Prepared in cooperation with the
JOHNSON COUNTY STORMWATER MANAGEMENT PROGRAM

Bottom-Sediment Accumulation and Quality in Shawnee Mission Lake, Johnson County, Kansas, 2006

1966

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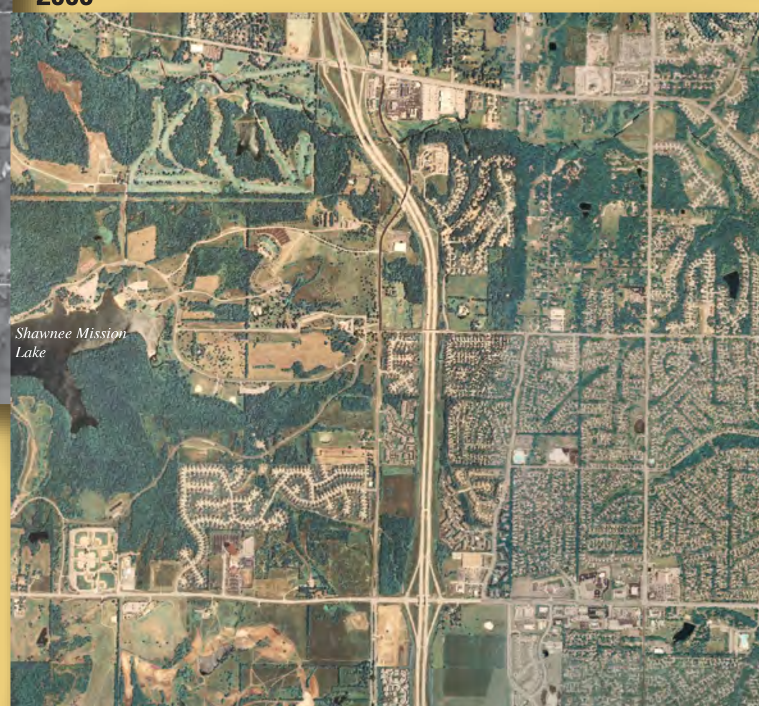

Scientific Investigations Report 2007–5274
Revised August 2009

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

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By Casey J. Lee, Kyle E. Juracek, and Christopher C. Fuller

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Conversion Factors, Abbreviations, and Datum

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
micron (µm)	0.00003937	inch (in.)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
	Mass	
gram (g)	0.002205	pound (lb)
	Density	
pound per cubic foot (lb/ft^3)	.01602	gram per cubic centimeter (g/cm^3)
	Rate	
inch per year (in/yr)	2.54	centimeter per year (cm/yr)
	Concentration	
milligram per kilogram (mg/kg)	1.0	part per million (ppm)

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

Bottom-Sediment Accumulation and Quality in Shawnee Mission Lake, Johnson County, Kansas, 2006

By Casey J. Lee, Kyle E. Juracek, and Christopher C. Fuller

Abstract

Shawnee Mission Lake is an artificial impoundment central to Shawnee Mission Park, the largest public park in Johnson County, Kansas. The Shawnee Mission Lake watershed has remained relatively undeveloped since the completion of the dam in 1962. However, recent (1990–2006) urban development has been a cause for concern regarding the quantity and quality of sediment entering the reservoir. The U.S. Geological Survey collected two cores of bottom sediment to assess sediment accumulation and quality in Shawnee Mission Lake. Results from this study indicate that sediment accumulation has remained relatively constant from 1970–2006 at the downstream portion of the reservoir. Runoff from urban portions of the watershed are likely responsible for larger concentrations of selected trace elements in more recently deposited reservoir sediment. Information provided in this report can be used by Johnson County officials to help determine the current and future recreational capacity of the lake.

Introduction

In 1954, 1,248 acres of land were purchased by the Shawnee Mission Park District in north-central Johnson County, Kansas, for the development of a "big outdoor community playground" named Shawnee Mission Park (Barnes, 1956) (fig. 1). The centerpiece of the park is Shawnee Mission Lake, a 150-acre reservoir completed in 1962. The lake is one of the largest reservoirs in Johnson County, supporting swimming, boating, and fishing for area residents. Artificial impoundments such as Shawnee Mission Lake retain water and suspended sediment contributed by the surrounding watershed. Sediment accumulation in surface-water impoundments decreases water-storage capacity and can degrade the recreational and aesthetic value of the lake (Morris and Fan, 1997).

Watersheds with little or no land disturbance typically yield the least amount of suspended sediment. Construction activities associated with urban development have been shown to increase stream-sediment loads by 100 times when compared to reference conditions (Wolman, 1967). After development, impervious surfaces, such as roads, driveways, and rooftops, route rainwater directly into streams, increasing stream velocities and the erosion of sediment from stream channels (Leopold and others, 2005). Nutrients, trace elements, and radionuclides adsorbed to sediment can act to degrade water quality in streams and lakes. Analysis of these chemical constituents in lake-bottom sediment can provide a history of sediment loading and quality in the watershed, which then can be related to changes in land use.

Prior to residential construction, the 1,860-acre Shawnee Mission Lake watershed was characterized by undisturbed, timbered rolling hills. Because of concerns regarding recent (1990–2006) urban development in the Shawnee Mission Lake watershed, the U.S. Geological Survey (USGS), in cooperation with the Johnson County Stormwater Management Program, undertook a study of sediment deposition and quality in Shawnee Mission Lake.

Purpose and Scope

This report describes bottom-sediment accumulation and quality in Shawnee Mission Lake. The U.S. Geological Survey collected two cores of bottom sediment in 2006 from Shawnee Mission Lake to estimate the amount of sediment deposition from 1962–2006 and to characterize the quality of sediment using historical reconstruction techniques (Juracek, 2004; Van Metre and others, 2004). Results of nutrient, trace element, and radionuclide analysis of sediment cores collected in 2006 are described. These results support Federal, State, and local watershed efforts to improve water quality and to identify processes leading to increased transport of fluvial sediment. Information provided in this study can be used by Johnson County officials to help determine the current and future recreational capacity of Shawnee Mission Lake.

Acknowledgments

The authors are grateful to the Johnson County Museum for access to historical newspapers and aerial photography. The authors also thank Shannon Porter of the Johnson County Automated Information Mapping System for

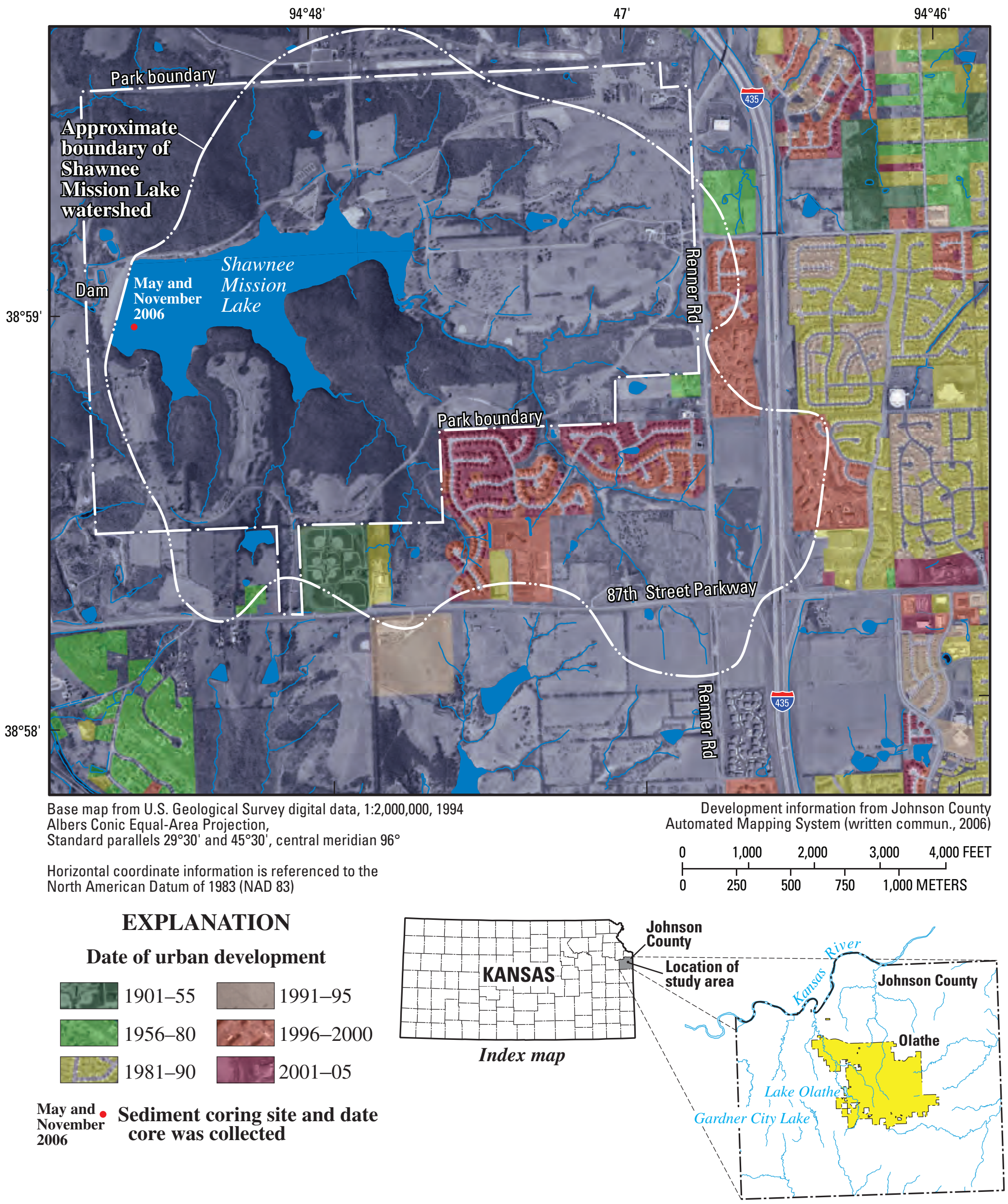

Figure 1. Urban development in and near the Shawnee Mission Lake watershed, Johnson County, Kansas, 2006.

assistance in obtaining and working with geographic information system data.

Methods

Sample Collection and Laboratory Methods

Two cores of bottom sediment from Shawnee Mission Lake (fig. 1) were collected in May (core 1) and November of 2006 (core 2) using a gravity corer (fig. 2). Sediment cores were collected near the dam (fig. 1) because sediment accumulation there is typically the most homogenous and least prone to disturbance (Van Metre and others, 2004). Water depth at the coring sites was approximately 40 ft; the gravity corer was dropped into the sediment from a height of approximately 10 ft above the lake bottom. Although several cores were collected in May and November 2006, recovering a range of 10 to 21 in. of sediment, the two cores that were selected for analysis penetrated to original, pre-impoundment soils, which were distinguished from entrained sediment by the presence of rocks and root hairs. The use of a gravity corer can result in collection of a sediment profile shorter than the amount of actual sediment deposition. This “core shortening” results from the friction of the sediment against the inner wall of the sample tube and may not be uniform throughout the core. Studies in Kansas reservoirs have indicated core recoveries in the range of 50 to 75 percent of deposited sediments (Juracek, 2004).

Core 1 penetrated impoundment soils to a depth of 20.5 inches and was sampled every 2 inches. Core 2

Figure 2. Photograph showing pontoon boat mounted with gravity corer used to collect bottom sediment cores from Shawnee Mission Lake May and November 2006.

penetrated impoundment sediment to a depth of 13 inches, and was subsampled every 1 inch. Core 1 was used for analysis of 4 radionuclides, nitrogen, phosphorus, and 27 trace elements; core 2 was analyzed for bulk density and radionuclides. Bulk-density analysis was performed using methods described in Guy (1969). Radionuclides were analyzed at the USGS laboratory in Menlo Park, California, using a high-resolution gamma spectrometer with an intrinsic germanium detector (Robbins and Edgington, 1986; Fuller and others, 1999). Nutrient and trace element analysis of lake sediment was performed by the USGS Sediment Trace Element Partitioning Laboratory in Atlanta, Georgia. Sediment was sieved to less than 63 µm (to compensate for potential grain-size differences) and analyzed for nutrients and trace elements using methods described in Horowitz and others (2001).

Quality Control

One duplicate sample was analyzed for nutrient and trace element data. Relative percentage differences between original and duplicate analyses were generally within 10 percent, with the exception of cadmium (40 percent), selenium (31 percent), and tin (13 percent). Concentrations of these analytes were near laboratory reporting levels, thus small differences in concentration resulted in large percentage differences between original and duplicate analyses. Uncertainty estimates for radionuclide analyses are based on activity level and instrument calibration error. These estimates ranged from 0.01 to 0.07 picocuries/gram for cesium-137 and from 0.12 to 0.47 for "excess" lead-210.

Age and Accumulation Rates of Lake-Bottom Sediment

Environmental activities of the radionuclides natural beryllium-7 (^{7}Be), anthropogenic cesium-137 (^{137}Cs), and lead-210 (^{210}Pb), were measured in the sediment cores to date the ages of lake-bottom sediment (tables 1 and 2). These radionuclides were found entrained on bottom sediment through atmospheric fallout to the lake surface and surrounding watershed, and subsequent deposition to the lake bottom. After deposition, radionuclides decayed at varying rates depending on their respective half-lives (53.3 days for ^{7}Be, 30.3 years for ^{137}Cs, and 22.3 years for ^{210}Pb) (Holmes, 1998).

^{7}Be is produced in the upper atmosphere by cosmic ray interaction with nitrogen. Because of its short half-life, detection in lake-bottom sediment indicates recent sediment accumulation and mixing of sediment. ^{137}Cs was artificially produced as a byproduct of nuclear fission; global release to the environment occurred from above-ground nuclear weapons testing. Measurable fallout of ^{137}Cs began in 1952. Maximum fallout deposition occurred in 1963–64; then decreased steadily due to the nuclear test ban treaty of 1963 (Ritchie and McHenry, 1990). ^{210}Pb is a naturally occurring isotope in the uranium-238 decay series. When compared to the activity of its long-lived parent, ^{226}Ra, levels of "excess" ^{210}Pb in lake-bottom sediment can be used to age date core-sediment profiles.

The constant flux:constant sedimentation method (Appleby and Oldfield, 1992) was used to age date sediment intervals from "excess" ^{210}Pb profiles. The ^{137}Cs profile then was used as a test of the "excess" ^{210}Pb-derived sediment accumulation rate and as an indicator of sediment mixing or reworking (Fuller and others, 1999). Precipitation data recorded at Olathe, Kansas, generally indicate even distribution of precipitation amount and intensity since 1962 (fig. 3).

^{7}Be was not detected in either sediment core because sediment with detectable activity was diluted by previously deposited sediment in which ^{7}Be activity had decayed to less than laboratory reporting levels (tables 1 and 2). ^{137}Cs activity had well-defined peak values in both cores followed by an exponential decrease in activity (fig. 4), indicating that sediment profiles in the cores were undisturbed by mixing (Van Metre and others, 1997). Excess ^{210}Pb data had a two-slope exponential decrease in core 1 (1 in/yr from 1964–1970; 0.19 in/yr from 1970–2006) and a more uniform exponential decrease in core 2 (fig. 4). Anomalies in constant decay rate in the 7- and 9-in. depth intervals (fig. 4*B*) of core 2 may have been caused by shoreline erosion, road construction at the inception of the park, or by soils disturbed during construction of the reservoir. Data below a depth of about 15 in. in core 1, and below 11 in. in core 2, had little excess ^{210}Pb activity and represent original, pre-impoundment soils (tables 1 and 2).

Sediment accumulation rates were estimated at 0.31 in/yr in core 1 and 0.26 in/yr in core 2 for 1964–2006. Mass accumulation rates for core 2 of 0.07 lbs per square ft were calculated with excess ^{210}Pb and bulk density using the CF:CS method (Appleby and Oldfield, 1992). These rates

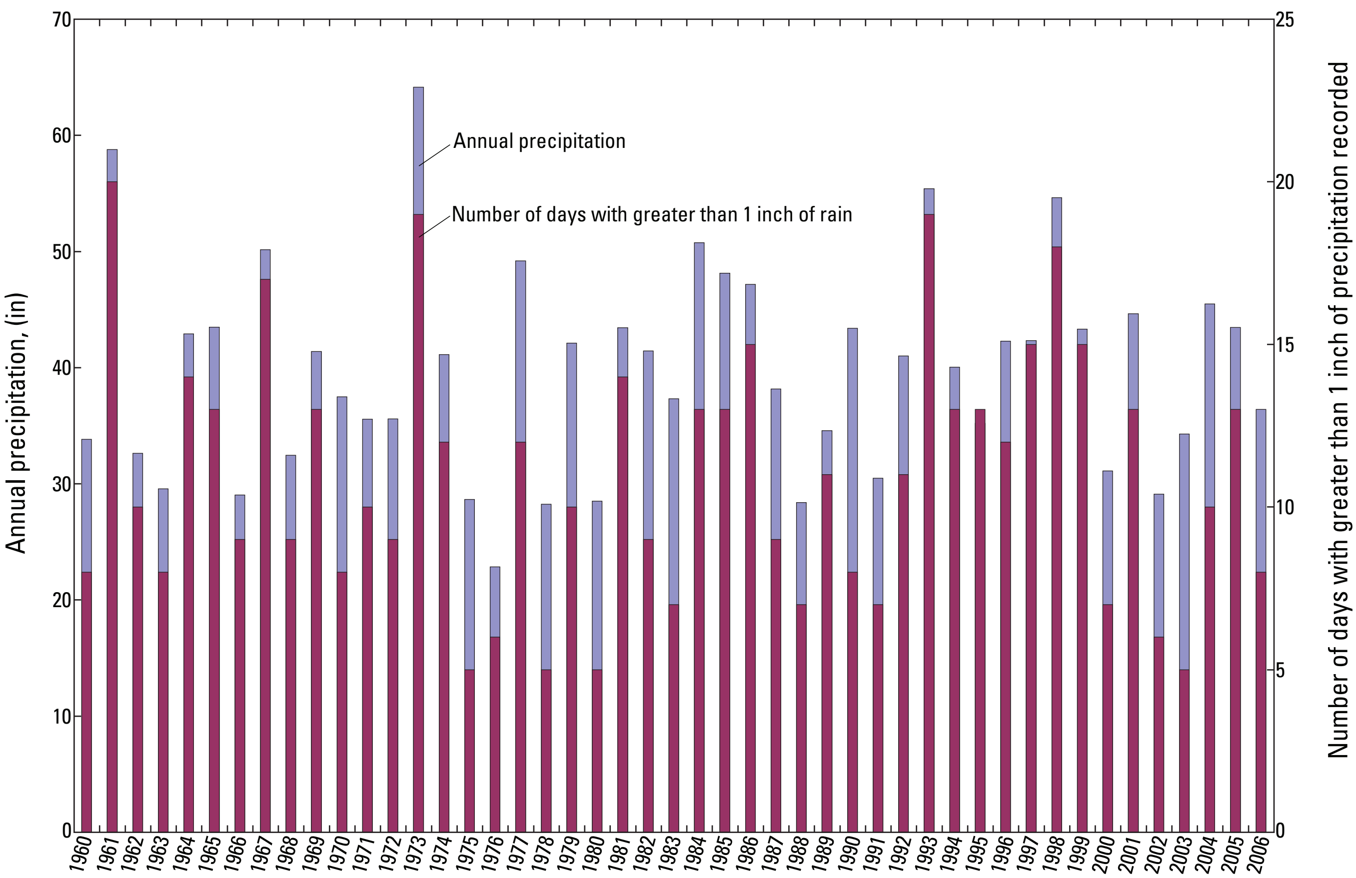

Figure 3. Annual precipitation and number of days in which greater than 1 inch of rainfall, Olathe, Kansas, 1960–2006 (Data from National Oceanic and Atmospheric Administration, 2007).

Table 1. Activities and concentrations of radionuclides, nutrients, and trace elements in core 1, Shawnee Mission Lake bottom sediment, May 2006.

[<LRL, less than laboratory reporting level; mg/kg, milligrams per kilogram; dpm/g, disintegrations per minute per gram; n, number of samples collected; in, inches; --, not determined]

Constituent	Laboratory reporting level	Probable effect concentration[1]	Concentration at specified depth intervals (inches)					
			0–2	2–4	4–6	6–8	8–10	10–12
Radionuclides								
^{7}Beryllium	0.04 dpm/g	--	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL
^{137}Cesium	0.07 dpm/g	--	0.29	0.42	0.55	0.51	1.1	1.7
"Excess" ^{210}Lead	0.07 dpm/g	--	2.4	2.2	1.8	1.4	1.5	1.4
Nutrients								
Nitrogen	100 mg/kg	--	3,600	3,400	6,900	3,000	3,800	3,600
Phosphorus	100 mg/kg	--	1,100	1,000	1,000	1,000	1,300	1,300
Trace elements								
Aluminum	1 mg/kg	--	9.0	8.8	8.5	8.6	8.2	8.0
Antimony	.1 mg/kg	--	1.4	1.4	1.3	1.3	1.3	1.4
Arsenic	.1 mg/kg	33	20	24	21	19	21	20
Barium	1 mg/kg	--	760	750	750	760	700	750
Berlyllium	.1 mg/kg	--	2.6	2.6	2.4	2.4	2.3	2.3
Cadmium	.1 mg/kg	5.0	.6	.7	.6	.5	.6	.8
Chromium	1 mg/kg	111	110	99	90	89	86	84
Cobalt	1 mg/kg	--	15	16	15	13	12	15
Copper	1 mg/kg	149	32	32	31	31	30	30
Iron	1,000 mg/kg	--	46,000	47,000	46,000	43,000	42,000	42,000
Lead	1 mg/kg	128	33	31	29	33	38	35
Lithium	1 mg/kg	--	59	58	53	52	50	50
Manganese	10 mg/kg	--	1,200	1,200	1,500	1,100	1,200	1,200
Molybdenum	1 mg/kg	--	1.6	1.8	1.3	1.4	1.5	1.7
Nickel	1 mg/kg	49	49	47	43	41	39	41
Selenium	.1 mg/kg	--	1.2	1.4	1.1	1.3	1.3	1.3
Silver	.5 mg/kg	--	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL
Strontium	1 mg/kg	--	140	140	140	120	140	160
Sulfur	1,000 mg/kg	--	4,000	5,600	5,600	3,300	4,600	5,300
Thallium	50 mg/kg	--	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL
Tin	.1 mg/kg	--	2.3	3.8	3.8	3.2	2.6	4.2
Titanium	50 mg/kg	--	4,200	4,200	4,000	4,000	3,800	4,000
Total carbon	1,000 mg/kg	--	32,000	31,000	68,000	30,000	40,000	38,000
Total organic carbon	1,000 mg/kg	--	28,000	29,000	28,000	26,000	31,000	29,000
Uranium	.05 mg/kg	--	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL
Vanadium	1 mg/kg	--	140	130	130	130	120	120
Zinc	1 mg/kg	459	170	170	150	150	140	130

Table 1. Activities and concentrations of radionuclides, nutrients, and trace elements in core 1, Shawnee Mission Lake bottom sediment, May 2006.—Continued

[<LRL, less than laboratory reporting level; dpm/g, disintegrations per minute per gram; mg/kg, milligrams per kilogram; n, number of samples collected; in, inches; --, not determined]

Constituent	Laboratory reporting level	Probable effect concentration[1]	Concentration at specified depth intervals (inches)			
			12–14	14–16	16–18	18–20.5
			Radionuclides			
^{7}Beryllium	0.04 dpm/g	--	<LRL	<LRL	<LRL	<LRL
^{137}Cesium	0.07 dpm/g	--	5.5	0.41	0.37	0.37
"Excess" ^{210}Lead	0.07 dpm/g	--	1.3	.34	-.13	.20
			Nutrients			
Nitrogen	100 mg/kg	--	3,000	1,200	870	1,000
Phosphorus	100 mg/kg	--	1,200	810	630	530
			Trace elements			
Aluminum	1 mg/kg	--	9.1	8.4	7.2	6.1
Antimony	.1 mg/kg	--	1.4	1.2	1.0	.9
Arsenic	.1 mg/kg	33	18	9.7	9.1	7.7
Barium	1 mg/kg	--	790	760	740	720
Berlyllium	.1 mg/kg	--	2.7	2.5	2.1	1.7
Cadmium	.1 mg/kg	5.0	.8	.6	.3	.2
Chromium	1 mg/kg	111	95	87	72	59
Cobalt	1 mg/kg	--	15	13	11	9
Copper	1 mg/kg	149	38	27	23	18
Iron	1,000 mg/kg	--	46,000	39,000	33,000	26,000
Lead	1 mg/kg	128	34	24	22	18
Lithium	1 mg/kg	--	55	46	39	31
Manganese	10 mg/kg	--	1,200	770	660	550
Molybdenum	1 mg/kg	--	1.5	<LRL	0.8	<LRL
Nickel	1 mg/kg	49	45	38	31	24
Selenium	.1 mg/kg	--	1.2	.6	.6	.5
Silver	.5 mg/kg	--	<LRL	<LRL	.8	<LRL
Strontium	1 mg/kg	--	120	120	110	120
Sulfur	1,000 mg/kg	--	2,900	440	250	210
Thallium	50 mg/kg	--	<LRL	<LRL	<LRL	<LRL
Tin	.1 mg/kg	--	2.8	2.5	1.8	2.8
Titanium	50 mg/kg	--	4,300	4,300	4,200	4,100
Total carbon	1,000 mg/kg	--	30,000	11,000	8,000	8,000
Total organic carbon	1,000 mg/kg	--	26,000	10,000	8,000	7,000
Uranium	.05 mg/kg	--	<LRL	<LRL	<LRL	<LRL
Vanadium	1 mg/kg	--	140	120	100	84
Zinc	1 mg/kg	459	150	120	93	72

[1]From MacDonald and others (2000).

Table 2. Activities of radionuclides in core 2, Shawnee Mission Lake bottom sediment, Johnson County, Kansas, November 2006.

[lb/ft³, pound per cubic foot; <LRL, less than laboratory reporting level; dpm/g, disintegrations per minute per gram; in, inches]

Constituent	Unit of measure-ment	Bulk density or concentrations at specified depth interval (inches)												
		0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13
Bulk density (lb/ft³)														
Bulk Density	lb/ft³	8.52	18.5	15.6	14.3	17.1	19.7	15.8	17.6	16.2	18.3	24.4	48.9	47.5
Radionuclides														
^{7}Beryllium	0.04 dpm/g	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL	<LRL
^{137}Cesium	0.07 dpm/g	.25	.26	.41	.50	.46	.69	1.1	1.1	1.3	1.5	3.2	.94	.29
"Excess" ^{210}lead	0.07 dpm/g	8.1	6.9	6.8	5.6	5.0	4.7	4.3	2.1	3.2	3.7	2.4	.32	.74

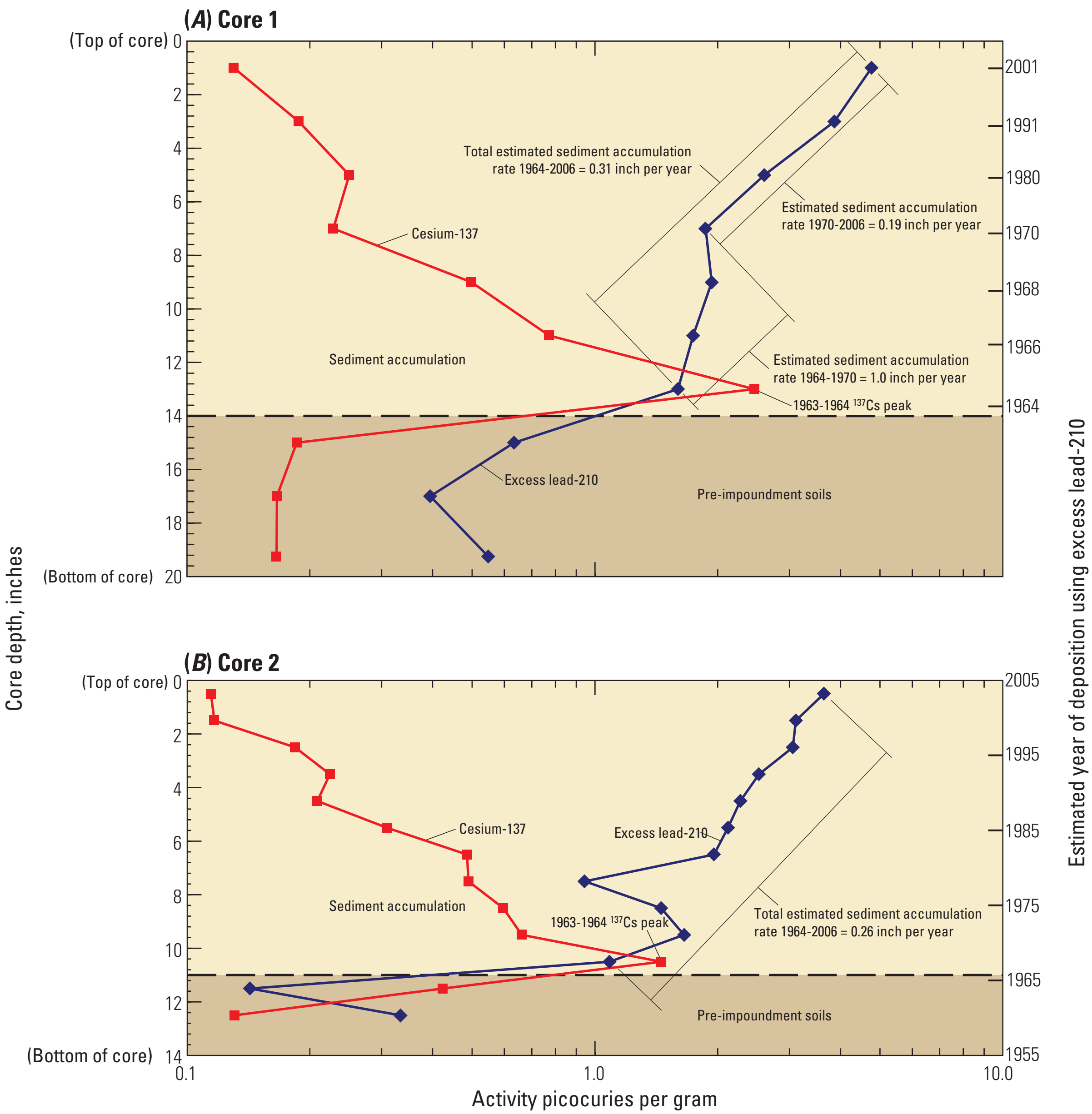

Figure 4. Cesium-137 and excess lead-210 activity in relation to core depth and estimated year of deposition in Shawnee Mission Lake bottom sediment.

were used to assign average dates of deposition for each vertical core depth interval. The resulting dates agree well with the known 1963-64 peak in ^{137}Cs fallout delivery (fig. 4).

Core 1 indicated accelerated deposition from 1964–70 (approximately 1 in/year), with substantially less deposition from 1970–2006 (approximately 0.19 in/yr; fig. 4*A*). Increased erosion rates during early stages of the park may be related to soil disturbance during construction of the park and lake and (or) potential effects from core shortening. However, sediment accumulation rates calculated from the core 2 generally were constant during the past 45 years (0.26 in/yr; fig. 4*B*). Deposition rates calculated from sediment-coring methods did not indicate increased sediment loading associated with recent residential construction in the watershed. Erosion-control measures such as stormwater detention basins or protection of riparian areas enacted during residential construction may have minimized transport of sediment into area streams. Additionally, sediment loading from residential construction may have been deposited in the upstream end of the lake, remained in suspension long enough to pass through the impoundment outflow, or was underrepresented due to core shortening during sample collection.

Differences in deposition rates between the two cores collected for this study are likely related to differences in the length of sediment penetrated in each core sample. These differences are caused by localized variation in either sediment deposition or in the amount of "core shortening" between samples.

Nutrient and Trace Element Concentrations

Nutrient and trace element concentrations in lake-bottom sediment were used to characterize current (2006) and historical sediment quality in Shawnee Mission Lake and the surrounding watershed (table 1). Selected nutrient and trace element data were compared to data collected from two other Johnson County lakes of similar size and age—Gardner City Lake (impounded in 1940; Juracek, 2004), and Lake Olathe (impounded in 1956; Mau, 2000) (fig. 4). Constituents compared between Johnson County lakes have either previously been used to age-date sediment or have been observed to increase in urbanized watersheds were chosen for analysis (Van Metre and others 2004; Mahler and others, 2006). Trace element concentrations were compared to probable effect concentrations (PECs), which are concentrations above which a particular constituent shows a statistical relation to adverse biological effects (MacDonald and others, 2000). These guidelines are used exclusively for comparative purposes and do not imply direct cause-effect relations between sediment concentrations and adverse biological effects.

Nutrient and trace element concentrations in Shawnee Mission Lake bottom sediment generally were within the range of the other area lakes and were less than respective PEC values. Shawnee Mission Lake also had slightly larger particulate total nitrogen concentrations than the other two area lakes, including a large spike in values (6,900 mg/kg) in the core interval between 4 and 6 in,; the cause of this spike is unknown as there was no evidence of pronounced changes in land use during this period. Nickel was the only constituent with values equal to (or larger than) the PEC (49 mg/kg). Although concentrations of nutrients and trace elements in Shawnee Mission Lake sediment generally were within the range of the other two area lakes, selected trace elements had increasing concentrations in more recent sediment from Shawnee Mission Lake (fig. 5). Among the three lakes, increases in chromium, lead, nickel, and zinc in more recent (1990–present) deposition were exclusive to Shawnee Mission Lake and likely are indicative of localized urbanization (table 1, fig. 5). Atmospheric deposition (for chromium, lead, nickel, and zinc), roof shingles (particularly for lead and zinc) and tire wear (zinc) have been shown to be important sources of contamination in urban environments (Van Metre and Mahler, 2003; Mahler and others, 2006). Major human-related sources of nickel include industrial and indirect emission of nickel as an impurity in coal and oil combustion (U.S. Environmental Protection Agency, 1984).

Summary

The U.S. Geological Survey, in cooperation with the Johnson County Stormwater Management Program, undertook a study to characterize sediment accumulation and quality in Shawnee Mission Lake. Two bottom-sediment cores were collected from Shawnee Mission Lake to characterize sediment accumulation and quality relative to ongoing urbanization in the upstream watershed. Both cores had similar average sediment accumulation rates (core 1, 0.31 in/yr; core 2, 0.26 in/yr), and neither core indicated increased sediment deposition associated with recent urban development in the watershed. However sediment accumulation estimates could be affected by uneven distribution of sediment deposition across the reservoir or by shortening of the sediment core during sampling. Recent urban development (1990 to present) in the Shawnee Mission Lake watershed is likely associated with increasing concentrations of chromium, lead, nickel, and zinc in recently deposited bottom sediment. Information on the rates and quality of sediment accumulation can be used by Johnson County officials to help determine the current and future recreational capacity of the lake.

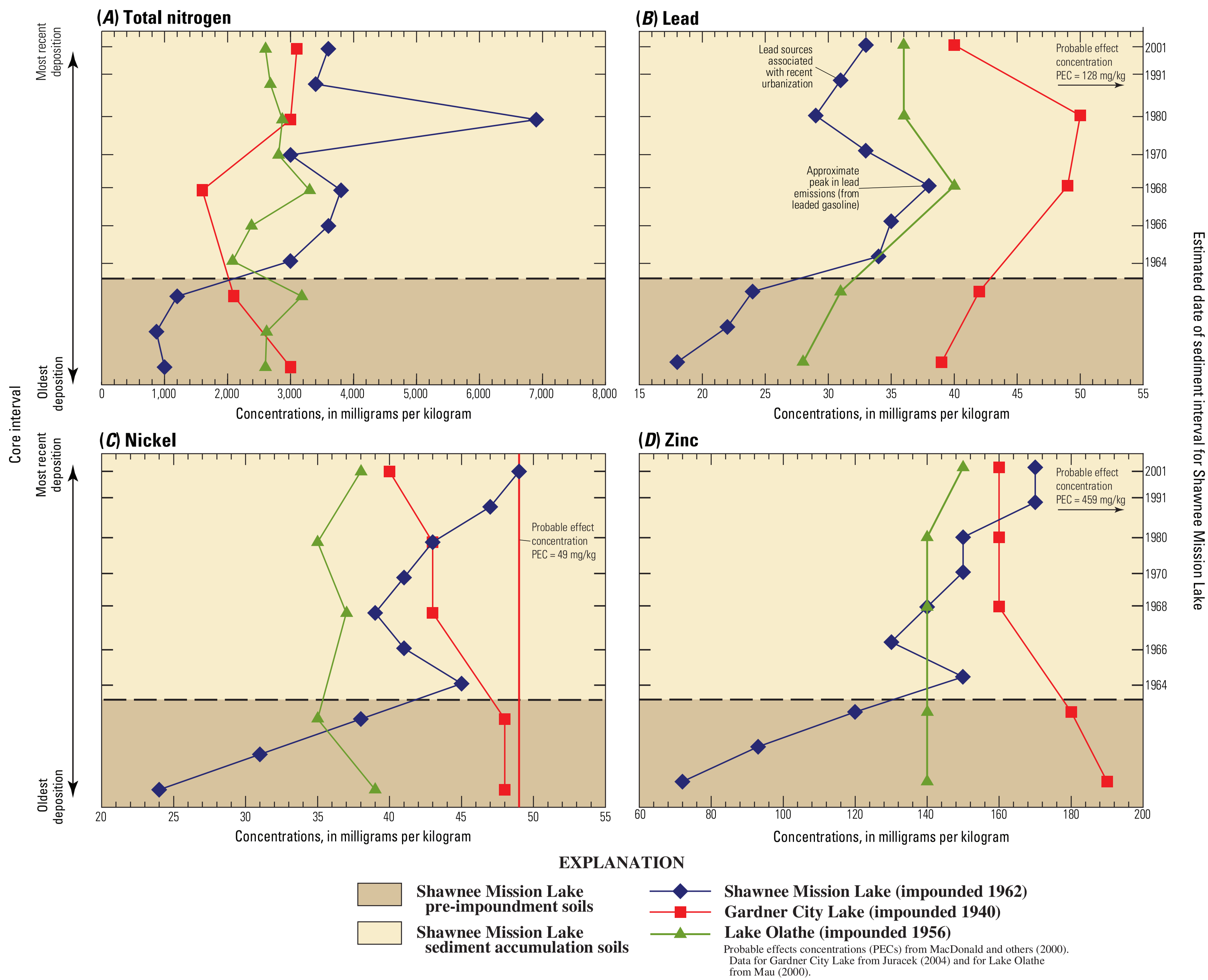

Figure 5. Selected nutrient and trace element profiles in bottom-sediment cores from three Johnson County lakes. Probable effects concentrations (PECs) from MacDonald and others (2000). Data for Gardner City Lake from Juracek (2004) and for Lake Olathe from Mau (2000).

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