year period		
	1997-1999	1998-2000	1999-2001
Illinois River near Watts (07195500)	z = 1.190 p = 0.2341	z = 0.7210 p = 0.4709	z = 0.9155 p = 0.3599
Flint Creek near Kansas (07196000)	z = 0.6371 p = 0.5240	z = 2.049 **p = 0.0405**	z = 2.659 **p = 0.0078**
Illinois River at Chewey (07196090)	z = 1.259 p = 0.2080	z = 2.664 **p = 0.0077**	z = 2.940 **p = 0.0033**
Illinois River near Tahlequah (07196500)	z = 3.752 **p = 0.0002**	z = 3.988 **p = 0.0001**	z = 3.913 **p = 0.0001**
Baron Fork at Eldon (07197000)	z = 1.532 p = 0.1257	z = 2.160 **p = 0.0308**	z = 2.414 **p = 0.0158**

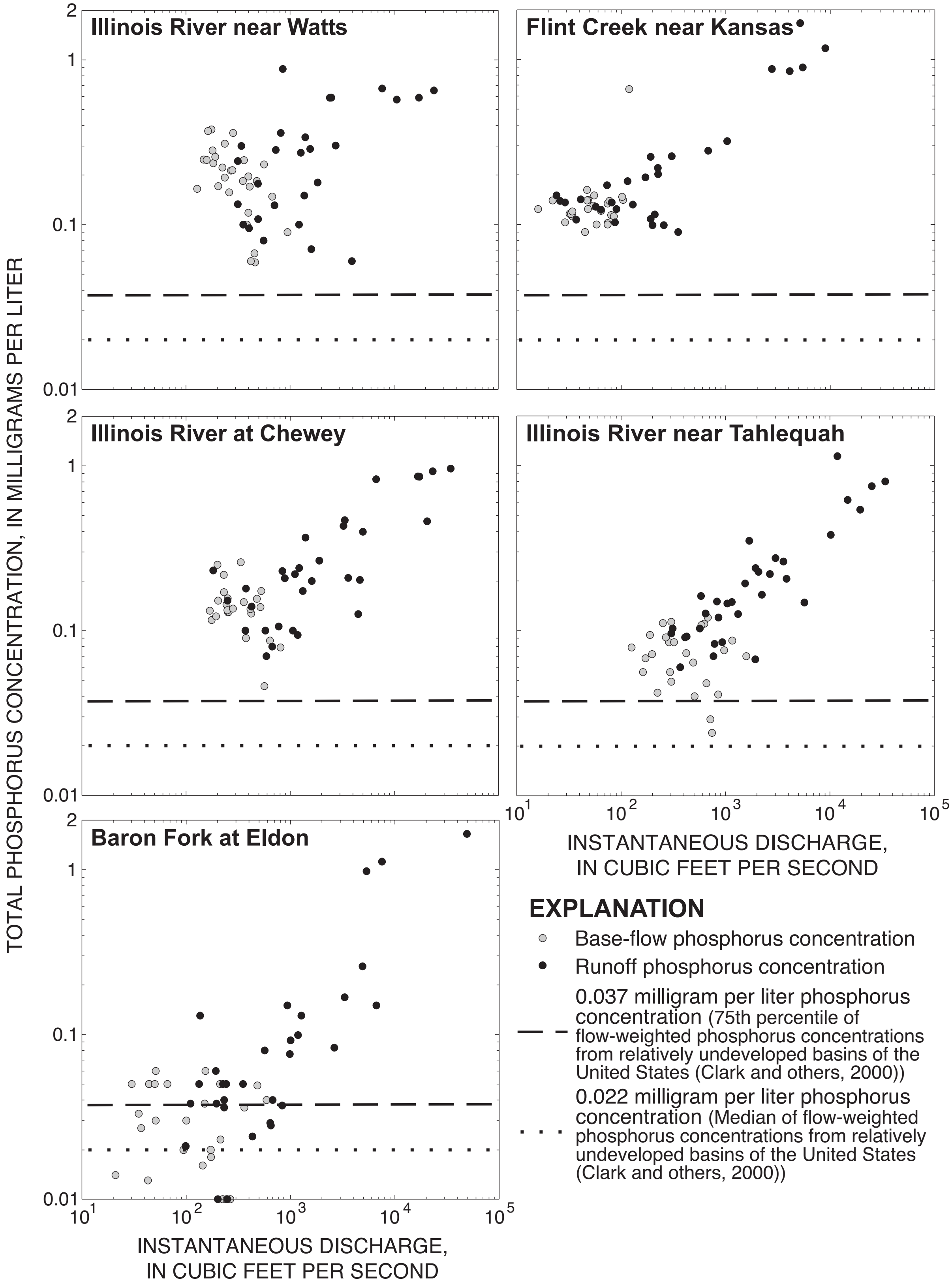

Figure 4. Phosphorus concentrations from base-flow and runoff water samples collected at water-quality stations in the Illinois River basin, Oklahoma, 1997-2001.

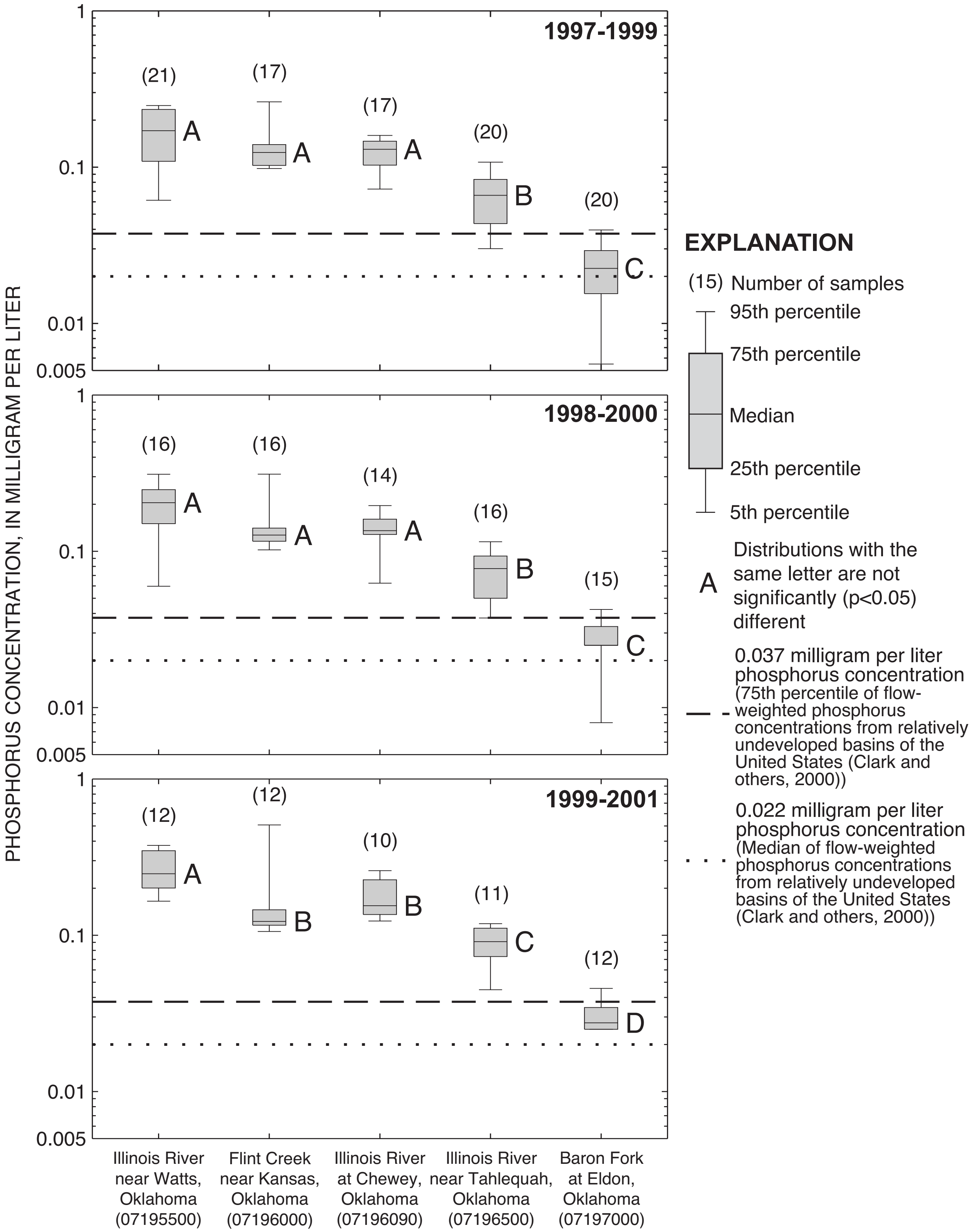

Figure 5. Distributions of **base-flow** phosphorus concentrations from water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001.

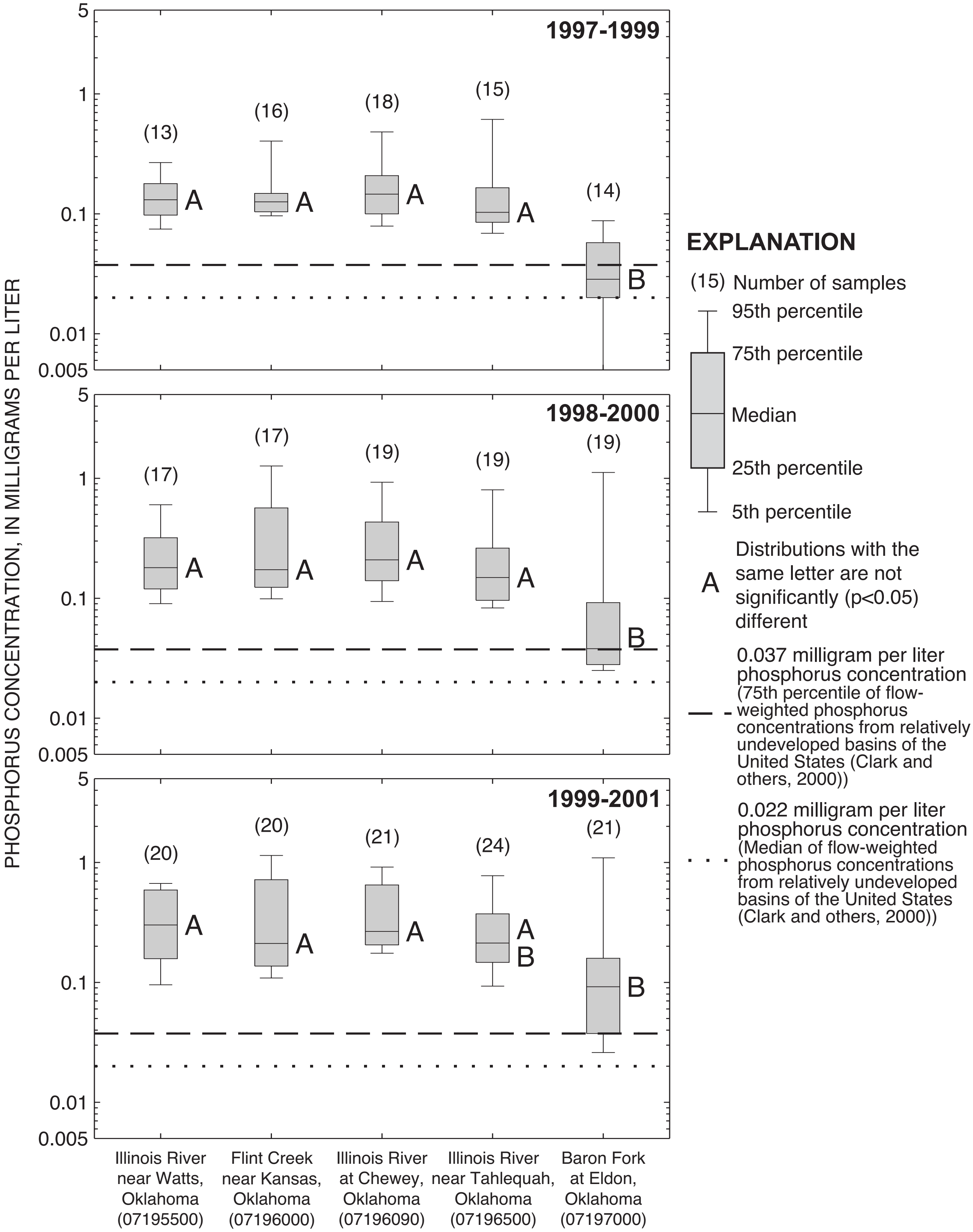

Figure 6. Distributions of **runoff** phosphorus concentrations from water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001.

stream bank erosion, and the addition of phosphorus from non-point sources.

Estimated Annual Loads

Linear regression models developed by LOADEST2 for the estimation of phosphorus loads for all 3-year periods at each station are listed in table 4. Estimated mean annual phosphorus loads (referred to as mean annual total loads) were substantially greater at the Illinois River stations than at Flint Creek and the Baron Fork, primarily because of greater streamflow at the stations on the Illinois River (tables 1 and 5). Annual total loads in the Illinois River increased from Watts to Tahlequah, mostly because of the increase in runoff load with drainage area (table 5). Annual total loads appeared to generally increase with time during 1997-2001 at all stations, but this increase might be partly attributable to the beginning of runoff-event sampling in the basin in July 1999.

Annual base-flow loads were least in the Baron Fork, despite a larger drainage basin and greater base flow than Flint Creek, which receives phosphorus from larger wastewater discharges (fig. 2). Annual base-flow loads at stations on the Illinois River were about 10 times greater than those on the Baron Fork and were about 5 times greater than those on Flint Creek. Except for the Illinois River near Watts, 1999-2001 period, annual base-flow phosphorus loads did not substantially increase in the basin from 1997-2001 (table 5).

Annual runoff loads in the basin increased with increasing drainage area and with increasing streamflow (tables 1 and 5). The portion of annual phosphorus load contributed by runoff increased in the downstream direction in the Illinois River (Watts to Tahlequah) (table 5). Runoff components of the annual total load ranged from 58.7 to 96.8 percent from 1997 to 2001 (table 5). At Flint Creek and Illinois River stations, the range in average runoff component was 58.7 to 87.4 percent of the annual total load with less than 41.5 percent of the days including substantial runoff (runoff component greater than 30 percent of total flow) (tables 5 and 6). Runoff components of the annual total load at the Baron Fork ranged from 86.6 to 96.8 percent (table 5). Annual runoff loads appeared to substantially increase over the three time periods at all stations in the basin. The most significant increase occurred between the 1997-1999 period and the 1998-2000 period, which coincides with the beginning of runoff-event sampling in the basin in July 1999. Therefore, the increase may be partly caused by the beginning of runoff-event sampling in the basin. The resuspension of temporarily retained phosphorus on the streambed or banks or additions of non-point source phosphorus components in the watershed that occur during runoff seem to dominate phosphorus transport in the Illinois River basin.

Estimated Seasonal Loads

Base-flow phosphorus loads generally were least in fall (September through November) and greatest in spring (March through May) for all periods at all stations in the Illinois River basin (table 7). Runoff phosphorus loads were least in fall for all periods at all stations. Runoff loads generally were greatest in spring for period 1997-1999, but were greatest in summer (June through August) for periods 1998-2000 and 1999-2001. The shift in seasonal trends between the 3-year periods may be a result of the 1999 onset of sampling of runoff events. Streamflows and phosphorus concentrations from runoff events like the June 2000 peak flow (maximum streamflow event for the 1997-2001 period; table 1, fig. 3) may have been sufficient to shift the greatest seasonal loads from spring to summer at all stations for periods 1998-2000 and 1999-2001.

Yields

Total yields of phosphorus ranged from 107 to 797 pounds per year per square mile (lbs/yr/mi^2), with greatest yields being reported for Flint Creek near Kansas (365 to 797 lbs/yr/mi^2) and the least yields being reported for Baron Fork at Eldon (107 to 440 lbs/yr/mi^2) (table 5). The greater yields in Flint Creek may be caused by the wastewater-treatment plant discharging to that stream (fig. 2). Base-flow yields did not substantially change over the three periods at any station except Illinois River near Watts (1999-2001). Base-flow yields also decreased downstream in the Illinois River possibly because of dilution. Runoff yields more than doubled between the 1997-1999 period and the 1999-2001 period. Because yield (mean load divided by drainage area) is proportional to load, this increase might be partly attributable to the beginning of runoff-event sampling in the basin in July 1999.

Estimated Mean Flow-Weighted Concentrations

Estimated mean flow-weighted phosphorus concentrations at the stations in the basin were more than 10 times greater than the median and were consistently greater than the 75th percentile of flow-weighted phosphorus concentrations in relatively undeveloped basins of the United States (0.022 mg/L and 0.037 mg/L, respectively, Clark and others, 2000; fig. 7, table 8). In addition, flow-weighted phosphorus concentrations in 1999-2001 at all Illinois River stations and at Flint Creek were equal to or greater than the 75th percentile of all NAWQA stations in the United States (0.29 mg/L, David Mueller, U.S. Geological Survey, written commun., 2003).

Estimated Phosphorus Loads into Lake Tenkiller

Phosphorus loads entering Lake Tenkiller can be estimated by adding the loads of the Baron Fork and the Illinois River near Tahlequah. Phosphorus loads at these stations do not represent

Table 4. Regression models developed using total phosphorus concentrations from water samples and streamflows collected at water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001

[ln, natural logarithm; L, daily load in pounds per day; Q, mean daily streamflow in cubic foot per second; dectime, time factor in decimal years]

Station name (number)	3-year period	Number of observations	Number of uncensored observations[1]	Regression model	Estimated residual variance[2]
Illinois River near Watts (07195500)	1997-1999	34	34	ln(L) = 5.56 + 0.703*ln(Q) + 0.150*dectime	0.167
	1998-2000	33	33	ln(L) = 5.43 + 1.09*ln(Q) + 0.480*dectime	0.163
	1999-2001	32	31	ln(L) = 6.53 + 1.12*ln(Q) + 0.320*dectime	0.287
Flint Creek near Kansas (07196000)	1997-1999	33	33	ln(L) = 3.71 + 1.22*ln(Q) + 0.192*dectime	0.160
	1998-2000	33	33	ln(L) = 3.98 + 1.39*ln(Q) + 0.140*dectime	0.166
	1999-2001	32	32	ln(L) = 4.73 + 1.43*ln(Q) - 0.00295*dectime	0.142
Illinois River at Chewey (07196090)	1997-1999	35	35	ln(L) = 5.61 + 1.20*ln(Q) + 0.228*dectime	0.165
	1998-2000	33	33	ln(L) = 6.13 + 1.30*ln(Q) + 0.336*dectime	0.161
	1999-2001	31	31	ln(L) = 7.10 + 1.35*ln(Q) + 0.213*dectime	0.112
Illinois River near Tahl-equah (07196500)	1997-1999	35	35	ln(L) = 5.28 + 1.39*ln(Q) + 0.285*dectime	0.261
	1998-2000	35	35	ln(L) = 5.75 + 1.45*ln(Q) + 0.274*dectime	0.189
	1999-2001	35	34	ln(L) = 6.63 + 1.50*ln(Q) + 0.0566*dectime	0.108
Baron Fork at Eldon (07197000)	1997-1999	34	24	ln(L) = 2.85 + 1.28*ln(Q) + 0.349*dectime	0.346
	1998-2000	34	21	ln(L) = 3.16 + 1.60*ln(Q) + 0.380*dectime	0.560
	1999-2001	33	22	ln(L) = 4.35 + 1.64*ln(Q) + 0.168*dectime	0.375

[1] Censored observations are most often a result of an analysis value lower than the laboratory reporting limit.

[2] 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 model.

Table 5. Mean annual phosphorus loads and yields estimated from phosphorus concentrations in water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001

[mi^2, square miles; lb/yr, pounds per year; lb/yr/mi^2, pounds per year per square mile; SD, standard deviation. Mean and standard deviation of the total load are calculated by LOADEST2 and are statistics of all data in the 3-year period. Means of base-flow loads are calculated from base-flow data only; means of runoff loads are calculated from runoff data only. Differences between total load and the sum of base-flow plus runoff loads are due to rounding within LOADEST2.]

Station name (number)	Drainage area (mi^2)	3-year period	Mean annual total load (±SD) (lb/yr)	Total yield (lb/yr/mi^2)	Mean annual base-flow load (lb/yr)	Base-flow yield (lb/yr/mi^2)	Mean annual runoff load (lb/yr)	Runoff yield (lb/yr/mi^2)	Load delivered during runoff
Illinois River near Watts (07195500)	635	1997-1999	164,000 ± 17,900	258	69,600	110	96,200	151	58.7
		1998-2000	329,000 ± 33,200	518	73,500	116	256,000	403	77.8
		1999-2001	438,000 ± 51,100	690	97,700	154	356,000	561	81.3
Flint Creek near Kansas (07196000)	110	1997-1999	40,200 ± 5,110	365	11,900	108	29,500	268	73.4
		1998-2000	80,400 ± 9,500	731	12,200	111	68,300	621	85.0
		1999-2001	87,700 ± 8,400	797	12,700	115	73,400	667	83.7
Illinois River at Chewey (07196090)	820	1997-1999	292,000 ± 29,200	356	74,300	90.6	217,000	265	74.3
		1998-2000	438,000 ± 43,800	534	74,200	90.5	382,000	466	87.2
		1999-2001	548,000 ± 40,200	668	79,400	96.8	465,000	567	84.9
Illinois River near Tahlequah (07196500)	959	1997-1999	307,000 ± 47,400	320	68,800	71.7	238,000	248	77.5
		1998-2000	511,000 ± 65,800	533	67,000	69.9	446,000	465	87.3
		1999-2001	621,000 ± 47,500	648	68,600	71.5	543,000	566	87.4
Baron Fork at Eldon (07197000)	307	1997-1999	32,800 ± 7,300	107	4,570	14.9	28,400	92.5	86.6
		1998-2000	124,000 ± 33,600	404	4,920	16.0	120,000	391	96.8
		1999-2001	135,000 ± 24,800	440	5,980	19.5	128,000	417	94.8

Table 6. Number of days of base flow and runoff designated by Base-Flow Index (BFI) program at water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001

Station name (number)	3-year period	Spring		Summer		Fall		Winter		Total		Percent of runoff days in period
		Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	
Illinois River near Watts (07195500)	1997-1999	150	126	207	69	206	67	142	128	705	390	35.6
	1998-2000	142	134	189	87	198	75	152	119	681	415	37.9
	1999-2001	160	116	172	104	204	69	138	133	674	422	38.5
Flint Creek near Kansas (07196000)	1997-1999	171	105	201	75	207	66	174	96	753	342	31.2
	1998-2000	158	118	194	82	193	80	187	84	732	364	33.2
	1999-2001	182	94	185	91	189	84	161	110	717	379	34.6
Illinois River at Chewey (07196090)	1997-1999	155	121	209	67	205	68	143	127	712	383	35.0
	1998-2000	142	134	192	84	198	75	153	118	685	411	37.5
	1999-2001	159	117	176	100	203	70	139	132	677	419	38.2
Illinois River near Tahlequah (07196500)	1997-1999	175	101	201	75	179	94	147	123	702	393	35.9
	1998-2000	159	117	193	83	167	106	147	124	666	430	39.2
	1999-2001	166	110	159	117	187	86	129	142	641	455	41.5
Baron Fork at Eldon (07197000)	1997-1999	117	159	197	79	184	89	149	121	647	448	40.9
	1998-2000	91	185	194	82	172	101	148	123	605	491	44.8
	1999-2001	130	146	168	108	196	77	129	142	623	473	43.2

Table 7. Seasonal phosphorus loads estimated from phosphorus concentrations in water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001

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

Flow type	Station name (number)	Spring	Summer	Fall	Winter
	1997-1999				
Base Flow	Illinois River near Watts (07195500)	22,200	17,900	14,600	14,900
	Flint Creek near Kansas (07196000)	4,880	2,290	1,770	2,970
	Illinois River at Chewey (07196090)	31,400	17,100	10,900	15,000
	Illinois River near Tahlequah (07196500)	37,500	12,300	5,300	13,800
	Baron Fork at Eldon (07197000)	1,810	788	389	1,570
Runoff	Illinois River near Watts (07195500)	41,300	15,000	8,750	31,100
	Flint Creek near Kansas (07196000)	12,700	5,220	1,590	9,980
	Illinois River at Chewey (07196090)	97,200	34,200	11,600	73,200
	Illinois River near Tahlequah (07196500)	103,000	38,000	13,400	84,500
	Baron Fork at Eldon (07197000)	14,000	2,270	1,680	10,400
	1998-2000				
Base Flow	Illinois River near Watts (07195500)	23,700	18,800	14,300	16,900
	Flint Creek near Kansas (07196000)	3,970	2,980	1,810	3,490
	Illinois River at Chewey (07196090)	27,400	18,600	11,700	16,400
	Illinois River near Tahlequah (07196500)	33,000	14,500	5,790	13,800
	Baron Fork at Eldon (07197000)	1,660	1,250	343	1,660
Runoff	Illinois River near Watts (07195500)	79,100	116,000	19,300	41,300
	Flint Creek near Kansas (07196000)	15,600	41,300	2,990	8,650
	Illinois River at Chewey (07196090)	110,000	191,000	20,500	60,600
	Illinois River near Tahlequah (07196500)	112,000	240,000	23,300	71,100
	Baron Fork at Eldon (07197000)	30,200	67,800	5,220	17,100
	1999-2001				
Base Flow	Illinois River near Watts (07195500)	35,000	22,900	18,600	21,300
	Flint Creek near Kansas (07196000)	5,190	2,860	1,340	3,330
	Illinois River at Chewey (07196090)	31,100	18,700	12,400	17,400
	Illinois River near Tahlequah (07196500)	34,000	13,900	6,360	14,200
	Baron Fork at Eldon (07197000)	2,680	1,140	421	1,750
Runoff	Illinois River near Watts (07195500)	76,900	124,000	26,700	129,000
	Flint Creek near Kansas (07196000)	13,000	40,600	2,260	17,400
	Illinois River at Chewey (07196090)	94,000	194,000	21,700	156,000
	Illinois River near Tahlequah (07196500)	106,000	248,000	20,000	169,000
	Baron Fork at Eldon (07197000)	24,300	62,600	2,950	38,100

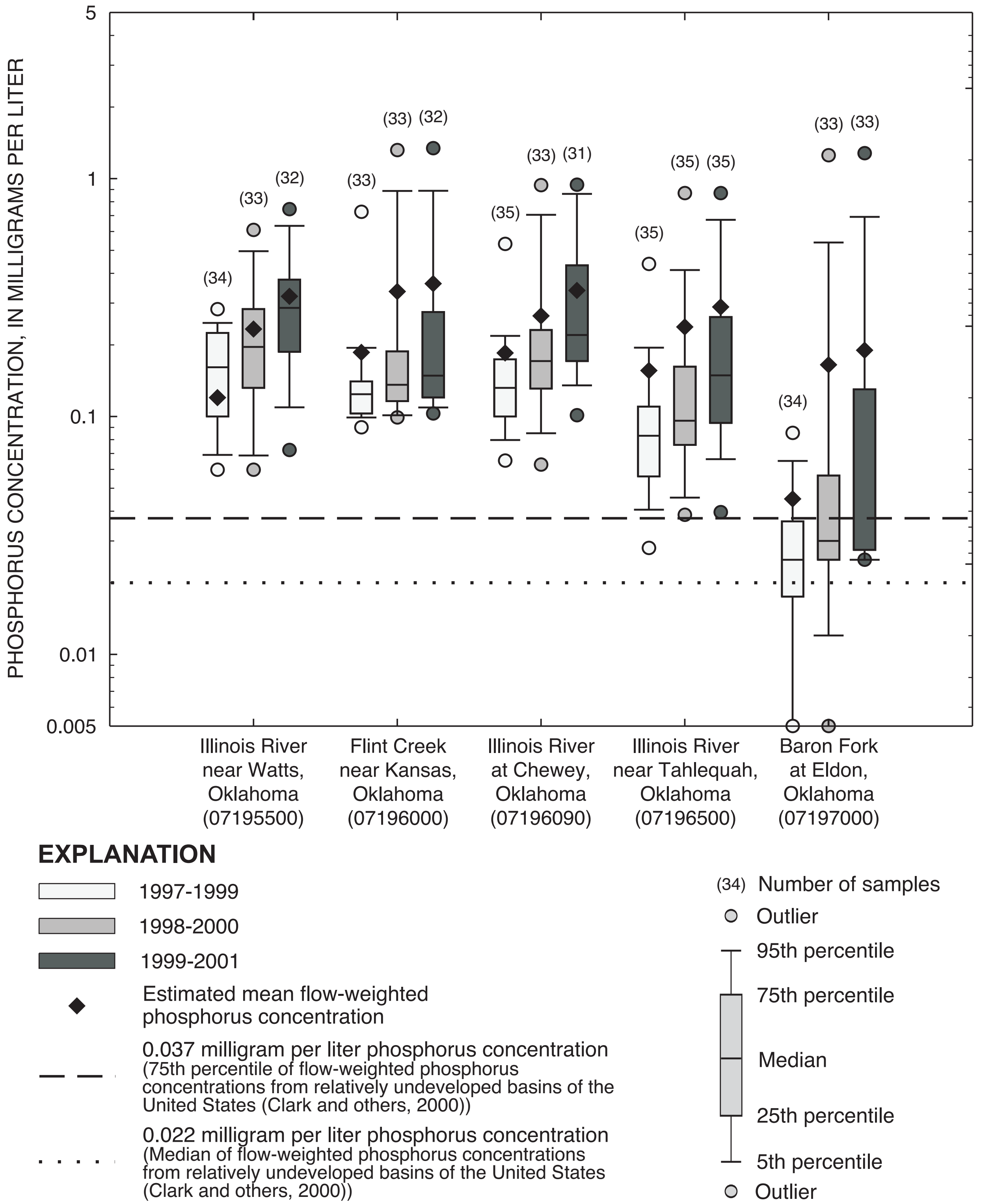

Figure 7. Instantaneous phosphorus concentrations from water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001. Mean flow-weighted phosphorus concentrations are calculated from loads estimated by LOADEST2.

Table 8. Mean annual phosphorus loads, mean annual streamflows, and mean flow-weighted phosphorus concentrations for water-quality stations in the Illinois River basin, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001

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

Station name (number)	3-year period	Mean annual phosphorus load (lb/yr)	Mean annual streamflow for years of study (ft^3/s)	Mean flow-weighted phosphorus concentration (mg/L)
Illinois River near Watts (07195500)	1997-1999	164,000	692	0.120
	1998-2000	329,000	718	0.233
	1999-2001	438,000	696	0.320
Flint Creek near Kansas (07196000)	1997-1999	40,200	110	0.186
	1998-2000	80,400	122	0.335
	1999-2001	87,700	123	0.362
Illinois River at Chewey (07196090)	1997-1999	292,000	802	0.185
	1998-2000	438,000	840	0.265
	1999-2001	548,000	819	0.339
Illinois River near Tahlequah (07196500)	1997-1999	307,000	1,000	0.156
	1998-2000	511,000	1,090	0.238
	1999-2001	621,000	1,090	0.289
Baron Fork at Eldon (07197000)	1997-1999	32,800	369	0.045
	1998-2000	124,000	382	0.165
	1999-2001	135,000	360	0.190

the entire phosphorus load into Lake Tenkiller, but the drainage area of these stations accounts for more than 80 percent of the drainage basin of the lake. The Illinois River and Baron Fork contributed a mean load of about 577,000 pounds per year of phosphorus to Lake Tenkiller from 1997 through 2001 (table 9). More than 86 percent of the annual phosphorus load was transported to Lake Tenkiller by runoff. The Illinois River transported about 13 times more of the phosphorus load during base flow and almost 5 times more of the phosphorus load during runoff to the lake than the Baron Fork (table 9).

Summary

The Illinois River and tributaries, Flint Creek and the Baron Fork, are designated scenic rivers in Oklahoma. Streams in the Illinois River basin are susceptible to potentially large concentrations of phosphorus from point sources and non-point sources. Recent phosphorus increases in streams in the basin have resulted in excess algae growth, which have limited the aesthetic benefits of water bodies in the basin, especially the Illinois River and Lake Tenkiller. The Oklahoma Water Resources Board has established a standard for total phosphorus not to exceed the 30-day geometric mean concentration of 0.037 milligram of phosphorus per liter in Oklahoma Scenic Rivers.

In July 1999, the U.S. Geological Survey, in cooperation with the Oklahoma Scenic Rivers Commission and the Oklahoma Water Resources Board, supplemented fixed period, bimonthly water-quality sampling with six runoff-event samplings per year to better determine water quality over the range of streamflows in the basin for 1997-2001. Phosphorus concentrations, loads, and yields were determined for three 3-year periods—1997-1999, 1998-2000, and 1999-2001.

Phosphorus concentrations were significantly greater in runoff-event samples than in base-flow samples for the 1998-2000 and 1999-2001 periods at Flint Creek near Kansas, Illinois River at Chewey, Illinois River near Tahlequah, and Baron Fork at Eldon, but this difference was not significant at Illinois River near Watts. Phosphorus concentrations generally decreased with increasing base flow in the Illinois River as a result of ground-water dilution. Phosphorus concentrations during runoff events increased with increasing streamflow in all streams, possibly because of resuspension of phosphorus from the streambed, stream bank erosion, and the addition of non-point source phosphorus components.

Estimated mean annual phosphorus loads were substantially greater at the Illinois River stations than at Flint Creek and the Baron Fork, and loads appeared to generally increase with time during 1997-2001 at all stations, but this increase might be partly attributable to the beginning of runoff-event sampling in the basin in July 1999.

Base-flow phosphorus loads at stations on the Illinois River were about 10 times greater than those on the Baron Fork and 5 times greater than those on Flint Creek. Runoff phosphorus loads increased with increasing drainage area and increasing streamflow. Runoff components of the annual total phosphorus load ranged from 58.7 to 96.8 percent from 1997-2001.

Seasonal base-flow loads generally were least in fall (September through November) and were greatest in spring (March through May) for all periods at all stations in the Illinois River basin. Seasonal runoff loads were least in fall for all periods, were greatest in spring in 1997-1999, and were greatest in summer (June through August) for 1998-2000 and 1999-2001.

Total yields of phosphorus ranged from 107 to 797 pounds per year per square mile. Greatest yields were at Flint Creek near Kansas (365 to 797 pounds per year per square mile) and the least yields were at Baron Fork at Eldon (107 to 440 pounds per year per square mile). Base-flow yields did not substantially change over the three periods at any station except Illinois River near Watts (1999-2001). Runoff yields more than doubled between the 1997-1999 period and the 1999-2001 period at all stations, but this increase might be partly attributable to the beginning of runoff-event sampling in the basin.

Estimated mean flow-weighted concentrations were more than 10 times greater than the median and were consistently greater than the 75th percentile of flow-weighted phosphorus concentrations in samples collected at relatively undeveloped basins of the United States (0.022 milligram per liter and 0.037 milligram per liter, respectively). In addition, flow-weighted phosphorus concentrations in 1999-2001 at all Illinois River stations and at Flint Creek near Kansas were equal to or greater than the 75th percentile of all National Water-Quality Assessment Program stations in the United States (0.29 milligram per liter).

The annual average (1997-2001) phosphorus load entering Lake Tenkiller was about 577,000 pounds per year. More than 86 percent of the phosphorus load was transported to the lake by runoff.

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Table 9. Summary of phosphorus loads to Lake Tenkiller, Oklahoma, periods 1997-1999, 1998-2000, and 1999-2001

[lb/yr, pounds per year. Mean and standard deviation of the total load are calculated by LOADEST2 and are statistics of all data in the 3-year period. Means of base-flow loads are calculated from base-flow data only; means of runoff loads are calculated from runoff data only. Differences between total load and the sum of base-flow plus runoff loads are due to rounding within LOADEST2.]

Flow type	3-year period	Total mean annual phosphorus load[1] per period (lb/yr)	Average total mean annual phosphorus load[1], 1997-2001 (lb/yr)	Illinois River near Tahlequah component per period (percent)	Average Illinois River near Tahlequah component, 1997-2001 (percent)	Baron Fork at Eldon component per period (percent)	Average Baron Fork at Eldon component, 1997-2001 (percent)
Base flow	1997-1999	73,400	73,300	93.7	93.0	6.22	7.03
	1998-2000	71,900		93.2		6.84	
	1999-2001	74,600		92.0		8.02	
Runoff	1997-1999	266,000	501,000	89.5	83.1	10.7	17.0
	1998-2000	566,000		78.8		21.2	
	1999-2001	671,000		80.9		19.1	
Total	1997-1999	340,000	577,000	90.3	84.0	9.68	15.7
	1998-2000	635,000		80.8		19.7	
	1999-2001	756,000		81.0		17.7	

[1]Loads are calculated by adding loads from Illinois River near Tahlequah to loads from Baron Fork at Eldon (table 5).

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Appendixes

Appendix 1a. Instantaneous streamflows and total phosphorus concentrations for Illinois River near Watts, Oklahoma, from 1997-2001

[ft^3/s, cubic foot per second; mg/L, milligram per liter; <, less than; all water-quality and streamflow data available at http://water.usgs.gov/ok/nwis]

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
01-23-1997	1145	385	.10
02-11-1997	1145	557	.08
03-21-1997	1245	945	.09
04-24-1997	1000	479	.18
05-20-1997	1550	361	.25
06-24-1997	1115	410	.17
07-24-1997	0900	183	.24
08-22-1997	1025	315	.24
09-16-1997	1040	224	.22
10-20-1997	1515	236	.19
11-18-1997	0950	355	.10
12-02-1997	1330	398	.12
01-23-1998	1210	673	.15
02-09-1998	1520	462	.06
03-24-1998	1200	1,600	.07
04-23-1998	1100	455	.07
05-13-1998	0850	420	.06
06-23-1998	1437	204	.17
07-15-1998	1500	180	.28
08-19-1998	1335	128	.17
09-23-1998	1455	492	.18
10-20-1998	0935	270	.21
11-17-1998	0950	315	.13
12-08-1998	1420	493	.11
01-07-1999	1030	404	.10
02-03-1999	0850	709	.13
03-24-1999	1230	1,220	.10
04-07-1999	1040	1,840	.18
05-04-1999	1035	1,370	.16
06-16-1999	1230	562	.23
08-12-1999	0810	260	.16
10-21-1999	1115	148	.25
12-01-1999	1420	158	.25

Appendix 1a. Instantaneous streamflows and total phosphorus concentrations for Illinois River near Watts, Oklahoma, from 1997-2001—Continued.

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
12-10-1999	1610	729	.28
02-18-2000	0835	1,560	.29
04-12-2000	0920	1,270	.27
05-07-2000	1052	2,410	.59
06-18-2000	0950	10,600	.57
06-22-2000	0745	24,100	.65
07-18-2000	1345	398	.20
08-15-2000	1445	191	.26
09-26-2000	1530	341	.30
10-24-2000	1030	176	.38
11-07-2000	0720	1,400	.34
12-08-2000	1430	279	.21
01-30-2001	1100	2,740	.30
02-15-2001	1100	7,660	.67
04-18-2001	1115	352	.18
05-18-2001	1120	851	.88
06-15-2001	1230	3,930	<.06
08-15-2001	1530	163	.37
09-18-2001	1250	815	.36
10-11-2001	1230	2,490	.59
10-23-2001	0800	236	.31
12-11-2001	1515	284	.36
12-17-2001	1420	17,300	.59

Appendix 1b. Instantaneous streamflows and total phosphorus concentrations for Flint Creek near Kansas, Oklahoma, from 1997-2001

[ft^3/s, cubic foot per second; mg/L milligram per liter; all water-quality and streamflow data available at http://water.usgs.gov/ok/nwis]

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
01-22-1997	1515	45	.09
02-12-1997	1420	58	.10
03-13-1997	1210	350	.09
04-23-1997	1100	104	.14
05-15-1997	1030	74	.10
06-23-1997	1210	57	.13
07-23-1997	1420	22	.14
08-21-1997	1210	64	.12
09-17-1997	1350	34	.11
10-15-1997	1810	41	.14
11-19-1997	1215	37	.11
12-02-1997	1520	90	.12
01-13-1998	1205	255	.10
02-09-1998	1245	74	.10
03-10-1998	1600	199	.10
04-22-1998	1625	74	.13
06-04-1998	0730	47	.16
07-14-1998	0825	29	.14
08-18-1998	1205	16	.12
09-22-1998	0805	24	.16
10-21-1998	0935	54	.13
11-16-1998	1040	77	.14
12-09-1998	1320	80	.11
01-07-1999	0835	87	.10
02-02-1999	0955	129	.13
03-24-1999	1530	209	.12
04-06-1999	1115	225	.20
05-04-1999	1145	2,760	.88
06-15-1999	1520	119	.66
08-12-1999	1320	48	.12
10-20-1999	1705	29	.10
12-02-1999	1000	32	.12
12-10-1999	1315	115	.18

Appendix 1b. Instantaneous streamflows and total phosphorus concentrations for Flint Creek near Kansas, Oklahoma, from 1997-2001—Continued.

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
02-18-2000	0830	81	.14
04-17-2000	1200	48	.14
05-07-2000	0922	170	.19
06-17-2000	1200	5,150	1.66
06-21-2000	1700	5,450	.90
06-28-2000	1430	8,970	1.17
07-19-2000	1520	102	.15
08-15-2000	0730	47	.14
10-11-2000	1230	33	.12
10-27-2000	1100	73	.17
11-06-2000	2000	191	.26
12-12-2000	1020	64	.12
01-29-2001	1130	191	.11
02-15-2001	0830	678	.28
02-24-2001	1435	4,090	.85
04-17-2001	1335	85	.11
06-15-2001	1040	304	.26
08-14-2001	1035	26	.14
10-11-2001	1045	224	.22
10-30-2001	1430	34	.12
12-06-2001	1330	55	.15
12-17-2001	1045	1,030	.32

Appendix 1c. Instantaneous streamflows and total phosphorus concentrations for Illinois River at Chewey, Oklahoma, from 1997-2001

[ft^3/s, cubic foot per second; mg/L, milligram per liter; all water-quality and streamflow data available at http://water.usgs.gov/ok/nwis]

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
01-21-1997	1645	376	.09
02-11-1997	0915	671	.08
03-25-1997	1130	1,060	.10
04-24-1997	1430	638	.09
05-13-1997	0900	422	.13
06-25-1997	1010	478	.16
07-15-1997	0845	244	.14
08-26-1997	1440	250	.15
09-10-1997	1250	176	.12
10-21-1997	0945	253	.13
11-14-1997	1010	371	.10
12-03-1997	0900	577	.10
01-28-1998	0935	1,180	.09
02-19-1998	1550	807	.08
03-18-1998	1600	4,490	.13
04-23-1998	1450	564	.05
05-13-1998	1200	527	.17
06-18-1998	0955	256	.13
07-15-1998	1405	249	.13
08-18-1998	1105	169	.13
09-22-1998	1330	182	.23
10-20-1998	0920	358	.15
11-05-1998	1100	426	.14
12-16-1998	1050	775	.11
01-06-1999	1510	590	.07
02-02-1999	0920	1,320	.17
03-15-1999	1700	4,660	.20
04-06-1999	1400	3,600	.21
05-04-1999	0905	3,240	.43
06-24-1999	1530	1,610	.20
07-01-1999	1110	23,300	.93
08-13-1999	1100	282	.14
10-20-1999	1550	194	.12

Appendix 1c. Instantaneous streamflows and total phosphorus concentrations for Illinois River at Chewey, Oklahoma, from 1997-2001—Continued.

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
12-01-1999	1235	203	.15
12-11-1999	1140	886	.21
02-16-2000	1105	231	.17
04-12-2000	1445	1,400	.37
05-07-2000	1450	3,340	.47
06-18-2000	1235	16,800	.86
06-22-2000	1215	34,700	.96
08-16-2000	1310	251	.16
09-26-2000	1330	840	.23
10-23-2000	1430	230	.22
11-07-2000	1230	1,900	.27
12-07-2000	1255	415	.14
01-30-2001	1245	4,980	.40
02-15-2001	1320	6,670	.83
02-25-2001	1010	20,600	.46
04-18-2001	1715	518	.14
05-18-2001	1635	1,220	.24
06-27-2001	0945	376	.18
08-15-2001	1300	200	.25
10-11-2001	1605	1,110	.22
12-11-2001	1210	335	.26
12-17-2001	1740	17,400	.86

Appendix 1d. Instantaneous streamflows and total phosphorus concentrations for Illinois River near Tahlequah, Oklahoma, from 1997-2001

[ft^3/s, cubic foot per second; mg/L milligram per liter; E, estimated; <, less than; all water-quality and streamflow data available at http://water.usgs.gov/ok/nwis]

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
01-09-1997	1000	505	.04
02-10-1997	1550	766	.07
03-20-1997	1300	1,580	.07
04-25-1997	1340	742	.02
05-15-1997	0835	490	.06
06-25-1997	1515	626	.11
07-17-1997	1225	294	.06
08-22-1997	1450	568	.10
09-11-1997	1555	171	.07
10-22-1997	0925	287	.09
11-13-1997	0840	302	.05
12-03-1997	1120	929	.09
01-15-1998	1220	1,930	.07
02-10-1998	1445	657	.05
03-17-1998	1430	5,700	.15
04-22-1998	1230	849	.04
05-14-1998	0920	716	.03
06-16-1998	1537	321	.09
07-13-1998	1515	302	.10
08-17-1998	1610	198	.07
09-01-1998	1150	126	.08
10-19-1998	1200	424	.09
11-02-1998	1505	410	.09
12-15-1998	1340	1,320	.13
01-05-1999	0755	785	.08
02-01-1999	1240	1,940	.24
03-23-1999	1330	2,230	.17
04-05-1999	1335	3,590	.26
05-03-1999	1450	1,160	.09
06-08-1999	1125	970	.08
07-01-1999	1615	11,800	1.14
08-11-1999	1045	302	.11
10-20-1999	1050	162	.06

Appendix 1d. Instantaneous streamflows and total phosphorus concentrations for Illinois River near Tahlequah, Oklahoma, from 1997-2001—Continued.

[ft^3/s, cubic foot per second; mg/L milligram per liter; E, estimated; <, less than; all water-quality and streamflow data available at http://water.usgs.gov/ok/nwis]

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
12-01-1999	1400	223	E.04
12-11-1999	1400	856	.12
02-15-2000	1700	268	.09
04-13-2000	0910	1,150	.15
05-08-2000	0920	3,010	.28
06-18-2000	1635	14,800	.62
06-22-2000	1630	33,900	.80
07-20-2000	1200	677	.12
08-29-2000	1630	189	.09
09-26-2000	1045	1,040	.15
10-19-2000	1415	251	.11
10-27-2000	1600	582	.16
11-07-2000	1400	1,540	.19
12-12-2000	1215	420	.07
01-31-2001	1040	3,840	.21
02-16-2001	1315	10,200	.38
02-25-2001	1505	25,200	.75
04-23-2001	1430	588	.11
05-19-2001	1410	2,070	.23
06-26-2001	1530	645	.13
08-16-2001	1110	312	.10
10-12-2001	1100	2,660	.22
10-24-2001	0850	368	<.06
11-05-2001	1250	1,690	.35
12-05-2001	1330	828	.16
12-18-2001	1210	19,500	.54

Appendix 1e. Instantaneous streamflows and total phosphorus concentrations for Baron Fork at Eldon, Oklahoma, from 1997-2001

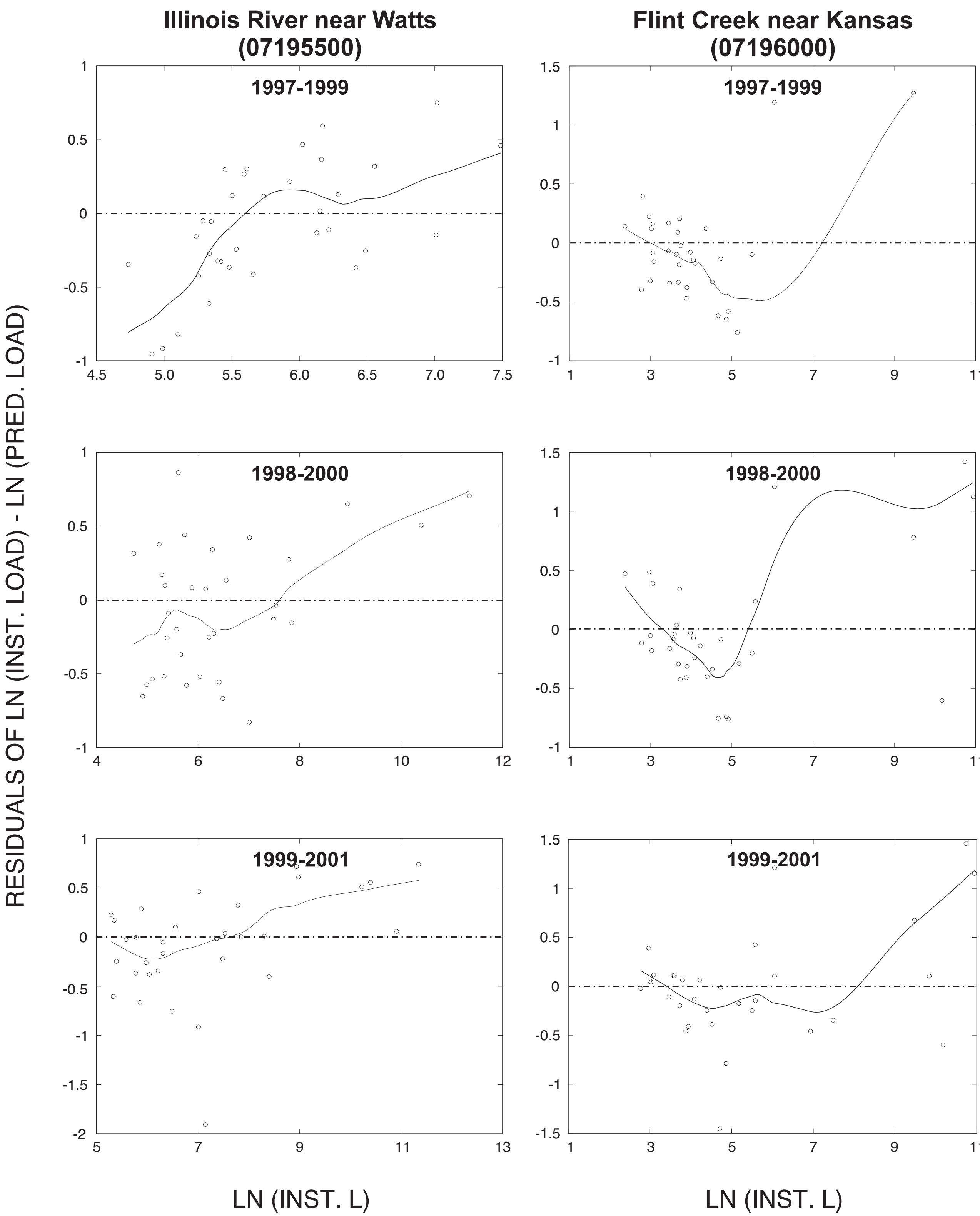
[ft^3/s, cubic foot per second; mg/L, milligram per liter; <, less than; E, estimated; all water-quality and streamflow data available at http://water.usgs.gov/ok/nwis]

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
01-09-1997	1145	153	.02
02-10-1997	1240	253	<.01
03-10-1997	1510	589	.04
04-25-1997	1230	270	<.01
05-13-1997	1625	173	.02
06-25-1997	1630	213	.02
07-16-1997	1555	144	.02
08-22-1997	1230	90	.02
09-12-1997	0910	43	.01
10-22-1997	0815	86	.02
11-13-1997	1330	100	.03
12-03-1997	1700	431	.02
01-15-1998	0945	648	.03
02-10-1998	1210	228	.01
03-19-1998	1300	2,630	.08
04-22-1998	1420	248	<.01
05-11-1998	1550	205	<.01
06-02-1998	1055	133	.05
07-21-1998	0830	35	.03
08-18-1998	0820	21	.01
09-21-1998	1340	37	.03
10-19-1998	1420	195	E.04
11-16-1998	1125	242	<.05
12-14-1998	1420	638	.03
01-05-1999	0945	211	<.05
02-01-1999	1120	565	.08
03-23-1999	1645	831	E.04
04-05-1999	1420	1,000	.09
05-03-1999	1105	481	E.05
06-07-1999	1135	361	E.04
08-11-1999	0830	44	<.05
10-20-1999	0845	30	<.05
12-02-1999	0750	44	<.05

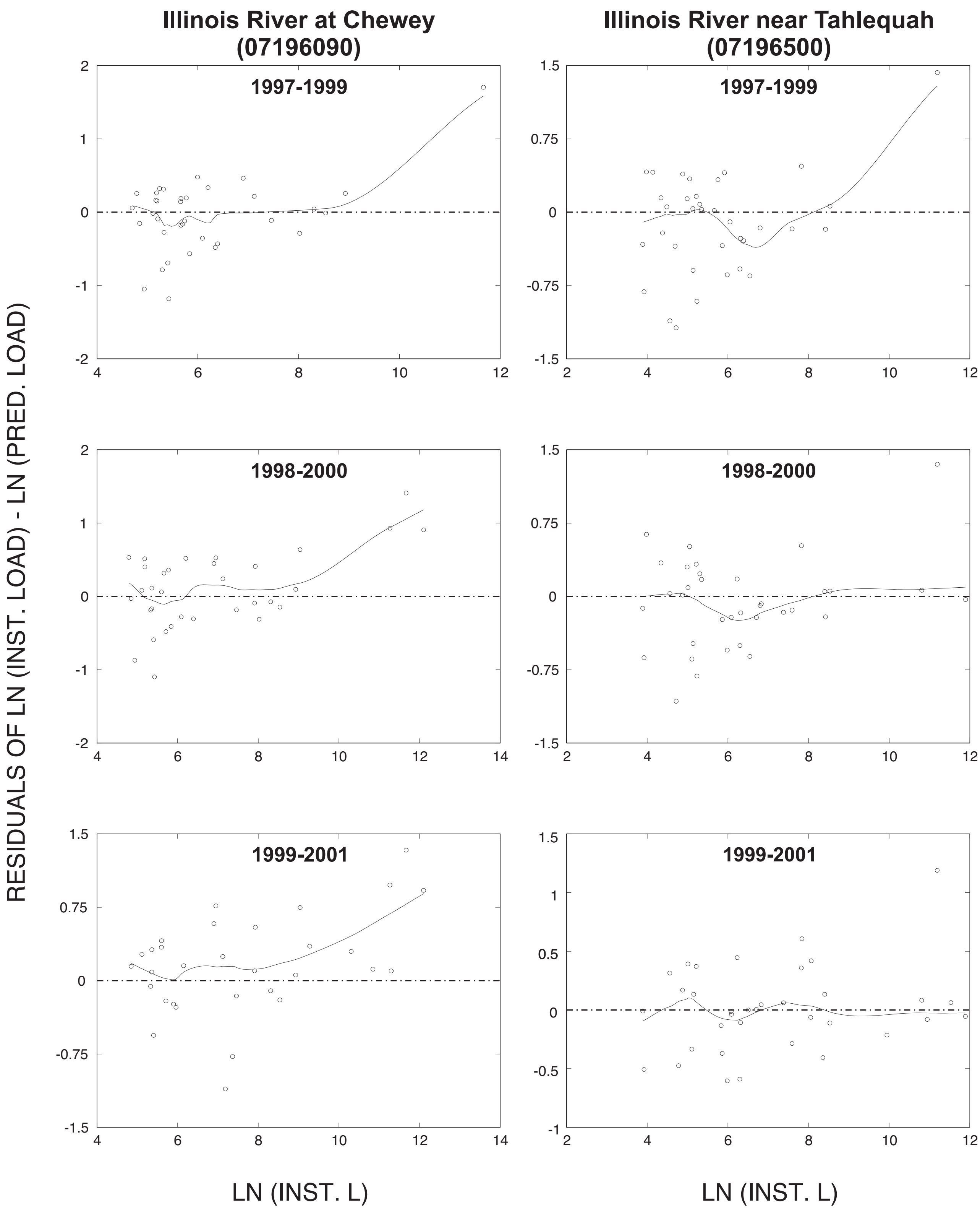
Appendix 1e. Instantaneous streamflows and total phosphorus concentrations for Baron Fork at Eldon, Oklahoma, from 1997-2001—Continued.

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentration (mg/L)
12-10-1999	1115	225	<.05
02-16-2000	0730	66	<.05
04-13-2000	1050	350	<.05
05-07-2000	1645	985	.08
06-17-2000	1540	7,520	1.12
06-21-2000	1345	49,100	1.65
06-28-2000	1630	5,350	.98
07-20-2000	0930	150	E.04
08-30-2000	1100	50	<.05
10-24-2000	1435	51	<.06
10-27-2000	1320	110	E.04
11-07-2000	0930	1,180	.10
12-20-2000	1530	192	<.06
01-30-2001	1015	1,270	.13
02-16-2001	1145	3,300	.17
02-25-2001	1240	4,900	.26
04-23-2001	1610	153	<.06
05-18-2001	1500	673	E.04
06-25-2001	1630	231	E.04
08-16-2001	0930	51	E.03
10-11-2001	1740	927	.15
10-23-2001	1555	136	.13
12-05-2001	1245	231	E.04
12-17-2001	1400	6,650	.15

Appendix 2. Residuals plots of ln(instantaneous load) – ln(predicted load) in relation to ln(instananeous load) for stations in the Illinois River basin, periods 1997-1999, 1998-2000, and 1999-2001.



Appendix 2. Residuals plots of ln(instantaneous load) – ln(predicted load) in relation to ln(instananeous load) for stations in the Illinois River basin, periods 1997-1999, 1998-2000, and 1999-2001.—Continued



Appendix 2. Residuals plots of ln(instantaneous load) – ln(predicted load) in relation to ln(instananeous load) for stations in the Illinois River basin, periods 1997-1999, 1998-2000, and 1999-2001.—Continued