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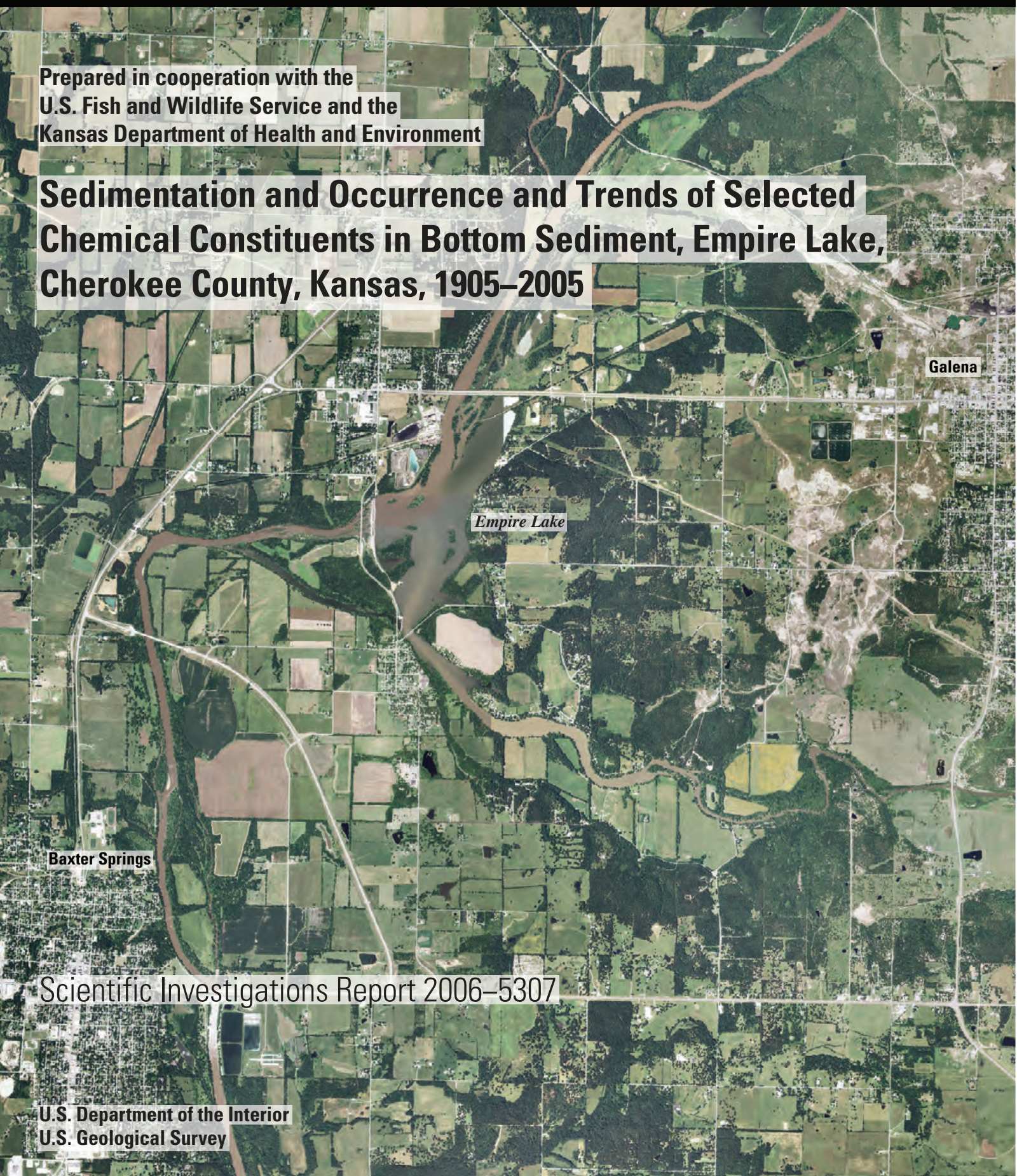
Sedimentation and Occurrence and Trends of Selected Chemical Constituents in Bottom Sediment, Empire Lake, Cherokee County, Kansas, 1905–2005



Scientific Investigations Report 2006–5307

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

Sedimentation and Occurrence and Trends of Selected Chemical Constituents in Bottom Sediment, Empire Lake, Cherokee County, Kansas, 1905–2005

By Kyle E. Juracek

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U.S. Geological Survey

U.S. Department of the Interior
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Back cover: Photographs showing sediment-thickness measurement and sediment coring operations on Empire Lake, Cherokee County, Kansas, summer 2005.

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Conversion Factors, Abbreviations, and Datum

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
foot (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
millimeter (mm)	0.03937	inch (in.)
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)
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)
gram per cubic centimeter (g/cm^3)	62.43	pound per cubic foot (lb/ft^3)
microgram per gram (µg/g)	1.0	part per million (ppm)
microgram per liter (µg/L)	1.0	part per billion (ppb)
milligram per kilogram (mg/kg)	1.0	part per million (ppm)
percent concentration	10,000	milligram per kilogram (mg/kg)
pound (lb)	0.4536	kilogram (kg)
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
Volume		
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot (ft^3)	2.296×10^{-5}	acre-foot (acre-ft)

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:

$$°C = (°F - 32) / 1.8.$$

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83).

Sedimentation and Occurrence and Trends of Selected Chemical Constituents in Bottom Sediment, Empire Lake, Cherokee County, Kansas, 1905–2005

By Kyle E. Juracek

Abstract

For about 100 years (1850–1950), the Tri-State Mining District in parts of southeast Kansas, southwest Missouri, and northeast Oklahoma was one of the primary sources of lead and zinc ore in the world. The mining activity in the Tri-State District has resulted in substantial historical and ongoing input of cadmium, lead, and zinc to the environment including Empire Lake in Cherokee County, southeast Kansas. The environmental contamination caused by the decades of mining activity resulted in southeast Cherokee County being listed on the U.S. Environmental Protection Agency's National Priority List as a superfund hazardous waste site in 1983. To provide some of the information needed to support efforts to restore the ecological health of Empire Lake, a 2-year study was begun by the U.S. Geological Survey in cooperation with the U.S. Fish and Wildlife Service and the Kansas Department of Health and Environment. A combination of sediment-thickness mapping and bottom-sediment coring was used to investigate sediment deposition and the occurrence of cadmium, lead, zinc, and other selected constituents in the bottom sediment of Empire Lake.

The total estimated volume and mass of bottom sediment in Empire Lake were 44 million cubic feet and 2,400 million pounds, respectively. Most of the bottom sediment was located in the main body and the Shoal Creek arm of the reservoir. Minimal sedimentation was evident in the Spring River arm of the reservoir. The total mass of cadmium, lead, and zinc in the bottom sediment of Empire Lake was estimated to be 78,000 pounds, 650,000 pounds, and 12 million pounds, respectively.

In the bottom sediment of Empire Lake, cadmium concentrations ranged from 7.3 to 76 mg/kg (milligrams per kilogram) with an overall median concentration of 29 mg/kg. Compared to an estimated background concentration of 0.4 mg/kg, the historical mining activity increased the median cadmium concentration by about 7,200 percent. Lead concentrations ranged from 100 to 950 mg/kg with an overall median concentration of 270 mg/kg. Compared to an estimated background concentration of 33 mg/kg, the median lead concentration was increased by about 720 percent as a result of mining activities. The range in zinc concentrations was 1,300 to 13,000 mg/kg with an overall median concentration of 4,900 mg/kg. Compared to an estimated background concentration of 92 mg/kg, the median zinc concentration was increased by about 5,200 percent. Within Empire Lake, the largest sediment concentrations of cadmium, lead, and zinc were measured in the main body of the reservoir. Within the Spring River arm of the reservoir, increased concentrations in the downstream direction likely were the result of tributary inflow from Short Creek, which drains an area that has been substantially affected by historical lead and zinc mining.

Compared to nonenforceable sediment-quality guidelines, all Empire Lake sediment samples (representing 21 coring sites) had cadmium concentrations that exceeded the probable-effects guideline (4.98 mg/kg), which represents the concentration above which toxic biological effects usually or frequently occur. With one exception, cadmium concentrations exceeded the probable-effects guideline by about 180 to about 1,400 percent. With one exception, all sediment samples had lead concentrations that exceeded the probable-effects guideline (128 mg/kg) by about 10 to about 640 percent. All sediment samples had zinc concentrations that exceeded the probable-effects guideline (459 mg/kg) by about 180 to about 2,700 percent.

Overall, cadmium, lead, and zinc concentrations in the bottom sediment of Empire Lake have decreased over time following the end of lead and zinc mining in the area. However, the concentrations in the most recently deposited bottom sediment (determined for 4 of 21 coring sites) still exceeded the probable-effects guideline by about 440 to 640 percent for cadmium, about 40 to 80 percent for lead, and about 580 to 970 percent for zinc. The decrease in concentrations primarily was characterized by a pronounced pre-1954 decline after which time the concentrations remained relatively stable.

Above-background concentrations of cadmium, lead, and zinc were measured for soil samples collected from the flood plain adjacent to the Spring River and Shoal Creek arms of Empire Lake as well as for a soil sample of the submerged flood plain in the main body of Empire Lake. For all three trace elements, concentrations in the flood-plain soil samples were similar to or larger than the threshold-effects guidelines, which represent the concentrations above which toxic biological effects occasionally occur. For the submerged flood-plain soil sample, concentrations of all three trace elements exceeded the

probable-effects guideline. Likewise, concentrations of cadmium, lead, and zinc in exceedance of the probable-effects guidelines were measured for recently deposited channel-bed sediment in the Spring River immediately downstream from Empire Lake. Thus, mining-related cadmium, lead, and zinc contamination in the vicinity of Empire Lake was not confined to the reservoir bottom sediment. Some of the contaminated sediment transported through Empire Lake will be deposited in downstream environments likely as far as Grand Lake O' the Cherokees in Oklahoma.

Introduction

The Spring River Basin drains most of the Tri-State Mining District (hereafter referred to as the Tri-State District) that includes parts of southeast Kansas, southwest Missouri, and northeast Oklahoma (fig. 1). For about 100 years (1850–1950), the Tri-State District was one of the primary sources of lead and zinc ore in the world (Brosius and Sawin, 2001). Until 1945, the area was the world's largest producer of lead and zinc concentrates, accounting for 50 percent of the zinc and 10 percent of the lead produced in the United States (Gibson, 1972). In the Kansas part of the Tri-State District, mining began with the discovery of lead and zinc ore near Galena, Kansas (fig. 1), in the 1870s and continued for about a century (Clark, 1970; Brosius and Sawin, 2001). Over time, particularly in and near the town of Galena, the landscape in parts of Cherokee County became dominated by open pits, tailings piles, and ore-smelter waste dumps. So disturbed was the landscape by mining activity in the vicinity of Galena that it came to be known as "Hell's Half Acre" (Brosius and Sawin, 2001).

Although the mining has stopped and some remediation has occurred, the legacy of contaminated sediments in the Spring River Basin, including Empire Lake, remains. The environmental contamination caused by the decades of mining activity resulted in southeast Cherokee County being listed on the U.S. Environmental Protection Agency's (USEPA) National Priority List as a superfund hazardous waste site in 1983 (U.S. Environmental Protection Agency, 2004). Authority for the establishment of superfund sites was given to USEPA through provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA; U.S. Code Title 42, Chapter 103). The provisions of this act provide a means to assess injured public natural resources through the direction and oversight of natural resource trustees. For the Cherokee County superfund site, the trustees are the U.S. Department of the Interior (DOI) as represented by the U.S. Fish and Wildlife Service (USFWS) and the State of Kansas as represented by the Kansas Department of Health and Environment (KDHE) with assistance from the Kansas Department of Wildlife and Parks. The process by which the trustees assess injured resources is known as natural resource damage assessment (NRDA) (Cherokee County Trustee Council, 2004).

CERCLA required the promulgation of regulations for NRDAs, and the responsibility for rule making was given to the DOI by Presidential Executive Order 12580 (January 23, 1987). DOI regulations and processes for conducting a NRDA are detailed in the Code of Federal Regulations Title 43, Part 11, which describes the following five major steps: (1) preassessment, (2) assessment planning, (3) injury determination and quantification, (4) pathway determination, and (5) damage determination and restoration (Cherokee County Trustee Council, 2004). The study described in this report was conducted to assist the trustees with the injury determination and quantification step of the Cherokee County superfund site NRDA.

Concern about environmental contamination in the area also was evidenced by the fact that the State of Kansas, in 2004, established a total maximum daily load (TMDL) for the Spring River Valley to address sediment and water-quality issues caused by trace element contamination (Kansas Department of Health and Environment, 2004). KDHE, as part of its 2006 fish-consumption advisories, recommended not eating shellfish (mussels, clams, and crayfish) from the Spring River (Center Creek confluence to Oklahoma State line) and Shoal Creek (Missouri State line to Empire Lake) because of cadmium and lead contamination (Kansas Department of Health and Environment, 2006).

The Spring River Basin is home to the Neosho madtom (*Noturus placidus*), a species of catfish listed as threatened under the Endangered Species Act (U.S. Fish and Wildlife Service, 1991, 2004). Although still found in the Spring River downstream from Empire Lake and in upstream reaches in Missouri, the madtom apparently has been eliminated from the Spring River immediately upstream from Empire Lake in Kansas (John Miesner, U.S. Fish and Wildlife Service, oral commun., 2003). The absence of the madtom may be attributable to habitat degradation or toxicological effects caused by increased concentrations of cadmium, lead, and zinc in water and sediment resulting from the historical mining activity (Wildhaber and others, 1998, 1999, 2000). Other species (for example, mussels) also are at risk (Angelo and others, 2005).

Historical mining activity also has affected human health. For example, Neuberger and others (1990) reported an increased occurrence of several health problems for residents of Galena, Kansas, that was attributed to mining-related contamination.

Empire Lake is a reservoir that was formed with the completion of a dam on the Spring River at Lowell, Kansas, in 1905 (Cherokee County Republican, vol. XII, no. 50, January 12, 1905) (fig. 1). Including the backwater area in the Spring River and Shoal Creek arms upstream from the main body of the reservoir, the surface area of Empire Lake is about 1 mi^2. In response to a wash out believed to have occurred in 1909, a second dam, referred to as the "bypass," was completed between the towns of Lowell and Riverton, Kansas, in 1913 (Duane Zerr, Empire District Electric Company, written commun., 2003). In this report, the original and bypass dams will be referred to as Lowell Dam and Riverton Dam, respectively. For most of its history, Empire Lake has served as a cooling lake for a coal-fired powerplant (located on the lake's west shore) that is currently (2006) owned and operated by the Empire District

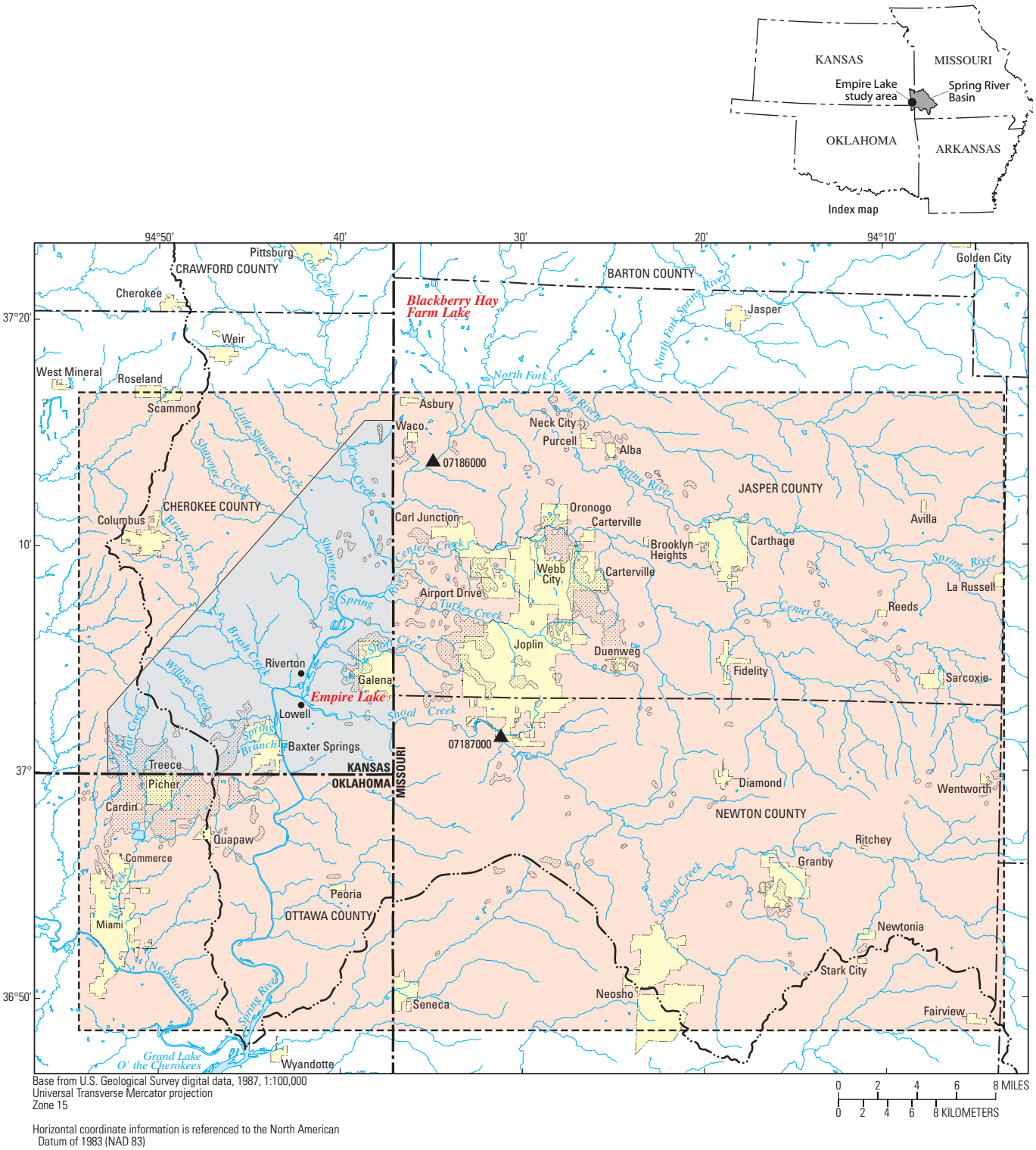


Figure 1. Location of Empire Lake, Blackberry Hay Farm Lake, the Spring River system, the Cherokee County superfund site, and lead and zinc mined areas in the Tri-State Mining District, Kansas, Missouri, and Oklahoma.

Electric Company. The lake also is used for recreation and provides habitat for fish and wildlife.

The chemical quality of sediment is an important environmental concern because sediment may act as a sink for some water-quality constituents and as a source of constituents to the overlying water column and biota (Baudo and others, 1990; Zoumis and others, 2001). Once in the food chain, sediment-derived constituents may pose an even greater concern due to bioaccumulation. Degradation of sediment quality can result from various types of human activity including mining. 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- and water-quality records and to determine a present-day baseline with which to evaluate long-term changes in reservoir sediment and water quality, which then may be related to changes in human activity in the basin.

For restoration purposes, USFWS requires several types of information including: (1) a determination of trace element concentrations in sediment in Empire Lake and the Spring River Basin; (2) a determination of the thickness, total volume, and total mass of contaminated sediment in Empire Lake; (3) an assessment of the spatial variability in trace element concentrations in sediment throughout the Spring River Basin; and (4) an assessment of the temporal variability of trace element concentrations in sediment that may reflect changes caused by human activity. Together, these types of information will be important for the prioritization, planning, and undertaking of restoration projects designed to improve the ecological health of Empire Lake and the Spring River Basin.

Previous Investigations

Several previous studies have examined the effects of lead and zinc mining on water and sediment quality in or near Empire Lake. Because of potential differences in analytical procedures, the sediment chemistry results reported for the previous studies (with the exception of Pope, 2005) may not be directly comparable with the results reported in the present study.

Barks (1977) investigated the effects of abandoned lead and zinc mines and tailings piles on water and sediment quality in the vicinity of Joplin, Missouri. Water from abandoned lead and zinc mines in the area, some of which discharges at the surface, was found to have average dissolved zinc concentrations of 9,400 µg/L. Mine-water discharges increased the dissolved zinc concentrations in receiving streams from an estimated background concentration of about 40 µg/L to about 500 µg/L during low-flow conditions. In runoff from tailings areas, dissolved zinc concentrations averaged 16,000 µg/L. Runoff from one tailings area during a summer storm contained maximum dissolved cadmium, lead, and zinc concentrations of 1,400, 400, and 200,000 µg/L, respectively. The mining activity also resulted in increased zinc concentrations in stream-bottom sediment from an estimated background concentration of about 100 µg/g to about 2,500 µg/g and increased lead concentrations in stream-bottom sediment from an estimated background concentration of about 20 µg/g to about 450 µg/g (Barks, 1977). The stream bottom-sediment samples, described as sandy, were not sieved to isolate the silt-clay fraction prior to analyses to determine trace element concentrations. Spring River tributaries sampled as part of the Barks (1977) study included Center, Short, and Turkey Creeks (fig. 1).

An extensive study of the effects of abandoned lead and zinc mines on hydrology and surface- and ground-water quality in Cherokee County, Kansas, and adjacent areas, was completed by Spruill (1987). Water from mines located mostly in the vicinity of Galena, Kansas (fig. 1) had median concentrations of 180 µg/L for dissolved cadmium, 240 µg/L for dissolved lead, and 37,600 µg/L for dissolved zinc. Of the four sampled streams that were affected by lead and zinc mining and provide flow directly or indirectly to Empire Lake (that is, Center, Shoal, Short, and Turkey Creeks; fig. 1), Short Creek had the largest concentrations of dissolved cadmium (170 µg/L) and zinc (25,000 µg/L) (Spruill, 1987).

Ferrington and others (1989) completed a study to determine the occurrence and biological effects of cadmium, lead, manganese, and zinc in the Short Creek/Empire Lake aquatic system in Cherokee County, Kansas. As part of this study, bottom sediment was sampled at multiple sites within the Spring River and Shoal Creek arms of the reservoir as well as the main body of Empire Lake. Bottom sediment throughout Empire Lake was found to have elevated concentrations of all four trace elements. The largest concentrations of cadmium, lead, and zinc were detected in two samples collected from the Spring River arm near the mouth of Short Creek (fig. 1). At this location, mean concentrations of cadmium, lead, and zinc were about 129, 1,600, and 23,000 µg/g, respectively (Ferrington and others, 1989). The bottom-sediment samples were not sieved to isolate the silt-clay fraction prior to analyses to determine trace element concentrations. Overall, the results indicated substantial transport and accumulation of sediment-associated trace elements in Empire Lake. It was concluded that the primary biological effect of large cadmium, lead, and zinc concentrations in the bottom sediment of Empire Lake was a reduction of benthic macroinvertebrate densities and, presumably, overall productivity of the reservoir system (Ferrington and others, 1989).

A study to determine concentrations of trace elements and organic compounds in sediment and biota of the Spring River Basin, including Empire Lake, was completed by the U.S. Fish and Wildlife Service (1992). As part of the study, two bottom-sediment samples were collected from a site in both the Spring River and Shoal Creek arms of the reservoir upstream from the main body of Empire Lake (fig. 2). Cadmium concentrations in the bottom sediment averaged about 26 µg/g for the sampling site in the Spring River arm and about 23 µg/g for the sampling site in the Shoal Creek arm. For lead, the respective average sediment concentrations for the Spring River and Shoal Creek sites were 165 and 230 µg/g. Average zinc concentrations in the sediment for the Spring River and Shoal Creek sites were

3,580 and 3,300 µg/g, respectively (U.S. Fish and Wildlife Service, 1992). It is uncertain if the bottom-sediment samples were sieved to isolate the silt-clay fraction prior to analyses to determine trace element concentrations.

Davis and Schumacher (1992) conducted an appraisal of surface-water quality in the Spring River Basin of southwestern Missouri and southeastern Kansas using existing water-quality data collected from the early 1960s to September 1987 by the U.S. Geological Survey (USGS) and KDHE. Results indicated that several Spring River tributaries, including Brush, Center, Cow, Turkey, and Short Creeks (fig. 1), are significantly affected by lead-zinc or coal mining. The effect of the contaminated tributaries on the water quality of the Spring River was determined through a comparison of water-quality data collected at the Spring River sampling sites located near Waco, Missouri (upstream from the tributary inflows), and Baxter Springs, Kansas (downstream from the tributary inflows) (fig. 1). Increased median concentrations of several constituents were documented including an increase for dissolved zinc from 30 to 310 µg/L. The largest single source of dissolved zinc to the Spring River was determined to be Short Creek (Davis and Schumacher, 1992).

Angelo and others (2005) investigated the effects of historical lead and zinc mining activity on mussel populations in the Spring River Basin. As part of the study, mussel species diversity, densities, and concentrations of cadmium, lead, and zinc in streambed sediment and mussel soft tissue were determined at selected sites along the Spring River and tributary streams. Mussels apparently were not present in the downstream reaches of Center, Shoal, Short, Turkey, and Willow Creeks. Also, mussel diversity and density were substantially reduced in the Spring River downstream from Center and Turkey Creeks. Angelo and others (2005) concluded that residual effects of the historical lead and zinc mining activity continue to degrade the aquatic environment and impede the recovery or establishment of viable mussel populations in much of the Kansas part of the Spring River Basin.

A study by Pope (2005) provided an assessment of streambed sediment quality along the main stem and major tributaries of both the Spring River and Tar Creek within the boundary of the Cherokee County, Kansas, superfund site (fig. 1). All sediment samples were collected to a depth of 0.8 in. and sieved to isolate the less than 0.063-mm (silt- and clay-size particles) fraction for analysis. Concentrations ranged from 0.6 to 460 mg/kg for cadmium, 22 to 7,400 mg/kg for lead, and 100 to 45,000 mg/kg for zinc, with respective median concentrations of 13, 180, and 1,800 mg/kg. The largest concentrations were measured in the Short Creek, Tar Creek, and Spring Branch Creek Basins. Proceeding downstream along the 22-mi length of the Spring River within the study area, it was determined that sediment concentrations of cadmium, lead, and zinc increased about 18, 7, and 17 times, respectively.

Current Study

A 2-year study by USGS, in cooperation with USFWS and KDHE, was begun in 2004 to investigate sedimentation in Empire Lake as well as the deposition of selected chemical constituents. This study represents phase II of a sediment study conducted by USGS. Phase I was the aforementioned assessment of sediment quality along the main stem and major tributaries of the Spring River and Tar Creek completed by Pope (2005). The specific objectives of the phase II study were to:

1. Estimate the thickness, total volume, and total mass of bottom sediment in Empire Lake;
2. Estimate the total mass of cadmium, lead, and zinc in the bottom sediment of Empire Lake;
3. Assess the spatial and temporal variability of cadmium, lead, and zinc concentrations in the bottom sediment of Empire Lake;
4. Estimate background constituent concentrations in sediment in the Spring River Basin;
5. Assess the quality of the Empire Lake bottom sediment with respect to available guidelines;
6. Relate, to the extent possible, any observed temporal trends in bottom-sediment constituent concentrations to documented changes in human activity in the Spring River Basin; and
7. Provide a baseline of information on Empire Lake conditions with which to compare future conditions that may represent a response to changes in human activity in the Spring River Basin.

The purpose of this report is to present the results of the USGS study to estimate sedimentation and to determine the occurrence of, and temporal trends in, selected chemical constituents in the bottom sediment of Empire Lake. In 2005, sediment thickness was measured at 428 sites within the reservoir. Also, 30 sediment cores were collected and analyzed for bulk density and (or) selected chemical constituents. Cadmium, lead, and zinc concentrations in the bottom sediment of Empire Lake were of primary interest in this study because they are the major contaminants input to the environment as a result of the historical mining activity. Other constituents, including additional trace elements and nutrients, were analyzed to provide a more comprehensive assessment of sediment quality in the reservoir. In this report, background constituent concentrations were defined as sediment concentrations that were minimally affected by historical lead and zinc mining.

Results presented in this report will assist USFWS in efforts to evaluate the ecological health of Empire Lake. Also, the results will assist KDHE in evaluating the implementation of existing TMDLs and in developing new TMDLs for constituents found to contribute to water-quality impairment in Empire Lake and the Spring River 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 and sediment and water quality.

Description of Spring River Basin

Empire Lake is nested within the Spring River Basin that drains about 2,500 mi^2 of southwestern Missouri, southeastern Kansas, and northeastern Oklahoma (Seaber and others, 1987) (fig. 1). Principal sources of flow into Empire Lake are the Spring River and Shoal Creek. Additionally, important tributaries to the Spring River or Empire Lake in Cherokee County, Kansas, include Center Creek, Cow Creek, Shawnee Creek, Short Creek, and Turkey Creek. Center, Short, and Turkey Creeks drain areas that have been substantially affected by historical lead and zinc mining (fig. 1).

The Spring River Basin overlaps two physiographic provinces as defined by Fenneman (1938, 1946). The southeast two-thirds of the basin is located in the Springfield Plateau Section of the Ozark Plateaus Province. This part of the basin is underlain by limestone of Mississippian age (Fenneman, 1938). The northwest one-third of the basin, including the Kansas part of the basin located west of the Spring River, is located in the Osage Plains Section of the Central Lowland Province. This part of the basin is underlain by shale with interbedded sandstone and limestone of Pennsylvanian age (Fenneman, 1938). Topographically, the basin is characterized by gently rolling uplands dissected by streams.

The lead and zinc ores in the Tri-State District occur in the cherty limestones of Mississippian age. The ores are believed to have resulted from hydrothermal (that is, hot, metal-bearing) solutions that originated from deep within the earth. As these solutions moved vertically into the porous and permeable cherty limestones, an overlying impermeable layer of shale forced them to migrate laterally. As they spread, the solutions deposited sphalerite (zinc sulfide), galena (lead sulfide), and other associated minerals (Brosius and Sawin, 2001).

Several major soil associations are present within the Spring River Basin. Soils in the Missouri part of the basin are described by Allgood and Persinger (1979). Information on soils in the Kansas part of the basin is provided by the U.S. Department of Agriculture, Soil Conservation Service (1973, 1985).

The climate in the Spring River Basin is characterized as subhumid continental (Stringer, 1972). Long-term, mean annual precipitation at Joplin, Missouri (period of record 1948–2004) averages about 42 in. (High Plains Regional Climate Center, 2005) (fig. 1).

Land use in the Spring River Basin is predominantly a mix of cropland, grassland, and woodland (Davis and Schumacher, 1992). Historically, numerous sites within the basin were mined for coal, lead, and zinc. The distribution of the major lead- and zinc-mined areas within the basin is shown in figure 1.

Acknowledgments

The author gratefully acknowledges Duane Zerr (Empire District Electric Company, Riverton, Kansas) for sharing his knowledge of the history of Empire Lake and conditions within the reservoir. Also, the author thanks John Miesner (U.S. Fish and Wildlife Service, Manhattan, Kansas) for his help in completing the sediment coring for this study.

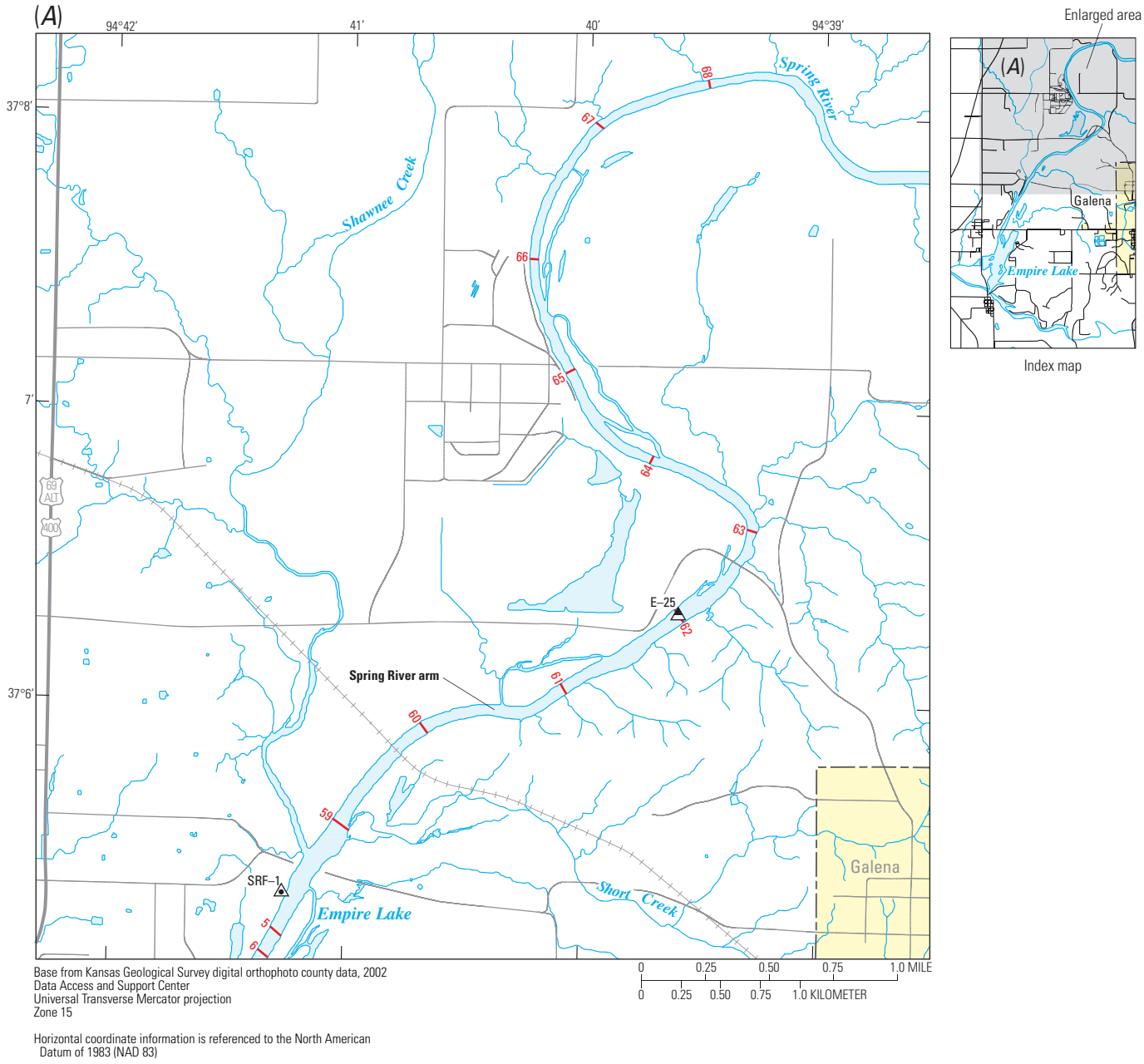
Methods

Most of the study objectives described in this report were accomplished using newly collected information. The required information for Empire Lake was obtained through the measurement of bottom-sediment thickness and the collection and analysis of bottom-sediment cores. A bottom-sediment core from nearby Blackberry Hay Farm Lake (northwest Jasper County, Missouri) was collected and analyzed to provide an indication of background constituent concentrations. Floodplain soils also were sampled and analyzed.

Measurement of Bottom-Sediment Thickness

To provide the information necessary for estimating the total volume of bottom sediment in Empire Lake, a survey was conducted to estimate bottom-sediment thicknesses throughout the reservoir. For this purpose, a series of transects were established at an approximate spacing of 500 ft within the main body of Empire Lake as well as upstream in the Spring River and Shoal Creek arms of the reservoir. Because little sediment was measured along the first several transects of the Spring River arm, the decision was made to adjust the spacing to about every 0.5 mi upstream from the Shawnee Creek confluence (fig. 2). In both the Spring River and Shoal Creek arms, the survey was extended upstream as far as boat access would allow. In both cases, a shallow gravel bar eventually was encountered that was believed to be near where the channel reverted from a backwater to a riverine environment.

Along each transect, multiple measurements of bottom-sediment thickness were made. The spacing of the measurement sites depended mostly on the length of the transect and the complexity of the lakebed topography, and occasionally on the sediment thickness encountered. Typically, the spacing was either 50 or 100 ft. Along the longer transects within the main body of Empire Lake, sediment thickness was measured at as many as 12 to 15 sites. Along the transects within the Spring River and Shoal Creek arms, sediment thickness typically was measured at five to eight sites. Sediment thickness was measured at nine sites in both area B and area P of the reservoir (fig. 2*B*). Because of restricted boat access, thickness measurements were limited to the western part of area P.



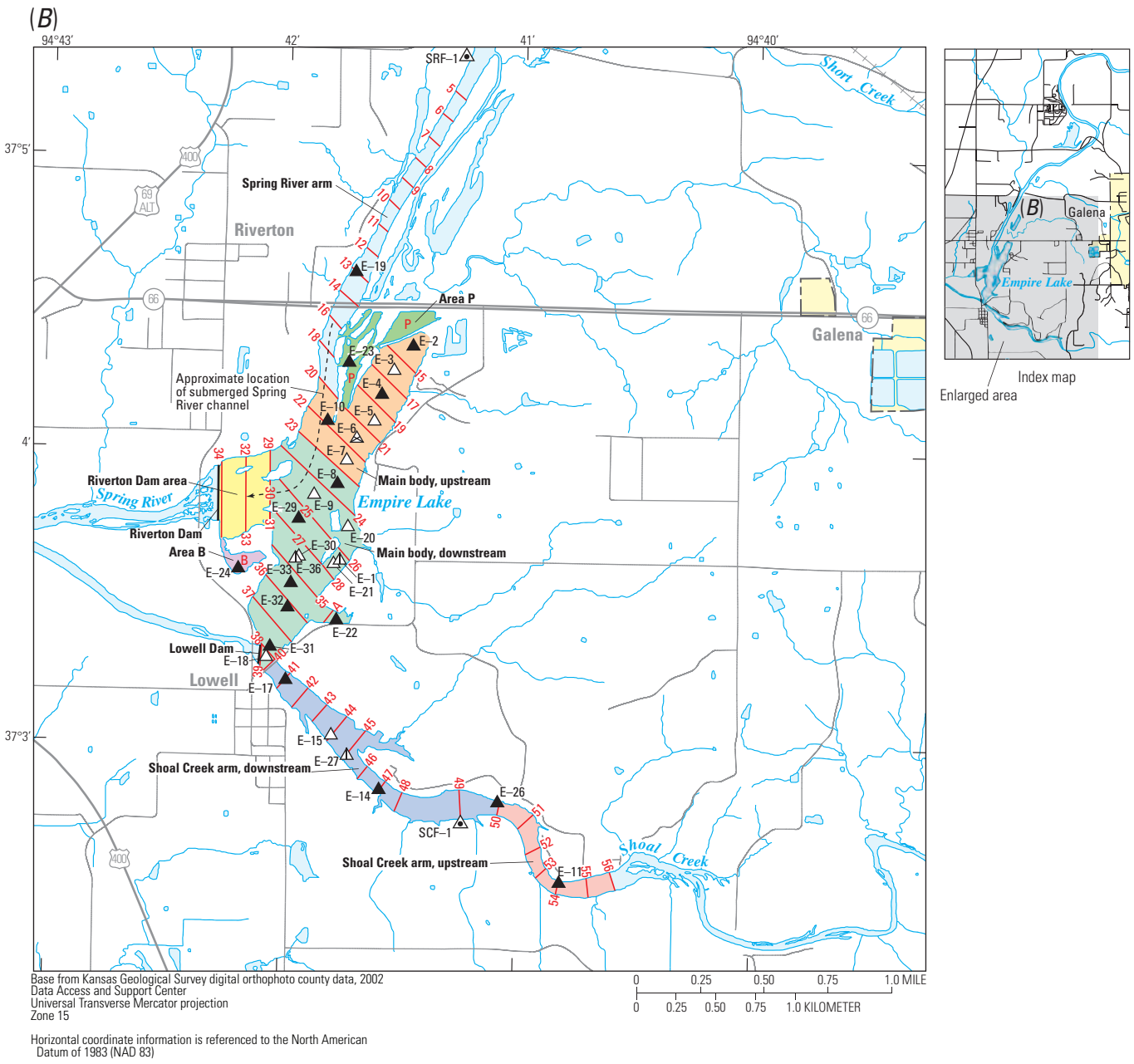
EXPLANATION

59 — **Transect line and identifier**

E–25 ▲ **Coring site and identifier—**Sample collected for chemical composite analysis

SRF–1 ▲ **Soil sampling site and identifier**

Figure 2. Location of transect lines, reservoir segments, bottom-sediment coring sites, and flood-plain soil sampling sites. Reservoir segments are shown by colored areas on map and described in table 1.



EXPLANATION

52 — **Transect line and identifier**

E–11 ▲ **Coring site and identifier**—Samples collected for bulk-density determination and chemical composite analysis

E–15 △ **Coring site and identifier**—Samples collected for bulk-density determination only

E–27 ⚠ **Coring site and identifier**—Samples collected for chemical trend analysis

E–6 ◬ **Coring site and identifier**—Samples collected for bulk-density determination and chemical trend analysis

SCF–1 ◬ **Soil sampling site and identifier**

Figure 2. Location of transect lines, reservoir segments, bottom-sediment coring sites, and flood-plain soil sampling sites. —Continued
Reservoir segments are shown by colored areas on map and described in table 1.

At each site, sediment thickness was measured using a specially designed sediment pole (designed and constructed by the College of Engineering Shops, University of Wisconsin, Madison, Wisconsin). The pole, constructed of aluminum, consists of multiple 8-ft connectable sections to accommodate surveys done in environments that vary in terms of water depth and sediment thickness. Length on the pole is marked off in increments of 0.1 ft. A light-weight polyvinyl chloride (PVC) shoe, designed to be denser than water and less dense than the bottom sediment, fits over the pole and rests on a lip at the bottom of the pole. The purpose of the shoe is to assist in detecting the sediment-water interface on the lakebed as the pole is slowly lowered from a boat. A measurement was made by lowering the pole vertically down to the lakebed and recording the water depth as indicated on the pole. Then, the pole was pushed through the sediment to refusal. The depth to refusal was recorded, and sediment thickness was estimated as refusal depth minus water depth. The latitude and longitude for each measurement site was obtained using global positioning system (GPS) technology.

Although typically readily detectable, the depth to refusal was occasionally uncertain because the sediment pole did not stop abruptly as it was pushed into the lakebed. When encountered, this situation may be indicative of a poorly defined boundary between the bottom sediment and the underlying original pre-reservoir material. At such sites the estimated sediment thickness was of uncertain accuracy. However, the mean sediment thickness along individual transects and within the segments used to estimate the total volume of sediment in the reservoir (described in the following section) was believed to be representative.

In all, bottom-sediment thickness was measured at a total of 428 sites. For each measurement site, the latitude, longitude, depth to lakebed (that is, water depth), depth to refusal, estimated sediment thickness, and descriptive notes (if any) are provided in table A1 in the "Supplemental Information" section at the back of this report.

Estimation of Bottom-Sediment Volume, Mass, and Constituent Mass

Total bottom-sediment volume (sediment plus water and gases) in Empire Lake was estimated using a partitioning approach in which the reservoir was divided into segments as determined by the location of the sediment-thickness transects (fig. 2). Segments were delineated with the primary objective being to divide the reservoir into areas of relatively uniform bottom-sediment thickness. The geographic extent of the seven segments that were established is described in table 1 and shown in figure 2.

The Spring River arm of the reservoir (located upstream from transect 20) (fig. 2*A*,*B*) was not included as a segment for bottom-sediment volume estimation because of what was interpreted to be a general lack of deposited sediment. Typically, along this arm (transects 5–14, 16, 18, 59–68), the bottom material encountered was bare gravel or rock. When fine sediment was measured, it typically was at relatively shallow sites located near the shore. The thickness of this nearshore material, when encountered, was usually substantial (table A1 at the back of this report). Given its location and thickness, the material in question was interpreted to be original channel-bank or bench material that was submerged when Empire Lake was completed. Likewise, the relatively thick sediment deposits measured in the Shoal Creek arm also may include some submerged original channel-bank or bench material at some sites.

The evidence obtained from the bottom-sediment thickness measurements indicated that the Spring River, despite the backwater imposed by Empire Lake, maintains sufficient flow velocity to prevent sediment accumulation within its channel both upstream from and through the main body of the reservoir. Downstream from transect 20, the primary flow path of the Spring River is traceable by multiple sites with zero sediment thickness located along transects 22 through 25 and 29 through 34 (fig. 2*B*, table A1).

The bottom-sediment volume for each reservoir segment was computed as the total surface area multiplied by the mean thickness of the bottom sediment. The total surface area for each segment was determined using geographic information system (GIS) software and 2002 digital orthophotos of Cherokee County, Kansas (scale: 1:12,000) (Kansas Data Access and Support Center, 2006). With two exceptions, the mean sediment thickness for each segment was computed as the weighted average of the mean sediment thicknesses for the transects that defined the boundary of, or were contained within, the segment. Transect length was used as the weighting factor. The two exceptions were areas B and P (fig. 2*B*). In these areas, mean sediment thickness was computed as the average of the individual site measurements that were not collected along transects. The segment results then were combined to provide an estimate of the total volume of bottom sediment in the reservoir.

Total bottom-sediment mass (dry weight) in Empire Lake was estimated using the same segments as described previously. For each segment, a representative bulk density was computed using the bulk densities that were determined from sediment cores (see discussion in "Physical Analyses" section). Bottom-sediment mass was computed for each segment as the bottom-sediment volume multiplied by the representative bulk density. The segment results then were combined to provide an estimate of the total mass of bottom sediment in the reservoir.

With three exceptions, the representative bulk density for each reservoir segment was computed as the average of the mean bulk densities determined for the coring sites located within the segment. For four segments (that is, two main body segments and two Shoal Creek segments), the mean bulk densities for anywhere from 2 to 11 coring sites were averaged to provide the representative bulk density. Two of the exceptions were areas B and P for which the mean bulk density for a single coring site was used as the representative bulk density. The other exception was the Riverton Dam area (fig. 2*B*), for which thin or absent sediment deposits necessitated the use of a mean bulk density from an upstream coring site (E–10, see fig. 2*B*) believed to be in a similar depositional environment.

The total mass of cadmium, lead, and zinc in the bottom sediment of Empire Lake was estimated as the median

Table 1. Description of geographic extent of reservoir segments used for the estimation of total bottom-sediment volume in Empire Lake, southeast Kansas.

Reservoir segment (fig. 2*B*)	Description of geographic extent
Shoal Creek arm (upstream)	Area between transects 50 and 56.
Shoal Creek arm (downstream)	Area between transects 40 and 50.
Main body (downstream)	Area between Lowell Dam and transects 23, 29, 30, 31, and 40.
Main body (upstream)	Area between transects 20, 23, and the shoreline upstream from transect 15.
Area B	The small pond (and connecting channel) south of Riverton Dam.
Area P	The complex backwater area located between the Spring River channel and the main body of Empire Lake.
Riverton Dam area	Area between Riverton Dam and transects 29, 30, and 31.

concentration of each trace element multiplied by the total mass of bottom sediment. The median concentrations were determined using the 19 cores used for chemical analysis that were collected within the reservoir segments used in the estimation of bottom-sediment volume and mass (fig. 2*B*). For each of the four trend cores (described in the following section), the trace element concentrations for the individual core intervals were averaged to provide a representative concentration for the core prior to the computation of the overall median using all 19 cores.

Sediment-Core Collection, Handling, and Processing

Bottom-sediment cores were collected in the spring and summer of 2005 at 30 sites (fig. 2*A*,*B*) within Empire Lake. The coring sites were located to provide a spatially representative sample of bottom sediment in the reservoir. Of the 30 cores, 9 were used for bulk-density determinations only, 4 were used for chemical analysis only, and 17 were used for both bulk-density determinations and chemical analysis (table 2). Of the 21 cores used for chemical analysis, 17 were analyzed as composite samples. Cores E–1, E–6, E–27, and E–36 were divided into intervals, sampled, and analyzed to assess trends in constituent deposition over the life of the reservoir. A sample of the original flood-plain soil at the bottom of core E–36 also was collected for chemical analysis. Additionally, a surficial soil sample was collected for chemical analysis from the Spring River (site SRF–1) and Shoal Creek (site SCF–1) flood plains (fig. 2). The soil samples were collected to a depth of about 1 in. using a polished aluminum hand trowel.

To provide an estimate of background constituent concentrations in sediment in the Spring River Basin, a reference reservoir was selected for sampling using several criteria. The reference reservoir was considered acceptable if: (1) it was located in the Spring River Basin (and in or near the Tri-State District); (2) it was located in an area underlain by Mississippian bedrock (that is, the formation that contains the lead and zinc ores); (3) there was no historical lead and zinc mining in or near the reservoir basin; (4) there was no urban land use in or near the reservoir basin; (5) the reservoir was at least 50 years old; and (6) the reservoir had boat access. No reservoir was found that satisfied all of the criteria. The available candidates were limited, in part, because few reservoirs in the Spring River Basin are located in an area underlain by Mississippian bedrock.

The reference reservoir selected, Blackberry Hay Farm Lake, satisfied all of the criteria except for the fact that it is located in an area underlain by Pennsylvanian bedrock. The reservoir is located just outside of the Tri-State District in northwest Jasper County, Missouri (fig. 1). Available information (that is, aerial photographs and topographic maps) indicated that the reservoir was completed some time between 1938 and 1954. There was no evidence of historical lead and zinc mining in its basin. One bottom-sediment core (BHF–1) was collected from this reservoir and divided into 13 intervals for sampling and chemical and trend analyses. Because the reservoir is located in an area underlain by Pennsylvanian bedrock, the constituent concentrations in the bottom sediment may provide a somewhat lower estimate of background concentrations than if the reservoir was located in an area underlain by Mississippian bedrock.

With two exceptions, bottom-sediment cores for this study were collected from a pontoon boat using a gravity corer. The exceptions were cores from sites E–23 and E–24 (fig. 2*B*) in Empire Lake, where restricted access and (or) shallow water depth dictated that the cores be collected from a smaller boat by hand driving the core liners into the reservoir bottom. 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 A2 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 that may be only about one-half of 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"

Table 2. Use of bottom-sediment cores collected from Empire Lake, southeast Kansas, 2005.

[X, analysis performed; --, analysis not performed]

Coring site number (fig. 2)	Use of bottom-sediment core		
	Bulk-density determination	Chemical composite analysis[1]	Chemical trend analysis[1]
E–1	--	--	X[2]
E–2	X	X	--
E–3	X	--	--
E–4	X	X	--
E–5	X	--	--
E–6	X	--	X[3]
E–7	X	--	--
E–8	X	X	--
E–9	X	--	--
E–10	X	X	--
E–11	X	X	--
E–14	X	X	--
E–15	X	--	--
E–17	X	X	--
E–18	X	--	--
E–19	X	X	--
E–20	X	--	--
E–21	X	--	--
E–22	X	X	--
E–23	X	X	--
E–24	X	X	--
E–25	--	X	--
E–26	X	X	--
E–27	--	--	X[4]
E–29	X	X	--
E–30	X	--	--
E–31	X	X	--
E–32	X	X	--
E–33	X	X	--
E–36	--	--	X[5]

[1]Chemical analyses performed are listed in table 3. Age dating, using cesium-137, only performed for trend cores E–27 and E–36.

[2]Three core intervals analyzed.

[3]Five core intervals analyzed.

[4]Fourteen core intervals analyzed.

[5]Fifteen core intervals analyzed.

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 (for all sites that penetration of the entire sediment thickness was achieved) indicated that core recovery was typically in the range of 70 to 90 percent. Estimated sediment thickness, length of core recovered, and estimated recovery percentage for the coring sites are provided in table A2 at the back of this report.

Upon collection, the bottom and top of each sediment core was covered with a plastic end cap that was secured to the liner with electrical tape. Both ends of each core were sealed with a chain-of-custody sticker. The sediment cores were transported to the USGS laboratory in Lawrence, Kansas, where they were stored vertically and refrigerated (at 4–5 ^{o}C) in a locked walk-in cooler. Typically, the cores were processed within 1 month after collection. 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 sediment cores. The 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, seed pods, leaves), the boundary between the sediment deposited in the reservoir and the underlying original (pre-reservoir) land-surface (or channel-bed) material was determined. Typically, the bottom sediment was characterized by higher moisture content, finer texture, and little if any visible organic matter as compared to the original material.

The number of samples 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. For composite sampling purposes, an approximately uniform volume of sediment (defined as the space occupied by the sediment particles, water, and gases as measured in cubic units) was removed from the entire length of the core, homogenized, and sampled. Plastic utensils were used for the sediment removal, homogenization, and sampling. The utensils were thoroughly cleaned with tap-water and wiped dry with a clean paper towel prior to each reuse. The sediment was homogenized in a glass bowl that also was thoroughly cleaned (as previously described) prior to each reuse. For trend analyses, a core was divided into multiple intervals of equal length. From each interval, an approximately equal volume of sediment was removed lengthwise from both halves and combined. The combined sediment volume for each interval was homogenized and sampled for subsequent chemical analyses. All samples for chemical analyses were placed in plastic jars that were labeled and sealed with a chain-of-custody sticker. The samples then were packed in ice in coolers that

were taped shut and sealed with a chain-of-custody sticker prior to shipment to other laboratories for analyses.

Physical Analyses

Physical analyses included bulk-density determinations and particle-size analyses. A total of 26 sediment cores from Empire Lake were analyzed to estimate bulk density. For this purpose, each core was divided into one to seven intervals of equal length. The number of intervals was dependent on the length of each core. From each interval, a 1-in. thick volume of sediment was removed using a putty knife, weighed to the nearest 0.10 g, oven dried at about 45 ^{o}C 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:

$$D_b = m/v, \quad (1)$$

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:

$$v = h(\pi d^2/4), \quad (2)$$

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). In all, 86 bulk-density determinations were completed at the USGS laboratory in Lawrence, Kansas (table A5 at the back of this report).

Results for all sampled intervals were averaged to compute the mean bulk density for each core. The bulk densities then were converted to pounds per cubic foot for use in subsequent computations.

Particle-size analysis was 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. The sediment samples used for chemical analyses (with the exception of core E–1) 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) and Grosbois and others (2001).

Chemical Analyses, Quality Control, and Age Dating

The sediment and soil samples were analyzed for nutrients (total nitrogen and total phosphorus), organic and total carbon, and 26 trace elements. A complete list of the constituents for which analyses were performed is provided in table 3. Prior to the chemical analyses, the sediment and soil samples were wet sieved to isolate the less than 0.063-mm fraction (that is, the silt and clay) using a 0.063-mm polyester screen held in a polycarbonate frame. The screen was replaced between samples. Chemical analyses of the sediment and soil samples were performed at the USGS Sediment Trace Element Partitioning Laboratory in Atlanta, Georgia. Chain-of-custody procedures were followed at the laboratory during sample storage, processing,

Table 3. Chemical analyses performed on bottom-sediment samples from Empire Lake, southeast Kansas, Blackberry Hay Farm Lake, southwest Missouri, and soil samples from the Spring River and Shoal Creek flood plains, southeast Kansas, 2005.

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

Nutrients			
Total nitrogen (100 mg/kg)	Total phosphorus (50 mg/kg)		
Carbon			
Carbon, total organic (TOC) (0.1%)	Carbon, total (0.1%)		
Trace elements			
Aluminum (0.1%)	Cobalt (1.0 mg/kg)	Molybdenum (1.0 mg/kg)	Tin (1.0 mg/kg)
Antimony (0.1 mg/kg)	Copper (1.0 mg/kg)	Nickel (1.0 mg/kg)	Titanium (0.01%)
Arsenic (0.1 mg/kg)	Iron (0.1%)	Selenium (0.1 mg/kg)	Uranium (50 mg/kg)
Barium (1.0 mg/kg)	Lead (1.0 mg/kg)	Silver (0.5 mg/kg)	Vanadium (1.0 mg/kg)
Beryllium (0.1 mg/kg)	Lithium (1.0 mg/kg)	Strontium (1.0 mg/kg)	Zinc (1.0 mg/kg)
Cadmium (0.1 mg/kg)	Manganese (10.0 mg/kg)	Sulfur (0.1%)	
Chromium (1.0 mg/kg)	Mercury (0.01 mg/kg)	Thallium (50 mg/kg)	
Radionuclides			
Cesium-137 (0.05 pCi/g)[1]	Lead-210 (0.1 pCi/g)[1]		

[1]For cesium-137 and lead-210, a minimum detection concentration (MDC), rather than a method reporting limit, is reported. The MDC reported may vary because of several factors including the size of the sample.

and analysis. Analyses of sediment and soil samples 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).

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 Empire Lake as well as an analysis of standard reference samples. Split-replicate samples were analyzed for seven bottom-sediment-cores (E–2, E–8, E–10, E–14, E–19, E–22, and E–24). For each core, a representative volume of sediment was removed, homogenized, and sampled twice to provide the split-replicate samples. Both samples were analyzed for all constituents. The relative percentage difference (RPD) was computed as the absolute value of the difference in the replicate analyses divided by the mean and expressed as a percentage.

The RPDs computed for the constituents detected in the split-replicate samples are provided in table 4. A target goal for variability among analyses of split-replicate samples was a RPD of $\pm$20 percent except when constituent concentrations were near or less than method reporting limits. With the exception of total nitrogen, manganese, molybdenum, selenium, and silver, analytical variability was minimal with mean RPDs less than 10 percent. Total nitrogen, manganese, molybdenum, selenium, and silver had mean RPDs of 27.5, 11.7, 16.7, 45.7, and 20.5 percent, respectively.

Results for the analysis of standard reference samples are provided in table A3 in the "Supplemental Information" section at the back of this report. A target goal for acceptable results of analysis of reference samples was within published limits for each constituent for each standard or $\pm$10 percent of the most probable value for the constituent (whichever was greater), except when constituent concentrations were near or less than method reporting limits. Of the 578 results presented in table A3, analytical precision could not be determined for 168 results typically because either the reference sample concentration had not been determined for the constituent in question or it was near or less than the method reporting limit. Of the remaining 410 results, about 93 percent met the target goal as previously defined.

Age dating of the bottom sediment was accomplished by determining the activity of cesium-137 (^{137}Cs). ^{137}Cs is a radioactive isotope that is a by-product 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, 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 Empire Lake trend cores E–27 and E–36 (fig. 2*B*) and for Blackberry Hay Farm Lake (fig. 1) trend core BHF–1. Although analyzed, lead-210 (^{210}Pb) was not used for age-dating purposes because requisite assumptions (constant rate of supply of ^{210}Pb and constant sedimentation rate) were violated for Empire Lake and typically are violated for reservoirs in general (Van Metre and others, 2004). Analysis of sediment samples for ^{137}Cs and ^{210}Pb activity was performed at the USGS National Water-Quality Laboratory in Denver, Colorado, using gamma-ray spectrometry (American Society for Testing and Materials, 2004). The ^{137}Cs and ^{210}Pb activities for trend cores E–27, E–36, and BHF–1 are provided in table A4 in the "Supplemental Information" section at the back of this report.

Trend Analysis

Three sediment cores (E–6, E–27, and E–36) collected from Empire Lake and one sediment core (BHF–1) collected from Blackberry Hay Farm Lake were used for chemical trend analyses. The cores were analyzed for nutrients, carbon, and trace elements (table 3). Temporal trends in constituent concentrations (versus depth in the sediment profile) were examined 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). Temporal trends were considered to be significantly positive (constituent concentration increased toward the top of the sediment core) or negative (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. In the results, a possible temporal trend will be considered meaningful only if the change in constituent concentration is 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).

Sediment-Quality Guidelines and Background Information for Chemical Constituents Selected for Study

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 (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

Table 4. Relative percentage differences for constituent concentrations in split-replicate samples from bottom-sediment cores from Empire Lake, southeast Kansas, 2005.

[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							
	Site E–2	Site E–8	Site E–10	Site E–14	Site E–19	Site E–22	Site E–24	Mean
Nutrients								
Total nitrogen	46.2	66.6	12.8	66.6	0	0	0	27.5
Total phosphorus	18.0	2.8	0	7.6	3.0	12.4	6.4	7.2
Carbon								
Carbon (total organic, TOC)	6.4	0	4.6	0	0	0	6.4	2.5
Carbon (total)	16.2	0	13.4	5.2	5.4	0	0	5.7
Trace elements								
Aluminum	7.2	5.6	5.2	2.0	0	11.0	0	4.4
Antimony	0	0	0	0	0	0	0	0
Arsenic	0	3.4	3.6	6.6	0	9.8	3.6	3.9
Barium	8.8	1.8	4.0	1.8	2.0	5.2	2.0	3.7
Beryllium	13.4	4.4	5.2	5.2	0	11.2	6.4	6.5
Cadmium	4.4	2.4	10.6	3.6	0	10.6	4.0	5.1
Chromium	16.6	4.6	1.4	1.6	4.6	10.0	5.4	6.3
Cobalt	10.0	0	12.6	8.0	0	17.2	0	6.8
Copper	6.2	2.6	3.8	3.8	0	8.0	0	3.5
Iron	10.6	7.4	7.6	5.2	4.2	10.0	0	6.4
Lead	0	6.0	11.2	0	0	6.0	0	3.3
Lithium	0	5.8	10.0	3.2	2.8	10.2	0	4.6
Manganese	4.6	1.4	11.4	15.6	34.2	10.2	4.8	11.7
Molybdenum	--	0	--	0	66.6	0	--	16.7
Nickel	13.4	4.2	7.4	4.0	4.0	13.6	0	6.7
Selenium	100	85.8	11.8	33.4	33.4	33.4	22.2	45.7
Silver	--	--	--	18.2	25.0	18.2	--	20.5
Strontium	6.6	2.6	2.6	0	1.2	2.6	1.2	2.4
Sulfur	9.8	0	6.8	8.6	0	8.0	4.4	5.4
Thallium	--	--	--	--	--	--	--	--
Tin	0	0	0	0	28.6	40.0	0	9.8
Titanium	10.0	4.2	6.2	0	0	6.2	4.4	4.4
Uranium	--	--	--	--	--	--	--	--
Vanadium	10.8	2.4	6.2	0	0	9.2	1.6	4.3
Zinc	16.6	1.2	0	2.0	4.4	14.4	0	5.5

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 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 SQGs indicated that the differences were generally small (table 5). The largest difference was for the zinc PEL and PEC. In this case, the PEC (459 mg/kg) was about 69 percent larger than the PEL (271 mg/kg). For this study, the 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 (table 5). In this report, the options used to assess sediment quality are referred to as the threshold-effects guideline and the probable-effects guideline.

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). If phosphorus concentrations are too large, algal growth may become excessive. Such eutrophic conditions can cause taste-and-odor problems for water suppliers. Additionally, excessive algal growth may be detrimental to aquatic life in, as well as discourage 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 because many contaminants specifically sorb to organic material (Karickhoff, 1984).

Trace Elements

Trace elements are important determinants of sediment quality because of their potential toxicity to living organisms (Forstner and Wittman, 1981). Trace elements may be defined as elements that typically are found in the environment in relatively small (less than 0.1 percent) concentrations (Adriano, 1986; Pais and Jones, 1997). Using this definition, the majority 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, 1986).

Table 5. Sediment-quality guidelines (SQGs) for selected trace elements and associated bioaccumulation index.

[Values in milligrams per kilogram. 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]

Trace element	USEPA (1997)		MacDonald and others (2000)		Bio-accumulation index[1]
	TEL	PEL	TEC	PEC	
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
Mercury	.13	.696	.18	1.06	high
Nickel	15.9	42.8	22.7	48.6	moderate
Silver	.733	1.77	--	--	moderate
Zinc	124	271	121	459	high

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

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, 1986).

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 (Adriano, 1986; Lide, 1993; Pais and Jones, 1997).

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). Information on the bioaccumulation index (Pais and Jones, 1997) for trace elements with available SQGs is provided in table 5.

Bottom-Sediment Volume and Mass

The total volume of bottom sediment in Empire Lake was estimated by partitioning the reservoir into segments, computing bottom-sediment volume separately for each segment, and then summing all segment results. The total estimated volume of bottom sediment in Empire Lake was 44 million ft^3 or about 1,000 acre-ft. Table 6 provides the estimated surface area, mean bottom-sediment thickness, and computed bottom-sediment volume for each reservoir segment. The mean bottom-sediment thickness along each transect for which bottom-sediment thickness was measured is provided in figure 3.

Bottom-sediment mass for each reservoir segment was estimated as the computed bottom-sediment volume multiplied by the representative bulk density of the sediment. Bulk densities, estimated at 26 sites in the reservoir, ranged from a mean of 38.4 lb/ft^3 for core samples from site E–11 to a mean of 64.6 lb/ft^3 for core samples from site E–30 (fig. 4). A complete listing of the bulk-density estimate(s) for all 26 sediment cores is provided in table A5 in the "Supplemental Information" section at the back of this report.

The total mass of bottom sediment in Empire Lake, estimated as the sum of the sediment mass computed for the individual reservoir segments, was 2,400 million lb. Table 7 provides the estimated bottom-sediment volume, representative bulk density, and computed bottom-sediment mass for each reservoir segment.

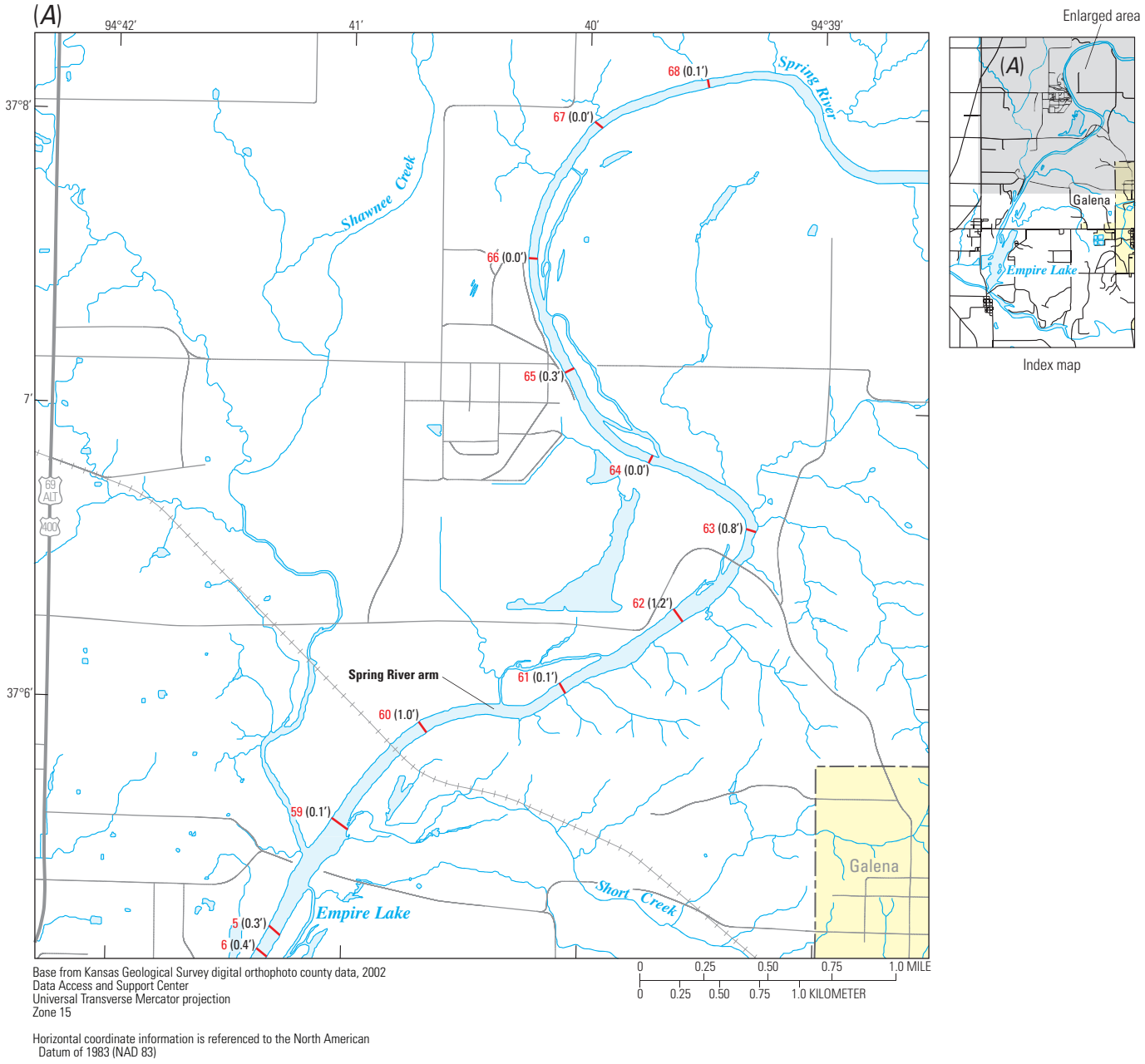
A particle-size analysis was performed to determine the percentage of sand (that is, particles larger than 0.063 mm in diameter) and silt and (or) clay (that is, particles smaller than 0.063 mm in diameter) in the sediment cores. Particle-size analyses were completed for 20 cores (that is, every core for which chemical analyses were performed with the exception of core E–1). Overall, the silt and (or) clay content of the sediment ranged from 76 percent (composite core E–10) to 98 percent (trend core E–36) with a mean of 92 percent. For each of the four trend cores (E–1, E–6, E–27, and E–36), the percentage of silt and (or) clay for the individual intervals was averaged to provide a representative percentage for the core prior to the computation of the overall mean using all 20 cores. The

Table 6. Estimated surface area, mean bottom-sediment thickness, and computed bottom-sediment volume in segments of Empire Lake, southeast Kansas, July and August 2005.

[The computed bottom-sediment volume for each segment has been rounded to three significant figures. The total bottom-sediment volume has been rounded to two significant figures.]

Reservoir segment (table 1, fig. 2*B*)	Estimated surface area (square feet)	Mean bottom-sediment thickness (feet)	Computed bottom-sediment volume[1] (cubic feet)
Shoal Creek arm (upstream)	1,150,000	1.8	2,070,000
Shoal Creek arm (downstream)	3,070,000	4.1	12,600,000
Main body (downstream)	6,140,000	3.2	19,600,000
Main body (upstream)	3,640,000	1.7	6,190,000
Area B	279,000	.9	251,000
Area P	971,000	3.7	3,590,000
Riverton Dam area	1,590,000	.1	159,000
Total for reservoir			44,000,000

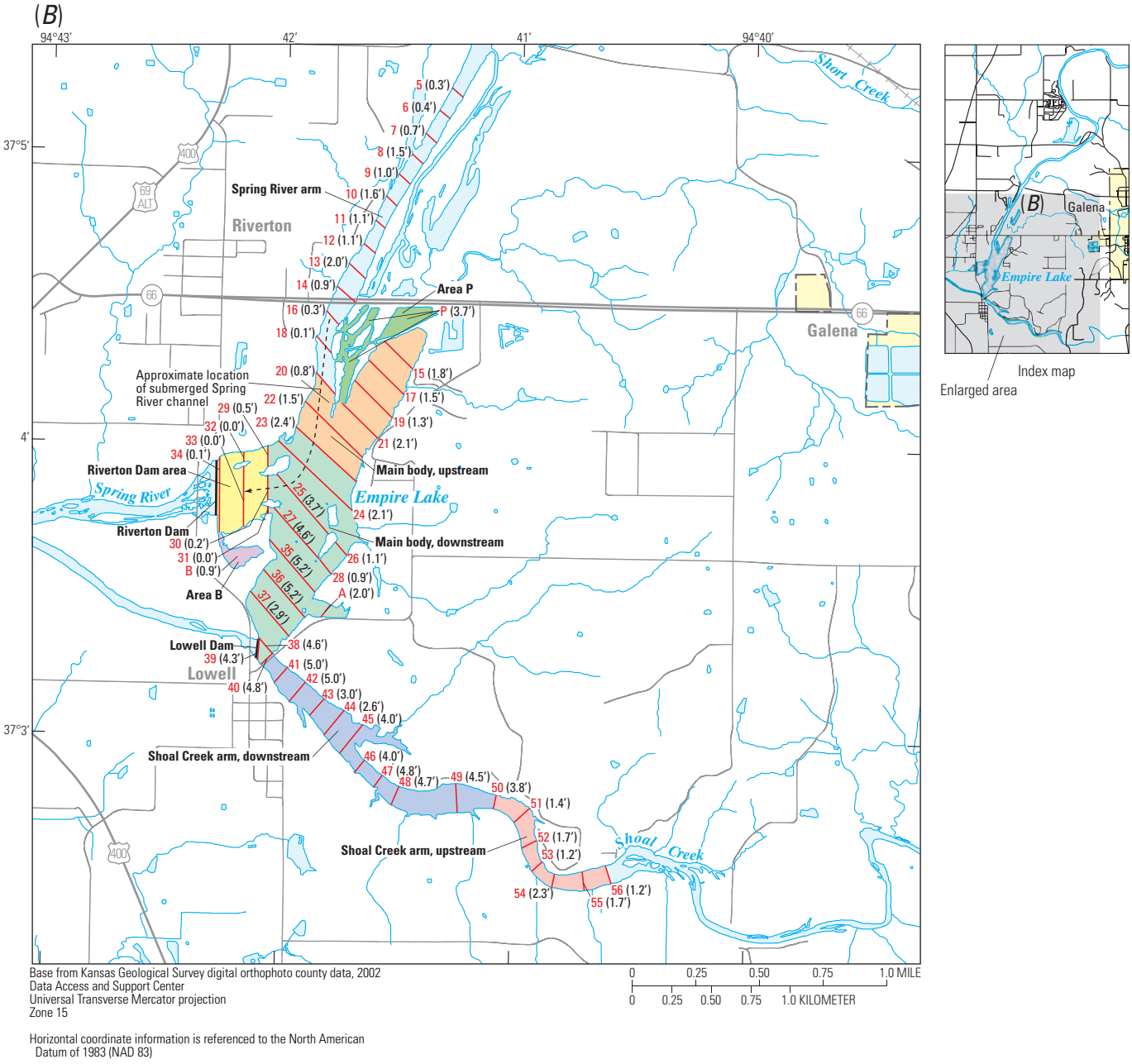
[1]Bottom-sediment volume is computed as estimated surface area multiplied by mean bottom-sediment thickness.



EXPLANATION

59 (0.1′) —— **Transect line and identifier—**Number in parentheses ( ) is mean bottom-sediment thickness, in feet

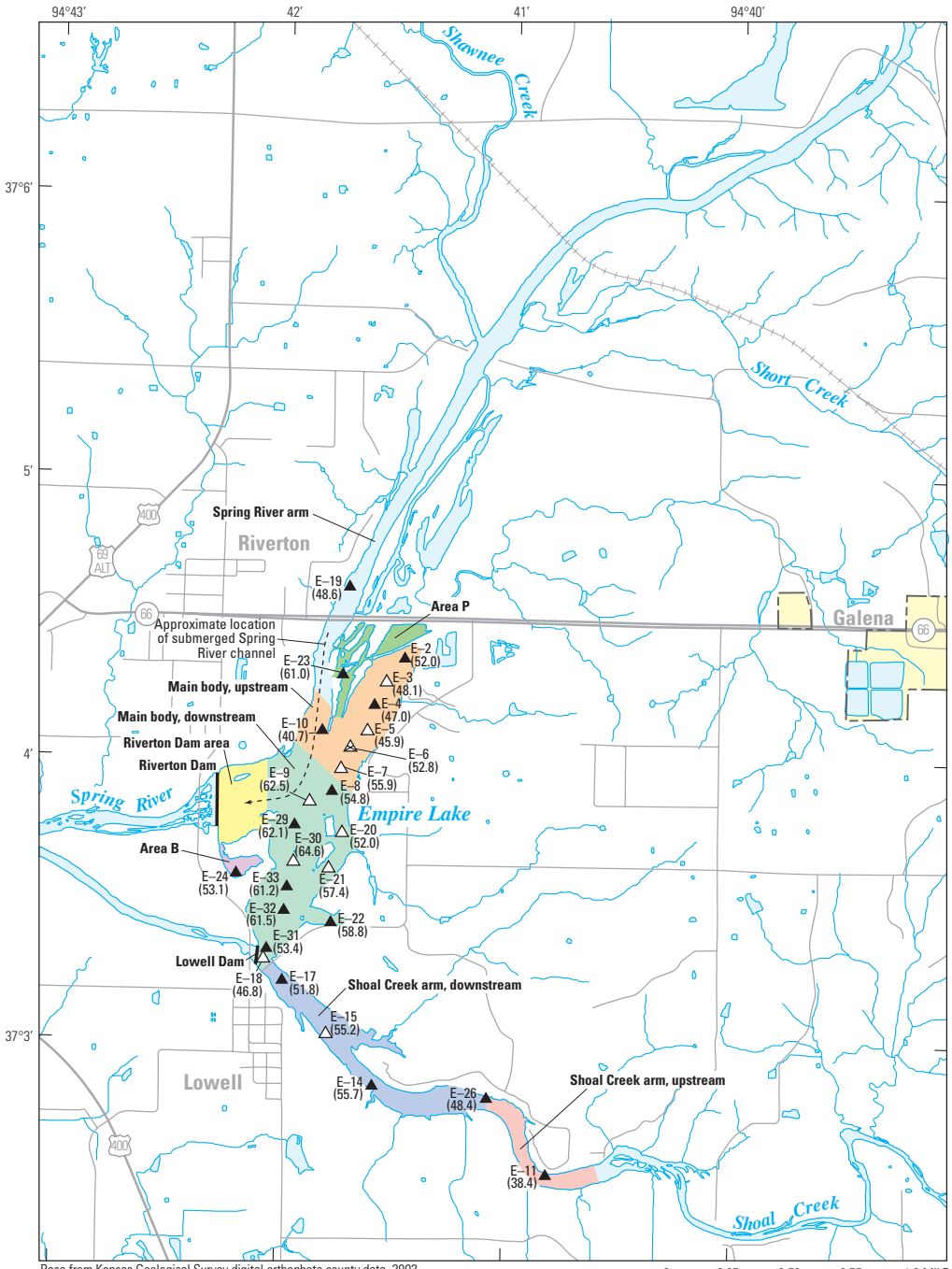
Figure 3. Mean bottom-sediment thickness along transects, and within two areas, of Empire Lake, July and August 2005. Reservoir segments are shown by colored areas on map and described in table 1.



EXPLANATION

54 (2.3′) —— **Transect line and identifier—**Number in parentheses ( ) is mean bottom-sediment thickness, in feet

Figure 3. Mean bottom-sediment thickness along transects, and within two areas, of Empire Lake, July and August 2005.—Continued
Reservoir segments are shown by colored areas on map and described in table 1.



Base from Kansas Geological Survey digital orthophoto county data, 2002
Data Access and Support Center
Universal Transverse Mercator projection
Zone 15

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

EXPLANATION

E–15 (55.2) △ **Bulk-density coring site and identifier—**Bulk-density determination only. Number in parentheses ( ) is computed mean bulk density, in pounds per cubic foot

E–11 (38.4) ▲ **Composite coring site and identifier—**Bulk-density determination and chemical composite analysis. Number in parentheses ( ) is computed mean bulk density, in pounds per cubic foot

E–6 (52.8) ◬ **Trend coring site and identifier—**Bulk-density determination and chemical trend analysis. Number in parentheses ( ) is computed mean bulk density, in pounds per cubic foot

Figure 4. Estimated mean bulk density of bottom sediment at coring sites in Empire Lake, 2005. Reservoir segments are shown by colored areas on map and described in table 1.

Table 7. Computed bottom-sediment volume, representative bulk density, and computed bottom-sediment mass in segments of Empire Lake, southeast Kansas, July and August 2005.

[The computed bottom-sediment mass for each segment has been rounded to three significant figures. The total bottom-sediment mass has been rounded to two significant figures.]

Reservoir segment (table 1, fig. 2*B*)	Computed bottom-sediment volume (cubic feet)	Representative bulk density (pounds per cubic foot)	Computed bottom-sediment mass[1] (pounds)
Shoal Creek arm (upstream)	2,070,000	43.4	89,800,000
Shoal Creek arm (downstream)	12,600,000	52.8	665,000,000
Main body (downstream)	19,600,000	57.7	1,130,000,000
Main body (upstream)	6,190,000	48.9	303,000,000
Area B	251,000	53.1	13,300,000
Area P	3,590,000	61.0	219,000,000
Riverton Dam area	159,000	40.7	6,470,000
Total for reservoir			2,400,000,000

[1]Bottom-sediment mass is computed as estimated bottom-sediment volume multiplied by representative bulk density.

particle-size data for Empire Lake is provided in tables A7 through A13 in the "Supplemental Information" section at the back of this report.

Age-Dating Results and Implications for Sediment Transport and Deposition

Age dating of the bottom sediment in Empire Lake was accomplished by determining the activity of ^{137}Cs in trend cores E–27 and E–36. For core E–27 (fig. 5*A*), the absence of ^{137}Cs activity in the lower (older) part of the core (intervals 1 through 9) indicated pre-1954 (date approximate) sediment that was deposited prior to atmospheric fallout of ^{137}Cs. The ^{137}Cs activity measured for the upper (most-recent) part of the core (intervals 10 through 14) indicated post-1954 sediment. The relatively uniform ^{137}Cs activity in the upper part of the core may be accounted for by two possible explanations. One possibility is that the upper part of the core provides a complete record of sediment deposition since 1954. However, the lack of a well-defined 1963–64 peak is indicative of substantial postdepositional mixing (possible causes include wave action and bioturbation). A second possibility is that the upper part of the core only represents sediment deposition that post-dates the 1963–64 peak. In other words, part of the depositional record at this location may have been removed (for example, by one or more floods). Given the relatively low level of ^{137}Cs activity measured (compared to core BHF–1 from nearby Blackberry Hay Farm Lake, fig. 5*C*), the second possibility was considered more likely.

For core E–36 (fig. 5*B*), the absence of ^{137}Cs activity throughout most of the core (intervals 1 through 14) indicated pre-1954 sediment. Only the top (most-recent) interval had measureable ^{137}Cs activity. At this location, it appears that most of the post-1954 sediment either was not deposited or was deposited and subsequently removed. Given the relatively shallow water depth at this location (about 4 ft, table A2 at the back of this report), it is possible that historic sediment deposition at this location only occurred until a threshold water depth was reached after which little additional deposition of fine-grained sediment particles was possible (that is, flow currents and wind-induced turbulence kept the sediment in suspension until it was transported out of the reservoir). If suspended sediment is uniformly distributed and settles vertically, sediment deposition is directly proportional to water depth (Morris and Fan, 1998). Additional evidence in support of the interpretation that a substantial amount of sediment was transported through Empire Lake was the elevated concentrations of cadmium, lead, and zinc in recently deposited channel-bed sediment of the Spring River immediately downstream from Empire Lake (Pope, 2005).

As evidenced by the ^{137}Cs results for cores E–27 (fig. 5*A*) and E–36 (fig. 5*B*), the bottom sediment in Empire Lake does not appear to provide a complete and undisturbed record of sediment deposition over the life of the reservoir. This contention is based on the fact that the ^{137}Cs profile for both cores lacked a well-defined peak followed by a uniform, exponential decrease. Also, the limited relative thickness of post-1954 sediment in both cores, compared to the thickness of pre-1954 sediment, indicated that post-1954 sediment is underrepresented in the reservoir. Finally, it is uncertain to what extent the sediment (pre- and post-1954) has been mixed. For these reasons, any trends in constituent concentrations for these two cores likely are not representative of changes that occurred over the entire history of the reservoir.

On the basis of the ^{137}Cs evidence, it appears that the sediment trap efficiency of Empire Lake has decreased over the life of the reservoir. This is the expected consequence as water-storage capacity is lost because of sedimentation (Morris and Fan,

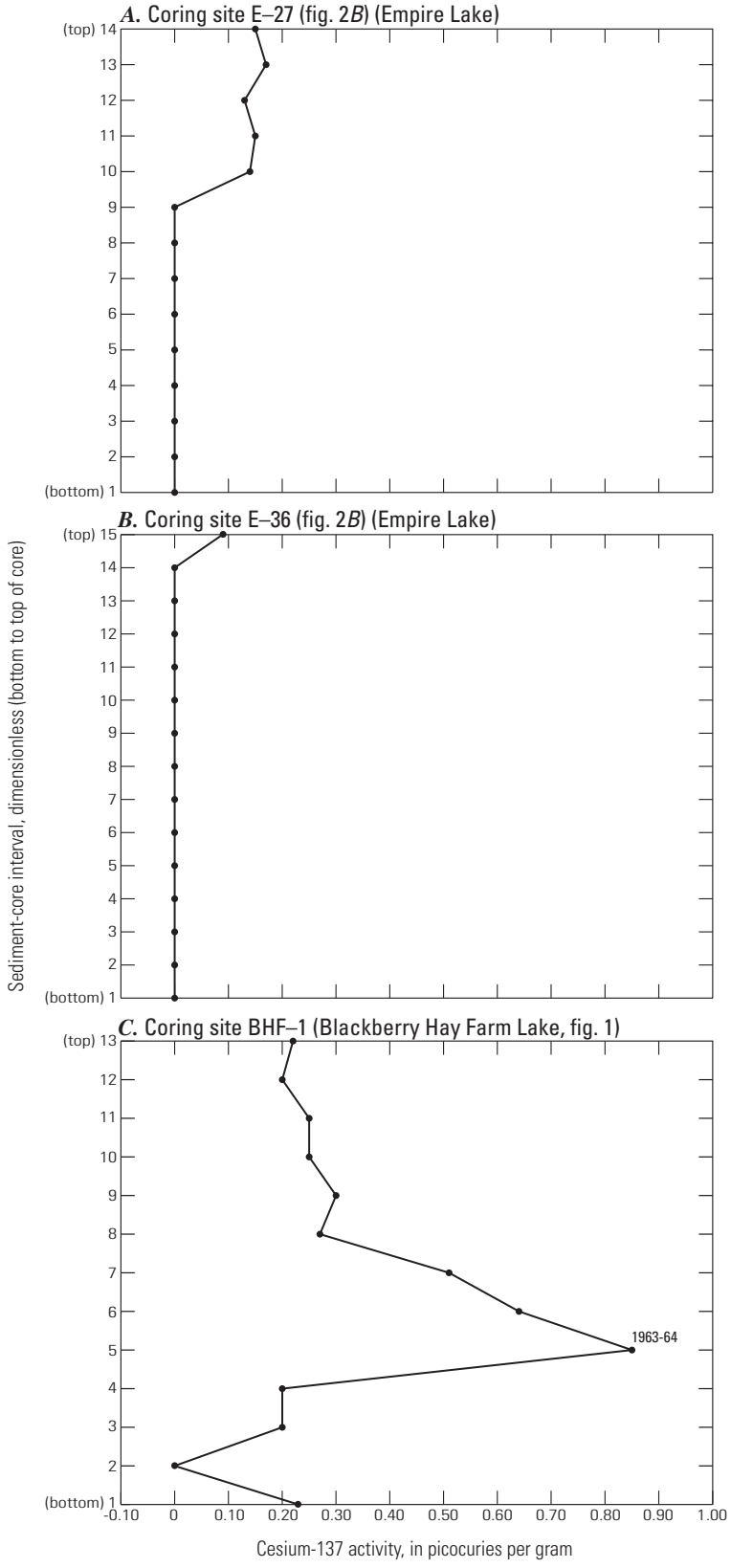


Figure 5. Variation in cesium-137 activity with depth of bottom-sediment samples collected from coring sites E–27 and E–36 in Empire Lake, southeast Kansas, and coring site BHF–1 in Blackberry Hay Farm Lake, southwest Missouri, September 2005.

1998). During low-inflow periods, some sediment deposition may occur in Empire Lake. However, during high-inflow periods, most of the suspended-sediment load may be transported through the reservoir and deposited downstream. Also, the turbulence caused by the high inflows likely resuspends and transports some of the previously deposited sediment in the reservoir. Thus, during high-inflow periods, Empire Lake may be a net source of sediment.

In contrast, the ^{137}Cs profile for Blackberry Hay Farm Lake core BHF–1 (fig. 5*C*) had a well-defined peak followed by a generally uniform exponential decrease. Because this core indicated relatively undisturbed bottom sediment, any constituent trends may be considered representative of changes that occurred over the entire history of the reservoir.

Occurrence of, and Trends in, Selected Chemical Constituents

This section describes the occurrence of, and trends in, selected chemical constituents in bottom-sediment samples collected from Empire Lake and Blackberry Hay Farm Lake (fig. 1). Additionally, sediment quality is assessed with reference to available SQGs for the trace elements. Throughout this section it is important to keep in mind that any indicated trends in constituent concentrations in the bottom sediment of Empire Lake likely are not representative of changes that occurred over the entire history of the reservoir, as evidenced by the ^{137}Cs results for trend cores E–27 (fig. 5*A*) and E–36 (fig. 5*B*).

Nutrients and Total Organic Carbon

Total nitrogen concentrations in the Empire Lake composite cores ranged from 1,000 to 2,500 mg/kg with most concentrations either 1,000 or 2,000 mg/kg (tables A7, A9, A10, and A11 at the back of this report). The trend cores indicated minimal variability in total nitrogen concentrations over time with a typical concentration of 1,200 mg/kg for core E–1 (table A6 at the back of this report) and 2,000 mg/kg for cores E–6, E–27, and E–36 (tables A8, A12, and A13 at the back of this report). Likewise, for Blackberry Hay Farm Lake, trend core BHF–1 indicated minimal variability in total nitrogen over time with concentrations consistently at or near 1,000 mg/kg (table A14 at the back of this report).

Total phosphorus concentrations in the Empire Lake composite cores ranged from 610 to 1,200 mg/kg (tables A7, A9, A10, and A11). Similarly, total phosphorus concentrations in the trend cores ranged from 550 to 1,300 mg/kg (tables A6, A8, A12, and A13). Trend cores E–1 (table A6) and E–36 (table A13) indicated relatively uniform total phosphorus concentrations over time. However, for trend cores E–6 (table A8) and E–27 (table A12), a possible positive trend was indicated. In the case of core E–27, the trend was statistically significant (Spearman's rho = 0.65, two-sided p-value = 0.011). Examination of the concentration profile for core E–27 indicated that the increase in total phosphorus was confined to the top (most-recent) one-fourth of the core. For Blackberry Hay Farm Lake, total phosphorus concentrations ranged from 280 to 690 mg/kg in trend core BHF–1 (table A14). A statistically significant positive trend also was indicated for this core (Spearman's rho = 0.76, two-sided p-value = 0.003). Again, the increase in total phosphorus was confined to the top (most-recent) one-fourth of the core. The increased total phosphorus at the top of cores E–27 and BHF–1 does not appear to be due to analytical variance as the concentrations are not within 10 percent of the mean concentration for each core.

TOC in the Empire Lake composite cores ranged from 1.4 to 2.3 percent with most cores (12 of 17) having a TOC content of 1.6 to 1.8 percent (tables A7, A9, A10, and A11). Similarly, TOC in the trend cores ranged from 1.3 to 2.4 percent (tables A6, A8, A12, and A13). Trend cores E–1 (table A6) and E–27 (table A12) indicated relatively uniform TOC content over time. However, for trend cores E–6 (table A8) and E–36 (table A13), a possible negative trend was indicated. The trend for core E–6 was statistically significant (Spearman's rho = -0.97, two-sided p-value = 0.005). However, this trend was not considered to be meaningful as it could be explained by analytical variance. The trend for core E–36 also was statistically significant (Spearman's rho = - 0.81, two-sided p-value = 0.0003). Examination of the concentration profile for core E–36 indicated that, with the exception of the bottom (oldest) core interval and the top (most-recent) two core intervals, the trend could be explained by analytical variance. Thus, this trend may not be meaningful. For Blackberry Hay Farm Lake, trend core BHF–1 indicated minimal variability in TOC over time with concentrations ranging from 0.9 to 1.3 percent (table A14).

Cadmium

The Empire Lake composite cores had cadmium concentrations that ranged from 7.3 mg/kg for core E-25 to 72 mg/kg for core E–29 (tables 8, A7, A9, A10, and A11). For the trend cores E–1, E–6, E–27, and E–36, cadmium concentrations for the sampled intervals ranged from 18 to 76 mg/kg (tables 8, A6, A8, A12, and A13). Overall, using the cadmium concentrations for all 17 composite cores and the mean cadmium concentrations for the four trend cores (fig. 6), the respective mean and median cadmium concentrations for the Empire Lake sediment cores were 35 and 29 mg/kg. Using the median cadmium concentration for the 19 cores used for chemical analysis that were collected within the reservoir segments used in the estimation of bottom-sediment volume and mass (that is, 32 mg/kg), the total mass of cadmium in the Empire Lake bottom sediment was estimated to be 78,000 lb.

To provide an indication of the effects of the historical lead and zinc mining on trace element concentrations in the bottom sediment of Empire Lake, the median concentrations were compared to background conditions as represented by the median concentrations in core BHF–1 collected from Blackberry Hay

Table 8. Summary of cadmium, lead, and zinc concentrations in bottom-sediment samples collected from Empire Lake composite and trend cores, southeast Kansas, and Blackberry Hay Farm Lake trend core BHF–1, southwest Missouri, 2005.

[mg/kg, milligrams per kilogram]

Trace element	Empire Lake			Blackberry Hay Farm Lake	
	Range in concentrations for composite cores[1] (fig. 2)	Range in concentrations for trend cores[2] (fig. 2)	Median concentration[3]	Range in concentrations for trend core BHF–1	Median concentration[4]
Cadmium, mg/kg	7.3–72	18–76	29	0.1–0.5	0.4
Lead, mg/kg	100–950	170–730	270	24–40	33
Zinc, mg/kg	1,300–11,000	3,100–13,000	4,900	38–120	92

[1]Seventeen composite cores analyzed.

[2]Four trend cores (37 core intervals) analyzed.

[3]Median concentration computed using the trace element concentrations for the 17 composite cores and the mean trace element concentrations for the 4 trend cores.

[4]Median concentration computed for 13-interval trend core BHF–1.

Farm Lake (fig. 1). The median cadmium concentration in core BHF–1 was 0.4 mg/kg (tables 8, A14).

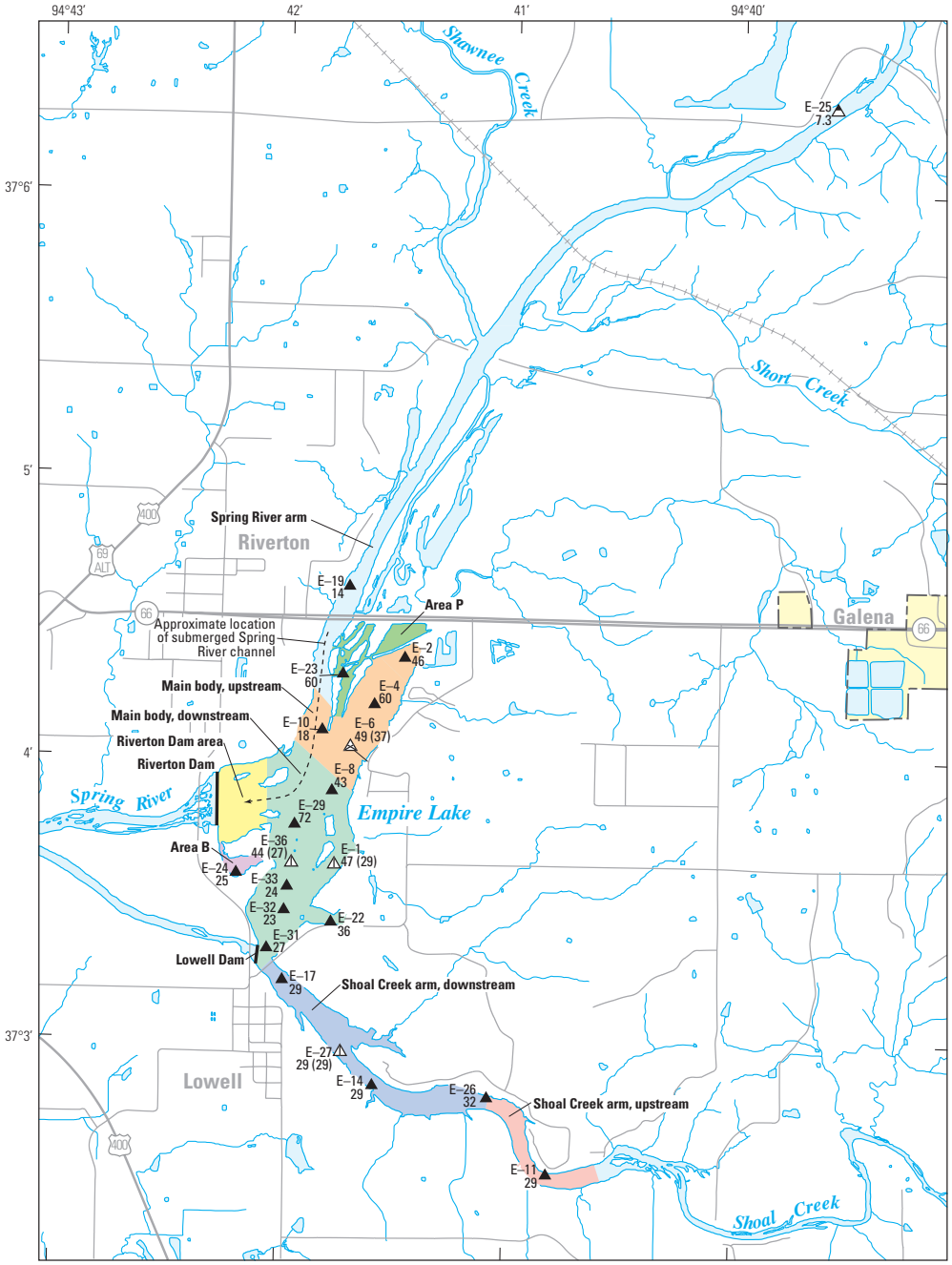
In phase I of this study, Pope (2005) estimated the background concentration of cadmium to be 0.6 mg/kg on the basis of results for streambed-sediment samples collected at sites minimally affected by historical lead and zinc mining within the Cherokee County superfund site (fig. 1). For a streambed-sediment sample collected from the Spring River upstream from the Cow Creek confluence and near the Kansas-Missouri State line (fig. 1), Pope (2005) reported a cadmium concentration of 0.9 mg/kg. Upstream from the State line in Missouri, the Spring River drains a basin 70 percent of which is underlain by Mississippian bedrock (that is, the formation that contains the lead and zinc ores) and 30 percent of which is underlain by Pennsylvanian bedrock. According to Barks (1977), about 93 percent of the lead and zinc mined areas within the Tri-State District are drained by Center, Short, and Turkey Creeks, which enter the Spring River downstream from Cow Creek. However, some lead and zinc mining also occurred within the Spring River Basin upstream from those three tributaries and may have affected trace element concentrations in the Spring River sediment. Given the location of the Spring River sampling site upstream from the Cow Creek confluence, it was believed that the small cadmium concentration reported by Pope (that is, 0.9 mg/kg) was representative of either background sediment concentrations or sediment concentrations that were slightly elevated above background by historical lead and zinc mining and (or) subsequent redistribution of mining wastes. In this context, the use of 0.4 mg/kg as the background cadmium concentration was considered reasonable. Likewise, in the following sections, the use of the median lead and zinc concentrations for core BHF–1 as the background concentrations also was considered reasonable. Using 0.4 mg/kg as the background concentration, the historical mining activity increased the median concentration of cadmium in the bottom sediment of Empire Lake by about 7,200 percent.

Sediment quality was assessed by comparing the trace element concentrations in the bottom sediment with available SQGs. For Empire Lake, all bottom-sediment samples analyzed had cadmium concentrations that exceeded both the threshold- and probable-effects guidelines (0.99 and 4.98 mg/kg, respectively; table 5). With the exception of composite core E–25 (7.3 mg/kg), the cadmium concentrations exceeded the probable-effects guideline by anywhere from about 180 to about 1,400 percent. The cadmium concentration for the top (most recently deposited) interval of trend cores E–1, E–6, E–27, and E–36 ranged from 27 to 37 mg/kg (fig. 6) (that is, about 440 to 640 percent larger than the probable-effects guideline). In comparison, all bottom-sediment samples analyzed for Blackberry Hay Farm Lake core BHF–1 had cadmium concentrations that were less than the threshold-effects guideline (table A14).

Temporal trend analyses, with a significance level of 0.05, indicated a statistically significant negative trend for Empire Lake cores E-6 (fig. 7*A*) and E–36 (fig. 7*C*) (table 9). Because most of the intervals were not within 10 percent of the mean cadmium concentration, the negative trend for both cores does not appear to be due to analytical variance. A negative trend also was indicated for the three-interval core E–1 (table A6). A statistically significant negative trend was not indicated for core E–27 (fig. 7*B*). In addition, no trend in cadmium concentrations was indicated for Blackberry Hay Farm Lake core BHF–1 (fig. 8*A*, table 9).

Lead

Lead concentrations in the Empire Lake composite cores ranged from 100 mg/kg for core E–25 to 950 mg/kg for core E–29 (tables 8, A7, A9, A10, and A11). For the trend cores, lead concentrations for the sampled intervals ranged from 170 to 730 mg/kg (tables 8, A6, A8, A12, and A13). Overall, using the lead concentrations for all 17 composite cores and the mean lead concentrations for the four trend cores (fig. 9), the



EXPLANATION

E–11 29 ▲ **Composite coring site and identifier—**Bulk-density determination and chemical composite analysis. Number is estimated mean cadmium concentration, in milligrams per kilogram

E–25 7.3 △ **Composite coring site and identifier—**Chemical composite analysis only. Number is estimated mean cadmium concentration, in milligrams per kilogram

E–1 47 (29) ⚠ **Trend coring site and identifier—**Chemical trend analysis only. Number is estimated mean cadmium concentration, in milligrams per kilogram. Number in parentheses ( ) is cadmium concentration for most recently deposited sediment, in milligrams per kilogram

E–6 49 (37) ◬ **Bulk-density and trend coring site and identifier—**Bulk-density determination and chemical trend analysis. Number is estimated mean cadmium concentration, in milligrams per kilogram. Number in parentheses ( ) is cadmium concentration for most recently deposited sediment, in milligrams per kilogram

Figure 6. Cadmium concentrations for the composite cores and mean cadmium concentrations for the trend cores collected from Empire Lake, 2005. Reservoir segments are shown by colored areas on map and described in table 1.

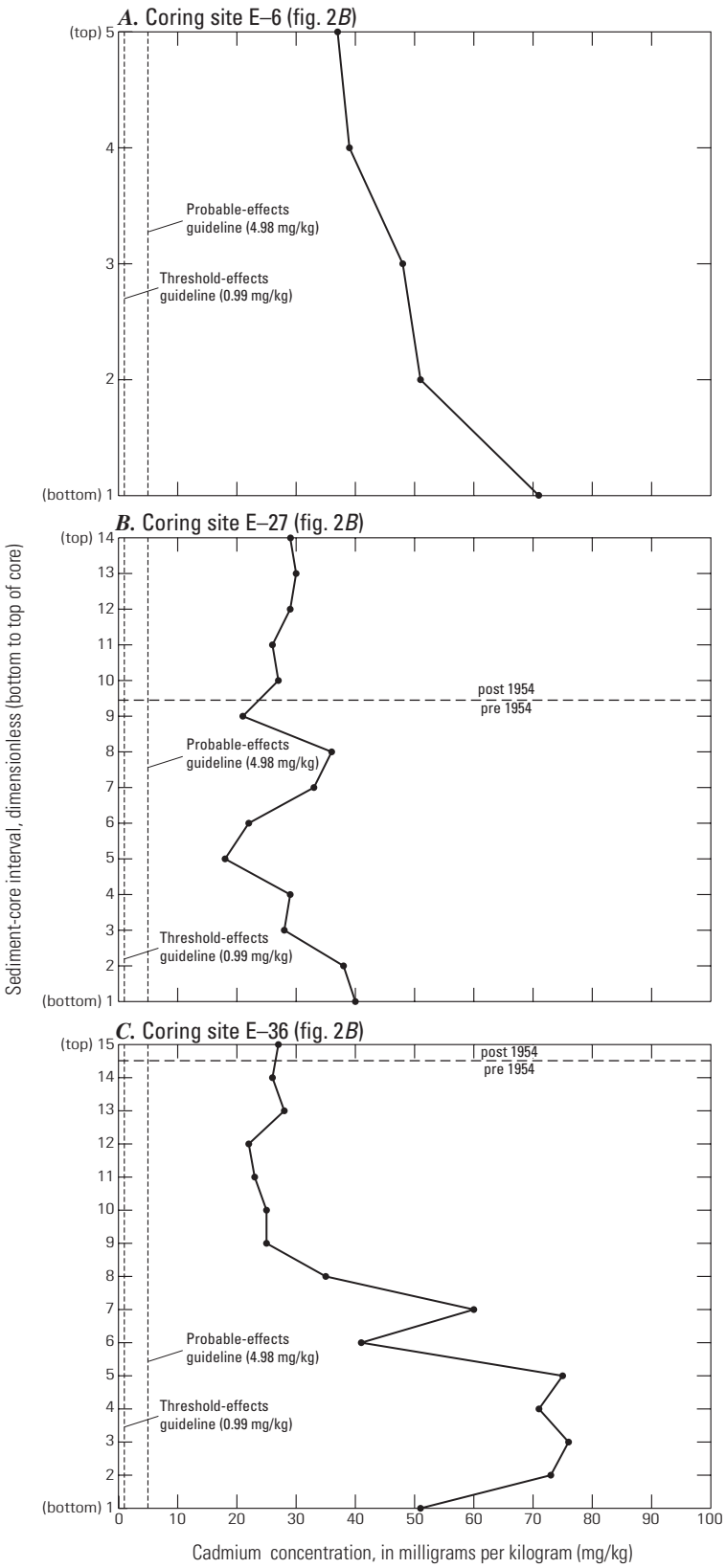


Figure 7. Variation in cadmium concentrations with depth of bottom-sediment samples collected from coring sites E–6, E–27, and E–36 in Empire Lake, August and September 2005. Sediment-quality guidelines from MacDonald and others (2000).

Table 9. Results of trend tests on concentrations of selected trace elements in bottom-sediment samples collected from Empire Lake cores E–6, E–27, and E–36, southeast Kansas, and Blackberry Hay Farm Lake core BHF–1, southwest Missouri, August and September 2005.

[--, not determined]

Trace element	Spearman's rho	Trend test at 0.05 level of significance (two-sided p-value)
Empire Lake core E–6 (fig. 2*B*)		
Arsenic	- 0.10	no trend (0.873)
Cadmium	- 1.00	negative trend (0)
Chromium	.56	no trend (0.322)
Copper	- .80	no trend (0.104)
Lead	- 1.00	negative trend (0)
Nickel	- .70	no trend (0.188)
Silver	--	--
Zinc	- 1.00	negative trend (0)
Empire Lake core E–27 (fig. 2*B*)		
Arsenic	- .71	negative trend (0.004)
Cadmium	- .23	no trend (0.434)
Chromium	.59	positive trend (0.027)
Copper	- .88	negative trend (0.00003)
Lead	- .78	negative trend (0.001)
Nickel	.31	no trend (0.283)
Silver	--	--
Zinc	- .84	negative trend (0.0002)
Empire Lake core E–36 (fig. 2*B*)		
Arsenic	- .71	negative trend (0.003)
Cadmium	- .77	negative trend (0.0009)
Chromium	- .20	no trend (0.478)
Copper	- .51	no trend (0.052)
Lead	- .83	negative trend (0.0001)
Nickel	- .43	no trend (0.113)
Silver	--	--
Zinc	- .87	negative trend (0.00003)
Blackberry Hay Farm Lake core BHF–1 (fig. 1)		
Arsenic	.54	no trend (0.057)
Cadmium	.36	no trend (0.227)
Chromium	.37	no trend (0.209)
Copper	.53	no trend (0.064)
Lead	- .20	no trend (0.517)
Nickel	- .10	no trend (0.741)
Silver	--	--
Zinc	.64	positive trend (0.018)

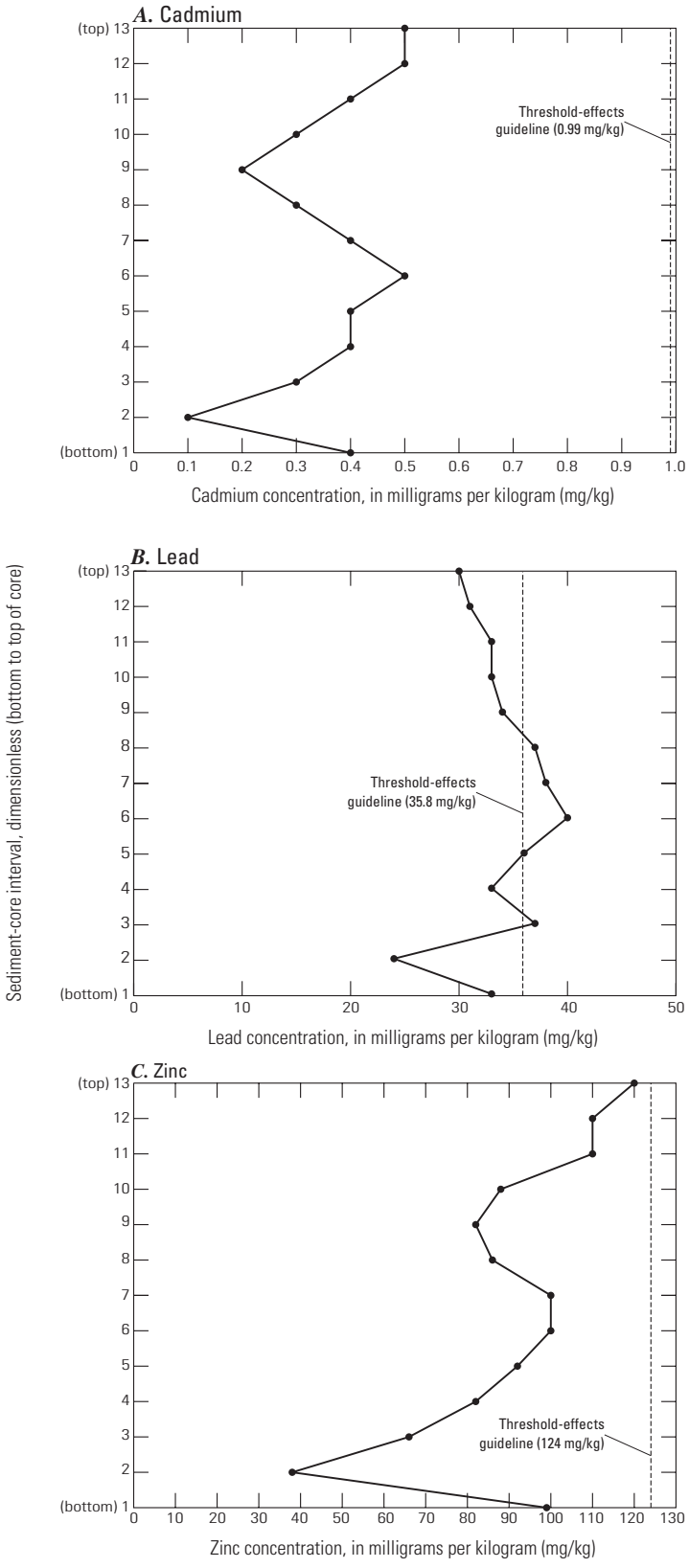
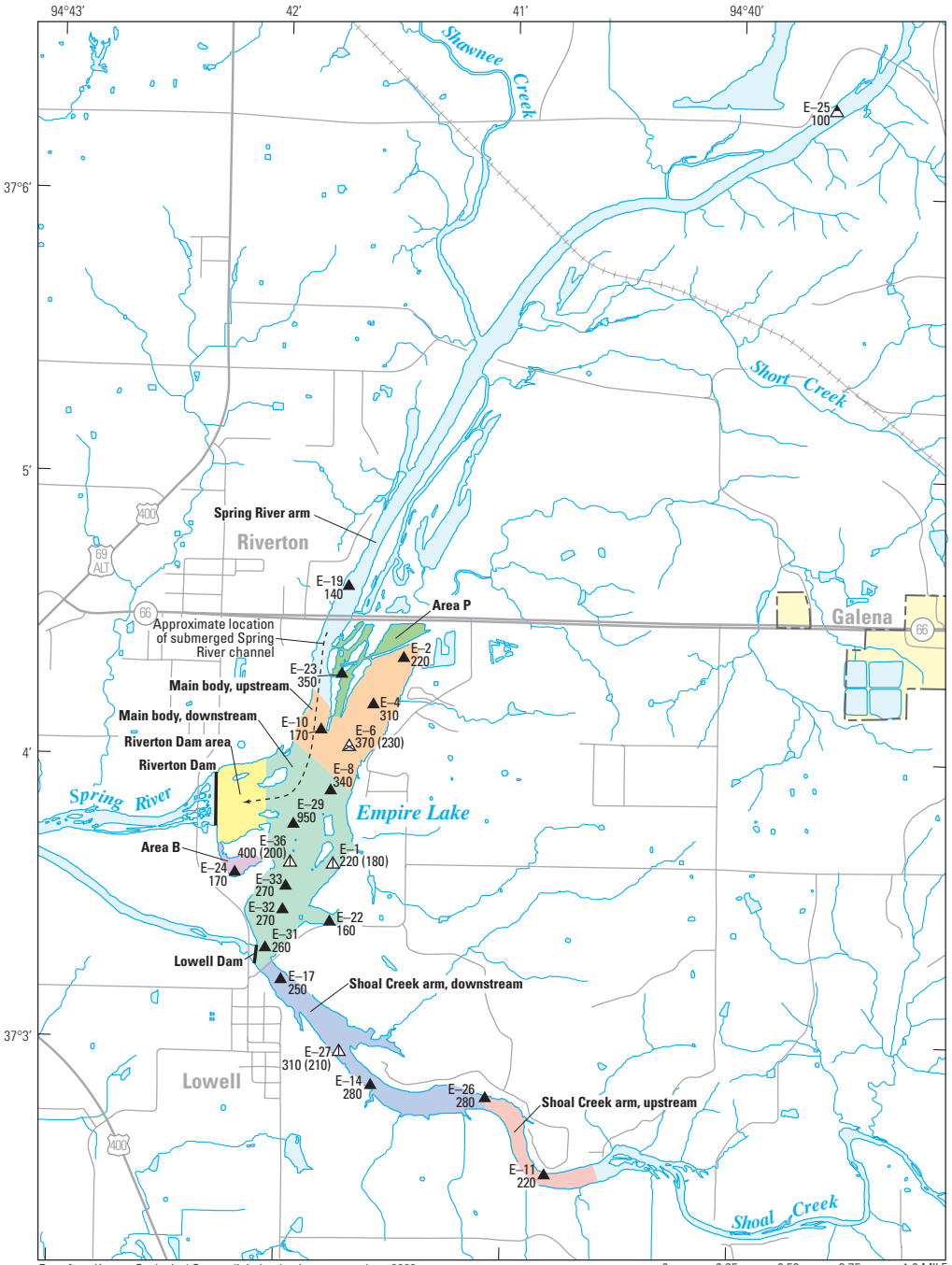


Figure 8. Cadmium, lead, and zinc concentrations with depth of bottom-sediment samples from coring site BHF–1 in Blackberry Hay Farm Lake, September 2005. Sediment-quality guidelines from U.S. Environmental Protection Agency (1997) and MacDonald and others (2000).



EXPLANATION

E–11 220 ▲ **Composite coring site and identifier—**Bulk-density determination and chemical composite analysis. Number is estimated mean lead concentration, in milligrams per kilogram

E–25 100 △ **Composite coring site and identifier—**Chemical composite analysis only. Number is estimated mean lead concentration, in milligrams per kilogram

E–6 370 (230) ◬ **Trend coring site and identifier—**Bulk-density determination and chemical trend analysis. Number is estimated mean lead concentration, in milligrams per kilogram. Number in parentheses ( ) is lead concentration for most recently deposited sediment, in milligrams per kilogram

E–1 220 (180) ⚠ **Trend coring site and identifier—**Chemical trend analysis only. Number is estimated mean lead concentration, in milligrams per kilogram. Number in parentheses ( ) is lead concentration for most recently deposited sediment, in milligrams per kilogram

Figure 9. Lead concentrations for the composite cores and mean lead concentrations for the trend cores collected from Empire Lake, 2005. Reservoir segments are shown by colored areas on map and described in table 1.

respective mean and median lead concentrations for the Empire Lake sediment cores were 290 and 270 mg/kg. Using the median lead concentration for the 19 cores used for chemical analysis that were collected within the reservoir segments used in the estimation of bottom-sediment volume and mass (that is, 270 mg/kg), the total mass of lead in the Empire Lake bottom sediment was estimated to be 650,000 lb.

The background lead concentration, represented by the median lead concentration in Blackberry Hay Farm Lake core BHF–1, was 33 mg/kg (tables 8, A14). Pope (2005) estimated the background concentration of lead to be 20 mg/kg on the basis of results for streambed-sediment samples collected at sites minimally affected by historical lead and zinc mining within the Cherokee County superfund site (fig. 1). Nationally, Horowitz and others (1991) estimated the background concentration of lead in sediment to be 23 mg/kg. Using 33 mg/kg as the background concentration, the historical mining activity increased the median concentration of lead in the bottom sediment of Empire Lake by about 720 percent.

For Empire Lake, all bottom-sediment samples analyzed had lead concentrations that exceeded the threshold-effects guideline (35.8 mg/kg). With the exception of composite core E–25 (100 mg/kg), the lead concentrations also exceeded the probable-effects guideline (128 mg/kg) by anywhere from about 10 to about 640 percent. The lead concentration for the top (most recently deposited) interval of trend cores E–1, E–6, E–27, and E–36 ranged from 180 to 230 mg/kg (fig. 9) (that is, about 40 to 80 percent larger than the probable-effects guideline). In comparison, the bottom-sediment samples analyzed for Blackberry Hay Farm Lake core BHF–1 had lead concentrations that were less than or equal to 40 mg/kg, and most were less than the threshold-effects guideline (table A14).

Temporal trend analyses, with a significance level of 0.05, indicated a statistically significant negative trend for Empire Lake cores E–6, E–27, and E–36 (fig. 10) (table 9). The negative trends do not appear to be due to analytical variance as all or most of the intervals were not within 10 percent of the mean lead concentration for each core. A possible negative trend also was indicated for the three-interval core E–1 (table A6). No trend in lead concentrations was indicated for Blackberry Hay Farm Lake core BHF–1 (fig. 8*B*, table 9).

Zinc

The Empire Lake composite cores had zinc concentrations that ranged from 1,300 mg/kg for core E–25 to 11,000 mg/kg for core E–29 (tables 8, A7, A9, A10, and A11). For the trend cores, zinc concentrations for the sampled intervals ranged from 3,100 to 13,000 mg/kg (tables 8, A6, A8, A12, and A13). Overall, using the zinc concentrations for all 17 composite cores and the mean zinc concentrations for the four trend cores (fig. 11), the respective mean and median zinc concentrations for the Empire Lake sediment cores were 5,600 and 4,900 mg/kg. Using the median zinc concentration for the 19 cores used for chemical analysis that were collected within the reservoir segments used in the estimation of bottom-sediment volume and mass (that is, 5,100 mg/kg), the total mass of zinc in the Empire Lake bottom sediment was estimated to be 12 million lb.

The background zinc concentration, represented by the median zinc concentration in Blackberry Hay Farm Lake core BHF–1, was 92 mg/kg (tables 8, A14). Pope (2005) estimated the background concentration of zinc to be 100 mg/kg on the basis of the result for a streambed-sediment sample collected at a site minimally affected by historical lead and zinc mining within the Cherokee County superfund site (fig. 1). Nationally, Horowitz and others (1991) estimated the background concentration of zinc in sediment to be 88 mg/kg. Using 92 mg/kg as the background concentration, the historical mining activity increased the median concentration of zinc in the bottom sediment of Empire Lake by about 5,200 percent.

All bottom-sediment samples analyzed for Empire Lake had zinc concentrations that exceeded both the threshold- and probable-effects guidelines (124 and 459 mg/kg, respectively; table 5). The zinc concentrations exceeded the probable-effects guideline by anywhere from about 180 to about 2,700 percent. The zinc concentration for the top (most recently deposited) interval of trend cores E–1, E–6, E–27, and E–36 ranged from 3,100 to 4,900 mg/kg (fig. 11) (that is, about 580 to 970 percent larger than the probable-effects guideline). For Blackberry Hay Farm Lake core BHF–1, all of the bottom-sediment samples analyzed had zinc concentrations that were less than or equal to 120 mg/kg and less than the threshold-effects guideline (table A14).

Temporal trend analyses, with a significance level of 0.05, indicated a statistically significant negative trend for Empire Lake cores E–6, E–27, and E–36 (fig. 12, table 9). The negative trends do not appear to be due to analytical variance as all or most of the intervals were not within 10 percent of the mean zinc concentration for each core. A negative trend also was indicated for the three-interval core E–1 (table A6). A statistically significant positive trend was indicated for Blackberry Hay Farm Lake core BHF–1 (fig. 8*C*, table 9). A possible explanation for the increase in zinc concentrations is increased vehicular traffic in the basin since tire wear is a known source of zinc (Callender and Rice, 2000). In Empire Lake, the zinc in the bottom sediment contributed by tire wear is considered negligible compared to the zinc contributed by historical mining activity. In areas with no history of mining, zinc (and other trace elements) also may originate from road and railroad beds where chat (mill tailings) was used.

Other Trace Elements

In this section, the results for arsenic, chromium, copper, mercury, nickel, and silver are presented. Overall, the bottom-sediment concentrations of arsenic and chromium in Empire Lake were similar to those in Blackberry Hay Farm Lake, whereas the concentrations of copper and nickel in Empire Lake were substantially larger. Silver typically was not detected in the bottom sediment of either reservoir. Mercury results were

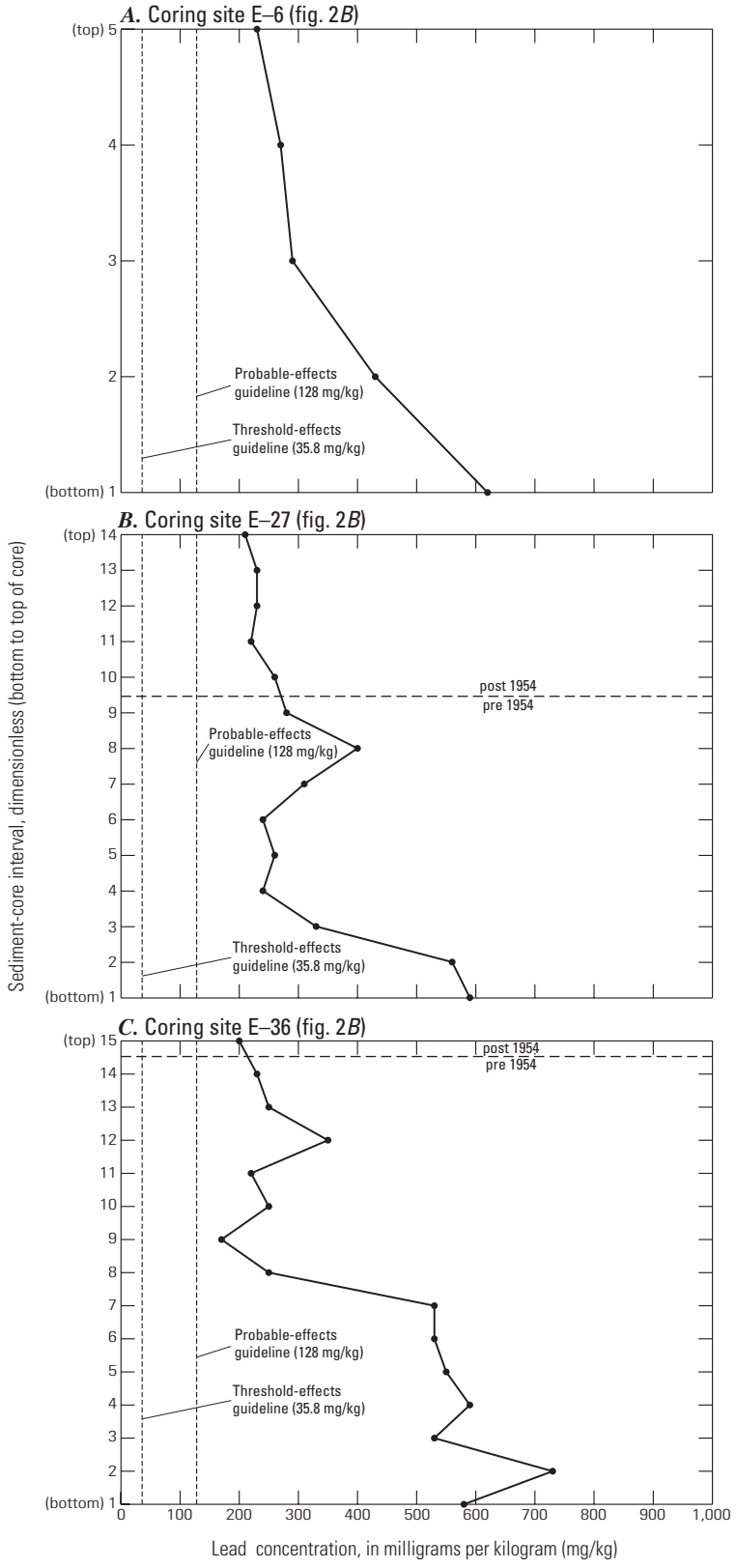
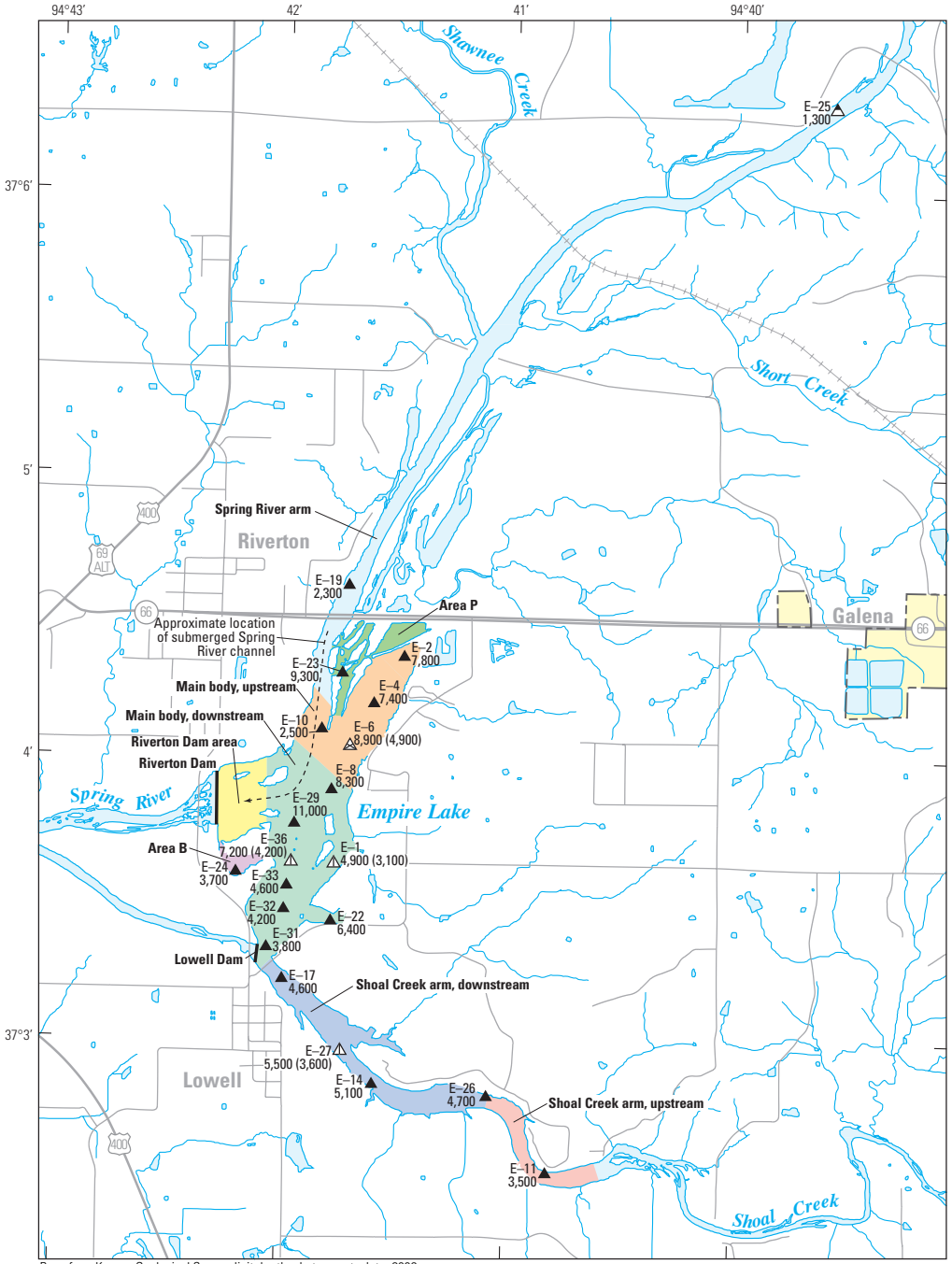


Figure 10. Variation in lead concentrations with depth of bottom-sediment samples from coring sites E–6, E–27, and E–36 in Empire Lake, August and September 2005. Sediment-quality guidelines from MacDonald and others (2000).



Base from Kansas Geological Survey digital orthophoto county data, 2002
Data Access and Support Center
Universal Transverse Mercator projection
Zone 15

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

EXPLANATION

E–11 3,500 ▲ **Composite coring site and identifier—**Bulk-density determination and chemical composite analysis. Number is estimated mean zinc concentration, in milligrams per kilogram

E–25 1,300 △ **Composite coring site and identifier—**Chemical composite analysis only. Number is estimated mean zinc concentration, in milligrams per kilogram

E–6 8,900 (4,900) ◬ **Trend coring site and identifier—**Bulk-density determination and chemical trend analysis. Number is estimated mean zinc concentration, in milligrams per kilogram. Number in parentheses ( ) is zinc concentration for most recently deposited sediment, in milligrams per kilogram

E–1 4,900 (3,100) ⚠ **Trend coring site and identifier—**Chemical trend analysis only. Number is estimated mean zinc concentration, in milligrams per kilogram. Number in parentheses ( ) is zinc concentration for most recently deposited sediment, in milligrams per kilogram

Figure 11. Zinc concentrations for the composite cores and mean zinc concentrations for the trend cores collected from Empire Lake, 2005. Reservoir segments are shown by colored areas on map and described in table 1.

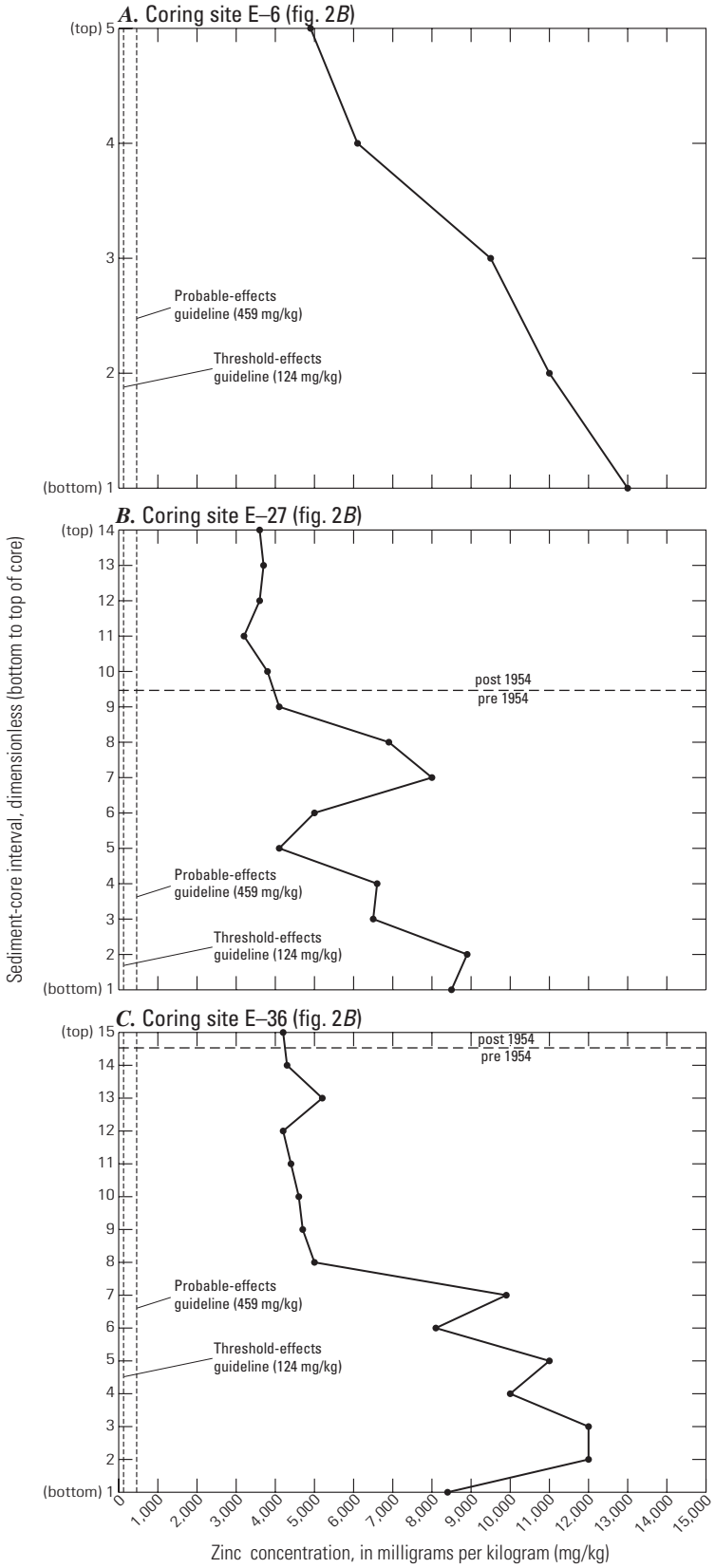


Figure 12. Variation in zinc concentrations with depth of bottom-sediment samples collected from coring sites E–6, E–27, and E–36 in Empire Lake, August and September 2005. Sediment-quality guidelines from U.S. Environmental Protection Agency (1997) and MacDonald and others (2000).

only available for a single Empire Lake core. The chemical data for the Empire Lake composite cores are provided in tables A7, A9, A10, and A11. For Empire Lake trend cores E–1, E–6, E–27, and E–36, the chemical data are provided in tables A6, A8, A12, and A13, respectively. The chemical data for Blackberry Hay Farm Lake trend core BHF–1 are provided in table A14.

With the exception of trend core E–6 (table A8), arsenic concentrations in the bottom sediment of Empire Lake were less than the threshold-effects guideline (9.79 mg/kg, table 5). For trend core E–6, the middle three intervals had arsenic concentrations that were greater than the threshold-effects guideline but less than the probable-effects guideline (41.6 mg/kg, table 5). Statistically significant negative trends in arsenic concentrations were indicated for trend cores E–27 and E–36 (table 9). The trend for core E–27 does not appear to be due to analytical variance as most of the intervals were not within 10 percent of the mean concentration. For trend core E–36, about one-half of the intervals were within 10 percent of the mean concentration. A negative trend also was indicated for the three-interval core E–1. In contrast, a possible positive trend in arsenic concentrations (significant at the 0.06 level) was indicated for Blackberry Hay Farm Lake core BHF–1 (table 9). However, the positive trend may be due to analytical variance.

Typically, chromium concentrations in the bottom sediment of both Empire and Blackberry Hay Farm Lake were greater than the threshold-effects guideline (52.3 mg/kg, table 5) but less than the probable-effects guideline (160 mg/kg, table 5). A statistically significant positive trend in chromium concentrations was indicated for trend core E–27 (table 9). However, because most of the intervals were within 10 percent of the mean concentration, the trend may be due to analytical variance. In contrast, a possible negative trend was indicated for the three-interval core E–1.

The results for copper were more variable. Of the 17 composite cores analyzed for Empire Lake, 11 had copper concentrations that were less than the threshold-effects guideline (31.6 mg/kg, table 5), whereas the remaining six cores had concentrations that were greater than the threshold-effects guideline but less than the probable-effects guideline (149 mg/kg, table 5). For Empire Lake trend cores E–1, E–6, and E–36, most or all of the intervals had copper concentrations that were greater than the threshold-effects guideline but less than the probable-effects guideline. However, for Empire Lake trend core E–27, 11 of 14 intervals had copper concentrations that were less than the threshold-effects guideline. All intervals of Blackberry Hay Farm Lake core BHF–1 had copper concentrations that were less than the threshold-effects guideline.

Overall, a negative trend was indicated for copper concentrations in the bottom sediment of Empire Lake; although, only the trend for core E–27 was statistically significant at the 0.05 level (table 9). For each core, the trend does not appear to be due to analytical variance as most of the intervals were not within 10 percent of the mean concentration. A negative trend also was indicated for the three-interval core E–1. No trend in copper concentrations was indicated for Blackberry Hay Farm Lake core BHF–1 (table 9).

Mercury results were only available for Empire Lake core E–1. The top (most-recent) interval had a mercury concentration that was less than the threshold-effects guideline (0.18 mg/kg, table 5). The bottom (oldest) two intervals of the core had mercury concentrations that were greater than the threshold-effects guideline but less than the probable-effects guideline (1.06 mg/kg, table 5).

With few exceptions, nickel concentrations in the bottom sediment of Empire Lake typically were greater than the threshold-effects guideline (22.7 mg/kg, table 5) but less than the probable-effects guideline (48.6 mg/kg, table 5). Exceptions included composite cores E–4 and E–8, and trend core E–6, for which nickel concentrations exceeded the probable-effects guideline. For trend core E–6, the nickel concentration in the top (most-recent) interval was between the two guidelines, whereas concentrations in the bottom (oldest) four intervals were greater than the probable-effects guideline. Nickel concentrations for Blackberry Hay Farm Lake core BHF–1 typically were less than the threshold-effects guideline. No statistically significant trends in nickel concentrations were indicated (table 9).

Silver was not detected in 8 of 17 composite cores for Empire Lake. Of the remaining nine cores for which silver was detected, five cores had concentrations less than the threshold-effects guideline (0.733 mg/kg, table 5), and four cores had concentrations greater than the threshold-effects guideline but less than the probable-effects guideline (1.77 mg/kg, table 5). For the trend cores, silver was not detected in all or most of the intervals. Although, for the top (most-recent) six intervals of trend core E–27, silver was detected at concentrations that were greater than the threshold-effects guideline but less than the probable-effects guideline. Silver typically was not detected in Blackberry Hay Farm Lake core BHF–1.

Variability of Trace Element Concentrations in Relation to Mining Activity and Other Factors

In this section, the variability of cadmium, lead, and zinc concentrations in the bottom sediment of Empire Lake was interpreted in relation to historical mining activity and other factors. Spatially, variability was assessed using the trace element concentrations for the 17 composite cores along with the mean concentrations for the four trend cores. Temporally, variability was assessed using the four trend cores.

Spatially, several patterns were indicated in the bottom sediment of Empire Lake. Within the Spring River arm of the reservoir, three cores (in downstream order, E–25, E–19, and E–10) indicated increasing cadmium, lead, and zinc concentrations in the downstream direction (figs. 6, 9, and 11). The downstream increase in concentrations likely was caused by tributary

inflow from Short Creek, which drains an area that has been substantially affected by historical lead and zinc mining (fig. 1). Similarly, in phase I of this study, Pope (2005) determined that streambed-sediment concentrations of cadmium, lead, and zinc increased in the downstream direction along the 22-mi length of the Spring River sampled within the Cherokee County superfund site. Along the Spring River, the downstream increase in concentrations likely was caused, in part, by the successive tributary inflows from Center, Turkey, and Short Creeks, which drain areas that have been substantially affected by historical lead and zinc mining (fig. 1). Streambed-sediment samples for these three creeks contained concentrations of cadmium, lead, and zinc that were much larger than background concentrations (Barks, 1977; Pope, 2005).

Within the Shoal Creek arm, five cores (in downstream order, E–11, E–26, E–14, E–27, and E–17) indicated uniform cadmium concentrations in the downstream direction (fig. 6). Lead and zinc concentrations increased in the downstream direction in the first four cores then decreased for core E–17 (figs. 9 and 11). A possible explanation for the downstream increase in lead and zinc concentrations in the first four cores is related to the particle-size composition of the sediment. Because fine particles (that is, clay) are preferentially transported and deposited farther downstream in a reservoir than coarse particles (that is, silt) and because trace element concentrations generally increase as particle size decreases (Horowitz, 1991), the downstream increase in lead and zinc concentrations may be indicative of increasing amounts of fine particles in the sediment. The decreased lead and zinc concentrations in core E–17 possibly represent an influx of compositionally different sediment from a minor tributary, shoreline erosion, and (or) the main body of Empire Lake.

In terms of relative magnitude, the concentrations of cadmium, lead, and zinc in the Spring River arm of the reservoir were substantially less than concentrations in the main body and the Shoal Creek arm (figs. 6, 9, and 11). Results of the sediment-thickness mapping indicate that minimal bottom sediment was deposited within the Spring River arm. Thus, the sediment that was sampled may be representative of recently deposited material that is only stored temporarily before being remobilized and transported downstream. If this interpretation is valid, then the relatively small concentrations of cadmium, lead, and zinc in the Spring River arm may be indicative of less-contaminated sediments originating from the mining-affected areas of this part of the Spring River Basin (possibly due, in part, to remediation efforts and landscape stabilization) and (or) a relative increase in the contribution of minimally contaminated sediments from such sources as Shawnee Creek (fig. 1).

Several lines of evidence indicate the transport of contaminated sediment downstream from Empire Lake. The evidence includes: (1) minimal sediment deposition in the Spring River arm of the reservoir; (2) underrepresented post-1954 sediment in Empire Lake trend cores E–27 and E–36; (3) relatively small concentrations of cadmium, lead, and zinc in the sediment sampled for the Spring River arm of the reservoir; and (4) elevated concentrations of cadmium, lead, and zinc in recently deposited channel-bed sediment of the Spring River immediately downstream from Empire Lake. These elevated concentrations typically exceeded the probable-effects guidelines (Pope, 2005) and were within the range of concentrations measured for the bottom sediment in Empire Lake. Some of the contaminated sediment transported through Empire Lake will be deposited in downstream environments likely as far as Grand Lake O' the Cherokees in Oklahoma. Previously, Pita and Hyne (1975) documented increased lead and zinc concentrations in the uppermost layer of bottom sediment in Grand Lake O' the Cherokees.

The largest cadmium, lead, and zinc concentrations were measured for bottom sediment in the main body of Empire Lake (figs. 6, 9, and 11; tables A12 and A13). As evidenced by the ^{137}Cs activity for trend core E–36 (fig. 5*B*), the bottom sediment in the main body of the reservoir does not represent a complete record of deposition. Instead, with the exception of the top (most-recent) interval, trend core E–36 consisted of pre-1954 sediment. Similarly, most of trend core E–27 in the Shoal Creek arm of the reservoir consisted of pre-1954 sediment. The pre-1954 sediment included inputs of cadmium, lead, and zinc that were deposited during and after the historical peak period of lead and zinc mining in the Kansas and Missouri parts of the Tri-State District. In the Kansas part, major production of lead and zinc concentrates occurred from about 1920 to 1950. Major production in the Galena area ended by about 1920, but it continued until about 1950 downstream from Empire Lake in the vicinity of Baxter Springs and Treece (fig. 1). In the Missouri part, major production occurred from about 1880 to 1920 (Spruill, 1987).

The occurrence of the largest cadmium, lead, and zinc concentrations in the main body of Empire Lake indicated that, historically, sources contributing to the Spring River probably provided larger inputs than sources contributing to Shoal Creek. The probable larger historical trace element concentrations in the sediment delivered by the Spring River may be indicative of the proximity of the main stem and tributaries to areas that were affected substantially by lead and zinc mining. For example, the channel networks of Center, Turkey, and Short Creeks (tributaries of the Spring River) apparently flow through or near more mining-affected areas than does the channel network of Shoal Creek (fig. 1). However, possibly due, in part, to landscape stabilization over time as well as remediation efforts, the concentrations in the most recently deposited sediment in the main body of Empire Lake (core E–36) were similar to the most recently deposited sediment in the Shoal Creek arm of the reservoir (core E–27) (figs. 6, 9, and 11).

Temporally, the four trend cores indicated negative trends for cadmium, lead, and zinc concentrations (tables A6, A8, A12, and A13). With the exception of the cadmium trend for core E–27, the trends for cores E–6, E–27, and E–36 were statistically significant (table 9). However, as indicated by the ^{137}Cs results for cores E–27 (fig. 5*A*) and E–36 (fig. 5*B*), the trends likely are not representative of changes that occurred over the entire history of the reservoir. Instead, the trends may be mostly indicative of pre-1954 changes.

Inspection of the concentration profiles for the more-detailed trend cores E–27 and E–36 (14 and 15 intervals, respectively) indicated that the negative trends for cadmium, lead, and zinc were not continuous as suggested by the less-detailed trend core E–6 (5 intervals) (figs. 7*A*, 10*A*, and 12*A*). For trend core E–27, an initial negative trend (intervals 1–6) was interrupted by a period of increased concentrations (intervals 7 and 8). Then, following a pronounced decrease (interval 9), the concentrations essentially were uniform (intervals 10–14) (figs. 7*B*, 10*B*, and 12*B*). For trend core E–36, concentrations initially were variable with no well-defined trend (intervals 1–7). Then, there was a pronounced decrease (interval 8) after which the concentrations essentially were uniform (intervals 9–15) (figs. 7*C*, 10*C*, and 12*C*). The abrupt decrease in concentrations in the middle of trend core E–36 created a bimodal distribution consisting of larger concentrations for the older sediments and smaller concentrations for the more-recent sediments.

The absence of a well-defined ^{137}Cs profile in cores E–27 and E–36 (figs. 5*A* and 5*B*) limited the ability to assign a date to the pronounced decrease in concentrations. Moreover, uncertainty as to how much sediment removal and mixing have occurred further restricted the ability to assign a date. However, given that the pronounced decrease occurred in both cores prior to the first detection of ^{137}Cs activity, it appears that the decrease happened before 1954. With the available information it is not possible to assign a more exact date. Because the exact date is unknown, the explanation for the pronounced decrease is necessarily uncertain. Although, it is reasonable to propose that historical changes in mining activity, in part, would account for the pronounced decrease. As previously stated, major lead and zinc production in areas upstream from Empire Lake ended about 1920. Other factors that may affect trace element concentrations include precipitation, runoff, vegetation, remediation, and landscape stabilization.

One specific possibility that could account for the pronounced pre-1954 decrease in cadmium, lead, and zinc concentrations is as follows. With the end of major lead and zinc production in areas upstream from Empire Lake by about 1920, sediment concentrations of cadmium, lead, and zinc steadily declined. A major flood, during the period of declining concentrations, removed some of the previously deposited sediment in Empire Lake. The missing record in the sediment profile potentially would be evidenced by a pronounced decrease in cadmium, lead, and zinc concentrations. Between 1923 and 1954, the largest flood measured for the Spring River near Waco, Missouri (USGS streamflow-gaging station 07186000, period of record 1923 to 2005) (fig. 1) occurred on May 19, 1943, with a peak discharge of 103,000 ft^3/s. This flood was the second largest for the period of record, exceeded only by the peak of September 26, 1993 (151,000 ft^3/s). The largest flood measured during the period of record for Shoal Creek above Joplin, Missouri (USGS streamflow-gaging station 07187000, period of record 1924 to 2005) (fig. 1) occurred on May 18, 1943, with a peak discharge of 62,100 ft^3/s (U.S. Geological Survey, 2006). Thus, if the proposed possibility is valid, a potential date for the pronounced decrease in concentrations is 1943.

To further assess temporal changes in cadmium, lead, and zinc concentrations over time, the most recently deposited pre-1954 sediment was compared with the post-1954 sediment in trend cores E–27 and E–36. For trend core E–27, the post-1954 concentrations (intervals 10–14) generally were similar to the most-recent pre-1954 concentrations (interval 9) (figs. 7*B*, 10*B*, and 12*B*). Likewise, for trend core E–36, the post-1954 concentrations (interval 15) were similar to the most-recent pre-1954 concentrations (interval 14) (figs. 7*C*, 10*C*, and 12*C*). This comparison indicated that cadmium, lead, and zinc concentrations in the sediment deposited in Empire Lake may not have changed substantially over the past 50 or more years. However, the concentrations may have been affected by sediment removal and (or) mixing.

Although the focus of this study was the bottom sediment in Empire Lake, three additional samples were collected to assess trace element contamination on the flood plain. The concentrations of cadmium, lead, and zinc for all three samples exceeded background concentrations. For the Spring River flood plain (site SRF–1, fig. 2*A*), the concentrations of cadmium and lead were greater than the threshold-effects guidelines (0.99 and 35.8 mg/kg, respectively) but less than the probable-effects guidelines (4.98 and 128 mg/kg, respectively). The zinc concentration was greater than the probable-effects guideline (459 mg/kg) (table A15 at the back of this report). For the Shoal Creek flood plain (site SCF–1, fig. 2*B*), the cadmium concentration was slightly less than the threshold-effects guideline, the lead concentration was slightly greater than the threshold-effects guideline, and the zinc concentration was between the threshold- and probable-effects guidelines (table A15). For both flood-plain samples, the concentrations of cadmium, lead, and zinc were substantially smaller than the concentrations in the Empire Lake bottom sediment. This observation may be indicative of a larger percentage of coarse particles (that is, silt) in the samples analyzed. The sample of original flood-plain material collected from the bottom of trend core E–36 (fig. 2*B*) contained concentrations of cadmium, lead, and zinc that, although substantially less than the concentrations in the immediately overlying sediment, still exceeded the probable-effects guidelines (table A13). Concentrations of cadmium, lead, and zinc that exceeded the probable-effects guidelines also were found in recently deposited channel-bed sediment in the Spring River immediately downstream from Empire Lake (Pope, 2005). Thus, cadmium, lead, and zinc contamination in the vicinity of Empire Lake was not confined to the reservoir bottom sediment.

Summary and Conclusions

A combination of sediment-thickness mapping and bottom-sediment coring completed in 2005 was used to investigate sedimentation and the occurrence of selected chemical constituents in bottom sediment of Empire Lake, a reservoir in

Cherokee County, Kansas, that has been affected by historical lead and zinc mining. The major results of this study are listed below:

1. The total estimated volume and mass of bottom sediment in Empire Lake was 44 million ft^3 and 2,400 million lb, respectively.
2. The total estimated mass of cadmium, lead, and zinc in the bottom sediment of Empire Lake was 78,000, 650,000, and 12 million lb, respectively.
3. Median cadmium, lead, and zinc concentrations in the bottom sediment of Empire Lake were 29, 270, and 4,900 mg/kg, respectively.
4. Cadmium, lead, and zinc concentrations in the bottom sediment of Empire Lake were much larger than the estimated background concentrations.
5. Cadmium, lead, and zinc concentrations in nearly all bottom-sediment samples from Empire Lake greatly exceeded the probable-effects guidelines, which represent the concentrations above which toxic biological effects usually or frequently occur.
6. Cadmium, lead, and zinc concentrations in the bottom sediment of Empire Lake decreased prior to 1954 and have remained relatively constant since.
7. Mining-related cadmium, lead, and zinc contamination in the vicinity of Empire Lake was not confined to the reservoir bottom sediment as elevated concentrations of the three trace elements were measured in flood-plain soils near the reservoir.
8. During high-inflow periods, Empire Lake may be a net source of contaminated sediment.
9. The presence of contaminated sediment in the Spring River immediately downstream from Empire Lake indicated that contaminated sediment that passes through, or originates from, Empire Lake will be deposited in downstream environments likely as far as Grand Lake O' the Cherokees in Oklahoma.

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Supplemental Information

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 5 (8–1–2005)						
A	37.08668	94.68768	15.0	15.6	0.6	hard bottom
B	37.08679	94.68788	19.2	19.2	0	gravel
C	37.08689	94.68802	19.8	19.8	0	gravel
D	37.08699	94.68811	20.1	20.1	0	gravel
E	37.08705	94.68829	18.3	19.3	1.0	rock bottom
Transect 6 (8–1–2005)						
A	37.08574	94.68910	19.0	19.4	.4	rock under mud
B	37.08569	94.68901	21.2	21.2	0	gravel
C	37.08558	94.68884	21.3	21.3	0	gravel
D	37.08548	94.68870	21.0	21.5	.5	gravel under mud
E	37.08540	94.68858	17.7	18.8	1.1	hard bottom
Transect 7 (8–1–2005)						
A	37.08404	94.68952	20.8	22.2	1.4	rock under mud
B	37.08416	94.68975	20.8	20.8	0	gravel
C	37.08428	94.68982	20.2	20.4	.2	gravel under mud
D	37.08439	94.68994	20.5	20.5	0	gravel
E	37.08446	94.69009	9.2	11.0	1.8	dense & hard bottom
Transect 8 (8–1–2005)						
A	37.08329	94.69107	3.1	7.5	4.4	very dense at depth
B	37.08317	94.69096	16.9	18.0	1.1	hard bottom
C	37.08306	94.69083	20.5	21.4	.9	gravel under mud
D	37.08296	94.69073	22.0	22.0	0	gravel
E	37.08286	94.69057	21.5	22.1	.6	hard bottom
F	37.08286	94.69041	17.5	19.3	1.8	hard bottom
Transect 9 (8–1–2005)						
A	37.08169	94.69134	21.1	23.6	2.5	rock under mud
B	37.08173	94.69143	24.8	24.8	0	gravel
C	37.08185	94.69163	22.4	22.4	0	gravel
D	37.08193	94.69169	21.5	21.7	.2	gravel under mud
E	37.08204	94.69187	15.8	17.8	2.0	very dense
Transect 10 (8–1–2005)						
A	37.08080	94.69270	21.1	21.9	.8	gravel under mud
B	37.08063	94.69258	22.9	22.9	0	gravel
C	37.08062	94.69251	23.4	23.4	0	gravel
D	37.08045	94.69234	21.6	23.4	1.8	gravel under mud
E	37.08037	94.69227	18.8	24.2	5.4	rock under mud
Transect 11 (8–1–2005)						
A	37.07918	94.69316	21.5	25.4	3.9	gravel under mud
B	37.07925	94.69329	24.9	25.4	.5	gravel under mud
C	37.07935	94.69341	25.3	25.3	0	gravel
D	37.07943	94.69357	23.8	23.8	0	rock

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 12 (8–1–2005)						
A	37.07815	94.69440	23.7	23.7	0	gravel
B	37.07793	94.69412	25.2	25.2	0	gravel
C	37.07790	94.69402	23.7	24.9	1.2	gravel under mud
D	37.07774	94.69386	12.6	15.9	3.3	very dense at bottom
Transect 13 (8–1–2005)						
A	37.07631	94.69443	10.0	17.1	7.1	
B	37.07634	94.69460	16.3	19.5	3.2	rock under mud
C	37.07639	94.69468	18.1	19.4	1.3	gravel under mud
D	37.07649	94.69493	21.4	21.4	0	gravel
E	37.07665	94.69505	23.1	23.1	0	gravel
F	37.07676	94.69512	23.6	24.1	.5	gravel under mud
G	37.07674	94.69519	22.6	23.9	1.3	rock under mud
H	37.07688	94.69538	7.4	9.9	2.5	rock under mud
Transect 14 (8–1–2005)						
A	37.07484	94.69533	11.5	11.6	.1	gravel under mud
B	37.07502	94.69535	13.3	13.3	0	gravel
C	37.07516	94.69553	13.2	13.2	0	gravel
D	37.07532	94.69579	16.0	16.0	0	gravel
E	37.07547	94.69606	17.2	19.1	1.9	gravel under mud
F	37.07556	94.69622	10.9	14.5	3.6	very dense, may be old bank material
Transect 15 (7–11–2005)						
A	37.07232	94.69261	2.3	4.7	2.4	
B	37.07196	94.69208	2.8	5.2	2.4	
C	37.07155	94.69159	2.9	4.9	2.0	
D	37.07123	94.69111	2.3	2.8	.5	
Transect 16 (7–12–2005)						
A	37.07356	94.69623	18.4	18.8	.4	gravel under mud
B	37.07375	94.69647	14.9	14.9	0	gravel
C	37.07395	94.69672	16.7	16.7	0	gravel
D	37.07414	94.69692	21.4	22.1	.7	gravel under mud
Transect 17 (7–11–2005)						
A	37.07118	94.69361	2.6	3.5	.9	
B	37.07080	94.69307	3.0	4.7	1.7	
C	37.07046	94.69259	3.1	5.6	2.5	
D	37.07007	94.69212	2.8	5.0	2.2	
E	37.06973	94.69163	2.0	2.2	.2	
Transect 18 (7–12–2005)						
A	37.07204	94.69684	14.6	14.6	0	gravel
B	37.07225	94.69704	19.5	19.5	0	gravel
C	37.07249	94.69731	22.3	22.3	0	gravel
D	37.07264	94.69754	22.1	22.1	0	rock
E	37.07272	94.69765	12.0	12.5	.5	

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 19 (7–11–2005)						
A	37.07003	94.69464	2.8	3.5	0.7	
B	37.06968	94.69421	3.3	3.4	.1	
C	37.06928	94.69361	3.4	6.2	2.8	
D	37.06886	94.69320	3.4	6.6	3.2	
E	37.06851	94.69265	2.9	3.8	.9	
F	37.06834	94.69243	2.3	2.4	.1	
Transect 20 (7–12–2005)						
A	37.06967	94.69646	9.2	10.6	1.4	
B	37.06991	94.69682	21.1	21.1	0	gravel
C	37.07019	94.69711	18.5	18.5	0	gravel /rock
D	37.07036	94.69727	25.7	25.7	0	gravel/rock
E	37.07055	94.69749	23.4	23.4	0	gravel
F	37.07063	94.69766	15.0	18.2	3.2	
Transect 21 (7–11–2005)						
A	37.06729	94.69358	2.6	5.6	3.0	
B	37.06744	94.69381	3.3	6.3	3.0	
C	37.06785	94.69435	3.6	5.8	2.2	
D	37.06822	94.69480	3.5	3.5	0	
E	37.06860	94.69530	3.3	5.4	2.1	
Transect 22 (7–11–2005)						
A	37.06604	94.69445	2.2	3.6	1.4	
B	37.06642	94.69497	3.0	5.9	2.9	
C	37.06680	94.69546	3.0	3.8	.8	
D	37.06717	94.69596	2.9	5.4	2.5	
E	37.06733	94.69621	2.9	3.5	.6	
F	37.06753	94.69647	2.9	8.2	5.3	
G	37.06773	94.69676	2.8	3.8	1.0	
H	37.06791	94.69701	18.5	20.9	2.4	
I	37.06806	94.69714	22.3	23.4	1.1	
J	37.06824	94.69746	14.5	14.5	0	gravel
K	37.06844	94.69767	9.4	9.4	0	gravel
L	37.06866	94.69795	7.9	7.9	0	
M	37.06886	94.69821	5.2	6.7	1.5	
Transect 23 (7–11–2005)						
A	37.06737	94.69886	7.4	11.4	4.0	
B	37.06722	94.69857	8.3	8.3	0	gravel
C	37.06704	94.69829	10.6	10.6	0	
D	37.06689	94.69803	14.3	14.7	0.4	
E	37.06680	94.69780	18.6	20.3	1.7	
F	37.06653	94.69758	15.3	17.7	2.4	
G	37.06635	94.69729	6.2	11.8	5.6	
H	37.06617	94.69704	2.4	7.6	5.2	
I	37.06575	94.69645	2.6	4.0	1.4	
J	37.06541	94.69600	2.7	5.7	3.0	

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 23 (7–11–2005)—Continued						
K	37.06506	94.69546	2.9	6.3	3.4	
L	37.06470	94.69497	2.3	3.6	1.3	
Transect 24 (7–11–2005)						
A	37.06329	94.69553	2.4	4.4	2.0	
B	37.06365	94.69607	2.4	3.3	.9	
C	37.06406	94.69660	2.7	6.4	3.7	
D	37.06444	94.69709	2.7	5.1	2.4	
E	37.06475	94.69757	2.5	6.8	4.3	
F	37.06495	94.69778	2.8	7.4	4.6	
G	37.06513	94.69812	11.7	14.3	2.6	
H	37.06535	94.69840	11.4	11.4	0	
I	37.06550	94.69863	10.7	10.8	.1	sand/gravel
J	37.06568	94.69884	11.4	12.4	1.0	gravel under mud
K	37.06590	94.69907	9.7	13.5	3.8	
L	37.06617	94.69942	8.0	8.0	0	rock?
M	37.06635	94.69975	13.6	14.9	1.3	gravel under mud
Transect 25 (7–11–2005)						
A	37.06477	94.70029	9.9	9.9	0	gravel
B	37.06456	94.70006	6.8	6.8	0	gravel
C	37.06436	94.69983	6.2	6.2	0	gravel
D	37.06413	94.69962	12.6	17.8	5.2	
E	37.06392	94.69943	10.4	15.6	5.2	
F	37.06377	94.69911	6.3	12.5	6.2	
G	37.06353	94.69893	3.3	8.6	5.3	grainy mud on pole
H	37.06314	94.69845	3.3	8.5	5.2	grainy mud on pole
I	37.06271	94.69799	3.6	7.8	4.2	
J	37.06233	94.69756	3.6	7.6	4.0	
K	37.06210	94.69730	3.0	7.6	4.6	
L	37.06173	94.69685	1.9	6.9	5.0	
Transect 26 (7–13–2005)						
A	37.06093	94.69608	1.6	2.0	.4	
B	37.06077	94.69587	1.9	3.7	1.8	
C	37.06060	94.69558	1.6	2.8	1.2	
D	37.06049	94.69546	1.2	2.3	1.1	
Transect 27 (7–13–2005)						
A	37.06284	94.70038	3.9	3.9	0	
B	37.06274	94.70014	5.3	10.7	5.4	
C	37.06232	94.69984	4.0	8.5	4.5	
D	37.06193	94.69934	3.8	9.8	6.0	
E	37.06154	94.69885	3.5	9.1	5.6	
F	37.06116	94.69848	3.8	8.5	4.7	
G	37.06069	94.69803	3.8	10.1	6.3	
H	37.06033	94.69755	2.7	7.3	4.6	

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 28 (7–13–2005)						
A	37.06001	94.69722	1.9	2.8	0.9	
B	37.05974	94.69707	2.0	3.2	1.2	
C	37.05959	94.69680	2.0	3.1	1.1	
D	37.05945	94.69666	1.6	2.2	.6	
E	37.05933	94.69639	1.1	1.7	.6	
Transect 29 (7–13–2005)						
A	37.06640	94.70110	1.5	1.9	.4	
B	37.06609	94.70123	5.9	6.1	.2	
C	37.06583	94.70109	9.0	9.0	0	gravel
D	37.06565	94.70115	8.8	8.8	0	gravel
E	37.06532	94.70109	1.3	3.3	2.0	
Transect 30 (7–13–2005)						
A	37.06474	94.70105	3.0	4.0	1.0	
B	37.06454	94.70107	10.4	10.4	0	hard pan
C	37.06431	94.70106	5.0	5.0	0	hard pan
D	37.06396	94.70105	7.5	7.5	0	hard pan
E	37.06378	94.70112	6.7	6.7	0	gravel
Transect 31 (7–13–2005)						
A	37.06288	94.70102	7.0	7.0	0	hard pan
B	37.06275	94.70100	3.8	3.8	0	hard pan
Transect 32 (7–13–2005)						
A	37.06592	94.70280	4.5	4.5	0	hard bed, unknown
B	37.06580	94.70277	6.0	6.0	0	gravel
C	37.06565	94.70278	4.2	4.2	0	gravel
Transect 33 (7–13–2005)						
A	37.06505	94.70279	6.1	6.1	0	gravel
B	37.06474	94.70277	7.5	7.5	0	hard bed
C	37.06449	94.70277	11.0	11.1	.1	hard bed
D	37.06422	94.70278	9.5	9.5	0	gravel
E	37.06393	94.70279	6.9	6.9	0	hard pan
F	37.06372	94.70278	8.5	8.5	0	gravel
G	37.06339	94.70273	5.4	5.5	.1	hard pan
H	37.06310	94.70274	5.2	5.2	0	hard pan
I	37.06284	94.70274	3.8	3.8	0	hard pan
J	37.06254	94.70273	3.5	3.7	.2	hard pan
Transect 34 (7–12–2005)						
A	37.06215	94.70449	2.5	2.5	0	rock
B	37.06252	94.70447	1.6	1.6	0	rock
C	37.06281	94.70445	6.4	6.4	0	rock
D	37.06305	94.70446	8.0	8.1	.1	gravel under mud
E	37.06335	94.70447	9.0	9.7	.7	
F	37.06361	94.70447	8.3	8.5	.2	
G	37.06388	94.70448	8.5	8.5	0	gravel

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 34 (7–12–2005)—Continued						
H	37.06415	94.70450	8.0	8.0	0	gravel
I	37.06443	94.70451	7.7	7.7	0	gravel
J	37.06470	94.70450	7.5	7.8	.3	
K	37.06494	94.70450	5.0	5.0	0	gravel
L	37.06522	94.70450	6.1	6.1	0	gravel
M	37.06554	94.70448	5.2	5.2	0	rock?
N	37.06185	94.70448	6.1	6.1	0	rock
O	37.06169	94.70444	1.9	1.9	0	rock
Transect 35 (7–13–2005)						
A	37.06089	94.70064	1.3	1.9	.6	
B	37.06052	94.70020	2.2	9.3	7.1	
C	37.06015	94.69971	4.6	11.3	6.7	
D	37.05975	94.69924	3.9	10.4	6.5	
E	37.05934	94.69882	3.5	9.4	5.9	
F	37.05890	94.69834	3.4	9.7	6.3	
G	37.05854	94.69785	2.3	5.9	3.6	
Transect 36 (7–13–2005)						
A	37.05927	94.70111	3.0	8.9	5.9	
B	37.05894	94.70062	3.4	4.2	.8	
C	37.05850	94.70016	3.8	5.5	1.7	
D	37.05806	94.69972	3.8	10.7	6.9	
E	37.05791	94.69952	4.3	11.0	6.7	
F	37.05769	94.69927	4.0	11.3	7.3	
G	37.05719	94.69880	2.3	8.6	6.3	
H	37.05699	94.69857	1.7	7.3	5.6	
Transect 37 (7–13–2005)						
A	37.05810	94.70201	1.7	4.4	2.7	
B	37.05776	94.70166	3.7	8.5	4.8	
C	37.05734	94.70119	5.3	7.4	2.1	
D	37.05695	94.70074	5.0	6.3	1.3	
E	37.05673	94.70053	3.8	4.3	.5	
F	37.05654	94.70030	7.0	8.4	1.4	
G	37.05631	94.70006	5.3	10.7	5.4	
H	37.05611	94.69983	2.8	7.1	4.3	
I	37.05590	94.69962	2.2	5.4	3.2	
Transect 38 (7–13–2005)						
A	37.05544	94.70140	11.7	12.1	.4	rock
B	37.05536	94.70126	13.5	19.6	6.1	
C	37.05527	94.70118	14.6	20.5	5.9	
D	37.05513	94.70102	15.6	20.9	5.3	
E	37.05507	94.70100	16.2	20.0	3.8	rock under mud
F	37.05494	94.70076	9.0	14.9	5.9	
G	37.05488	94.70066	4.2	9.3	5.1	

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 39 (7–13–2005)						
A	37.05539	94.70149	12.1	12.1	0	rock
B	37.05521	94.70147	14.9	19.4	4.5	
C	37.05503	94.70147	14.1	19.4	5.3	
D	37.05490	94.70145	14.5	18.4	3.9	
E	37.05476	94.70149	14.0	17.9	3.9	
F	37.05463	94.70150	12.1	17.6	5.5	
G	37.05451	94.70154	10.7	16.5	5.8	
H	37.05440	94.70155	9.1	14.8	5.7	
Transect 40 (7–13–2005)						
A	37.05450	94.70062	11.7	14.7	3.0	
B	37.05441	94.70081	17.2	22.0	4.8	
C	37.05431	94.70092	16.5	23.0	6.5	
D	37.05422	94.70101	13.5	19.9	6.4	
E	37.05407	94.70119	6.8	10.2	3.4	
Transect 41 (7–12–2005)						
A	37.05381	94.69962	9.5	14.6	5.1	
B	37.05363	94.69966	13.8	19.7	5.9	
C	37.05352	94.69976	12.7	17.4	4.7	
D	37.05337	94.69984	9.0	12.0	3.0	
E	37.05331	94.70000	6.8	11.7	4.9	
F	37.05324	94.70017	4.8	11.0	6.2	
G	37.05312	94.70022	3.4	8.5	5.1	
Transect 42 (7–12–2005)						
A	37.05289	94.69833	6.9	13.4	6.5	
B	37.05278	94.69844	8.0	15.4	7.4	
C	37.05274	94.69854	11.9	15.8	3.9	
D	37.05252	94.69870	9.9	12.3	2.4	
E	37.05233	94.69889	5.3	11.3	6.0	
F	37.05244	94.69867	9.3	12.4	3.1	
G	37.05225	94.69894	4.0	9.7	5.7	
H	37.05215	94.69909	2.8	7.7	4.9	
I	37.05207	94.69916	2.2	7.5	5.3	
Transect 43 (7–12–2005)						
A	37.05204	94.69688	3.5	6.6	3.1	
B	37.05192	94.69701	3.5	6.2	2.7	
C	37.05178	94.69713	5.9	9.5	3.6	
D	37.05168	94.69721	9.5	14.5	5.0	
E	37.05159	94.69734	11.3	13.7	2.4	
F	37.05150	94.69744	11.3	14.6	3.3	
G	37.05136	94.69761	9.4	13.0	3.6	
H	37.05121	94.69773	2.4	2.4	0	

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 44 (7–12–2005)						
A	37.05140	94.69541	2.4	2.9	0.5	
B	37.05113	94.69561	2.5	6.1	3.6	
C	37.05092	94.69587	2.9	6.8	3.9	
D	37.05080	94.69602	4.0	7.4	3.4	
E	37.05071	94.69614	6.5	8.0	1.5	
F	37.05058	94.69623	10.0	13.0	3.0	
G	37.05050	94.69633	10.7	15.4	4.7	
H	37.05037	94.69641	10.7	14.1	3.4	
I	37.05030	94.69654	9.5	11.2	1.7	gravel under mud
J	37.05019	94.69664	3.3	3.4	.1	
Transect 45 (7–12–2005)						
A	37.05061	94.69413	2.8	8.0	5.2	
B	37.05047	94.69431	3.0	8.9	5.9	
C	37.05037	94.69435	3.0	5.6	2.6	
D	37.05020	94.69442	2.6	7.1	4.5	
E	37.05015	94.69447	2.5	6.9	4.4	
F	37.05002	94.69458	2.2	4.7	2.5	
G	37.04989	94.69467	2.0	3.1	1.1	
H	37.04979	94.69492	2.5	6.3	3.8	
I	37.04964	94.69494	3.5	8.5	5.0	
J	37.04958	94.69493	5.0	11.0	6.0	
K	37.04952	94.69517	12.0	16.0	4.0	
L	37.04942	94.69528	11.5	17.0	5.5	
M	37.04926	94.69539	10.8	16.5	5.7	
N	37.04907	94.69550	2.0	2.0	0	hard bottom
Transect 46 (7–12–2005)						
A	37.04855	94.69405	12.0	17.4	5.4	
B	37.04835	94.69413	14.3	17.7	3.4	
C	37.04825	94.69415	13.8	19.2	5.4	
D	37.04818	94.69426	11.0	14.3	3.3	
E	37.04809	94.69437	5.2	7.9	2.7	
Transect 47 (7–12–2005)						
A	37.04725	94.69312	9.4	14.9	5.5	
B	37.04735	94.69290	13.0	18.6	5.6	
C	37.04745	94.69282	13.8	19.0	5.2	
D	37.04756	94.69278	12.6	15.9	3.3	
E	37.04772	94.69261	5.0	9.4	4.4	
Transect 48 (7–12–2005)						
A	37.04708	94.69138	7.7	13.2	5.5	
B	37.04697	94.69151	10.0	14.7	4.7	
C	37.04679	94.69148	9.9	13.2	3.3	
D	37.04675	94.69148	9.8	14.3	4.5	
E	37.04657	94.69159	8.5	13.0	4.5	

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 48 (7–12–2005)—Continued						
F	37.04637	94.69155	6.4	10.9	4.5	
G	37.04636	94.69176	6.5	12.4	5.9	
Transect 49 (7–12–2005)						
A	37.04731	94.68737	3.6	9.1	5.5	
B	37.04729	94.68729	6.3	9.4	3.1	
C	37.04711	94.68726	7.4	12.5	5.1	
D	37.04692	94.68724	7.4	9.6	2.2	
E	37.04678	94.68724	7.5	9.2	1.7	
F	37.04661	94.68722	6.9	12.5	5.6	
G	37.04655	94.68722	5.9	11.9	6.0	
H	37.04633	94.68718	3.7	7.8	4.1	
I	37.04623	94.68717	3.1	9.3	6.2	
J	37.04604	94.68712	2.1	7.5	5.4	
Transect 50 (7–12–2005)						
A	37.04670	94.68445	13.5	17.6	4.1	
B	37.04656	94.68442	12.5	16.5	4.0	
C	37.04644	94.68445	10.2	16.1	5.9	
D	37.04630	94.68445	10.0	13.0	3.0	
E	37.04613	94.68456	3.7	5.7	2.0	
Transect 51 (7–12–2005)						
A	37.04535	94.68305	4.2	4.3	.1	
B	37.04542	94.68294	7.5	7.6	.1	
C	37.04559	94.68281	9.6	13.8	4.2	
D	37.04563	94.68263	8.9	8.9	0	
E	37.04580	94.68254	6.0	6.6	.6	
F	37.04582	94.68235	6.0	8.5	2.5	
G	37.04597	94.68220	4.2	6.6	2.4	
Transect 52 (7–12–2005)						
A	37.04416	94.68169	3.2	3.8	.6	
B	37.04411	94.68190	6.1	6.3	.2	gravel under mud
C	37.04407	94.68205	10.0	14.8	4.8	
D	37.04401	94.68218	11.4	12.2	.8	gravel under mud
E	37.04393	94.68232	11.5	15.4	3.9	
F	37.04390	94.68244	5.0	5.0	0	rock
Transect 53 (7–12–2005)						
A	37.04263	94.68165	3.8	3.8	0	gravel
B	37.04280	94.68138	15.5	17.2	1.7	
C	37.04287	94.68118	10.4	12.2	1.8	
Transect 54 (7–12–2005)						
A	37.04230	94.68015	10.5	12.2	1.7	
B	37.04207	94.68018	7.5	8.9	1.4	
C	37.04191	94.68014	6.8	7.1	.3	
D	37.04169	94.68033	8.0	13.9	5.9	

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 55 (7–12–2005)						
A	37.04161	94.67809	7.7	10.0	2.3	
B	37.04171	94.67807	8.6	11.3	2.7	
C	37.04190	94.67804	7.4	9.1	1.7	
D	37.04204	94.67804	6.6	6.6	0	gravel
E	37.04217	94.67806	5.7	5.7	0	gravel
F	37.04230	94.67811	6.1	7.8	1.7	gravel under mud
G	37.04241	94.67812	4.9	8.1	3.2	
Transect 56 (7–12–2005)						
A	37.04277	94.67651	1.5	1.5	0	gravel
B	37.04257	94.67648	2.9	2.9	0	gravel
C	37.04256	94.67641	3.2	3.2	0	gravel
D	37.04240	94.67636	3.9	3.9	0	gravel
E	37.04220	94.67627	8.0	8.0	0	gravel
F	37.04207	94.67625	6.6	10.3	3.7	
G	37.04197	94.67619	3.8	8.2	4.4	
Transect 59 (8–19–2005)						
A	37.09272	94.68311	1.3	1.3	0	gravel likely coming from Short Creek
B	37.09283	94.68325	9.4	9.8	.4	gravel under mud
C	37.09292	94.68339	11.0	11.0	0	gravel
D	37.09300	94.68353	13.5	13.5	0	gravel
E	37.09306	94.68369	14.4	14.4	0	rock
F	37.09314	94.68383	14.9	14.9	0	gravel
G	37.09322	94.68400	14.3	14.3	0	rock
Transect 60 (8–19–2005)						
A	37.09831	94.67756	6.5	11.2	4.7	sediment on pole grainy; dense material, may be submerged original bank
B	37.09836	94.67769	13.6	14.0	.4	
C	37.09850	94.67775	16.0	16.0	0	
D	37.09861	94.67786	19.1	19.1	0	
E	37.09872	94.67794	21.3	21.3	0	
Transect 61 (8–18–2005)						
A	37.10064	94.66778	9.5	10.1	.6	mud over gravel
B	37.10075	94.66786	11.3	11.3	0	gravel
C	37.10086	94.66792	12.8	12.8	0	gravel
D	37.10097	94.66800	15.4	15.4	0	gravel
E	37.10108	94.66808	18.2	18.2	0	gravel
Transect 62 (8–18–2005)						
A	37.10486	94.65969	15.0	15.0	0	gravel
B	37.10500	94.65972	13.3	13.3	0	gravel
C	37.10514	94.65983	12.3	12.3	0	gravel
D	37.10522	94.65992	11.5	13.2	1.7	mud over hard bottom
E	37.10536	94.66006	5.5	10.0	4.5	mud over hard bottom

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
Transect 63 (8–18–2005)						
A	37.10997	94.65464	17.1	17.1	0	rock
B	37.10997	94.65472	17.6	17.6	0	rock
C	37.11003	94.65486	17.9	17.9	0	rock
D	37.11006	94.65492	18.3	18.3	0	rock
E	37.11006	94.65506	11.3	15.1	3.8	mud over hard bottom
Transect 64 (8–18–2005)						
A	37.11408	94.66194	10.7	10.7	0	gravel
B	37.11403	94.66194	11.9	11.9	0	gravel
C	37.11392	94.66200	14.4	14.4	0	gravel
D	37.11386	94.66206	14.5	14.5	0	rock
E	37.11375	94.66208	7.5	7.5	0	rock
Transect 65 (8–18–2005)						
A	37.11900	94.66764	11.1	12.6	1.5	mud over gravel
B	37.11897	94.66775	11.7	11.7	0	gravel
C	37.11892	94.66786	11.8	11.8	0	gravel
D	37.11886	94.66797	13.2	13.2	0	rock
E	37.11878	94.66806	9.8	9.8	0	rock
Transect 66 (8–18–2005)						
A	37.12514	94.67033	7.8	7.8	0	gravel
B	37.12525	94.67044	9.2	9.2	0	gravel
C	37.12525	94.67056	10.1	10.1	0	gravel
D	37.12525	94.67067	11.5	11.5	0	gravel
E	37.12522	94.67081	9.4	9.4	0	rock
Transect 67 (8–18–2005)						
A	37.13275	94.66589	6.0	6.0	0	gravel
B	37.13278	94.66597	7.1	7.1	0	gravel
C	37.13281	94.66606	8.9	8.9	0	rock
D	37.13289	94.66611	12.4	12.4	0	rock
E	37.13294	94.66619	11.9	11.9	0	rock
Transect 68 (8–18–2005)						
A	37.13514	94.65833	11.1	11.5	.4	
B	37.13522	94.65833	9.9	9.9	0	
C	37.13531	94.65833	11.4	11.4	0	gravel
D	37.13536	94.65839	12.2	12.2	0	rock
E	37.13542	94.65839	10.8	10.8	0	rock
Transect A (7–13–2005)						
A	37.05693	94.69694	1.7	2.8	1.1	
B	37.05702	94.69687	1.8	5.9	4.1	
C	37.05719	94.69676	2.4	6.2	3.8	
D	37.05736	94.69664	2.0	2.6	.6	
E	37.05745	94.69651	1.5	1.8	.3	

Table A1. Latitude, longitude, depth to lakebed, depth to refusal, and estimated sediment thickness at sediment-thickness measurement sites (fig. 2) in Empire Lake, southeast Kansas, July and August 2005.—Continued

Transect site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth to lakebed (feet)	Depth to refusal (feet)	Estimated sediment thickness (feet)	Notes
			Area P (7–13–2005)			
A	37.07007	94.69551	1.7	6.4	4.7	
B	37.07016	94.69576	1.5	6.3	4.8	
C	37.07103	94.69517	1.3	5.9	4.6	
D	37.07120	94.69532	1.6	5.0	3.4	
E	37.07143	94.69555	2.4	6.8	4.4	
F	37.07220	94.69577	1.6	4.2	2.6	
G	37.07253	94.69530	2.5	3.1	.6	
H	37.07384	94.69484	2.5	8.8	6.3	
I	37.07161	94.69564	2.5	4.5	2.0	
			Area B (7–12–2005)			
A	37.06046	94.70402	2.1	3.3	1.2	
B	37.06005	94.70373	1.7	3.4	1.7	
C	37.05966	94.70341	0.5	3.0	2.5	
D	37.06016	94.70270	1.8	2.3	.5	
E	37.06047	94.70274	2.5	3.0	.5	
F	37.06044	94.70194	2.5	3.2	.7	
G	37.06083	94.70430	2.5	2.5	0	rock
H	37.06114	94.70423	1.7	2.3	.6	
I	37.06120	94.70445	2.5	2.5	0	rock

Table A2. Latitude and longitude coordinates, water depth, estimated penetration depth, length of recovered core, and estimated recovery percentage for bottom-sediment coring sites at Empire Lake, southeast Kansas, and Blackberry Hay Farm Lake, southwest Missouri, 2005.

[--, not determined]

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
Empire Lake							
E–1	04/01/05	37.06039	94.69606	2.5	--	--	--
E–2	08/02/05	37.07260	94.69108	2.3	2.0	1.4	70
E–3	08/02/05	37.07121	94.69240	3.0	2.8	2.4	86
E–4	08/02/05	37.06984	94.69327	3.0	3.1	2.5	81
E–5	08/02/05	37.06832	94.69375	2.8	3.9	3.4	87
E–6	08/02/05	37.06732	94.69498	2.9	2.8	2.4	86
E–7	08/02/05	37.06605	94.69563	2.7	3.7	2.8	76
E–8	08/02/05	37.06474	94.69629	2.5	3.9	3.2	82
E–9	08/02/05	37.06411	94.69791	2.7	4.6	3.5	76
E–10	04/01/05	37.06831	94.69706	22.0	--	1.0	--
E–11	08/08/05	37.04225	94.68015	11.4	--	1.0	--
E–14	08/08/05	37.04740	94.69299	13.3	6.1	4.4	72
E–15	08/08/05	37.05042	94.69643	10.7	5.4	4.3	80
E–17	08/08/05	37.05356	94.69971	13.6	5.6	4.3	77
E–18	08/08/05	37.05481	94.70113	16.3	6.3	4.1	65
E–19	08/08/05	37.07680	94.69522	20.5	2.9	1.7	59
E–20	08/09/05	37.06228	94.69550	1.8	3.1	2.2	71
E–21	08/09/05	37.06019	94.69644	2.0	1.8	1.2	67
E–22	08/09/05	37.05701	94.69622	1.5	4.5	3.6	80
E–23	08/19/05	37.07161	94.69564	2.5	--	2.5	--
E–24	08/19/05	37.05981	94.70325	1.3	--	1.5	--
E–25	09/15/05	37.10519	94.65992	11.0	1.2	1.1	92
E–26	09/15/05	37.04674	94.68456	13.4	4.5	2.6	58
E–27	09/15/05	37.04933	94.69536	11.2	5.1	3.8	75
E–29	09/15/05	37.06271	94.69899	3.0	8.3	5.7	69
E–30	09/15/05	37.06054	94.69901	4.0	8.7	7.0	80
E–31	09/15/05	37.05541	94.70093	13.6	8.9	6.9	78
E–32	09/15/05	37.05769	94.69967	4.7	8.5	6.3	74
E–33	09/16/05	37.05906	94.69948	3.9	8.2	5.9	72
E–36	09/16/05	37.06054	94.69905	3.8	7.7	5.7	74
Blackberry Hay Farm Lake							
BHF–1	09/16/05	37.32275	94.59892	6.6	3.5	2.6	74

Table A3. Results of chemical analyses of reference samples and comparison to most probable values.

[Shading indicates values outside of published limits for each constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; %, percent dry weight; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined or not applicable; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

Sample source	Sample code		Aluminum		Antimony		Arsenic		Barium	
			Concentration (%)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV
NIST	2709	MPV	7.50±0.06	--	7.9±0.6	--	17.7±0.8	--	968±40	--
			7.4	-1.3	7.4	-6.3	19.0	7.3	1,000	3.3
			7.5	0	7.3	-7.6	18.0	1.7	1,000	3.3
NIST	2711 MT. Soil	MPV	6.53±0.09	--	19.4±1.8	--	105±8	--	726±38	--
			6.5	-.5	19.0	-2.1	110	4.8	760	4.7
			6.4	-2.0	19.0	-2.1	100	-4.8	760	4.7
NIST	1646a	MPV	2.30±0.02	--	.3	--	6.23±0.21	--	210	--
			2.3	0	.3	0	6.0	-3.7	220	4.8
			2.3	0	.3	0	6.0	-3.7	220	4.8
USGS	MAG–1	MPV	8.66±0.16	--	0.96±0.10	--	9.2±1.2	--	479±41	--
			8.6	-.7	.9	-6.3	9.3	1.1	520	8.6
			8.7	.5	.9	-6.3	8.8	-4.3	500	4.4
USGS	STM–1	MPV	9.73±0.12	--	1.66±0.15	--	4.6±0.6	--	560±60	--
			9.6	-1.3	1.6	-3.6	4.5	-2.2	620	10.7
			9.9	1.7	1.4	-15.7	5.2	13.0	600	7.1
USGS	SDO–1	MPV	6.49±0.14	--	4.1-4.8	--	68.5±8.6	--	397±38	--
			6.4	-1.4	4.4	--	69.0	.7	--	--
			6.3	-2.9	4.3	--	67.0	-2.2	--	--
USGS	SGR–1	MPV	3.45±0.11	--	3.4±0.5	--	67±5	--	290±40	--
			3.5	1.4	3.1	-8.8	64	-4.5	280	-3.4
			3.5	1.4	2.9	-14.7	61	-9.0	270	-6.9
USGS	SCO–1	MPV	7.23±0.11	--	2.5±0.1	--	12.4±1.4	--	570±30	--
			7.2	-.4	2.4	-4.0	13.0	4.8	600	5.3
			7.3	1.0	2.4	-4.0	11.0	-11.3	580	1.8
USGS	QLO–1	MPV	8.56±0.10	--	2.1±0.4	--	3.5±1.8	--	1,370±80	--
			8.6	.5	1.6	-23.8	1.2	-65.7	1,500	9.5
			8.5	-.7	1.7	-19.0	2.0	-42.9	1,400	2.2
USGS	GSP–2	MPV	7.88±0.11	--	--	--	--	--	1,340±44	--
			7.8	-1.0	.4	--	1.3	--	1,400	4.5
			7.9	.3	.5	--	.5	--	1,400	4.5

Table A3. Results of chemical analyses of reference samples and comparison to most probable values.—Continued

[Shading indicates values outside of published limits for each constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; %, percent dry weight; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined or not applicable; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

Sample source	Sample code		Beryllium		Cadmium		Carbon, organic, total		Carbon, total	
			Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (%)	Percent difference from MPV	Concentration (%)	Percent difference from MPV
NIST	2709	MPV	--	--	0.4	--	--	--	1.2(?)	--
			5.5	--	.3	-25.0	1.1	--	1.1	-8.3
			5.6	--	.4	0	1.1	--	1.1	-8.3
NIST	2711 MT. Soil	MPV	--	--	41.70±0.25	--	--	--	2.0	--
			2.4	--	40	-4.1	1.7	--	1.7	-15.0
			2.2	--	40	-4.1	1.7	--	1.8	-10.0
NIST	1646a	MPV	<1	--	.2	--	--	--	--	--
			.9	--	.1	--	.5	--	2.0	--
			.9	--	.1	--	.6	--	0.6	--
USGS	MAG–1	MPV	3.2±0.4	--	0.2±0.1	--	--	--	2.15±0.40	--
			3.2	0	.2	--	2.2	--	2.3	7.0
			2.9	-9.4	.2	--	2.2	--	2.3	7.0
USGS	STM–1	MPV	9.6±0.6	--	0.27±0.05	--	--	--	0	--
			10.0	4.2	.3	11.1	<.1	--	<.1	--
			9.3	-3.1	.2	--	.1	--	<.1	--
USGS	SDO–1	MPV	3.3±0.6	--	--	--	--	--	9.95±0.44	--
			3.3	0	.1	--	9.3	--	9.8	-1.5
			3.0	-9.1	<.1	--	9.6	--	9.5	-4.5
USGS	SGR–1	MPV	1.06±0.16	--	0.93±0.05	--	24.8	--	28.0	--
			1.1	3.8	1.1	18.3	25.0	0.8	27.0	-3.6
			1.0	-5.7	1.1	18.3	27.0	8.9	27.0	-3.6
USGS	SCO–1	MPV	1.84±0.20	--	.14	--	--	--	0.81±0.12	--
			1.8	-2.2	.1	--	1.0	--	1.0	23.5
			1.7	-7.6	.1	--	1.0	--	1.0	23.5
USGS	QLO–1	MPV	1.89±0.17	--	.05?	--	--	--	<.01	--
			2.0	5.8	<.1	--	<.1	--	<.1	--
			1.7	-10.1	<.1	--	.1	--	<.1	--
USGS	GSP–2	MPV	1.5±0.2	--	--	--	--	--	--	--
			1.6	6.7	<.1	--	.1	--	.1	--
			1.5	0	<.1	--	.1	--	.1	--

Table A3. Results of chemical analyses of reference samples and comparison to most probable values.—Continued

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Sample source	Sample code		Chromium		Cobalt		Copper		Iron	
			Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (%)	Percent difference from MPV
NIST	2709	MPV	130±4	--	13.4±0.7	--	34.6±0.7	--	3.5±0.11	--
			120	-7.7	13	-3.0	33	-4.6	3.5	0
			120	-7.7	14	4.5	34	-1.7	3.6	2.9
NIST	2711 MT. Soil	MPV	47	--	10	--	114±2	--	2.89±0.06	--
			45	-4.3	9	-10.0	110	-3.5	2.8	-3.1
			44	-6.4	10	0	110	-3.5	2.8	-3.1
NIST	1646a	MPV	41±2	--	5	--	10±0.34	--	2.00±0.04	--
			39	-4.9	4	-20.0	9	-10.0	1.9	-5.0
			41	0	5	0	10	0	2.0	0
USGS	MAG–1	MPV	97±8	--	20.4±1.6	--	30±3	--	4.75±0.21	--
			100	3.1	22	7.8	28	-6.7	4.9	3.2
			99	2.1	21	2.9	27	-10.0	4.8	1.1
USGS	STM–1	MPV	4.3±2.6	--	0.90±0.15	--	4.6±2.0	--	3.65±0.07	--
			2.7	-37.2	<1	--	4	-13.0	3.6	-1.4
			5	16.3	<1	--	4	-13.0	3.6	-1.4
USGS	SDO–1	MPV	66.4±7.6	--	46.8±6.3	--	60.2±9.6	--	6.53±0.15	--
			70	5.4	49	4.7	55	-8.6	6.4	-2.0
			64	-3.6	46	-1.7	53	-12.0	6.3	-3.5
USGS	SGR–1	MPV	30±3	--	11.8±1.5	--	66±9	--	2.12±0.10	--
			33	10.0	11	-6.8	62	-6.1	2.0	-5.7
			31	3.3	11	-6.8	60	-9.1	2.0	-5.7
USGS	SCO–1	MPV	68±5	--	10.5±0.8	--	28.7±1.9	--	3.59±0.13	--
			72	5.9	11	4.8	28	-2.4	3.6	.3
			67	-1.5	11	4.8	27	-5.9	3.5	-2.5
USGS	QLO–1	MPV	3.2±1.7	--	7.2±0.5	--	29±3	--	3.04±0.10	--
			3	-6.3	7	-2.8	26	-10.3	3.0	-1.3
			4	25.0	7	-2.8	26	-10.3	2.9	-4.6
USGS	GSP–2	MPV	20±6	--	7±1	--	43±4	--	3.43±0.11	--
			16	-20.0	7	0	44	2.3	3.4	-.9
			21	5.0	7	0	43	0	3.3	-3.8

Table A3. Results of chemical analyses of reference samples and comparison to most probable values.—Continued

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Sample source	Sample code		Lead		Lithium		Manganese		Molybdenum	
			Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV
NIST	2709	MPV	18.9±0.5	--	--	--	538±17	--	2.0(?)	--
			19	0.5	54	--	530	-1.5	2	0
			20	5.8	55	--	530	-1.5	2	0
NIST	2711 MT. Soil	MPV	1,162±31	--	--	--	638±28	--	2	--
			1,200	3.3	28	--	640	.3	2	0
			1,100	-5.3	26	--	620	-2.8	2	0
NIST	1646a	MPV	12±1	--	17	--	234±3	--	2	--
			12	0	17	0	230	-1.7	2	0
			11	-8.3	17	0	230	-1.7	2	0
USGS	MAG–1	MPV	24±3	--	79±4	--	760±70	--	1.6±0.6	--
			28	16.7	81	2.5	720	-5.3	1	--
			26	8.3	78	-1.3	700	-7.9	1	--
USGS	STM–1	MPV	17.7±1.8	--	32±8	--	1,700±120	--	5.2±0.9	--
			18	1.7	37	15.6	1,600	-5.9	5	-3.8
			16	-9.6	36	12.5	1,600	-5.9	5	-3.8
USGS	SDO–1	MPV	27.9±5.2	--	28.6±5.5	--	325±39	--	134±21	--
			25	-10.4	32	11.9	310	-4.6	150	11.9
			23	-17.6	29	1.4	300	-7.7	140	4.5
USGS	SGR–1	MPV	38±4	--	147±26	--	267±34	--	35.1±0.9	--
			42	10.5	130	-11.6	230	-13.9	34	-3.1
			41	7.9	130	-11.6	230	-13.9	34	-3.1
USGS	SCO–1	MPV	31±3	--	45±3	--	408±30	--	1.37±0.16	--
			33	6.5	46	2.2	380	-6.9	1	--
			31	0	43	-4.4	380	-6.9	1	--
USGS	QLO–1	MPV	20.4±0.8	--	25±2	--	721±49	--	2.6±0.3	--
			21	2.9	27	8.0	680	-5.7	3	15.4
			21	2.9	25	0	680	-5.7	2	-23.1
USGS	GSP–2	MPV	42±3	--	36±1	--	320±20	--	2.1±0.6	--
			44	4.8	36	0	300	-6.3	2	-4.8
			40	-4.8	34	-5.6	300	-6.3	2	-4.8

Table A3. Results of chemical analyses of reference samples and comparison to most probable values.—Continued

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Sample source	Sample code		Nickel		Nitrogen, total		Phosphorus		Selenium	
			Concentration (mg/kg)	Percent difference from MPV	Concentration (%)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV
NIST	2709	MPV	88±5	--	--	--	620±50	--	1.57±0.08	--
			85	-3.4	0.07	--	650	4.8	1.6	1.9
			85	-3.4	.10	--	630	1.6	1.6	1.9
NIST	2711 MT. Soil	MPV	20.6±1.1	--	--	--	860±70	--	1.52±0.14	--
			21	1.9	.10	--	880	2.3	.9	-40.8
			19	-7.8	.10	--	810	-5.8	1.6	5.3
NIST	1646a	MPV	23	--	--	--	270±10	--	0.19±0.03	--
			22	-4.3	.10	--	280	3.7	.1	--
			21	-8.7	.06	--	280	3.7	.2	--
USGS	MAG–1	MPV	53±8	--	--	--	710±90	--	1.16±0.12	--
			50	-5.7	.30	--	760	7.0	1.0	-13.8
			45	-15.1	.30	--	690	-2.8	1.2	3.4
USGS	STM–1	MPV	3.0±1.6	--	--	--	690±60	--	0.008±0.002	--
			3	0	<.01	--	730	5.8	.1	--
			2	-33.3	<.1	--	680	-1.4	<.1	--
USGS	SDO–1	MPV	99.5±9.9	--	0.35±0.04	--	480±31	--	1.9-6.8	--
			97	-2.5	.30	-14.3	500	4.2	2.1	--
			92	-7.5	.40	14.3	450	-6.3	2.2	--
USGS	SGR–1	MPV	29±5	--	--	--	1,430±290	--	3.5±0.28	--
			29	0	1.00	--	1,200	-16.1	3.5	0
			26	-10.3	.90	--	1,200	-16.1	3.8	8.6
USGS	SCO–1	MPV	27±4	--	--	--	900±90	--	0.89±0.06	--
			26	-3.7	<.01	--	960	6.7	.8	-10.1
			24	-11.1	.06	--	860	-4.4	.9	1.1
USGS	QLO–1	MPV	5.8±3.6	--	--	--	1,110±70	--	0.009±0.002	--
			3	-48.3	<.01	--	1,200	8.1	<.1	--
			2	-65.5	<.1	--	1,100	-.9	<.1	--
USGS	GSP–2	MPV	17±2	--	--	--	1,300±100	--	--	--
			16	-5.9	<.01	--	1,300	0	.1	--
			15	-11.8	<.1	--	1,200	-7.7	.1	--

Table A3. Results of chemical analyses of reference samples and comparison to most probable values.—Continued

[Shading indicates values outside of published limits for each constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; %, percent dry weight; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined or not applicable; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

Sample source	Sample code		Silver		Strontium		Sulfur, total		Thallium	
			Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (%)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV
NIST	2709	MPV	0.41±0.03	--	231±2	--	0.089±0.02	--	0.74±0.05	--
			<.5	--	240	3.9	.08	--	<50	--
			<.5	--	240	3.9	.08	--	<50	--
NIST	2711 MT. Soil	MPV	4.63±0.39	--	245.3±0.7	--	0.042±0.001	--	2.47±0.15	--
			5.0	8.0	250	1.9	.04	--	<50	--
			5.0	8.0	250	1.9	.04	--	<50	--
NIST	1646a	MPV	<.3	--	68	--	0.35±0.04	--	<.5	--
			<.5	--	72	5.9	.34	-2.9	<50	--
			<.5	--	72	5.9	.32	-8.6	<50	--
USGS	MAG–1	MPV	.08	--	146±15	--	0.39±0.07	--	0.590±?	--
			<.5	--	160	9.6	.36	-7.7	<50	--
			<.5	--	140	-4.1	.32	-17.9	<50	--
USGS	STM–1	MPV	.08	--	700±30	--	<.01	--	0.260±0.050	--
			<.5	--	690	-1.4	<.01	--	<50	--
			<.5	--	700	0	<.01	--	<50	--
USGS	SDO–1	MPV	0.1-0.2	--	75.1±11	--	5.35±0.44	--	8.3?	--
			<.6	--	85	13.2	5.10	-4.7	<50	--
			<.5	--	79	5.2	4.90	-8.4	<50	--
USGS	SGR–1	MPV	0.01-0.20	--	420±30	--	1.53±0.11	--	0.330±?	--
			<.5	--	400	-4.8	1.40	-8.5	<50	--
			<.5	--	390	-7.1	1.40	-8.5	<50	--
USGS	SCO–1	MPV	.13	--	174+16	--	0.063±0.009	--	0.72±0.13	--
			<.5	--	190	9.2	.06	--	<50	--
			<.5	--	170	-2.3	.06	--	<50	--
USGS	QLO–1	MPV	.06	--	336±12	--	<.01	--	0.220±0.040	--
			<.5	--	340	1.2	<.01	--	<50	--
			<.5	--	320	-4.8	<.01	--	<50	--
USGS	GSP–2	MPV	--	--	240±10	--	--	--	1.1	--
			<.5	--	250	4.2	.04	--	<50	--
			<.5	--	250	4.2	.04	--	<50	--

Table A3. Results of chemical analyses of reference samples and comparison to most probable values.—Continued

[Shading indicates values outside of published limits for each constituent or ±10 percent of the most probable value, whichever is greater. MPV, most probable value; %, percent dry weight; mg/kg, milligrams per kilogram; NIST, National Institute of Standards and Technology; --, not determined or not applicable; USGS, U.S. Geological Survey; ?, actual value in question; <, less than]

Sample source	Sample code		Tin		Titanium		Vanadium		Uranium		Zinc	
			Concentration (mg/kg)	Percent difference from MPV	Concentration (%)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV	Concentration (mg/kg)	Percent difference from MPV
NIST	2709	MPV	--	--	0.342±0.024	--	112±5	--	3	--	106±3	--
			3	--	.34	-0.6	110	-1.8	<50	--	110	3.8
			2	--	.34	-.6	110	-1.8	<50	--	110	3.8
NIST	2711 MT. Soil	MPV	--	--	0.306±0.023	--	81.6±2.9	--	2.6	--	350.4±4.8	--
			4	--	.31	1.3	82	.5	<50	--	360	2.7
			4	--	.30	-2.0	79	-3.2	<50	--	360	2.7
NIST	1646a	MPV	1	--	0.46±0.02	--	45±1	--	2	--	49±2	--
			2	100.0	.46	0	44	-2.2	<50	--	49	0
			<1	--	.44	-4.3	43	-4.4	<50	--	49	0
USGS	MAG–1	MPV	4	--	0.450±0.040	--	140±6	--	2.7±0.3	--	130±6	--
			3	-25.0	.43	-4.4	140	0	<50	--	140	7.7
			4	0	.41	-8.9	130	-7.1	<50	--	140	7.7
USGS	STM–1	MPV	6.8±1.2	--	0.081±0.007	--	8.7±5.2	--	9.06±0.13	--	235±22	--
			8	17.6	.08	-1.2	3	-65.5	<50	--	250	6.4
			8	17.6	.08	-1.2	3	-65.5	<50	--	240	2.1
USGS	SDO–1	MPV	3.7±1.2	--	0.426±0.019	--	160±21	--	48.8±6.5	--	64.1±6.9	--
			3	-18.9	.41	-3.8	160	0	51	4.5	70	9.2
			2	-45.9	.41	-3.8	150	-6.3	<50	--	70	9.2
USGS	SGR–1	MPV	1.9±0.6	--	0.152±0.015	--	128±6	--	5.4±0.4	--	74±9	--
			2	5.3	.15	-1.3	120	-6.3	<50	--	81	9.5
			1	--	.14	-7.9	120	-6.3	<50	--	75	1.4
USGS	SCO–1	MPV	3.7±0.8	--	0.376±0.039	--	131±13	--	3.0±0.2	--	103±8	--
			4	8.1	.35	-6.9	130	-.8	<50	--	110	6.8
			3	-18.9	.33	-12.2	120	-8.4	<50	--	100	-2.9
USGS	QLO–1	MPV	2.3±0.1	--	0.374±0.020	--	54±6	--	1.94±0.12	--	61±3	--
			2	-13.0	.38	1.6	50	-7.4	<50	--	65	6.6
			2	-13.0	.35	-6.4	48	-11.1	<50	--	60	-1.6
USGS	GSP–2	MPV	--	--	0.40±0.01	--	52±4	--	2.4	--	120±10	--
			7	--	.40	0	53	1.9	<50	--	120	0
			6	--	.39	-2.5	50	-3.8	<50	--	120	0

Table A4. Cesium-137 and lead-210 activities for bottom-sediment samples collected from coring sites E–27 and E–36 in Empire Lake (fig. 2*B*), southeast Kansas, and coring site BHF–1 in Blackberry Hay Farm Lake (fig. 1), southwest Missouri, September 2005.

[All activities in picocuries per gram. <, less than; --, not applicable]

Sediment core interval	Coring site E–27		Coring site E–36		Coring site BHF–1	
	Cesium-137	Lead-210	Cesium-137	Lead-210	Cesium-137	Lead-210
1 (bottom)	<0.05	1.42	<0.05	0.69	0.23	1.73
2	<.05	1.22	<.05	.76	<.05	1.47
3	<.05	1.44	<.05	.96	.20	.59
4	<.05	1.01	<.05	1.09	.20	1.52
5	<.05	1.62	<.05	.91	.85	1.84
6	<.05	1.54	<.05	1.07	.64	1.96
7	<.05	1.01	<.05	.77	.51	2.23
8	<.05	1.62	<.05	.84	.27	1.27
9	<.05	1.51	<.05	1.00	.30	2.32
10	.14	2.09	<.05	.80	.25	2.34
11	.15	3.26	<.05	.95	.25	1.87
12	.13	3.92	<.05	1.01	.20	3.12
13	.17	3.85	<.05	.96	.22	3.87
14	.15	3.80	<.05	1.05	--	--
15 (top)	--	--	.09	1.53	--	--

Table A5. Estimated bulk density of bottom sediment at coring sites in Empire Lake, southeast Kansas, 2005.

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

Coring site number (fig. 2)	Depth interval (inches)	Estimated bulk density (lb/ft^3)	Computed mean bulk density[1] (lb/ft^3)
E–2	0–7.25	46.0	--
	7.25–14.5	58.1	52.0
E–3	0–9.0	44.7	--
	9.0–18.0	51.2	--
	18.0–27.0	48.4	48.1
E–4	0–9.0	43.9	--
	9.0–18.0	47.5	--
	18.0–27.0	49.6	47.0
E–5	0–11.0	43.2	--
	11.0–22.0	47.7	--
	22.0–33.0	46.9	45.9
E–6	0–10.5	49.6	--
	10.5–21.0	56.0	52.8
E–7	0–10.7	55.3	--
	10.7–21.4	54.0	--
	21.4–32.1	58.4	55.9
E–8	0–10.7	55.7	--
	10.7–21.4	55.3	--
	21.4–32.1	53.3	54.8
E–9	0–10.5	65.3	--
	10.5–21.0	61.6	--
	21.0–31.5	58.4	--
	31.5–42.0	64.6	62.5
E–10	0–12.0	40.7	40.7
E–11	0–8.0	38.4	38.4
E–14	0–12.4	44.9	--
	12.4–24.8	46.5	--
	24.8–37.2	64.9	--
	37.2–49.6	66.6	55.7
E–15	0–12.0	46.4	--
	12.0–24.0	59.7	--
	24.0–36.0	57.6	--
	36.0–48.0	57.2	55.2
E–17	0–11.5	42.9	--
	11.5–23.0	48.5	--
	23.0–34.5	56.2	--
	34.5–46.0	59.6	51.8
E–18	0–11.5	40.3	--
	11.5–23.0	45.2	--
	23.0–34.5	45.3	--
	34.5–46.0	56.2	46.8
E–19	0–9.5	45.2	--
	9.5–19.0	52.0	48.6
E–20	0–11.0	52.2	--
	11.0–22.0	51.8	52.0
E–21	0–11.0	57.4	57.4
E–22	0–9.5	47.0	--
	9.5–19.0	63.5	--
	19.0–28.5	62.0	--
	28.5–38.0	62.9	58.8
E–23	0–7.0	58.4	--
	8.0–14.0	63.6	61.0
E–24	0–9.0	53.1	53.1
E–26	0–10.0	45.7	--
	10.0–20.0	44.6	--
	20.0–30.0	54.8	48.4
E–29	0–11.0	64.5	--
	11.0–22.0	58.1	--
	22.0–33.0	56.7	--
	33.0–44.0	58.8	--
	44.0–55.0	67.1	--
	55.0–66.0	67.6	62.1
E–30	0–10.7	59.8	--
	10.7–21.4	65.5	--
	21.4–32.1	68.3	--
	32.1–42.8	63.6	--
	42.8–53.5	65.6	64.6

Table A5. Estimated bulk density of bottom sediment at coring sites in Empire Lake, southeast Kansas, 2005.—Continued

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

Coring site number (fig. 2)	Depth interval (inches)	Estimated bulk density (lb/ft^3)	Computed mean bulk density[1] (lb/ft^3)
E–31	0–11.4	43.3	--
	11.4–22.8	50.8	--
	22.8–34.2	49.5	--
	34.2–45.6	57.6	--
	45.6–57.0	53.1	--
	57.0–68.4	56.7	--
	68.4–79.8	62.6	53.4
E–32	0–12.0	49.2	--
	12.0–24.0	58.7	--
	24.0–36.0	65.6	--
	36.0–48.0	67.4	--
	48.0–60.0	62.0	--
	60.0–72.0	66.0	61.5
E–33	0–11.4	58.9	--
	11.4–22.8	57.3	--
	22.8–34.2	63.3	--
	34.2–45.6	64.9	--
	45.6–57.0	60.5	--
	57.0–68.4	62.4	61.2

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

Table A6. Constituent concentrations for bottom-sediment samples collected from coring site E–1 (fig. 2*B*) in Empire Lake, southeast Kansas, April 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration		
	Interval 1 (bottom of core)	Interval 2 (middle of core)	Interval 3 (top of core)
Nutrients			
Total nitrogen (TN), mg/kg	1,200	1,200	1,300
Total phosphorus (TP), mg/kg	620	630	580
Carbon			
Carbon (total organic, TOC), %	1.3	1.3	1.4
Carbon (total), %	1.6	1.6	1.8
Trace elements			
Aluminum, %	4.5	3.9	3.2
Antimony, mg/kg	.7	.7	.5
Arsenic, mg/kg	6.2	4.5	3.3
Barium, mg/kg	490	470	450
Beryllium, mg/kg	1.7	1.4	1.1
Cadmium, mg/kg	61	52	29
Chromium, mg/kg	77	74	48
Cobalt, mg/kg	18	13	9.1
Copper, mg/kg	47	36	21
Iron, %	1.9	1.6	1.3
Lead, mg/kg	240	230	180
Lithium, mg/kg	30	26	21
Manganese, mg/kg	500	410	380
Mercury, mg/kg	.22	.29	.12
Molybdenum, mg/kg	.8	<1.0	<1.0
Nickel, mg/kg	42	39	24
Selenium, mg/kg	.9	.9	.7
Silver, mg/kg	<.5	<.5	<.5
Strontium, mg/kg	73	68	67
Sulfur, %	.22	.17	.09
Thallium, mg/kg	<50	<50	<50
Tin, mg/kg	--	--	--
Titanium, %	.45	.42	.39
Uranium, mg/kg	<50	<50	<50
Vanadium, mg/kg	61	51	40
Zinc, mg/kg	7,200	4,500	3,100

Table A7. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring sites E–2, E–4, E–8, E–10, and E–11 (fig. 2*B*) in Empire Lake, southeast Kansas, April and August 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration				
	Site E–2	Site E–4	Site E–8	Site E–10	Site E–11
Percentage of silt and clay	77	96	96	76	88
Nutrients					
Total nitrogen (TN), mg/kg	1,000	1,800	2,000	2,500	2,000
Total phosphorus (TP), mg/kg	730	730	740	1,200	1,100
Carbon					
Carbon (total organic, TOC), %	1.5	1.9	1.8	2.1	2.3
Carbon (total), %	1.7	2.0	2.0	2.4	2.6
Trace elements					
Aluminum, %	4.3	5.7	5.6	5.6	4.3
Antimony, mg/kg	.8	1.0	.9	1.0	.7
Arsenic, mg/kg	5.8	8.3	9.2	8.3	4.5
Barium, mg/kg	470	510	540	500	490
Beryllium, mg/kg	1.6	2.2	2.3	1.9	1.6
Cadmium, mg/kg	46	60	43	18	29
Chromium, mg/kg	65	72	65	67	61
Cobalt, mg/kg	21	23	16	15	9
Copper, mg/kg	33	44	38	26	24
Iron, %	2.0	2.6	2.8	2.5	1.7
Lead, mg/kg	220	310	340	170	220
Lithium, mg/kg	30	41	36	38	26
Manganese, mg/kg	900	710	670	820	450
Mercury, mg/kg	--	--	--	--	-
Molybdenum, mg/kg	1	<2	1	3	1
Nickel, mg/kg	48	55	49	26	23
Selenium, mg/kg	.2	.9	1.0	.9	.3
Silver, mg/kg	<.5	<1.0	<.5	.9	1.2
Strontium, mg/kg	78	79	79	77	67
Sulfur, %	.32	.34	.24	.15	.15
Thallium, mg/kg	<50	<50	<50	<50	<50
Tin, mg/kg	4	4	3	3	3
Titanium, %	.42	.47	.49	.50	.45
Uranium, mg/kg	<50	<50	<50	<50	<50
Vanadium, mg/kg	59	81	82	78	58
Zinc, mg/kg	7,800	7,400	8,300	2,500	3,500

Table A8. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site E–6 (fig. 2*B*) in Empire Lake, southeast Kansas, August 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration				
	Interval 1 (bottom of core)	Interval 2	Interval 3	Interval 4	Interval 5 (top of core)
Percentage of silt and clay	95	98	98	95	96
Nutrients					
Total nitrogen (TN), mg/kg	2,000	2,000	2,000	1,000	2,000
Total phosphorus (TP), mg/kg	820	830	730	1,300	940
Carbon					
Carbon (total organic, TOC), %	2.1	2.0	1.8	1.7	1.7
Carbon (total), %	2.3	2.2	1.9	1.8	2.3
Trace elements					
Aluminum, %	5.9	6.3	6.0	5.8	4.8
Antimony, mg/kg	1.0	1.0	1.0	1.0	.8
Arsenic, mg/kg	8.7	12	11	16	6.0
Barium, mg/kg	560	560	550	560	520
Beryllium, mg/kg	2.7	2.9	2.4	2.1	1.7
Cadmium, mg/kg	71	51	48	39	37
Chromium, mg/kg	70	70	67	84	72
Cobalt, mg/kg	24	22	23	23	15
Copper, mg/kg	59	65	35	48	34
Iron, %	3.2	3.3	2.8	2.9	2.2
Lead, mg/kg	620	430	290	270	230
Lithium, mg/kg	37	40	38	38	33
Manganese, mg/kg	1,500	790	490	700	970
Mercury, mg/kg	--	--	--	--	--
Molybdenum, mg/kg	1	1	1	2	1
Nickel, mg/kg	56	71	63	51	33
Selenium, mg/kg	1.4	1.2	.9	.8	.5
Silver, mg/kg	<.5	<.5	<.5	.5	.9
Strontium, mg/kg	83	80	79	83	84
Sulfur, %	.30	.23	.32	.30	.18
Thallium, mg/kg	<50	<50	<50	<50	<50
Tin, mg/kg	2	3	4	5	6
Titanium, %	.50	.47	.52	.53	.45
Uranium, mg/kg	<50	<50	<50	<50	<50
Vanadium, mg/kg	90	93	89	86	64
Zinc, mg/kg	13,000	11,000	9,500	6,100	4,900

Table A9. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring sites E–14, E–17, E–19, and E–22 (fig. 2*B*) in Empire Lake, southeast Kansas, August 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration			
	Site E–14	Site E–17	Site E–19	Site E–22
Percentage of silt and clay	97	94	93	96
Nutrients				
Total nitrogen (TN), mg/kg	1,000	1,000	2,000	1,000
Total phosphorus (TP), mg/kg	810	790	970	610
Carbon				
Carbon (total organic, TOC), %	1.8	1.7	1.7	1.4
Carbon (total), %	1.9	1.9	1.8	1.6
Trace elements				
Aluminum, %	4.9	4.6	5.2	4.3
Antimony, mg/kg	.8	.8	.8	.8
Arsenic, mg/kg	6.3	5.6	7.4	5.8
Barium, mg/kg	570	530	490	560
Beryllium, mg/kg	2.0	1.8	1.8	1.7
Cadmium, mg/kg	29	29	14	36
Chromium, mg/kg	62	68	65	57
Cobalt, mg/kg	13	12	14	16
Copper, mg/kg	27	31	20	24
Iron, %	2.0	1.8	2.3	1.9
Lead, mg/kg	280	250	140	160
Lithium, mg/kg	31	29	34	28
Manganese, mg/kg	760	610	630	840
Mercury, mg/kg	--	--	--	--
Molybdenum, mg/kg	1	1	2	1
Nickel, mg/kg	26	24	26	41
Selenium, mg/kg	.7	.5	.7	.7
Silver, mg/kg	.6	.5	.7	.5
Strontium, mg/kg	71	70	80	77
Sulfur, %	.11	.13	.13	.24
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	4	5	4	3
Titanium, %	.49	.46	.49	.47
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	70	64	76	62
Zinc, mg/kg	5,100	4,600	2,300	6,400

Table A10. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring sites E–23, E–24, E–25, and E–26 (fig. 2*B*) in Empire Lake, southeast Kansas, August and September 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration			
	Site E–23	Site E–24	Site E–25	Site E–26
Percentage of silt and clay	90	88	86	96
Nutrients				
Total nitrogen (TN), mg/kg	1,000	1,000	2,000	2,000
Total phosphorus (TP), mg/kg	830	610	1,100	760
Carbon				
Carbon (total organic, TOC), %	1.6	1.6	1.7	1.8
Carbon (total), %	1.8	1.8	1.8	2.0
Trace elements				
Aluminum, %	5.1	4.2	5.4	4.5
Antimony, mg/kg	.9	.7	.9	.8
Arsenic, mg/kg	9.1	5.6	7.2	4.7
Barium, mg/kg	510	520	530	520
Beryllium, mg/kg	2.2	1.5	1.9	1.8
Cadmium, mg/kg	60	25	7.3	32
Chromium, mg/kg	66	73	65	56
Cobalt, mg/kg	16	12	16	11
Copper, mg/kg	49	28	20	25
Iron, %	2.6	1.7	2.5	1.7
Lead, mg/kg	350	170	100	280
Lithium, mg/kg	34	29	36	28
Manganese, mg/kg	1,100	620	1,100	530
Mercury, mg/kg	--	--	--	--
Molybdenum, mg/kg	1	<1	1	1
Nickel, mg/kg	39	32	33	22
Selenium, mg/kg	1.0	.5	.8	1.0
Silver, mg/kg	.8	<.5	<.5	.8
Strontium, mg/kg	78	77	84	69
Sulfur, %	.33	.23	.10	.13
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	3	3	3	6
Titanium, %	.47	.45	.49	.47
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	75	59	79	62
Zinc, mg/kg	9,300	3,700	1,300	4,700

Table A11. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring sites E–29, E–31, E–32, and E–33 (fig. 2*B*) in Empire Lake, southeast Kansas, September 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration			
	Site E–29	Site E–31	Site E–32	Site E–33
Percentage of silt and clay	95	97	95	94
Nutrients				
Total nitrogen (TN), mg/kg	2,000	2,000	2,000	2,000
Total phosphorus (TP), mg/kg	820	880	730	730
Carbon				
Carbon (total organic, TOC), %	1.8	1.8	1.7	1.6
Carbon (total), %	2.1	2.1	1.9	1.9
Trace elements				
Aluminum, %	5.6	5.0	4.5	4.7
Antimony, mg/kg	1.1	.8	.8	.9
Arsenic, mg/kg	10	5.8	6.0	7.2
Barium, mg/kg	490	530	530	540
Beryllium, mg/kg	2.4	1.8	1.8	1.8
Cadmium, mg/kg	72	27	23	24
Chromium, mg/kg	69	71	62	63
Cobalt, mg/kg	13	13	12	13
Copper, mg/kg	56	41	27	31
Iron, %	2.9	2.0	1.9	2.1
Lead, mg/kg	950	260	270	270
Lithium, mg/kg	34	30	28	30
Manganese, mg/kg	490	690	670	670
Mercury, mg/kg	--	--	--	--
Molybdenum, mg/kg	1	1	1	1
Nickel, mg/kg	42	25	26	30
Selenium, mg/kg	1.7	.9	.6	1.0
Silver, mg/kg	<.5	<.5	<.5	.5
Strontium, mg/kg	75	68	70	71
Sulfur, %	.40	.10	.10	.10
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	3	4	3	3
Titanium, %	.44	.47	.48	.46
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	80	64	66	69
Zinc, mg/kg	11,000	3,800	4,200	4,600

Table A12. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site E–27 (fig. 2*B*) in Empire Lake, southeast Kansas, September 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

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	98	100	100	99	99
Nutrients					
Total nitrogen (TN), mg/kg	2,000	2,000	2,000	2,000	2,000
Total phosphorus (TP), mg/kg	680	700	710	710	570
Carbon					
Carbon (total organic, TOC), %	1.9	1.7	1.8	1.8	1.6
Carbon (total), %	2.0	1.8	2.0	2.0	1.7
Trace elements					
Aluminum, %	5.0	5.0	5.6	5.4	4.5
Antimony, mg/kg	.9	.9	1.1	.9	.8
Arsenic, mg/kg	5.5	6.3	6.9	7.2	5.7
Barium, mg/kg	570	580	620	650	590
Beryllium, mg/kg	2.0	2.1	2.2	2.1	1.7
Cadmium, mg/kg	40	38	28	29	18
Chromium, mg/kg	54	54	55	54	50
Cobalt, mg/kg	13	12	14	16	13
Copper, mg/kg	42	43	33	30	26
Iron, %	1.9	2.0	2.2	2.3	1.8
Lead, mg/kg	590	560	330	240	260
Lithium, mg/kg	30	30	32	32	27
Manganese, mg/kg	370	610	820	1,500	1,300
Mercury, mg/kg	--	--	--	--	-
Molybdenum, mg/kg	1	1	1	1	1
Nickel, mg/kg	23	24	24	24	18
Selenium, mg/kg	1.2	1.3	1.0	.8	.8
Silver, mg/kg	<.5	<.5	<.5	<.5	<.5
Strontium, mg/kg	67	68	67	67	66
Sulfur, %	.17	.13	.07	.07	.09
Thallium, mg/kg	<50	<50	<50	<50	<50
Tin, mg/kg	2	3	3	2	2
Titanium, %	.48	.49	.51	.54	.50
Uranium, mg/kg	<50	<50	<50	<50	<50
Vanadium, mg/kg	70	72	76	76	63
Zinc, mg/kg	8,500	8,900	6,500	6,600	4,100

Table A12. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site E–27 (fig. 2*B*) in Empire Lake, southeast Kansas, September 2005.—Continued

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration				
	Interval 6	Interval 7	Interval 8	Interval 9	Interval 10
Percentage of silt and clay	66	98	99	97	93
Nutrients					
Total nitrogen (TN), mg/kg	2,000	2,000	2,000	2,000	2,000
Total phosphorus (TP), mg/kg	650	770	700	640	710
Carbon					
Carbon (total organic, TOC), %	1.6	1.8	1.7	1.6	1.7
Carbon (total), %	1.8	2.0	2.0	1.8	1.9
Trace elements					
Aluminum, %	5.3	5.5	4.8	4.7	4.3
Antimony, mg/kg	1.0	.8	1.0	.9	.8
Arsenic, mg/kg	7.0	7.1	5.6	4.7	4.5
Barium, mg/kg	630	630	580	560	530
Beryllium, mg/kg	2.0	2.3	2.1	1.8	1.6
Cadmium, mg/kg	22	33	36	21	27
Chromium, mg/kg	54	55	58	54	57
Cobalt, mg/kg	14	16	14	12	11
Copper, mg/kg	27	31	31	26	24
Iron, %	2.1	2.3	1.9	1.9	1.7
Lead, mg/kg	240	310	400	280	260
Lithium, mg/kg	31	33	30	29	27
Manganese, mg/kg	900	1,000	820	560	420
Mercury, mg/kg	--	--	--	--	--
Molybdenum, mg/kg	1	1	1	1	<1
Nickel, mg/kg	22	28	23	21	25
Selenium, mg/kg	.8	1.0	.6	.8	.9
Silver, mg/kg	<.5	<.5	<.5	1.2	1.4
Strontium, mg/kg	67	67	65	66	66
Sulfur, %	.08	.10	.11	.09	.12
Thallium, mg/kg	<50	<50	<50	<50	<50
Tin, mg/kg	3	4	3	3	3
Titanium, %	.52	.50	.50	.50	.46
Uranium, mg/kg	<50	<50	<50	<50	<50
Vanadium, mg/kg	74	79	71	66	57
Zinc, mg/kg	5,000	8,000	6,900	4,100	3,800

Table A12. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site E–27 (fig. 2*B*) in Empire Lake, southeast Kansas, September 2005.—Continued

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration			
	Interval 11	Interval 12	Interval 13	Interval 14 (top of core)
Percentage of silt and clay	76	96	97	94
Nutrients				
Total nitrogen (TN), mg/kg	2,000	2,000	2,000	2,000
Total phosphorus (TP), mg/kg	780	950	1,100	1,100
Carbon				
Carbon (total organic, TOC), %	1.9	2.2	2.4	2.3
Carbon (total), %	2.0	2.3	2.4	2.5
Trace elements				
Aluminum, %	4.1	4.5	4.5	4.5
Antimony, mg/kg	.8	.7	.7	.7
Arsenic, mg/kg	4.9	3.8	4.9	4.4
Barium, mg/kg	510	530	530	540
Beryllium, mg/kg	1.5	1.7	1.7	1.7
Cadmium, mg/kg	26	29	30	29
Chromium, mg/kg	52	61	60	63
Cobalt, mg/kg	9	10	11	9
Copper, mg/kg	22	24	24	23
Iron, %	1.6	1.7	1.8	1.8
Lead, mg/kg	220	230	230	210
Lithium, mg/kg	25	28	28	27
Manganese, mg/kg	410	450	540	630
Mercury, mg/kg	--	--	--	--
Molybdenum, mg/kg	1	1	1	1
Nickel, mg/kg	23	25	26	24
Selenium, mg/kg	1.0	1.1	1.2	.9
Silver, mg/kg	1.0	1.3	1.2	1.6
Strontium, mg/kg	65	70	71	71
Sulfur, %	.12	.14	.16	.14
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	3	3	2	3
Titanium, %	.45	.45	.45	.46
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	53	59	61	59
Zinc, mg/kg	3,200	3,600	3,700	3,600

Table A13. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site E–36 (fig. 2*B*) in Empire Lake, southeast Kansas, September 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration			
	Interval 0 (original flood-plain material)	Interval 1 (bottom of core)	Interval 2	Interval 3
Percentage of silt and clay	82	100	98	99
Nutrients				
Total nitrogen (TN), mg/kg	2,000	2,000	2,000	2,000
Total phosphorus (TP), mg/kg	500	710	760	630
Carbon				
Carbon (total organic, TOC), %	1.6	2.2	2.0	1.9
Carbon (total), %	1.6	2.4	2.4	2.2
Trace elements				
Aluminum, %	4.2	5.5	5.5	5.1
Antimony, mg/kg	.7	1.0	1.2	.9
Arsenic, mg/kg	4.9	8.1	9.6	8.5
Barium, mg/kg	480	500	460	470
Beryllium, mg/kg	1.4	2.1	2.2	2.1
Cadmium, mg/kg	12	51	73	76
Chromium, mg/kg	47	61	66	57
Cobalt, mg/kg	9	16	16	13
Copper, mg/kg	17	43	53	45
Iron, %	1.7	2.7	3.1	2.6
Lead, mg/kg	380	580	730	530
Lithium, mg/kg	26	32	32	30
Manganese, mg/kg	170	730	650	410
Mercury, mg/kg	--	--	--	--
Molybdenum, mg/kg	<1	1	1	1
Nickel, mg/kg	18	33	40	41
Selenium, mg/kg	.6	1.3	1.5	1.2
Silver, mg/kg	<.5	<.5	<.5	<.5
Strontium, mg/kg	67	72	71	70
Sulfur, %	.04	.31	.44	.30
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	2	3	3	2
Titanium, %	.43	.45	.43	.43
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	58	76	77	71
Zinc, mg/kg	1,700	8,400	12,000	12,000

Table A13. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site E–36 (fig. 2*B*) in Empire Lake, southeast Kansas, September 2005.—Continued

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration			
	Interval 4	Interval 5	Interval 6	Interval 7
Percentage of silt and clay	99	100	97	99
Nutrients				
Total nitrogen (TN), mg/kg	2,000	2,000	2,000	2,000
Total phosphorus (TP), mg/kg	720	620	550	650
Carbon				
Carbon (total organic, TOC), %	2.0	1.9	1.6	1.9
Carbon (total), %	2.1	2.2	1.9	2.1
Trace elements				
Aluminum, %	5.8	5.3	4.4	5.4
Antimony, mg/kg	1.0	1.0	.9	.9
Arsenic, mg/kg	9.1	7.9	6.6	8.1
Barium, mg/kg	500	480	490	520
Beryllium, mg/kg	2.6	2.1	1.8	2.0
Cadmium, mg/kg	71	75	41	60
Chromium, mg/kg	64	61	50	57
Cobalt, mg/kg	14	13	10	13
Copper, mg/kg	48	39	41	41
Iron, %	3.1	2.5	2.0	2.4
Lead, mg/kg	590	550	530	530
Lithium, mg/kg	35	32	26	32
Manganese, mg/kg	450	420	580	480
Mercury, mg/kg	--	--	--	--
Molybdenum, mg/kg	1	1	1	1
Nickel, mg/kg	46	41	27	38
Selenium, mg/kg	1.4	1.2	1.1	1.2
Silver, mg/kg	<.5	<.5	<.5	<.5
Strontium, mg/kg	74	72	65	69
Sulfur, %	.27	.33	.20	.27
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	3	2	2	2
Titanium, %	.46	.44	.43	.46
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	81	73	61	74
Zinc, mg/kg	10,000	11,000	8,100	9,900

Table A13. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site E–36 (fig. 2*B*) in Empire Lake, southeast Kansas, September 2005.—Continued

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration			
	Interval 8	Interval 9	Interval 10	Interval 11
Percentage of silt and clay	100	100	96	100
Nutrients				
Total nitrogen (TN), mg/kg	2,000	2,000	2,000	2,000
Total phosphorus (TP), mg/kg	640	610	690	610
Carbon				
Carbon (total organic, TOC), %	1.9	1.8	2.0	1.7
Carbon (total), %	2.1	2.0	2.1	1.8
Trace elements				
Aluminum, %	5.9	5.6	6.1	5.3
Antimony, mg/kg	.8	.9	.9	.9
Arsenic, mg/kg	8.5	7.2	7.9	6.4
Barium, mg/kg	520	530	540	520
Beryllium, mg/kg	2.2	2.0	2.2	2.0
Cadmium, mg/kg	35	25	25	23
Chromium, mg/kg	60	57	63	57
Cobalt, mg/kg	16	14	14	14
Copper, mg/kg	27	24	28	25
Iron, %	3.0	2.6	3.0	2.6
Lead, mg/kg	250	170	250	220
Lithium, mg/kg	35	34	35	32
Manganese, mg/kg	510	450	540	630
Mercury, mg/kg	--	--	--	--
Molybdenum, mg/kg	1	1	1	1
Nickel, mg/kg	48	41	40	37
Selenium, mg/kg	.9	.9	1.0	1.0
Silver, mg/kg	<.5	<.5	<.5	<.5
Strontium, mg/kg	73	73	73	71
Sulfur, %	.16	.13	.14	.16
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	3	3	3	4
Titanium, %	.47	.50	.49	.49
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	78	76	83	74
Zinc, mg/kg	5,000	4,700	4,600	4,400

Table A13. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site E–36 (fig. 2*B*) in Empire Lake, southeast Kansas, September 2005.—Continued

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration			
	Interval 12	Interval 13	Interval 14	Interval 15 (top of core)
Percentage of silt and clay	96	99	97	86
Nutrients				
Total nitrogen (TN), mg/kg	2,000	2,000	1,000	1,000
Total phosphorus (TP), mg/kg	610	590	570	770
Carbon				
Carbon (total organic, TOC), %	1.6	1.6	1.5	1.4
Carbon (total), %	1.7	1.8	1.6	1.6
Trace elements				
Aluminum, %	5.1	5.0	5.3	4.5
Antimony, mg/kg	1.0	.8	.8	.7
Arsenic, mg/kg	5.8	5.0	7.9	6.9
Barium, mg/kg	540	510	520	470
Beryllium, mg/kg	1.9	1.8	1.8	1.5
Cadmium, mg/kg	22	28	26	27
Chromium, mg/kg	54	53	58	69
Cobalt, mg/kg	13	15	15	12
Copper, mg/kg	26	25	38	51
Iron, %	2.2	2.2	2.1	1.9
Lead, mg/kg	350	250	230	200
Lithium, mg/kg	30	30	32	28
Manganese, mg/kg	670	590	340	300
Mercury, mg/kg	--	--	--	--
Molybdenum, mg/kg	1	1	1	1
Nickel, mg/kg	28	35	31	30
Selenium, mg/kg	1.1	.7	.8	.7
Silver, mg/kg	.6	<.5	<.5	<.5
Strontium, mg/kg	68	67	71	67
Sulfur, %	.09	.14	.13	.19
Thallium, mg/kg	<50	<50	<50	<50
Tin, mg/kg	3	3	4	2
Titanium, %	.48	.46	.50	.42
Uranium, mg/kg	<50	<50	<50	<50
Vanadium, mg/kg	69	67	70	58
Zinc, mg/kg	4,200	5,200	4,300	4,200

Table A14. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site BHF–1 in Blackberry Hay Farm Lake (fig. 1), southwest Missouri, September 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

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	93	82	84	48	71
Nutrients					
Total nitrogen (TN), mg/kg	1,000	800	1,000	1,000	1,000
Total phosphorus (TP), mg/kg	430	280	340	340	410
Carbon					
Carbon (total organic, TOC), %	1.2	.9	1.1	1.0	1.3
Carbon (total), %	1.2	.9	1.2	1.1	1.2
Trace elements					
Aluminum, %	4.7	3.4	4.0	4.1	4.8
Antimony, mg/kg	.9	.8	1.0	.9	.9
Arsenic, mg/kg	6.7	5.9	6.1	5.9	7.2
Barium, mg/kg	470	380	440	490	460
Beryllium, mg/kg	1.5	1.2	1.4	1.4	1.5
Cadmium, mg/kg	.4	.1	.3	.4	.4
Chromium, mg/kg	56	42	49	50	57
Cobalt, mg/kg	9	10	11	10	11
Copper, mg/kg	13	8.8	11	11	13
Iron, %	2.1	1.8	1.8	1.7	2.1
Lead, mg/kg	33	24	37	33	36
Lithium, mg/kg	32	24	28	30	34
Manganese, mg/kg	400	400	290	330	450
Mercury, mg/kg	--	--	--	--	--
Molybdenum, mg/kg	1	1	1	1	1
Nickel, mg/kg	27	12	14	14	16
Selenium, mg/kg	.7	.5	.6	.6	.4
Silver, mg/kg	.6	.6	<.5	<.5	<.5
Strontium, mg/kg	73	57	65	69	73
Sulfur, %	.07	.02	.03	.04	.06
Thallium, mg/kg	<50	<50	<50	<50	<50
Tin, mg/kg	2	1	2	2	2
Titanium, %	.50	.43	.47	.49	.50
Uranium, mg/kg	<50	<50	<50	<50	<50
Vanadium, mg/kg	74	58	65	63	73
Zinc, mg/kg	99	38	66	82	92

Table A14. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site BHF–1 in Blackberry Hay Farm Lake (fig. 1), southwest Missouri, September 2005.—Continued

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration				
	Interval 6	Interval 7	Interval 8	Interval 9	Interval 10
Percentage of silt and clay	98	98	98	96	95
Nutrients					
Total nitrogen (TN), mg/kg	1,000	1,000	1,000	1,000	1,000
Total phosphorus (TP), mg/kg	450	450	450	420	420
Carbon					
Carbon (total organic, TOC), %	1.2	1.3	1.2	1.1	1.1
Carbon (total), %	1.3	1.4	1.2	1.3	1.2
Trace elements					
Aluminum, %	5.1	5.2	5.3	5.1	4.9
Antimony, mg/kg	1.0	1.0	1.0	1.0	1.0
Arsenic, mg/kg	7.9	7.7	7.4	6.4	6.5
Barium, mg/kg	500	510	530	520	500
Beryllium, mg/kg	1.7	1.7	1.7	1.6	1.6
Cadmium, mg/kg	.5	.4	.3	.2	.3
Chromium, mg/kg	60	59	61	58	56
Cobalt, mg/kg	11	12	11	10	11
Copper, mg/kg	13	13	14	13	13
Iron, %	2.3	2.3	2.2	2.1	2.0
Lead, mg/kg	40	38	37	34	33
Lithium, mg/kg	36	35	36	34	33
Manganese, mg/kg	480	460	420	380	360
Mercury, mg/kg	--	--	--	--	--
Molybdenum, mg/kg	1	1	1	1	1
Nickel, mg/kg	18	18	17	16	16
Selenium, mg/kg	.6	.7	.8	.7	.8
Silver, mg/kg	<.5	<.5	<.5	<.5	.6
Strontium, mg/kg	75	76	78	78	76
Sulfur, %	.05	.05	.07	.08	.07
Thallium, mg/kg	<50	<50	<50	<50	<50
Tin, mg/kg	2	2	2	2	2
Titanium, %	.52	.49	.52	.54	.51
Uranium, mg/kg	<50	<50	<50	<50	<50
Vanadium, mg/kg	80	80	83	79	77
Zinc, mg/kg	100	100	86	82	88

Table A14. Percentage of silt and clay and constituent concentrations for bottom-sediment samples collected from coring site BHF–1 in Blackberry Hay Farm Lake (fig. 1), southwest Missouri, September 2005.—Continued

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration		
	Interval 11	Interval 12	Interval 13 (top of core)
Percentage of silt and clay	94	91	95
Nutrients			
Total nitrogen (TN), mg/kg	1,000	1,000	1,000
Total phosphorus (TP), mg/kg	480	590	690
Carbon			
Carbon (total organic, TOC), %	1.1	1.1	1.1
Carbon (total), %	1.2	1.1	1.3
Trace elements			
Aluminum, %	4.9	4.6	4.6
Antimony, mg/kg	.9	.9	.9
Arsenic, mg/kg	7.1	7.4	8.1
Barium, mg/kg	500	480	470
Beryllium, mg/kg	1.6	1.5	1.5
Cadmium, mg/kg	.4	.5	.5
Chromium, mg/kg	61	56	55
Cobalt, mg/kg	12	11	11
Copper, mg/kg	13	13	13
Iron, %	2.1	2.1	2.2
Lead, mg/kg	33	31	30
Lithium, mg/kg	34	31	31
Manganese, mg/kg	400	500	680
Mercury, mg/kg	--	--	--
Molybdenum, mg/kg	1	1	1
Nickel, mg/kg	16	14	14
Selenium, mg/kg	.6	.5	.7
Silver, mg/kg	.6	<.5	<.5
Strontium, mg/kg	76	73	74
Sulfur, %	.07	.04	.03
Thallium, mg/kg	<50	<50	<50
Tin, mg/kg	2	2	2
Titanium, %	.53	.49	.49
Uranium, mg/kg	<50	<50	<50
Vanadium, mg/kg	79	74	75
Zinc, mg/kg	110	110	120

Table A15. Percentage of silt and clay and constituent concentrations for flood-plain soil samples collected from sites SCF–1 and SRF–1 (fig. 2*B*) near Empire Lake, southeast Kansas, August 2005.

[mg/kg, milligrams per kilogram; %, percent dry weight; <, less than; --, not determined]

Constituent and unit of measurement	Constituent concentration	
	Site SCF–1	Site SRF–1
Percentage of silt and clay	70	48
Nutrients		
Total nitrogen (TN), mg/kg	1,600	1,400
Total phosphorus (TP), mg/kg	480	650
Carbon		
Carbon (total organic, TOC), %	1.4	1.2
Carbon (total), %	1.4	1.3
Trace elements		
Aluminum, %	2.9	3.9
Antimony, mg/kg	.8	.8
Arsenic, mg/kg	3.8	5.1
Barium, mg/kg	450	430
Beryllium, mg/kg	1.0	1.3
Cadmium, mg/kg	.9	4.3
Chromium, mg/kg	35	48
Cobalt, mg/kg	6	9
Copper, mg/kg	12	13
Iron, %	1.1	1.6
Lead, mg/kg	36	68
Lithium, mg/kg	20	27
Manganese, mg/kg	490	520
Mercury, mg/kg	--	--
Molybdenum, mg/kg	1	1
Nickel, mg/kg	9	15
Selenium, mg/kg	.2	.4
Silver, mg/kg	<.5	<1.0
Strontium, mg/kg	59	69
Sulfur, %	.02	.04
Thallium, mg/kg	<50	<100
Tin, mg/kg	1	1
Titanium, %	.43	.46
Uranium, mg/kg	<50	<100
Vanadium, mg/kg	42	57
Zinc, mg/kg	200	750

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