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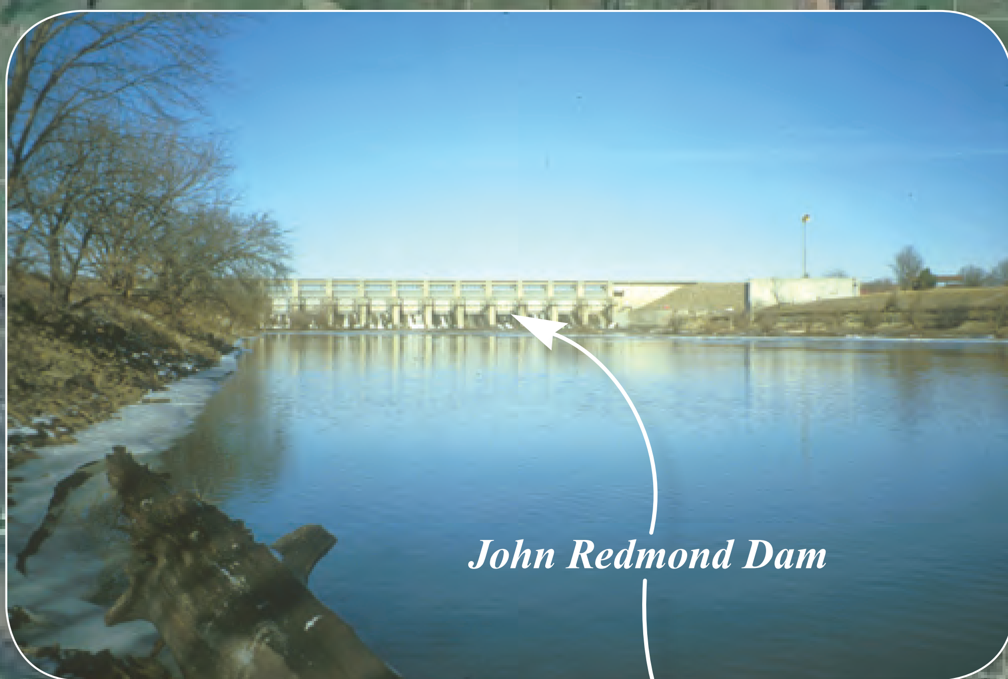
Sedimentation, Sediment Quality, and Upstream Channel Stability, John Redmond Reservoir, East-Central Kansas, 1964–2009



Scientific Investigations Report 2010–5191

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

Front cover photograph index

John Redmond Dam on the Neosho River (photograph taken by Kyle Juracek, USGS).

Background image from USGS-*The National Map*

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Conversion Factors, Abbreviations, and Datums

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
gram (g)	0.03527	ounce (oz)
milligram per kilogram (mg/kg)	1.0	part per million (ppm)
pound (lb)	0.4536	kilogram (kg)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)

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

$$°F=(1.8\times°C)+32$$

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

$$°C=(°F-32)/1.8$$

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

Elevation information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Acknowledgments

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Sedimentation, Sediment Quality, and Upstream Channel Stability, John Redmond Reservoir, East-Central Kansas, 1964–2009

By Kyle E. Juracek

Abstract

A combination of available bathymetric-survey information, bottom-sediment coring, and historical streamgage information was used to investigate sedimentation, sediment quality, and upstream channel stability for John Redmond Reservoir, east-central Kansas. Ongoing sedimentation is reducing the ability of the reservoir to serve several purposes including flood control, water supply, and recreation. The total estimated volume and mass of bottom sediment deposited between 1964 and 2009 in the conservation pool of the reservoir was 1.46 billion cubic feet and 55.8 billion pounds, respectively. The estimated sediment volume occupied about 41 percent of the conservation-pool, water-storage capacity of the reservoir. Water-storage capacity in the conservation pool has been lost to sedimentation at a rate of about 1 percent annually. Mean annual net sediment deposition since 1964 in the conservation pool of the reservoir was estimated to be 1.24 billion pounds per year. Mean annual net sediment yield from the reservoir basin was estimated to be 411,000 pounds per square mile per year.

Information from sediment cores shows that throughout the history of John Redmond Reservoir, total nitrogen concentrations in the deposited sediment generally were uniform indicating consistent nitrogen inputs to the reservoir. Total phosphorus concentrations in the deposited sediment were more variable than total nitrogen indicating the possibility of changing phosphorus inputs to the reservoir. As the principal limiting factor for primary production in most freshwater environments, phosphorus is of particular importance because increased inputs can contribute to accelerated reservoir eutrophication and the production of algal toxins and taste-and-odor compounds. The mean annual net loads of total nitrogen and total phosphorus deposited in the bottom sediment of the reservoir were estimated to be 2,350,000 pounds per year and 1,030,000 pounds per year, respectively. The estimated mean annual net yields of total nitrogen and total phosphorus from the reservoir basin were 779 pounds per square mile per year and 342 pounds per square mile per year, respectively.

Trace element concentrations in the bottom sediment of John Redmond Reservoir generally were uniform over time. As is typical for eastern Kansas reservoirs, arsenic, chromium, and nickel concentrations typically exceeded the threshold-effects guidelines, which represent the concentrations above which toxic biological effects occasionally occur. Trace element concentrations did not exceed the probable-effects guidelines (available for eight trace elements), which represent the concentrations above which toxic biological effects usually or frequently occur. Organochlorine compounds either were not detected or were detected at concentrations that were less than the threshold-effects guidelines.

Stream channel banks, compared to channel beds, likely are a more important source of sediment to John Redmond Reservoir from the upstream basin. Other sediment sources include surface-soil erosion in the basin and shoreline erosion in the reservoir.

Introduction

Sediment is a primary concern for reservoirs in Kansas and nationally for physical and chemical reasons. Physically, ongoing sedimentation reduces the water-storage capacity of reservoirs for multiple uses including flood control, water supply, recreation, and habitat for fish and wildlife. Chemically, sediment quality is an important environmental concern because sediment may act as a sink for water-quality constituents and, under certain conditions, as a source of constituents to the overlying water column and biota (Forstner and Wittmann, 1981; Baudo and others, 1990; Zoumis and others, 2001). Sediment-associated constituents of concern include nutrients (for example, phosphorus), trace elements, several pesticides, and polychlorinated biphenyls (PCBs) (Wetzel, 2001; Agency for Toxic Substances and Disease Registry, 2010). Once in the food chain, some sediment-derived constituents may pose an even greater concern because of bioaccumulation (Pais and Jones, 1997; Smol, 2002). An analysis of reservoir bottom sediment can provide historical information on sediment deposition as well as the occurrence of sediment-bound constituents. Such information may be used to partly reconstruct historical sediment-quality and water-quality conditions and to provide a present-day baseline with which

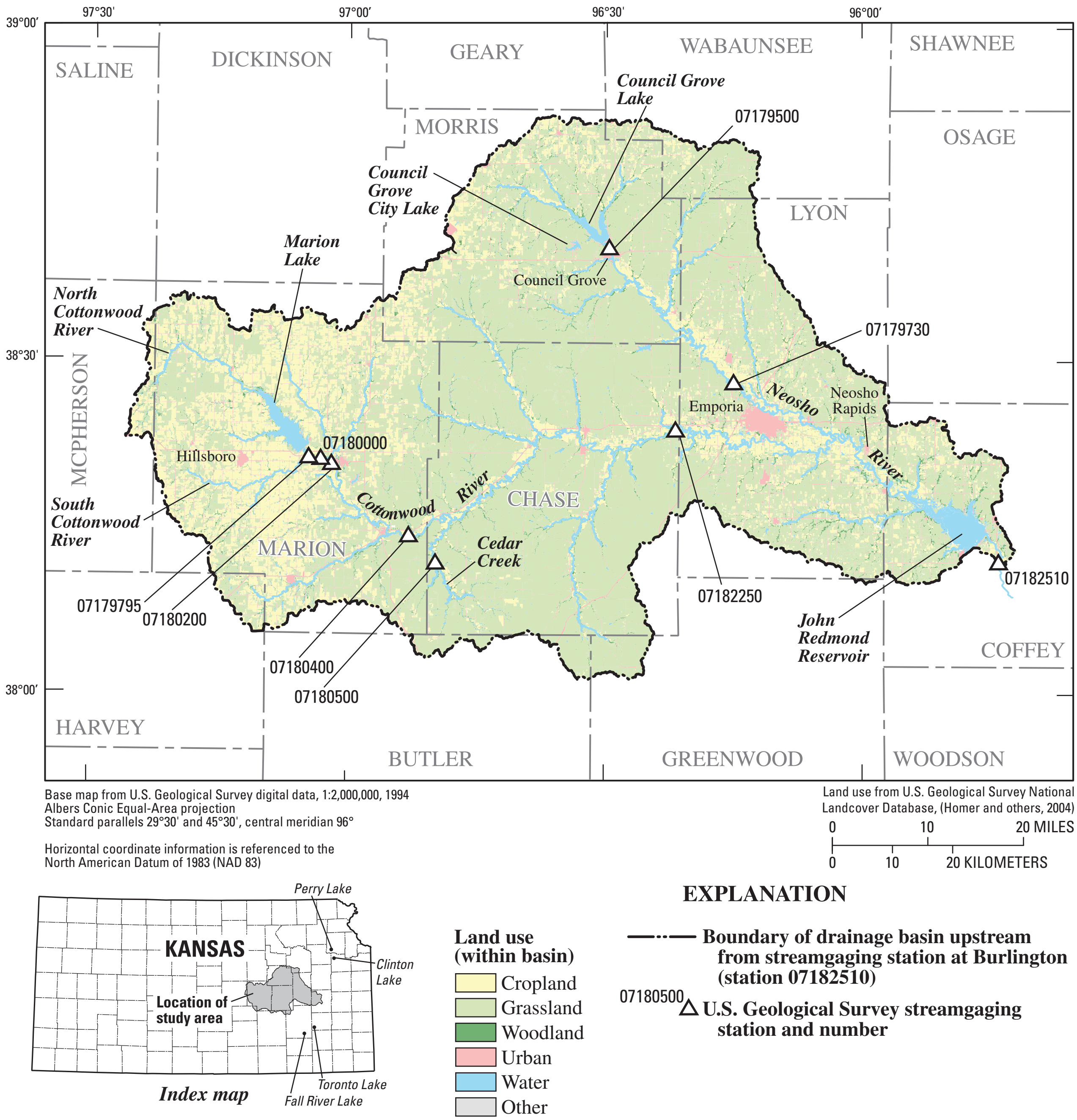

Figure 1. John Redmond Reservoir Basin, John Redmond Reservoir, selected U.S. Geological Survey streamgages, and land use (2000) in the John Redmond Reservoir Basin, east-central Kansas.

to evaluate long-term changes in reservoir sediment and water quality that may be related to changes in human activity in the basin (Charles and Hites, 1987; Van Metre and Callender, 1996; Van Metre and Mahler, 2004; Juracek and Ziegler, 2006). In the case of John Redmond Reservoir, the U.S. Army Corps of Engineers (USACE) required information on sedimentation, sediment quality, and upstream channel stability in order to develop a sediment management plan for the reservoir and its basin.

John Redmond Reservoir is a Federal impoundment on the Neosho River in Coffey County, east-central Kansas (fig. 1). The reservoir officially was completed in 1964 by USACE with an original design life of 50 years. The reservoir is used for several purposes including flood control, water supply, water quality, recreation, and wildlife objectives (U.S. Army Corps of Engineers, 2009). In 1963, the reservoir had a surface area of about 9,800 acres and a water-storage capacity of about 82,200 acre-ft (acre-feet) at the present-day (2009) conservation-pool elevation of 1,039 ft (feet) above the National Geodetic Vertical Datum of 1929 (NGVD29). In 1991, the surface area and water-storage capacity at the conservation-pool elevation of 1,039 ft were about 9,700 acres and 60,700 acre-ft, respectively (Tony Clyde, U.S. Army Corps of Engineers, written commun., 2009). Based on a bathymetric survey completed in 2007 by the Kansas Biological Survey (KBS) (Kansas Biological Survey, 2010), the Kansas Water Office (KWO) estimated the 2007 surface area and water-storage capacity at the conservation-pool elevation of 1,039 ft to be about 8,800 acres and 50,200 acre-ft (Kansas Water Office, 2010). The decreases in surface area and storage capacity are the result of ongoing sedimentation. Since 1964, the reservoir has lost an estimated 42 percent of its conservation-pool storage capacity as of 2010. The estimated sedimentation rate of 739 acre-ft per year is about 80 percent more than the sedimentation rate (404 acre-ft per year) that was originally projected for the conservation pool by USACE at the time the reservoir was completed (Kansas Water Office, 2010). To partially compensate for the lost water-storage capacity, USACE reallocated storage in the reservoir by raising the conservation-pool elevation from 1,036 to 1,039 ft in 1976 (Terry Lyons, U.S. Army Corps of Engineers, written commun., 2009).

As sedimentation continues, the ability of John Redmond Reservoir to serve its various purposes will continue to decline. Concern about the condition of the reservoir was evidenced by the 1998 listing of John Redmond Reservoir under Section 303(d) of the Federal Clean Water Act of 1972 for eutrophication and siltation (Kansas Department of Health and Environment, 2009). The 303(d) list is a priority list that identifies water bodies that do not meet water-quality standards that are based on the use of the water bodies. For each impaired water body on the 303(d) list, a State is required by the Federal Clean Water Act to develop a total maximum daily load (TMDL), which is an estimate of the maximum pollutant load (material transported during a specified time period) from point and nonpoint sources that a receiving water can accept without exceeding water-quality standards (U. S. Environmental Protection Agency, 1991).

A 1.5-year study by the U.S. Geological Survey (USGS), in cooperation with USACE, was begun in 2009 to investigate sedimentation in John Redmond Reservoir as well as the deposition of selected chemical constituents in the bottom sediment of the reservoir and channel stability upstream from the reservoir. Specific objectives of the study were to:

1. Estimate the volume, mass, mean annual net deposition, and mean annual net yield of sediment for the reservoir;
2. Determine the occurrence and trends of selected chemical constituents in the bottom sediment of the reservoir;
3. Determine the mean annual net loads and yields of selected nutrients from the reservoir basin;
4. Assess the quality of the reservoir bottom sediment with respect to available guidelines; and
5. Assess the stability of the Neosho and Cottonwood River channels upstream from the reservoir as a partial indicator of sediment sources.

Purpose and Scope

The purpose of this report is to present the results of the USGS study to estimate sedimentation for John Redmond Reservoir, to determine the occurrence of, and temporal trends in, selected chemical constituents deposited in the bottom sediment of the reservoir, and to assess channel stability upstream from the reservoir. Study objectives were met by using available bathymetric information from USACE and KBS, by the collection and analysis of sediment cores in July and August 2009, and by the analysis of available USGS streamgage information. Results presented in this report will assist USACE in efforts to evaluate the ecological health of John Redmond Reservoir and to evaluate sediment management options for the reservoir and its basin. From a national perspective, the methods and results presented in this report provide guidance and perspective for future reservoir studies concerned with the issues of sedimentation, sediment quality, and sediment sources.

Description of John Redmond Reservoir Basin

The John Redmond Reservoir Basin is an area of about 3,015 mi^2 (square miles) that drains part of east-central Kansas (fig. 1). Physiographically, the basin is mostly located in the Osage Plains section of the Central Lowland Province (Fenneman, 1946; Schoewe, 1949). The downstream one-third of the basin is located in the Osage Cuestas physiographic division, whereas the upstream two-thirds of the basin is located mostly in the Flint Hills Upland physiographic division. The Osage Cuestas generally consist of a series of irregular northeast-southwest trending escarpments between which are flat to gently rolling plains. The topography of the Flint Hills Upland is characterized as gently rolling. Throughout the Osage Plains, the underlying bedrock is primarily limestone and shale of Permian and Pennsylvanian age (Schoewe, 1949). The bedrock is overlain by Quaternary alluvium in the valleys of the Neosho River and its major tributaries (Kansas Geological Survey, 1964; Marcher and others, 1984). Soils in the basin mostly are classified as silty-clay loam (material with 27 to 40 percent clay, 40 percent or more silt, and 20 percent or less sand) or silty clay (material with 40 percent or more clay, 40 percent or more silt, and 20 percent or less sand) (U.S. Department of Agriculture, 1994). Erodibility of these soil classes generally are similar (Brady and Weil, 1999). Land use in the basin is predominantly a mix of cropland and grassland (fig. 1).

Long-term, mean annual precipitation in the basin ranges from about 33 in. (inches) at Hillsboro (period of record 1945–2008), in the western part of the basin, to about 36 in. at Neosho Rapids (period of record 1905-2008) in the eastern part (fig. 1) (High Plains Regional Climate Center, 2009). Most of the precipitation is received during the growing season (generally, April–September).

Methods

The objectives of this study were accomplished using available and newly collected information. Available information included bathymetric surveys completed by USACE in 1963 and 1991, a 2007 bathymetric survey completed by KBS, and historical USGS streamgage information. New information was obtained through the collection and analysis of multiple bottom-sediment cores.

Estimation of Bottom-Sediment Volume, Mass, Mean Annual Net Deposition, and Mean Annual Net Yield

The bottom-sediment volume (sediment plus pore water and gases) in the conservation pool of John Redmond Reservoir was estimated by subtracting the updated water-storage capacity from the original water-storage capacity for the reservoir. The original water-storage capacity (at a lake surface elevation of 1,039 feet) was estimated by USACE in 1963 to be 82,230 acre-ft (Tony Clyde, U.S. Army Corps of Engineers, written commun., 2009). The 2007 water-storage capacity (at a lake elevation of 1,039 ft) was estimated by KWO to be 50,227 acre-ft (Kansas Water Office, 2010). The bottom-sediment volume was estimated as the 1963 water-storage capacity minus the 2007 water-storage capacity. The mean annual volume of sediment deposited (1964–2007) was computed as the bottom-sediment volume divided by the number of years of deposition (43 years). Then, to provide an estimate of the current (2009) bottom-sediment volume, the mean annual volume of sediment deposited (1964–2007) was multiplied by the age of the reservoir (45 years).

Bottom-sediment mass was estimated by multiplying the current (2009) bottom-sediment volume by the representative bulk density. The representative bulk density for the reservoir was computed as the average of the mean bulk densities that were determined from sediment cores (see discussion in “Physical Analyses” section later in this report). Because bulk density varies with location and the representative bulk density only accounts for four sites in the reservoir, the estimated total bottom-sediment mass has a potential error of unknown magnitude.

The mean annual mass of sediment (dry weight) deposited was estimated as the bottom-sediment mass divided by the age of the reservoir. Mean annual sediment yield from the reservoir basin was estimated by dividing the mean annual mass of sediment deposited by the area of the basin. Because sediment losses are not accounted for (for example, as a result of reservoir outflow), the estimated mean annual sediment deposition and yield represent net, rather than total, values. However, given that sediment trap efficiencies for large reservoirs typically are greater than 90 percent (Brune, 1953; Williams and Wolman, 1984; Shotbolt and others, 2005; Vanoni, 2006), the sediment losses through outflow likely are minimal. In a recent study, Lee and others (2008) estimated the trap efficiency for John Redmond Reservoir from February 21, 2007 to February 21, 2008 to be 91 percent.

Sediment-Core Collection and Processing

Bottom-sediment cores were collected in July and August of 2009 at five sites (fig. 2) within John Redmond Reservoir. Two cores were collected at coring sites JR-1 and JR-3 for planned physical and chemical analyses. Of the five sites cored, two were used for chemical analyses and bulk-density determinations (JR-1 and JR-3), one was used for chemical analyses only (JR-5), and two were used for bulk-density determinations only (JR-2 and JR-4) (fig. 2).

The bottom-sediment cores were collected from a pontoon boat using a gravity corer. The liner used for all cores was cellulose acetate butyrate transparent tubing with a 2.625-in. inside diameter. The latitude and longitude for each coring site, obtained using GPS technology, are provided in table A1 in the “Supplemental Information” section at the back of this report.

When using a gravity corer, a phenomenon referred to as “core shortening” occurs that results in a recovered sediment core the length of which is less than the actual thickness of sediment penetrated (Emery and Hulsemann, 1964). Core shortening is caused by the friction of the sediment against the inner wall of the core liner as the corer penetrates the sediment (Emery and Hulsemann, 1964; Hongve and Erlandsen, 1979; Blomqvist, 1985; Blomqvist and Bostrom, 1987). In “normal” lake-bottom sediment, which is characterized by uniform texture with decreasing water content at depth, core shortening results in a core that provides a thinned but complete representation of all of the sediment layers that were penetrated (Emery and Hulsemann, 1964; Hongve and Erlandsen, 1979). In this study, a comparison of the length of core recovered by gravity coring to the thickness of sediment penetrated (penetration of the entire sediment thickness was achieved for all cores) indicated that core recovery averaged about 80 to 90 percent. The thickness of sediment penetrated was computed as the total depth of corer penetration (as measured from the water surface) minus the water depth. Estimated penetration depth, length of core recovered, and estimated recovery percentage for the coring sites are provided in table A1 at the back of this report.

The sediment cores were transported to the USGS laboratory in Lawrence, Kansas, where they were stored vertically and refrigerated (at 4–5 ºC) until processed. The core liners were cut lengthwise in two places 180 degrees apart. The cuts were completed with a 4-in. hand-held circular saw with its blade set at a depth to minimize penetration of the cores. The

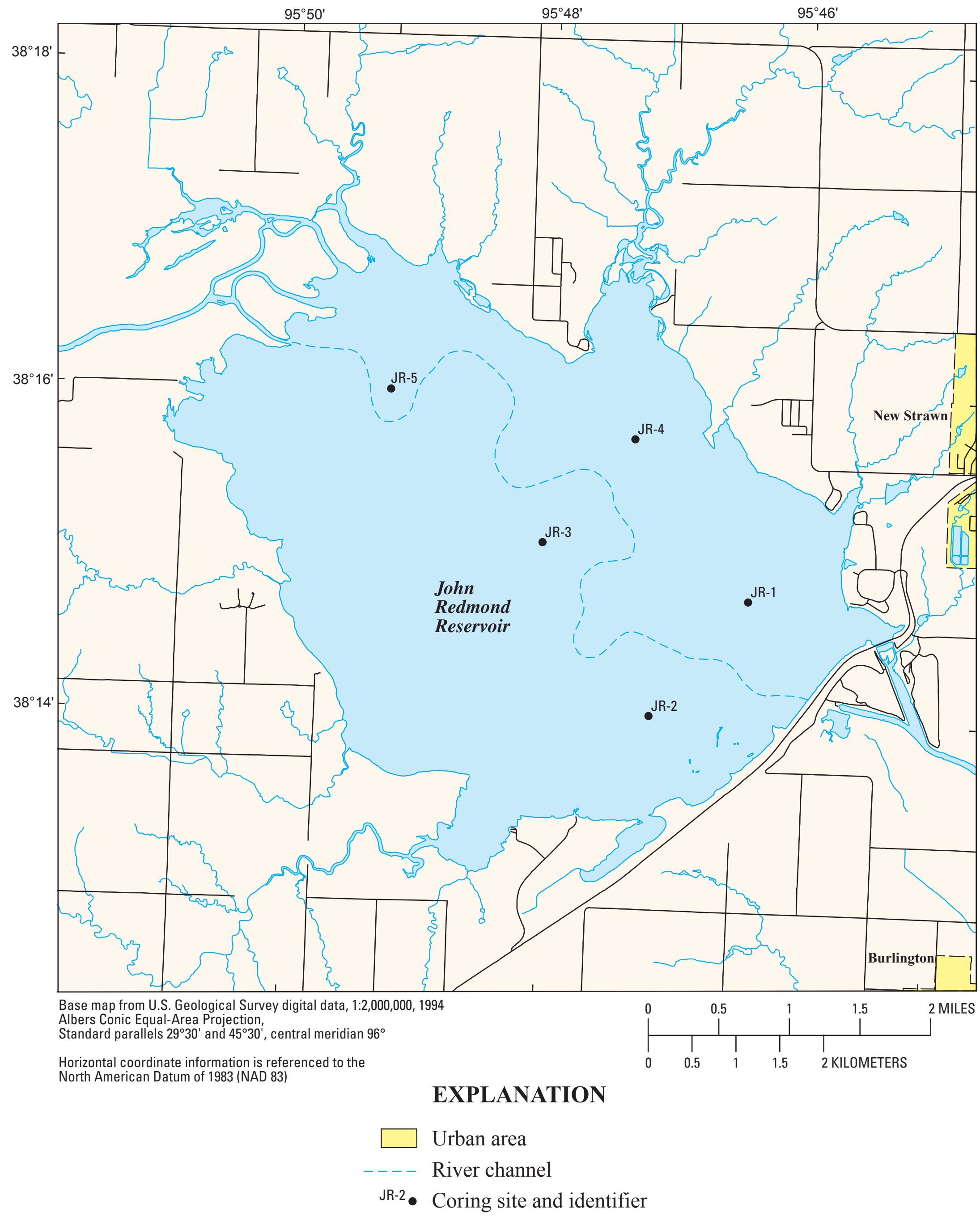

Figure 2. Bottom-sediment coring sites in John Redmond Reservoir, east-central Kansas.

cores were split in half by pulling a tightly held nylon string through the length of the cores and allowing the halves to separate. Once split, the relatively undisturbed inner parts of the cores were exposed for examination and sampling. On the basis of differences in moisture content, texture, and organic matter content (for example, root hairs, sticks), the boundary between the sediment deposited in the reservoir and the underlying original (pre-reservoir) land-surface material was determined. Typically, the deposited bottom sediment was characterized by higher moisture content, finer texture, and little if any visible organic matter as compared to the original material. Excluding the original material at the bottom of each core, the thickness of deposited bottom sediment recovered ranged from about 4.5 to 6.0 ft for cores JR-1 to JR-4, and about 0.8 ft for core JR-5. Only the deposited bottom sediment was sampled for the physical and chemical analyses described in the following sections.

Physical Analyses

Physical analyses of bottom sediments included bulk-density determinations and particle-size analyses. Sediment cores from coring sites JR-1, JR-2, JR-3, and JR-4 within John Redmond Reservoir were analyzed to determine bulk density. For this purpose, each core was divided into intervals of about one foot in length. The number of intervals was dependent on the length of each core. From each interval, a 1-in. thick cylindrical volume of sediment was removed using a putty knife, weighed to the nearest 0.10 gram, oven dried at about 40 ºC for 96 hours, and reweighed. Oven drying of the sample continued as it was reweighed on a daily basis until no additional moisture loss was observed. Bulk density was computed as follows:

$$D_b = m/v, \tag{1}$$

where D_b is the bulk density (in grams per cubic centimeter), m is the mass (dry weight) of the sample (in grams), and v is the volume of the sample (in cubic centimeters). The volume for a cylindrical sample was computed as:

$$v = h(\pi d^2/4), \tag{2}$$

where v is the volume of the sample (in cubic centimeters), h is the height (length) of the sample (in centimeters), and d is the diameter of the sample (in centimeters) (Gordon and others, 1992). The bulk densities were converted to pounds per cubic foot for use in subsequent computations. In all, 21 bulk-density determinations were completed at the USGS laboratory in Lawrence, Kansas (table A2 at the back of this report).

Results for all sampled intervals were averaged to determine the mean bulk density for each core. The representative bulk density for the reservoir was computed as the average of the mean bulk densities determined for the four individual cores.

Particle-size analysis was performed to determine the percentage of sand (that is, particles larger than 0.063 mm (millimeters) in diameter) and silt and (or) clay (that is, particles smaller than 0.063 mm in diameter) in the sediment cores. The sediment samples used for constituent analyses (that is, nutrients, carbon, and trace elements) also were used for particle-size analyses. The particle-size analyses were completed at the USGS Sediment Trace Element Partitioning Laboratory in Atlanta, Georgia, according to the methods presented in Guy (1969).

Table 1. Chemical analyses for bottom-sediment samples from John Redmond Reservoir, east-central Kansas, 2009.

[Number in parentheses is the method reporting limit for each constituent. mg/kg, milligrams per kilogram; %, percent dry weight; µg/kg, micrograms per kilogram; dpm/g, disintegrations per minute per gram]

Nutrients			
Total nitrogen (100 mg/kg)	Total phosphorus (50 mg/kg)		
Carbon			
Carbon, total organic (0.1%)	Carbon, total (0.1%)		
Trace elements			
Aluminum (0.1%)	Cobalt (1.0 mg/kg)	Nickel (1.0 mg/kg)	Titanium (0.01%)
Antimony (0.1 mg/kg)	Copper (1.0 mg/kg)	Selenium (0.1 mg/kg)	Uranium (50 mg/kg)
Arsenic (0.1 mg/kg)	Iron (0.1%)	Silver (0.5 mg/kg)	Vanadium (1.0 mg/kg)
Barium (1.0 mg/kg)	Lead (1.0 mg/kg)	Strontium (1.0 mg/kg)	Zinc (1.0 mg/kg)
Beryllium (0.1 mg/kg)	Lithium (1.0 mg/kg)	Sulfur (0.01%)	
Cadmium (0.1 mg/kg)	Manganese (10.0 mg/kg)	Thallium (50 mg/kg)	
Chromium (1.0 mg/kg)	Molybdenum (1.0 mg/kg)	Tin (1.0 mg/kg)	
Organochlorine compounds			
Aldrin (2.0 µg/kg)	cis-Chlordane (1.0 µg/kg)	Hexachlorobenzene (3.0 µg/kg)	p,p’-DDT (1.0 µg/kg)
alpha-HCH (1.5 µg/kg)	Dieldrin (0.5 µg/kg)	Lindane (0.5 µg/kg)	p,p’-Methoxychlor (3.5 µg/kg)
Aroclor 1016/1242 (5.0 µg/kg)	Endosulfan (0.5 µg/kg)	Mirex (1.5 µg/kg)	Toxaphene (200 µg/kg)
Aroclor 1254 (5.0 µg/kg)	Endrin (1.0 µg/kg)	p,p’-DDD (2.5 µg/kg)	trans-Chlordane (0.5 µg/kg)
Aroclor 1260 (5.0 µg/kg)	Heptachlor (1.0 µg/kg)	p,p’-DDE (1.5 µg/kg)	trans-Nonachlor (1.0 µg/kg)
beta-HCH (0.5 µg/kg)	Heptachlor epoxide (1.5 µg/kg)		
Radionuclide			
Cesium-137 (0.05 dpm/g)			

Chemical Analyses, Quality Control, and Age Dating

The number of samples for chemical analysis removed from each core was dependent on the length of the core, the intended use of the core, and the amount of material required for analyses. In all cases, care was taken to avoid sampling the sediment that came into contact with the core liner and the saw blade. Each core was divided into multiple intervals of equal length. An approximately equal volume of sediment (defined as the space occupied by the sediment particles, water, and gases as measured in cubic units) was removed lengthwise from both halves of each interval and combined. The combined sediment volume for each interval was homogenized and sampled for subsequent chemical analyses.

A 10-interval core from coring site JR-1, an 8-interval core from site JR-3, and a 2-interval core from site JR-5 were analyzed for nutrients (total nitrogen and total phosphorus), organic and total carbon, and 25 trace elements. Also, separate cores from coring sites JR-1 and JR-3 were analyzed for 22 organochlorine compounds (top, middle, and bottom of each core). A complete list of the constituents for which analyses were performed is provided in table 1. Constituent analyses of bottom-sediment samples were performed at the USGS National Water-Quality Laboratory in Denver, Colorado, and the USGS Sediment Trace Element Partitioning Laboratory in Atlanta, Georgia. Analyses for total nitrogen and carbon concentrations were performed using the methods described by Horowitz and others (2001). Analyses for total phosphorus and trace elements were performed using the methods described by Fishman and Friedman (1989), Arbogast (1996), and Briggs and Meier (1999). Analyses for organochlorine compounds were performed using the methods described by Noriega and others (2004).

Quality control for the chemical analyses of sediment samples was provided by an evaluation of variability that involved an analysis of split-replicate samples collected from coring sites JR-1 and JR-3. The split-replicate samples were obtained by removing a representative volume of sediment from each selected core interval, homogenizing it, and sampling it twice. Two split-replicate samples were analyzed for nutrients, carbon, and trace elements. One split-replicate sample was analyzed for organochlorine compounds. The relative percentage difference between the replicate sample concentrations was computed as the absolute value of the difference in the replicate analyses divided by the mean and expressed as a percentage.

With the exception of antimony (15.8 percent) and tin (20.0 percent), mean relative percentage differences were less than 8 percent. Relative percentage differences were not computed for the organochlorine compounds because they were not detected in the samples analyzed. The relative percentage differences computed for the constituents detected in the split-replicate samples are provided in table 2.

Age dating of the bottom sediment was achieved by determining the activity of cesium-137 (^{137}Cs). ^{137}Cs is a radioactive isotope that is a byproduct of aboveground nuclear weapons testing. Measurable activity of this isotope first appeared in the atmosphere about 1952, peaked during 1963–64, and has since declined (Ritchie and McHenry, 1990). Measurable activity in soils began about 1954 (Wise, 1980). ^{137}Cs is an effective marker for age dating bottom sediment in reservoirs constructed before 1963–64 (Van Metre and others,

Table 2. Relative percentage differences for constituent concentrations in split-replicate samples from bottom-sediment cores from John Redmond Reservoir, east-central Kansas.

[Location of coring sites shown in figure 2. --, not calculated because constituent was not detected in one or both of the split-replicate samples]

Constituent	Relative percentage difference		
	JR-1	JR-3	Mean
Nutrients			
Total nitrogen	0	0	0
Total phosphorus	4.6	3.4	4.0
Carbon			
Carbon, total organic	12.5	0	6.3
Carbon, total	4.4	0	2.2
Trace elements			
Aluminum	4.7	3.2	4.0
Antimony	31.6	0	15.8
Arsenic	9.5	0	4.8
Barium	4.9	2.9	3.9
Beryllium	3.9	0	2.0
Cadmium	0	0	0
Chromium	3.8	3.4	3.6
Cobalt	0	0	0
Copper	4.1	3.3	3.7
Iron	4.8	4.4	4.6
Lead	3.8	3.6	3.7
Lithium	3.6	3.0	3.3
Manganese	4.7	2.6	3.7
Molybdenum	0	--	--
Nickel	5.3	2.5	3.9
Selenium	0	15.4	7.7
Silver	--	--	--
Strontium	4.9	4.9	4.9
Sulfur	13.3	0	6.7
Thallium	--	--	--
Tin	40.0	0	20.0
Titanium	2.3	2.2	2.3
Uranium	--	--	--
Vanadium	8.7	0	4.4
Zinc	0	7.4	3.7

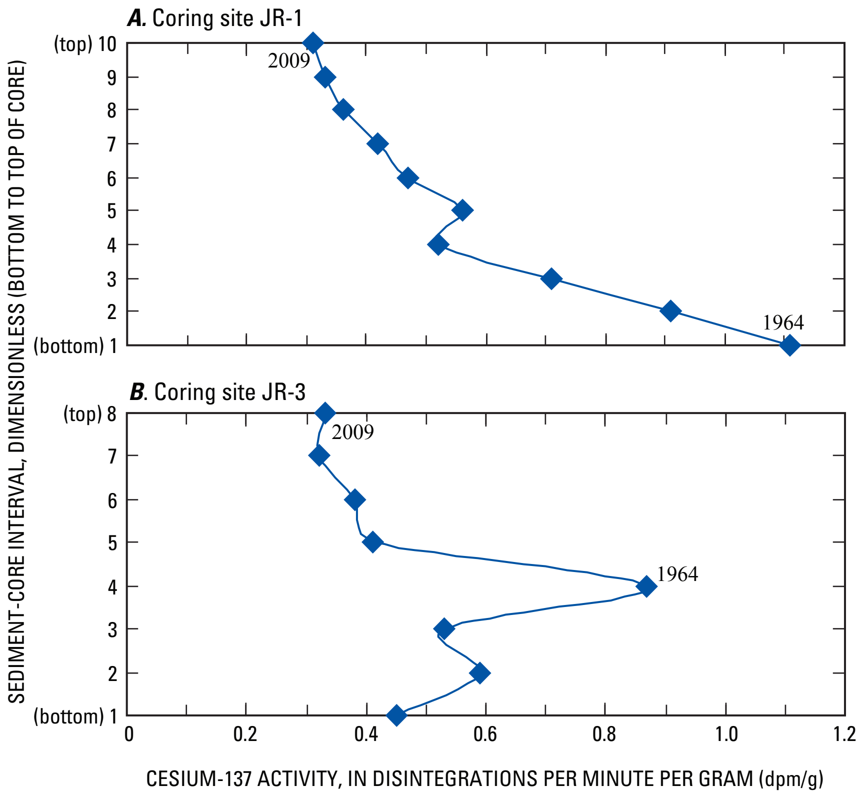

Figure 3. Variation in cesium-137 activity with depth of bottom-sediment samples collected from coring sites (*A*) JR-1 and (*B*) JR-3 in John Redmond Reservoir, east-central Kansas, July and August 2009.

1997). It also can be used to demonstrate that the sediment is relatively undisturbed if the 1963–64 peak is well-defined and a generally uniform, exponential decrease in ^{137}Cs activity follows the 1963–64 peak. Age dating of sediment using ^{137}Cs was attempted for coring sites JR-1 and JR-3 (fig. 2). Because John Redmond Reservoir was completed at the same time as the ^{137}Cs peak (1964), it was anticipated that the use of ^{137}Cs in this study would be limited to an assessment of postdepositional disturbance. Analysis of sediment samples for ^{137}Cs activity was performed at the USGS Florida Integrated Science Center in St. Petersburg, Florida, using gamma-ray spectrometry (Holmes and others, 2001).

Given the correspondence of the dates for the ^{137}Cs peak and the completion of the reservoir, the anticipated profile of ^{137}Cs activity for a minimally disturbed site was one with a peak in ^{137}Cs activity at the bottom of the core followed by a uniform, exponential decrease in activity to the top of the core. Such a profile was measured for coring site JR-1 (fig. 3*A*). Thus, for this site it was concluded that the bottom sediment was relatively undisturbed and any trends in constituent deposition may be considered meaningful. For coring site JR-3, a well-defined peak in ^{137}Cs activity near the middle of the core followed by a generally uniform, exponential decrease in activity to the top of the core was measured (fig. 3*B*). The location of the ^{137}Cs peak near the middle of the core indicated substantial deposition at the site before the deposition of the sediment that contained the ^{137}Cs peak. A possible explanation is that site JR-3 was located in a topographic depression on the original flood plain that was filling with sediment before the closure of the dam. If this interpretation is correct, then the bottom sediment at this site also may be relatively undisturbed.

Estimation of Nutrient Loads and Yields

The mean annual load and yield of total nitrogen (TN) and total phosphorus (TP) was estimated for John Redmond Reservoir for the period 1964 to 2009. For each nutrient, mean annual load was estimated as the representative sediment concentration multiplied by the mean annual mass of sediment deposited in the reservoir. The representative sediment concentration was computed as the median of the sample intervals analyzed for cores JR-1, JR-3, and JR-5.

The mean annual yield for each nutrient was estimated by dividing the mean annual load by the area of the John Redmond Reservoir Basin. Because sediment losses are not accounted for (for example, as a result of reservoir outflow), the computed loads and yields represent net, rather than total, values.

Trend Analysis

Temporal trends in nutrient, carbon, and trace element concentrations (in relation to depth in the sediment profile) were examined for coring sites JR-1 (10-interval core) and JR-3 (8-interval core) by computing a nonparametric Spearman's rho correlation coefficient. An advantage of Spearman's rho is that, because it is based on ranks, it is more resistant to outlier effects than the more commonly used Pearson's r correlation coefficient (Helsel and Hirsch, 1992). Measures of correlation are dimensionless and scaled to be in the range of -1.0 to 1.0. A value of 0 indicates no relation between two variables. Temporal trends were considered to be significantly positive (with a value between 0 and 1.0 indicating that the constituent concentration increased toward the top of the sediment core) or negative (with a value between 0 and -1.0 indicating that the constituent concentration decreased toward the top of the sediment core) if the probability (two-sided p-value) of rejecting a correct hypothesis (in this case, no trend) was less than or equal to 0.05. A possible temporal trend was only considered meaningful if the change in constituent concentration was beyond the variability that could be explained by analytical variance (defined here as the mean constituent concentration in the sediment core plus or minus 10 percent). The possibility must be recognized that constituent concentrations in the cores may have been affected by diagenesis (that is, postdepositional changes caused by processes such as remobilization and diffusion).

Channel-Stability Analysis

A geomorphic analysis of channel stability was completed for eight USGS streamgages located upstream from John Redmond Reservoir and downstream from Marion and Council Grove Lakes (fig. 1, table 3). Typically, streamgages provide the only long-term, continuous source of channel-geometry information for the sites being monitored. Streamgage information can be used for various geomorphic purposes including documentation of channel changes (for example, channel-bed erosion or deposition, channel-width change), reconstruction of historical channel conditions, estimation of process rates, and the estimation of future channel changes (Juracek and Fitzpatrick, 2009). In this study, the geomorphic analysis was focused on an assessment of channel stability at each streamgage site as evidenced by changes in channel-bed elevation and channel width.

At any given location and time along a stream, a relation exists between stage (that is, the height of the water in the channel above a given datum) and discharge (that is, streamflow volume per unit time). For streamgages these relations are quantified on rating curves and updated as necessary to accommodate changes in channel shape, slope, and other factors that affect the relation. Each rating represents a best-fit line through the measurement data (that is, paired measurements of stage and discharge). Discharge measurements at,

Table 3. U.S. Geological Survey (USGS) streamgages used in the channel-stability analysis.

[mi^2, square miles]

USGS streamgage number (fig. 1)	USGS streamgage name	Drainage area (mi^2)	Period of record
07179500	Neosho River at Council Grove, KS	250	1944–2009
07179730	Neosho River near Americus, KS	622	1963–2009
07179795	North Cottonwood River below Marion Lake, KS	200	1968–2009
07180000	Cottonwood River near Marion, KS	329	1938–1968
07180200	Cottonwood River at Marion, KS	502	1984–1999
07180400	Cottonwood River near Florence, KS	754	1961–2009
07180500	Cedar Creek near Cedar Point, KS	110	1943–2009
07182250	Cottonwood River near Plymouth, KS	1,740	1963–2009

and stage-discharge ratings for, USGS streamgages are made using standard USGS techniques (Buchanan and Somers, 1969; Kennedy, 1984) with a typical accuracy of about ±5 percent (Kennedy, 1983; Sauer and Meyer, 1992).

By computing the stage that relates to a reference discharge for each rating curve developed during the entire period of record of a streamgage (and correcting to a common datum, if necessary), trends in the elevation of the channel bed can be inferred by plotting the resulting time-series data. Ideally, the reference discharge selected is a relatively low flow that is sensitive to change. Use of a low discharge minimizes the effects of variations in channel width on flow depth (Simon and Hupp, 1992). Reference discharges previously used have included the mean annual discharge for the period of record (Juracek, 2004a) and the discharge exceeded 95 percent of the time (Williams and Wolman, 1984). In this study, the mean annual discharge for the period of record was used as the reference discharge to investigate possible changes in channel-bed elevation.

If the stage for the reference discharge (hereafter referred to as the reference stage) has a downward trend, it may be inferred that the channel-bed elevation has declined with time because of erosion. Conversely, if the reference stage has an upward trend, it may be inferred that the channel-bed elevation has risen with time as a result of deposition. An abrupt increase or decrease in reference stage may be indicative of a relatively rapid change in channel-bed elevation. The absence of a pronounced change or trend indicates that the channel bed essentially has been stable.

A statistical test was used to determine the significance of any observed trends in channel-bed elevation change. For this purpose, a nonparametric Spearman's rho correlation coefficient was computed. A trend was considered to be significant if the probability (two-sided p-value) of rejecting a correct hypothesis (in this case, no trend) was less than or equal to 0.05.

Changes in channel width were assessed through an analysis of discharge-width relations. For each streamgage site, discharge-width relations were grouped into approximate 5-year successive intervals (to get a representative range of in-channel flow conditions) that covered the period of record. Plotting of the successive intervals was used to determine if channel width changed over time.

Several possible limitations may restrict or prevent the use of streamgage data to assess channel stability. First, for an area of interest, there may be an inadequate number of streamgages with a sufficiently long period of record. Second, an existing streamgage may not be ideal because it is located in a reach that is unrepresentative or essentially stable as a result of one or more natural or human-caused conditions. Third, discharge measurements made at different cross sections (locations) may be a concern because the potential variability introduced may affect interpretation of geomorphic change. For a comprehensive discussion of the potential limitations of using streamgage data for geomorphic applications see Juracek and Fitzpatrick (2009).

Sediment-Quality Guidelines

The U.S. Environmental Protection Agency (USEPA) has adopted nonenforceable sediment-quality guidelines (SQGs) in the form of level-of-concern concentrations for several trace elements and organochlorine compounds (U.S. Environmental Protection Agency, 1997). These level-of-concern concentrations were derived from biological-effects correlations made on the basis of paired onsite and laboratory data to relate incidence of adverse biological effects in aquatic organisms to dry-weight sediment concentrations. Two such level-of-concern guidelines adopted by USEPA are referred to as the threshold-effects level (TEL) and the probable-effects level (PEL). The TEL is assumed to represent the concentration below which toxic biological effects rarely occur. In the range of concentrations between the TEL and PEL, toxic effects occasionally occur. Toxic effects usually or frequently occur at concentrations above the PEL.

USEPA cautions that the TEL and PEL guidelines are intended for use as screening tools for possible hazardous levels of chemicals and are not regulatory criteria. This cautionary statement is made because, although biological-effects correlation identifies level-of-concern concentrations associated with the likelihood of adverse organism response, the comparison may not demonstrate that a particular chemical is solely responsible. In fact, biological-effects correlations may not indicate direct cause-and-effect relations because sediments may contain a mixture of chemicals that contribute to the adverse effects to some degree. Thus, for any given site, these guidelines may be over- or underprotective (U.S. Environmental Protection Agency, 1997).

MacDonald and others (2000) developed consensus-based SQGs for several trace elements that were computed as the geometric mean of several previously published SQGs. The consensus-based SQGs consist of a threshold-effect concentration (TEC) and a probable-effect concentration (PEC). The TEC represents the concentration below which adverse effects are not expected to occur, whereas the PEC represents the concentration above which adverse effects are expected to occur more often than not. An evaluation of the reliability of the SQGs indicated that most of the individual TECs and PECs provide an accurate basis for predicting the presence or absence of sediment toxicity (MacDonald and others, 2000).

A comparison of the two sets of trace-element SQGs indicated some differences (table 4). The largest difference was for the zinc PEL and PEC. In this case, the PEC [459 mg/kg (milligrams per kilogram)] was about 69 percent larger than the PEL (271 mg/kg). For this study, the trace-element SQGs used were selected to provide a less-stringent assessment. Thus, for each trace element for which SQGs were available, the larger of the two options for threshold effects and probable effects was selected for the purpose of assessing sediment quality (see shaded values in table 4). The options used to assess sediment quality are hereafter referred to as the threshold-effects guideline and the probable-effects guideline. In this report, discussion of constituent concentrations with respect to SQGs was limited to the eight trace elements and six organochlorine compounds for which guidelines were available.

Background Information for Chemical Constituents Selected for Study

Nutrients and Total Organic Carbon

Nutrients, such as nitrogen and phosphorus, are necessary for growth and reproduction of plants. In most freshwater environments, phosphorus is the principal limiting factor for primary production (Hakanson and Jansson, 1983; Wetzel, 2001). If phosphorus concentrations are too large, algal growth may become excessive and possibly result in the production of algal toxins and taste-and-odor compounds. Additionally, excessive algal growth may be detrimental to aquatic life and limit recreational use of a lake. Major human-related sources of nutrients include fertilizer application, livestock production, and sewage-treatment plants.

Total organic carbon (TOC), an approximate determination of total organic material in a sediment sample, is important because various organic solutes can form complexes, which in turn affect trace element solubilities (Hem, 1989). The organic carbon content of sediment also is important

Table 4. Sediment-quality guidelines for selected trace elements and organochlorine compounds, and associated bioaccumulation index.

[Values in milligrams per kilogram for trace elements and micrograms per kilogram for organochlorine compounds. Shading represents guidelines to which sediment concentrations were compared in this report. USEPA, U.S. Environmental Protection Agency; TEL, threshold-effects level; PEL, probable-effects level; TEC, threshold-effects concentration; PEC, probable-effects concentration; --, not available; PCBs, polychlorinated biphenyls]

Constituent	USEPA (1997)		MacDonald and others (2000)		Bio-accumulation index[1]
	TEL	PEL	TEC	PEC	
Trace elements					
Arsenic	7.24	41.6	9.79	33.0	moderate
Cadmium	.676	4.21	.99	4.98	moderate
Chromium	52.3	160	43.4	111	moderate
Copper	18.7	108	31.6	149	high
Lead	30.2	112	35.8	128	moderate
Nickel	15.9	42.8	22.7	48.6	moderate
Silver	.733	1.77	--	--	moderate
Zinc	124	271	121	459	high
Organochlorine compounds[2]					
Chlordane	2.26	4.79	--	--	--
p,p’-DDD	1.22	7.81	--	--	--
p,p’-DDE	2.07	374	--	--	--
p,p’-DDT	1.19	4.77	--	--	--
Dieldrin	.715	4.3	--	--	--
Gross PCBs	21.6	189	--	--	--

[1]Bioaccumulation index information for trace elements from Pais and Jones (1997).

[2]TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

because many contaminants specifically sorb to the organic material in sediment (Karickhoff, 1984; Horowitz, 1991).

Trace Elements

Trace elements are important determinants of sediment quality because of their potential toxicity to living organisms (Forstner and Wittman, 1981; Smol, 2002; Luoma and Rainbow, 2008). Trace elements may be defined as elements that typically are detected in the environment in relatively low (less than 0.1 percent) concentrations (Pais and Jones, 1997; Adriano, 2001). Using this definition, most of the elements analyzed in this study may be considered trace elements. Exceptions, which are some of the abundant rock-forming elements, include aluminum and iron (Adriano, 2001).

Trace elements in sediment originate naturally from the rock and soil within a basin. Elevated concentrations of sediment-associated trace elements may be attributable to several human-related sources including fertilizers, liming materials, pesticides, irrigation water, animal and human wastes, coal-combustion residues, leaching from landfills, mining, metal-smelting industries, and automobile emissions (Forstner and Wittman, 1981; Davies, 1983; Adriano, 2001; Luoma and Rainbow, 2008).

The health of living organisms is dependent on a sufficient intake of various trace elements. Many elements, such as cobalt, copper, iron, manganese, and zinc, are essential for plants, animals, and humans. Other elements, such as arsenic and chromium, are required by animals and humans but are not essential for plants. Nonessential elements for plants, animals, and humans include cadmium, mercury, and lead (Lide, 1993; Pais and Jones, 1997; Adriano, 2001; Marmiroli and Maestri, 2008).

Toxicity is a function of several factors including the type of organism, availability of a trace element in the environment, and its potential to bioaccumulate once in the food chain. The daily intake of trace elements by animals and humans may be classified as deficient, optimal, or toxic. Most, if not all, trace elements may be toxic in animals and humans if the concentrations are sufficiently large (Pais and Jones, 1997; Smol, 2002; Luoma and Rainbow, 2008). Information on the bioaccumulation index (Pais and Jones, 1997) for trace elements with available SQGs is provided in table 4. The bioaccumulation index provides a relative ranking of the tendency of a trace element to accumulate in organisms.

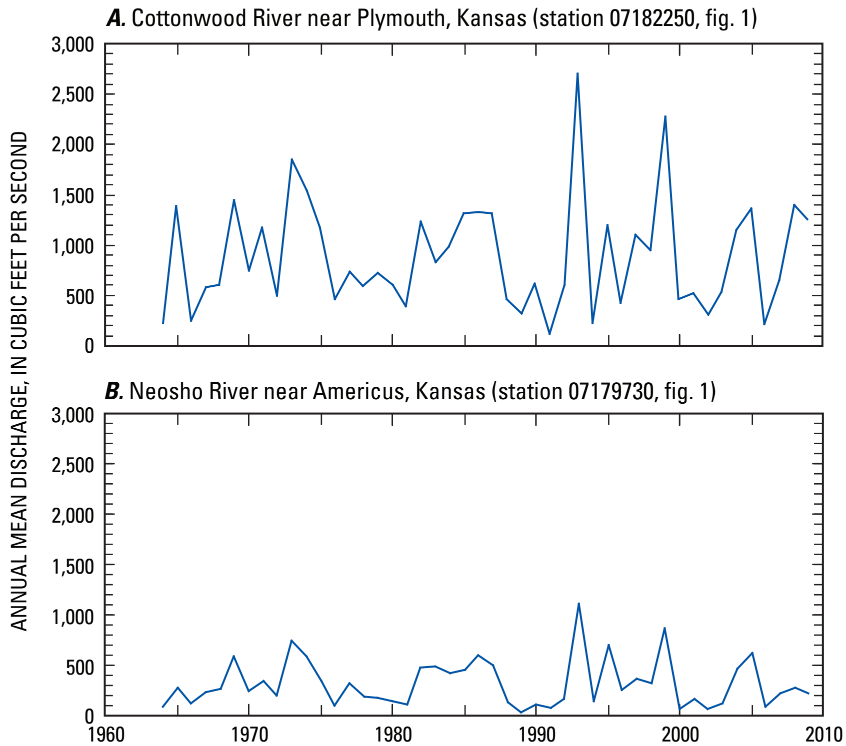

Figure 4. Variation in annual mean discharge for the Cottonwood River near Plymouth and the Neosho River near Americus, Kansas.

Organochlorine Compounds

Historically, organochlorine compounds have been manufactured and used extensively for a variety of urban, agricultural, and industrial applications. The use of organochlorine insecticides in agriculture in the United States began in the 1940s and increased to peak levels during the 1950s and 1960s. Then, because of their persistence, a tendency to bioaccumulate, and potential effects on wildlife and human health, many organochlorine insecticides were banned or severely restricted during the 1970s (Nowell and others, 1999). For example, in the United States the use of DDT was banned in 1972 (Manahan, 2000) followed by bans of aldrin and dieldrin in 1983 (Alloway and Ayres, 1997).

Polychlorinated biphenyls (PCBs), organochlorine compounds that were first produced industrially in 1929, were used for a variety of applications including ink and paint additives, plasticizers, and coolant-insulation fluids in transformers and capacitors (Alloway and Ayres, 1997; Manahan, 2000). PCBs were identified as environmental pollutants in 1966 with toxic effects similar to those of DDT. By 1977, worldwide production of PCBs had practically ceased (Alloway and Ayres, 1997). However, because of their persistence, PCBs remain widespread in the environment.

Sedimentation

Based on the mean annual volume of water-storage capacity lost to sedimentation from 1964 to 2007, and extrapolating to 2009, the total volume of bottom sediment in the conservation pool of John Redmond Reservoir was estimated to be 1.46 billion ft^3 (cubic feet) or about 33,500 acre-ft. The estimated sediment volume occupied about 41 percent of the conservation-pool, water-storage capacity of the reservoir. Water-storage capacity in the conservation pool has been lost to sedimentation at a rate of about 1 percent annually. Because most of the deposited sediment is contributed by large inflows to the reservoir (Lee and others, 2008), an indication of the year-to-year variability in sedimentation is provided by the year-to-year variability in discharge at two USGS streamgages located upstream from the reservoir—the Cottonwood River near Plymouth (station 07182250) and the Neosho River near Americus (station 07179730) (fig. 1). As shown in figure 4, inflows to the reservoir from the two rivers generally were correlated over time. On average, the Cottonwood River contributes about 180 percent more flow annually than the Neosho River (U.S. Geological Survey, 2010).

Mean annual net sediment yield, computed as the total volume of deposited sediment (33,500 acre-ft) divided by the basin area (3,015 mi^2) and reservoir age (45 years), was estimated to be 0.25 acre-ft/mi^2/yr (acre-feet per square mile per year). A comparison of the volumetric sediment yield with

Table 5. Sediment yield, precipitation, and land use for selected reservoir basins in Kansas.

[Reservoir basins are ordered from largest to smallest in sediment yield. Information for reservoirs other than John Redmond Reservoir from Juracek, 2004b, 2008]

Reservoir basin	Sediment yield (acre-feet per square mile per year)	Mean annual precipitation (inches)	Land use	
			Cropland (percent)	Grassland and woodland (percent)
Small reservoir basins				
Mound City Lake	2.03	40	16.3	79.5
Crystal Lake	1.72	40	10.7	66.0
Mission Lake	1.42	35	69.9	26.4
Gardner City Lake	.85	39	30.8	46.4
Otis Creek Reservoir	.71	33	.1	96.5
Lake Afton	.66	30	81.0	15.2
Large reservoir basins				
Perry Lake	1.59	37	40.0	57.0
Hillsdale Lake	.97	41	35.4	57.3
Tuttle Creek Lake	.40	30	66.0	32.0
Fall River Lake	.34	38	4.0	93.0
John Redmond Reservoir	.25	35	21.0	71.6
Cheney Reservoir	.22	27	72.7	25.4
Webster Reservoir	.03	21	61.1	38.3

other selected reservoir basins in Kansas is provided in table 5. Among the reservoirs compared, the sediment yield for John Redmond Reservoir was relatively low. In an analysis performed in 2004 that included 11 reservoirs listed in table 5 (Fall River Lake and John Redmond Reservoir excluded), a statistically significant positive correlation (significant at the 0.001 level) between sediment yield and mean annual precipitation (Spearman's rho = 0.86) was indicated (Juracek, 2004b). Thus, for the 11 reservoirs included in the analysis, mean annual precipitation was the best predictor of sediment yield. In the same analysis, no statistically significant correlation (at the 0.05 level) was indicated for the relation between sediment yield and mean soil permeability, mean slope, or land use. Within a given basin, sediment yield is spatially and temporally variable as a result of the complex interaction among several factors including topography, soil types, precipitation, vegetation, human disturbance, and sediment storage (Morris and Fan, 1998).

The total mass of bottom sediment in the conservation pool, computed as the total volume of bottom sediment multiplied by the representative bulk density of the sediment (38.2 lb/ft^3 (pounds per cubic foot)), was estimated to be 55.8 billion lb. Mean annual net sediment deposition, computed as the total bottom-sediment mass divided by reservoir age, was estimated to be 1.24 billion lb/yr. Mean annual net sediment yield, computed as the mean annual net deposition divided by basin area, was estimated to be 411,000 $(lb/mi^2)/yr$.

Particle-size analyses were performed to determine the percentage of sand (that is, particles larger than 0.063 mm in diameter) and silt and (or) clay (that is, particles smaller than 0.063 mm in diameter) in the sediment cores. For the 20 sediment samples analyzed, the percentage of silt and (or) clay was equal to or greater than 96 percent and typically was equal to or greater than 99 percent (tables A3, A4, and A5 at the back of this report).

Occurrence and Trends of Selected Chemical Constituents and Sediment Quality

This section describes the occurrence of, and trends in, selected chemical constituents in bottom-sediment samples collected from John Redmond Reservoir. Chemical analyses were performed using sediment samples from coring sites JR-1, JR-3, and JR-5 (fig. 2). A total of 20 sediment samples were analyzed for nutrients, carbon, and trace elements. Six samples were analyzed for organochlorine compounds. Sediment quality was assessed with reference to available SQGs for selected trace elements and organochlorine compounds (table 4).

Nutrients and Total Organic Carbon

TN concentrations in the bottom sediment of John Redmond Reservoir generally were uniform with depth at coring

Table 6. Median nutrient and trace element concentrations in the bottom sediment of selected U.S. Army Corps of Engineers' reservoirs in eastern Kansas.

[Location of reservoirs shown in figure 1. Shading indicates median concentration greater than threshold-effects guideline listed in table 4.]

Constituent	Median concentration, in milligrams per kilogram				
	John Redmond Reservoir	Clinton Lake[1]	Fall River Lake[2]	Perry Lake[3]	Toronto Lake[4]
			Nutrients		
Total nitrogen	1,900	2,200	2,000	2,500	2,100
Total phosphorus	835	970	820	1,100	940
			Trace elements		
Arsenic	11	13	13	19	14
Cadmium	0.4	0.6	0.4	0.5	0.4
Chromium	80	92	100	99	110
Copper	26	29	25	33	29
Lead	28	26	30	28	32
Nickel	39	41	44	50	51
Zinc	120	130	130	120	140

[1]U.S. Geological Survey, unpublished data, 2009.

[2]Juracek (2008).

[3]Juracek (2003).

[4]U.S. Geological Survey, unpublished data, 2008.

sites JR-1 and JR-3 (fig. 5) indicating consistent inputs to the reservoir over time. For both sites, TN concentrations generally varied within 10 percent of the mean concentration for each core. Overall, using the sediment samples from coring sites JR-1, JR-3, and JR-5 (that is, 20 samples), TN concentrations ranged from 1,400 to 2,200 mg/kg (tables A3, A4, and A5). Computed using the sediment samples from all three coring sites, both the mean and median TN concentrations were 1,900 mg/kg. The estimated mean annual net load of TN deposited in the reservoir bottom sediment was 2,350,000 lb. The estimated mean annual net yield of TN from the reservoir basin was 779 (lb/mi^2)/yr. Statistically significant trends in TN deposition (at the 0.05 level of significance) were not indicated for coring sites JR-1 and JR-3. Compared to four other USACE reservoirs in eastern Kansas, TN concentrations in John Redmond Reservoir either were comparable or somewhat smaller (table 6).

TP concentrations in the bottom sediment of John Redmond Reservoir ranged from 670 to 990 mg/kg (tables A3, A4, and A5) indicating the possibility of changing inputs to the reservoir. Computed using the sediment samples from all three coring sites, both the mean and median TP concentrations were 835 mg/kg. The estimated mean annual net load of TP deposited in the reservoir bottom sediment was 1,030,000 lb. The estimated mean annual net yield of TP from the reservoir basin was 342 (lb/mi^2)/yr. Statistically significant trends in TP deposition (at the 0.05 level of significance) were not indicated for coring sites JR-1 and JR-3 (fig. 5). Compared to four other USACE reservoirs in eastern Kansas, TP concentrations in John Redmond Reservoir were similar to Fall River Lake and smaller than the other three reservoirs (table 6).

TOC concentrations generally were uniform over time at the three coring sites. Overall, TOC concentrations ranged from 1.3 to 1.8 percent (tables A3, A4, and A5). Computed using the sediment samples from all three coring sites, the mean and median concentrations were 1.5 and 1.6 percent, respectively.

Trace Elements

Trace element concentrations in the bottom sediment of John Redmond Reservoir generally were uniform over time (tables A3, A4, and A5). Trend analyses, with a significance level of 0.05, were completed for all trace elements. For coring site JR-1, a statistically significant negative trend for lead (Spearman's rho = -0.81) and a statistically significant positive trend for strontium (Spearman's rho = 0.85) were indicated. For coring site JR-3, a statistically significant negative trend for lead (Spearman's rho = -0.83) and statistically significant positive trends for manganese (Spearman's rho = 0.74) and strontium (Spearman's rho = 0.79) were indicated. Because most or all of the core intervals had concentrations that were within 10 percent of the mean concentration for each core, the lead and strontium trends may be a result of analytical variance. The indicated positive trend for manganese at coring site JR-3 does not appear to be caused by analytical variance as most of the concentrations were not within 10 percent of the mean concentration.

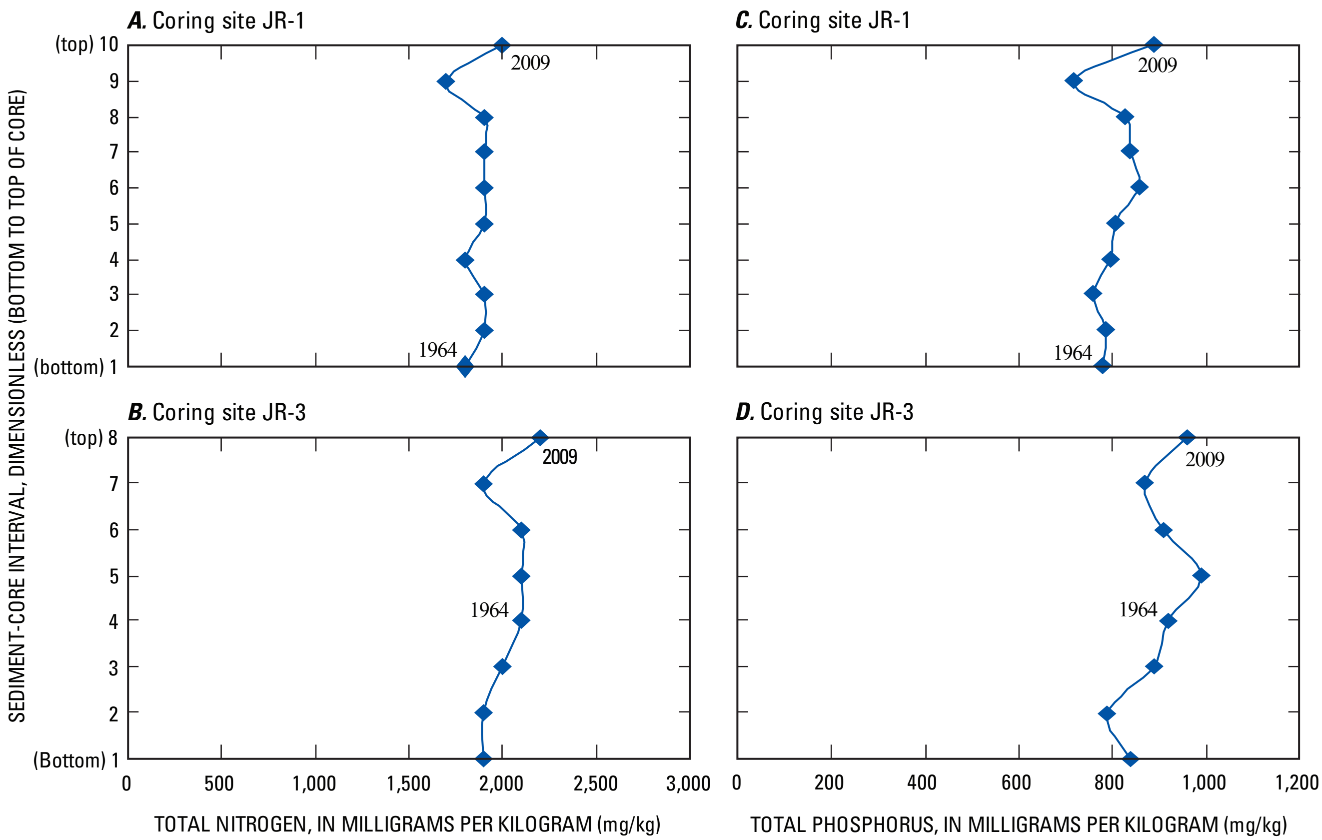

Figure 5. Variation in total nitrogen and total phosphorus concentrations with depth of bottom-sediment samples collected from coring sites JR-1 and JR-3 in John Redmond Reservoir, east-central Kansas, July and August 2009.

Sediment quality was assessed for the eight trace elements for which SQGs were available (table 4). Silver generally was not detected in the reservoir bottom sediment. Cadmium, copper, and lead concentrations were less than the respective threshold-effects guidelines. Zinc concentrations were less than the threshold-effects guideline in samples from coring sites JR-1 and JR-5. However, zinc concentrations typically were greater than the threshold-effects guideline in samples from coring site JR-3. All or most arsenic, chromium, and nickel concentrations were greater than the respective threshold-effects guidelines. Sediment concentrations of arsenic, chromium, and nickel greater than the respective threshold-effects guidelines are typical for reservoirs in eastern Kansas (Juracek, 2003, 2004b, 2008; Juracek and Mau, 2002). For these three trace elements, the measured concentrations may be indicative of natural contributions from soils and bedrock (Luoma and Rainbow, 2008). No trace element concentrations exceeded the probable-effects guidelines (tables A3, A4, and A5). A comparison of selected trace element concentrations in John Redmond Reservoir with four other USACE reservoirs in eastern Kansas is provided in table 6.

Organochlorine Compounds

With the exception of p,p'-DDE (a degradation product of p,p'-DDT), organochlorine compounds (table 1) were not detected in the bottom-sediment samples analyzed for John Redmond Reservoir. The detections of p,p'-DDE were only for the bottom (oldest) sample analyzed for coring sites JR-1 and JR-3 (fig. 2). For both samples, the concentration of p,p'-DDE was less than the threshold-effects guideline (2.07 µg/kg).

Upstream Channel Stability

An assessment of channel stability at eight streamgage sites located within the Neosho River Basin upstream from John Redmond Reservoir was completed using streamgage information to investigate historical changes in channel-bed elevation and channel width. Analyses of discharge-width relations over the period of record for each streamgage indicated no pronounced changes in channel width. However, onsite channel inspections in March 2010 documented active channel-bank erosion in the vicinity of each streamgage that ranged from minor to substantial. Large, recent bank slumps were observed upstream from the Cottonwood River near Florence streamgage site (station 07180400), upstream from the Cedar Creek near Cedar Point streamgage site (station 07180500), and downstream from the Cottonwood River near Plymouth streamgage site (station 07182250) (fig. 1). The fact that no pronounced changes in channel width were indicated by the analyses of discharge-width relations may be accounted for by several possible explanations. First, the amount of channel-width change at each site (if any) may have been less than what the analyses were able to detect. Second, the locations where substantial bank erosion has occurred may be different from where the discharge-width data were collected. For example, high-flow discharge measurements typically are made at a bridge whereas the location(s) of substantial bank erosion may be upstream or downstream from the bridge. A related complication is the fact that channel banks at and near bridges sometimes are stabilized with riprap. Thus, channel-width changes upstream or downstream from the bridge may be unlikely at the bridge. Third, channel width may not change appreciably at a site over time if erosion on one bank is offset by deposition on the opposite bank. This is the case in a stable river that is actively meandering, as erosion on the outer bank of a meander (cutbank) is balanced by deposition on the inner bank of a meander (point bar) (Leopold, 1994; Knighton, 1998).

In the following sections, the results of analyses to assess historical changes in channel-bed elevation are presented. The results presented include the type, magnitude, timing, rate, and trend of channel-bed elevation changes at each site as appropriate.

Neosho River at Council Grove

The Neosho River at Council Grove streamgage (station 07179500, fig. 1, table 3) is located 1.7 river mi downstream from Council Grove Lake, a reservoir that was completed by USACE in 1964. Initially, from 1944 to 1951, changes in the reference stage (for 100 ft^3/s (cubic feet per second)) were minor and indicated that the channel-bed elevation was essentially stable. From 1951 to 1987, the reference stage steadily decreased from 8.90 to 7.35 ft (fig. 6). For this period, a statistically significant negative trend was indicated (Spearman's rho = -0.98, two-side p-value = 0.00000). During this period, the channel bed degraded a total of 1.55 ft at an average rate of about 0.04 ft/yr. The reference stage was constant from 1987 through 1996 indicating that the channel bed was stable during this time. In January 1997, a concrete weir was installed across the channel about 0.25 mi downstream from the streamgage. As a result, the reference stage increased from 7.35 to 8.80 ft. Since the installation of the weir, the reference stage remained unchanged at 8.80 ft through 2009 indicating that the channel bed was stable. The channel bed at the streamgage site is composed of limestone bedrock with a light overburden of gravel and silt. Given the resistant nature of the bed material and the presence of the weir, additional degradation of the channel bed at this site likely will be minimal.

The long-term (1951 to 1987) degradation of the channel bed at this site likely was caused, at least in part, by the upstream presence of Council Grove Lake as well as Council Grove City Lake (completed in 1942) (fig. 1). Reservoirs trap and permanently store much of the sediment load delivered from the upstream basin. For large reservoirs, the sediment trap efficiency typically is greater than 90 percent (Brune, 1953; Williams and Wolman, 1984; Shotbolt and others, 2005; Vanoni, 2006). Downstream from the dam, a river typically will scour, and thus lower, its channel bed as the sediment-depleted water emerging from the spillway attempts to replenish its sediment load. Channel-bed erosion has been documented downstream from several large reservoirs in Kansas (Juracek, 2001).

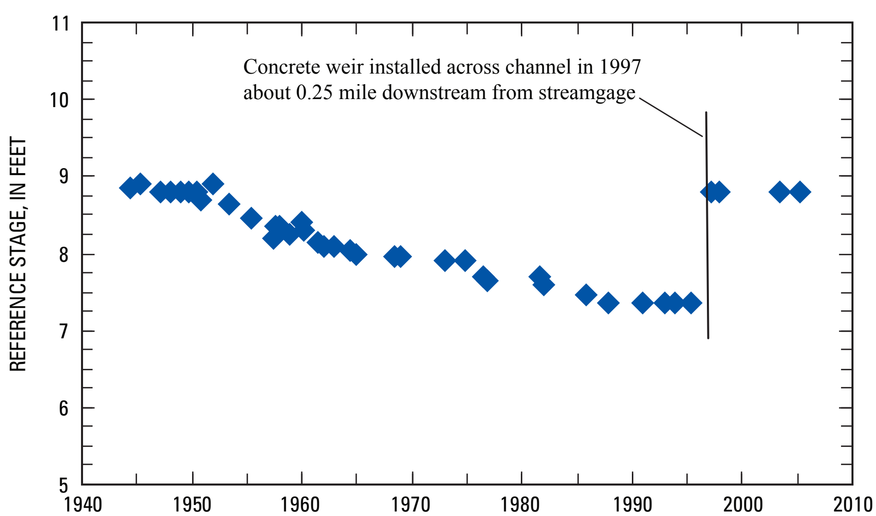

Figure 6. Variation in stream stage for mean annual discharge (100 cubic feet per second) at Neosho River at Council Grove streamgage (station 07179500), 1944–2009.

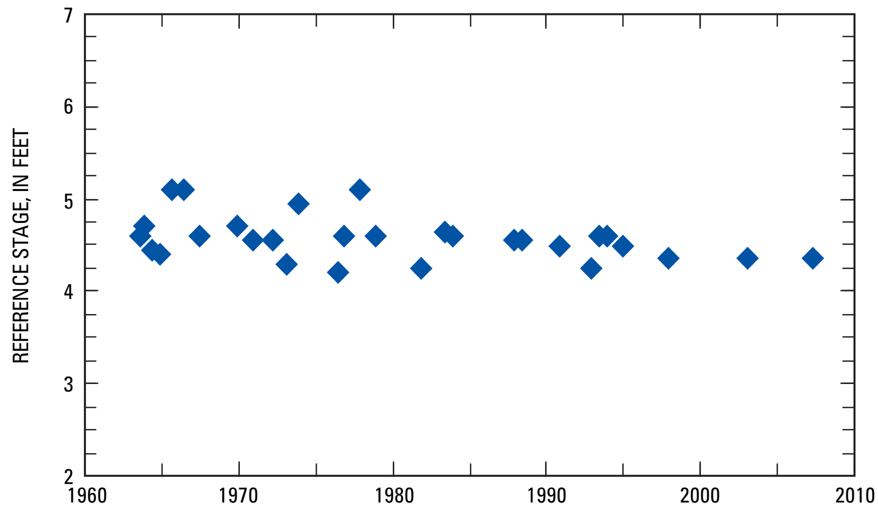

Figure 7. Variation in stream stage for mean annual discharge (300 cubic feet per second) at Neosho River near Americus streamgage (station 07179730), 1963–2009.

Neosho River near Americus

The Neosho River near Americus streamgage (station 07179730, fig. 1, table 3) is located 0.1 river mi downstream from an in-channel overflow dam and about 39 river mi downstream from the streamgage at Council Grove. From 1963 to 2009, the reference stage (for 300 ft^3/s) was relatively stable as it varied within 0.5 ft of the mean value of 4.6 ft (fig. 7). The channel-bed elevation at this site appeared to be fluctuating in response to scour (erosion) and fill (deposition) processes that may reflect short-term changes in response to individual flow events. Bank slumping has occurred in the vicinity of the streamgage (J.P. Marshall, U.S. Geological Survey, written commun., 1987). The reference stage was constant at 4.35 ft from 1997 through 2009 indicating that the channel bed was stable during this time.

North Cottonwood River below Marion Lake

The North Cottonwood River below Marion Lake streamgage (station 07179795, fig.1, table 3) is located 0.25 river mi downstream from Marion Lake, a reservoir that was completed by USACE in 1968. The streamgage also is located 1.8 river mi upstream from the confluence with the South Cottonwood River. The reference stage (for 80 ft^3/s)

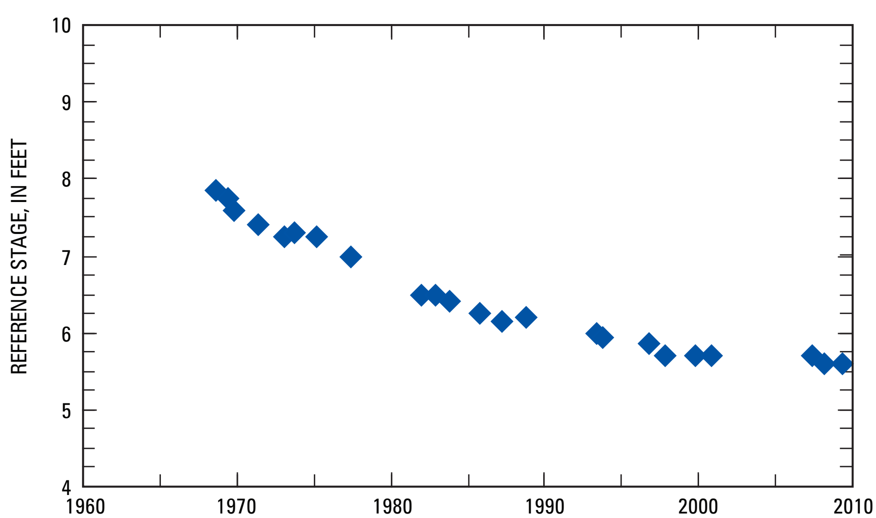

Figure 8. Variation in stream stage for mean annual discharge (80 cubic feet per second) at North Cottonwood River below Marion Lake streamgage (station 07179795), 1968–2009.

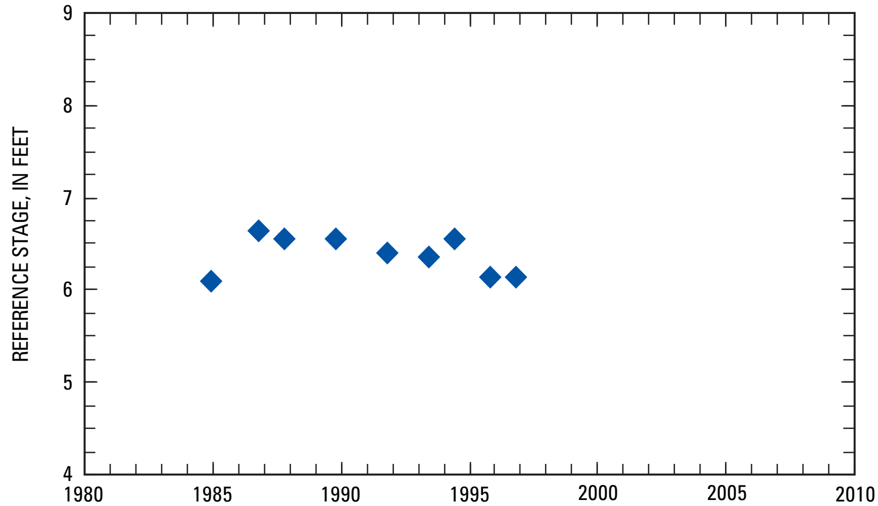

Figure 9. Variation in stream stage for mean annual discharge (200 cubic feet per second) at Cottonwood River at Marion streamgage (station 07180200), 1984–99.

steadily decreased from 7.85 ft in 1968 to 5.70 ft in 1997 (fig. 8). The long-term channel-bed degradation at this site likely was a result of sediment-depleted water emerging from the spillway at Marion Lake. For 1968–97, a statistically significant negative trend was indicated (Spearman's rho = -0.99, two-side p-value = 0.00000). During this period, the channel bed degraded a total of 2.15 ft at an average rate of about 0.07 ft/yr. The reference stage essentially was constant from 1998 through 2009 indicating that the channel bed was stable during this time. Onsite inspection in March 2010 determined that the channel bed in the vicinity of the streamgage was mostly composed of limestone cobbles. Thus, additional degradation of the channel bed at this site likely will be minimal.

Cottonwood River at and near Marion

The Cottonwood River at Marion streamgage (station 07180200, fig. 1, table 3) is located 2.7 river mi downstream from the confluence of the North Cottonwood and South Cottonwood Rivers. This streamgage was only operated from 1984 to 1999. During this period, the reference stage (for 200 ft^3/s) was relatively stable as it varied within 0.3 ft of the mean value of 6.4 ft (fig. 9). The channel-bed elevation at this site appeared to be fluctuating in response to minor scour and fill processes.

A similar pattern of relative channel-bed stability also was indicated by the Cottonwood River near Marion streamgage (station 07180000, fig.1, table 3), which was located 1.7 river mi upstream from the "at Marion"

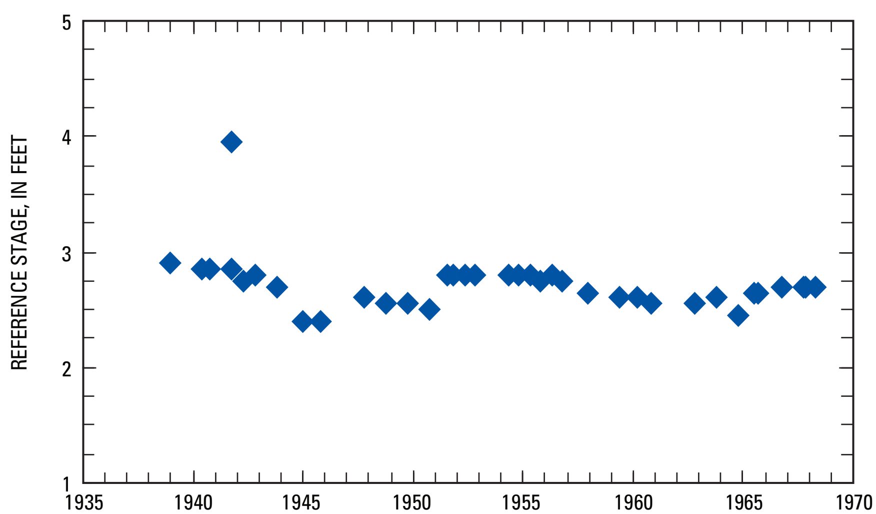

Figure 10. Variation in stream stage for mean annual discharge (110 cubic feet per second) at Cottonwood River near Marion streamgage (station 07180000), 1938–68.

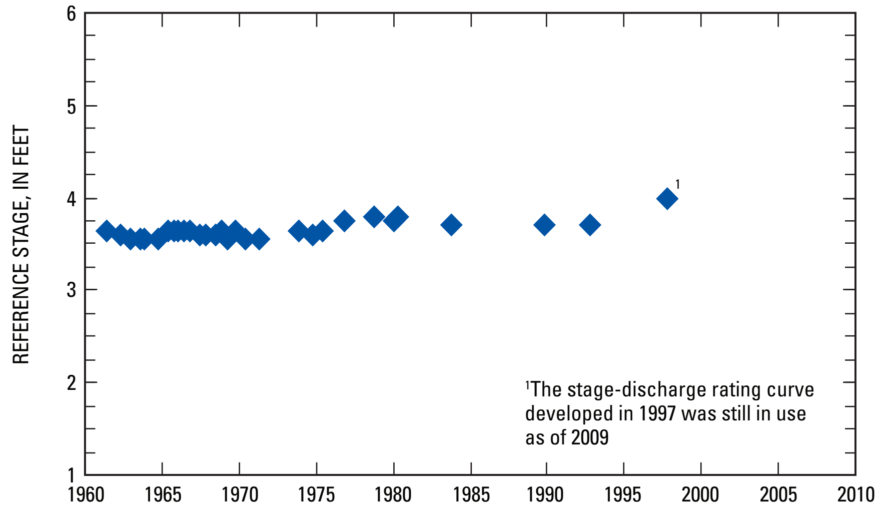

Figure 11. Variation in stream stage for mean annual discharge (300 cubic feet per second) at Cottonwood River near Florence streamgage (station 07180400), 1961–2009.

streamgage site and was operated from 1938 to 1968. With one exception, the reference stage (for 110 ft^3/s) at the "near Marion" streamgage site varied within 0.3 ft of the mean value of 2.7 ft (fig. 10). The exception occurred in 1941 when the reference stage temporarily increased 1.1 ft apparently as a result of bank slumping in the vicinity of the streamgage (B.L. Hobbs, U.S. Geological Survey, written commun., 1942).

Cottonwood River near Florence

The Cottonwood River near Florence streamgage (station 07180400, fig. 1, table 3) is located about 20 river mi downstream from the "at Marion" streamgage site. From 1961 to 2009, the reference stage (for 300 ft^3/s) indicated a generally stable channel bed as it varied within 0.3 ft of the mean value of 3.7 ft (fig. 11). The channel bed at the streamgage site is mostly composed of limestone cobbles and gravel. Given the resistant nature of the bed material, substantial degradation of the channel bed at this site is unlikely. The stability of the channel bed at this site was evidenced by the fact that the stage-discharge rating curve developed in 1997 was still in use as of 2009.

Cottonwood River near Plymouth

The Cottonwood River near Plymouth streamgage (station 07182250, fig. 1, table 3) is located about 63 river mi downstream from the "near Florence" streamgage site. Unlike the upstream Cottonwood River streamgages at Marion and near Florence, changes in the reference stage (for 900 ft^3/s) at

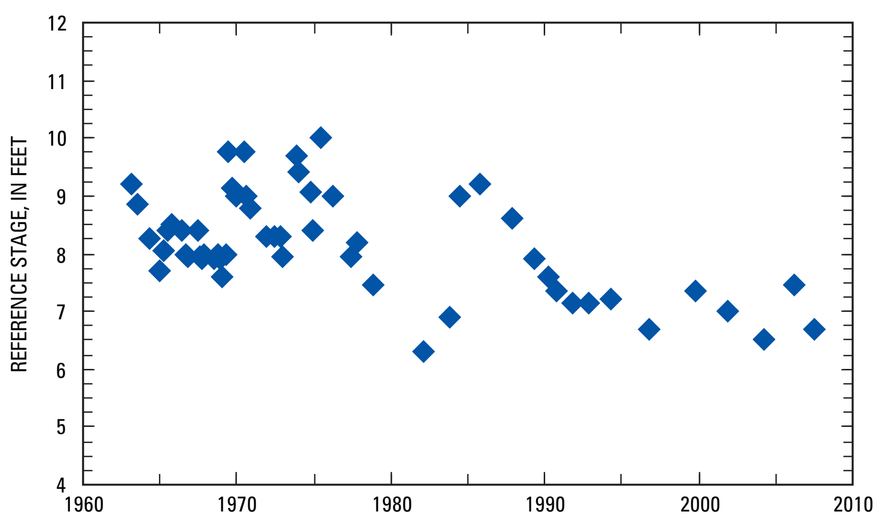

Figure 12. Variation in stream stage for mean annual discharge (900 cubic feet per second) at Cottonwood River near Plymouth streamgage (station 07182250), 1963–2009.

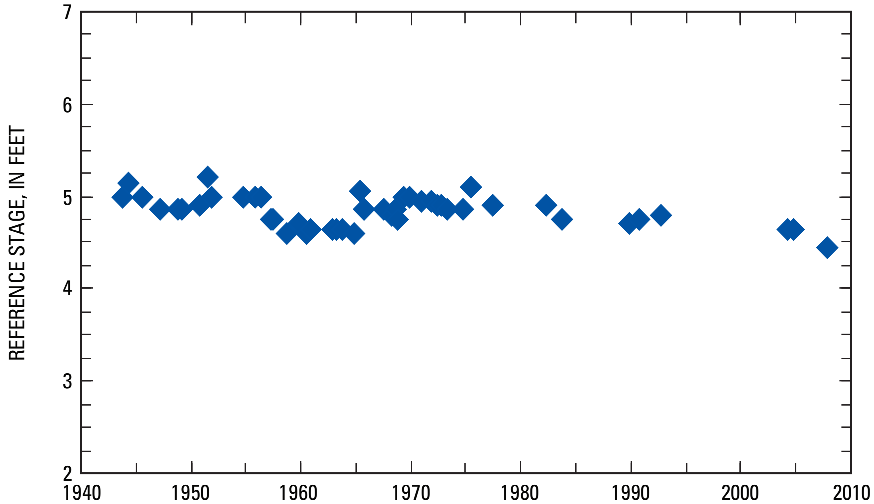

Figure 13. Variation in stream stage for mean annual discharge (60 cubic feet per second) at Cedar Creek near Cedar Point streamgage (station 07180500), 1943–2009.

this site indicated substantial variability in channel-bed elevation over time in response to scour and fill processes (fig. 12). The largest fluctuations in channel-bed elevation occurred from 1963 to 1990 when the reference stage ranged from 6.3 to 10.0 ft. From 1991 to 2009, the channel bed was more stable as the reference stage varied within 0.5 ft of the mean value of 7.0 ft. Bank slumping has occurred repeatedly at this site following high flows when the banks are saturated (J.R. Barnard, U.S. Geological Survey, oral commun., 2010). Bank slumps were responsible for the pronounced increases in reference stage that occurred in 1969 (C.O. Geiger, U.S. Geological Survey, written commun., 1969) and 1984 (G.G. Quy II, U.S. Geological Survey, written commun., 1987) and likely were a contributing factor for other changes in reference stage.

Cedar Creek near Cedar Point

The Cedar Creek near Cedar Point streamgage (station 07180500, fig. 1, table 3) is located about 10 stream mi upstream from the confluence with the Cottonwood River. From 1943 to 2009, the reference stage (for 60 ft^3/s) indicated a generally stable channel bed as it varied within 0.4 ft of the mean value of 4.8 ft (fig. 13). The channel bed at the streamgage site is composed of limestone bedrock with a light overburden of gravel and silt. Given the resistant nature of the bed material, substantial degradation of the channel bed at this site is unlikely.

Vegetation and Channel-Bank Stability

Vegetation can increase or decrease channel-bank stability depending on the type of vegetation in relation to the site conditions. At the bank surface it can increase resistance to erosion by providing a protective cover and by reducing near-bank flow velocity and turbulence. At depth it can increase resistance to erosion through root systems that enhance the cohesive strength of the bank material (Thorne, 1990). Whereas trees have been shown to increase the resistance of banks to erosion (Beeson and Doyle, 1995), there also are situations where trees can have the opposite effect. For example, in the case where the height of a steep bank exceeds the rooting depth of trees growing on top of the bank, the weight of the trees generally will reduce bank stability and increase the likelihood of bank failure (Thorne, 1990).

The banks of the Neosho and Cottonwood Rivers upstream from John Redmond Reservoir typically are partially or completely covered by trees. At a given location, the trees may increase or decrease bank stability depending on the size and density of the trees in relation to the height and slope of the bank. The accumulation of a 1.5-mi long logjam on the Neosho River immediately upstream from John Redmond Reservoir by 2004 (U.S. Army Corps of Engineers, 2005), in combination with evidence from USGS streamgage information (see “Upstream Channel Stability” section of this report), indicated that bank slumping likely is a common occurrence upstream from the reservoir. Based on a comparison of 1991 and 2006 aerial photographs, The Watershed Institute (2007) determined that channel-bank erosion rates along the Neosho and Cottonwood Rivers upstream from the reservoir tended to increase as the width of the wooded riparian corridor decreased.

Sediment Sources for John Redmond Reservoir

An effective management plan to reduce the sediment load delivered to John Redmond Reservoir requires an understanding of the type and relative importance of various sediment sources (Collins and Walling, 2004; Walling, 2005).

In this discussion, sediment refers to silt and clay because particle-size analyses determined that the bottom sediment in the reservoir was at least 96 percent silt and clay. The sediment deposited in the reservoir mostly originates from four possible sources. Three of the sources are upstream from the reservoir and include channel beds, channel banks, and surface soils within the basin (Waters, 1995). The fourth source is the shoreline surrounding the reservoir (Morris and Fan, 1998). Any of these four sources potentially may contribute a substantial amount of sediment to the reservoir. Surface-soil and shoreline erosion were not addressed in this study. Atmospheric deposition was assumed to be relatively insignificant.

Channel beds are not considered to be a major present-day source of sediment to the reservoir. In order for channel beds to be a true source, pronounced bed erosion (downcutting) would be required. Long-term channel-bed degradation was indicated at streamgages located immediately downstream from Council Grove and Marion Lakes. However, the channel beds at these locations have stabilized (figs. 6, 8). At the other streamgages investigated, the channel beds either were stable or fluctuated in response to scour and fill processes (figs. 7, 9–13). In the former case, the channel beds were composed of resistant material (for example, bedrock or cobble) that is very unlikely to provide a substantial source of sediment. In the later case, the channel beds appear to serve as a temporary storage location (for example, for material introduced from bank slumping or erosion of surface soils) from which deposited sediment is subsequently remobilized and transported downstream. Finally, channel-bed erosion for some distance upstream from John Redmond Reservoir likely will be minimal because the reservoir provides base-level control.

Channel banks likely are a substantial source of sediment to the reservoir. As previously discussed, the combined evidence of USGS streamgage information, large accumulations of woody debris in the Neosho River channel, aerial photographs, and onsite inspections indicated that bank erosion is an active and ongoing process upstream from the reservoir.

For John Redmond Reservoir, the relative importance (that is, in terms of the amount of sediment contributed) of the four sources is uncertain. Determination of the relative importance of sediment sources may be possible using chemical tracers or other methods. For example, in a recent study of Perry Lake, Kansas, chemical tracers were used to determine that channel banks were more important than surface soils as sediment sources for the reservoir (Juracek and Ziegler, 2009).

As part of an overall understanding of sediment sources, it is important to keep three considerations in mind. First, sediment yield can vary substantially throughout a basin and a small percentage of a basin can account for a large percentage of the sediment yield (Morris and Fan, 1998; Russell and others, 2001; Lee and others, 2009). Second, the contribution of sediment from channel erosion tends to become more important with distance downstream in a basin (Knighton, 1998; Lawler and others, 1999; Walling, 2005; Juracek and Ziegler, 2009). Finally, the relative contribution of various sediment sources likely will change over time.

Summary and Conclusions

A 1.5-year study by the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers, was begun in 2009 to investigate sedimentation in John Redmond Reservoir and the deposition of selected chemical constituents in the bottom sediment of the reservoir for 1964 through 2009. Channel stability upstream from the reservoir also was assessed. The study used a combination of available bathymetric-survey information, bottom-sediment coring completed in 2009, and historical streamgage information. The major results of this study are listed below:

1. The total estimated volume and mass of bottom sediment in the conservation pool of John Redmond Reservoir was 1.46 billion ft^3 and 55.8 billion lb, respectively. Ongoing sedimentation is reducing the ability of the reservoir to serve several purposes including flood control, water supply, and recreation.

2. The estimated sediment volume occupied about 41 percent of the conservation-pool, water-storage capacity of John Redmond Reservoir. Water-storage capacity in the conservation pool has been lost to sedimentation at a rate of about 1 percent annually.

3. Mean annual net sediment deposition in the conservation pool of John Redmond Reservoir was estimated to be 1.24 billion lb/yr.

4. Mean annual net sediment yield from the John Redmond Reservoir Basin was estimated to be 411,000 $(lb/mi^2)/yr$.

5. Total nitrogen concentrations in the bottom sediment of John Redmond Reservoir generally were uniform over time, with an overall median concentration of 1,900 mg/kg, and indicated consistent inputs to the reservoir.

6. The mean annual net load and yield of total nitrogen deposited in the bottom sediment of John Redmond Reservoir was estimated to be 2,350,000 lb/yr and 779 $(lb/mi^2)/yr$, respectively.

7. Total phosphorus concentrations in the bottom sediment of John Redmond Reservoir were variable over time, with an overall median concentration of 835 mg/kg, and indicated the possibility of changing inputs to the reservoir. As the principal limiting factor for primary production in most freshwater environments, phosphorus is of particular importance because increased inputs can contribute to accelerated reservoir eutrophication and the production of algal toxins and taste-and-odor compounds.

8. The mean annual net load and yield of total phosphorus deposited in the bottom sediment of John Redmond Reservoir was estimated to be 1,030,000 lb/yr and 342 $(lb/mi^2)/yr$, respectively.

9. Trace element concentrations in the bottom sediment of John Redmond Reservoir generally were uniform over time.

10. As is typical for eastern Kansas reservoirs, arsenic, chromium, and nickel concentrations in the bottom sediment of John Redmond Reservoir typically exceeded the threshold-effects guidelines, which represent the concentrations above which toxic biological effects occasionally occur.

11. Trace element concentrations did not exceed the probable-effects guidelines (available for eight trace elements), which represent the concentrations above which toxic biological effects usually or frequently occur.

12. Organochlorine compounds either were not detected or were detected at concentrations that were less than the threshold-effects guidelines.

13. Stream channel banks, compared to channel beds, likely are a more important source of sediment to John Redmond Reservoir from the upstream basin.

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Supplemental Information

Table A1. Latitude and longitude coordinates, water depth, estimated penetration depth, length of recovered core, and estimated recovery percentage for bottom-sediment coring sites at John Redmond Reservoir, east-central Kansas, 2009.

Coring site number (fig. 2)	Date cored (month/day/year)	Latitude (decimal degrees)	Longitude (decimal degrees)	Water depth (feet)	Estimated penetration depth (feet)	Length of recovered core (feet)	Estimated recovery percentage
JR-1	07/07/09	38.24583	95.77361	12.0	7.9	6.5	82
JR-2	07/07/09	38.23389	95.78611	12.5	7.6	6.5	86
JR-3	08/10/09	38.25139	95.80056	6.4	5.6	5.3	95
JR-4	08/10/09	38.26222	95.78889	5.0	6.3	5.0	79
JR-5	07/07/09	38.26667	95.82083	8.5	5.8	4.6	79

Table A2. Estimated bulk density of bottom sediment at coring sites in John Redmond Reservoir, east-central Kansas.

[lb/ft^3, pounds per cubic foot; --, not applicable]

Coring site number (fig. 2)	Depth interval, below sediment-water interface (feet)	Estimated bulk density (lb/ft^3)	Computed mean bulk density[1] (lb/ft^3)
JR-1	0–0.98	27.9	--
	0.98–1.96	33.7	--
	1.96–2.94	35.1	--
	2.94–3.92	37.8	--
	3.92–4.90	40.7	--
	4.90–5.90	44.3	--
			36.6
JR-2	0–1.0	31.9	--
	1.0–2.0	32.9	--
	2.0–3.0	37.5	--
	3.0–4.0	35.8	--
	4.0–5.0	41.0	--
	5.0-6.0	40.5	--
			36.6
JR-3	0–1.09	32.3	--
	1.09–2.18	33.2	--
	2.18–3.27	33.9	--
	3.27–4.36	43.8	--
			35.8
JR-4	0–0.94	42.2	--
	0.94–1.88	39.4	--
	1.88–2.82	42.2	--
	2.82–3.76	50.4	--
	3.76–4.68	44.6	--
			43.8

[1]Mean bulk density computed as the average of the bulk densities for the individual depth intervals for each core.

Table A3. Percentage of silt and clay and nutrient, carbon, and trace element concentrations for bottom-sediment samples collected from coring site JR-1 (fig. 2) in John Redmond Reservoir, east-central Kansas, July 2009.

[Shading indicates concentration greater than threshold-effects guideline listed in table 4. >, greater than; mg/kg, milligrams per kilogram; %, percent dry weight; <, less than]

Constituent and unit of measurement	Constituent concentration				
	Interval 1 (bottom of core)	Interval 2	Interval 3	Interval 4	Interval 5
Percentage of silt and clay	>99	>99	>99	>99	>99
		Nutrients			
Total nitrogen, mg/kg	1,800	1,900	1,900	1,800	1,900
Total phosphorus, mg/kg	780	790	760	800	810
		Carbon			
Carbon (total organic), %	1.5	1.5	1.4	1.5	1.5
Carbon (total), %	1.9	1.9	2.2	2.0	2.3
		Trace elements			
Aluminum, %	8.3	9.1	8.7	8.9	9.1
Antimony, mg/kg	.7	.7	.7	.7	.7
Arsenic, mg/kg	11	12	11	12	11
Barium, mg/kg	620	620	630	650	630
Beryllium, mg/kg	2.4	2.6	2.5	2.5	2.6
Cadmium, mg/kg	.4	.4	.4	.4	.4
Chromium, mg/kg	75	81	79	80	83
Cobalt, mg/kg	13	13	13	13	14
Copper, mg/kg	24	26	25	26	26
Iron, %	3.9	4.4	4.2	4.2	4.4
Lead, mg/kg	29	30	28	29	28
Lithium, mg/kg	52	58	56	57	58
Manganese, mg/kg	790	730	720	740	740
Molybdenum, mg/kg	1	1	1	1	1
Nickel, mg/kg	35	39	39	39	40
Selenium, mg/kg	.6	.6	.6	.6	.6
Silver, mg/kg	<.5	<.5	<.5	<.5	<.5
Strontium, mg/kg	160	180	190	200	200
Sulfur, %	.05	.08	.09	.09	.09
Thallium, mg/kg	<50	<50	<50	<50	<50
Tin, mg/kg	3	3	2	3	3
Titanium, %	.45	.44	.45	.46	.46
Uranium, mg/kg	<50	<50	<50	<50	<50
Vanadium, mg/kg	110	120	120	120	120
Zinc, mg/kg	120	120	120	120	120

Table A3. Percentage of silt and clay and nutrient, carbon, and trace element concentrations for bottom-sediment samples collected from coring site JR-1 (fig. 2) in John Redmond Reservoir, east-central Kansas, July 2009.—Continued

[Shading indicates concentration greater than threshold-effects guideline listed in table 4. >, greater than; mg/kg, milligrams per kilogram; %, percent dry weight; <, less than]

Constituent and unit of measurement	Constituent concentration				
	Interval 6	Interval 7	Interval 8	Interval 9	Interval 10 (top of core)
Percentage of silt and clay	>99	>99	>99	>99	>99
	Nutrients				
Total nitrogen, mg/kg	1,900	1,900	1,900	1,700	2,000
Total phosphorus, mg/kg	860	840	830	720	890
	Carbon				
Carbon (total organic), %	1.6	1.6	1.4	1.4	1.5
Carbon (total), %	2.3	2.5	2.4	2.2	2.2
	Trace elements				
Aluminum, %	8.8	8.8	9.0	8.3	8.8
Antimony, mg/kg	.7	.7	.7	.7	1.1
Arsenic, mg/kg	11	11	11	9.4	11
Barium, mg/kg	620	620	640	610	630
Beryllium, mg/kg	2.5	2.6	2.6	2.4	2.6
Cadmium, mg/kg	.4	.4	.4	.4	.4
Chromium, mg/kg	79	80	82	75	80
Cobalt, mg/kg	13	14	14	13	14
Copper, mg/kg	26	26	26	24	25
Iron, %	4.4	4.3	4.4	4.0	4.3
Lead, mg/kg	27	28	28	26	27
Lithium, mg/kg	57	57	58	53	56
Manganese, mg/kg	810	830	860	680	880
Molybdenum, mg/kg	1	1	1	1	1
Nickel, mg/kg	39	39	40	37	39
Selenium, mg/kg	.6	.6	.6	.6	.6
Silver, mg/kg	<.5	<.5	<.5	<.5	<.5
Strontium, mg/kg	210	190	210	220	210
Sulfur, %	.10	.08	.09	.14	.08
Thallium, mg/kg	<50	<50	<50	<50	<50
Tin, mg/kg	3	3	3	3	2
Titanium, %	.43	.43	.45	.43	.44
Uranium, mg/kg	<50	<50	<50	<50	<50
Vanadium, mg/kg	120	120	120	110	120
Zinc, mg/kg	120	120	120	110	120

Table A4. Percentage of silt and clay and nutrient, carbon, and trace element concentrations for bottom-sediment samples collected from coring site JR-3 (fig. 2) in John Redmond Reservoir, east-central Kansas, August 2009.

[Shading indicates concentration greater than threshold-effects guideline listed in table 4. mg/kg, milligrams per kilogram; %, percent dry weight; <, less than]

Constituent and unit of measurement	Constituent concentration			
	Interval 1 (bottom of core)	Interval 2	Interval 3	Interval 4
Percentage of silt and clay	99	98	99	99
	Nutrients			
Total nitrogen, mg/kg	1,900	1,900	2,000	2,100
Total phosphorus, mg/kg	840	790	890	920
	Carbon			
Carbon (total organic), %	1.7	1.6	1.6	1.6
Carbon (total), %	2.0	1.9	2.1	2.4
	Trace elements			
Aluminum, %	9.3	8.6	9.6	9.1
Antimony, mg/kg	1.0	.9	.9	1.0
Arsenic, mg/kg	11	11	12	12
Barium, mg/kg	700	670	700	680
Beryllium, mg/kg	2.9	2.7	2.9	2.8
Cadmium, mg/kg	.4	.3	.4	.4
Chromium, mg/kg	88	80	90	86
Cobalt, mg/kg	14	14	15	15
Copper, mg/kg	30	28	31	29
Iron, %	4.4	4.0	4.6	4.4
Lead, mg/kg	28	28	28	28
Lithium, mg/kg	65	59	67	64
Manganese, mg/kg	700	650	770	860
Molybdenum, mg/kg	<1	<1	<1	<1
Nickel, mg/kg	39	36	40	39
Selenium, mg/kg	.6	.6	.7	.6
Silver, mg/kg	<.5	.5	<.5	<.5
Strontium, mg/kg	180	190	210	210
Sulfur, %	.10	.10	.08	.09
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	3	3	3	3
Titanium, %	.44	.43	.45	.44
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	140	130	140	130
Zinc, mg/kg	140	120	140	130

Table A4. Percentage of silt and clay and nutrient, carbon, and trace element concentrations for bottom-sediment samples collected from coring site JR-3 (fig. 2) in John Redmond Reservoir, east-central Kansas, August 2009.—Continued

[Shading indicates concentration greater than threshold-effects guideline listed in table 4. mg/kg, milligrams per kilogram; %, percent dry weight; <, less than]

Constituent and unit of measurement	Constituent concentration			
	Interval 5	Interval 6	Interval 7	Interval 8 (top of core)
Percentage of silt and clay	99	99	99	99
Nutrients				
Total nitrogen, mg/kg	2,100	2,100	1,900	2,200
Total phosphorus, mg/kg	990	910	870	960
Carbon				
Carbon (total organic), %	1.6	1.6	1.6	1.8
Carbon (total), %	2.2	2.2	2.2	2.6
Trace elements				
Aluminum, %	9.1	9.1	8.7	8.9
Antimony, mg/kg	1.0	1.0	.9	.9
Arsenic, mg/kg	12	12	10	9.9
Barium, mg/kg	690	680	660	660
Beryllium, mg/kg	2.8	2.8	2.7	2.8
Cadmium, mg/kg	.3	.4	.4	.4
Chromium, mg/kg	55	84	81	84
Cobalt, mg/kg	16	15	15	15
Copper, mg/kg	29	29	29	29
Iron, %	4.3	4.4	4.2	4.3
Lead, mg/kg	27	26	25	27
Lithium, mg/kg	63	65	60	62
Manganese, mg/kg	940	910	820	920
Molybdenum, mg/kg	<1	<1	<1	<1
Nickel, mg/kg	39	38	36	39
Selenium, mg/kg	.7	.6	.6	.6
Silver, mg/kg	<.5	<.5	<.5	<.5
Strontium, mg/kg	210	220	230	210
Sulfur, %	.08	.10	.10	.08
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	2	3	3	3
Titanium, %	.45	.44	.44	.45
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	130	130	130	130
Zinc, mg/kg	130	130	120	130

Table A5. Percentage of silt and clay and nutrient, carbon, and trace element concentrations for bottom-sediment samples collected from coring site JR-5 (fig. 2) in John Redmond Reservoir, east-central Kansas, July 2009.

[Shading indicates concentration greater than threshold-effects guideline listed in table 4. mg/kg, milligrams per kilogram; %, percent dry weight; <, less than]

Constituent and unit of measurement	Constituent concentration	
	Interval 1 (bottom of core)	Interval 2 (top of core)
Percentage of silt and clay	98	96
Nutrients		
Total nitrogen, mg/kg	1,400	1,700
Total phosphorus, mg/kg	670	780
Carbon		
Carbon (total organic), %	1.3	1.6
Carbon (total), %	1.8	2.1
Trace elements		
Aluminum, %	7.1	7.9
Antimony, mg/kg	.9	.9
Arsenic, mg/kg	7.7	8.2
Barium, mg/kg	650	660
Beryllium, mg/kg	2.2	2.4
Cadmium, mg/kg	.3	.3
Chromium, mg/kg	67	75
Cobalt, mg/kg	14	14
Copper, mg/kg	22	26
Iron, %	3.0	3.6
Lead, mg/kg	21	23
Lithium, mg/kg	47	54
Manganese, mg/kg	500	590
Molybdenum, mg/kg	<1	<1
Nickel, mg/kg	28	32
Selenium, mg/kg	.5	.5
Silver, mg/kg	<.5	<.5
Strontium, mg/kg	200	190
Sulfur, %	.09	.07
Thallium, mg/kg	<50	<50
Tin, mg/kg	2	2
Titanium, %	.43	.44
Uranium, mg/kg	<50	<50
Vanadium, mg/kg	100	110
Zinc, mg/kg	93	110

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Bank slumping along the Cottonwood River near Plymouth, Kansas (photograph taken by Kyle Juracek, USGS).

Bank erosion along the Neosho River near Americus, Kansas (photograph taken by Kyle Juracek, USGS).

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