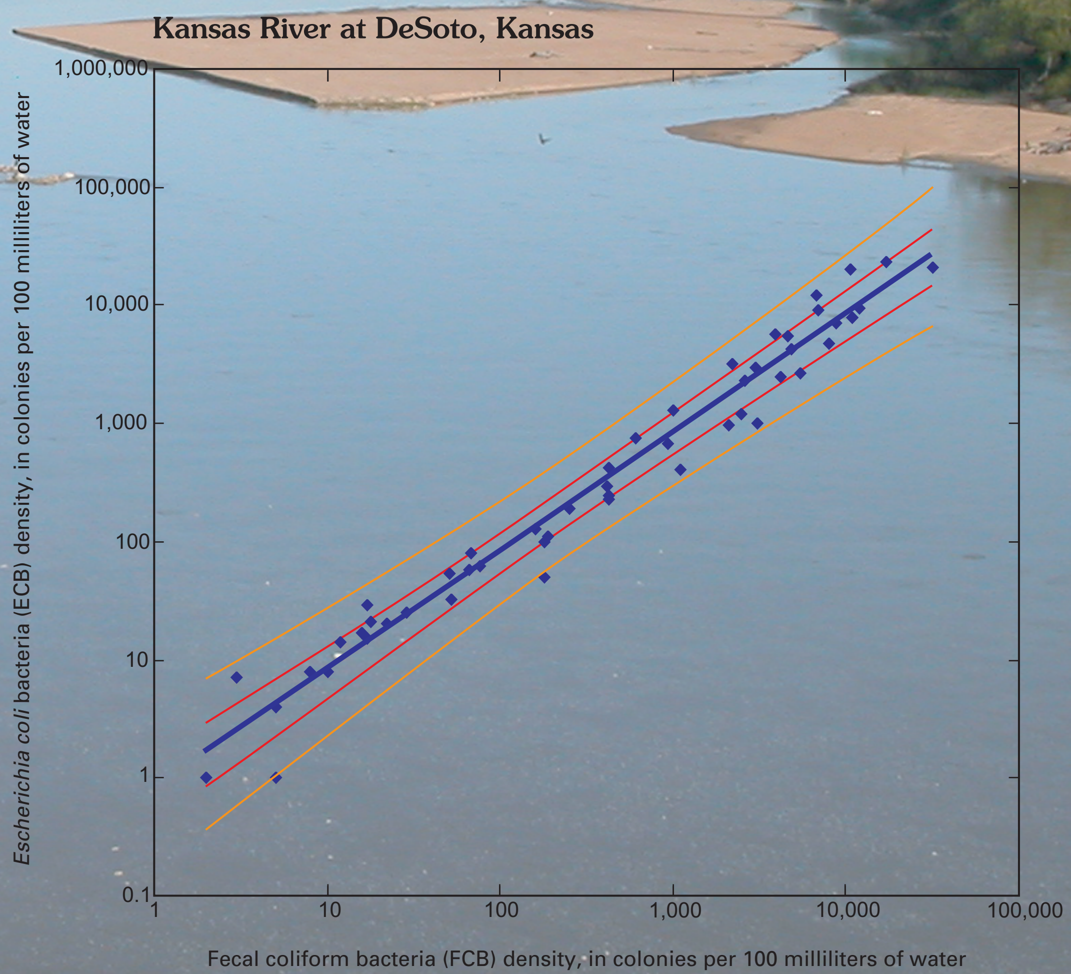
Prepared in cooperation with the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY

Comparison and Continuous Estimates of Fecal Coliform and Escherichia Coli Bacteria in Selected Kansas Streams, May 1999 Through April 2002

Water-Resources Investigations Report 03–4056



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By PATRICK P. RASMUSSEN and ANDREW C. ZIEGLER

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CONVERSION FACTORS, WATER-QUALITY ABBREVIATIONS, AND DATUM

Multiply	By	To obtain
acre	4,047	square meter (m^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
liter (L)	33.82	ounce, fluid (oz)
mile (mi)	1.609	kilometer (km)
milliliter (mL)	0.0338	ounce, fluid (oz)
nanometer (nm)	3.937×10^{-8}	inch (in.)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$^{o}C=5/9\ (^{o}F - 32)$$

$$^{o}F=9/5(^{o}C) + 32.$$

Water-Quality Abbreviations

col/100 mL—colonies per 100 milliliters of water
µS/cm—microsiemens per centimeter at 25 °C

Datum

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

Comparison and Continuous Estimates of Fecal Coliform and *Escherichia Coli* Bacteria in Selected Kansas Streams, May 1999 Through April 2002

By Patrick P. Rasmussen *and* Andrew C. Ziegler

Abstract

The sanitary quality of water and its use as a public-water supply and for recreational activities, such as swimming, wading, boating, and fishing, can be evaluated on the basis of fecal coliform and *Escherichia coli* (*E. coli*) bacteria densities. This report describes the overall sanitary quality of surface water in selected Kansas streams, the relation between fecal coliform and *E. coli*, the relation between turbidity and bacteria densities, and how continuous bacteria estimates can be used to evaluate the water-quality conditions in selected Kansas streams.

Samples for fecal coliform and *E. coli* were collected at 28 surface-water sites in Kansas. Of the 318 samples collected, 18 percent exceeded the current Kansas Department of Health and Environment (KDHE) secondary contact recreational, single-sample criterion for fecal coliform (2,000 colonies per 100 milliliters of water). Of the 219 samples collected during the recreation months (April 1 through October 31), 21 percent exceeded the current (2003) KDHE single-sample fecal coliform criterion for secondary contact recreation (2,000 colonies per 100 milliliters of water) and 36 percent exceeded the U.S. Environmental Protection Agency (USEPA) recommended single-sample primary contact recreational criterion for *E. coli* (576 colonies per 100 milliliters of water). Comparisons of fecal coliform and *E. coli* criteria indicated that more than one-half of the streams sampled could exceed USEPA recommended *E. coli* criteria more frequently than the current KDHE fecal coliform criteria. In addition, the ratios of *E. coli* to fecal coliform (EC/FC) were smallest for sites with slightly saline water (specific conductance greater than 1,000 microsiemens per centimeter at 25 degrees Celsius), indicating that *E. coli* may not be a good indicator of sanitary quality for those streams. *Enterococci* bacteria may provide a more accurate assessment of the potential for swimming-related illnesses in these streams.

Ratios of EC/FC and linear regression models were developed for estimating *E. coli* densities on the basis of measured fecal coliform densities for six individual and six groups of surface-water sites. Regression models developed for the six individual surface-water sites and six groups of sites explain at least 89 percent of the variability in *E. coli* densities. The EC/FC ratios and regression models are site specific and make it possible to convert historic fecal coliform bacteria data to estimated *E. coli* densities for the selected sites. The EC/FC ratios can be used to estimate *E. coli* for any range of historical fecal coliform densities, and in some cases with less error than the regression models. The basin- and statewide regression models explained at least 93 percent of the variance and best represent the sites where a majority of the data used to develop the models were collected (Kansas and Little Arkansas Basins).

Comparison of the current (2003) KDHE geometric-mean primary contact criterion for fecal coliform bacteria of 200 col/100 mL to the 2002 USEPA recommended geometric-mean criterion

of 126 col/100 mL for *E. coli* results in an EC/FC ratio of 0.63. The geometric-mean EC/FC ratio for all sites except Rattlesnake Creek (site 21) is 0.77, indicating that considerably more than 63 percent of the fecal coliform is *E. coli*. This potentially could lead to more exceedances of the recommended *E. coli* criterion, where the water now meets the current (2003) 200-col/100 mL fecal coliform criterion.

In this report, turbidity was found to be a reliable estimator of bacteria densities. Regression models are provided for estimating fecal coliform and *E. coli* bacteria densities using continuous turbidity measurements. Prediction intervals also are provided to show the uncertainty associated with using the regression models. Eighty percent of all measured sample densities and individual turbidity-based estimates from the regression models were in agreement as exceeding or being less than the primary and secondary contact recreational criteria. The continuous turbidity measurements and regression models were used to construct probability curves that can be used to estimate bacteria concentrations on the basis of measured turbidity values. Duration curves developed for six sites using the hourly estimates of bacteria density indicate that the current KDHE (fecal coliform bacteria) and USEPA recommended (*E. coli* bacteria) primary contact recreational criteria were exceeded for 21 to 94 and 31 to 97 percent of the spring and summer, respectively. Estimated bacteria densities most commonly exceeded the current and recommended criteria in the spring (April through June). Hourly estimates provided in real time (available on the World Wide Web at http://ks.water.usgs.gov/Kansas/rtqw/) allow the public and water-management agencies to make decisions in regard to whether planned water activities are appropriate by considering current stream conditions relative to water-quality criteria.

Annual and seasonal loads and yields were calculated using hourly estimated fecal coliform and *E. coli* bacteria densities and streamflow at six surface-water sites for the calendar years 2000 and 2001. Estimated bacteria loads in 2001 were about 2 to 8 times larger than the bacteria loads in 2000 for the Kansas and Little Arkansas Rivers. Data from major point sources upstream from the surface-water sites in these basins indicate that nonpoint sources accounted for more than 97 percent of the annual loads. Mean daily bacteria loads in 2000 were largest in the winter for five sites and in the spring for one site. In 2001, mean daily bacteria loads were largest in the spring for four sites and in the winter for two sites. Annual load differences are caused by varying hydrologic conditions and higher streamflow caused by overland runoff. Surface-water sites in the Little Arkansas River Basin had the largest bacteria yield per acre of watershed.

INTRODUCTION

Fecal coliform bacteria have long been used as an indicator organism for the sanitary quality of water for drinking or body-contact recreation. The presence of fecal coliform bacteria in water indicates the possible presence of pathogens, such as *entero-*, *rota-*, and *reoviruses*, found in feces of warmblooded animals. These bacteria and pathogens may cause human diseases ranging from mild diarrhea to respiratory disease, septicemia, meningitis, and polio (Dufour, 1977; Pepper and others, 1996). The fecal coliform bacteria group can include any combination of *Escherichia coli (E. coli)* and species of the *Klebsiella, Enterobacter, and Citrobacter* genera (Gleeson and Gray, 1997). Fecal coliform bacteria are found in the feces of all warmblooded animals, but some members of the group also can originate in soil and water (Holt and others, 1993).

In 1986, the U.S. Environmental Protection Agency (USEPA) recommended that States use *E. coli* or *enterococci* bacteria rather than fecal coliform as indicators of fecal contamination for recreational water. *E. coli* is the only member of the fecal group that is exclusively fecal in origin and, therefore, is definitive evidence of fecal contamination from warmblooded animals. Measuring only *E. coli* or *enterococci*, rather than the entire fecal coliform or fecal streptococci group, has been shown to give a better indication of possible contamination by organisms associated with swimming illnesses (Cabelli, 1977; Dufour and Cabelli, 1984). USEPA also suggests that *E. coli* is not as reliable an indicator as *enterococci* in marine water or freshwater streams with high salinity. In 2002, USEPA issued revised guidelines with recommended numeric criteria on the basis of risk exposure (U.S. Environmental Protection Agency, 2002).

The Kansas Department of Health and Environment (2001) lists fecal coliform criteria for Kansas streams designated for either primary contact (full-body) or secondary contact (noncontact) recreational use (table 1). During primary contact recreation, the body is immersed in surface water to the extent that some inadvertent ingestion of water is probable. This use includes boating, mussel harvesting, swimming, skin diving, water skiing, and wind surfing. During secondary contact recreation, ingestion of water is not probable. This use includes wading, fishing, trapping, and hunting (Kansas Department of Health and Environment, 2001). The State of Kansas is currently (2003) evaluating the use of *E. coli* as the primary indicator bacteria.

Current (2003) surface-water-quality criteria for Kansas state that the geometric mean (the exponent of the mean of the logarithmic transformed data) for fecal coliform bacteria of at least five samples collected over separate 24-hour periods during a 30-day period shall not exceed 200 col/100 mL of water (Kansas Department of Health and Environment, 2001). This criterion is in effect April 1 through October 31 for water designated for primary contact recreational use (designated recreation period). Fecal coliform bacteria shall not exceed 2,000 col/100 mL for any single sample collected from November 1 through March 31 for surface water designated for primary contact recreational use. Surface water designated for secondary contact recreational use shall not exceed 2,000 col/100 mL for a single sample throughout the year (Kansas Department of Health and Environment, 2001).

USEPA recommended criteria for *E. coli* in water designated for primary contact recreational use are based on a geometric-mean density for five samples collected over 30 days and a single-sample density (table 1). The ranges of geometric-mean (126 to

Table 1. Current (2003) Kansas and U.S. Environmental Protection Agency recommended indicator bacteria criteria

[All values are in colonies per 100 milliliters of water. KDHE, Kansas Department of Health and Environment; USEPA, U.S. Environmental Protection Agency; *E. coli*, *Escherichia coli* bacteria; --, no criteria]

		Type of recreational water					
		Primary contact recreation[2]					Secondary contact recreation[3]
			Single-sample maximum allowable density				
Indicator bacteria type	Illness rate (per 1,000 swimmers)	Geometric mean[1]	Designated beach area	Moderate full-body contact	Lightly used full-body contact	Infrequently used full-body contact	Single-sample maximum allowable density
Fecal coliform (KDHE, 2001)	8	200	--	--	--	--	2,000
USEPA recommended *E. coli* criteria (USEPA, 2002)	8	126	235	298	406	576	--
	9	160	300	381	524	736	--
	10	206	383	487	669	941	--
	11	263	490	622	855	1,202	--
	12	336	626	795	1,092	1,536	--
	13	429	799	1,016	1,396	1,962	--
	14	548	1,021	1,298	1,783	2,507	--

[1]Geometric mean of at least five samples collected during separate 24-hour periods within a 30-day period.

[2]Recreation during which the body is immersed in surface water to the extent that some inadvertent ingestion of water is probable. This use shall include boating, mussel harvesting, swimming, skin diving, water skiing, and wind surfing. These criteria shall be in effect from April 1 through October 31 of each year (KDHE, 2001).

[3]Recreation during which ingestion of surface water is not probable. This use shall include wading, fishing, trapping, and hunting. These criteria shall be in effect from January 1 through December 31 of each year (KDHE, 2001).

548 col/100 mL) and single-sample (235 to 2,507 col/100 mL) criteria vary on the basis of the illness rate (8 to 14 illnesses per 1,000 swimmers). USEPA currently (2003) has no recommended criteria for secondary contact recreational use (U.S. Environmental Protection Agency, 2002).

Section 303(d) of the Federal Clean Water Act of 1972 requires States to identify all water bodies where State water-quality criteria are not being met. In Kansas, 64 percent of the 59,423 stream mi monitored by the Kansas Department of Health and Environment (KDHE) in 1998–99 fully supported all uses (Kansas Department of Health and Environment, 2000). About 83 percent fully or partially supported all uses. In 1998, fecal coliform bacteria was listed as an impairment for 611 of the 774 water-quality-limited stream segments (or 79 percent) listed on the 303 (d) list for Kansas (Kansas Department of Health and Environment, 2000).

The Federal Clean Water Act also requires that States establish total maximum daily loads (TMDLs) to meet established water-quality criteria and to ensure protection of a water body's designated beneficial uses. A TMDL is a calculation and allocation among sources of the maximum amount of a contaminant that a water body can receive and still /meet water-quality criteria (U.S. Environmental Protection Agency, 1999).

In May 2000, Wichita, Kansas, water-resource managers were forced to cancel water activities to be held in the Arkansas River during an annual river festival due to unsafe bacteria densities in the stream. Water samples were collected daily prior to and throughout the planned events. Water-resource managers then would decide if the streams were safe for the planned events on the basis of these results. Analytical methods used to attain these results required 24 hours. Therefore, managers were making critical public-health decisions on the basis of stream conditions for the previous day. Densities of bacteria can change substantially in just a few hours, possibly exceeding single-sample criteria for secondary contact recreational use.

In May 1999, the U.S. Geological Survey (USGS) with several Federal, State and local agencies, began collecting samples for analysis of fecal coliform and *E. coli* bacteria at 28 surface-water sites in Kansas (fig. 1). A comparative bacteria data set will benefit the State of Kansas by helping to estimate *E. coli* densities on the basis of historical fecal coliform data. A comparative data set also can be used to determine how the new USEPA recommended criteria will affect compliance of streams within the State if adopted. A method is necessary to provide real-time continuous estimates of the sanitary quality of Kansas streams and to evaluate best management practices and TMDL goals. The USGS, in cooperation with KDHE and USEPA, evaluated bacteria data collected at 28 surface-water sites to address these needs.

Indicator bacteria densities are highly variable and are dependent on the source of the bacteria and the hydrologic and environmental conditions. Possible sources of fecal coliform bacteria contamination include municipal wastewater discharges, seepage from domestic septic systems, combined sewer overflows, runoff or seepage from livestock-producing areas, and wildlife populations. Point sources such as wastewater treatment facilities and combined sewer overflows often discharge potential contaminants directly into streams. Fecal coliform bacteria in undisturbed feces of warmblooded animals deposited on the land surface can survive for a year or more (Bohn and Buckhouse, 1985). Rainfall on these surfaces transport fecal coliform bacteria into or along the surface of soil and eventually into surface water and sometimes ground water. Runoff from grazed areas can have 5 to 10 times the amount of fecal coliform bacteria than runoff from ungrazed areas, but both sources of runoff can exceed recommended water-quality criteria (Doran and Linn, 1979).

Once bacteria reach a stream, they can survive for days or months depending on water temperature and water-quality conditions (Sherer and others, 1992; Howell and others, 1996). The survival rate of bacteria can increase as temperature decreases or as ultraviolet penetration into water is decreased (Fujioka and Narikawa, 1982). Fecal coliform bacteria tend to adsorb to suspended sediment such as silt and clay in the water (Kittrel and Furfari, 1963; Hendricks, 1970), extending their survivability. When stream velocities are slow, the sediment tends to settle out of water to the bottom of the stream. Densities of fecal indicator bacteria in sediment can be 100 to 1,000 times the densities in the overlying water column (Ashbolt and others, 1993), and their survivability can increase to 85 times the survivability in the overlying water column (Sherer and others, 1992; Davies and others, 1995). These bacteria and fine sediment can be re-suspended when they are disturbed, for example by

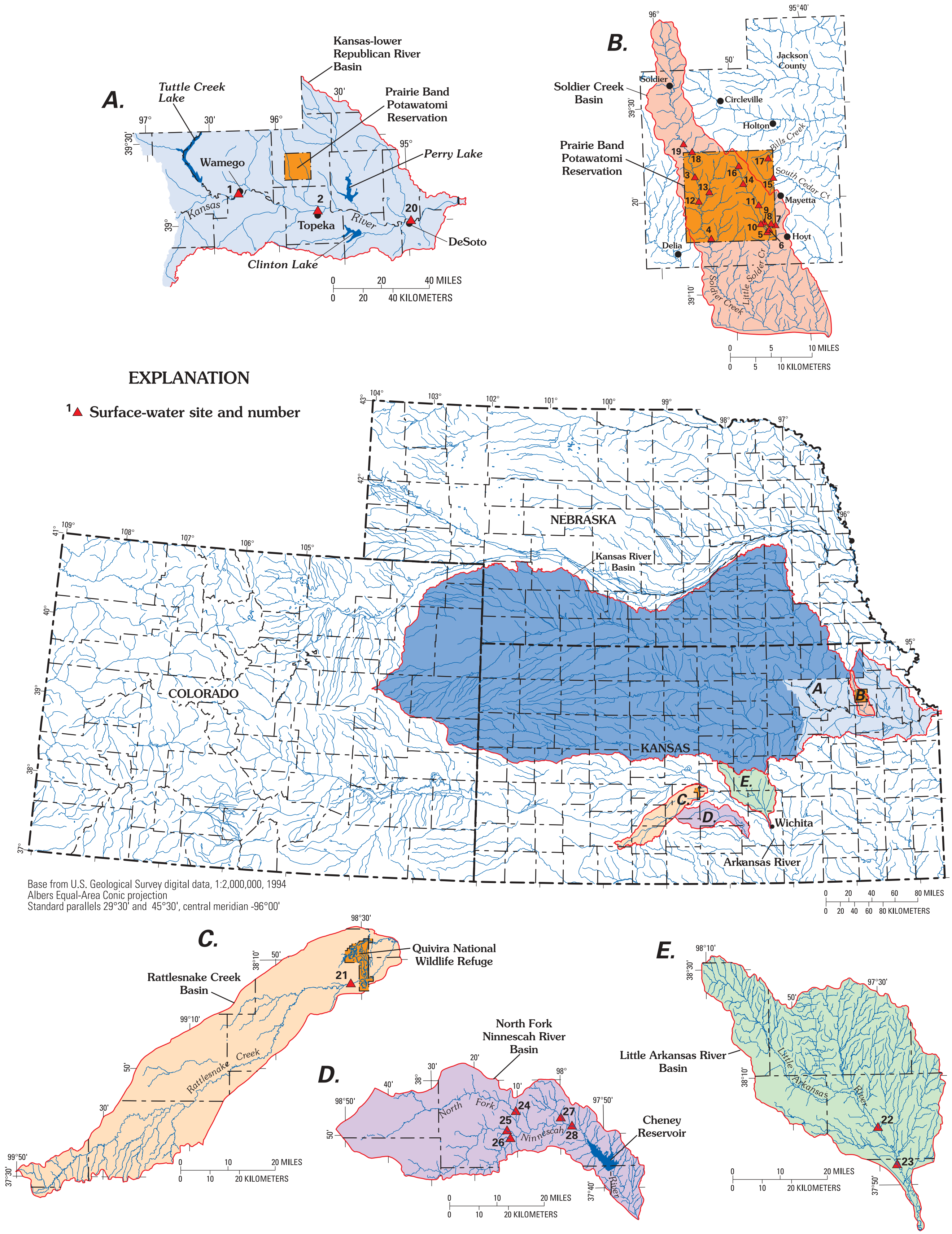


Figure 1. Location of surface-water sites in Kansas where fecal coliform and *Escherichia coli* samples were collected, May 1999 through April 2002.

dredging, by animals walking in the stream, and by higher flow when stream velocities increase.

PURPOSE AND SCOPE

This report was prepared in cooperation with KDHE and USEPA and funded in part through the Kansas State Water Plan Fund. This report describes (1) the sanitary water quality, (2) the relation between fecal coliform and *E. coli*, (3) the relations between turbidity and fecal coliform and *E. coli*, and (4) how continuous bacteria estimates can be used to evaluate water-quality conditions in selected Kansas streams. The relations between turbidity and fecal coliform and *E. coli* were used to estimate bacteria densities at selected sites for the period of the study.

From May 1999 through April 2002, the U.S. Geological Survey (USGS) collected 318 samples at 28 surface-water sites (fig. 1) for the analysis of both fecal coliform and *E. coli* bacteria. These samples were part of ongoing data-collection efforts partially funded by USGS and KDHE, USEPA, the U.S. Fish and Wildlife Service, Big Bend Groundwater Management District No. 5, Prairie Band Potawatomi Nation, and the city of Wichita. During bacteria sample collection, in-stream turbidity was measured at 11 of the 28 sites. In-stream turbidity also was measured continuously for most of the study period at 7 of the 28 sites (table 2). Twenty-two of the surface-water sites were on stream segments that have been designated for primary contact recreation and, therefore, must adhere to the most stringent bacteria criteria (table 1). The remaining six sites were located on small streams that have been designated for secondary contact recreation and must meet less stringent criteria to be in compliance. All 28 sites represent watersheds in predominately agricultural areas. The streamflow at sites 1, 2, and 20 located on the Kansas River are affected by large reservoirs (fig. 1*A*).

The USEPA recommended *E. coli* geometric-mean criterion (126 col/100 mL) and single-sample criteria for designated beach area (235 col/100 mL) and infrequently used full-body contact (576 col/100 mL) for an illness rate of 8 per 1,000 swimmers and for infrequently used full-body contact (2,507 col/100 mL) for an illness rate of 14 per 1,000 swimmers will be used for comparison of measured and estimated density discussed in this report.

The methods described in this report can be used to provide real-time continuous estimates of the sanitary quality of selected streams in Kansas. Currently (2003), a World Wide Web page (http://ks.water.usgs.gov/Kansas/rtqw) provides water-resource managers with the information necessary to make decisions about sanitary quality on the basis of real-time water-quality estimates, which can improve response times for drinking-water treatment and environmental monitoring. Long-term continuous monitoring allows users to construct bacteria duration curves to help assess the effectiveness of TMDLs for selected streams and the results of resource-management practices. The methods described in this report may be appropriate for monitoring water quality elsewhere in the Nation.

METHODS

Bacteria Sample Collection and Analysis

Samples for bacteria analysis were collected at each surface-water site by submerging a sterile 1-L bottle into the stream near the center of the flow. The sample was chilled, then processed by a membrane filtration technique within 6 hours of collection for identification and enumeration of fecal coliform and *E. coli* bacteria (Myers and Wilde, 1999).

The membrane filter technique was used, although this method may underestimate the number of viable coliform bacteria (Eaton and others, 1995). Assuming that bacteria were randomly distributed and followed a Poisson distribution, approximate 95-percent confidence limits for the true population mean were constructed as follows:

$$\text{upper limit} = [c + (2 \times \sqrt{c})], \qquad (1)$$

and

$$\text{lower limit} = [c - (2 \times \sqrt{c})], \qquad (2)$$

where c is the count of bacteria in a single petri dish.

For ideal counts of fecal coliform, the 95-percent confidence interval for the lower limit of the ideal range is 20 to 60 colonies with corresponding confidence-interval widths of ± 9 to ± 15 colonies (or ± 25 to 45 percent). Ideal plate counts for *E. coli* range from 20 to 80 colonies with corresponding confidence-interval widths ranging from ± 9 to ± 18 colonies. Bacteria densities calculated on the basis of counts outside of these ranges were considered nonideal counts. Of the 318 samples analyzed, 83 (26 percent)

Table 2. Surface-water sites in Kansas where bacteria samples were collected during May 1999 through April 2002

[mi^2, square miles; --, not determined]

Site number (fig. 1)	Station number	Station name	Total drainage area (unregulated drainage area) (mi^2)	Designated recreation use	Continuous in-stream turbidity measure-ments
1	06887500	Kansas River at Wamego, Kansas	55,280 (5,922)	primary	yes
2	06889000	Kansas River at Topeka, Kansas	56,720 (7,362)	primary	yes
3	06889180	Soldier Creek near St. Clere, Kansas	80	primary	no
4	391557095531100	Soldier Creek, 1 Road near Delia, Kansas	--	primary	no
5	391628095452800	Little Soldier Creek, 126 Road near Hoyt, Kansas	--	primary	no
6	391629095452400	Big Elm Creek, P Road near Hoyt, Kansas	--	secondary	no
7	391704095441700	Little Elm Creek, Q Road near Hoyt, Kansas	--	secondary	no
8	391720095445400	Big Elm Creek, 134 Road near Hoyt, Kansas	--	secondary	no
9	391720095454200	Little Soldier Creek, 134 Road near Mayetta, Kansas	--	primary	no
10	391721095460900	Little Soldier tributary, 134 Road near Hoyt, Kansas	--	primary	no
11	391915095463100	Little Soldier Creek, 0 Road near Mayetta, Kansas	--	primary	no
12	391956095544000	Soldier Creek, 158 Road near St. Clere, Kansas	--	primary	no
13	392049095531300	Crow Creek, 166 Road near St. Clere, Kansas	--	secondary	no
14	392143095482700	Little Soldier Creek, 174 Road near Mayetta, Kansas	--	primary	no
15	392212095441800	South Cedar Creek, Highway 75 near Mayetta, Kansas	--	secondary	no
16	392328095490300	Little Soldier Creek, 190 Road near Mayetta, Kansas	--	primary	no
17	392425095445100	Bills Creek, Highway 75 near Holton, Kansas	--	secondary	no
18	392603095563000	Soldier Creek tributary, G Road near Circleville, Kansas	--	primary	no
19	392603095563000	Soldier Creek, 214 Road near Circleville, Kansas	--	primary	no
20	06892350	Kansas River at DeSoto, Kansas	59,756 (8,914)	primary	yes
21	07142575	Rattlesnake Creek near Zenith, Kansas.	1,047	primary	yes
22	07143672	Little Arkansas River at Highway 50 near Halstead, Kansas.	759	primary	yes
23	07144100	Little Arkansas River near Sedgwick, Kansas.	1,239	primary	yes
24	07144601	North Fork Ninnescah River at Arlington, Kansas.	322	primary	no
25	07144660	Silver Creek near Arlington, Kansas.	194	primary	no
26	07144680	Goose Creek near Arlington, Kansas.	46.6	primary	no
27	07144730	Red Rock Creek near Pretty Prairie, Kansas.	53.2	primary	no
28	07144780	North Fork Ninnescah River above Cheney Reservoir, Kansas.	713	primary	yes[1]

[1]Although continuous in-stream turbidity measurements were made at this site during the study period, the data were insufficient for regression modeling.

fecal coliform and 130 (41 percent) *E. coli* densities were based on nonideal counts.

Forty-seven samples were collected for duplicate analysis including both ideal and nonideal counts. Fecal coliform were analyzed in 44 of the 47 samples, and *E. coli* were analyzed in 35 of the 47 samples. The percentage difference was calculated using equation 3:

$$\text{percentage difference} = 100 \times \frac{|C_1 - C_2|}{\frac{|C_1 + C_2|}{2}}, \qquad (3)$$

where

C_1 is the density for the first sample, in colonies/100 mL of water; and

C_2 is the density for the duplicate sample, in colonies per 100 mL of water.

The percentage difference for the fecal coliform and *E. coli* duplicate samples ranged from 0 to 127 and 0 to 83 percent, respectively. The high percentage differences occurred when counts were nonideal. The average percentage difference was 37 percent for fecal coliform and 14 percent for *E. coli*. A possible cause for the large uncertainty in the analysis may be the difficulty in obtaining a representative subsample, especially for highly turbid samples.

Turbidity Measurements

Turbidity is the reduction in the transparency of a solution due to the presence of suspended and dissolved substances. Primary contributors to turbidity in water include clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton, and microscopic organisms (American Public Health Association and others, 1992). Turbidity measurement techniques record the collective optical properties of the solution that cause light to be scattered or attenuated rather than transmitted in straight lines; the higher the intensity of scatter or attenuated light, the higher the value of the turbidity. The smaller the turbidity value, the clearer the water. Turbidity typically is expressed in nephelometric turbidity units (NTU). Depending on the method used, turbidity as NTU can be defined as the intensity of light of a specified wavelength scattered or attenuated by suspended particles or absorbed at a method-specified angle, usually 90 degrees, from the path of incident light.

Currently approved methods for the measurement of turbidity in the USGS include those that conform to USEPA Method 180.1 (U.S. Environmental Protection Agency, 1979), ASTM Method D1889–00 (American Society of Testing and Materials, 2000), ISO Method 7027 (International Organization for Standardization, 1999), GLI Method 2 (Great Lakes Instruments, Inc., 1992), and standard methods recommended by the American Water Works Association and the Water Environment Federation (Clesceri and others, 1998). Turbidity measurements for this study were made with a YSI 6026 turbidity probe (Yellow Springs Instruments, Yellow Springs, Ohio). The YSI 6026 conforms to the ISO Method 7027 measurement standard with a light source of 860 $\pm$ 30 nm and single detector oriented at 90 degrees from the incident light path. Turbidity values from other turbidity probes or sensors may not be comparable with the turbidity values and the relations that use turbidity in this report (Sadar, 2002; Ziegler, 2002).

Typically, during bacteria sample collection, turbidity was measured using a multiparameter monitor (fig. 2) also capable of measuring physical properties, including specific conductance, pH, water temperature, dissolved oxygen, and sometimes fluorescence. The monitor was cleaned and calibrated before each use to ensure accurate measurements (Wilde and Radtke, 1998). Prior to each measurement, a mechanical wiper on the turbidity probe rotated across the sensor, removing air bubbles and particles that may interfere with the turbidity reading. Turbidity measurements were recorded at a minimum of 10 locations throughout the cross section of the stream, termed onsite-monitor cross-section measurements in this report. The mean of the measurements was recorded as the turbidity for the sample collected. The turbidity sensor on the multiparameter monitor used during sample collection was capable of measuring a range from 0 to 6,000 NTU (very muddy water). Turbidity of Kansas streams can exceed 6,000 NTU during periods of high flow related to runoff.

At 7 of the 28 surface-water sites, the same multiparameter monitors (fig. 2) were installed in-stream and used to continuously measure the turbidity and other physical properties of the water. The in-stream monitors were cleaned and calibrated every 2 to 6 weeks, and recorded measurements were adjusted on the basis of measurements made just before and after monitor cleaning and calibration (Wagner and others, 2000). The turbidity sensors on the continuous, in-stream monitors were capable of measuring a range from 0 (clear water) to 1,000–1,500 NTU (muddy water). Measurements from the water-quality monitor

Figure 2. Multiparameter monitor used to measure turbidity, specific conductance, pH, water temperature, dissolved oxygen, and fluorescence in water during sample collection and for in-stream continuous monitoring.

were recorded hourly and transmitted via satellite every 4 hours and were made available on the World Wide Web (http://ks.water.usgs.gov/Kansas/rtqw). Every 2 to 6 weeks the hourly data were downloaded from the data-collection platform and then uploaded to the USGS database.

The continuous, in-stream monitors also were calibrated to the stream cross section (Rasmussen and others, 2002). Onsite-monitor cross-section measurements were compared with the point measurement of the in-stream monitor. If the comparison differed by more than 10 percent, the in-stream monitor was relocated to a more representative location within the cross section. The in-stream monitor was not relocated on the basis of temporary stream conditions (as the result of storm runoff), but only as a result of long-term variations. A check of the continuous in-stream turbidity-sensor measurements was made by comparing the average of the cross-section measurements with the in-stream values (fig. 3). The closer the regression slope was to 1.0, the more representative the data from the continuous in-stream monitor were of the turbidity of the stream cross section without correction. At least 20 to 30 measurements over a 2-year period throughout the range of turbidity values were necessary to develop a robust relation. The number of measurements at site 28 were not sufficient to develop such a relation.

Turbidity duration curves were used for determining at what turbidity level a cross-section measurement or a bacteria sample was necessary to adequately represent the range of conditions (fig. 4). Cross-section turbidity measurements plotted on the duration curve represent ranges of turbidity values for which cross-sectional measurements need to be made and when bacteria samples need to be collected. The more evenly distributed the measurements and samples are along the duration curve, the more representative those turbidity values and bacteria samples are for the site for the period of record. The duration curve also provides a complete summary of the turbidity conditions at a particular site for a particular time period. Instantaneous measurements every hour were used to construct these duration curves (rather than daily values), so the maximum and the minimum value of the curve are the maximum and minimum measured values for this period. The 50-percent exceedance value is the median of the instantaneous values for the time period.

Development of Regression Models to Estimate Bacteria Densities

One purpose of this report is to relate the density of fecal coliform bacteria to *E. coli* bacteria in surface water. Also, the density of bacteria was related to turbidity.

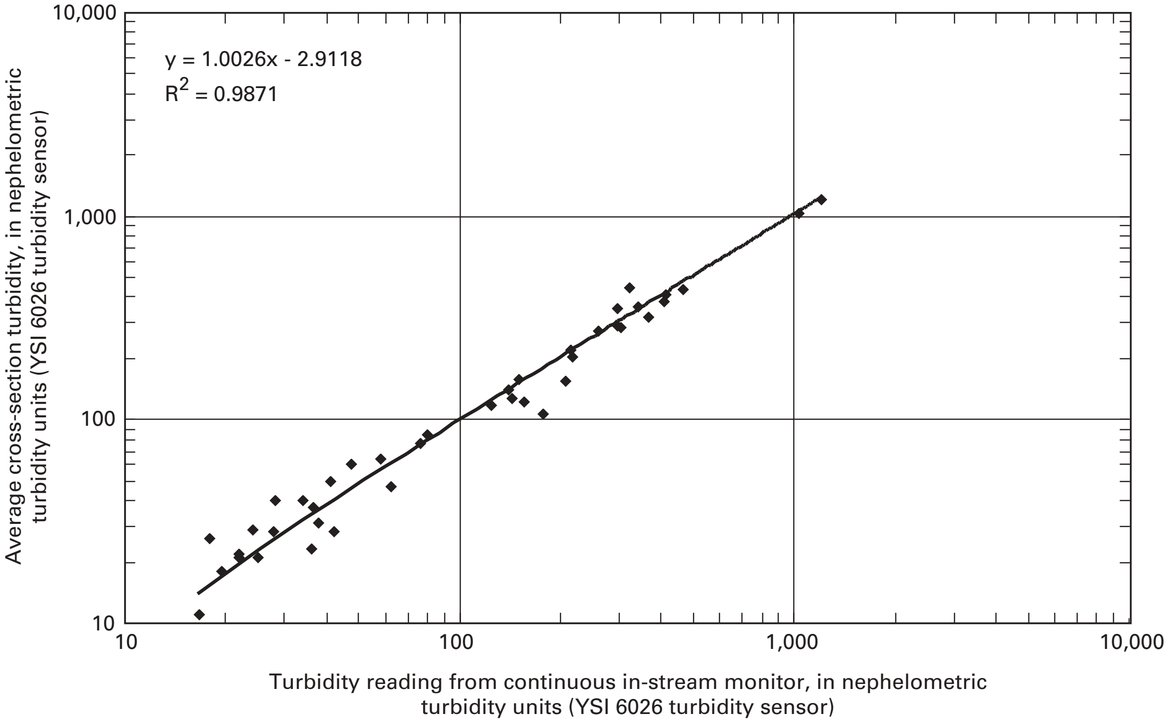


Figure 3. Comparison of continuous, in-stream and cross-section turbidity values for Kansas River at Topeka, Kansas, July 1999 through April 2002.

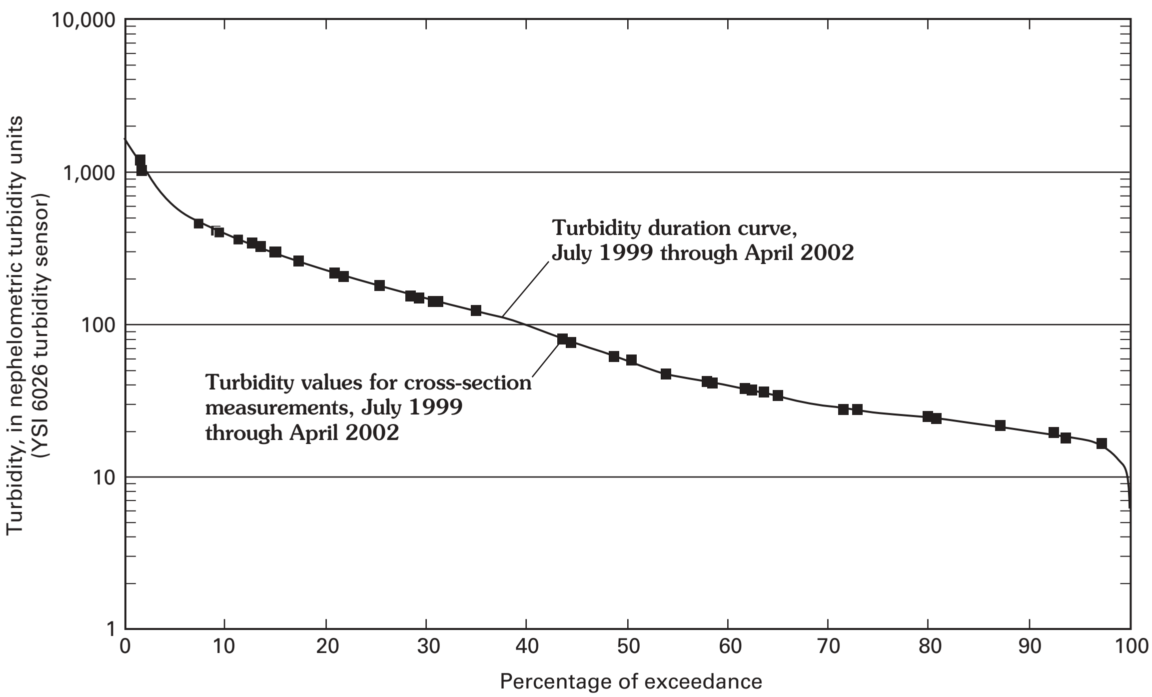


Figure 4. Turbidity duration curve for Kansas River at DeSoto, Kansas, July 1999 through April 2002.

It is possible to express one constituent concentration in terms of another constituent or constituents using simple regression models (Helsel and Hirsch, 1992). The regression analysis used in this report has been modified from work originally done by Christensen and others (2000). Although constituent measurements may be related statistically, it does not necessarily mean that the independent variable causes the concentrations of the dependent variable to occur. Linear regression was used for this study because the estimators of the parameters are from an explicit mathematical expression. The simplest regression model can be expressed as:

$$y_i = mx_i + b + e_i \qquad i = 1,2,....n, \tag{4}$$

where

- y_i is the ith observation of the dependent variable;
- m is the slope;
- x_i is the ith observation of the independent (explanatory) variable;
- b is the intercept;
- e_i is the random error for the ith observation; and
- n is the sample size.

The terms m and b represent the parameters that need to be estimated from the data set. The most common estimation technique is least squares (Helsel and Hirsch, 1992). In least-squares estimation, the error term, e_i, usually is assumed to be normally distributed with a mean equal to zero and constant variance, σ^2.

Regression models were first developed for estimating *E. coli* from fecal coliform bacteria densities. As a member of the fecal coliform group, *E. coli* should correlate well with fecal coliform. The data were log transformed to improve the linearity of the relation.

Regression models then were developed to estimate bacteria densities (fecal coliform and *E. coli*) on the basis of varying water-quantity and -quality characteristics. The first step in developing an effective regression model for a specific surface-water site was to plot each possible explanatory variable against the response variable and examine patterns in the data. All explanatory and response variables (except time) were log transformed to convert all models presented herein to linear models. Log transformations of variables can eliminate curvature and simplify analysis of the data (Ott, 1993, p. 454).

Next, to determine which explanatory variable or variables to include in the regression model for each constituent of concern, an overall model-building method (Helsel and Hirsch, 1992, p. 312–314) was used. The possible explanatory variables included each of the cross-section-averaged sensor measurements (specific conductance, pH, water temperature, turbidity, and dissolved oxygen) from the multiparameter monitor, streamflow, stage, and time. All possible regression models were evaluated. Explanatory variables were considered significant if the p-value (probability value) was less than 0.05. If there were several acceptable models (p-value less than 0.05), the one with the lowest PRESS statistic was chosen. Minimizing PRESS (acronym for "PRediction Error Sum of Squares") means that the equation produces the least error when making new predictions (Helsel and Hirsch, 1992, p. 248). Additionally, explanatory variables were included in a model only if there was a physical basis or explanation for their inclusion.

In addition to the PRESS, three common diagnostic statistics were used to evaluate the regression models described in this report. These statistics are the mean square error *(MSE)*, the coefficient of determination *(R^2)*, and the relative mean absolute error *(RMAE)*. *MSE* is calculated as follows:

$$MSE = \frac{\sum_{i=1}^{n} [y_i - E(y_i)]^2}{n-k}, \tag{5}$$

where

- y_i represents the value of y, in log units, at the ith data point;
- $E(y_i)$ is the estimated value of y, in log units, at the ith data point (where $E(y_i) = mx_i + b$);
- n is the number of samples; and
- k is the number of explanatory variables in the model.

The *MSE* is determined for each regression model to assess the variance between estimated and measured values. *MSE* in this report is expressed in log units. Using the *MSE*, the model standard prediction error as a percentage was calculated using equation 6:

model standard prediction error, as a percentage =

$$100 \times \sqrt{e^{[(2.3026)^2 \times MSE]} - 1}, \tag{6}$$

where e is the base of natural logarithms.

MSE is a dimensional measure. Dimensional measures often are required in practice for the purpose of comparing constituents or properties with different dimensions (units of measure). A dimensionless measure of fitting y on x is the R^2, or the fraction of the variance explained by the regression:

$$R^2 = 1.0 - (SSE/SS_y). \quad (7)$$

SSE (error sum of squares) and SS_y (sums of squares y) are calculated as follows:

$$SSE = \sum_{i=1}^{n} [y_i - E(y_i)]^2 \text{ , and} \quad (8)$$

$$SS_y = \sum_{i=1}^{n} (y_i - \bar{y})^2 , \quad (9)$$

where $\bar{y}$ is the mean of *y*, in log units./

The R^2 ranges from 0 to 1 and often is called the multiple coefficient of determination in multiple linear regression.

The *RMAE*, expressed as a percentage, is calculated as follows:

$$RMAE = \frac{\frac{1}{n}\sum_{i=1}^{n} |A - B|}{M_B} \times 100 , \quad (10)$$

where

A is the estimated density, in colonies per 100 milliliters of water;

B is the measured density, in colonies per 100 milliliters of water; and

M_B is the mean (average) of all the measured densities, in colonies per 100 milliliters of water.

Graphical plots were constructed to examine the linearity of the relation between explanatory and response variables. Outliers were identified graphically and investigated to determine their validity. No outliers were eliminated from the data used to develop the models contained in this report.

Prediction intervals were determined to evaluate the uncertainty of the estimates using the regression model (Helsel and Hirsch, 1992). Prediction intervals defined a range of values for the dependent variable for a given level of uncertainty. For this report, both 50- and 90-percent prediction intervals were determined for each model. For a given independent variable(s), the 90-percent prediction interval represented the range of values expected for the dependent variable 90 percent of the time. The larger the range of values, the more uncertainty there was associated with the regression model. The prediction interval for a single response, $\hat{y}$, is:

$$10^{\left(E(y_i) - t \times s\sqrt{1 + \frac{1}{n} + \frac{(x_i - x_a)^2}{SS_x}}\right)} ,$$

$$10^{\left(E(y_i) + t \times s\sqrt{1 + \frac{1}{n} + \frac{(x_i - x_a)^2}{SS_x}}\right)} , \quad (11)$$

where

$E(y_i)$ is the regression-estimated value, in log units, at x_i;

t is the value of the student's t distribution having *n*-2 degrees of freedom with the exceedance probability of $\alpha/2$ (value obtained from *t* tables in the appendix of most statistics textbooks);

s is the standard error of regression calculated using equation 12;

n is the number of samples;

x_i is a specified value of *x*, in log units;

x_a is the mean (average) of *x*, in log units;

SS_x is the sum of squares *x*, in log units; and

$$s = \sqrt{(SS_y - b_1 S_{xy})/(n-2)} , \quad (12)$$

where

SS_y is the sum of squares *y*, in log units;

b_1 is the estimate of β_1 ;

SS_{xy} is the sums of *xy* cross products, in log units, using equation 13; and

n is the number of samples.

$$S_{xy} = \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) , \quad (13)$$

where

x_i represents the value of *x* at the *i*th data point, in log units;

$\bar{x}$ is the mean of *x*, in log units;

y_i represents the value of *y* at the *i*th data point, in log units; and

$\bar{y}$ is the mean of *y*, in log units.

SS_x is calculated using equation 14:

$$SS_x = \sum_{i=1}^{n} (x_i - x_a)^2 \quad (14)$$

A regression-estimated 30-day geometric mean was calculated every hour for comparison to geometric-mean criteria. The following equation was used:

$$GM = 720\sqrt{y_1 \times y_2 \times y_3 \times \ldots y_{720}}\ , \quad (15)$$

where

GM is the 30-day geometric mean for 720 regression-estimated hourly values of y, in colonies per 100 milliliters of water; and

y_i is the regression-estimated value, in colonies per 100 milliliters of water, for the ith hour.

Although prediction intervals are good indicators of uncertainty, a range of values is not very useful for determining recreational quality of a stream. Probability of exceedance provides water managers with a single value for decisionmaking. For this study, probabilities of exceeding primary and secondary contact recreational use criteria were determined for each regression model as follows:

Prob ($E(y_i)$ > Std) = 1 – the area below the standard normal curve for a value greater than Z, (16)

where

Z is $(E(y_i) - Log_{10}(Std)) / \sqrt{MSE}$;

$E(y_i)$/ is either the regression-estimated value at x_i when comparing hourly estimates to the single-sample criteria or the 30-day geometric mean of hourly measurements when comparing to the geometric-mean criteria;

Std is 200 col/100 mL for fecal coliform bacteria, geometric mean of five samples collected over a 30-day period for primary contact recreational use at an illness rate of 8 per 1,000 swimmers; 2,000 col/100 mL for fecal coliform, single sample for primary and secondary recreational use at an illness rate of 8 illnesses per 1,000 swimmers; 126 col/100 mL for *E. coli* bacteria, geometric mean of five samples collected over a 30-day period for primary contact recreational use at an illness rate of 8 per 1,000 swimmers; 235 col/100 mL for *E. coli* bacteria, USEPA recommended single-sample criterion for designated beach areas at 8 illnesses per 1,000 swimmers; and 2,507 col/100 mL for *E. coli* bacteria, USEPA recommended single-sample criterion for infrequently used full-body contact at 14 illnesses per 1,000 swimmers.

The area under the standard normal curve can be obtained from any statistics textbook that has a table for upper-tailed areas for the standard normal curve.

To assess the utility of the regression models, the percentage of samples that were in agreement with measured samples as to whether the criterion was exceeded or not exceeded was calculated. Comparisons were made between the turbidity-estimated and measured values that were used to develop the regression model. The estimate was in agreement if it and the measured value both exceeded the criterion or if both values were less than the criterion. A false negative occurred if the estimated value was less than the criterion and the measured value exceeded the criterion. A false positive occurred when the estimated value exceeded the criterion and the measured value was less than the criterion.

Because all of the response and explanatory variables were log transformed, retransformation of regression-estimated concentrations was necessary. However, retransformation can cause an underestimation of chemical loads when adding individual load estimates over a long period of time. Applying Duan's bias correction factor (Duan, 1983) to the annual load calculation allows correction for this underestimation. Cohn and others (1989), Gilroy and others (1990), and Hirsch and others (1993) provide additional information on interpreting the results of regression-based load estimates:

$$L_D = 10^{[b + m\log(NTU)]} \times \frac{\sum_{i=1}^{n} 10^{e_i}}{n} \times Q\ , \quad (17)$$

where

L_D is the load of bacteria, in colonies;

b is y-intercept from the regression model;

m is the slope from the regression model;

NTU is the measured turbidity, in nephelometric turbidity units;

e_i is the residual or the difference between each measured and estimated bacteria density, in log units;

n is the number of samples; and

Q is the streamflow, in cubic feet per second.

MEASURED BACTERIA DENSITIES

Three hundred and eighteen samples were collected from the 28 surface-water sites and analyzed for fecal coliform and *E. coli* from May 1999 through April 2002 (table 3). Measured densities of fecal coliform and *E. coli* bacteria ranged from 1 to 71,000 and 1 to 75,000 col/100 mL of water, respectively. Eighteen percent of all 318 samples collected exceeded the current (2003) KDHE secondary contact recreational criterion for fecal coliform bacteria (2,000 col/100 mL of water). Samples collected in the summer and fall (July 1–October 31) when higher than normal flow (runoff from rainfall) and large turbidity values occur (data on file with U.S. Geological Survey, Lawrence, Kansas, http://water.usgs.gov/ks/nwis/qw/) had the largest densities of bacteria. During the recreational period (April 1 through October 31), 219 samples were collected. Of these samples, fecal coliform densities in 47 exceeded 2,000 col/100 mL (21 percent), and *E. coli* densities in 78 samples exceeded 576 col/100 mL (36 percent).

The smallest bacteria densities occurred primarily during low flow and small turbidity values. In this report, low flow is defined as streamflow that was unaffected by storm runoff. Of the 99 samples collected during the winter months (November 1 through March 31), fecal coliform densities in 10 (10 percent) exceeded the 2,000-col/100 mL criterion for secondary contact recreation.

COMPARISON OF FECAL COLIFORM AND *ESCHERICHIA COLI* DENSITIES

Escherichia coli (*E. coli*) is the dominant bacteria of the fecal coliform group and the relation between the two bacteria in water is apparent in figure 5. Site-by-site, basin- or subbasin-wide, and statewide comparisons were made using *E. coli*/fecal coliform (EC/FC) ratios and regression models. Data sets with 15 or more samples were used for comparison. Both EC/FC ratios and regression models were developed so that *E. coli* densities could be estimated on the basis of historical fecal coliform data at these sites and a statewide comparison between the two indicator bacteria could be made.

Ratios of EC/FC were calculated using geometric means for samples (table 4). The EC/FC ratios ranged from 0.48 for Rattlesnake Creek near Zenith (site 21) to 0.96 for Kansas River at Wamego (site 1). The geometric mean of the EC/FC ratio for all 318 samples was 0.77. The variation between sites probably is due to site-specific sources of bacteria and water-quality conditions. The EC/FC ratios were smallest in streams with elevated salinity (or specific conductance greater than 1,000 μS/cm). For example, the mean specific conductance for Rattlesnake Creek near Zenith (site 21) was 3,790 μS/cm compared to 855 μS/cm for Kansas River at Topeka (site 2, fig. 6). Elevated salinity decreases the survivability of *E. coli* bacteria (U.S. Environmental Protection Agency, 1986) and, therefore, decreases the EC/FC ratio. However, the survivability of *enterococci* is not affected by saline water, and therefore, it may be a more reliable indicator of swimming-related illnesses in these streams (U.S. Environmental Protection Agency, 1986).

Simple linear regression was used to further define the relation between fecal coliform and *E. coli* bacteria at six individual surface-water sites and six groups of surface-water sites (table 4). The R^2 for the *E. coli*/fecal coliform regression models for individual sites ranged from 0.32 for Rattlesnake Creek near Zenith (site 21) to 0.98 for Little Arkansas River at Highway 50 near Halstead (site 22). In models for individual sites on the Kansas (sites 1, 2, and 20) and Little Arkansas Rivers (sites 22 and 23), the slopes (m) ranged from 0.901 to 1.00, and the R^2s were 0.89 or greater. The high R^2s for the models indicate a strong correlation between fecal coliform and *E. coli*. At these sites, fecal coliform is a reliable indicator, explaining at least 89 percent of the variability of *E. coli*. For these sites, *E. coli* could be estimated from historical fecal coliform data with a good degree of reliability. The low R^2 for the Rattlesnake Creek near Zenith (site 21) regression model is a further indication that water-quality conditions at this site are decreasing the survivability of the *E. coli* and, therefore, decreasing the correlation between *E. coli* and fecal coliform. For this site, *E. coli* cannot be reliably estimated with this model.

The two models for 17 sites in and around the Soldier Creek Basin (sites 3–19) and 5 sites in the North Fork Ninnescah River Basin (sites 24–28) have R^2s of 0.88 and 0.70, respectively. The slope (0.936) and the R^2 for the Soldier Creek sites are comparable to the slope and R^2 for the Kansas River sites. The lower R^2 for the North Fork Ninnescah River Basin model compared to the Kansas River and Soldier Creek sites probably is an indication of water-quality conditions unfavorable for the survivability of *E. coli* (specific

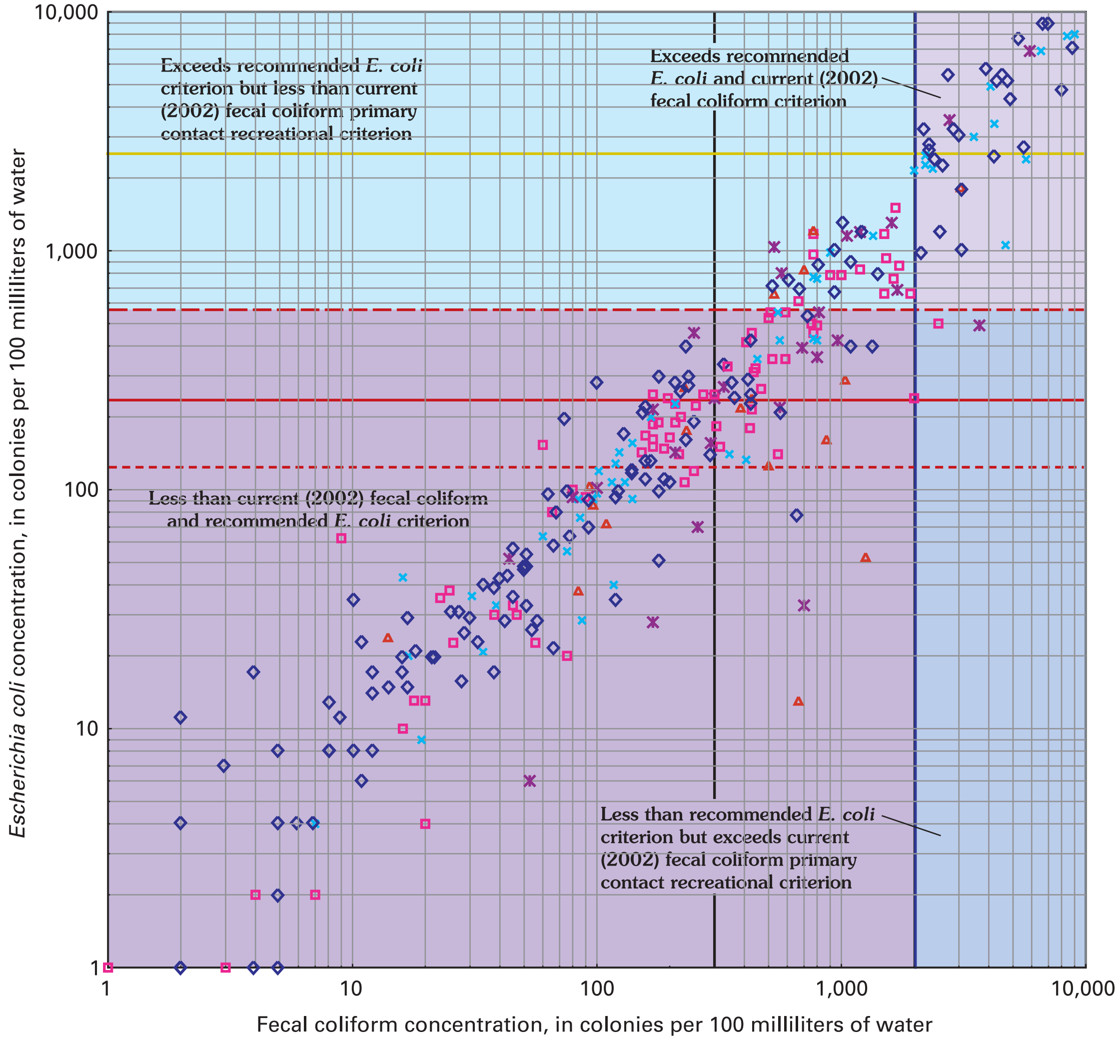
Table 3. Statistical summary for fecal coliform and *Escherichia coli* (*E. coli*) bacteria densities measured in samples collected from and turbidity measurements made at surface-water sites on selected Kansas streams, May 1999 through April 2002

[KLR, Kansas-lower Republican River Basin; RSC, Rattlesnake Creek Basin; LARK, Little Arkansas River Basin; NFNR, North Fork Ninnescah River Basin; --, not determined]

			Fecal coliform bacteria					*E. coli* bacteria					Turbidity		
			Densities (colonies per 100 milliliters)		Percentage of samples exceeding indicated water-quality criteria (colonies per 100 milliliters) [1]			Densities (colonies per 100 milliliters)		Percentage of samples exceeding indicated recommended water-quality criteria (colonies per 100 milliliters) [2]				Measurements (nephelometric turbidity units)	
Site number (fig. 1)	Basin name	Number of samples	Minimum	Maximum	April 1–June 30 (2,000)	July 1–October 31 (2,000)	November 1–March 31 (2,000)	Minimum	Maximum	April 1–June 30 (576)	July 1–October 31 (576)	November 1–March 31 (576)	Number of samples	Minimum	Maximum
1	KLR	46	2	11,000	2	4	2	1	5,200	4	7	7	34	11	1,210
2	KLR	47	2	71,000	4	13	6	2	75,000	6	15	9	36	12	6,240
3–19	KLR	76	1	2,500	0	1	0	1	1,500	4	14	1	0	--	--
20	KLR	52	2	32,000	8	25	8	1	23,000	10	27	10	42	9	4,210
21	RSC	18	14	3,100	6	0	0	13	1,800	11	11	0	17	5	348
22	LARK	23	17	36,000	9	17	4	20	41,000	9	22	4	17	4	863
23	LARK	28	7	25,000	7	18	4	4	23,000	14	21	7	18	5	1,300
24–28	NFNR	28	44	39,000	0	14	0	6	10,000	0	32	0	28	3	395

[1]Water-quality criteria from Kansas Department of Health and Environment (2001).

[2]Recommended water-quality criteria from U.S. Environmental Protection Agency (2002).



EXPLANATION

- ◇ Kansas-lower Republican River Basin (sites 1, 2, 20)
- ▫ Soldier Creek Basin (sites 3–19)
- △ Rattlesnake Creek Basin (site 21)
- × Little Arkansas River Basin (sites 22, 23)
- ✱ North Fork Ninnescah River Basin (sites 24-28)
- Current (2003) Kansas Department of Health and Environment fecal coliform for primary contact recreation (geometric mean of five samples collected within a 30-day period, illness rate of 8 per 1,000 swimmers)
- Current (2003) Kansas Department of Health and Environment water-quality fecal coliform criterion single-sample criterion for secondary contact recreation (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended *E. coli* criterion for primary recreation (geometric mean of five samples collected within a 30-day period, illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for a designated beach area (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 14 per 1,000 swimmers)

Figure 5. Comparison of measured fecal coliform and *Escherichia coli* (*E. coli*) bacteria densities at 28 surface-water sites, May 1999 through April 2002. Current (2003) water-quality criteria from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

Table 4. Regression and geometric-mean statistics for comparison of fecal coliform and *Escherichia coli (E. coli)* bacteria densities at selected individual surface-water sites and for selected basins in Kansas, May 1999 through April 2002

[R^2, coefficient of determination; *MSE*, mean square error; *n*, number of samples; *RMAE*, relative mean absolute error; SS_x, sum of squares *x*; *ECB*, *Escherichia coli* (*E. coli*) bacteria; *FCB*, fecal coliform bacteria]

	Regression statistics									Geometric-mean statistics	
						Range in bacteria densities (colonies per 100 milliliters of water)					
Site number (fig. 1)	Model	R^2	*MSE* (log units)	Model standard error of estimate (percent)	*n*	Fecal coliform	*E. coli*	*RMAE* (percent)	SS_x (log units)	*E. coli* and fecal coliform ratio	*RMAE* (percent)
	Individual sites										
1	$Log_{10}ECB = 0.901 log_{10}FCB + 0.173$	0.89	0.0840	75	46	2–1,000	1–5,200	62	3.70	0.96	76
2	$Log_{10}ECB = 0.977 log_{10}FCB – 0.00966$	.94	.0696	65	47	2–71,000	2–75,000	39	3.13	.86	33
20	$Log_{10}ECB = 1.00 log_{10}FCB – 0.0916$	.97	.0453	62	52	2–32,000	40–23,000	36	2.26	.81	34
21	$Log_{10}ECB = 0.595 log_{10}FCB + 0.708$	.32	.240	160	18	14–3,100	6–1,800	67	3.84	.48	62
22	$Log_{10}ECB = 0.983 log_{10}FCB + 0.00391$	.98	.0191	33	23	17–36,000	30–41,000	22	.401	.91	19
23	$Log_{10}ECB = 0.998 log_{10}FCB – 0.115$	.95	.0504	55	28	7–25,000	29–23,000	28	1.31	.76	28
	Kansas-lower Republican River Basin										
1–20	$Log_{10}ECB = 0.960 log_{10}FCB + 0.00780$	.93	.0655	64	221	1–71,000	1–75,000	42	14.3	.82	36
1, 2, 20	$Log_{10}ECB = 0.966 log_{10}FCB + 0.0209$	.94	.0657	64	145	2–71,000	1–75,000	20	9.4	.87	36
	Soldier Creek Basin										
3–19	$Log_{10}ECB = 0.936 log_{10}FCB + 0.0119$	.88	.0623	52	76	1–2,500	1–1,500	34	4.61	.73	40
	Little Arkansas River Basin										
22, 23	$Log_{10}ECB = 0.993 log_{10}FCB – 0.0645$	.96	.0366	46	51	7–36,000	4–41,000	25	1.80	.83	24
	North Fork Ninnescah River Basin										
24–28	$Log_{10}ECB = 0.932 log_{10}FCB – 0.0493$	.70	.158	114	28	44–39,000	14–10,000	62	4.11	.58	79
	Kansas-lower Republican and Little Arkansas River Basins (statewide)										
1–20, 22, 23	$Log_{10}ECB = 0.966 log_{10}FCB – 0.00428$	.94	.0599	61	272	1–71,000	1–75,000	37	16.2	.82	33

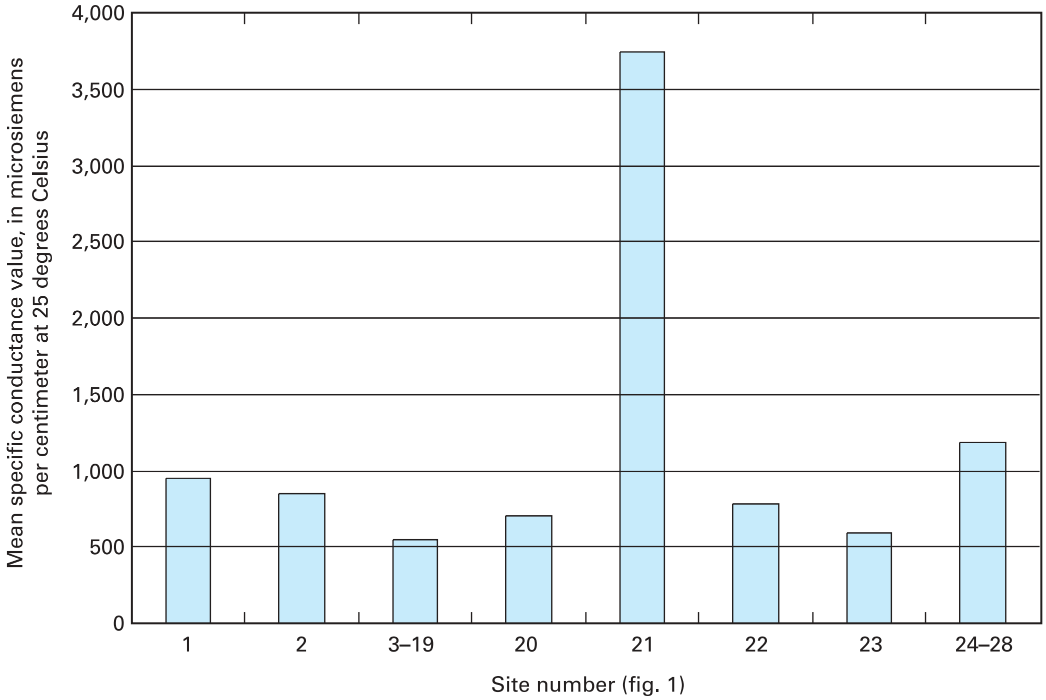


Figure 6. Mean specific conductance for bacteria samples collected at selected surface-water sites, May 1999 through April 2002.

conductance = 1,210 µS/cm, fig. 6). Even so, both models could be used to estimate *E. coli* densities with some degree of reliability. The regression models in table 4 are specific to the sites or groups of sites that they were developed for and only relevant for the density ranges listed.

Simple linear regression was used to further determine if a single model could be used to estimate *E. coli* bacteria at more than one site within a river basin. Data were combined for the three sites on the Kansas River (sites 1, 2, 20), all 20 sites in the Kansas-lower Republican River Basin (sites 1–20), and for both sites in the Little Arkansas River Basin (sites 22, 23) to develop a single model for each group to estimate *E. coli* from fecal coliform (table 4). The slopes and R^2s for the two Kansas-lower Republican River Basin models are nearly identical indicating that a single model probably is sufficient for all the sites in the basin. Although the Kansas-lower Republican River Basin model appears to be nearly as reliable as the individual site and group models, the Kansas-lower Republican River Basin model best represents the three Kansas River sites where a majority of the data were collected (145 of the 221 samples were from three Kansas River sites). The Kansas-lower Republican River Basin model reasonably represents the Soldier Creek sites (sites 3–19, fig. 1) for the limited amount of data collected in that basin (76 samples representing 17 sites). To determine if the model represents all the Soldier Creek sites, more samples would need to be collected at each site for a variety of hydrologic conditions. The Little Arkansas River Basin model indicates that 96 percent of the variability is explained. The data for the Little Arkansas River Basin model are more evenly distributed between sites 22 and 23 and, therefore, reliably estimate *E. coli* concentrations at each site.

The statewide model only included sites with mean specific conductance less than 1,000 µS/cm (sites 1–20, 22, 23). The model describes 94 percent of the variability and appears to sufficiently explain the EC/FC relation at the 22 sites. For the reasons previously discussed, sites that have fewer samples are underrepresented by the statewide model and, therefore, it is not appropriate for use at these sites.

Comparisons of fecal coliform and regression-estimated *E. coli* bacteria densities for all 12 models are shown in figure 7. The uncertainty for each of the models is graphically displayed by the prediction intervals. The closer the intervals are to one another, the less uncertainty for that particular regression model at a specified probability. The 50- and 90-percent prediction intervals were plotted to show the difference in ranges. Given any measured fecal

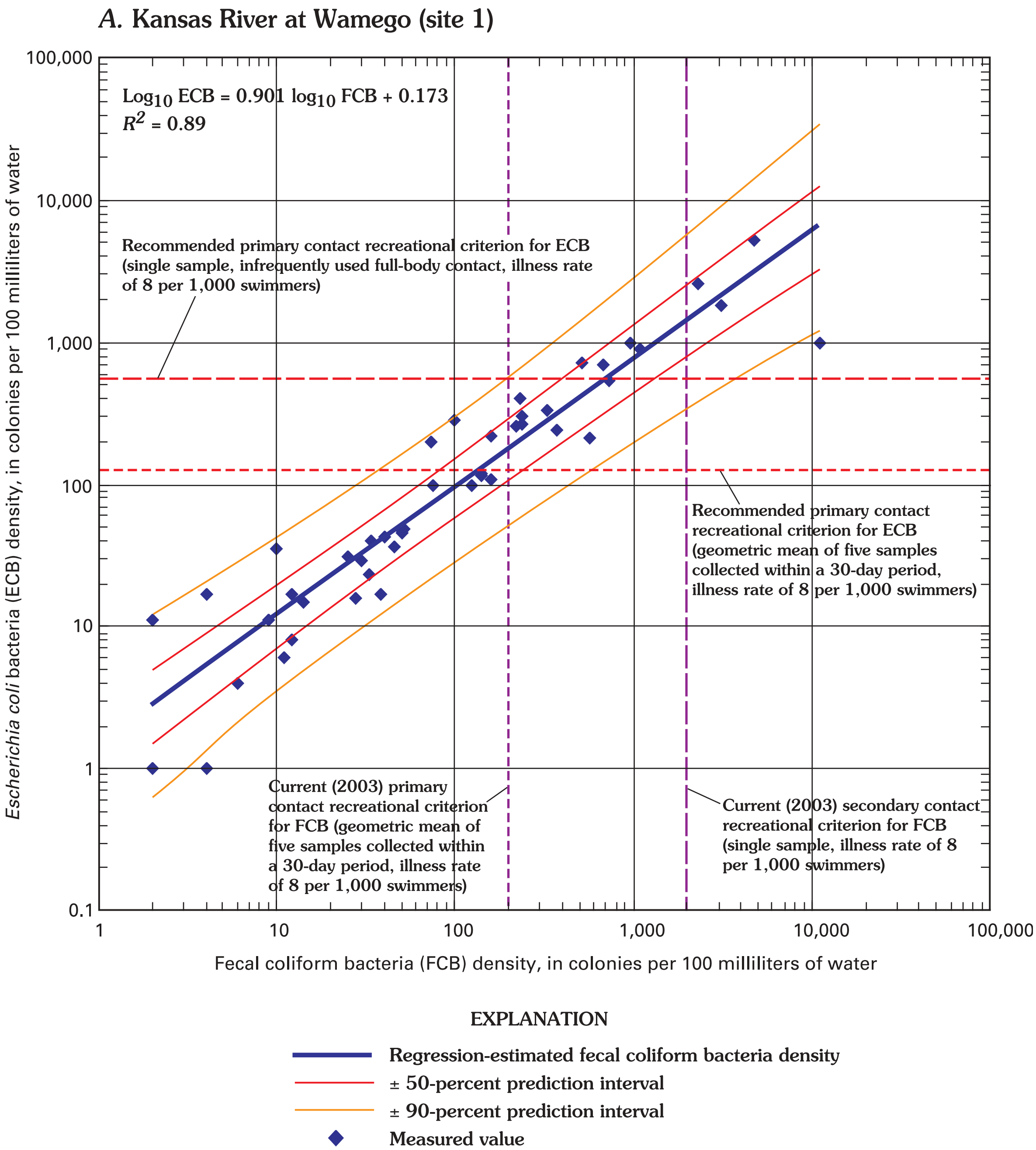


Figure 7*A*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for Kansas River at Wamego (site 1, fig. 1), July 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

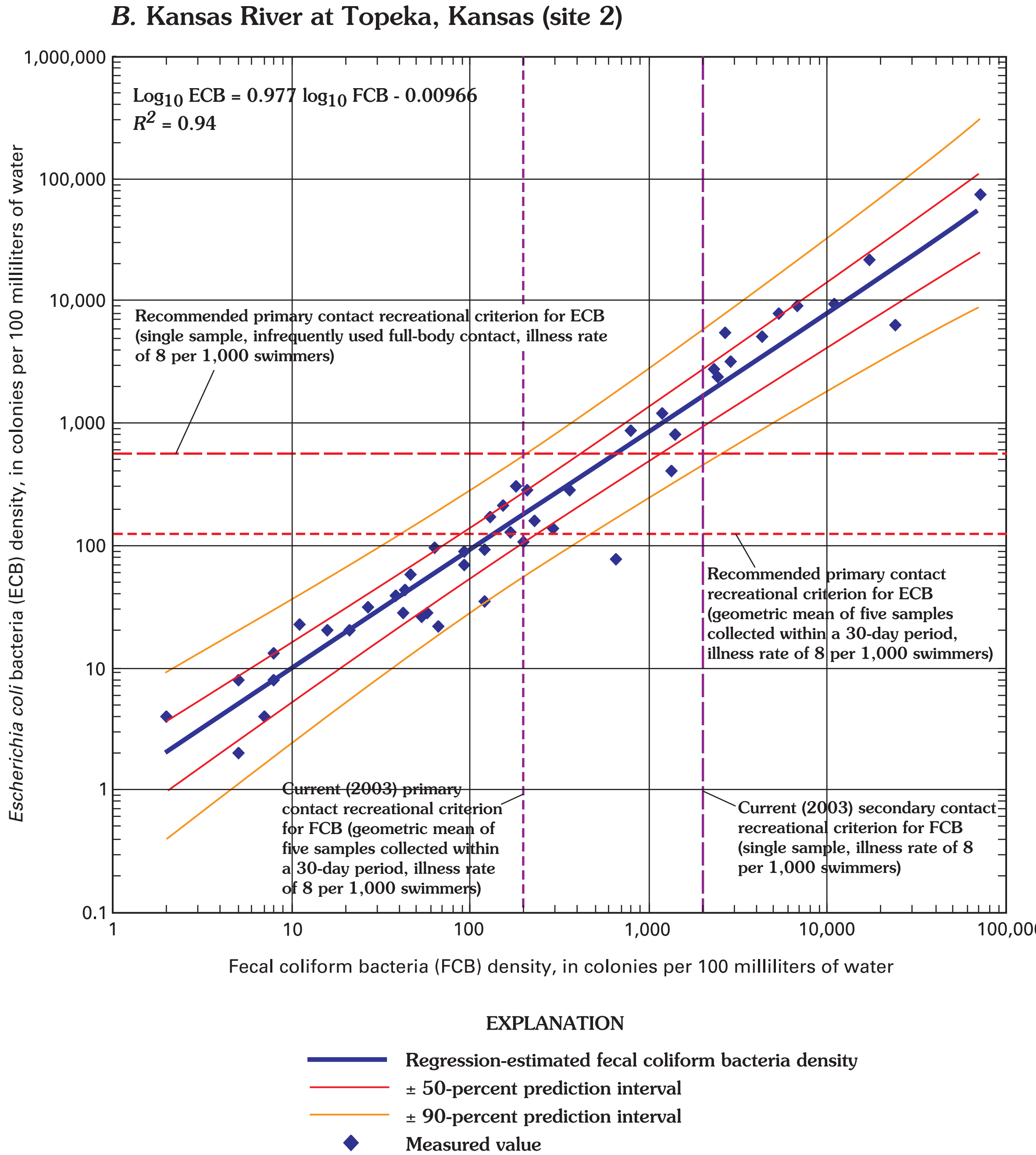


Figure 7*B*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for Kansas River at Topeka (site 2, fig. 1), July 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

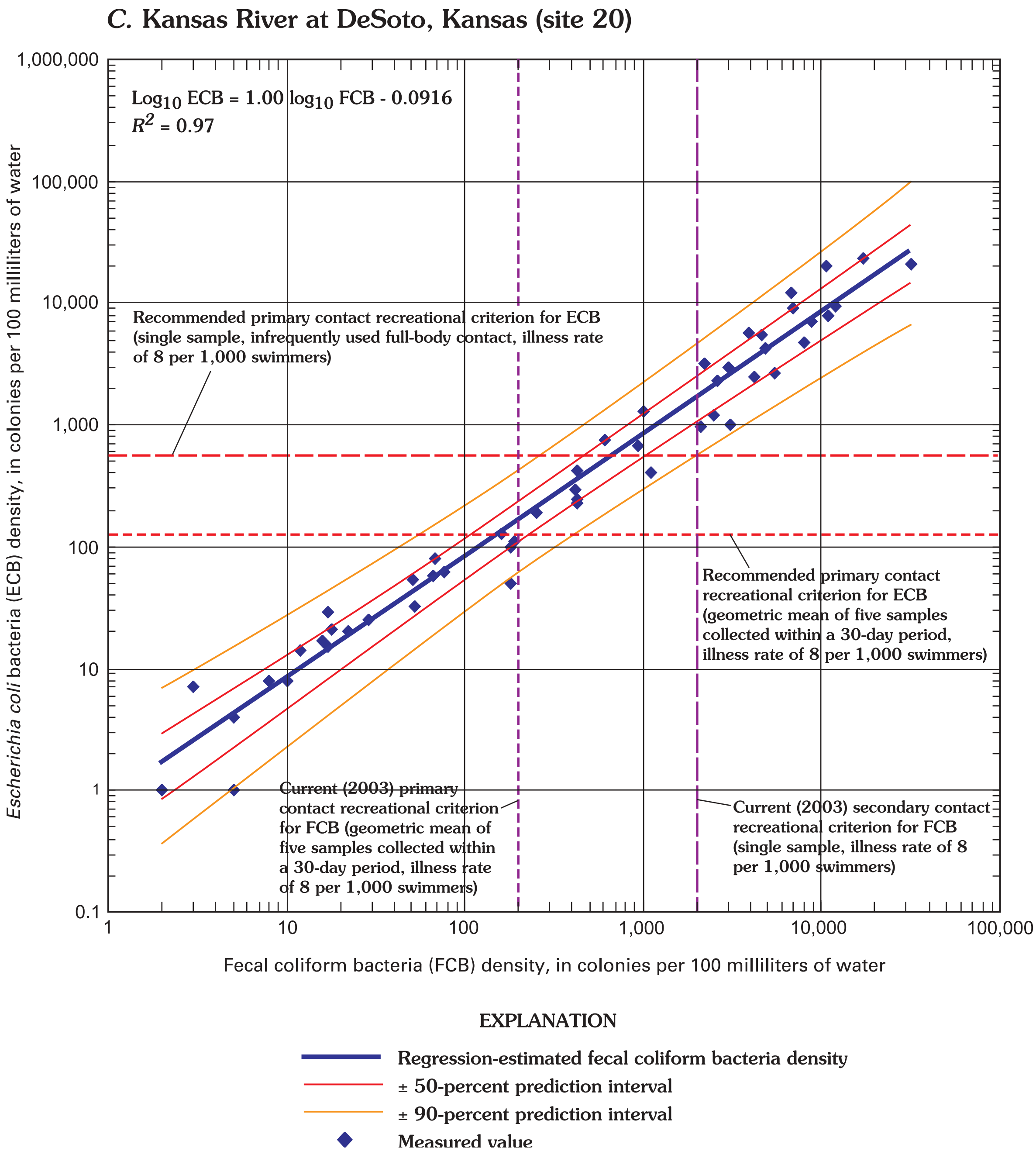


Figure 7*C*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for Kansas River at DeSoto (site 20, fig. 1), July 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

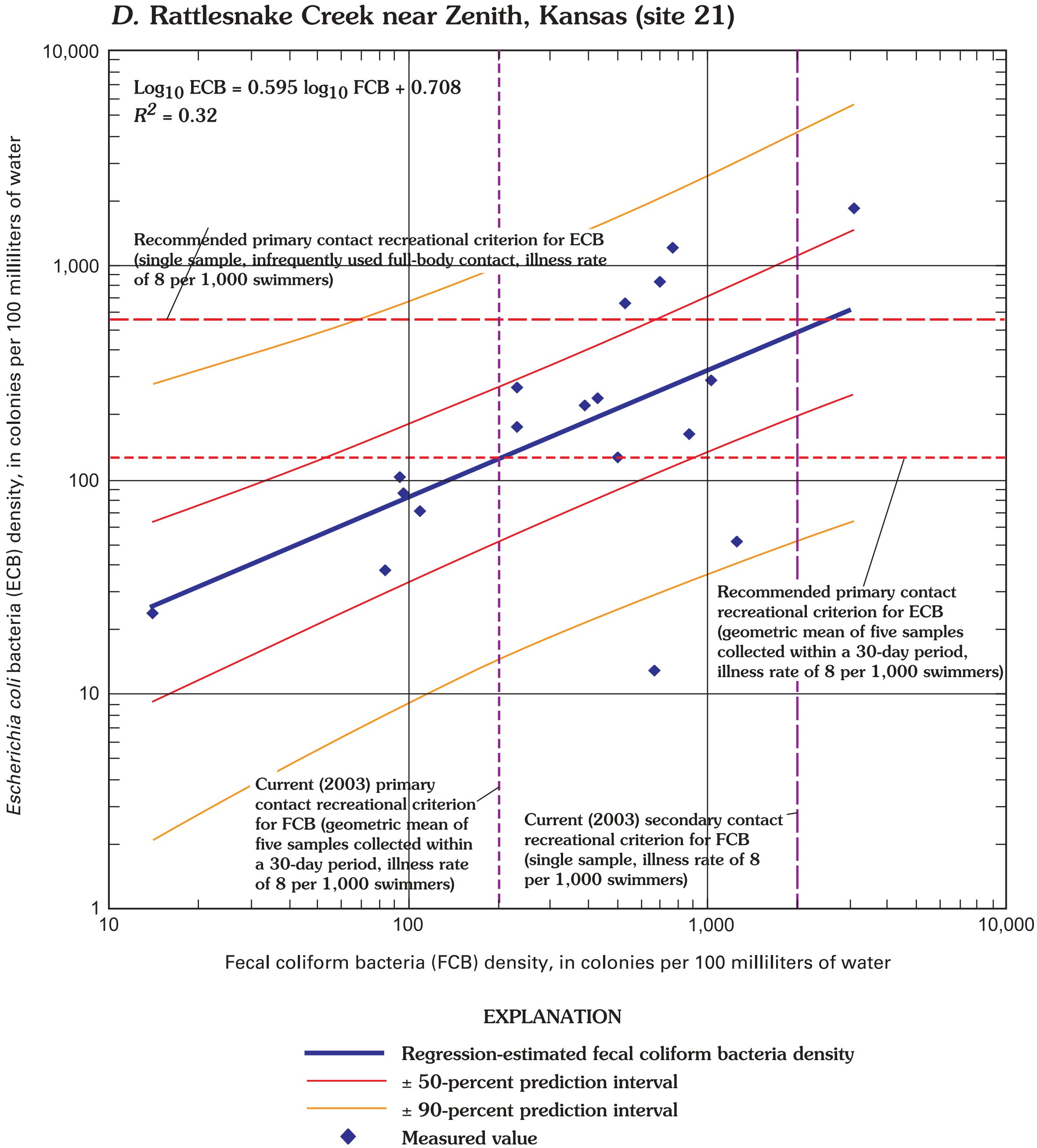


Figure 7*D*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for Rattlesnake Creek near Zenith (site 21, fig. 1), May 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

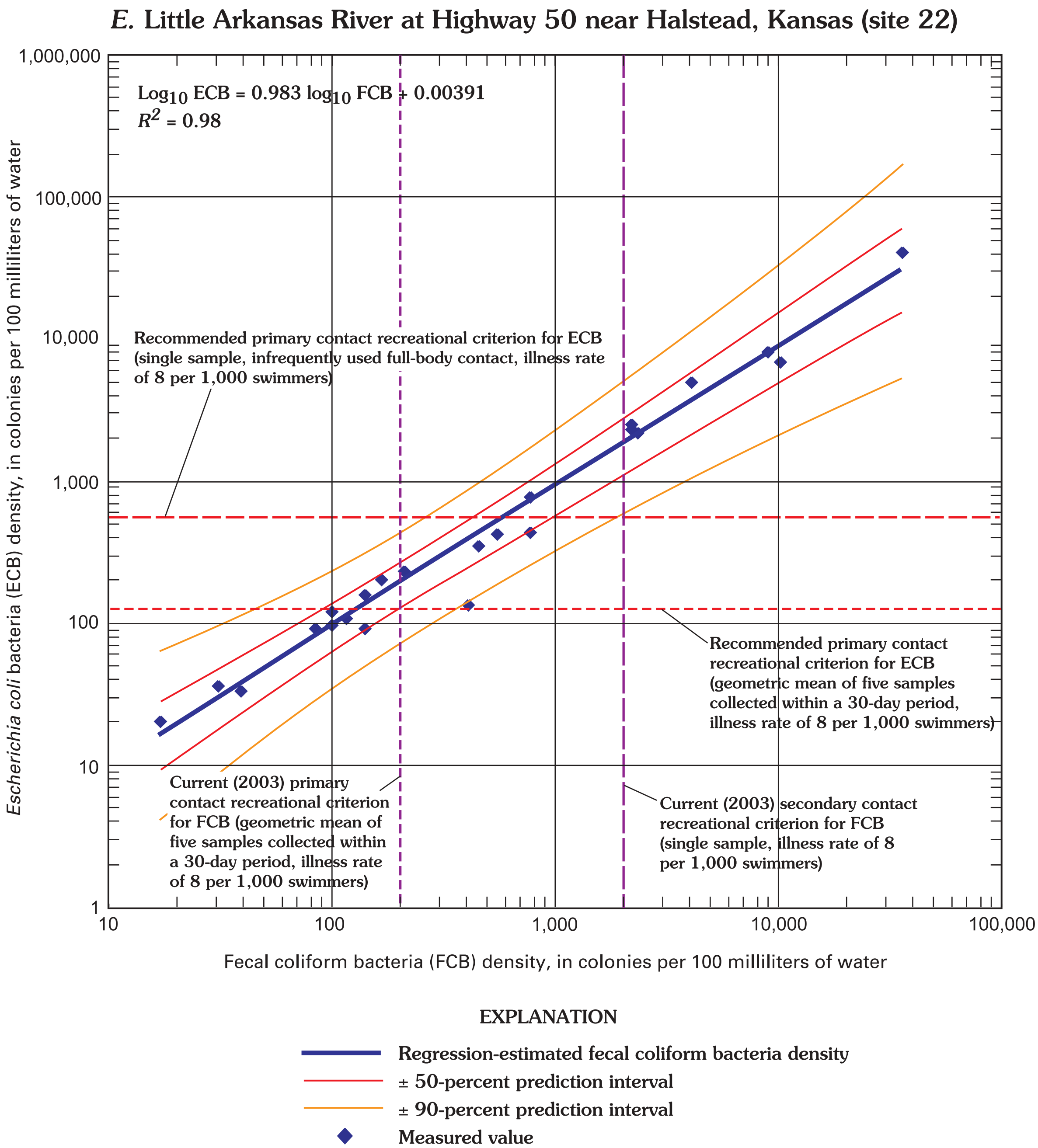


Figure 7*E*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for Little Arkansas River at Highway 50 near Halstead (site 22, fig. 1), May 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

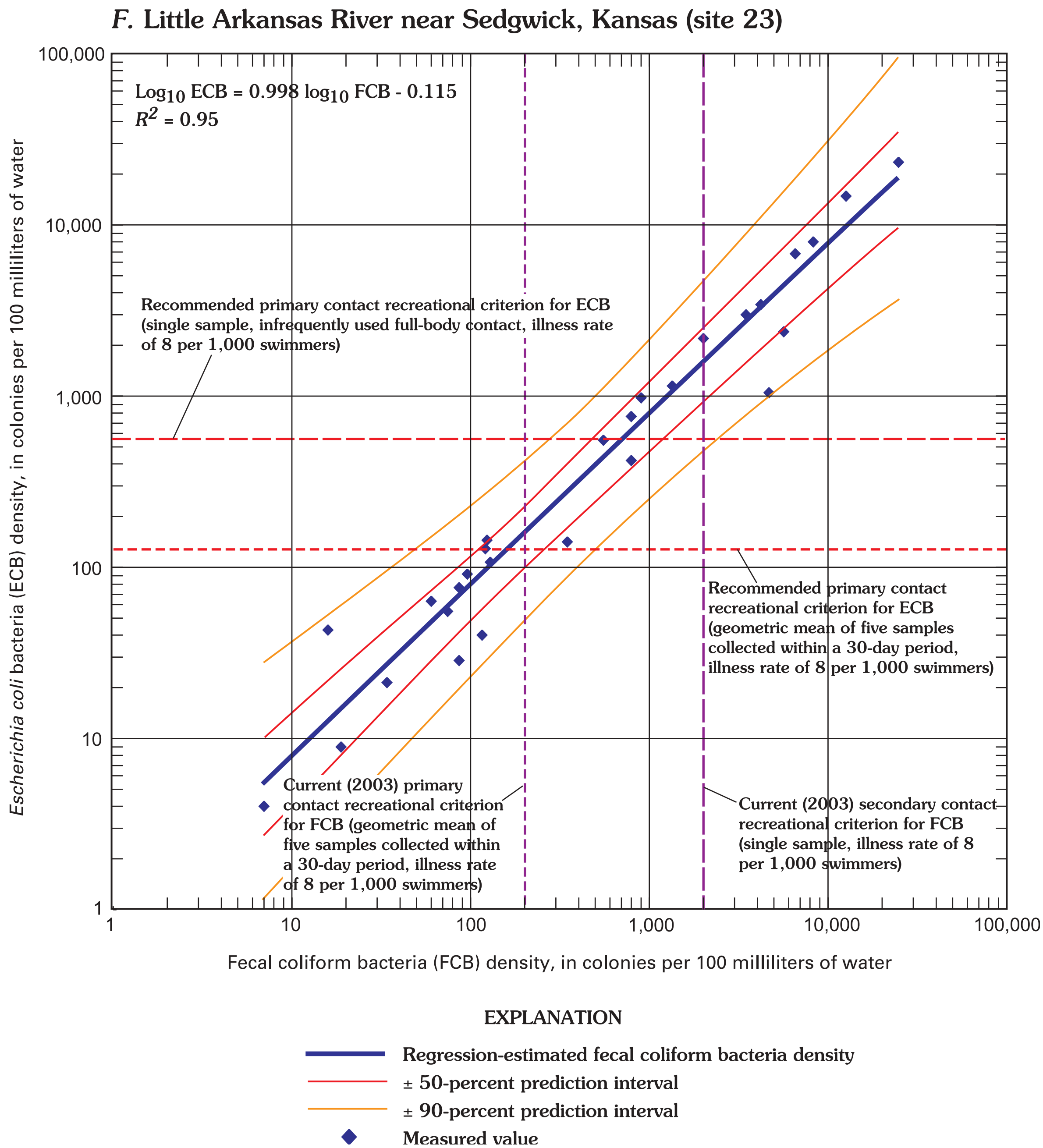


Figure 7*F*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for Little Arkansas River near Sedgwick (site 23, fig. 1), May 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

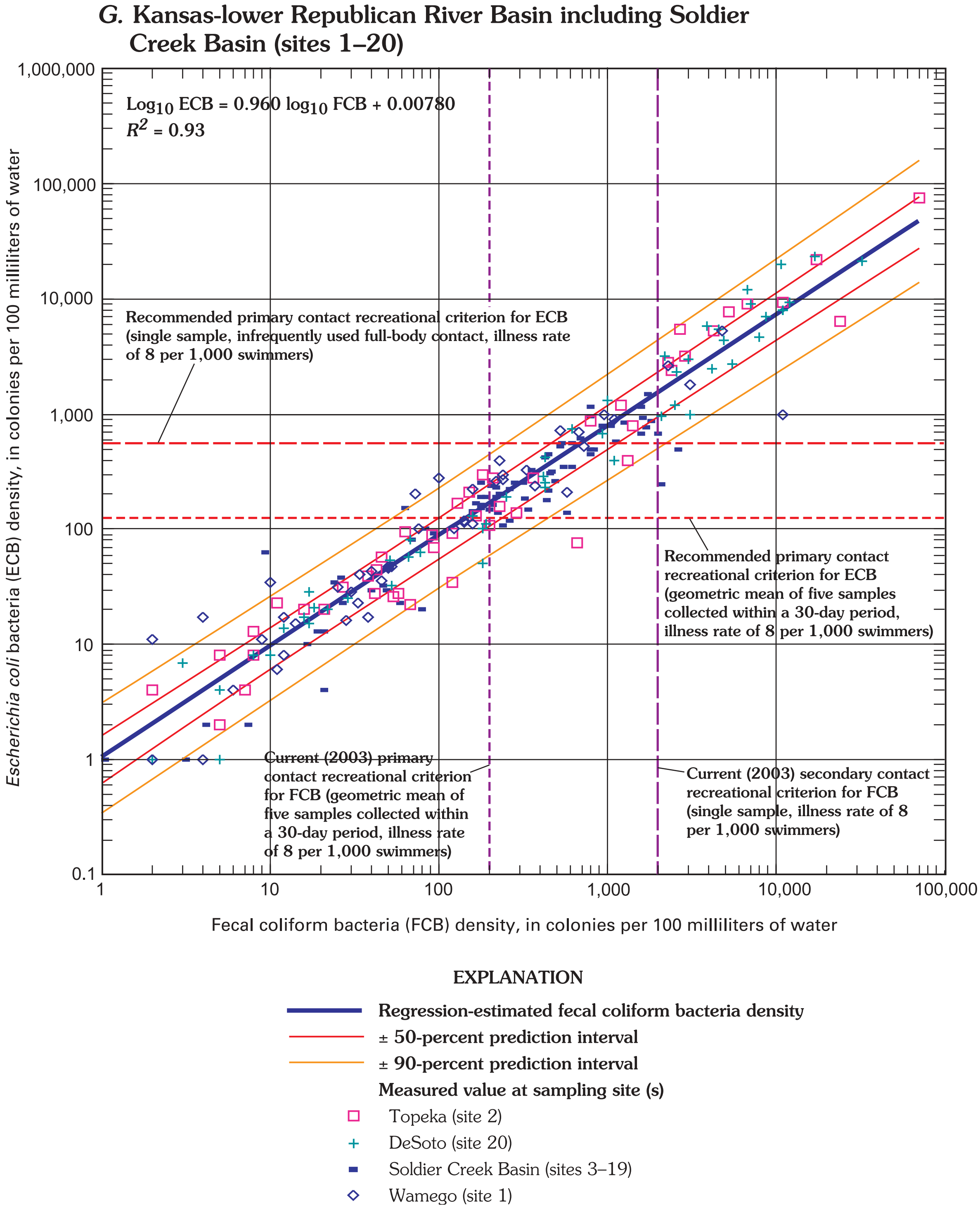


Figure 7*G*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for sites in the Kansas-lower Republican River Basin (sites 1–20; fig. 1), May 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

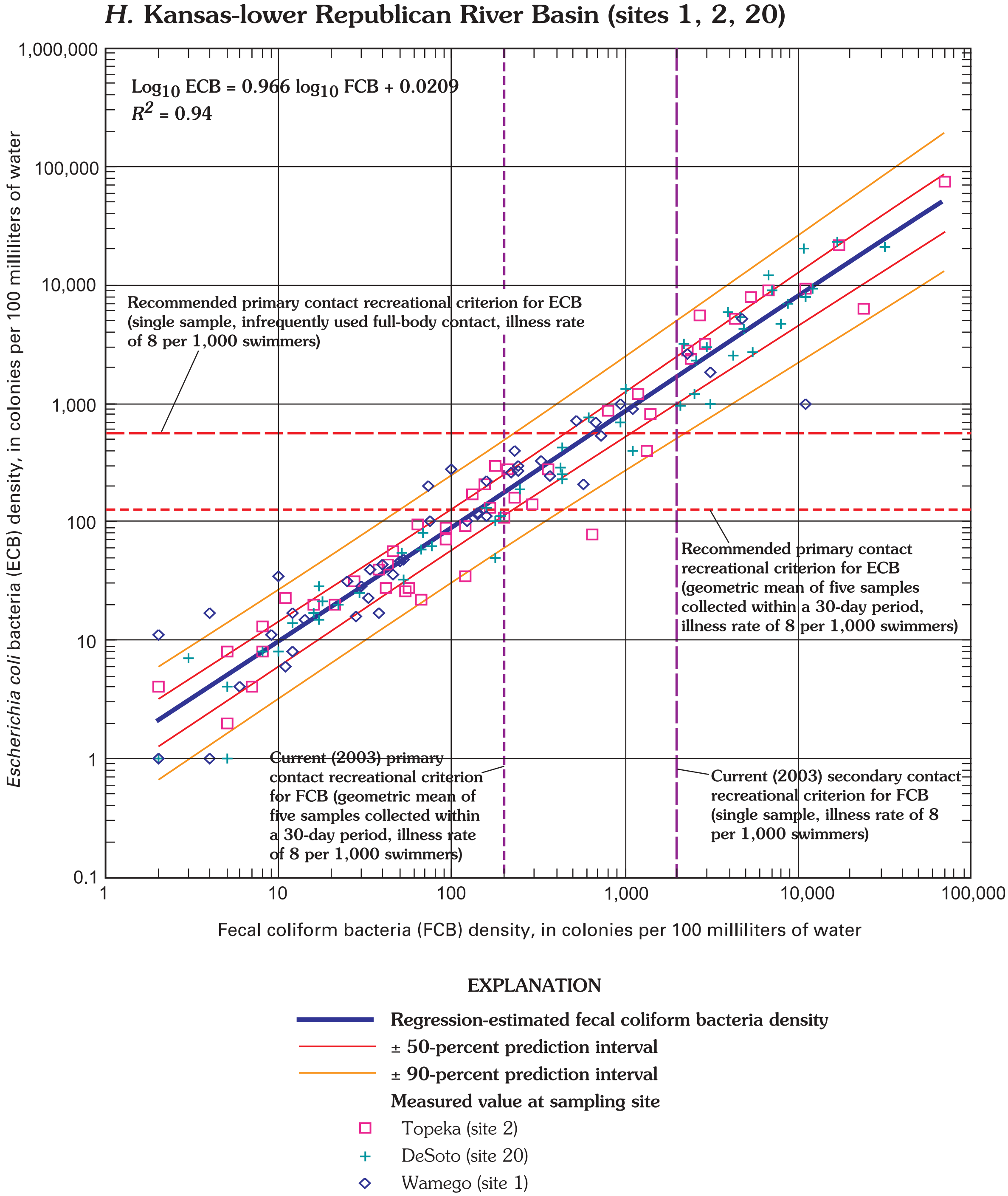


Figure 7*H*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for sites in Kansas-lower Republican River (sites 1, 2, 20; fig. 1), May 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

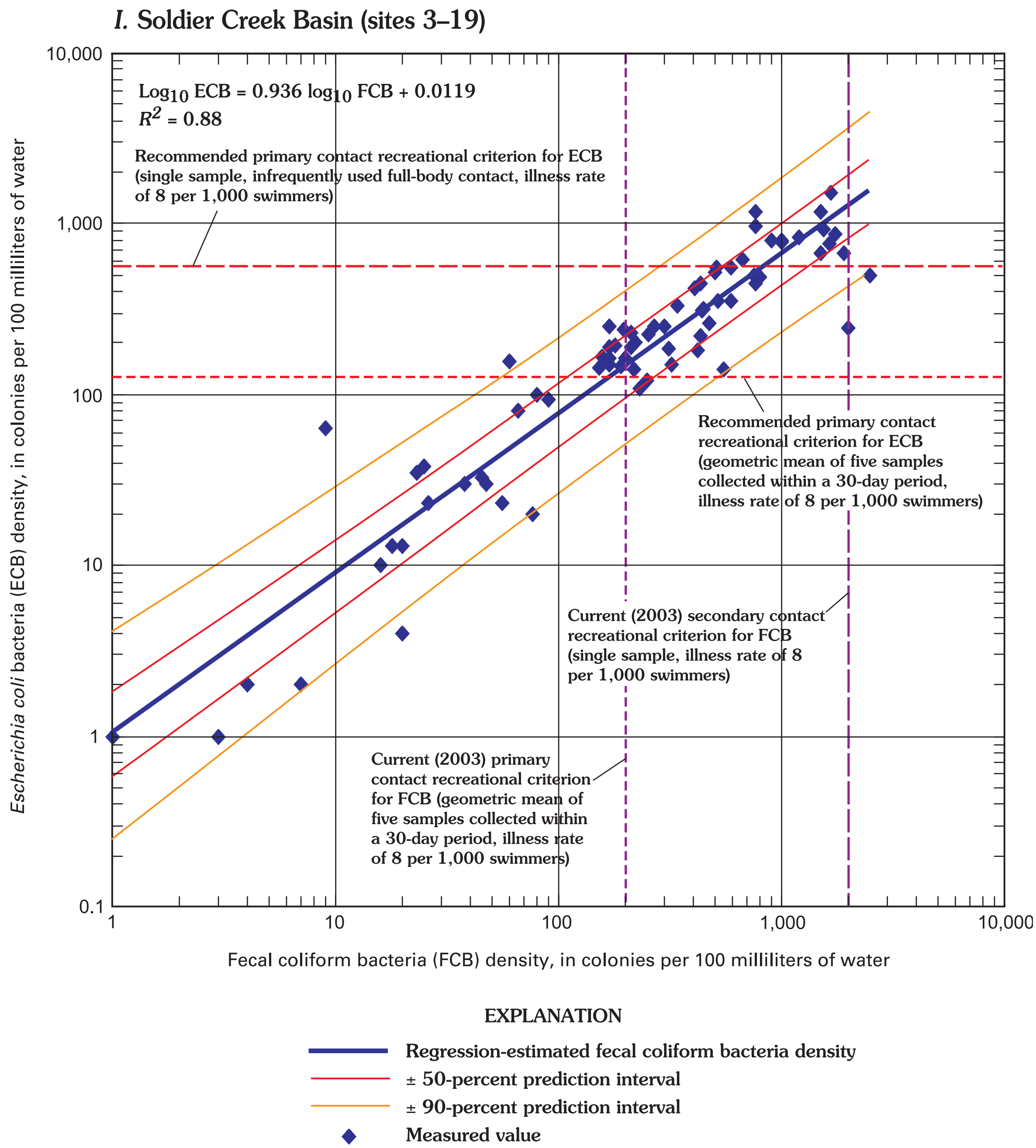


Figure 7*I*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for sites in Soldier Creek Basin (sites 3–19, fig. 1), May 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

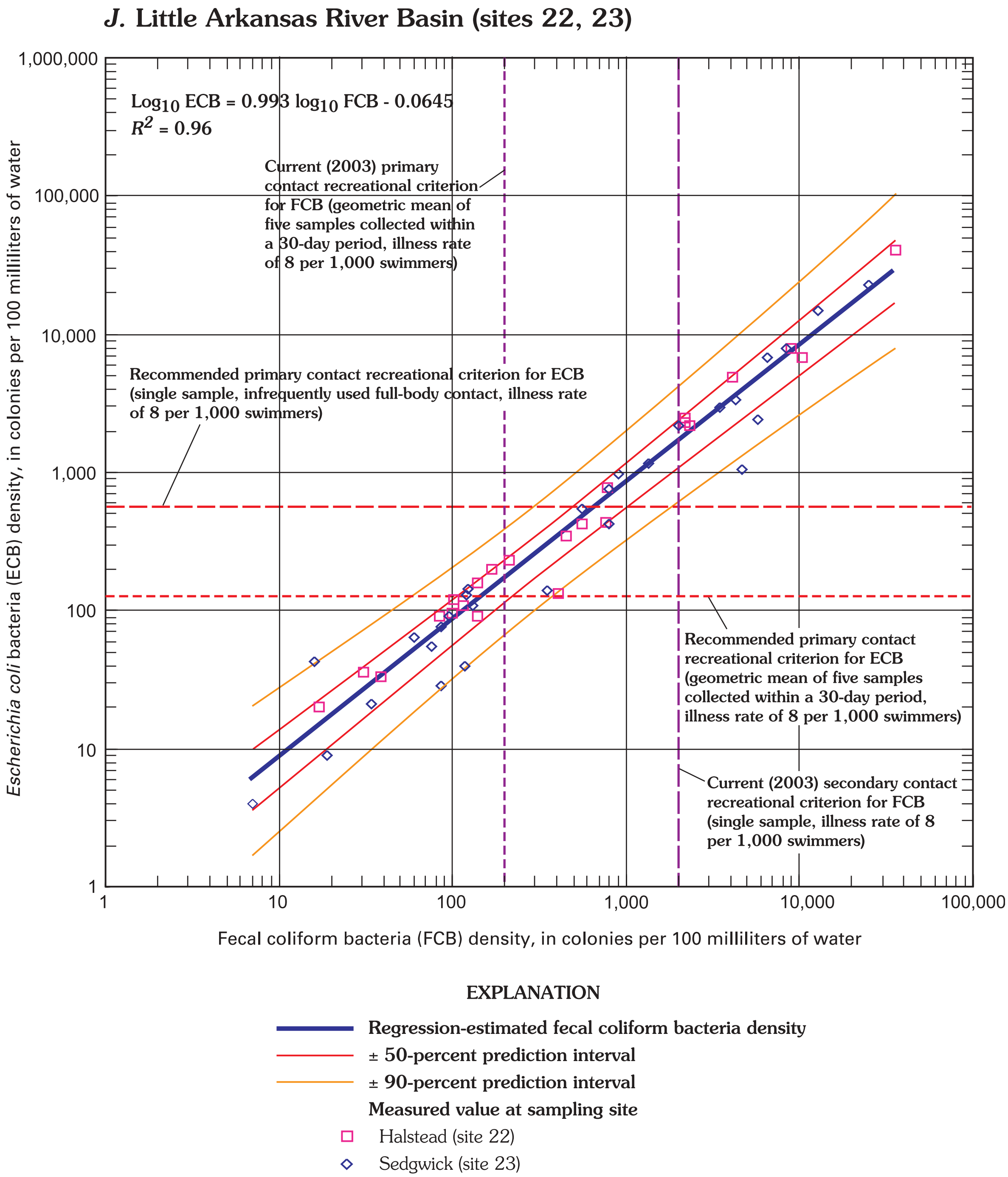


Figure 7*J*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for sites in the Little Arkansas River Basin (sites 22, 23; fig. 1), May 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

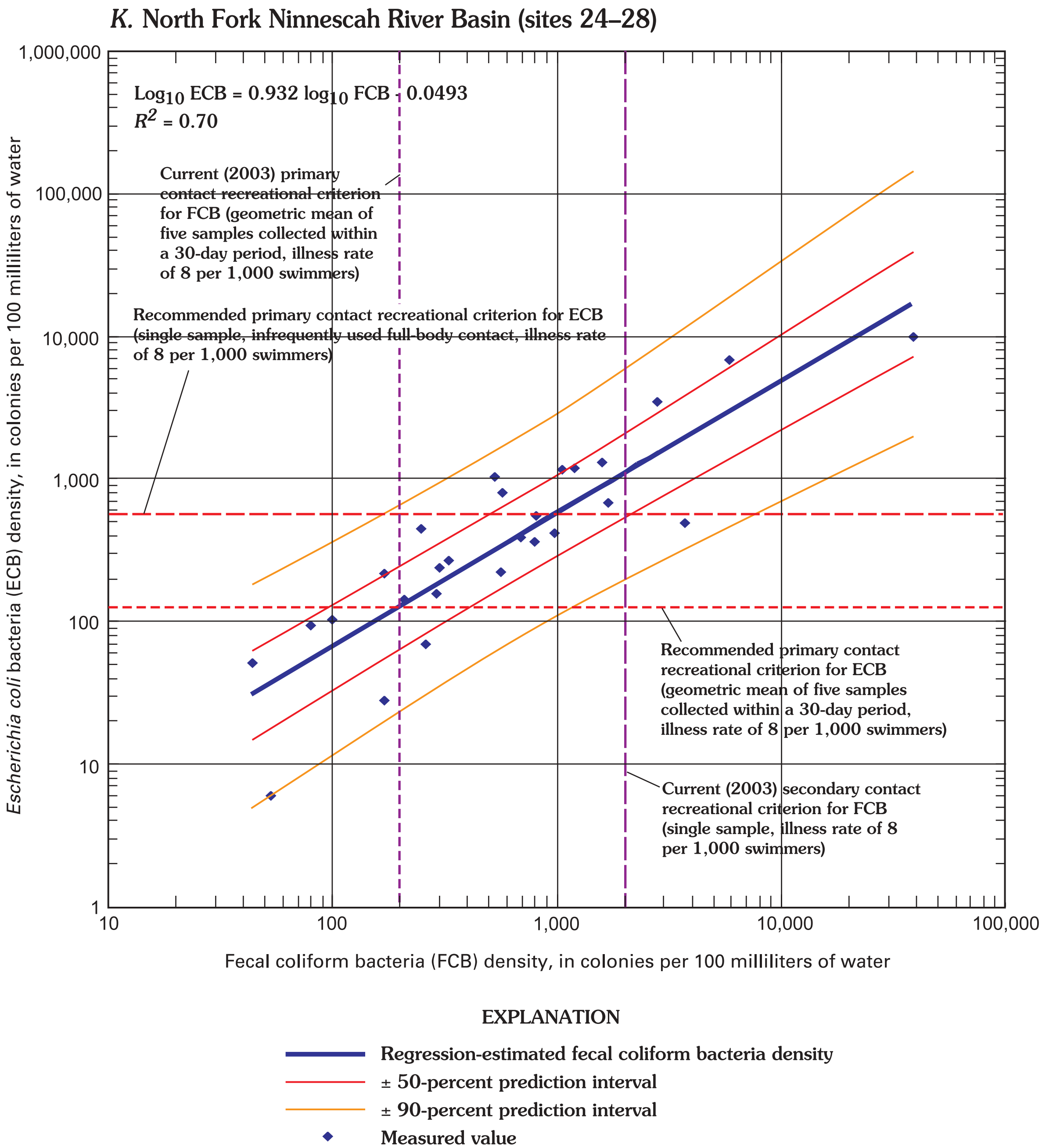


Figure 7*K*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for sites in the North Fork Ninnescah Basin (site 24–28; fig. 1), May 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

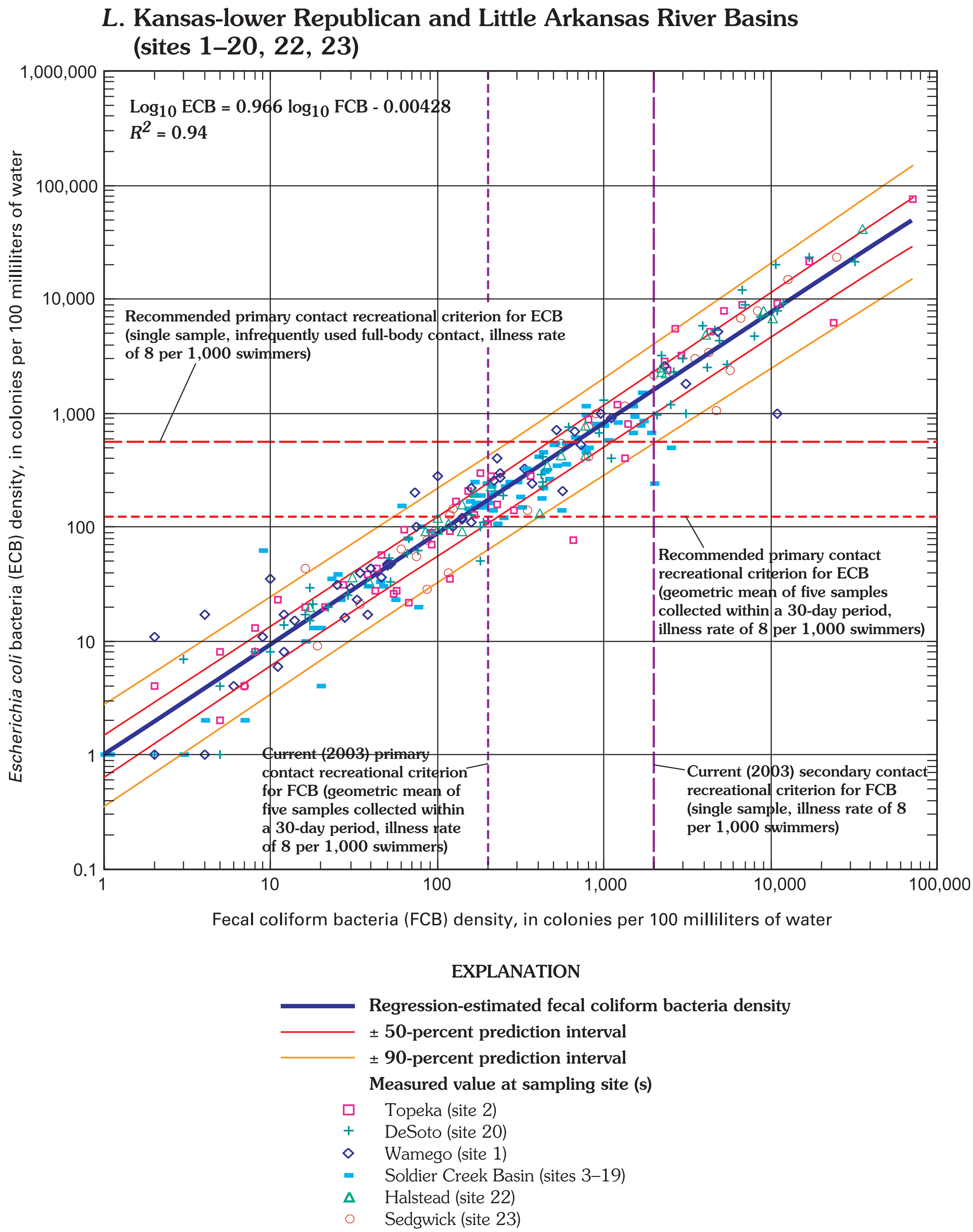


Figure 7*L*. Comparison of measured fecal coliform and *Escherichia coli* bacteria densities, regression-estimated fecal coliform bacteria density, and prediction intervals for sites in the Kansas-lower Republican River and Little Arkansas River Basins (sites 1–20, 22, 23; fig. 1), May 1999 through April 2002. Current (2003) water-quality criterion from Kansas Department of Health and Environment (2001), and recommended criteria from U.S. Environmental Protection Agency (2002).

coliform within the range of values plotted, there is a 90-percent chance that the resulting estimated *E. coli* density will be within the 90-percent prediction interval.

The geometric-mean EC/FC ratio for each site or group of sites is the preferred method for estimating *E. coli* from fecal coliform densities. Fecal coliform density was multiplied by the appropriate ratio to obtain an estimate of the *E. coli* density in the sample. Unlike regression models that are to be used only for the range of fecal coliform densities that were used to develop the model, the EC/FC ratios can be used for any fecal coliform density. A comparison of the *RMAE* for the two methods indicated that there was some site-to-site variation, and the EC/FC ratio was the better or equally good estimator for 8 of the 12 sites.

Comparison of the current (2003) geometric-mean criterion for fecal coliform bacteria of 200 col/100 mL to the 2002 USEPA recommended geometric-mean criterion of 126 col/100 mL for *E. coli* results in an EC/FC ratio of 0.63. The geometric-mean EC/FC ratio for all sites except Rattlesnake Creek (site 21) is 0.77, indicating that considerably more than 63 percent of the fecal coliform is *E. coli*. This potentially could lead to more exceedances of the recommended *E. coli* criterion, where the water now meets the current KDHE (2003) 200-col/100 mL fecal coliform criterion.

CONTINUOUSLY ESTIMATED BACTERIA DENSITIES

Statistical relations between in-stream turbidity measurements and bacteria densities were developed for 6 of the 28 surface-water sites. These relations allow for continuous estimates of both fecal coliform and *E. coli* bacteria. Continuous estimates of indicator bacteria densities can be used to define duration curves to examine seasonal variability and the frequency at which densities potentially exceed water-quality criteria. Continuous estimates of loads and yields of indicator bacteria can be used to examine annual and seasonal variation in loads. Additionally, real-time estimates of bacteria densities and the probability that current (2003) water-quality criteria at surface-water sites may be exceeded can be made available through the World Wide Web.

Relation Between Turbidity and Fecal Coliform Density

A defined statistical relation between turbidity and fecal coliform bacteria densities was developed for six of the seven surface-water sites where real-time, continuous multiparameter monitors with turbidity sensors were deployed (table 2). A comparison of measured turbidity and fecal coliform bacteria densities generally shows a strong correlation (fig. 8). Simple linear regression analysis was performed on data from these six sites to define a relation between turbidity and fecal coliform. The regression models are site specific and applicable only for the range of turbidity values listed in table 5.

Turbidity was the best estimator of all the averaged cross-section water-quality measurements and streamflow [Note: Only turbidity values from a YSI 6026 turbidity sensor are appropriate for the relations described in this report (see “Methods” section of this report).] The explanatory and response variables were log transformed prior to fitting the regression models. The regression models used to estimate fecal coliform bacteria densities for the Kansas River (sites 1, 2, and 20, fig. 1) and the Little Arkansas River (sites 22 and 23) had slopes (*m*) that ranged from 1.13 (site 22) to 1.40 (site 20). The difference in slope probably is due to differences in bacteria sources, flow regimes, and water chemistry. The R^2s for these sites were equal to or greater than 0.62, indicating more than 62 percent of the variability in the bacteria concentrations was explained by turbidity. The range of turbidity and fecal coliform data spanned three orders of magnitude, describing a majority of the streamflow and turbidity conditions at these sites. The slope and R^2 for site 21 (Rattlesnake Creek near Zenith) were 0.542 and 0.16, respectively. The lower R^2 indicates that turbidity and fecal coliform were not well correlated for this site. The poor relation probably is related to the decreased survivability of *E. coli* (the dominant member of the fecal coliform group) because of elevated salinity concentrations at this site.

For the six fecal coliform regression models, uncertainties, expressed as model standard error of estimate in percent (*SEE*), ranged from $\pm$145 to $\pm$310 percent. The smallest *SEE*s were for sites with the smallest range of turbidities for collected samples indicating that sites with highly variable turbidity increase the uncertainty. When considering the uncertainty for estimating bacteria concentrations on the basis of turbidity measurements, it is important to

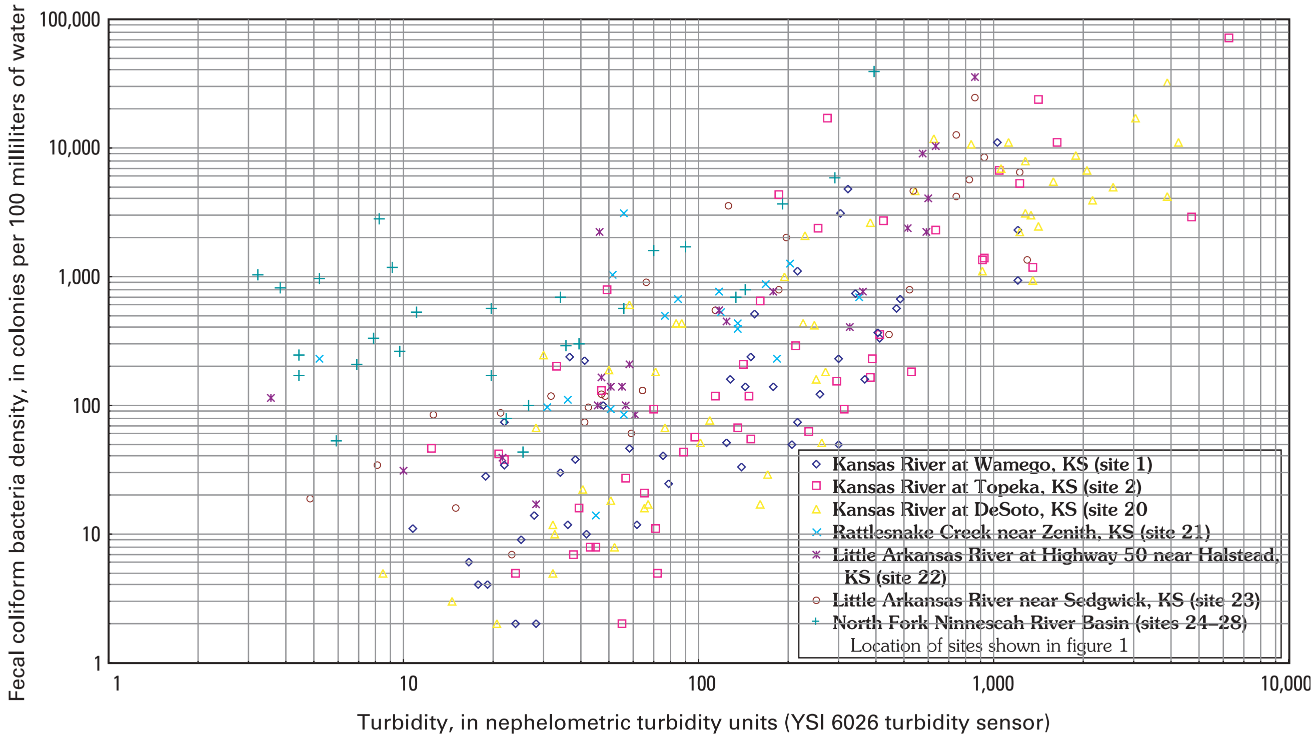


Figure 8. Comparison of measured turbidity and fecal coliform bacteria densities at selected surface-water sites, May 1999 through April 2002.

remember the uncertainty associated with the membrane filtration technique, which was discussed in the "Methods" section of this report.

Comparisons of measured turbidity and regression-estimated fecal coliform bacteria densities for the six surface-water sites are shown in figure 9. The uncertainty for each of the models is graphically displayed with the prediction intervals. The closer the intervals are to one another, the less uncertainty for that particular regression model at a specified probability. The 50- and 90-percent prediction intervals were plotted to show the difference in ranges. Given any measured turbidity within the range of values plotted, there is a 90-percent chance that the resulting estimated fecal coliform value will be within the 90-percent prediction interval.

Estimates from the regression models were compared to measured sample densities, and the percentage of estimated values that were in agreement as exceeding or being less than the water-quality criteria are reported in table 6. At least 70 percent of the regression-estimated values were in agreement with measured sample densities as being less than or greater than 200 col/100 mL for all sites except Rattlesnake Creek near Zenith (site 21). All of the model estimates were in agreement with the measured densities as being less than 2,000 col/100 mL at least 84 percent of the time. The regression-model estimates were in agreement with measured densities greater than 2,000 col/100 mL at least 81 percent of the time for sites 20, 22, and 23. The models estimates for sites 1, 2, and 21 were in agreement with measured densities greater than 2,000 col/100 mL less than 55 percent of the time. The regression-model estimates for the Kansas River at Wamego (site 1) were in agreement for only one of the four samples that had measured densities greater than 2,000 col/100 mL. The regression model for Rattlesnake Creek (site 21) did not accurately estimated densities less than 200 or greater than 2,000 col/100 mL due to the low slope of the model and the limitation of the continuous turbidity sensor. The maximum turbidity the continuous sensor could measure was 1,000 to 1,500 NTU, and the corresponding estimated fecal coliform bacteria density was 1,700 col/100 mL.

The regression models and continuous (hourly) turbidity data collected at the six surface-water sites were used to continuously estimate fecal coliform bacteria densities for May 1999 through April 2002 (fig. 10). Fecal coliform bacteria densities from

Table 5. Regression models and statistics for estimating fecal coliform bacteria densities using turbidity measurements at selected surface-water sites in Kansas, May 1999 through April 2002

[R^2, coefficient of determination; *MSE*, mean square error; *n*, number of samples; *RMAE*, relative mean absolute error; SS_x, sum of squares *x*; *RPD*, relative percentage difference; *FCB*, fecal coliform bacteria; *NTU*, turbidity]

Site number (fig. 1)	Regression model	R^2	*MSE* (log units)	Model standard error of estimate (percent)	*n*	Range in fecal coliform bacteria densities (colonies per 100 milliliters)	Range in turbidity (nephelometric turbidity units)	*RMAE* (percent)	SS_x (log units)	Median *RPD* (percent)	Bias-correction factor (Duan, 1983)
1	$\mathrm{Log}_{10}FCB = 1.30\log_{10}NTU - 0.663$	0.66	0.273	180	46	2–11,000	11–1,211	127	12.0	80	2.04
2	$\mathrm{Log}_{10}FCB = 1.36\log_{10}NTU - 0.740$	.62	.449	310	47	2–71,000	12–6,240	100	20.2	80	3.48
20	$\mathrm{Log}_{10}FCB = 1.40\log_{10}NTU - 0.793$	.78	.304	200	52	2–32,000	9–4,210	64	15.2	95	2.13
21	$\mathrm{Log}_{10}FCB = 0.542\log_{10}NTU + 1.51$	.16	.274	180	18	14–3,100	5–350	63	4.39	85	1.80
22	$\mathrm{Log}_{10}FCB = 1.13\log_{10}NTU + 0.378$	.69	.249	165	23	17–36,000	4–860	73	5.23	70	2.12
23	$\mathrm{Log}_{10}FCB = 1.19\log_{10}NTU + 0.198$	.79	.210	145	28	7–25,000	5–1,300	66	5.47	40	1.58

A. Kansas River at Wamego (site 1)

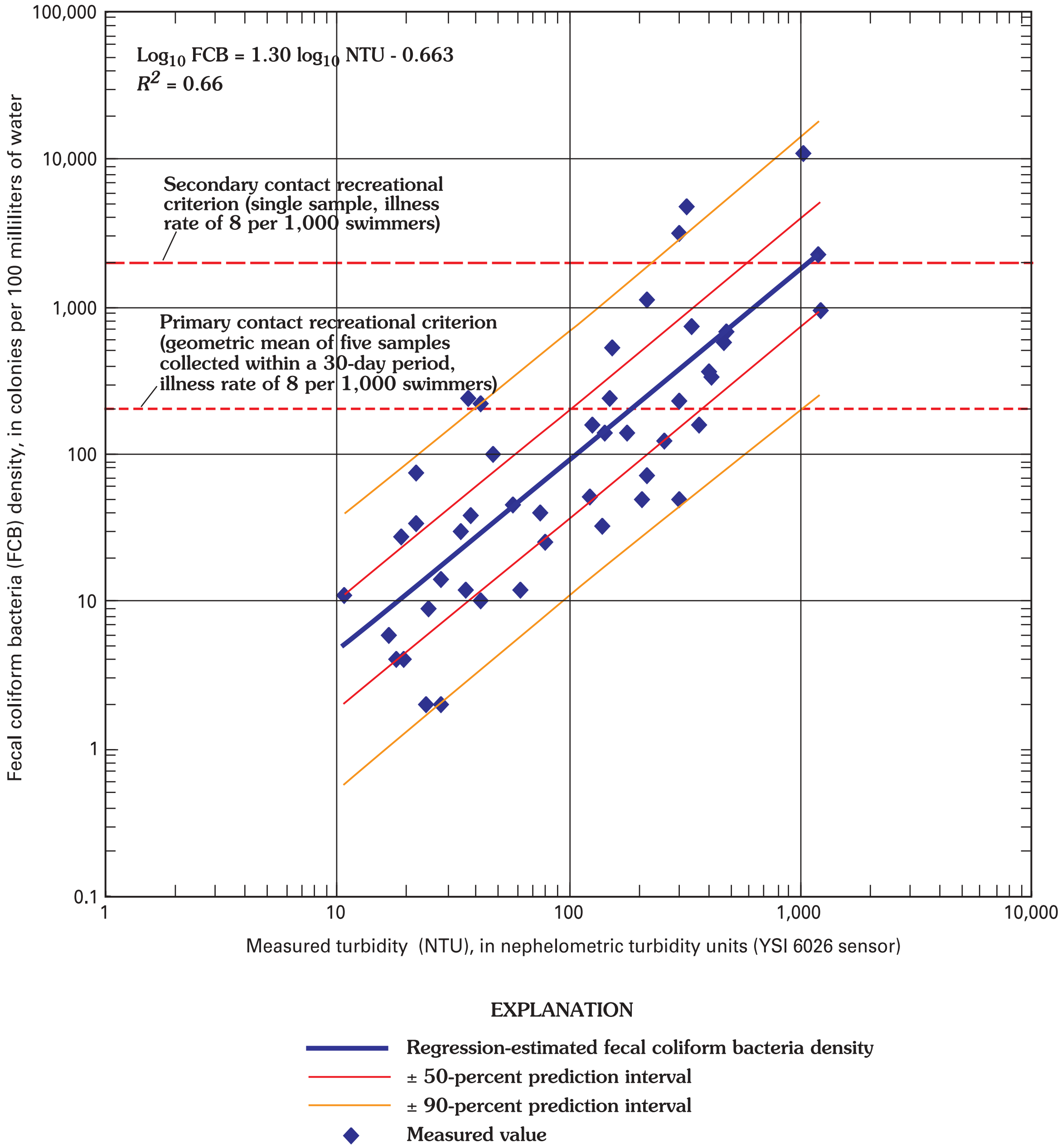


Figure 9*A*. Comparison of measured turbidity and fecal coliform bacteria densities, regression-estimated fecal coliform bacteria densities, and prediction intervals for Kansas River at Wamego (site 1, fig. 1), July 1999 through April 2002. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

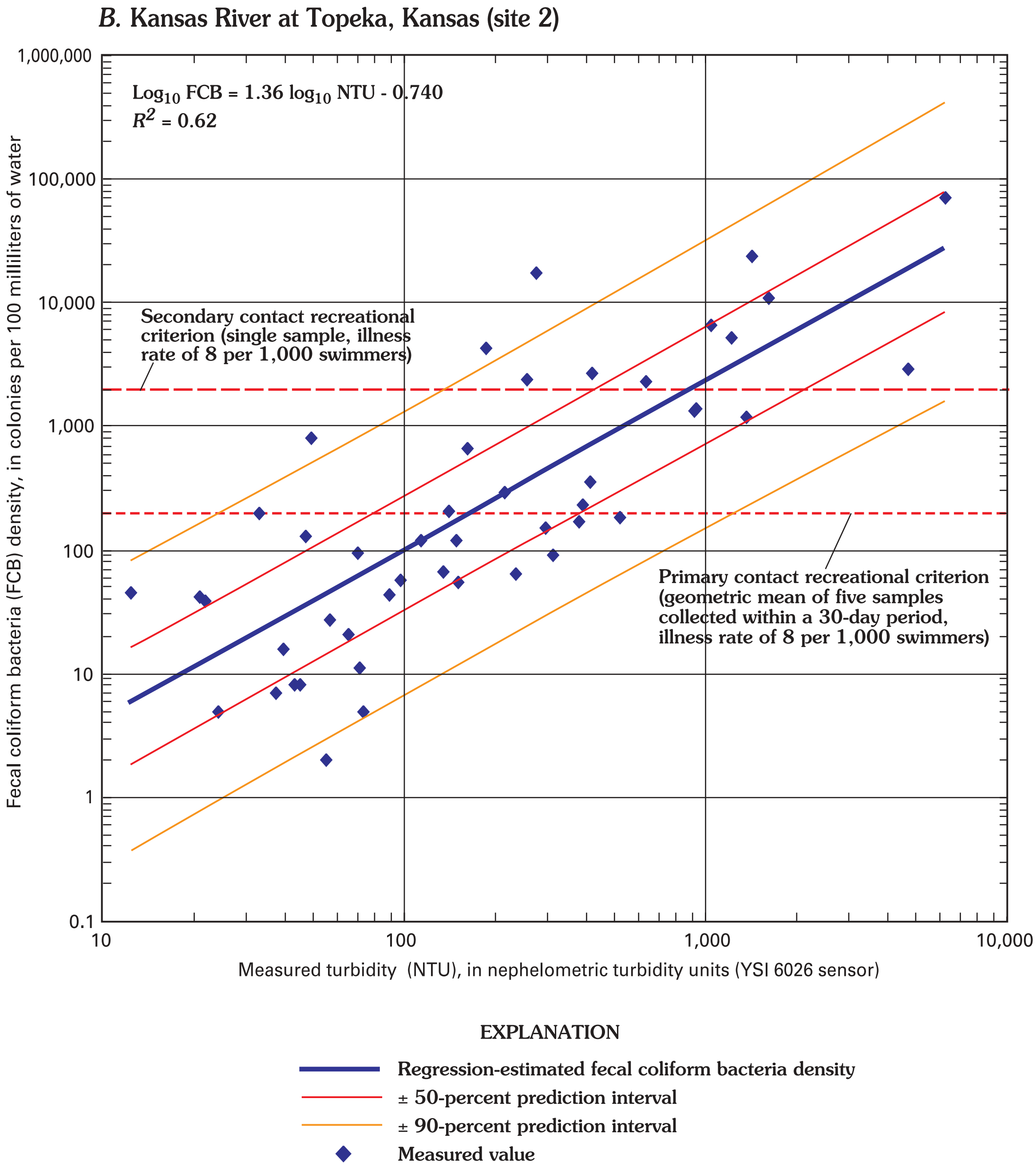


Figure 9*B*. Comparison of measured turbidity and fecal coliform bacteria densities, regression-estimated fecal coliform bacteria densities, and prediction intervals for Kansas River at Topeka (site 2, fig. 1), July 1999 through April 2002. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

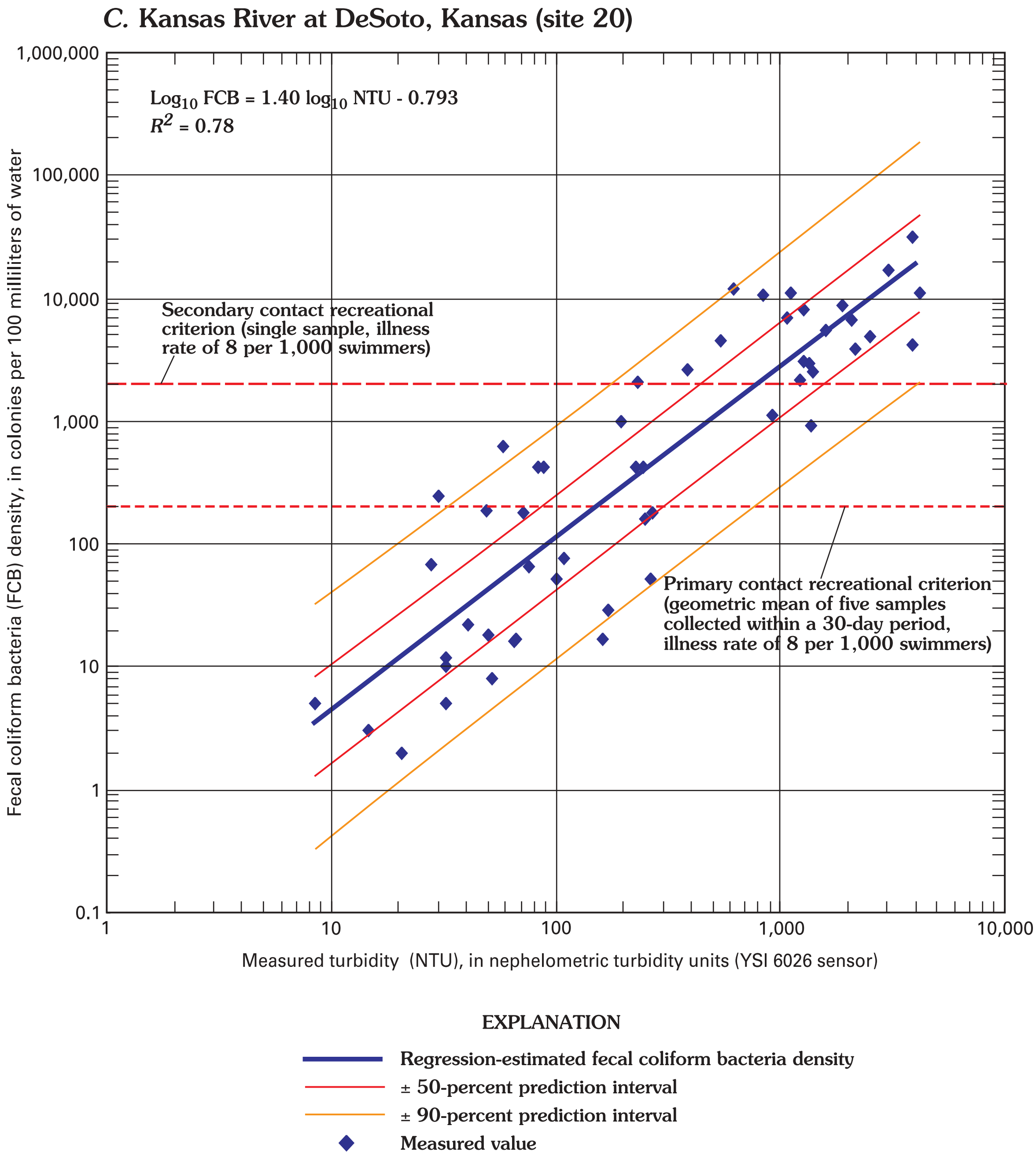


Figure 9*C*. Comparison of measured turbidity and fecal coliform bacteria densities, regression-estimated fecal coliform bacteria densities, and prediction intervals for Kansas River at DeSoto (site 20, fig. 1), July 1999 through April 2002. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

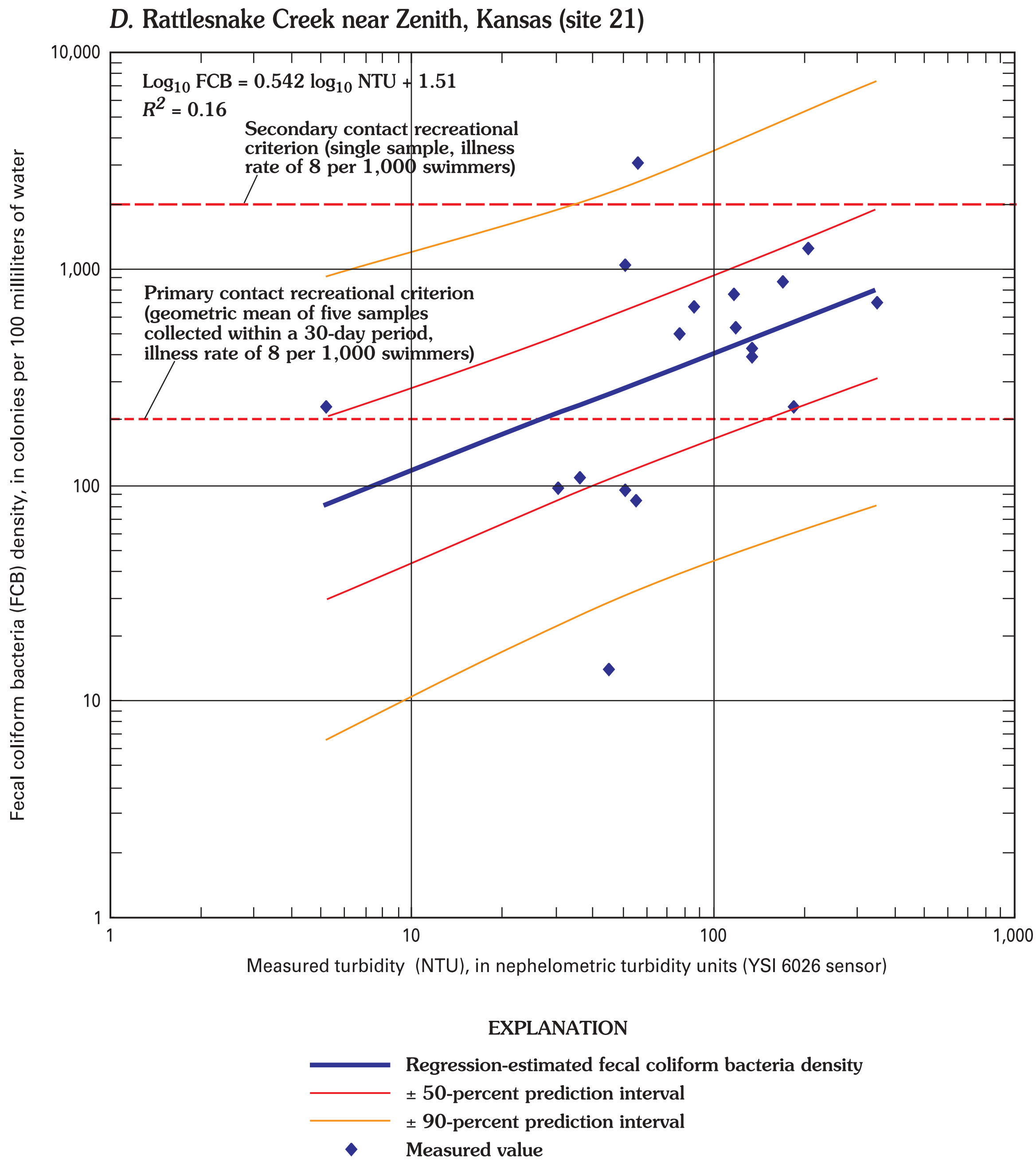


Figure 9*D*. Comparison of measured turbidity and fecal coliform bacteria densities, regression-estimated fecal coliform bacteria densities, and prediction intervals for Rattlesnake Creek near Zenith (site 21, fig. 1), May 1999 through April 2002. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

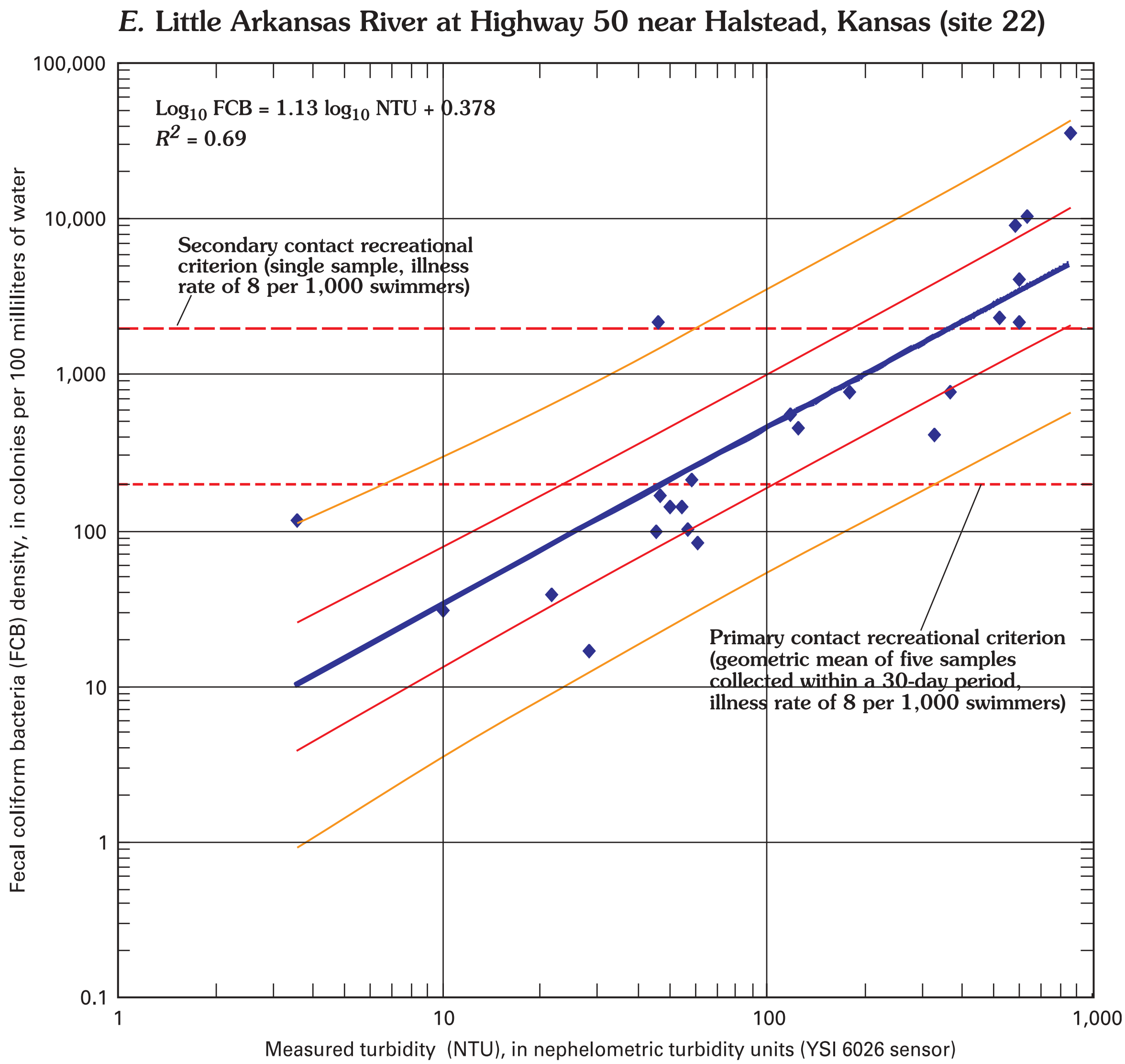


Figure 9*E*. Comparison of measured turbidity and fecal coliform bacteria densities, regression-estimated fecal coliform bacteria densities, and prediction intervals for Little Arkansas River at Highway 50 near Halstead (site 22, fig. 1), May 1999 through April 2002. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

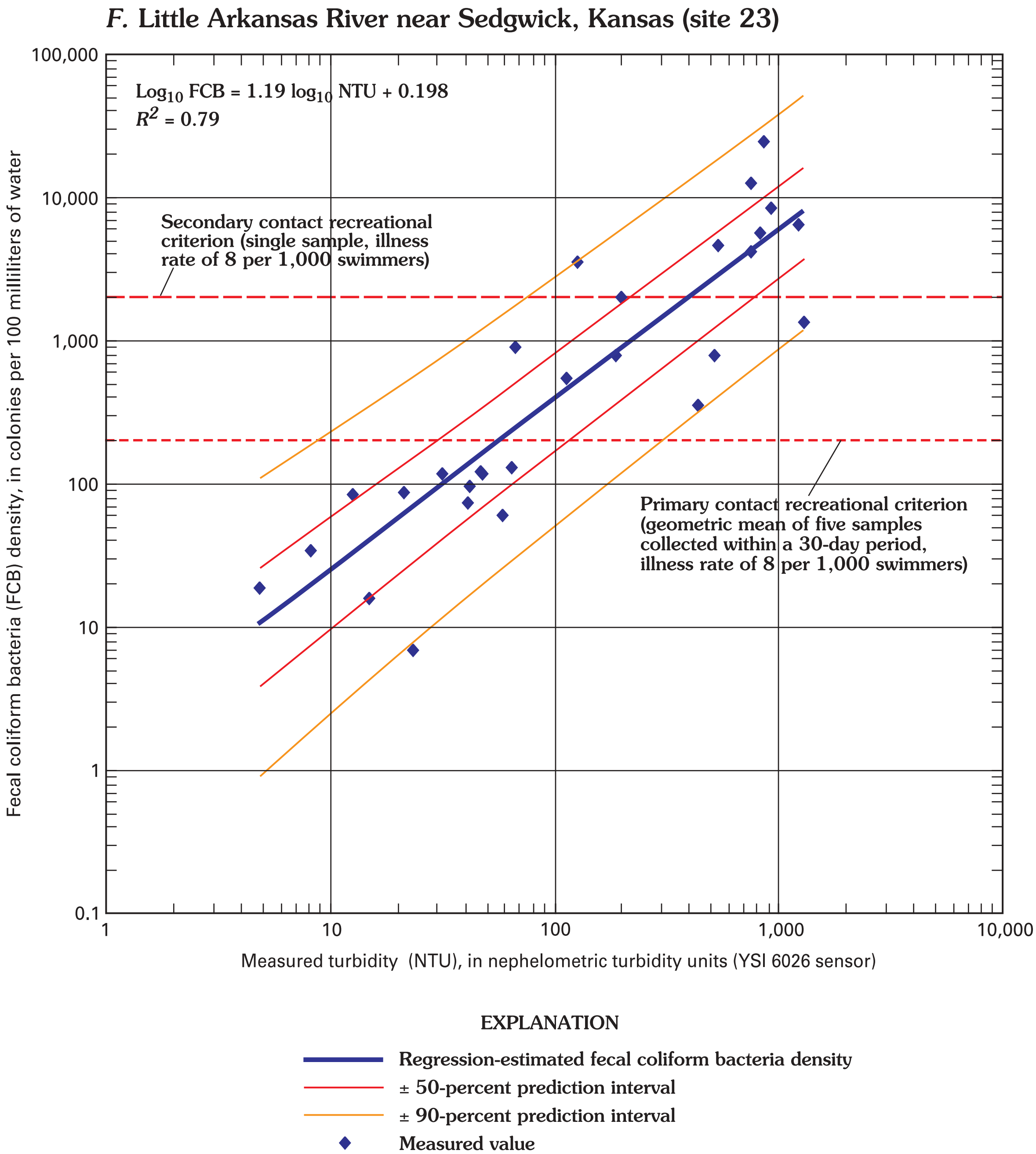


Figure 9*F*. Comparison of measured turbidity and fecal coliform bacteria densities, regression-estimated fecal coliform bacteria densities, and prediction intervals for Little Arkansas River near Sedgwick (site 23, fig. 1), May 1999 through April 2002. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

Table 6. Percentage of regression-model estimates in agreement with measured fecal coliform bacteria densities in relation to primary and secondary contact recreational criteria for selected surface-water sites in Kansas, May 1999 through April 2002

[Recreational water-quality criteria from Kansas Department of Health and Environment (2001). <, less than; >, greater than; col/100 mL, colonies per 100 milliliters of water]

Site number (fig. 1)	Site name	Percentage of estimated values <200 col/100 mL that were in agreement with measured sample densities <200 col/100 mL (total number of samples with densities <200 col/100 mL)	Percentage of estimated values >200 col/100 mL that were in agreement with measured sample densities >200 col/100 mL (total number of samples with densities >200 col/mL)	Percentage of estimated values <2,000 col/100 mL that were in agreement with measured sample densities <2,000 col/100 mL (total number of samples with densities <2,000 col/100 mL)	Percentage of estimated values >2,000 col/100 mL that were in agreement with measured sample densities >2,000 col/100 mL (total number of samples with densities >2,000 col/mL)
1	Kansas River at Wamego	83(30)	75 (16)	98(42)	25 (4)
2	Kansas River at Topeka	81 (26)	85 (20)	97 (36)	55 (11)
20	Kansas River at DeSoto	82 (22)	87 (30)	94 (31)	81 (21)
21	Rattlesnake Creek near Zenith	0 (5)	92 (13)	100 (17)	0 (1)
22	Little Arkansas River at Highway 50 near Halstead	70 (10)	92 (13)	100 (16)	86 (7)
23	Little Arkansas River near Sedgwick	85 (13)	100 (15)	84 (19)	88 (8)

collected water samples were plotted with the regression-estimated densities to give some indication of how well the regression models represented in-stream conditions. The percentage of time that the stream exceeded a water-quality criteria was calculated and is shown on these graphs, which gives an indication of the probability that a stream will meet water-quality criteria and TMDL goals. A moving 30-day geometric mean was also plotted for comparison with the primary contact recreational geometric-mean criteria.

The percentage of estimated hourly fecal coliform bacteria densities that were greater than recreational-use criteria were divided into three seasons—spring (April through June), summer (July through October), and winter (November through March). The seasons are consistent with the seasons KDHE uses to determine TMDL listings. Spring had the highest percentage of hourly estimated fecal coliform densities greater than the geometric-mean and single-sample criteria. For instance, estimated fecal coliform densities in the spring at the three Kansas River sites (1, 2, 20) indicate that the single-sample criterion (2,000 col/100 mL) was exceeded between 1 and 10 percent of the time for the period July 1999 through April 2002 (table 7). The regression-estimated hourly fecal coliform density exceedances at the two sites (22, 23) on the Little Arkansas River were between 20 and 22 percent in the spring. A comparison of fecal coliform bacteria densities at sites on the two rivers for the spring indicated that the geometric-mean criterion (200 col/100 mL) was exceeded 54 to 83 percent of the time. The percentages of exceedance of 200 and 2,000 col/100 mL for the three sites on the Kansas River generally increased from upstream to downstream. The number of estimated hourly densities greater than 200 col/100 mL for the Little Arkansas River sites decreased from upstream to downstream in the spring and summer.

The continuous turbidity data presented in this report had days of no data or incomplete data mostly due to removal of the multiparameter monitor during periods of ice conditions or equipment malfunctions. For these periods, turbidity values were interpolated between the values prior to and after the period of no data. During these periods, streamflow was stable indicating that turbidity also was probably stable. These data are highlighted in red on the graphs (fig. 10). None of the interpolated turbidity values were greater than 240 NTU, corresponding to an estimated fecal coliform density of 314 col/100 mL for that particular site. A limitation of applying regression models to continuous data is that the in-stream turbidity sensor maximum varies between 1,000 to 1,500 NTU, truncating the actual turbidity peak. This truncation is evident in the graphs (fig. 10) where the estimated fecal coliform density was at its maximum for several hours (or days). For these instances, actual fecal coliform

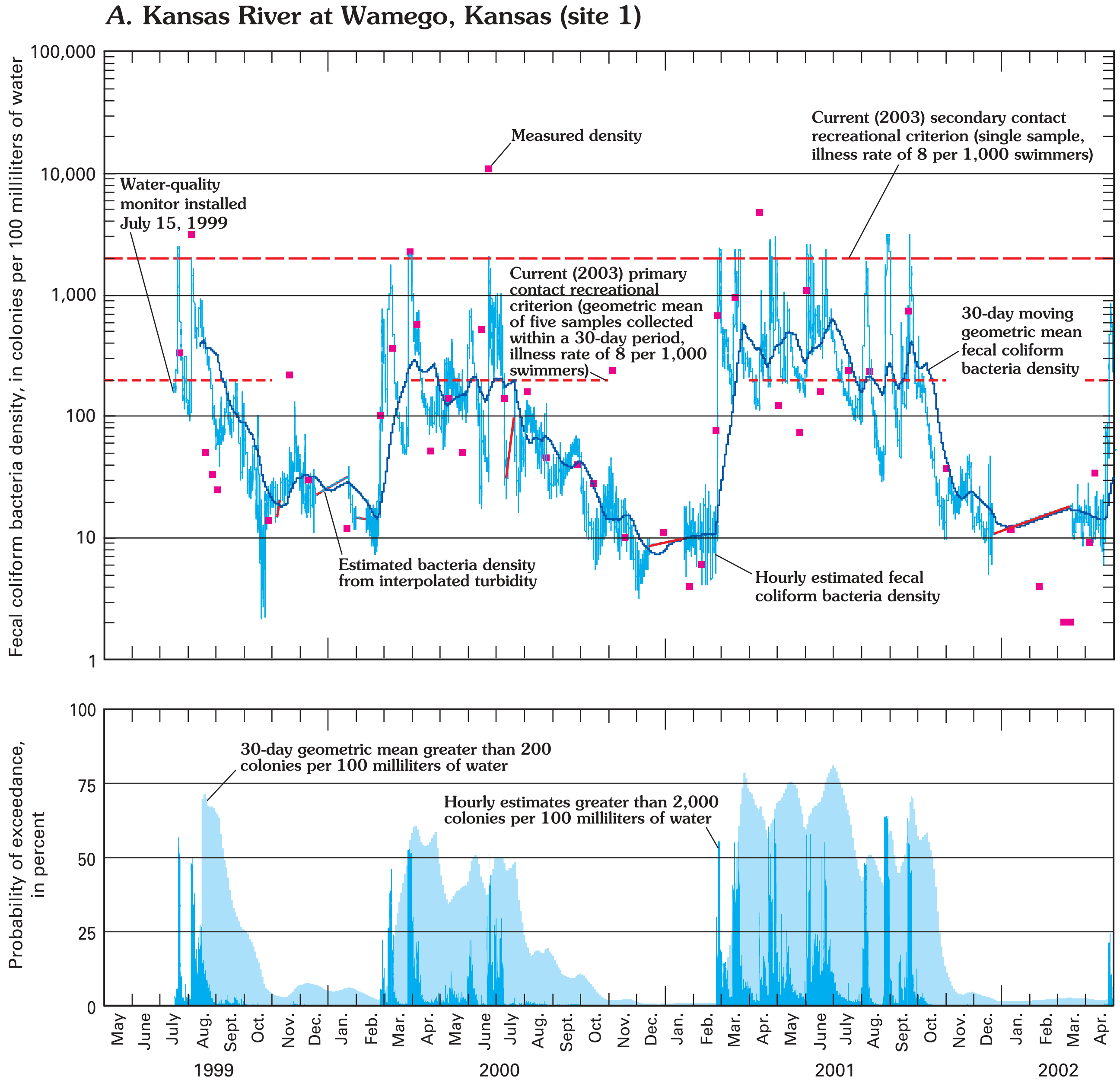


Figure 10*A*. Comparison of measured and regression-estimated fecal coliform bacteria densities for Kansas River at Wamego (site 1, fig. 1), May 1999 through April 2002, and probability of exceedance of water-quality criteria. Current (2003) recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

bacteria densities were unknown but were likely greater than the regression-estimated density.

Probability and Duration of Estimated Fecal Coliform Densities

The continuous estimated fecal coliform bacteria densities can be displayed as probabilities and durations that allow for easier identification of water quality for a particular stream segment relative to water-quality criteria. The public and water-management agencies can use probability values and duration curves to assess short- and long-term water-quality conditions relative to water-quality criteria. These assessments can assist in evaluating best management practices and in determining or evaluating TMDLs.

The estimated fecal coliform bacteria densities provided in the previous section need to be considered with the uncertainty of the estimate in mind. To simplify this consideration process, the probability of

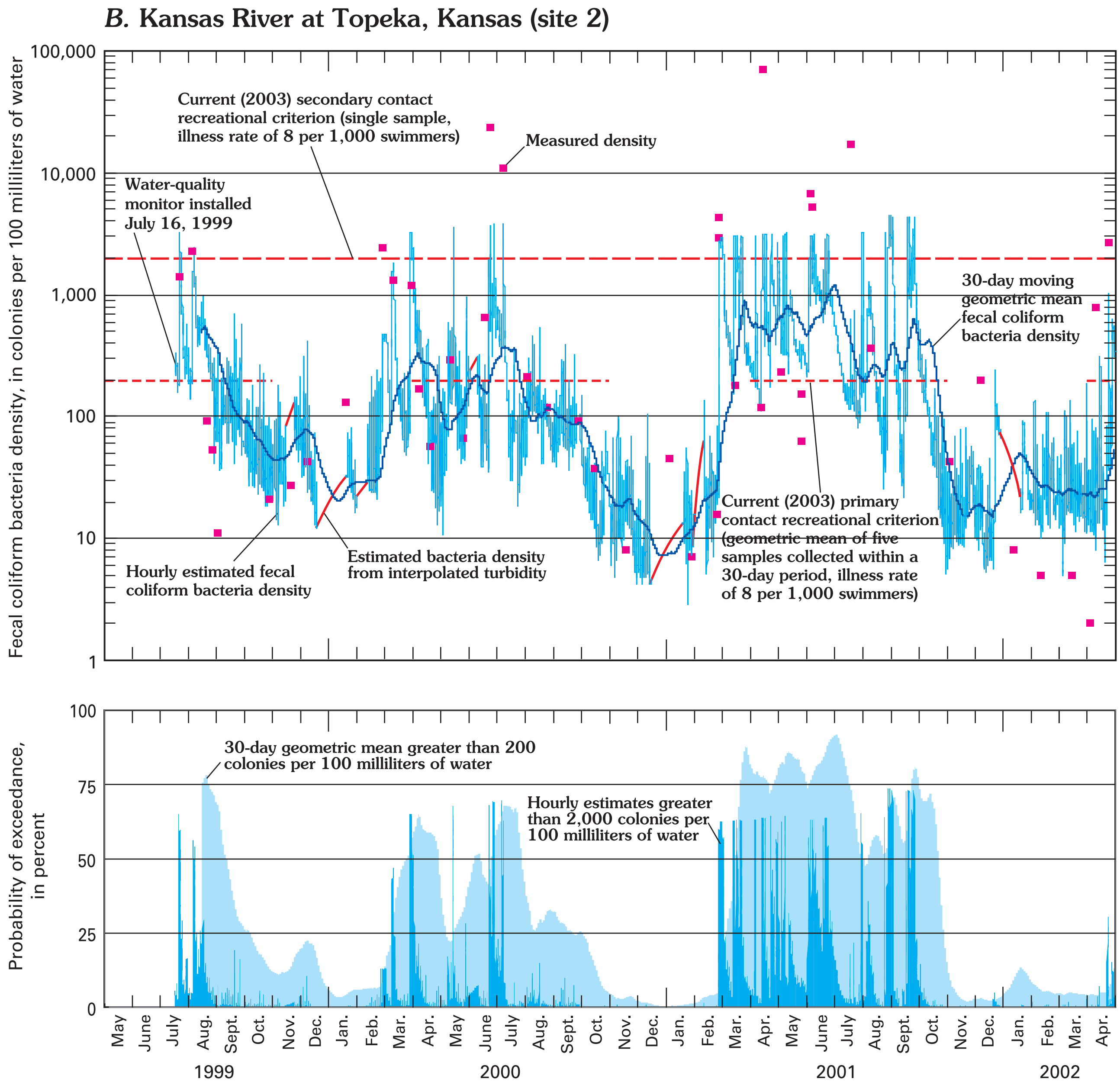


Figure 10*B*. Comparison of measured and regression-estimated fecal coliform bacteria densities for Kansas River at Topeka (site 2, fig. 1), May 1999 through April 2002, and probability of exceedance of water-quality criteria. Current (2003) recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

exceeding (at the 95-percent confidence level) current (2003) geometric-mean criterion (200 col/100 mL) or single-sample criterion (2,000 col/100 mL) can be displayed for each 30-day geometric mean of the hourly estimates or of the hourly estimates, respectively. Figure 10 illustrates the probability (expressed as a percentage) that the maximum 30-day geometric-mean estimate and the maximum hourly estimate for each day of the study period exceeds the respective criteria. Real-time hourly probability values available on the World Wide Web (http://ks.water.usgs.gov/Kansas/rtqw/) provide the public and water managers information when considering public health and safety for recreation water bodies.

The relation between turbidity and fecal coliform bacteria also can be displayed as probability curves (fig. 11). Each curve represents a fecal coliform density and is plotted using turbidity (x axis) and the probability that the actual fecal coliform density is equal to or greater than the estimated density (y axis). The

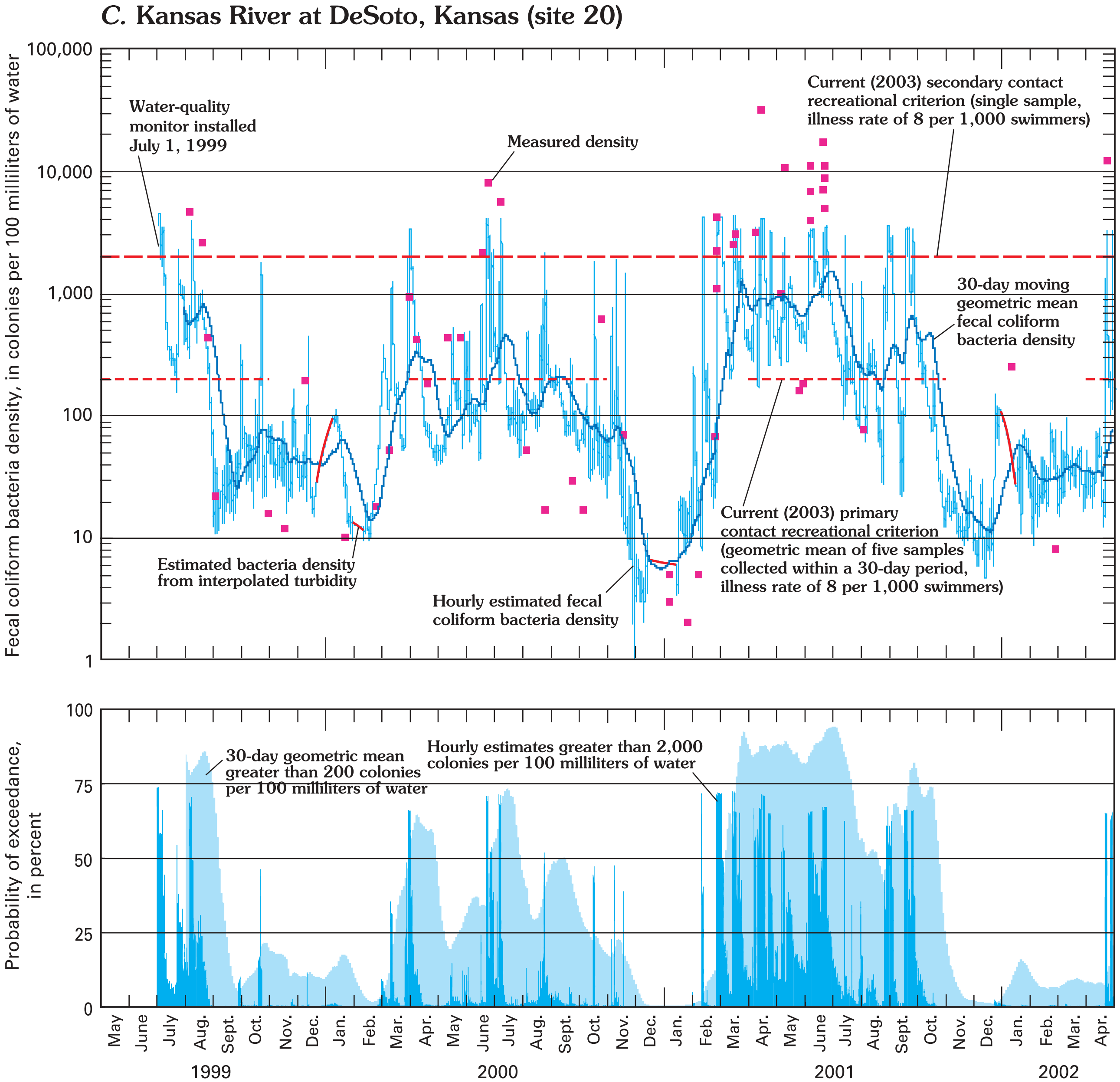


Figure 10*C*. Comparison of measured and regression-estimated fecal coliform bacteria densities for Kansas River at DeSoto (site 20, fig. 1), May 1999 through April 2002, and probability of exceedance of water-quality criteria. Current (2003) recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

figures can be used to estimate fecal coliform concentrations on the basis of measured turbidity values. [Note: Only turbidity values from a YSI 6026 turbidity sensor are appropriate for relations described in report. See “Methods” section of this report.] For instance, the actual fecal coliform bacteria density in the Kansas River at Wamego (site 1) for a turbidity value of 100 NTU has a 99-percent chance of being less than 2,000 col/100 mL and a 25-percent chance of being greater than 200 col/100 mL (fig. 11*A*). For a turbidity value of 1,000 NTU in the Kansas River at Wamego (site 1), there is a 45-percent chance that the actual fecal coliform bacteria density is greater than 2,000 col/100 mL and a 96-percent chance that it is greater than 200 col/100 mL.

Duration curves were plotted using the hourly estimates of fecal coliform bacteria density for the six selected surface-water sites from May or July 1999 through April 2002 (fig. 12). The data are plotted against the frequency of each hourly value occurring

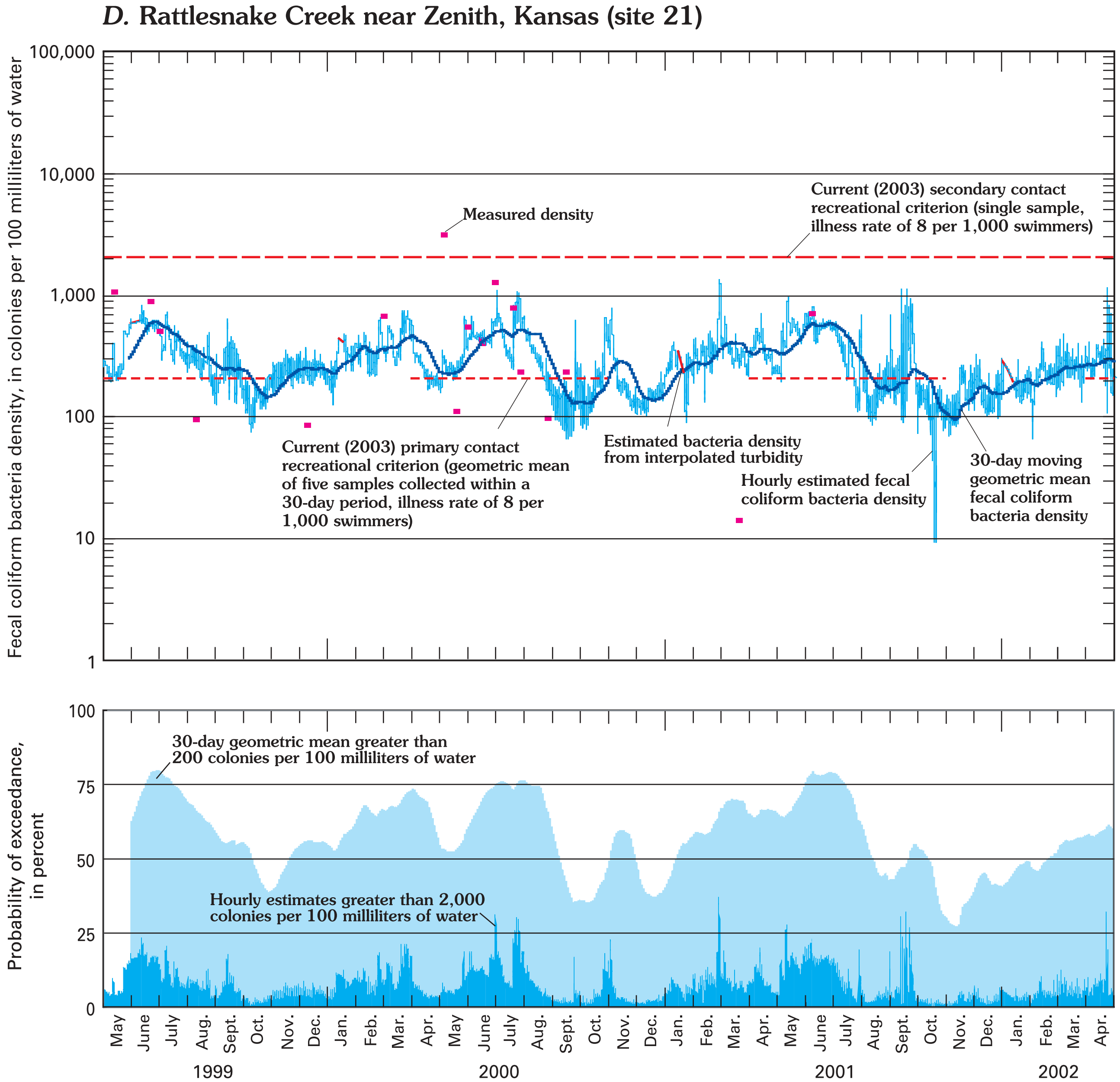


Figure 10*D*. Comparison of measured and regression-estimated fecal coliform bacteria densities for Rattlesnake Creek near Zenith (site 21, fig. 1), May 1999 through April 2002, and probability of exceedance of water-quality criteria. Current (2003) recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

within the period. The duration curves are an excellent summary of the estimated bacteria densities for the given period and can be used for many purposes. The minimum (100-percent exceedance), median (50-percent exceedance), and maximum (0-percent exceedance) estimated bacteria densities can be easily obtained from the curve. The curves also give an indication of how frequently the estimated bacteria densities exceeded a specified water-quality criteria for a given period.

Duration curves for the entire study period indicate the single-sample secondary contact criterion for fecal coliform bacteria density (2,000 col/100 mL) was exceeded between 0 and 14 percent of the time for the six surface-water sites. During the designated recreation period (April through October), exceedances of the geometric-mean primary contact criterion (200 col/100 mL) occurred between 54 and 94 percent of the spring (April through June) and 21 and 59 percent of the summer (July through October). Duration

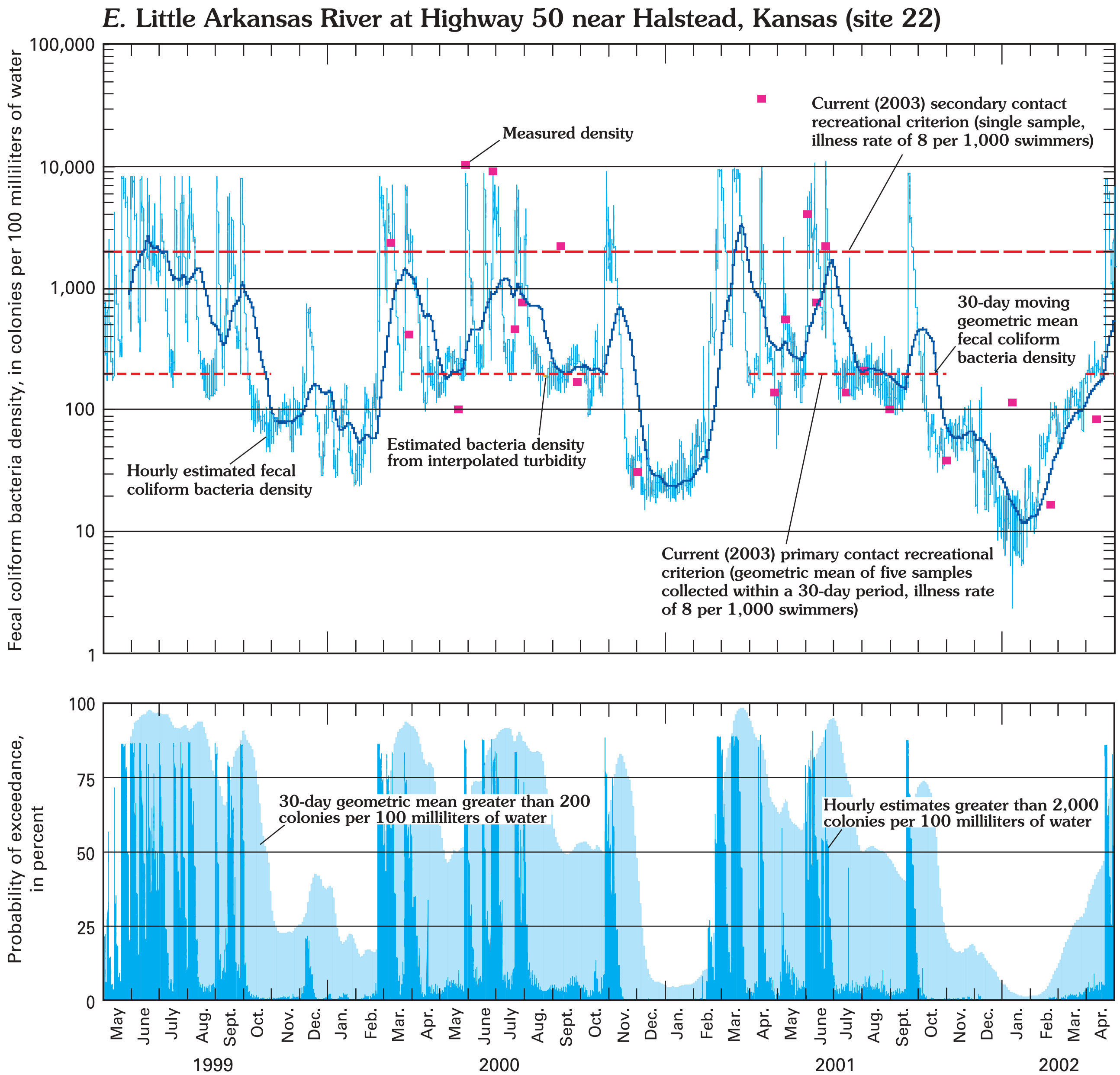


Figure 10*E*. Comparison of measured and regression-estimated fecal coliform bacteria densities for Little Arkansas River at Highway 50 near Halstead (site 22, fig. 1), May 1999 through April 2002, and probability of exceedance of water-quality criteria. Current (2003) recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

curves for estimated fecal coliform densities for spring (April through June), summer (July through October), and winter (November through March) illustrate the differences between the three seasons. For all sites except Rattlesnake Creek, the median estimated bacteria density in the spring was at least 2 times the median summer density and about 10 times the median winter density. The seasonal differences are largest for the three Kansas River sites (1, 2, 20) indicating that reservoir releases (very low turbidity and bacteria densities) predominate the streamflow in the winter. The streamflow duration curve for each site (fig. 12) is plotted with the bacteria duration curves to provide a comparison of streamflow and bacteria density.

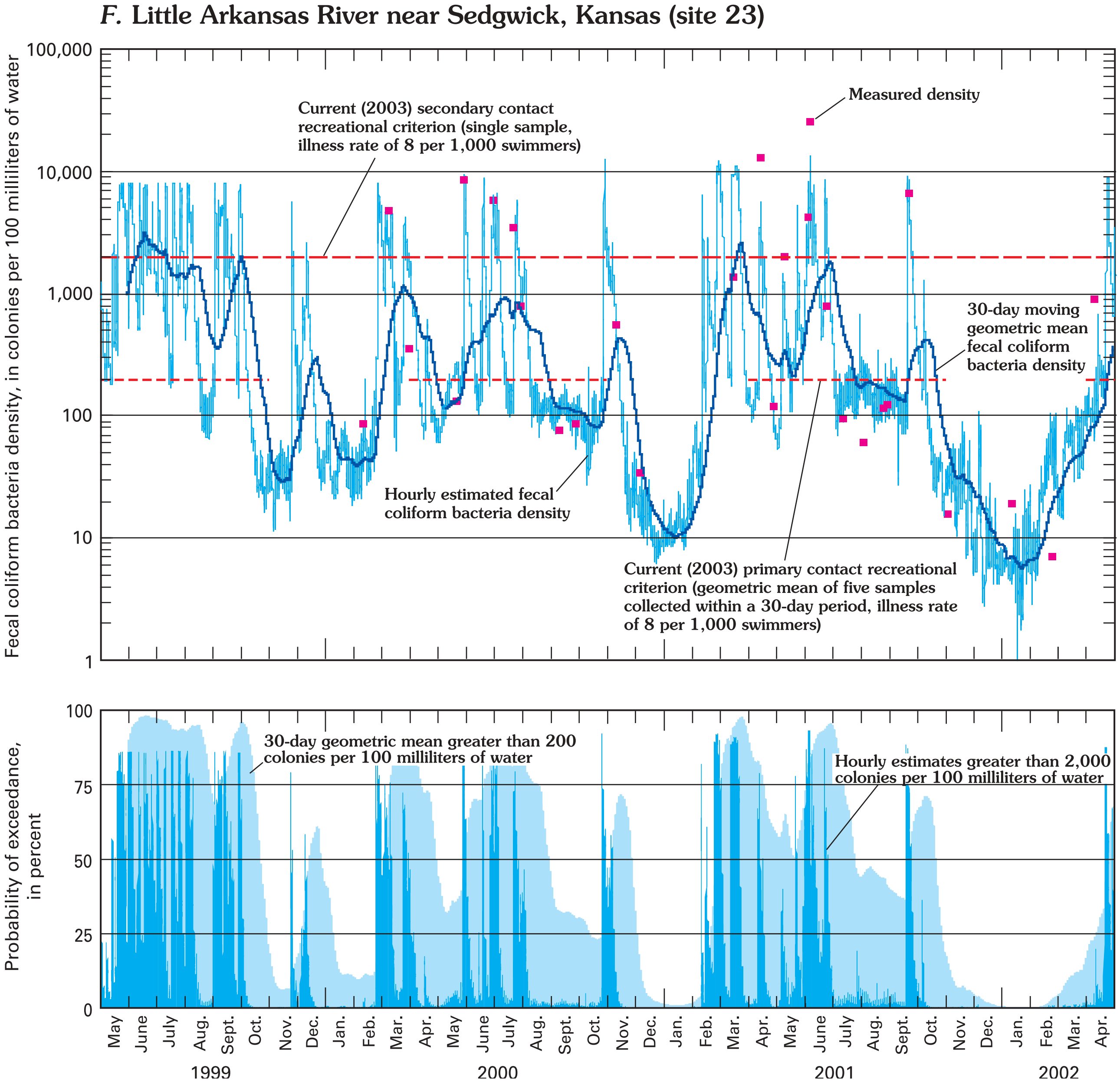


Figure 10*F*. Comparison of measured and regression-estimated fecal coliform bacteria densities for Little Arkansas River near Sedgwick (site 23, fig. 1), May 1999 through April 2002, and probability of exceedance of water-quality criteria. Current (2003) recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

Relation Between Turbidity and *Escherichia Coli* Density

A statistically defined relation between turbidity and *E. coli* bacteria densities also was developed for six of the seven surface-water sites where real-time, continuous multiparameter monitors with turbidity sensors are deployed (table 2). A comparison of turbidity measurements and *E. coli* densities (fig. 13) is somewhat less correlated than that between turbidity and fecal coliform densities (fig. 8). Simple linear regression analysis was performed on data from these six sites to define a relation between turbidity and *E. coli* (table 8). The regression models are site specific and applicable only for the range of turbidity values listed in table 8.

Turbidity was the best estimator of all the averaged cross-section water-quality measurements and streamflow [Note: Only turbidity values from a YSI 6026 turbidity sensor are appropriate for relations described in report. See “Methods” section of this

Table 7. Percentage of estimated hourly fecal coliform bacteria densities that were greater than recreational-use criteria for selected surface-water sites in Kansas, May or July 1999 through April 2002

[Numbers are percentage of estimated hourly fecal coliform densities. Recreational-use criteria from Kansas Department of Health and Environment (2001)]

Site number (fig. 1)	Percentage greater than geometric-mean criterion (200 col/mL)			Percentage greater than single-sample criterion (2,000 col/mL)		
	Spring (April–June)	Summer (July–October)	Winter (November–March)	Spring (April–June)	Summer (July–October)	Winter (November–March)
[1]1	54	21	11	1	2	2
[2]2	62	29	12	7	4	3
[3]20	58	41	13	10	6	3
21	94	53	68	0	0	0
22	83	59	22	20	12	9
23	70	40	24	22	14	8

[1]July 15, 1999, through April 2002. [2]July 16, 1999, through April 2002. [3]July 1, 1999, through April 2002.

report]. The explanatory and response variables were log transformed prior to fitting the regression models. The regression models used to estimate *E. coli* bacteria densities for the Kansas River (sites 1, 2, and 20, fig. 1) and the Little Arkansas River (sites 22 and 23) had slopes (*m*) that ranged from 1.01 (site 22) to 1.40 (site 20). The site-to-site variation in slope probably results from differences in bacteria sources, flow regimes, and water chemistry. The R^2s were equal to or greater than 0.59, indicating more than 59 percent of the variability in the bacteria concentrations was explained by turbidity. The range of turbidity and *E. coli* data spanned three orders of magnitude, describing a majority of the streamflow conditions at these sites. The regression model for site 21 was not significant, and therefore, no model was reported. The poor relation between turbidity and *E. coli* at this site probably is related to the decreased survivability of *E. coli* (the dominant member of the fecal coliform group) because of elevated salinity concentrations at this site.

For the five *E. coli* regression models, uncertainties, expressed as model standard error of estimate (*SEE*) in percent, ranged from ±185 to ±350 percent. The smallest *SEE*s were for sites with the smallest range of turbidities for collected samples. When considering the uncertainty for estimating bacteria concentrations on the basis of turbidity measurements, it is important to remember the uncertainty associated with the membrane filtration technique, which was discussed in the “Methods” section of this report.

Comparisons of measured turbidity versus regression-estimated *E. coli* bacteria densities for all five surface-water sites are shown in figure 14. The uncertainty for each of the models is graphically displayed with the prediction intervals. The closer the intervals are to one another, the less uncertainty for that particular regression model at a specified probability. The 50- and 90-percent prediction intervals were plotted to show the difference in ranges. Given any measured turbidity within the range of values plotted, there is a 90-percent chance that the resulting estimated fecal coliform value will be within the 90-percent prediction interval.

Estimates from the regression models were compared to measured sample densities and the percentage of estimated values that were in agreement as exceeding or being less than the recommended criteria are reported in table 9. All of the model estimates were in agreement for measured densities greater than 126 and less than 576 col/100 mL at least 84 percent of the time. At least 79 percent of the estimates were in agreement with measured densities less than 126 col/100 mL for all sites except site 22 where 50 percent were in agreement. The regression-model estimates were in agreement with measured densities greater than 576 col/100 mL at least 83 percent of the time for sites 20, 22, and 23. The regression-model estimates for sites 1 and 2 were in agreement with measured densities greater than 576 col/100 mL at least 38 percent of the time. The regression-model estimates for Kansas River at Wamego (site 1) were in agreement with only three of the eight samples that had measured densities greater than 576 col/100 mL (table 9), whereas estimates for the Kansas River at DeSoto (site 20) were in agreement with 83 percent of

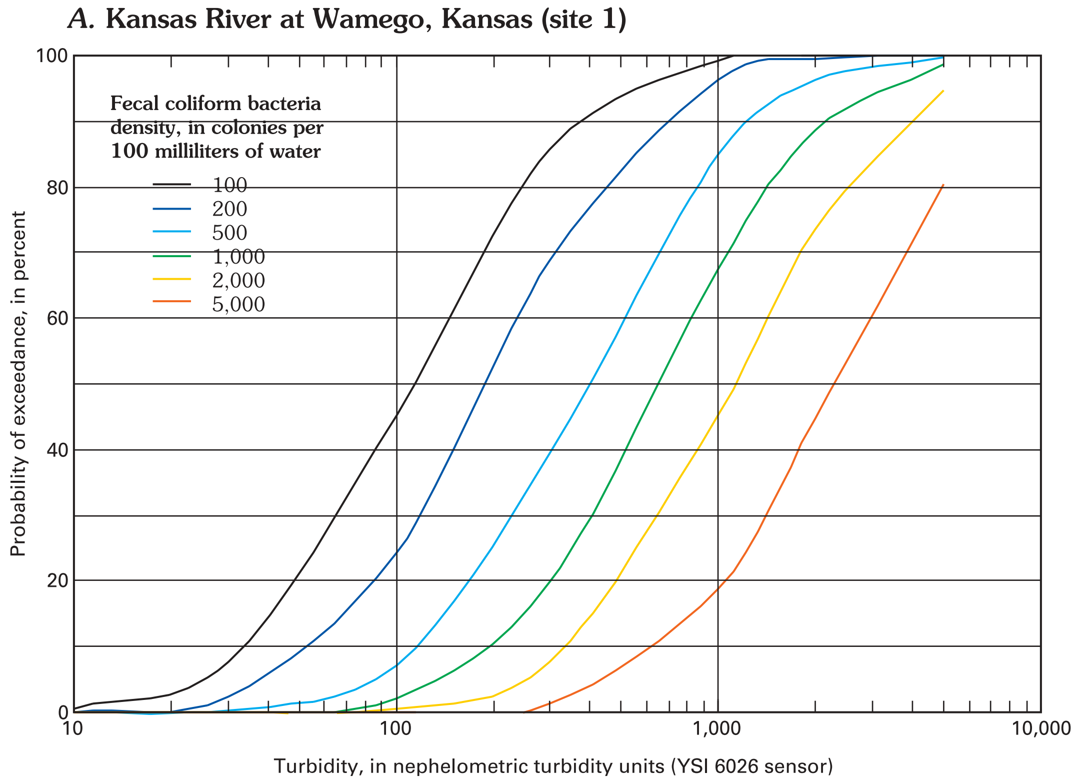


Figure 11*A*. Comparison of measured turbidity and the probability of exceeding selected fecal coliform bacteria densities for Kansas River at Wamego (site 1, fig. 1), July 1999 through April 2002.

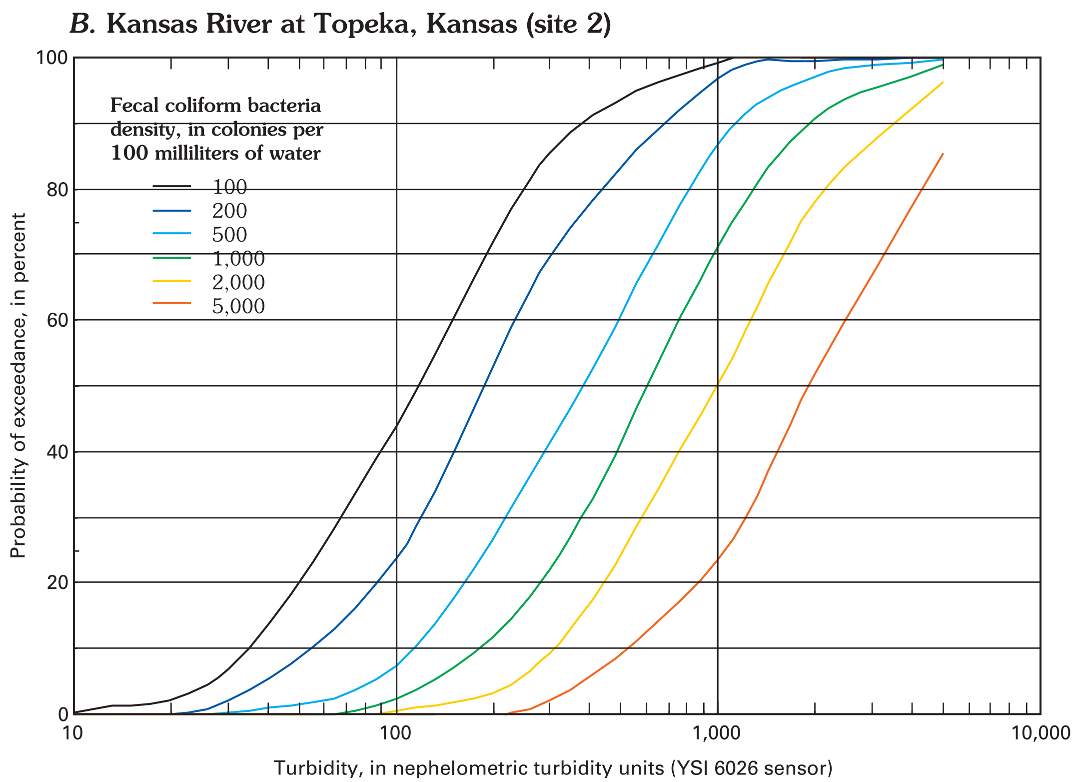


Figure 11*B*. Comparison of measured turbidity and the probability of exceeding selected fecal coliform bacteria densities for Kansas River at Topeka (site 2, fig.1), July 1999 through April 2002.

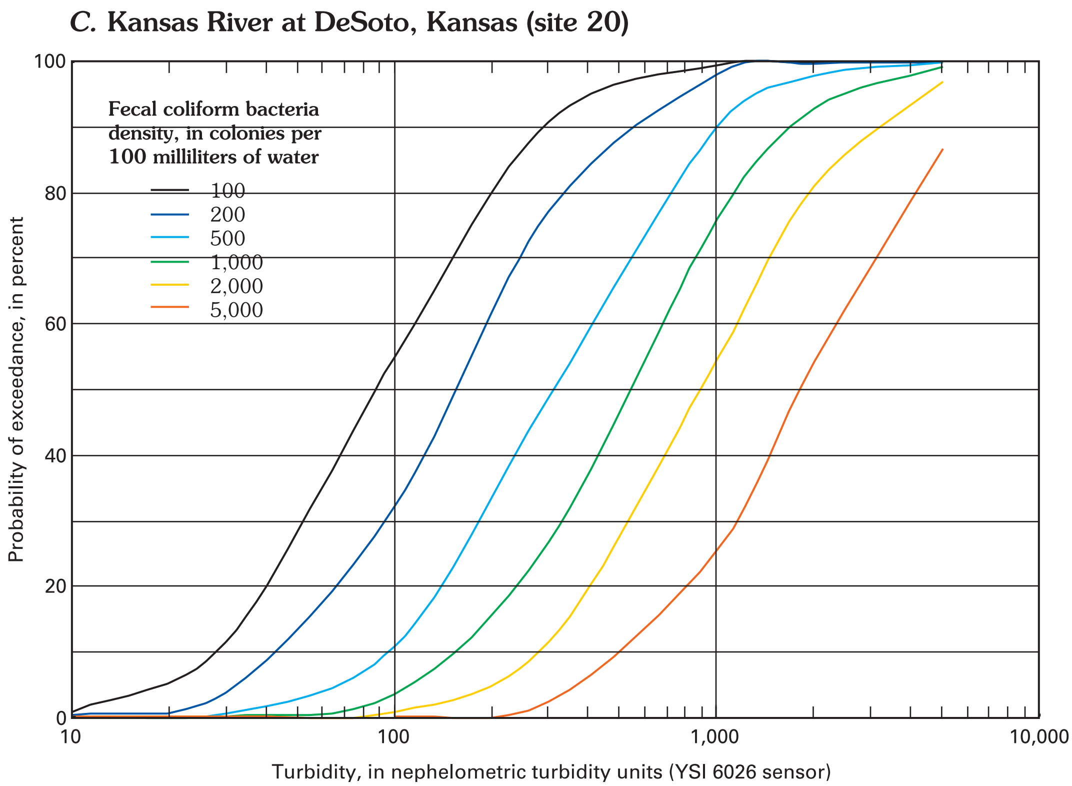


Figure 11*C*. Comparison of measured turbidity and the probability of exceeding selected fecal coliform bacteria densities for Kansas River at DeSoto (site 20, fig. 1), July 1999 through April 2002.

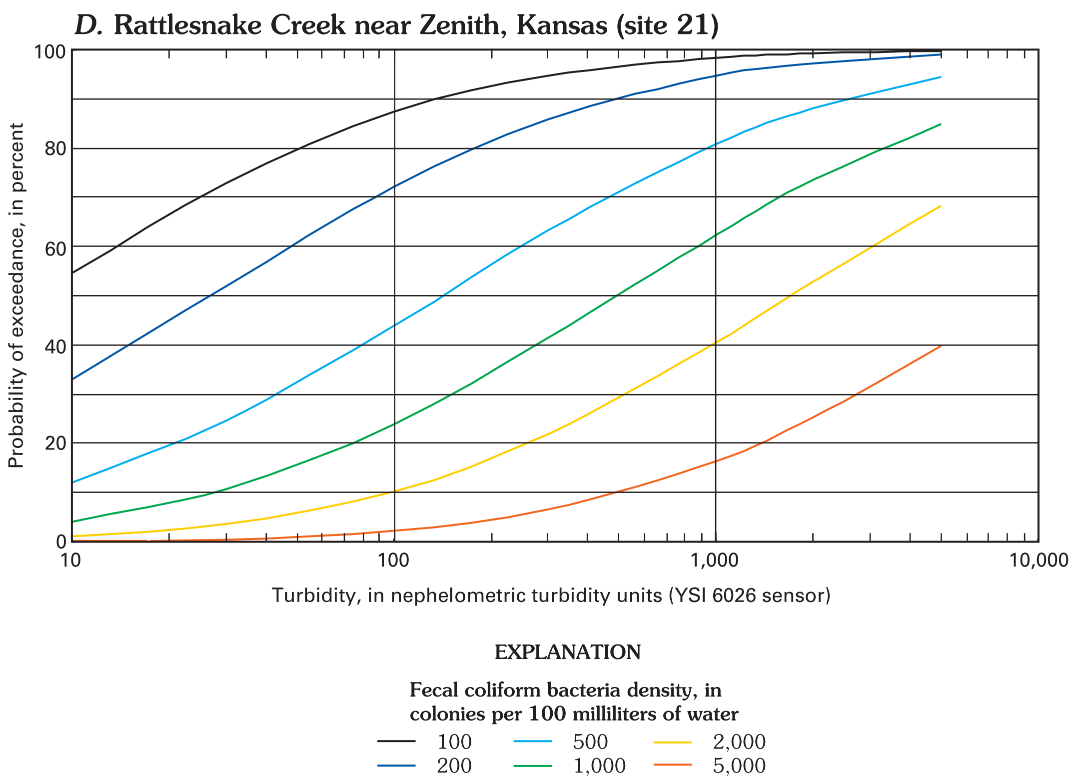


Figure 11*D*. Comparison of measured turbidity and the probability of exceeding selected fecal coliform bacteria densities for Rattlesnake Creek near Zenith (site 21, fig. 1), May 1999 through April 2002.

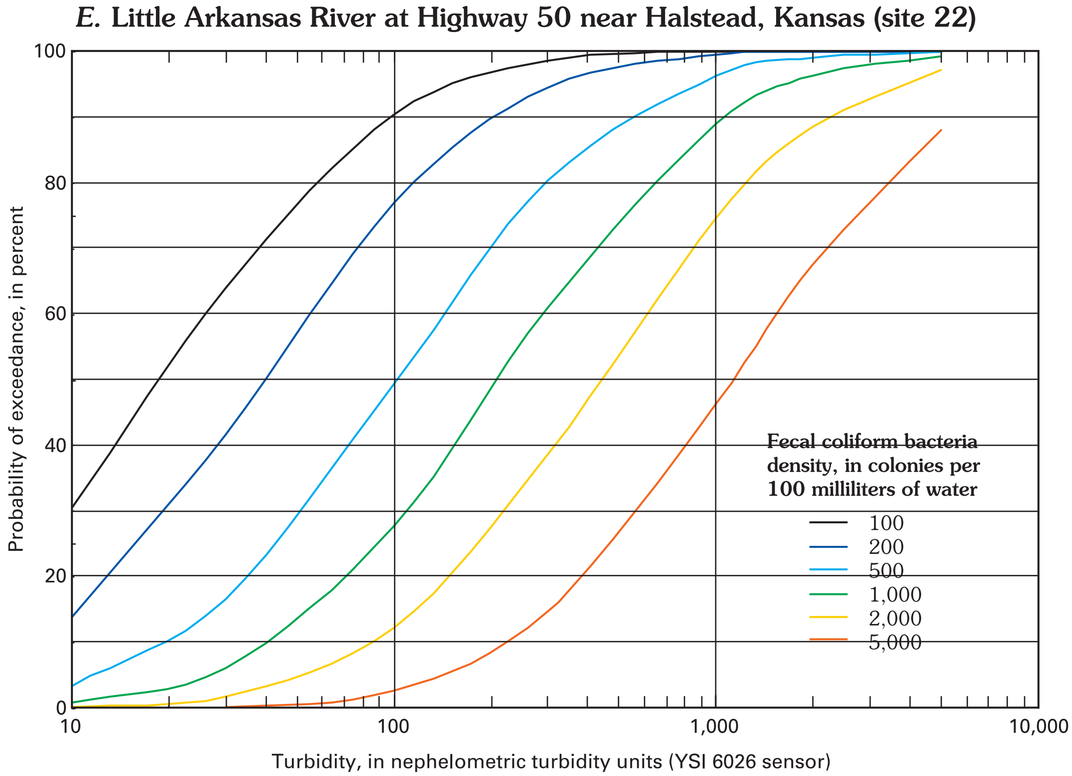


Figure 11*E*. Comparison of measured turbidity and the probability of exceeding selected fecal coliform bacteria densities for Little Arkansas River at Highway 50 near Halstead (site 22, fig. 1), May 1999 through April 2002.

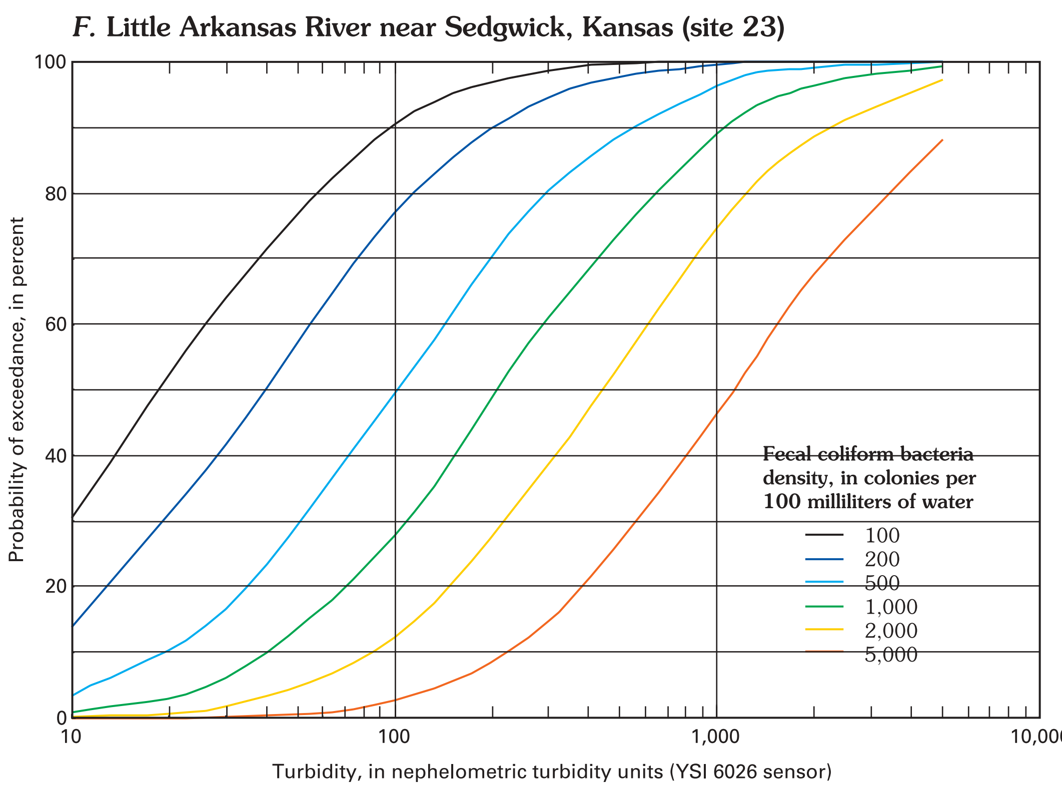


Figure 11*F*. Comparison of measured turbidity and the probability of exceeding selected fecal coliform bacteria densities for Little Arkansas River near Sedgwick (site 23, fig. 1), May 1999 through April 2002.

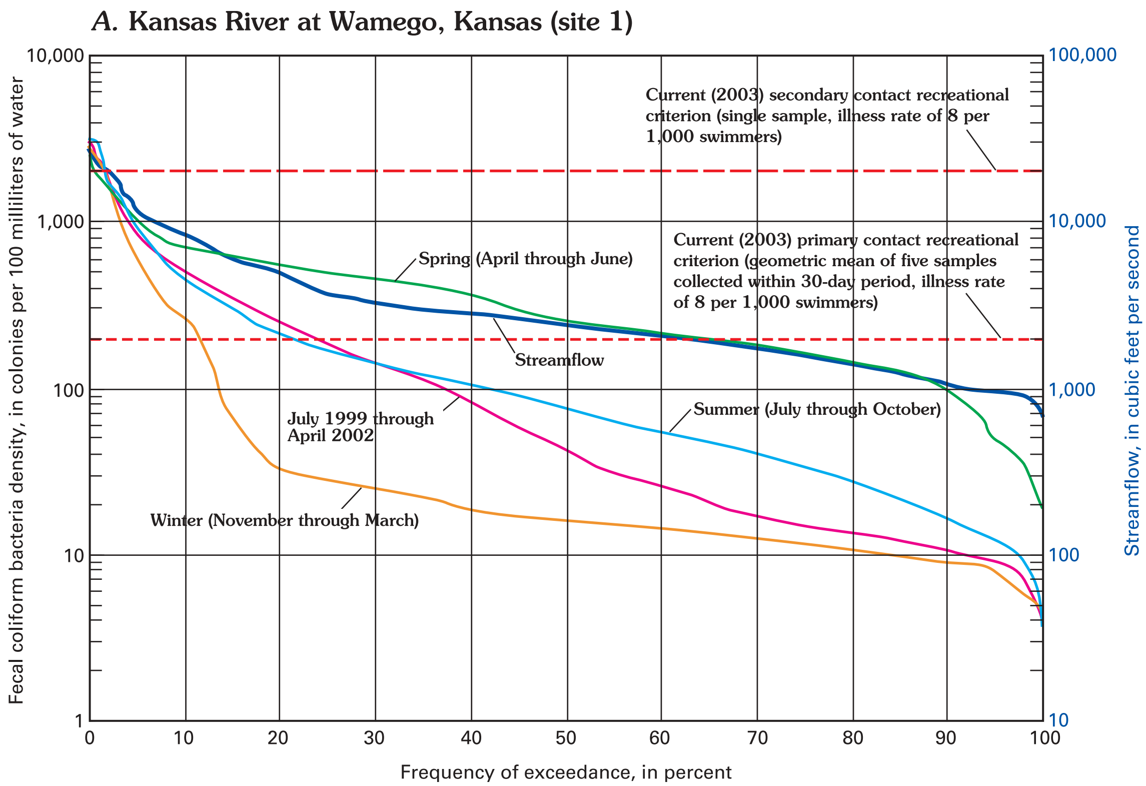


Figure 12*A*. Estimated fecal coliform bacteria densities for Kansas River at Wamego (site 1, fig. 1), July 1999 through April 2002, and for spring, summer, and winter months. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

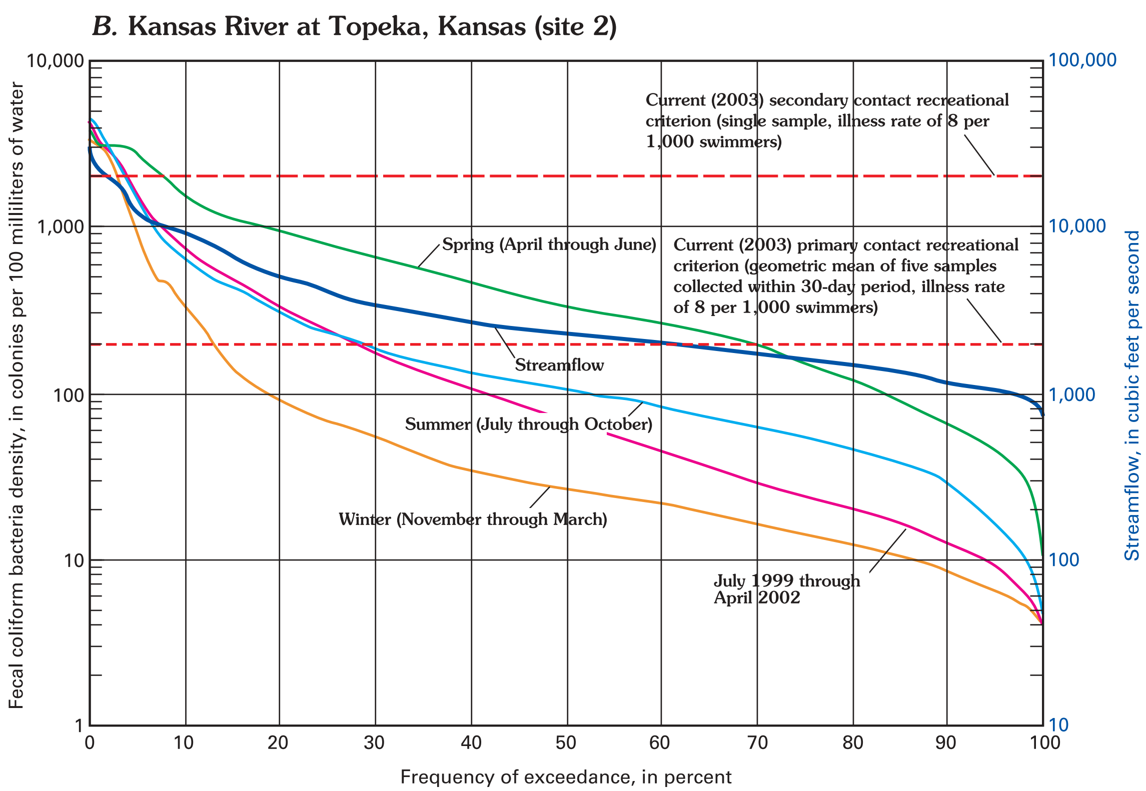


Figure 12*B*. Estimated fecal coliform bacteria densities for Kansas River at Topeka (site 2, fig. 1), July 1999 through April 2002, and for spring, summer, and winter months. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

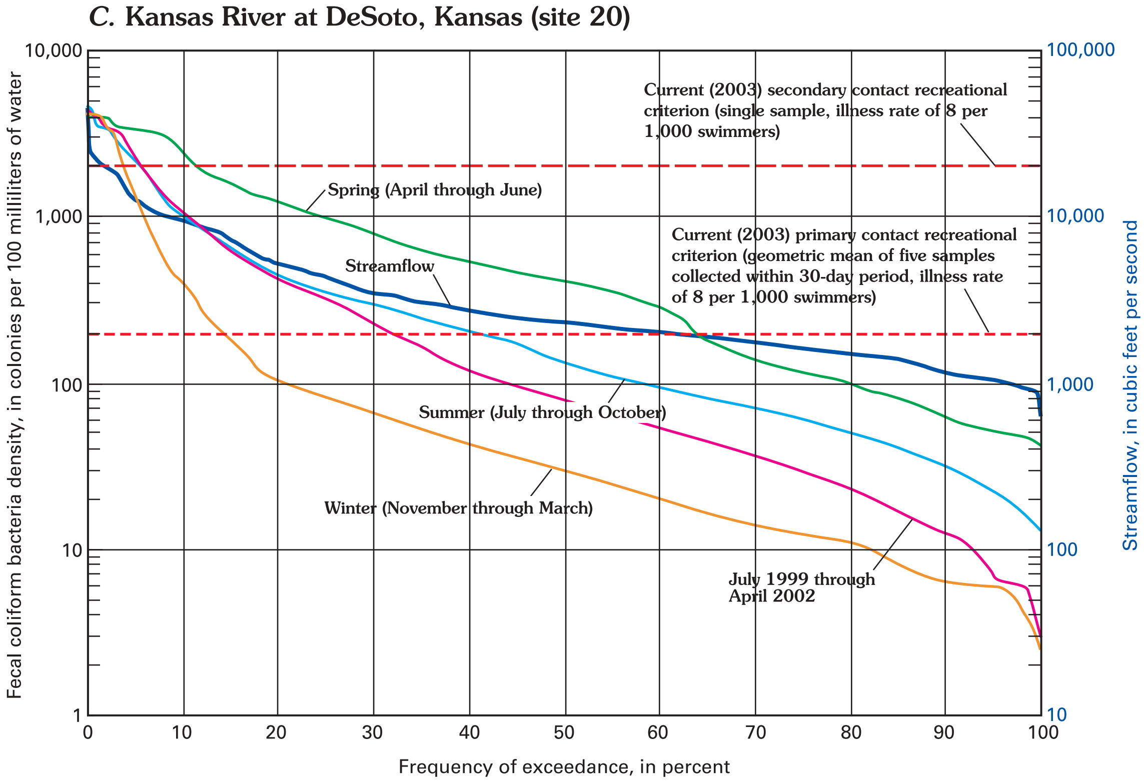


Figure 12*C*. Estimated fecal coliform bacteria densities for Kansas River at DeSoto (site 20, fig. 1), July 1999 through April 2002, and for spring, summer, and winter months. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

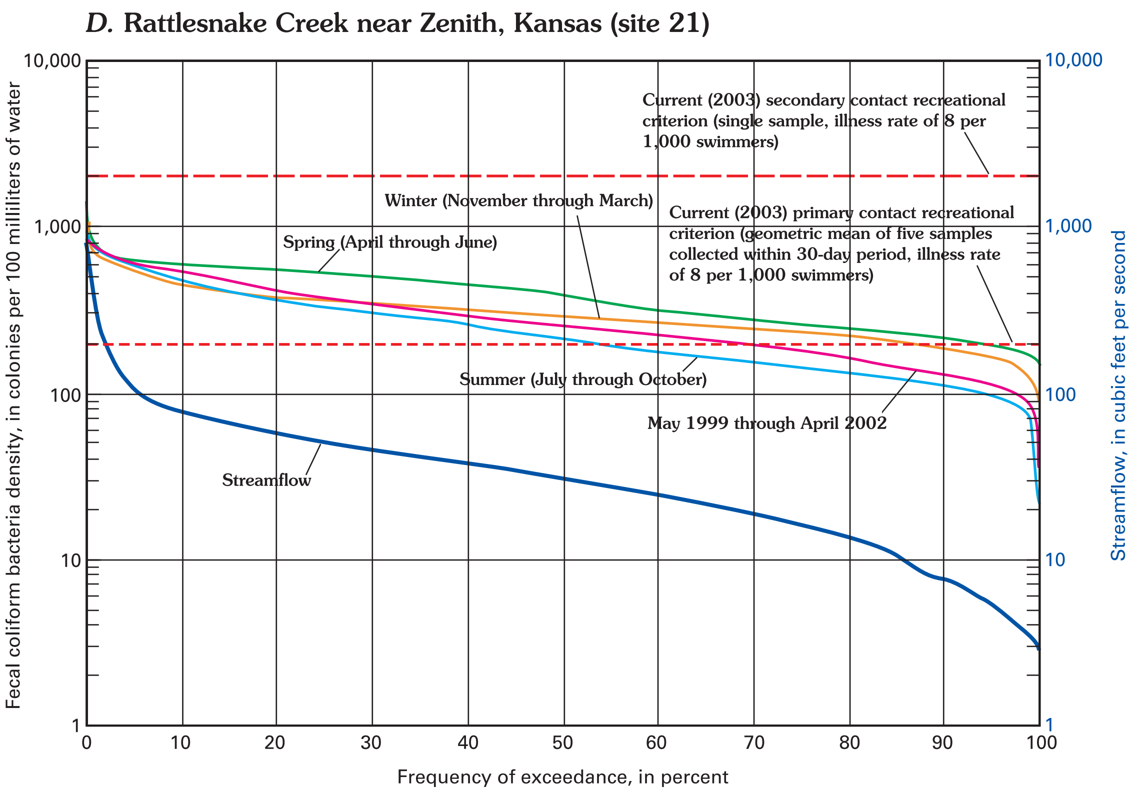


Figure 12*D*. Estimated fecal coliform bacteria densities for Rattlesnake Creek near Zenith (site 21, fig. 1), May 1999 through April 2002, and for spring, summer, and winter months. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

E. Little Arkansas River at Highway 50 near Halstead, Kansas (site 22)

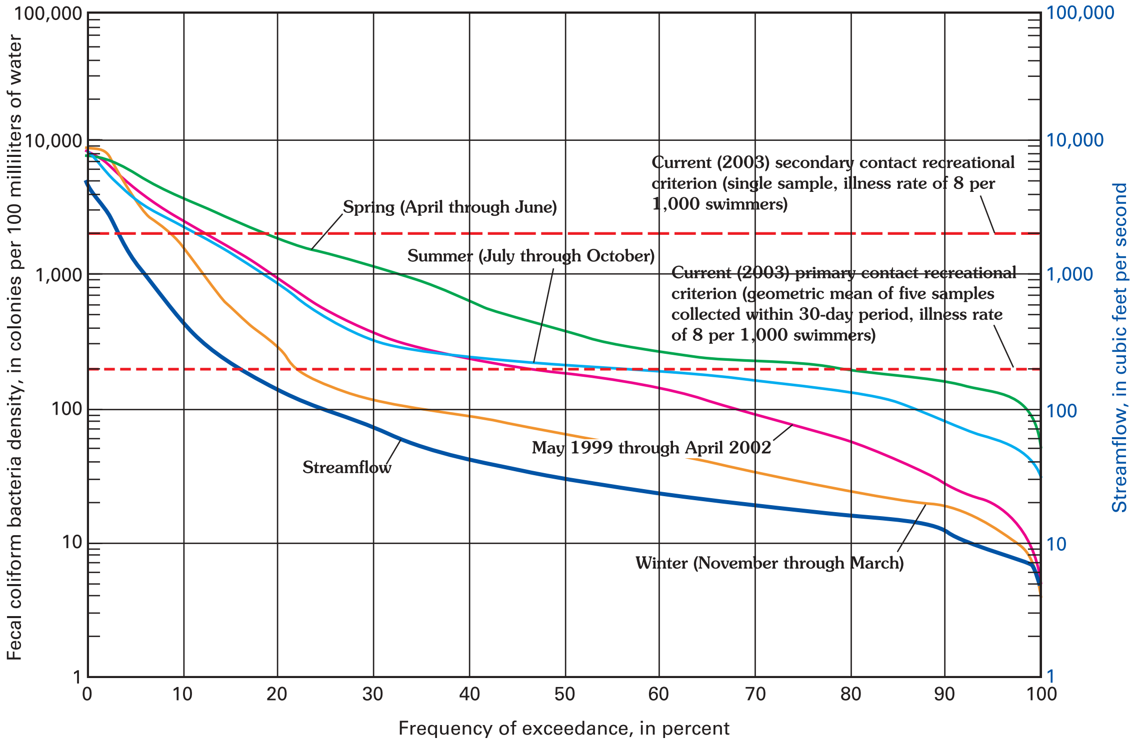


Figure 12*E*. Estimated fecal coliform bacteria densities for Little Arkansas River at Highway 50 near Halstead (site 22, fig. 1), May 1999 through April 2002, and for spring, summer, and winter months. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

F. Little Arkansas River near Sedgwick, Kansas (site 23)

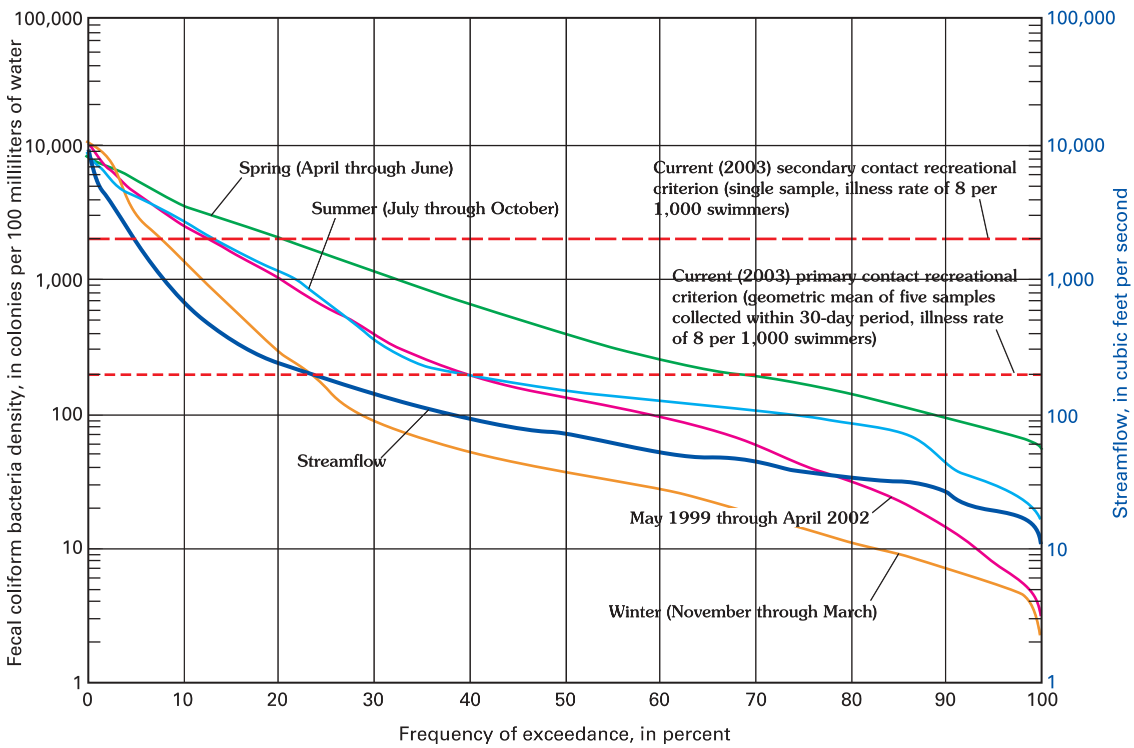


Figure 12*F*. Estimated fecal coliform bacteria densities for Little Arkansas River near Sedgwick (site 23, fig. 1), May 1999 through April 2002, and for spring, summer, and winter months. Recreational water-quality criteria established by Kansas Department of Health and Environment (2001).

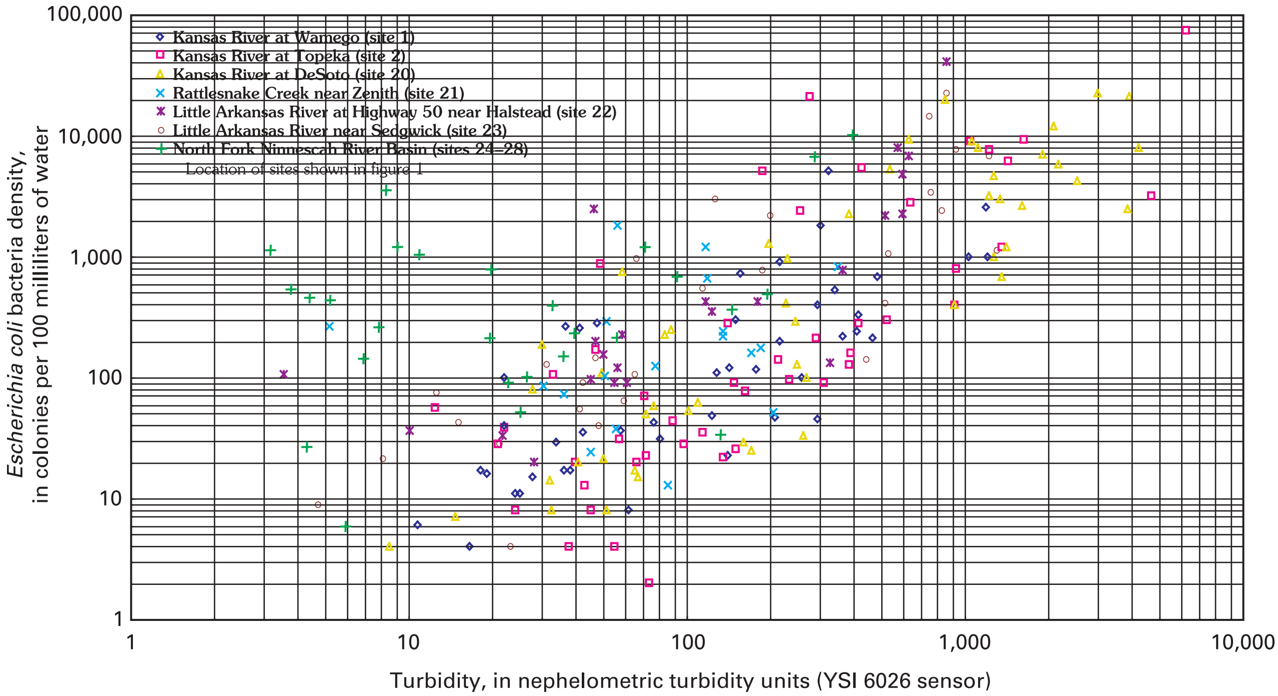


Figure 13. Comparison of measured turbidity and *Escherichia coli* bacteria densities at selected surface-water sites, May 1999 through April 2002.

the 24 samples that had measured densities greater than 576 col/100 mL.

The regression models and continuous (hourly) turbidity data collected at the five surface-water sites were used to continuously estimate *E. coli* bacteria densities for May or July 1999 through April 2002 (fig. 15). Measured *E. coli* bacteria densities from collected water samples were plotted with the regression-estimated densities to give some indication of how well the regression models represented in-stream conditions. The percentage of time that the stream exceeded a water-quality criteria was calculated and is shown on these graphs, which gives an indication of the probability that a stream will meet water-quality criteria and TMDL goals.

The percentage of estimated hourly *E. coli* densities that were greater than USEPA recommended recreational-use criteria were divided into three seasons (table 10). Spring had the highest percentage of samples that exceeded the geometric-mean and single-sample criteria followed by summer and then winter. Estimated *E. coli* densities in the spring (April through June) at the three Kansas River sites (1, 2, 20) indicate that the single-sample criterion (576 col/100 mL) was exceeded between 9 and 29 percent of the time (table 10). The *E. coli* density single-sample criterion was exceeded at the two sites on the Little Arkansas River (sites 22, 23) 41 and 39 percent, respectively, of the time in the spring. A comparison of estimated *E. coli* densities in the two rivers for the spring indicate that the geometric-mean criterion of 126 col/100 mL was exceeded 62 to 97 percent of the time. The percentage of exceedance of 576 col/100 mL for sites on the Kansas River increase from upstream to downstream in the spring, summer, and winter. The percentage of hourly concentrations greater than 576 col/100 mL in the Little Arkansas River decreased slightly from upstream to downstream in the spring, summer, and winter.

The continuous turbidity data for this report had days of no data or incomplete data due to removal of the multiparameter monitor during periods of ice conditions or equipment malfunctions. For these periods, turbidity values were interpolated between the values prior to and after the period of no data. These data are highlighted in red on the graphs (fig. 15). None of the interpolated turbidity values were greater than 240 NTU, corresponding to an estimated *E. coli* density of 269 col/100 mL for the specific site. A limitation to applying regression models to continuous data is that the in-stream turbidity sensor maximum varies between 1,000 to 1,500 NTU, truncating the actual turbidity peak. This truncation is evident in the graphs (fig. 15) where the estimated *E. coli* density is

Table 8. Regression models and statistics for estimating *Escherichia coli* (*E. coli*) bacteria densities using turbidity measurements (using a YSI model 6026) at selected surface-water sites in Kansas, May 1999 through April 2002

[R^2, coefficient of determination; *MSE*, mean square error; *n*, number of samples; *RMAE*, relative mean absolute error; SS_x, sum of squares *x*; *RPD*, relative percentage difference; *ECB*, *Escherichia coli* bacteria; *NTU*, turbidity measured using a YSI model 6026 turbidity probe; --, not determined]

Site number (fig. 1)	Regression model	R^2	*MSE* (log units)	Standard error of estimate (percent)	*n*	Range in *E. coli* bacteria densities (colonies per 100 milliliters)	Range in turbidity (nephelometric turbidity units)	*RMAE* (percent)	SS_X (log units)	Median *RPD* (percent)	Bias-correction factor (Duan, 1983)
1	$Log_{10}ECB = 1.18log_{10}NTU - 0.457$	0.60	0.294	195	46	1–5,200	11–1,200	127	13.0	80	2.16
2	$Log_{10}ECB = 1.33log_{10}NTU – 0.746$	.59	.492	350	47	2–75,000	12–6,200	84	22.2	85	4.28
20	$Log_{10}ECB = 1.40log_{10}NTU – 0.883$	.76	.350	230	52	1–23,000	9–4,210	71	17.5	75	2.36
21	No significant relation	--	--	--	18	--	--	--	--	--	--
22	$Log_{10}ECB = 1.01log_{10}NTU + 0.439$	.63	.290	190	23	20–41,000	4–860	77	6.08	70	2.28
23	$Log_{10}ECB = 1.17log_{10}NTU + 0.111$	.73	.278	185	28	4–23,000	5–1,300	76	7.23	70	1.88

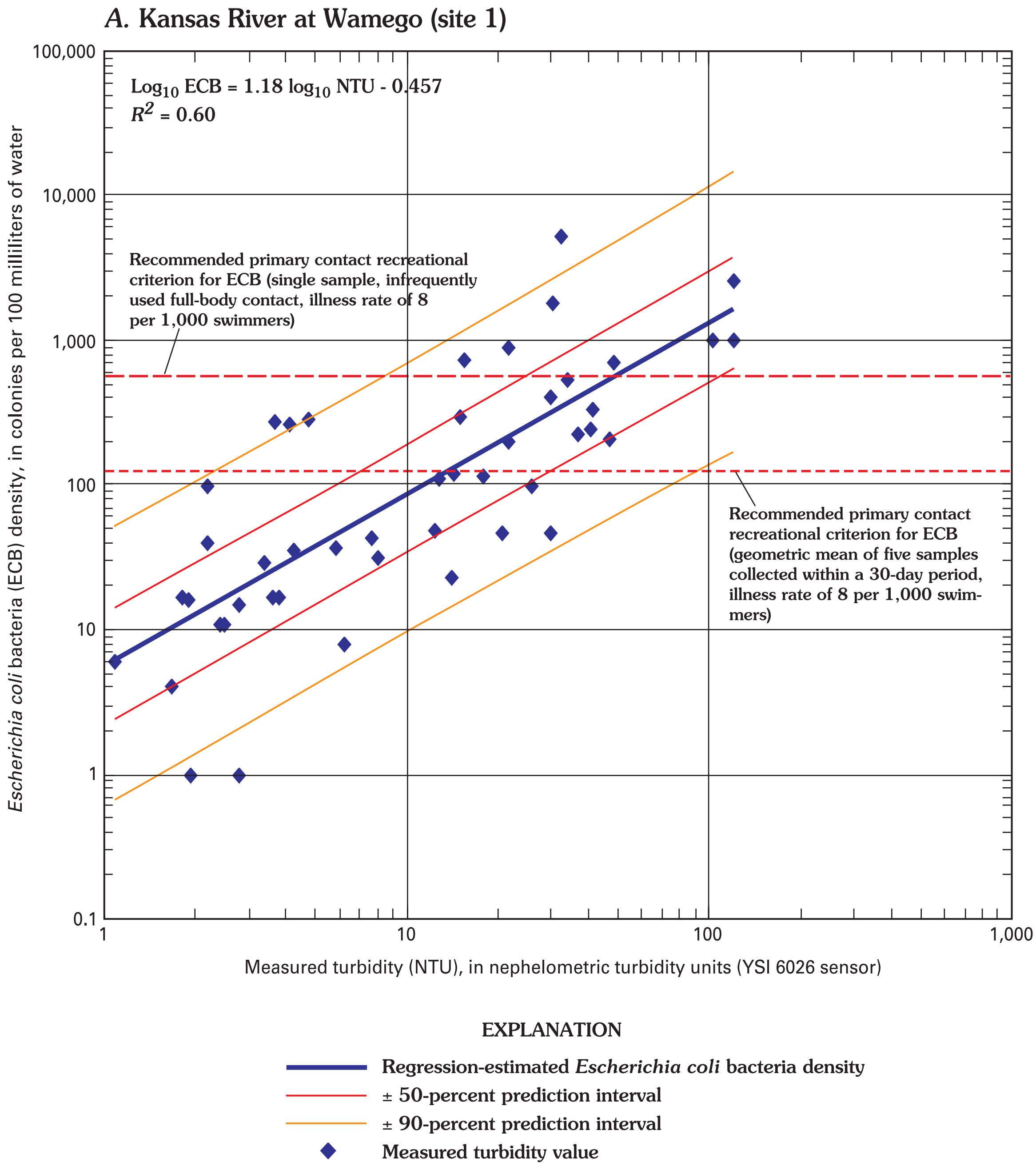


Figure 14*A*. Comparison of measured turbidity and regression-estimated *Escherichia coli* bacteria densities and prediction intervals for Kansas River at Wamego (site 1, fig. 1), July 1999 through April 2002. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).

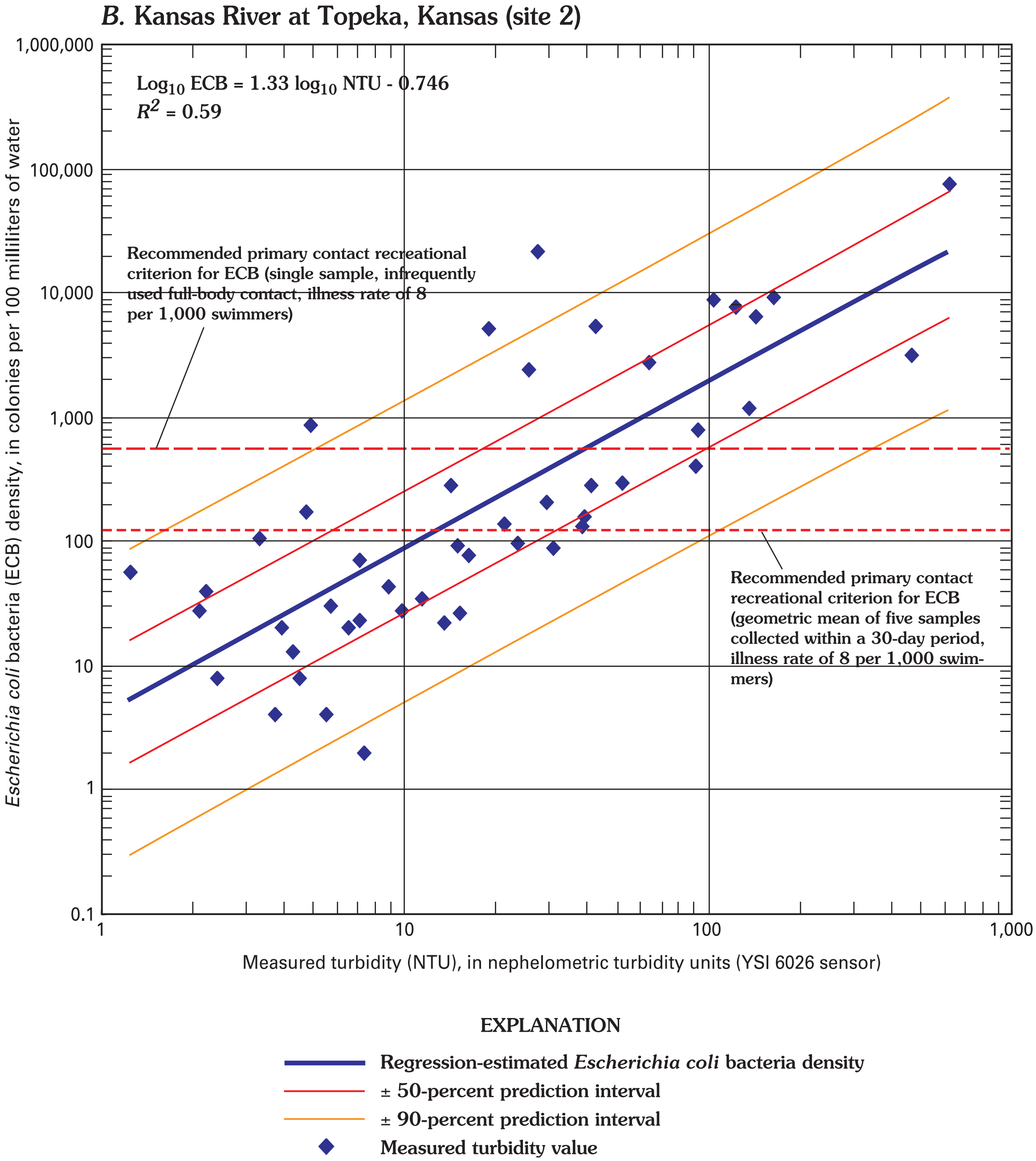


Figure 14*B*. Comparison of measured turbidity and regression-estimated *Escherichia coli* bacteria densities and prediction intervals for Kansas River at Topeka (site 2, fig. 1), July 1999 through April 2002. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).

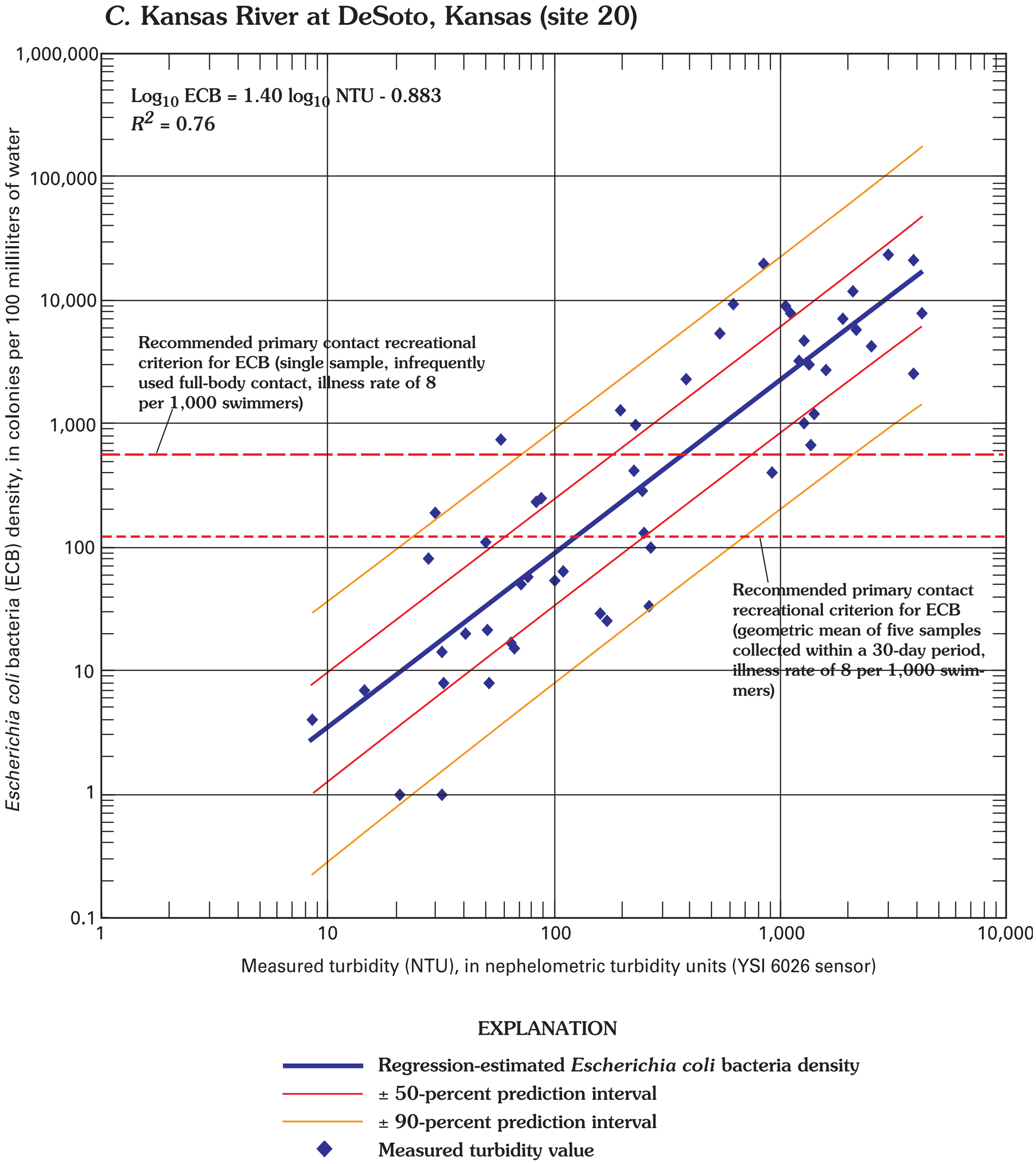


Figure 14*C*. Comparison of measured turbidity and regression-estimated *Escherichia coli* bacteria densities and prediction intervals for Kansas River at DeSoto (site 20, fig. 1), July 1999 through April 2002. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).

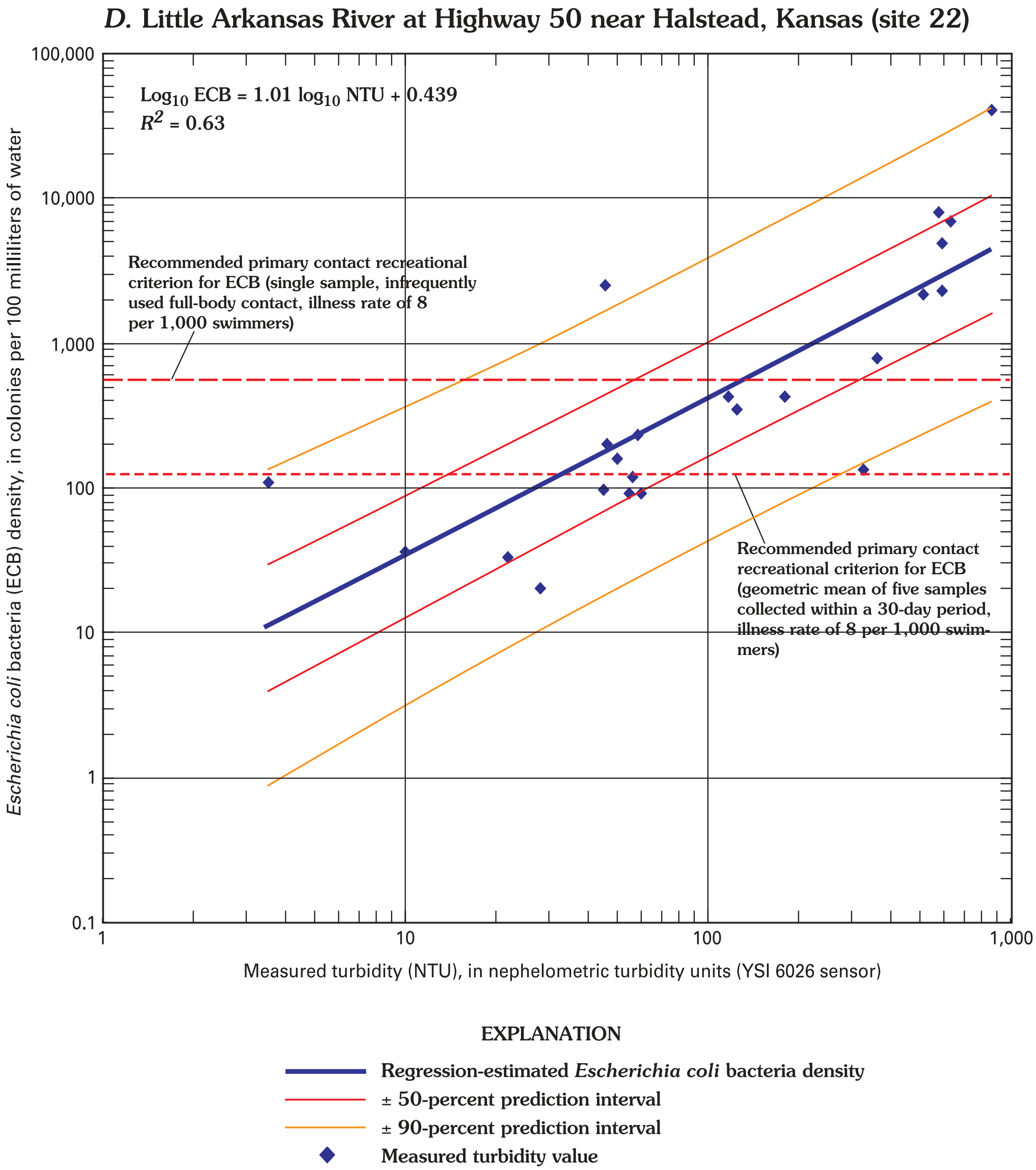


Figure 14*D*. Comparison of measured turbidity and regression-estimated *Escherichia coli* bacteria densities and prediction intervals for Little Arkansas River at Highway 50 near Halstead (site 22, fig. 1), May 1999 through April 2002. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).

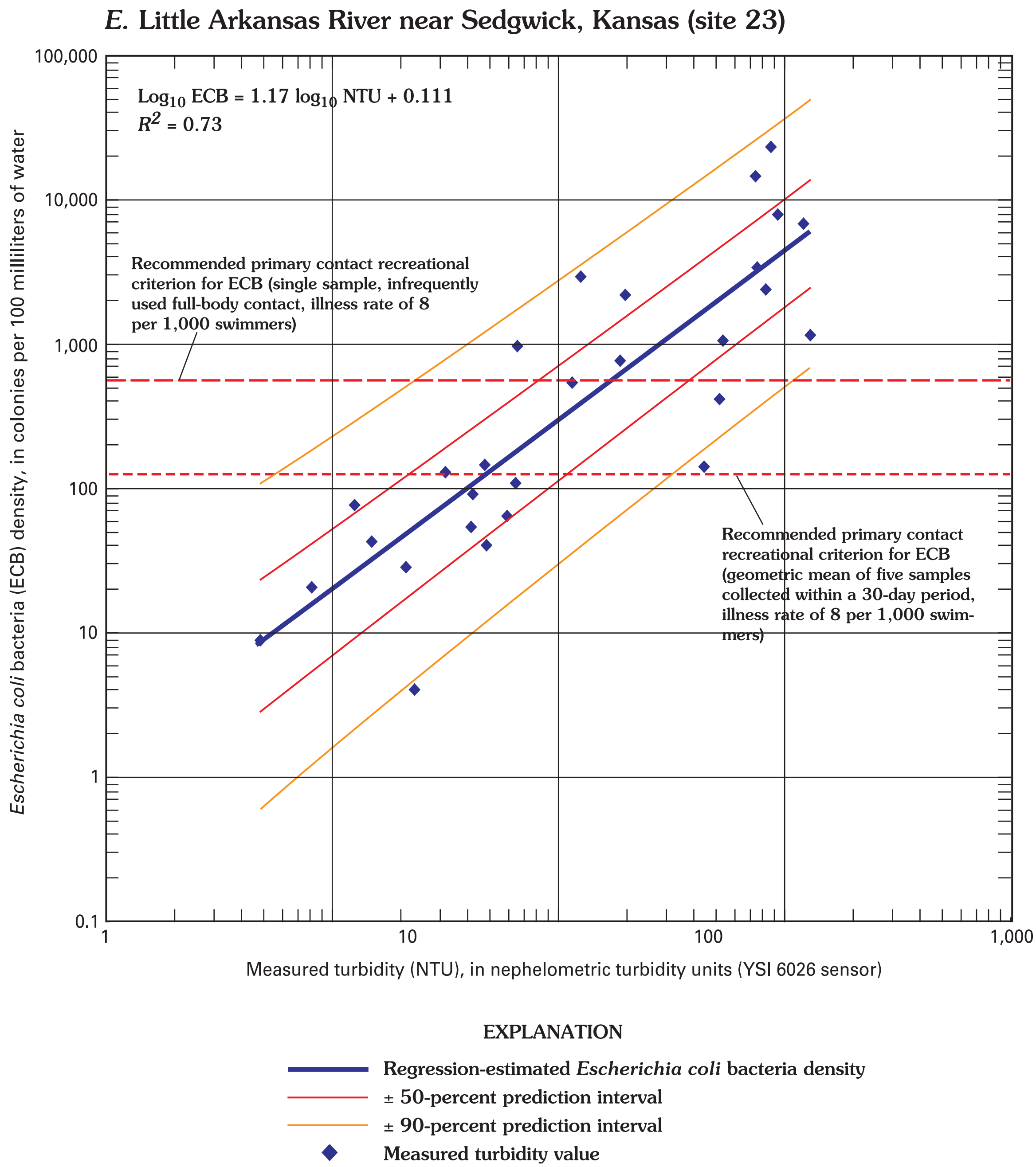


Figure 14*E*. Comparison of measured turbidity and regression-estimated *Escherichia coli* bacteria densities and prediction intervals for Little Arkansas River near Sedgwick (site 23, fig. 1), May 1999 through April 2002. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).

Table 9. Percentage of regression-model estimates in agreement with measured *Escherichia coli* bacteria densities in relation to U.S. Environmental Protection Agency recommended primary contact recreational criteria for selected surface-water sites in Kansas, May 1999 through April 2002

[Recommended recreational water-quality criteria from U.S. Environmental Protection Agency (2002). <, less than; >, greater than; col/100 mL, colonies per 100 milliliters of water; --, not determined]

Site no. (fig. 1)	Site name	Percentage of estimated values <126 col/100 mL that were in agreement with measured sample densities <126 col/100 mL (total number of samples with densities <126 col/100 mL)	Percentage of estimated values >126 col/100 mL that were in agreement with measured sample densities >126 col/100 mL (total number of samples with densities >126 col/100 mL)	Percentage of estimated values <576 col/100 mL that were in agreement with measured sample densities <576 col/100 mL (total number of samples with densities <576 col/100 mL)	Percentage of estimated values >576 col/100 mL that were in agreement with measured sample densities >576 col/100 mL (total number of samples with densities >576 col/100 mL)
1	Kansas River at Wamego	85 (27)	84 (19)	100 (38)	38 (8)
2	Kansas River at Topeka	79 (24)	91 (23)	94 (33)	64 (14)
20	Kansas River at DeSoto	81 (21)	87 (31)	96 (28)	83 (24)
21	Rattlesnake Creek near Zenith	-- (7)	-- (10)	-- (14)	-- (4)
22	Little Arkansas River at Highway 50 near Halstead	50 (8)	100 (15)	93 (15)	88 (8)
23	Little Arkansas River near Sedgwick	82 (11)	88 (17)	88 (16)	83 (12)

at its maximum for several hours (or days). For these instances, actual *E. coli* bacteria densities were likely greater than the plotted regression-estimated density.

Probability and Duration of Estimated *Escherichia Coli* Densities

The continuous estimated *E. coli* bacteria densities can be displayed as probabilities and durations that allow for easier identification of water quality for a particular stream segment. The public and water-management agencies can use probability values and duration curves to assess short- and long-term water-quality conditions relative to water-quality criteria. These assessments can assist in evaluating best management practices and in determining or evaluating TMDLs.

The estimated *E. coli* bacteria densities provided in the previous section need to be considered with the uncertainty of the estimate in mind. To simplify this consideration process, the probability (at the 95-percent confidence level) of exceeding the USEPA recommended criteria can be displayed for each of the hourly estimates. Figure 15 illustrates the probability (expressed as a percentage) that the maximum hourly estimate for each day of the study period exceeds the given criteria. Real-time hourly probability values available on the World Wide Web (http://ks.water.usgs.gov/Kansas/rtqw) provide the public and water managers information when considering public health and safety for recreation water bodies.

The relation between turbidity and *E. coli* bacteria density also can be displayed as probability curves (fig. 16). Each curve represents an *E. coli* density and is plotted using turbidity (x axis) and the probability that the actual *E. coli* density is equal to the estimated density (y axis). The figures can be used to estimate *E. coli* concentrations based on turbidity values. [Note: Only turbidity values from a YSI 6026 turbidity sensor are appropriate for relations described in report. See "Methods" section of this report.] For instance, the actual *E. coli* bacteria density for the Kansas River at Wamego (site 1) for a turbidity value of 100 NTU has a 94-percent chance of being less than 576 col/100 mL and a 36-percent chance of being greater than 126 col/100 mL (fig. 16*A*). For a turbidity value of 1,000 NTU for the Kansas River at Wamego (site 1), there is a 28-percent chance that the actual *E. coli* bacteria density is greater than 576 col/100 mL and a 97-percent chance that it is greater than 126 col/100 mL.

Duration curves were plotted using the hourly estimates of *E. coli* bacteria density for each of five surface-water sites (fig. 17). The duration curves represent the hourly estimated *E. coli* densities from May or July 1999 through April 2002. The data are plotted against the frequency of each hourly value occurring

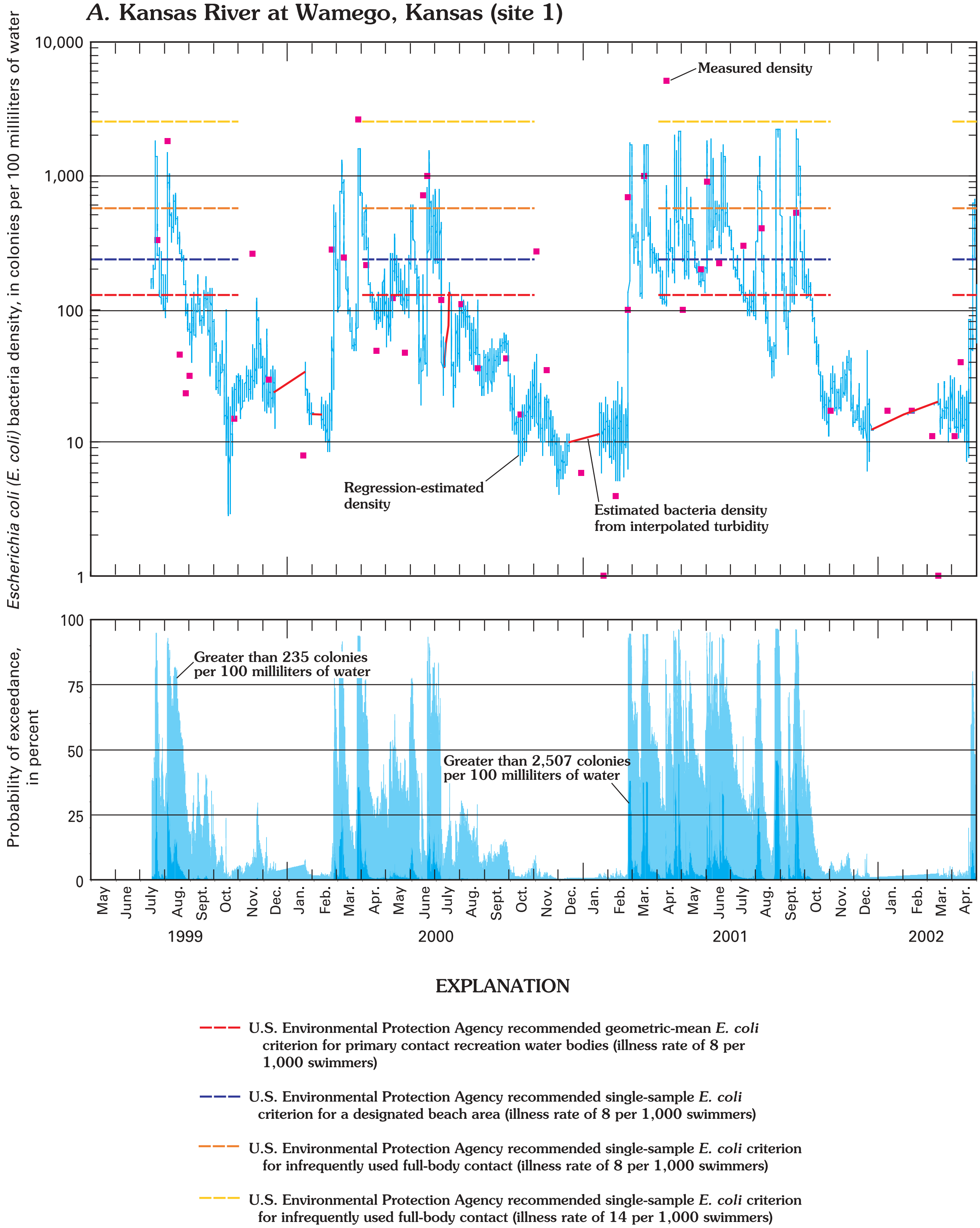
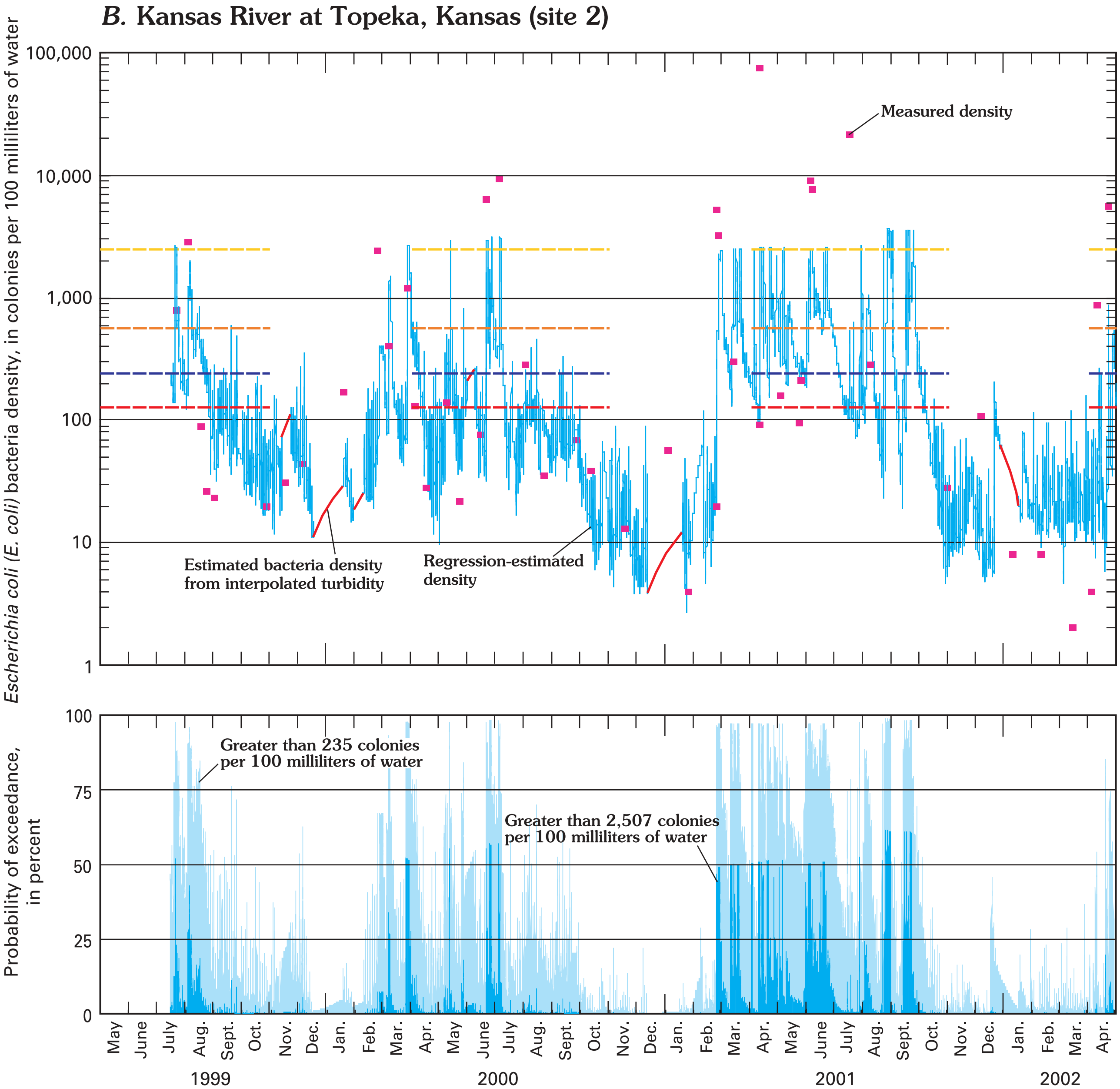


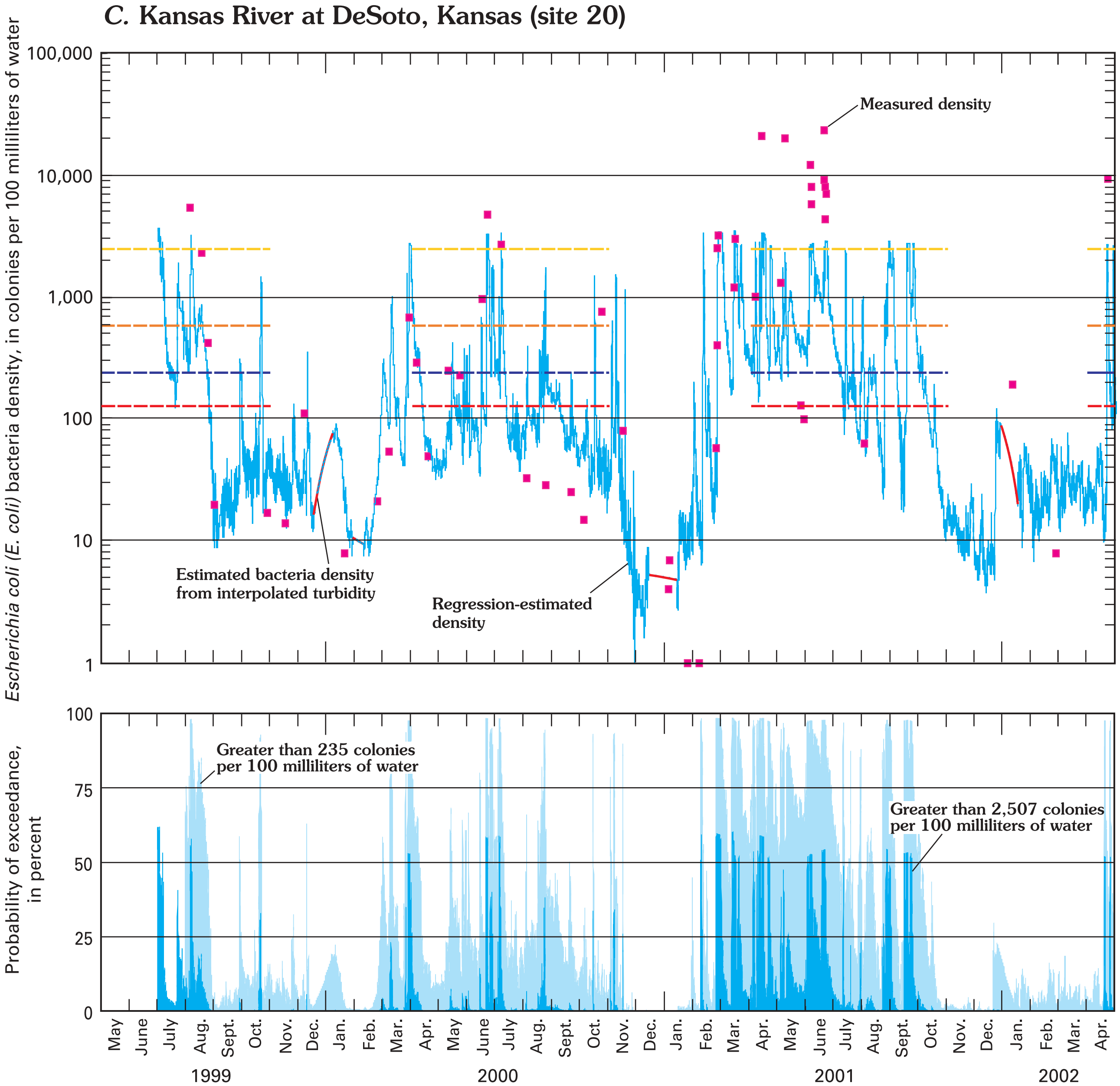
Figure 15*A*. Comparison of measured and regression-estimated *Escherichia coli* bacteria densities in samples from Kansas River at Wamego (site 1, fig. 1), July 1999 through April 2002, and probability of exceedance of water-quality criteria. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).



EXPLANATION

- U.S. Environmental Protection Agency recommended geometric-mean *E. coli* criterion for primary contact recreation water bodies (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for a designated beach area (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 14 per 1,000 swimmers)

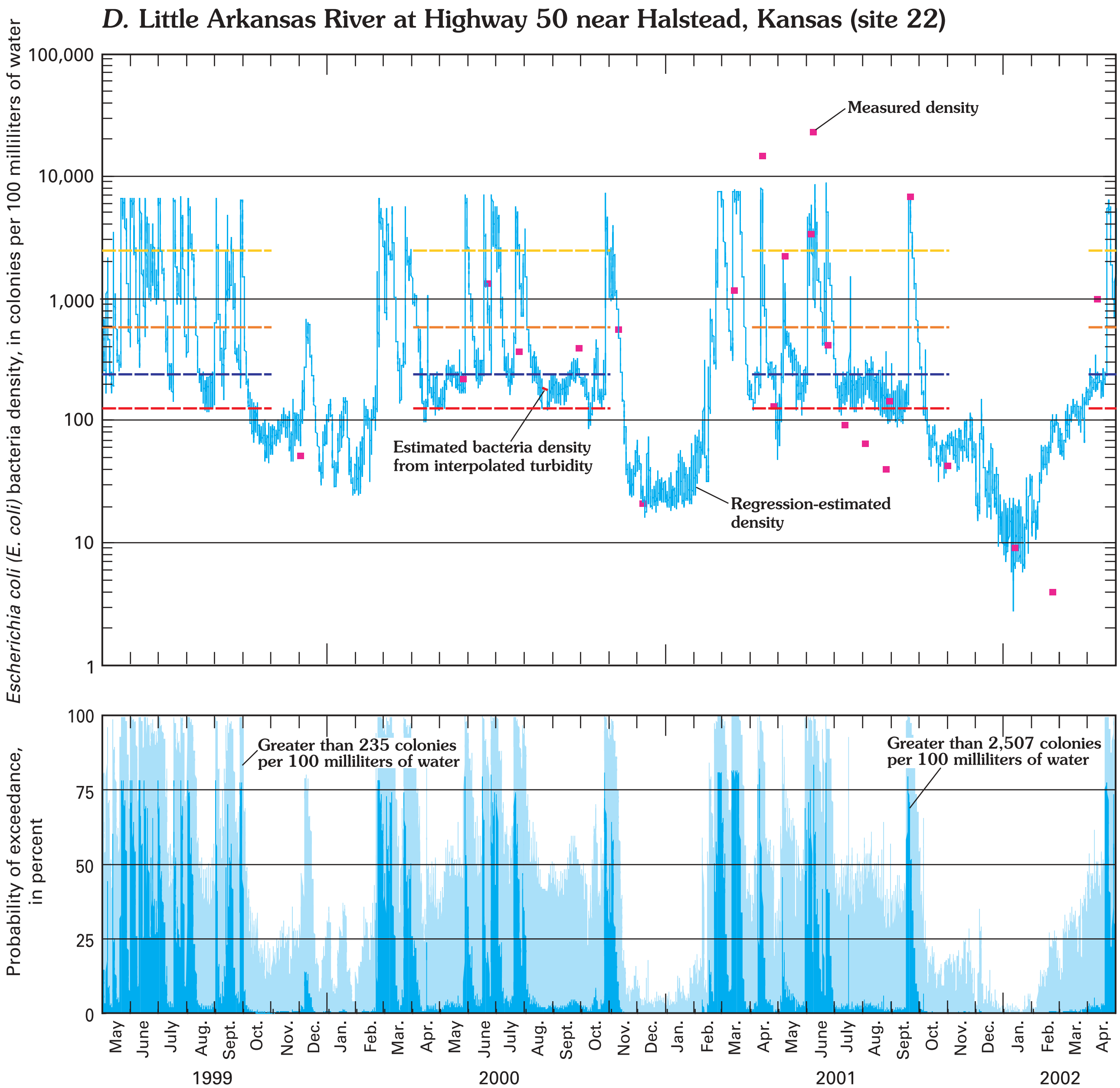
Figure 15*B*. Comparison of measured and regression-estimated *Escherichia coli* bacteria densities in samples from Kansas River at Topeka (site 2, fig. 1), July 1999 through April 2002, and probability of exceedance of water-quality criteria. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).



EXPLANATION

- U.S. Environmental Protection Agency recommended geometric-mean *E. coli* criterion for primary contact recreation water bodies (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for a designated beach area (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 14 per 1,000 swimmers)

Figure 15*C*. Comparison of measured and regression-estimated *Escherichia coli* bacteria densities in samples from Kansas River at DeSoto (site 20, fig. 1), July 1999 through April 2002, and probability of exceedance of water-quality criteria. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).



EXPLANATION

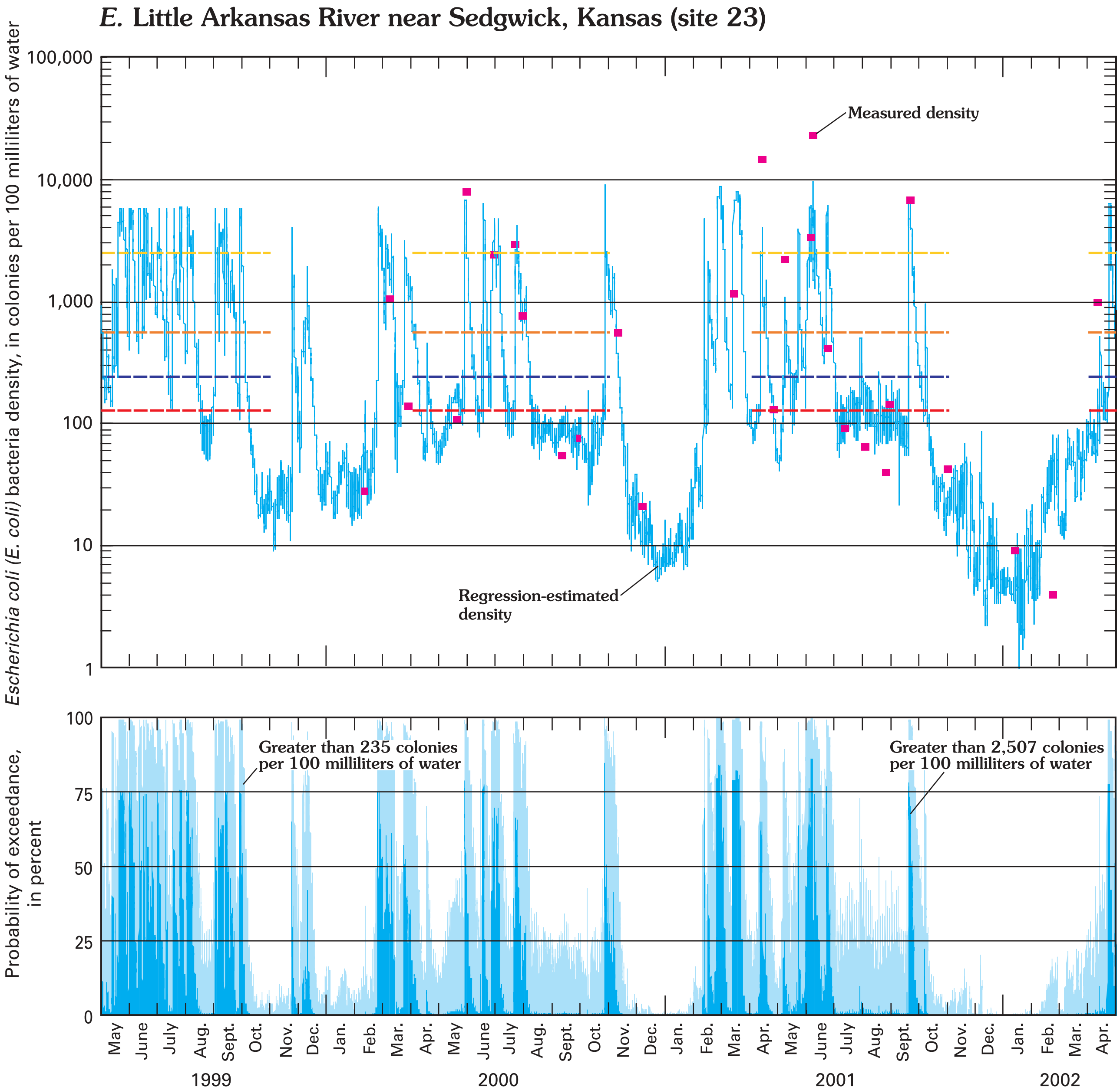
U.S. Environmental Protection Agency recommended geometric-mean *E. coli* criterion for primary contact recreation water bodies (illness rate of 8 per 1,000 swimmers)

U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for a designated beach area (illness rate of 8 per 1,000 swimmers)

U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 8 per 1,000 swimmers)

U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 14 per 1,000 swimmers)

Figure 15*D*. Comparison of measured and regression-estimated *Escherichia coli* bacteria densities in samples from Little Arkansas River at Highway 50 near Halstead (site 22, fig. 1), May 1999 through April 2002, and probability of exceedance of water-quality criteria. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).



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- U.S. Environmental Protection Agency recommended geometric-mean *E. coli* criterion for primary contact recreation water bodies (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for a designated beach area (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 14 per 1,000 swimmers)

Figure 15*E*. Comparison of measured and regression-estimated *Escherichia coli* bacteria densities in samples from Little Arkansas River near Sedgwick (site 23, fig. 1), May 1999 through April 2002, and probability of exceedance of water-quality criteria. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).

Table 10. Percentage of estimated hourly *Escherichia coli* bacteria densities that were greater than U.S. Environmental Protection Agency recommended recreational criteria for five selected surface-water sites in Kansas, May or July 1999 through April 2002

[Numbers are percentage of estimated hourly *Escherichia coli* densities. Recreational criteria from U.S. Environmental Protection Agency (2002). col/100 mL, colonies per 100 milliliters of water]

Site number (fig. 1)	Percentage greater than geometric-mean criterion (126 col/mL)			Percentage greater than single-sample criterion (576 col/mL)		
	Spring (April–June)	Summer (July–October)	Winter (November–March)	Spring (April–June)	Summer (July–October)	Winter (November–March)
[1]1	68	31	13	9	7	4
[2]2	68	37	13	26	10	5
[3]20	62	47	15	29	14	6
22	97	83	22	41	23	15
23	78	47	25	39	24	14

[1]July 16, 1999, through April 2002. [2]July 15, 1999, through April 2002. [3]July 1, 1999, through April 2002.

within the period. The duration curves are an excellent summary of the estimated bacteria densities for the given period and can be used for many purposes. The minimum (100-percent exceedance), median (50-percent exceedance), and maximum (0-percent exceedance) estimated bacteria densities can be easily obtained from the curve. The curves also give an indication of how frequently the estimated bacteria densities exceeded a specific water-quality criteria over a given period.

Durations curves for the entire study period indicate that the USEPA recommended single-sample criterion for *E. coli* bacteria density for infrequently used full-body contact (576 col/100 mL) was exceeded between 8 and 24 percent of the time for the five surface-water sites. During the designated recreation period (April through October), exceedances of the USEPA recommended geometric-mean criterion (126 col/100 mL) occurred between 62 and 97 percent of the spring (April through June) and 31 and 83 percent of the summer (July through October). Duration curves for estimated *E. coli* densities for spring (April through June), summer (July through October), and winter (November through March) illustrate the differences among the three seasons. For all five sites, the median estimated *E. coli* density in the spring was at least 2 times greater than the median winter density. The seasonal differences were largest for the three Kansas River sites (1, 2, 20), indicating that reservoir releases (low turbidity and low *E. coli* densities) predominate the streamflow in the winter. The streamflow duration curve for each site is plotted with the bacteria duration curves to provide a comparison of streamflow and bacteria density.

ESTIMATED BACTERIA LOADS AND YIELDS

Bacteria loads were calculated to determine total number of colonies being transported in each stream annually and during spring, summer, and winter for 2000 and 2001. Hourly regression-estimated fecal coliform and *E. coli* bacteria densities were multiplied by streamflow and the bias-correction factor (tables 5 and 8) to estimate seasonal and annual loads and yields at six surface-water sites with continuous turbidity measurements. Continuous loads of bacteria can be used to evaluated point- and nonpoint-source contributions and seasonal differences. Bacteria yields were calculated by dividing loads by corresponding drainage areas to determine the number of colonies per acre for a given time period. Land use is similar for the three stream basins represented by the six surface-water sites, but the drainage area for the Kansas River Basin is more than 44 times as large as the drainage areas for the Rattlesnake Creek and Little Arkansas River Basins. Considering the entire drainage area when calculating bacteria yields at Wamego, Topeka, and DeSoto on the Kansas River is inappropriate due to the reservoirs within the basin. Sediment and bacteria flowing into a reservoir are trapped by the reservoir. Two previous studies in Kansas (Pope, 1995; Mau and Pope, 1999) determined that bacteria densities in the outflow of three reservoirs were usually less than 15 col/100 mL. Therefore, the drainage areas for the sites in the Kansas River Basin were modified so that only the unregulated portions of the basin were used to define yield.

There are limitations for calculating loads and yields using the continuous data. The maximum for the turbidity sensors used at the continuous sites was

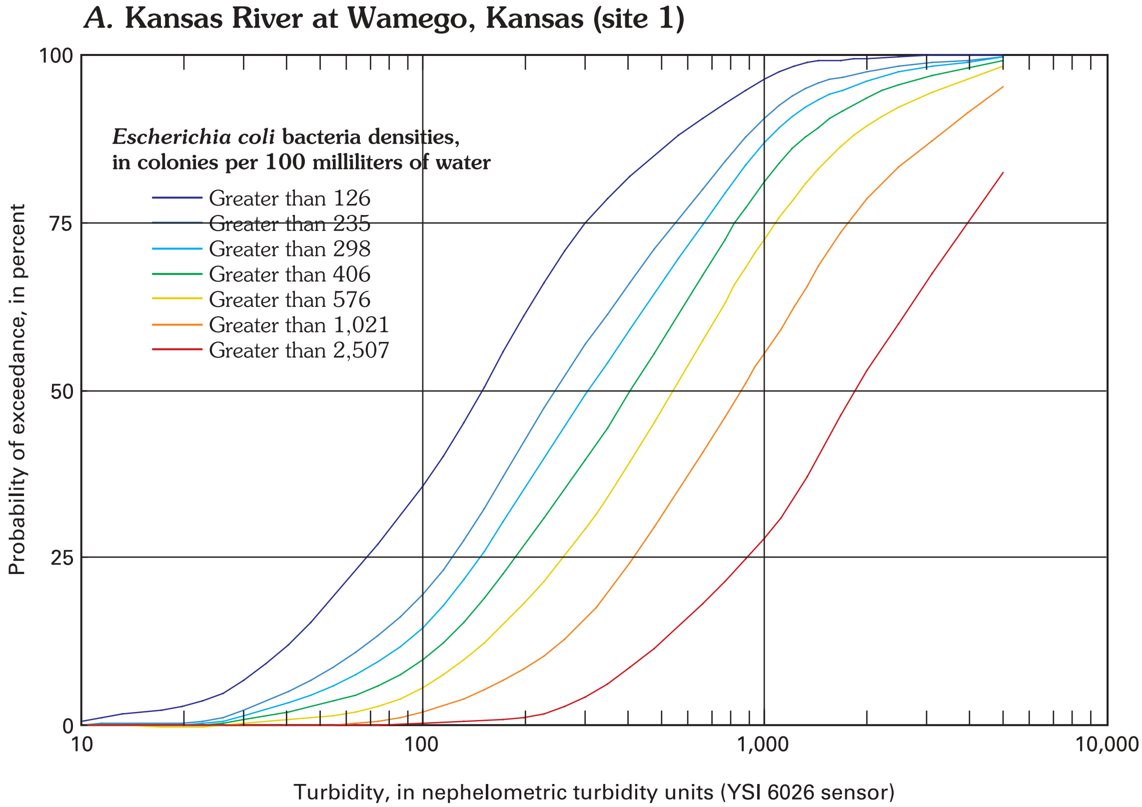


Figure 16*A*. Comparison of measured turbidity and the probability of exceeding selected *Escherichia coli* bacteria densities for Kansas River at Wamego (site 1, fig. 1), July 1999 through April 2002.

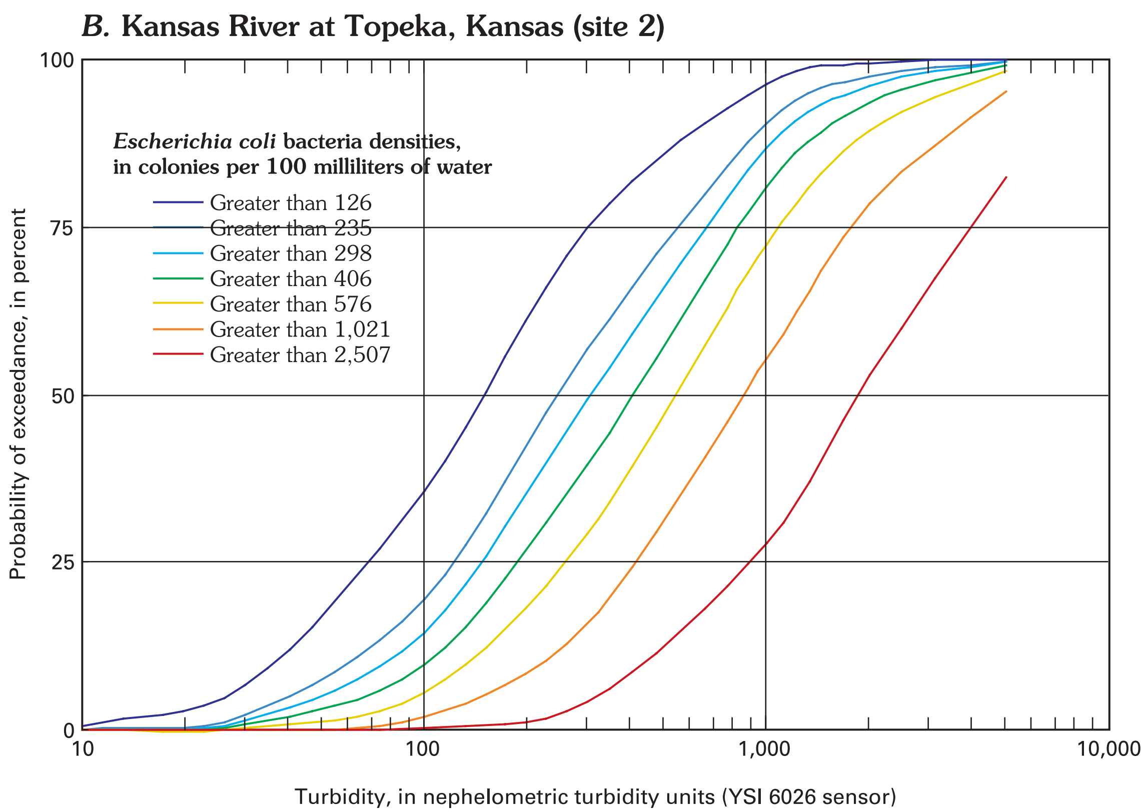


Figure 16*B*. Comparison of measured turbidity and the probability of exceeding selected *Escherichia coli* bacteria densities for Kansas River at Topeka (site 2, fig. 1), July 1999 through April 2002.

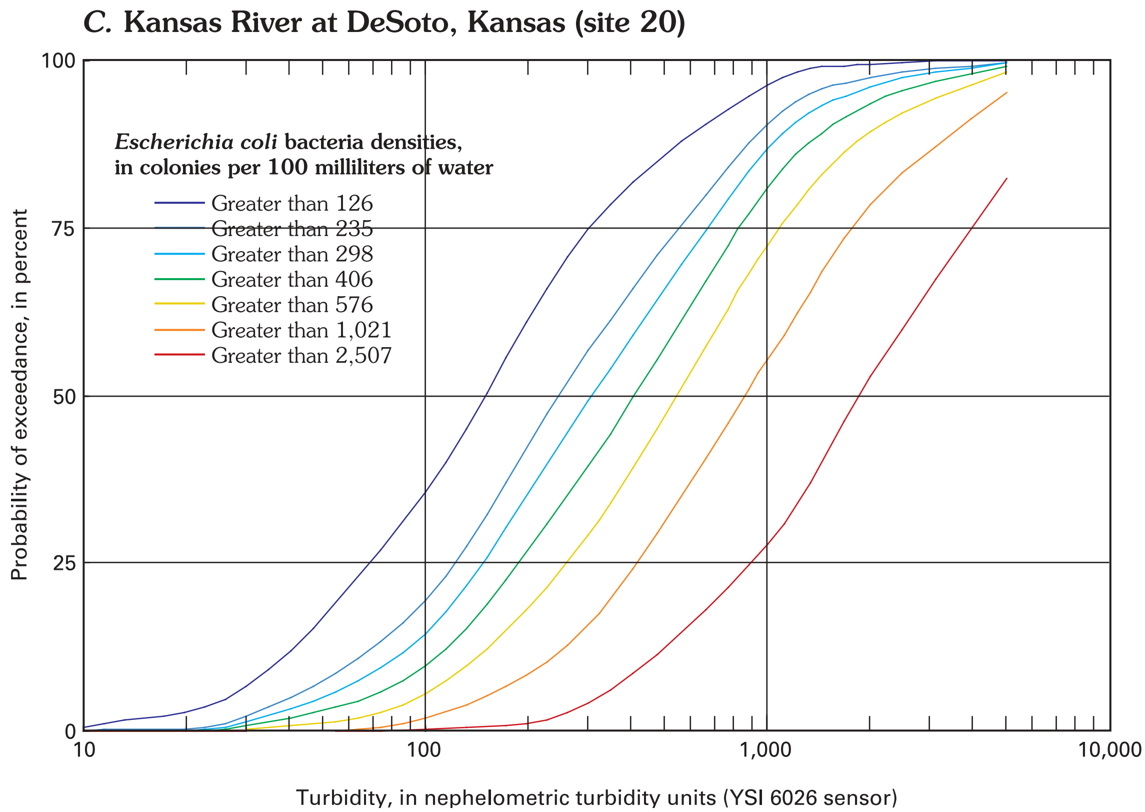


Figure 16*C*. Comparison of measured turbidity and the probability of exceeding selected *Escherichia coli* bacteria densities for Kansas River at DeSoto (site 20, fig. 1), July 1999 through April 2002.

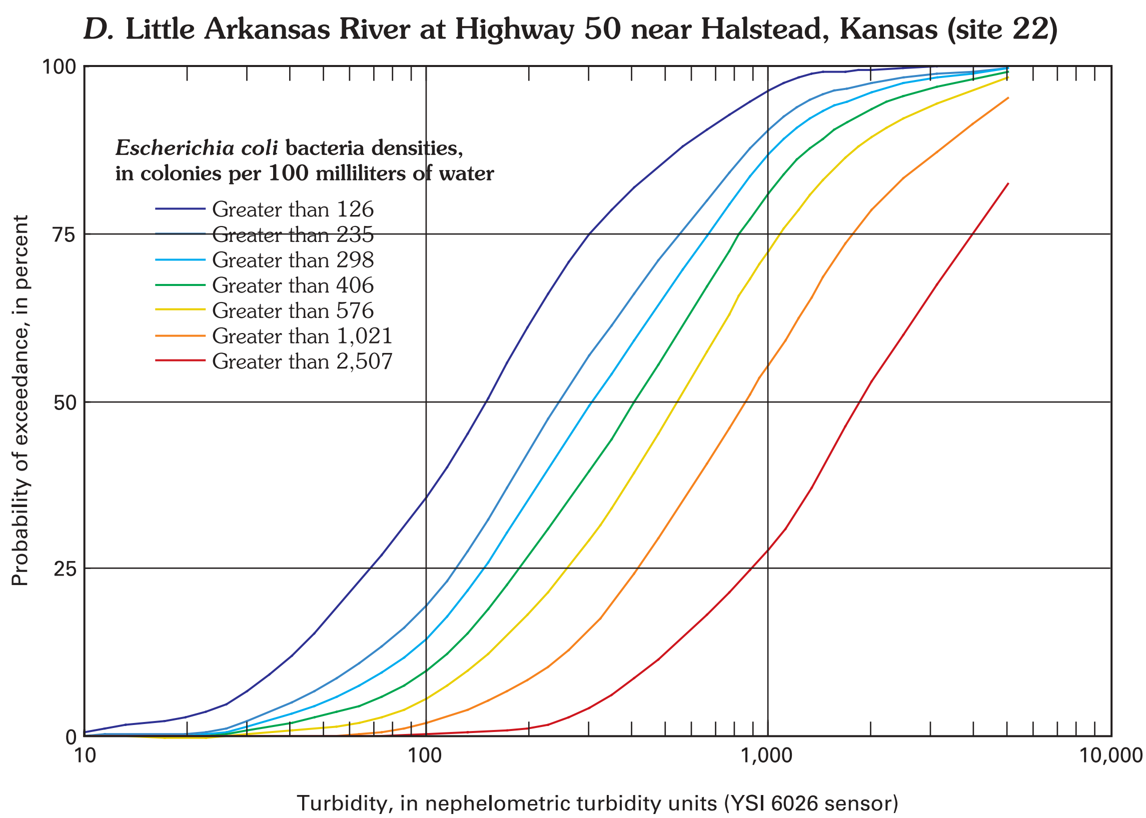


Figure 16*D*. Comparison of measured turbidity and the probability of exceeding selected *Escherichia coli* bacteria densities for Little Arkansas River at Highway 50 near Halstead (site 22, fig. 1), May 1999 through April 2002.

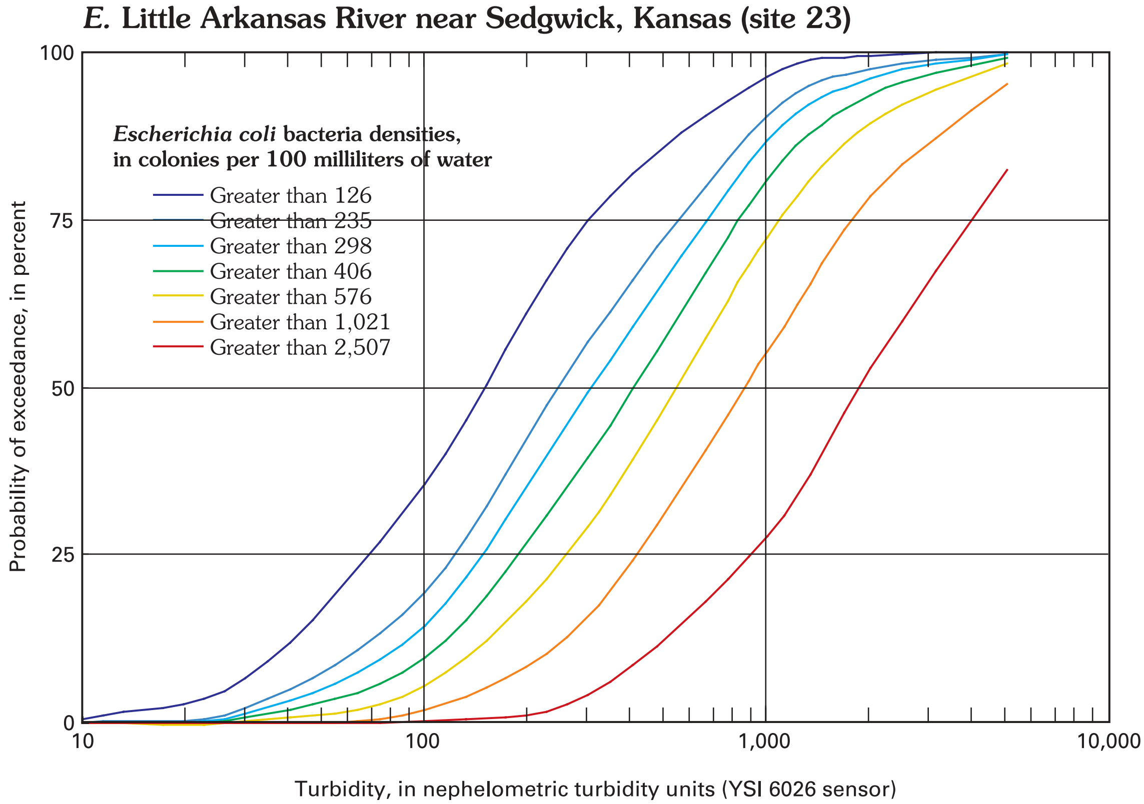
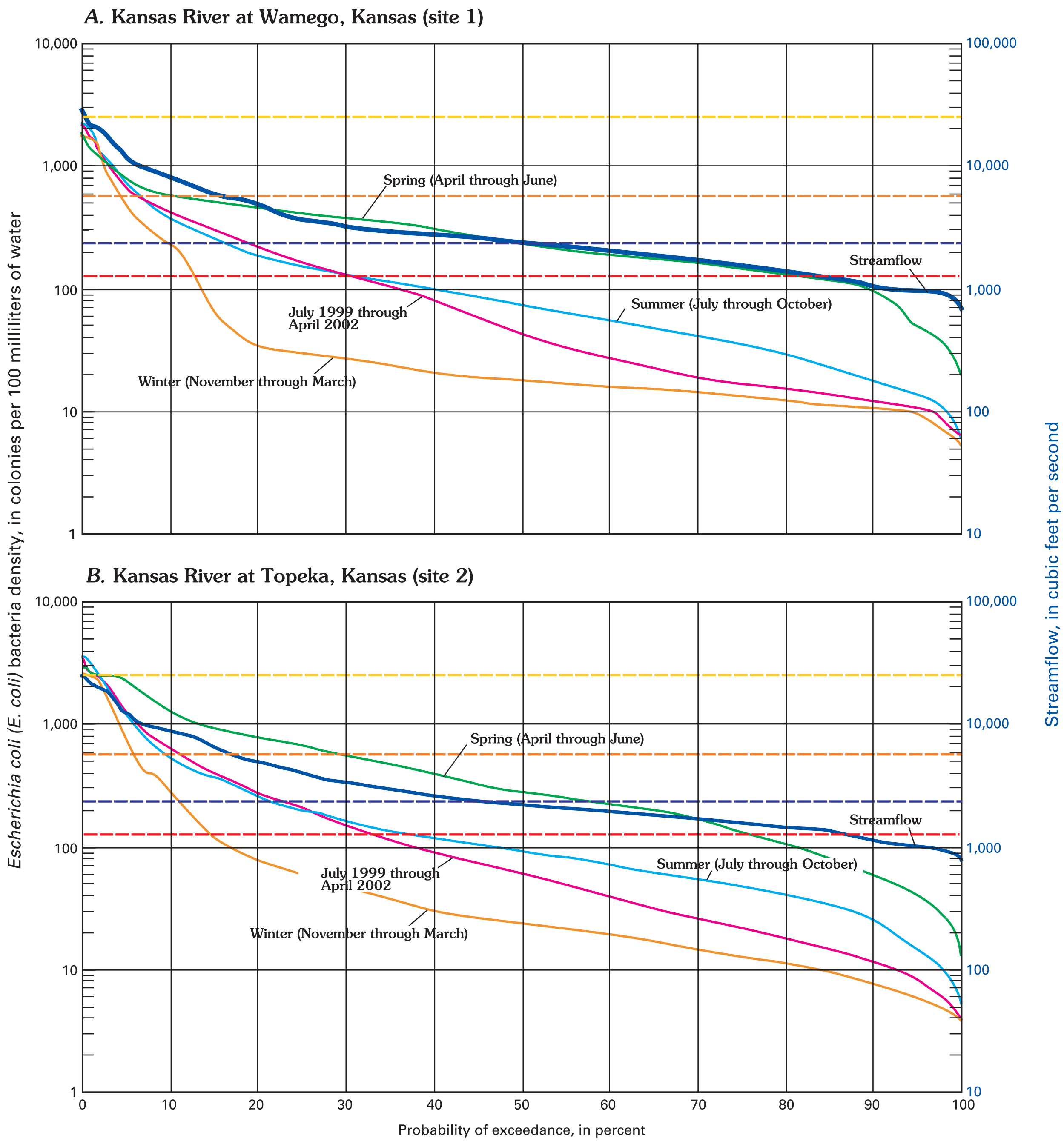


Figure 16*E*. Comparison of measured turbidity and the probability of exceeding selected *Escherichia coli* bacteria densities for Little Arkansas River near Sedgwick (site 23, fig. 1), May 1999 through April 2002.

between 1,000 and 1,500 NTU depending on the sensor. When the actual turbidity was greater than the maximum a sensor can measure, the sensor reported only the maximum value. During these truncated periods, loads were calculated on the basis of the sensor's maximum reading. For these reasons the regression-estimated loads are conservative by an unknown amount. Comparisons of measured load from samples and the corresponding regression-estimated load indicate that the truncated estimates of bacteria load underrepresent the actual load by as much as 20 times. If the in-stream turbidity sensor could measure turbidity values greater than 1,000 NTU (minimum sensor maxima), the regression-estimated bacteria loads would be higher. Values greater than 1,000 NTU were reported for five of the six surface-water sites in 0.8 to 8.9 percent of the hourly turbidity measurements recorded during 2000 and 2001 (table 11). However, the loads for these periods when turbidity was greater than 1,000 NTU accounted for as much as 77 percent of the annual bacteria load. Regression-estimated loads can be greatly underestimated in some cases and only slightly underestimated in others. For these reasons, caution is advised when considering and comparing estimated seasonal and annual bacteria loads and yields among years and sites.

Another limitation when calculating estimated loads and yields is bacteria loss rate. Bacteria loss rate represents bacteria mortality rate, loss due to solar radiation, and loss due to settling. The loss rate varies on the basis of environmental, water-quality, and streamflow conditions. The bacteria loss rate is unknown for the six sites during the study period. For this study, bacteria loss is ignored, and therefore, the point-source loads are overestimated and yields are underestimated.

Regression-estimated total annual bacteria loads in 2001 were about 2 to 8 times larger than the total annual bacteria loads in 2000 for all six surface-water sites except site 21, where bacteria loads in 2000 were 1.2 times higher than bacteria loads in 2001 (table 11). The annual difference probably can be attributed mostly to varying hydrologic conditions. Wet periods tend to contribute more overland runoff and, therefore, more nonpoint-source bacteria to the stream. Mean daily streamflows for the Kansas and Little Arkansas



EXPLANATION

- U.S. Environmental Protection Agency recommended geometric-mean *E. coli* criterion for primary contact recreation water bodies (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for a designated beach area (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 8 per 1,000 swimmers)
- U.S. Environmental Protection Agency recommended single-sample *E. coli* criterion for infrequently used full-body contact (illness rate of 14 per 1,000 swimmers)

Figure 17. Estimated *Escherichia coli* bacteria densities for *(A)* Kansas River at Wamego (site 1, fig. 1) and *(B)* Kansas River at Topeka (site 2, fig. 1), July 1999 through April 2002, and for spring, summer, and winter months. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).

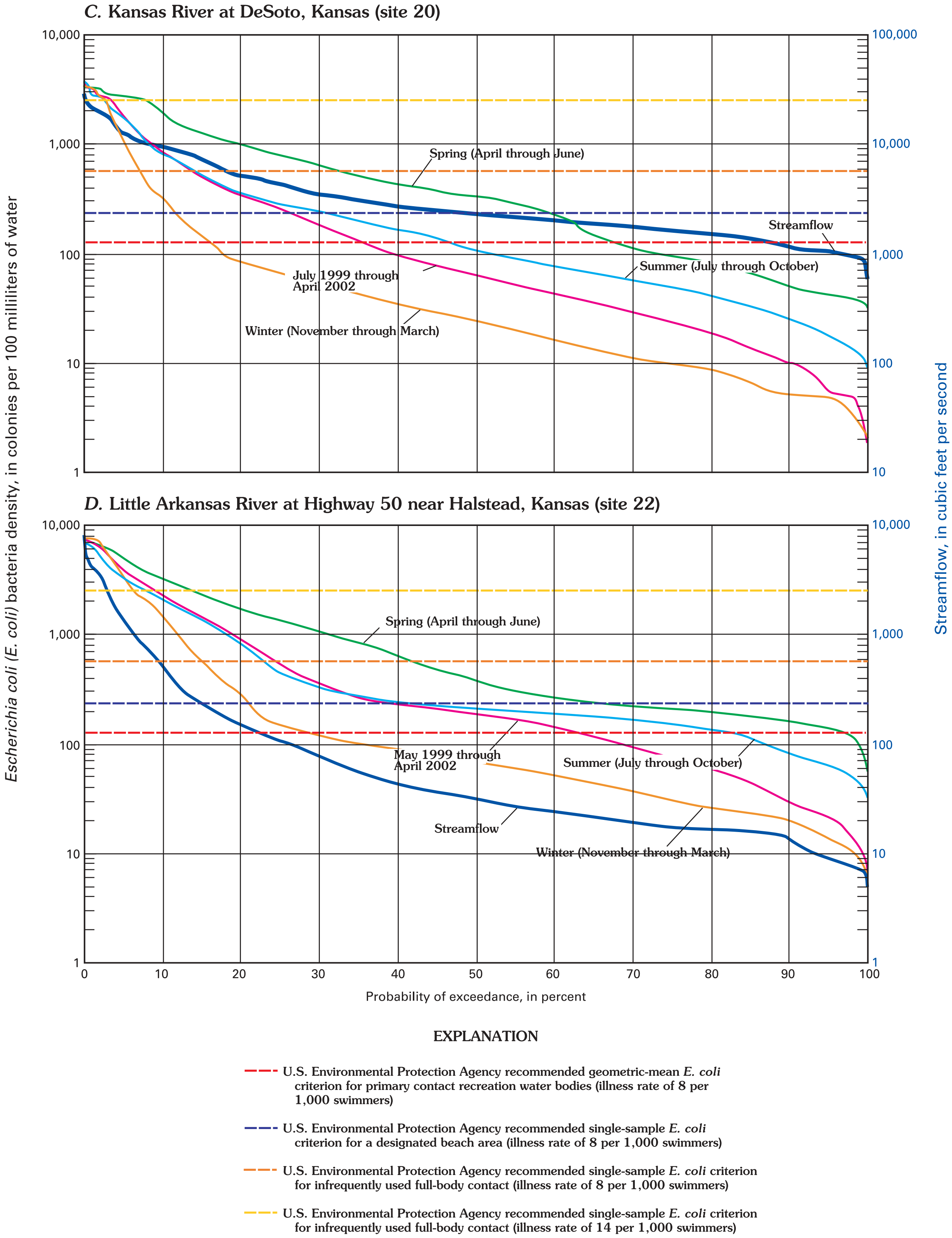


Figure 17. Estimated *Escherichia coli* bacteria densities for *(C)* Kansas River at DeSoto (site 20, fig. 1), July 1999 through April 2002, and *(D)* Little Arkansas River at Highway 50 near Halstead (site 22, fig. 1), May 1999 through April 2002, and for spring, summer, and winter months. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).

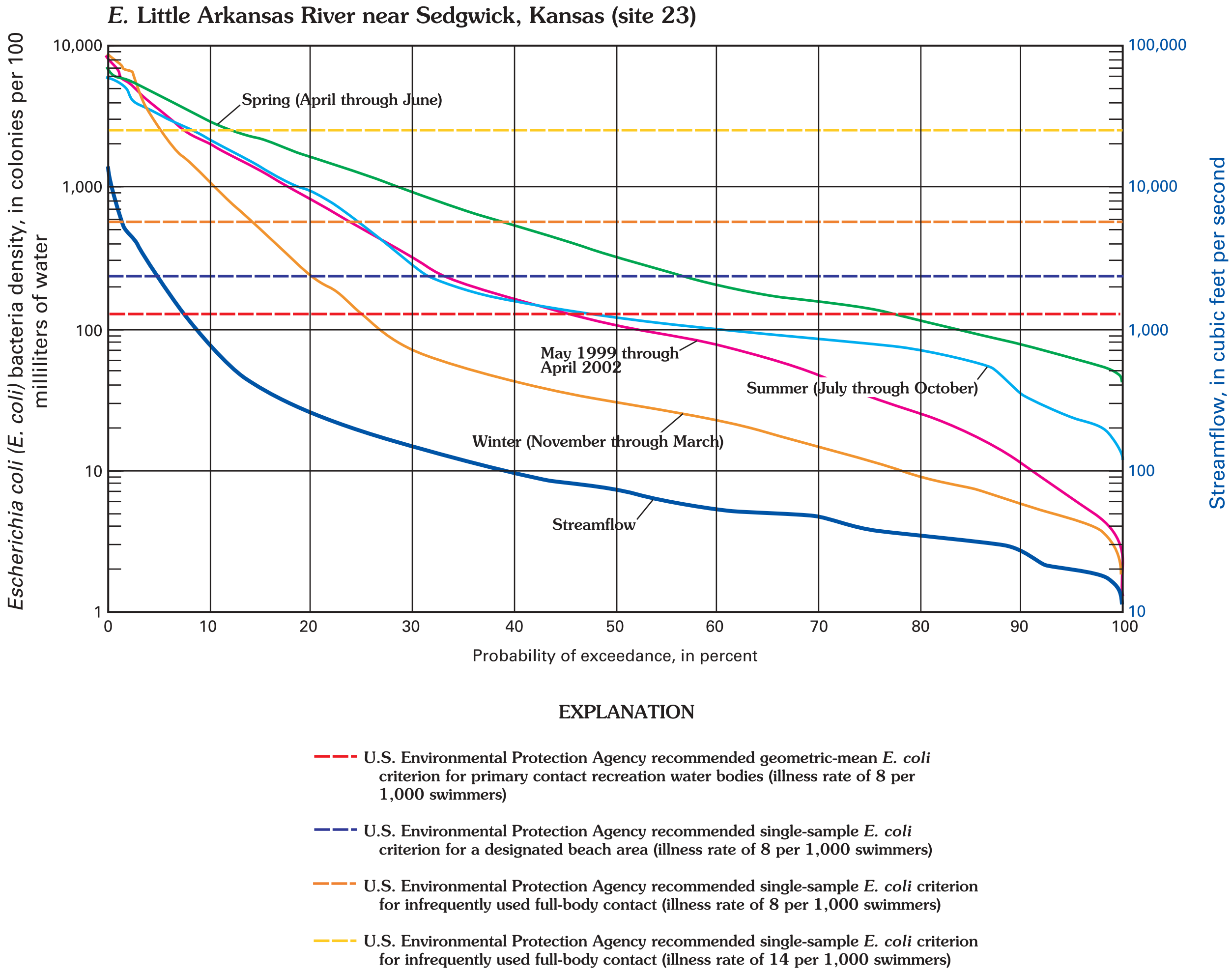


Figure 17. Estimated *Escherichia coli* bacteria densities for *(E)* Little Arkansas River near Sedgwick (site 23, fig. 1), May 1999 through April 2002, and for spring, summer, and winter months. Recreational water-quality criteria recommended by U.S. Environmental Protection Agency (2002).

River sites were higher in 2001 (table 12) than in 2000. Bacteria loads in 2000 and 2001 were largest for the Kansas River at Topeka (site 2) and DeSoto (site 20). Loads for Topeka were slightly more than the loads for DeSoto in 2000, indicating bacterial decay and that reservoir releases from Perry and Clinton Lakes may have diluted the bacteria densities. The loads in the Little Arkansas River for 2000 and 2001 generally were larger for the Sedgwick site (site 23) than for the Halstead site (site 22).

Fecal coliform bacteria and streamflow data for major point sources (municipal sewage-treatment facilities) upstream from the six surface-water sites were obtained from KDHE (written commun., 2002). For the Kansas River (sites 1, 2, 20), data from nine point sources from Wamego to DeSoto were used to estimate that 2.9 percent or less of the regression-estimated total fecal coliform bacteria loads in the Kansas River for 2000 and 2001 were from point sources. There were no point-source discharges into Rattlesnake Creek upstream from site 21 in 2000 and 2001. Six point-source discharges into the Little Arkansas River contributed less than about 0.4 percent of the regression-estimated total fecal coliform bacteria load for 2000 and 2001. The small percentages of point-source fecal coliform bacteria load contributions indicate that nonpoint sources account for at least 97 percent of the regression-estimated annual fecal coliform bacteria load at these six surface-water sites. Agriculture is the predominant land use in the three basins; therefore, nonpoint sources of fecal coliform bacteria in the three basins are largely from agricultural runoff from cropland, pastures, and rangeland, with a small percentage resulting from urban runoff.

Table 11. Estimated seasonal and annual loads and yields of indicator bacteria for six surface-water sites in Kansas, January 2000 through December 2001

[All values are rounded to three significant figures. --, not determined; >, greater than; NTU, nephelometric turbidity units; values in parentheses are percentage of estimated load when turbidity was greater than 1,000 NTU; KDHE, Kansas Department of Health and Environment]

		Loads (billion colonies)					Adjusted yield (million colonies per acre)			
Site number (fig. 1)	Percentage of hourly turbidity values >1,000 NTU	Spring (April–June, 91 days)	Summer (July–October, 123 days)	Winter (November–March, 152 days in 2000 and 151 days in 2001)	Total annual	Total point-source loads (KDHE, written commun., 2002)	Spring (April–June, 91 days)	Summer (July–October, 123 days)	Winter (November–March, 152 days)	Total annual
2000 Fecal coliform bacteria										
1	0.9	2,790,000 (1.6)	1,030,000 (0)	7,180,000 (53)	11,000,000 (35)	32,600	736	273	1,890	2,900
2	1.7	9,250,000 (36)	5,870,000 (49)	14,000,000 (55)	29,100,000 (42)	33,100	1,960	1,250	2,960	6,170
20	1.5	9,680,000 (36)	6,980,000 (27)	9,180,000 (49)	25,800,000 (40)	739,000	1,700	1,220	1,610	4,530
21	0	75,800 (0)	65,200 (0)	181,000 (0)	322,000 (0)	0	113	97.2	270	480
22	1.7	2,390,000 (36)	2,440,000 (12)	8,910,000 (15)	13,700,000 (18)	60,100	4,930	5,020	18,300	28,300
23	.8	1,680,000 (31)	3,830,000 (3.9)	8,230,000 (5.6)	13,700,000 (8.2)	60,200	2,120	4,820	10,400	17,300
2001 Fecal coliform bacteria										
1	4.5	22,500,000 (7.1)	12,300,000 (41)	13,600,000 (50)	48,400,000(39)	9,750	5,930	3,260	3,580	12,800
2	7.9	90,900,000 (41)	43,700,000 (63)	46,300,000 (62)	181,000,000 (39)	13,500	19,300	9,280	9,840	38,400
20	8.9	110,000,000 (48)	40,100,000 (44)	62,400,000 (67)	213,000,000 (53)	447,000	19,300	7,030	10,900	37,300
21	0	166,000 (0)	1,270 (0)	91,700 (0)	270,000 (0)	0	248	18.9	137	403
22	4.7	5,360,000 (24)	3,390,000 (72)	16,300,000 (96)	25,000,000 (77)	25,600	11,000	6,970	33,500	51,500
23	5.0	7,540,000 (20)	4,580,000 (77)	21,300,000 (97)	33,400,000 (77)	26,600	9,510	5,780	26,800	42,100
2000 *Escherichia coli* bacteria										
1	.9	2,510,000 (1.6)	1,030,000 (0)	5,880,000 (53)	9,410,000 (35)	--	661	271	155	2,480
2	1.7	9,510,000 (36)	6,070,000 (49)	14,200,000 (55)	29,800,000 (42)	--	2,020	1,290	3,020	6,330
20	1.5	8,720,000 (36)	6,290,000 (27)	8,270,000 (49)	23,300,000 (40)	--	1,530	1,100	1,450	4,080
21	--	--	--	--	--	--	--	--	--	--
22	1.7	2,130,000 (36)	2,180,000 (12)	8,000,000 (15)	12,300,000 (18)	--	4,380	4,490	16,500	25,300
23	.8	1,480,000 (31)	3,370,000 (3.9)	7,670,000 (5.6)	12,100,000 (8.2)	--	1,870	4,250	9,170	15,300
2001 *Escherichia coli* bacteria										
1	4.5	19,200,000 (7.1)	10,200,000 (41)	11,300,000 (50)	40,700,000 (39)	--	5,080	2,680	2,980	10,700
2	7.9	92,900,000 (41)	44,500,000 (63)	47,600,000 (62)	185,000,000 (39)	--	19,700	9,450	10,100	39,300
20	8.9	99,400,000 (48)	36,100,000 (44)	56,200,000 (67)	192,000,000 (53)	--	17,400	6,330	9,850	33,600
21	--	--	--	--	--	--	--	--	--	--
22	4.7	4,800,000 (24)	2,960,000 (72)	14,000,000 (96)	21,800,000 (77)	--	9,890	6,090	28,900	44,800
23	5.0	6,640,000 (20)	4,010,000 (77)	18,500,000 (97)	29,100,000 (77)	--	8,370	5,050	2,330	36,700

Table 12. Seasonal and annual mean daily streamflow for six surface-water sites in Kansas, January 2000 through December 2001

[Streamflows are in cubic feet per second. All values are rounded to three significant figures]

Site number (fig. 1)	2000 mean daily streamflow				2001 mean daily streamflow			
	Spring (April–June)	Summer (July–October)	Winter (November–March)	Annual mean	Spring (April–June)	Summer (July–October)	Winter (November–March)	Annual mean
1	2,170	2,300	2,500	2,320	9,050	3,840	3,960	5,620
2	2,460	2,340	2,520	2,440	10,500	4,350	5,180	6,680
20	3,220	2,820	3,320	3,120	14,200	7,000	6,300	9,170
21	59	24	61	48	81	9	40	43
22	182	118	385	228	385	102	275	254
23	239	263	583	362	678	191	491	453

Regression-estimated winter bacteria loads were greater than spring or summer bacteria loads for all sites except site 21 in 2000 (table 11). The large winter loads primarily were due to increased streamflow that occurred in late February and March and the unequal number of days in each season. Bacteria loads in 2001 at sites 1, 2, 20, and 21 were largest in the spring when mean daily streamflows were highest for the year (table 12).

To compare each season on an equal basis, mean daily loads were calculated by dividing the regression-estimated seasonal load by the number of days within the season. Seasonal mean daily bacteria loads indicated that in 2000 mean daily bacteria loads were largest in the winter for sites 1, 21, 22, and 23 and in the spring for sites 2 and 20 (fig. 18). In 2001, mean daily bacteria load and streamflows were greatest in the spring at surface-water sites on the Kansas River and Rattlesnake Creek (sites 1, 2, 20, and 21) and largest in the winter at sites on the Little Arkansas River (sites 22 and 23).

Estimated fecal coliform and *E. coli* yields generally were largest for the Little Arkansas River Basin (sites 22, 23) for 2000 and 2001 compared to other sites (fig. 19, table 11). The larger yields for the Little Arkansas River Basin indicate that the land use in the basin is contributing more bacteria per acre than similar agricultural land use in the Kansas River Basin. Such differences might include a greater number of livestock, more areas dedicated to livestock, or fewer structures controlling runoff from pastures.

SUMMARY

Current State criteria for sanitary quality of streams in Kansas are based on fecal coliform bacteria densities. In 1986, the U.S. Environmental Protection Agency (USEPA) recommended that fecal coliform bacteria be replaced by either *Escherichia coli* (*E. coli*) or *enterococci* densities in recreational water-quality criteria as an indicator of fecal contamination. *E. coli* bacteria are a definitive indicator of fecal contamination and give a better indication of possible exposure to swimming-associated illnesses. In 2002, the USEPA issued revised guidelines with recommended numeric criteria on the basis of risk exposure. The State of Kansas is currently (2003) evaluating the use of *E. coli* as the primary indicator bacteria.

In May 1999, the U.S. Geological Survey (USGS), in cooperation with several Federal, State, and local agencies, began collecting samples for analysis of fecal coliform and *E. coli* bacteria at 28 surface-water sites in Kansas. This report, prepared by the USGS in cooperation with KDHE and USEPA and funded in part through the Kansas State Water Plan Fund, describes the overall sanitary quality of surface water in selected Kansas streams, compares the samples to current (2003) State of Kansas water-quality criteria for fecal coliform and U.S. Environmental Protection Agency (USEPA) recommended criteria for *E. coli*, and describes the relation of bacteria densities to turbidity and how this relation can be used to estimate the occurrence of bacteria.

Results indicate that, of the 219 samples collected during the designated recreation period (April 1 through October 31), 21 percent exceeded the current (2003) Kansas Department of Health and Environment (KDHE) single-sample fecal coliform criterion for secondary contact recreation (2,000 col/100 mL of water) and that 36 percent exceeded the USEPA recommended single-sample primary contact recreational criterion for *E. coli* (576 colonies/100 mL of water).

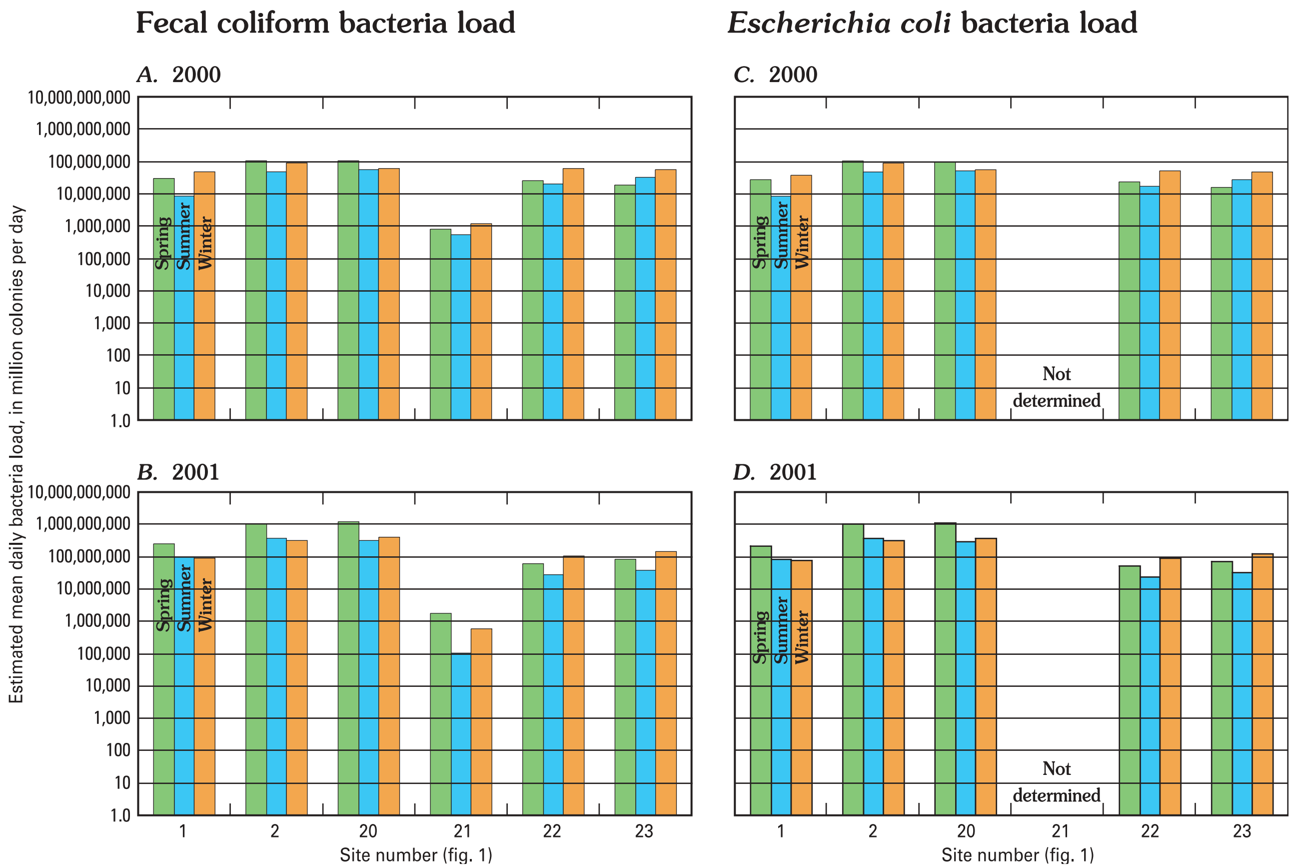


Figure 18. Comparison of estimated mean daily bacteria loads for spring, summer, and winter for six selected surface-water sites, January 2000 through December 2001.

The exceedances occurred mostly during high flow and increased turbidity conditions when surface-water runoff was greatest. Eighteen percent of all 318 samples collected exceeded the current (2003) KDHE secondary contact recreational criterion for fecal coliform bacteria (2,000 colonies/100 mL of water).

The ratio of the USEPA recommended *E. coli* criterion (126 col/100 mL) and the current (2003) KDHE fecal coliform criterion (200 col/100 mL) is 0.63. Comparison of this ratio to the single-site ratios indicates that five of the six ratios calculated for six selected surface-water sites exceeded 0.63. Therefore, at those five sites, the USEPA recommended *E. coli* criteria could be exceeded more frequently than the current (2003) KDHE fecal coliform criteria. The surface-water sites with ratios that were less than 0.63 probably would have *E. coli* bacteria densities that exceed the recommended *E. coli* criteria less frequently. The geometric mean of the *E. coli*/fecal coliform (EC/FC) ratios for all 28 surface-water sites was 0.77. The smaller ratios for Rattlesnake Creek near Zenith (0.48) and the sites on the North Fork Ninnescah River (0.58) probably were caused by the large salinity (or specific conductance greater than 1,000 µS/cm) values in the streams that may decrease the survivability of the *E. coli* and may not affect the other members of the fecal coliform group to the same extent. *Enterococci* survivability is not greatly affected by saline water and may be a better indicator bacteria for sites with saline water.

Ratios of EC/FC and linear regression models were developed for estimating *E. coli* densities on the basis of measured fecal coliform densities for six individual and six groups of surface-water sites. The relative mean absolute errors (*RMAE*s) for EC/FC ratios were less than or equal to the *RMAE*s for 8 of the 12 regression models, indicating that the ratios might be a better method for estimating *E. coli*. For regression models developed for individual surface-water sites on the Kansas River (sites 1, 2, and 20) and the Little Arkansas River (sites 22 and 23), the coefficients of determination (R^2) were greater than 0.89. For these sites, fecal coliform densities were a reliable

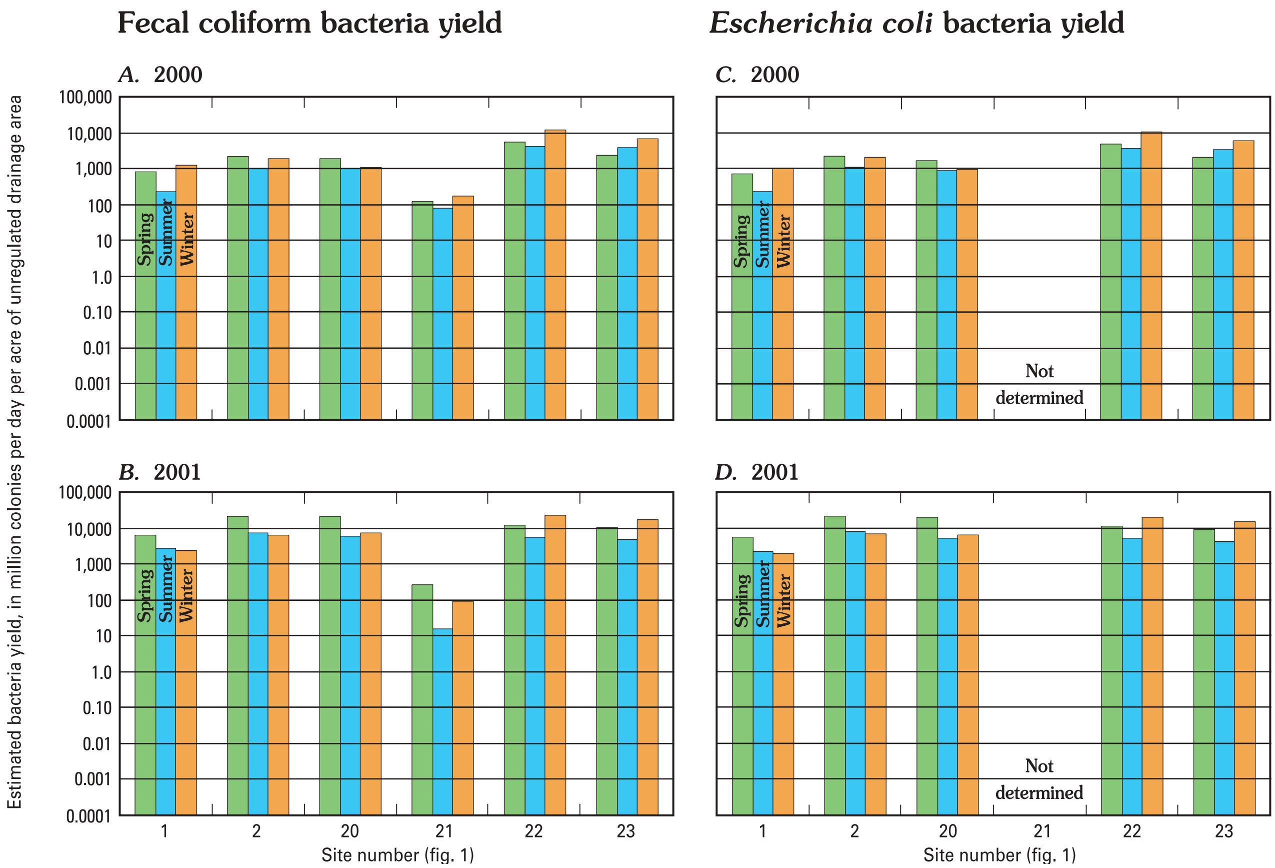


Figure 19. Comparison of regression-estimated bacteria yields from unregulated drainage areas for six selected surface-water sites, January 2000 through December 2001.

indicator bacteria, explaining at least 89 percent of the variability in *E. coli* densities. The regression models are site specific and only relevant for the ranges of measured densities. Regression models can be used to convert historic fecal coliform bacteria densities to estimated *E. coli* densities for the selected sites only for the ranges indicated. The EC/FC ratios can be used to estimate *E. coli* densities for any historical fecal coliform density, and in some cases with less error.

Simple linear regression was used to further determine if one model could be used to estimate *E. coli* bacteria on a basin- or statewide basis. The explained variance for the two Kansas-lower Republican River Basin regression models exceeded 93 percent, indicating that a single model probably is sufficient for all the sites sampled in the basin. The regression model best represents the three Kansas River sites where a majority of the data used to develop the model were collected. The Little Arkansas River Basin regression model indicates that 96 percent of the variability for the two sites is explained. The data for the Little Arkansas River Basin model are more evenly distributed between the two sites (22 and 23) than are data used to develop models for the other basins and, therefore, reliably estimate *E. coli* concentrations at each site. The statewide model only included sites with mean specific conductance less than 1,000 μS/cm (site 1–20, 22, 23). The model describes 94 percent of the variability and appears to sufficiently explain the EC/FC relation at the 22 sites. However, sites that have fewer samples are underrepresented by the statewide model and, therefore, the statewide model may not be appropriate for use at these sites.

Linear regression models were developed for selected surface-water sites to estimate fecal coliform and *E. coli* bacteria densities on the basis of continuous turbidity measurements. These regression models are site specific and only relevant for the range of turbidity values measured. The fecal coliform and *E. coli* regression models for surface-water sites on the Kansas and Little Arkansas Rivers had R^2s ranging from 0.59 to 0.79. The ability to estimate fecal coliform and *E. coli* bacteria densities on the basis of continuous turbidity measurements allows water users to assess whether streams are safe for recreational activities such as swimming, boating, and fishing. Only 16 percent of the variance for fecal coliform is explained (R^2=0.16) by the regression model for Rattlesnake Creek, indicating that turbidity and fecal coliform density are not well correlated for this site.

With a defined relation for turbidity and bacteria and continuous monitoring of turbidity, instantaneous, daily, and annual estimates of bacteria densities are possible. These estimates are displayed almost instantaneously via the World Wide Web (URL http://ks.water.usgs.gov/Kansas/rtqw), providing real-time data indicating the sanitary quality of the water relative to water-quality criteria. Annual continuous data indicate the possibility of the stream meeting water-quality criteria and total maximum daily load (TMDL) goals. For instance, the continuous data used in this report show that, proportionally, spring generally has the greatest number of estimated bacteria densities that exceed KDHE and recommended USEPA criteria. Sites along the Kansas River from upstream to downstream showed an increase in the number of estimates that exceeded the KDHE and recommended USEPA criteria.

The log-normal probability at the 95-percent confidence level was calculated for each of the hourly estimates of the current (KDHE) and recommended (USEPA) criteria. These values illustrate the probability (expressed as a percentage) that each hourly estimate exceeds the criteria. These estimates, displayed in real time (URL http://ks.water.usgs.gov/Kansas/rtqw/), can be used by the public and water-management agencies to make decisions in regard to whether planned water activities are appropriate by considering current stream conditions relative to the criteria. Water suppliers can use the timely information to determine when and how much to adjust water-treatment strategies.

Accuracy of the regression-model estimates was compared to measured sample densities and also was assessed by calculating the percentage of estimated values that were in agreement as exceeding or being less than the specified water-quality criteria. A majority of the regression-model estimates were in agreement with measured densities as either exceeding or not exceeding the specified water-quality criteria for at least 80 percent of the measured densities.

The relations between turbidity and fecal coliform bacteria and turbidity and *E. coli* bacteria were displayed as probability curves. The curves can be used to estimate fecal coliform or *E. coli* concentrations on the basis of measured turbidity values. Hourly estimated bacteria densities also were used to develop bacteria duration curves. Durations curves for the entire study period indicate that the current single-sample criterion for fecal coliform (2,000 col/100 mL) and the USEPA recommended single-sample criterion for *E. coli* (576 col/100 mL) were exceeded between 0 and 14 percent and 8 to 24 percent of the time, respectively. Exceedances of the primary-contact geometric-mean fecal coliform criterion (200 col/100 mL) and the USEPA recommended *E. coli* criterion (126 col/100 mL) occurred between 21 to 94 percent and 31 to 97 percent, respectively, of the time during the designated recreation period (April through October).

Duration curves for estimated fecal coliform for spring (April through June), summer (July through October), and winter (November through March) illustrate the differences among the three seasons. For all sites except Rattlesnake Creek, the median estimated bacteria density in the spring was at least 2 times the median summer density and about 10 times the median winter density. The seasonal differences were largest at the three Kansas River sites, indicating that reservoir releases (very low turbidity and bacteria densities) predominate the streamflow during the winter.

Hourly estimated fecal coliform and *E. coli* bacteria densities and streamflow were used to compute seasonal and annual loads and yields at six surface-water sites with continuous turbidity measurements for the calendar years 2000 and 2001. Overall, estimated total annual bacteria loads for the Kansas and Little Arkansas Rivers in 2001 were about 2 to 8 times larger than the estimated bacteria loads in 2000. The difference probably is due to wet conditions in 2001 contributing greater overland runoff and, therefore, greater nonpoint-source contributions of bacteria to the stream. Bacteria loads in 2000 and 2001 were largest for the Kansas River at Topeka (site 2) and DeSoto (site 20). Data for major point sources upstream from the surface-water sites were obtained from KDHE. Point sources accounted for 2.9 percent or less of the regression-estimated annual bacteria load for 2000 and 2001 for the six surface-water sites. Nonpoint sources were the predominant source for bacteria loads in these streams.

Winter bacteria loads were larger than spring or summer loads for all sites except site 21 in 2000. These large winter loads primarily were due to high streamflow that occurred in late February and March and dissimilar time periods for each season. Bacteria loads at sites 1, 2, 20, and 21 were largest for the spring in 2001. Mean daily bacteria loads in 2000 were largest in the winter for sites 1, 21, 22, and 23 and in the spring for sites 2 and 20. In 2001, mean daily bacteria loads and streamflows were largest in the spring at sites on the Kansas River and Rattlesnake Creek (sites 1, 2, 20, and 21) and largest in the winter at sites on the Little Arkansas River (sites 22 and 23).

Bacteria yields were calculated by dividing the regression-estimated loads by the unregulated drainage area for each surface-water site. Yields calculated in this fashion indicate that the Little Arkansas Basin had the greatest number of colonies per acre of the three streams (including the Kansas River and Rattlesnake Creek surface-water sites).

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