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Summary of Surface-Water Quality Data from the Illinois River Basin in Northeast Oklahoma, 1970–2007

Scientific Investigations Report 2009–5182
Revised April 2010

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

Front cover:

Underwater photo, Baron Fork near Eldon, Oklahoma, August 2003. Photograph by W.J. Andrews, U.S. Geological Survey.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Mass	
pound (lb)	0.4536	kilogram (kg)
ton per year (ton/yr)	0.9072	metric ton per year
	Load	
pound per day (lb/day)	0.4546	Kilogram per day (kg/day)
	Application rate	
pound per acre per year [(lb/acre)/yr]	1.121	kilogram per hectare per year [(kg/ha)/yr]

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

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

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

Summary of Surface-Water Quality Data from the Illinois River Basin in Northeast Oklahoma, 1970–2007

By William J. Andrews, Mark F. Becker, S. Jerrod Smith, and Robert L. Tortorelli

Abstract

The quality of streams in the Illinois River Basin of northeastern Oklahoma is potentially threatened by increased quantities of wastes discharged from increasing human populations, grazing of about 160,000 cattle, and confined animal feeding operations raising about 20 million chickens. Increasing numbers of humans and livestock in the basin contribute nutrients and bacteria to surface water and groundwater, causing greater than the typical concentrations of those constituents for this region. Consequences of increasing contributions of these substances can include increased algal growth (eutrophication) in streams and lakes; impairment of habitat for native aquatic animals, including desirable game fish species; impairment of drinking-water quality by sediments, turbidity, taste-and-odor causing chemicals, toxic algal compounds, and bacteria; and reduction in the aesthetic quality of the streams.

The U.S. Geological Survey, in cooperation with the Oklahoma Scenic Rivers Commission, prepared this report to summarize the surface-water-quality data collected by the U.S. Geological Survey at five long-term surface-water-quality monitoring sites. The data summarized include major ions, nutrients, sediment, and fecal-indicator bacteria from the Illinois River Basin in Oklahoma for 1970 through 2007.

General water chemistry, concentrations of nitrogen and phosphorus compounds, chlorophyll-*a* (an indicator of algal biomass), fecal-indicator bacteria counts, and sediment concentrations were similar among the five long-term monitoring sites in the Illinois River Basin in northeast Oklahoma. Most water samples were phosphorus-limited, meaning that they contained a smaller proportion of phosphorus, relative to nitrogen, than typically occurs in algal tissues. Greater degrees of nitrogen limitation occurred at three of the five sites which were sampled back to the 1970s, probably due to use of detergents containing greater concentrations of phosphorus than in subsequent periods. Concentrations of nitrogen, phosphorus, and sediment, and counts of bacteria generally increased with streamflow at the five sites, probably due to runoff from the land surface and re-suspension of streambed sediments. Phosphorus concentrations typically exceeded the Oklahoma standard of 0.037 milligrams per liter for Scenic Rivers. Concentrations of chlorophyll-*a* in phytoplankton in water samples collected at the five sites were not well correlated with streamflow, nor to concentrations of the nutrients nitrogen and phosphorus, probably because much of the algae growing in these streams are periphyton attached to streambed cobbles and other debris, rather than phytoplankton in the water column. Sediment concentrations correlated with phosphorus concentrations in water samples collected at the sites, probably due to sorption of phosphorus to soil particles and streambed sediments and runoff of soils and animal wastes at the land surface and resuspension of streambed sediments and phosphorus during wet, high-flow periods. Fecal coliform bacteria counts at the five sites sometimes exceeded the Oklahoma Primary Body Contact Standard of 400 colonies per 100 milliliters when streamflows were greater than 1000 cubic feet per second.

Ultimately, Lake Tenkiller, an important ecological and economic resource for the region, receives the compounds that runoff the land surface or seep to local streams from groundwater in the basin. Because of eutrophication from increased nutrient loading, Lake Tenkiller is listed for impairment by diminished dissolved oxygen concentrations, phosphorus, and chlorophyll-*a* by the State of Oklahoma in evaluation of surface-water quality required by section 303d of the Clean Water Act.

Stored phosphorus in soils and streambed and lakebed sediments may continue to provide phosphorus to local streams and lakes for decades to come. Steps are being made to reduce local sources of phosphorus, including upgrades in capacity and effectiveness of municipal wastewater treatment plants, and exporting phosphorus-rich poultry litter from parts of the basin to cropland outside of the basin.

Introduction

The Illinois River Basin drains 1,653 square miles (4,281 square kilometers) in northeastern Oklahoma and northwestern Arkansas (fig. 1). The topography, ecology, and economy of the Illinois River Basin are all derived, at least in part, by the quantities and patterns of naturally flowing water. The Oklahoma Scenic Rivers Act of 1970 designated the Illinois River, and two of its tributaries, Flint Creek and Baron Fork (formerly Barren Fork), as Scenic Rivers to protect water quality and preserve fish, wildlife, and outdoor recreational values

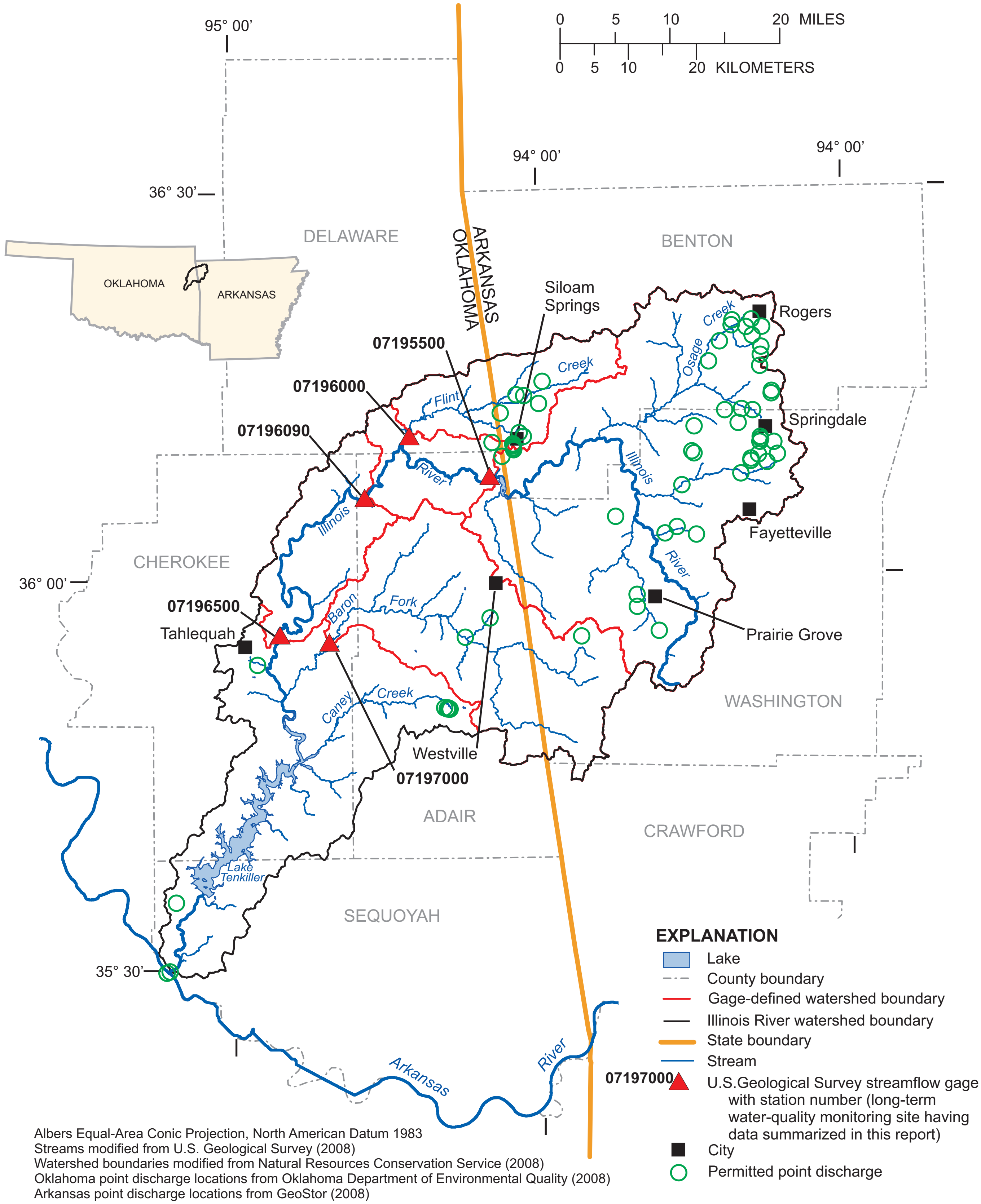


Figure 1. The Illinois River Basin, Arkansas and Oklahoma, with locations of permitted point discharge sites.

for the benefit of the people of Oklahoma and visitors to the State (Oklahoma Legislature, 1970). The Oklahoma Scenic Rivers Commission, created in 1977, enforces the Oklahoma Scenic Rivers Act (Oklahoma Legislature, 1977).

About half of the basin is devoted to grazing of cattle and horses and raising poultry, consisting mostly of about 20 million broiler chickens. Wastes generated by rapid growth in human populations in parts of the basin are additional potential sources of nutrients and bacteria. These sources of nutrients and bacteria, combined with the relatively high vulnerability of water in the basin to contamination because of the karstic setting, have combined to increase contamination of local streams by nutrients, bacteria, chlorophyll-*a,* and sediment.

The upstream half of the basin has a rapidly growing economy with a large livestock agriculture sector and has had rapid growth in human population because of growth of large corporate headquarters, a state university, and retirement communities. The downstream half of the basin is less intensively developed, relying on water-based recreation in scenic rivers and Lake Tenkiller as a large part of local economic activity. In addition to aesthetic issues possibly reducing tourism, numerous cities, towns, and other landowners in both states rely on surface water for drinking-water supplies or on groundwater from wells very near to streams, that can be affected by degraded surface-water quality. Many streams in the area may be phosphorus-limited, meaning that relatively small additions of phosphorus may notably increase growth of algae. Phosphorus typically is sorbed to soil and sediments. So phosphorus tends to wash into local streams or be resuspended into local water bodies in greatest amounts during storm runoff/high-flow periods. Bacteria from animal wastes also tend to increase greatly in local streams during high streamflows, similarly being washed from land surfaces by rainfall.

The U.S. Geological Survey (USGS), in cooperation with the Oklahoma Scenic Rivers Commission (OSRC), prepared this report to summarize the surface-water-quality data collected by the USGS at five long-term water-quality monitoring sites. These data include major ions, nutrients, sediment, fecal-indicator bacteria, chlorophyll-*a*, and from the Illinois River Basin in Oklahoma from 1970 through 2007.

Purpose and Scope

The purpose of this report is to summarize water-quality data and describe probable sources of and transport of common water contaminants in streams designated as Scenic Rivers in the Oklahoma part of the Illinois River Basin. Water-quality data collected by the U.S. Geological Survey at five long-term water-quality monitoring sites for periods as long as 1970 to 2007, including major ions, nutrients, fecal-indicator bacteria, chlorophyll-*a*, sediment, and are summarized in this report. This report is intended to inform the OSRC and the general public about water-quality issues and data collected in this basin in a readily understandable manner.

Methods

Water-quality and streamflow data described in the Hydrology and Water Quality sections of this report were retrieved from the U.S. Geological Survey National Water Information System (NWIS; *http://waterdata.usgs.gov/nwis*). Information regarding hydrogeology, climatology, populations of livestock and humans, and water-quality degradation in the Illinois River Basin were gathered from a variety of reports by the U.S. Geological Survey, state agencies, and universities. Estimates of livestock numbers were based on the 2007 census of agriculture (Arkansas Agricultural Statistics Service, 2008; and Oklahoma Agricultural Statistics Service, 2008). Estimates of per capita emissions of nutrients in waste for humans and livestock were based on livestock numbers for counties in the basin in 2007. County livestock numbers were amortized for the part of each county in the Illinois River Basin, which assumes that livestock are equally distributed in those counties. Per capita and from nutrient-emission data for humans and livestock derived from Strauss (2000) and Gollehon and others (2001). Locations of poultry houses in the upstream part of the Basin in 2006 were from Arkansas State Highway and Transportation (2008). Locations of poultry houses in the downstream part of the basin in summer 2006 were determined from National Agriculture Imagery Program aerial photographs obtained from Oklahoma GIS Council (2007). The five long-term water-quality monitoring stations summarized in this report were selected based on location, from near to where the Illinois River flows from Arkansas into Oklahoma, to downstream from Tahlequah, the largest city close to the river in Oklahoma. Those 5 sites had from 8 to more than 40 years of water-quality sampling and streamflow data.

Hydrologic Setting

Hydrology

The Illinois River Basin is underlain by cherty limestones of the Springfield Plateau aquifer that commonly are karstic (fractured and partially dissolved, with fissures, sinkholes, underground streams, and caverns) and are deeply incised by streams and rivers. The karstic nature of the rocks underlying this basin is responsible for the rolling hills topography and underground caverns and conduits that facilitate rapid recharge and seepage of groundwater.

Climate

The climate of the Illinois River Basin is humid temperate. Average annual precipitation in the basin ranges from 46.5 to 48.6 inches; average annual temperatures range from 60 to 61 degrees Fahrenheit, with average maximum temperatures of 70 to 71 degrees, and average minimum temperatures of 48 to 49 degrees (National Oceanic and Atmospheric Administration, 2007; Oklahoma Climatological Survey, 2007a, b, c, d). Precipitation amounts tend to vary over the basin during the spring storm season, with several inches per day commonly falling from storms. About 40 percent (20 inches) of the annual mean precipitation of nearly 50 inches falls from March to June in the basin (Oklahoma Climatological Survey, 2007e). After the spring storm season, summer tends to be dry. During a second storm season in autumn (September to November), nearly 30 percent of annual precipitation falls (Oklahoma Climatological Survey, 2007e). Winters in the basin are relatively dry (Oklahoma Climatological Survey, 2007e). Mean annual lake evaporation in this basin has been estimated to be about 50 inches (Johnson and Duchon, 1995), with evapotranspiration (the combination of evaporation from soils and transpiration of water by plants) estimated to range from 30 to 35 inches per year in Oklahoma (Hanson, 1991).

Streamflow

Streamflow in the Illinois River Basin is highly varied and generally increases with the basin drainage area associated with any given site (tables 1 and 2). The greatest mean monthly streamflows in the basin are from March through June (when spring rains occur) and the least mean monthly streamflows occur in summer dry periods from July through August (table 2, Blazs and others, 2001–2006).

The USGS has continuously operated a stream gage on the Illinois River near Tahlequah since 1936. Streamflow at that and other gages is reported in cubic feet per second (ft^3/s); that is, a volume of water moving through a cross-sectional area of the stream in one second. Peak streamflow and low streamflow are reported by various methods. One method is to report the average streamflow during a specific period of time. Examples of the variability of streamflow in the Illinois River are the extreme flows recorded at the Illinois River near Tahlequah gage such as: (1) the maximum mean daily streamflow of 90,400 ft^3/s on May 11, 1950, and (2) the minimum mean daily streamflow of 0.10 ft^3/s on October 10, 1956. The mean annual streamflow at that gage from 1936 to 2007 is 929 ft^3/s.

Streamflow during periods of no runoff from precipitation is referred to as base flow. Base flow in the Illinois River is sustained by a combination of groundwater discharging from seeps and springs and discharges by humans into the river and tributaries, such as municipal wastewater emanating from treatment plants and seepage from on-site septic systems. Extended dry periods or droughts can reduce ground-water levels thus reducing the base flow in the Illinois River (fig. 2). For 1936 to 2007, base flow ranged from 29.7 (in 1943) to 72.5 (in 1963) percent of annual flow at the Illinois River near Tahlequah gage (Jason M. Lewis, U.S. Geological Survey, written commun., 2009).

Table 1. Drainage-basin area of long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

Station number	Station name	Drainage basin area (square miles)
07195500	Illinois River near Watts, Oklahoma	635
07196000	Flint Creek near Kansas, Oklahoma	110
07196090	Illinois River at Chewey, Oklahoma	825
07197000	Baron Fork at Eldon, Oklahoma	307
07196500	Illinois River near Tahlequah, Oklahoma	959

Groundwater

The Illinois River Basin is underlain by a series of limestone, sandstone, and shale strata on the southwestern edge of the Ozarks uplift (Marcher and Bingham, 1989; and Petersen and others, 1999a). Lands underlain by limestone, gypsum,

Table 2. Mean monthly streamflow for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma during the period of record and the 10 year period, 1996–2006.

[units in cubic feet per second; POR, period of record or length of gage operation, data not available for the Illinois River at Chewey, Oklahoma, which is ungaged]

Station	Month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Illinois River near Watts, 1956–2006 (POR)	346	646	665	601	698	956	1,016	968	685	368	239	289
Illinois River near Watts, 1996–2006	234	568	569	756	765	840	891	735	734	431	233	289
Flint Creek near Kansas, 1956–2006 (POR)	69	126	124	113	122	172	176	178	147	67	45	57
Flint Creek near Kansas, 1996–2006	38	82	84	121	131	143	118	122	143	83	39	38
Baron Fork at Eldon, 1949–2006 (POR)	166	321	319	318	392	523	579	613	341	151	76	114
Baron Fork at Eldon, 1996–2006	110	323	315	429	420	463	547	393	390	161	77	116
Illinois River near Tahlequah, 1936–2006 (POR)	519	900	907	882	1,118	1,426	1,562	1,612	1,042	509	353	360
Illinois River near Tahlequah, 1996–2006	357	798	865	1,130	1,155	1,289	1,309	1,118	1,132	660	320	363

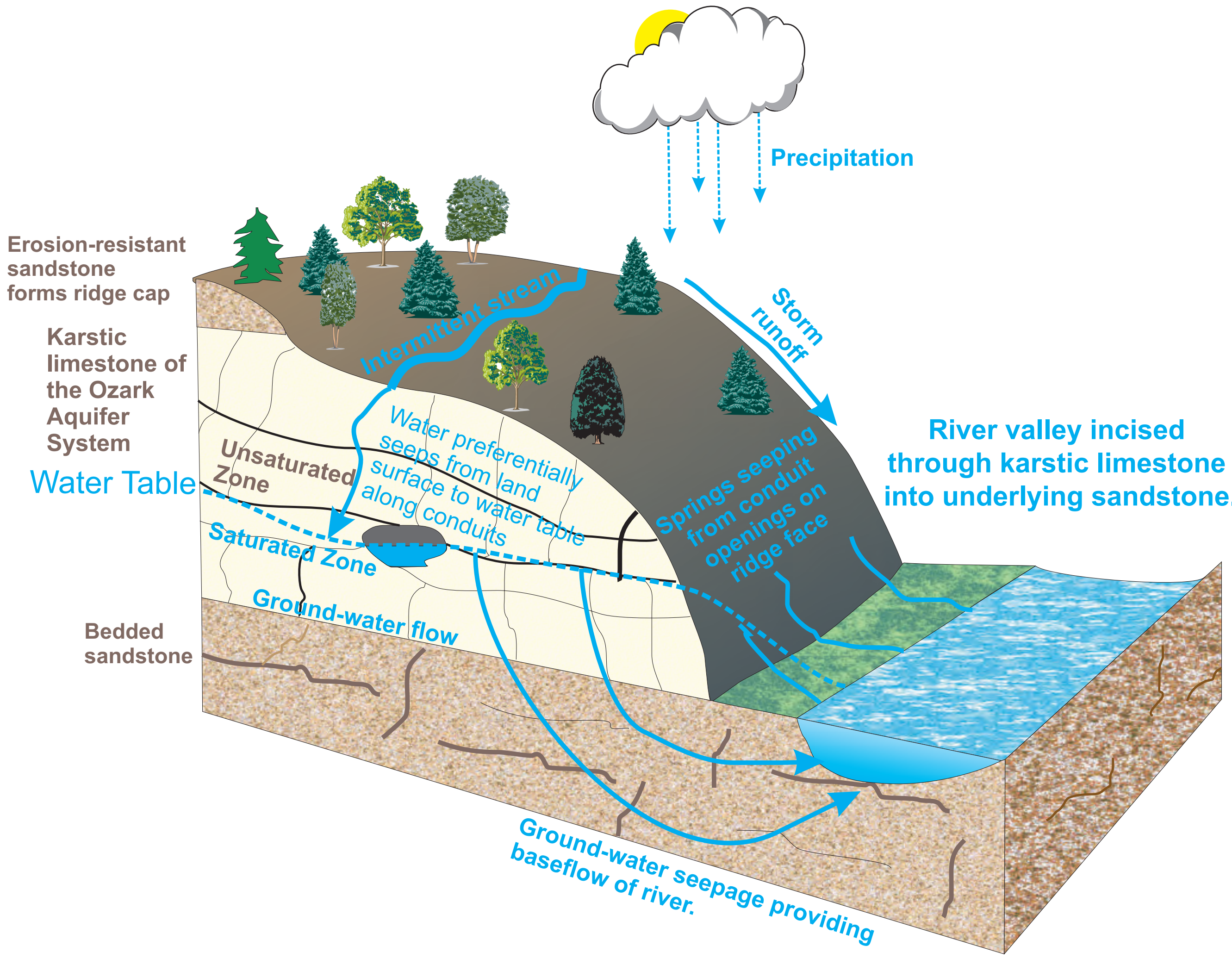


Figure 2. Schematic diagram of the hydrologic cycle in the Illinois River Basin, Arkansas and Oklahoma.

and other highly soluble rocks in humid environments commonly are characterized by karstic topography, that has hilly relief, sinkholes, caves, and numerous springs (figs. 2, 3 and 4). Because of rapid seepage of water from the land surface to underlying aquifers and dissolution of carbonate rocks, human activities, such as urbanization, agriculture, water withdrawals, and deforestation, can quickly have negative effects on water quality, land-surface stability, and underground cave ecosystems (Petersen and others, 1999a; and U.S. Geological Survey, 2007).

Land Use, Water Use, and Economics

Land Use

Land uses in the Illinois River Basin are primarily agriculture (pasture and hay (42.17 percent) and forested (43.52 percent)). Minor amounts of commercial and residential land uses are in agricultural areas, with most of urban and suburban areas occurring in the upstream end of the basin in Arkansas (fig. 5, and Multi-Resolution Land Characteristics Consortium, 2008).

Major agricultural activities in the basin include the raising of poultry and swine in confined animal feeding operations (CAFOs) and cattle grazed on pastures fertilized with commercial fertilizer, and litter and manure from CAFOs. In 2007, approximately 20 million laying hens, broilers, or turkeys; 14,000 hogs; and 160,000 cattle on pasture resided in the basin, with the most of those livestock being raised in the upstream part of the basin (fig. 6, table 3, Arkansas Agricultural Statistics Service, 2008; and Oklahoma Agricultural Statistics Service, 2008). Manures from CAFOs commonly are applied as fertilizers to pastures in the basin, potentially comprising many tons per day production of nitrogen and phosphorus compounds (fig. 7, Carreira and others, 2007). Nitrogen production in manures in these counties ranged from a few hundred pounds to more than 60,000 pounds per day (fig. 7). Phosphorus production in manures in these counties ranged from a few hundred pounds about 21,000 pounds per

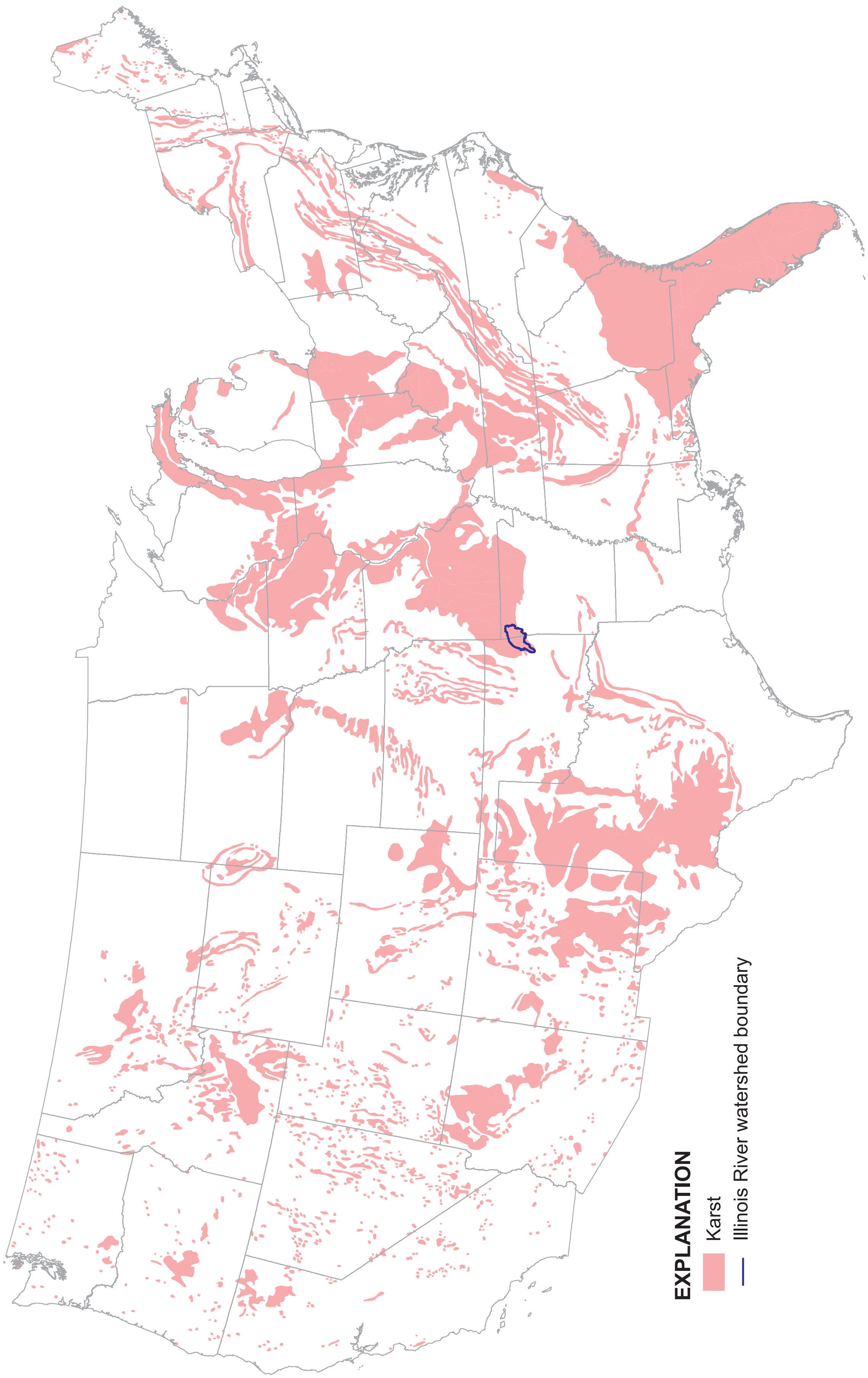
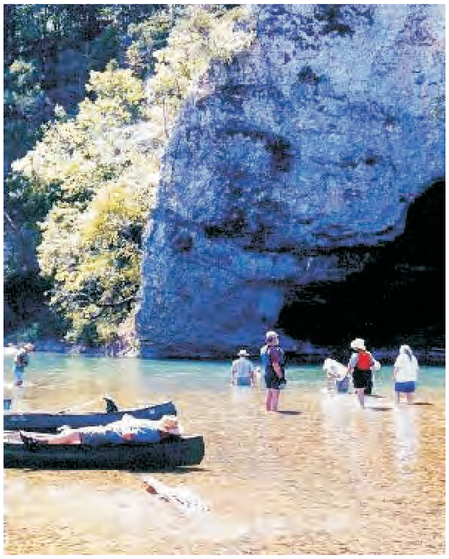
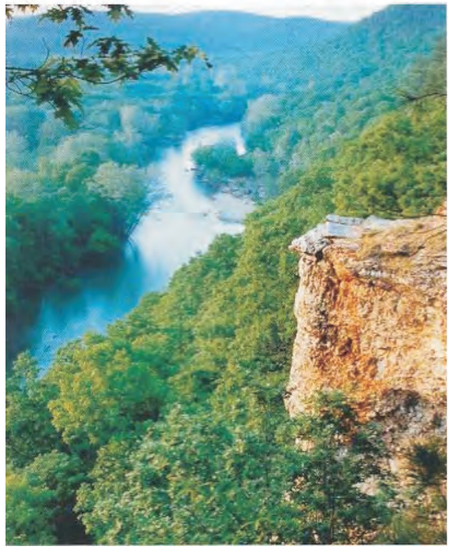


Figure 3. Karstic areas of the United States (U.S. Geological Survey, 2008).



Elephant Rock, an example of karstic dissolution of limestone and a spring discharging from underground caves in Sparrowhawk Loop of the Illinois River Valley (Northeastern State University photo).



Photograph showing incision of the Illinois River throgh limestone strata (Ed Fite, Oklahoma Scenic Rivers Commission photo).

Watercress and water willow growing along the spring-fed Caney Creek in the Illinois River Basin (Jim Petersen, U.S. Geological Survey photo).

Figure 4. Karstic features and plant life in the Illinois River Basin in Oklahoma.

day (fig. 7). Concern about saturation of local soils with phosphorus and subsequent runoff of that nutrient to local streams and lakes led the State of Arkansas to enact nutrient management statutes in 2003 (Carreira and others, 2007). Since 2005, poultry litter export from the Illinois River Basin has increased to almost 70,000 tons per year of about 350,000 tons produced annually. Litter export is assisted by state subsidies, though concerns exist that the amount of litter exported from the basin is not yet sufficient to notably reduce phosphorus loading to local streams and lakes (Smith, 2008; and Oklahoma Conservation Commission, 2009a). Litter production and application amounts reported by county in Oklahoma in 2008 (Oklahoma Conservation Commission, 2009b), if scaled for the percentages of the four counties in the basin (table 3), indicate that about 26,700 tons of litter were produced and 15,600 tons of litter were applied, indicating export of about 11,100 tons of litter from the basin. Several factors may affect such estimates, such as long-term storage and composting of poultry litter by producers (Dan Parrish, Oklahoma Department of Agriculture, Food, and Forestry, oral commun., 2009), incorrect reporting of litter production and application, or variable rates of production and application across those counties. Most of the poultry litter exported from the Illinois River Basin has been applied to cropland in other parts of Oklahoma, though a potential market exists in cotton-growing areas in the Mississippi Embayment in eastern Arkansas (Smith, 2008; and Carriera and others, 2007).

The number and distribution of the human population in the Illinois River Basin also have important implications for water quality. The upstream part of the basin in northwestern Arkansas contains the Fayetteville-Springdale-Rogers Metropolitan Statistical Area (MSA, urban center), that was the sixth-fastest-growing MSA in the U.S. from 1990 to 2007, having a 74 percent increase in population from 211,000 to 367,000 (fig. 8; Carreira and others, 2007). Reasons for growth in that area include the presence of headquarters of large, fast-growing international corporations such as Walmart, Tyson Foods, and J.B. Hunt Transportation; growing educational institutions such as the University of Arkansas (enrolled student body of 17,929 in 2007), and increasing numbers of retirees seeking relatively low-cost rural living (Rogers-Lowell Area Chamber of Commerce, 2006; and University of Arkansas, 2007). Population centers and the approximate numbers of residents in the basin include: Springdale, Arkansas (63,082, 2006 estimate); Fayetteville, Arkansas (68,726, 2006 estimate); Rogers, Arkansas (52,181, 2006 estimate), Siloam Springs, Arkansas (10,843 in the 2000 Census); Prairie Grove, Arkansas (2,540 in the 2000 Census); Tahlequah, Oklahoma (14,458 in the 2000 Census); and Westville, Oklahoma (1,596 in the 2000 Census) (U.S. Census Bureau, 2008b).

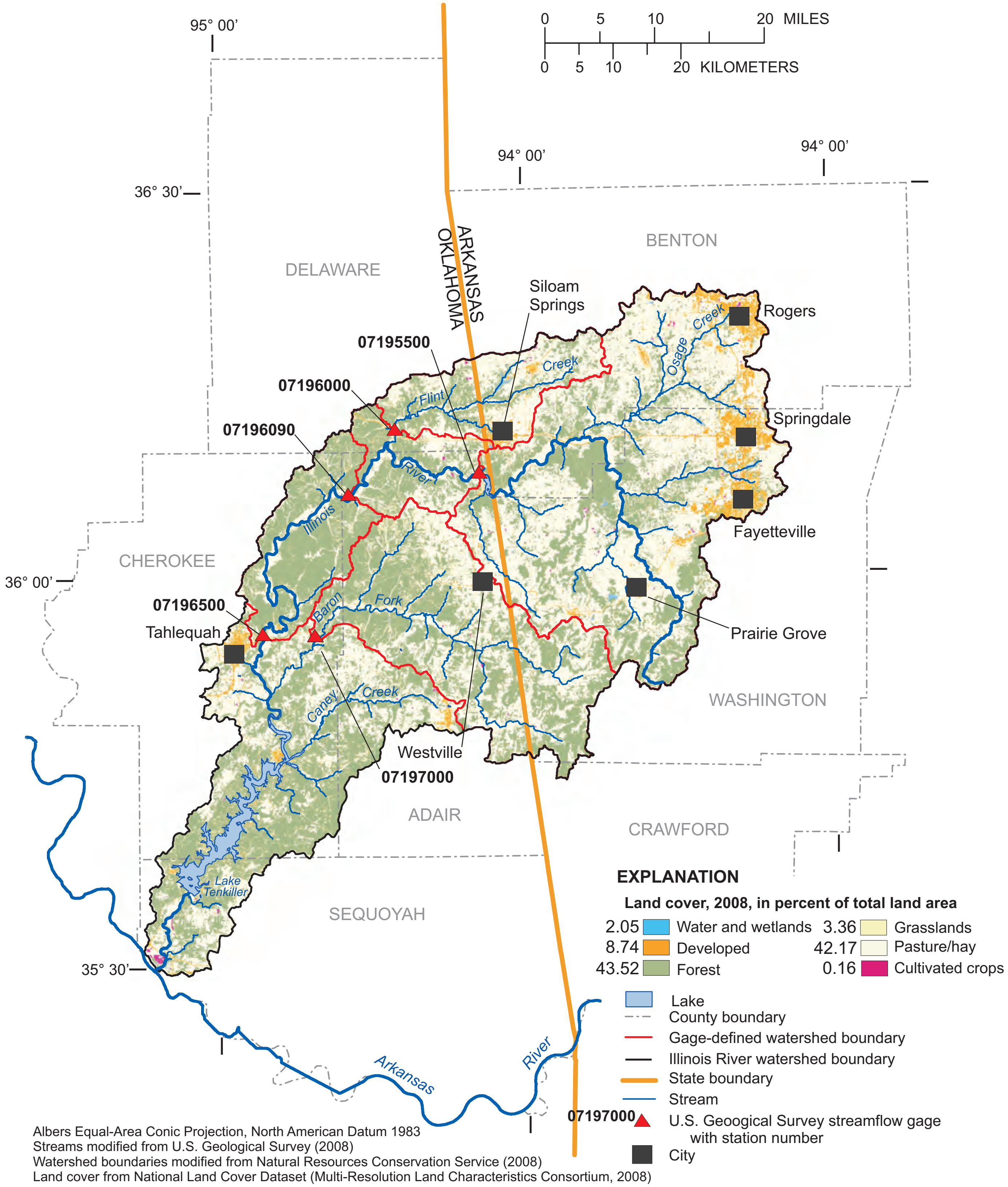
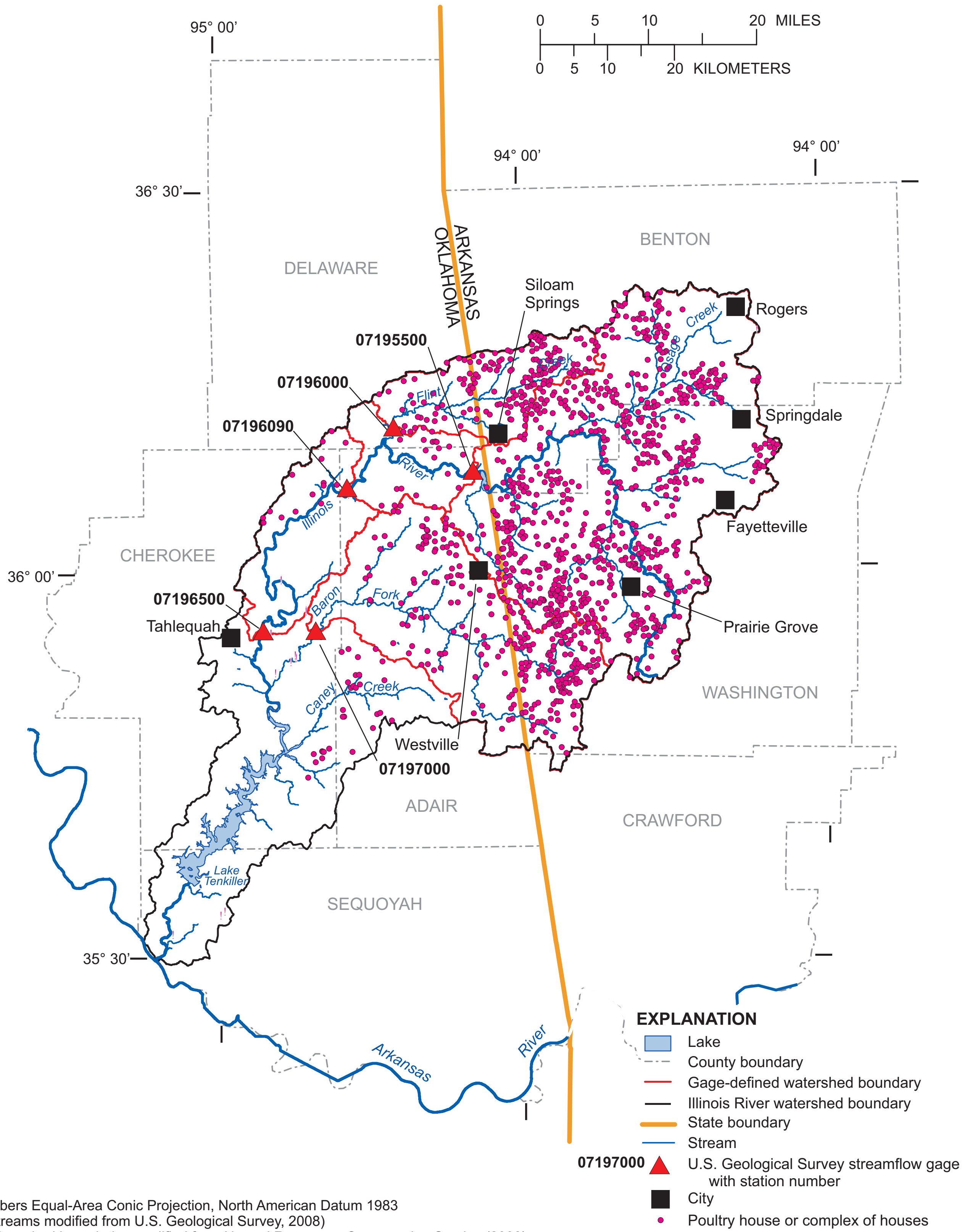


Figure 5. Land cover in the Illinois River Basin, Arkansas and Oklahoma in 2008.



Albers Equal-Area Conic Projection, North American Datum 1983
Streams modified from U.S. Geological Survey, 2008)
Watershed boundaries modified from Natural Resources Conservation Service (2008)
Arkansas poultry houses from 2006 images from Arkansas State Highway and Transportation Department (2008)
Oklahoma poultry houses from 2006 summer images from National Agriculture Imagery Program (Oklahoma GIS Council, 2007)

Figure 6. Distribution of poultry confined animal feeding houses in the Illinois River Basin, Arkansas and Oklahoma in 2006.

Table 3. Approximate numbers of livestock and human residents in the counties comprising the Illinois River Basin, and in the parts of those counties in the basin, 2005–2007.

[%, percentage; --, unknown]

County, state	Estimated total livestock numbers by county, 2007						Estimated human residents, 2007
	Cattle and calves	Swine	Broilers	Layers	Turkeys	Horses	
Benton, Arkansas	[1]94,588	--	[1]20,360,012	[1]1,664,829	[1]577,344	[1]3,415	[3]203,107
Washington, Arkansas	[1]102,394	[1]28,417	[1]20,487,381	[1]1,482,401	[1]1,347,582	[1]4,808	[3]194,292
Adair, Oklahoma	[2]61,191	[2]609	[2]4,405,354	[2]266,977	--	[2]2,330	[3]21,902
Cherokee, Oklahoma	[2]49,048	[2]552	[2]347,183	[2]21,552	[2]89,607	[2]2,803	[3]45,393
Delaware, Oklahoma	[2]83,197	[2]449	[2]9,174,334	[2]1,113,570	--	[2]2,791	[3]40,406
Sequoyah, Oklahoma	[2]40,701	--	[2]282,656	[2]459,876	[2]76	[2]2,330	[3]41,024

County, state (percentage of county land area in basin)	Estimated total livestock numbers in the Illinois River watershed by county, 2007						Estimated human residents, 2007
	Cattle and calves	Swine	Broilers	Layers	Turkeys	Horses	
Benton, Arkansas (34.2%)	32,349	--	6,963,124	569,372	197,452	1,168	69,463
Washington, Arkansas (47.6%)	48,740	13,526	9,751,993	705,623	641,449	2,289	92,483
Adair, Oklahoma (69.0%)	42,222	420	3,039,694	184,214	--	1,608	15,112
Cherokee, Oklahoma (44.7%)	21,924	247	155,191	9,634	40,054	1,253	20,291
Delaware, Oklahoma (9.74%)	8,103	44	893,580	108,462	--	272	3,936
Sequoyah, Oklahoma (10.5%)	4,274	--	29,679	47,827	8	242	4,308
Estimated total numbers	**157,612**	**14,237**	**20,833,261**	**1,625,132**	**878,963**	**6,832**	**205,593**

[1] 2007 County Estimates (Arkansas Agricultural Statistics Service, 2008).

[2] 2007 County Estimates (Oklahoma Agricultural Statistics Service, 2008).

[3] 2007 County Population Estimates (U.S. Census Bureau, 2008a).

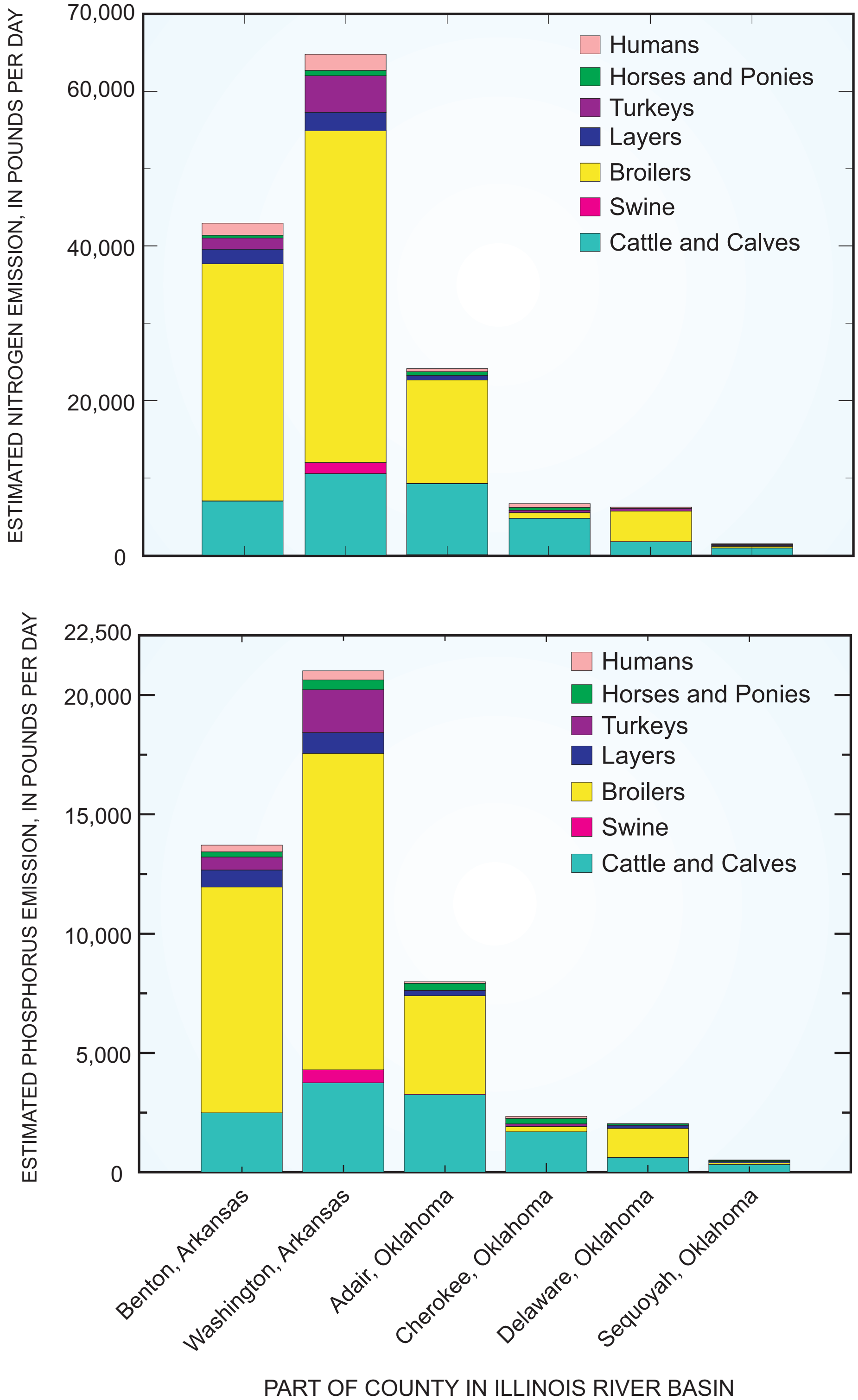
Water Use

Water use is an important element in describing the Illinois River Basin because it: (1) affects the amount of water in local streams and lakes available to dilute and assimilate contaminants, and (2) can affect the quantities of contaminants discharged to local streams, depending on the activity, water treatment methods, and the proximity of the use to those streams. The water-use estimates for this basin were for the year 2005 (Holland, 2007; and Robert L. Tortorelli, U.S. Geological Survey, written commun., 2009). The compilation for the part of the basin in Oklahoma was done specifically for the Illinois River Basin. Because data for the part of the basin in Arkansas were computed by county (Holland, 2007) water uses for the parts of those counties in the Illinois River Basin were estimated by scaling county water-use numbers by the percentages of the counties in the basin (listed on table 3), which assumes that water uses were evenly distributed across those counties. Water withdrawals of nearly 378 million gallons per day at the American Electric Power plant from Swepco Lake and Siloam Springs in Arkansas were not included in water-use estimates in this report. Surface-water withdrawal sites for public supplies tend to be clustered along Osage and Flint Creeks in the upstream part of the basin and around Lake Tenkiller in the downstream part of the basin (fig. 9). Most of the public-supply wells in the basin are along the Illinois River in the downstream part of the basin (fig. 9).

A slightly greater amount of water use was estimated for the upstream part of the basin in Arkansas (23.33 million gallons per day) than in the downstream part of the basin in Oklahoma (21.88 million gallons per day). Surface-water use is predominant in the Illinois River Basin, comprising about 93 percent of total water use (fig. 10). Domestic self-supplied ground-water use comprised 6.5 percent of total water use in the downstream part of the basin in Oklahoma and comprised 1.1 percent of total water use in the upstream part of the basin in Arkansas. Approximately 20,000 gallons per day of groundwater were withdrawn by public water supplies in the downstream part of the basin in Oklahoma, whereas about 380,000 gallons per day of groundwater were withdrawn for that purpose in the upstream part of the basin in Arkansas.

Water and the Local Economy

The lower part of the basin, in particular along the Illinois River and Flint and Baron Fork Creeks in Oklahoma, including small cities such as Tahlequah in Oklahoma, relies strongly on tourism to support the local economy. The amount of tourism and economic effect of tourism in the basin is highly dependent on aesthetically pleasing water and water



(Data Sources: Arkansas Agricultural Statistics Service, 2008; Oklahoma Agricultural Statistics Service, 2008; Strauss, 2000; and Gollihon and others, 2001)

Figure 7. Stacked bar charts of approximate daily nitrogen and phosphorus output, in pounds per day, by humans and livestock in the parts of counties in the Illinois River Basin in 2007.

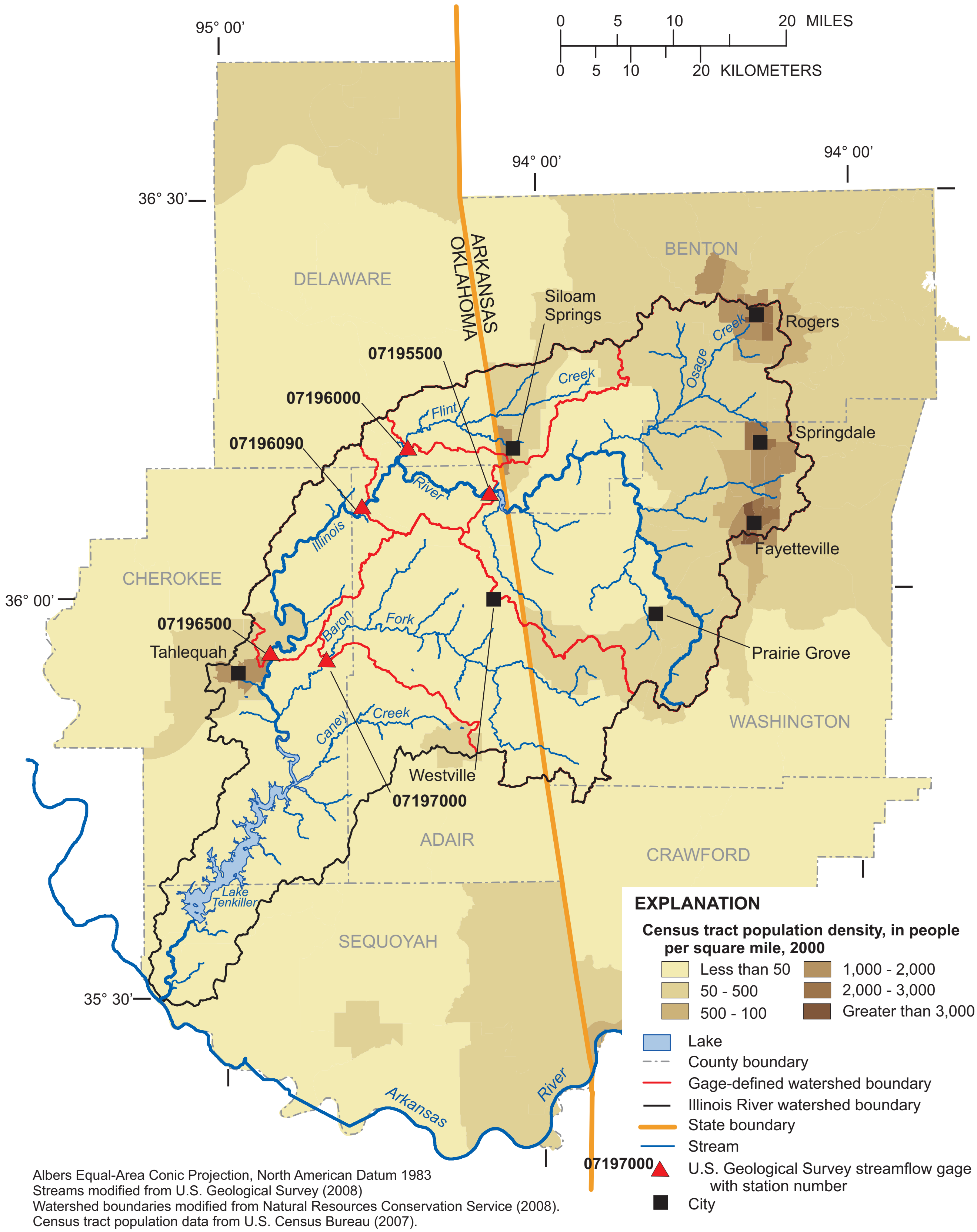


Figure 8. Distribution of human population density in the Illinois River Basin, Arkansas and Oklahoma in 2000.

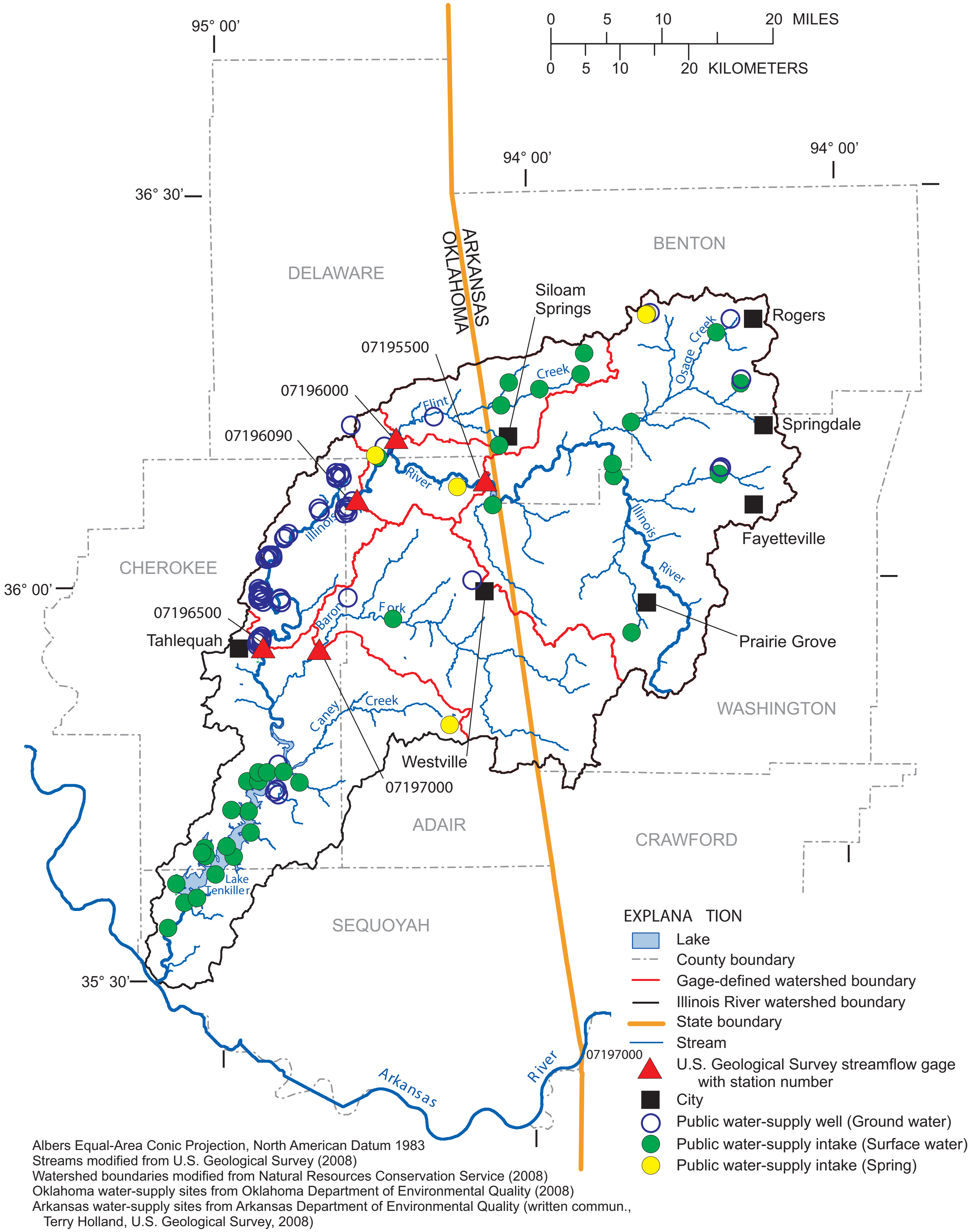


Figure 9. Locations of public water supply intakes and wells in the Illinois River Basin, Arkansas and Oklahoma.

quality that is safe for primary body contact for the 400,000 tourists who spend about $12 million annually in the basin, much of that on water-related recreational activities (Ed Fite, Oklahoma Scenic Rivers Commission, oral commun., 2009). An additional $30 million is spent each year by about 2,000,000 visitors to Lake Tenkiller (Don Nowlin, Greater Tenkiller Area Association, oral commun., 2009).

Water-Quality Degradation by Nutrients

Six streams in Arkansas and five streams in Oklahoma in the Illinois River Basin were listed for exceeding water-quality standards established by Section 303d of the Clean Water Act in 2004 (U.S. Environmental Protection Agency, 2007). The quality of 7 of those 11 streams was impaired by total phosphorus, including the Illinois River and Tenkiller Ferry Lake (commonly referred to as Lake Tenkiller) (fig. 1). Nitrate was the cause of water-quality impairment in 2 of the 11 impaired streams, and bacteria, organic enrichment (lack of dissolved oxygen), and the condition of fish habitat being the causes of impairment of one stream each in the basin (U.S. Environmental Protection Agency, 2007). The quality of water in Lake Tenkiller has been notably degraded for several years by algal blooms (that limit recreational use and can be toxic to livestock and aquatic animals), anoxic water because of metabolism of living algae and decay of plant matter (that can suffocate aquatic animals and cause taste and odor problems), and increased turbidity (Steele and others, 2003). Some species of algae also produce organic compounds that can be toxic to fish, shellfish, humans, livestock, and wildlife (Creekmore, 1999).

Phosphorus and nitrogen are necessary nutrients for plant and animal growth. However, only limited amounts of nutrients can be effectively used by plants and animals in an ecosystem. An overabundance of nutrients causes vigorous plant growth. This plant growth is commonly in the form of algae in waterways. Nutrients entering the watershed are classified by the general sources and pathways. A point source directly discharges nutrients and/or other substances into the environment, an example being a wastewater treatment plant that discharges treated municipal wastewater to a stream. Another type of source is nonpoint that introduces contaminants to surface water diffusely in precipitation runoff. Runoff of manure and inorganic fertilizer applied to the land surface are common nonpoint sources of nutrients and/or bacteria in rural areas.

Phosphorous and ammonium-nitrogen tend to adsorb to soil particles. Ammonium (NH_4^+) in soils, animal wastes, and water is converted rapidly to nitrate (NO_3^-) in oxidizing conditions. Nitrate is much more soluble in water and more available to plants than ammonium. Soils over much of the basin are believed to contain as much phosphorus as can be effectively absorbed (Nelson and Trost, 2002). Most additional loading from livestock manure is believed to be transported in runoff to local streams that can cause eutrophication of streams and lakes and build up phosphorus-enriched sediments in those water bodies that can continue to be sources of phosphorus to the streams through erosion and leaching. Storm and others (1996) estimated dissolved phosphorus yields (amounts of a substance running off or leaching from a given unit of land area per unit of time) of more than 1 pound per acre per year for much of the upstream part of the basin. Storm and others (1996) also estimated that nonpoint sources produced

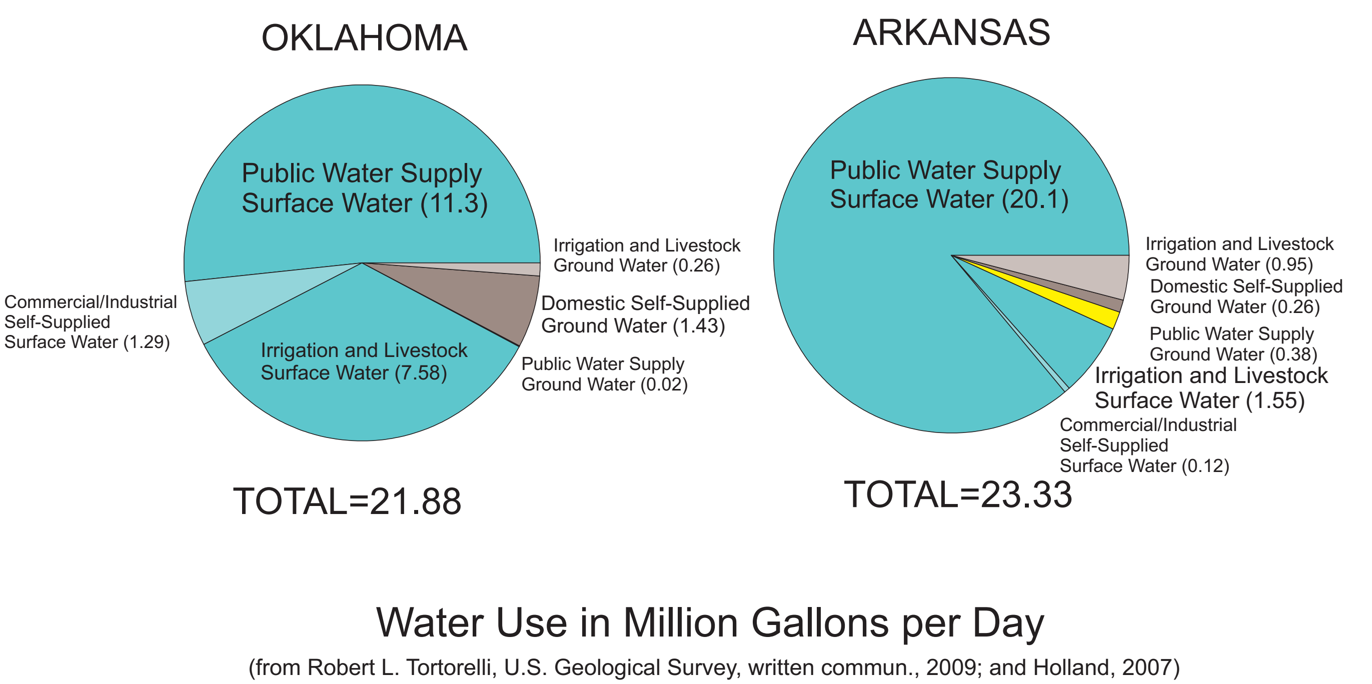


Figure 10. Water use in 2005 in the Illinois River Basin, Arkansas and Oklahoma.

by humans (such as pastures, poultry houses, and septic tanks) produced about two-thirds (67 percent) of the phosphorus reaching the Illinois River, with point sources (such as outfalls from municipal wastewater treatment plants) producing all but 2 percent of the remaining phosphorus loading (31 percent total). Phosphorus concentrations in streams in the upstream part of the basin tend to decrease exponentially with distance downstream from wastewater outfalls to streams, indicating storage in streambed sediments (Haggard and others, 2003), and uptake by aquatic plants and animals. Substantial investments ($186,500,000) have been made since 2000 on upgrading capacity and phosphorus removal capabilities at municipal wastewater treatment plants in northwestern Arkansas (Melnichak, 2008). Such improvements are likely to diminish loading of phosphorus to stream segments downstream from such plant outfalls and perhaps to farther downstream areas. Efforts to export poultry litter from the basin also may help, with time, to reduce loading of phosphorus to streams in the basin (Young and others, 2005).

Water Quality

Surface water and groundwater in the Illinois River Basin and the surrounding Ozarks region generally contains large amounts of calcium and bicarbonate dissolved from limestone, making most water in the region relatively hard (Adamski, 2000). Nitrate dissolved in the water is derived from natural sources such as bedrock, and human activities such as agriculture, seepage of human wastewater from septic tanks, and discharges of municipal wastewater from point sources.

Streamflow has a substantial effect on surface-water quality in the Illinois River Basin and adjoining basins in the Ozarks, with storm runoff flushing contaminants from the land surface, increasing concentrations of nutrients, bacteria, and sediment in streams (Petersen and others, 1999a). Runoff water from storms is likely to contain phosphorus that is commonly attached to particles of soil and other organic matter (Hem, 1992). Large streamflows from storms also may scour and resuspend streambed sediments containing phosphorus. Nitrogen and phosphorus compounds such as nitrate, ammonium, and orthophosphate can contribute to eutrophication, or excessive growth of algae and other plants, in streams.

General-Water Quality

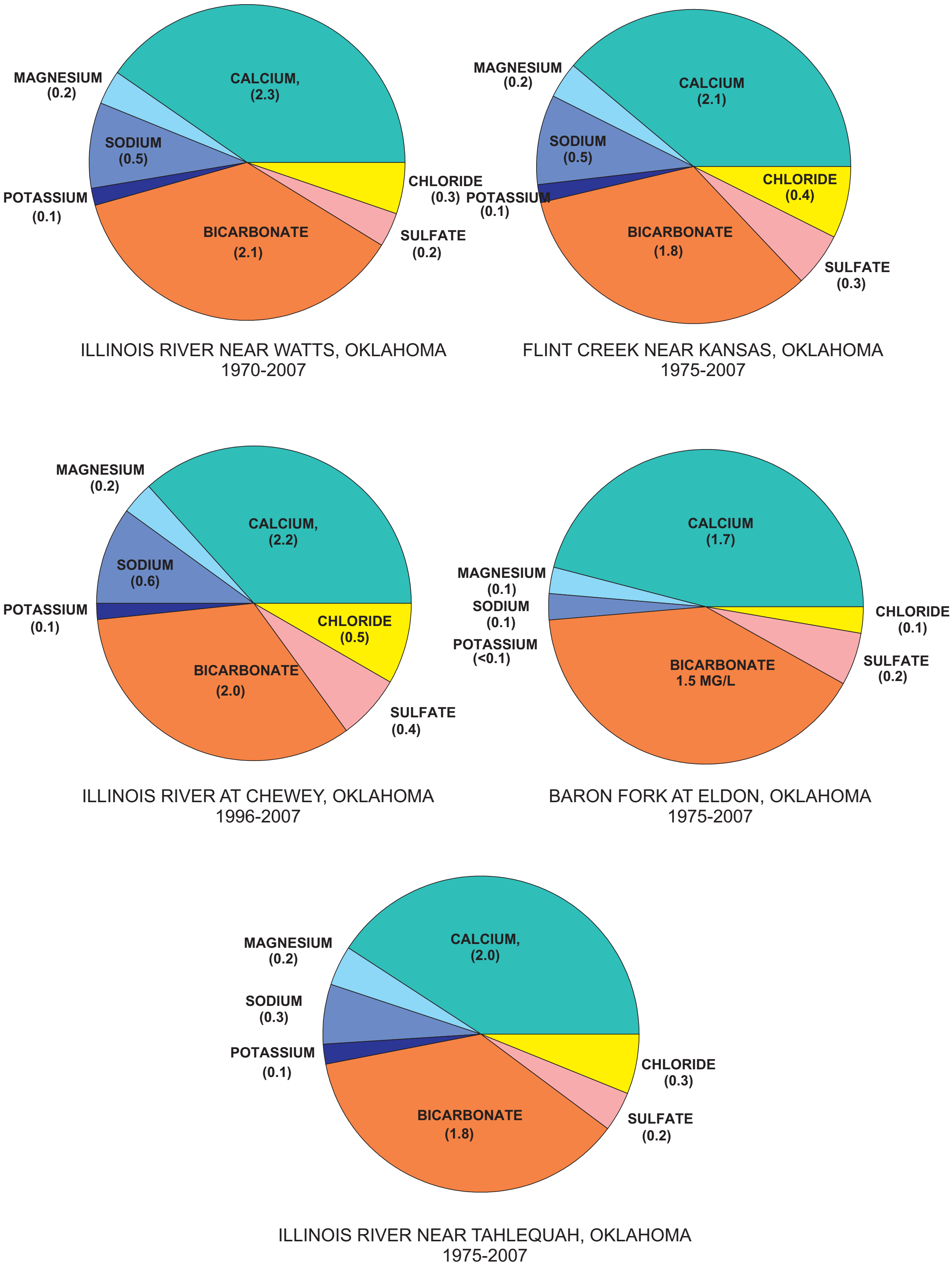
Groundwater seeping to rivers and streams in the Illinois River Basin is likely to be classified as hard water, containing abundant calcium and bicarbonate. Trace element concentrations in water are generally low in this basin. Forested areas of the region typically have the best water quality, with agricultural and urban land uses contributing greater amounts of nutrients, pesticides, and fecal-indicator bacteria to water in streams and aquifers (Petersen and others, 1999a and 1999b). Median concentrations of the major ions—calcium, magnesium, sodium, potassium, bicarbonate, chloride, and sulfate—were similar between sites sampled in the basin (fig. 11), although water samples from the Baron Fork at Eldon, Oklahoma, site had slightly smaller median concentrations of those ions than the other gaging stations. About 90 percent of the water samples analyzed for major ions collected at the five stations were collected at base-flow conditions, so those concentrations primarily reflect the quality of groundwater seeping to these streams.

Nutrients

Water quality in 11 stream segments in the Illinois River Basin, including the Illinois River, Flint Creek, the Baron Fork, and Lake Tenkiller have been listed as being impaired by elevated phosphorus concentrations under section 303d of the Clean Water Act (U.S. Environmental Protection Agency, 2007). Gollehon and others (2001) estimated that Washington and Benton Counties in Arkansas produced greater quantities of nitrogen and phosphorus in livestock manure than could be assimilated by soils. According to Goodwin (2004), phosphorus-based best management practices and local soil phosphorus concentrations indicate that 300,000 tons of poultry litter would need to be exported from those counties annually to minimize runoff of phosphorus to local streams and lakes. Counties in the Oklahoma part of the basin, with smaller quantities of manure from livestock (table 3), have generated quantities of nitrogen and phosphorus from livestock manure that were estimated to be 25 percent or less of the soil capacity to assimilate those nutrients (Gollehon and others, 2001).

Groundwater, the source of base flow to streams in the basin, had greater nutrient concentrations in areas of agricultural land uses, compared to forested land uses, but nitrate nitrogen concentrations in groundwater in the basin rarely exceed the drinking-water standard of 10 milligrams per liter (Petersen and others, 1999a).

Critical issues for minimizing eutrophication of surface waters are: (a) reduction in the quantities of nutrients running off to or seeping into surface water, and (b) control of the ratios of nutrients, particularly of nitrogen and phosphorus in surface water. The ratio between nitrogen and phosphorus by weight in most green algae is 7.2 to 1, or 16 to 1 on a molecular-ratio basis (Allan, 1995). Because green algae take up those nutrients in a similar ratio in algal biomass, those ratios between nitrogen and phosphorus are considered to be ideal for growth. Nitrogen-to-phosphorus ratios of 20 to 1 or greater indicate potential deficiency of phosphorus; whereas, ratios of 10 to 1 or less indicate potential deficiency of nitrogen (United Nations Environment Programme, 2007). Nitrogen-to-phosphorus ratios are useful for general guidance as to what nutrient may be most likely to encourage plant growth in surface water, but if nutrient concentrations are sufficiently large, then these nutrients also may be available for uptake, regardless of the ratios. A greater part of total phosphorus than total nitrogen also may not be readily available for plant uptake, being bound to small colloids or other particles



[pie charts are percentages of major ions, expressed in milliequivalents per lite; milliequivalents per liter in parenthesesr]

Figure 11. Percentages of major ions in milliequivalents per liter in surface-water samples collected at selected stations in the Illinois River Basin in Oklahoma.

in water (Jones and Knowlton, 1993). When phosphorus concentrations are increased relative to nitrogen, commonly because of use and discharge of phosphorus-containing detergents or runoff of phosphorus-rich fertilizers and soils into water bodies, blue-green algae (known as cyanobacteria) tend to bloom (Levich, 1996). In addition to blooming in phosphorus-enriched waters, blue-green algae, that can extract nitrogen from air to supplement relatively nitrogen-poor environments, can exacerbate "hypereutrophic" conditions.

Hypereutrophic conditions in lakes and streams happen when water has concentrations of greater than 40 micrograms per liter (µg/L) chlorophyll-*a* (a pigment used by plants for photosynthesis), total phosphorus concentration greater than 100 µg/L, and total nitrogen concentration greater than 1,200 µg/L) (Jones and Knowlton, 1993). Hypereutrophic conditions are characterized by extreme growth of algae that: (a) discolor and cloud water (reducing feeding of predator fish), (b) decrease dissolved oxygen concentrations in water as part of algal respiration and plant-tissue decay, (c) increase sedimentation (filling in lakes and gravel spawning beds), (d) emit organic chemicals that cause taste and odor in water and can be toxic, (e) decrease diversity of aquatic species, and (f) change the dominant aquatic biota (Mason, 2002; Creekmore, 1999). Although suspended algae (phytoplankton) tend to be washed downstream in rivers, flowing water is not immune to the effects of eutrophication. Attached filamentous and colonial algae (periphyton), and other plants that can cover stream bottoms, affect the habitats of fish and other aquatic animals by covering gravel streambeds used for spawning.

Growth of colonial and filamentous blue-green algae in nutrient-enriched waters tends to be unimpeded by naturally occurring grazing crustaceans that have difficulty consuming blue-green algae because of the physical structure, poor nutritional quality, and toxins contained in the blue-green algal tissues (Levich, 1996). Such lack of grazing limits available food for organisms higher up in the food chain when blue-green algae are dominant in streams and lakes (Levich, 1996). Water samples intermittently collected from the Illinois River Basin, from 1975–2007 generally were deficient in total phosphorus, relative to nitrogen, meaning that phosphorus may be a limiting nutrient for eutrophication in the basin (fig. 12). For waters in which algal and plant growth is limited by phosphorus, controlling phosphorus discharges to the river and the tributaries can be the most cost-effective means of limiting eutrophication.

Phosphorus in the Illinois River Basin is derived from point and nonpoint sources. Large concentrations of phosphorous relative to nitrogen in the Illinois River prior to 1982 (fig. 12) may be, in part, related to the use of phosphorus in laundry detergents (Litke, 1999). The use of phosphorous in detergents gradually tapered off after peaking in 1970, due partly to the voluntary withdrawal of phosphates from those products by the industry from 1972 to 1994 (Litke, 1999). Stream sites draining agricultural areas of the basin (nonpoint source) tend to have fish communities dominated by primarily planktivorous (plant-eating) fish such as stonerollers; whereas fish communities in streams in this region receiving lesser amounts of nutrients in forested basins had greater numbers of carnivorous (animal-eating) members of the sunfish group, including basses, that are more popular with anglers (Petersen and others, 1999a).

Concentrations

Phosphorus concentrations in Ozark streams typically are greater in streams draining agricultural areas and downstream from wastewater-treatment plants, than in streams draining forested areas (Petersen and others, 1999a, 1999b). Runoff from pastures fertilized with animal manures may be substantial sources of phosphorus to rivers in the basin (Arkansas Department of Environmental Quality, 2000). Streams receiving point-source inflows of wastewater from municipal and industrial treatment plants can have phosphorus concentrations substantially greater than concentrations typically detected in streams draining agricultural areas of the basin (Petersen and others, 1999a, 1999b; Haggard and others, 2003). Numerous cities, towns, and smaller entities discharge treated municipal wastewater to the Illinois River and the tributaries (fig. 1).

U.S. Environmental Protection Agency (1986) recommends that the concentration of total phosphorus not exceed 0.1 mg/L in streams at the point of inflow to lakes or reservoirs (Petersen and others, 1999b). The State of Oklahoma set a standard/limit for total phosphorus of 0.037 mg/L, with not more than 25 percent of samples allowed to exceed that standard during any 3-month period to minimize potential eutrophication of Scenic Rivers in Oklahoma (State of Oklahoma, 2006). That standard is based on the 75th percentile of flow-weighted total phosphorus concentrations in streams draining 85 relatively undeveloped basins across the United States (Clark and others, 2000).

Water-quality samples were collected at the Illinois River near Watts and near Tahlequah, Oklahoma stations on a periodic basis prior to 1999, without regard to streamflow. Because streamflow is typically at or near base flow during much of the year, most of the water-quality samples prior to 1999 were collected at or near base-flow conditions (figs. 13 and 14). Water-quality sampling procedures at these and neighboring stations were modified after 1999 to collect samples at six high-flow and six base-flow periods annually, to gain better understanding of the effects of high streamflows on nutrient concentrations and to better determine annual flow-weighted concentrations of nutrients and time-trends in flow-weighted nutrient concentrations in the Illinois River, as described in Pickup and others (2003) and Tortorelli and Pickup (2006).

Concentrations of total nitrogen (sum of nitrate, nitrite, ammonium, and organic nitrogen) and of total phosphorus generally increased with increasing streamflow at all of the long-term water-quality monitoring sites, with most phosphorus concentrations exceeding the Oklahoma standard for Scenic Rivers of 0.037 mg/L, except at the Baron Fork at Eldon, Oklahoma site (figs. 15 and 16). Increases in

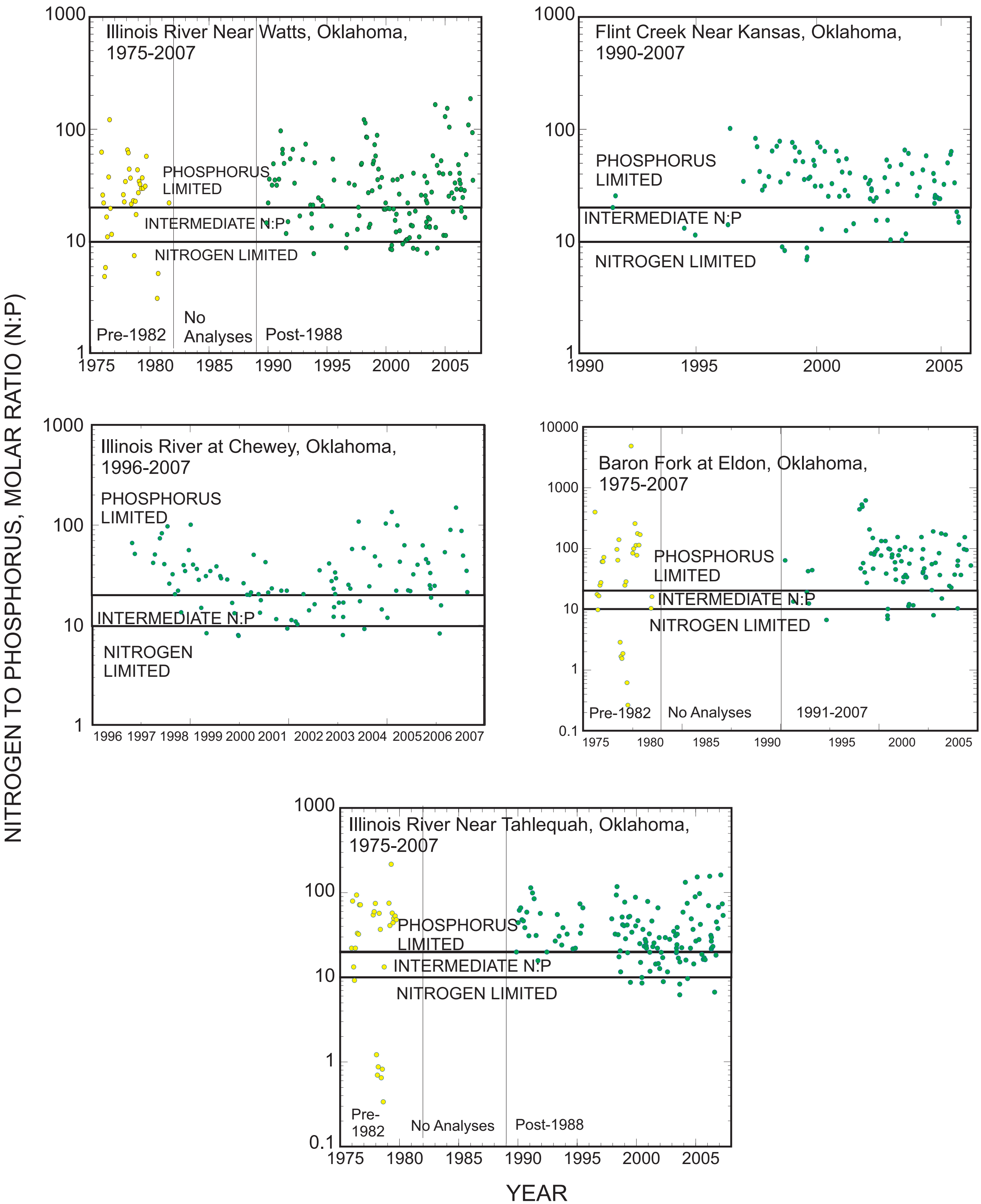


Figure 12. Molar ratios of total nitrogen and total phosphorus with time for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

concentrations of these nutrients with increases in streamflow indicate that storm runoff in parts of the basin upstream from these stations carries substantial quantities of nutrients from soils, animal wastes, and other sources. If point-sources of nutrients, such as municipal wastewater treatment plants, were the primary sources of nutrients in the river, then nutrient concentrations would tend to decrease with increasing streamflow, because of dilution of relatively constant discharges of nutrients from such sources. The data at these sites indicated that nonpoint sources of nutrients exceeded contributions from nutrient point sources (figs. 15 and 16). However, build-up of nutrient-rich sediments in stream segments downstream from wastewater treatment plants may become re-suspended during high streamflows, complicating analysis of relative proportions of nutrient sources at varying streamflow conditions.

Loads, Flow-Weighted Concentrations, and Trends

Pickup and others (2003) reported for 1997 through 2001 that flow-weighted total phosphorus concentrations generally increased at these long-term water-quality monitoring sites, but that the increase may have been partially because of increased sampling at high flows starting in 1999. Flow-weighted concentrations are estimates of the mean concentrations of a substance in the total volume of water flowing past a given point in a stream for a given period of time. During the period from 1997-2001, an annual average of 577,000 pounds of phosphorus flowed down the Illinois River into Lake Tenkiller, with more than 86 percent of that phosphorus being transported during runoff (Pickup and others, 2003). Tortorelli and Pickup (2006) reported for 2000 through 2004 that estimated annual phosphorus loads were greater at the sites on the Illinois River, ranging from 331,000 to 559,000 pounds per year, compared to 32,300 to 154,000 pounds per year in the Flint Creek and Baron Fork tributaries to the Illinois River. Seasonal estimated base-flow loads were greatest in the spring and least in autumn, with seasonal estimated runoff-loads varying, depending on the time periods measured (Tortorelli and Pickup, 2006). For 2000 through 2004 at these sites, flow-weighted total phosphorus concentrations tended to decrease slightly, except at the Flint Creek near Kansas, Oklahoma station (Tortorelli and Pickup, 2006). Mean annual phosphorus loads from 2000-2004 flowing down the Illinois River to Lake Tenkiller ranged from 391,000 pounds to 712,000 pounds, with 83–90 percent of those loads being transported during runoff (Tortorelli and Pickup, 2006).

Rebich and Demcheck (2007) reported on changes in streamflow, and concentrations, loads, and flow-adjusted concentrations of nutrients at these sites and about 100 other sites in the south-central U.S. from 1997–2004. That report indicated that flow-weighted concentrations of total nitrogen and total phosphorus were increasing during that period at most of the sampled sites in the Illinois River Basin (table 4). Analyses of changes in fertilizer use, livestock manure production, human population density and land management practices during that period in this basin indicated that for most stations, annual increases of 5 to 10 kilograms of phosphorus per square kilometer seeping to local streams from increases in fertilizer use and 5 to more than 10 kilograms per square kilometer in annual increases in phosphorus reaching local streams from increases in livestock raised in the basin (Rebich and Demcheck, 2007).

Chlorophyll-*a*

Chlorophyll-*a*, a green pigment contributing to photosynthesis in algae and plants, is a commonly measured surrogate for the biomass of phytoplankton (suspended algae) in water of lakes and the biomass of periphyton (attached algae) on streambeds. Concentrations of chlorophyll-*a* in water samples collected at four stations in the Illinois River Basin in Oklahoma did not show substantive relations with total streamflow (fig. 17), nor with the concentrations of total nitrogen (fig. 18) and total phosphorus (fig. 19). Substantial numbers of phytoplankton commonly bloom in near-surface waters of lakes, such as Lake Tenkiller, that receive water with elevated concentrations of nitrogen and phosphorus during the summer, when sunlight needed for photosynthesis is strongest.

Phytoplankton tend to be continuously washed downstream in flowing streams rather than accumulating in large numbers in the water column. In flowing streams receiving water with elevated concentrations of nutrients, periphyton (algae attached to streambed rocks and gravels) are more likely to grow in dense filaments or colonies than suspended phytoplankton (fig. 20), although single-celled suspended algae such as diatoms also may increase turbidity of streams. Agricultural areas in the Ozarks region tend to contribute greater concentrations of nutrients to streams than forested areas and have fewer trees shading stream channels, contributing to increased growth of periphyton and increased abundance of species of fish known as stonerollers, that graze on streambed periphyton (Peterson and others, 1999a and 1999b; and Petersen and Femmer, 2002). Filamentous, nitrogen-fixing blue-green algae of the genus *Calothrix* (fig. 20) are among the most common periphyton in Ozark streams (Petersen and Femmer, 2002).

Bacteria

Bacteria are everywhere and are intricately linked to larger ecosystem processes. Bacteria have adapted to very specific environmental conditions. When the conditions are favorable, bacteria thrive and multiply. Because bacteria are specific to environments, some are used as indicators of nutrient sources and ecologic health. Of concern in the Illinois River Basin are bacteria that are referred to as “enteric” that live in the intestines of birds and mammals. These bacteria are commonly referred to as “fecal indicator bacteria” or simply “fecal bacteria.” When found in abundance, these bacteria indicate the introduction of animal waste into the environment. These waste products may contain other harmful bacteria or

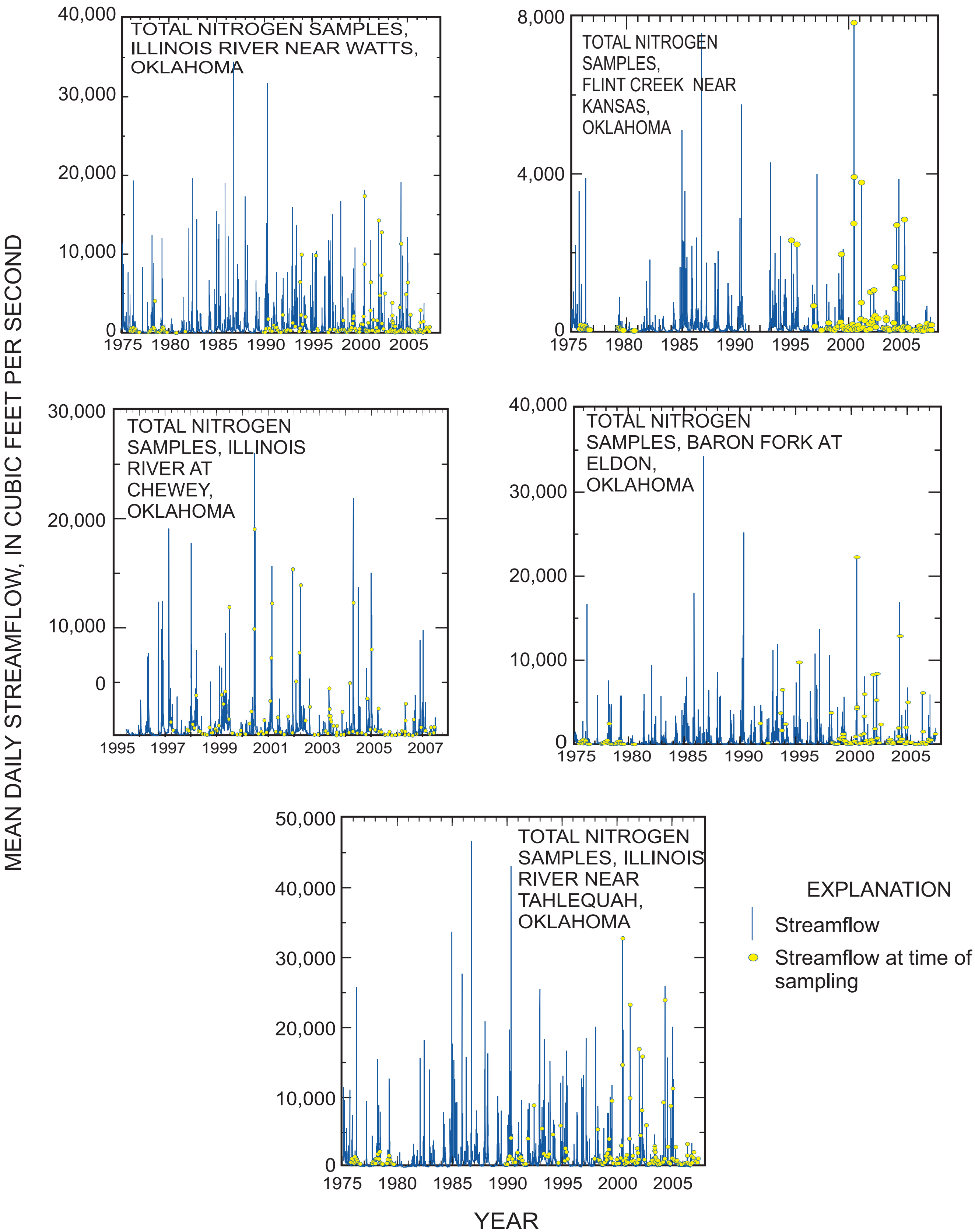


Figure 13. Mean daily streamflow and mean daily streamflow on sampling days for total nitrogen for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

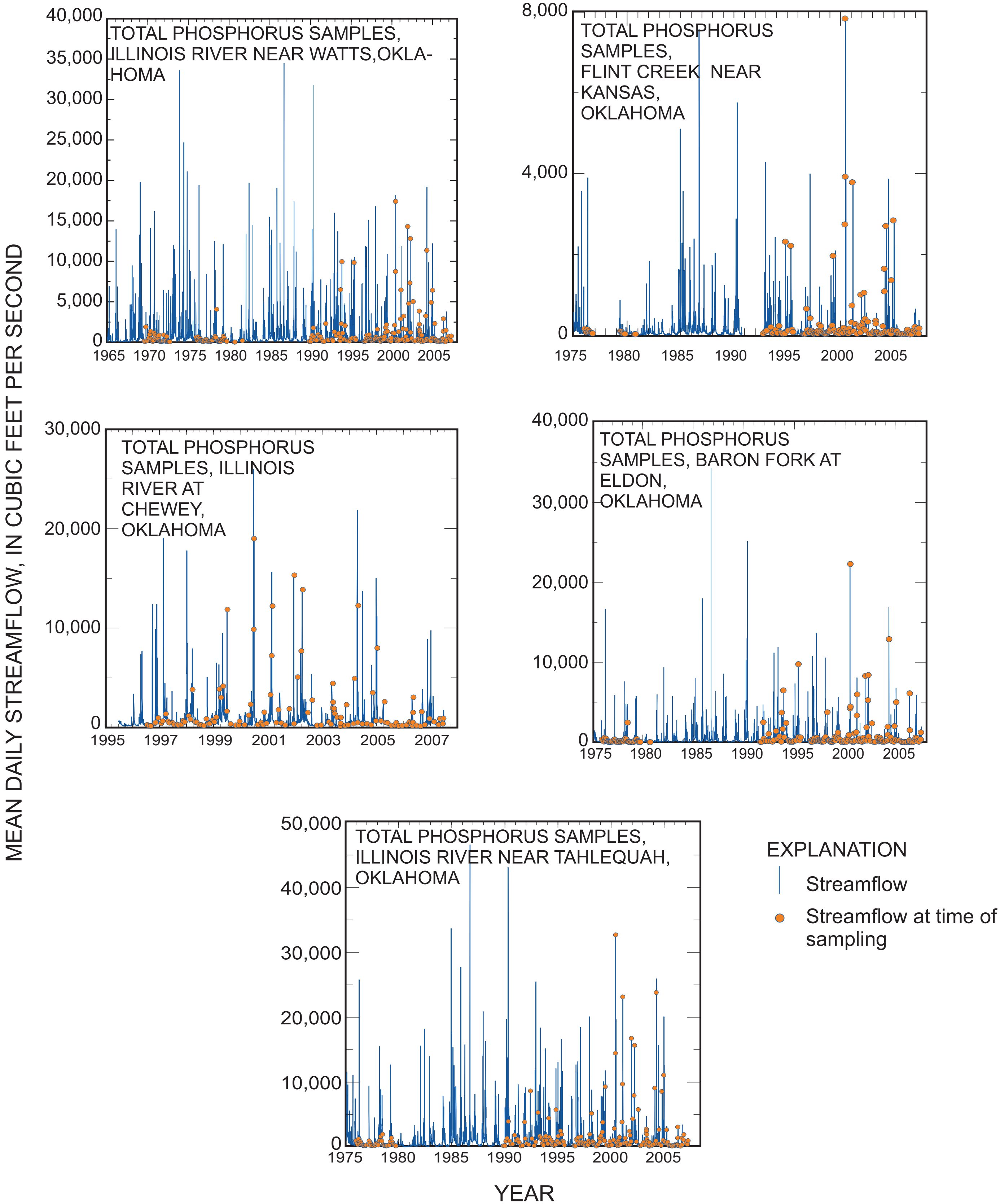


Figure 14. Mean daily streamflow and mean daily streamflow on sampling days for total phosphorus for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

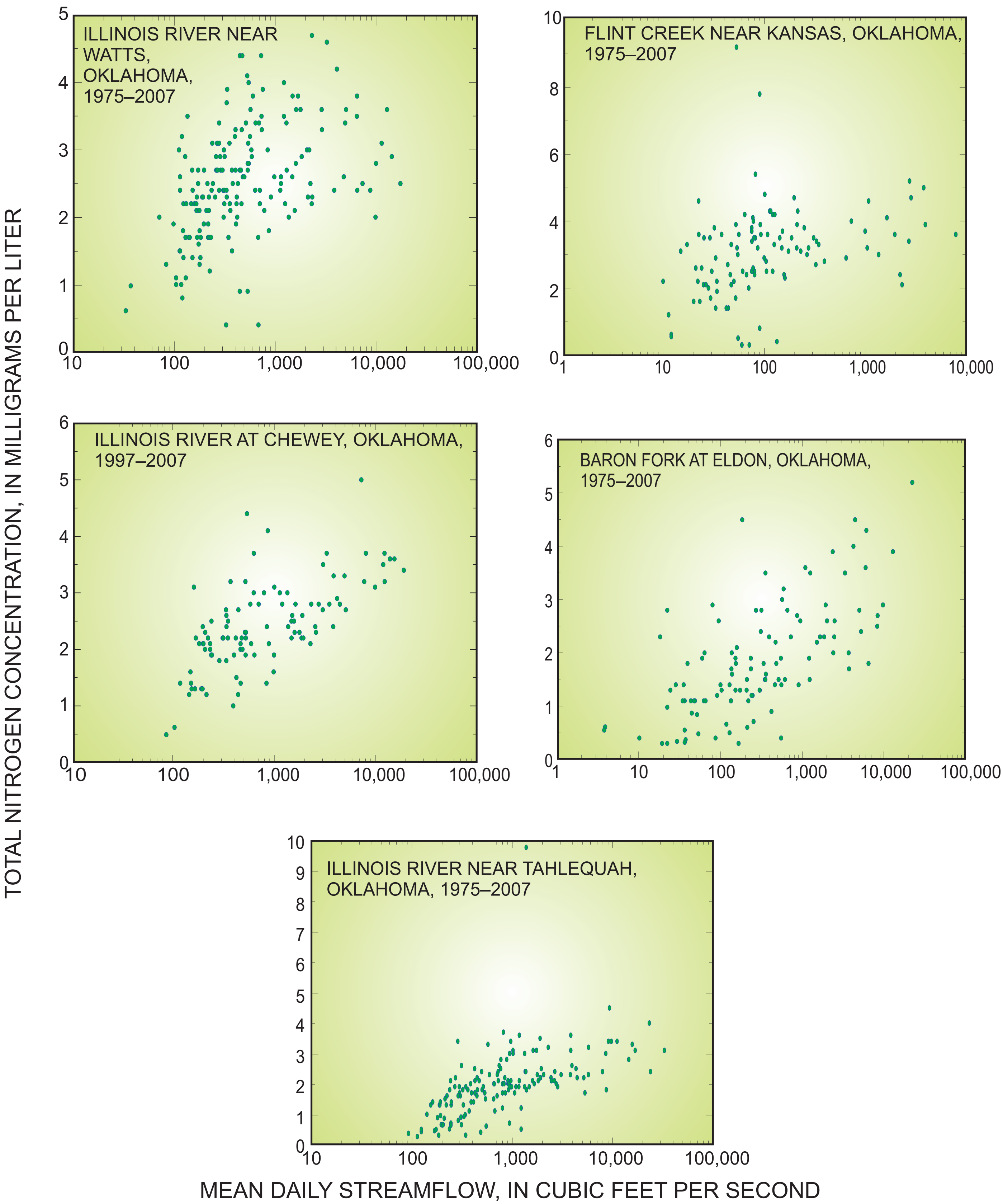


Figure 15. Total nitrogen concentration compared to mean daily streamflow for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

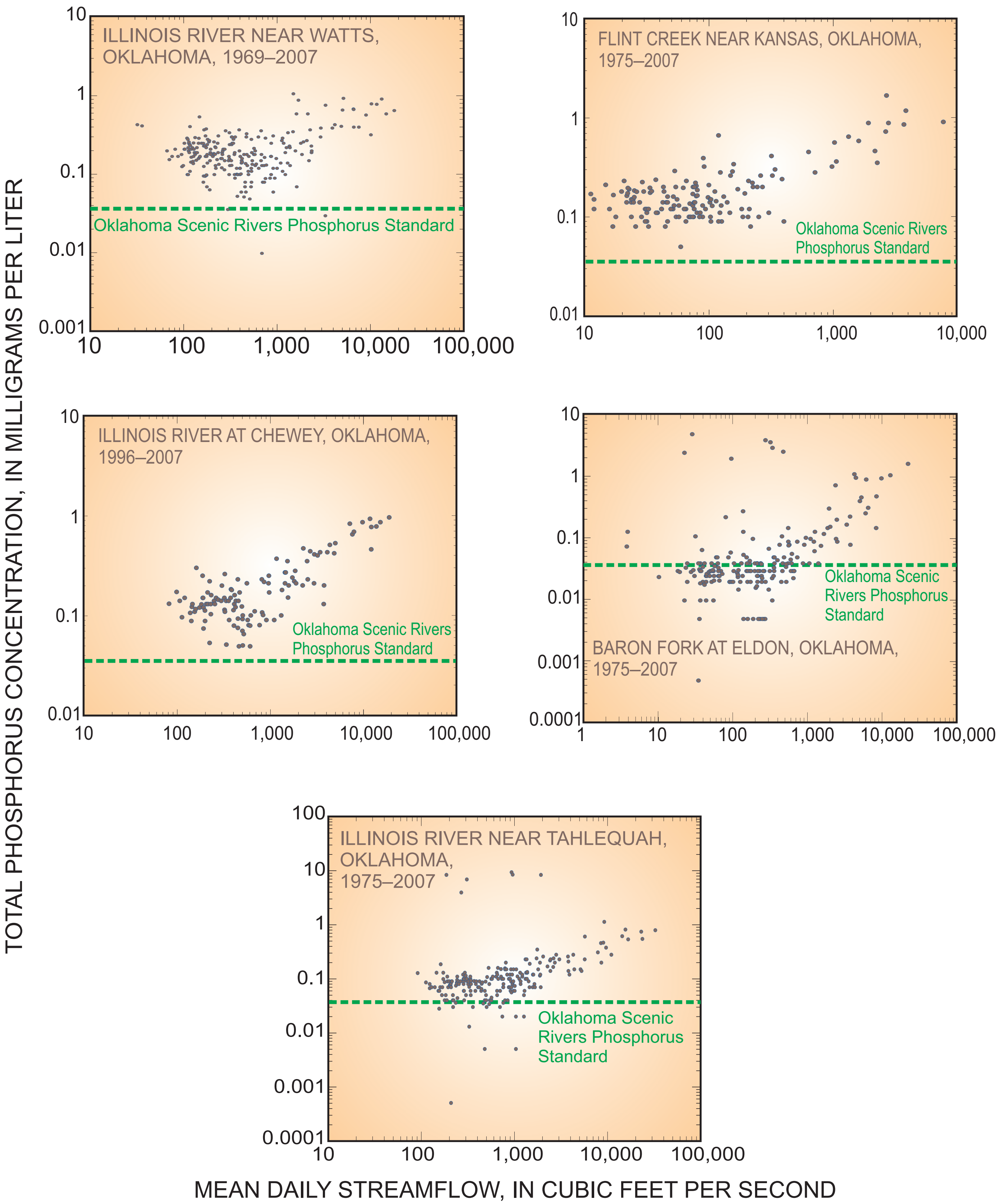


Figure 16. Total phosphorus concentration compared to mean daily streamflow for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

Table 4. Trends of streamflow, and total nitrogen and phosphorus concentrations, loads, and flow-adjusted concentrations at long-term water-quality monitoring sites in the Illinois River Basin from 1997-2004 (Rebich and Demcheck, 2007).

Station name	Trends, in percent per year, by parameter						
	Streamflow	Total nitrogen concentration	Total nitrogen load	Flow-adjusted total nitrogen concentration	Total phosphorus concentration	Total phosphorus load	Flow-adjusted total phosphorus concentration
Illinois River near Watts, Oklahoma	-3.9	None	-4.1	None	5.4	None	6.5
Flint Creek near Kansas Oklahoma	-3.5	4.1	None	4.8	8.3	None	10
Baron Fork at Eldon, Oklahoma	-4.5	None	None	3.1	None	None	5
Illinois River near Tahlequah, Oklahoma	-3.8	None	None	2.0	5.4	None	9.4

viruses that are not easily detected. Because of the potential for disease outbreaks from ingestion of bacteria by recreational users of streams, the State of Oklahoma set “primary body contact” limits of 400 colonies of fecal coliform bacteria, 235 colonies of *Escherichia coli* (*E. coli*) bacteria, and 33 colonies of enterococci (a subgroup of fecal streptococci) as geometric means of 5 samples collected during 30 days (for Scenic Rivers) per 100 milliters (mL) of water (State of Oklahoma, 2006).

Bacteria and the nutrients nitrogen and phosphorus have similar patterns of occurrence in the Illinois River and neighboring Ozark Basins. Bacteria are detected generally in greatest abundance in agricultural areas, with more than 25 percent of surface-water samples in those areas containing fecal coliform bacteria at counts greater than 200 colonies/100 mL (Petersen and others, 1999a).

Types of Bacteria Analyzed

Water samples collected from the Illinois River, Flint Creek, and Baron Fork were periodically analyzed by the USGS for fecal coliform, *E. coli,* and fecal streptococcal bacteria from 1993 to 2006. *E. coli* bacteria are a subgroup of fecal coliform bacteria that typically are detected in smaller counts than fecal coliform bacteria. Rates and timing of transport from the land surface to water bodies such as rivers and lakes can have substantial effects on fecal-indicator bacteria counts in those water bodies. Fecal-indicator bacteria, being acclimated to conditions in the digestive tracts of animals, tend to die-off with time after exiting the host animals in solid wastes. A study by Schumacher (2003) showed that *E. coli* in land-applied litter can survive in fields for as long as 8 weeks after application. Runoff soon after land application of animal manures is more likely to cause runoff of larger numbers of viable bacteria than runoff several weeks after such applications. Although fecal streptococcal bacteria generally are detected in smaller numbers than fecal coliform bacteria in animal wastes, fecal streptococcal bacteria tend to survive for longer periods of time outside of the hosts—as long as 20.1 days, as opposed to 13.4 days in soils for fecal coliform bacteria (Van Donsel and others, 1967; and Cohen and Shuval, 1972). Although fecal streptococcal bacteria tend to survive longer outside of the hosts, concerns about variability in their survival rates and in methodology used to culture this type of bacteria have led to greater reliance on counts of fecal coliform bacteria and enterococci (a subgroup of fecal streptococcal bacteria) to indicate possible contamination of water by fecal matter (Wilhelm and Maluk, 1998).

Bacterial Abundance

Water quality in five stream segments in the Illinois River Basin, including the Illinois River, Flint Creek, and the Baron Fork have been listed as being impaired by elevated fecal streptococcal (enterococci) bacteria counts under section 303d of the Clean Water Act (U.S. Environmental Protection Agency, 2007). Fecal coliform bacteria counts in water samples from the five stations summarized in this report generally ranged from 1 to 10,000 colonies per 100 mL (fig. 21). As with other constituents, apparent increases in bacteria counts after 1999 may be primarily artifacts of a change in sampling regime at that time that targeted sampling of six high-flow and six base-flow samples per year, compared to previous periodic sampling, that primarily sampled those sites at base-flow conditions.

Possible Sources of Bacteria

Humans, livestock, and wildlife comprise the major probable sources of fecal-indicator bacteria to the Illinois River and the tributaries. Whereas *E. coli* bacteria are believed to come only from the wastes of warm-blooded animals, fecal coliform bacteria can be derived from other sources, including effluents from paper mills, textile mills, and sugar beet processing (Dufour, 1976), but those sources are not present in the upstream parts of the Illinois River Basin. Viable bacteria from human wastes may be directly discharged to local streams from outfalls of municipal wastewater treatment plants or may seep from septic tanks through local soils into the karstic Springfield Plateau aquifer. Karstic aquifers, because

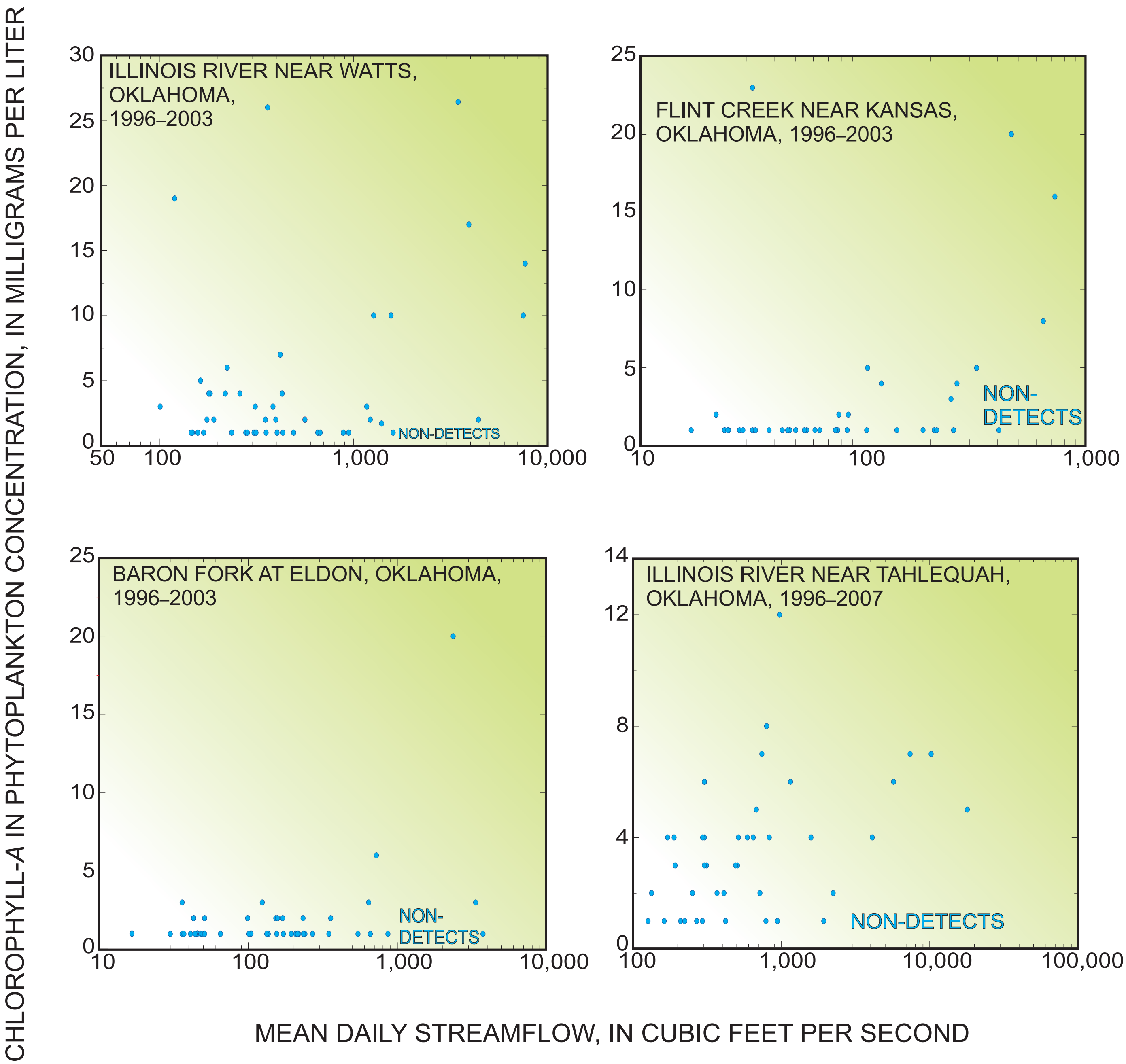


Figure 17. Mean daily streamflow compared to chlorophyll-*a* concentration in water samples from long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

of large interconnected voids, can have relatively small filtering ability, and can have relatively high ground-water flow rates from recharge areas to local streams (Lindsey and others, 2009). Rapidly-flowing groundwater is more likely to transport live bacteria to streams than groundwater that takes weeks, months, or years to seep from recharge areas to springs and streams. Wastes and entrained bacteria from livestock and wildlife typically are discharged in more diffuse manners (nonpoint source) than human wastes (point source), with livestock wastes being spread on land as fertilizers and through annual deposition on pastures.

Trends in Bacteria with Streamflow

Similar to phosphorus and nitrogen, increased amounts of fecal indicator bacteria are washed off of the land surface from soils and animal wastes during rainy periods, with bacteria counts generally increasing exponentially with streamflow in the Illinois River (fig. 22). If the sources of fecal indicator bacteria in the basin were primarily point sources, such as municipal wastewater treatment plants, then counts of those bacteria should decrease (be diluted) with increased streamflow. Upward trends of fecal indicator bacteria counts with

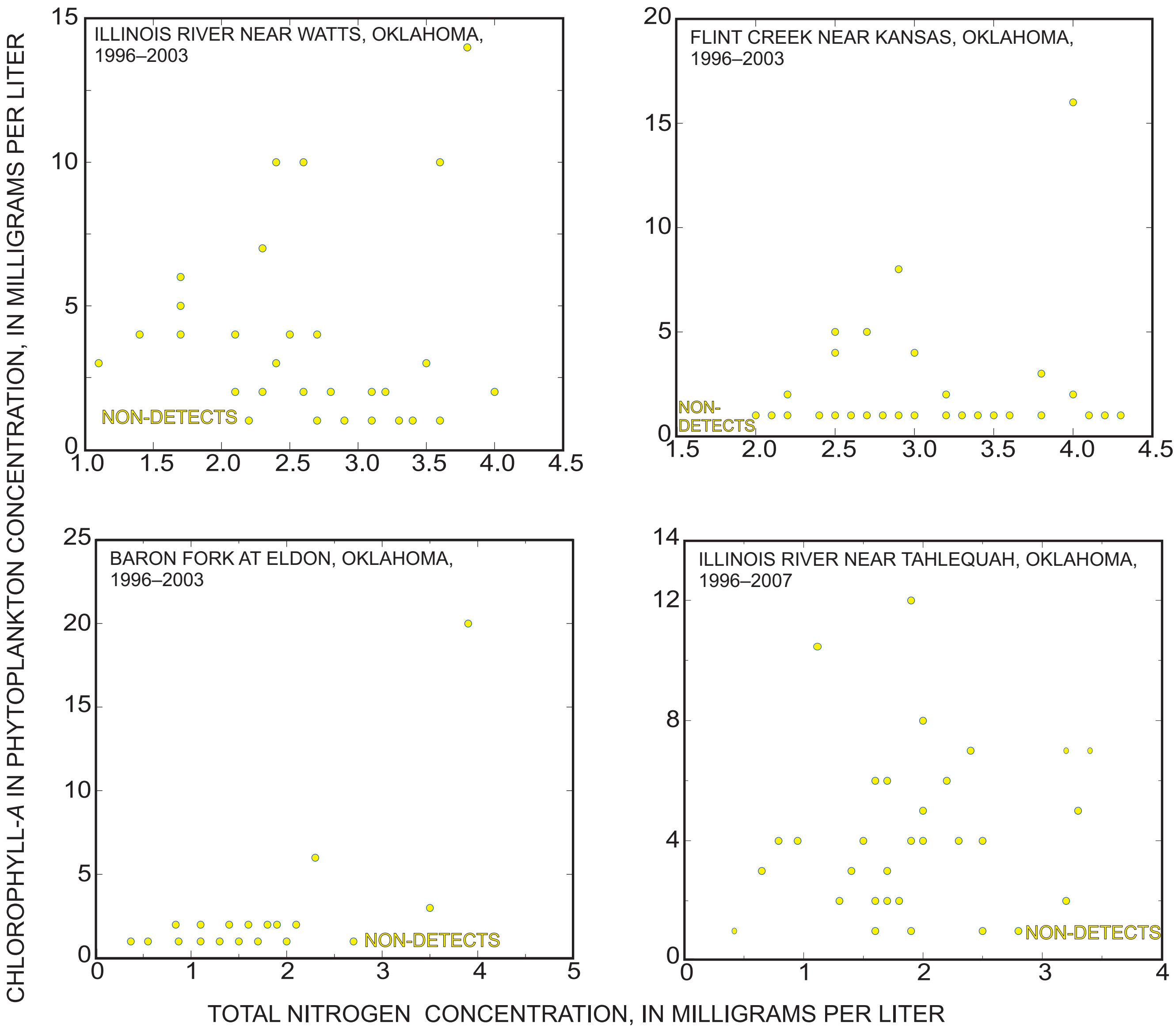


Figure 18. Total nitrogen concentration compared to chlorophyll-*a* concentration in water samples from long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

increasing streamflow indicate that nonpoint sources, such as urban and agricultural runoff, are more likely to be the major sources of these bacteria in the Illinois River as described in Storm and others (1996), Pickup and others (2003), and Tortorelli and Pickup (2006). The primary body contact standard for Oklahoma is shown on the graphs in figure 22 as a benchmark for bacteria counts that might pose risks to human health. The Oklahoma State standard is not a fixed number for any one sample, but rather a frequency of exceedances for a 30-day period. Specifically, no more than 10 percent of samples collected during 30-day periods shall exceed 400 fecal coliform colonies per 100 mL of water (State of Oklahoma, 2006).

Fecal coliform bacteria counts at the five stations summarized in this report commonly exceeded the State of Oklahoma primary body contact standard of 400 colonies per 100 mL at stream discharges exceeding 1,000 ft^3/sec. However, recreational activities that involve primary body contact with the water of this river are less likely to occur at higher flows, because of safety issues, than at base-flow conditions, when fecal coliform bacteria counts generally do not exceed the standard.

Sediment

Sediment is composed of organic and inorganic particles of soils and other materials that are washed or blown into streams and lakes. Sediment naturally occurs in all streams, but the amounts of sediment running off to streams are

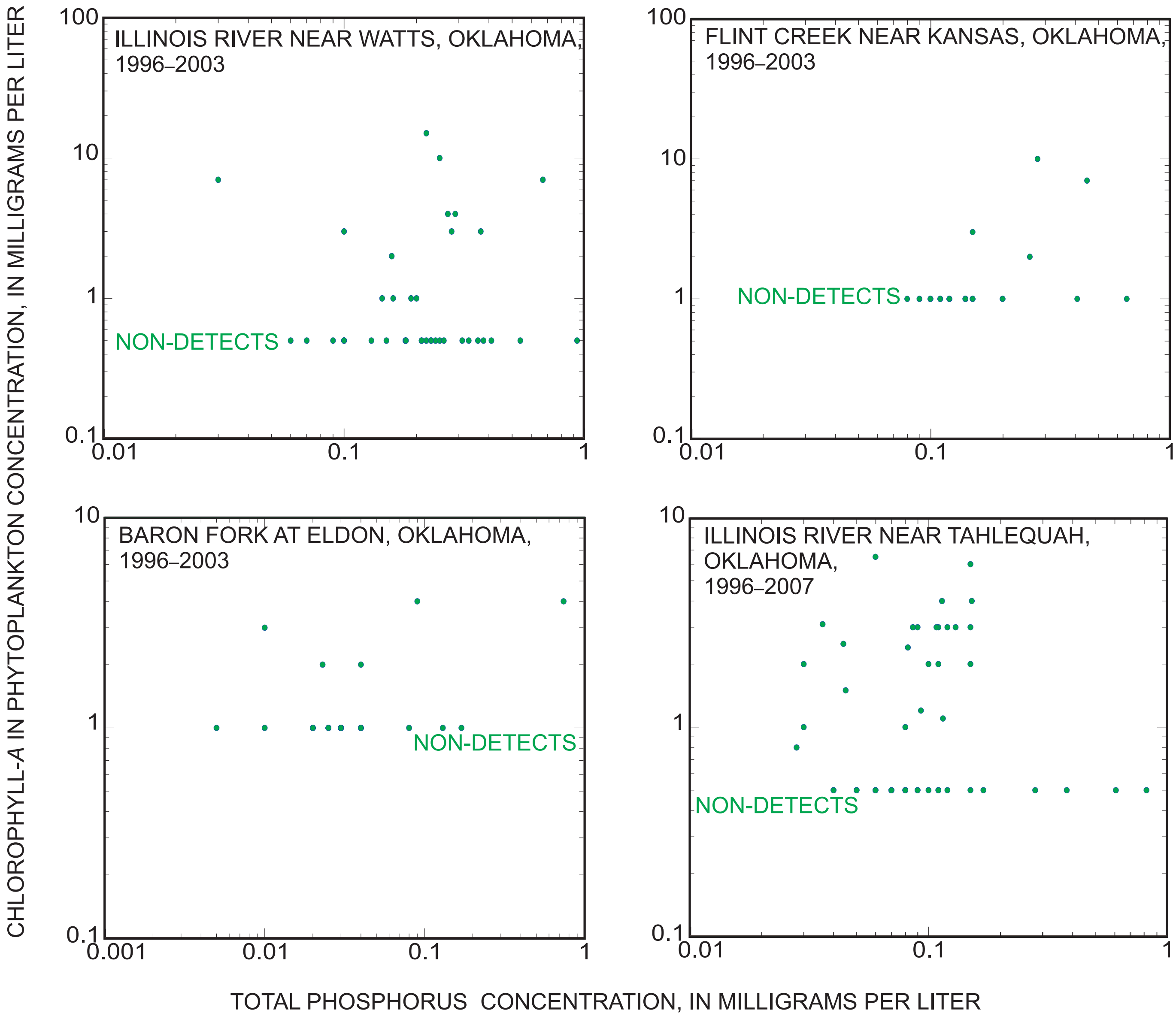


Figure 19. Total phosphorus concentration compared to chlorophyll-*a* concentration in water samples from long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

increased by removing vegetation from the land surface by activities such as construction of buildings and roads, plowing of cropland, overgrazing of pastures, cutting of timber, and fires. More intense development of land for either urban or agricultural purposes typically increases yields of sediment per unit of land area in river basins. Increased concentrations of suspended sediment in streams can degrade habitat and spawning ground for fish and amphibians by: (a) increasing water temperatures, (b) reducing dissolved oxygen in water, (c) reducing visibility for predator species, and (d) infilling gravel on streambeds used for spawning. Increased sediment loads also can increase scouring of bridges and streambanks, fill up downstream reservoirs, and reduce the aesthetic value of recreational streams.

Types of Suspended Sediment

Suspended sediment is composed of two major types of sediment—organic and inorganic. Organic sediments are composed of fragments of terrestrial and aquatic plants and animals, organic matter from topsoil, and animal wastes. Inorganic sediments generally are composed of fragments of rocks and minerals dominated by silica (such as quartz and clays) or carbonate (such as calcite and dolomite).

Relations of Sediment with Streamflow and Phosphorus Concentrations

Suspended sediment concentrations in the Illinois River tend to increase exponentially with streamflow (fig. 23),

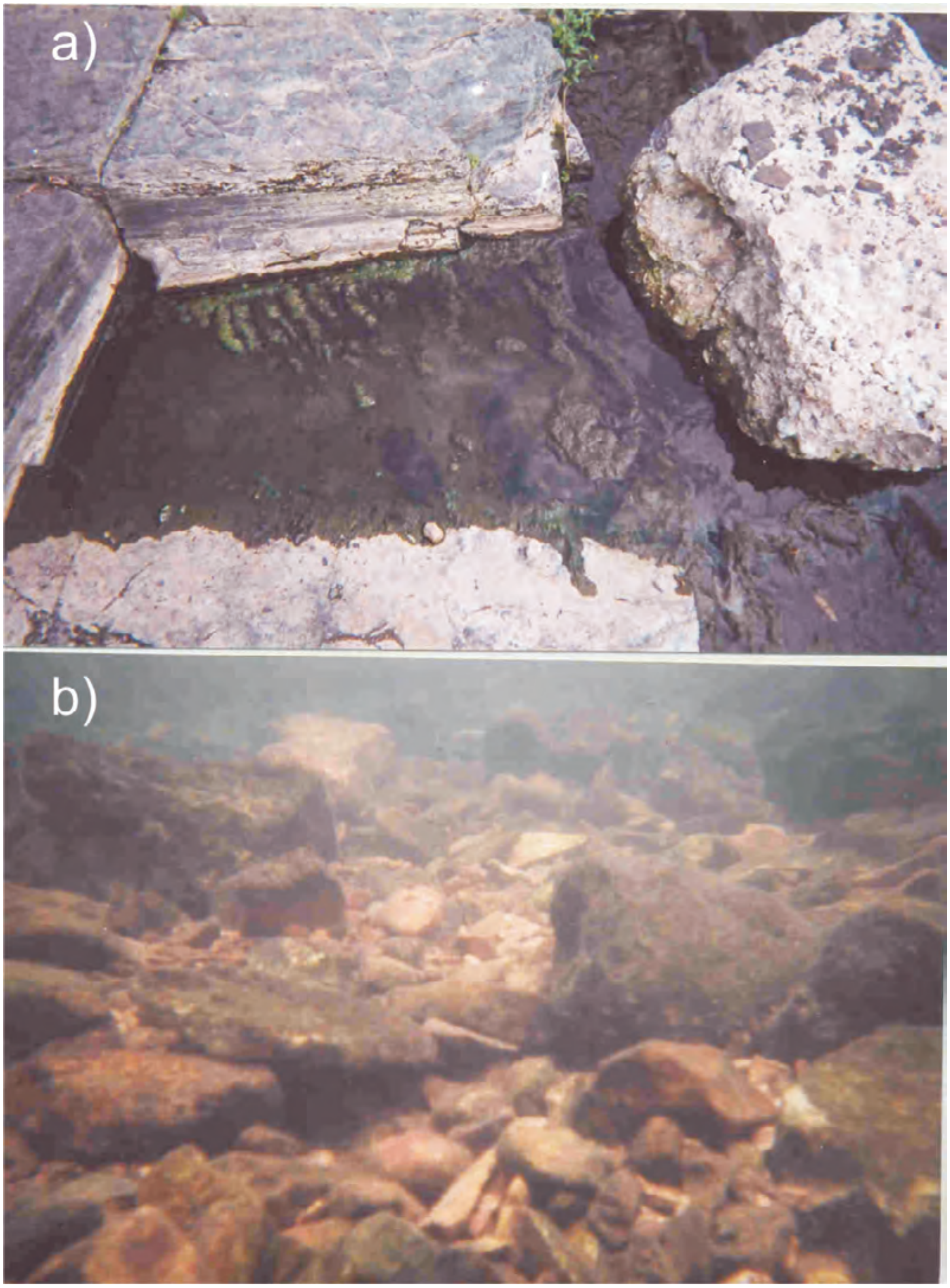


Figure 20. Filamentous periphyton algae growing on streambed rocks at a) Flint Creek north of New Hope Ranch, and b) Baron Fork near Eldon, Oklahoma (W.J. Andrews photographs U.S. Geological Survey, August 2003)..

because of flushing of sediments from the land surface by rainfall and resuspension of streambed sediments by faster-flowing water during runoff. Phosphorus typically is strongly sorbed to oxides of iron, manganese, and aluminum in soils (Van Riemsdijk and others, 1984; Hamad and others, 1992; and Hem, 1992), but that sorptive capacity for phosphorus can be overwhelmed through application of phosphorus-rich animal wastes (Siddique and Robinson, 2003). Because of relatively large phosphorus concentrations in animal wastes deposited at the land surface and sorption of phosphorus to metallic minerals in soil particles, phosphorus is transported primarily by runoff of animal wastes and soil particles on or near the land surface, as shown by increasing total phosphorus concentrations in the Illinois River with increasing suspended sediment concentrations (and greater streamflows) (fig. 24). Total phosphorus concentrations generally increased with

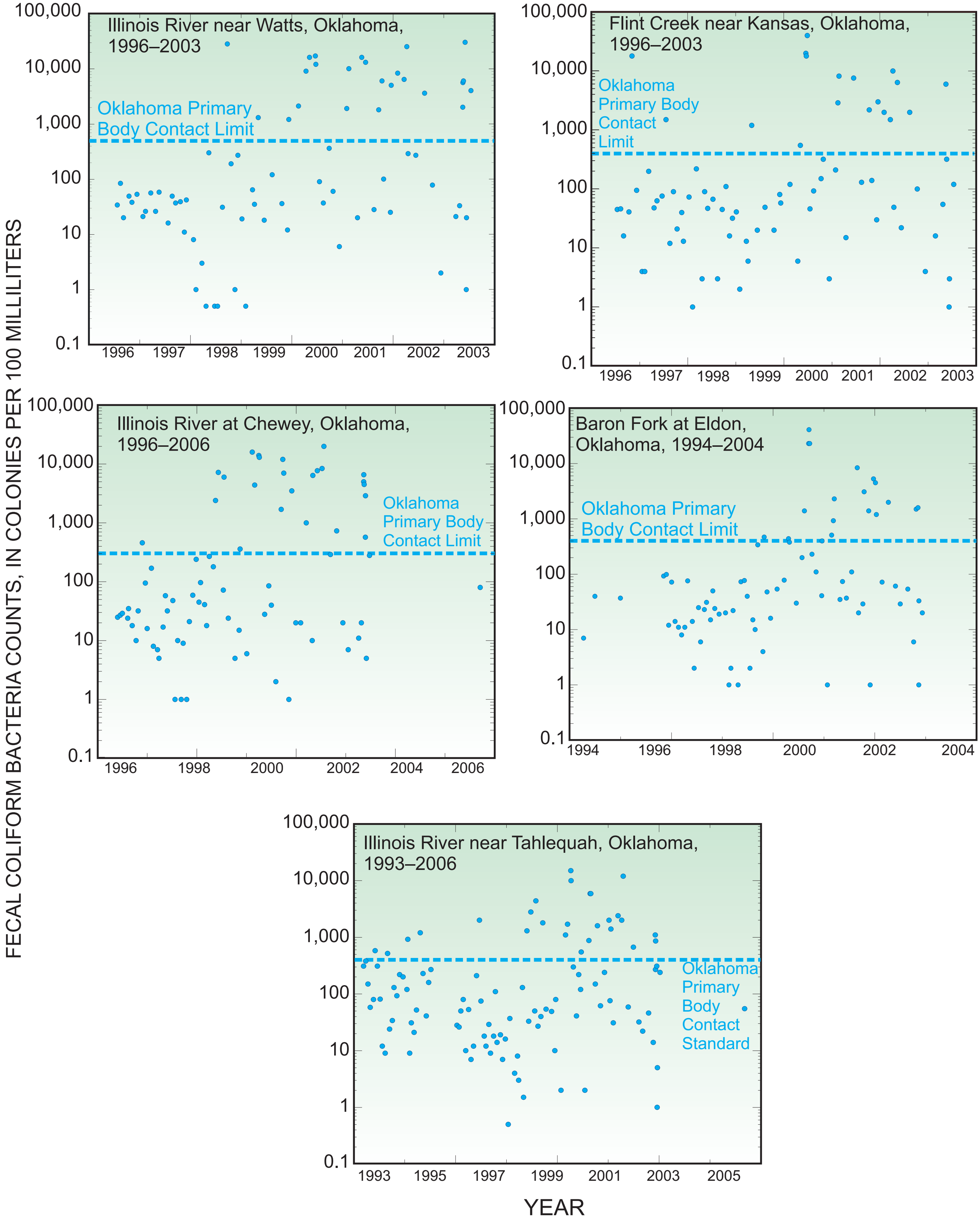


Figure 21. Fecal coliform bacteria counts with time for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

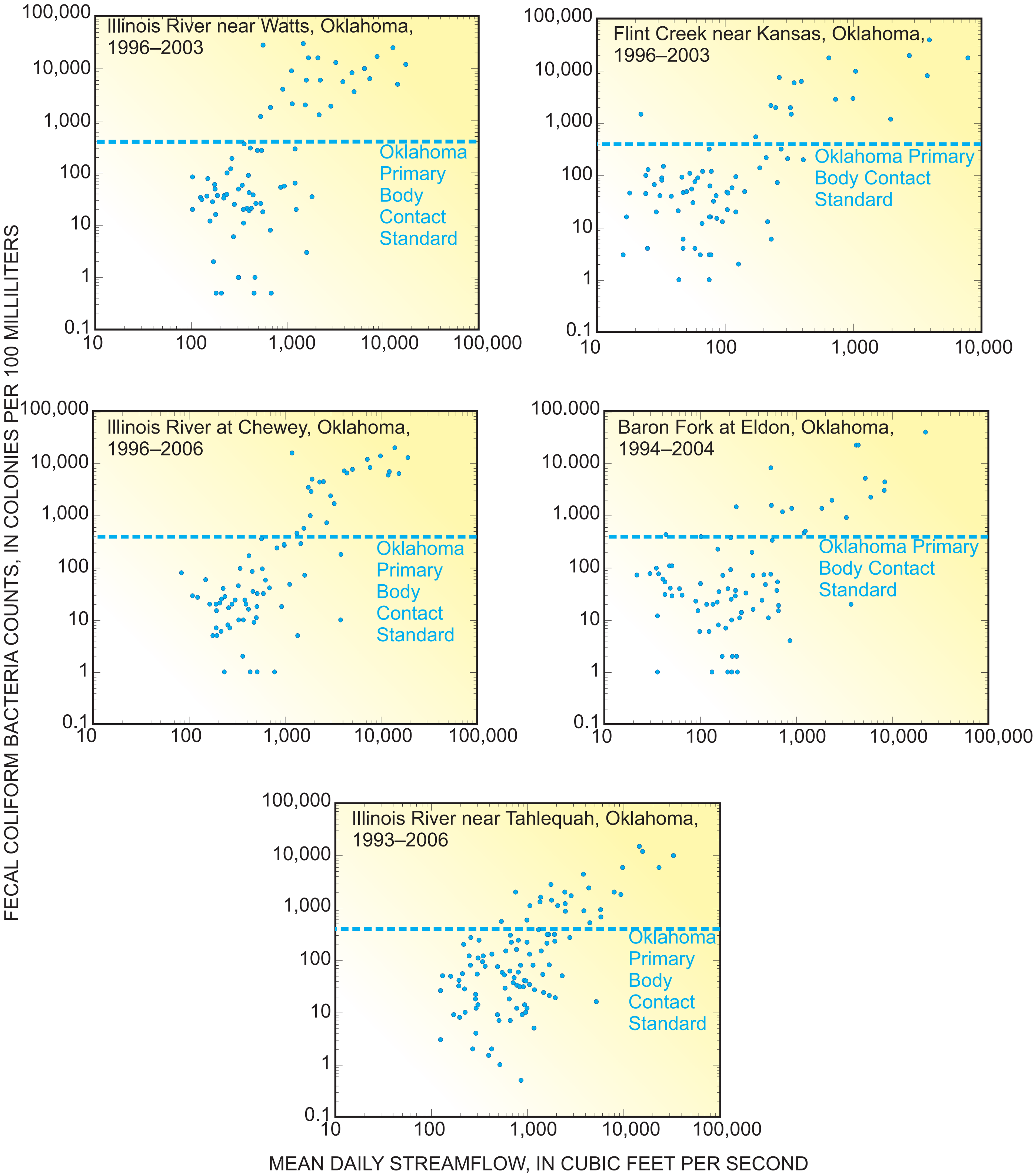


Figure 22. Fecal coliform bacteria counts compared to streamflow for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

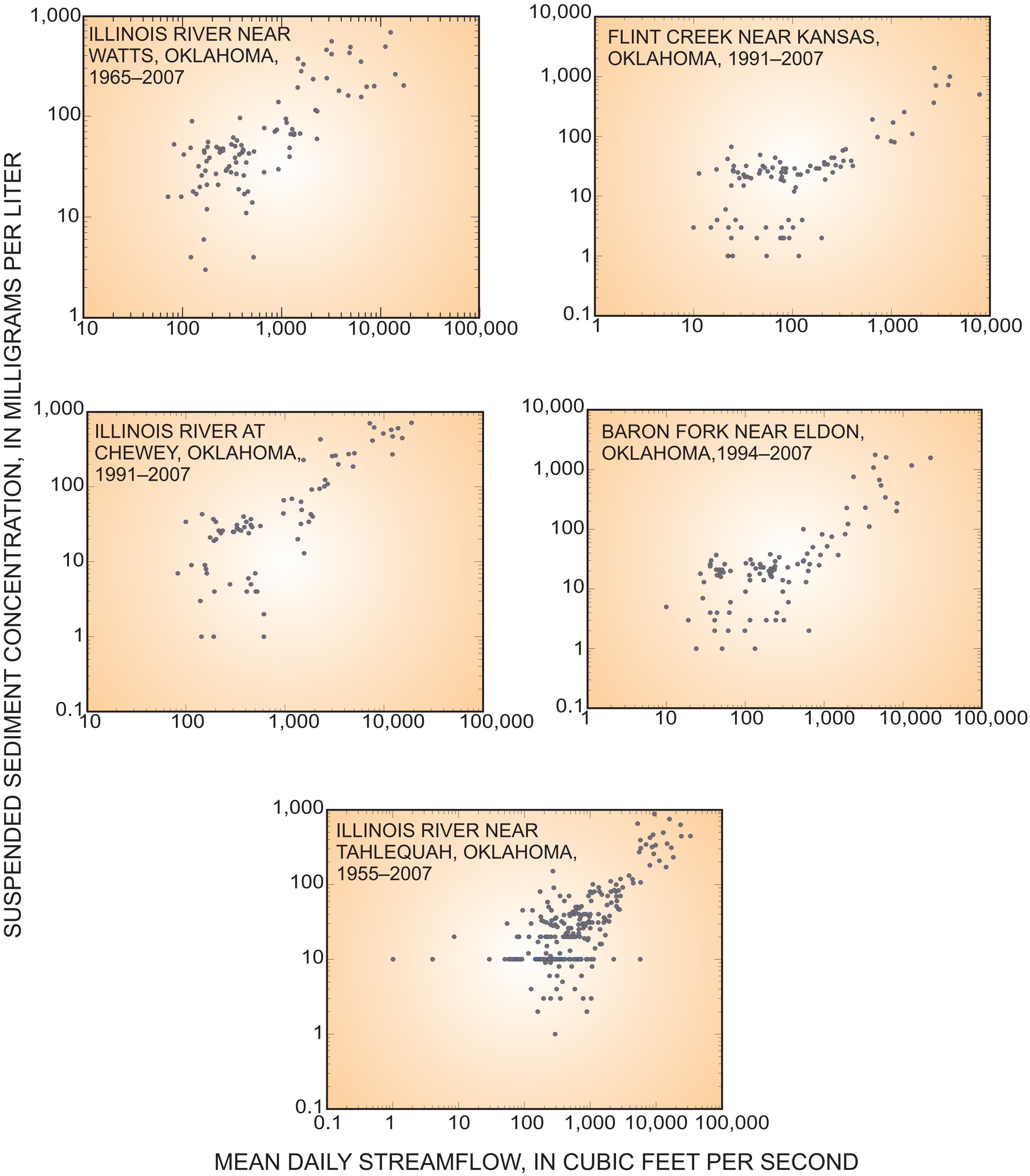


Figure 23. Suspended sediment concentration compared to mean daily streamflow for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

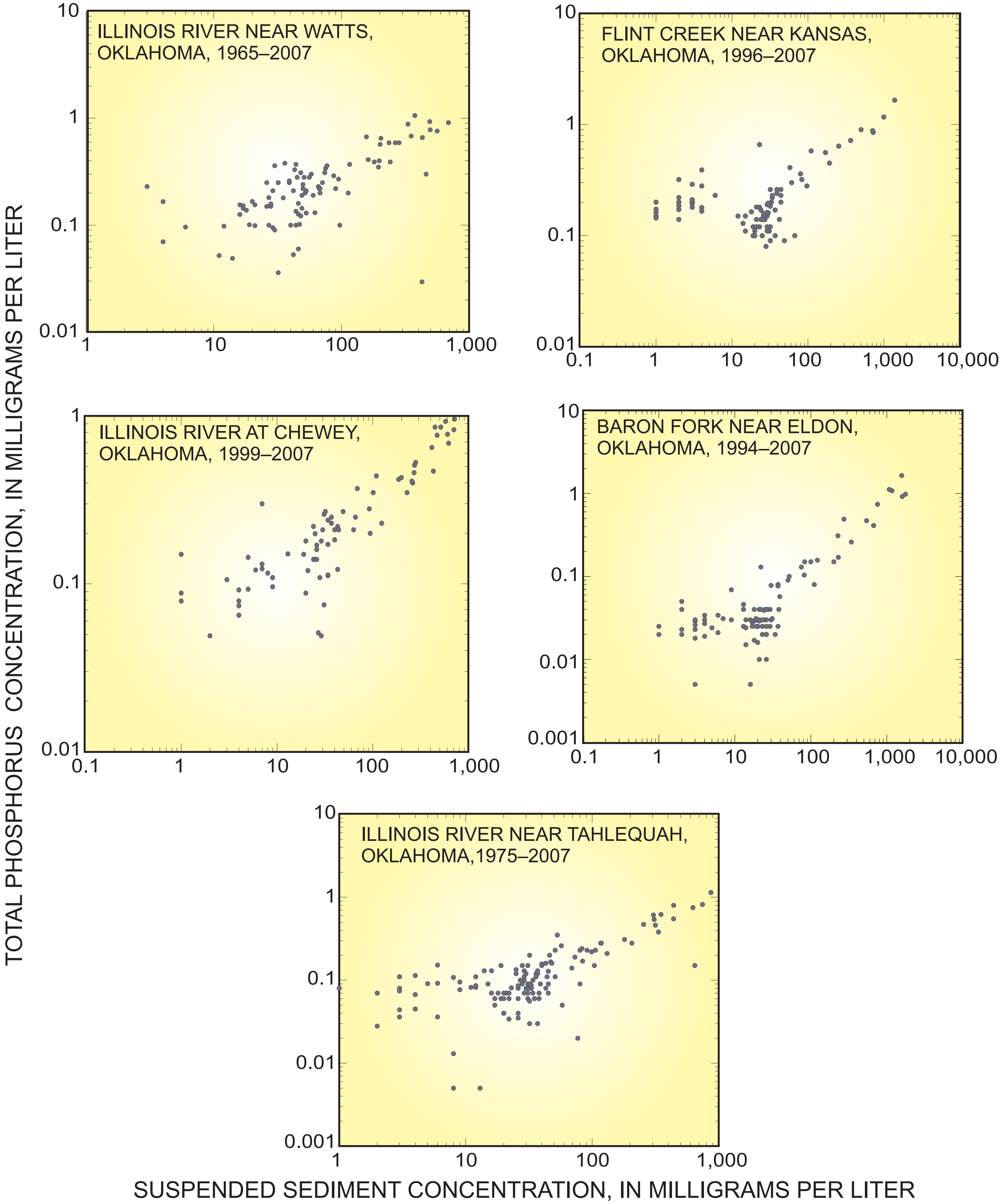


Figure 24. Suspended sediment concentration compared to total phosphorus concentration for long-term water-quality monitoring sites in the Illinois River Basin in Oklahoma.

suspended sediment concentrations greater than 20 milligrams per liter (fig. 24), corresponding to streamflows of about 150 ft^3/sec at both the Illinois River near Watts and the Illinois River near Tahlequah, Oklahoma, stations (fig. 23) These phosphorus increases indicate that higher streamflows transport most of the annual yield of sediment and phosphorus in the lower half of the Illinois River Basin.

Summary

The Illinois River Basin of northwestern Arkansas and northeastern Oklahoma is composed of 1,653 square miles of land area, about half of that is devoted to grazing of cattle and horses. Approximately 20 million birds, mostly broiler chickens, are also raised in the basin at any given time. Wastes generated by rapid growth in human populations in parts of the basin are additional potential sources of nutrients and bacteria. Those sources of nutrients and bacteria, combined with the relatively high vulnerability of water in the basin to contamination because of the karstic setting, have combined to increase contamination of local streams by nutrients, bacteria, and sediments.

Whereas the upstream half of the basin has a rapidly growing economy of livestock-based agriculture and has had rapid growth in human population because of growth of large corporate headquarters, a state university, and retirement communities, the downstream half of the basin is less intensively developed, relying on water-based recreation in scenic rivers and Lake Tenkiller as a large part of the local economy. In addition to aesthetic issues possibly reducing tourism, numerous cities, towns, and smaller entities in both states rely on surface water for drinking-water supplies, or on groundwater from wells near to streams that can be affected by degraded surface-water quality. Many streams in the area may be phosphorus-limited, meaning that relatively small additions of phosphorus may notably increase growth of algae. Phosphorus typically is sorbed to soil and sediments on streambeds, so phosphorus tends to wash into local streams or be resuspended into local water bodies in greatest amounts during storm runoff/high streamflow. Bacteria from animal wastes also tend to increase greatly in local streams during high streamflows, similarly being washed from land surfaces by rainfall.

General-water chemistry, concentrations of nitrogen and phosphorus compounds, chlorophyll-*a* (an indicator of algal biomass), and fecal-indicator bacteria generally were similar between the five sampling sites. Most water samples were phosphorus-limited, meaning that they contained a smaller proportion of phosphorus, relative to nitrogen, than typically occurs in algal tissues. Greater degrees of nitrogen limitation occurred at three of the five sites which were sampled back to the 1970s, probably due to use of detergents containing greater concentrations of phosphorus than in subsequent periods. Concentrations of nitrogen, phosphorus, and sediment, and counts of fecal-indicator bacteria generally increased with streamflow at the five sites, probably due to runoff from the land surface and re-suspension of streambed sediments. Phosphorus concentrations typically exceeded the Oklahoma standard of 0.37 milligrams per liter for Scenic Rivers. Concentrations of chlorophyll-*a* in phytoplankton in water samples collected at the five sites were not well correlated with streamflow, nor to concentrations of the nutrients nitrogen and phosphorus, probably because much of the algae growing in these streams are periphyton attached to streambed cobbles and other debris, rather than phytoplankton in the water column. Sediment concentrations correlated with phosphorus concentrations in water samples collected at the sites, probably due to sorption of phosphorus to soil particles and streambed sediments and runoff of soils and animal wastes at the land surface and resuspension of streambed sediments during high-flow periods. Fecal coliform bacteria counts at the five sites sometimes exceeded the Oklahoma Primary Body Contact Standard of 400 colonies per 100 milliliters when streamflows were greater than 1,000 cubic feet per second.

Ultimately, Lake Tenkiller receives the compounds that runoff the land surface or seep to local streams from groundwater in the basin. Lakes are more likely than streams to suffer from notable degradation by algal growth (eutrophication) because of not having sufficient flow to wash such organisms downstream. The environments of flowing streams, however, are not immune to the effects of nutrient enrichment and algal growth. Nutrient enrichment of streams or lakes can cause eutrophication that: (a) discolors and clouds water (reducing feeding of predator fish), (b) decreases dissolved oxygen concentrations in water as part of algal respiration and plant-tissue decay, (c) increases sedimentation (filling in lakes and gravel spawning beds), (d) emits organic chemicals that cause taste and odor in water and can be toxic, (e) decreases diversity of aquatic species, and (f) changes the dominant aquatic biota.

Long-term storage of phosphorus in soils in the basin and in streambed and lakebed sediments may continue to provide phosphorus to local streams for decades to come, but steps are being taken to reduce local discharges of phosphorus, including upgrades in capacity and effectiveness of municipal wastewater treatment plants, and exporting phosphorus-rich poultry litter out of the basin.

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Glossary

aquatic Life forms or substances in water.

aquifer A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield large quantities of water to wells and springs (New Mexico Office of State Engineer, 1999).

base flow Streamflow derived from ground-water seepage, synonymous with "low flow".

climate The sum total of the meteorological elements that characterize the average and extreme condition of the atmosphere during a long period of time at any one place or region of the earth's surface (Langbein and Iseri, 1960).

concentration The mass of a substance dissolved per unit volume of liquid or contained in a unit mass of solid.

conduit A natural or manmade channel through that substances can be conveyed. In the context of karstic hydrology, a conduit is a cavernous channel eroded during centuries in carbonate rocks that readily conveys groundwater at relatively rapid flow rates.

criterion A number or narrative statement assigned to protect a designated beneficial use. A water-quality standard set by the state.

cubic feet per second A unit expressing rates of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, with water flowing at an average velocity of 1 foot per second (Langbein and Iseri, 1960).

datum A point, line, or surface used as a reference, such as in surveying.

ecosystem A natural unit including all life forms and nonliving physical elements that function together.

eutrophication Nutrient enrichment (particularly of nitrogen and phosphorus) in aquatic ecosystems that leads to increased productivity, including excessive growth of algae and other aquatic plants (Graham and others, 2008). Excessive eutrophication changes aquatic habitat by changes in dissolved oxygen concentration, water temperature, availability of spawning beds, and visibility for predator fish. Aesthetic effects of hypereutrophication include degradation of water quality for swimming and other recreational activities and increases in concentrations of taste-and-odor-producing organic compounds in drinking water.

fecal-indicator bacteria Bacteria that typically are found in digestive tracts of warm-blooded animals. Large numbers of these bacteria per unit of water indicate runoff or seepage of feces into streams and lakes and greater potential for pathogenic (disease-causing) microorganisms to be detected in water.

flow-adjusted A mean concentration of a constituent in water obtained by dividing the load of a constituent flowing down a stream in a period of time divided by the total stream flow during that period of time.

gage A device used to measure and record the elevation of water in a stream or lake in a semi-continuous manner. In a flowing stream, comparisons of measured streamflows to surface-water elevations are used to estimate streamflow, commonly at 15-minute intervals.

gage height The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term stage although gage height is more appropriate when used with a reading on a gage (Langbein and Iseri, 1960).

hydrograph A graph showing stage, flow, velocity, or other properties of water with respect to time (Langbein and Iseri, 1960).

karst Topography that is formed on limestone, dolomite, gypsum beds, and other rocks by dissolution and is characterized by closed depressions, sinkholes, caves, and underground streams (modified from New Mexico Office of State Engineer, 1999).

load The mass of a substance flowing past a given point in a stream per unit of time, derived from multiplying streamflow by the aqueous concentration of a substance by unit correction factors. Loads are typically expressed in pounds or kilograms per day.

milliequivalents per Liter (meq/L) The amount of material that will release or react with a millimole of electrical charges on particles such as OH-, H+, or electrons. Milliequivalents per Liter are computed by multiplying the concentration of an ionic substance by the atomic mass of the ionic substance and the charge of the ion.

milligrams per liter (mg/L) Milligrams of a substance dissolved in one liter of water, that is the same as a part per million in freshwater because one liter of distilled water weighs one million milligrams (one kilogram). This measure is equivalent to parts per million (ppm) (Colorado Geological Survey, 2008).

molar ratio Ratio of moles of two compounds with moles being determined by dividing concentrations by the molar weight (sum of atomic weights) of a substance.

nonpoint source A source of contaminant(s) discharged over a wide land area that runs off or seeps to streams, lakes and oceans, such as runoff from streets, parking lots, lawns, agricultural land, individual septic systems, and construction sites (modified from New Mexico Office of State Engineer, 1999).

nutrient An element such as nitrogen or phosphorus needed for growth of plants and animals.

nutrient limitation A nutrient is considered to be limited if that nutrient is not available in sufficient quantities to support plant and animal growth. Additions of limited nutrients can cause rapid growth of algae and other aquatic organisms in streams and lakes.

periphyton A mixture of algae, cyanobactor, bacteria, and detritus which is attached to submerged surfaces in aquatic systems.

phytoplankton Microscopic plants, primarily algae that are suspended in the water columns of aquatic systems.

point source The source of contaminant(s) discharged from any identifiable point, including wastewater discharges from ditches, channels, sewers, tunnels and containers of various kinds (New Mexico State Office of Engineer, 2005).

precipitation Includes atmospheric hail, mist, rain, sleet and snow that descend upon the earth; the quantity of water accumulated from these events (New Mexico Office of State Engineer, 1999).

primary body contact recreation criteria Water-quality criteria set by the state to protect humans having direct body contact with the water where a possibility of ingestion exists, swimming being one example.

recharge Addition of water to an aquifer by infiltration, either directly into the aquifer or indirectly through another rock formation. Recharge may be natural, as when precipitation infiltrates to the water table, or artificial, as when water is injected through wells or spread over permeable surfaces for the purpose of recharging an aquifer (modified from New Mexico Office of State Engineer, 1999).

runoff That part of the precipitation that appears in surface streams (Langbein and Iseri, 1960).

secondary body contact recreation criteria Water-quality criteria set by the state to protect humans from having indirect body contact with the water where a possibility of ingestion exists, such as boating and fishing.

sediment Fragmented rock and organic materials that are transported by, suspended in, or deposited by water or air. Sediments tend to accumulate in horizontal layers/beds in still or slow-flowing water.

streamflow Discharge in a natural channel of a surface stream course (New Mexico Office of State Engineer, 1999).

surrogate In hydrology, a water-quality or other constituent used to predict the concentration or occurrence of another water-quality constituent.

sustainability A decision-making concept describing development that meets the needs of the present generation without compromising the ability of future generations to meet their needs (modified from New Mexico Office of State Engineer, 1999).

total nitrogen The sum of concentrations of ammonium, nitrate, nitrite, and organic forms of nitrogen, expressed as the concentration of nitrogen, in a water sample.

total phosphorus The sum of concentrations of phosphorus in the forms of orthophosphate (PO_4^{-3}), polyphosphate (phosphate polymers linked by hydroxyl (OH^-) groups and hydrogen atoms), organically bound phosphate ($OP(OR)_3$), and other forms of phosphorus, expressed as the concentration of phosphorus, in a water sample.

wastewater Water that contains dissolved or suspended solids as a result of human use (New Mexico Office of State Engineer, 1999).

wastewater treatment Processing of wastewater for the removal or reduction in the concentration of dissolved solids or other undesirable constituents (modified from New Mexico Office of State Engineer, 1999).

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