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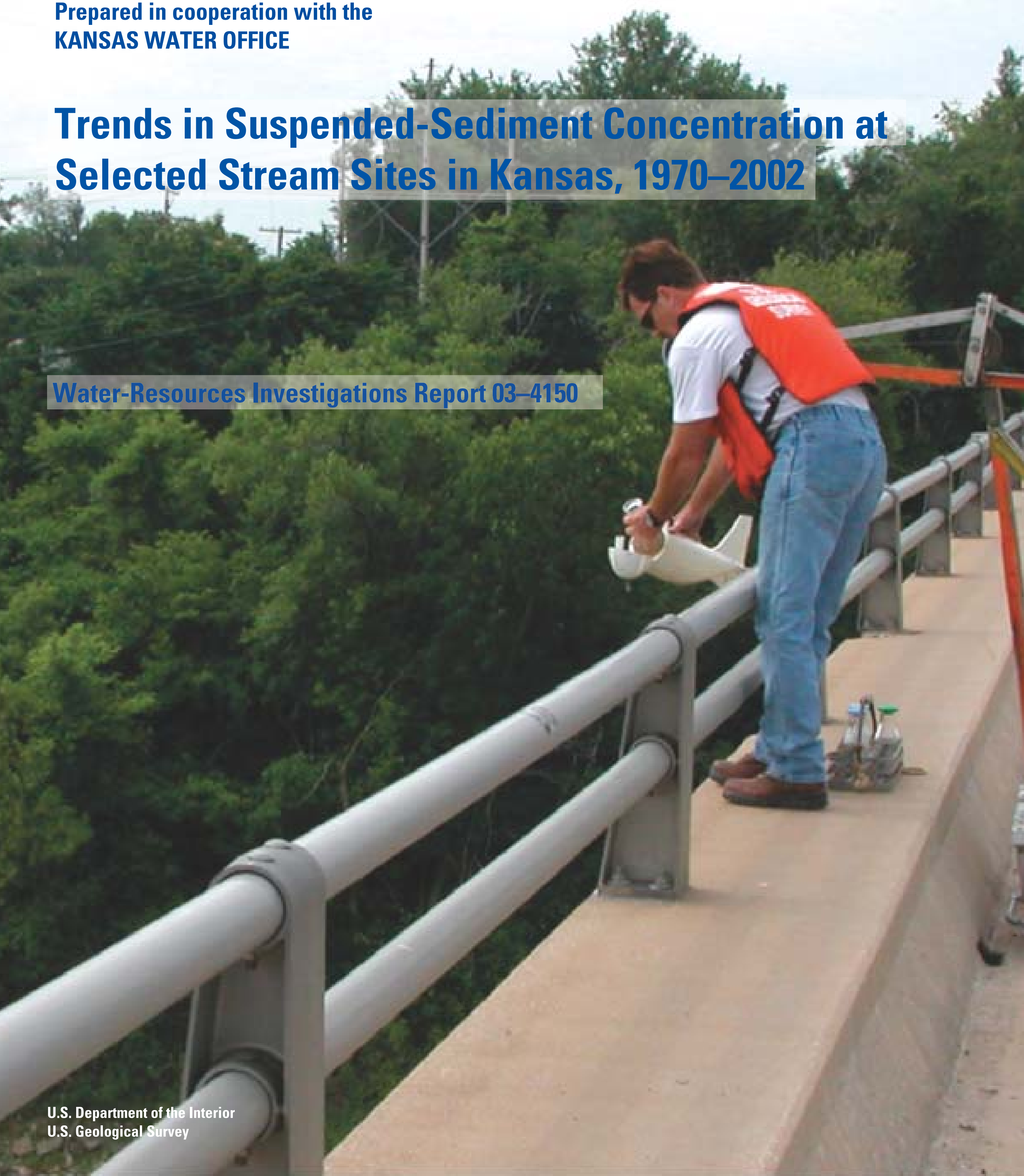
Trends in Suspended-Sediment Concentration at Selected Stream Sites in Kansas, 1970–2002

Water-Resources Investigations Report 03–4150



U.S. Department of the Interior
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By JAMES E. PUTNAM and LARRY M. POPE

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Lawrence, Kansas
2003

U.S. Department of the Interior

Gale A. Norton, Secretary

U.S. Geological Survey

Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
4821 Quail Crest Place
Lawrence, KS 66049–3839

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CONVERSION FACTORS, ABBREVIATIONS, DATUM, AND DEFINITION

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)
inch (in.)	2.54	centimeter (cm)
inch per hour (in/h)	2.54	centimeter per hour (cm/h)
mile (mi)	1.609	kilometer (km)
milligram per liter (mg/L)	5.39	pound per day (lb/d)
milligram per liter per year [(mg/L)/yr]	1,967	pound per year (lb/yr)
pound per day (lb/d)	453.6	gram per day (g/d)
pound per year (lb/yr)	453.6	gram per year (g/yr)
square mile (mi^2)	2.590	square kilometer (km^2)

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

Water year, as used in this report, is the 12-month period beginning October 1 and ending September 30. The water year is designated by the calendar year in which it ends. For example, the 12-month period beginning October 1, 1999, and ending September 30, 2000, is called the 2000 water year.

Trends in Suspended-Sediment Concentration at Selected Stream Sites in Kansas, 1970–2002

By James E. Putnam *and* Larry M. Pope

Abstract

Knowledge of erosion, transport, and deposition of sediment relative to streams and impoundments is important to those involved directly or indirectly in the development and management of water resources. Monitoring the quantity of sediment in streams and impoundments is important because:

(1) sediment may degrade the water quality of streams for such uses as municipal water supply,

(2) sediment is detrimental to the health of some species of aquatic animals and plants, and

(3) accumulation of sediment in water-supply impoundments decreases the amount of storage and, therefore, water available for users.

One of the objectives of the Kansas Water Plan is to reduce the amount of sediment in Kansas streams by 2010. During the last 30 years, millions of dollars have been spent in Kansas watersheds to reduce sediment transport to streams. Because the last evaluation of trends in suspended-sediment concentrations in Kansas was completed in 1985, 14 sediment sampling sites that represent 10 of the 12 major river basins in Kansas were reestablished in 2000. The purpose of this report is to present the results of time-trend analyses at the reestablished sediment data-collection sites for the period of about 1970–2002 and to evaluate changes in the watersheds that may explain the trends.

Time-trend tests for 13 of 14 sediment sampling sites in Kansas for the period from about 1970 to 2002 indicated that 3 of the 13 sites tested had statistically significant decreasing suspended-sediment concentrations; however, only 2 sites, Walnut River at Winfield and Elk River at Elk Falls, had trends that were statistically significant at the 0.05 probability level. Increasing suspended-sediment concentrations were indicated at three sites although none were statistically significant at the 0.05 probability level. Samples from five of the six sampling sites located upstream from reservoirs indicated decreasing suspended-sediment concentrations. Watershed impoundments located in the respective river basins may contribute to the decreasing suspended-sediment trends exhibited at most of the sampling sites because the impoundments are designed to trap sediment. Both sites that exhibited statistically significant decreasing suspended-sediment concentrations have a large number of watershed impoundments located in their respective drainage basins. The relation between percentage of the watershed affected by impoundments and trend in suspended-sediment concentration for 11 sites indicated that, as the number of impoundments in the watershed increases, suspended-sediment concentration decreases. Other conservation practices, such as terracing of farm fields and contour farming, also may contribute to the reduced suspended-sediment concentrations if their use has increased during the period of analysis.

Regression models were developed for 13 of 14 sediment sampling sites in Kansas and can be used to estimate suspended-sediment concentration if the range in stream discharge for which they were developed is not exceeded and if time

trends in suspended-sediment concentrations are not significant. For those sites that had a statistically significant trend in suspended-sediment concentration, a second regression model was developed using samples collected during 2000–02. Past and current studies by the U.S. Geological Survey have shown that regression models can be developed between in-stream measurements of turbidity and laboratory-analyzed sediment samples. Regression models were developed for the relations between discharge and suspended-sediment concentration and turbidity and suspended-sediment concentration for 10 sediment sampling sites using samples collected during 2000–02.

INTRODUCTION

Fluvial sediment is composed of fragmentary material that originates from weathering rocks, chemical and biological precipitates, and decomposed organic material (Federal Inter-Agency Sedimentation Project, 1963). Sediment can degrade the water quality of streams for uses such as municipal water supply and is detrimental to the health of some species of aquatic animals and plants. Sediment deposition decreases the water-storage volume in water-supply lakes and, therefore, the water available to users. For these reasons, sediment has been added to the Kansas 303(d) list of constituents that can impair Kansas streams and lakes (Kansas Department of Health and Environment, 1998).

The Kansas Water Plan (KWP) is administered by the Kansas Water Office and documents how the State intends to achieve the proper utilization and control of the water resources of Kansas (Kansas Water Office, 2003a). In October 1998, the Kansas Water Authority approved objectives for 2010 as part of the KWP. The objectives were developed to define targets to quantify achievement of the KWP long-range goals (Kansas Water Office, 2003a). One objective is to reduce the average concentration of sediment that can adversely affect the water quality of Kansas streams and reservoirs.

During 1970–2002, numerous land-use and land-management practices have been completed within watersheds in an attempt to reduce erosion rates and stream-sediment concentrations. Increased terracing of farm fields during this period has helped to control runoff from fields and, therefore, the amount of sediment transported to streams. Hundreds of flood-control structures (impoundments) and other erosion-control structures have been constructed throughout the State in an effort to decrease sources of sediment transport to the surface water of Kansas (Brian Lang, Natural Resources Conservation Service (NRCS), written commun., 2003; Matt Scherer, Kansas Department of Agriculture, Division of Water Resources, written commun., 2003). The U.S. Army Corps of Engineers has constructed several large flood-control reservoirs in Kansas during the last 30 years. Because of the large investment by local, State, and Federal agencies to reduce sediment, a logical question to ask and one important to the Kansas Water Office is, "how have these practices affected sediment in Kansas streams?"

A comprehensive suspended-sediment data-collection network has not been operated in Kansas for many years, and the last evaluation of sediment data was completed by the U.S. Geological Survey (USGS) in cooperation with the Kansas Water Office in 1985 (Jordan, 1985). Jordan's study summarized sediment trends at 38 sites that were not affected by large reservoirs and found statistically significant trends at 19 sites. Sixteen of the 19 trends were toward lower sediment concentrations; three trends were toward higher sediment concentrations.

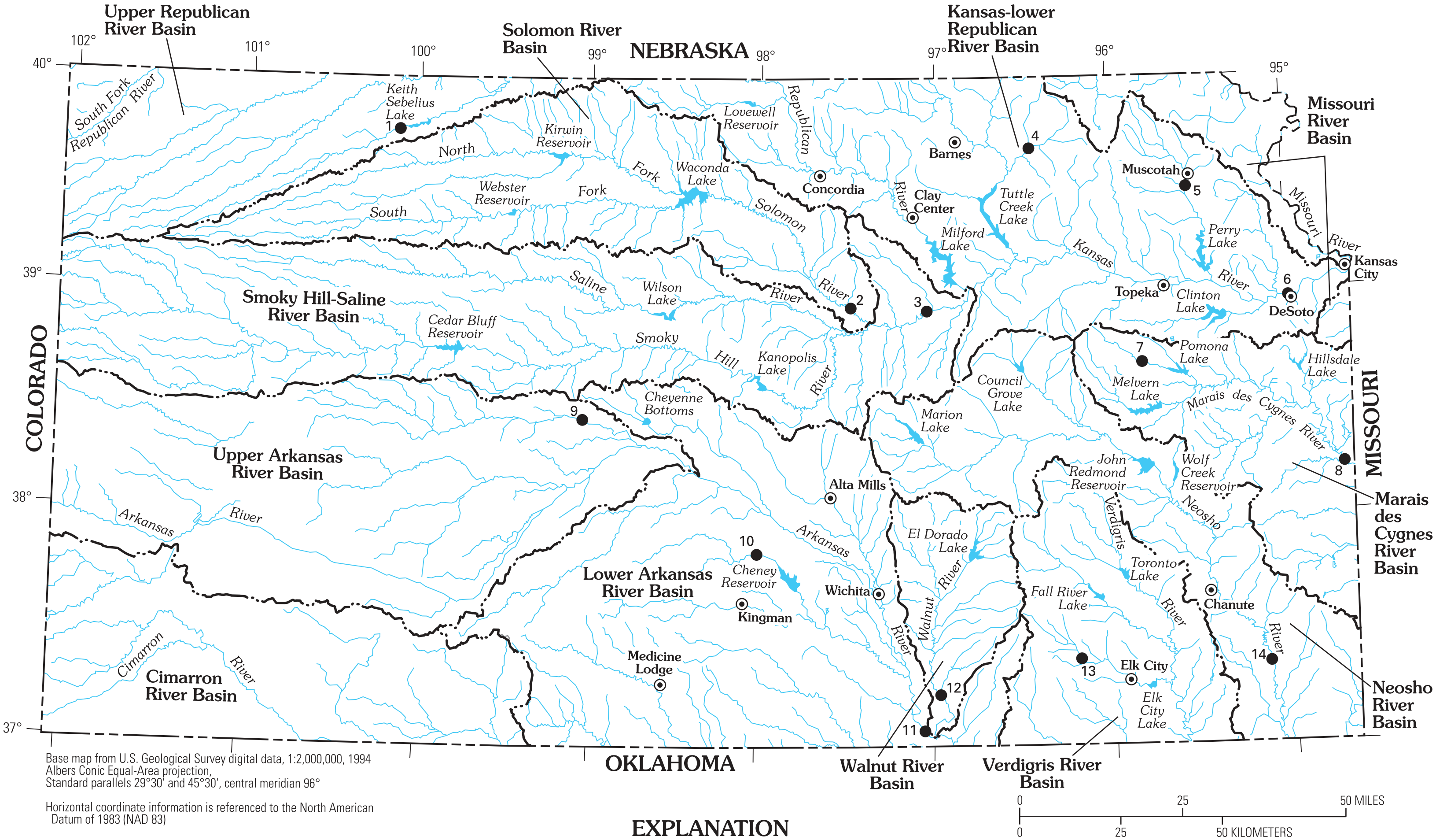
A 3-year study by the USGS, in cooperation with the Kansas Water Office, and partly supported by the Kansas State Water Plan Fund began in 2000 to determine trends in suspended-sediment concentrations at selected sites in 10 of the 12 major river basins in Kansas. The specific study objectives were to:

(1) Identify stream sites in 10 of the 12 major river basins in Kansas with long-term streamflow and suspended-sediment data;

(2) Reestablish a suspended-sediment data-collection network in Kansas covering most of the major river basins in the State on the basis of information obtained from completion of objective 1; and

(3) Examine historical and newly collected data for time trends in suspended-sediment concentrations in the 10 major river basins.

The purpose of this report is to present a summary of data collected and results of time-trend analyses at selected suspended-sediment sites in 10 of the 12 major river basins in Kansas (fig. 1) for 1970–2002. Additionally, regression models were developed for



EXPLANATION

Boundary of major river basin

●12 Sediment sampling site and map index number

Figure 1. Location of major river basins and sediment sampling sites in Kansas.

estimation of sediment concentration. No sampling sites were selected in the Missouri River Basin or the Cimarron River Basin because no historical suspended-sediment data were available for stream sites in these basins. Sediment samples were collected at 14 sites in Kansas, and time trends were computed for 13 of the 14 sites (fig. 1). No time trend was computed for site 8, Marais des Cygnes River at Kansas-Missouri State line (fig. 1) because historic sediment-sample collection was extremely variable, with many samples collected for only a short period of time.

Methods and results of the time-trend analyses presented in this report will be used by the State to evaluate the effectiveness of erosion-control and land-management practices financed by the KWP Fund during 1970–2002. The reestablishment of a sediment network and the results of the sediment time-trend analyses will provide a part of the information needed to meet the State Water Plan 2010 objective to reduce the average concentration of sediment in Kansas streams and lakes. The regression models developed for this report can be used to estimate suspended-sediment concentration and sediment loads. Results of this report also may provide a part of the information needed to meet the KWP objective to ensure that sufficient surface-water storage is available to meet projected 2040 needs. Also, results of the time-trend analyses may lead to modifications of future sediment data-collection networks.

Background

Fluvial sediment is defined as fragmentary material that originates mostly from weathering rocks and is transported by, suspended in, or deposited from water; it includes chemical and biological precipitates and decomposed organic material, such as humus. Knowledge of erosion, transport, and deposition of sediment relative to streams and impoundments is important to those involved directly or indirectly in the development and management of water resources (Edwards and Glysson, 1999). Information on the quantity of suspended sediment in streams is important to municipal water suppliers and for the design of hydraulic structures such as dams and impoundments. Impoundments trap sediment and, therefore, decrease the amount of sediment transported to streams. However, as the impoundment fills with sediment, the volume of the impoundment decreases, and less water is available for water users. Water-resource managers and regulators use sediment information to help establish criteria for water-quality standards and goals. Suspended sediment can cause problems for fish by clogging gills and for aquatic plants by reducing light penetration and thus limiting growth. Sediment can provide a medium for accumulation and transport of other chemicals such as phosphorus and bacteria that can degrade water quality in streams (Christensen, 2001).

Sediment data-collection programs in Kansas have changed considerably since the first half of the 20th century and have been modified to meet the needs of State and Federal agencies. Systematic programs of sediment data collection began during the late 1930s in connection with studies for Federal reservoir design (Jordan, 1985). In 1957, the Kansas Water Resources Board, predecessor of the Kansas Water Office, began an extensive sediment data-collection program with the USGS to provide a broader knowledge of sediment in Kansas streams. The sediment network was redesigned in 1961, 1965, and 1977, adding or discontinuing sites and changing frequency of sampling as needs changed. Sediment data were collected as part of the USGS National Stream Quality Accounting Network (NASQAN) from 1975 through 1986 at seven stream sites in Kansas.

Time trends for sediment concentrations in Kansas have not been studied since 1985. As a part of a network evaluation for sediment data collection, Jordan (1985) evaluated trends for 38 sediment sites not affected by large reservoirs. Results of time-trend analyses and location of the sediment-sampling sites from Jordan (1985) for the 19 sites that had statistically significant time trends in sediment concentration are shown in figure 13 and table 7 in the “Supplemental Information” section at the end of this report. Sudden decreases (step trends) in flow-adjusted concentrations were found at sites 2, 7, 10, 11, 12, 14, and 17 (table 7, “Supplemental Information” section) that were short distances downstream from large reservoirs. One of Jordan’s conclusions was that some sediment sampling sites could be discontinued from the sediment network, and data collection could be resumed in 1992 to reevaluate trends with new data (Jordan, 1985); however, this reevaluation never occurred, and sediment data collection has been sporadic since 1985 with a small number of samples collected during floods and samples collected for specific needs in other USGS water-quality studies.

Factors Affecting Sediment Transport

Sediment transport is affected by the type of terrain in the watershed, land-management features, such as crop cover or tillage practices, soil permeability, variations in timing and intensity of precipitation, and stream-channel characteristics. The following discussion describes the variability of these factors that affect sediment transport in Kansas streams.

Kansas encompasses an area of about 82,000 mi^2. Major river basins in Kansas are the Cimarron, Kansas-lower Republican, lower Arkansas, Marais des Cygnes, Missouri, Neosho, Smoky Hill-Saline, Solomon, upper Arkansas, upper Republican, Verdigris, and Walnut (fig. 1). Numerous Federal reservoirs are located throughout the eastern two-thirds of the State. Land use is predominantly agricultural with cropland, grassland, and woodland accounting for 53.0, 42.7, and 2.5 percent of the State, respectively (Juracek, 2000). Grassland dominates the flood plains of western Kansas, whereas cropland dominates the flood plains in eastern Kansas (fig. 2).

Terrain varies throughout Kansas and includes flat plains, rolling hills, sandhills, and steep slopes (Moody and others, 1986). Soil permeability ranges from 0 to about 17.6 in/h, with a mean of about 1.6 in/h. The highest soil-permeability values occur in the Cimarron and upper and lower Arkansas River Basins of southwest and south-central Kansas. Soil permeability also is generally higher in the western half of the State. Across the State, soil permeability is typically higher in the flood plains of the major rivers and streams (Juracek, 2000).

Large spatial and temporal variations in precipitation and streamflow characterize hydrologic conditions in Kansas. In extreme southeastern Kansas, mean annual precipitation exceeds 40 in., and mean annual runoff exceeds 10 in. In the east, stream channels are deeply incised in wide, alluvial flood plains, and streamflow generally is perennial. In extreme western Kansas, mean annual precipitation is less than 20 in., and mean annual runoff is less than 0.1 in. In western Kansas, streams generally have shallow, ill-defined channels, and streamflow generally is ephemeral (Putnam and others, 2002).

The major river basins having relatively high runoff rates are the Kansas-lower Republican, Marais des Cygnes, Missouri, Neosho, Verdigris, and Walnut. These basins are located in eastern Kansas where soil permeability generally is less and precipitation typically is greater. The major river basins having relatively low runoff rates are the Cimarron, lower Arkansas, Smoky Hill-Saline, Solomon, upper Arkansas, and upper Republican. These basins are located in western Kansas where soil permeability generally is higher and precipitation typically is less (Juracek, 1999).

STUDY METHODS

Site Selection and Sample Collection

Fourteen sediment sampling sites were selected within 10 of the 12 major river basins in Kansas (fig. 1, table 1). Sampling sites were selected using the following criteria:

(1) sufficient historic sediment concentration data available for reliable trend analysis;
(2) sites located upstream from reservoirs; and
(3) sites located downstream from reservoirs or located in the downstream-most location in a river basin.

Sites were established at existing USGS streamflow-gaging stations. Sampling sites were not established in the Cimarron and Missouri River Basins because little or no historical sediment data existed in the USGS National Water Information System (NWIS) database.

Sediment samples were collected following USGS sampling protocol described in Edwards and Glysson (1999). About six samples per year were collected at each site from 2000–02 to represent various streamflow conditions and seasons (fig. 3). Stream discharge was measured during sampling, either directly (Buchanan and Somers, 1969) or by obtaining a stream discharge from the stage-discharge relation at the streamflow-gaging station (Kennedy, 1984). Samples were collected to provide a depth- and width-integrated composite sample representative of suspended-sediment concentration in the stream's cross section. Samples were analyzed at the USGS sediment laboratory in Iowa City, Iowa, using methods described in Guy (1977). A statistical summary of streamflow and sediment data used in this report is presented in table 2.

The primary purpose of this report was to investigate possible trends in sediment concentration during the last 30 years. The trends may be affected by land-use changes in the watersheds. Therefore, the period of record selected for the trend tests was from 1970 through 2002, depending on data availability at each

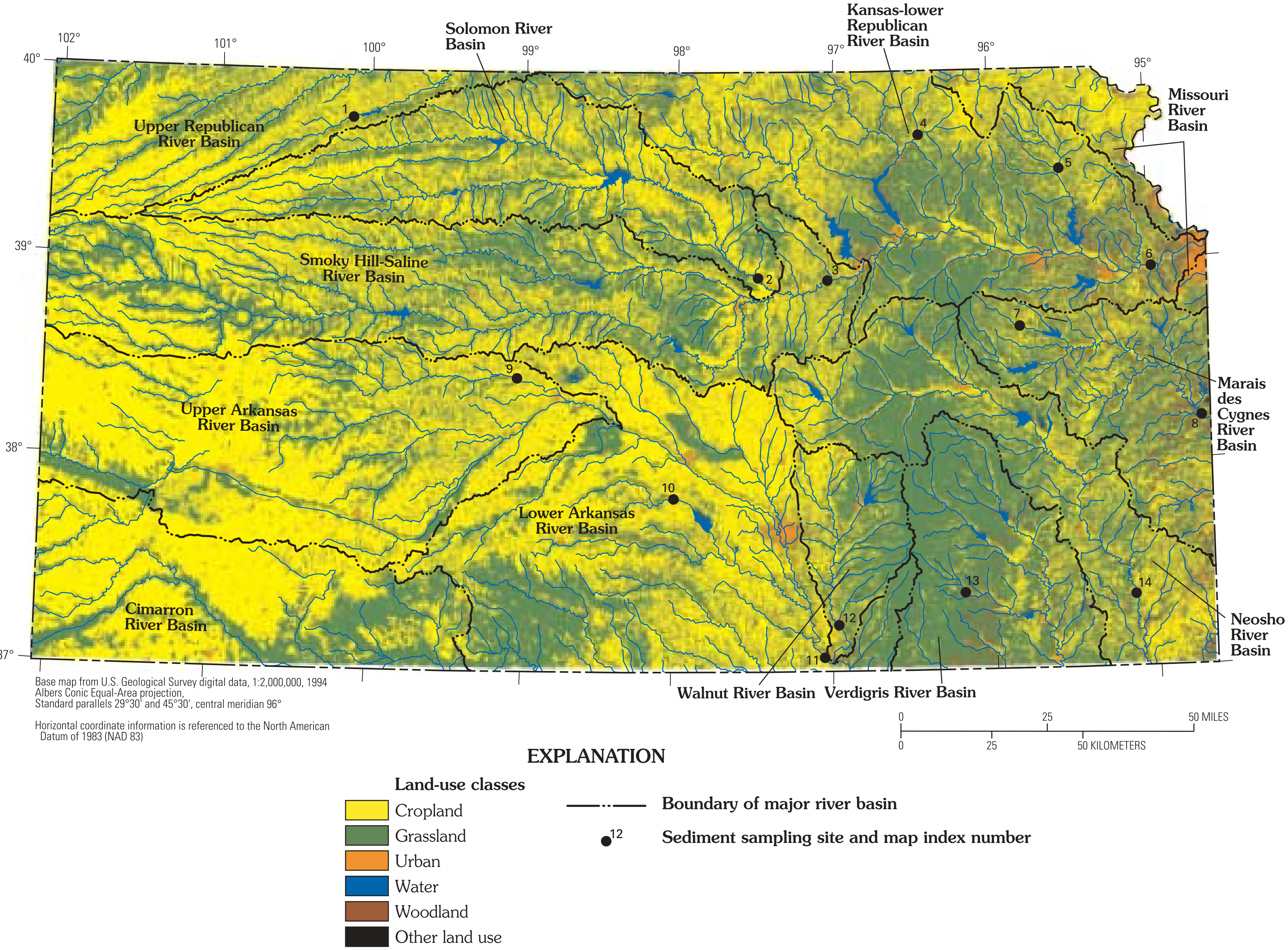


Figure 2. Land use in Kansas, 1988–90 (land use from Kansas Applied Remote Sensing Program, 1993).

Table 1. Description of 14 sediment sampling sites in Kansas

[NASQAN, National Stream Quality Accounting Network]

Sampling-site map index number (fig. 1)	U.S. Geological Survey site identification number	Sampling-site name	Major river basin	Contributing drainage area (square miles)	Remarks
1	06847900	Prairie Dog Creek above Keith Sebelius Lake, Kansas	Upper Republican	590	Upstream from Keith Sebelius Lake.
2	06876900	Solomon River at Niles, Kansas	Solomon	6,770	Downstream-most site, downstream from Waconda Lake.
3	06877600	Smoky Hill River at Enterprise, Kansas	Smoky Hill-Saline	19,260	Downstream-most site, former NASQAN site, downstream from several reservoirs.
4	06885500	Black Vermillion River near Frankfort, Kansas	Kansas-lower Republican	410	Upstream from Tuttle Creek Lake.
5	06890100	Delaware River near Muscotah, Kansas	Kansas-lower Republican	431	Upstream from Perry Lake.
6	06892350	Kansas River at DeSoto, Kansas	Kansas-lower Republican	59,756	Downstream-most site, former NASQAN site, downstream from several reservoirs.
7	06911900	Dragoon Creek near Burlingame, Kansas	Marais des Cygnes	114	Upstream from Pomona Lake.
8	06916600	Marais des Cygnes River near Kansas-Missouri State line, Kansas	Marais des Cygnes	3,230	Downstream-most site, downstream from several reservoirs.
9	07141900	Walnut Creek at Albert, Kansas	Upper Arkansas	1,410	Downstream-most site.
10	07144780	North Fork Ninnescah River above Cheney Reservoir, Kansas	Lower Arkansas	734	Upstream from Cheney Reservoir.
11	07146500	Arkansas River at Arkansas City, Kansas	Lower Arkansas	43,713	Downstream-most site, former NASQAN site.
12	07147800	Walnut River at Winfield, Kansas	Walnut	1,880	Downstream-most site, downstream from El Dorado Lake.
13	07169800	Elk River at Elk Falls, Kansas	Verdigris	220	Upstream from Elk City Lake.
14	07183500	Neosho River near Parsons, Kansas	Neosho	4,905	Downstream-most site, former NASQAN site, downstream from John Redmond Reservoir.

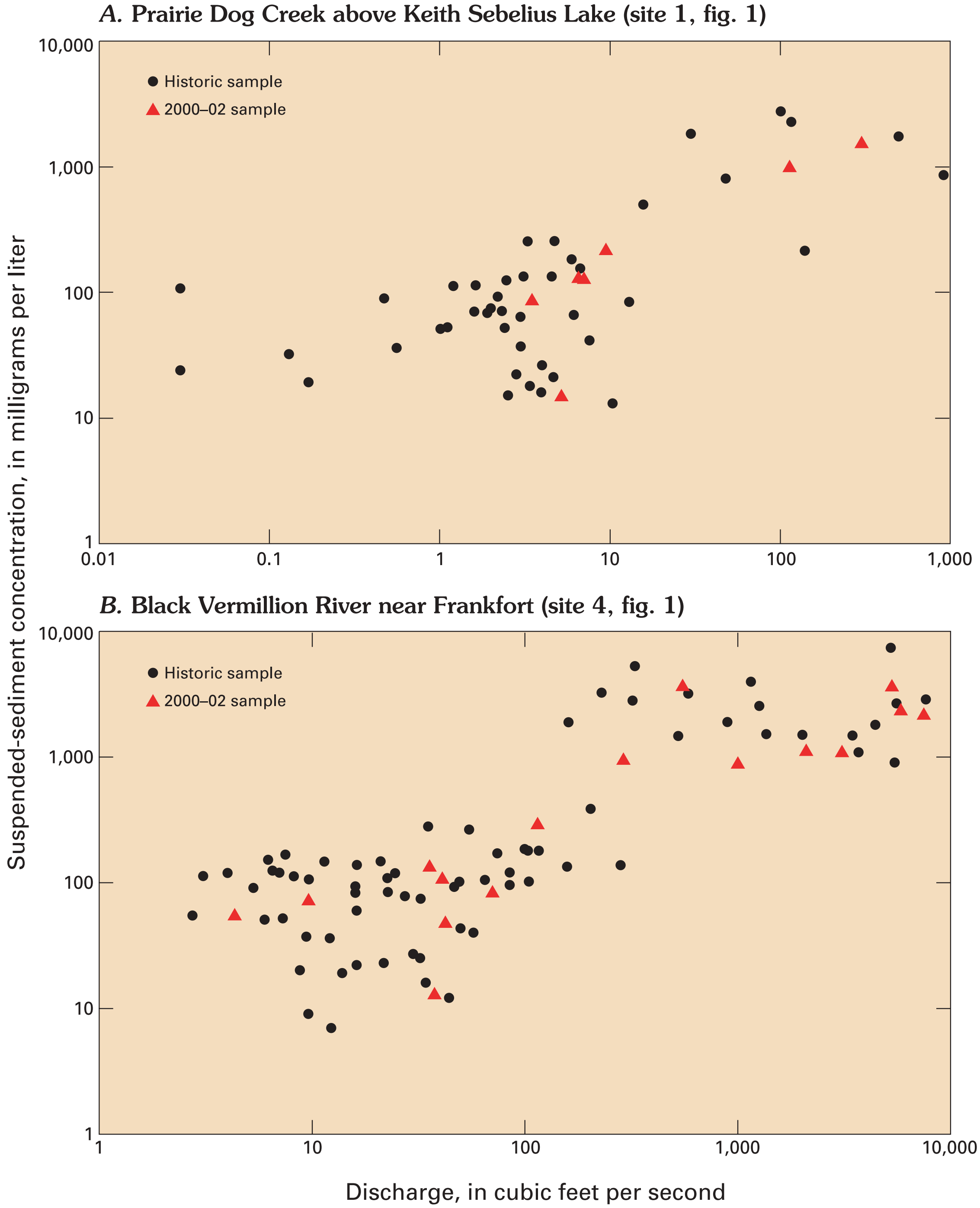
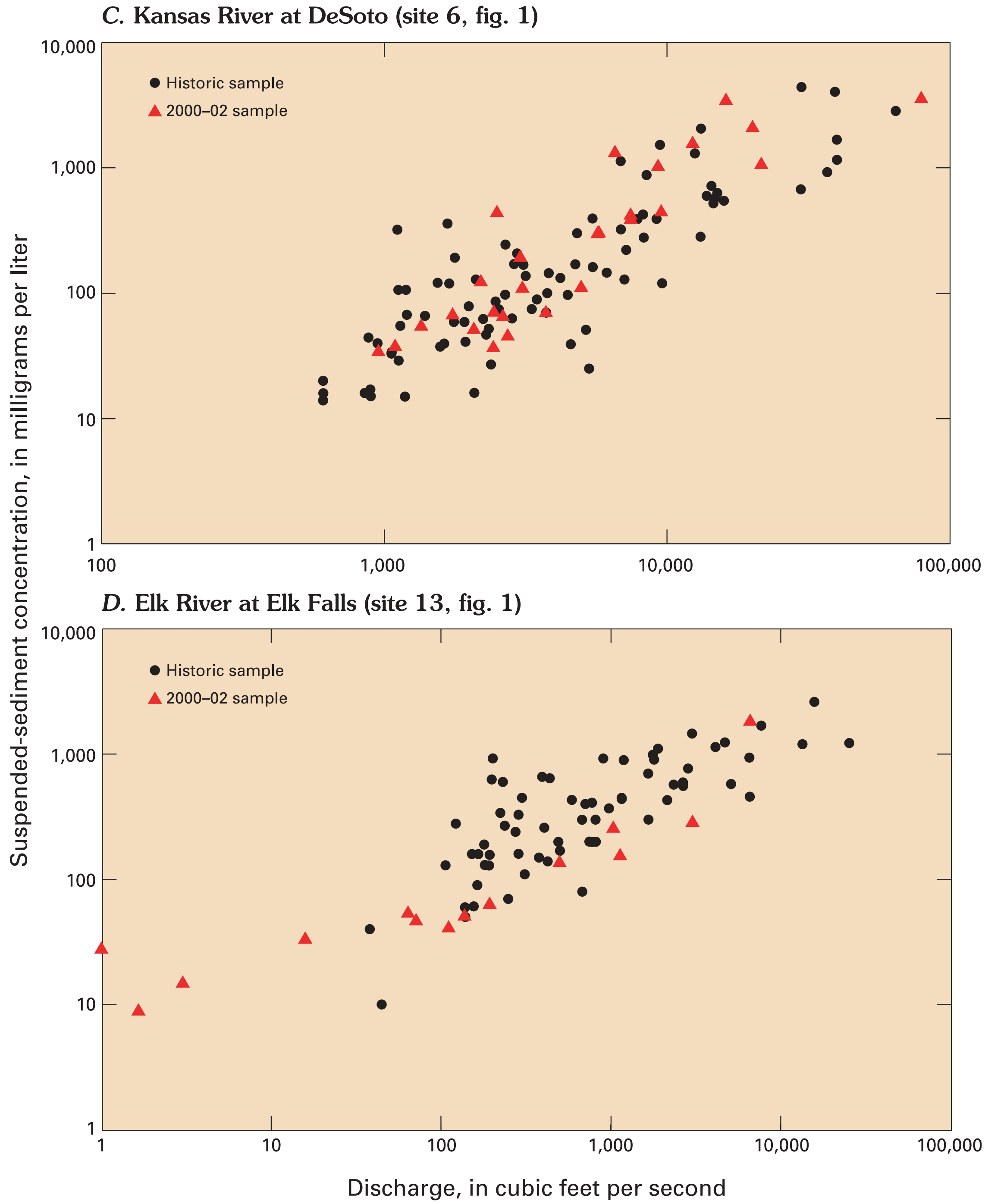


Figure 3. Comparison of suspended-sediment concentrations in historic sediment samples and 2000–02 samples collected at *(A)* site 1, Prairie Dog Creek above Keith Sebelius Lake (fig. 1, table 1), *(B)* site 4, Black Vermillion River near Frankfort (fig. 1, table 1), *(C)* site 6, Kansas River at DeSoto (1999–2001 samples) (fig. 1, table 1), and *(D)* site 13, Elk River at Elk Falls (fig. 1, table 1).

sampling site. Historical sediment data used for trend tests was from the USGS NWIS database. Data consisted of sediment samples collected on a routine schedule (for example, quarterly or bi-monthly) and samples collected more often (for example, samples collected 20 times per month). Some of the data available were not used in the analysis. If the streamflow rate at the time of sampling was not in the database, those samples were not used in the analysis. Single-vertical samples collected at various locations across



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the stream and not composited also were not used in the analysis. At some sites, USGS observers collected numerous samples during a 1-month period, on nearly a daily basis. Jordan (1985) did not use daily sediment samples in his report because daily values are strongly serially correlated, which decreases the value of the additional data for seasonal trend analysis. However, the seasonal Kendall test for trends (discussed later in this report) allows for selection of samples throughout the period of record, regardless of uneven sampling

Table 2. Statistical summary of discharge and suspended-sediment concentration data used for time-trend analysis at 14 sediment sampling sites in Kansas

[ft^3/s, cubic feet per second; mg/L, milligrams per liter]

Sampling-site map index number (fig. 1)	Historical period of record		Number of samples collected during water years 2000–02	Discharge at time of sampling (ft^3/s)				Suspended-sediment concentration (mg/L)			
	Water years	Total number of samples		Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median
1	1975–93	43	7	0.03	911	48.5	3.71	13	2,750	337	88.6
2	1970–87	143	13	32.0	9,030	791	196	7.0	6,440	641	268
3	1971–95	168	16	50.7	42,400	2,280	541	10	4,500	571	196
4	1976–90	70	16	2.74	7,660	845	47.7	7.0	7,370	808	123
5	1977–90	164	15	.04	14,000	973	138	1.0	11,700	1,300	257
6	1978–92	69	[1]27	608	79,000	7,840	3,580	14	4,400	479	132
7	1975–92	77	14	.02	6,040	360	29.2	3.0	4,480	353	56.0
8	1971–2002	560	21	1.1	47,400	6,030	3,220	5.0	5,150	540	344
9	1971–93	41	13	.06	2,840	391	55.0	17.5	2,750	702	345
10	1970–90	236	[1]24	.90	12,500	241	84.0	1.0	2,100	170	72.0
11	1971–88	126	13	207	29,900	3,320	1,510	5.0	5,620	478	182
12	1971–85	68	15	3.0	34,300	2,340	368	8.0	3,330	358	68.0
13	1970–80	66	14	1.0	25,000	1,800	488	8.9	2,360	453	286
14	1975–94	144	21	7.4	37,900	2,840	609	5.0	878	126	50.4

[1]Samples collected 1999–2001.

frequency. Therefore, most of the observer data were used in the analyses described in this report unless the samples did not meet the previously described criteria.

Development of Regression Models and Trend Analysis

The statistical analysis computer program ESTIMATE TREND (ESTREND) (Schertz and others, 1991) was used for computation of sediment time trends in this report. ESTREND allows the user to perform summary statistical analysis of a data set, to explore the seasonal sampling frequency, to determine flow-adjusted concentrations using various regression models and data-smoothing techniques, and to perform trend analysis using the seasonal Kendall test.

The emphasis of this report was not to compare trends among selected sites but rather to determine if trends existed at individual sites from 1970 through 2002. A comparison between trends published in the earlier study by Jordan (1985) and trends determined from ESTREND using the same period of record provided an indication of similarity of results from the two methods. Results of the comparison are shown in table 3. The trends generally compared well, especially for those sites with statistically significant trends; that is, those with a probability value (p-value) less than or equal to 0.05. Differences in trend slopes may be caused either by the type of regression model selected by Jordan (1985) for flow adjustment and the model used in ESTREND or differences in the definition of seasons or selection of samples within seasons.

Generally, sediment concentrations are related to rate of streamflow. Higher velocities can transport more and larger grain sizes of sediment. Because of this relation, any trends in sediment concentration may be obscured due to variability of streamflow. For example, during floods, higher sediment concentrations would be typical, whereas during low-flow periods sediment concentrations are expected to be much lower. Therefore, to test for trends in sediment concentrations, the effects of streamflow are removed by flow adjustment of the sediment concentrations. One approach used to flow adjust the sediment concentrations is least-squares regression analysis (Helsel and Hirsch, 1992). A regression model is fit to the relation between streamflow and sediment concentration. An example of this relation from ESTREND output for one site is shown in figure 4. The residual, the measured sediment concentration or logarithm of concentration minus the sediment concentration or logarithm of concentration computed by the regression model, is the flow-adjusted sediment concentration used for the trend test.

Several regression models were tested for fit, and the model that appeared to fit the data well and had reasonably distributed residuals was used for all sites. The general regression model as described by Schertz and others (1991) is of the form:

$$\log_{10}SSC = b_0 + b_1 \log_{10}Q + b_2(\log_{10}Q)^2, \qquad (1)$$

where
SSC is the estimated sediment concentration (dimensionless);
Q is the instantaneous discharge, in cubic feet per second;
$\log_{10}$ is the base-10 logarithm; and
b_0, b_1, and b_2 are the coefficient parameters estimated in the regression procedure.

The resultant flow-adjusted concentrations using this model are in units of base-10 logarithms and are dimensionless ratios of measured concentration to regression-estimated concentration. The regression models developed for 13 sediment-sampling sites are shown in table 8 in the “Supplemental Information” section at the end of this report. Generally, the regression models used for flow adjustment should not be used to estimate sediment concentration because their errors of estimate are large and their use may lead to erroneous results if a trend exists or if applied to data outside the range for which they were developed (Jordan, 1985). To provide for evaluation of one of these concerns, the data range used to develop the regression models is shown in table 8 (“Supplemental Information” section). Furthermore, for those sites that indicated a statistically significant time trend, Walnut River at Winfield (site 12, fig. 1, table 1) and Elk River at Elk Falls (site 13, fig. 1, table 1), a second regression model was developed using only data collected during 2000–02. The diagnostic statistics shown with each regression equation and included in table 8 (“Supplemental Information” section) were computed using methods described in Helsel and Hirsch (1992). The bias-correction factor is multiplied by the estimated suspended-sediment concentration computed from the regression equation and corrects for retransformation from logarithmic units to original units (Duan, 1983).

Table 3. Comparison of sediment concentration trends computed by Jordan (1985) and trends computed using ESTREND

[probability levels (p-values) less than or equal to 0.05 are statistically significant; percent/yr, percent per year]

Sampling-site map index number (fig. 1)	U.S. Geological Survey site identification number	Sampling-site name	Period of record (water years)	Jordan (1985) trend results		ESTREND trend results	
				Slope (percent/yr)	Probability level	Slope (percent/yr)	Probability level
2	06876900	Solomon River at Niles, Kansas	1960–62, 1973–83	- 0.80	0.57	0.20	0.92
3	06877600	Smoky Hill River at Enterprise, Kansas	1960, 1961 1973–83	-2.2	.19	-1.5	.68
10	07144780	North Fork Ninnescah River above Cheney Reservoir, Kansas	1973–83	. 7[1]	.68	- .50	.86
11	07146500	Arkansas River at Arkansas City, Kansas	1943–45, 1958, 1961–62, 1973–83	- 2.7	.00	- 2.7	.01
12	07147800	Walnut River at Winfield, Kansas	1943–45, 1961–62, 1973–74, 1976–77, 1979–83	- 2.7	.00	- 2.1	.04
13	07169800	Elk River at Elk Falls, Kansas	1967–77, 1980	- 4.7	.04	- 5.1	.06

[1]Units in milligram per liter per year.

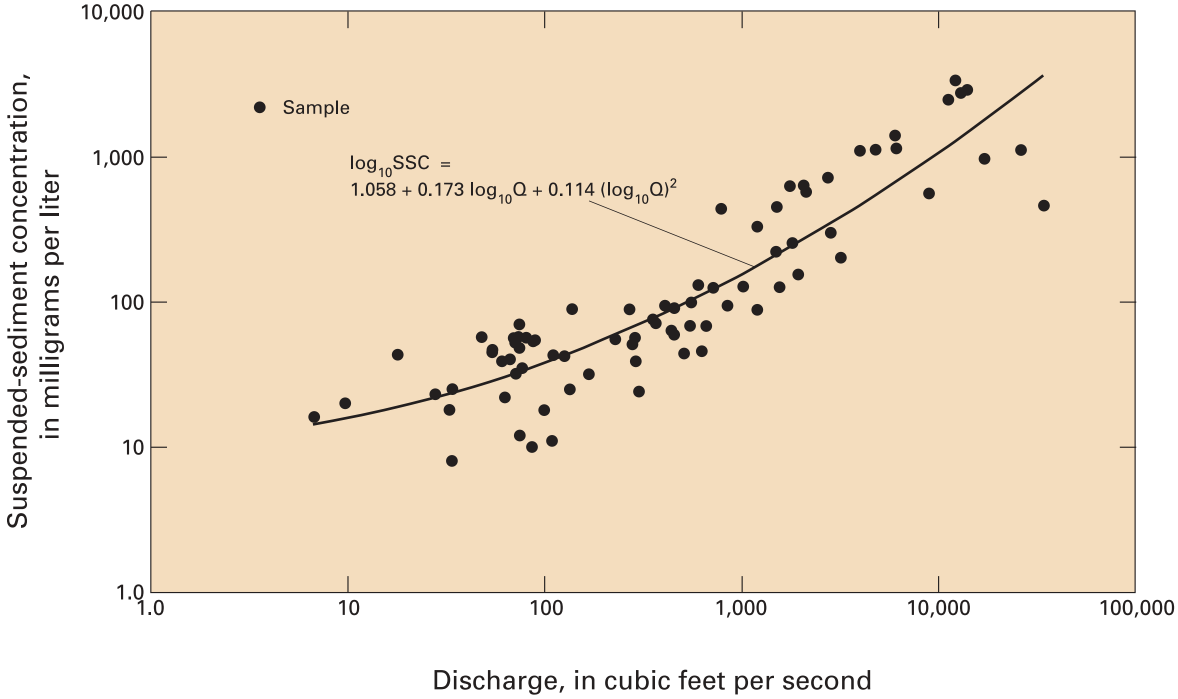

Figure 4. Relation between suspended-sediment concentration and discharge for site 12, Walnut River at Winfield (fig. 1, table 1).

ESTREND uses the nonparametric seasonal Kendall test for trend analysis (Schertz and others, 1991; Helsel and Hirsch, 1992). The seasonal Kendall test is a nonparametric test for monotonic trend in water quality. The test, which is a generalization of the Mann-Kendall test (Mann, 1945; Kendall, 1975), reduces the adverse effect that seasonal differences in the relation of concentration to discharge may have on trend detection by only making comparisons of data from similar seasons. In general, seasons should be just long enough so that there is some data available for most of the seasons in most of the years of record. For example, if data are collected at a monthly frequency, the seasons should be defined as 12 monthly seasons. The test makes all possible pair-wise comparisons of a time-ordered set of water-quality values. If a later data value (in time) is larger, a plus is recorded; if the later data value is smaller, a minus is recorded. The test statistic is computed as the difference between the total number of pluses (increases in time) and the total number of minuses (decreases in time) in the record. As deviations of the test statistic from zero become larger, the likelihood of trend in the data is greater, and the rejection of the null hypothesis (no trend) is more likely. For each test, the p-value is the probability of incorrectly rejecting the null hypothesis of no trend.

Data sets for most of the sampling sites in this report were similar (fig. 5), with few samples collected at the beginning and end periods and more samples collected in the middle periods of the record and some periods when no samples were collected. Site 8, Marais des Cygnes River near Kansas-Missouri State line (fig. 1, table 1), was not analyzed for time trends because sediment-sample collection was extremely variable (1 sample collected in 1979, 534 samples collected during 1980–82, and 21 samples collected during 2000–02).

A 12-season Kendall test (comparisons between monthly samples) was used in the Jordan (1985) study because sufficient data were available for comparisons. ESTREND allows for the selection of seasons for comparison when changes in sampling frequency differ throughout the period of analysis. Because of the variability of sampling frequency during the period of study, about 1970–2002, a four-season Kendall test was used for trend analysis in this report; that is, four 3-month seasons beginning in October. Trends were assumed to be statistically significant at the probability level less than or equal to 0.05. ESTREND computes a trend slope that represents the median rate of change of suspended-sediment concentration for the selected period of record and a probability value (p-value).

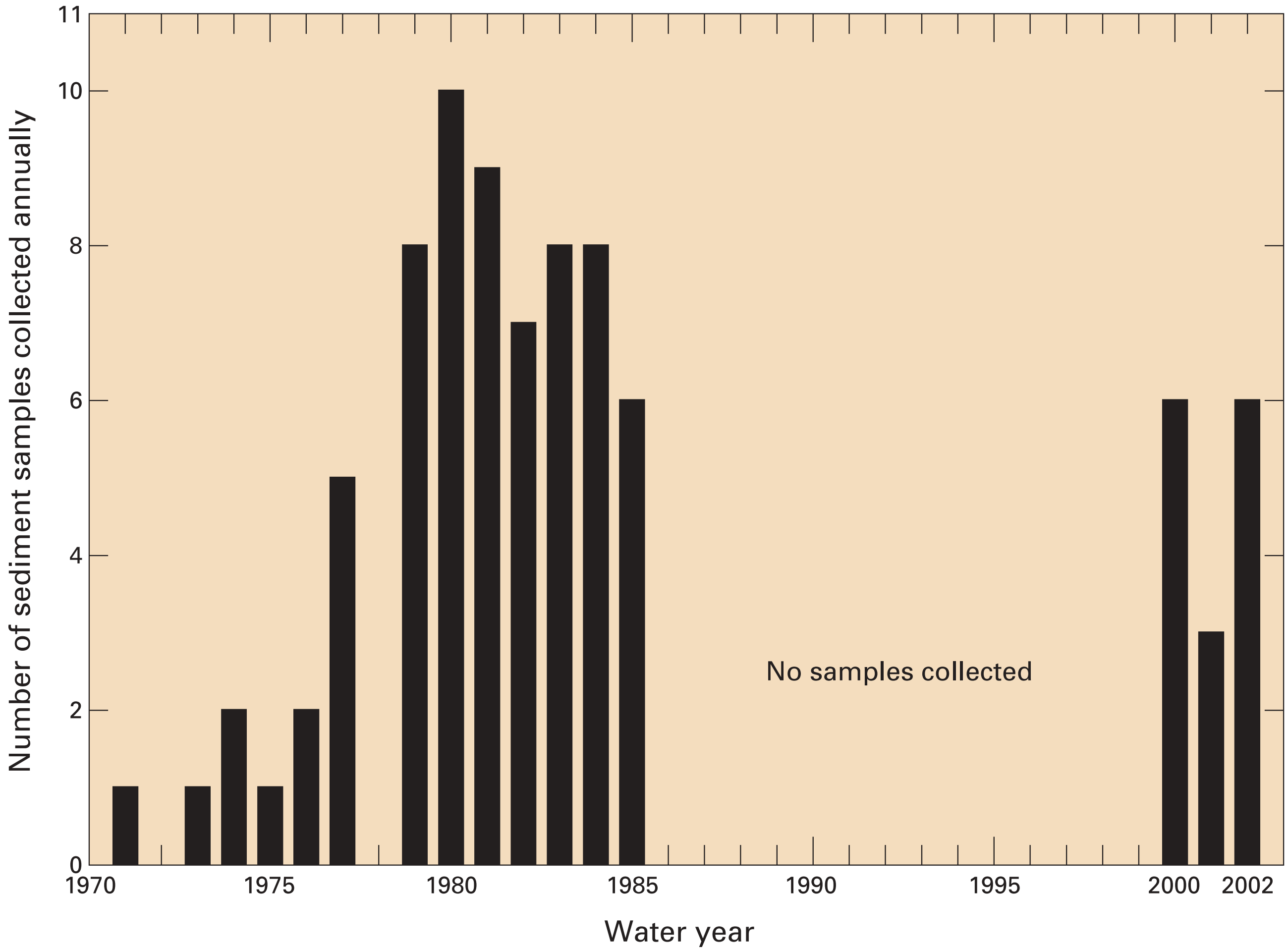

Figure 5. Number of sediment samples collected annually at site 12, Walnut River at Winfield (fig. 1, table 1).

RESULTS OF TREND ANALYSES

Results of the trend analyses are shown in table 4. Ten of the 13 sites tested indicated decreasing trends (toward smaller sediment concentrations); two of the decreasing trends were significant at probability level less than or equal to 0.05 (95-percent confidence). Data from three sites indicated increasing trends (toward larger sediment concentrations); none of the increasing trends were significant at a probability level less than or equal to 0.05. The number of stations with negative trends and not significant at the 0.05 probability level does not necessarily mean a trend does not exist. It is possible that the slope of the trend was not steep enough or available data not complete enough to show statistical significance (Jordan, 1985).

Data from five of the six sites located upstream from lakes or reservoirs indicated decreasing sediment concentrations. Data from site 12, Walnut River at Winfield, and site 13, Elk River at Elk Falls, indicated significant decreasing sediment concentrations at the 0.05 probability level (table 4). Jordan's analysis also indicated significant decreasing trends at these sites for the periods 1943–83 and 1967–80, respectively (sites 10 and 15, table 7, in "Supplemental Information" section at the end of this report). Data from site 9, Walnut Creek at Albert (table 4), indicated a trend toward smaller sediment concentrations with a probability level of 0.10 using a four-season Kendall test; however, a three-season Kendall test and a 12-season Kendall test indicated a significant trend with a probability level less than or equal to 0.04. Therefore, a significant trend cannot be ruled out at this site, and perhaps additional data collection would confirm a significant trend. Jordan's analysis indicated a statistically significant decrease in sediment concentration for site 11, Arkansas River at Arkansas City (tables 3 and 4), for the period 1943–83; however, analysis of the 1971–2002 period (table 4) indicated no significant trend.

Table 4. Results of time-trend analysis of suspended-sediment concentrations at 14 sediment sampling sites in Kansas

[Shading indicates significant at 95-percent confidence level (probability value less than or equal to 0.05); percent/yr, percent per year; NA, not available]

Sampling-site map index number (fig. 1)	U.S. Geological Survey site identification number	Sampling-site name	Period of record (water years)	Total number of samples collected (number of samples used in trend analysis)	Kendall test on flow-adjusted sediment concentration: Slope (percent/yr)	Kendall test on flow-adjusted sediment concentration: Probability level
1	06847900	Prairie Dog Creek above Keith Sebelius Lake, Kansas	1975–2002	50 (33)	-1.6	0.61
2	06876900	Solomon River at Niles, Kansas	1970–2002	156 (66)	-1.1	.46
3	06877600	Smoky Hill River at Enterprise, Kansas	1971–2002	184 (96)	-.20	.92
4	06885500	Black Vermillion River near Frankfort, Kansas	1976–2002	86 (28)	2.3	.46
5	06890100	Delaware River near Muscotah, Kansas	1977–2002	181 (32)	-1.0	.49
6	06892350	Kansas River at DeSoto, Kansas	1978–2002	169 (60)	1.6	.24
7	06911900	Dragoon Creek near Burlingame, Kansas	1975–2002	91 (50)	-.80	.51
8	06916600	Marais des Cygnes River near Kansas-Missouri State line, Kansas	1971–2002	NA	NA	NA
9	07141900	Walnut Creek at Albert, Kansas	1971–2002	54 (32)	-2.2	.10
10	07144780	North Fork Ninnescah River above Cheney Reservoir, Kansas	1970–2002	260 (84)	-.30	.80
11	07146500	Arkansas River at Arkansas City, Kansas	1971–2002	138 (68)	-1.1	.64
12	07147800	Walnut River at Winfield, Kansas	1971–2002	83 (40)	-2.8	.02
13	07169800	Elk River at Elk Falls, Kansas	1970–2002	80 (27)	-5.7	.00
14	07183500	Neosho River near Parsons, Kansas	1975–2002	165 (86)	.90	.20

There are inherent problems with the sampling period for some of the sites used for the time-trend tests in this report. The seasonal Kendall test for trends works well for data sets with gaps in sample collection; however, the sediment samples need to represent the variability of streamflow during the analyzed period to result in an accurate statistical test. For example, if most samples were collected during high flow (or low flow) only, the statistical test would be biased. The trend test works best with samples collected at regularly spaced intervals within a year to preclude any temporal bias in the sample data (Schertz and others, 1991). Figure 6 shows mean annual discharge for the 1971–2002 period for two sites, Smoky Hill River at Enterprise (site 3, fig. 1, table 4) and Arkansas River at Arkansas City (site 11, fig. 1,

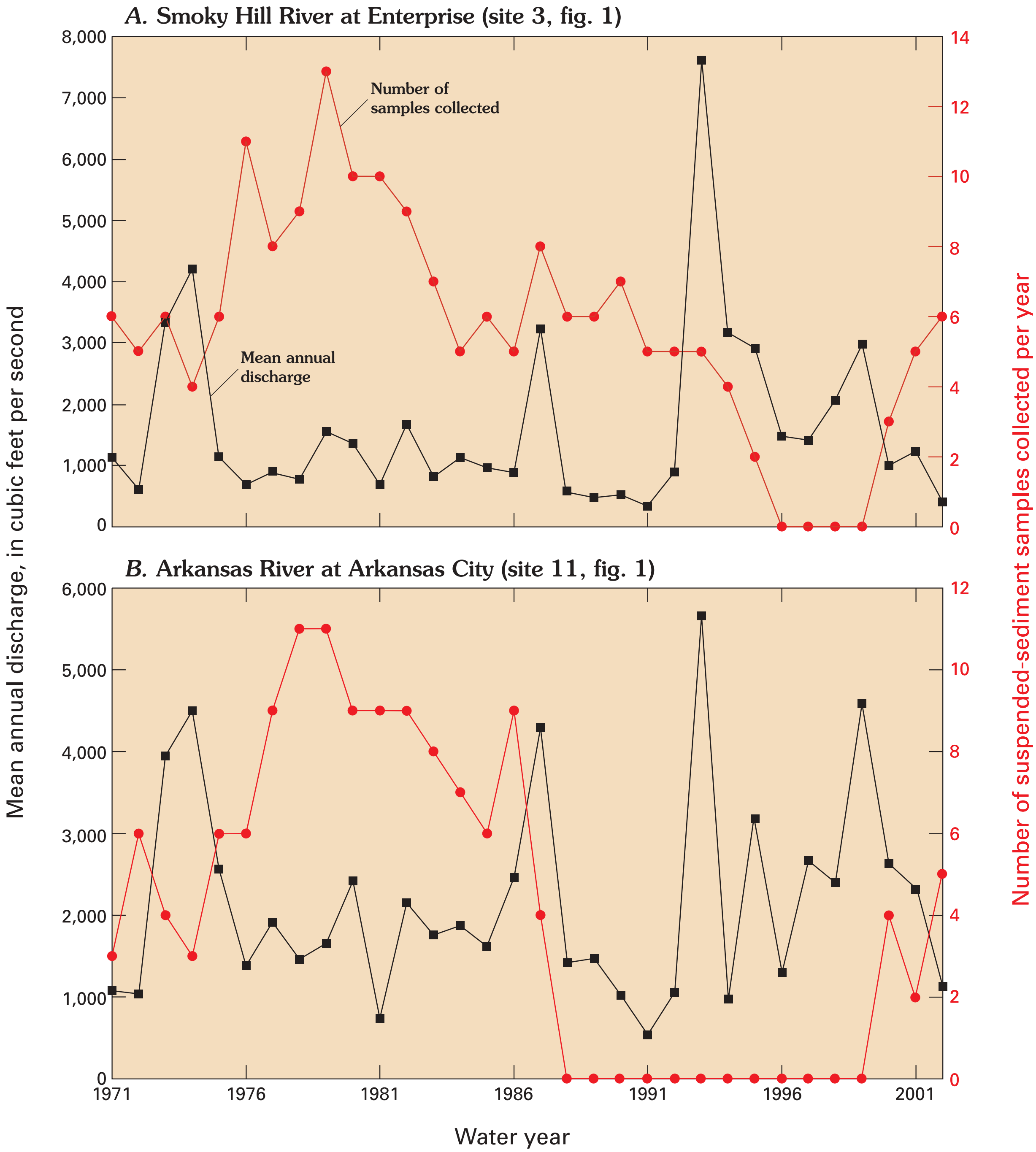

Figure 6. **Mean annual discharge and number of suspended-sediment samples collected annually at *(A)* site 3, Smoky Hill River at Enterprise (fig. 1, table 1), and at *(B)* site 11, Arkansas River at Arkansas City (fig. 1, table 1).**

table 4), plotted with the number of sediment samples collected per year. Because both of these sites were NASQAN water-quality sampling sites, samples were collected on a regular, fixed schedule. Sediment samples at the Enterprise site (fig. 6*A*) were collected during all flow conditions including the extreme high flow of 1993. However, no sediment samples were collected at the Arkansas City site (fig. 6*B*) during 1993 through 1999, periods of above-normal flow. These two sites are characteristic of many sites analyzed in this report. The nonsampled period probably does not significantly affect the trend analysis for most sites because the recent samples (2000–02) are comparable with historic samples. It can be assumed that for those sites that did not have a statistically significant trend at the 0.05 probability level, a trend may exist; inadequate data may be the reason no trend was identified.

The seasonal Kendall test is very sensitive to the sampling period at the beginning and ending (BE) portions of the sampling record. The BE record consists of approximately the first and last one-fifths of the entire record (as defined by years), and the middle record (MI) is the middle three-fifths (Schertz and others, 1991). The BE record for the Enterprise site (fig. 6*A*) is about 1971–76 and 1997–2002. About 29 percent of the total samples were collected at the Enterprise site in the BE record period, whereas about 71 percent of the samples were collected in the MI period. Ideally, to provide the best statistical result, two-fifths, or about 40 percent of the samples should be collected during the BE record period. The Arkansas City site (fig. 6*B*) indicated a similar sampling frequency with about 24 percent of the samples collected during the BE record period. The remaining sampling sites indicated similar sampling patterns. This problem was somewhat reduced by selecting a four-season Kendall test because it best represented the data sets throughout the sampled period and because the same number of samples were selected per year during most of the sampling period.

EVALUATION OF TREND RESULTS

As stated earlier in this report, results of sediment trend tests will be used by the State to evaluate the effectiveness of erosion-control and land-management practices financed by the KWP Fund during the last 30 years. The three sites that indicated statistically significant trends at the 0.05 probability level or trends at the 0.10 probability level (sites 9, 12, and 13, table 4) have drainage areas of 1,410, 1,880, and 220 mi^2, respectively. Small erosion-control impoundments completed within these large watersheds generally would not result in significant changes in sediment trends unless many similar impoundments were placed throughout the watershed. However, a large number of watershed impoundments and smaller flood-control structures located within the watershed would have a significant effect on sediment concentration trends because these structures are designed to trap large amounts of sediment during moderate to high flow.

Most small watershed impoundments and flood-control structures in Kansas were built as a result of the Flood Control Act of 1944 (PL78–534) and the Watershed Protection and Flood Prevention Act of 1953 (PL83–566). There are 823 flood-control and grade-stabilization structures in Kansas constructed with financial assistance from the U.S. Department of Agriculture, National Resources Conservation Service (NRCS) (Brian Lang, NRCS, written commun., 2003). Most of the structures in the NRCS database are small-watershed dams; however, the database does include small stock ponds and other flood-control structures such as bank-stabilization structures.

The Kansas State Conservation Commission (SCC) administers a watershed dam conservation program and since 1974 has provided financial assistance for construction of small watershed lakes in Kansas. The SCC receives funding from the KWP Fund for construction and maintenance of small watershed impoundments and other conservation projects. There are currently 484 small watershed impoundments in Kansas constructed by SCC (Matt Scherer, Kansas Department of Agriculture, Division of Water Resources, written commun., 2003) (fig. 7). The Kansas Water Office, in cooperation with the SCC, developed the Multipurpose Lake Program in 1985. This program was developed, in part, to provide a reliable water supply for small towns and rural water districts, to reduce flooding, and to provide a mechanism to ensure that adequate measures are installed in the watershed to protect the lakes from pollution and siltation (Kansas Water Office, 2003b).

Small watershed impoundments provide a source of water for small towns and rural water districts and have recreational uses. Watershed lakes help control flooding and improve water quality in the watershed because they are designed to trap sediment and contaminants. It is this latter benefit that can be a predom-

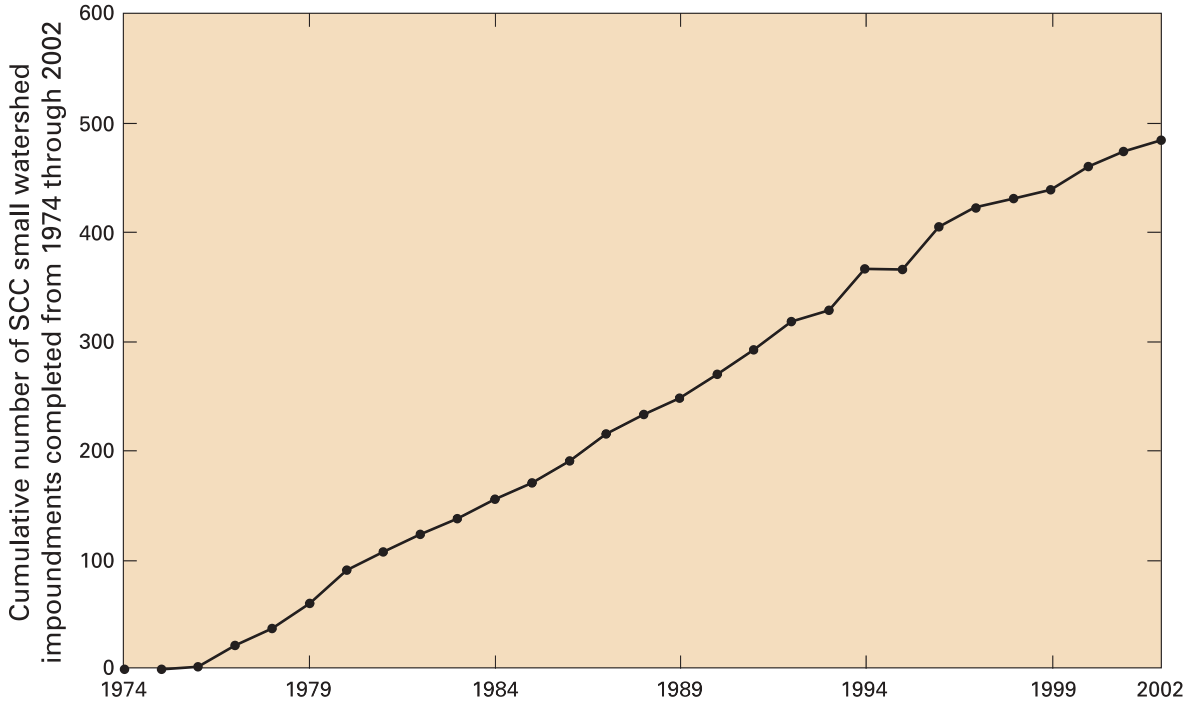

Figure 7. Cumulative number of small watershed impoundments in Kansas completed and funded by Kansas State Conservation Commission (SCC), 1974–2002 (data from Matt Scherer, Kansas Department of Agriculture, Division of Water Resources, written commun., 2003).

inant factor in reducing sediment transport in a watershed, especially if a large number of small impoundments are located within the watershed. There are 83 watershed districts in Kansas that plan and administer the construction and maintenance of small watershed impoundments in the State. For this report, the watershed district activity was measured by the span of years during which flood-control structures were completed and by the percentage of the drainage area from which floodwater was detained and sediment was trapped. The percentage of the drainage area that is affected by impoundments upstream from selected sediment-sampling sites is shown in table 5. This information was not compiled for the sites with very large drainage areas—site 6, Kansas River at DeSoto (fig. 1), and site 11, Arkansas River at Arkansas City (fig. 1). A large percentage of the basins upstream from both sediment sampling sites that had significant time trends in sediment concentration are affected by impoundments (sites 12 and 13, tables 4 and 5).

Data from site 12, Walnut River at Winfield (table 4), indicated a significant trend toward smaller sediment concentrations, decreasing at an average rate of 2.8 percent per year (table 4). Since 1950, 170 NRCS flood-control structures have been constructed in the Walnut River watershed area (fig. 8) (Brian Lang, NRCS, written commun., 2003). These structures affect runoff from more than 500 mi^2 or 27 percent of Walnut River Basin. The SCC has funded construction of 14 small watershed impoundments in the Walnut River Basin that affect runoff from about 1 percent of the basin. El Dorado Lake, also located within the Walnut River Basin, was constructed by the U.S. Army Corps of Engineers and completed in 1981. El Dorado Lake has a drainage area of 247 mi^2, 13 percent of the Walnut River's total drainage area. Therefore, El Dorado Lake and the watershed impoundments affect about 41 percent of the Walnut River at Winfield drainage area. Figure 9 shows the location of NRCS flood-control structures and SCC watershed impoundments in the Walnut River watershed. Some of the NRCS and SCC impoundments are plotted together and may indicate that both NRCS and SCC funds were used for construction.

Jordan (1985) performed a seasonal step test for the Winfield site to confirm sudden changes in sediment concentration downstream from El Dorado Lake. The test indicated a significant (0.05 level) step trend

Table 5. Percentage of watershed drainage area affected by impoundments upstream from selected sediment sampling sites in Kansas

[mi^2, square miles]

Sampling-site map index number (fig. 1)	Drainage area (mi^2)	Percentage of watershed affected by impoundments
1	590	0
2	6,770	77.7
3	19,260	69.0
4	410	25.6
5	431	14.6
7	114	1.0
9	1,410	36.8
10	734	0
12	1,880	41.0
13	220	68.0
14	4,905	63.0

to smaller concentrations, thus indicating that El Dorado Lake has a substantial effect on reducing sediment concentrations. Because a large number of streams in the Walnut River at Winfield watershed flow through El Dorado Lake and the small watershed lakes and because a large amount of the sediment moving in the streams is trapped, the lake and impoundments may be a dominant factor in explaining the decreasing sediment trends at the Winfield site.

Site 13, Elk River at Elk Falls (table 4), located upstream from Elk City Lake, also indicated a significant trend toward smaller suspended-sediment concentration, decreasing at an average rate of 5.7 percent per year at (table 4). The 26 NRCS flood-control structures in the Elk River Basin were constructed in the 1970s and affect runoff from about 68 percent of the Elk River drainage area (table 5 and fig. 10). The smaller suspended-sediment concentrations at this site may be the result of the large percentage of the watershed area affected by flood-control structures.

The effects of impoundments on suspended-sediment concentration can be shown by the relation between the percentage of the watershed affected by impoundments and the suspended-sediment trend, in percent change per year (fig. 11). Generally, as the percentage of watershed affected by impoundment increases, the change in suspended-sediment concentration decreases (more negative changes per year). One of the anomalies in figure 11 is site 4, Black Vermillion River near Frankfort (fig. 1, table 4). The Frankfort site is located in a subbasin that has a high runoff potential and very high crop acreage, and other

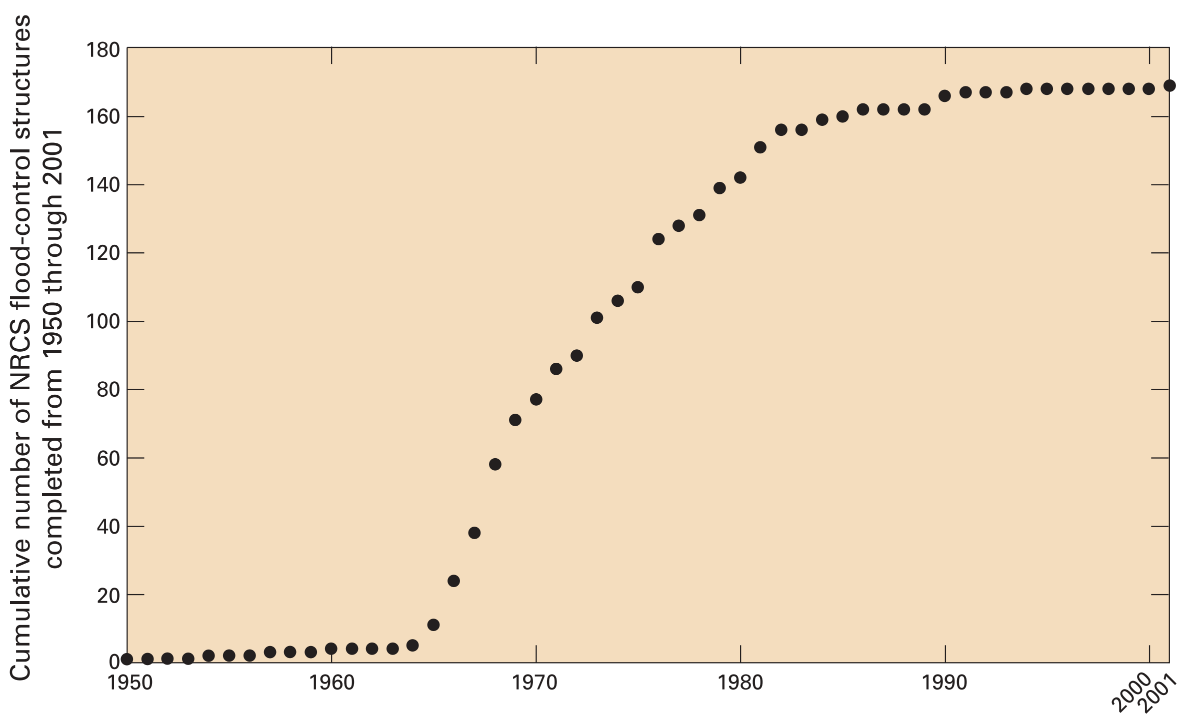

Figure 8. Cumulative number of flood-control structures in the Walnut River Basin upstream from Winfield completed and funded by Natural Resources Conservation Service (NRCS), 1950–2001 (data from Brian Lang, NRCS, written commun., 2003).

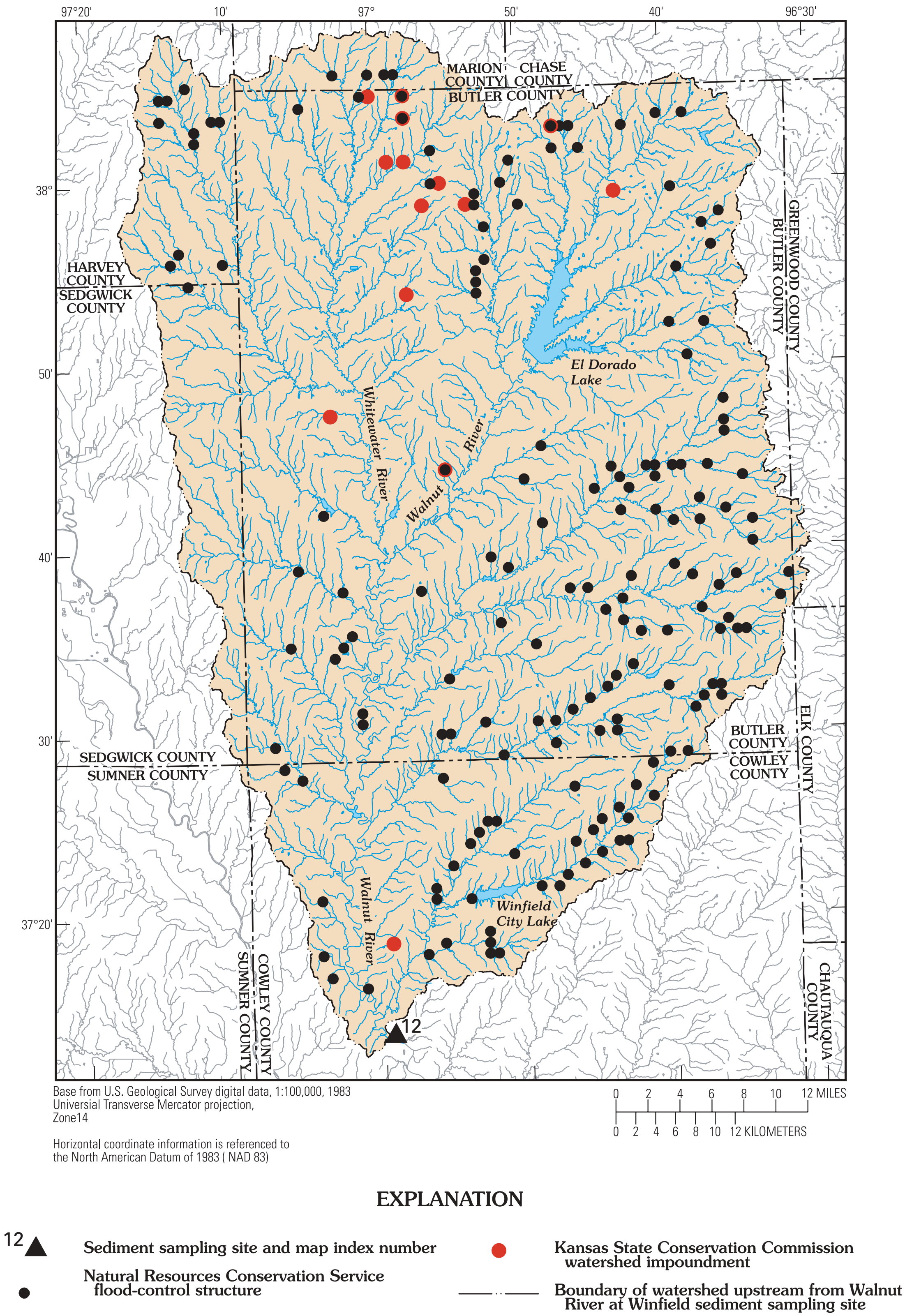

Figure 9. Location of Natural Resources Conservation Service flood-control structures and Kansas State Conservation Commission watershed impoundments in the Walnut River Basin upstream from Winfield.

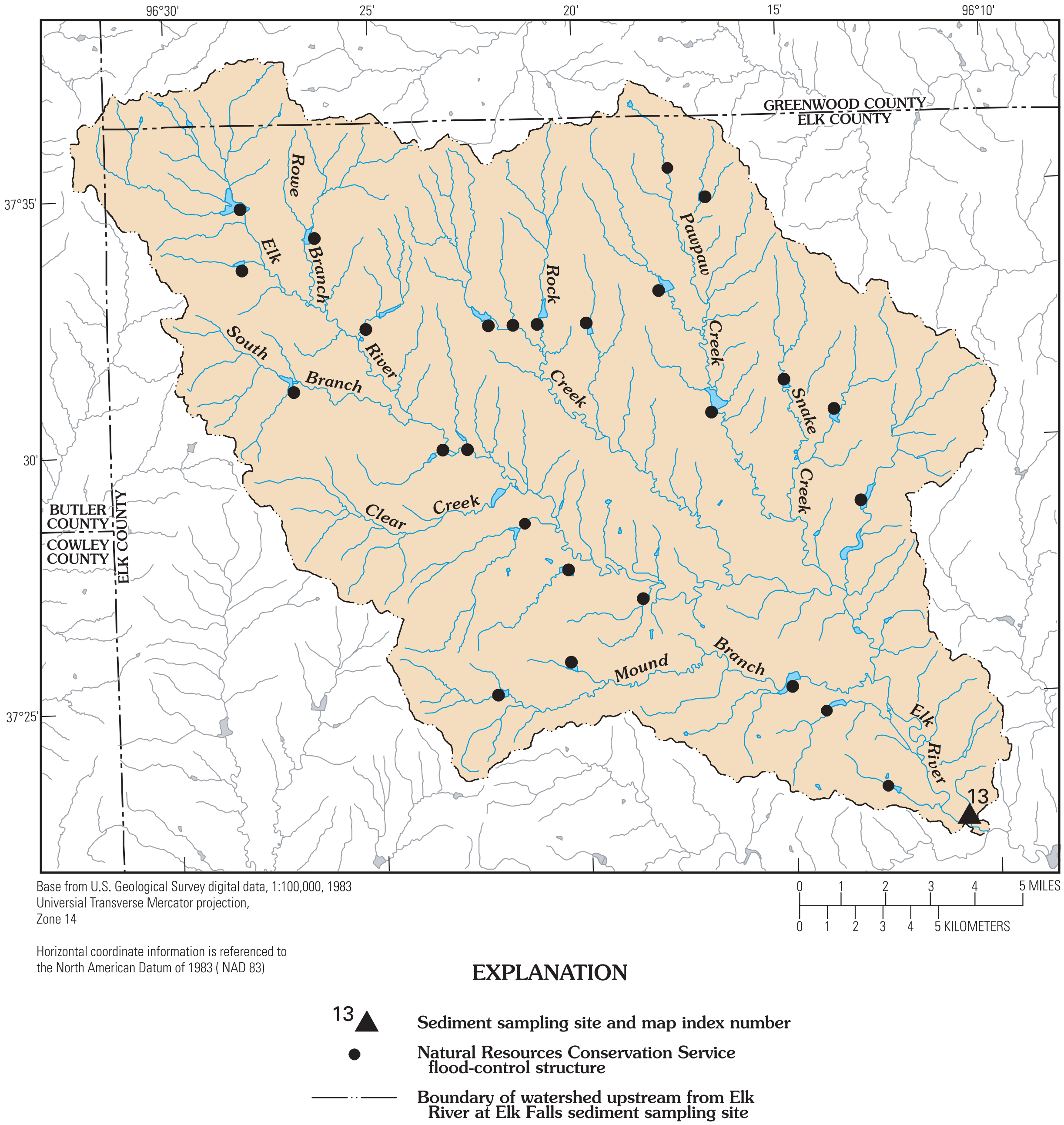

Figure 10. Location of Natural Resources Conservation Service (NRCS) flood-control structures in the Elk River Basin upstream from Elk Falls (data from Brian Lang, NRCS, written commun., 2003).

topographic characteristics in the subbasin contribute to excess runoff (Juracek, 2000). Although there are many impoundments located within this subbasin, about 70, the Black Vermillion River still transports large amounts of sediment. Site 2, Solomon River at Niles (fig. 1, table 4), also does not follow the trend of the other sites in figure 11. Waconda Lake, located about 60 mi upstream from the Niles sampling site, affects more than 70 percent of the Niles watershed, and SCC and NRCS impoundments affect less than 3 percent of the watershed between the lake and the sampling site. The large distance between Waconda Lake and the Niles site and the small number of impoundments located between the lake and the sampling site may account for the lack of a significant suspended-sediment concentration trend at the Niles site.

There are other conservation practices that occur throughout the watersheds that can affect the rate of

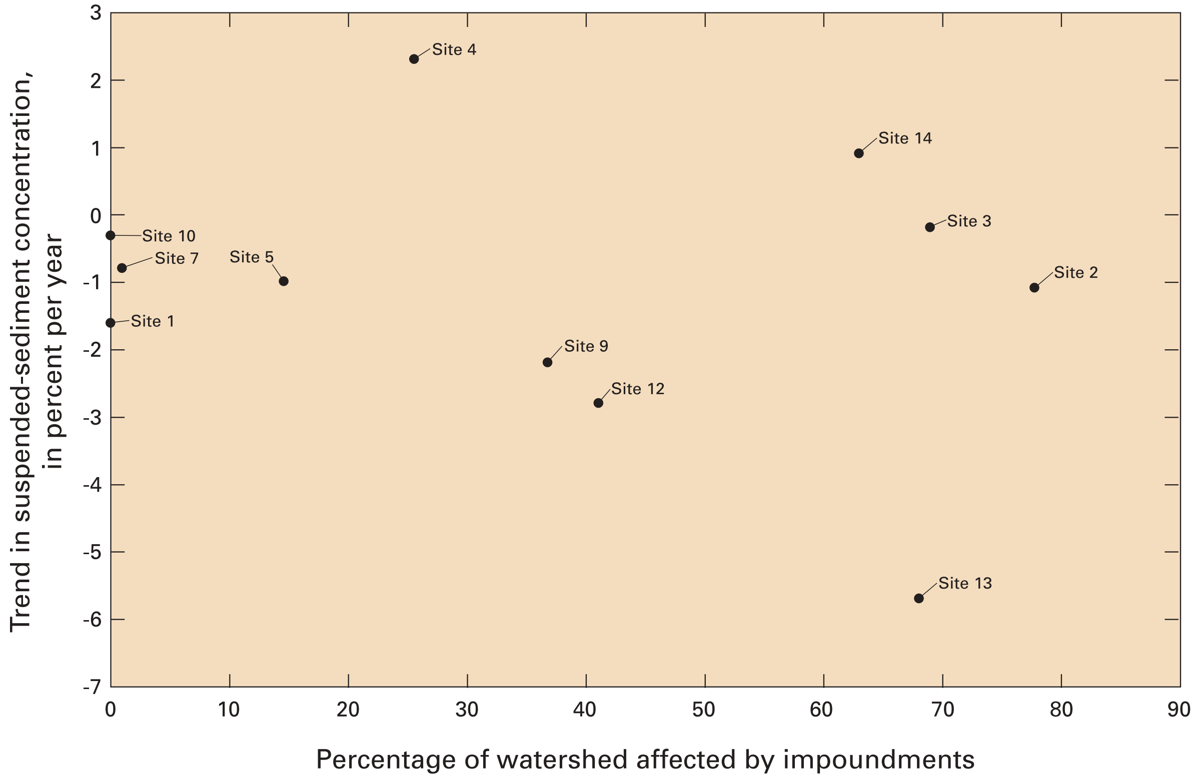

Figure 11. Relation between percentage of watershed affected by impoundments and suspended-sediment trends for 11 sediment sampling sites in Kansas.

sediment transport to streams; however, this information is difficult to quantify by watershed. The following information is available statewide from the National Resources Inventory (NRI) compiled by the NRCS in 1997. In 1982, Kansas had 3.2 million acres of cropland eroded by water at rates exceeding the tolerable limit, whereas in 1997, total cropland eroded decreased to 2 million acres (Natural Resources Conservation Service, 1997). There are several conservation practices that, in part, account for the decrease in eroded cropland. Structural practices such as ponds and terraces and management practices such as contour farming and crop-residue management benefit the State by reducing sediment transport to streams. Conversion of cropland to the U.S. Department of Agriculture's Conservation Reserve Program also reduces erosion. The NRCS indicated that throughout the years, Kansas land users have installed enough terraces to reach the moon and back, roughly 450,000 mi (Natural Resources Conservation Service, 1997). These practices, in addition to construction of small watershed impoundments financed by State and Federal agencies, significantly affect the rate of sediment transport to streams and probably account for the decreasing sediment trends at most of the sites sampled for in this report.

USE OF TURBIDITY TO DEVELOP REGRESSION EQUATIONS FOR ESTIMATING SUSPENDED-SEDIMENT CONCENTRATION

As discussed previously in this report, the relation between discharge and sediment concentration was used to develop a regression model for flow adjustment of sediment concentration. The regression equations developed using discharge as an explanatory variable are shown in table 8 in the "Supplemental Information" section at the end of this report. An alternative approach has been used by the USGS to develop more robust, site-specific regression models that can be used to estimate sediment concentration. Sensor technology currently (2003) is not available to directly measure many water-quality constituents such as suspended-sediment concentration. The USGS has developed regression models at a number of sites to relate laboratory-analyzed suspended-sediment samples with in-stream measurements of turbidity. The regression models are used to estimate a continuous record of suspended-sediment concentrations and loads (Christensen, 2001; Christensen and others, 2003).

No continuous in-stream measurements of turbidity were collected for this report; however, turbidity was measured directly during sediment sampling at most sites. Currently (2003) 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 for 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 at sites 6, 10, 11, 12, and 13 (fig. 1) 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. Turbidity samples were collected at sites 1, 2, 3, 4, 5, 7, 8, 9, and 14, and turbidity was measured using a HF Scientific Micro 1000 laboratory turbidimeter (HF Scientific, Inc., Fort Myers, Florida). The HF Micro 1000 conforms to the USEPA Method 180.1 standard.

Regression models for estimating sediment concentration were developed using samples collected during 2000–02. A summary of the diagnostic statistics for the 10 sites that had sufficient data for modeling is shown in table 6. Graphs of the regression models for two sites are shown in figure 12. Sites 1 and 9 (fig. 1, table 4) are not listed in table 6 because too few samples were collected to develop the models. Sites 8 and 11 (fig. 1, table 4) are not shown in table 6 because the regression models were not significant. Two diagnostic statistics used to evaluate regression models—R^2, the coefficient of determination, and MSE, the mean square error—also are shown in table 6, and a description of the method to determine these statistics is provided in Helsel and Hirsch (1992). R^2 gives an indication of variance between estimated and measured values. For example, values of R^2 close to 1 indicate less variance in data compared to an R^2 of 0.40. MSE also indicates variance between estimated and measured values, and the variance is less as MSE values decrease. The diagnostic statistics shown in table 6 for the two regression models indicate that turbidity provides a better surrogate for sediment concentration than discharge. The regression equations using turbidity as an explanatory

Table 6. Diagnostic statistics for the relations between discharge and suspended-sediment concentration and turbidity and suspended-sediment concentration for selected sediment sampling sites in Kansas

[R^2, coefficient of determination; MSE, mean square error]

Sampling-site map index number (fig. 1)	Number of samples	Discharge-sediment relation		Turbidity-sediment relation	
		R^2	MSE (log units)	R^2	MSE (log units)
2	10	0.79	0.0931	0.96	0.0195
3	12	.90	.0443	.92	.0370
4	9	.73	.2759	.74	.2624
5	11	.81	.1322	.88	.0840
6	25	.80	.0905	.93	.0321
7	13	.81	.1612	.80	.1710
10	21	.76	.0962	.76	.0978
12	15	.82	.0959	.93	.0372
13	13	.81	.0719	.93	.0282
14	18	.87	.0496	.89	.0418

variable for 10 sediment sampling sites are provided in table 8 in the “Supplemental Information” section at the end of this report.

It was not reasonable to install water-quality monitors to measure turbidity at all sites included in this report because of high equipment and operation costs. However, if the objective were to study how planned erosion-control projects will affect a specific watershed, water-quality monitors could provide more information than would a discrete sampling program. Continuous turbidity measurements and continued suspended-sediment sampling would provide data necessary to improve site-specific regression models.

FUTURE SEDIMENT DATA-COLLECTION NEEDS

Jordan concluded in the 1985 sediment-network analysis that some sampling sites could be discontinued and reestablished in about 1992 to collect new data. This never happened because adequate funding has not been available for the sediment data-collection network since about 1985. Evaluating sediment trends will be important in the future to measure how and if conservation practices in watersheds are improving water quality. However, future trend analyses will be difficult if sampling frequency is erratic or if no samples are collected for long periods of time. Reestablishing sampling sites that represent major river

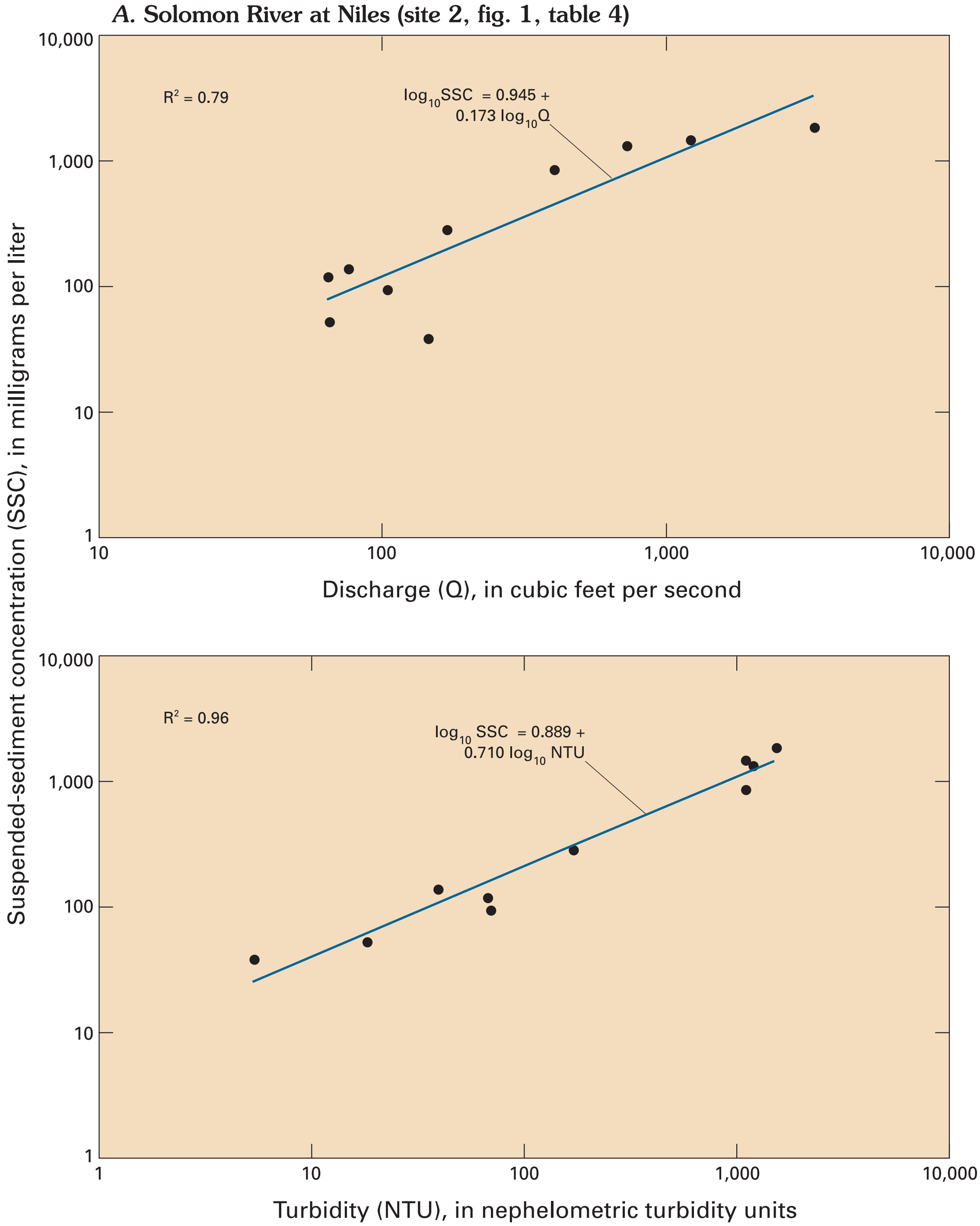

Figure 12. Relations between discharge and suspended-sediment concentration and turbidity and suspended-sediment concentration for *(A)* site 2, Solomon River at Niles, and for *(B)* site 12, Walnut River at Winfield.

basins or sites located where changes in the watersheds are occurring or planned would allow assessment of the effects these changes have on suspended-sediment concentrations in streams. The sample frequency used during the 2000–02 period, about six samples per year, would provide adequate data to describe seasonal variability in suspended-sediment concentrations and provide samples that represent the full range of streamflow.

Additional sediment samples are needed at sites 1, 8, and 9 (fig. 1, table 4) to define trends. Only seven sediment samples were collected at site 1, Prairie Dog

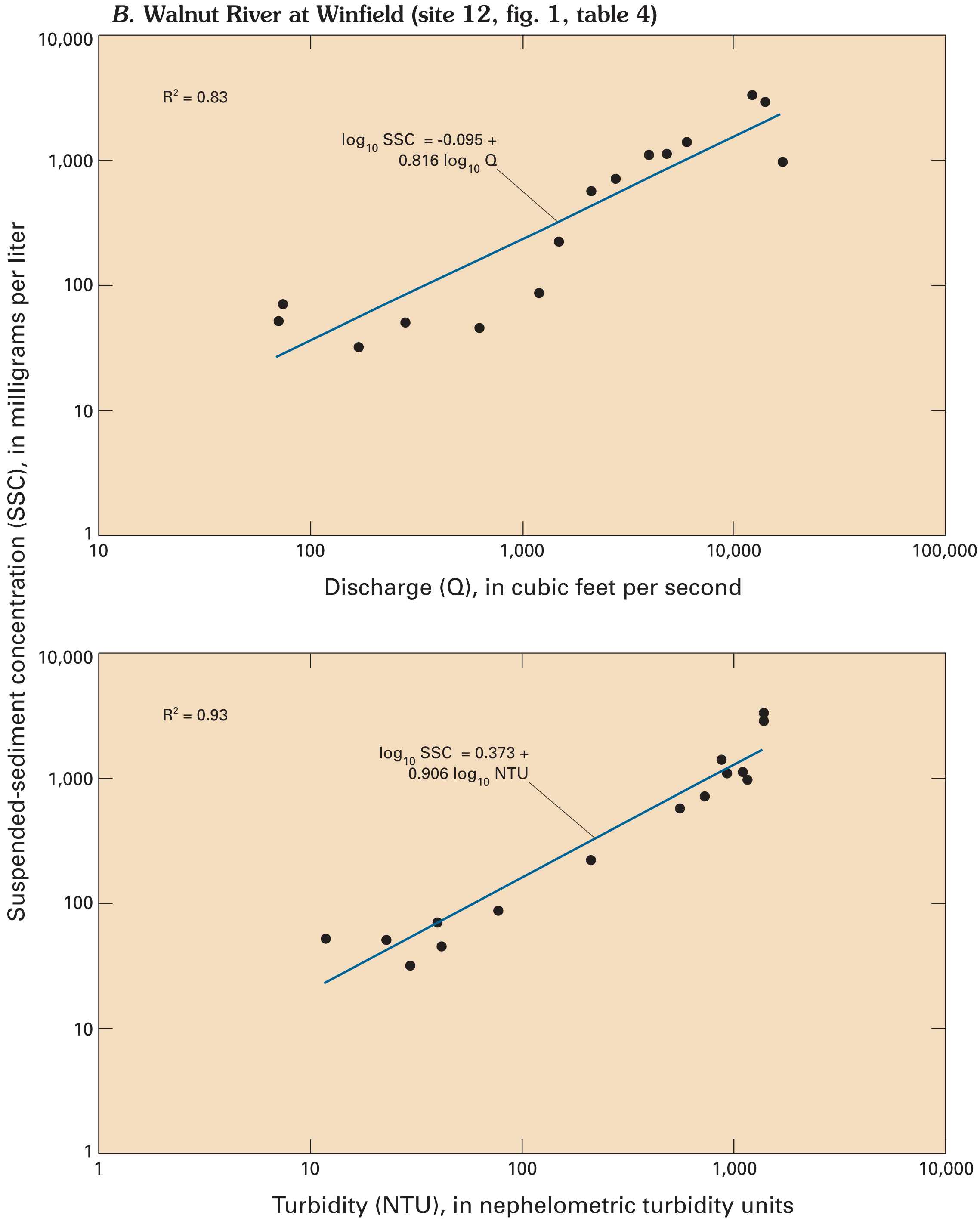

Figure 12. Relations between discharge and suspended-sediment concentration and turbidity and suspended-sediment concentration for *(A)* site 2, Solomon River at Niles, and for *(B)* site 12, Walnut River at Winfield—Continued.

Creek above Keith Sebelius Lake, during 2000–02. Additional sediment samples at this site would confirm whether a trend in suspended-sediment concentration exists. Site 8, Marais des Cygnes River at Kansas-Missouri State line, was not analyzed for time trend because sediment-sample collection was extremely variable. A significant trend in suspended-sediment concentration could not be confirmed at the 0.05 probability level at site 9, Walnut Creek at Albert (fig. 1, table 4); additional sediment samples may confirm if a trend exists at this site.

An alternative approach that may provide adequate sediment data for future trend studies would be to use the following strategy. The sites selected for this report represent 10 of the major river basins in Kansas, and the sampling sites selected within these basins could be used as the base sediment-data collection network of the future. In-stream monitor measurements of turbidity and results of periodic sediment sampling at these sites (or other priority sites added on a rotational basis as needs change) could be used to develop regression equations for the relation between turbidity and suspended-sediment concentration in areas where a significant number of impoundments are planned. From this relation, a continuous record of estimated suspended-sediment concentration can be developed. Once the relations are established at network sites, sediment sampling would be necessary only to verify the regression relations if changes in the watershed occur. Changes in the relations between discharge and suspended-sediment concentration and turbidity and suspended-sediment concentration can indicate changes in the basin, such as implementation of best management practices (BMPs). This strategy would provide adequate sediment data to evaluate sediment trends in the future or to monitor continuous sediment concentrations and loads. Because of the high cost of installation and operation of water-quality monitors, this approach may be more cost effective to use at a few sites in a specific watershed where BMPs are planned rather than for a statewide network. This data-collection approach would provide adequate data to monitor long-term effects of the BMPs on the watershed.

SUMMARY AND CONCLUSIONS

Time-trend tests for 13 of 14 sediment-sampling sites in Kansas for the period from about 1970 to 2002 indicated that 3 of the 13 sites tested had statistically signficiant decreasing suspended-sediment concentrations that were statistically significant at the 0.10 probability level. No statistically significant trends were found at 10 sites. Sediment trends were decreasing at five of the six sites located upstream from lakes. Site 12, Walnut River at Winfield, and site 13, Elk River at Elk Falls, were the only sites that had statistically significant suspended-sediment concentration trends at the 0.05 probability level—both decreasing trends. An earlier study by the U.S. Geological Survey (USGS) in 1985 indicated statistically significant decreasing suspended-sediment concentrations at the Winfield site for the period 1943–83 and at the Elk Falls site for the period 1967–80. Site 9, Walnut Creek at Albert (fig. 1, table 4), indicated decreasing suspended-sediment concentrations significant at the 0.10 probability level. Lack of a statistically significant trend at the 0.05 probability level does not necessarily mean that a trend does not exist but could result from variability of suspended-sediment concentration with discharge.

Watershed impoundments and flood-control structures constructed with financial assistance from the Kansas State Conservation Commission and Natural Resources Conservation Service are designed to trap sediment and may affect sediment transport. Other conservation practices such as terraces and contour farming also reduce sediment transport to streams; however, these practices are more difficult to quantify by watershed. Both sites that indicated statistically significant trends toward smaller sediment concentrations, Walnut River at Winfield and Elk River at Elk Falls, have a large percentage of their drainage area affected by impoundments and flood-control structures, 41 and 68 percent of the drainage areas, respectively.

The relation between the percentage of the watershed affected by impoundments and suspended-sediment concentration trend indicated that, as the number of impoundments in the watershed increases, suspended-sediment concentration decreases. Other conservation practices, such as contour farming, crop-residue management, and installation of terraces, also may contribute to the reduction of sediment transport to streams.

Regression models were developed for 13 of 14 sediment-sampling sites to estimate suspended-sediment concentration from discharge. For those sites that had significant time trends in sediment concentration, a second regression model was developed using only samples collected during 2000–02.

On the basis of past investigations by the USGS and current work at a number of sites, a reliable relation between turbidity and sediment concentration can be developed and used to estimate sediment concentration. Regression equations can be developed from a comparison of the analytical results of periodic sediment sampling and in-stream monitor measurements of turbidity. From this relation, a continuous record of estimated suspended-sediment concentration can be developed from continuously recorded in-stream measurements of turbidity. Turbidity measurements were collected at most sites during the 2000–02 sampling period. Diagnostic statistics for the relations between discharge and suspended-sediment concentration and turbidity and suspended-sediment concentration indicated that turbidity is a better surrogate for suspended-sediment concentration than discharge. If in-stream measurements of turbidity were collected continuously and periodic sediment sampling was continued at priority sites, a continuous record of suspended-sediment concentration could be estimated in the future.

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SUPPLEMENTAL INFORMATION

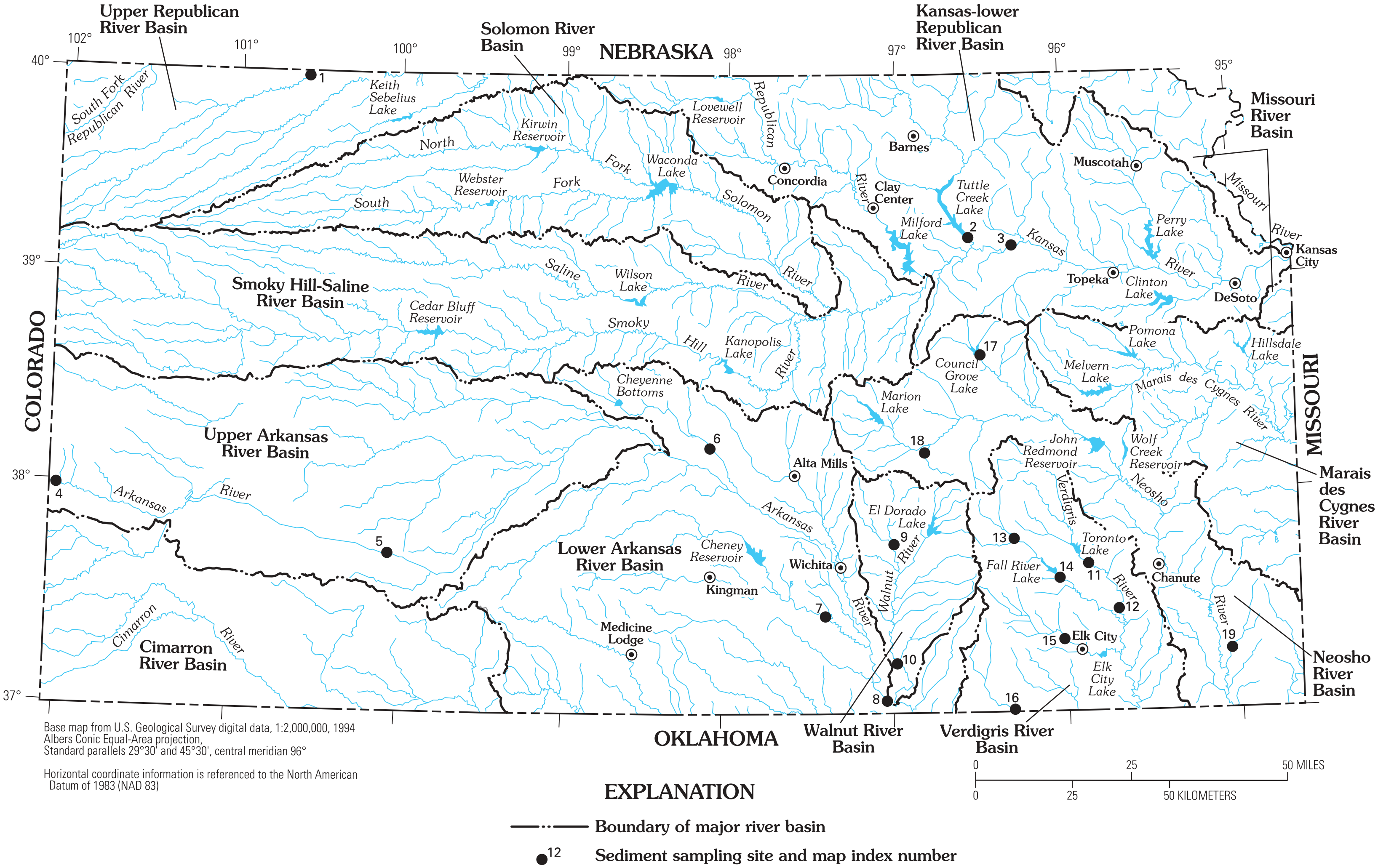

Figure 13. Location of major river basins and sediment sampling sites with statistically significant time trends from Jordan (1985).

Table 7. Results of statistically significant time-trend analysis of suspended-sediment concentrations through 1983 (Jordan, 1985)

Sampling-site map index number (fig. 13)	U.S. Geological Survey site identification number	Sampling-site name	Water years	Major river basin	Slope (percent per year)	Probability level	Remarks
1	06846500	Beaver Creek at Cedar Bluffs, Kansas	1962–63, 1973–75, 1977, 1979, 1981, 1983	Upper Republican	[1]-97	0.00	No watershed district.
2	06887000	Big Blue River near Manhattan, Kansas	1975–83	Kansas-lower Republican	[1]-2.6	.02	Directly downstream from Tuttle Creek Lake. Measurements all made after completion of lake.
3	06887500	Kansas River at Wamego, Kansas	1960–61, 1973–83	Kansas-lower Republican	-5.1	.00	Downstream from reservoirs. Watershed-district flood-control structures, 1971–83, 4 percent of drainage area.
4	07137500	Arkansas River near Coolidge, Kansas	1958, 1962, 1975–83	Upper Arkansas	12	.01	Downstream from John Martin Reservoir in Colorado, measurements all made after completion of reservoir. No watershed district.
5	07139500	Arkansas River at Dodge City, Kansas	1958, 1961, 1973–81	Upper Arkansas	[1]93	.00	Downstream from John Martin Reservoir in Colorado, measurements all made after completion of reservoir. Watershed-district flood-control structures, 1968–69, 0.2 percent of drainage area.
6	07143300	Cow Creek near Lyons, Kansas	1939–52, 1958, 1960–63, 1965–66, 1971, 1973–83	Lower Arkansas	-1.6	.00	Cheyenne Bottoms wetland enlarged about 1955. No watershed district.
7	07145500	Ninnescah River near Peck, Kansas	1940–52, 1954, 1958, 1960–62, 1973–83	Lower Arkansas	-18.3	.00	Downstream from Cheney Reservoir. Watershed-district flood-control structures, 1962, 1972, 0.6 percent of drainage area.

Table 7. Results of statistically significant time-trend analysis of suspended-sediment concentrations through 1983 (Jordan, 1985)—Continued

Sampling-site map index number (fig. 13)	U.S. Geological Survey site identification number	Sampling-site name	Water years	Major river basin	Slope (percent per year)	Probability level	Remarks
8	07146500	Arkansas River at Arkansas City, Kansas	1943–45, 1958, 1961–62, 1973–83	Lower Arkansas	-2.7	0.00	Watershed-district flood-control structures, 1962–83, 0.7 percent of drainage area.
9	07147070	Whitewater River at Towanda, Kansas	1961–62, 1976–83	Walnut	-3.7	.04	Probably biased; only high flows sampled in 1961–62, Watershed-district flood-control structures, 1976–81, 15 percent of drainage area.
10	07147800	Walnut River at Winfield, Kansas	1943–45, 1961–62, 1973–74, 1976–77, 1979–83	Walnut	-2.7	.00	Downstream from El Dorado Lake. Watershed-district flood-control structures, 1965–82, 28 percent of drainage area.
11	07166000	Verdigris River near Coyville, Kansas	1940–52, 1954–78	Verdigris	[1]-26	.00	Downstream from Toronto Lake. Watershed-district flood-control structures all upstream from Toronto Lake, all completed after lake.
12	07166500	Verdigris River near Altoona, Kansas	1940–78	Verdigris	-3.4	.00	Downstream from Toronto Lake. Watershed-district flood-control structures all upstream from Toronto Lake, all completed after lake.
13	07167000	Fall River near Eureka, Kansas	1947–48, 1950–51, 1954–76	Verdigris	-3.5	.00	Upstream from Fall River Lake. Watershed-district flood-control structures, 1965–71, 50 percent of drainage area.

Table 7. Results of statistically significant time-trend analysis of suspended-sediment concentrations through 1983 (Jordan, 1985)—Continued

Sampling-site map index number (fig. 13)	U.S. Geological Survey site identification number	Sampling-site name	Water years	Major river basin	Slope (percent per year)	Probability level	Remarks
14	07168500	Fall River near Fall River, Kansas	1940–49, 1951–52, 1955, 1957–78	Verdigris	[1]-10	0.00	Downstream from Fall River Lake. Watershed-district flood-control structures all upstream from lake, all completed after lake.
15	07169800	Elk River at Elk Falls, Kansas	1967–78, 1980	Verdigris	-4.7	.04	Upstream from Elk City Lake. Watershed-district flood-control structures, 1973–79, 52 percent of drainage area.
16	07172000	Caney River near Elgin, Kansas	1940–53, 1955–78	Verdigris	-4.0	.00	Watershed-district flood-control structures, 1965–82, 40 percent of drainage area.
17	07179500	Neosho River at Council Grove, Kansas	1940–47, 1950, 1955–56, 1958–64, 1969–72, 1978–79, 1982	Neosho	[1]14	.00	Downstream from Council Grove Lake. No watershed district.
18	07180500	Cedar Creek near Cedar Point, Kansas	1940–48, 1951–52, 1957–79, 1982	Neosho	-2.8	.00	No watershed district.
19	07184000	Lightning Creek near McCune, Kansas	1940–46, 1976–83	Neosho	3.6	.00	No watershed district. Probably affected by strip-mine ponds.

[1]Units in milligrams per liter per year.

Table 8. Regression equations for estimation of suspended-sediment concentrations at 13 sediment sampling sites in Kansas, 2000–02

[n, number of samples; R^2, coefficient of determination; MSE, mean square error; SSC, suspended-sediment concentration, in milligrams per liter; Q, discharge, in cubic feet per second; NTU, turbidity, in nephelometric turbidity units]

Sampling-site map index number (fig. 1)	Site name and number/regression equation	Data range[1]	n	R^2	MSE (log units)	Model standard error of prediction (percent)	Bias-correction factor (Duan, 1983)
1	**Prairie Dog Creek above Keith Sebelius Lake (site 06847900)**						
	$\log_{10}SSC = 1.682 + 0.268\log_{10}Q + 0.129(\log_{10}Q)^2$	Q=0.03–911 SSC=13–2,750	50	0.56	0.180	+166/-62.4	1.49
2	**Solomon River at Niles (site 06876900)**						
	$\log_{10}SSC = -0.161 + 1.351\log_{10}Q - 0.116(\log_{10}Q)^2$	Q=32–9,030 SSC=7–6,440	129	.57	.138	+135/-57.5	1.36
	$\log_{10}SSC = 0.889 + 0.710\log_{10}NTU$	SSC=38–1,850 NTU=5–1,500	10	.96	.020	+37.9/-27.5	1.04
3	**Smoky Hill River at Enterprise (site 06877600)**						
	$\log_{10}SSC = -1.147 + 1.542\log_{10}Q - 0.112(\log_{10}Q)^2$	Q=51–42,400 SSC=10–4,500	178	.65	.132	+131/-133	1.60
	$\log_{10}SSC = 0.777 + 0.783\log_{10}NTU$	SSC=53–3,270 NTU=14–1,600	12	.92	.037	+55.7/-35.8	1.08
4	**Black Vermillion River near Frankfort (site 06885500)**						
	$\log_{10}SSC = 1.382 + 0.300\log_{10}Q + 0.075(\log_{10}Q)^2$	Q=2.7–7,660 SSC=7–7,370	86	.66	.197	+178/-64.0	1.67
	$\log_{10}SSC = 0.585 + 0.878\log_{10}NTU$	SSC=13–3,680 NTU=3–2,600	9	.74	.262	+225/-69.2	2.03
5	**Delaware River near Muscotah (site 06890100)**						
	$\log_{10}SSC = 1.270 + 0.257\log_{10}Q + 0.116(\log_{10}Q)^2$	Q=0.04–14,000 SSC=1–11,700	181	.68	.260	+223/-69.1	2.16
	$\log_{10}SSC = 0.252 + 0.961\log_{10}NTU$	SSC=54–5,860 NTU=12–4,400	11	.88	.084	+94.9/-47.9	1.20
6	**Kansas River at DeSoto (site 06892350)**						
	$\log_{10}SSC = -2.226 + 1.342\log_{10}Q - 0.029(\log_{10}Q)^2$	Q=608–79,000 SSC=14–4,400	169	.74	.102	+109/-52.1	1.35
	$\log_{10}SSC = 0.259 + 0.904\log_{10}NTU$	SSC=35–3,660 NTU=11–3,900	25	.93	.032	+51.1/-33.8	1.08

Table 8. Regression equations for estimation of suspended-sediment concentrations at 13 sediment sampling sites in Kansas, 2000–02—Continued

Sampling-site map index number (fig. 1)	Site name and number/regression equation	Data range[1]	n	R^2	MSE (log units)	Model standard error of prediction (percent)	Bias-correction factor (Duan, 1983)
7	**Dragoon Creek near Burlingame (site 06911900)**						
	$\log_{10}SSC = 1.374 + 0.087\log_{10}Q + 0.135(\log_{10}Q)^2$	Q=0.02–6,040 SSC=3–4,480	90	0.71	0.123	+124/-55.4	1.32
	$\log_{10}SSC = 0.733 + 0.742\log_{10}NTU$	SSC=16–3,150 NTU=3–3,400	13	.80	.171	+159/-61.4	1.32
9	**Walnut Creek at Albert (site 07141900)**						
	$\log_{10}SSC = 2.085 + 0.246\log_{10}Q + 0.003(\log_{10}Q)^2$	Q=0.06–2,840 SSC=17–2,750	43	.41	.129	+129/-99.6	1.30
10	**North Fork Ninnescah River above Cheney Reservoir (site 07144780)**						
	$\log_{10}SSC = 1.808 - 0.419\log_{10}Q + 0.225(\log_{10}Q)^2$	Q=0.90–12,500 SSC=1–2,100	208	.40	.135	+133/-57.1	1.52
	$\log_{10}SSC = -0.079 + 1.170\log_{10}NTU$	SSC=22–2,100 NTU=15–580	21	.76	.098	+106/-51.4	1.33
11	**Arkansas River at Arkansas City (site 07146500)**						
	$\log_{10}SSC = -1.478 + 1.435\log_{10}Q - 0.079(\log_{10}Q)^2$	Q=207–29,900 SSC=5.0–5,620	130	.57	.164	+154/-60.6	1.66
12	**Walnut River at Winfield (site 07147800)**						
	$\log_{10}SSC = 1.058 + 0.035\log_{10}Q + 0.114(\log_{10}Q)^2$	Q=3–34,300 SSC=8–3,330	79	.81	.080	+91.8/-47.9	1.20
	$\log_{10}SSC = -0.095 + 0.816\log_{10}Q$	Q=71–17,100 SSC=32–3,330	15	.83	.096	+104/-51.0	1.21
	$\log_{10}SSC = 0.374 + 0.906\log_{10}NTU$	SSC=32–3,330 NTU=12–1,400	15	.93	.037	+55.7/-35.8	1.10
13	**Elk River at Elk Falls (site 07169800)**						
	$\log_{10}SSC = 0.978 + 0.480\log_{10}Q + 0.016(\log_{10}Q)^2$	Q=1.0–25,000 SSC=8.9–2,360	80	.71	.086	+96.4/-49.1	1.26
	$\log_{10}SSC = 0.952 + 0.461\log_{10}Q$	Q=1.0–6,500 SSC=8.9–1,880	13	.81	.072	+85.5/-46.1	1.22
	$\log_{10}SSC = 0.243 + 0.880\log_{10}NTU$	SSC=8.9–1,880 NTU=4–1,600	13	.93	.028	+47.0/-32.0	1.06

Table 8. Regression equations for estimation of suspended-sediment concentrations at 13 sediment sampling sites in Kansas, 2000–02—Continued

Sampling-site map index number (fig. 1)	Site name and number/regression equation	Data range[1]	n	R^2	MSE (log units)	Model standard error of prediction (percent)	Bias-correction factor (Duan, 1983)
14	**Neosho River near Parsons (site 07183500)**						
	$\log_{10}SSC = 1.720 - 0.472\log_{10}Q + 0.167(\log_{10}Q)^2$	Q=7.4–37,900 SSC=5.0–878	165	0.67	0.088	+98.0/-49.5	1.26
	$\log_{10}SSC = 0.408 + 0.850\log_{10}NTU$	SSC=17–878 NTU=9–1,500	18	.89	.042	+60.3/-37.6	1.10

[1]Concentration ranges and sample sizes are not always the same as table 2, page 10, because these data represent a subset of table 2.