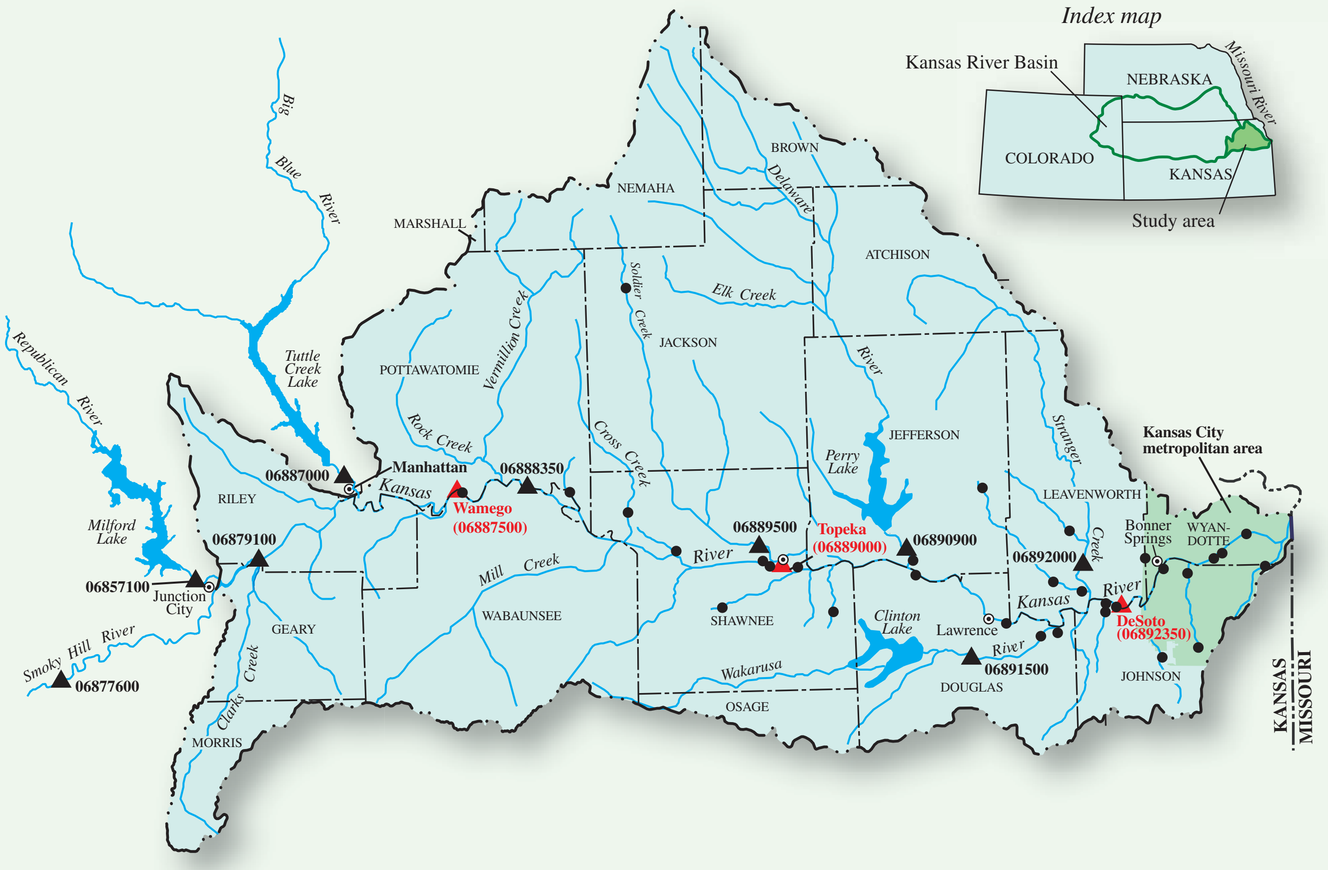
USGS
science for a changing world

Prepared in cooperation with the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

Estimation of Constituent Concentrations, Densities, Loads, and Yields in Lower Kansas River, Northeast Kansas, Using Regression Models and Continuous Water-Quality Monitoring, January 2000 Through December 2003



Scientific Investigations Report 2005–5165

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

Estimation of Constituent Concentrations, Densities, Loads, and Yields in Lower Kansas River, Northeast Kansas, Using Regression Models and Continuous Water-Quality Monitoring, January 2000 Through December 2003

By Teresa J. Rasmussen, Andrew C. Ziegler, and Patrick P. Rasmussen

Scientific Investigations Report 2005–5165

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

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

U.S. Geological Survey, Reston, Virginia: 2005

For sale by U.S. Geological Survey, Information Services
Box 25286, Denver Federal Center
Denver, CO 80225

For more information about the USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: http://www.usgs.gov/

Suggested citation:
Rasmussen, T.J., Ziegler, A.C., and Rasmussen, P.P., 2005, Estimation of constituent concentrations, densities, loads, and yields in lower Kansas River, northeast Kansas, using regression models and continuous water-quality monitoring, January 2000 through December 2003: U.S. Geological Survey Scientific Investigations Report 2005–5165, 117 p.

Back cover: Photograph showing Kansas River at DeSoto upstream from Wyandotte Street bridge, August 7, 2000 (taken by Michael Kemppainen, USGS, Lawrence, Kansas).

Prepared by the U.S. Geological Survey in Lawrence, Kansas (http://ks.water.usgs.gov)

Contents

Figures

Tables

Conversion Factors, Abbreviations, Calculation of Loads, Datums, and Definitions

Conversion Factors and Abbreviations

Multiply	By	To obtain
	Length	
feet (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
nanometer	3.937×10^{-8}	inch (in.)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Mass	
pound (lb)	453.6	gram (g)
pound per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)
pound per acre per year [(lb/acre)/yr]	1.121	kilogram per hectare per year [(kg/ha)/yr]
pound per day (lb/d)	0.4536	kilogram per day (kg/d)
ton (short)	0.9072	megagram
ton per day (ton/d)	0.0105	kilogram per second (kg/s)
ton per square mile per year [(ton/mi^2)/yr]	0.3503	tonne per square kilometer per year [(tonne/km^2)/yr]
ton per year (ton/yr)	0.9072	megagram per year (megagram/yr)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
milliliter (mL)	0.0338	ounce, fluid (oz)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
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)

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:

$$°C=(°F-32)/1.8.$$

Calculation of Loads

Multiply	By	By	To obtain
colonies per 100 milliliters (col/100 mL)	0.02447	streamflow, in ft^3/s	billion colonies per day (billion col/d)
micrograms per liter (µg/L)	0.00539	streamflow, in ft^3/s	pounds per day (lb/d)
milligrams per liter (mg/L)	5.39	streamflow, in ft^3/s	pounds per day (lb/d)

Datums

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

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

Definitions

Altitude, as used in this report, refers to distance above the vertical datum.

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

Diurnal, as used in this report, means having a daily cycle.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Water year is the 12-month period beginning October 1 and ending September 30. The water year is designated by the year in which it ends. For example, the year ending September 30, 1999, is called the "1999 water year."

Estimation of Constituent Concentrations, Densities, Loads, and Yields in Lower Kansas River, Northeast Kansas, Using Regression Models and Continuous Water-Quality Monitoring, January 2000 Through December 2003

By Teresa J. Rasmussen, Andrew C. Ziegler, and Patrick P. Rasmussen

Abstract

The lower Kansas River is an important source of drinking water for hundreds of thousands of people in northeast Kansas. Constituents of concern identified by the Kansas Department of Health and Environment (KDHE) for streams in the lower Kansas River Basin include sulfate, chloride, nutrients, atrazine, bacteria, and sediment. Real-time continuous water-quality monitors were operated at three locations along the lower Kansas River from July 1999 through September 2004 to provide in-stream measurements of specific conductance, pH, water temperature, turbidity, and dissolved oxygen and to estimate concentrations for constituents of concern. Estimates of concentration and densities were combined with streamflow to calculate constituent loads and yields from January 2000 through December 2003. The Wamego monitoring site is located 44 river miles upstream from the Topeka monitoring site, which is 65 river miles upstream from the DeSoto monitoring site, which is 18 river miles upstream from where the Kansas River flows into the Missouri River. Land use in the Kansas River Basin is dominated by grassland and cropland, and streamflow is affected substantially by reservoirs.

Water quality at the three monitoring sites varied with hydrologic conditions, season, and proximity to constituent sources. Nutrient and sediment concentrations and bacteria densities were substantially larger during periods of increased streamflow, indicating important contributions from nonpoint sources in the drainage basin.

During the study period, pH remained well above the KDHE lower criterion of 6.5 standard units at all sites in all years, but exceeded the upper criterion of 8.5 standard units annually between 2 percent of the time (Wamego in 2001) and 65 percent of the time (DeSoto in 2003). The dissolved oxygen concentration was less than the minimum aquatic-life-support criterion of 5.0 milligrams per liter less than 1 percent of the time at all sites.

Dissolved solids, a measure of the dissolved material in water, exceeded 500 milligrams per liter about one-half of the time at the three Kansas River sites. Larger dissolved-solids concentrations upstream likely were a result of water inflow from the highly mineralized Smoky Hill River that is diluted by tributary flow as it moves downstream.

Concentrations of total nitrogen and total phosphorus at the three monitoring sites exceeded the ecoregion water-quality criteria suggested by the U.S. Environmental Protection Agency during the entire study period. Median nitrogen and phosphorus concentrations were similar at all three sites, and nutrient load increased moving from the upstream to downstream sites. Total nitrogen and total phosphorus yields were nearly the same from site to site indicating that nutrient sources were evenly distributed throughout the lower Kansas River Basin. About 11 percent of the total nitrogen load and 12 percent of the total phosphorus load at DeSoto during 2000–03 originated from wastewater-treatment facilities.

Escherichia coli bacteria densities were largest at the middle site, Topeka. On average, 83 percent of the annual bacteria load at DeSoto during 2000–03 occurred during 10 percent of the time, primarily in conjunction with runoff.

The average annual sediment loads at the middle and downstream monitoring sites (Topeka and DeSoto) were nearly double those at the upstream site (Wamego). The average annual sediment yield was largest at Topeka. On average, 64 percent of the annual suspended-sediment load at DeSoto during 2000–03 occurred during 10 percent of the time. Trapping of sediment by reservoirs located on contributing tributaries decreases transport of sediment and sediment-related constituents.

The average annual suspended-sediment load in the Kansas River at DeSoto during 2000–03 was estimated at 1.66 million tons. An estimated 13 percent of this load consisted of sand-size particles, so approximately 216,000 tons of sand were transported in the water column at DeSoto during the 4-year period. This estimate does not include sand transported as bedload, the quantity of which is unknown but likely is considerably larger than sand transported as suspended load. An estimated 1.4 million tons of material (90 to 95 percent sand) were removed from the Kansas River by commercial dredging operations in 2003.

Continuous water-quality monitoring provides numerous advantages to programs dealing with total maximum daily loads over traditional water-quality studies relying on discrete sampling alone. Continuous water-quality data can be used to construct duration curves that define the magnitude and frequency of water-quality conditions and possibly to differentiate between base-flow and runoff conditions. Continuous data also can be used to identify the hydrologic and seasonal conditions during which specific impairments occur. The data also can be used to help understand and quantify variability, and to identify, monitor, and evaluate changes in conditions over time. This information is important for developing and implementing total maximum daily loads and other water-quality management plans. The continuous streamflow and water-quality data and estimated concentrations, densities, and loads are available at http://ks.water.usgs.gov/Kansas/rtqw/

Introduction

The Kansas River Basin extends 500 mi west from Kansas City, Kansas, and drains about 60,000 mi^2 of land in Colorado, Nebraska, and Kansas (fig. 1). The downstream part of the river basin (the lower Kansas River) in northeast Kansas supports an increasing population of more than 700,000 people (U.S. Census Bureau, 2002) and a wide range of agricultural and urban activities. The lower Kansas River provides drinking water for several municipalities including Manhattan, Topeka, Lawrence, and the Kansas part of the Kansas City metropolitan area.

In Kansas, 1,108 water bodies were identified as water-quality impaired in the 1998 section 303(d) list required by the 1972 amendments to the Federal Clean Water Act. Of those, 136 were located in the Kansas River Basin. Most impairments in the Kansas River Basin were caused by excessive levels of nutrients, bacteria, and sediment (Kansas Department of Health and Environment, 1998). The 2004 section 303(d) list also included impairments related to nutrients, bacteria, and sediment (Kansas Department of Health and Environment, 2004a).

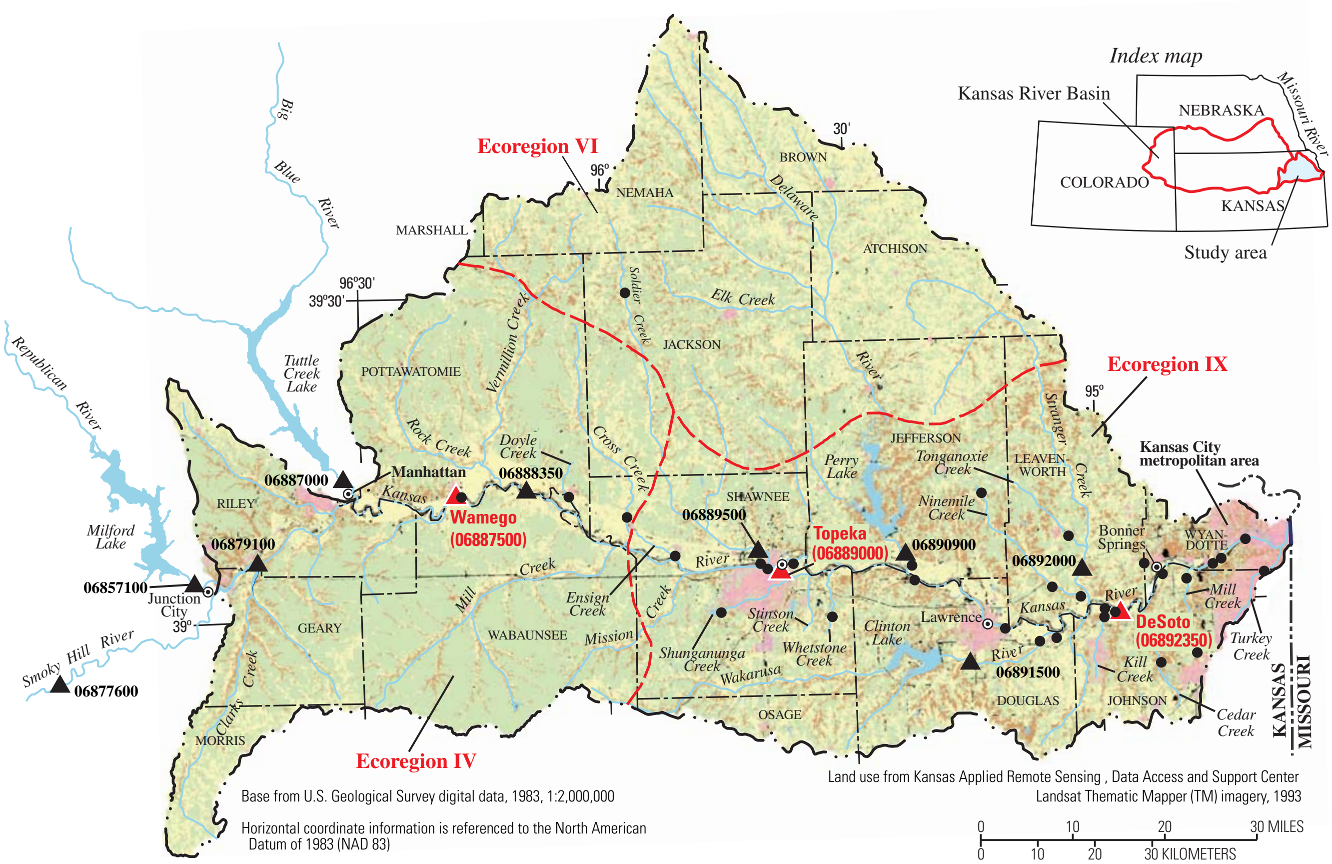
The Clean Water Act requires that States establish total maximum daily loads (TMDLs) to meet water-quality criteria and to protect designated beneficial uses for each water body (Kansas Department of Health and Environment, 2004b). A TMDL is the maximum quantity of a contaminant that a water body can receive and meet water-quality criteria. Kansas is under a consent decree requiring that TMDLs be submitted to the U.S. Environmental Protection Agency (USEPA) for all water-quality limited waters by 2006 (Kansas Department of Health and Environment, 2004b). Because of its importance for municipal water supply, recreation, and aquatic-life support, the Kansas River Basin was selected as the State's first priority among 12 major river basins for the development and implementation of TMDLs (Kansas Department of Health and Environment, 2004b). Current (2005) river segments or stream sites for the Kansas River Basin where TMDLs were developed in 1999 are listed in table 1.

In regulatory applications to achieve a given water-quality criterion, it is necessary to determine the maximum allowable constituent load from contributing sources. A constituent load is the mass or weight of a constituent compound transported in a specified unit of time from one location to another in a water body (U.S. Environmental Protection Agency, 2003a). It is the product of the volume of water (streamflow) that the constituent is using as its transport medium and the concentration or density of the constituent in the water (Rice and Izuno, 2001). Because streamflow is dynamic, the maximum allowable load varies with streamflow conditions. Most State TMDL programs, however, do not incorporate varying hydrologic conditions into load allocation calculations (Stiles, 2002). Recognizing the effect of changing streamflow on loads, Kansas developed a TMDL calculation method that combines streamflow duration information with water-quality criterion, resulting in load allocations that change with varying streamflow conditions (Stiles, 2002).

Nutrient enrichment has been identified as one of the leading causes of impairment for rivers and streams in Kansas (U.S. Environmental Protection Agency, 2005). In 2001, USEPA published ecoregion nutrient criteria for specified geographic regions of the United States with the expectation that States would adopt nutrient criteria by the end of 2004 (U.S. Environmental Protection Agency, 2003b). However, in 2002 USEPA withdrew its requirement for nutrient criteria to be adopted in 2004 and instead encouraged nutrient management plans be submitted. In 2004, KDHE submitted the Surface Water Nutrient Reduction Plan, which describes strategies for reducing nutrient levels by establishing fixed reduction targets in lieu of criteria (Kansas Department of Health and Environment, 2004d).

Several water-quality studies have been conducted during the past 50 years on the Kansas River, including Angino and O'Brien (1968), McClelland (1974), Jordan and Stamer (1995), and Helgesen (1996). These studies were intended to describe general water-quality characteristics rather than constituent load. All of the previous studies used approaches that relied extensively on discrete water-sampling methods. Although discrete samples are valuable for determining instantaneous constituent concentrations, they may not accurately describe daily, monthly, or annual variability in loading characteristics because concentration, density, and streamflow can fluctuate substantially between samples. Discrete samples provide information about concentrations and densities at the precise time the samples were collected but provide no information about concentrations and densities between samples.

A system for continuously monitoring water-quality constituents has numerous advantages over traditional water-quality studies relying on sampling alone. TMDL programs can benefit from continuous data because they provide the foundation for a more comprehensive evaluation of the variability in loading characteristics and water-quality degradation than provided by discrete water-quality samples. For TMDLs, the data can be used to identify impairments, to define contributing factors such as hydrology, season, and sources, to evaluate goals, and to monitor changes. Continuous concentration or



EXPLANATION

Land use

- Cropland
- Grassland
- Woodland
- Residential
- Commercial
- Water
- Other

Boundary of lower Kansas River Basin in Kansas

Boundary of ecoregion—From U.S. Environmental Protection Agency (2003b)

Wamego (06887500) **U.S. Geological Survey streamflow-gaging station with continuous water-quality monitor**—Number in parentheses ( ) is station number

06877600 **U.S. Geological Survey streamflow-gaging station and number**

Municipal and (or) industrial wastewater discharge site—From M.B. Tate, Kansas Department of Health and Environment, written commun. (2004)

Figure 1. Location of Kansas River Basin, U.S. Geological Survey streamflow-gaging stations, continuous water-quality monitors, wastewater discharge sites, and 1993 land use in lower Kansas River Basin, northeast Kansas.

density estimates can be used to construct cumulative frequency distribution (duration) curves to determine percentage of time that estimated concentrations or densities exceed water-quality criteria. Estimated concentration, density, and load duration curves can be used to evaluate current water-quality conditions and estimate the duration and magnitude of potential water-quality degradation. Duration curves also can be used to differentiate between base-flow and runoff conditions. Examination of differences in regression-estimated concentrations, densities, and loads at a series of sensor stations along a stream allows the analysis of upstream-to-downstream changes in water quality.

In situations where discrete samples and constituent concentration or density data are necessary for regulatory requirements, monitoring by continuous sensor data allows regulatory agencies to optimize sampling efforts. In some cases it may be more cost effective to use continuous monitors for critical constituent monitoring rather than intensive discrete sampling. When continuous estimates are considered over the long term, it may be possible to identify changes in water-quality conditions resulting from land-use changes and implementation of best-management practices in the watershed.

Table 1. Kansas River segments or sites for which total maximum daily loads (TMDLs) were developed in 1999.

[Information from Kansas Department of Health and Environment (2004b; 2004c)]

River segment or site	Water-quality impairment	Implementation priority
[1]Upper Kansas River	Fecal coliform bacteria	Medium
	Chloride	Low
	Sulfate	Low
[2]Kansas River near Wamego	Fecal coliform bacteria	Medium
[3]Kansas River at Topeka	Fecal coliform bacteria	Medium
	Ammonia	High
[4]Kansas River below Topeka	Nutrients, biological oxygen demand	Low
[5]Kansas River at Lawrence	Fecal coliform bacteria	Medium
	Ammonia	Addressed with permit
	Nutrients, biological oxygen demand	Medium
	Chlordane	Low
[6]Lower Kansas River	Fecal coliform bacteria	Medium
	Nutrients, biological oxygen demand	Medium
	Sediment, biological impact	Medium
	Chlordane	Low

[1]Upper Kansas River includes the Kansas River from Junction City to the confluence with the Big Blue River.

[2]Kansas River near Wamego includes the Kansas River from the confluence with the Big Blue River to the confluence with Vermillion Creek.

[3]Kansas River at Topeka incudes the Kansas River from the confluence with Mission Creek to the confluence with Soldier Creek.

[4]Kansas River below Topeka includes the Kansas River from the confluence with Soldier Creek to the confluence with the Delaware River.

[5]Kansas River at Lawrence includes the Kansas River from the confluence with the Delaware River to the confluence with the Wakarusa River.

[6]Lower Kansas River includes the Kansas River from the confluence with the Wakarusa River to the confluence with the Missouri River.

The U.S. Geological Survey (USGS) has been collecting streamflow data in Kansas for more than 100 years (Perry, 2000). Limited continuous water-quality data for specific conductance, pH, water temperature, and dissolved oxygen have been available since the 1960s (Albert, 1964). Albert (1964) used continuous specific conductance and temperature data to estimate chloride concentrations and loads in the Little Arkansas River Basin in south-central Kansas during 1959–60. Recent technological developments have made it possible to continuously measure additional water properties, most notably turbidity.

In July 1999, USGS and the Kansas Department of Health and Environment (KDHE) with assistance from the U.S. Environmental Protection Agency (USEPA) began a cooperative effort to describe water quality and transport in the lower Kansas Basin. Continuous monitoring of water-quality conditions was used in this study to capture the daily and seasonal variability that may be overlooked using discrete samples alone. Describing the variability is important to TMDL programs because it lends a better understanding of the processes that determine water-quality conditions.

Purpose and Scope

The purpose of this report is to describe water-quality conditions in the lower Kansas River Basin in northeast Kansas using continuous in-stream sensor measurements. Specific conductance, pH, water temperature, turbidity, and dissolved oxygen were monitored at three different locations in the lower Kansas River from July 1999 through September 2004. The continuous measurements were used in conjunction with discrete water samples to develop regression models that then were used to estimate concentrations, densities, loads, and yields of selected constituents. Continuous regression-based concentrations or densities, were estimated for selected major ions, dissolved solids, suspended solids, nutrients (phosphorus and nitrogen species), sediment, and bacteria (*Escherichia coli*, fecal coliform, and enterococci), and triazine herbicides (atrazine). Continuous daily, monthly, seasonal, and annual loads were calculated from concentration or density estimates and streamflow. Although data collection started in 1999 and continued into 2004, most of the data summaries presented in this report are for complete years of data, including 2000, 2001, 2002, and 2003. The continuous streamflow and water-quality data, and estimated concentrations, densities, and loads are available at http://ks.water.usgs.gov/Kansas/rtqw/

The data are used to describe differences in concentrations, densities, loads, and yields during the 4-year period and to characterize these differences relative to known hydrologic conditions, contributing drainage area, constituent sources, and human activity. The results presented in this report may be used to better understand concentration, density, and load fluctuations during changing seasonal and flow conditions, to optimize manual collection of water samples, and to evaluate current or proposed water-quality criteria. Similar techniques may be useful in other river basins throughout the Nation.

Description of Study Area

The Kansas River is formed by the confluence of the Smoky Hill and Republican Rivers near Junction City, Kansas (fig. 1). From there it flows 170 river miles east to the Missouri River in Kansas City, Kansas. Mean annual precipitation varies from 32 in. in the western part to 40 in. in the eastern part of the study area (Daly and others, 1997). Eighteen Federal reservoirs impound water on all the major tributaries of the Kansas River, controlling 85 percent of the drainage area (Perry, 1994).

The mean streamflow rate of the Kansas River at DeSoto (station 06892350, fig. 1), the downstream-most monitoring location on the Kansas River, for water years 1999–2003 (October 1, 1999, through September 30, 2003), which generally coincides with the study period, was about 6,500 ft^3/s (table 2) and is slightly less than the historic mean of about 7,400 ft^3/s on the basis of data collected from 1918 to 2003 (Putnam and Schneider, 2004). Of the total flow at DeSoto during the 5-year period (1999–2003), the largest contribution (29 percent) came from the Big Blue River after discharge from Tuttle Creek Lake. The next largest flow contribution (18 percent) came from the Smoky Hill River. The Delaware River downstream from Perry Lake contributed 10 percent, the Republican River downstream from Milford Lake contributed 8 percent, and the Wakarusa River downstream from Clinton Lake contributed 4 percent of the streamflow at DeSoto. The remaining 31 percent came from combined miscellaneous sources including tributaries (including Vermillion, Mill, Soldier, and Stranger Creeks), direct rainfall and runoff, and ground-water contributions. There are no reservoirs on tributaries between Wamego and Topeka; therefore, all reservoir contributions to Kansas River flow at Topeka originate upstream from Wamego.

Typically, reservoirs change streamflow regimes by reducing the magnitude of peak flows and increasing the magnitude of low flows (Williams and Wolman, 1984). Transport of constituents through regulated river systems is affected by interaction between the chemistry of the inflowing water and processes occurring within the reservoir (Thornton and others, 1990). Sites located upstream from reservoirs may have characteristic and distinct chemical signatures, whereas chemical passage through the reservoirs acts to merge and collapse the individual signatures (Kelly, 2001). Reservoirs serve as repositories, or sinks, for contaminants such as nutrients, pesticides, and sediment-associated contaminants (U.S. Environmental Protection Agency, 1984; Humenik and others, 1987). Although most of the sediment entering reservoirs is permanently trapped and deposited on the bottom, chemicals such as soluble herbicides remain in the water column and are stored temporarily until flushed from the reservoir which results in smaller peak concentrations that can persist for much longer periods (Stamer and others, 1998).

According to 1993 data, land use in the lower Kansas River Basin was about 56 percent grassland, 30 percent cropland, 8 percent woodland, and 2 percent urban (fig. 1). Although urban development represents a very small fraction of the total basin land use, major urban and industrial areas are located along the river at Manhattan, Topeka, Lawrence, and Kansas City, Kansas. All of these cities, in addition to many smaller communities, use water from the Kansas River for municipal water supply. Potential point sources of contamination in the Kansas River Basin upstream from DeSoto include 30 municipal and industrial wastewater discharges, 22 of which are downstream from Manhattan and have a combined design outflow of 90 Mgal/d (139 ft^3/s) (Mike Tate, KDHE, written commun., 2004), and livestock operations (poultry, swine, and beef). Potential nonpoint sources of contamination include agricultural and urban runoff and seepage from onsite waste systems (septic systems). Both point and nonpoint sources can contribute nutrients, bacteria, sediment, and other constituents to the river.

Kansas River channel degradation (lowering of the streambed) and associated bank erosion has been a growing concern because of secondary impacts such as lowering of water-surface elevations in the river and alluvial aquifer, alteration of aquatic and terrestrial habitat, and reduction in the integrity of man-made structures (Kansas Water Office, 2005). The four primary causes of channel degradation in the Kansas River are long-term natural processes, commercial sand and gravel dredging, reservoir operations, and channel degradation of the Missouri River (Kansas Water Office, 2005).

The Kansas River is an important source of sand and gravel for the Kansas City metropolitan area and other communities along the river (U.S. Army Corps of Engineers, 1990). Dredging operations, primarily hydraulic extraction from the river channel, rely on natural river dynamics to maintain a constantly renewing source of minable materials. Dredging in the Kansas River is regulated by the U.S. Army Corps of Engineers and the Kansas Department of Agriculture, Division of Water Resources. During the 4-year period from 1984 through 1987, 14.9 million tons (an average of 3.7 million tons annually) of dredging materials were removed from the Kansas River (U.S. Army Corps of Engineers, 1990). The U.S. Army Corps of Engineers began limiting dredging activities in the early 1990s after concluding that commercial dredging activities on the Kansas River were a major factor affecting riverbed degradation, bank erosion, channel widening, natural resource losses, and damages to nondredging interests (U.S. Army Corps of Engineers, 1990). In 2003, 1.4 million tons of dredging material were removed from the Kansas River (Josh Marx, U.S. Army Corps of Engineers, Kansas City District, oral commun., June 2005).

Table 2. Tributary streamflow information for lower Kansas River Basin in northeast Kansas through water year 2003.

[Data from Putnam and Schneider (2004). ft^3/s, cubic feet per second]

Main-stem station name Tributary station name	Station number (fig. 1)	Mean annual streamflow (ft^3/s), by water year						Historic streamflow (ft^3/s)	
		1999	2000	2001	2002	2003	5-year mean	Mean	Beginning of record (water year)
Republican River below Milford Dam	06857100	1,246	237	587	332	82	497	908	1968
Smoky Hill River at Enterprise	06877600	2,978	998	1,230	400	380	1,197	1,591	1935
Kansas River at Fort Riley	06879100	5,228	1,342	1,989	843	515	1,983	2,790	1965
Big Blue River near Manhattan (below Tuttle Creek Lake)	06887000	3,909	1,114	2,732	1,017	836	1,922	2,423	1963
Kansas River at Wamego	06887500	9,982	2,596	4,831	2,052	1,405	4,173	5,164	1920
Kansas River near Belvue	06888350	10,870	2,702	5,173	2,180	1,385	4,462	6,570	1983
Kansas River at Topeka	06889000	11,850	2,638	5,520	2,203	1,518	4,746	5,808	1918
Soldier Creek near Topeka	06889500	458	64	175	64	35	159	156	1936
Delaware River below Perry Dam	06890900	1,781	158	1,018	317	42	663	704	1970
Wakarusa River near Lawrence	06891500	728	48	215	157	21	234	249	1978
Stranger Creek near Tonganoxie	06892000	674	67	495	115	33	277	249	1930
Kansas River at DeSoto	06892350	16,680	3,249	7,823	3,057	1,824	6,527	7,410	1918

Main-stem station name Tributary station name	Station number (fig. 1)	Percentage of mean annual streamflow of Kansas River at DeSoto by water year						Percentage of historic streamflow	
		1999	2000	2001	2002	2003	5-year mean	Mean	Beginning of record (water year)
Republican River below Milford Dam	06857100	7	7	8	11	4	8	12	1968
Smoky Hill River at Enterprise	06877600	18	31	16	13	21	18	21	1935
Kansas River at Fort Riley	06879100	31	41	25	28	28	30	38	1965
Big Blue River near Manhattan (below Tuttle Creek Lake)	06887000	23	34	35	33	46	29	33	1963
Kansas River at Wamego	06887500	60	80	62	67	77	64	70	1920
Kansas River near Belvue	06888350	65	83	66	71	76	68	89	1983
Kansas River at Topeka	06889000	71	81	71	72	83	73	78	1918
Soldier Creek near Topeka	06889500	3	2	2	2	2	2	2	1936
Delaware River below Perry Dam	06890900	11	5	13	10	2	10	10	1970
Wakarusa River near Lawrence	06891500	4	1	3	5	1	4	3	1978
Stranger Creek near Tonganoxie	06892000	4	2	6	4	2	4	3	1930
Kansas River at DeSoto	06892350	100	100	100	100	100	100	100	1918

Landforms in the lower Kansas River Basin are characterized by two dominant physiographic regions (fig. 2). The Glaciated Region, north of the Kansas River, consists of deposits of glacial till composed of silt, clay, sand, gravel, and boulders that overlie bedrock of primarily shale and limestone, with some sandstone. South of the Kansas River, which represents the southern boundary of glaciation, are the Osage Cuestas and the Flint Hills Uplands. Nearly all soils in the lower Kansas River Basin are prone to erosion, but the hilly topography combined with the larger quantities of precipitation in the eastern part of the basin create conditions especially favorable for erosion (Jordan and Stamer, 1995; Helgesen, 1996).

Water-Quality Standards

The Clean Water Act of 1972 established the foundation for all States to develop water-quality protection programs (U.S. Environmental Protection Agency, 1972). Water-quality standards, which include designated uses, water-quality criteria, and antidegradation requirements, are established by States and approved by USEPA. Criteria are developed to protect the designated uses and can be either numeric or narrative. Table 3 contains relevant water-quality criteria used to help describe water-quality conditions in the Kansas River during this study. In addition to criteria established by KDHE, the table includes criteria recommended or suggested by USEPA that are not

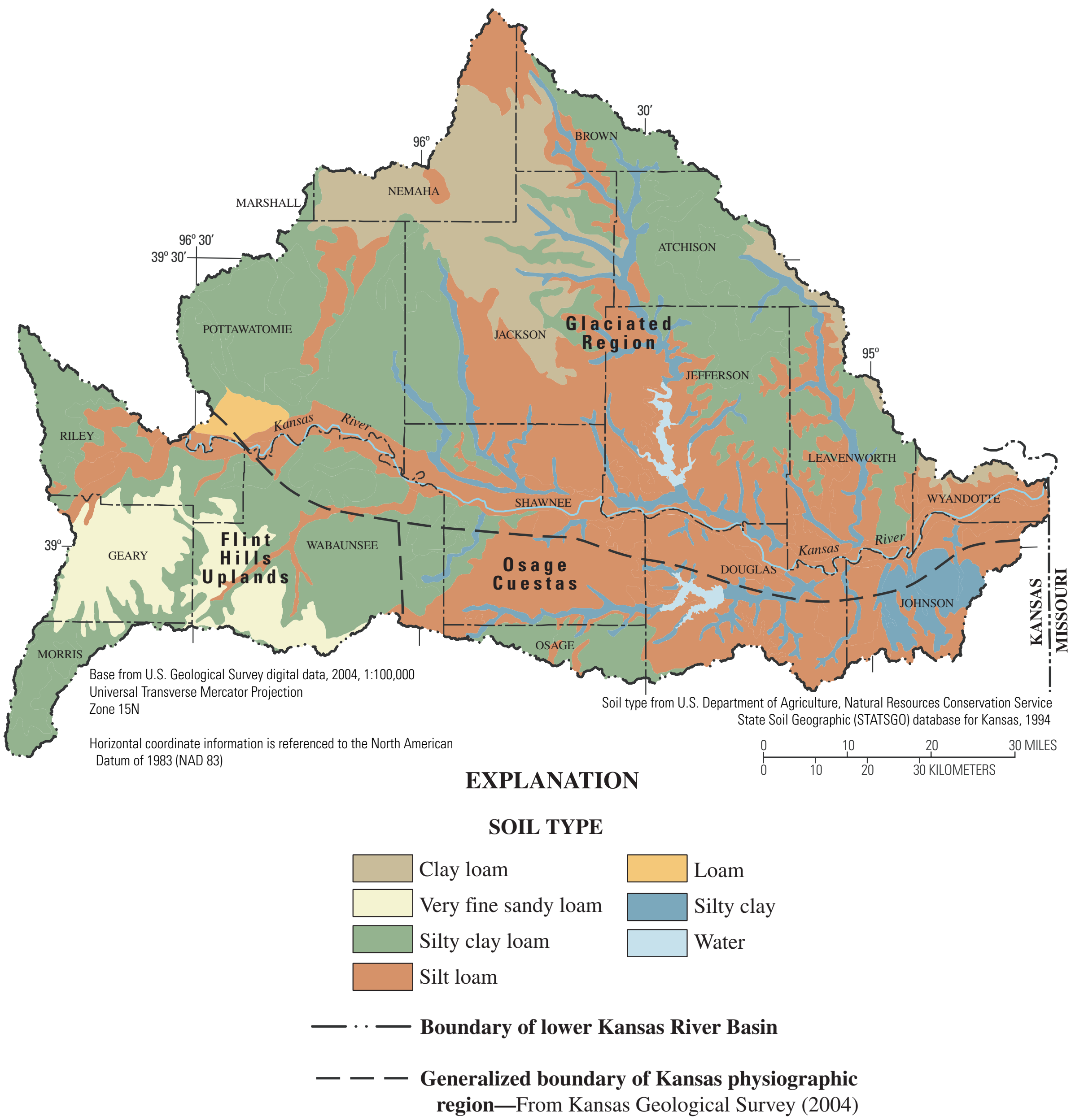


Figure 2. Soil types in lower Kansas River Basin.

Table 3. Water-quality constituents and criteria used to describe water-quality conditions in the lower Kansas River, northeast Kansas.

[mg/L, milligrams per liter or parts per million; col/100 mL, colonies per 100 milliliters of water; µg/L, micrograms per liter or parts per billion; FNU, formazin nephelometric turbidity units; USEPA, U.S. Environmental Protection Agency; SDWR, Secondary Drinking-Water Regulation (nonenforceable); KDHE, Kansas Department of Health and Environment; MCL, Maximum Contaminant Level (enforceable); ^{o}C, degrees Celsius; ^{o}F, degrees Fahrenheit]

Constituent (abbreviation)	Criteria	Criteria description and source
Specific conductance (SC)	none	Useful indicator for dissolved substances in water for chemical treatment.
pH	not less than 6.5 and not more than 8.5 standard units	Aquatic-life-support use criteria (KDHE, 2003).
Water temperature (WT)	Narrative criteria	A discharge from an artificial source shall not elevate the temperature above 32 ^{o}C (90 ^{o}F) and not raise the temperature more than 3 ^{o}C above natural conditions. Useful to determine chemical treatment of drinking water (KDHE, 2003).
Turbidity (FNU)	4.21 FNU	Proposed nutrient criterion for streams in Ecoregion IV (USEPA, 2003b).
	5.70 FNU	Proposed nutrient criterion for streams in Ecoregion IX (USEPA, 2003b).
Dissolved oxygen (DO)	not less than 5.0 mg/L	Aquatic-life-support use criterion (KDHE, 2003).
Hardness ($CaCO_3$)	none	No numeric criterion developed. Information is useful for water treatment.
Alkalinity (Alk)	none	No numeric criterion developed. Information is useful for water treatment.
Dissolved solids (DS)	500 mg/L	SDWR[1] for finished drinking water (USEPA, 2003c).
Calcium (Ca)	none	No numeric criterion developed. Information is useful for water treatment.
Sodium (Na)	20 mg/L	Nonenforceable advisory level for persons on low sodium diets; taste threshold of 30–60 mg/L (USEPA, 2003c).
Bicarbonate (HCO_3)	none	No numeric criterion developed. Information is useful for water treatment.
Sulfate (SO_4)	250 mg/L	SDWR[1] for finished drinking water (USEPA, 2003c).
	1,000 mg/L	Livestock watering criterion (KDHE, 2003).
Chloride (Cl)	250 mg/L	SDWR[1] for finished drinking water (USEPA, 2003c).
	860 mg/L	Acute aquatic-life criterion (KDHE, 2003).
Fluoride (F)	4.0 mg/L	MCL[2] for fluoride in finished drinking water (USEPA, 2003c).
	1.0 mg/L	Irrigation criterion (KDHE, 2003).
	2.0 mg/L	Livestock watering criterion and domestic water supply (KDHE, 2003).
Total nitrogen (TN)	0.56 mg/L as nitrogen	Suggested nutrient criterion for streams in Ecoregion IV (USEPA, 2003b).
	0.69 mg/L as nitrogen	Suggested nutrient criterion for streams in Ecoregion IX (USEPA, 2003b).
Total phosphorus (TP)	0.023 mg/L as phosphorus	Proposed nutrient criterion for streams in Ecoregion IV (USEPA, 2003b).
	0.0366 mg/L as phosphorus	Proposed nutrient criterion for streams in Ecoregion IX (USEPA, 2003b).
Boron (B)	0.75 mg/L	Irrigation criterion (KDHE, 2003).
	5.0 mg/L	Livestock watering criterion (KDHE, 2003).
Atrazine (Atr)	3.0 µg/L	MCL[2] for atrazine in finished drinking water as an annual average (USEPA, 2003c) and KDHE chronic aquatic-life criterion for atrazine (KDHE, 2003).
	170 µg/L	Acute aquatic-life criterion (KDHE, 2003).

Table 3. Water-quality constituents and criteria used to describe water-quality conditions in the lower Kansas River, northeast Kansas.—Continued

[mg/L, milligrams per liter or parts per million; col/100 mL, colonies per 100 milliliters of water; µg/L, micrograms per liter or parts per billion; FNU, formazin nephelometric turbidity units; USEPA, U.S. Environmental Protection Agency; SDWR[1], Secondary Drinking-Water Regulation (nonenforceable); KDHE, Kansas Department of Health and Environment; MCL[2], Maximum Contaminant Level (enforceable); °C, degrees Celsius; °F, degrees Fahrenheit]

Constituent (abbreviation)	Criteria	Criteria description and source
Escherichia coli bacteria (ECB)	160 col/100 mL	Primary contact (swimming in swim beach) recreation criterion from April through October for a geometric mean of at least five samples in 30-day period (KDHE, 2003).
	262 col/100 mL	Primary contact (swimming in public water or public access) recreation criterion from April through October for a geometric mean of at least five samples in 30-day period (KDHE, 2003).
	427 col/100 mL	Primary contact (swimming in private water, no access) recreation criterion from April through October for a geometric mean of at least five samples in 30-day period (KDHE, 2003).
	2,358 col/100 mL	Primary contact (swimming in swim beach, public-water or public access) recreation criterion from November through March for a geometric mean of at least five samples in 30-day period (KDHE, 2003).
	3,843 col/100 mL	Primary contact (swimming in private water, no access) recreation criterion from November through March for a geometric mean of at least five samples in 30-day period (KDHE, 2003).
	2,358 col/100 mL	Secondary contact (wading in public water or public access) recreation criterion at any time during the year for a geometric mean of at least five samples in a 30-day period (KDHE, 2003).
	3,843 col/100 mL	Secondary contact (wading in private water, no access) recreation criterion at any time during the year for a geometric mean of at least five samples in a 30-day period (KDHE, 2003).
Fecal coliform bacteria (FCB)	200 col/100 mL	Prior to 2003, primary contact (boating and swimming) recreation criterion during the spring, summer, and fall (April 1 through October 31 each year) for a geometric mean of five samples collected over a 30-day period (KDHE, 2001).
	2,000 col/100 mL	Prior to 2003, primary contact (boating and swimming) recreation criterion during the winter (November 1–March 31) for any single sample (KDHE, 2001).
	2,000 col/100 mL	Prior to 2003, secondary contact (wading and fishing) recreation criterion at any time during the year for a single sample (KDHE, 2001).
Suspended-sediment concentration (SSC)	Narrative criteria	Suspended solids added by artificial sources shall not interfere with aquatic life (KDHE, 2003).
Total suspended solids (TSS)	Narrative criteria	Suspended solids added by artificial sources shall not interfere with aquatic life (KDHE, 2003).

[1]SDWRs are nonenforceable criteria for drinking water promulgated by USEPA and the States. The criteria values are set for aesthetic reasons. For example, concentrations of chloride that exceed 250 mg/L may add a salty taste to the water, and sulfate concentrations exceeding 250 mg/L may have laxative effects when consumed.

[2]MCLs are enforceable criteria for drinking water promulgated by USEPA and the States. The criteria are assigned at levels where there is a known adverse effect on humans consuming water exceeding the criteria values.

enforceable. Maximum Contaminant Levels (MCLs) and Secondary Drinking-Water Regulations (SDWRs) apply to finished drinking water rather than to untreated surface water. However, they are included when no other criteria exist as a means of comparison.

Previous Studies

Because of its historical, economic, and ecological value, the Kansas River has been the subject of several studies for a variety of purposes. Various studies have evaluated water-quality conditions and trends, flooding characteristics, geomorphology, effects of dredging, and the effects of urbanization (Jordan and Stamer, 1995; Pope, 1995; Helgesen, 1996; Pope and Putnam, 1997; Rasmussen and Ziegler, 2003). Water-quality studies have investigated dissolved solids, major ions, nutrients, metals and trace elements, radioactivity, pesticides, bacteria, biological indicators including macroinvertebrates and fish, and sediment. One of the most comprehensive water-quality studies began in 1986 as part of the USGS National Water-Quality Assessment (NAWQA) Program, resulting in a series of reports. The study described in this report is the first comprehensive Kansas River study, however, that characterizes water quality and changes in constituent load on the basis of continuously measured data over a period of several years.

A summary of significant findings from previous water-quality studies includes:

- Although commercial dredging had little effect on water-quality constituents and plankton composition, the effects on benthic invertebrates and fish populations, caused by habitat transformation, were significant (Cross and deNoyelles, 1982).
- Commercial dredging activities on the Kansas River have been a major factor affecting riverbed degradation, bank erosion, channel widening, natural resource losses, and damages to nondredging interests in and along the downstream part of the river. The total amount of material extracted from the Kansas River for commercial dredging purposes from 1984 through 1987 was 14.9 million tons, and of this total, 11.7 million tons (78 percent) were extracted from the reach of the river from Bonner Springs downstream to the confluence of the Kansas and Missouri Rivers (U.S. Army Corps of Engineers, 1990).
- The overall median suspended-sediment concentration was 280 mg/L in the Kansas River at DeSoto, on the basis of data collected from 1963 to 1986 (Jordan and Stamer, 1995).
- Large sediment yields occur due to erodible soils, row-crop production, and excessive precipitation and runoff (Jordan and Stamer, 1995).
- The most severe dissolved oxygen deficiencies (concentrations less than 5.0 mg/L) were caused by wastewater-treatment discharges into tributaries (Pope, 1995).
- Concentrations of dissolved solids commonly exceeded 500 mg/L, primarily due to inflow of water from the Smoky Hill River. The Smoky Hill River contributed large concentrations of sodium and chloride ions to the Kansas River as a result of ground-water discharge from the underlying aquifer (Jordan and Stamer, 1995; Helgesen, 1996).
- No significant changes occurred in median concentrations of dissolved solids, nutrients, metals, or bacteria in the Kansas River at Topeka as a result of urban runoff from Topeka (Pope and Putnam, 1997).
- In general, the downstream reaches of the Kansas River (Topeka and downstream) are economically favorable for river dredging for sand and gravel production (Brady and others, 1998).
- Greater than 97 percent of the bacteria load in the Kansas River during July 1988 through July 1989 was contributed by nonpoint sources. *Escherichia coli (E. coli)* concentrations can be reliably estimated from historical fecal coliform bacteria. Turbidity is a reliable surrogate for *E. coli* bacteria (Rasmussen and Ziegler, 2003).

Methods

Data Collection and Analysis

Three USGS streamflow-gaging stations on the Kansas River (fig. 1) were equipped with continuous water-quality monitors (fig. 3) from July 1999 through September 2004. Each monitor provided continuous (hourly) measurements of specific conductance, pH, water temperature, turbidity, and dissolved oxygen. The data are available in real time on USGS Web pages (http://ks.water.usgs.gov/Kansas/rtqw/ and http://waterdata.usgs.gov/ks/nwis/), which facilitated prompt response in verifying the data and optimizing discrete sample collection. Monitor maintenance and data reporting followed standard procedures described in Wagner and others (2000).

In addition to continuous monitoring, discrete water samples were collected from each site according to methods described by Wilde and others (1999). Clean-sampling procedures were followed and isokinetic, depth-integrated sampling methods were used. Samples were analyzed at the USGS National Water-Quality Laboratory in Denver, Colorado, for nutrients, bacteria, sediment, and other constituents (full samples as indicated in fig. 4, constituents listed in table 4). Data qualified by the analyzing laboratory as “estimated” (for example, bacteria in the “nonideal” count range as defined by the analytical method protocol) were treated the same as unqualified data. These discrete samples were collected throughout the

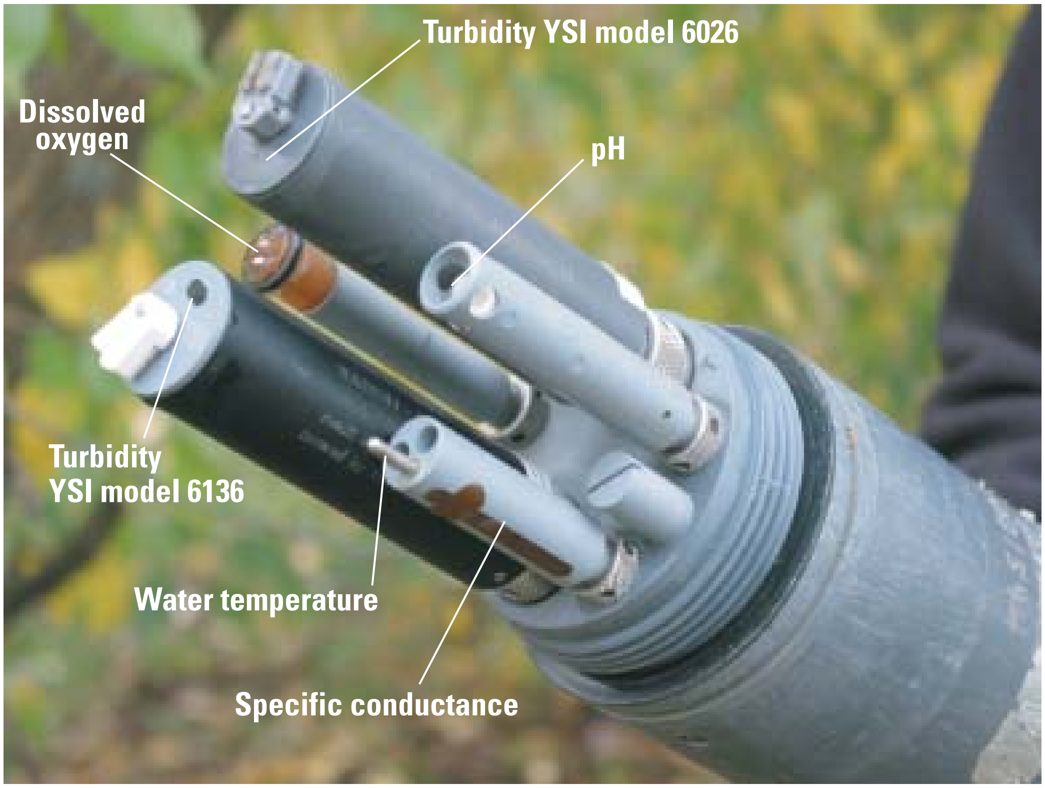


Figure 3. Water-quality monitor used to measure continuous, in-stream specific conductance, pH, water temperature, turbidity, and dissolved oxygen at three monitoring sites on lower Kansas River, July 1999 through September 2004.

range of streamflow and sensor conditions recorded at each site. The discrete samples that were collected represented about 90 percent of the flow duration curve for the river. Duration curves for streamflow, specific conductance, and turbidity were used to evaluate sample distribution and adapt sampling strategies to fill voids in data along the curves. For example, discrete sample values are shown on turbidity duration curves for the three monitoring sites in figure 4. In figure 4, the point values represent mean cross-section turbidity at the time of sample collection, and the curve represents hourly turbidity measurements from the continuous monitor for the entire study period. Sample collection was determined by closely monitoring the real-time continuous water-quality data and optimizing sample collection times to coincide with gaps remaining on the duration curves. Additional samples were collected independently by KDHE using their protocols (Kansas Department of Health and Environment, 2000). The KDHE samples were used to evaluate regression models by plotting the sampled concentrations with estimated concentrations and examining whether the estimated concentrations fell within acceptable uncertainty ranges.

Discrete quality-control samples, including blank and replicate samples, were collected and analyzed to assess the variability among samples resulting from collection, processing, shipping, and laboratory procedures conducted at different sampling times (Wilde and others, 1999). Equipment blank samples were collected to measure a combination of the potential contamination from the equipment used in sample collection and environmental conditions in the laboratory, and rinse blank samples were collected to measure the effectiveness of equipment cleaning protocols. Replicate samples were collected to evaluate laboratory and subsample bias and precision. Results from equipment and rinse blank samples indicated that laboratory procedures were acceptable (table 4). The largest relative percentage difference between replicate samples occurred in bacteria analysis, which had differences as large as 127 percent. With the exception of bacteria, differences ranged from 0 to 36 percent. The largest percentage differences occurred when constituent concentrations were very small, resulting in negligible differences in sample results.

Continuous in-stream sensor data were compared to average cross-section data at the monitor location to verify that the continuous data were representative of cross-section conditions. Data comparisons were made for specific conductance, pH, water temperature, turbidity, and dissolved oxygen. Generally, if the comparison differed by more than 10 percent during normal flow conditions, the monitor was relocated to a more representative location within the cross section. The width of the Kansas River at the monitoring sites varied from less than 400 ft during low-flow conditions to more than 1,000 ft during high-flow conditions. Maximum depth was sometimes less than 4 ft. These factors, along with constantly shifting sandbars, contributed to ever-changing mixing conditions and challenges keeping water-quality monitors submerged in water but not buried in sand and silt.

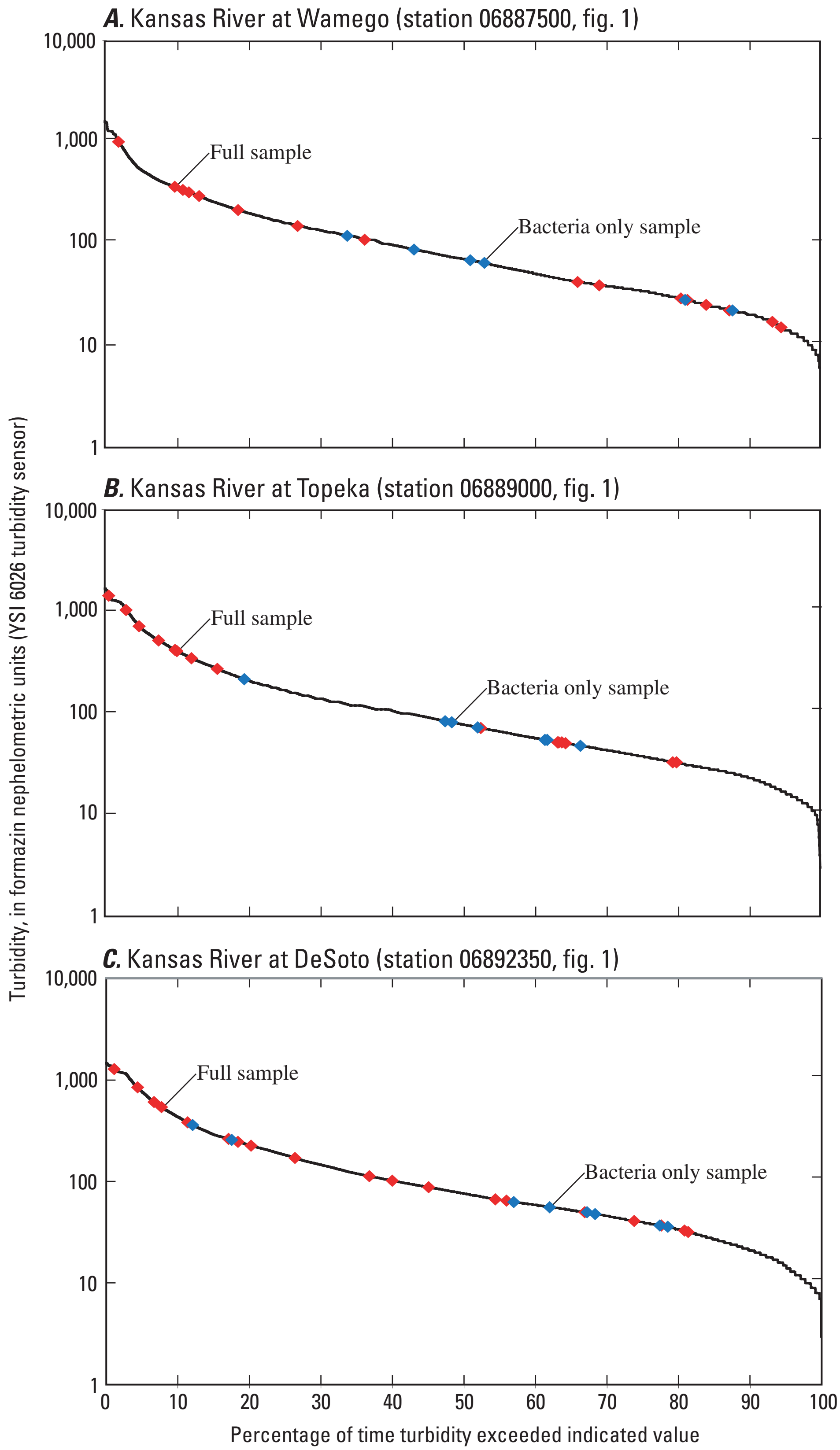


Figure 4. Discrete-sample values and turbidity duration curves for the continuous water-quality monitoring sites on lower Kansas River, July 1999 through December 2003.

Table 4. Water-quality constituents, parameter codes, units of measurement, detection levels, and results of replicate, blank, and environmental sample analysis.

[RPD, relative percentage difference; mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter; col/100 mL, colonies per 100 milliliters of water; --, not determined]

Constituent	U.S. Geological Survey parameter code	Units of measurement	Detection level	Replicate sample results				Blank sample results		Environmental sample results	
				Number of replicate pairs	Minimum RPD[1]	Mean RPD	Maximum RPD	Number of blank samples	Concentration range in blank samples	Number of environmental samples	Concentration or density range in environmental samples
Acid neutralizing capacity	00419	mg/L	1	5	0	2.2	9.0	4	1.1–1.9	55	108–258
Dissolved solids	70300	mg/L	10	4	.50	2.0	4.5	0	--	68	186–1,010
Calcium, dissolved	00915	mg/L	.012	4	1.0	3.2	8.2	4	<0.01–0.04	67	34–114
Magnesium, dissolved	00925	mg/L	.008	4	.50	2.6	6.3	4	<0.01	67	6.7–30
Sodium, dissolved	00930	mg/L	.09	4	1.1	3.1	7.3	4	0.03–0.06	66	14–206
Sulfate, dissolved	00945	mg/L	.11	4	0	.30	1.3	0	--	69	33–222
Chloride, dissolved	00940	mg/L	.33	3	0	1.1	2.5	4	<0.08–0.55	68	14–312
Fluoride, dissolved	00950	mg/L	.11	4	.50	2.6	7.3	4	<0.16	67	0.2–0.4
Nitrogen nitrate, dissolved	00618	mg/L	.10	2	0	12	24	0	--	79	<0.01–1.8
Nitrogen nitrite plus nitrate, dissolved	00631	mg/L	.10	5	.20	5.4	23	0	--	83	<0.01–1.8
Nitrogen, ammonia dissolved	00608	mg/L	.041	5	0	2.4	12	0	--	49	<0.02–0.26
Nitrogen, ammonia plus organic, dissolved	00623	mg/L	.10	5	.30	3.2	6.2	4	<0.10–0.05	82	0.1–1.1
Nitrogen, ammonia plus organic, total	00625	mg/L	.10	5	2.1	4.3	8.4	4	<0.10–0.06	72	0.44–3.7
Phosphorus, total	00665	mg/L	.06	5	1.1	5.0	9.8	0	--	69	0.12–5.8
Boron, dissolved	01020	µg/L	13	4	1.8	2.6	3.4	4	11–13	67	38–155
Escherichia coli (E. coli) bacteria	90902	col/100 mL	1	19	0	32	88	140	[2]3 (1–3)	161	<2–22,000
Fecal coliform bacteria	31625	col/100 mL	1	14	4.0	46	127	165	[2]4(1–2)	175	<2–21,000
Enterococci bacteria	90909	col/100 mL	1	14	0	27	102	52	[2]16(1–11)	79	8–165,000
Triazine herbicide	34756	µg/L	.10	11	1.9	9.6	36	1	<0.002	144	0.11–13
Suspended sediment	80154	mg/L	10	4	1.4	4.7	7.3	0	--	66	12–5,340
Total suspended solids	00530	mg/L	10	4	2.3	5.0	7.8	0	--	59	<10–1,570

[1] $RPD = \left[|A - B| / \left(\frac{A+B}{2} \right) \right] \times 100$, where A and B are concentrations in each replicate pair.

[2]Leading number indicates number of blank samples with bacteria colonies; numbers in parentheses indicate range in number of bacteria colonies.

The most cross-sectional variability among in-stream measurements occurred with turbidity. Comparisons of continuous, in-stream turbidity values and average cross-sectional turbidity values are shown in figure 5. On the basis of both slope of the regression and median RPD, turbidity readings from the continuous monitor at each of the monitoring sites underrepresent average cross-section turbidity by less than 10 percent. Continuous monitor readings were affected by location of the monitor vertically in the stream and within the cross section and by site mixing conditions.

Regression Models

Regression analysis was used to develop relations between the continuous sensor measurements, streamflow, time, and discretely sampled constituent concentrations. Site-specific regression models were developed using plots of each possible explanatory (independent) variable and the response (dependent) variable and visually and statistically examining the residual plots for patterns. Explanatory and response variables (except time) were log transformed, if necessary, to develop a linear relation. An overall model-building method was used (Helsel and Hirsch, 1992). Many data transformations and all possible regression equations were evaluated. Generally, if there were several acceptable models (F-test p-value less than 0.05), the one with the smallest prediction error sum of squares (PRESS) statistic was selected. The PRESS statistic is a measure of goodness of fit of a regression model (Helsel and Hirsch, 1992). Explanatory variables were included in a model only if there was a physical basis for their inclusion.

For variables that were log-transformed, retransformation of regression-estimated concentrations was necessary. Retransformation can cause bias (underestimation) in the constituent loads when adding individual load estimates over a period of time (Helsel and Hirsch, 1992). Therefore, the estimated hourly concentration and density values were multiplied by a log-transformation bias correction factor, or smear factor, to correct for this underestimation. Duan's smearing estimator (Duan, 1983) was used because it is the least complex and most easily applied of two bias correction methods recommended by Cohn and Gilroy (1991).

Uncertainty of the estimates for the regression models was determined using 90-percent prediction intervals (Helsel and Hirsch, 1992). Probabilities of exceeding water-quality standards, recommended criteria, or guidelines of the State of Kansas and USEPA also were estimated and are displayed on the World Wide Web at http://ks.water.usgs.gov/Kansas/rtqw/. Regression methods used in this study are described in greater detail in Cohn and others (1989), Helsel and Hirsch (1992), Hirsch and others (1993), and Rasmussen and Ziegler (2003). The continuous concentration and density estimates, uncertainty, and duration curves for the three monitoring sites are available on the World Wide Web at URL http://ks.water.usgs.gov/Kansas/rtqw/.

Estimation of Constituent Loads and Yields

Loads in the river were calculated for each constituent to determine total transport at each of the three Kansas River sites seasonally and annually. Hourly regression-estimated concentrations and densities were multiplied by a bias correction factor (Duan smear factor; Duan, 1983) and by streamflow and then summed over the appropriate period of time. Because continuous monitor data are used to calculate concentrations, densities, and loads and continuous monitor data were estimated for some periods of missing record, loads and yields include some estimated data. Additional information about estimated data is provided in the following section describing sensor limitations. For method comparison purposes, annual loads for selected constituents were estimated using streamflow-based regression and discrete-sample data sets, in addition to regressions for continuous water-quality sensor data.

Constituent yields from the contributing drainage areas were calculated by dividing loads by corresponding drainage areas to determine constituent load per acre. Yields are important for comparing relative contributions of each basin. The drainage areas used for calculating yield for sediment and sediment-related constituents at each site were adjusted to include only parts of the basin unregulated by Federal reservoirs. Because many constituents can be related statistically to sediment and because sediment flowing into reservoirs is trapped, it was not appropriate to include reservoir drainage areas in the total drainage area used to determine yield for sediment-related constituents. Unregulated drainage area was estimated by subtracting the drainage areas of upstream Federal reservoirs from the total drainage area at each monitoring site. Drainage areas for numerous smaller impoundments in the Kansas River Basin were not taken into account in the calculation of unregulated drainage area even though they also trap sediment. Yields for dissolved constituents were calculated using total drainage area because these constituents generally will pass through the reservoir.

In-Stream Sensor Limitations

A specified range of operation is associated with each sensor on the in-stream monitor. Conditions in the Kansas River remained within these specified ranges except turbidity. Turbidity sensors used in the study were capable of measuring a range from 0 to about 1,700 formazin nephelometric units (FNUs), depending on the individual sensor (Ziegler, 2002; Anderson, 2004). Turbidity instrument and unit information are summarized in table 5.

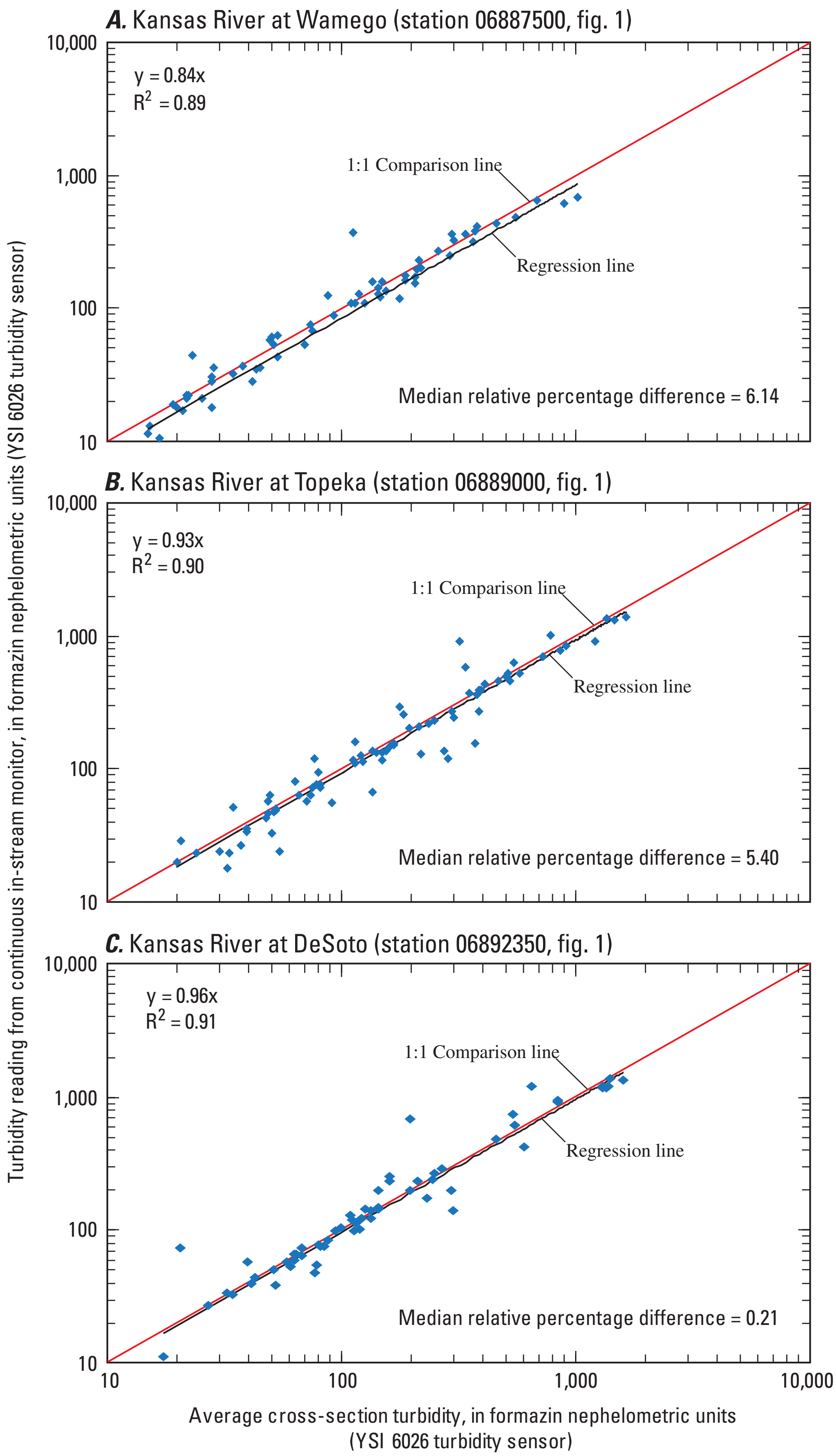


Figure 5. Comparison of continuous, in-stream turbidity values and average cross-section turbidity values for three monitoring sites on lower Kansas River, July 1999 through December 2003.

Table 5. Description of different turbidity instruments used in study of the lower Kansas River in northeast Kansas.

[FNU, formazin nephelometric units; FNRU, formazin nephelometric ratio units]

Instrument	Reporting units	Instrument method	Detector geometry	Upper limit of measurement	Method source
Hach model 2100AN, laboratory	Formazin nephelometric ratio units (FNRU)	Wavelength monochrome (spectral output near infrared, 780–900 nanometers).	90 degrees to incident beam; instrument algorithm uses combination of detector readings that may differ for values of varying magnitude.	10,000 FNRU	ISO 7027[1]
YSI model 6026, in-stream	Formazin nephelometric units (FNU)	Wavelength monochrome (spectral output near infrared, 780–900 nanometers).	90 degrees to incident beam.	1,000 FNU[2]	ISO 7027[1]
YSI model 6136, in-stream	Formazin nephelometric units (FNU)	Wavelength monochrome (spectral output near infrared, 780–900 nanometers).	90 degrees to incident beam.	1,000 FNU[2]	ISO 7027[1]

[1]ISO 7027 defines the optical geometry for formazin nephelometric measurements. The detector angle must be 90 degrees plus or minus 2.5 degrees to the incident light beam. The light source must be a light-emitting diode (LED) with wavelength 850 plus or minus 60 nanometers (International Organization for Standardization, 1999).

[2]According to manufacturer specifications, the upper limit of measurement is 1,000 FNU; however, individual sensors are capable of measuring turbidity as large as 2,000 FNU.

Turbidity conditions occasionally exceeded the upper measurement limit for each sensor during the study. When the actual turbidity was greater than the maximum a sensor could measure, the sensor reported only the maximum value. The largest part of the turbidity data affected by sensor maximization occurred in 2001 when 2.9 percent of the continuous turbidity values were truncated for the Topeka monitoring site and 2.6 percent were truncated for the DeSoto site (table 6). Turbidity maximization occurred about 1 percent of the time or less in other years.

Because loads usually are largest during very turbid conditions, upper range turbidity values can be an important consideration in estimating total loads for several constituents, especially sediment and sediment-associated constituents. Therefore, considerable effort was made to estimate turbidity during truncation periods. Initially, streamflow was used as a substitute surrogate when the turbidity sensor was maximized. However, the resulting concentration, density, and load estimates derived from regression equations using streamflow as an explanatory variable were smaller than the estimates derived from the maximized turbidity value, which already was likely underestimating the constituents. Streamflow was unsuitable as a substitute surrogate for several reasons. First, turbidity and streamflow peak values do not necessarily coincide during runoff (fig. 6). Second, the size and shape of the turbidity curve were neither consistent nor predictable from one runoff occurrence to the next. The timing of turbidity peak values relative to streamflow peak values depended on the particular runoff occurrence, the source of the sediment contribution (overland flow or channel) and its distance from the monitoring site, and whether reservoir releases were a factor. Generally, turbidity of streamflow originating from reservoirs is less than turbidity of streamflow originating from runoff occurrences. Therefore, a streamflow pressure wave originating from a reservoir release increased streamflow at the Kansas River monitoring site but, through dilution, decreased turbidity. A third reason that streamflow was not a suitable substitute for large turbidity values is that streamflow is simply a less reliable estimator than turbidity for most water-quality constituents, as indicated by the coefficients of determination (R^2) and mean square errors (MSE) associated with streamflow-estimated regression models when compared to turbidity-estimated models (see table 9 in section on "Comparison of Regression-Estimated and Discrete-Sample Constituent Concentrations"). Fourth, streamflow typically underestimates water-quality constituents at large concentrations as found by Horowitz (2003) when evaluating suspended-sediment flux. Horowitz (2003) demonstrated that regression models using streamflow as the explanatory variable for suspended-sediment concentration underestimate large, and overestimate small, sediment concentrations. The same is true for regression models using turbidity as the explanatory variable; however, the magnitude of the estimation errors generally is smaller for the statistical reasons just stated.

Therefore, it was determined that the best approach for handling turbidity sensor maximization was to refrain from altering the data and simply maintain the values recorded by the sensor. For this reason, the regression-estimated concentrations and densities, and consequently loads and yields, during times of truncation are understated by an unknown amount. Rasmussen and Ziegler (2003) found that comparisons of measured load from samples and the corresponding regression-estimated load indicated that the truncated estimates of bacteria load underrepresented the actual load by as much as 20 percent. The difference between estimated and actual load included factors other than maximized turbidity data, such as sampling bias and inherent uncertainty in the regression equations.

Technology has improved since the study began in 1999 resulting in the availability of sensors capable of measuring larger turbidity values. The turbidity sensors initially deployed and used throughout the study were YSI model 6026 (Yellow Springs Instruments, Yellow Springs, Ohio). A newer turbidity sensor, YSI model 6136, was made available during the study and was deployed side-by-side with the YSI model 6026 sensors (fig. 3) to make comparisons between the two models in anticipation of replacing the existing sensors. Side-by-side comparisons were made during 2004. Results of the

Table 6. Summary of turbidity sensor maximum measurements at Kansas River water-quality monitoring sites, northeast Kansas.

[FNU, formazin nephelometric turbidity units (YSI 6026 sensor)]

Calendar year	Wamego (station 06887500, fig. 1)			Topeka (station 06889000, fig. 1)			DeSoto (station 06892350, fig. 1)		
	Maximum FNU	Number of continuous measurements	Percentage of continuous measurements affected	Maximum FNU	Number of continuous measurements	Percentage of continuous measurements affected	Maximum FNU	Number of continuous measurements	Percentage of continuous measurements affected
2000	1,220	7,121	0.6	1,520	6,781	0.8	1,370	7,403	0.6
2001	1,620	7,834	.9	1,690	7,813	2.9	1,410	8,313	2.6
2002	1,300	6,784	0	1,300	8,199	.9	1,200	8,127	.7
2003	1,400	6,483	1.1	1,700	7,128	.5	1,450	7,330	.5
Average	1,380	7,056	.6	1,450	7,480	1.3	1,360	7,793	1.1

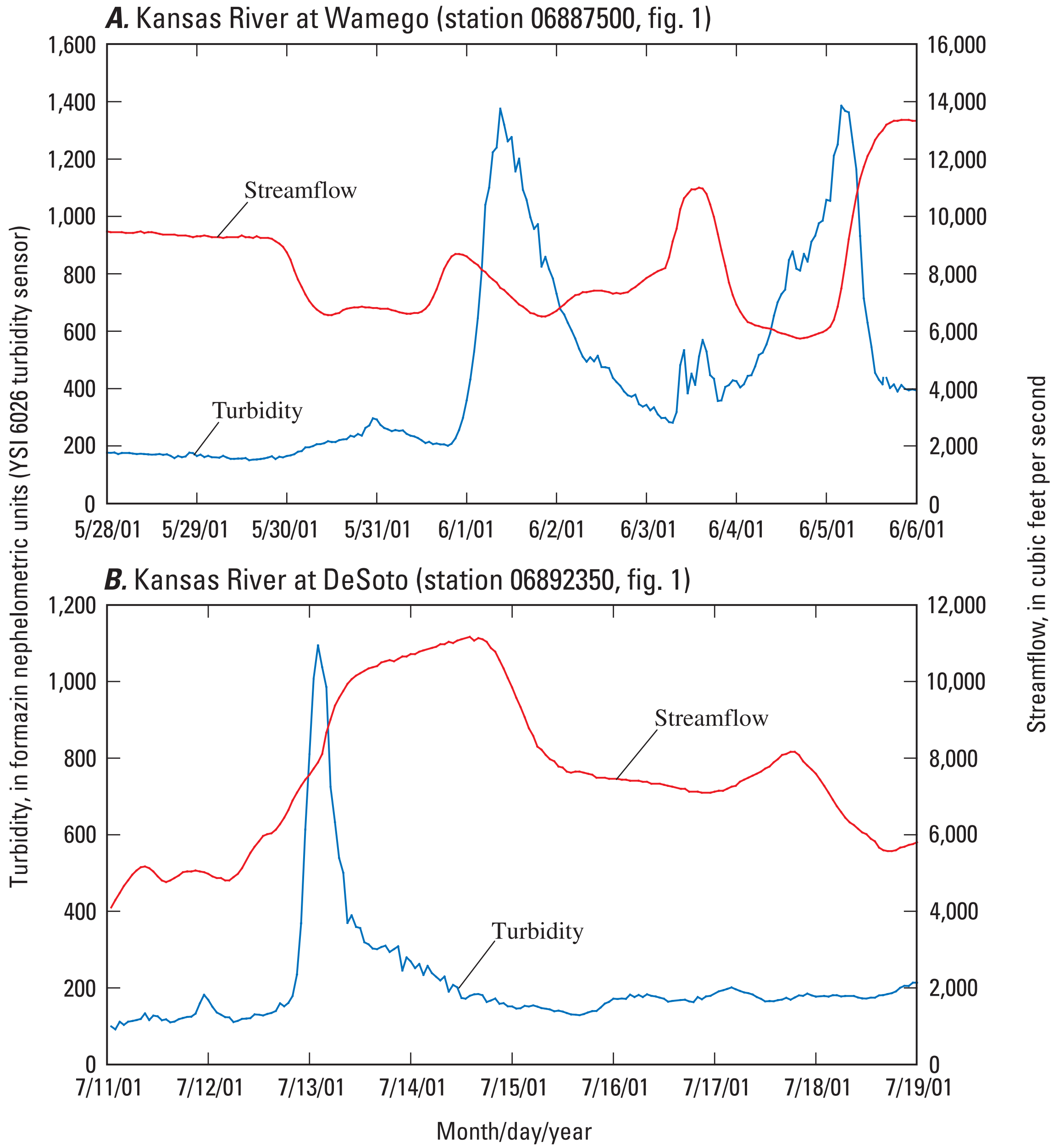


Figure 6. Comparison of streamflow and turbidity for Kansas River at Wamego, May 28–June 6, 2001, and at DeSoto, July 11–19, 2001.

comparison,which can be used as conversion factors for future studies, are presented in figure 7. Analysis of covariance (Hirsch and others, 1993) was used to determine that site-specific regressions are not significantly different from each other at the 95-percent probability level (p = 0.05). The newer YSI model 6136 turbidity sensor measures larger turbidity values (as indicated by the line slopes in fig. 7) and provides measurements that correlate more closely with data from the laboratory turbidity meter Hach model 2100AN (Hach Company, Loveland, Colorado), which is considered the industry standard (YSI Environmental, 2003). A comparison between the YSI model 6026 and Hach model 2100AN data is presented in figure 8. Each of the three turbidity instruments described was compliant with the ISO 7027 standard which describes acceptable methods for measuring turbidity (International Organization for Standardization, 1999). However, the figures illustrate that differences between measurement technologies are substantial. All regression models in this report use the YSI model 6026 turbidity sensor.

Continuous data occasionally were missed during periods when the water-quality instruments malfunctioned or during winter when freezing conditions prevented deployment of the instruments. Most of these missing data occurred during stable streamflow conditions, so missing continuous data values were estimated by interpolating between known values. Therefore, duration curves for continuous measurements and estimated

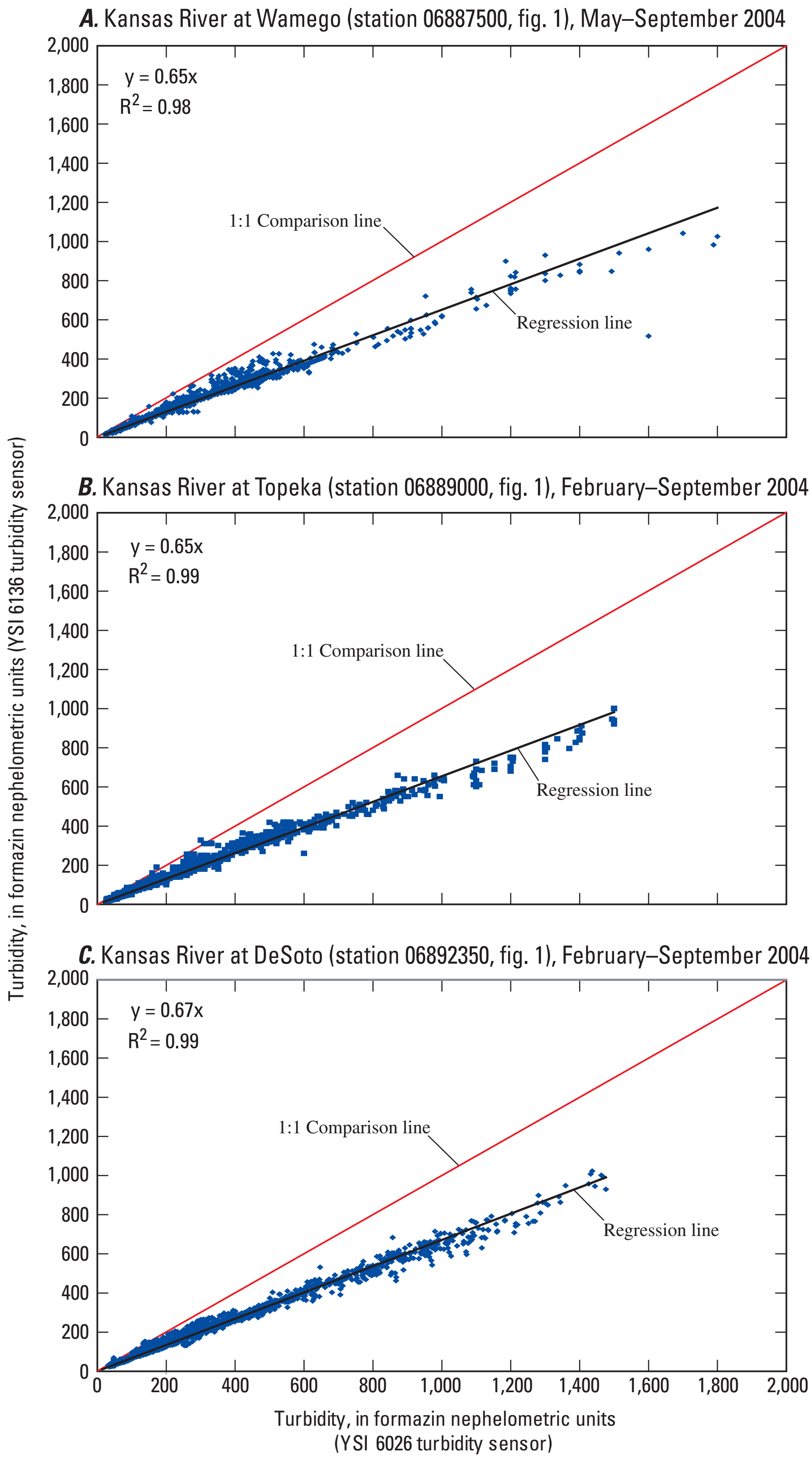


Figure 7. Comparison of turbidity values measured using YSI model 6026 and YSI model 6136 sensors at monitoring sites on Kansas River at Wamego, May–September 2004, Topeka, February–September 2004, and DeSoto, February–September 2004.

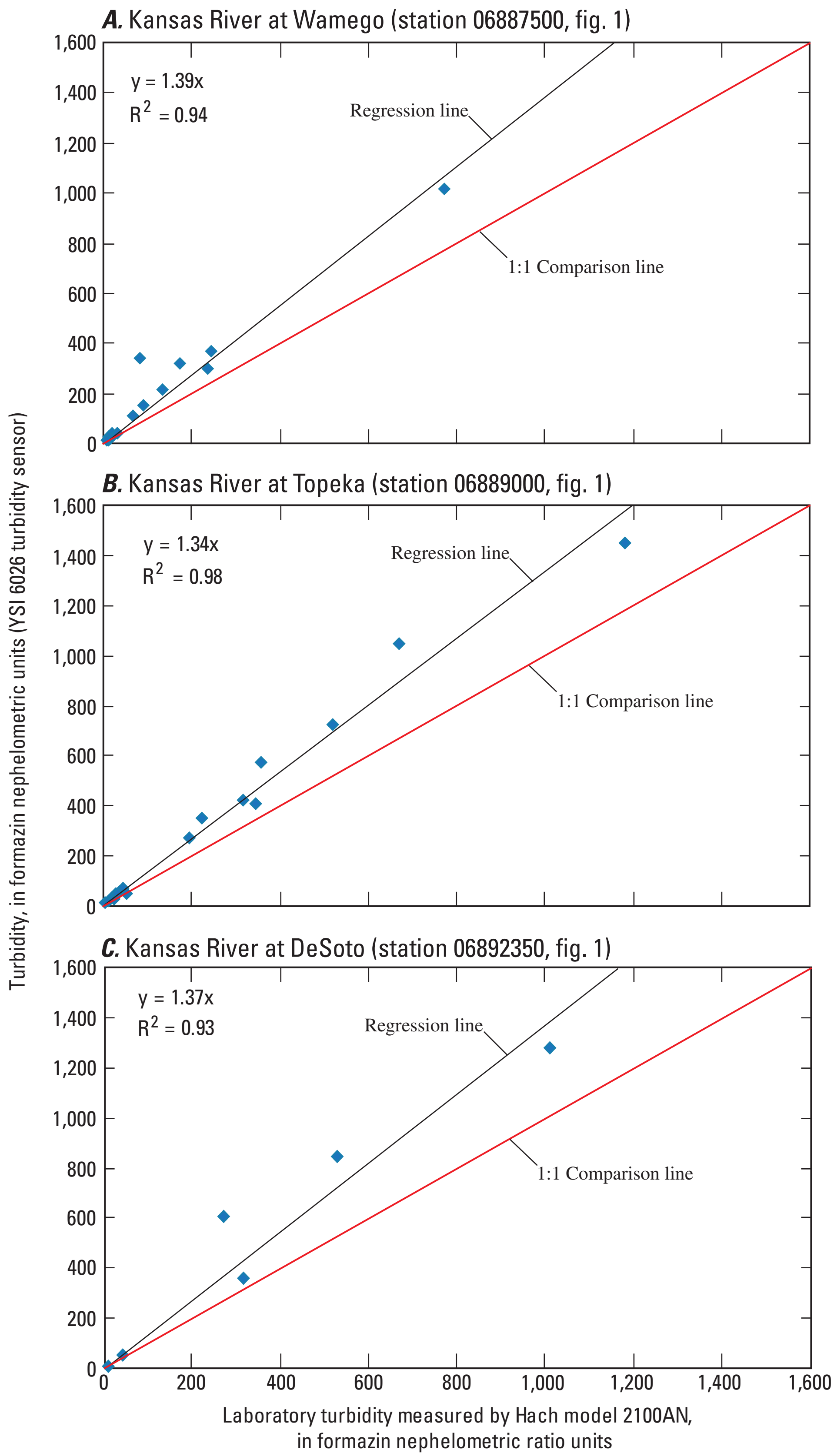


Figure 8. Comparison of turbidity values measured in-stream by YSI model 6026 sensor and in laboratory by Hach model 2100AN meter for Kansas River at Wamego, Topeka, and DeSoto, October 2000 through September 2003.

concentrations and densities of constituents discussed in this report include estimated values during periods when data were missing and streamflow was stable. In addition, loads and yields for constituents discussed in this report were calculated using estimated data. Concentration, density, and load information for the remaining constituents presented in the appendixes does not include estimated data.

Results of Continuous and Discrete-Sample Data Collection and Regression Analysis

Continuous Streamflow and Water-Quality Sensor Data

Continuously measured streamflow, specific conductance, pH, water temperature, turbidity, and dissolved oxygen at the three monitoring sites are described in this section. Annual summaries of continuous data are presented in table 7 and include estimated hourly values for 0 to 34 percent of the annual record. Seasonal data comparisons were made by grouping the data in three seasonal periods. April through June data represented the spring runoff season, July through October data represented variable conditions that are representative of summer and fall, and November through March data represented winter base-flow conditions. Median, rather than mean, values are used for comparison because they are easily obtained from duration curves and they are useful for describing central tendency of data sets regardless of skewness (Hirsch and others, 1993).

An example of the information provided by the continuous measurements is shown in figure 9. At the DeSoto monitoring site, distinct diurnal fluctuations in pH and dissolved oxygen occurred during a 10-day period in April 2002 (fig. 9*A*). Both pH and dissolved oxygen exhibited diurnal fluctuations until changes in streamflow and turbidity, which were caused by runoff, disturbed the pattern. More extreme fluctuations often occur in late summer (August and September) when temperatures are higher and streamflow is less. Daily variability in pH and dissolved oxygen indicates photosynthetic activity. Variability may be an indication of changes in nutrient levels, light penetration, and metabolic and abiotic activity. Also, in the spring (April and May) of 2002 at the same site, specific conductance ranged from 300 to 900 μS/cm, and turbidity (measured with a YSI model 6026 sensor) ranged from about 25 to 1,200 FNU (fig. 9*B*). During this time period, turbidity peaks and specific conductance valleys generally coincided with streamflow peaks; however, the shapes of the curves varied, and the rising and falling turbidity slopes were the steepest. Rapid changes in water-quality conditions, particularly turbidity, generally are associated with runoff. Describing this diurnal and wet-weather variability is important in understanding concentration, density, and loading characteristics associated with sediment and other sediment-associated constituents like bacteria and some nutrients.

Streamflow

Streamflow is an important factor affecting water-quality constituent concentrations. Curves showing annual and seasonal duration of continuous streamflow data are illustrated in figures 10 and 11.

During the study period, streamflow at DeSoto was highest, and streamflow at Topeka was only slightly higher than at Wamego. For continuous measurements at the upstream monitoring site, Wamego, the year with the highest median annual streamflow during the study period, 2,960 ft^3/s, was 2001 compared to the lowest median hourly streamflow, 1,330 ft^3/s, which occurred in 2003 (table 7). At the middle monitoring site, Topeka, the highest median hourly streamflow occurred in 2001 at 3,480 ft^3/s, and the lowest median hourly streamflow was in 2002 at 1,370 ft^3/s. At the downstream monitoring site, DeSoto, the highest median hourly streamflow (4,680 ft^3/s) occurred in 2001, and the lowest (1,820 ft^3/s) was in 2003. Streamflow ranged from a minimum of 233 ft^3/s at Topeka in 2003 to a maximum of 80,700 ft^3/s at DeSoto in 2001. Streamflow conditions in 2001 at each site most closely resembled historical streamflow conditions (fig. 10). At each site, seasonal streamflow generally was highest during April through June and lowest during November through March (fig. 11).

The largest annual streamflow volumes occurred at DeSoto where the average annual streamflow volume was 44 percent larger than the average streamflow volume at Wamego (table 8). The streamflow volume in 2001 was 2.2 (at Wamego) to 3.3 (at DeSoto) times larger than the smallest annual streamflow volume, which occurred in 2003 at each site (table 8). The largest streamflow yield each year was at DeSoto (table 8). For the discrete samples collected from July 1999 through December 2003, streamflow ranged from 643 ft^3/s at Wamego to 79,000 ft^3/s at DeSoto (table 7).

Specific Conductance

Specific conductance is a measure of the water's ability to conduct an electrical current, which usually is associated with the concentration of ionized substances in water (Hem, 1985). Specific conductance is affected by soil and rock composition; size of the watershed, which affects contact with soil before runoff reaches streams; evaporation, which concentrates dissolved solids; and contaminant sources, including agricultural and urban runoff (Jordan and Stamer, 1995). In most Kansas streams, specific conductance is larger during low flow because of ground-water contribution of dissolved carbonate minerals found in underlying limestone (Jordan and Stamer, 1995).

Continuous specific conductance values varied from 158 μS/cm at DeSoto in 2003 to 1,510 μS/cm at Wamego in 2000 (table 7). The annual median specific conductance value at Wamego (50-percent frequency of exceedance) during the study period was about 15 percent larger than the median at DeSoto (fig. 12). Specific conductance was largest in 2000 at all sites and generally largest between November and March

Table 7. Summary of data for continuous (hourly) measurements and discrete-sample analysis at three water-quality monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; FNU, formazin nephelometric units; mg/L, milligrams per liter]

Calendar year	Wamego						Topeka						DeSoto					
	Number of hourly measurements or samples	Estimated hourly values (percent)	Minimum	Mean	Median	Maximum	Number of hourly measurements or samples	Estimated hourly values (percent)	Minimum	Mean	Median	Maximum	Number of hourly measurements or samples	Estimated hourly values (percent)	Minimum	Mean	Median	Maximum
Streamflow (ft^3/s)																		
2000	8,784	0	646	2,420	2,140	14,100	8,784	0	627	2,480	2,210	12,800	8,784	0	492	3,040	2,400	16,200
2001	8,760	0	758	5,260	2,960	31,500	8,760	0	732	5,870	3,480	44,500	8,760	0	1,100	8,340	4,680	80,700
2002	8,760	0	602	1,720	1,360	7,230	8,760	0	487	1,830	1,370	12,800	8,760	0	280	2,600	1,900	21,700
2003	8,760	0	505	1,650	1,330	8,120	8,760	0	233	1,690	1,500	8,390	8,760	0	388	1,940	1,820	11,900
Average 2000–03	8,766	0	628	2,760	1,950	15,200	8,766	0	520	2,970	2,140	19,600	8,766	0	565	3,980	2,700	32,600
Discrete samples 1999–2003	21		643	4,070	2,270	23,000	28		681	4,370	1,470	21,000	34		949	7,160	2,880	79,000
Specific conductance (µS/cm)																		
2000	8,784	18	474	1,040	1,120	1,510	8,784	20	189	990	1,040	1,500	8,784	19	288	919	922	1,300
2001	8,760	13	279	756	763	1,370	8,760	11	279	728	701	1,240	8,760	8	235	654	597	1,170
2002	8,760	22	491	884	914	1,450	8,760	6	263	832	843	1,160	8,760	6	288	762	779	1,060
2003	8,760	21	277	756	679	1,500	8,760	21	292	769	689	1,320	8,760	14	158	741	669	1,190
Average 2000–03	8,766	18	380	859	869	1,460	8,766	14	256	830	818	1,300	8,766	12	242	769	742	1,180
Discrete samples 1999–2003	20		450	844	790	1,790	22		361	768	698	1,580	27		308	799	867	1,430
pH (standard units)																		
2000	8,784	16	7.7	8.3	8.3	8.7	8,784	17	7.0	8.3	8.3	9.4	8,784	14	7.6	8.4	8.4	9.2
2001	8,760	12	7.1	8.0	8.0	8.9	8,760	11	7.8	8.3	8.3	9.3	8,760	7	7.6	8.3	8.2	9.2
2002	8,760	34	8.0	8.6	8.6	9.4	8,760	4	7.5	8.4	8.4	9.1	8,760	5	7.4	8.4	8.4	9.2
2003	8,760	21	7.5	8.5	8.4	9.4	8,760	19	7.4	8.5	8.5	9.6	8,760	15	7.6	8.6	8.7	9.5
Average 2000–03	8,766	21	7.6	8.4	8.3	9.1	8,766	13	7.4	8.4	8.4	9.4	8,766	10	7.6	8.4	8.4	9.3
Discrete samples 1999–2003	20		7.7	8.1	8.2	8.6	21		7.4	8.1	8.2	8.8	26		7.3	8.1	8.1	8.7

Table 7. Summary of data for continuous (hourly) measurements and discrete-sample analysis at three water-quality monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; FNU, formazin nephelometric units; mg/L, milligrams per liter]

Calendar year	Wamego						Topeka						DeSoto					
	Number of hourly measurements or samples	Estimated hourly values (percent)	Minimum	Mean	Median	Maximum	Number of hourly measurements or samples	Estimated hourly values (percent)	Minimum	Mean	Median	Maximum	Number of hourly measurements or samples	Estimated hourly values (percent)	Minimum	Mean	Median	Maximum
Water temperature (°C)																		
2000	8,784	15	0	15.2	16.5	33.6	8,784	17	0.1	15.6	17.1	33.4	8,784	15	0	15.7	16.6	34.3
2001	8,760	11	-.2	14.6	15.7	33.6	8,760	11	0	14.9	16.1	33.2	8,760	6	0	15.1	16.4	34.1
2002	8,760	23	0	15.2	14.7	34.0	8,760	5	0	15.2	15.2	33.1	8,760	5	7.0	15.3	15.4	34.8
2003	8,760	21	0	14.8	16.2	32.8	8,760	19	.1	15.4	16.4	32.1	8,760	14	0	15.5	16.3	33.9
Average 2000–03	8,766	18	0	15.0	15.8	33.5	8,766	3	0	15.3	16.2	33.0	8,766	10	1.8	15.4	16.2	34.3
Discrete samples 1999–2003	20		.1	14.6	18.2	28.3	28		.1	16.8	17.2	28.8	34		.1	20.0	21.2	31.4
Turbidity (FNU)																		
2000	8,784	19	8	122	58	[1]1,220	8,784	23	10	135	74	[1]1,520	8,784	15	3	131	85	[1]1,370
2001	8,760	11	10	237	146	[1]1,620	8,760	11	8	292	151	[1]1,690	8,760	5	9	310	180	[1]1,410
2002	8,760	23	6	61	36	[1]1,300	8,760	6	8	83	45	[1]1,300	8,760	7	6	92	49	[1]1,200
2003	8,760	26	9	110	59	[1]1,400	8,760	19	3	124	61	[1]1,700	8,760	16	7	116	71	[1]1,450
Average 2000–03	8,766	20	8	133	75	[1]1,380	8,766	15	10	158	83	[1]1,550	8,766	11	6	162	96	[1]1,360
Discrete samples 1999–2003	20		11	159	42	1,020	28		12	251	59	[1]1,450	34		11	215	165	[1]1,600
Dissolved oxygen (mg/L)																		
2000	8,784	20	6.2	11.2	10.7	17.1	8,784	25	4.6	10.8	10.4	16.8	8,784	18	5.5	11.4	11.5	17.1
2001	8,760	23	5.0	11.1	10.4	18.9	8,760	17	6.4	10.8	10.6	16.4	8,760	15	5.9	10.9	10.3	18.3
2002	8,760	27	4.9	11.2	11.4	18.5	8,760	12	4.2	11.3	11.3	18.4	8,760	16	4.3	10.6	10.8	18.9
2003	8,760	26	5.9	10.7	10.1	17.6	8,760	28	3.8	10.4	10.4	17.7	8,760	18	4.2	10.7	10.5	19.0
Average 2000–03	8,766	24	5.5	11.0	10.6	18.0	8,766	20	4.8	10.7	10.7	17.3	8,766	17	5.0	10.9	10.8	18.3
Discrete samples 1999–2003	20		6.6	10.9	9.9	17.1	21		7.1	10.4	9.3	15.0	26		6.2	9.6	9.2	14.7

[1]Actual turbidity greater than maximum sensor value.

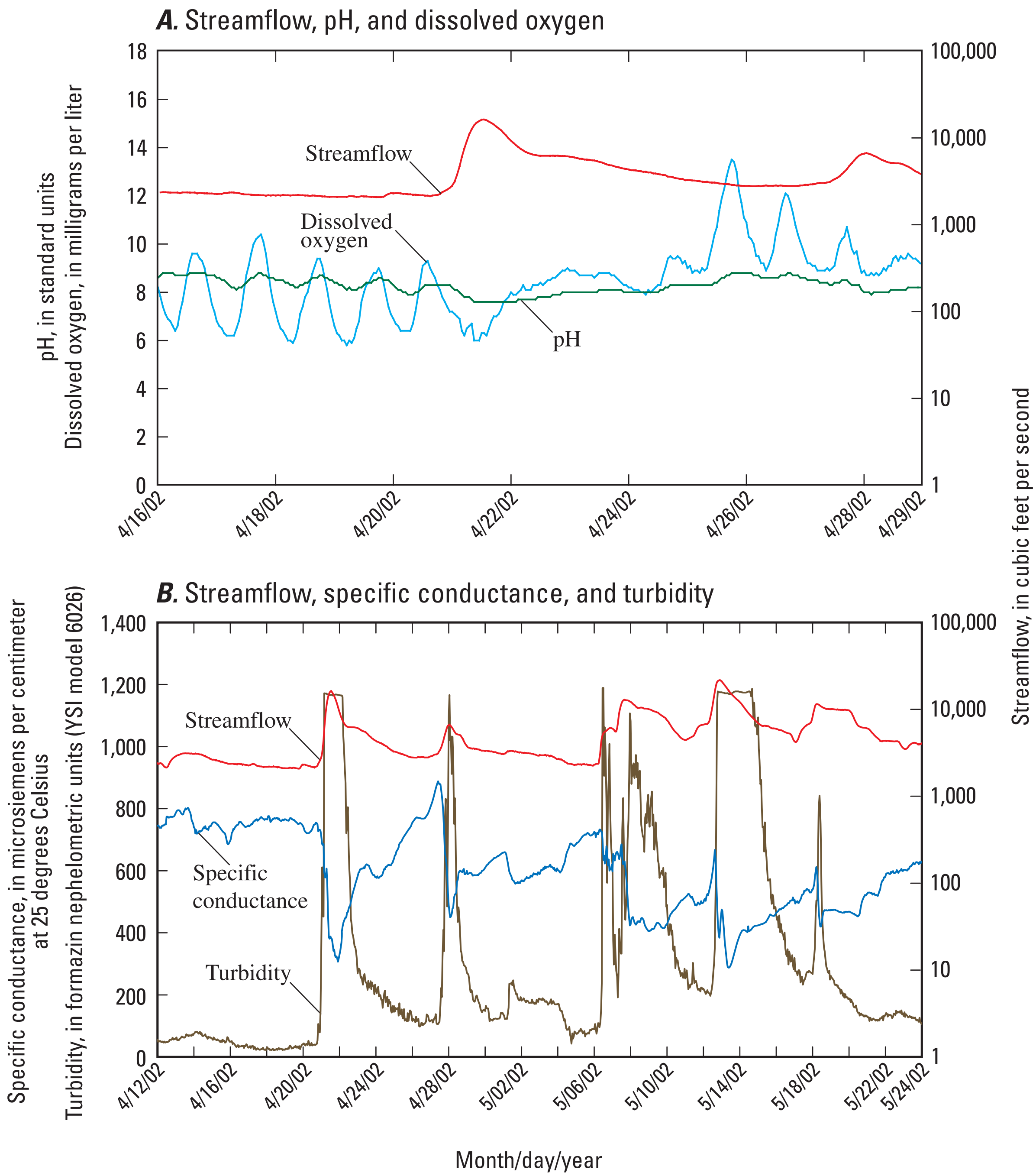


Figure 9. Comparison of continuous measurements of *(A)* streamflow, pH, and dissolved oxygen concentrations, April 16–29, 2002, and *(B)* streamflow, specific conductance, and turbidity, April 12–May 24, 2002, for Kansas River at DeSoto.

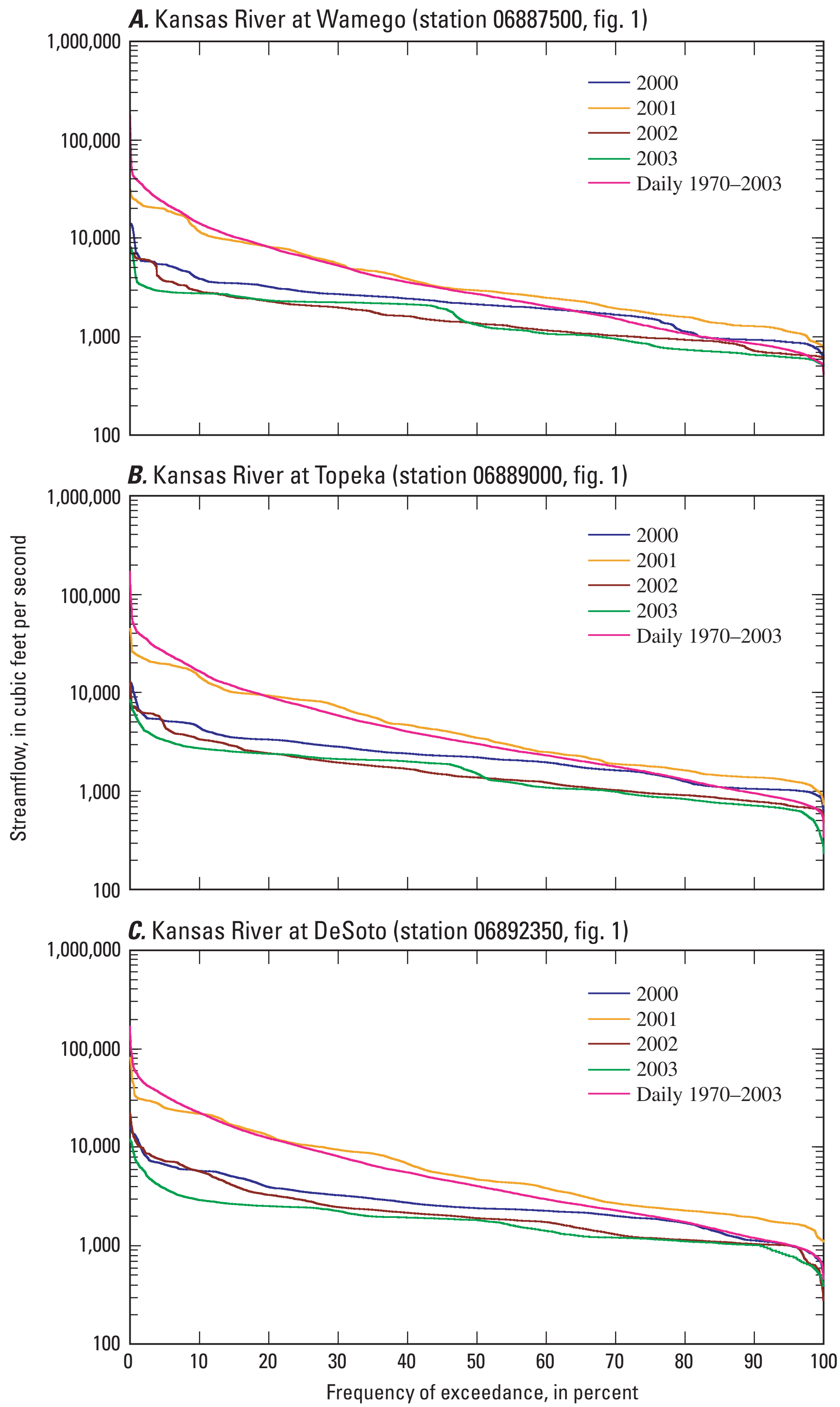


Figure 10. Annual duration curves for measured hourly streamflow at three Kansas River monitoring sites, 2000–03.

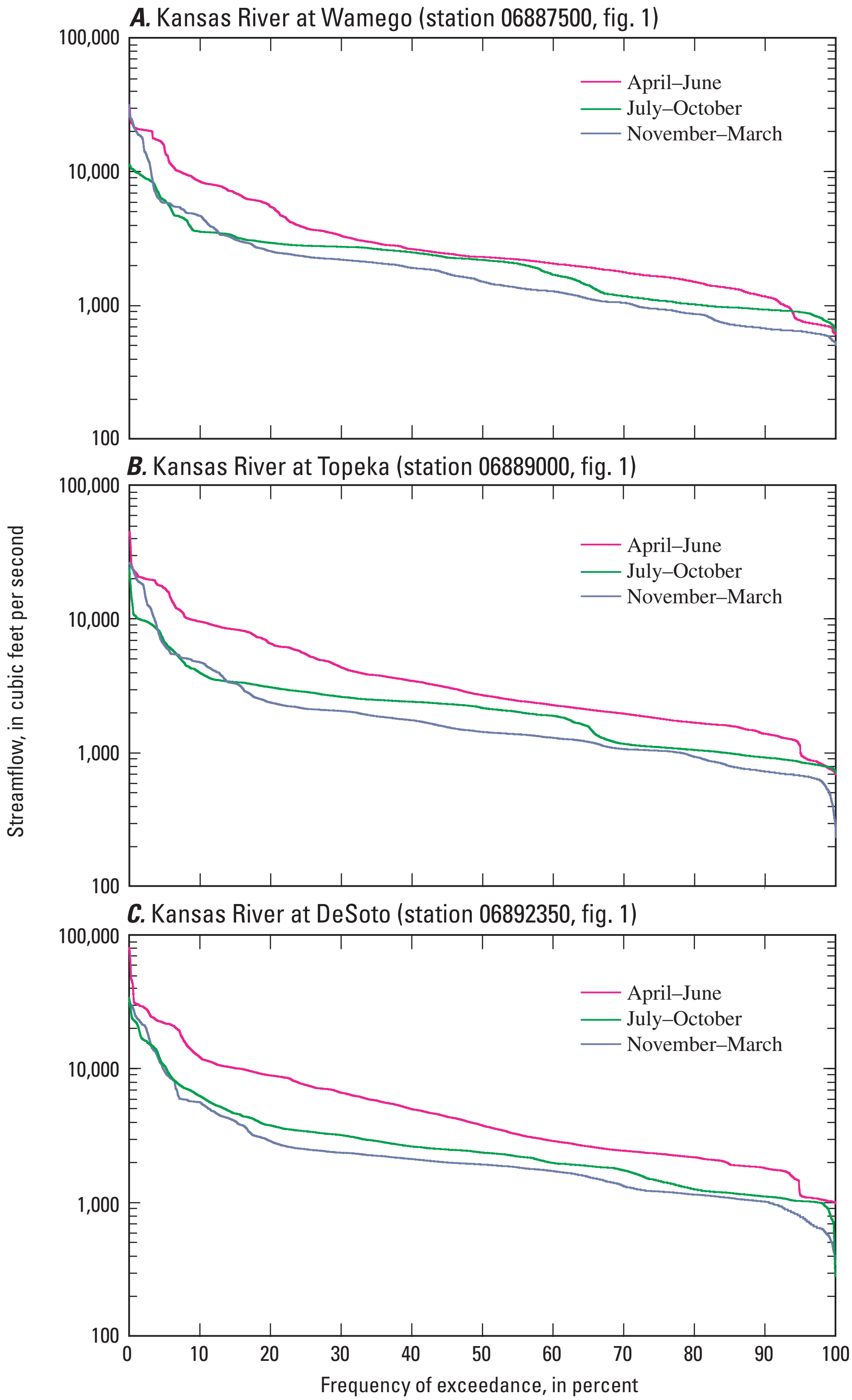


Figure 11. Seasonal duration curves for measured hourly streamflow at three Kansas River monitoring sites, January 2000 through December 2003.

Table 8. Streamflow volume and yield at three monitoring sites on the lower Kansas River, northeast Kansas, 2000–03.

{mi^2, square miles]

Calendar year	Streamflow volume (million acre-feet per year)				Calendar year	Streamflow yield (acre-feet per square mile per year)		
	April–June	July–October	November–March	Total		Wamego	Topeka	DeSoto
	Wamego				Total drainage area (mi^2)	55,280	56,720	59,756
2000	9.4	13.5	19.2	42.1	2000	761	761	885
2001	39.2	22.4	29.8	91.4	2001	1,650	1,800	2,420
2002	11.4	6.9	11.6	30.0	2002	543	561	756
2003	7.9	13.2	7.5	28.6	2003	518	518	563
Average 2000–03	17.0	14.0	17.0	48.0	Average 2000–03	869	910	1,160
	Topeka							
2000	10.7	13.7	18.8	43.2				
2001	45.3	25.4	31.3	102				
2002	13.8	6.8	11.2	31.8				
2003	9.5	12.3	7.5	29.4				
Average 2000–03	19.8	14.6	17.2	51.6				
	DeSoto							
2000	14.0	16.5	22.4	52.9				
2001	61.7	40.7	42.5	145				
2002	22.9	9.2	13.1	45.2				
2003	11.6	12.9	9.1	33.7				
Average 2000–03	27.5	19.8	21.8	69.1				

except within the 15-percent exceedance range when large specific conductance values also occurred from April through June and July through October (fig. 13). Specific conductance is strongly affected by contributions from the Smoky Hill River. Of the total streamflow at DeSoto, 31 percent originated from the Smoky Hill River in 2000 (table 2), the year specific conductance was largest, and only 16 percent originated from the Smoky Hill River in 2001, the year specific conductance was smallest. Typically, specific conductance at the three monitoring sites was largest at Wamego, especially when the relative contribution from the Smoky Hill Basin was large, followed by Topeka and then DeSoto.

Upstream sites on the Kansas River have the largest specific conductance values because of the inflow of large concentrations of chloride, sulfate, and other ions from the Smoky Hill River (Jordan and Stamer, 1995). Often the larger specific conductance values in river water upstream are diluted by less conductive tributary contributions and reservoir releases as water flows downstream, resulting in decreased specific conductance values (Jordan and Stamer, 1995). However, this upstream-to-downstream specific conductance decrease did not hold true in 2003. During 2003, the median specific conductance was nearly the same, from 669 to 689 µS/cm, at all three sites because it was a relatively dry year resulting in minimal dilution effects from uncontrolled tributaries in the downstream direction. Outflows from Milford, Tuttle Creek, Perry, and Clinton Lakes contributed about 53 percent of the total streamflow in the Kansas River at DeSoto in 2003 (table 2). A dilution effect also is evident during runoff when specific conductance typically decreases sharply in response to increasing streamflow. The inverse relation between specific conductance and streamflow often is less distinct when streamflow is affected by reservoir releases. Also, occasionally the decrease in specific conductance caused by dilution from tributaries is preceded by an abrupt increase just prior to the flood wave. The spike is very brief and may be caused by pressure from the flood wave pushing highly mineralized stream water originating from ground water in front of it, causing it to accumulate in the wave front (Hem, 1992). For the discrete samples collected during this study, specific conductance values ranged from 308 µS/cm at DeSoto to 1,790 µS/cm at Wamego. Median specific conductance values in the discrete samples ranged from 698 µS/cm at Topeka to 867 µS/cm at DeSoto (table 7).

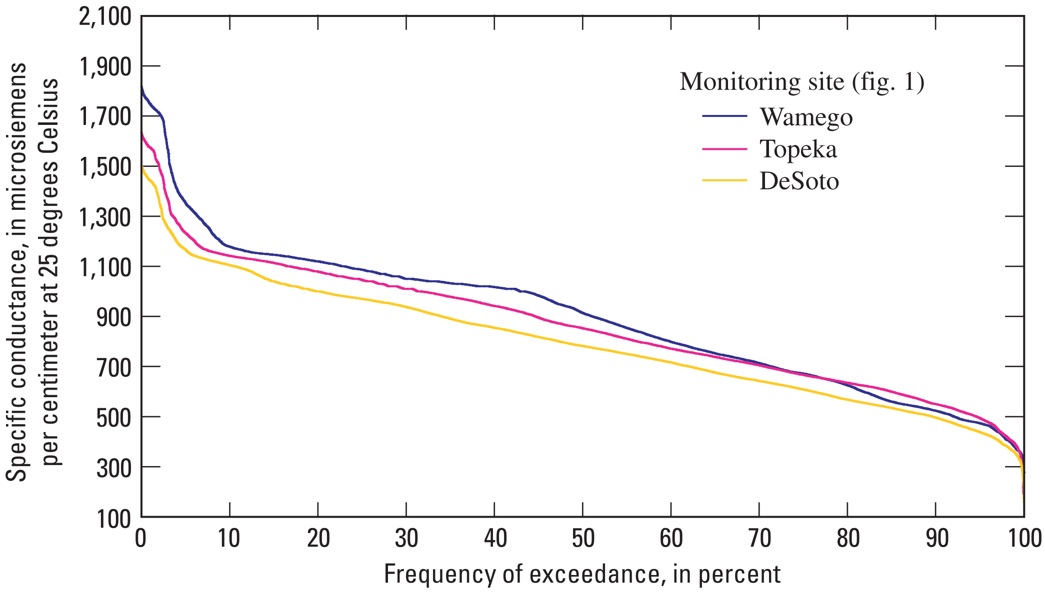


Figure 12. Duration curves for measured specific conductance at three Kansas River monitoring sites, January 2000 through December 2003.

pH

pH is a measure of the effective hydrogen ion concentration and is used as an index of the status of equilibrium reactions in water (Hem, 1992). Specifically, pH is the negative base-10 logarithm of hydrogen ion activity and is measured on a scale of 0 to 14. pH is an important factor in determining the solubility and biological availability of chemicals, and it affects the physiological functions of plants and animals. The pH of natural water generally ranges from 6.5 to 8.5 standard units (Hem, 1992). Kansas aquatic-life-support criteria require that pH levels in streams remain not less that 6.5 and not more than 8.5 standard units (Kansas Department of Health and Environment, 2001).

During the study period, minimum continuous pH measurements remained well above the lower criterion of 6.5 standard units (table 7), but pH measurements exceeded the upper criterion annually at each site at least 20 percent of the time except at Wamego in 2000 and 2001 when exceedance occurred less than 10 percent of the time (fig. 14). pH exceeded the upper criterion annually between 2 percent of the time (Wamego in 2001) and 65 percent of the time (DeSoto in 2003). Continuous pH values ranged from 7.0 standard units at Topeka in 2000 to 9.6 standard units, also at Topeka in 2003. During 2002 and 2003, the annual median pH value at all three sites was 8.4 or larger indicating that the upper criterion was exceeded almost 50 percent of the time at all three monitoring sites during those years.

Generally, large pH values occurred throughout the year but most frequently during late summer which is included in the July through October period (fig. 15). Diurnal variations in pH were minimal (about 0.2 standard unit) during winter and about 1.0 standard unit during the summer. pH is affected by photosynthetic activity. Photosynthesis uses up dissolved carbon dioxide, which results in a reduction in acidity so pH increases during daylight hours (Wetzel, 2001). Respiration produces carbon dioxide, which dissolves in water as carbonic acid thereby lowering pH at night when no photosynthesis occurs. Therefore, pH generally increases during daylight hours and during the growing season. Usually pH decreases and the diurnal variability decreases when streamflow and (or) turbidity increases. pH in discrete samples ranged from 7.3 standard units at DeSoto to 8.8 standard units at Topeka (table 7).

Water Temperature

Water temperature has an important effect on the density of water, the solubility of constituents in water, specific conductance, pH, the rate of chemical reactions, and biological activity in water (Radtke and others, 1998). Kansas water-quality criteria require that discharges to streams not raise the water temperature more than 3 °C or raise the temperature above 32 °C (Kansas Department of Health and Environment, 2003). Changes in water temperature in the Kansas River are caused primarily by climatic factors including air temperature and precipitation. Continuous water temperatures measured during the study period ranged from -0.2 °C, at the Wamego site in the winter 2001, to as high as 34.8 °C at the DeSoto site in 2002 (table 7). Daily temperature fluctuations ranged from about 2 to 6 °C throughout the year at each site. Generally, water temperatures were similar at all three sites during the study period and annually. The coldest water temperatures occurred from November through March, and the warmest water temperatures were from July through October (fig. 16).

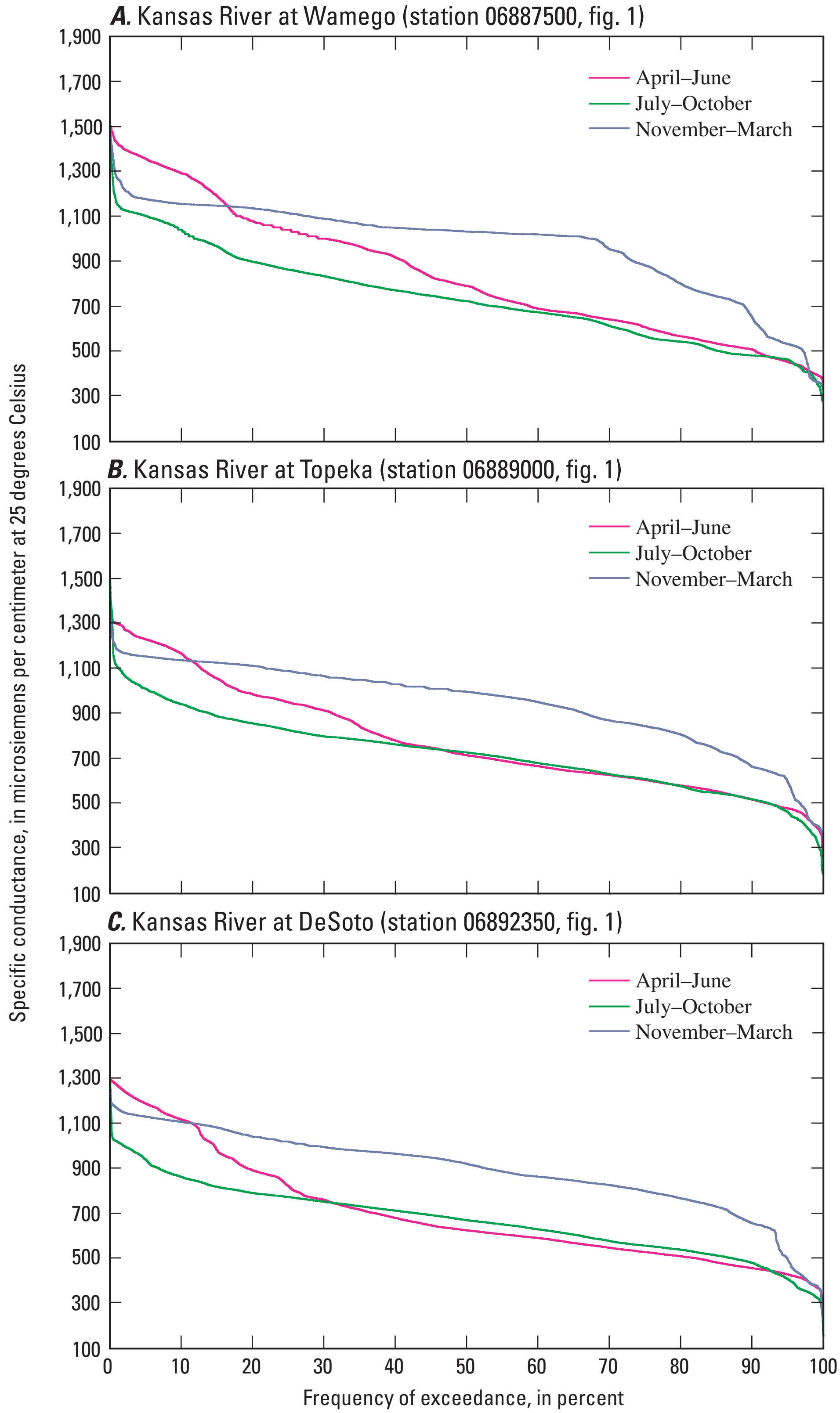


Figure 13. Seasonal duration curves for measured specific conductance at three Kansas River monitoring sites, January 2000 through December 2003.

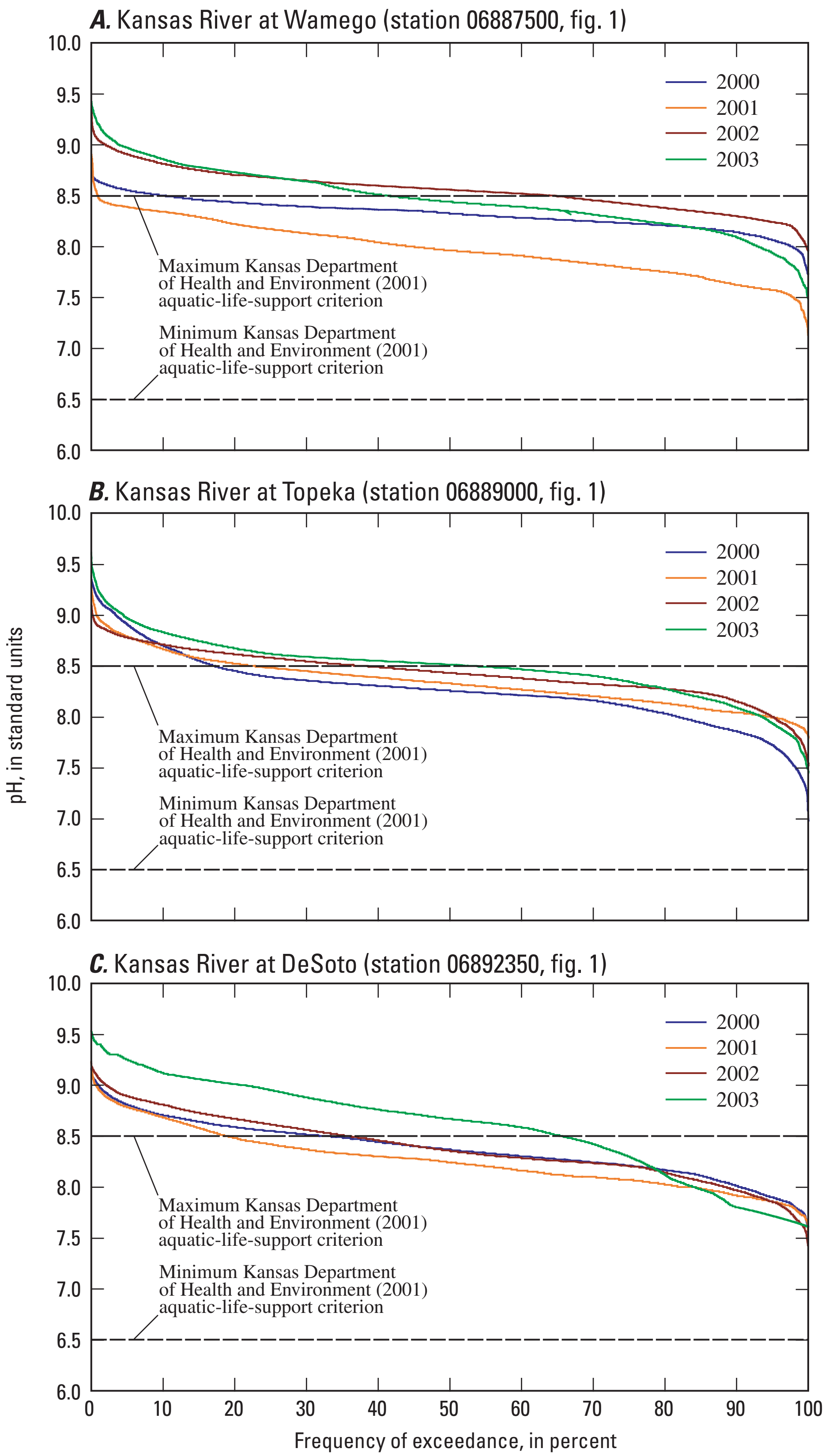


Figure 14. Annual duration curves for measured hourly pH at three Kansas River monitoring sites, January 2000 through December 2003.

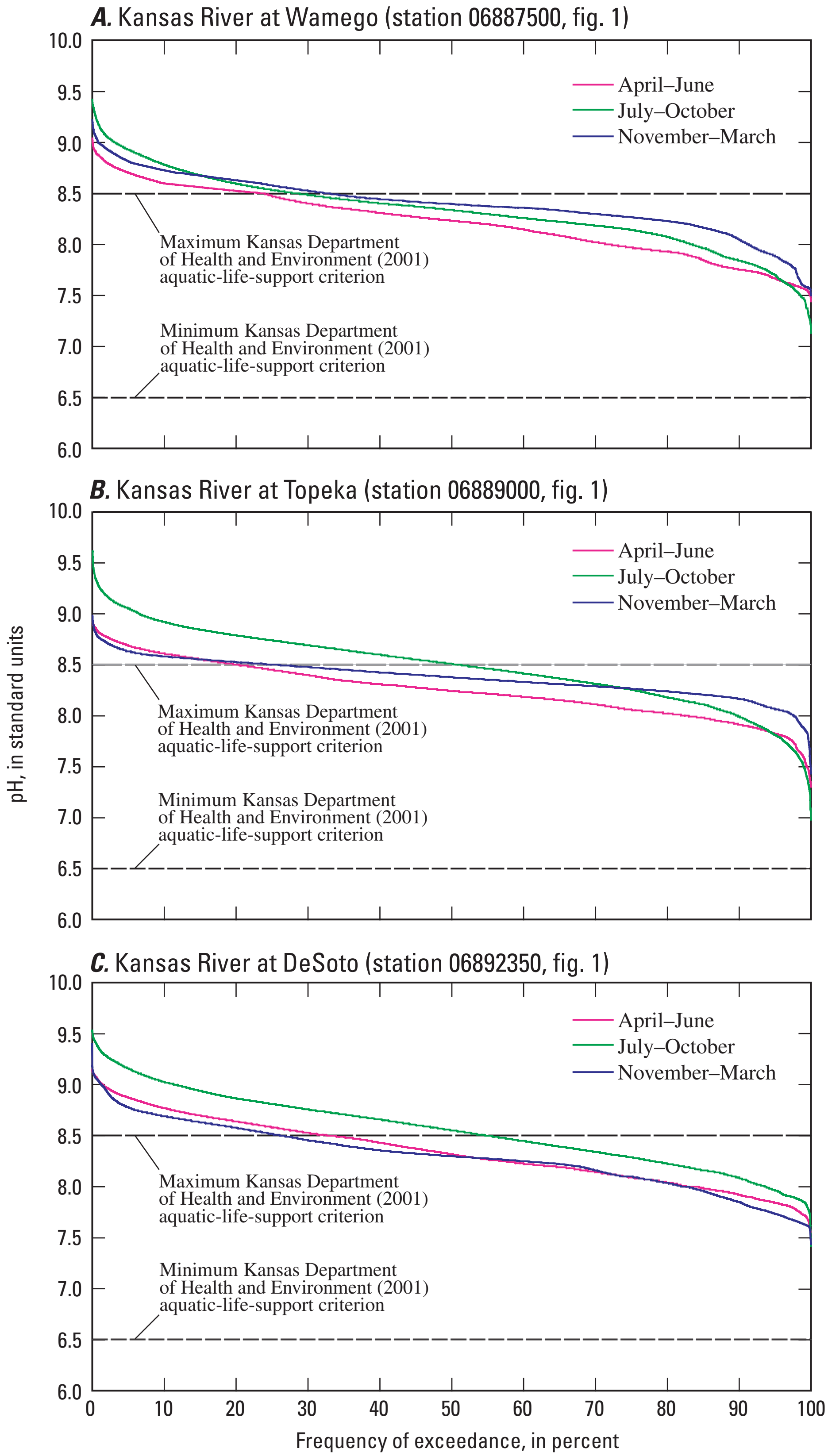


Figure 15. Seasonal duration curves and measured pH at three Kansas River monitoring sites, January 2000 through December 2003.

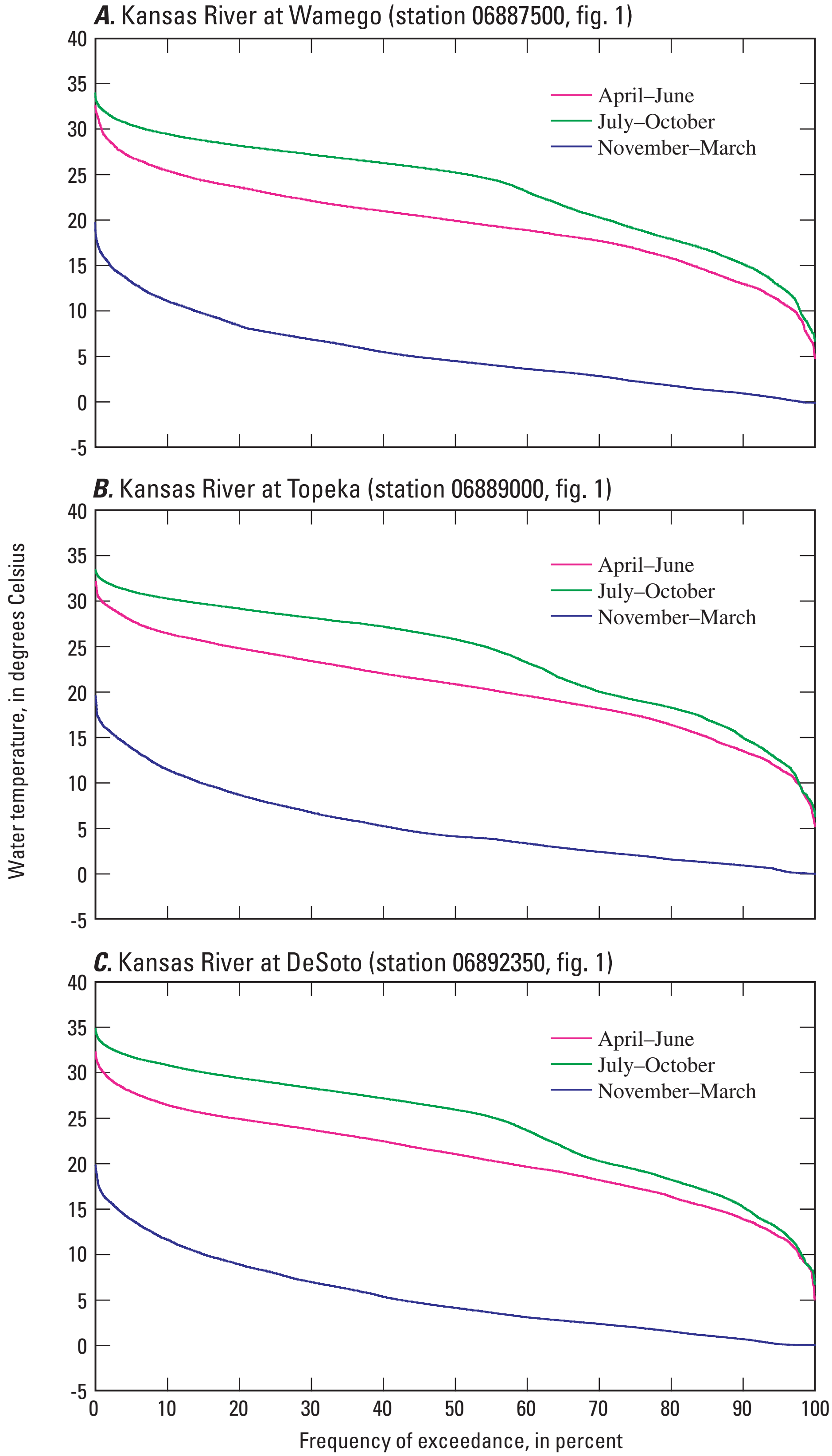


Figure 16. Seasonal duration curves for measured water temperature at three Kansas River monitoring sites, January 2000 through December 2003.

Turbidity

Turbidity, which can make water appear cloudy or muddy, is caused by the presence of suspended and dissolved matter such as clay, silt, finely divided organic matter, plankton and other microscopic organisms, organic acids, and dyes (ASTM International, 2003). Turbidity is affected by the amount of precipitation and runoff, intensity and duration of storms, slope of the river channel, geomorphic structure of the channel, origin of the water including point and nonpoint sources, and time of travel from the point of origin to the point of measurement. Although turbid water is not necessarily harmful, particulates in water provide attachment sites for nutrients, pesticides, bacteria, and other potential contaminants. Also, increased turbidity affects light penetration and reduces photosynthesis, smothers benthic habitats, and interferes with feeding activities. However, very large values of turbidity for short periods of time may be less harmful than smaller values that persist (Wetzel, 2001).

Continuous in-stream turbidity measurements ranged from less than 10 FNUs at each site to greater than 1,200 FNUs at each site annually (table 7). Measurement of turbidity in the discrete samples ranged from 11 FNU at Wamego to 1,600 FNU at DeSoto. As described in the “Methods” section, technological limitations of the sensors prevented measurements as large as the conditions that occurred. The upper range of measurement for the in-stream sensors varied from 1,200 to about 1,700 FNUs (table 7). Generally, turbidity was smallest at the upstream site, Wamego, and largest at the downstream site, DeSoto. Generally, turbidity at each site was largest in 2001 (fig. 17), which corresponded to the largest annual flow rates (fig. 10) and volume (table 8), and from April through June (fig. 18). At each site, the annual turbidity duration curves tend to diverge at exceedance frequencies less than about 70 percent (fig. 17), probably as a result of runoff occurrences. The divergent point may be a method of delineating base-flow conditions from runoff conditions. The smallest turbidity values occurred during base-flow (low-flow) conditions, and the largest turbidity values occurred during stormwater runoff.

Turbidity generally increased as stormwater runoff moved downstream from Wamego to DeSoto possibly because additional sediment was collected from the streambed and banks due to increased streamflow velocity and volume. Increased turbidity may be a result of more vulnerable soils and bank slopes in the downstream part of the basin. Furthermore, multiple turbidity peaks during the same storm indicate the sequence of tributary flow contributions. Often an increase in the frequency of turbidity peaks occurs moving downstream from Wamego to Topeka. Diurnal turbidity fluctuations, which may be caused by fluctuations in biological productivity (algal biomass) or by temperature changes that affect water density, were evident during low-flow periods.

Dissolved Oxygen

The dissolved oxygen (DO) concentration in surface water is related primarily to photosynthetic activity of aquatic plants and atmospheric reaeration (Radtke and others, 1998). It is a significant factor in chemical reactions and the survival of aquatic organisms. Kansas aquatic-life-support criterion require that DO concentrations are not less than 5.0 mg/L (Kansas Department of Health and Environment, 2001).

During the study period, continuous DO concentrations ranged from 3.8 mg/L at Topeka in 2003 to as much as 19.0 mg/L at DeSoto in 2003 (table 7). DO concentrations were less than the 5.0-mg/L criterion at at least one of the sites sometime during each year except 2001; however, DO concentrations less than 5.0 mg/L occurred less than 1 percent of the time (fig. 19). DO concentrations less than 5.0 mg/L occurred at all sites in 2002 and at Topeka and DeSoto in 2003 (table 7), and from April through June and July through October (fig. 20), which includes summer low-flow conditions. Largest DO concentrations occurred during winter because the solubility of oxygen is greater in colder water (Hem, 1992). The crossover of the seasonal April–June duration curves and July–October duration curves at each site (fig. 20) shows that more variability in DO occurs from July to October. Diurnal DO fluctuations were most extreme during summer when DO varied by as much as about 8 mg/L.

Large daily DO variations occur due to daily temperature fluctuations and alternating effects of photosynthesis, respiration, and decomposition. Oxygen is produced during photosynthesis, which requires sunlight and can only occur during the day. Oxygen is consumed during respiration and decomposition, which can occur any time of day or night. During the night when no photosynthesis is taking place to produce oxygen, DO declines until just before dawn when photosynthesis resumes. Discrete DO measurements for the study period ranged from 6.2 mg/L at DeSoto to 17.1 mg/L at Wamego.

Relations Between Streamflow, Specific Conductance, and Turbidity

Regression models using continuous measurements of streamflow, specific conductance, and turbidity at the three monitoring sites as both explanatory and response variables were developed to show the relation between the in-stream measurements and to compare relations from site to site (table 9). In addition, the models may be used to estimate values for periods when measured data are not available. For example, turbidity may be estimated at DeSoto using streamflow for periods prior to installation of the turbidity sensor if the associated uncertainty (R^2 of 0.53, indicating 53 percent of the variance in turbidity is explained by streamflow) is acceptable. In addition to the statistical uncertainty, application of these models and other models presented in this report to periods outside the period of study assumes that the relation between variables has not changed when, in fact, the relation could change over time.

Sensor measurements in table 9 may not be consistent with measurements in table 7 (and subsequent tables presenting regression models) because regression models require paired data values (collected concurrently), which do not exist for all

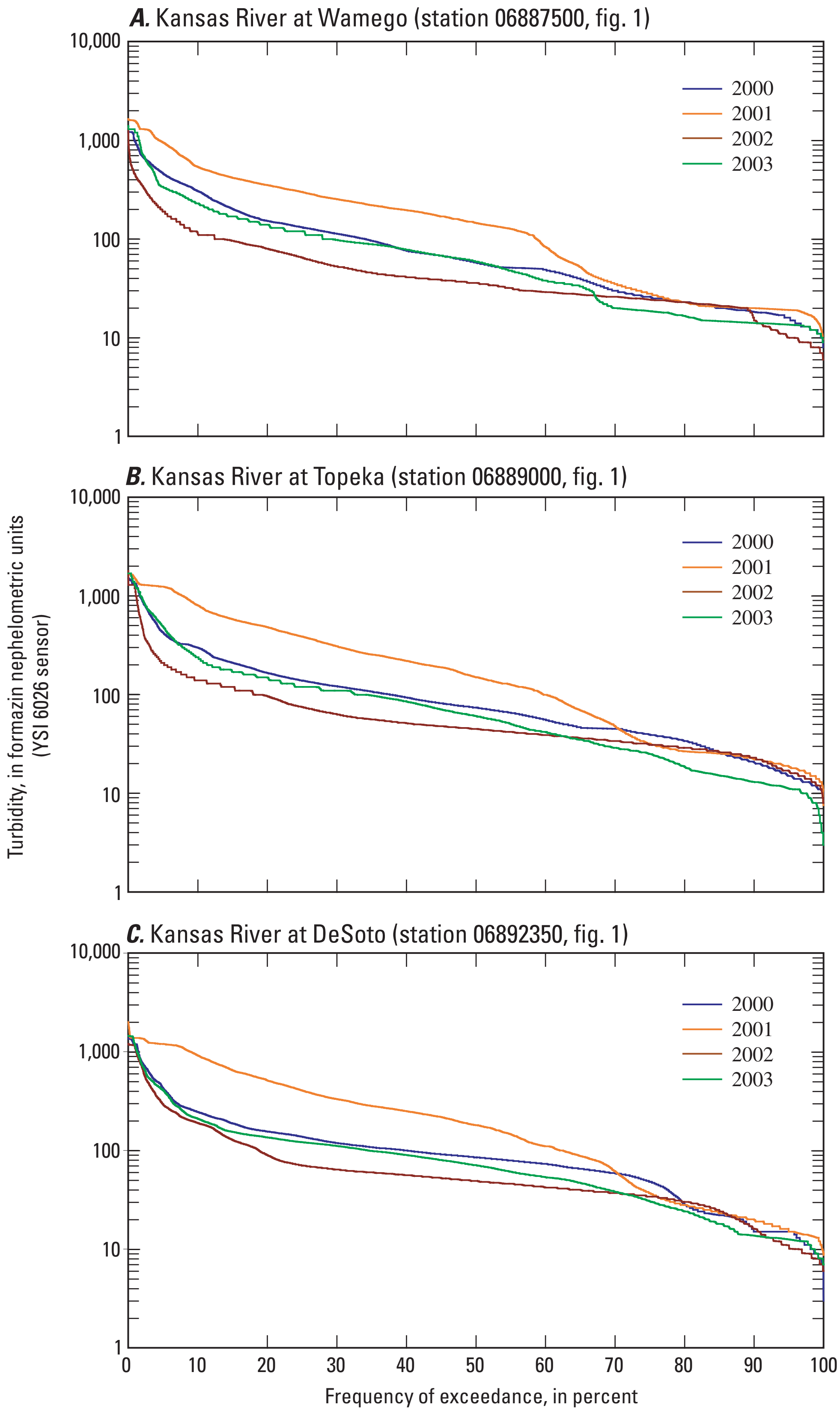


Figure 17. Annual duration curves for measured turbidity at three Kansas River monitoring sites, January 2000 through December 2003.

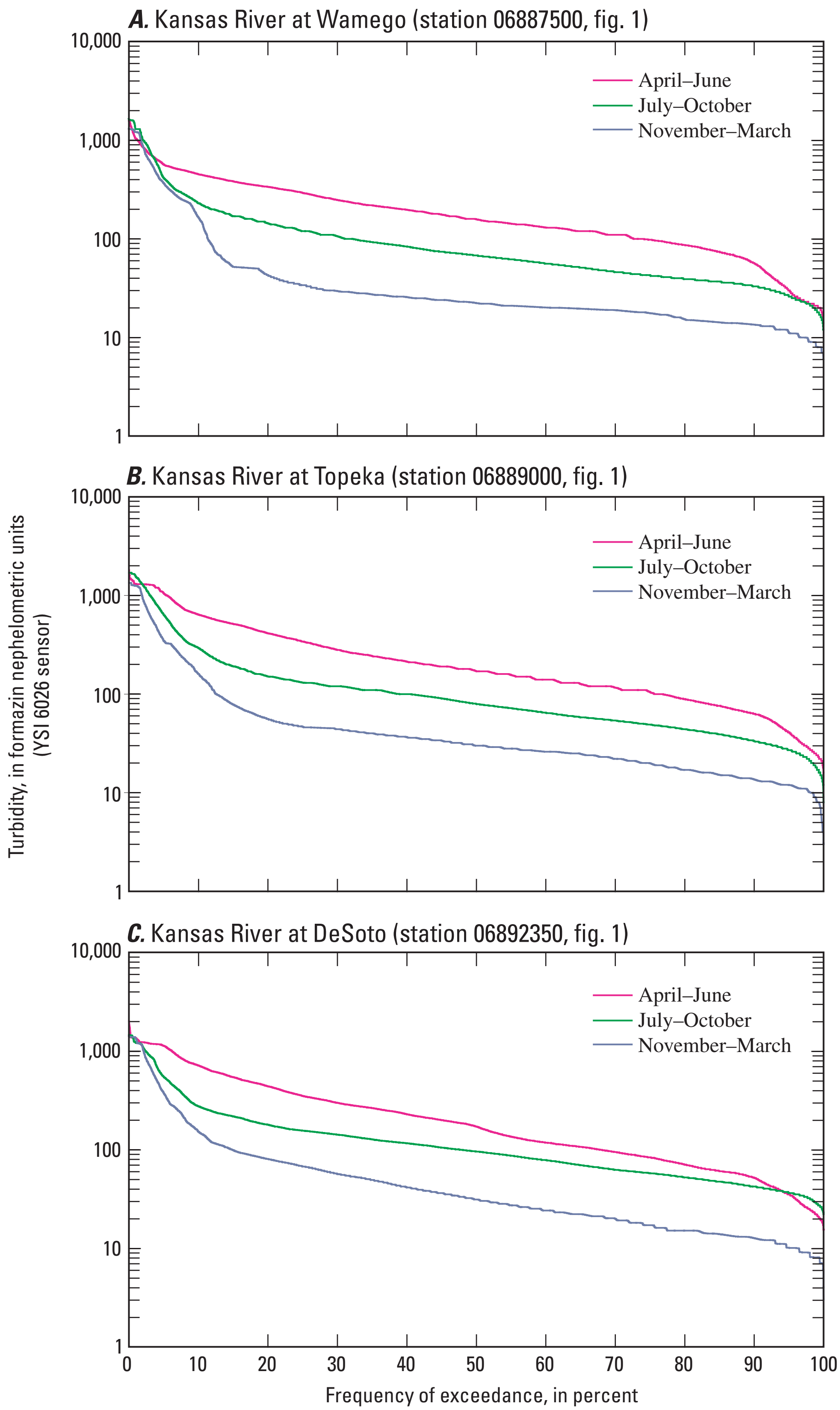


Figure 18. Seasonal duration curves for measured turbidity at three Kansas River monitoring sites, January 2000 through December 2003.

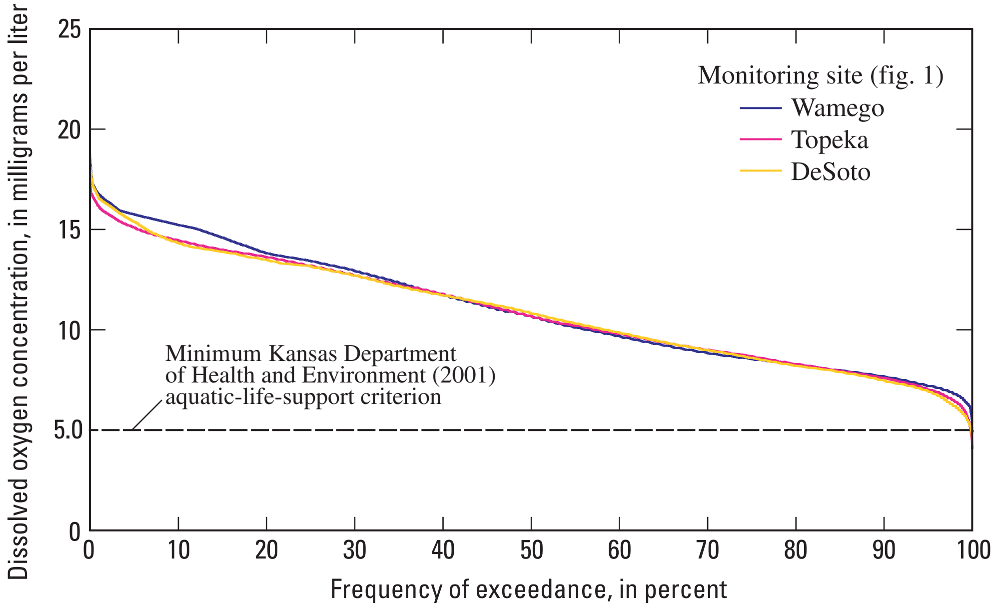


Figure 19. Duration curves for measured dissolved oxygen at three Kansas River monitoring sites, January 2000 through December 2003.

data points. For example, the minimum streamflow at Topeka during the study period (233 ft^3/s, table 7) occurred in February 2003. The continuous monitor was not deployed during that time because of winter weather conditions so there are no monitor data to pair with the streamflow measurements. The smallest streamflow value with concurrent specific conductance and turbidity measurements is 487 ft^3/s at Topeka (table 9). Also, table 7 includes some estimated hourly values, but no estimated values were used to develop regression models. Another reason that continuous data in table 7 may not match information summarized in the regression tables is that table 7 shows continuous data collected from January 2000 through December 2003, and regression models were developed using data collected from July 1999 through December 2003.

Specific conductance is inversely related to both streamflow and turbidity. The relation between specific conductance and streamflow is similar at all sites, with comparable slopes and intercepts and an R^2 ranging from 0.43 to 0.50 (table 9). The relation between specific conductance and turbidity, however, differs from site to site. Both the R^2 and slope increase downstream from Wamego (R^2 is 0.25 and slope is -1.74) to DeSoto (R^2 is 0.57 and slope is -3.01). The smaller R^2 upstream is probably caused by variability associated with the primary source of streamflow alternating between the Smoky Hill River, releases from Tuttle Creek Lake, and overland flow. The steeper slope at DeSoto is caused by generally smaller specific conductance and larger turbidity (table 7) at the downstream site.

Although the largest turbidity values occurred during stormwater runoff, peak turbidity values often did not coincide with peak discharge (fig. 6). The coefficient of determination (R^2) for a regression between turbidity and streamflow was calculated at between 0.52 and 0.60 (table 9), so about one-half to six-tenths of the variability in turbidity could be explained statistically by streamflow. A comparison of continuously measured streamflow and turbidity (fig. 21) shows a generally poor relation. Hysteresis effects can be seen in the curved patterns within the data plotted in figure 21. Hysteresis is caused by differences in turbidity during the rising and falling limbs of a streamflow peak (Ongley, 1996). An increase in streamflow causes an increase in turbidity from additional suspended material in the water. Because the amount of suspended material is somewhat limited, turbidity may decline even though streamflow continues to increase. Turbidity at a particular streamflow value may be much different when the streamflow is decreasing compared to when it is rising, resulting in a loop pattern when streamflow is plotted in relation to turbidity. Turbidity values may be larger during either the rising or falling limb of a streamflow peak, depending on the source of the suspended material. Sediment originating from the stream channel typically causes larger turbidity values as streamflow increases, and sediment originating from more distant basin sources may cause larger turbidity values as streamflow decreases (Asselman, 1999).

Regression-Estimated Constituent Concentrations, Densities, Loads, and Yields

In this section, the best available regression models for estimating 23 different water-quality constituents are presented and discussed. In addition, alternative models are evaluated and relations between various constituents discussed. Finally, regression-estimated concentrations, densities, loads, and

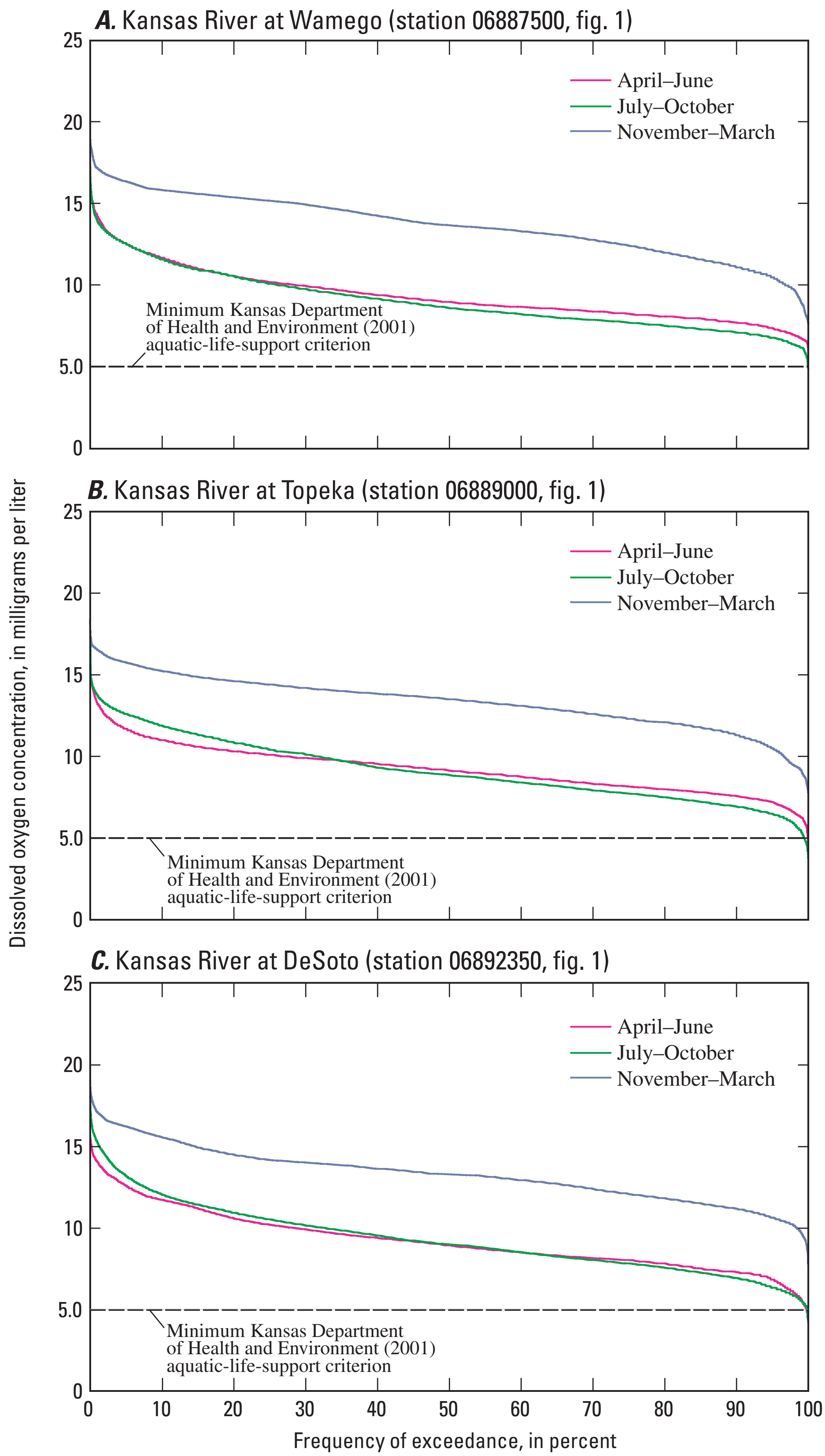


Figure 20. Seasonal duration curves for measured dissolved oxygen at three Kansas River monitoring sites, January through December 2003.

Table 9. Regression models and statistics showing relations between continuous sensor measurements at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003.

[R^2, coefficient of determination; MSE, mean square error; n, number of sensor measurements; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius (µS/cm); Q, streamflow, in cubic feet per second (ft^3/s); TBY, turbidity in formazin nephelometric units (FNU); --, not applicable]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias-correction factor (Duan, 1983)	Sensor measurements					
					n	Range in response variable	Range in explanatory variable	Mean	Median	Standard deviation
				Specific conductance (µS/cm) from streamflow (ft^3/s)						
Wamego	logSC = -0.288logQ + 3.84	0.46	0.0104	1.03	28,546	SC 277–1,510	--	822	796	250
						--	Q 505–31,100	2,890	1,940	3,520
Topeka	logSC = -0.236logQ + 3.68	.43	.0083	1.02	29,981	SC 189–1,500	--	802	786	210
						--	Q 487–44,500	3,100	2,030	3,670
DeSoto	logSC = -0.249logQ + 3.71	.50	.0078	1.02	30,832	SC 158–1,300	--	741	737	200
						--	Q 280–80,700	4,150	2,340	5,400
				Turbidity (FNU) from streamflow (ft^3/s)						
Wamego	logTBY = 1.06logQ - 1.61	.52	.114	1.43	28,246	TBY 6–1,620	--	152	71	226
						--	Q 505–31,100	2,890	1,940	3,520
Topeka	logTBY = 1.15logQ - 1.89	.60	.098	1.35	29,945	TBY 3–1,700	--	172	76	268
						--	Q 487–44,500	3,120	2,040	3,700
DeSoto	logTBY = 1.12logQ - 1.93	.53	.09	1.28	31,197	TBY 3–1,450	--	175	80	261
						--	Q 280–80,700	4,150	2,340	5,390
				Turbidity (FNU) from specific conductance (µS/cm)						
Wamego	logTBY = -1.74logSC + 6.93	.25	.186	1.70	27,804	TBY 6–1,620	--	152	71	226
						--	SC 277–1,510	822	796	250
Topeka	logTBY = -2.65logSC + 1.56	.41	.144	1.51	29,323	TBY 3–1,700	--	172	76	268
						--	SC 189–1,500	802	786	210
DeSoto	logTBY = -3.01logSC + 10.5	.57	.106	1.36	30,239	TBY 3–1,450	--	175	80	261
						--	SC 158–1,300	741	737	200
				Turbidity (FNU) from streamflow and specific conductance (µS/cm)						
Wamego	logTBY = 1.04logQ - 0.077logSC - 1.35	.52	.115	1.43	27,803	TBY 6–1,620	--	152	71	226
						--	Q 505–31,100	2,890	1,940	3,520
						--	SC 277–1,510	822	796	250
Topeka	logTBY = 0.919logQ - 0.972logSC + 1.66	.62	.09	1.30	29,322	TBY 3–1,700	--	172	76	268
						--	Q 487–44,500	3,090	2,030	3,370
						--	SC 189–1,500	802	786	210
DeSoto	logTBY = 0.75logQ - 1.52logSC + 3.69	.71	.071	1.21	30,198	TBY 3–1,450	--	175	80	261
						--	Q 280–80,700	4,150	2,340	5,400
						--	SC 158–1,300	741	737	200

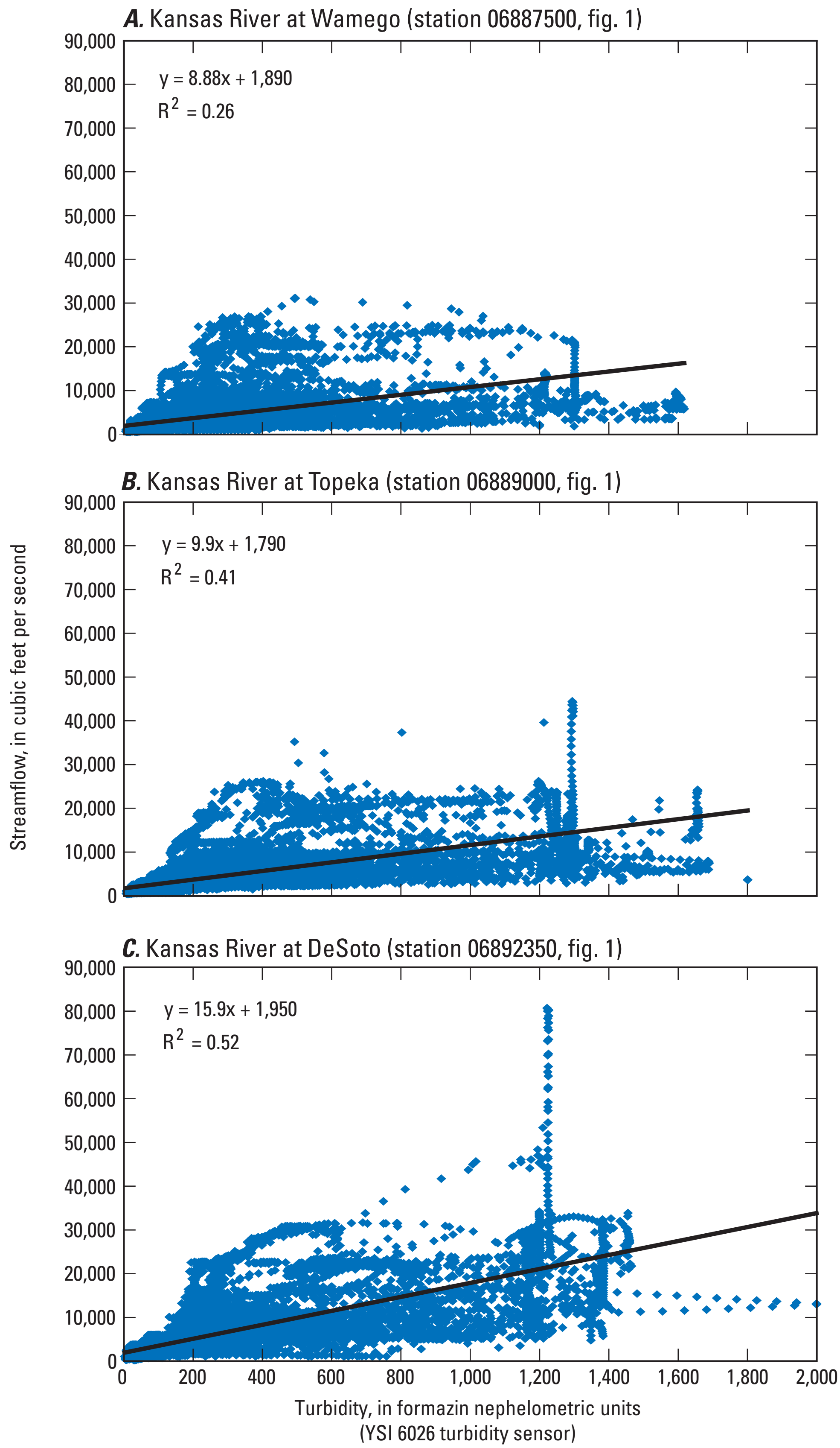


Figure 21. Comparison of continuously measured streamflow and turbidity at three Kansas River monitoring sites, January 2000 through December 2003.

yields for five selected constituents are presented and discussed. Concentrations and densities are presented using duration curves, and loads and yields are summarized in tables.

Regression models for estimating water-quality constituents are presented in table 10. Different models were provided for each Kansas River site, and models that combined data from the three sites also were developed for all constituents. Models were included in table 10 if at least one significant (p-value less than 0.05) explanatory variable was found. Equations in table 10 represent the best available models for estimating the listed constituents including the site-specific models used to estimate loads and yields in the "Comparison of Load Estimates" section of this report. Summaries of discrete-sample data in table 10 may not match summaries in table 7 because table 10 presents specific information for each constituent, generally a subset of the data in table 7.

Uncertainties associated with each model were evaluated on the basis of diagnostic statistics (R^2, coefficient of determination, and MSE, mean square error) and the range and distribution of discrete samples and continuous data. Uncertainties associated with each model varied because of the number of samples collected, water-quality conditions at the time of sample collection, cross-section variability during sample collection, sampling and analytical error, and strength of the relation (as measured by R^2 and MSE) between explanatory and response variables.

Specific conductance and turbidity were the most common explanatory variables used in the models. Specific conductance is the primary explanatory variable for models estimating major ions because of the strong relation between dissolved ions and conductivity. Turbidity was the primary explanatory variable for constituents associated with particulates, such as unfiltered nutrient species, bacteria, and suspended-sediment concentration. Most of the models used just one explanatory variable, and the same variable was used in the site-specific equations as was used in the combined equation.

Water-quality constituents with regression models having the least uncertainty (R^2 larger than 0.90, small MSE, and residual plots generally symmetric) included dissolved solids, magnesium, sodium, sulfate (with the exception of the model for the monitoring site at Wamego, which has an R^2 of 0.89), chloride, and suspended-sediment concentration (except for the DeSoto monitoring site with an R^2 of 0.88). An R^2 value greater than 0.90 indicates that at least 90 percent of the variance in the response variable is accounted for by the explanatory variable. Total nitrogen and total phosphorus have R^2 values between 0.57 and 0.85. The indicator bacteria (*E. coli*, fecal coliform, and enterococci) have R^2 values between 0.52 and 0.71.

Graphs comparing the explanatory variable to the response variable for dissolved-solids, total nitrogen, total phosphorus, *E. coli* bacteria, and suspended-sediment concentration or density models are shown in figure 22. For each constituent, a regression line is shown for each individual monitoring site along with a regression line for the model using combined data from all the sites. The 90-percent prediction interval applies to the regression line for the model using combined data. Of the constituents shown, models with the least variability, within as well as between sites, are for dissolved solids. Analysis of covariance indicated that the regression lines and slopes for suspended sediment were significantly different from site to site. Regressions for dissolved solids, however, may not be significantly different, so the regression model developed by combining data from the three monitoring sites (table 10) may be as accurate for estimating dissolved-solids concentrations as the site-specific models. A notable slope difference between site models exists for *E. coli* bacteria density and suspended-sediment concentration. For *E. coli* bacteria, the flatter slope associated with the Wamego model indicates that at small turbidity values (less than about 100 FNUs) the corresponding *E. coli* density at Wamego is larger than at the other two sites, and at larger turbidity values, Wamego *E. coli* densities are smaller than at the other sites. For suspended-sediment concentration, the regression line for the Topeka model is steeper than the regression lines for the other two sites, indicating that when turbidity is greater than about 50 FNUs, the corresponding suspended-sediment concentration at Topeka is larger than the concentrations at the other two sites.

Additional regression models included in tables 11 and 12 show statistical relations between various water-quality measurements and constituents. Regression models in table 11 use streamflow data, rather than turbidity or specific conductance, to estimate some of the same water-quality constituents presented in table 10. Site data were combined for simplification. The models in tables 11 and 12 are presented to demonstrate the statistical relation between particular variables and to provide alternative estimation models to those presented in table 10. Generally, the R^2 values are smaller and the MSE values are larger in tables 11 and 12 than in table 10, indicating that the table 10 models are better. When comparing R^2 and error values for different models, it is evident that turbidity is a better explanatory variable for sediment-associated constituents than streamflow, resulting in improved estimates. Regression models shown in table 12 demonstrate the strong statistical relations between suspended-sediment concentration and constituents associated with particulates (total nitrogen and phosphorus, bacteria, total suspended solids).

In describing the results of data analysis in this report, dissolved solids, total nitrogen, total phosphorus, *E. coli* bacteria, and suspended sediment are discussed in detail because they represent constituents of particular concern to KDHE within the study area. Estimated concentration, density, and load duration data for additional constituents not discussed in this section are presented in appendixes 1 and 2, respectively. As described in the "Methods" section, concentration, density, load, and yield information for the five constituents just listed include estimated data during periods of missing record. No attempt was made, however, to estimate data during periods of missing record for the additional constituents presented in the appendixes.

Seasonal comparisons of concentration, density, and load data were made by grouping the data according to three different seasons, spring (April through June, which includes

Table 10. Regression models and statistics for estimating selected constituent concentrations and densities in water at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003.

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; µg/L, micrograms per liter; ( ), number of values in sample set that were less than the detection limit; log, refers to $\log_{10}$; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); WT, water temperature, in degrees Celsius (°C); TBY, turbidity, in formazin nephelometric units (FNUs); --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias-correction factor (Duan, 1983)	Discrete sample results					
					n	Range in response variable	Range in explanatory variable	Mean	Median	Standard deviation
					Acid neutralizing capacity, (ANC) unfiltered, field, mg/L as $CaCO_3$					
Wamego	logANC = 0.568logSC+0.582	0.68	0.0036	1.01	17(0)	ANC 120–258	--	179	178	43
						--	SC 503–1,790	890	872	322
Topeka	logANC =0.516logSC+0.746	.76	.00245	1.01	17(0)	ANC 111–240	--	172	161	39
						--	SC 416–1,580	792	725	308
DeSoto	logANC = 0.508logSC+0.767	.66	.00329	1.01	21(0)	ANC 108–249	--	182	189	38
						--	SC 347–1,430	885	933	275
Combined	logANC = 0.524logSC+0.718	.69	.00294	1.01	55(0)	ANC 108–258	--	178	178	39
						--	SC 347–1,790	856	872	298
					Dissolved solids (DS), mg/L					
Wamego	logDS = 0.938logSC-0.034	.96	.00101	1.00	20(0)	DS 278–1,010	--	512	475	183
						--	SC 448–1,790	844	790	322
Topeka	logDS =0.978logSC-0.156	.99	.00042	1.00	22(0)	DS 238–900	--	462	417	180
						--	SC 361–1,580	768	698	307
DeSoto	logDS = 0.966logSC-0.115	.99	.00026	1.00	26(0)	DS 186–848	--	486	534	186
						--	SC 308–1,430	799	890	315
Combined	logDS =0.964logSC-0.113	.98	.00051	1.00	68(0)	DS 186–1,010	--	486	468	182
						--	SC 308–1,790	802	777	311
					Calcium (Ca), dissolved, mg/L					
Wamego	logCa = 0.787logSC-0.465	.94	.00105	1.00	20(0)	Ca 35–114	--	68	64	20
						--	SC 448–1,790	844	790	322
Topeka	logCa = 0.704logSC-0.218	.87	.00231	1.01	21(0)	Ca 40–101	--	64	57	20
						--	SC 361–1,580	756	671	309
DeSoto	logCa = 0.730logSC-0.287	.87	.00294	1.01	26(0)	Ca 34–105	--	67	68	21
						--	SC 308–1,430	795	842	314
Combined	logCa = 0.733logSC-0.300	.89	.00211	1.01	67(0)	Ca 34–114	--	66	63	20
						--	SC 308–1,790	797	776	312

Table 10. Regression models and statistics for estimating selected constituent concentrations and densities in water at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003—Continued

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; µg/L, micrograms per liter; ( ), number of values in sample set that were less than the detection limit; log, refers to $\log_{10}$; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); WT, water temperature, in degrees Celsius (°C); TBY, turbidity, in formazin nephelometric units (FNUs); --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias-correction factor (Duan, 1983)	Discrete sample results					
					n	Range in response variable	Range in explanatory variable	Mean	Median	Standard deviation
Magnesium (Mg), dissolved, mg/L										
Wamego	logMg = 0.912logSC-1.46	0.92	0.00176	1.00	20(0)	Mg 7.9–30	--	17	16	5.5
						--	SC 448–1,790	844	790	322
Topeka	logMg = 0.855SC-1.27	.97	.00078	1.00	21(0)	Mg 8.–30		15	15	5.5
						--	SC 361–1,580	756	671	309
DeSoto	logMg = 0.954logSC-1.54	.97	.00111	1.00	26(0)	Mg 6.7–28	--	17	17	6.4
							SC 308–1,430	795	842	314
Combined	logMg = 0.906logSC-1.42	.95	.00142	1.00	67(0)	Mg 6.7–30		16	15	5.8
						--	SC 308–1,790	797	776	312
Sodium (Na), dissolved, mg/L										
Wamego	logNa = 1.46logSC-2.39	.99	.00062	1.00	19(0)	Na 30–206	--	79	66	42
						--	SC 448–1,790	862	803	321
Topeka	logNa = 1.53logSC-2.63	.97	.0025	1.01	21(0)	Na 16–178	--	64	51	39
						--	SC 361–1,580	756	671	309
DeSoto	logNa = 1.49logSC-2.51	.96	.0039	1.01	26(0)	Na 14–160	--	68	72	38
						--	SC 308–1,430	795	842	314
Combined	logNa = 1.50logSC-2.53	.96	.0025	1.01	66(0)	Na 14–206	--	70	71	40
						--	SC 308–1,790	802	777	312
Sulfate (SO4), dissolved, mg/L										
Wamego	logSO4 = 1.05logSC-1.05	.89	.00357	1.01	20(0)	SO4 42–222	--	106	103	42
						--	SC 448–1,790	844	790	322
Topeka	logSO4 = 1.12logSC-1.28	.97	.00126	1.00	22(0)	SO4 40–197	--	94	80	42
						--	SC 361–1,580	768	698	307
DeSoto	logSO4 = 1.24logSC-1.57	.97	.00198	1.00	27(0)	SO4 33–189	--	110	126	49
						--	SC 308–1,430	799	867	309
Combined	logSO4 = 1.16logSC-1.36	.94	.00261	1.01	69(0)	SO4 33–222	--	104	103	45
						--	SC 308–1,790	802	778	309

Table 10. Regression models and statistics for estimating selected constituent concentrations and densities in water at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003—Continued

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; µg/L, micrograms per liter; ( ), number of values in sample set that were less than the detection limit; log, refers to log_{10}; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); WT, water temperature, in degrees Celsius (°C); TBY, turbidity, in formazin nephelometric units (FNUs); --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias-correction factor (Duan, 1983)	Discrete sample results					
					n	Range in response variable	Range in explanatory variable	Mean	Median	Standard deviation
				Chloride (Cl), dissolved, mg/L						
Wamego	logCl = 1.60logSC-2.73	0.97	0.00169	1.00	19(0)	Cl 33–312	--	101	85	64
						--	SC 448–1,790	861	803	321
Topeka	logCl = 1.74logSC-3.14	.97	.00316	1.00	22(0)	Cl 20–260	--	85	75	56
						--	SC 361–1,580	768	698	307
DeSoto	logCl = 1.66logSC-2.93	.95	.00552	1.01	27(0)	Cl 14–229	--	84	86	52
						--	SC 308–1,430	799	867	309
Combined	logCl = 1.68logSC-2.97	.96	.00379	1.01	68(0)	Cl 14–312	--	88	85	57
						--	SC 308–1,790	807	790	309
				Fluoride (F), dissolved, mg/L						
Wamego	logF = 0.170logSC-0.98	.23	.0025	1.01	20(0)	F 0.2–0.4	--	.3	.3	.04
						--	SC 448–1,790	844	790	322
Topeka	logF = 0.217logSC-1.10	.62	.00091	1.00	21(0)	F 0.3–0.4	--	.3	.3	.04
						--	SC 361–1,580	756	671	309
DeSoto	logF = 0.162logSC-0.97	.45	.0013	1.00	26(0)	F 0.2–0.4	--	.3	.3	.03
						--	SC 308–1,430	795	842	314
Combined	logF = 0.179logSC-1.01	.40	.00152	1.00	67(0)	F 0.2–0.4	--	.3	.3	.04
						--	SC 308–1,790	797	776	312
				Nitrate as nitrogen, dissolved, mg/L						
Wamego	NO3 = 1.03logQ-0.334logWT-2.33	.69	.0982	1.00	19(0)	NO3 0.04–1.8	--	.87	.85	.53
						--	Q 643–23,000	4,280	2,270	5,550
						--	WT 0.1–28.3	14.4	18.2	9.7
Topeka	NO3 = 0.797logQ-0.298logWT-1.73	.57	.1301	1.00	27(0)	NO3 <0.01–1.8	--	.63	.60	.53
						--	Q 681–21,000	2,640	1,400	5,860
						--	WT 0.1–31.0	16.8	17.2	9.8
DeSoto	NO3 = 0.644logQ-0.612logWT-1.15	.71	.0602	1.00	33(0)	NO3 0.01–1.4	--	.4	.25	.44
						--	Q 949–79,000	7,200	2,630	14,000
						--	WT 0.1–31.4	20	21	8.7
Combined	NO3=0.716logQ-0.442logWT-1.40	.53	.1326	1.00	79(0)	NO3 0.01–1.8	--	.59	.54	.53
						--	Q 643–79,000	5,500	2,270	10,000
						--	WT 0.1–31.4	18.3	19.1	9.6

Table 10. Regression models and statistics for estimating selected constituent concentrations and densities in water at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003—Continued

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; µg/L, micrograms per liter; ( ), number of values in sample set that were less than the detection limit; log, refers to log_{10}; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); WT, water temperature, in degrees Celsius (°C); TBY, turbidity, in formazin nephelometric units (FNUs); --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias-correction factor (Duan, 1983)	Discrete sample results					
					n	Range in response variable	Range in explanatory variable	Mean	Median	Standard deviation
Nitrite plus nitrate as nitrogen (N+N), dissolved, mg/L										
Wamego	N+N = 1.09logQ-0.397logWT-2.53	0.66	0.121	1.00	21(2)	N+N <0.01–1.8	--	0.81	0.85	0.57
						--	Q 643–23,000	4,070	2,270	5,320
						--	WT 0.1–28.3	15	18	9.8
Topeka	N+N = 0.742logQ-0.329logWT-1.54	.49	.1605	1.00	28(3)	N+N <0.01–1.8	--	.62	.60	.54
						--	Q 681–21,000	4,370	1,470	5,760
						--	WT 0.1–31.0	16.8	17.2	9.80
DeSoto	N+N = 0.914logQ-0.541logWT-2.04	.69	.0976	1.00	34(10)	N+N <0.01–1.6	--	.54	.34	.54
						--	Q 949–79,000	7,160	2,880	13,800
						--	WT 0.1–31.4	20.0	21.2	8.6
Combined	N+N = 0.855logQ-0.435logWT-1.84	.57	.1335	1.00	83(15)	N+N <0.01–1.8	--	.63	.62	.55
						--	Q 643–79,000	5,430	2,430	9,810
						--	WT 0.1–31.4	17.6	19.1	9.45
Nitrogen, ammonia (NH3), dissolved, mg/L										
Wamego	logNH3 = 0.462logTBY-0.295logWT-2.20	.51	.0485	1.11	19(12)	NH3 <0.02–0.14	--	.04	.04	.03
						--	TBY 11–1,020	168	65	240
						--	WT 0.1–28.3	16	18	9.8
Topeka	logNH3 = 0.305logTBY-0.329logWT-1.98	.51	.0506	1.14	28(17)	NH3 <0.02–0.23	--	.04	.04	.04
						--	TBY 12–1,450	251	59	369
						--	WT 0.1–31.0	16.8	17.2	9.8
DeSoto	logNH3 = 0.158logTBY-0.693logWT-1.31	.58	.0743	1.30	34(20)	NH3 <0.02–0.26	--	.04	.02	.05
						--	TBY 11–1,600	215	65	335
						--	WT 0.1–31.4	20.0	21.2	8.6
Combined	logNH3 = 0.280logTBY-0.401logWT-1.85	.38	.0794	1.28	81(49)	NH3 <0.02–0.26	--	.04	.03	.04
						--	TBY 11–1,600	215	65	335
						--	WT 0.1–31.4	18	19	9.7

Table 10. Regression models and statistics for estimating selected constituent concentrations and densities in water at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003—Continued

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; µg/L, micrograms per liter; ( ), number of values in sample set that were less than the detection limit; log, refers to log_{10}; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); WT, water temperature, in degrees Celsius (°C); TBY, turbidity, in formazin nephelometric units (FNUs); --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias-correction factor (Duan, 1983)	Discrete sample results					
					n	Range in response variable	Range in explanatory variable	Mean	Median	Standard deviation
				Nitrogen, ammonia plus organic, dissolved (DKN), mg/L						
Wamego	logDKN = -0.739logSC+1.75	0.57	0.011	1.03	21(0)	DKN 0.22–1.1	--	0.42	0.36	0.20
						--	SC 448–1,790	890	838	334
Topeka	logDKN = -0.379logSC+0.642	.53	.00429	1.01	27(0)	DKN 0.23–0.57	--	.38	.38	.08
						--	SC 310–1,580	784	778	307
DeSoto	No model	--	--	--	34(0)	DKN 0.10–0.59	--	.35	.34	.09
Combined	No model	--	--	--	82(0)	DKN 0.10–1.1	--	.38	.36	.12
				Nitrogen, ammonia plus organic, total (TKN), mg/L						
Wamego	logTKN = 0.283logTBY-0.518	.59	.0204	1.05	19(0)	TKN 0.44–3.7	--	1.2	1.1	.75
						--	TBY 11–1,020	182	65	251
Topeka	logTKN = 0.287logTBY-0.499	.66	.0148	1.03	24(0)	TKN 0.55–3.6	--	1.3	1.3	.69
						--	TBY 12–1,450	251	59	369
DeSoto	logTKN = 0.198logTBY-0.309	.44	.014	1.01	28(0)	TKN 0.54–3.0	--	1.3	1.2	.54
						--	TBY 11–1,600	215	65	335
Combined	logTKN = 0.256logTBY-0.438	.56	.0156	1.04	72(0)	TKN 0.44–3.7	--	1.3	1.2	.64
						--	TBY 11–1,600	220	64	326
				Nitrogen, total (TN), mg/L						
Wamego	logTN = 0.237logTBY-0.179	.71	.0083	1.02	17(2)	TN 1.1–4.6	--	2.0	1.8	.88
						--	TBY 11–1,020	182	65	251
Topeka	logTN = 0.268logTBY-0.281	.72	.0097	1.02	24(3)	TN 1.2–4.4	--	2.0	1.6	.95
						--	TBY 33–1,450	251	59	369
DeSoto	logTN = 0.239logTBY-0.263	.57	.0138	1.04	28(10)	TN 1.0–4.6	--	1.9	1.5	.89
						--	TBY 11–1,600	266	78	392
Combined	logTN = 0.242logTBY-0.236	.62	.0116	1.03	69(15)	TN 1.0–4.6	--	1.9	1.6	.90
						--	TBY 11–1,600	240	65	350

Table 10. Regression models and statistics for estimating selected constituent concentrations and densities in water at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003—Continued

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; µg/L, micrograms per liter; ( ), number of values in sample set that were less than the detection limit; log, refers to log_{10}; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); WT, water temperature, in degrees Celsius (°C); TBY, turbidity, in formazin nephelometric units (FNUs); --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias-correction factor (Duan, 1983)	Discrete sample results					
					n	Range in response variable	Range in explanatory variable	Mean	Median	Standard deviation
				Phosphorus, total (TP), mg/L						
Wamego	logTP = 0.368logTBY-1.20	0.85	0.0086	1.02	17(0)	TP 0.12–1.1	--	0.36	0.30	0.23
						--	TBY 11–1,020	182	65	251
Topeka	logTP = 0.392logTBY-1.26	.83	.011	1.03	23(0)	TP 0.16–1.2	--	.42	.26	.29
						--	TBY 12–1,450	261	63	374
DeSoto	logTP = 0.335logTBY-1.17	.68	.0149	1.04	29(0)	TP 0.18–1.1	--	.36	.26	.24
						--	TBY 11–1,600	215	65	335
Combined	logTP =0.364logTBY-1.21	.78	.0118	1.03	69(0)	TP 0.12–1.2	--	.38	.26	.25
						--	TBY 11–1,600	222	65	327
				Boron (B), dissolved, µg/L						
Wamego	logB = 0.723logSC-0.177	.92	.00101	1.00	19(0)	B 52–144	--	87	90	23
						--	SC 448–1,790	862	803	321
Topeka	logB = 0.727logSC-0.172	.89	.00212	1.01	22(0)	B 47–138	--	83	82	24
						--	SC 361–1,580	768	698	307
DeSoto	logB = 0.793logSC-0.355	.89	.00308	1.01	26(0)	B 38–155	--	88	89	31
						--	SC 308–1,430	794	842	314
Combined	logB = 0.749logSC-0.236	.89	.00223	1.01	67(0)	B 38–155	--	86	86	27
						--	SC 308–1,790	802	777	312
				Triazine herbicide (TRI), µg/L as atrazine						
Wamego	logTRI = -0.186cos(2*pi*day/365)-0.0434sin(2*pi*day/365)-0.135	.20	.0741	1.00	48(0)	TRI 0.11–8.2	--	.99	.79	1.2
						--	SC 448–1,790	942	931	291
Topeka	logTRI = -0.576logSC-0.254cos(2*pi*day/365)-0.0294sin(2*pi*day/365)+1.58	.50	.0603	1.18	55(0)	TRI 0.23–8.7	--	1.2	.87	1.3
						--	SC 310–1,580	824	889	294
DeSoto	logTRI = -0.699logSC-0.239cos(2*pi*day/365)-0.0098sin(2*pi*day/365)+1.89	.50	.0796	1.24	41(0)	TRI 0.19–13	--	1.4	.89	2.3
						--	SC 166–1,430	778	783	316
Combined	logTRI = -0.627logSC0.215cos(2*pi*day)-0.0313sin(2*pi*365)+1.71	.42	.0676	1.21	144(0)	TRI 0.11–13	--	1.2	.80	1.6
						--	SC 166–1,790	850	882	305

Table 10. Regression models and statistics for estimating selected constituent concentrations and densities in water at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003—Continued

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; µg/L, micrograms per liter; ( ), number of values in sample set that were less than the detection limit; log, refers to log_{10}; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); WT, water temperature, in degrees Celsius (°C); TBY, turbidity, in formazin nephelometric units (FNUs); --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias-correction factor (Duan, 1983)	Discrete sample results					
					n	Range in response variable	Range in explanatory variable	Mean	Median	Standard deviation
				E. coli bacteria (ECB), colonies per 100 milliliters						
Wamego	logECB = 1.15logTBY-0.425	0.54	0.324	2.32	52(0)	ECB <2–5,200	--	319	67	776
						--	TBY 11–1,200	187	78	258
Topeka	logECB = 1.62logTBY-1.38	.56	.516	4.56	59(0)	ECB <2–22,000	--	1,580	77	4,310
						--	TBY 12–1,450	232	89	303
DeSoto	logECB = 1.55logTBY-1.16	.71	.3354	2.33	50(0)	ECB <2–20,000	--	1,360	61	3,400
						--	TBY 9–1,600	279	80	402
Combined	logECB = 1.45logTBY-0.992	.59	.4036	3.18	161(0)	ECB <2–22,000	--	1,070	61	3,250
						--	TBY 9–1,600	222	81	316
				Fecal coliform bacteria (FCB), colonies per 100 milliliters						
Wamego	logFCB = 1.19logTBY-0.448	.62	.26	2.04	56(0)	FCB <2–11,000	--	516	74	1,620
						--	TBY 11–1,200	196	95	259
Topeka	logFCB = 1.42logTBY-0.89	.52	.486	3.85	65(0)	FCB <2– 21,000	--	1,320	100	3,600
						--	TBY 12–1,450	248	114	301
DeSoto	logFCB = 1.53logTBY-1.05	.68	.351	2.24	54(0)	FCB <2–12,000	--	1,330	130	2,750
						--	TBY 9–1,600	270	95	376
Combined	logFCB = 1.39logTBY-0.802	.60	.3701	2.77	175(0)	FCB <2–21,000	--	1,070	93	2,840
						--	TBY 9–1,600	238	101	314
				Enterococci (ENT) bacteria, colonies per 100 milliliters						
Wamego	logENT = 1.35logTBY+0.048	.60	.461	3.52	26(0)	ENT 15–165,000	--	10,300	385	34,200
						--	TBY 17–1,210	227	90	314
Topeka	logENT = 1.51logTBY-0.374	.54	.588	3.86	37(0)	ENT 8–100,000	--	7,880	800	18,400
						--	TBY 21–1,450	279	149	338
DeSoto	logENT = 1.64logTBY-0.768	.67	.497	2.91	16(0)	ENT 12–41,000	--	7,470	1,060	13,600
						--	TBY 21–1,220	358	223	408
Combined	logENT = 1.46logTBY-0.250	.58	.511	3.62	79(0)	ENT 8–165,000	--	8,560	540	23,500
						--	TBY 17–1,450	278	149	343

Table 10. Regression models and statistics for estimating selected constituent concentrations and densities in water at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003—Continued

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; µg/L, micrograms per liter; ( ), number of values in sample set that were less than the detection limit; log, refers to $\log_{10}$; SC, specific conductance, in microsiemens per centimeter at 25 degrees Celsius; Q, streamflow, in cubic feet per second (ft^3/s); WT, water temperature, in degrees Celsius (°C); TBY, turbidity, in formazin nephelometric units (FNUs); --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias-correction factor (Duan, 1983)	Discrete sample results					
					n	Range in response variable	Range in explanatory variable	Mean	Median	Standard deviation
				Suspended-sediment concentration (SSC), mg/L						
Wamego	logSSC = 1.10logQ-1.67	0.66	0.1361	1.42	18(0)	SSC 15–1,940	--	310	113	492
						--	Q 643–23,000	4,400	2,310	5,690
Topeka	logSSC = 1.40logQ-2.54	.81	.1141	1.29	20(0)	SSC 12–5,340	--	746	79	1,288
						--	Q 681–21,000	5,240	1,720	6,520
DeSoto	logSSC = 1.30logQ-2.39	.81	.0855	1.25	28(0)	SSC 35–3,360	--	647	163	997
						--	Q 949–79,000	8,460	3,400	15,000
Combined	logSSC = 1.26logQ-2.15	.76	.1119	1.35	66(0)	SSC 12–5,340	--	585	120	996
						--	Q 643–79,000	6,380	2,680	10,800
				Suspended-sediment concentration (SSC), mg/L						
Wamego	logSSC = 0.910logTBY+0.271	.95	.0158	1.06	20(0)	SSC 15–1,100	--	228	75	304
						--	TBY 11–1,020	159	42	237
Topeka	logSSC = 1.09logTBY-0.0537	.98	.0017	1.03	19(0)	SSC 12– 2,450	--	504	77	717
						--	TBY 12–1,450	302	66	401
DeSoto	logSSC = 0.904logTBY+0.264	.88	.0392	1.09	24(0)	SSC 35–1,610	--	314	112	442
						--	TBY 11–1,600	292	102	419
Combined	logSSC = 0.969logTBY+0.161	.93	.026	1.07	62(0)	SSC 12–2,450	--	348	78	518
						--	TBY 11–1,600	260	70	364
				Total suspended solids (TSS), mg/L						
Wamego	logTSS = 0.923logTBY+0.087	.94	.0212	1.05	17(0)	TSS 10–900	--	164	108	234
						--	TBY 11–1,020	198	110	263
Topeka	logTSS = 0.987logTBY+0.020	.83	.0816	1.20	20(0)	TSS 10–1,570	--	332	76	489
						--	TBY 12–1,450	289	60	394
DeSoto	logTSS = 0.863logTBY+0.204	.88	.0322	1.07	22(0)	TSS <10–1,210	--	208	95	296
						--	TBY 10–1,600	270	107	370
Combined	logTSS = 0.929logTBY+0.093	.87	.0448	1.12	59(0)	TSS <10–1,570	--	233	77	360
						--	TBY 11–1,600	250	72	347

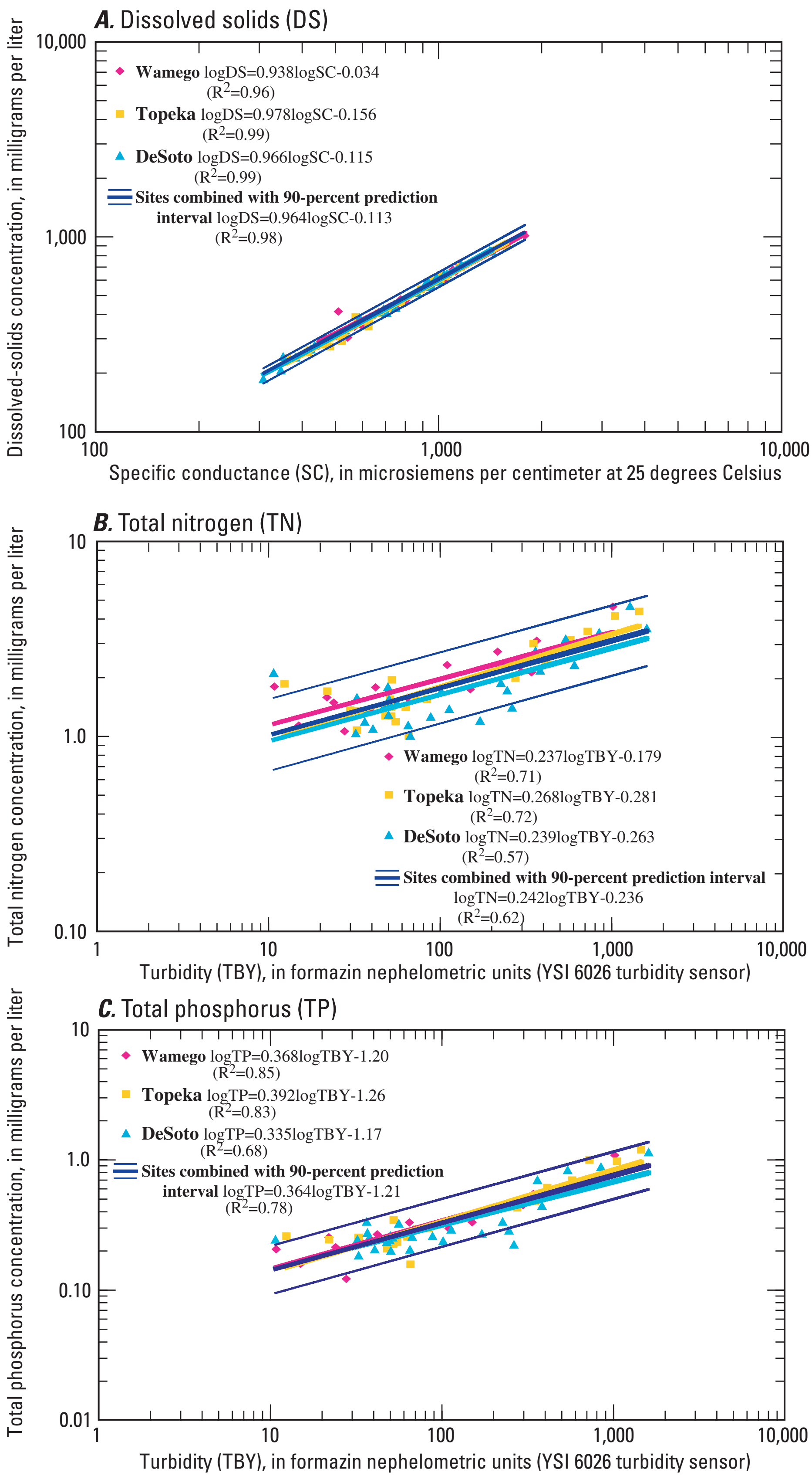


Figure 22. Comparison of explanatory and response variables for selected water-quality-constituent regression models.

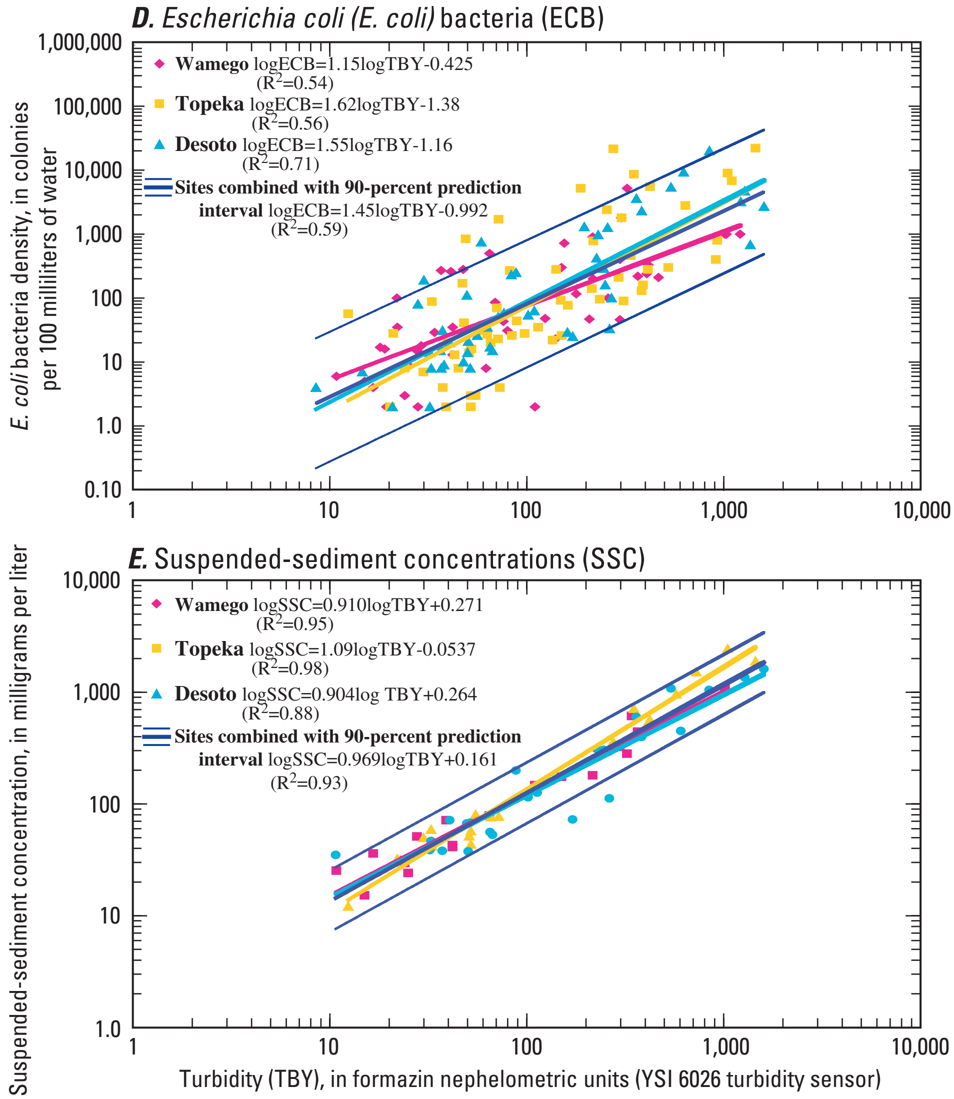


Figure 22. Comparison of explanatory and response variables for selected water-quality-constituent regression models.—Continued

91 days), summer and fall (July through October, which includes 123 days), and winter (November through March, which includes 151 days). Estimated continuous concentration or density durations for each of the constituents described in the following sections are presented in table 13, and loads and yields are presented in table 14. Figures 23–32 in the following sections show the estimated concentration or density duration curves for the period 2000–03 and for seasons. Tables containing continuous concentration, density, and load duration information for additional water-quality constituents are provided in appendixes 1 and 2. Missing data were estimated (as described in the "Methods" section) for constituents discussed in this section. Missing data were not estimated for constituents included in the appendixes.

Dissolved Solids

Dissolved solids in surface water primarily consist of the major ions calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride. These ions originate from the decomposition of soils and rocks (Hem, 1992) and are abundant within the study area. Because specific conductance is a measure of the ionized substances in water, all the regression models for major ions included specific conductance as an explanatory variable (table 10). Therefore, variability in dissolved-solids and major ion concentrations is directly related to that of specific conductance. Generally, concentrations were largest during low-flow conditions and decreased, often within 1 hour, during runoff because of the dilution effect, regardless of whether the flow was from stormwater runoff or reservoir release. However, changes in streamflow account for just less than one-half of the

Table 11. Regression models and statistics for estimating selected constituents using streamflow as the explanatory variable at three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003.

[R^2, coefficient of determination; MSE, mean square error; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; ANC, acid neutralizing capacity; Q, streamflow, in cubic feet per second; DS, dissolved solids; Ca, calcium; Mg, magnesium; Na, sodium; SO4, sulfate; Cl, chloride; TN, total nitrogen; TP, total phosphorus; *E. coli*, *Escherichia coli* bacteria; ECB, *E. coli* bacteria; FCB, fecal coliform bacteria; ENT, enterococci bacteria; SSC, suspended-sediment concentration; TSS, total suspended solids]

Constituent and unit of measurement	Regression model	R^2	MSE
Acid neutralizing capacity, unfiltered, field, mg/L as $CaCO_3$	logANC = -0.093logQ-2.57	0.19	0.0077
Dissolved solids, mg/L	logDS = -0.285logQ+3.65	.60	.0118
Calcium, dissolved, mg/L	logCa = -0.19logQ+2.47	.42	.0108
Magnesium, dissolved, mg/L	logMg = -0.266logQ+2.11	.57	.0116
Sodium, dissolved, mg/L	logNa = -0.47logQ+3.43	.67	.0236
Sulfate, dissolved, mg/L	logSO4 = -0.312logQ+3.07	.47	.023
Chloride, dissolved, mg/L	logCl = -0.528logQ+3.71	.67	.0295
Nitrogen, total, mg/L	logTN =0 .356logQ-0.943	.29	.0653
Phosphorus, total, mg/L	logTP = 0.423logQ-1.87	.31	.0878
E. coli bacteria, colonies per 100 milliliters	logECB = 1.60logQ-3.35	.50	.571
Fecal coliform bacteria, colonies per 100 milliliters	logFCB = 1.42logQ-2.71	.43	.641
Enterococci bacteria, colonies per 100 milliliters	logENT = 1.81logQ-3.43	.54	.722
Suspended-sediment concentration, mg/L	logSSC = 1.26logQ-2.15	.76	.1119
Total suspended solids, mg/L	logTSS = 1.17logQ-1.98	.63	.174

variability in specific conductance (table 9, R^2 ranges from 0.43 to 0.50). Proximity to sources of dissolved solids, as with Wamego's nearness to the Smoky Hill River mineral source, and relative contributions from ground water also contributed to the variability. USEPA Secondary Drinking-Water Regulations (SDWRs) recommend that dissolved-solids concentrations be less than 500 mg/L (U.S. Environmental Protection Agency, 2002).

Estimated continuous dissolved-solids concentrations in the Kansas River during the study period ranged from about 102 mg/L at DeSoto in 2003 to almost 900 mg/L at Wamego and Topeka in 2000 (table 13). Dissolved-solids concentrations exceeded 500 mg/L from 40 to almost 60 percent of the time at the three sites (fig. 23). Annually, median dissolved-solids concentrations were largest at Wamego and decreased downstream. Larger dissolved-solids concentrations upstream were a result of water inflow from the Smoky Hill River (Jordan and Stamer, 1995; Helgesen, 1996), which is diluted by tributary flow as it moves downstream. Concentrations generally were smallest during the spring and summer months and largest during the winter months (fig. 24). The flat duration curve for November through March, which is most apparent at Wamego, may be caused by a lack of reservoir releases to dilute constant inflow from the Smoky Hill River and may be related to ground-water inflow. Dissolved-solids concentrations in 68 discrete samples ranged from 186 mg/L at DeSoto to slightly more than 1,000 mg/L at Wamego (table 10). The mean discrete-sample concentration was largest at Wamego (512 mg/L) and smallest at Topeka (462 mg/L) (table 10).

Dissolved-solids loads were largest at DeSoto, averaging about 1.5 million tons annually from 2000 to 2003 (table 14). Wamego and Topeka loads were similar; each averaged about 1.2 million tons annually. The largest daily loads occurred in April through June followed by November through March (table 14). On average during the 4-year period, 23 percent of the annual dissolved-solids load at DeSoto occurred during 10 percent of the time (table 15). The largest yields occurred at DeSoto, with a 4-year average of about 78 (lb/acre)/yr, which is about 15 percent larger than the average annual yields of 68 lb/acre at Topeka and Wamego (table 14).

Total Nitrogen

Nutrients, including various forms of nitrogen and phosphorus species, are important for proper plant and animal growth and reproduction but in excess can lead to eutrophication (U.S. Geological Survey, 1999). Symptoms of eutrophication include low dissolved oxygen, reduced water clarity, algal blooms, depletion of desirable flora and fauna, and taste-and-odor problems in source water used for drinking. In addition, increased algae and turbidity require additional treatment for drinking purposes (Devlin and others, 2000).

Dominant forms of nitrogen in water include nitrite, nitrate, ammonia, and organic nitrogen. Major sources of nitrogen include fertilizers, wastewater discharges, animal waste, plant residue, and biological fixation. Total nitrogen is defined analytically as total Kieldahl nitrogen (organic nitrogen plus

Table 12. Regression models and statistics for estimating selected constituents using suspended-sediment concentrations (SSC) in discrete samples from three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003.

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias correction factor	Discrete sample results					
					n	Range in response variable	Range in SSC (mg/L)	Mean	Median	Standard deviation
Nitrogen, ammonia plus organic, total (TKN), mg/L										
Wamego	logTKN = 0.350logSSC-0.662	0.53	0.0489	1.12	21	TKN 0.44–8.8	--	1.7	1.1	1.9
						--	SSC 15–1,940	397	147	581
Topeka	logTKN = 0.372logSSC-0.738	.79	.0233	1.06	22	TKN 0.53–8.7	--	1.8	1.3	1.9
						--	SSC 12–5,340	791	79	1,300
DeSoto	logTKN = 0.335logSSC-0.643	.45	.0532	1.14	28	TKN 0.33–15	--	1.9	1.1	2.7
						--	SSC 35–3,540	531	162	803
Combined	logTKN = 0.352logSSC-0.682	.59	.0405	1.11	71	TKN 0.33–15	--	1.8	1.2	2.2
						--	SSC 12–5,340	572	126	932
Nitrogen, total (TN), mg/L										
Wamego	logTN = 0.293logSSC-0.315	.66	.0205	1.05	22	TN 1.0–10	--	2.4	1.8	2.1
						--	SSC 15–1,940	380	113	572
Topeka	logTN =0.296logSSC-0.354	.79	.0146	1.04	22	TN 1.0–9.3	--	2.6	1.8	2.0
						--	SSC 12–5,340	791	79	1,290
DeSoto	logTN =0.294logSSC-0.398	.55	.0301	1.08	29	TN 1.0–16	--	2.5	1.7	2.7
						--	SSC 35–3,660	639	199	979
Combined	logTN = 0.288logSSC-0.345	.64	.0225	1.06	73	TN 1.0–16	--	2.5	1.8	2.3
						--	SSC 12–5,340	607	126	990
Phosphorus, total (TP), mg/L										
Wamego	logTP = 0.437logSSC - 1.40	.73	.0326	1.08	21	TP 0.12–3.3	--	.54	.30	.70
						--	SSC 15–1,940	397	147	580
Topeka	logTP = 0.425logSSC - 1.35	.85	.0197	1.05	21	TP 0.16–3.4	--	.66	.30	.77
						--	SSC 12–5,340	827	80	1,310
DeSoto	logTP = 0.508logSSC - 1.57	.81	.0246	1.07	27	TP 0.18–5.8	--	.64	.27	1.1
						--	SSC 35–3,540	535	126	818
Combined	logTP = 0.459logSSC - 1.44	.79	.0258	1.08	66	TP 0.12–5.8	--	.63	.29	.89
						--	SSC 12–5,340	607	161	957

Table 12. Regression models and statistics for estimating selected constituents using suspended-sediment concentrations (SSC) in discrete samples from three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003.—Continued

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias correction factor	Discrete sample results					
					n	Range in response variable	Range in SSC (mg/L)	Mean	Median	Standard deviation
Escherichia coli (E. coli) bacteria (ECB), colonies per 100 milliliters										
Wamego	logECB = 1.56logSSC-1.33	0.85	0.2393	2.19	16	ECB 3–6,700	--	1,160	260	2,060
						--	SSC 15–1,940	447	178	637
Topeka	logECB = 1.70logSSC-1.44	.70	.8239	5.56	17	ECB <2–75,000	--	9,222	280	18,500
						--	SSC 12–5,340	871	80	1,430
DeSoto	logECB = 1.70logSSC-1.61	.87	.1720	1.50	24	ECB 8–21,000	--	2,990	217	6,010
						--	SSC 38–3,540	592	252	851
Combined	logECB = 1.66logSSC-1.49	.79	.3640	3.27	57	ECB <2–75,000	--	4,340	250	11,200
						--	SSC 12–5,340	635	180	1,010
Fecal coliform bacteria (FCB), colonies per 100 milliliters										
Wamego	logFCB = 1.46logSSC-1.10	.80	.2506	2.11	18	FCB <2–9,000	--	1,108	110	2,305
						--	SSC 15–1,940	410	161	609
Topeka	logFCB = 1.46logSSC-1.11	.59	.98	6.80	18	FCB <2–71,000	--	7,480	200	17,100
						--	SSC 12–5,340	922	221	1,390
DeSoto	logFCB = 1.71logSSC-1.56	.89	.1378	1.42	26	FCB 8–32,000	--	2,830	335	6,520
						--	SSC 38–3,540	553	162	828
Combined	logFCB = 1.55logSSC-1.25	.74	.3937	3.05	62	FCB <2–71,000	--	3,680	210	10,400
						--	SSC 12–5,340	619	161	983
Enterococci bacteria (ENT), colonies per 100 milliliters										
Wamego	logENT = 1.37logSSC-0.308	.75	.2880	1.95	14	ENT 25–140,000	--	11,600	1,030	37,000
						--	SSC 24–1,940	515	231	656
Topeka	logENT=1.70logSSC-1.16	.82	.3709	2.40	16	ENT 8–100,000	--	196,00	3,200	30,700
						--	SSC 42–5,340	1,070	547	1,420
DeSoto	Insufficient data	--	--	--	5	ENT 4,900–53,000	--	21,300	19,000	19,600
						--	SSC 602–3,540	1,740	1,360	1,160
Combined	logENT=1.55logSSC-0.75	.80	.2870	1.94	35	ENT 8–140,000	--	16,700	3,000	31,600
						--	SSC 24–5,340	944	529	1,180

Table 12. Regression models and statistics for estimating selected constituents using suspended-sediment concentrations (SSC) in discrete samples from three monitoring sites on lower Kansas River, northeast Kansas, July 1999–December 2003.—Continued

[R^2, coefficient of determination; MSE, mean square error; n, number of discrete samples; mg/L, milligrams per liter; --, not applicable; <, less than]

Monitoring site (fig. 1)	Regression model	R^2	MSE	Bias correction factor	Discrete sample results					
					n	Range in response variable	Range in SSC (mg/L)	Mean	Median	Standard deviation
Total suspended solids (TSS), mg/L										
Wamego	logTSS = 1.07logSSC - 0.323	0.97	0.0194	1.05	18	TSS 10–2,800	--	374	113	709
						--	SSC 15–1,940	410	161	609
Topeka	logTSS = 0.879logSSC + 0.105	.87	.0761	1.18	21	TSS 10–2,400	--	465	84	656
						--	SSC 12–5,340	827	80	1,310
DeSoto	logTSS = 0.913logSSC - 0.0485	.91	.0349	1.08	27	TSS 10–2,410	--	424	120	625
						--	SSC 35–3,660	669	199	1,010
Combined	logTSS = 0.941logSSC - 0.0287	.91	.0442	1.10	66	TSS 10–2,800	--	424	115	649
						--	SSC 12–5,340	649	161	1,030

Table 13. Estimated continuous concentration or density durations for selected water-quality constituents at three monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.

[Concentrations and densities were estimated from equations presented in table 9.]

Calendar year and monitoring site (fig. 1)	Number of values	Mean	Standard deviation	Concentration or density at indicated frequency of exceedance, in percent										
				Minimum	99	95	90	75	50 (median)	25	10	5	1	Maximum
Dissolved solids (milligrams per liter)														
2000														
Wamego	8,783	623	126	299	354	392	421	527	670	694	771	807	846	887
Topeka	8,783	594	115	118	270	412	437	490	624	682	709	740	779	889
DeSoto	8,783	559	116	182	274	358	409	467	561	665	690	720	764	780
2001														
Wamego	8,759	462	142	182	231	253	278	330	468	608	653	668	748	807
Topeka	8,759	439	129	172	229	254	284	329	424	531	628	669	702	738
DeSoto	8,759	402	129	150	201	235	256	297	369	502	599	624	684	705
2002														
Wamego	8,759	536	92	309	321	357	408	459	554	619	629	636	670	854
Topeka	8,759	501	81	162	327	366	391	441	508	566	606	623	641	693
DeSoto	8,759	467	87	182	260	310	329	422	477	525	580	599	618	642
2003														
Wamego	8,759	462	133	181	228	301	307	343	419	610	644	665	704	881
Topeka	8,759	464	121	180	223	315	328	370	417	585	637	650	658	787
DeSoto	8,759	454	117	102	227	306	332	368	411	568	618	654	706	718
Total nitrogen (milligrams per liter)														
2000														
Wamego	8,783	1.9	.50	1.1	1.2	1.3	1.4	1.5	1.8	2.2	2.6	2.9	3.4	3.6
Topeka	8,783	1.8	.51	.99	1.0	1.1	1.2	1.4	1.7	2.0	2.5	2.7	3.7	3.8
DeSoto	8,783	1.6	.41	.74	.96	1.1	1.1	1.4	1.6	1.8	2.1	2.4	3.1	3.2

Table 13. Estimated continuous concentration or density durations for selected water-quality constituents at three monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[Concentrations and densities were estimated from equations presented in table 9.]

Calendar year and monitoring site (fig. 1)	Number of values	Mean	Standard deviation	Concentration or density at indicated frequency of exceedance, in percent										
				Minimum	99	95	90	75	50 (median)	25	10	5	1	Maximum
Total nitrogen (milligrams per liter)—Continued														
2001														
Wamego	8,759	2.2	0.66	1.2	1.3	1.4	1.4	1.5	2.2	2.6	3.0	3.4	3.9	3.9
Topeka	8,759	2.1	.75	.92	1.1	1.2	1.2	1.4	2.0	2.6	3.2	3.6	3.8	3.9
DeSoto	8,759	2.0	.62	.95	1.0	1.1	1.2	1.4	2.0	2.4	2.9	3.1	3.2	3.5
2002														
Wamego	8,759	1.7	.35	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.1	2.3	2.9	3.7
Topeka	8,759	1.6	.40	.93	1.0	1.1	1.2	1.3	1.5	1.7	2.0	2.2	3.6	4.0
DeSoto	8,759	1.5	.37	.87	.93	1.0	1.1	1.3	1.4	1.6	2.0	2.2	3.0	3.1
2003														
Wamego	8,759	1.8	.51	1.1	1.2	1.2	1.3	1.4	1.8	2.1	2.5	2.7	3.6	3.8
Topeka	8,759	1.7	.56	.72	.92	1.0	1.1	1.3	1.6	1.9	2.3	2.8	3.6	3.9
DeSoto	8,759	1.6	.41	.90	.96	1.0	1.1	1.3	1.6	1.8	2.0	2.4	3.0	3.2
Total phosphorus (milligrams per liter)														
2000														
Wamego	8,783	.32	.14	.14	.16	.18	.19	.21	.29	.39	.53	.62	.81	.88
Topeka	8,783	.34	.15	.14	.15	.16	.19	.24	.31	.39	.53	.61	.95	1.0
DeSoto	8,783	.32	.11	.10	.15	.17	.17	.26	.31	.37	.44	.54	.75	.79
2001														
Wamego	8,759	.41	.19	.15	.18	.19	.19	.22	.40	.53	.65	.80	.97	.98
Topeka	8,759	.44	.23	.13	.16	.18	.19	.22	.40	.59	.78	.93	1.0	1.0
DeSoto	8,759	.41	.18	.15	.17	.17	.19	.24	.40	.53	.69	.76	.79	.90
2002														
Wamego	8,759	.26	.09	.12	.14	.15	.18	.21	.24	.30	.37	.44	.61	.90
Topeka	8,759	.28	.11	.13	.15	.17	.19	.22	.25	.31	.39	.46	.91	1.1
DeSoto	8,759	.28	.10	.13	.14	.16	.18	.23	.26	.29	.41	.47	.73	.76

Table 13. Estimated continuous concentration or density durations for selected water-quality constituents at three monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[Concentrations and densities were estimated from equations presented in table 9.]

Calendar year and monitoring site (fig. 1)	Number of values	Mean	Standard deviation	Concentration or density at indicated frequency of exceedance, in percent										
				Minimum	99	95	90	75	50 (median)	25	10	5	1	Maximum
Total phosphorus (milligrams per liter)—Continued														
2003														
Wamego	8,759	0.31	0.14	0.14	0.16	0.17	0.17	0.19	0.29	0.37	0.48	0.55	0.87	0.93
Topeka	8,759	.31	.16	.09	.13	.15	.15	.20	.28	.37	.49	.64	.94	1.0
DeSoto	8,759	.30	.11	.13	.15	.16	.17	.22	.29	.35	.42	.53	.74	.81
***E. coli* bacteria (colonies per 100 milliliters of water)**														
2000														
Wamego	8,783	243	422	10	15	21	25	37	93	239	632	1,000	2,370	3,090
Topeka	8,783	1,000	3,110	8	10	15	26	73	203	563	1,969	3,480	22,100	27,100
DeSoto	4,407	860	1,930	2	5	4	11	65	158	334	814	1,930	9,450	12,800
2001														
Wamego	8,759	522	782	12	20	26	27	40	269	617	1,210	2,320	4,140	4,370
Topeka	8,759	3,130	5,820	5	14	22	29	52	643	2,990	9,730	19,700	26,800	32,200
DeSoto	8,759	1,780	2,960	5	9	11	17	43	505	1,780	6,300	9,540	11,900	21,100
2002														
Wamego	8,759	108	187	7	10	12	21	34	54	106	205	364	985	3,320
Topeka	8,759	515	2,340	6	11	19	31	50	91	207	570	1,100	18,500	35,700
DeSoto	8,759	325	1,120	3	4	7	12	38	67	117	549	1,100	8,120	9,550
2003														
Wamego	8,759	219	454	11	15	18	18	25	95	215	453	706	3,030	3,620
Topeka	8,759	992	3,480	1	5	10	12	35	148	444	1,360	4,340	21,100	32,500
DeSoto	8,759	438	1,400	3	5	8	9	32	119	273	639	1,790	8,810	12,800

Table 13. Estimated continuous concentration or density durations for selected water-quality constituents at three monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[Concentrations and densities were estimated from equations presented in table 9.]

Calendar year and monitoring site (fig. 1)	Number of values	Mean	Standard deviation	Concentration or density at indicated frequency of exceedance, in percent										
				Minimum	99	95	90	75	50 (median)	25	10	5	1	Maximum
Suspended-sediment concentration (milligrams per liter)														
2000														
Wamego	8,783	148	190	13	19	25	28	38	80	168	363	529	1,030	1,270
Topeka	8,783	204	351	11	13	17	25	50	99	197	458	672	2,330	2,670
DeSoto	8,783	156	188	5	15	23	23	66	111	172	289	479	1,210	1,370
2001														
Wamego	8,759	273	320	15	24	29	30	41	185	356	608	1,020	1,600	1,680
Topeka	8,759	469	624	8	16	22	27	40	216	606	1,340	2,160	2,640	3,000
DeSoto	8,759	340	365	14	20	23	30	52	219	456	954	1,220	1,380	1,930
2002														
Wamego	8,759	80	94	10	13	16	25	36	52	88	149	234	515	1,350
Topeka	8,759	120	263	9	14	20	28	39	58	101	199	309	2,070	3,220
DeSoto	8,759	113	163	10	13	17	25	49	68	93	230	346	1,110	1,220
2003														
Wamego	8,759	134	195	15	19	21	22	28	81	154	279	396	1,250	1,440
Topeka	8,759	188	377	3	8	13	15	31	80	168	358	779	2,260	3,020
DeSoto	8,759	139	187	12	15	20	21	44	94	153	251	457	1,160	1,440

Table 14. Estimated load and yield for selected water-quality constituents at three monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.

[Estimated loads and yields are rounded to three significant figures. (lb/acre)/yr, pounds per acre per year; mi^2, square miles; (), average daily load]

Calendar year	Estimated load				Calendar year	Estimated yield		
	April–June (91 days)	July–October (123 days)	November–March (151 days)	Total		Wamego	Topeka	DeSoto
Wamego	Dissolved-solids load (tons)				Total drainage area (mi^2)	Dissolved-solids yield [(lb/acre)/yr]		
						55,280	56,720	59,756
2000	369,000	365,000	651,000	1,390,000	2000	78	75	80
2001	715,000	471,000	690,000	1,880,000	2001	106	112	136
2002	277,000	192,000	392,000	861,000	2002	49	46	55
2003	195,000	244,000	215,000	654,000	2003	37	38	41
Average 2000–03	389,000 (4,270)	318,000 (2,580)	487,000 (3,220)	1,190,000 (3,260)	Average 2000–03	68	68	78
Topeka								
2000	369,000	366,000	626,000	1,360,000				
2001	863,000	513,000	657,000	2,030,000				
2002	318,000	180,000	341,000	839,000				
2003	215,000	240,000	226,000	681,000				
Average 2000–03	441,000 (4,850)	325,000 (2,640)	463,000 (3,010)	1,230,000 (3,370)				
DeSoto								
2000	437,000	407,000	688,000	1,530,000				
2001	1,090,000	685,000	831,000	2,610,000				
2002	440,000	226,000	388,000	1,050,000				
2003	249,000	249,000	281,000	779,000				
Average 2000–03	554,000 (6,090)	392,000 (3,190)	547,000 (3,620)	1,490,000 (4,080)				

Table 14. Estimated load and yield for selected water-quality constituents at three monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[Estimated loads and yields are rounded to three significant figures. (lb/acre)/yr, pounds per acre per year; mi^2, square miles; (), average daily load]

Calendar year	Estimated load				Calendar year	Estimated yield		
	April–June (91 days)	July–October (123 days)	November–March (151 days)	Total		Wamego	Topeka	DeSoto
Wamego	Total nitrogen load (tons)				Unregulated drainage area (mi^2)	Total nitrogen yield [(lb/acre)/yr]		
						5,922	7,362	8,914
2000	1,270	1,400	2,190	4,860	2000	2.6	2.0	1.9
2001	6,080	3,160	3,850	13,100	2001	6.9	6.4	6.9
2002	1,300	690	940	2,930	2002	1.5	1.4	1.6
2003	1,030	1,580	640	3,250	2003	1.7	1.4	1.2
Average 2000–03	2,420 (26.6)	1,710 (13.9)	1,910 (12.6)	6,040 (16.5)	Average 2000–03	3.2	2.8	2.9
Topeka								
2000	1,360	1,480	1,980	4,820				
2001	7,300	3,610	4,210	15,100				
2002	1,710	610	880	3,200				
2003	1,230	1,400	550	3,180				
Average 2000–03	2,900 (31.9)	1,780 (14.5)	1,910 (12.6)	6,580 (18.0)				
DeSoto								
2000	1,610	1,770	2,130	5,510				
2001	9,150	5,140	5,420	19,700				
2002	2,770	750	990	4,510				
2003	1,290	1,420	680	3,390				
Average 2000–03	3,710 (40.8)	2,270 (18.5)	2,310 (15.3)	8,280 (22.7)				
Wamego	Total phosphorus load (tons)				Unregulated drainage area (mi^2)	Total phosphorus yield [(lb/acre)/yr		
						5,922	7,362	8,914
2000	250	240	410	900	2000	.47	.41	.39
2001	1,260	630	750	2,640	2001	1.4	1.4	1.6
2002	230	110	140	480	2002	.25	.26	.32
2003	190	290	100	580	2003	.31	.27	.24
Average 2000–03	480 (5.27)	320 (2.60)	350 (2.32)	1,150 (3.15)	Average 2000–03	.61	.60	.62
Topeka								
2000	290	290	390	970				
2001	1,690	810	930	3,430				
2002	350	110	150	610				
2003	260	280	90	630				
Average 2000–03	650 (7.14)	370 (3.01)	390 (2.58)	1,410 (3.86)				

Table 14. Estimated load and yield for selected water-quality constituents at three monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[Estimated loads and yields are rounded to three significant figures. (lb/acre)/yr, pounds per acre per year; mi^2, square miles; (), average daily load]

Calendar year	Estimated load				Calendar year	Estimated yield		
	April–June (91 days)	July–October (123 days)	November–March (151 days)	Total		Wamego	Topeka	DeSoto
DeSoto	Total phosphorus load (tons)—Continued							
2000	340	360	420	1,120				
2001	2,120	1,090	1,220	4,430				
2002	590	130	180	900				
2003	270	290	120	680				
Average 2000–03	830 (91.2)	470 (3.82)	490 (3.25)	1,780 (4.88)				
Wamego	*Escherichia coli* load (billons of colonies per day)				Unregulated drainage area (mi^2)	*Escherichia coli* yield (million colonies per day per acre)		
						5,922	7,362	8,914
2000	26,000	8,160	35,700	8,800,000	2000	6.36	28.2	15.0
2001	197,000	77,000	69,000	37,800,000	2001	27.3	183	130
2002	15,100	3,280	1,400	1,990,000	2002	1.43	12.5	11.1
2003	18,600	25,600	2,900	5,280,000	2003	3.81	18.0	8.32
Average 2000–03	64,200	28,500	27,200	13,500,000	Average 2000–03	9.73	60.5	41.1
Topeka								
2000	163,000	77,200	159,000	48,400,000				
2001	1,690,000	643,000	543,000	316,000,000				
2002	224,000	4,730	2,910	21,400,000				
2003	136,000	144,000	5,230	30,900,000				
Average 2000–03	553,000	217,000	178,000	104,000,000				
DeSoto								
2000	130,000	67,300	73,600	31,300,000				
2001	1,550,000	402,000	531,000	271,000,000				
2002	245,000	2,870	2,620	23,100,000				
2003	84,800	75,600	2,130	17,300,000				
Average 2000–03	502,000	137,000	152,000	85,700,000				
Wamego	Suspended-sediment load (tons)				Unregulated drainage area (mi^2)	Suspended-sediment yield [(lb/acre)/yr]		
						5,922	7,362	8,914
2000	151,000	81,000	292,000	524,000	2000	277	358	266
2001	1,024,000	510,000	573,000	2,110,000	2001	1,110	2,030	1,710
2002	100,000	34,800	24,100	159,000	2002	84	173	202
2003	111,000	179,000	30,000	320,000	2003	169	226	151
Average 2000–03	347,000 (3,810)	201,000 (1,630)	230,000 (1,520)	778,000 (2,130)	Average 2000–03	410	698	582

Table 14. Estimated load and yield for selected water-quality constituents at three monitoring sites on lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[Estimated loads and yields are rounded to three significant figures. (lb/acre)/yr, pounds per acre per year; mi^2, square miles; (), average daily load]

Calendar year	Estimated load				Calendar year	Estimated yield		
	April–June (91 days)	July–October (123 days)	November–March (151 days)	Total		Wamego	Topeka	DeSoto
	Suspended-sediment load (tons)—Continued							
Topeka								
2000	273,000	191,000	381,000	845,000				
2001	2,440,000	1,120,000	1,240,000	4,800,000				
2002	346,000	31,400	31,200	409,000				
2003	239,000	268,000	25,900	533,000				
Average 2000–03	825,000 (9,070)	403,000 (3,280)	420,000 (2,780)	1,650,000 (4,520)				
DeSoto								
2000	265,000	227,000	268,000	760,000				
2001	2,510,000	1,030,000	1,340,000	4,880,000				
2002	497,000	36,700	42,600	576,000				
2003	193,000	209,000	29,500	432,000				
Average 2000–03	866,000 (9,520)	376,000 (3,060)	420,000 (2,780)	1,660,000 (4,550)				

ammonia) plus nitrite and nitrate. Kansas has no numeric water-quality criteria for total nitrogen but has set a general goal of reducing total nitrogen export by 30 percent (Kansas Department of Health and Environment, 2004d). USEPA suggested criterion for total nitrogen is 0.56 mg/L for Ecoregion IV (U.S. Environmental Protection Agency, 2003b), which includes the Kansas River at Wamego (fig. 1). The Topeka and DeSoto sites are within Ecoregion IX (fig. 1), which has a suggested total nitrogen criterion of 0.69 mg/L (U.S. Environmental Protection Agency, 2003b).

Estimated total nitrogen concentrations during the study period ranged from about 0.72 mg/L at Topeka in 2003 to 4.0 mg/L at Topeka in 2002 (table 13). Except within the 10-percent exceedance frequency range, total nitrogen concentrations were slightly larger at Wamego, followed by Topeka, then DeSoto (fig. 25). Ecoregion criteria suggested by USEPA were always exceeded at the three sites. Also at all three sites, total nitrogen concentrations were largest in 2001, the wettest year of the study period, indicating that nonpoint-source contributions were substantial. Except within the 5-percent exceedance range when concentration estimates may be affected by turbidity sensor maximization, the largest concentrations occurred from April through June, coinciding with extensive fertilizer application and stormwater runoff. The smallest concentrations occurred in November through March (fig. 26). Discrete total nitrogen concentrations in samples collected during the study period ranged from 1.0 to 16 mg/L (table 12). However, some large nitrogen concentrations were not included in the table 10 regression models because they corresponded to conditions when the turbidity sensors were maximized. Total nitrogen concentrations in discrete samples used for regressions ranged from 1.0 to 4.6 mg/L with a mean of about 2.0 mg/L at each site (table 10).

Annual total nitrogen loads ranged from about 2,900 tons at Wamego in 2002 to about 20,000 tons at DeSoto in 2001 (table 14). The largest loads occurred annually at the downstream site, DeSoto, followed by Topeka and then Wamego except in 2003 when the total nitrogen load at Wamego was slightly larger than the load at Topeka. Large differences in annual load from year to year can be attributed primarily to hydrologic variability. Seasonally, average daily total nitrogen load was about twice as large from April through June as it was during each of the other seasons (table 14). On average, 37 percent of the annual total nitrogen load at DeSoto occurred during 10 percent of the time (table 15). The average annual yield ranged from 2.8 lb/acre at Topeka to 3.2 lb/acre at Wamego. Yields varied with hydrologic conditions; the largest yields at each site occurred in 2001 when the yield was two to three times larger than each of the other years (table 14), corresponding to the largest streamflow volume (table 8). Similar yield characteristics at the three sites indicate that total nitrogen sources were evenly distributed throughout the lower Kansas River Basin.

Nitrogen and discharge data for major municipal wastewater-treatment facilities (WWTFs) that discharge into the Kansas River between Junction City and DeSoto were obtained from KDHE (written commun., 2005) to estimate percentage total nitrogen contribution from point sources. Subsequent calculations indicated that the total nitrogen contribution from the six major WWTFs with design flows larger than 3 Mgal/d averaged 11 percent of the annual total nitrogen load at DeSoto during 2000–03.

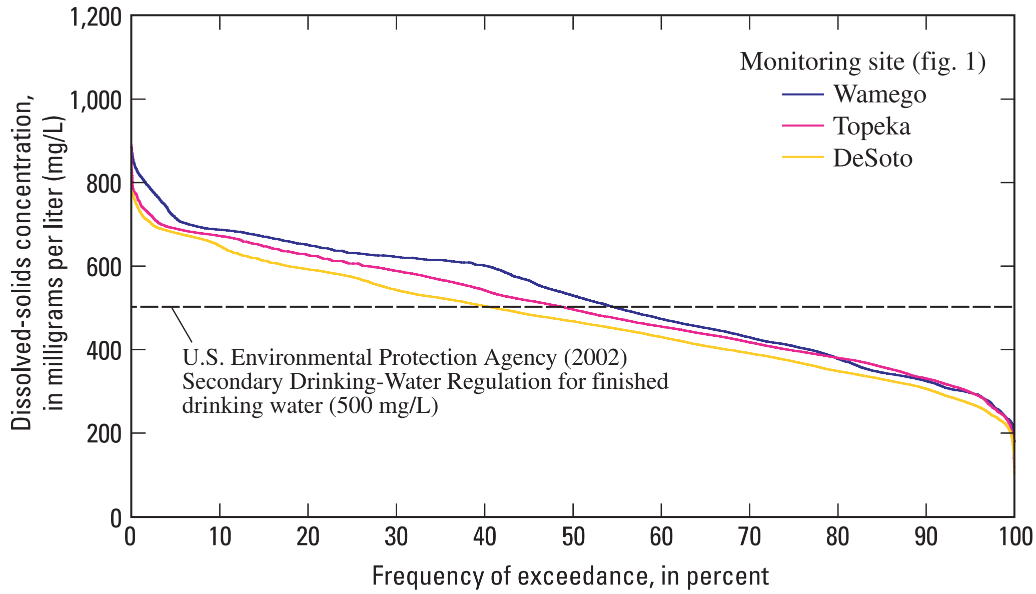


Figure 23. Duration curves for estimated dissolved-solids concentrations at three Kansas River monitoring sites, January 2000–December 2003.

Total Phosphorus

Phosphorus in surface water occurs in either dissolved or particulate form. Primary sources of phosphorus include fertilizers, wastewater discharges, animal waste, and soil erosion. Kansas has no numeric water-quality criteria for total phosphorus but has set a goal of reducing total phosphorus export from the State by 30 percent (Kansas Department of Health and Environment, 2004d). USEPA suggested criterion for total phosphorus is 0.0230 mg/L for Ecoregion IV (fig. 1), which includes the Kansas River at Wamego. The Topeka and DeSoto sites are within Ecoregion IX (fig. 1), which has a suggested total phosphorus criterion of 0.0366 mg/L (U.S. Environmental Protection Agency, 2003b).

Estimated total phosphorus concentrations during the study period ranged from about 0.10 to about 1.1 mg/L at the three sites (table 13). Site-to-site variability was minimal except at the upper end of the duration curve where Topeka phosphorus concentrations were slightly larger than the other two sites (fig. 27). USEPA suggested ecoregion criteria were always exceeded at the three sites by a factor of at least three. Generally, total phosphorus concentrations were largest from April through June and smallest from November through March (fig. 28). Total phosphorus concentrations in discrete samples ranged from 0.12 to 5.8 mg/L (table 12) during the study period. Some larger phosphorus concentrations were not included in the table 10 regression models because they corresponded with conditions when the turbidity sensors were maximized. Total phosphorus concentrations in the discrete samples used for regressions ranged from 0.12 to 1.2 mg/L (table 10).

Average daily total phosphorus loads increased in a downstream direction, from an average of 1,150 ton/yr at Wamego to 1,780 ton/yr at DeSoto (table 14). The largest loads occurred during the wettest year, 2001, when the DeSoto load was 4,430 tons, the Topeka load was 3,430 tons, and the Wamego load was 2,640 tons. Average daily total phosphorus loads were largest from April through June when daily loads were two to three times larger than during the other two seasons. On average, 40 percent of the annual total phosphorus load at DeSoto occurred during 10 percent of the time (table 15). Total phosphorus yields were nearly the same at all sites (table 14), indicating that phosphorus sources in the basin are uniformly distributed. Actual phosphorus and streamflow data obtained from KDHE (written commun., 2005) for WWTF discharges between Junction City and DeSoto indicated that point sources contributed 12 percent of the annual total phosphorus load at DeSoto during 2000–03.

E. Coli Bacteria

Escherichia coli (E. coli) is an indicator bacteria used to evaluate the sanitary quality of water and its use as a public water supply and for recreational activities such as swimming, wading, boating, and fishing (American Public Health Association and others, 1992). The presence of *E. coli* indicates the possible presence of pathogens found in feces of warmblooded animals (Dufour, 1977). These bacteria and pathogens may cause human diseases ranging from mild diarrhea to respiratory disease, septicemia, meningitis, and polio (Dufour, 1977).

After many years of regulating fecal coliform bacteria in surface water, KDHE implemented *E. coli* criteria to replace fecal coliform as the water-quality indicator. Primary contact recreational use criteria for *E. coli* state that for the three use classifications of water (table 3), a geometric mean of five

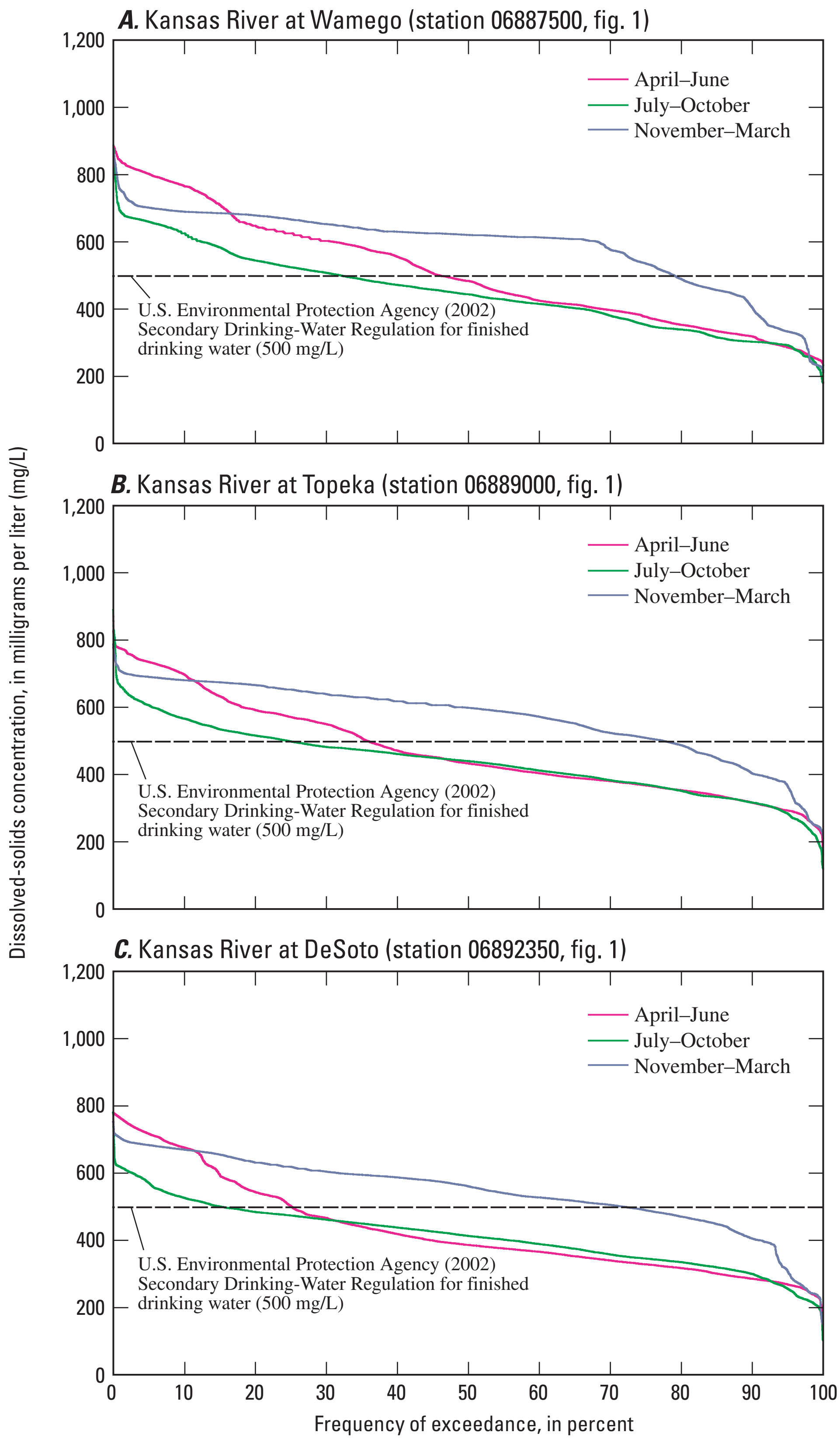


Figure 24. Seasonal duration curves for estimated dissolved-solids concentrations at three Kansas River monitoring sites, January 2000–December 2003.

Table 15. Percentage of annual streamflow volume and constituent load at the Kansas River at DeSoto monitoring site that occurred during 0- to 10-percent exceedance frequency period, 2000–03.

[All values are in percent. Location of monitoring site shown in figure 1]

Calendar year	Stream-flow	Dis-solved solids	Total nitrogen	Total phos-phorus	*Escher-ichia coli* bacteria	Sus-pended sedi-ment
2000	25	21	33	37	85	63
2001	33	29	39	41	68	55
2002	31	24	42	47	91	73
2003	23	19	32	36	86	63
Average 2000–03	28	23	37	40	83	63

samples collected during separate 24-hour periods within a 30-day period cannot exceed 160, 262, and 427 colony-forming units per 100 mL of water from April through October each year. From November through March primary contact criteria for *E. coli* are 2,358 or 3,843 col/100 mL for the three use classes (Kansas Department of Health and Environment, 2003). The criteria for the Kansas River sites are a geometric mean of 262 colony-forming units from April through October and 2,358 colony-forming units from November through March (Kansas Department of Health and Environment, 2003).

Rasmussen and Ziegler (2003) studied indicator bacteria in selected Kansas streams and published regression models for *E. coli* and fecal coliform bacteria for each of the three sites included in this study. The models, updated with additional data, are included here (table 10). The difference between the models presented here and those published by Rasmussen and Ziegler (2003) is that some data points used in their models have been deleted because the YSI turbidity instrument used for some high-range data collection was not equivalent to the YSI 6026 turbidity sensor used throughout the study described in this report. Differences between bacteria regression models account for slight differences in estimated loads and yields when comparing results in Rasmussen and Ziegler (2003) to results presented in this report.

Regression-estimated *E. coli* densities ranged from 1 col/100 mL at Topeka in 2003 to 35,700 col/100 mL at Topeka in 2002 (table 13). Largest bacteria densities throughout most of the range of conditions (more than 80 percent of the time) occurred at Topeka each year of the study period, whereas smallest densities occurred at Wamego (fig. 29). Median *E. coli* densities at Topeka were generally double the densities at Wamego. In the 95- to 99-percent exceedance range, Wamego densities generally exceeded both Topeka and DeSoto densities. Large bacteria densities occurred most frequently during spring runoff and were most prominent in 2001. Generally, bacteria densities at each site were largest from April through June, followed by July through October, and then November through March (fig. 30). In the 180 discrete bacteria samples collected during the study period, *E. coli* densities ranged from less than 2 to 75,000 col/100 mL of water (table 12). Some larger bacteria densities were not included in the table 10 regression models because they corresponded to conditions when the turbidity sensors were maximized.

Annual and seasonal differences in bacteria concentrations are caused primarily by varying hydrologic conditions. Larger

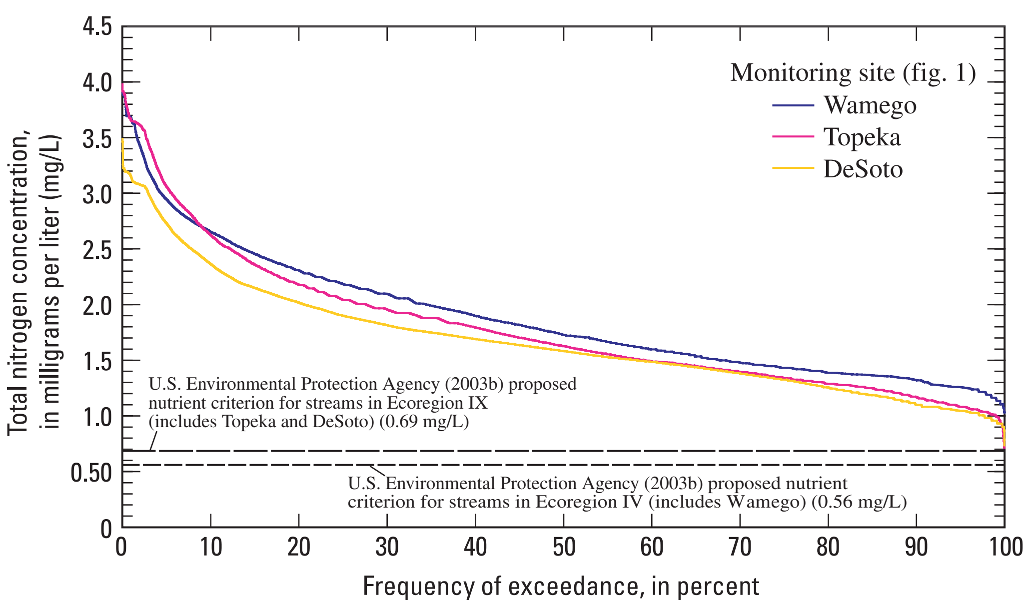


Figure 25. Duration curves for estimated total nitrogen concentrations at three Kansas River monitoring sites, January 2000–December 2003.

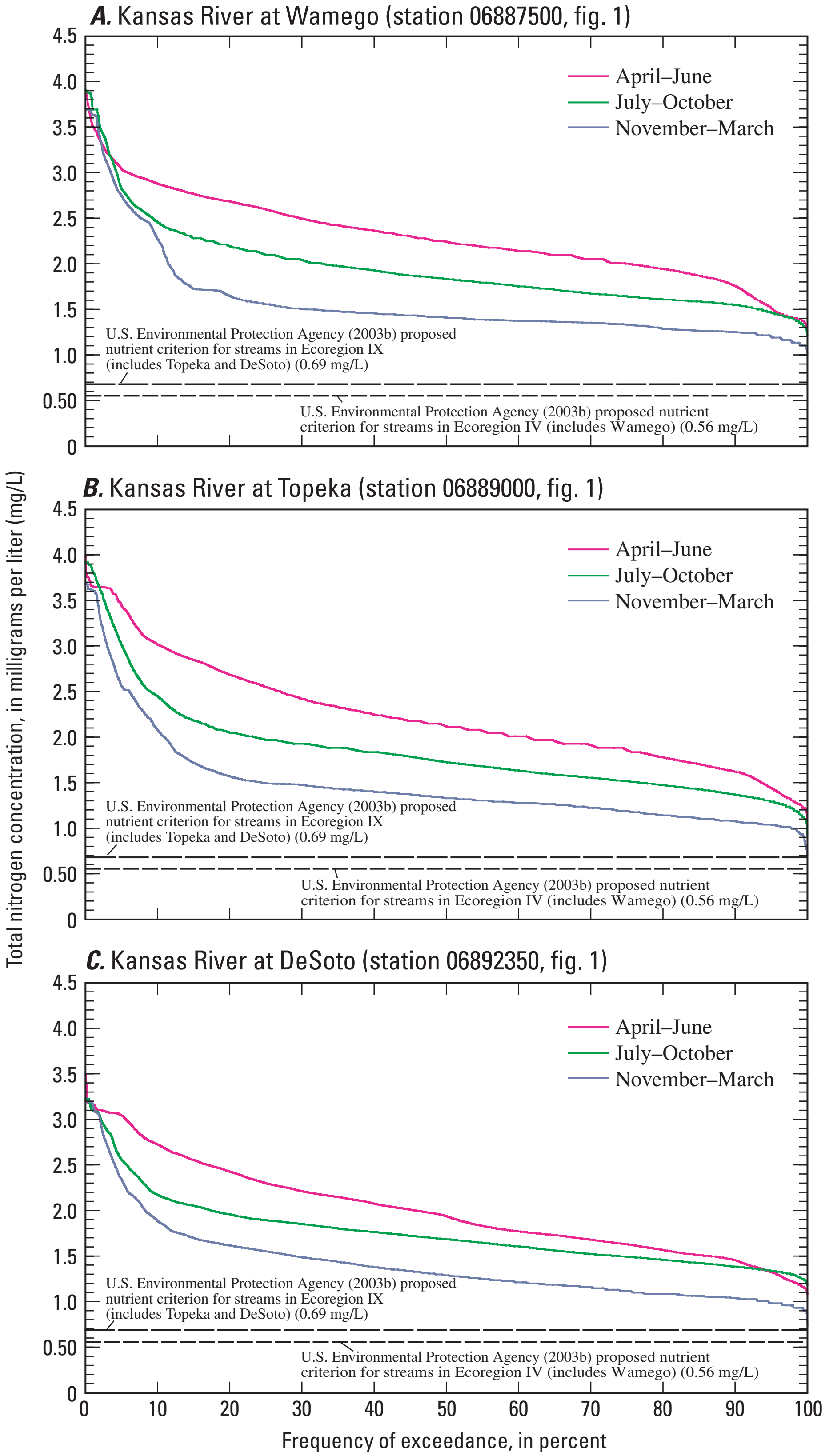


Figure 26. Seasonal duration curves for estimated total nitrogen concentrations at three Kansas River monitoring sites, January 2000–December 2003.

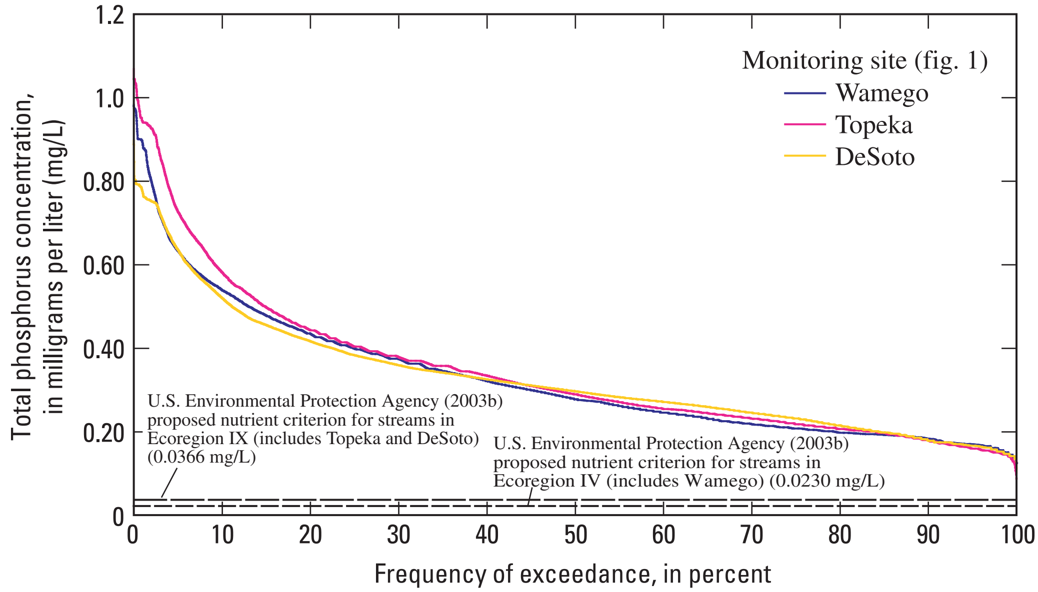


Figure 27. Duration curves for estimated total phosphorus concentrations at three Kansas River monitoring sites, January 2000–December 2003.

bacteria densities at Topeka are likely a result of larger contributions from nonpoint-source agricultural runoff in the monitoring-site drainage area. Although increased bacteria densities could be caused by wastewater-treatment-plant discharges upstream from the Topeka monitoring site, Rasmussen and Ziegler (2003) found that less than 3 percent of the bacteria loads in the Kansas River for 2000 and 2001 were from point sources.

The largest annual *E. coli* bacteria loads (table 14) occurred at Topeka each year except 2002 when the largest load occurred at DeSoto. The average *E. coli* bacteria load at Topeka was more than seven times larger than the average load at Wamego and 21 percent larger than the average load at DeSoto. The largest load at each site occurred in 2001, generally corresponding with the largest streamflow. At each site the total load in 2001 alone was more than two to three times the total load from the remaining years combined. Daily loads generally were largest during April through June, but in 2003, July through October daily loads were largest. On average, 83 percent of the annual bacteria load at DeSoto occurred during 10 percent of the time (table 15).

The average *E. coli* yield at Topeka was 47 percent larger than the average yield at DeSoto and nearly five times larger than the yield at Wamego (table 14). Bacteria densities that were larger at Topeka than at the downstream DeSoto site may be a result of bacterial die-off and dilution effects from reservoir releases downstream (Rasmussen and Ziegler, 2003).

Suspended Sediment

Sediment in the water affects light penetration, smothers benthic habitats, clogs gill structures, reduces photosynthesis, and interferes with water-treatment equipment (Devlin and McVay, 2001). Suspended sediment, particularly sediment composed of fine material (silt and clay), gives water a muddy appearance and provides attachment sites allowing accumulation and transport of nutrients, pesticides, and bacteria (Jordan and Stamer, 1995). The primary source of sediment is surface geology and soils. Predominant soils in the lower Kansas River Basin are mollisols, which are prone to erosion particularly when coupled with cultivated fields, moderate to steep slopes, and intense precipitation (Helgesen, 1996). KDHE narrative criteria for suspended sediment state that artificial sources shall not interfere with aquatic life. Artificial sources include sources that result from human activities and can be abated by construction of control structures, modification of operating practices, or restraint of activities (Kansas Department of Health and Environment, 2003.)

Estimated suspended-sediment concentrations during the study period ranged from 3 to at least 3,000 mg/L at Topeka during 2001–03 (table 13). Estimated concentrations at Topeka were the largest at exceedance frequencies smaller than 40 percent (fig. 31). Estimated concentrations at Wamego, the upstream monitoring site, were the smallest of the three sites throughout most of the exceedance range (fig. 31). Sediment concentrations at Wamego may be smaller because of the trapping effects of Tuttle Creek and Milford Lakes. The Topeka monitoring site used the turbidity sensor with the largest upper limit of measurement during the study period (table 5), which may have resulted in larger maximum sediment concentration estimates within the 0- to 2-percent exceedance range when compared to the other two sites. However, concentration duration curves for the study period (fig. 31) indicate that suspended-sediment concentrations in the 5- to 35-percent exceedance range, when sensor maximization was not a factor, were largest at Topeka. The Topeka drainage area is more distant

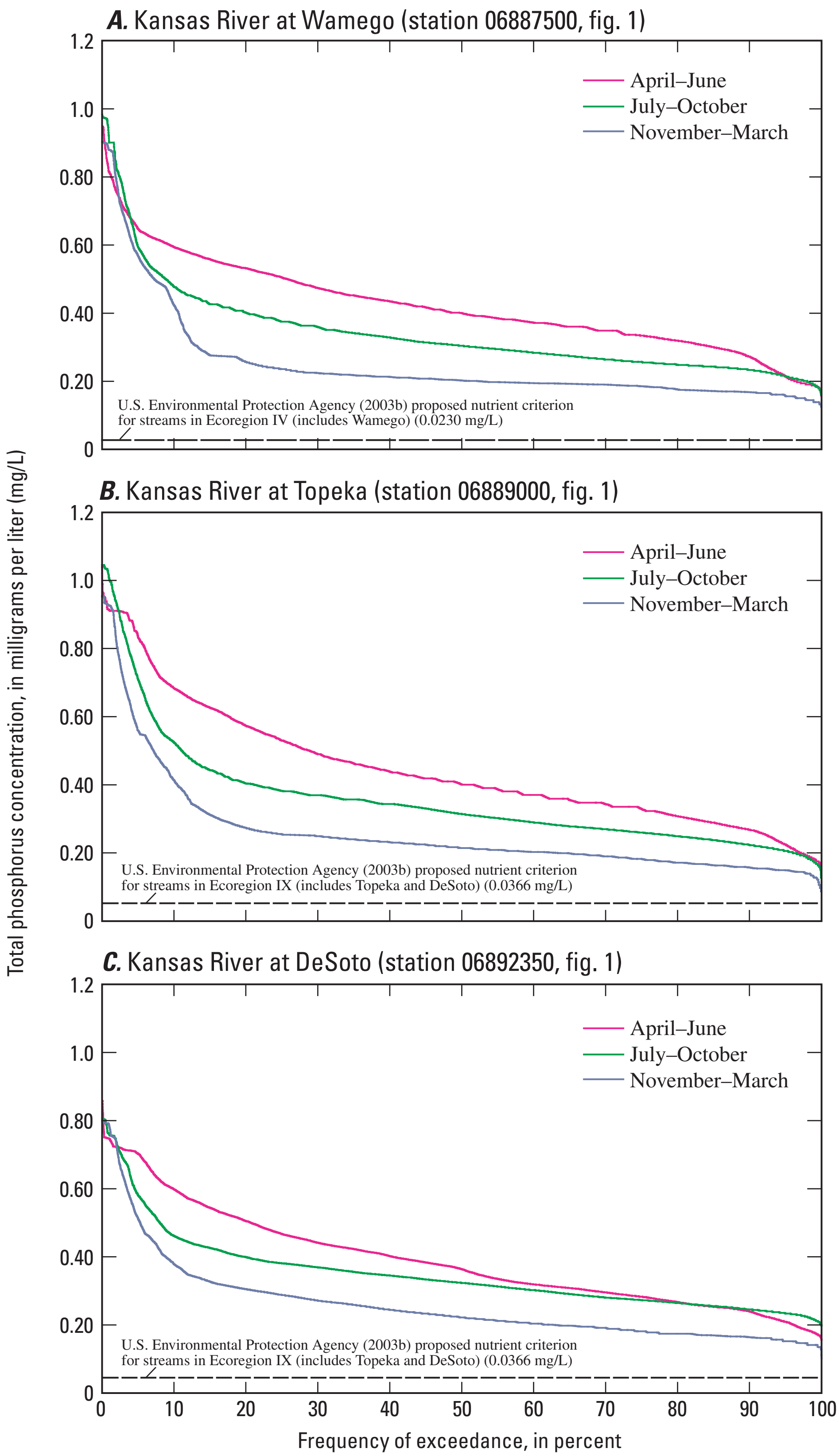


Figure 28. Seasonal duration curves for estimated total phosphorus concentrations at three Kansas River monitoring sites, January 2000–December 2003.

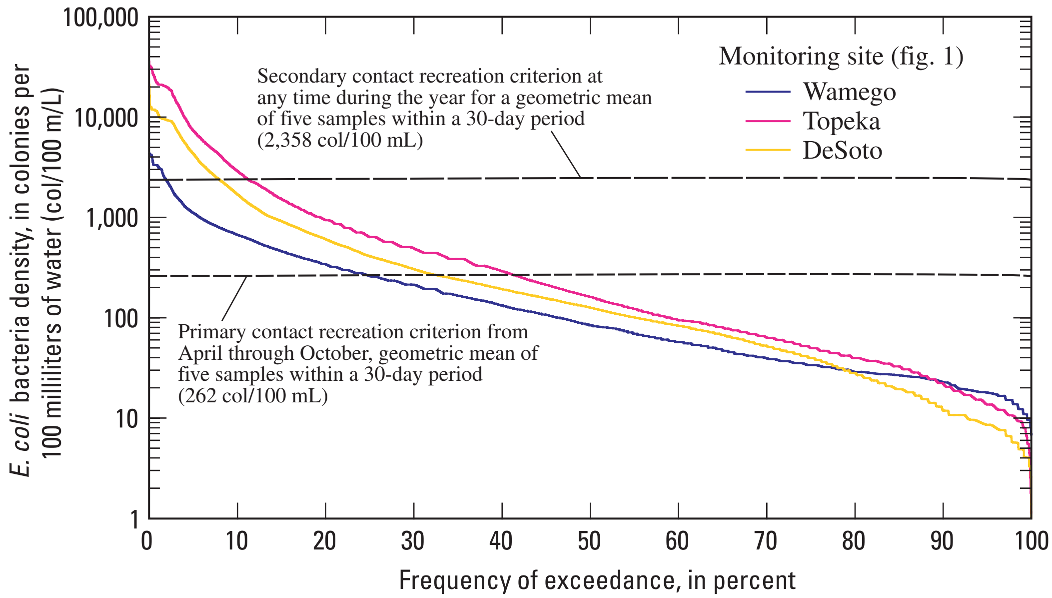


Figure 29. Duration curves for estimated *Escherichia coli (E. coli)* bacteria densities at three Kansas River monitoring sites, January 2000–December 2003. Recreation criteria from Kansas Department of Health and Environment (2003).

from major reservoirs that help trap sediment, which may result in larger suspended-sediment concentrations at that site (fig. 1).

Throughout most of the exceedance range, the largest suspended-sediment concentrations at all sites occurred from April through June (fig. 32), generally corresponding with largest precipitation, runoff, and streamflow conditions. The largest concentrations at Wamego, those exceeded less than 5 percent of the time, occurred from July through October, which may indicate that reservoirs trap more sediment during spring runoff and that during the summer less-turbid water with smaller sediment concentrations is released from the reservoirs. The April through June seasonal duration curve for Topeka has a shallow slope in the less than 3-percent exceedance range probably as a result of turbidity sensor maximization rather than actual leveling of suspended-sediment conditions.

By comparison, 73 discrete suspended-sediment samples were collected at the three Kansas River monitoring sites during the study period, ranging in concentration from 12 to 5,340 mg/L (table 12). The upper part of the suspended-sediment range for the discrete-sample data set is higher than for the regression-estimated data set because of turbidity sensor maximization. Sediment samples collected during conditions when sensor measurements were truncated were not used in developing the regression models. The largest mean and single-sample suspended-sediment concentrations occurred at Topeka. The smallest mean suspended-sediment concentration was at Wamego.

The average annual suspended-sediment loads at Topeka and DeSoto were nearly equal at about 1.65 million tons, more than double the average annual load at Wamego (table 14). The largest annual loads at each site occurred in 2001, corresponding with the largest streamflow of the study period. The sediment load at both Topeka and DeSoto was nearly 5 million tons in 2001, compared to Wamego which was less than one-half that amount, about 2.1 million tons. The suspended-sediment load in 2001 was more than 10 times larger than in 2002 at both Wamego and Topeka, and eight times larger at DeSoto. At each site, average daily loads were largest in April through June and smallest in November through March. During wet years like 2001, the April through June daily loads can be nearly triple the daily load during other seasons. On average, 63 percent of the annual suspended-sediment load at DeSoto occurred during 10 percent of the time (table 15).

The average annual sediment yield (table 14) was largest at the Topeka monitoring site [698 (lb/acre)/yr] followed by DeSoto [582 (lb/acre)/yr], and then Wamego [410 (lb/acre)/yr]. Large sediment loads and yields at Topeka again may be due to tributary contributions in the drainage area with less reservoir trapping or to streambanks and beds more prone to erosion. By comparison, Jordan and Stamer (1995) estimated annual suspended-sediment loads and yields for the Kansas River at Wamego and at DeSoto for water years 1978–86. Their estimates were based on 504 discrete samples from Wamego and 1,312 discrete samples from DeSoto collected over a 9-year period. They estimated an average annual suspended-sediment load of 9,700,000 ton/yr at Wamego and 16,000,000 ton/yr at DeSoto. Using only unregulated drainage area at each site to calculate yield, the estimated yield at Wamego is 5,120 (lb/acre)/yr and at DeSoto is 5,610 (lb/acre)/yr. Jordan (1995) estimated the average annual suspended-sediment load at DeSoto from May 1987 through April 1990 to be 4.1 million tons. The corresponding annual yield, using unregulated drainage area, is 1,440 (lb/acre)/yr. This estimate is comparable to

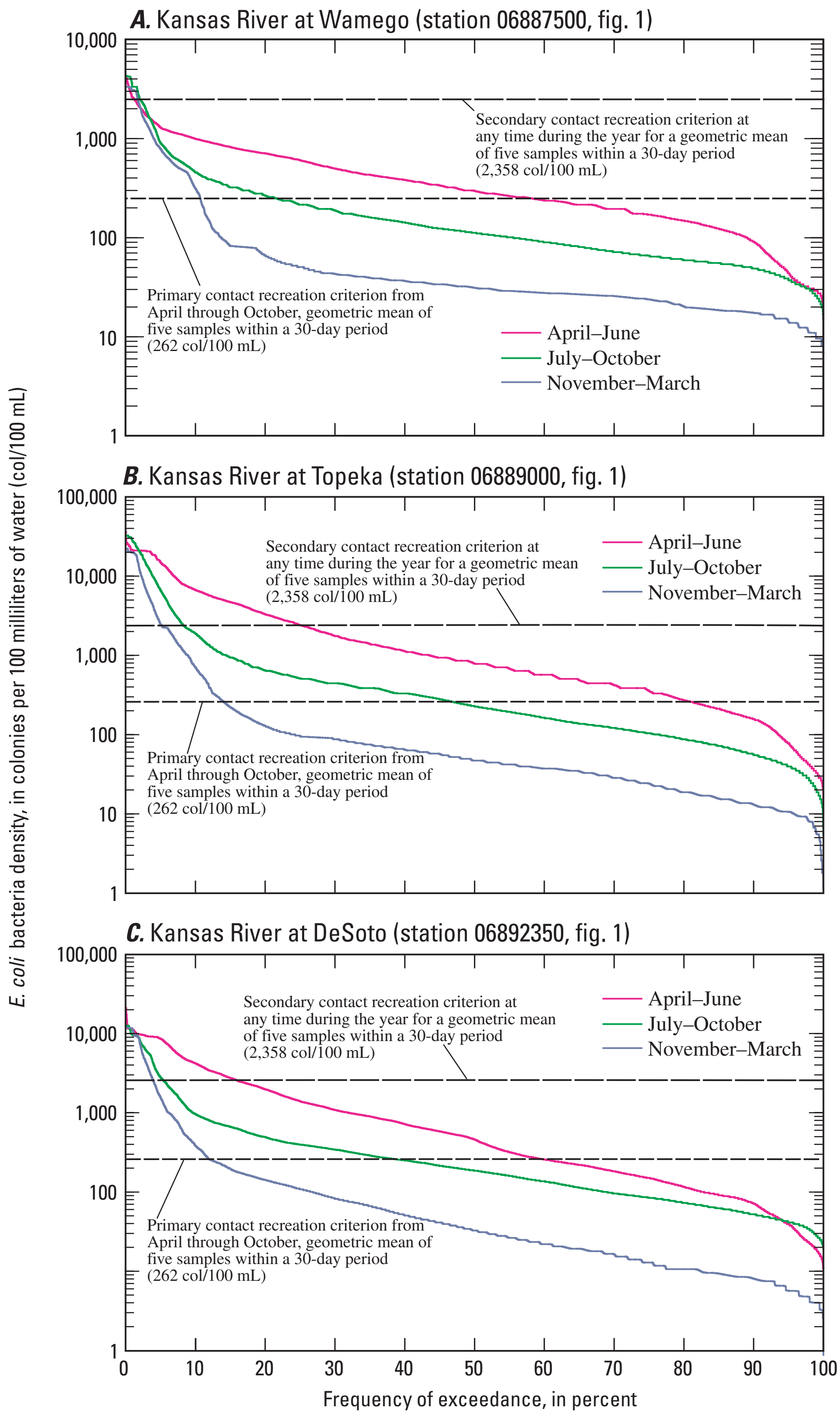


Figure 30. Seasonal duration curves for estimated *Escherichia coli* (*E. coli*) bacteria densities at three Kansas River monitoring sites, January 2000–December 2003. Recreation criteria from Kansas Department of Health and Environment (2003).

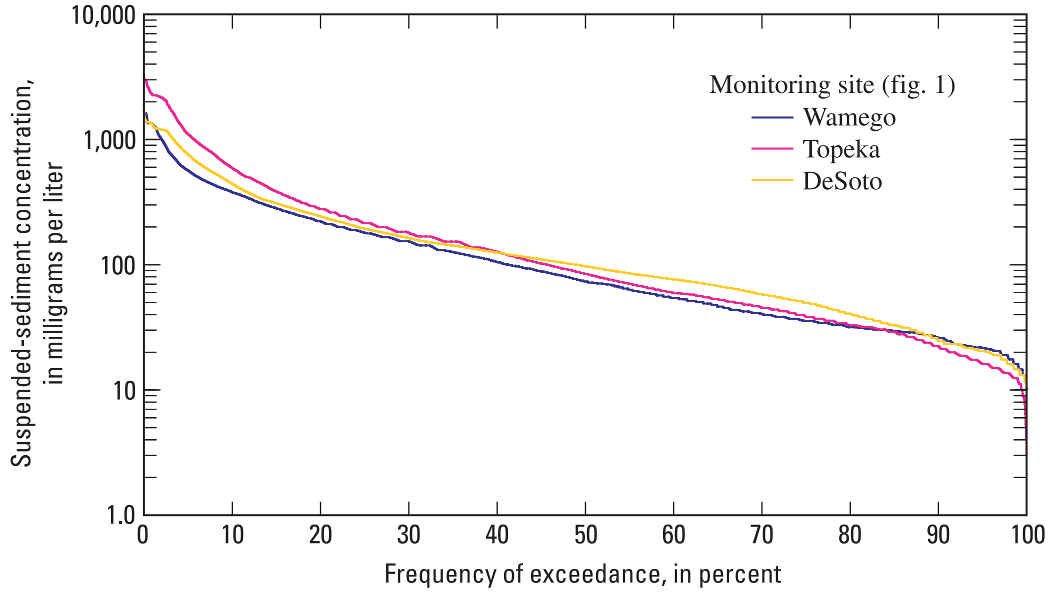


Figure 31. Duration curves for estimated suspended-sediment concentrations at three Kansas River monitoring sites, January 2000–December 2003.

the suspended-sediment load estimates in 2001 when streamflow most closely resembled historical streamflow conditions (fig. 10).

Jordan (1995) determined that, of the 38 suspended-sediment samples collected from the Kansas River at DeSoto from May 1987 through April 1990, the median percentage of particles with diameters larger than 0.062 mm, interpreted to represent the relative abundance of sand, was 13 percent. In 10 percent of the samples, at least 48 percent of the particles were larger than 0.062 mm in size. Generally, the suspended-sediment samples in Jordan's study and the study described in this report contained particles no larger than 1 mm in diameter. With an annual suspended-sediment load at DeSoto of 1.66 million tons (estimated for 2000–03, table 14) to 4.1 million tons (estimated for 1987–90 by Jordan, 1995), approximately 13 percent of which was sand-size particles, an estimated 216,000 to 533,000 tons of sand were transported annually in the water column at DeSoto. This estimate does not include sand transported as bedload (particles transported close to or on the channel bed), the quantity of which is unknown but is likely considerably larger than sand transported as suspended load. Coarse sediment, including sand-size particles, usually is transported as bedload except for short periods of suspended transport (Ritter, 1986). An estimated 1.4 million tons of material were removed from the Kansas River by commercial dredging operations in 2003, approximately 90 to 95 percent of which was sand (Josh Marx, U.S. Army Corps of Engineers, Kansas City District, oral commun., June 2005). Although it is not possible to quantify with the available data, the amount of material removed by dredging could be a substantial part of the total material being transported through the system.

Comparison of Load Estimates

In this section, for the five constituents just described, annual loads using regression estimates of concentration and density that were based on continuous turbidity measurements (table 10 equations), are compared to the load estimates using the approximately 20 discrete samples per site collected from 1999 through 2003. In addition, for suspended-sediment concentration, comparisons are made to loads estimated using continuous estimates of concentrations and densities that were based on streamflow regression models (table 10). For each of the comparisons, missing data in the continuous data set were estimated as described in the "Methods" section.

Table 16 shows comparisons between regression-estimated concentrations and densities and annual loads (using table 10 models), and loads estimated from discrete samples, for dissolved solids, total nitrogen, total phosphorus, *E. coli* bacteria, and suspended sediment. Turbidity was the water-quality sensor used to provide continuous estimates for each of the constituents except dissolved solids, which was estimated using specific conductance. The total annual load from continuous estimates (column F) is the sum of all the hourly estimates during the year. The total annual load from discrete samples (column G) is the mean daily load (column E) multiplied by 365 days per year. The mean daily load of the discrete samples (column E) is the mean measured streamflow (column A), multiplied by the mean concentration or density of the discrete samples collected throughout the study period (column C), and multiplied by the appropriate conversion factor to get estimated mean daily load in tons per day.

For each constituent except dissolved solids, the average 2000–03 estimated annual load from discrete samples was less than the estimated load from continuous data (table 16). For

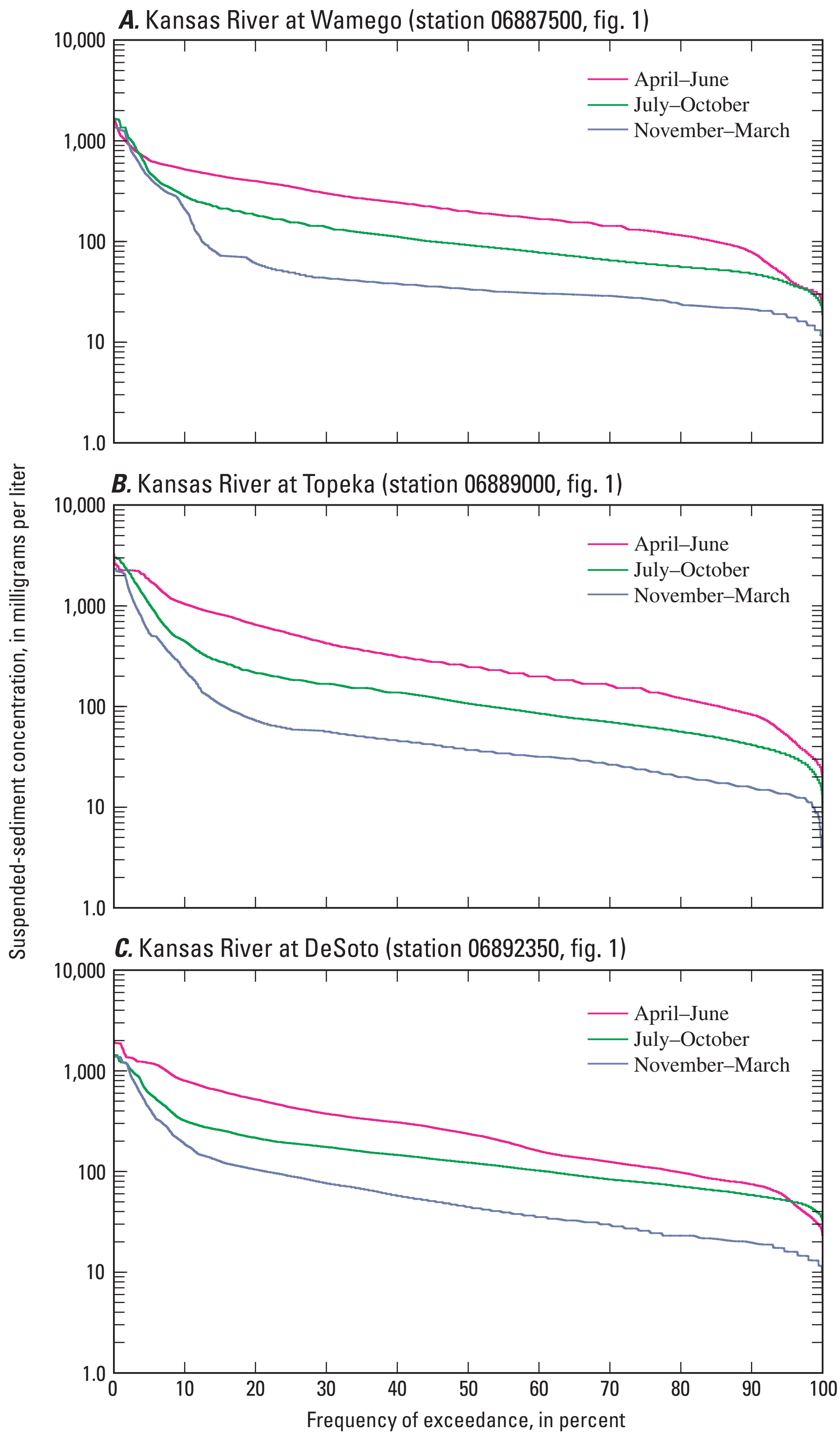


Figure 32. Seasonal duration curves for estimated suspended-sediment concentrations at three Kansas River monitoring sites, January 2000–December 2003.

Table 16. Comparison of estimated water-quality constituent loads that were based on continuous regression-estimated concentrations or densities and results of discrete-sample analysis at three monitoring sites on lower Kansas River, northeast Kansas, 2000–03.

[A–G are column identifiers. ft^3/s, cubic feet per second; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; *E. coli, Escherichia coli*]

Calendar year	Monitoring site (fig. 1)	Mean measured streamflow (ft^3/s) (A, table 7)	Mean concentration (mg/L or billon colonies), hourly estimates from continuous data (B)	Mean concentration (mg/L or billon colonies), discrete samples (C, table 10)	Relative percentage difference[1] (between columns B and C)	Mean daily load (tons), from hourly estimates based on continuous data (per day) (D)	Estimated mean daily load (tons), discrete samples (per day) (E=AxCx appropriate conversion factor)	Estimated total annual load (tons), sum of hourly estimates from continuous data (F)	Estimated total annual load (tons), from discrete samples (G=Ex365)	Differences between estimated total annual loads (tons) (F-G)	Relative percentage difference[1] (between columns F and G)
			Dissolved solids								
2000	Wamego	2,420	623	512	20	3,810	3,330	1,390,000	1,220,000	170,000	13
	Topeka	2,480	594	462	25	3,750	3,090	1,360,000	1,130,000	230,000	18
	DeSoto	3,040	559	486	14	4,210	3,980	1,530,000	1,450,000	80,000	5
2001	Wamego	5,260	462	512	-10	5,140	7,260	1,880,000	2,650,000	-770,000	-34
	Topeka	5,870	439	462	-5	5,570	7,310	2,030,000	2,670,000	-640,000	-27
	DeSoto	8,340	402	486	-19	7,130	10,900	2,610,000	3,990,000	-1,390,000	-42
2002	Wamego	1,720	536	512	5	2,360	2,380	861,000	870,000	-8,000	-1
	Topeka	1,830	501	462	8	2,300	2,280	839,000	833,000	6,000	1
	DeSoto	2,600	467	486	-4	2,890	3,400	1,050,000	1,240,000	-180,000	-16
2003	Wamego	1,650	462	512	-10	1,790	2,270	654,000	829,000	-175,000	-24
	Topeka	1,690	464	462	0	1,870	2,110	681,000	769,000	-88,000	-12
	DeSoto	1,940	454	486	-7	2,130	2,530	779,000	925,000	-145,000	-17
Average 2000–03	Wamego	2,760	521	512	2	3,280	3,810	1,190,000	1,390,000	-200,000	-16
	Topeka	2,970	500	462	8	3,370	3,700	1,230,000	1,350,000	-120,000	-9
	DeSoto	3,980	470	486	-3	4,090	5,210	1,490,000	1,900,000	-410,000	-24
			Total nitrogen								
2000	Wamego	2,420	1.9	2.0	-7	13	13	4,860	4,780	90	2
	Topeka	2,480	1.8	2.0	-12	13	13	4,820	4,850	-30	-1
	DeSoto	3,040	1.6	1.9	-12	15	15	5,510	5,560	-40	-1
2001	Wamego	5,260	2.2	2.0	8	36	28	13,100	10,400	2,700	23
	Topeka	5,870	2.1	2.0	6	41	32	15,100	11,500	3,600	27
	DeSoto	8,340	2.0	1.9	5	54	42	19,700	15,300	4,400	25

Table 16. Comparison of estimated water-quality constituent loads that were based on continuous regression-estimated concentrations or densities and results of discrete-sample analysis at three monitoring sites on lower Kansas River, northeast Kansas, 2000–03.—Continued

[A–G are column identifiers. ft^3/s, cubic feet per second; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; *E. coli, Escherichia coli*]

Calendar year	Monitoring site (fig. 1)	Mean measured streamflow (ft^3/s) (A, table 7)	Mean concentration (mg/L or billon colonies), hourly estimates from continuous data (B)	Mean concentration (mg/L or billon colonies), discrete samples (C, table 10)	Relative percentage difference[1] (between columns B and C)	Mean daily load (tons), from hourly estimates based on continuous data (per day) (D)	Estimated mean daily load (tons), discrete samples (per day) (E=AxCx appropriate conversion factor)	Estimated total annual load (tons), sum of hourly estimates from continuous data (F)	Estimated total annual load (tons), from discrete samples (G=Ex365)	Differences between estimated total annual loads (tons) (F-G)	Relative percentage difference[1] (between columns F and G)
			Total nitrogen—Continued								
2002	Wamego	1,720	1.7	2.0	-19	8.0	9.4	2,930	3,420	-490	-15
	Topeka	1,830	1.6	2.0	-23	8.8	9.8	3,200	3,590	-390	-11
	DeSoto	2,600	1.5	1.9	-21	12	13	4,510	4,760	-250	-5
2003	Wamego	1,650	1.8	2.0	-10	8.9	8.9	3,250	3,260	-20	-1
	Topeka	1,690	1.7	2.0	-17	8.7	9.1	3,180	3,310	-130	-4
	DeSoto	1,940	1.6	1.9	-16	9.3	9.7	3,390	3,540	-150	-4
Average 2000–03	Wamego	2,760	1.9	2.0	-7	16	15	6,040	5,460	570	10
	Topeka	2,970	1.8	2.0	-11	18	16	6,580	5,810	770	12
	DeSoto	3,980	1.7	1.9	-10	23	20	8,280	7,280	1,000	13
			Total phosphorus								
2000	Wamego	2,420	.32	.36	-12	2.4	2.3	900	856	33	4
	Topeka	2,480	.34	.42	-21	2.7	2.8	970	1,020	-53	-5
	DeSoto	3,040	.32	.36	-12	3.1	2.9	1,120	1,080	40	4
2001	Wamego	5,260	.41	.36	13	7.3	5.1	2,640	1,860	790	35
	Topeka	5,870	.44	.42	5	9.4	6.6	3,430	2,430	990	34
	DeSoto	8,340	.41	.36	13	12	8.1	4,430	2,950	1,480	40
2002	Wamego	1,720	.26	.36	-32	1.3	1.7	480	612	-133	-24
	Topeka	1,830	.28	.42	-40	1.7	2.1	610	757	-148	-22
	DeSoto	2,600	.28	.36	-25	2.5	2.5	900	921	-18	-2
2003	Wamego	1,650	.31	.36	-15	1.6	1.6	580	583	-1	0
	Topeka	1,690	.31	.42	-30	1.7	1.9	630	699	-67	-10
	DeSoto	1,940	.30	.36	-18	1.9	1.9	680	685	-7	-1

Table 16. Comparison of estimated water-quality constituent loads that were based on continuous regression-estimated concentrations or densities and results of discrete-sample analysis at three monitoring sites on lower Kansas River, northeast Kansas, 2000–03.—Continued

[A–G are column identifiers. ft^3/s, cubic feet per second; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; *E. coli, Escherichia coli*]

Calendar year	Monitoring site (fig. 1)	Mean measured streamflow (ft^3/s) (A, table 7)	Mean concentration (mg/L or billon colonies), hourly estimates from continuous data (B)	Mean concentration (mg/L or billon colonies), discrete samples (C, table 10)	Relative percentage difference[1] (between columns B and C)	Mean daily load (tons), from hourly estimates based on continuous data (per day) (D)	Estimated mean daily load (tons), discrete samples (per day) (E=AxCx appropriate conversion factor)	Estimated total annual load (tons), sum of hourly estimates from continuous data (F)	Estimated total annual load (tons), from discrete samples (G=Ex365)	Differences between estimated total annual loads (tons) (F-G)	Relative percentage difference[1] (between columns F and G)
			Total phosphorus—Continued								
Average 2000–03	Wamego	2,760	0.33	0.36	-10	3.2	2.7	1,164	978	186	17
	Topeka	2,970	.34	.42	-20	3.9	3.4	1,410	1,230	180	14
	DeSoto	3,980	.33	.36	-9	4.9	3.9	1,780	1,410	370	23
			E. coli bacteria								
2000	Wamego	2,420	243	319	-27	12	2,080	8,800,000	758,000	8,042,000	168
	Topeka	2,480	1,000	1,580	-45	66	10,600	48,400,000	3,850,000	44,550,000	171
	DeSoto	3,040	860	1,360	-45	43	11,100	31,300,000	4,060,000	27,240,000	154
2001	Wamego	5,260	522	319	48	52	4,520	37,800,000	1,650,000	36,150,000	183
	Topeka	5,870	3,130	1,580	66	432	25,000	316,000,000	9,130,000	305,870,000	189
	DeSoto	8,340	1,780	1,360	27	371	30,600	271,000,000	11,200,000	259,800,000	184
2002	Wamego	1,720	108	319	-99	3	1,480	1,990,000	542,000	1,438,000	114
	Topeka	1,830	515	1,580	-102	29	7,800	21,400,000	2,850,000	18,550,000	153
	DeSoto	2,600	325	1,360	-123	32	9,530	23,100,000	3,480,000	19,620,000	148
2003	Wamego	1,650	219	319	-37	7	1,420	5,280,000	517,000	4,763,000	164
	Topeka	1,690	992	1,580	-46	42	7,200	30,900,000	2,630,000	29,270,000	170
	DeSoto	1,940	438	1,360	-103	24	7,090	17,300,000	2,590,000	14,710,000	148
Average 2000–03	Wamego	2,760	273	319	-16	18	2,380	13,500,000	867,000	12,633,000	176
	Topeka	2,970	1,410	1,580	-11	142	12,600	104,000,000	4,610,000	99,390,000	183
	DeSoto	3,980	851	1,360	-46	117	14,600	85,700,000	5,320,000	80,280,000	177

Table 16. Comparison of estimated water-quality constituent loads that were based on continuous regression-estimated concentrations or densities and results of discrete-sample analysis at three monitoring sites on lower Kansas River, northeast Kansas, 2000–03.—Continued

[A–G are column identifiers. ft^3/s, cubic feet per second; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; *E. coli, Escherichia coli*]

Calendar year	Monitoring site (fig. 1)	Mean measured streamflow (ft^3/s) (A, table 7)	Mean concentration (mg/L or billon colonies), hourly estimates from continuous data (B)	Mean concentration (mg/L or billon colonies), discrete samples (C, table 10)	Relative percentage difference[1] (between columns B and C)	Mean daily load (tons), from hourly estimates based on continuous data (per day) (D)	Estimated mean daily load (tons), discrete samples (per day) (E=AxCx appropriate conversion factor)	Estimated total annual load (tons), sum of hourly estimates from continuous data (F)	Estimated total annual load (tons), from discrete samples (G=Ex365)	Differences between estimated total annual loads (tons) (F-G)	Relative percentage difference[1] (between columns F and G)
					Suspended sediment, in tons						
2000	Wamego	2,420	148	228	-43	1,440	1,480	524,000	541,900	-16,800	-3
	Topeka	2,480	204	504	-85	2,310	3,370	845,000	1,230,000	-386,000	-37
	DeSoto	3,040	156	314	-67	2,080	2,570	760,000	938,000	-178,000	-21
2001	Wamego	5,260	273	228	18	5,770	3,230	2,110,000	1,180,000	930,000	57
	Topeka	5,870	469	504	-7	13,100	7,980	4,800,000	2,910,000	1,880,000	49
	DeSoto	8,340	340	314	8	13,400	7,050	4,880,000	2,570,000	2,310,000	62
2002	Wamego	1,720	80	228	-96	434	1,060	159,000	387,000	-228,000	-84
	Topeka	1,830	120	504	-123	1,120	2,490	409,000	909,000	-501,000	-76
	DeSoto	2,600	113	314	-94	1,580	2,200	576,000	803,000	-226,000	-33
2003	Wamego	1,650	134	228	-52	878	1,010	320,000	369,000	-49,000	-14
	Topeka	1,690	188	504	-91	1,460	2,300	533,000	839,000	-305,000	-44
	DeSoto	1,940	139	314	-77	1,180	1,640	432,000	598,000	-167,000	-32
Average 2000–03	Wamego	2,760	159	228	-36	2,300	1,700	778,000	620,000	158,000	23
	Topeka	2,970	245	504	-69	4,620	4,030	1,650,000	1,470,000	170,000	11
	DeSoto	3,980	187	314	-51	5,540	3,360	1,660,000	1,230,000	430,000	30

[1] Relative percent difference $= \left[|B - C| / \frac{B + C}{2} \right] \times 100.$

dissolved solids, the only constituent of the five that used specific conductance as an explanatory variable in the regression model, the estimated mean annual load from discrete samples was larger than the load estimated using continuous data, with relative percentage differences (RPDs) of between 9 and 24 percent during the 2000–03 period. The average RPD between the two load estimates was largest for *E. coli*, about 180 percent at each site from 2000–03. The average RPD for total nitrogen, total phosphorus, and suspended sediment was between 10 and 30 percent during the same period.

For each constituent, the most substantial difference in annual load estimates occurred in 2001. For dissolved solids, estimated loads that were based on discrete samples were larger in 2001, with RPDs of 27 to 42 percent. For total nitrogen and total phosphorus, the RPDs were between 23 and 40 percent in 2001, a notable difference from the smaller load estimates typically provided by turbidity-estimated loads during other years. For *E. coli* bacteria, the discrete sample method tended to underestimate loads under all hydrologic conditions. Some of the annual load estimates from discrete samples were within 10 percent of the continuous load estimates. The estimates were close in part because the samples were collected over the range of hydrologic conditions rather than on a calendar basis, which tends to limit the magnitude of load estimation errors (Horowitz, 2003).

Using the discrete-sample data sets for the entire study period, the mean of the samples remains the same, so the variability in annual load estimated from discrete samples results from variability in streamflow only. The reason the entire data set is used to determine mean concentration of discrete samples, rather than dividing the samples by year, is that during some years of the sampling period only two or three samples were collected per site and during other years more than 10 samples were collected. One advantage to using continuous data to estimate loads is that estimates are valid even during years when only a few discrete samples are collected as long as there is no reason to believe the regression relations have changed.

A comparison between turbidity-estimated loads and streamflow-estimated loads for suspended sediment (fig. 33) indicates that the streamflow-estimated load was the largest for the 2000–03 period at all three monitoring sites. During 2001, streamflow-estimated suspended-sediment loads were about three times larger than turbidity-estimated loads at DeSoto and about 17 times larger than discrete-sample loads. The average relative percentage difference between turbidity-estimated load and streamflow-estimated load for the 2000–03 period was

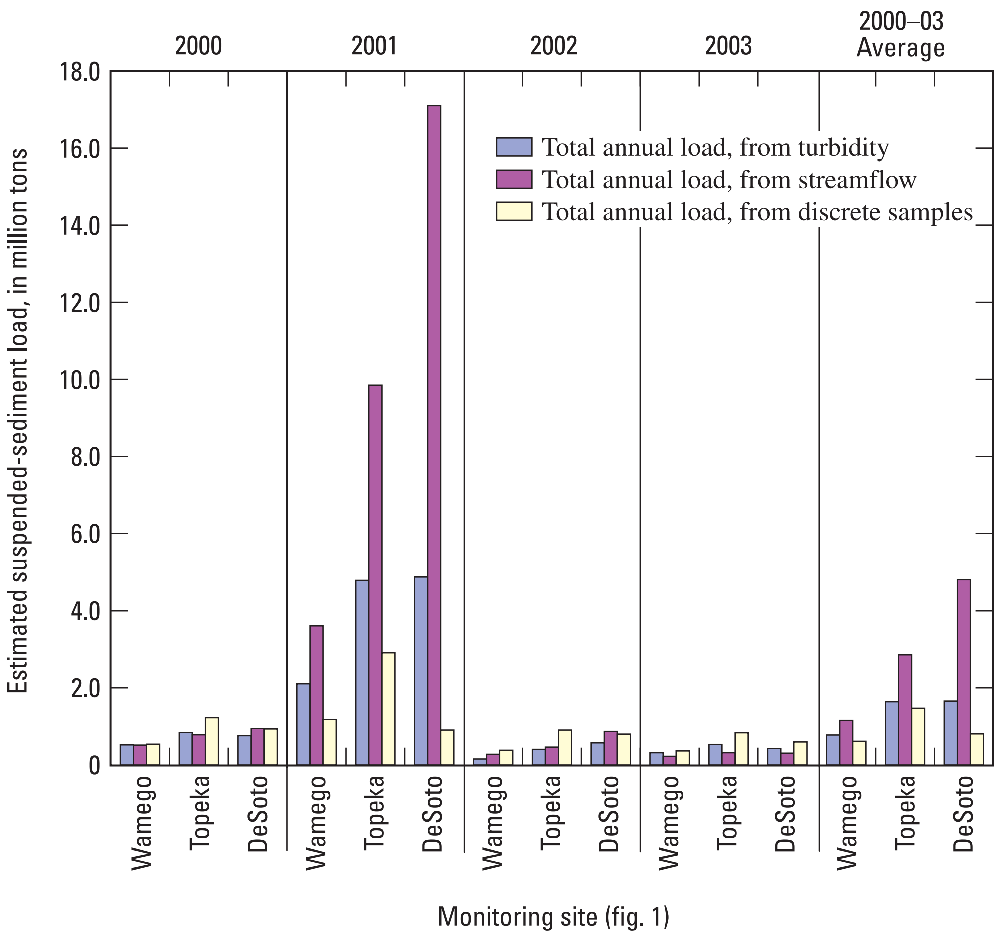


Figure 33. Comparison of methods used to estimate annual suspended-sediment loads at three monitoring sites, 2000–03, using different explanatory variables.

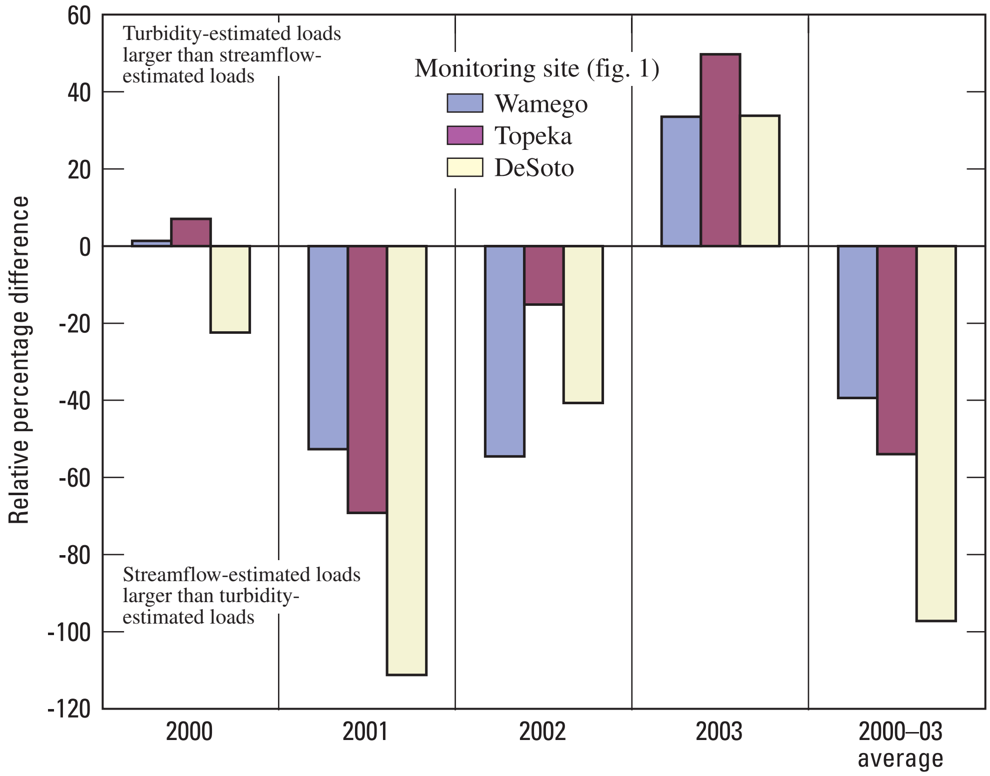


Figure 34. Comparison of relative percentage differences between turbidity-estimated annual suspended-sediment loads and streamflow-estimated annual suspended-sediment loads for three monitoring sites, 2000–03.

between 40 and 100 percent (fig. 34). The only year that turbidity-estimated loads were larger than streamflow-estimated loads was 2003, a dry year. When estimated suspended-sediment loads are analyzed by month over the study period, streamflow-estimated loads for all sites were the largest every month except August and for Wamego and Topeka in April and September (fig. 35).

The comparison of load estimation techniques indicated that annual load estimates can vary substantially depending on the explanatory variables used to develop the estimates. In each case, of the three explanatory variables used, loads that were estimated on the basis of turbidity were the best estimates as indicated by the R^2 and MSE. Regression-estimated loads using turbidity and streamflow are useful because they provide continuous information (often hourly) and, therefore, describe variability between samples, unlike loads estimated using discrete samples alone. Turbidity-estimated concentrations and loads often are better than streamflow-estimated concentrations and loads because the relation between suspended sediment and turbidity is stronger than the relation between suspended sediment and streamflow, as indicated by the R^2 and MSE values from the statistical analyses (tables 10 and 11). Suspended-sediment concentration is more closely related to turbidity than streamflow because suspended sediment is the principal component of turbidity.

The streamflow-based regression models tended to overestimate suspended-sediment loads during high-flow conditions. One reason for the overestimation is that during runoff large streamflow values are maintained for a longer period of time than are large turbidity values (fig. 6). The streamflow curve tended to be broader, both at the peak and the base, than the turbidity curve. The turbidity curve typically rose and fell much more quickly so that large concentrations were not sustained except during the most extreme flows and even then for a shorter duration than streamflow (fig. 6). Turbidity changes rapidly because the source and availability of suspended sediment changes rapidly. Streamflow-estimated sediment loads assumed that suspended-sediment concentrations remained large for a longer period of time than what actually occurred resulting in larger load estimates. Hysteresis effects (fig. 21) also contributed to larger estimation errors using streamflow-based regression models.

Summary and Conclusions

Continuous real-time water-quality monitors were installed by the U.S. Geological Survey (USGS) at three locations (Wamego, Topeka, and DeSoto) along the lower Kansas River in northeast Kansas to provide continuous measurement of specific conductance, pH, water temperature, turbidity, and

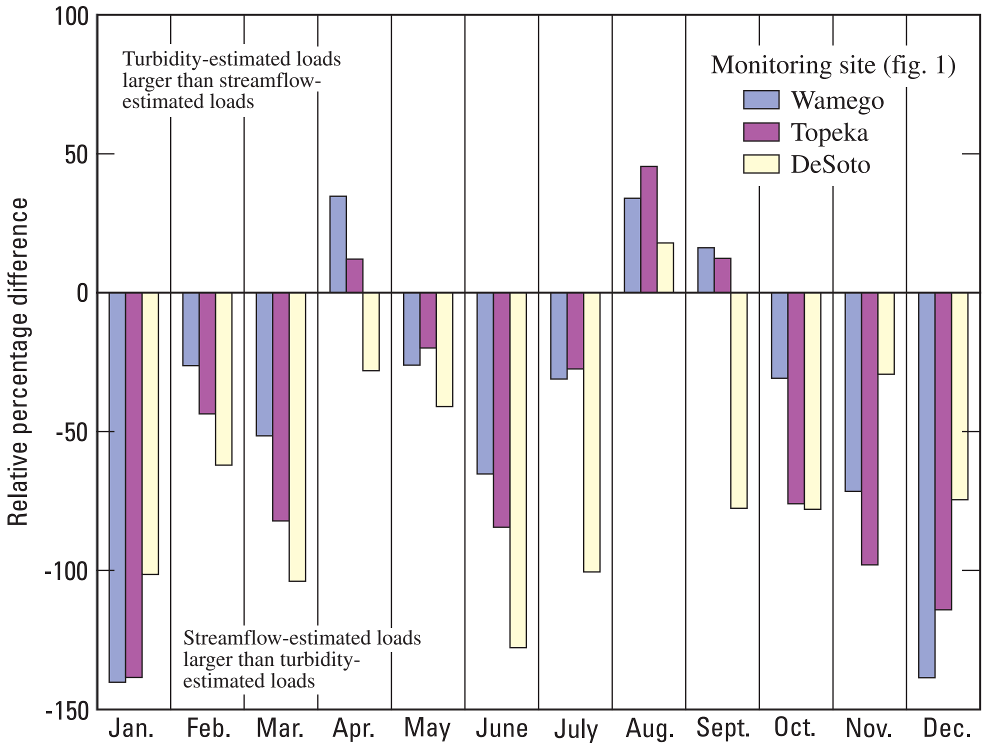


Figure 35. Comparison of relative percentage differences between average monthly turbidity-estimated suspended-sediment loads and average monthly streamflow-estimated suspended-sediment loads for three Kansas River monitoring sites, 2000–03.

dissolved oxygen from July 1999 through September 2004 as part of a study in cooperation with the Kansas Department of Health and Environment (KDHE) with assistance from the U.S. Environmental Protection Agency (USEPA). Water-quality samples also were collected and analyzed for dissolved solids, nutrients, bacteria, suspended sediment, and other constituents. Regression models then were developed relating the continuous data to the discrete-sample data. The discrete samples represented about 90 percent of the river's flow duration curve. Using this method, it was possible to provide continuous estimates of constituents of concern in real time and make the estimates available on a USGS Web site (http://ks.water.usgs.gov). Estimates of concentration and density were combined with streamflow to estimate loads and yields from the monitoring-site drainage areas from January 2000 through December 2003.

Water quality in the lower Kansas River is affected by point and nonpoint sources in the drainage basin, reservoirs, urban factors, dredging, and ground-water composition and contribution. Point sources primarily include industrial and wastewater-treatment facilities. Agriculture is the principal land use with 30 percent of the land use in the lower Kansas River Basin cropland and 56 percent grassland. During the 4-year study period, just over one-half of the total streamflow at each monitoring site originated from reservoirs. Generally, the reservoirs trap nutrients, bacteria, and sediment from their drainage basins, and reservoir outflows to the Kansas River dilute some downstream constituent concentrations. Large concentrations of dissolved solids during base flow were caused by mineralized ground water.

In-stream water-quality conditions at the three monitoring sites indicated variability with time of day, hydrologic conditions, and season. Streamflow ranged from a minimum of 233 ft^3/s at Topeka to a maximum of 80,700 ft^3/s at DeSoto. Annual streamflow volume at each site in 2001 was 2.2 to 3.3 times larger than the smallest annual streamflow volume, which occurred in 2003 at each site. Distinct diurnal fluctuations in pH and dissolved oxygen occurred, indicating photosynthetic activity, with the most extreme fluctuations taking place in late summer (August and September) when temperatures were higher and streamflow less. During the study period, pH remained well above the KDHE lower criterion of 6.5 standard units at all sites in all years, but exceeded the upper criterion of 8.5 standard units annually between 2 percent of the time (Wamego in 2001) and 65 percent of the time (DeSoto in 2003). Continuous in-stream turbidity measurements ranged from less than 10 FNUs to greater than 1,200 FNUs at each site annually. Technological limitations of the sensors prevented turbidity measurements as large as the conditions that occurred, particularly in 2001 when almost 3 percent of the hourly measurements at Topeka and DeSoto were affected by sensor maximization. The dissolved oxygen concentration was less than the minimum aquatic-life-support criterion of 5.0 mg/L at all sites sometime during each year except 2002; however, dissolved oxygen concentrations less than 5.0 mg/L occurred less than 1 percent of the time.

Although streamflow is an important factor affecting water-quality concentrations, increases and decreases in concentrations do not necessarily coincide with changes in streamflow. This is especially true for constituents associated with particulates. Continuous turbidity data indicated that turbidity peak values can arrive before, during, or after the associated streamflow peak values. Without continuous turbidity information this cannot be quantified. In-stream water-quality measurements, especially specific conductance and turbidity, can vary by large amounts in a short period of time during runoff, often less than 1 hour.

Annually, the median dissolved-solids concentrations were largest at Wamego and decreased at downstream sites. Larger dissolved-solids concentrations upstream were a result of water inflow from the highly mineralized Smoky Hill River, diluting concentrations as water moved downstream. Concentrations generally were smallest during the spring and summer months and largest during the winter months. Dissolved-solids concentrations exceeded 500 mg/L about 40 to almost 60 percent of the time at each site. Dissolved-solids loads were largest at DeSoto, averaging 1.5 million tons annually from 2000 to 2003. Wamego and Topeka loads were similar to each other, averaging about 1.2 million tons annually. The largest dissolved-solids yields occurred at Wamego, with an average of 78 (lb/acre)/yr, about 15 percent larger than the yields at Topeka and DeSoto.

USEPA suggested ecoregion criteria for total nitrogen and total phosphorus always were exceeded at each of the three sites. Except within the 10-percent exceedance frequency range, total nitrogen concentrations were largest at Wamego, followed by Topeka, then DeSoto. There was not a substantial difference in total phosphorus concentrations from upstream to downstream. The largest nutrient concentrations occurred from April through June, coinciding with extensive fertilizer application in the spring and stormwater runoff. Annual total nitrogen loads ranged from about 2,900 tons at Wamego in 2002 to about 20,000 tons at DeSoto in 2001. Total phosphorus loads increased from upstream to downstream, from an average of 1,150 ton/yr at Wamego to 1,780 ton/yr at DeSoto. Large differences in annual load from year to year can be attributed primarily to hydrologic variability. Total nitrogen and total phosphorus yields were nearly the same from site to site and varied with hydrologic conditions, the largest yields occurring in 2001. Similar yield characteristics at the three sites indicate that nutrient sources are evenly distributed throughout the lower Kansas River Basin. On average, about 40 percent of the annual nutrient load at DeSoto occurred during 10 percent of the time. Eleven percent of the total nitrogen load and 12 percent of the total phosphorus load at DeSoto from 2000–03 originated from wastewater-treatment facilities.

Continuously estimated *E. coli* densities in the Kansas River at Topeka ranged from 1 to more than 35,700 col/100 mL. The largest bacteria densities throughout most of the range of streamflow conditions (more than 80 percent of the time) occurred at Topeka each year of the study period, whereas the smallest densities occurred at Wamego. Median *E. coli* densities at Topeka generally were double the densities at Wamego. Larger bacteria densities at Topeka were likely a result of larger contributions from nonpoint-source agricultural and urban runoff in the drainage area. The largest annual bacteria loads and yields generally occurred at Topeka. The average *E. coli* bacteria load at Topeka was more than seven times larger than the average load at Wamego and 21 percent larger than the average load at DeSoto. On average, 83 percent of the annual bacteria load at DeSoto occurred during 10 percent of the time. Bacteria densities that were larger at Topeka and the smaller densities at the downstream DeSoto site may be a result of bacterial die-off and dilution effects from reservoir releases downstream.

Suspended-sediment concentrations ranged from 3 to at least 3,000 mg/L. Generally, the smallest concentrations occurred at Wamego and the largest at Topeka, the middle monitoring site. The average annual suspended-sediment loads at Topeka and DeSoto were nearly equal at about 1.65 million tons, double the mean annual load at Wamego. The mean annual sediment yield was largest at Topeka, followed by DeSoto, and then Wamego. Large sediment loads and yields at Topeka may be due to tributary contributions in the drainage area with less reservoir trapping or to streambanks and beds more prone to erosion. On average, 63 percent of the annual suspended-sediment load at DeSoto occurred during 10 percent of the time.

Of the estimated 1.4 million tons of material removed from the Kansas River by commercial dredging operations in 2003, approximately 90 to 95 percent was sand. With an annual suspended-sediment load at DeSoto of 1.66 million tons (estimated for 2000–03) to 4.1 million tons (estimated for 1987–90 by Jordan, 1995), approximately 13 percent of which was sand-size particles, an estimated 216,000 to 533,000 tons of sand were transported annually in the water column at DeSoto. This estimate does not include sand transported as bedload, the quantity of which is unknown but likely is considerably larger than sand transported as suspended load.

A comparison of load estimation techniques indicated that annual load estimates can vary substantially depending on the explanatory variables used to develop the estimates. Annual loads were determined using continuous estimates that were based on turbidity, using the results of discrete-sample analysis, and using continuous estimates that were based on streamflow. Load estimates differed by as much as 180 percent. For each constituent, the most substantial difference in annual load estimates occurred in 2001. Some of the annual load estimates from discrete samples were within 10 percent of the continuous load estimates. The estimates were close in part because the discrete samples were collected throughout the range of hydrologic conditions rather than on a calendar basis, which tended to limit the magnitude of load estimation errors. In each case, of the three explanatory variables used, loads that were based on turbidity provided the best estimates as indicated by the R^2 and MSE. Regression-estimated loads were useful because they provided continuous information (often hourly) and, therefore, described variability between samples, unlike loads estimated using discrete samples alone. Turbidity-estimated concentrations and loads often were better than streamflow-estimated concentrations and loads because the relation between sediment and turbidity was stronger than that between sediment and discharge, as indicated by the R^2 and MSE values from the statistical analyses.

A system for continuously monitoring water-quality constituents has numerous advantages over traditional water-quality studies relying on sampling alone. TMDL programs can benefit from continuous data because they provide the foundation for a more comprehensive evaluation of the variability in loading characteristics and water-quality degradation than provided by discrete water-quality samples. For TMDLs, the data can be used to identify impairments, to define contributing factors such as hydrology, season, and sources, to evaluate goals, and to monitor changes. Continuous concentration or density estimates can be used to construct cumulative frequency distribution (duration) curves to determine percentage of time that estimated concentrations or densities exceed water-quality criteria. Estimated concentration, density, and load duration curves can be used to evaluate current water-quality conditions and estimate the duration and magnitude of potential water-quality degradation. Duration curves also can be used to differentiate between base-flow and runoff conditions. Examination of differences in regression-estimated concentrations, densities, and loads at a series of sensor stations along a stream allows the analysis of upstream-to-downstream changes in water quality. In situations where discrete samples and constituent concentration or density data are necessary for regulatory requirements, monitoring by continuous sensor data allows regulatory agencies to optimize sampling efforts. In some cases it may be more cost effective to use continuous monitors for critical constituent monitoring rather than intensive discrete sampling. When continuous estimates are considered over the long term, it may be possible to identify changes in water-quality conditions resulting from land-use changes and implementation of best-management practices in the watershed.

References Cited

Albert, C.P., 1964, Brine in surface water of the Little Arkansas River Basin, Kansas: Kansas Department of Health Bulletin 1–5, 14 p.

Asselman, Nathalie, E.M., 1999, Suspended sediment dynamics in a large basin—the Rhine River: Hydrologic Processes, v. 13, p. 1437–1450.

American Public Health Association, American Water Works Association, and Water Environment Association, 1992, Standard methods for the examination of water and wastewater (18th ed.): Washington, D.C., American Public Health Association, p. 2-8 – 2-11.

Anderson, C.W., 2004, Turbidity, *in* National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. 6.7, p. 1–59.

Angino, E.E., and O’Brien, W.J., 1968, Effects of suspended material on water quality, *in* Proceedings of Symposium on Geochemistry, Precipitation, Evaporation, Soil Moisture, Hydrometry, General Assembly of Bern (September–October 1967): International Association of Science Hydrology, no. 78, p. 120–128.

ASTM International, 2003, D1889-00 standard test method for turbidity of water, *in* ASTM International, Annual book of ASTM standards, water and environmental technology: West Conshohocken, Pennsylvania, American Society for Testing and Materials, v. 11.01, 6 p.

Brady, L.L., Grisafe, D.A., McCauley, J.R., Ohlmacher, G.C., Quinodoz, H.A.M., and Nelson, K.A., 1998, The Kansas River corridor—it’s geologic setting, land use, economic geology, and hydrology: Kansas Geological Survey Open-File Report 98–2, unnumbered pages.

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

Cohn, T.A., and Gilroy, E.J., 1991, Estimating loads from periodic records: U.S. Geological Survey Branch of Systems Analysis Technical Memo 91.01, 81 p.

Cross, F., and deNoyelles, J., 1982, Report on the impacts of commercial dredging on the fishery of the lower Kansas River: U.S. Army Corps of Engineers, Kansas City District, DACW–41–79–C–0075, 283 p.

Daly, C., Taylor, C.H., and Gibson, W.P., 1997, The PRISM approach to mapping precipitation and temperature, *in* Reprints of 10th Conference on Applied Climatology, Reno, Nevada: American Meteorological Society, p. 10–12.

Devlin, D.L., and McVay, K.A., 2001, Suspended solids—a water quality concern for Kansas: Kansas State University Agricultural Experiment Station and Cooperative Extension Service, TMDL Fact Sheet No. 6, 2 p.

Devlin, D.L., Whitney, D.A., and McVay, K.A., 2000, Phosphorus and water quality in Kansas: Kansas State University Agricultural Experiment Station and Cooperative Extension Service, TMDL Fact Sheet No. 3, 2 p.

Duan, N., 1983, Smearing estimate—a nonparametric retransformation method: Journal of the American Statistical Association, v. 78, p. 605–610.

Dufour, A.P., 1977, *Escherichia coli*—fecal coliform, *in* Hoadley, A.W., and Dutka, B.J., eds., Bacterial indicator/health hazards associated with water, 1977: American Society for Testing and Materials, ASTM STP 635, p. 48–58.

Helgesen, J.O., 1996, Surface-water-quality assessment of the lower Kansas River Basin, Kansas and Nebraska—results of investigations, 1987–90: U.S. Geological Survey Water-Supply Paper 2451, 129 p.

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

Hem, J.D., 1992, Study and interpretation of chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hirsch, R.M., Helsel D.R., Cohn, T.A., and Gilroy, E.J., 1993, Statistical analysis of hydrologic data, *in* Maidment, D.R., ed., Handbook of hydrology: New York, McGraw-Hill, Inc., p. 17.1–17.55.

Horowitz, A.J., 2003, An evaluation of sediment rating curves for estimating suspended sediment concentrations for subsequent flux calculations: Hydrological Processes, v. 17, p. 3387–3409.

Humenik, F.J., Smolen, M.D., and Dressing, S.A., 1987, Pollution from nonpoint sources: Environmental Science & Technology, v. 21, no. 8, p. 737–742.

International Organization for Standardization, 1999, Water quality—determination of turbidity: Geneva, Switzerland, International Organization for Standardization, ISO 7027, 10 p.

Jordan, P.R., 1995, Surface-water-quality assessment of the lower Kansas River Basin, Kansas and Nebraska—suspended sediment conditions, May 1987 through April 1990, and trends, 1963 through April 1990: U.S. Geological Survey Water-Resources Investigations Report 94–4187, 36 p.

Jordan, P.R., and Stamer, J.K., eds., 1995, Surface-water-quality assessment of the lower Kansas River Basin, Kansas and Nebraska, analysis of data through 1986: U.S. Geological Survey Water-Supply Paper 2352–B, 161 p.

Kansas Applied Remote Sensing, 1993, Land cover: Information available on the Web, accessed May 4, 2005, at http://gisdasc.kgs.ku.edu/kgcc/catalog/coredata.cfm

Kansas Department of Health and Environment, 1998, Kansas water quality limited segments (303(d) List) July 1998: Topeka, Kansas, Secretary of State, 6 p.

Kansas Department of Health and Environment, 2000, Stream chemistry monitoring program quality assurance management plan: Information available on the Web, accessed December 16, 2004, at http://www.kdhe.state.ks.us/environment/qmp_2000.htm/download/scmp_QAMP.pdf

Kansas Department of Health and Environment, 2001, Kansas register, article 28-16-28e, Surface water quality standards: Topeka, Kansas, Secretary of State, 19 p.

Kansas Department of Health and Environment, 2003, Kansas register, article 28-16-28e, Surface water quality standards: Topeka, Kansas, Secretary of State, 19 p.

Kansas Department of Health and Environment, 2004a, Kansas 2004 (303(d) List): Topeka, Kansas, Secretary of State, 45 p.

Kansas Department of Health and Environment, 2004b, Basics of TMDLs: Information available on the Web, accessed July 30, 2004, at http://www.kdhe.state.ks.us/tmdl/basic.htm

Kansas Department of Health and Environment, 2004c, Kansas-lower Republican TMDLs: Information available on the Web, accessed July 30, 2004, at http://www.kdhe.state.ks.us/tmdl/klrtmdl.htm

Kansas Department of Health and Environment, 2004d, Surface Water Nutrient Reduction Plan, December 2004: Information available on the Web, accessed February 9, 2005, at http://www.kdhe.state.ks.us/water/download/ks_nutrient_reduction_plan_12_29_final.pdf

Kansas Geological Survey, 2004, Geology: Information available on the Web, accessed May 4, 2005, at http://gisdasc.kgs.ku.edu/kgcc/catalog/coredata.cfm

Kansas Water Office, 2005, Kansas River channel degradation: Topeka, Kansas, Report to the Kansas Water Authority, June 2005, 24 p.

Kelly, V.J., 2001, Influence of reservoirs on solute transport—a regional-scale approach: Hydrologic Processes, v. 15, p. 1227–1249.

McClelland, N.I., 1974, Water quality index application in the Kansas River Basin: U.S. Environmental Protection Agency, Report EPA–907/9–74–001, February 1974, 226 p.

Ongley, E., 1996, Sediment measurements, *in* Water quality monitoring—a practical guide to the design and implementation of freshwater quality studies and monitoring programs: Information available on the Web, accessed September 15, 2004, at http://www.who.int/docstore/water_sanitation_health/wqmonitor/ch15.htm

Perry, C.A., 1994, Effects of reservoirs on flood discharges in the Kansas and the Missouri River Basins, 1993: U.S. Geological Survey Circular 1120–E, 20 p.

Perry, C.A., 2000, Significant floods in the United States during the 20th century—USGS measures a century of floods: U.S. Geological Survey Fact Sheet 024–00, 4 p.

Pope, L.M., 1995, Surface-water quality assessment of the lower Kansas River Basin, Kansas and Nebraska—dissolved oxygen and *Escherichia coli* bacteria in streams during low flow, July 1988 through July 1989: U.S. Geological Survey Water-Resources Investigations Report 94–4077, 102 p.

Pope, L.M., and Putnam, J.E., 1997, Effects of urbanization on water quality in the Kansas River, Shunganunga Creek Basin and Soldier Creek, Topeka, Kansas, October 1993 through September 1995: U.S. Geological Survey Water-Resources Investigations Report 97–4045, 84 p.

Putnam, J.E., and Schneider, D.R., 2004, Water resources data—Kansas, water year 2003: U.S. Geological Survey Water-Data Report KS–03–1, 641 p.

Radtke, D.B., Kurklin, J.K., and Wilde, F.D., 1998a, Temperature, *in* National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. 6.1, 15 p.

Radtke, D.B., Kurklin, J.K., and Wilde, F.D., 1998b, Dissolved oxygen, *in* National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. 6.2, 38 p.

Rasmussen, P.P., and Ziegler, A.C., 2003, Comparison and continuous estimates of fecal coliform and *Escherichia coli* bacteria in selected Kansas streams, May 1999 through April 2002: U.S. Geological Survey Water-Resources Investigations Report 03–4056, 80 p.

Rice, R.W., and Izuno, F.T., 2001, Calculating nutrient loads: Miami, Florida, University of Florida Research Technical Bulletin 906, 11 p.

Ritter, D.F., 1986, Process geomorphology: Dubuque, Iowa, Wm. C. Brown Publishers, 579 p.

Stamer, J.K., Battaglin, W.A., and Goolsby, D.A., 1998, Herbicides in Midwestern reservoir outflows, 1992–93: U.S. Geological Survey Fact Sheet 134–98, 4 p.

Stiles, T.C., 2002, Incorporating hydrology in determining TMDL endpoints and allocations, *in* Proceedings from the National TMDL Science and Policy 2002 Specialty Conference, Watershed Environment Federation, November 2002.

Thornton, K.W., Kimmel, B.L., and Payne, F.E., eds., 1990, Reservoir limnology—ecological perspectives: New York, John Wiley & Sons, 246 p.

U.S. Army Corps of Engineers, 1990, Final regulatory report and environmental impact statement, commercial dredging activities on the Kansas River, Kansas: Kansas City District, 327 p.

U.S. Census Bureau, 2002, Census data for the State of Kansas: Information available on the Web, accessed July 12, 2003, at http://www.census.gov/census2000/states/ks.html

U.S. Department of Agriculture, 1994, State soil geographic (STATSGO) data base for Kansas: Information available on the Web, accessed October 25, 2004, at http://gisdasc.kgs.ukans.edu/kgcc/catalog/coredata.cfm

U.S. Environmental Protection Agency, 1972, Clean Water Act: Information available on the Web, accessed February 23, 2005, at http://www.epa.gov/history/topics/cwa/ index.htm

U.S. Environmental Protection Agency, 1984, Report to Congress—nonpoint source pollution in the U.S.: Washington, D.C., Office of Water Program Operations, Water Planning Division, unnumbered pages.

U.S. Environmental Protection Agency, 1993, Methods for determination of inorganic substances in environmental samples: Cincinnati, Ohio, U.S. Environmental Protection Agency, EPA/600/R–93/100, 178 p.

U.S. Environmental Protection Agency, 2002, List of drinking water contaminants & MCLs, July 2002: U.S. Environmental Protection Agency, Report EPA–816–F–02–013, information available on the Web, accessed July 12, 2004, at http://www.epa.gov/safewater/mcl.html

U.S. Environmental Protection Agency, 2003a, National management measures for the control of nonpoint pollution from agriculture: Information available on Web, accessed December 2003, at http://www.epa/gov/owow/nps/agmm

U.S. Environmental Protection Agency, 2003b, Ecoregional nutrient criteria: Information available on the Web, accessed July 9, 2003, at http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/

U.S. Environmental Protecton Agency, 2003c, National drinking water standards, June 2003: U.S. Environmental Protection Agency, Report EPA–816–F–03–016, information available on the Web, accessed July 12, 2004, at http://www.epa.gov/safewater/mcl.html

U.S. Environmental Protection Agency, 2005, Water quality assessment data for the State of Kansas year 2002: Information available on the Web, accessed April 7, 2005, at http://www.epa.gov/waters/305b/index.html

U.S. Geological Survey, 1999, The quality of our nation's water—nutrients and pesticides: U.S. Geological Survey Circular 1225, 82 p.

Wagner, R.J., Mattraw, H.C., Ritz, G.F., and Smith, B.A., 2000, Guidelines and standard procedures for continuous water-quality monitors—site selection, field operations, calibration, record computation, and reporting: U.S. Geological Survey Water-Resources Investigations Report 00–4252, 53 p.

Wetzel, R.G., 2001, Limnology lake and river ecosystems: New York, Academic Press, 1006 p.

Wilde, F.D., and Radtke, D.B., eds., 1998, Field measurements, *in* National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, p. 3–20.

Wilde, F.D., Radtke, D.B., Gibs, J., and Iwatsubo, R.T., eds., 1999, Collection of water samples, *in* National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, various paginaton.

Williams, G.P., and Wolman, M.G., 1984, Downstream effects of dams on alluvial rivers: U.S. Geological Survey Professional Paper 1286, 83 p.

YSI, Environmental, 2003, YSI 6136 turbidity sensor documentation: Information available on the Web, accessed May 10, 2003, at http://www.ysi.com/extranet/EPGKL.nsf/447554deba0f52f2852569f500696b21/f2c571cc22155adc85256b750076b4f5!OpenDocument

Ziegler, A.C., 2002, Definition of optical methods for turbidity and data reporting, *in* Proceedings of the Federal Interagency Workshop on Turbidity and Other Sediment Surrogates, April 30–May 2, 2002, Reno, Nevada: U.S. Geological Survey Circular 1250, 56 p.

Appendixes

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Acid neutralizing capacity, unfiltered, field, in milligrams per liter														
2000														
Wamego	7,235	27	128	196	141	148	156	172	205	213	229	234	241	247
Topeka	7,043	22	84	194	127	161	167	177	198	212	218	223	228	245
DeSoto	7,085	21	105	183	129	147	158	169	184	200	210	212	217	225
2001														
Wamego	7,596	30	94	160	109	114	122	134	164	183	200	209	223	233
Topeka	7,776	24	103	163	119	126	133	143	162	181	197	206	217	222
DeSoto	8,014	26	95	155	109	119	125	135	151	176	195	201	210	214
2002														
Wamego	6,784	19	130	177	133	141	148	164	178	193	201	203	210	241
Topeka	8,215	16	100	180	143	153	160	169	182	193	201	203	206	215
DeSoto	8,206	18	105	171	126	139	143	163	174	183	193	196	200	203
2003														
Wamego	6,933	27	94	158	107	128	129	137	153	174	201	206	214	246
Topeka	6,949	22	105	166	117	140	144	151	160	183	201	206	209	229
DeSoto	7,569	20	77	164	117	136	142	150	159	180	194	198	204	216

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Calcium, in milligrams per liter														
2000														
Wamego	7,235	15	44	80	50	54	58	66	84	89	98	100	100	110
Topeka	7,043	12	24	77	43	59	62	67	79	86	90	93	96	100
DeSoto	7,085	12	33	73	44	53	58	65	73	82	88	90	93	98
2001														
Wamego	7,596	16	29	61	35	38	41	47	62	72	82	86	94	100
Topeka	7,776	12	32	61	39	42	46	50	60	70	78	83	89	92
DeSoto	8,014	14	28	58	34	39	42	47	55	68	80	83	89	90
2002														
Wamego	6,784	10	45	69	46	50	54	62	69	78	82	83	87	100
Topeka	8,215	8.2	31	70	51	55	59	64	70	76	80	81	83	88
DeSoto	8,206	9.5	32	66	42	49	51	62	67	72	78	80	82	84
2003														
Wamego	6,933	14	29	59	34	44	44	48	56	67	82	85	90	110
Topeka	6,949	11	33	62	38	49	51	54	59	71	80	83	85	96
DeSoto	7,569	11	21	62	38	47	50	54	59	71	79	81	85	92

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Magnesium, dissolved, in milligrams per liter														
2000														
Wamego	7,235	4.1	9.6	19	11	12	13	16	20	22	24	25	26	28
Topeka	7,043	3.4	4.8	19	9.4	14	15	16	20	22	23	24	25	28
DeSoto	7,085	3.8	6.4	18	9.4	12	14	16	18	22	24	24	25	27
2001														
Wamego	7,596	4.2	5.9	14	7.4	8.0	8.9	10	14	17	20	21	23	25
Topeka	7,776	3.6	6.6	14	8.5	9.2	10	11	14	17	19	21	23	24
DeSoto	8,014	4.3	5.3	14	6.9	8.1	8.8	10	13	17	20	22	24	24
2002														
Wamego	6,784	2.8	9.9	16	10	11	12	14	16	19	20	20	21	26
Topeka	8,215	2.4	6.3	17	12	13	14	15	17	19	20	20	21	22
DeSoto	8,206	3.0	6.4	16	9.0	11	12	15	16	18	20	21	21	22
2003														
Wamego	6,933	3.8	5.9	14	7.2	9.5	9.7	11	13	16	20	21	22	27
Topeka	6,949	3.2	6.9	15	8.2	11	12	12	14	17	20	21	21	25
DeSoto	7,569	3.5	3.6	15	7.8	10	11	12	14	18	20	21	22	25

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Sodium, dissolved, in milligrams per liter														
2000														
Wamego	7,235	34	33	100	43	48	55	71	110	120	150	160	170	180
Topeka	7,043	27	7.2	89	24	49	55	65	92	110	120	130	140	170
DeSoto	7,085	24	14	77	26	39	48	58	74	96	110	110	120	140
2001														
Wamego	7,596	30	15	63	22	25	29	38	62	82	100	120	140	150
Topeka	7,776	24	13	55	20	24	28	34	50	70	90	100	120	130
DeSoto	8,014	24	11	49	16	21	24	30	42	66	89	97	110	120
2002														
Wamego	6,784	21	35	77	37	42	48	62	77	96	100	110	120	170
Topeka	8,215	17	12	71	35	42	48	57	71	85	95	98	100	120
DeSoto	8,206	17	14	62	25	33	36	53	63	74	87	91	95	100
2003														
Wamego	6,933	27	15	60	21	33	34	39	52	73	100	110	120	180
Topeka	6,949	23	14	57	19	33	35	41	48	72	95	100	110	140
DeSoto	7,569	20	5.9	55	20	31	35	41	49	71	88	94	100	120

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Sulfate, dissolved, in milligrams per liter														
2000														
Wamego	7,235	32	58	130	70	77	84	100	140	150	170	180	190	200
Topeka	7,043	27	19	120	45	76	82	93	120	140	150	160	160	190
DeSoto	7,085	32	30	120	50	69	82	98	120	150	170	170	180	200
2001														
Wamego	7,596	31	33	91	43	47	53	64	92	110	130	140	160	180
Topeka	7,776	26	29	81	40	44	50	58	77	98	120	130	140	150
DeSoto	8,014	34	24	83	34	42	46	56	74	110	140	150	170	170
2002														
Wamego	6,784	21	60	110	63	69	76	92	110	120	130	140	150	190
Topeka	8,215	18	27	98	59	68	75	85	100	110	120	130	130	140
DeSoto	8,206	24	30	100	48	60	65	90	100	120	140	140	150	150
2003														
Wamego	6,933	28	33	88	42	58	59	66	81	100	130	140	150	200
Topeka	6,949	24	30	83	38	56	59	66	75	100	120	130	130	160
DeSoto	7,569	28	14	93	40	58	64	73	84	110	140	140	160	180

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
					Chloride, dissolved, in milligrams per liter									
2000														
Wamego	7,235	44	36	120	47	54	62	83	140	150	180	200	210	230
Topeka	7,043	40	6.6	120	26	59	67	81	120	150	160	180	190	240
DeSoto	7,085	32	14	93	28	43	54	68	89	120	140	140	160	180
2001														
Wamego	7,596	38	15	74	23	26	31	41	72	98	130	140	170	190
Topeka	7,776	34	13	68	22	26	31	39	60	88	120	140	160	170
DeSoto	8,014	31	10	57	16	22	25	32	47	78	110	120	140	150
2002														
Wamego	6,784	27	38	91	40	47	54	72	90	120	130	130	140	210
Topeka	8,215	25	12	89	40	50	58	70	90	110	120	130	140	160
DeSoto	8,206	22	14	74	26	36	40	61	75	89	110	110	120	120
2003														
Wamego	6,933	34	15	69	22	36	36	44	59	86	130	140	150	220
Topeka	6,949	32	14	70	20	37	40	48	57	92	120	140	140	200
DeSoto	7,569	27	5.3	65	20	34	39	46	56	84	110	120	130	150

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
					Fluoride, dissolved, in milligrams per liter									
2000														
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,043	0.02	0.25	0.35	0.29	0.32	0.33	0.34	0.36	0.36	0.37	0.37	0.38	0.39
DeSoto	7,085	.01	.27	.32	.29	.30	.30	.31	.32	.33	.34	.34	.34	.34
2001														
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,776	.02	.27	.33	.29	.29	.30	.31	.33	.34	.35	.36	.37	.37
DeSoto	8,014	.02	.26	.30	.27	.28	.28	.29	.30	.32	.33	.33	.34	.34
2002														
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	8,215	.01	.27	.34	.31	.32	.32	.33	.34	.35	.36	.36	.36	.37
DeSoto	8,206	.01	.27	.31	.28	.29	.30	.31	.32	.32	.33	.33	.33	.33
2003														
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	6,949	.02	.27	.33	.28	.31	.31	.32	.32	.34	.36	.36	.36	.38
DeSoto	7,569	.01	.24	.31	.28	.29	.30	.30	.31	.32	.33	.33	.33	.34

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Nitrate as nitrogen, in milligrams per liter														
2000														
Wamego	7,474	0.24	0.14	0.69	0.24	0.31	0.36	0.53	0.70	0.83	1.0	1.1	1.4	1.6
Topeka	7,316	.18	.20	.59	.29	.32	.36	.46	.57	.66	.84	.91	1.2	1.3
DeSoto	7,452	.27	0	.36	0	.07	.10	.17	.25	.54	.68	.87	1.2	2.2
2001														
Wamego	7,787	.38	.37	.98	.50	.57	.59	.66	.86	1.3	1.6	1.7	2.0	2.3
Topeka	7,828	.30	.42	.86	.47	.51	.52	.57	.80	1.1	1.3	1.4	1.6	1.9
DeSoto	8,266	.46	.10	.70	.17	.22	.28	.37	.57	.86	1.2	1.9	2.2	2.3
2002														
Wamego	6,775	.23	.08	.50	.18	.24	.27	.31	.45	.61	.83	.96	1.2	1.4
Topeka	8,342	.23	.12	.49	.16	.19	.21	.29	.46	.66	.84	.90	1.1	1.3
DeSoto	8,284	.27	0	.34	0	0	0	.13	.34	.49	.69	.82	1.1	2.2
2003														
Wamego	6,907	.22	.04	.58	.11	.19	.25	.38	.67	.74	.78	.80	1.0	1.2
Topeka	7,078	.16	.12	.49	.15	.20	.24	.38	.53	.58	.64	.70	.89	1.1
DeSoto	7,508	.19	0	.26	0	0	.05	.14	.22	.36	.51	.62	.81	1.8

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Nitrite plus nitrate as nitrogen, dissolved, in milligrams per liter														
2000														
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,316	0.18	0.18	0.56	0.27	0.30	0.34	0.44	0.53	0.63	0.81	0.87	1.1	1.4
DeSoto	7,452	4.8	.73	3.9	.96	1.3	1.5	1.9	2.4	4.8	7.1	1.6	20	140
2001														
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,828	.29	.40	.81	.45	.48	.49	.54	.76	1.0	1.2	1.4	1.6	1.9
DeSoto	8,266	24	1.3	15	1.9	2.3	2.5	3.2	6.5	15	36	72	120	190
2002														
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	8,342	.23	.11	.48	.15	.18	.19	.28	.45	.63	.81	.87	1.1	1.3
DeSoto	8,284	3.0	.31	3.3	.82	.89	.95	1.6	2.6	4.0	6.1	8.3	14	86
2003														
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,078	.15	.12	.46	.14	.19	.23	.37	.49	.56	.62	.67	.85	1.0
DeSoto	7,508	1.5	.78	2.4	.88	1.0	1.2	1.7	2.1	2.6	3.6	4.4	8.0	38

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Nitrogen, ammonia plus organic, dissolved, in milligrams per liter														
2000														
Wamego	7,145	2.3	0.30	3.2	0.34	0.61	0.78	1.4	2.5	4.7	6.6	7.8	9.3	12
Topeka	7,043	.03	.28	.33	.29	.30	.30	.31	.32	.35	.37	.38	.45	.61
DeSoto	7,427	.24	.62	1.2	.77	.85	.93	1.1	1.2	1.3	1.5	1.7	2.0	2.1
2001														
Wamego	7,834	2.1	.25	2.3	.25	.36	.54	.81	1.3	3.7	5.9	6.4	7.9	1.9
Topeka	7,776	.04	.30	.38	.30	.32	.32	.35	.38	.41	.43	.45	.47	.52
DeSoto	8,313	.36	.76	1.4	.82	.88	.91	1.0	1.4	1.6	1.9	2.0	2.1	2.1
2002														
Wamego	6,784	2.7	.29	4.2	.62	1.1	1.6	2.3	3.7	4.9	8.3	1.6	12	15
Topeka	8,215	.02	.30	.35	.32	.32	.32	.33	.34	.36	.38	.39	.41	.54
DeSoto	8,127	.22	.71	1.1	.75	.78	.85	.99	1.1	1.1	1.4	1.5	2.0	2.0
2003														
Wamego	6,483	2.2	.27	3.1	.29	.60	1.0	1.7	2.4	4.0	6.8	8.2	9.8	11
Topeka	6,949	.04	.29	.37	.31	.32	.32	.34	.38	.40	.41	.42	.48	.52
DeSoto	7,330	.24	.73	1.2	.76	.84	.90	1.0	1.2	1.3	1.5	1.7	2.0	2.1

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Nitrogen, ammonia plus organic, total, in milligrams per liter														
2000														
Wamego	7,145	0.36	0.57	1.1	0.64	0.69	0.73	0.83	1.1	1.3	1.7	1.8	2.3	2.4
Topeka	6,805	.38	.64	1.2	.68	.75	.82	.99	1.2	1.4	1.7	2.0	2.6	2.7
DeSoto	7,427	.24	.52	1.1	.68	.82	.88	.96	1.0	1.1	1.2	1.4	2.2	3.2
2001														
Wamego	7,834	.46	.60	1.4	.68	.74	.76	.91	1.4	1.6	1.9	2.2	2.6	2.6
Topeka	7,813	.54	.60	1.5	.71	.77	.82	1.0	1.5	1.9	2.3	2.6	2.7	2.8
DeSoto	8,313	.49	0	.92	0	0	.27	.78	.92	1.0	1.4	2.0	2.5	3.1
2002														
Wamego	6,784	.25	.53	.97	.57	.61	.67	.82	.92	1.1	1.3	1.4	1.8	2.4
Topeka	8,199	.30	.60	1.1	.68	.74	.81	.89	.99	1.2	1.4	1.6	2.6	2.6
DeSoto	8,127	.19	.21	1.0	.71	.81	.87	.94	.99	1.0	1.1	1.1	2.0	2.8
2003														
Wamego	6,483	.34	.59	1.1	.63	.67	.72	.88	1.1	1.2	1.5	1.8	2.4	2.5
Topeka	7,128	.40	.46	1.2	.58	.68	.76	.94	1.2	1.4	1.7	2.1	2.7	2.8
DeSoto	7,290	.29	.92	1.1	.96	.99	1.0	1.0	1.0	1.1	1.2	1.6	2.8	3.4

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
					Boron, dissolved, in micrograms per liter									
2000														
Wamego	7,235	17	57	99	65	69	74	84	100	110	120	120	130	130
Topeka	7,043	34	68	220	120	170	180	190	230	250	260	270	280	300
DeSoto	7,085	17	40	96	55	67	75	84	95	110	120	120	120	130
2001														
Wamego	7,596	18	39	77	47	50	54	61	78	90	100	110	120	120
Topeka	7,776	37	90	170	110	120	130	140	170	200	220	240	260	270
DeSoto	8,014	19	34	74	42	48	52	59	70	89	100	110	120	120
2002														
Wamego	6,784	12	59	87	60	65	69	78	87	97	100	100	110	130
Topeka	8,215	24	86	200	140	160	170	180	200	220	230	230	240	250
DeSoto	8,206	13	40	86	53	61	64	79	88	95	100	110	110	110
2003														
Wamego	6,933	16	39	75	46	57	58	63	72	85	100	100	110	130
Topeka	6,949	33	93	180	110	140	140	160	170	200	230	240	240	280
DeSoto	7,569	16	25	80	47	60	64	69	76	93	100	110	110	120

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent: 1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum
Triazine herbicides, in micrograms per liter														
2000														
Wamego	8,784	0.24	0.47	0.77	0.47	0.48	0.48	0.54	0.73	1.0	1.1	1.1	1.1	1.1
Topeka	7,043	.78	.32	1.2	.32	.33	.37	.52	1.0	1.9	2.3	2.5	2.9	5.4
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2001														
Wamego	8,760	.24	.47	.77	.47	.48	.48	.54	.73	1.0	1.1	1.1	1.1	1.1
Topeka	7,776	.83	.30	1.4	.32	.35	.50	.67	1.2	2.1	2.6	3.0	3.2	3.8
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2002														
Wamego	8,760	.24	.47	.77	.47	.48	.48	.54	.73	1.0	1.1	1.1	1.1	1.1
Topeka	8,215	.71	.33	1.2	.34	.35	.37	.49	1.1	1.8	2.2	2.3	2.4	2.6
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2003														
Wamego	8,760	.24	.47	.77	.47	.48	.48	.54	.73	1.0	1.1	1.1	1.1	1.1
Topeka	6,949	.88	.33	1.5	.34	.35	.40	.73	1.4	2.3	2.8	2.9	3.3	3.8
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Fecal coliform bacteria, in colonies per 100 milliliters of water														
2000														
Wamego	7,145	490	9	280	14	18	24	42	120	280	750	1,100	2,900	3,400
Topeka	6,805	420	8	220	10	14	21	45	94	180	460	790	2,600	3,000
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2001														
Wamego	7,834	870	11	600	18	25	29	60	330	700	1,400	2,600	4,600	4,800
Topeka	7,813	690	6	510	12	16	21	52	250	650	1,400	2,400	3,000	3,400
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2002														
Wamego	6,784	210	6	120	9	11	17	38	62	130	240	420	1,100	3,700
Topeka	8,199	300	6	120	10	14	20	30	46	91	190	300	2,400	2,500
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2003														
Wamego	6,483	560	10	270	13	17	23	53	120	220	470	1,100	3,700	4,000
Topeka	7,128	460	2	220	5	9	16	36	90	180	410	970	2,800	3,500
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
Enterococci bacteria, in colonies per 100 milliliters of water														
2000														
Wamego	7,145	7,800	65	3,900	110	150	210	390	1,200	3,300	10,000	16,000	47,000	58,000
Topeka	6,805	14,000	53	5,000	70	120	190	500	1,300	2,800	9,600	19,000	86,000	100,000
DeSoto	7,427	8,600	3	3,000	18	42	91	420	820	1,900	4,800	13,000	55,000	69,000
2001														
Wamego	7,834	150,000	83	9,000	150	220	260	590	4,000	9,500	20,000	43,000	81,000	84,000
Topeka	7,813	23,000	35	14,000	88	140	190	600	4,400	15,000	41,000	78,000	100,000	120,000
DeSoto	8,313	17,000	17	10,000	33	57	73	220	2,900	10,000	38,000	56,000	70,000	73,000
2002														
Wamego	6,784	3,200	44	1,500	65	88	140	350	610	1,400	2,800	5,400	16,000	63,000
Topeka	8,199	9,400	38	2,400	70	110	170	290	510	1,200	3,200	5,600	78,000	82,000
DeSoto	8,127	6,600	9	1,700	15	22	42	150	270	500	2,600	4,900	51,000	56,000
2003														
Wamego	6,483	9,400	76	3,700	100	140	200	520	1,300	2,500	6,100	16,000	63,000	70,000
Topeka	7,128	15,000	9	5,100	31	69	130	380	1,200	2,800	8,100	24,000	92,000	120,000
DeSoto	7,330	8,900	12	2,800	18	37	68	240	710	1,500	3,800	11,000	58,000	76,000

Appendix 1. Regression-estimated concentrations or densities for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Concentration or density at indicated frequency of exceedance, in percent									Maximum
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	
					Total suspended solids, in milligrams per liter									
2000														
Wamego	7,145	140	9	114	13	16	19	30	66	129	278	377	788	905
Topeka	6,805	255	12	172	15	21	28	53	97	165	365	567	1,540	1,730
DeSoto	7,427	127	4	119	11	18	27	59	85	130	214	362	774	873
2001														
Wamego	7,834	227	10	208	15	20	22	40	147	264	446	738	1,150	1,170
Topeka	7,813	409	9	359f	17	23	28	60	218	482	943	1,430	1,740	1,930
DeSoto	8,313	233	11	234	16	21	24	43	164	323	640	778	877	896
2002														
Wamego	6,784	70	7	62	9	11	15	28	40	72	115	180	368	960
Topeka	8,199	181	10	101	15	20	27	37	54	94	177	258	1,440	1,490
DeSoto	8,127	107	8	76	10	12	18	35	48	65	154	216	744	778
2003														
Wamego	6,483	152	10	108	12	15	18	36	67	106	194	383	960	1,030
Topeka	7,128	271	4	170	9	14	22	44	94	165	328	672	1,600	1,940
DeSoto	7,330	127	9	108	11	17	23	45	78	116	190	335	798	916

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load									Maximum	Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile		
Acid neutralizing capacity, unfiltered, field, in tons per day															
2000															
Wamego	7,235	591	414	1,170	454	500	520	832	1,130	1,360	1,680	2,200	3,140	5,610	427,000
Topeka	7,043	613	356	1,220	534	570	585	684	1,130	1,480	1,850	2,400	3,340	5,570	445,000
DeSoto	7,085	868	275	1,500	405	552	612	968	1,310	1,800	2,820	3,010	4,620	7,220	548,000
2001															
Wamego	7,596	1,700	440	1,990	508	618	678	859	1,310	2,730	4,150	6,300	7,670	11,000	726,000
Topeka	7,776	2,090	424	2,480	603	720	765	939	1,630	3,410	5,770	7,330	8,580	16,200	905,000
DeSoto	8,014	2,850	551	3,210	754	886	980	1,180	2,050	4,190	7,750	8,710	11,400	29,200	1,170,000
2002															
Wamego	6,784	456	307	720	343	356	370	447	553	795	1,250	1,880	2,490	2,750	263,000
Topeka	8,215	542	268	843	352	377	399	457	665	1,030	1,540	2,040	2,830	4,320	308,000
DeSoto	8,206	786	147	1,100	313	478	504	571	889	1,280	2,140	2,760	4,000	7,800	402,000
2003															
Wamego	6,933	285	247	733	298	343	372	456	806	956	1,020	1,100	1,490	2,290	268,000
Topeka	6,949	355	300	794	342	376	400	469	828	964	1,180	1,410	1,930	3,080	290,000
DeSoto	7,529	418	276	860	346	449	499	587	796	1,000	1,240	1,560	2,600	4,400	314,000

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
Calcium, dissolved, in tons per day															
2000															
Wamego	7,235	221	176	465	191	207	215	341	453	550	678	835	1,190	2,210	170,000
Topeka	7,043	228	104	478	213	229	237	269	456	573	715	901	1,290	2,300	175,000
DeSoto	7,085	322	115	586	165	227	250	380	520	708	1,070	1,160	1,590	3,040	214,000
2001															
Wamego	7,596	566	184	710	213	255	276	334	493	925	1,420	2,150	2,610	3,780	259,000
Topeka	7,776	719	174	890	247	286	305	361	606	1,210	2,000	2,550	2,980	5,650	325,000
DeSoto	8,014	951	219	1,130	302	358	391	461	741	1,460	2,640	3,020	3,950	10,100	412,000
2002															
Wamego	6,784	160	122	274	137	144	148	173	213	318	463	712	896	980	100,000
Topeka	8,215	195	108	320	140	148	155	175	262	403	566	726	1,030	1,560	117,000
DeSoto	8,206	270	59.5	414	128	186	197	229	346	475	760	976	1,350	2,810	151,000
2003															
Wamego	6,933	94.8	84.4	267	122	139	148	176	284	335	366	401	553	771	97,000
Topeka	6,949	122	112	291	129	148	155	182	304	347	433	508	671	1,070	106,000
DeSoto	7,529	142	111	319	141	173	192	231	296	364	458	553	904	1,570	116,000

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
Magnesium, dissolved, in tons per day															
2000															
Wamego	7,235	51.4	43.4	111	47.1	50.2	52.3	82.0	108	131	159	194	279	546	40,500
Topeka	7,043	54.4	20.1	118	52.8	57.5	59.6	67.6	114	142	174	216	303	595	42,900
DeSoto	7,085	77.2	30.5	146	42.9	58.8	65.4	94.1	128	176	252	289	372	811	53,200
2001															
Wamego	7,596	122	45.2	159	52.6	62.0	66.2	78.3	113	202	314	467	577	831	58,000
Topeka	7,776	160	44.4	204	63.1	71.1	76.2	86.8	144	273	446	574	670	1,280	74,600
DeSoto	8,014	202	55.3	254	76.8	90.2	96.5	113	173	327	566	655	870	2,220	92,600
2002															
Wamego	6,784	35.5	27.1	63.8	31.9	34.4	35.4	40.2	49.9	76.4	106	162	201	219	23,300
Topeka	8,215	44.9	27.0	76.9	34.3	36.7	37.8	42.4	63.3	98.1	133	165	240	367	28,100
DeSoto	8,014	202	55.3	254	76.8	90.2	96.5	113	173	327	566	655	870	2,220	92,600
2003															
Wamego	6,933	20.5	18.4	60.5	27.8	33.2	35.3	41.5	63.1	74.1	83.2	90.6	121	183	22,100
Topeka	6,949	27.0	25.1	68.1	31.3	35.6	37.8	45.0	71.2	80.6	100	117	152	238	24,900
DeSoto	7,529	31.1	28.0	75.3	34.4	42.9	46.9	56.9	69.8	84.3	107	125	202	354	27,500

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
Sodium, dissolved, in tons per day															
2000															
Wamego	7,235	252	254	568	264	277	290	372	563	718	832	932	1,360	3,420	207,000
Topeka	7,043	233	30.5	524	231	268	289	329	501	639	766	880	1,310	3,260	191,000
DeSoto	7,085	300	141	582	184	248	285	359	507	733	929	1,150	1,450	3,810	212,000
2001															
Wamego	7,596	399	257	621	283	324	343	369	464	728	1,090	1,490	2,210	3,230	227,000
Topeka	7,776	456	230	675	271	317	331	359	504	825	1,310	1,720	2,190	3,920	246,000
DeSoto	8,014	550	216	799	281	343	373	422	615	984	1,570	1,880	2,560	6,490	291,000
2002															
Wamego	6,784	135	94.9	291	130	167	176	189	229	379	446	594	785	846	106,000
Topeka	8,215	155	117	307	131	152	161	180	250	407	504	592	841	1,340	112,000
DeSoto	8,206	178	66.1	359	138	170	185	231	318	443	558	691	888	2,270	131,000
2003															
Wamego	6,933	75.8	61.9	247	109	156	174	196	237	283	343	368	475	950	90,200
Topeka	6,949	80.8	72.5	243	109	124	148	194	239	270	338	395	498	990	88,700
DeSoto	7,529	97.1	101	266	127	153	171	216	249	290	360	424	657	1,110	96,900

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
Sulfate, dissolved, in tons per day															
2000															
Wamego	7,235	337	302	743	329	343	359	559	722	891	1,060	1,260	1,860	3,860	271,000
Topeka	7,043	314	78.7	702	314	351	372	414	698	858	1,040	1,210	1,760	3,860	256,000
DeSoto	7,085	486	213	940	288	394	444	597	827	1,160	1,520	1,860	2,310	5,710	343,000
2001															
Wamego	7,596	729	312	995	364	423	447	514	711	1,230	1,930	2,770	3,570	5,080	363,000
Topeka	7,776	799	282	1,080	391	430	456	505	776	1,400	2,200	2,950	3,490	6,620	394,000
DeSoto	8,014	1,060	362	1,440	488	576	624	712	1,060	1,800	3,010	3,540	4,780	12,100	526,000
2002															
Wamego	6,784	220	165	416	205	231	237	262	325	513	672	1,000	1,260	1,360	152,000
Topeka	8,215	240	167	440	195	215	225	246	364	574	734	895	1,310	2,030	161,000
DeSoto	8,206	326	103	607	220	284	305	377	537	725	974	1,250	1,600	3,930	221,000
2003															
Wamego	6,933	124	112	383	175	221	238	271	391	461	530	569	738	1,210	140,000
Topeka	6,949	136	127	372	175	195	222	267	376	431	535	625	805	1,220	136,000
DeSoto	7,529	173	178	454	216	264	286	362	425	497	618	730	1,140	2,010	166,000

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
					Chloride, dissolved, in tons per day										
2000															
Wamego	7,235	306	307	683	320	338	354	427	685	870	1,010	1,120	1,630	4,320	249,000
Topeka	7,043	306	28.0	678	292	348	377	431	630	842	1,000	1,140	1,720	4,480	247,000
DeSoto	7,085	363	176	697	225	297	350	425	606	886	1,100	1,380	1,770	4,800	255,000
2001															
Wamego	7,596	430	285	699	333	383	408	433	538	796	1,170	1,590	2,440	3,800	255,000
Topeka	7,776	515	290	796	321	391	415	447	592	945	1,470	2,010	2,570	4,490	290,000
DeSoto	8,014	585	243	889	321	385	430	497	706	1,090	1,680	2,040	2,780	7,030	325,000
2002															
Wamego	6,784	152	103	340	146	193	206	226	270	446	516	654	879	985	124,000
Topeka	8,215	188	140	384	159	188	202	229	310	507	639	722	996	1,620	140,000
DeSoto	8,206	197	80.9	418	165	198	218	274	374	520	647	770	986	2,580	152,000
2003															
Wamego	6,933	87.2	66.5	281	122	174	201	233	264	315	390	419	549	1,210	103,000
Topeka	6,949	95.8	81.5	293	126	146	173	246	289	322	405	470	585	1,330	107,000
DeSoto	7,529	111	112	306	139	175	197	248	287	341	412	485	755	1,270	112,000

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load									Maximum	Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile		
					Fluoride, dissolved, in tons per day										
2000															
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,043	1.25	0.855	2.27	0.950	0.998	1.02	1.26	2.06	2.80	3.45	4.58	7.11	1.5	828
DeSoto	7,085	1.74	.443	2.71	.679	.909	1.02	1.68	2.18	3.18	5.10	5.65	10.3	13.4	988
2001															
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,776	4.74	.725	5.27	1.03	1.30	1.37	1.77	3.39	7.36	13.4	16.0	19.3	36.1	1,923
DeSoto	8,014	6.50	.959	6.77	1.26	1.49	1.68	2.13	4.13	8.63	17.1	19.4	24.6	63.1	2,473
2002															
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	8,215	1.16	.472	1.63	.629	.677	.739	.861	1.24	1.92	3.05	4.29	5.86	9.40	596
DeSoto	8,206	1.73	.247	2.11	.521	.856	.901	1.01	1.59	2.40	4.42	5.73	8.77	16.6	772
2003															
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	6,949	.813	.525	1.62	.619	.669	.720	.890	1.69	2.03	2.43	2.97	4.59	6.86	592
DeSoto	7,529	.945	.467	1.68	.573	.798	.896	1.03	1.55	2.01	2.47	3.20	5.63	9.15	613

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
Nitrate as nitrogen, dissolved, in tons per day															
2000															
Wamego	7,474	5.65	0.278	5.11	0.518	0.759	0.955	1.67	4.18	6.24	8.62	13.7	24.8	59.5	1,870
Topeka	7,316	4.32	.504	4.35	.815	.948	1.1	1.70	3.46	5.57	7.81	11.8	23.3	41.4	1,590
DeSoto	7,452	4.52	0	3.63	0	.232	.458	.936	1.65	4.96	9.48	13.6	21.5	31.9	1,320
2001															
Wamego	7,787	28.1	.760	19.7	1.46	1.91	2.22	3.02	6.37	26.0	57.0	92.2	129	155	7,190
Topeka	7,828	24.0	1.06	18.7	1.73	2.08	2.39	3.19	8.00	24.7	56.5	72.1	106	190	6,810
DeSoto	8,266	26.0	.315	19.3	.992	1.56	1.87	2.85	9.28	24.4	52.6	73.3	114	260	7,030
2002															
Wamego	6,775	4.15	.139	2.84	.385	.557	.636	.787	1.27	2.52	6.43	10.9	19.9	23.5	1,040
Topeka	8,342	3.72	.246	3.03	.356	.444	.502	.760	1.66	3.86	7.13	11.1	17.1	41.0	1,110
DeSoto	8,284	4.29	0	2.91	0	0	0	.520	1.76	3.55	6.60	9.75	20.1	53.0	1,060
2003															
Wamego	6,907	2.70	.0635	3.35	.171	.358	.493	1.09	3.90	4.74	5.60	6.11	11.0	27.3	1,220
Topeka	7,078	2.47	.208	2.79	.284	.458	.600	.919	2.68	3.57	4.67	6.31	13.7	24.0	1,020
DeSoto	7,508	2.13	0	1.56	0	0	.150	.737	1.16	1.72	2.50	4.06	11.8	24.4	570

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
Nitrite plus nitrate as nitrogen, in tons per day															
2000															
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,316	4.06	0.456	4.11	0.765	0.905	1.06	1.65	3.25	5.27	7.63	11.1	21.9	39.0	1,500
DeSoto	7,452	66.4	1.43	42.2	2.27	4.20	6.14	9.28	16.5	45.5	104	182	338	896	15,400
2001															
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,828	22.7	1.12	17.6	1.70	2.06	2.31	3.04	7.46	23.3	52.6	67.7	101	177	6,420
DeSoto	8,266	972	4.02	457	8.98	13.3	15.4	24.0	108	469	1,110	1,810	4,880	11,500	167,000
2002															
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	8,342	3.49	.218	2.89	.326	.410	.466	.738	1.60	3.69	6.76	10.4	16.0	38.5	1,060
DeSoto	8,284	66.0	.237	31.5	2.15	2.53	2.82	5.16	13.5	29.0	69.7	110	279	1,090	11,500
2003															
Wamego	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Topeka	7,078	2.30	.202	2.63	.267	.437	.578	.924	2.53	3.38	4.33	5.89	12.9	22.6	961
DeSoto	7,508	26.7	1.31	15.5	2.20	2.96	3.48	6.82	11.1	14.8	21.2	38.9	135	365	5,670

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
Nitrogen, ammonia plus organic, dissolved, in tons per day															
2000															
Wamego	7,145	7.58	2.02	14.6	3.06	5.11	6.08	8.32	13.6	19.2	25.4	29.8	34.7	40.5	5,340
Topeka	7,043	1.59	.677	2.25	.747	.850	.878	1.18	1.88	2.90	3.59	4.49	9.57	15.1	821
DeSoto	7,427	11.0	1.14	11.4	1.92	2.34	2.86	5.73	7.94	12.7	22.2	29.2	68.1	87.1	4,160
2001															
Wamego	7,834	10.2	2.15	17.7	2.93	4.64	6.46	10.5	16.8	21.5	31.2	37.6	51.2	72.7	6,460
Topeka	7,776	7.00	.601	6.85	.861	1.16	1.24	1.78	4.05	9.64	18.0	22.9	29.7	52.8	2,500
DeSoto	8,313	44.9	2.55	38.2	3.24	3.93	5.02	6.85	20.0	48.9	105	130	177	441	14,000
2002															
Wamego	6,784	7.69	1.40	14.3	2.40	4.15	6.02	9.195	12.4	18.7	22.2	26.8	41.9	50.6	5,200
Topeka	8,215	1.54	.417	1.76	.566	.613	.695	.878	1.23	1.98	3.48	5.60	7.49	18.4	643
DeSoto	8,127	10.9	.681	8.71	1.27	2.18	2.64	3.34	5.14	8.71	20.7	29.8	55.1	118	3,180
2003															
Wamego	6,483	6.24	1.34	12.2	2.09	3.31	4.19	6.805	12.6	15.6	21.3	24.5	27.2	29.2	4,460
Topeka	6,949	1.23	.455	1.95	.54	.594	.663	.998	2.04	2.53	3.07	3.78	7.36	9.68	712
DeSoto	7,290	6.61	1.25	7.29	1.61	2.08	2.65	3.23	6.23	8.49	11.6	16.8	36.0	67.2	2,660

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load									Maximum	Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile		
Nitrogen, ammonia plus organic, total, in tons per day															
2000															
Wamego	7,145	8.87	1.21	7.93	1.49	1.66	1.80	3.25	6.60	9.16	12.9	20.8	45.7	90.2	2,900
Topeka	6,805	10.0	1.58	9.30	1.89	2.08	2.32	4.31	6.96	11.2	15.8	23.5	61.1	90.6	3,390
DeSoto	7,427	10.3	1.41	9.42	2.28	2.78	3.07	5.27	6.77	9.76	15.3	22.8	73.0	91.8	3,440
2001															
Wamego	7,834	27.7	1.40	23.6	1.69	2.23	2.59	4.37	12.0	33.5	65.0	90.6	114	172	8,610
Topeka	7,813	36.1	1.52	31.0	2.27	2.89	3.20	5.19	15.7	42.6	84.8	110	150	312	11,300
DeSoto	8,313	18.8	0	16.8	0	0	4.09	5.56	10.2	19.5	41.3	63.9	89.9	97.4	6,140
2002															
Wamego	6,784	4.31	.916	4.53	.992	1.10	1.29	2.32	2.89	4.4	10.6	15.7	20.7	26.7	1,650
Topeka	8,199	7.20	.794	6.05	1.23	1.47	1.84	2.49	3.55	6.21	13.1	22.2	33.3	90.0	2,210
DeSoto	8,127	8.46	.839	7.14	1.67	2.79	2.96	3.38	4.93	7.19	13.3	17.1	53.7	77.3	2,610
2003															
Wamego	6,483	5.19	.889	5.93	1.00	1.18	1.52	2.35	6.02	7.66	9.64	12.0	28.7	53.0	2,160
Topeka	7,128	6.39	.820	6.83	1.17	1.44	1.86	2.59	5.54	8.56	11.9	16.9	39.0	50.5	2,490
DeSoto	7,290	7.27	1.54	6.83	1.95	2.57	2.92	3.34	5.53	7.15	10.0	15.1	48.2	85.4	2,490

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
Boron, dissolved, in tons per day															
2000															
Wamego	7,235	282	216	582	235	256	266	425	563	682	845	1,060	1,510	2,780	212,000
Topeka	7,043	652	287	1,370	611	661	683	775	1,310	1,640	2,050	2,580	3,660	6,660	500,000
DeSoto	7,085	415	153	765	218	299	331	496	677	925	1,380	1,510	2,000	4,040	279,000
2001															
Wamego	7,596	747	227	918	262	316	344	422	627	1,210	1,860	2,810	3,400	4,940	335,000
Topeka	7,776	2,030	502	2,530	715	823	878	1,030	1,730	3,430	5,670	7,220	8,450	16,000	923,000
DeSoto	8,014	1,190	287	1,430	397	471	507	601	947	1,840	3,310	3,800	4,980	12,700	522,000
2002															
Wamego	6,784	208	153	348	172	179	185	219	269	397	592	904	1,160	1,270	127,000
Topeka	8,215	554	310	916	404	425	445	502	751	1,160	1,610	2,060	2,930	4,440	334,000
DeSoto	8,206	340	79	534	169	241	256	300	450	615	965	1,240	1,670	3,600	195,000
2003															
Wamego	6,933	125	111	343	153	173	185	222	368	435	472	514	709	988	125,000
Topeka	6,949	344	317	830	369	423	443	524	866	988	1,230	1,440	1,910	3,020	303,000
DeSoto	7,529	179	146	410	185	225	249	300	381	465	587	706	1,140	1,990	150,000

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum (pounds)	
					Triazine herbicide, in pounds per day										
2000															
Wamego	8,782	6.12	1.95	9.93	2.48	2.68	2.93	5.29	8.88	13.6	18.3	20.0	23.9	48.8	3,620
Topeka	7,043	15.4	2.61	16.1	3.28	3.50	3.88	5.51	8.99	26.7	40.2	45.2	56.5	148	58,800
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2001															
Wamego	8,758	27.5	2.10	23.9	2.41	2.95	3.50	6.05	13.1	32.8	58.4	88.9	121	184	8,720
Topeka	7,776	58.9	1.25	49.3	1.85	2.57	4.68	11.3	29.4	63.5	134	181	241	507	18,000
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2002															
Wamego	8,758	6.75	1.56	7.42	1.65	1.84	2.39	4.36	5.49	6.75	15.0	21.8	34.9	39.2	2,710
Topeka	8,215	11.4	1.29	11.2	1.74	2.35	2.72	3.82	7.82	12.2	28.3	37.1	51.7	108	4,080
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2003															
Wamego	8,758	5.69	1.43	7.55	1.53	1.73	1.87	2.73	6.66	11.5	16.5	17.4	21.0	39.1	2,760
Topeka	6,949	15.2	1.15	17.0	1.28	1.42	1.59	4.90	14.7	22.7	36.2	38.2	72.5	134	6,200
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum (billion colonies)	
					Fecal coliform bacteria, in trillon colonies per day										
2000															
Wamego	7,145	105	0.194	28.8	0.295	0.385	0.557	1.44	6.94	16.3	55.0	100	501	1,170	10,500
Topeka	6,805	85.3	.171	24.5	.244	.365	.539	1.84	5.21	12.0	38.2	74.8	548	818	8,940
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2001															
Wamego	7,834	216	.250	120	.443	.675	.878	2.61	28.6	128	390	549	1,010	1,940	43,800
Topeka	7,813	257	.166	132	.384	.559	.769	2.46	25.6	134	417	599	1,280	2,720	48,200
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2002															
Wamego	6,784	12.6	.0969	6.26	.135	.183	.289	1.13	1.61	5.68	17.6	26.7	54.9	215	2,280
Topeka	8,199	47.3	.0702	10.6	.163	.248	.474	.862	1.45	3.46	16.7	29.9	262	789	3,870
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2003															
Wamego	6,483	520	1.21	141	1.62	2.09	3.08	12.2	40.7	84.6	188	424	3,110	5,740	51,500
Topeka	7,128	52.6	.0462	16.3	.118	.176	.364	1.20	3.47	9.46	25.4	65.0	284	565	5,950
DeSoto	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum (billion colonies)	
Enterococci bacteria, in trillon colonies per day															
2000															
Wamego	7,145	1,740	1.46	423	2.34	3.20	4.83	13.4	74.4	193	764	1,430	8,150	19,800	154,000
Topeka	6,805	2,790	1.18	649	1.78	2.96	4.84	20.0	70.4	193	795	1,760	18,300	27,000	237,000
DeSoto	7,427	2,470	.0807	556	.426	.988	4.21	18.8	54.1	144	590	1,910	17,100	26,100	203,000
2001															
Wamego	7,834	3,510	1.97	1,790	3.67	5.88	7.80	25.6	355	1,790	5,580	8,600	17,300	33,000	653,000
Topeka	7,813	8,210	1.04	3,670	2.94	4.68	6.94	28.6	448	2,890	11,300	18,300	42,100	88,700	1,340,000
DeSoto	8,313	10,400	.972	4,410	1.43	2.31	3.80	12.8	389	2,860	12,900	25,700	48,500	113,000	1,610,000
2002															
Wamego	6,784	181	.699	76	1.02	1.43	2.38	10.4	15.7	61.9	201	330	775	3,350	27,700
Topeka	8,199	1,510	.449	260	1.21	2.00	4.29	8.75	15.9	46.5	285	557	8,330	25,800	94,900
DeSoto	8,127	1,970	.0854	355	.246	.556	1.44	5.82	10.7	28.9	338	871	10,300	28,600	130,000
2003															
Wamego	6,483	1,130	1.23	275	1.70	2.31	3.51	16.7	59.2	134	324	824	6,760	12,500	100,000
Topeka	7,128	1,770	.216	424	.789	1.27	3.04	12.3	45.0	149	503	1,660	9,230	20,100	155,000
DeSoto	7,290	1,470	.224	315	.393	.956	1.88	6.68	33.1	79.3	289	857	8,990	21,800	115,000

Appendix 2. Regression-estimated loads for selected water-quality constituents, lower Kansas River, northeast Kansas, January 2000–December 2003.—Continued

[--, not determined]

Calendar year and monitoring site (fig. 1)	Number of values	Standard deviation	Minimum	Mean	Load										Annual load (tons)
					1 percentile	5 percentile	10 percentile	25 percentile	50 percentile	75 percentile	90 percentile	95 percentile	99 percentile	Maximum	
					Total suspended solids, in tons per day										
2000															
Wamego	7,145	3,120	21.7	1,110	29.8	36.8	48.7	116	429	850	2,230	3,790	15,600	34,300	405,000
Topeka	6,805	5,560	29.9	1,910	41.2	57.5	79.4	242	593	1,240	3,310	5,930	35,500	53,000	697,000
DeSoto	7,427	3,870	13.1	1,580	29.4	48.1	117	293	596	1,210	3,060	5,910	26,100	36,200	577,000
2001															
Wamego	7,834	6,940	25.8	4,410	42.1	59.4	74.9	189	1,390	5,160	14,400	19,000	29,200	56,800	1,610,000
Topeka	7,813	17,100	30.7	9,750	62.6	86.3	114	310	2,480	10,900	31,000	41,400	83,200	178,000	3,560,000
DeSoto	8,313	16,100	51.9	9,160	73.0	92.8	132	271	2,400	9,960	28,400	41,100	71,100	172,000	3,340,000
2002															
Wamego	6,784	511	11.7	331	15.1	19.3	27.8	87.9	117	340	967	1,390	2,230	7,180	121,000
Topeka	8,199	3,150	12.9	887	27.3	39.3	69.2	117	189	403	1,680	2,960	17,200	51,400	324,000
DeSoto	8,127	3,350	8.07	1,050	18.5	34.8	61.7	136	209	451	2,240	4,490	18,100	44,700	383,000
2003															
Wamego	6,483	1,920	16.5	730	21.2	27.1	36.8	116	352	640	1,190	2,140	11,400	21,000	266,000
Topeka	7,128	3,400	10.3	1,290	21.0	29.9	56.3	153	403	967	2,240	5,090	18,800	34,800	471,000
DeSoto	7,290	2,310	18.7	930	28.4	47.8	68.2	135	414	703	1,620	3,070	14,000	29,100	340,000