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

Prepared in cooperation with the
CITY OF OLATHE, KANSAS, and the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

Sediment Deposition and Selected Water-Quality Characteristics in Cedar Lake and Lake Olathe, Northeast Kansas, 2000

Water-Resources Investigations Report 02–4073

Cover photograph: Shoreline of Lake Olathe, northeast Kansas, October 2001.

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By DAVID P. MAU

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
acre	640	square mile (mi^2)
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
acre-foot per year per square mile [(acre-ft/yr)/mi^2]	476.1	cubic meter per year per square kilometer
cubic foot (ft^3)	0.02832	cubic meter
degree Fahrenheit (°F)	([1])	degree Celsius
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
meter (m)	3.281	foot
microgram per gram (µg/g)	1.0000×10^{-6}	ounce per ounce
mile (mi)	1.609	kilometer
milligram (mg)	0.0000353	ounce
milligram per kilogram (mg/kg)	0.000016	ounce per pound
millimeter (mm)	0.03937	inch
pound (lb)	453.6	gram
pound per acre per year [(lb/acre)/yr]	1.121	kilogram per hectare per year
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
pound per year (lb/yr)	453.6	gram per year
pound per year per square mile [(lb/yr)/mi^2]	175.1	gram per year per square kilometer
square mile (mi^2)	2.590	square kilometer

[1]Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the equation:

$$°C = 5/9\ (°F - 32).$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Sediment Deposition and Selected Water-Quality Characteristics in Cedar Lake and Lake Olathe, Northeast Kansas, 2000

By David P. Mau

Abstract

The Lake Olathe watershed, located in northeast Kansas, was investigated using bathymetric survey data and reservoir bottom-sediment cores to determine sediment deposition, water-quality trends, and transport of nutrients (phosphorus and nitrogen species), selected trace elements, selected pesticides, and diatoms as indicators of eutrophic (organic-enriched and depleted oxygen supply) conditions. To determine sediment deposition and loads, bathymetric data from Cedar Lake and Lake Olathe, both located in the Lake Olathe watershed, were collected in 2000 and compared to historical topographic data collected when the lakes were built.

Approximately 338 acre-feet of sediment deposition has occurred in Cedar Lake since dam closure in 1938, and 317 acre-feet has occurred at Lake Olathe since 1956. Mean annual sediment deposition was 5.45 acre-feet per year (0.89 acre-feet per year per square mile) for Cedar Lake and 7.0 acre-feet per year (0.42 acre-feet per year per square mile) for Lake Olathe. Mean annual sediment loads for the two reservoirs were 9.6 million pounds per year for Cedar Lake and 12.6 million pounds per year for Lake Olathe.

Mean concentrations of total phosphorus in bottom-sediment samples from Cedar Lake ranged from 1,370 to 1,810 milligrams per kilogram, and concentrations in bottom-sediment samples from Lake Olathe ranged from 588 to 1,030 milligrams per kilogram. The implication of large total phosphorus concentrations in the bottom sediment of Cedar Lake is that inflow into Cedar Lake is rich in phosphorus and that adverse water-quality conditions could affect water quality in downstream Lake Olathe through discharge of water from Cedar Lake to Lake Olathe via Cedar Creek.

Mean annual phosphorus loads transported from the Lake Olathe watershed were estimated to be 14,700 pounds per year for Cedar Lake and 9,720 pounds per year for Lake Olathe. The mean annual phosphorus yields were estimated to be 3.74 pounds per acre per year for Cedar Lake and 0.91 pound per acre per year for Lake Olathe. Phosphorus yields in the Cedar Lake watershed were largest of the six Kansas impoundment watersheds recently studied.

Concentrations of total ammonia plus organic nitrogen as nitrogen in bottom sediment increased from upstream to downstream in both Cedar Lake and Lake Olathe. Mean concentrations of total ammonia plus organic nitrogen as nitrogen (N) ranged from 2,000 to 2,700 milligrams per kilogram in bottom-sediment samples from Cedar Lake and from 1,300 to 2,700 milligrams per kilogram in samples from Lake Olathe. There was no statistical significance between total ammonia plus organic nitrogen as nitrogen and depth of bottom sediment.

Concentrations of six trace elements in bottom sediment from Cedar Lake and Lake Olathe (arsenic, chromium, copper, lead, nickel, and zinc) exceeded the U.S. Environmental Protection

Agency Threshold Effects Levels (TELs) sediment-quality guidelines for aquatic organisms in sediment except for one lead concentration. Probable Effects Levels (PELs) for trace elements, however, were not exceeded at either lake.

Organochlorine and organophosphate insecticides were not detected in bottom-sediment samples from either Cedar Lake or Lake Olathe, but the acetanilide herbicides alachlor and metolachlor were detected in sediment from both lakes. The U.S. Environmental Protection Agency has not proposed TEL or PEL guideline concentrations for bottom sediment for any of the organophosphate, acetanilide, or triazine pesticides.

The diatoms (microscopic, single-celled organisms) *Cyclotella bodanica*, an indicator of low organic-enriched water, and *Cyclotella meneghiniana,* an indicator of organic-enriched water, were both present in bottom sediment from Lake Olathe. The presence of both of these diatoms suggests varying periods of low and high eutrophication in Lake Olathe from 1956 to 2000. The concentrations of two species in bottom sediment from Cedar Lake, *Aulacoseira cf alpigena* and *Cyclotella meneghiniana,* as well as two species in sediment from Lake Olathe, *Aulacoseira cf alpigena* and *Stephanodiscus nigare,* increased in sediment cores from the older bottom material to the more recent deposition near the top of the sediment cores. These diatom species indicate eutrophic conditions, and the increased concentration of these diatom species from the bottom of the cores to the sediment/water interface suggests that historically these lakes have been and continue to be eutrophic at times.

Comparison of constituent trends between Cedar Lake and Lake Olathe using reservoir bottom sediment was not possible because sediment from Cedar Lake was suspected of having been disturbed. However, trends that may be reflective of historical changes in water quality were not detected in sediment from either Cedar Lake or Lake Olathe for total phosphorus, trace elements (except lead), and organochlorine or organophosphate pesticides. A slight increasing trend in the concentration of total ammonia plus organic nitrogen as nitrogen was seen in the sediment profile from Lake Olathe but not in the profile from Cedar Lake. The acetanilide herbicides alachlor and metolachlor were more prevalent in more recently deposited sediment in Cedar Lake and Lake Olathe, as was the triazine herbicide atrazine in Lake Olathe bottom sediment, suggesting a possible increasing trend in lake-inflow water concentrations.

Trends in water-quality characteristics can be used by the Lake Olathe watershed managers to document historical changes in the watershed such as changes in land use, the suspension of the use of chlorinated insecticides, such as DDT and chlordane, and the use of hydrophobic fertilizers. The investigation described in this report provides a baseline of water-quality information to compare future changes in water quality or other watershed activities. With the addition of bathymetric surveys and the inclusion of additional reservoirs, reservoir sediment investigations can be used to estimate historical loads of phosphorus and other constituents in future water-quality assessments throughout Kansas.

INTRODUCTION

The effects of land use on water quality is an environmental issue that has gained increased public awareness. Point-source discharges to streams from municipal wastewater-treatment facilities and nonpoint-source discharges from residential septic systems, runoff from crop and livestock production, and stormwater contributions from urban areas, may result in contaminant transport to surface and ground water and ultimately to downstream reservoirs.

Many water-quality constituents adhere to sediment particles and are deposited in reservoirs, which act as sinks for these constituents. Large sediment concentrations frequently observed in Kansas reservoirs are responsible for turbidity levels that can reduce light penetration in the euphotic zone (that part of a water body in which there is sufficient light penetration to support photosynthesis). Large turbidity levels in combination with the presence of nutrients and pesticides may have detrimental effects on humans who use reservoirs as a drinking-water supply and on aquatic organisms, and can reduce the recreational value of the reservoir. Two reservoirs currently under investigation, Cedar Lake and Lake Olathe, are located in northeast Kansas (fig. 1). Lake Olathe serves as a supplemental drinking-water supply for approximately 90,000 residents in the city of Olathe and as a recreational resource for the community.

Cedar Lake was constructed by the city of Olathe in 1938 (Carly Adams, city of Olathe, written commun., 2001) and used as a supplemental water-supply source, but rapid sedimentation reduced the water-storage capacity of the lake. In response to the increasing water requirements of the city of Olathe, Lake Olathe was constructed in 1956 as a water-supply reservoir and to provide recreational use for boating, fishing, and swimming. As residential and commercial development increases in the Lake Olathe watershed, there is considerable interest in maintaining acceptable water quality in Lake Olathe for water supply and recreation.

Previous Investigations

Rapid urbanization and its potential effects on water quality in the Lake Olathe watershed led the city of Olathe to conduct a study of Lake Olathe in 1982–83 to determine the relation between nutrient loads and eutrophication (nutrient enrichment). The study was done with support from the U.S. Environmental Protection Agency (USEPA) Clean Lakes Program under section 314–A of the Federal Clean Water Act of 1972. The 13-month study (1982–83) examined the limnology and water quality of the lake, estimated nutrient loads into the lake as well as sources of nutrients in the watershed, and estimated nutrient loads for 2000. Recommendations were made in regard to management and long-term monitoring of the lake and watershed (Lee and Sears, 1985). During the 1982–83 study, the population for the city of Olathe was about 46,500 (Lee and Sears, 1985).

On the basis of a 1983 bathymetric survey and comparison to historical topographic maps, Lee and Sears (1985) estimated sediment deposition since 1956 to be about 16 acre-ft. Sediment loads to Lake Olathe were estimated to be about 23.6 million lb/yr and did not include the trapping of sediment in the more than 60 small impoundments in the watershed. Phosphorus loads calculated from water samples and estimates of streamflow were estimated to be 1,450 lb/yr and were expected to increase to 1,850 lb/yr by 2000 because of anticipated increased urbanization (Lee and Sears, 1985).

Tissue from channel catfish and other predator fish species were analyzed for selected trace elements and pesticides, and detectable concentrations of these constituents were found. However, reservoir bottom sediment was not analyzed, and water-quality analysis was limited to nutrients and algal determinations. The 1982–83 study concluded by recommending a future, phase-two monitoring effort to include comprehensive lake water-quality sampling during the summer months at multiple locations and depths.

The U.S. Geological Survey (USGS) has investigated reservoir sediment in Kirwin, Webster, and Cheney Reservoirs, and Waconda, Tuttle Creek, and Hillsdale Lakes (see fig. 1, index map) (Juracek, 1997; Christensen, 1999; Mau, 2001). These investigations included analysis of part or all of the following constituents: nutrients, selected trace elements, and pesticides. Sediment deposition varied considerably among the reservoirs investigated, increasing from west to east across the State along with increasing precipitation. Mean annual phosphorus yield showed similar increases from west to east with the lowest yield determined for Webster Reservoir, in the western part of Kansas, and the highest yield for Hillsdale Lake, located in the northeast part (Mau and Christensen, 2000).

Bathymetric surveys were done in 2000 for 23 small municipal lakes in Kansas, including Lake Olathe, by the U.S. Army Corps of Engineers, working for the Kansas Water Office. The total sediment deposition to Lake Olathe from 1956 to 2000, estimated on the basis of these surveys, was 30 acre-ft, or 0.67 acre-ft of sediment deposition per year (Kansas Water Office, 2001, p. 31).

Description of Current Investigation

In response to concerns of rapid sedimentation rates reducing the storage capacity and the quality of water in Lake Olathe, the USGS began a cooperative investigation in 2000 with the city of Olathe and the Kansas Department of Health and Environment (KDHE), with support from USEPA. The purpose of the current investigation was to provide a complete lake and watershed assessment of the Lake Olathe watershed. One of the objectives of the 2000 investigation described in this report was to identify trends in concentrations of selected water-quality constituents.

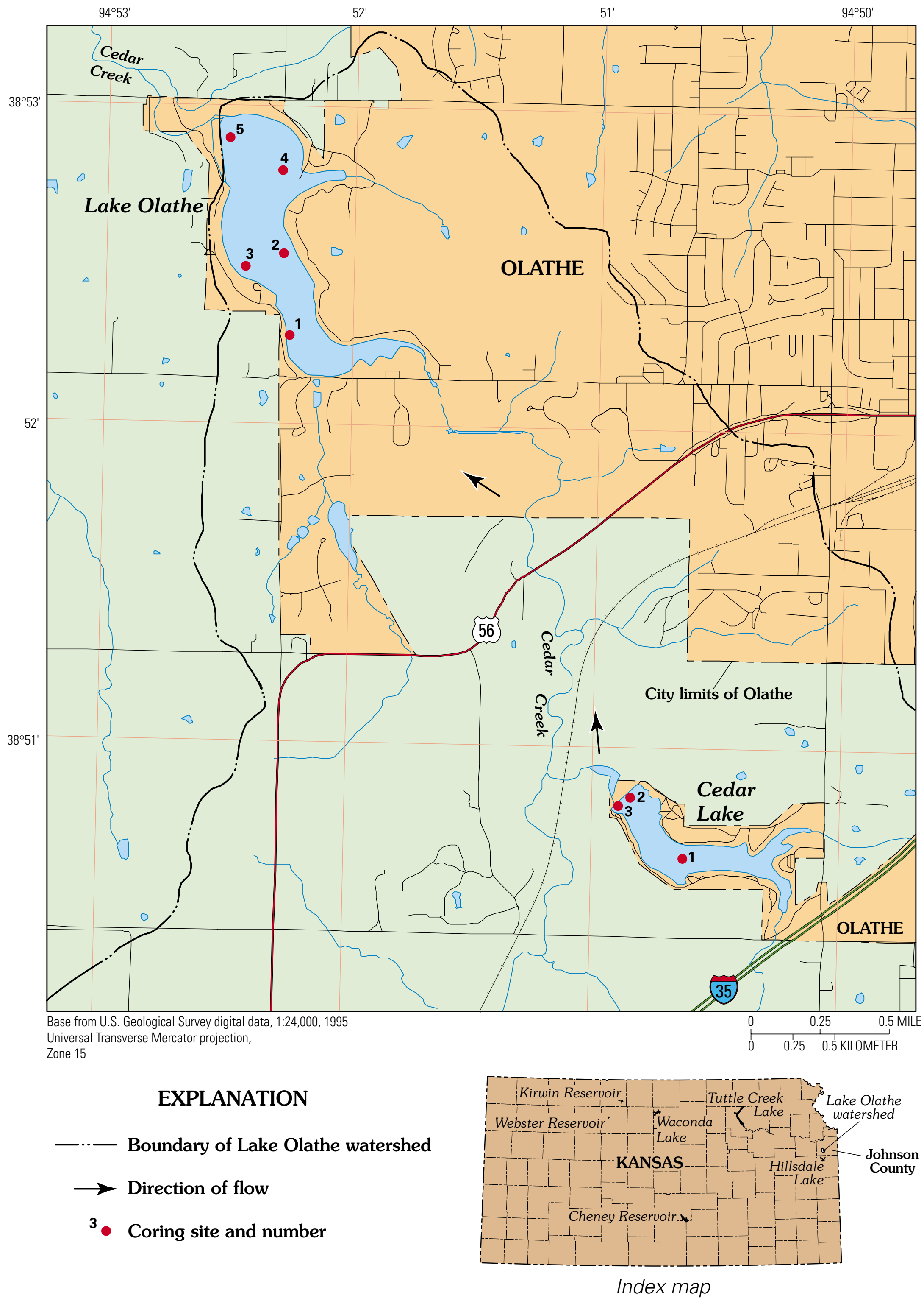

Figure 1. Location of Lake Olathe watershed in northeast Kansas and bottom-sediment coring sites in Cedar Lake and Lake Olathe.

Through chemical analysis and age dating of sediment cores, both baseline conditions and trends in water-quality constituents were determined to help identify the effects of land use on receiving water bodies as well as to help document the effectiveness of land-management practices.

The investigation also determined the transport of various constituents to Cedar Lake and Lake Olathe that can be useful in the establishment of total maximum daily loads (TMDLs). The Federal Clean Water Act of 1972 requires that all States implement TMDLs, which are an estimate of the maximum contaminant load (material transported during a specified time period) from point and nonpoint sources that a receiving water can accept without exceeding water-quality criteria. TMDL concerns at Lake Olathe include eutrophication (nutrient enrichment) and suspended sediment that affect water quality, clarity, and storage capacity of the lake. Nutrient enrichment and suspended sediment ultimately may affect taste and odor of the drinking-water supply from the lake and the trophic (nutrient status) condition of the lake.

Additional objectives of the investigation included estimation of the volume of accumulated sediment in both Cedar Lake and Lake Olathe since dam closures and estimation of the loads of selected water-quality constituents transported from the watershed to the lake bed. Some of the water-quality constituents may be toxic to aquatic organisms or possibly could bioaccumulate in the food chain.

The lack of long-term water-quality data for the Lake Olathe watershed can make interpretation of any trends in the watershed difficult. However, because many water-quality constituents attach to suspended sediment and are transported and deposited in a reservoir, an examination of reservoir bottom sediment was one method used to determine trends in water-quality constituents.

Purpose and Scope

The purposes of this report are to: (1) document the volume of sediment deposition in Cedar Lake and Lake Olathe, (2) determine transport (loads and yields) of selected water-quality constituents in the Lake Olathe watershed, and (3) evaluate trends in nutrients (phosphorus and nitrogen species), selected trace elements, selected pesticides, and diatom species (microscopic, single-celled organisms). The investigation included bathymetric surveys of both Cedar Lake and Lake Olathe as well as bottom-sediment coring at selected locations in both lakes. Data collection was done during June through August 2000.

The results of this investigation will provide estimates of the rate of sedimentation and estimates of loads of selected chemical constituents transported to Cedar Lake and Lake Olathe. Results also will help watershed managers understand contamination sources and provide a baseline to evaluate future progress made toward reduction in contaminant loads. Date markers were placed on top of the bottom sediment at one location in each lake to indicate the current (2000) sediment layer for future sampling reference. These markers will provide a definite time reference for future sediment sampling at these locations. The results from this investigation will support Federal, State, and local goals toward implementing watershed strategies to improve water quality. The results also may be used by various government agencies to establish TMDLs and to evaluate best-management practices (BMPs) designed to mitigate nonpoint-source contamination. These data can be used to determine the degree of success obtained through the current and future implementation of BMPs.

Acknowledgments

The author thanks Mr. Kevin Dobbs with the Kansas Biological Survey for his assistance with geographic information system (GIS) technology in determining historic storage volume and sediment deposition at Lake Olathe. The author also thanks Ms. Carly Adams with the city of Olathe for her assistance in obtaining reference material and other study needs.

DESCRIPTION OF LAKE OLATHE WATERSHED

Cedar Lake has a surface area of about 54 acres and a current (2000) water-storage volume of 334 acre-ft at the dam crest elevation of 1,001.0 ft above sea level. Lake Olathe has a surface area of about 170 acres and a current storage volume of 3,102 acre-ft at the dam crest elevation of 937.5 ft above sea level. The watershed area of 16.9 mi^2 (10,800 acres) encompasses both Cedar Lake and Lake Olathe as well as Cedar Creek, the main tributary joining the two lakes (fig. 1).

There are approximately 1,000 people in the watershed, most of whom live in single-family residences and farms in the area (Carly Adams, city of Olathe, written commun., 2001). Lake Olathe is located within the Olathe city limits, and there are no other towns in the watershed. A public, 18-hole golf course abuts Lake Olathe on the east.

The mean annual temperature in Olathe is about 55 ^{o}F, with a mean monthly range of 28 ^{o}F in January to 78 ^{o}F in July (National Oceanic and Atmospheric Administration, 1966–98). Mean annual precipitation (1961–90) is about 40 in., which occurs primarily during the growing season from April through September (National Oceanic and Atmospheric Administration, 1966–98).

The Lake Olathe watershed is underlain by sedimentary bedrock deposited during late Pennsylvanian time (about 285 to 300 million years ago) (Lee and Sears, 1985). The bedrock is mostly shale, with some prominent limestone layers and sandstone. Pre-Illinoian glacial till and a thin lens of loess (windblown Pleistocene deposits) cover the bedrock. Soils in the watershed were formed from windblown loess, glacial outwash, and residuals derived from the weathering of shale and limestone bedrock (Lee and Sears, 1985).

Land use in the Lake Olathe watershed is primarily agricultural cropland and grassland, which represent 83 percent of the watershed (fig. 2) (Kansas Geological Survey, 1993). Crop-production statistics were not available for the Lake Olathe watershed; therefore, the following statistics were based on figures for Johnson County where the watershed is located (fig. 1, index map). Crop production in the county declined from 108,000 acres of harvested cropland in 1960 to 71,000 acres harvested cropland in 2000 (fig. 3*A*) (Kansas State Board of Agriculture and U.S. Department of Agriculture, 1960–95; Kansas Department of Agriculture and U.S. Department of Agriculture, 1996–2000). Production of wheat, rye, corn, oats, and sorghum declined between 1960 and 1999 (fig. 3*A*). However, soybean and all hay production increased during the same period. Residential and commercial land use in Johnson County increased during the 40-year period from 1960–99, and similar residential and commercial growth was evident in the Lake Olathe watershed, from 2.0 percent of the watershed in 1985 to 15 percent in 1999 (Lee and Sears, 1985; Kevin Dobbs, Kansas Biological Survey, written commun., 2001).

Livestock production in Johnson County has been relatively stable for cattle and calves, averaging about 25,600 head annually from 1960 to 1999. However, annual inventories of hogs, sheep and lambs, and chickens declined during the same period (fig. 3*B*) (Kansas State Board of Agriculture and U.S. Department of Agriculture, 1960–95; Kansas Department of Agriculture and U.S. Department of Agriculture, 1996–2000).

METHODS

To meet the objectives of the investigation described in this report required information on reservoir sedimentation (depth and volume) relative to preimpoundment topography, density of sediment, and vertical variability in sediment chemical composition. Bathymetric surveys, or mapping of the reservoir bottom, provided the sedimentation information for calculation of mean sediment depth and volume. Sediment core samples collected at selected sites in both Cedar Lake and Lake Olathe provided sediment density and chemical and biological information to determine historical trends and transport of sediment and selected water-quality constituents.

Bathymetric Surveys

Bathymetric surveys were done by the USGS at both Cedar Lake and Lake Olathe in 2000 using a differential global positioning system (GPS) and a thermal depth-sounder recording fathometer. Both of these instruments were connected to a portable laptop computer, and the data collected from the instruments were filtered and manipulated through a computer software package. The GPS measured spatial position in latitude and longitude with an accuracy of 5 ft; horizontal control points were established each day at the beginning of the surveys to maintain accuracy. The fathometer measured depth with an accuracy of 0.1 ft; the fathometer was calibrated at the start of each day to maintain accuracy. The computer software package was used for survey planning, survey execution, and storage and editing of data. The software package also was used to generate preliminary contour maps of the lake bottoms that were exported to a GIS software program where final editing and curve smoothing of the contour lines were completed.

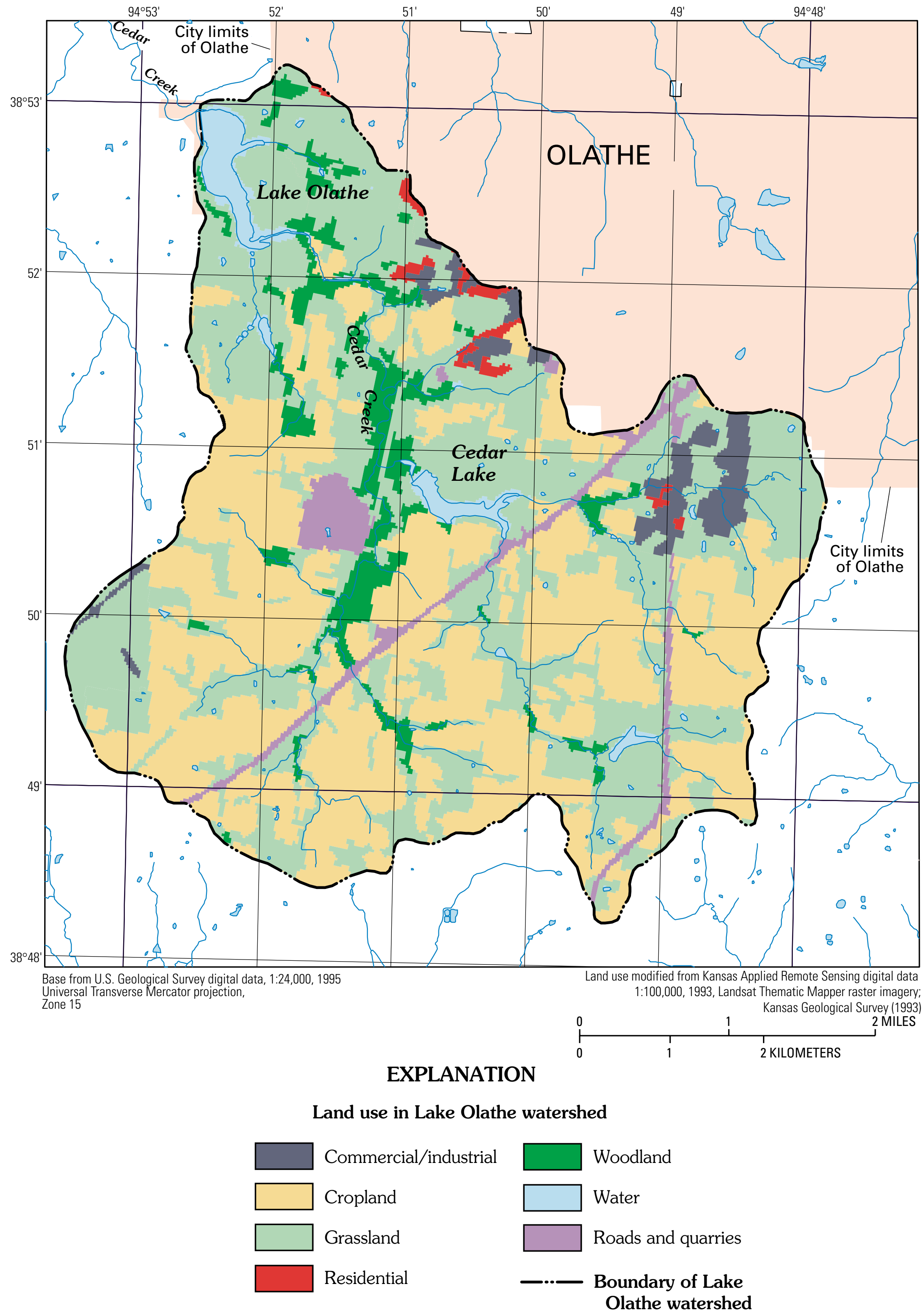

Figure 2. Land use in Lake Olathe watershed, 1993.

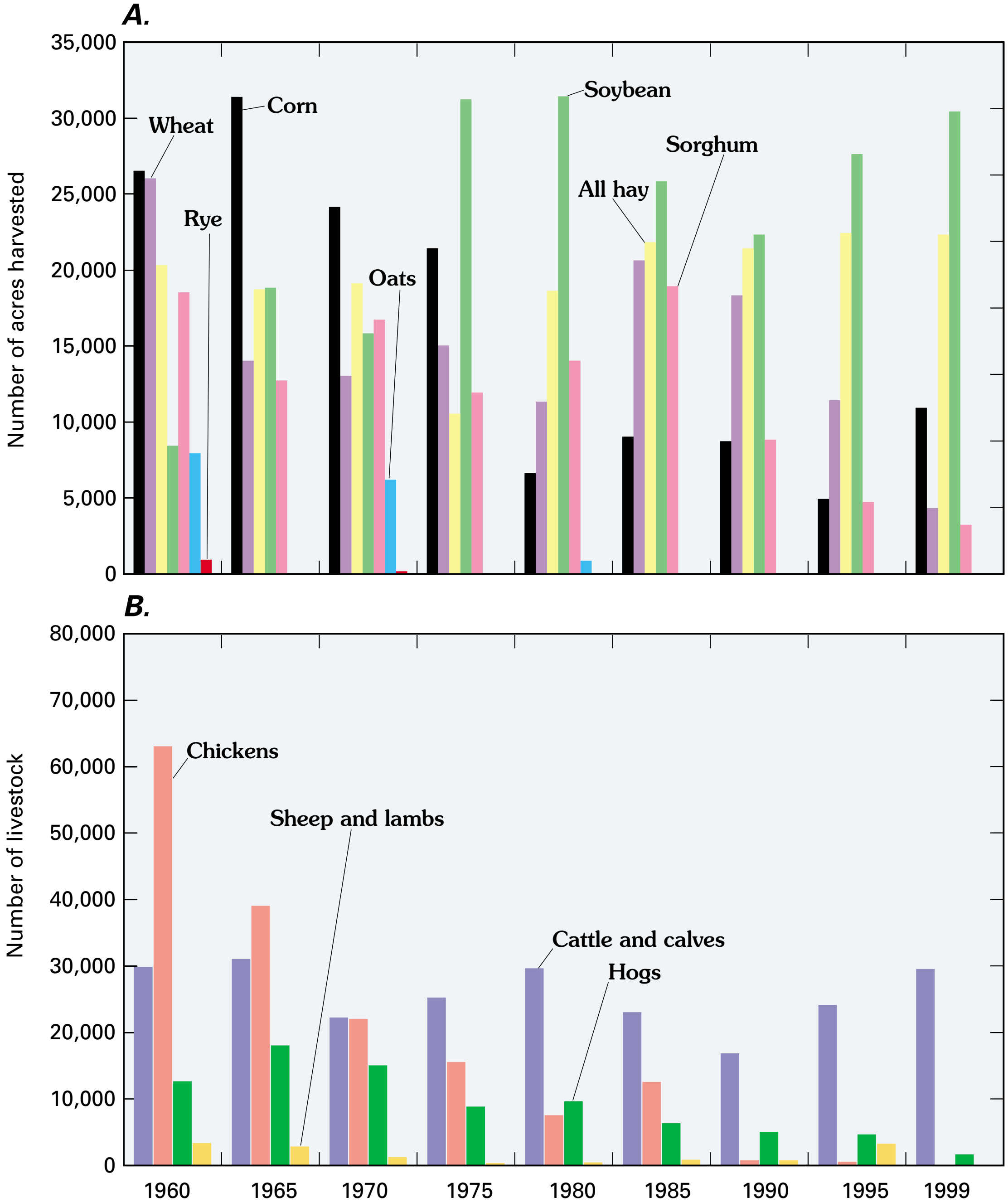

Figure 3. Number of *(A)* acres harvested and *(B)* livestock in Johnson County, Kansas, for selected years between 1960 and 1999 (sources of data: Kansas State Board of Agriculture and U.S. Department of Agriculture, 1960–95; Kansas Department of Agriculture and U.S. Department of Agriculture, 1996–2000).

The bathymetric surveys of both lakes were done using a pontoon boat on which the GPS and fathometer were mounted. Information on range lines used in the 1983 bathymetric survey of Lake Olathe by Lee and Sears (1985) was not used in the 2000 surveys because many of the temporary endpoints used to identify the range lines could not be found. Therefore, arbitrary range lines were assigned every 250 ft perpendicular to the longitudinal axis of each lake.

Estimation of Bottom-Sediment Depth and Volume

Estimation of bottom-sediment volume in Cedar Lake and Lake Olathe required area and depth of sediment deposition in each lake. The area was determined from historic contour maps and GIS map coverage of the lakes, and depth of sediment deposition was estimated by comparing topographic maps of lake areas prior to impoundment to 2000 bathymetric information for each lake.

A historic contour map of Cedar Lake prior to impoundment (1938) was obtained from the Kansas Department of Agriculture, Division of Water Resources (map on file with the USGS office, Lawrence, Kansas). The original design water-storage capacity for the lake (1938) was obtained from the historic contour map and was compared to the 2000 storage capacity, and the difference was assumed to be attributed to sediment deposition.

Historical and 2000 GIS map coverages were available for Lake Olathe. The 2000 map coverage was digitally overlayed on the historical (1954) map coverage, and using GIS, an elevation grid with 1-m cell sizes was created for each map. The elevation grid was used to interpolate the bathymetric point data between the contour lines and to calculate the net gain or loss of sediment volume for each cell. The cells were summed to provide either a net gain or loss of sediment volume for Lake Olathe (Kevin Dobbs, Kansas Biological Survey, written commun., 2001).

Reservoir Sediment-Core Collection, Processing, and Analysis

Reservoir bottom-sediment cores were collected and analyzed to provide a history of water quality in the watershed. The depth of bottom material was used as an indicator of sediment loads transported to the lakes and loss of water-storage capacity. Sediment mass in and chemical analysis of the bottom-sediment cores were used to estimate mass loads of chemical constituents transported into the lakes as well as to determine temporal and spatial trends of selected constituents in the watershed.

A gravity corer was used to collect bottom-sediment cores from Cedar Lake from one in-channel (historic stream channel prior to dam impoundment) coring site (Cedar Lake coring site 3) and two out-of-channel coring sites (Cedar Lake coring sites 1 and 2) (table 1, fig. 4). In-channel and out-of-channel sediment cores were collected to determine if there were any chemical or biological differences in sediment from the two topographical areas. Similarly, five sediment cores were collected from Lake Olathe from three in-channel coring sites (Lake Olathe coring sites 1, 2, and 5) and two out-of-channel coring sites (Lake Olathe coring sites 3 and 4) (table 1, fig. 4). The liner used in the gravity corer was transparent tubing made of cellulose acetate butyrate with a 2.88-in. outside diameter and a 2.63-in. inside diameter. Depending upon the required analyses, three to four sediment cores were collected at each coring site to provide sufficient material and briefly chilled prior to processing.

During this investigation all of the sediment cores used in the analyses were thought to have penetrated to pre-reservoir material. This was evident by a change in physical appearance of the sediment, differences in sediment grain-size composition, and the presence of pre-reservoir organic material such as root hairs, plant material, or small sticks. The presence of pre-reservoir material indicated that a complete sediment record had been collected for each core.

The sediment cores were processed at the USGS laboratory in Lawrence, Kansas. The plastic liners were cut longitudinally in two places and 180^{o} apart. The cuts were partially completed using a rotary handsaw and finished with a retractable razor knife set at a depth to minimize penetration of the sediment core. The cores were split in half by pulling a tightly held nylon string through the length of the two cuts and allowing the halves to separate. Depending upon the type of analysis as well as available bottom material in each core, the cores then were subsectioned into equal length intervals, and sediment samples from each

Table 1. Location of bottom-sediment coring sites in Cedar Lake and Lake Olathe, northeast Kansas, 2000

Coring site (fig. 1)	U.S. Geological Survey site identification number	Latitude	Longitude
		(degrees, minutes, seconds)	
	Cedar Lake		
1	385039094503800	38^{o}50'39"	94^{o}50'38"
2	385049094505300	38^{o}50'49"	94^{o}50'53"
3	385050094505100	38^{o}50'50"	94^{o}50'51"
	Lake Olathe		
1	385216094521500	38^{o}52'16"	94^{o}52'15"
2	385232094521600	38^{o}52'32"	94^{o}52'16"
3	385230094522600	38^{o}52'30"	94^{o}52'26"
4	385246094521600	38^{o}52'46"	94^{o}52'16"
5	385254094523100	38^{o}52'54"	94^{o}52'31"

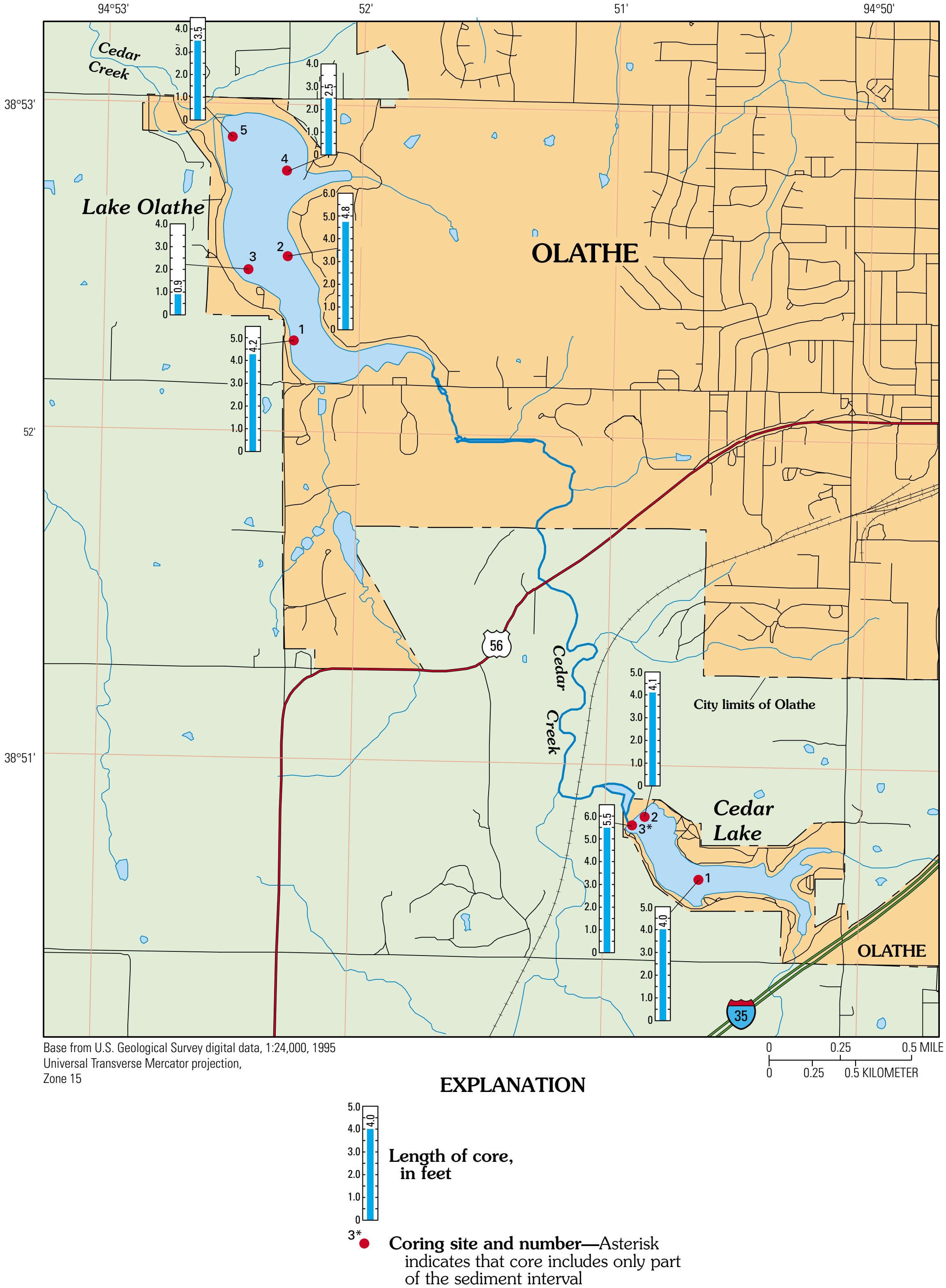

Figure 4. Average length of bottom-sediment cores collected from coring sites in Cedar Lake and Lake Olathe, 2000.

interval were removed for physical and chemical determinations (Cedar Lake coring site 3 and Lake Olathe coring site 5; fig. 1).

Analysis requirements from selected bottom-sediment sampling sites (Cedar Lake coring sites 1–2 and Lake Olathe coring sites 1–4; fig. 1) consisted of a mean chemical determination for the entire sediment core. In these instances, equal volumes of sediment from each interval were removed from the sediment core, placed in a mixing bowl, and mechanically homogenized. A sample of the homogenized mass then was sent to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado, for chemical analysis.

Sediment mass (in pounds) is a product of sediment volume (cubic feet) and sediment bulk density (pounds per cubic foot). Sediment bulk densities were determined from selected sediment cores. These sediment cores were subsectioned, weighed, and oven dried to remove all moisture. The dried subsectioned cores were reweighed, and the weights divided by the subsection volume to determine bulk density. Mean bulk densities for the entire sediment core were determined from the subsectioned mean bulk densities. Sediment-core mean bulk densities were used to calculate average bulk density for each lake.

Subsections of selected cores were analyzed for bulk density at the USGS laboratory in Lawrence, Kansas, according to methods presented in Guy (1969). Subsections also were analyzed for percentage of sand and silt and (or) clay at the USGS sediment laboratory in Iowa City, Iowa, according to methods presented in Guy (1969). Core subsections from selected sites were analyzed at the NWQL in Denver, Colorado, for total phosphorus, total ammonia plus organic nitrogen as nitrogen, and selected trace elements according to procedures presented in Fishman (1993). Analytical methods and reporting limits are presented in tables 12–14 (in "Supplemental Information" section of this report). In addition, organochlorine insecticides, organophosphate insecticides, and acetanilide and triazine herbicides were analyzed for selected core subsections at the USGS Organic Geochemistry Research Laboratory in Lawrence, Kansas, on the basis of procedures given in Mills and Thurman (1992).

The use of a gravity corer, such as used during this investigation, may produce a "core-shortening" phenomenon (Blomqvist, 1985). Core shortening refers to the difference between the depth of sediment penetration by the sample tube and the length of the core inside the sample tube. This phenomenon has been documented at length and is described as being caused by friction of the sediment against the inner wall of the sample tube as the gravity corer penetrates the sediment (Emery and Hulseman, 1964; Blomqvist and Bostrom, 1987). The friction causes the core sample to underrepresent the entire thickness of the penetrated sediment bed, presumably through a thinning of individual sediment layers during the penetration process. Compression of the sediment and loss of water content have been suggested as mechanisms that would explain core shortening, especially in very soft muds (Hongve and Erlandsen, 1979). If compression of sediment is a dominant physical mechanism to explain the core-shortening phenomenon, then sediment densities and, ultimately, calculations of total mass presented in this report may be biased. However, for most sediment cores collected from Cedar Lake and Lake Olathe, very soft muds were evident only in the upper few inches of the cores. Although core shortening affects the length of the retrieved sediment core (fig. 4), the entire core sample represents a complete sediment profile and, thus, a potential record of historical trends in water-quality constituents.

Reservoir bottom sediment may undergo mixing during storms or periods of flooding. This mixing can create difficulties in the analysis of trends in water-quality constituents. To determine whether bottom sediment had been disturbed, sediment cores from both Cedar Lake (coring site 3) and Lake Olathe (coring site 5) (fig. 4) were analyzed for cesium-137 by the NWQL (table 15, in "Supplemental Information" section of this report). Cesium-137, a by-product of thermonuclear-weapons testing in the 1950s and early 1960s, was widely dispersed by atmospheric deposition and potentially sorbed to soil particles (primarily clay). Detectable cesium-137 concentrations in sediment began about 1952 and peaked in 1963–64, followed by a steady decline in concentrations. Identifiable spikes outside of the 1963–64 peak in cesium-137 concentrations in the bottom-sediment core profile may be indicative of turbulence and resuspension of sediment. Analysis of sediment for chemical trends would not be appropriate under these conditions.

Because of its wide dispersal, cesium-137 also can be used to date sediment layers (Holmes, 1998). The ability to date sediment layers is important in determining the effectiveness of BMPs in managing chemical inputs to reservoirs. For example, if particular pesticides are not permitted for use, identification of a nonpermitted pesticide near the water-sediment interface may suggest continued use of the pesticide in the watershed.

Physical markers (commercially available blue plastic tarps) were placed on top of the bottom sediment over a 30-by-30-ft area in both Cedar Lake and Lake Olathe. The intent was to place this minimal degradable material as a layer on top of the reservoir bottom sediment and return in several years to those locations and remove sediment cores. The tarps would be identified by distinct blue layers in the sediment cores, and any sediment above the markers attributed to sediment deposition since 2000. The locations of the tarps were marked using a handheld GPS.

Analysis of Diatoms in Reservoir Sediment

Bottom-sediment cores from Cedar Lake and Lake Olathe were subsectioned and analyzed for diatom species. Diatoms are microscopic algae that have a siliceous shell and occur in both freshwater and marine environments. Diatoms are sensitive to environmental changes such as changes in nutrient concentrations, and therefore, identification of diatom taxa may indicate periods of eutrophication in lakes. Ten subsamples from one sediment core from each lake were submitted to BSA Environmental Services, Inc. (BSA), Beachwood, Ohio, where a subsample weighing 10 to 12 mg was extracted and cleaned using 30-percent hydrogen peroxide and concentrated nitric acid (Stoermer and others, 1995). The clean diatom subsample was suspended in glass-distilled water, placed in evaporation chambers similar to those devised by Battarbee (1973), and prepared on slides using NAPHRAX™. For each sampling date, diatom valves were counted along 18-mm transects using a microscope at 1000X magnification.

The number of identified and counted valves varied from 133 to 639 for the subsample from Cedar Lake and from 373 to 952 valves for the subsample from Lake Olathe. The counts were converted to percentage abundance within the subsample. An estimate of the total number of valves per gram of dry sediment also was made by relating the number of valves counted on a slide to the proportion of the area on the slide that was counted, taking into account dilution factors and the weight of sediment processed.

Quality Control

Multiple cores were collected at various sites in both Cedar Lake and Lake Olathe to provide sufficient sediment for both physical and chemical analyses. Quality control in the collection of bottom-sediment cores included evaluating laboratory analytical variability (precision and reproducibility).

Analytical precision and reproducibility were determined by analyzing split replicate samples of bottom-sediment cores. Split replicate samples were prepared by homogenizing like core subsections, then splitting each homogenized subsection into two samples. By homogenizing the sample and then splitting it into two samples, both samples should have been chemically equivalent, and any differences could be attributed to variability within the laboratory procedure. Percentage differences between split replicate concentrations were calculated as the absolute value of the quotient of the difference in replicate concentrations divided by the summation of replicate concentrations, multiplied by 100.

Analysis of split replicate samples from Lake Olathe coring site 5 showed little or no variability among the selected trace elements analyzed, with a median percentage difference of 1.71 percent (table 2). Percentage differences in holmium and silver were equal to or greater than 20 percent; however, the concentrations of these water-quality constituents were very low. The results generally indicate that laboratory precision and reproducibility differences were small (0 to 9.1 percent) and probably not a concern for this investigation.

Trend Analysis

Concentrations of total phosphorus and total ammonia plus organic nitrogen as nitrogen in bottom-sediment cores from Cedar Lake and Lake Olathe were analyzed to determine the existence of trends with depth in the sediment profile and whether phosphorus or nitrogen usage in the watershed was increasing or decreasing. Simple linear regression was used, along with Kendall's tau (τ), because each test offered different advantages over the other. A simple linear regression commonly is used to learn something about the relation between two variables, or estimate or predict values of one variable on the basis of knowledge of another variable (Helsel and Hirsch, 1992). Kendall's tau is more resistant to the effects of extreme

Table 2. Analytical results and percentage differences for selected trace elements in split replicate samples of bottom sediment from coring site 5, Lake Olathe, northeast Kansas, 2000

[R, split replicate sample; µg/g, micrograms per gram; <, less than; --, not applicable]

Trace element and unit of measurement	Concentration: Coring site 5 (fig. 1)	Concentration: Coring site 5R	Percentage difference	Trace element and unit of measurement	Concentration: Coring site 5 (fig. 1)	Concentration: Coring site 5R	Percentage difference
Aluminum, percent	8.9	9.2	1.7	Magnesium, percent	0.84	0.87	1.8
Antimony, µg/g	1.2	1.2	0	Manganese, µg/g	1,000	1,000	0
Arsenic, µg/g	15	15	0	Molybdenum, µg/g	.97	1.0	1.5
Barium, µg/g	780	780	0	Neodymium, µg/g	44	46	2.2
Beryllium, µg/g	2.6	2.6	0	Nickel, µg/g	35	36	1.4
Bismuth, µg/g	<1.0	<1.0	--	Niobium, µg/g	21	20	2.4
Cadmium, µg/g	.37	.44	8.6	Potassium, percent	1.9	2.1	5.0
Calcium, percent	1.1	.98	5.8	Scandium, µg/g	15	15	0
Cerium, µg/g	88	89	.56	Silver, µg/g	.43	.28	21
Chromium, µg/g	88	88	0	Sodium, percent	.39	.4	1.3
Cobalt, µg/g	10	10	0	Strontium, µg/g	130	130	0
Copper, µg/g	36	34	2.9	Tantalum, µg/g	1.8	1.5	9.1
Europium, µg/g	1.5	1.8	9.1	Thallium, µg/g	1	1	0
Gallium, µg/g	20	21	2.4	Thorium, µg/g	16	16	0
Gold, µg/g	<1.0	<1.0	--	Tin, µg/g	3.4	3.3	1.5
Holmium, µg/g	1.2	1.8	20	Titanium, percent	.53	.45	8.2
Iron, percent	4	4	0	Uranium, µg/g	4.3	4.1	2.4
Lanthanum, µg/g	58	54	3.6	Vanadium, µg/g	130	130	0
Lead, µg/g	36	32	5.9	Ytterbium, µg/g	2.8	3	3.4
Lithium, µg/g	45	46	1.1	Yttrium, µg/g	30	34	6.3
				Zinc, µg/g	140	130	3.7
				Median			**1.7**

values and to deviations from a linear relation, and may be more appropriate than simple linear regression for sample sizes less than 20 (Helsel and Hirsch, 1992). A positive Kendall's tau correlation on an x-y graph, where x is the horizontal axis and y is the vertical axis, indicates that y values increase more often than decrease as x values increase. A negative Kendall's tau correlation indicates the opposite; y values decrease more often than increase as x values increase. Kendall's tau was calculated for bottom-sediment cores from both lakes, and trends were considered significant if p-values (probability values) were less than 0.05 ($p<0.05$).

SEDIMENT DEPOSITION IN CEDAR LAKE AND LAKE OLATHE

One of the reasons for determining volume and mass of sediment deposition was to evaluate water-storage capacity and changes in capacity since impoundment. Cedar Lake and Lake Olathe serve different purposes, but decreased water-storage capacity from sediment deposition in each lake can affect lake allocations used for flood control, drinking-water supplies for the city of Olathe, recreation, and wildlife habitat. Estimates of sediment mass also provide information that can be used with chemical concentrations to determine watershed loads (mass) and yields (mass per unit area of watershed) of chemical constituents to the lakes.

Calculated Bottom-Sediment Volume and Mass

Total sediment volume deposited in Cedar Lake from 1938 through 2000 was approximately 338 acre-ft. This volume was calculated as the difference between the 1938 design volume for the lake (672 acre-ft)(Kansas Department of Agriculture; information on file at USGS office in Lawrence, Kansas) and the Cedar Lake reservoir volume determined from the 2000 bathymetric survey (334 acre-ft). The 1938 design plan of Cedar Lake available to the author did not provide information on water-surface elevation but did show the lake-surface area at the conservation pool (55.5 acres). The lake-surface area of Cedar Lake during the 2000 bathymetric survey was 54 acres; therefore, similar lake elevations were assumed for the two periods for the calculation of sediment deposition.

The mean annual sediment deposition rate to Cedar Lake for the 62-year period (1938–2000), calculated on the basis of 338 acre-ft of total sediment deposition, was 5.45 acre-ft/yr, or 0.89 (acre-ft/yr)/mi^2 of watershed, when divided by the 6.14 mi^2 (3,930 acres) of contributing-drainage area to Cedar Lake (Lee and Sears, 1985). The sediment deposition in Cedar Lake has reduced the water-storage capacity of the lake by approximately 50 percent in the past 62 years. At the current rate of sediment deposition, Cedar Lake will be fully silted in an additional 62 years.

Total sediment deposition in Lake Olathe was determined to be approximately 317 acre-ft. The sediment volume was calculated as the difference between the 1954 Lake Olathe design volume (3,419 acre-ft) determined from GIS coverage and the reservoir volume determined from the 2000 bathymetric survey at a water-surface elevation of 937.5 ft above sea level (3,102 acre-ft) (figs. 5–6). The mean annual sediment deposition rate for the period from 1956 through 2000 (45 years), calculated on the basis of 317 acre-ft, was 7.0 acre-ft/yr, or 0.42 (acre-ft/yr)/mi^2, when divided by the 16.6 mi^2 (10,630 acres) of contributing-drainage area from the watershed to Lake Olathe. On the basis of the water-storage capacity design volume for Lake Olathe, the total sediment deposition in 45 years has reduced the water-storage capacity of Lake Olathe by approximately 10 percent. In contrast, approximately 2,100 acre-ft of total sediment deposition was estimated for Hillsdale Lake (approximately 15 mi south of Lake Olathe, fig. 1) for the period 1981–96, or 0.97 (acre-ft/yr)/mi^2, when divided by the 144 mi^2 of contributing-drainage area from the watershed to the lake (Juracek, 1997).

Total sediment deposition was determined for Lake Olathe in two previous studies—the Kansas Clean Lakes Program (1982–83) (Lee and Sears, 1985) and the U.S. Army Corps of Engineers study done in 2000 for the Kansas Water Office (KWO) (Kansas Water Office, 2001). The Kansas Clean Lakes Program estimation of sediment deposition was based on a bathymetric survey done using a portable depth finder and stopwatch (Lee and Sears, 1985). The completed bathymetric map then was compared to the 1954 Lake Olathe topographic map to determine the sediment deposition during the intervening period. Total sediment deposition estimated from Lee and Sears (1985) was 16.3 acre-ft, substantially less than the 317 acre-ft determined during the 2000 investigation described in this report. Differences in deposition can be attributed in large part to technological advancements available in 2000 that were not available in 1982. Insufficient information describing the methods used to determine sediment deposition in 1982 preclude further comparison of the two methods.

The U.S. Army Corps of Engineers study for the Kansas Water Office was done in 2000 using a single-beam transducer and GPS system similar to the method used by the USGS, and total sediment deposition from this study was estimated to be 30 acre-ft (Kansas Water Office, 2001, p. 31), about 9 percent of the 317 acre-ft determined by the USGS. Data files from the U.S. Army Corps of Engineers study were made available to the USGS by KWO and indicated substantial differences in elevations used to define the reservoir bottom (E. Lewis, Kansas Water Office, oral commun., 2001). Elevation differences that were based on different reference datums may explain some, but not all, of the discrepancies between the USGS and U.S. Army Corps of Engineers studies. The USGS bathymetric study of Lake Olathe in 2000 used the 1935 reference datum (1,036.00 ft) and contour mapping to determine reservoir volume. The 1982–83 Kansas Clean Lakes Program used the same reference datum in their study. On the basis of the reservoir bottom elevations used by the U.S. Army Corps of Engineers, it is not clear how sediment deposition was calculated or whether historic design information from 1954 was used.

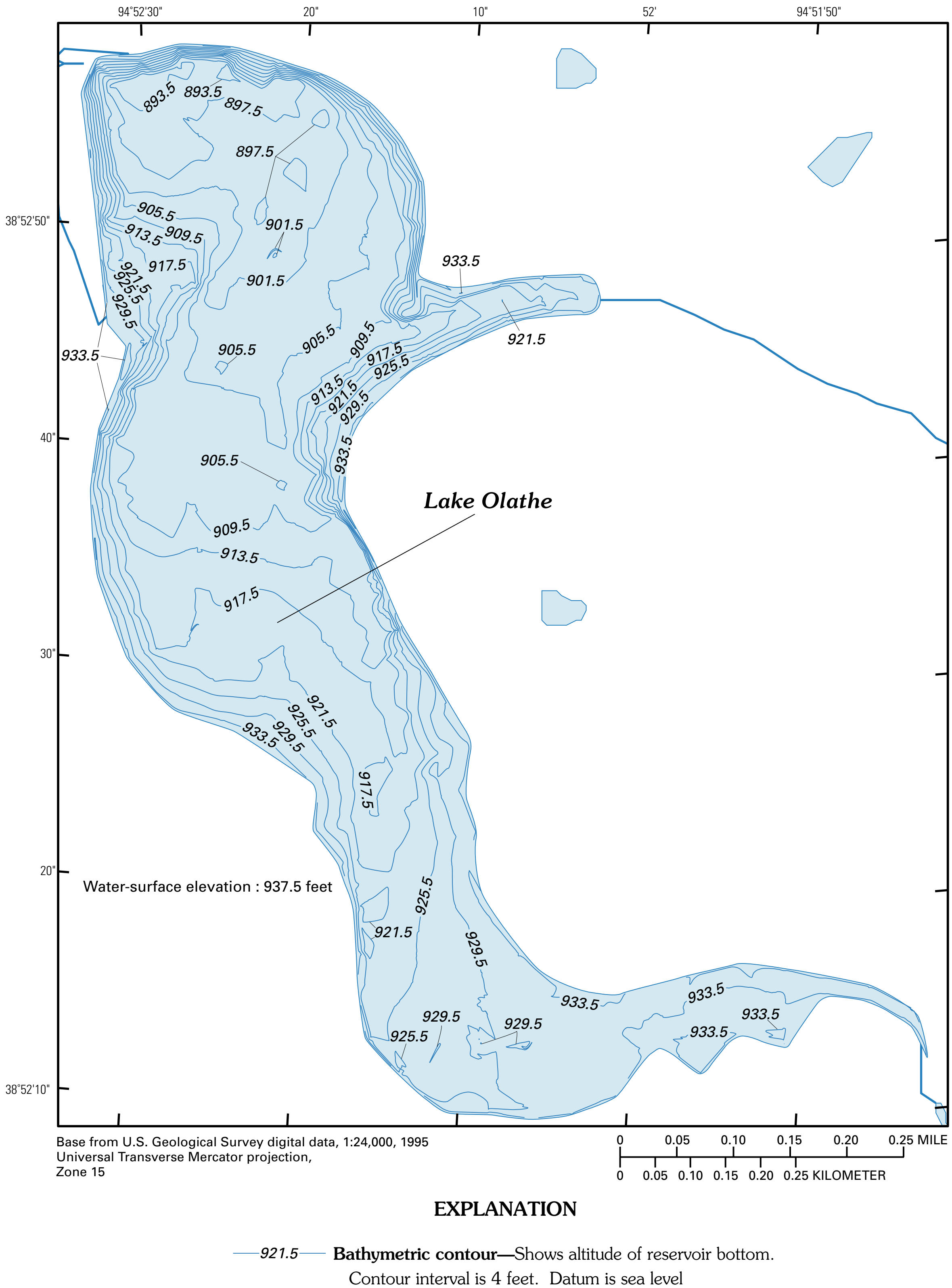

Figure 5. Bathymetric contours for Lake Olathe, 2000.

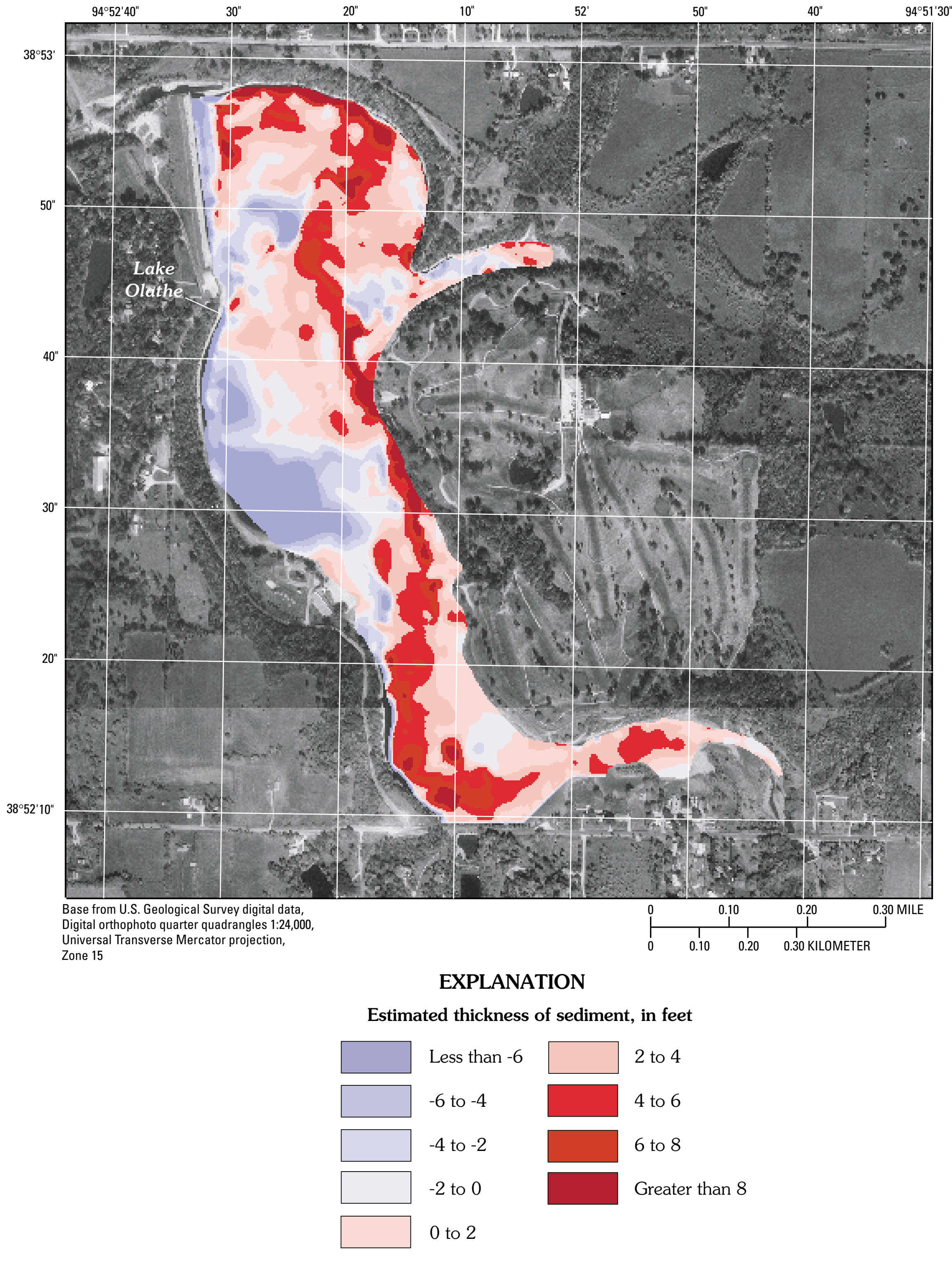

Figure 6. Estimated thickness of sediment in Lake Olathe, 1956–2000.

Table 3. Sediment deposition, loads, and yields estimated for Cedar Lake, Lake Olathe, and Hillsdale Lake, northeast Kansas

[mi^2, square miles; acre-ft, acre-feet; lb/ft^3, pounds per cubic foot; lb, pounds; lb/yr, pounds per year; $(lb/yr)/mi^2$, pounds per year per square mile; --, not applicable]

Lake	Drainage area (mi^2)	Number of years since dam closure	Total sediment deposition (acre-ft)	Mean sediment bulk density (lb/ft^3)	Total sediment mass (million lb)	Mean annual sediment load (million lb/yr)	Mean annual sediment yield [million $(lb/yr)/mi^2$]
Cedar Lake	6.14	62	338	40.4	595	9.6	1.56
Lake Olathe	16.6	45	317	40.9	567	12.6	.76
a. Kansas Clean Lakes Program (1982–83)[1]	--	--	16.3	--	--	--	--
b. Kansas Water Office (2001)	--	--	30	--	--	--	--
Hillsdale Lake[2]	144	15	2,100	--	3,973	265	1.84

[1]Lee and Sears (1985).
[2]Juracek (1997).

The total masses of bottom-sediment material in Cedar Lake and Lake Olathe were calculated by multiplying the bottom-sediment volume (total sediment deposition) from each lake by the mean sediment bulk densities (and appropriate conversion factor) as determined from the sediment cores from each lake (table 3). The mean bulk densities for each lake were calculated by averaging the mean bulk densities in the sediment cores from the in- and out-of-channel coring sites (table 4).

The total mass of bottom-sediment material for Cedar Lake was estimated to be 595 million lb and for Lake Olathe, 567 million lb. The mean annual sediment load for each lake, determined by dividing the sediment mass by the number of years of sediment deposition, was 9.6 million lb of bottom-sediment deposition per year for Cedar Lake and 12.6 million lb of bottom-sediment deposition per year for Lake Olathe.

Table 4. Estimated mean sediment bulk densities in both in-channel and out-of-channel bottom sediment, Cedar Lake and Lake Olathe, northeast Kansas, 2000

[lb/ft^3, pounds per cubic foot]

Coring sites (fig. 1)	Mean bulk density (lb/ft^3)
Cedar Lake	
1 (out-of-channel)	42.1
2 (out-of-channel)	45.7
3 (in-channel)	33.3
Mean	**40.4**
Lake Olathe	
1 (in-channel)	60.8
2 (in-channel)	56.4
3 (out-of-channel)	27.5
4 (out-of-channel)	29.5
5 (in-channel)	30.3
Mean	**40.9**

Comparisons of Sediment Deposition Among Cedar Lake, Lake Olathe, and Hillsdale Lake

Comparisons of Cedar Lake, Lake Olathe, and Hillsdale Lake were made to determine differences in sediment deposition among the three lakes. Hillsdale Lake was chosen because it is located close to the Lake Olathe watershed, and the two watersheds have similar topographic features and land-use patterns.

The total sediment deposition at Hillsdale Lake was 2,100 acre-ft (from 1981–96), more than six times greater than either Cedar Lake or Lake Olathe (table 3; Juracek, 1997). When the comparison was made on the basis of mean annual sediment yield (mean annual sediment deposition divided by the contributing-drainage area), the Hillsdale Lake watershed was the largest contributor of sediment but not substantially greater than the mean annual sediment yield from the drainage area to Cedar Lake (table 3). If the drainage area to Cedar Lake was excluded from the Lake Olathe watershed, the mean annual sediment yield to Lake Olathe would increase from 0.76 to 1.2 million $(lb/yr)/mi^2$, which is a more comparable yield relative to those determined for the Cedar Lake watershed [1.56 million $(lb/yr)/mi^2$] and the nearby Hillsdale Lake watershed [1.84 million $(lb/yr)/mi^2$]. The implication of this calculation is that sediment deposition would be more substantial in Lake Olathe if Cedar Lake did not intercept much of the sediment yield from the watershed. Also, the contributing-drainage area to Cedar Lake represents only 37 percent of the watershed, and yet the mean annual sediment yield is almost twice that contributed to Lake Olathe (table 3).

WATER-QUALITY CHARACTERISTICS

Analysis of reservoir bottom sediment can provide insight into water-quality characteristics of a reservoir watershed. These characteristics include historical perspectives on sediment and chemical transport and potential toxicological effects on aquatic organisms. Areal distribution of sediment in the lakes and physical and chemical composition were examined during this investigation to quantify chemical concentrations, identify trends in chemical deposition, and evaluate chemical composition in relation to sediment-quality guidelines for the protection of aquatic organisms. Identified trends in water-quality constituents were related to known watershed land-use and human-related characteristics.

Phosphorus

Phosphorus is a nutrient essential for the growth and reproduction of plants. It is used as an energy source in the cells of plants and animals and can have a direct effect on the production of phytoplankton populations, an important component of the food chain. Phosphorus availability is also a critical factor in eutrophication because it is often the limiting nutrient that controls biological production rates (Hem, 1992, p. 128). Excessive phosphorus in water bodies, where nitrogen is not a limiting factor, can accelerate eutrophication. Eutrophication is characterized by extensive algal growth (algal blooms) that may reduce the aesthetic and recreational value of water, and in severe cases may stress or kill aquatic organisms as a result of dissolved-oxygen depletion when algal blooms die.

Common sources of human-related phosphorus include inorganic phosphates added to agricultural soils as fertilizer, manure from confined animal-feeding operations, and treated human sewage disposed directly into receiving streams. Excessive phosphorus concentrations in soils from both natural and human-related sources can have detrimental effects on lakes located downgradient from the source areas and can promote excessive algal growth that lead to taste-and-odor problems in treated drinking water.

Phosphorus may be associated with sediment loads that are transported to lakes. Found primarily with the finer sediment fractions, the incorporation of phosphorus into sediment effectively removes phosphorus from the water column, and the reservoir sediment becomes the primary sink or trap for phosphorus (Morris and Fan, 1998, p. 4.18).

Concentrations in Reservoir Bottom Sediment

Reservoir sediment may contain large quantities of phosphorus. This phosphorus may have been transported into the lake in both particulate and dissolved forms. Analysis of the sediment was used in determining the extent of phosphorus deposition and to evaluate historical trends.

Mean concentrations of total phosphorus in the bottom-sediment cores from Cedar Lake ranged from 1,370 mg/kg at coring site 1, located upstream in the lake, to 1,810 mg/kg at coring site 3, located near the dam (fig. 7). The mean total phosphorus concentration in bottom-sediment samples from the three coring sites was 1,540 mg/kg. Although Cedar Lake is no longer used as a drinking-water supply, under anoxic conditions (low dissolved-oxygen concentrations) phosphorus released from the sediment to the water column could encourage algal blooms and lessen the suitability of water in the lake for aquatic habitat and recreation. Cedar Lake also discharges water to Lake Olathe through Cedar Creek when the water elevation of Cedar Lake exceeds the spillway elevation (1,001.0 ft above sea level); therefore, adverse water-quality conditions in Cedar Lake during such times could easily affect the water quality of the Lake Olathe drinking-water supply.

Mean concentrations of total phosphorus in the bottom-sediment cores from Lake Olathe ranged from 588 mg/kg at coring site 1, located the farthest upstream in the lake, to 1,030 mg/kg at coring site 5, located near the dam (fig. 7). The mean total phosphorus concentration in samples from the five coring sites was 774 mg/kg. It is possible that in-lake enrichment of phosphorus from phytoplankton growth and deposition as well as from lake hydraulics are contributing to the upstream-to-downstream increases in total phosphorus concentrations in Lake Olathe bottom sediment. External sources such as the public golf course and public latrines at the golf course and swimming

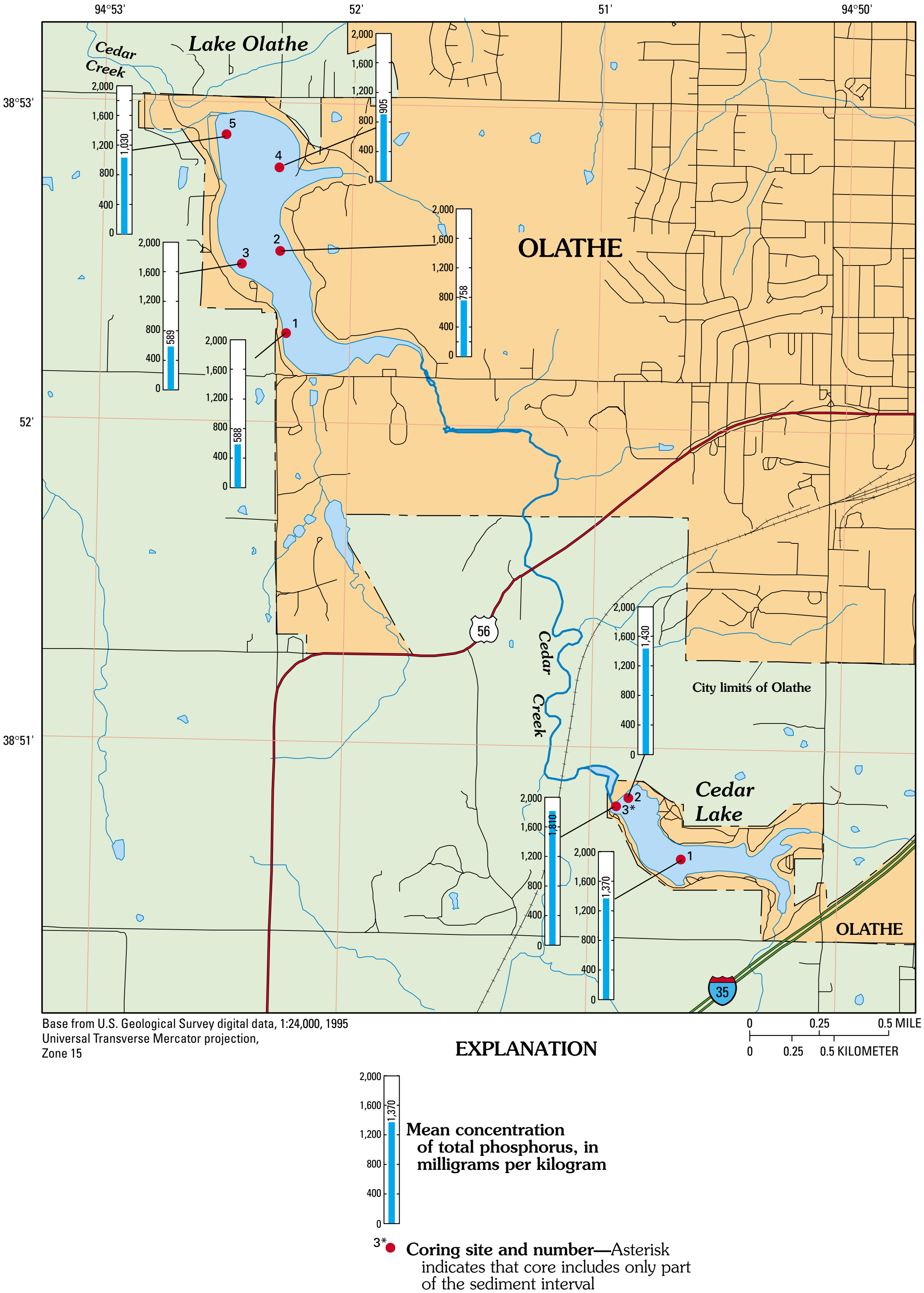

Figure 7. Mean concentrations of total phosphorus in bottom-sediment core samples collected from Cedar Lake and Lake Olathe, 2000.

beach also may contribute to the increased total phosphorus concentrations seen in the sediment cores near the dam (Carly Adams, city of Olathe, oral commun., 2001). There also may be some upstream-to-downstream transport of phosphorus through adsorption to silt and clay particles and the subsequent transport of these particles within the lake.

The difference in total phosphorus concentrations in bottom sediment between the two lakes may be related to historic agricultural and human-related practices. Fertilizer application to cropland as well as animal waste from livestock likely would include phosphorus compounds that could be transported to Cedar Lake, adsorbed to sediment, and deposited in the lake. It is also possible that septic systems from nearby farms and residences that existed or were developed in the 1930s, when Cedar Lake was created, may have leached phosphorus and other compounds into the lake. Cedar Lake also acts as a sediment trap for Lake Olathe, receiving sediment deposition that otherwise would be transported to Lake Olathe. Sediment transport of phosphorus and other hydrophobic compounds (compounds that adsorb to sediment) may be more prevalent in Cedar Lake than in Lake Olathe, where total sediment deposition is less.

Two previous reservoir-sediment studies of Cheney Reservoir in south-central Kansas (Pope, 1998; Mau, 2001) showed a strong linear relation between bottom-sediment particle size and total phosphorus concentration. The regression analysis by Pope (1998) was repeated in this investigation of Cedar Lake and Lake Olathe to determine whether a relation existed between the size of bottom-sediment particles and total phosphorus concentration.

Regression analysis is one method used to determine whether a relation exists between two variables. The correlation coefficient, r, is used as a measure of the strength of the relation and ranges from –1.0 to 1.0 depending on whether the relation is negative (indirect) or positive (direct). The closer the correlation coefficient is to –1.0 or 1.0, the stronger the relation between the two variables. The p-value (probability value) is used as a measure of the statistical significance of a relation. The statistical significance of a correlation increases as the p-value decreases. A 0.05 level of significance is used in this study to define statistically significant correlations.

Regression analysis to determine a relation between bottom-sediment particle size and total phosphorus concentration was inconclusive primarily because of a lack of variability in particle size; more than 97 percent of the sediment particle-size distribution in both lakes was represented by sediment particles less than 0.062 mm in diameter, the silt and clay fractions (fig. 8). The p-values for both lakes indicate that there is no statistical significance relating bottom-sediment particle size to total phosphorus concentrations.

The depositional trend of phosphorus in both Cedar Lake and Lake Olathe was compared to cesium-137 data. Cedar Lake was built in 1938; therefore, the cesium-137 profile of Cedar Lake was expected to be zero near the bottom of the core followed by increasing concentration until the1963–64 nuclear test ban treaty, with a long period of declining concentrations to the present day at the top of the core. The actual cesium-137 profile peaked at the bottom of the core (oldest sediment) and steadily declined with a slight inflection near the middle of the core (fig. 9). Two possible explanations may account for the cesium-137 profile of Cedar Lake: (1) an incomplete bottom-sediment core was obtained, or (2) dredging activity occurred in Cedar Lake, and sediment containing older cesium-137 concentrations was removed. The sediment core obtained from Cedar Lake was nearly 5 ft long. The initial core analysis showed complete core-barrel penetration through the sediment into the original bottom material, indicating that a complete bottom-sediment core was obtained. Although there was no confirmation of dredging, repair work on the dam face occurred in 1995, following significant water-seepage loss through the earthen dam over a 24-hour period in 1994 (Carly Adams, city of Olathe, oral commun., 2001). Repair-work documents did not indicate the use of lake sediment to shore the dam face. However, because it is possible that sediment near the dam was disturbed either during the rapid loss of water from the lake or during repair work on the dam, comparison of constituent trends using analytical results from coring site 3, located closest to Cedar Lake Dam would be inconclusive.

The depositional trend of phosphorus at Lake Olathe was supported by the cesium-137 analysis (fig. 9). Cesium-137 data in bottom sediment showed a peak in cesium-137 concentrations near the bottom of the core followed by a gradual decrease to the more recent deposition. Dredging activity and removal of 3 acre-ft of bottom sediment that occurred in the upper end of Lake Olathe in 1980 (Lee and Sears, 1985) may have disturbed the sediment profile and accounted for

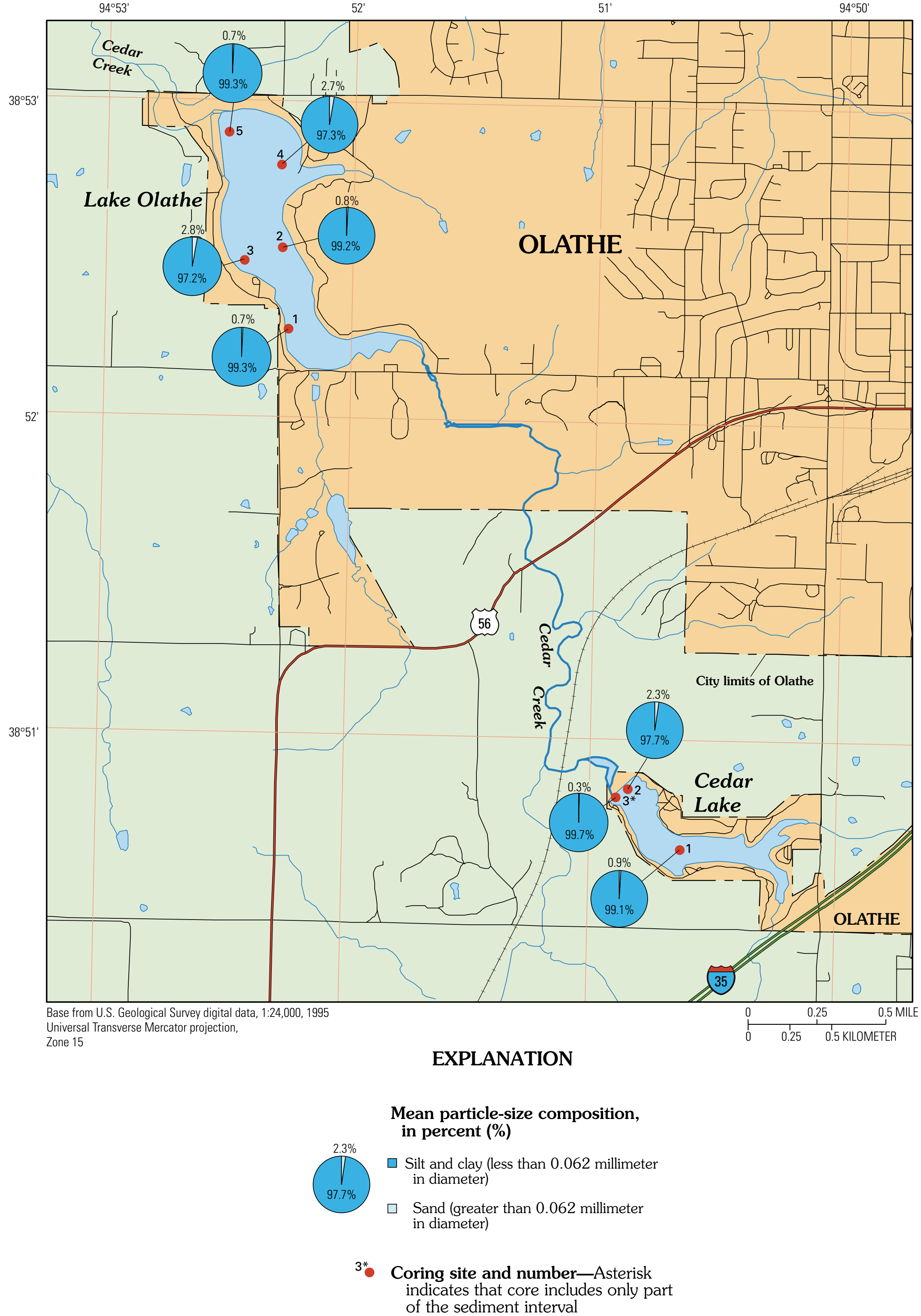

Figure 8. Mean particle-size composition of bottom-sediment cores collected from Cedar Lake and Lake Olathe, 2000.

slight variations in the cesium-137 profile near the top of the core. The cesium-137 data from the sediment core indicate that substantial disturbance of sediment layers has not occurred in Lake Olathe and, therefore, would not affect time-trend analysis.

Total phosphorus concentrations in a bottom-sediment core from Lake Olathe appeared to be increasing slightly from the older sediment to the newer sediment near the top of the core (fig. 10). However, the Kendall's tau trend test of the data set did not identify a trend (table 5). If there is a trend, the most likely source is leaking septic systems from residences located near Lake Olathe, which were identified in the 1982–83 Kansas Clean Lakes Program investigation of Lake Olathe (Lee and Sears, 1985). Additional sources of total phosphorus to Lake Olathe could include phosphorus adsorbed to suspended sediment particles transported from Cedar Lake via Cedar Creek, as well as fertilizer usage from either agricultural or urban sources. The extent of suspended sediment and nutrient transport from Cedar Lake to Lake Olathe via Cedar Creek is being investigated.

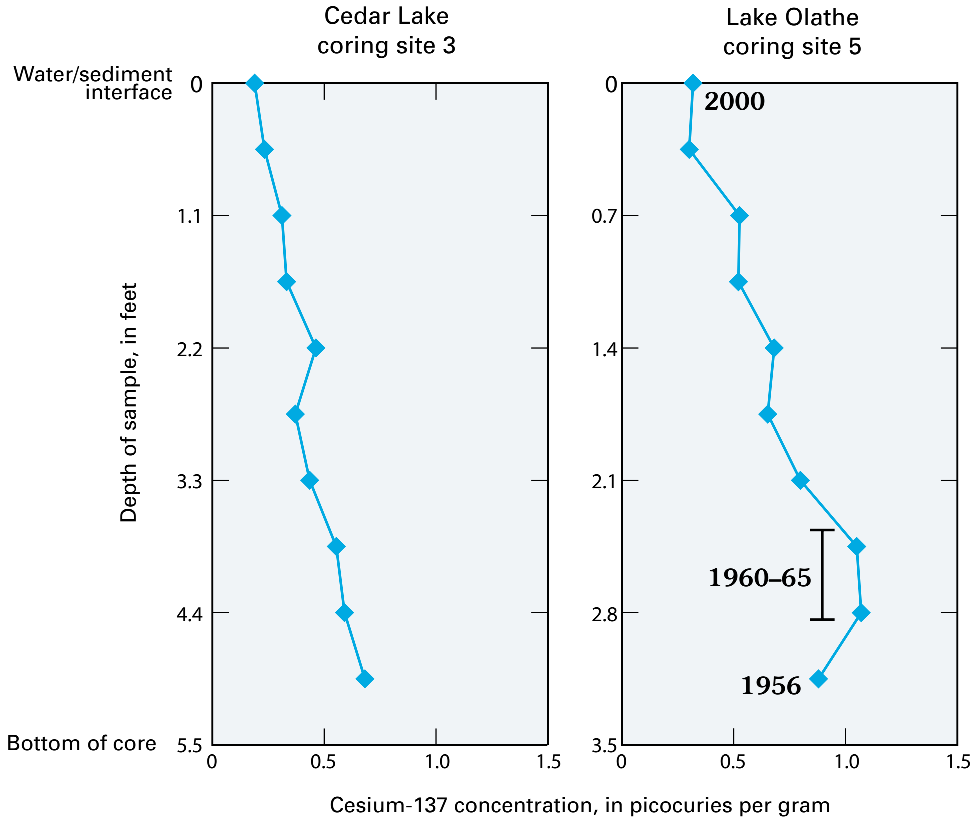

Figure 9. Relation between concentrations of cesium-137 and depths of bottom-sediment samples from coring site 3 in Cedar Lake, 1938–2000, and coring site 5 in Lake Olathe, 1956–2000. Location of coring sites shown in figure 1.

Estimates of Phosphorus Loads and Yields in Lake Olathe Watershed

Sediment loads and yields provide important information on the water-storage capacity and ecosystem of a reservoir, as well as activities within the watershed. Additionally, the evaluation of loads and yields of hydrophobic constituents, such as phosphorus, can be used by reservoir and watershed managers to help determine the effectiveness of BMPs or to implement new policies aimed at reducing the use or distribution of these constituents.

Phosphorus loads and yields in the Lake Olathe watershed were calculated on the basis of total sediment deposition previously reported in table 4. The total sediment deposition then was multiplied by the mean total phosphorus concentration in bottom sediment from each lake and, using the appropriate conversion factors to convert from International System to inch-pound units of measurement, divided by the number of years of sediment deposition to determine the annual mean phosphorus load in pounds per year (table 6). The mean annual phosphorus yield was determined by dividing the mean annual phosphorus load by the drainage area to each lake. The results of the sediment-based phosphorus yields for the Cedar Lake and Lake Olathe watersheds were compared to yields determined for the Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake watersheds.

Results of the load and yield calculations for Cedar Lake and Lake Olathe indicated that mean annual phosphorus loads for Cedar Lake, 14,700 lb/yr, were more than 50 percent larger than for Lake Olathe, 9,720 lb/yr, and that mean annual phosphorus yields were about four times larger for Cedar Lake,

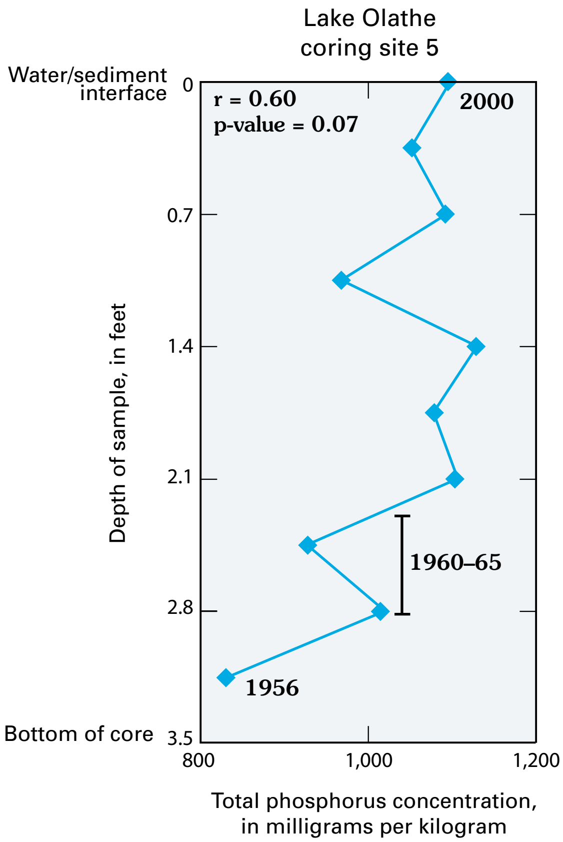

Figure 10. Relation between total phosphorus concentrations in bottom-sediment samples and depths of samples from coring site 5 in Lake Olathe, 1956–2000. Location of coring site shown in figure 1.

Table 5. Trend test analysis of concentrations of total phosphorus and total ammonia plus organic nitrogen (N) in bottom sediment from coring site 5 in Lake Olathe, northeast Kansas, 2000

Coring site (fig. 1)	Constituent	Number of samples with detections	Kendall's tau	Trend test at a 0.05 level of significance
Lake Olathe coring site 5	total phosphorus	10	0.378	no trend
	total ammonia plus organic nitrogen	10	.089	no trend

3.74 (lb/acre)/yr compared to 0.91 (lb/acre)/yr for Lake Olathe (table 6). The differences probably can be attributed to different agricultural and residential practices in the watershed as previously discussed in this report. The implication is that Cedar Lake acts as a water-quality buffer for Lake Olathe and that water quality in Lake Olathe would be changed substantially if Cedar Lake were removed and presumably would increase loads and yields to Lake Olathe.

Recent studies of phosphorus transported to Webster Reservoir (Mau and Christensen, 2000), Cheney Reservoir (Mau, 2001), Tuttle Creek Lake (Mau and Christensen, 2000), and Hillsdale Lake (Juracek, 1997) offer comparisons for the estimates of phosphorus transported into Cedar Lake and Lake Olathe. The mean annual phosphorus yield of the Cedar Lake subwatershed, 3.74 (lb/acre)/yr, was larger than the mean annual phosphorus yield from the other reservoir watersheds that were studied. The Lake Olathe watershed also transported more phosphorus annually per acre of drainage area, 0.91 (lb/acre)/yr, than the other reservoir watersheds studied by the USGS in Kansas, with the exception of Hillsdale Lake in northeast Kansas (Mau, 2001). However, if the Cedar Lake subwatershed was considered a noncontributing-drainage area to Lake Olathe, the mean annual phosphorus yield of the Lake Olathe watershed would be 1.41 (lb/acre)/yr, a difference of about 28 percent from the phosphorus yield estimated for Hillsdale Lake. On the basis of phosphorus deposited in reservoir bottom sediment, mean annual phosphorus yields were estimated to be 0.04 (lb/acre)/yr for the Webster Reservoir watershed (Mau and Christensen, 2000), 0.38 (lb/acre)/yr for the Cheney Reservoir watershed (Mau, 2001), 0.41 (lb/acre)/yr for the Tuttle Creek Lake watershed (Mau and Christensen, 2000), and 1.7 (lb/acre)/yr for the Hillsdale Lake watershed (Juracek, 1997).

Nitrogen

The presence of nitrogen, along with phosphorus, is essential for plant growth. Nitrogen also is important because it is used to synthesize proteins and, along with carbohydrates and fats, constitutes the major part of living substances (Reid and Wood, 1976). Nitrogen differs from phosphorus in that nitrogen is very mobile and not highly absorbed by soil, with the exception of ammonia (NH_3), which tends to adsorb to clay or organic particles (Morris and Fan, 1998). Contributions of nitrogen and phosphorus compounds to water bodies can lead to excessive algal growth, which may produce taste-and-odor problems in drinking water, stress aquatic organisms, and decrease the aesthetic and recreational value of the water body.

Table 6. Total phosphorus sediment loads and yields estimated for Cedar Lake, Lake Olathe, and other selected reservoir watersheds in Kansas

[million lb, million pounds; mg/kg, milligrams per kilogram; lb/yr, pounds per year; (lb/acre)/yr, pounds per acre per year]

Reservoir watershed or subwatershed	Number of years	Total sediment deposition (million lb)	Mean phosphorus concentration in sediment (mg/kg)	Mean annual phosphorus load (lb/yr)	Mean annual phosphorus yield [(lb/acre)/yr]
Cedar Lake	62	595	1,540	14,700	3.74
Lake Olathe	45	567	774	9,720	.91
Webster Reservoir[1]	42	3,300	374	29,400	.04
Cheney Reservoir[2]	34	15,400	480	226,000	.38
Tuttle Creek Lake[3]	37	194,000	481	2,520,000	.41
Hillsdale Lake[4]	15	4,000	583	154,000	1.7

[1]Christensen (1999); Mau and Christensen (2000).
[2]Mau (2001).
[3]Data on file with U.S. Geological Survey, Lawrence, Kansas; Mau and Christensen (2000).
[4]Juracek (1997); Mau and Christensen (2000).

There are many potential sources of nitrogen in the Lake Olathe watershed including leachate from septic systems, runoff from livestock wastes, runoff from agricultural and residential application of synthetic fertilizers, and atmospheric deposition (Carly Adams, city of Olathe, oral commun., 2001; Wetzel, 2001, p. 226). Leachate from public latrines, as well as leachate from private residential septic systems, may contribute nitrogen compounds to the watershed and lake. The application of synthetic fertilizers in Kansas has increased about 10-fold in the past 40 years (Kansas Department of Agriculture and U.S. Department of Agriculture, 1996). Nitrogen fertilizers not incorporated into the soil or used by plants can be washed off by excessive rains into nearby streams or infiltrate into ground water. Atmospheric deposition is another source of nitrogen in the watershed. Nitrogen represents 79 percent of the atmosphere and can be converted to ammonia and nitrate by cosmic radiation and subsequently deposited on soil through precipitation (Manahan, 1994, p. 160).

Mean concentrations of total ammonia plus organic nitrogen as nitrogen (N) ranged from 2,000 to 2,700 mg/kg in bottom-sediment samples from Cedar Lake and from 1,300 to 2,700 mg/kg in samples from Lake Olathe (fig. 11). The values are similar to concentrations of mean total ammonia plus organic nitrogen as nitrogen (N) analyzed in bottom-sediment cores collected in 1998 from Kirwin, Webster, and Cheney Reservoirs, and Waconda Lake (Christensen, 1999; Mau, 2001).

Total ammonia plus organic nitrogen as nitrogen (N) concentrations in bottom sediment were analyzed using the sediment profile at coring site 5 in Lake Olathe to determine whether trends existed from the older sediment deposited at the bottom of the core to the newer sediment at the top of the core. An evaluation of the correlation coefficient and p-value using a simple linear regression indicated that there was no statistical significance between total ammonia plus organic nitrogen as nitrogen (N) concentrations and depth (fig. 12). The application of Kendall's tau to the total ammonia plus organic nitrogen as nitrogen (N) data set for both lakes did not indicate trends in either lake (table 5).

Trace Elements

Trace element concentrations occur at levels of a few hundred micrograms per kilogram or less. Many trace elements are essential constituents of various enzymatic and cellular processes found in plants and animals but can be toxic in large concentrations (Pais and Jones, 1997). Found naturally in bottom sediment, trace elements can be enriched by human activities, such as those associated with industrial or commercial areas (Pais and Jones, 1997). Reservoir bottom sediment serves as a sink or trap for trace elements from the entire watershed, and therefore, analysis of the sediment can be used to evaluate the potential effects of watershed management practices and changes in land use.

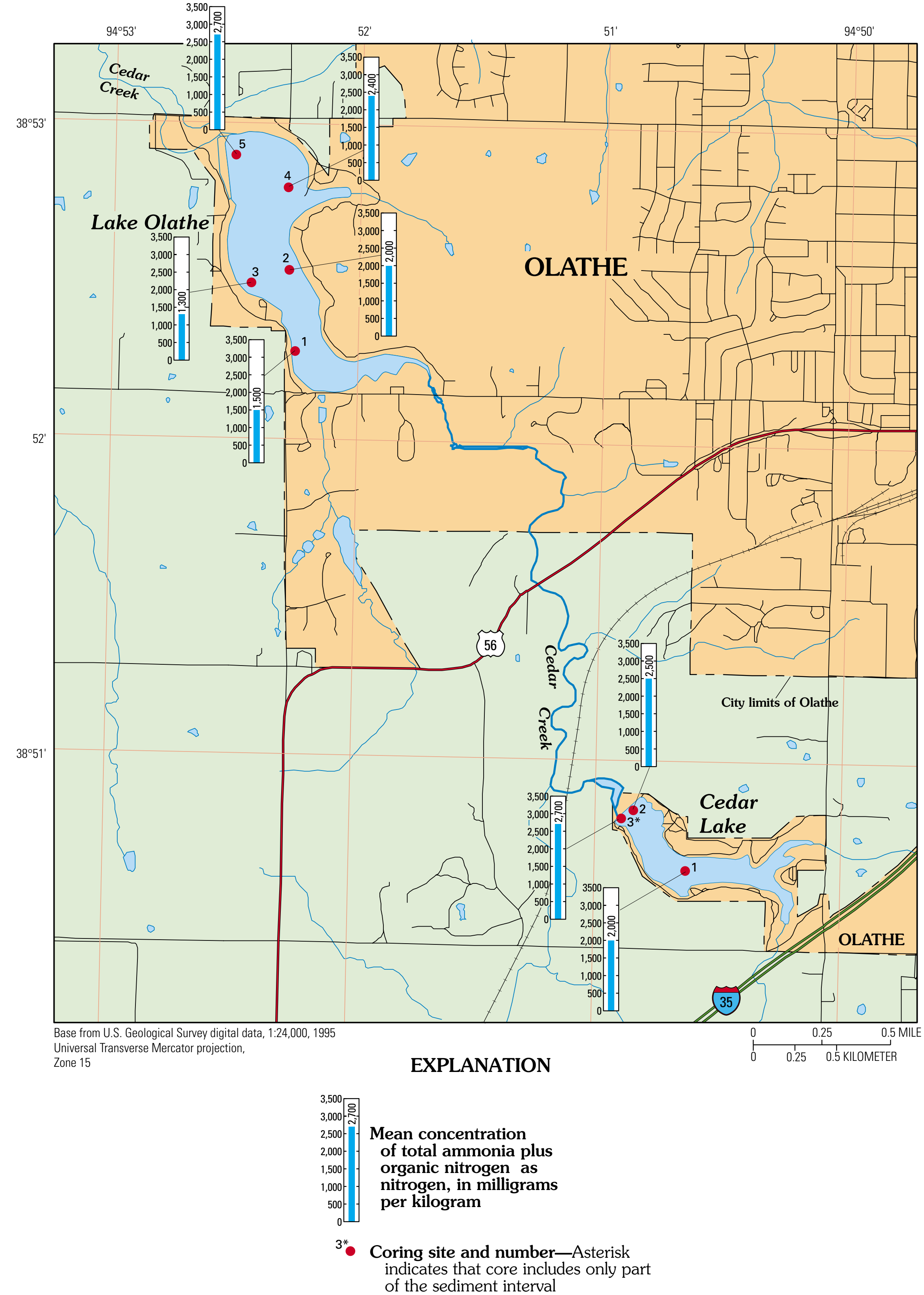

Figure 11. Mean concentrations of total ammonia plus organic nitrogen as nitrogen in bottom-sediment samples from Cedar Lake and Lake Olathe, 2000.

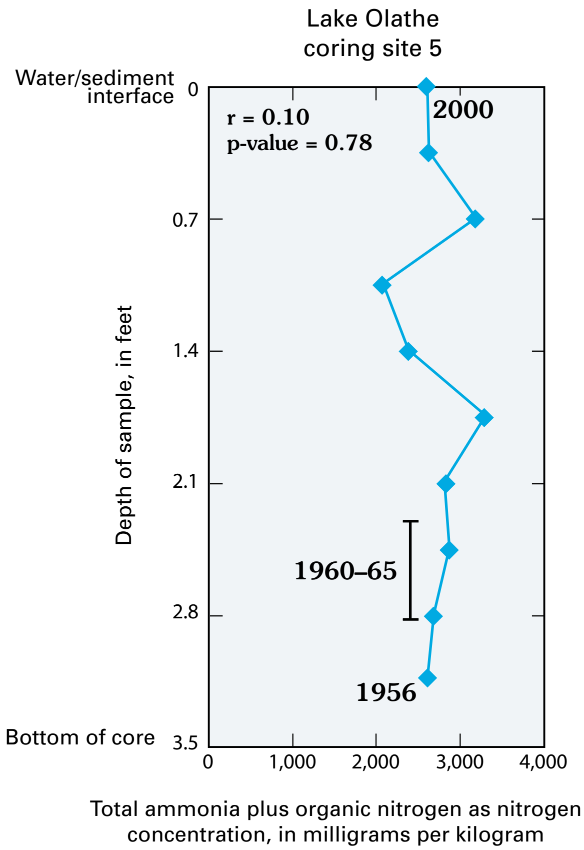

Figure 12. Relation between concentrations of total ammonia plus organic nitrogen as nitrogen in bottom-sediment samples and depths of samples from coring site 5 in Lake Olathe, 1956–2000. Location of coring site shown in figure 1.

One bottom-sediment core from both Cedar Lake and Lake Olathe was analyzed for trace elements (table 7; tables 16–17, in "Supplemental Information" section of this report). Each core was divided into five equal subsections and analyzed for trace elements. The mean value of each trace element analyzed from the five subsections was used in the discussion that follows. The data from one core in each lake did not provide sufficient information to determine whether any upstream-to-downstream trends in trace element concentrations existed.

The USEPA (1998) has established two sets of sediment-quality guidelines for selected trace elements—the Threshold Effects Level (TEL) and the Probable Effects Level (PEL). The smaller of the two guidelines (the TEL) is assumed to represent the concentrations below which toxic effects rarely occur. In the range between the TEL and PEL, toxic effects occasionally occur, and above the PEL guideline toxic effects frequently occur. The guidelines are used by the USEPA as screening tools and are not intended to have any regulatory implications. This cautionary statement is made because, although biological-effects correlation to trace element concentrations identifies levels-of-concern concentrations associated with the likelihood of adverse organism response, the particular procedure used may not demonstrate that a particular chemical is solely responsible. Biological-effects correlations may not indicate direct cause-and-effect relationships because coring sites may contain a mixture of chemicals that contribute to the adverse effects to differing degrees. Therefore, for any given site, these guidelines may be over- or underprotective.

Mean concentrations of trace elements in bottom-sediment samples from Cedar Lake and Lake Olathe exceeded the USEPA TEL sediment-quality guidelines for six of the eight trace elements that had guidelines (figs. 13–14, table 7). Mean concentrations of arsenic, chromium, copper, lead, nickel, and zinc exceeded the TELs in samples from Cedar Lake coring site 3 and from Lake Olathe coring site 5, placing them in the range where toxic effects occasionally occur. Cadmium and mercury concentrations in bottom-sediment samples from both lakes were less than the TEL sediment-quality guidelines. In addition, none of the PEL guidelines were exceeded in samples from either lake.

Mean concentrations of arsenic in bottom-sediment samples from both Cedar Lake and Lake Olathe were more than twice the TEL guideline for arsenic but much less than the PEL guideline (table 7). Arsenic has been used extensively as a pesticide, herbicide, and soil sterilant in agricultural soils in the United States, but it has only a moderate bioaccumulation effect because it is not very mobile (Pais and Jones, 1997, p. 86).

Mean chromium concentrations exceeded the TEL guideline by 79 percent in the bottom-sediment samples from Cedar Lake and by 73 percent in samples from Lake Olathe (table 7). Chromium is a toxic metal used in industry and is released in industrial wastewaters. The watershed does not support industrial activity; therefore, the source of chromium in the watershed is not well understood. However, chromium also is naturally present in the environment and may be a by-product of agricultural application of fertilizers. The content of chromium in most fertilizers ranges from 2 to 1,000 µg/g (Pais and Jones, 1997).

Mean copper concentrations in bottom sediment from both Cedar Lake and Lake Olathe exceeded the TEL guideline for copper (table 7). Copper is an

Table 7. Mean concentrations and sediment-quality guidelines for selected trace elements in bottom-sediment samples from Cedar Lake and Lake Olathe, northeast Kansas, 2000

[all values in micrograms per gram]

Coring site (fig. 1)	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Cedar Lake coring site 3	15	0.30	93	35	33	0.07	35	156
Lake Olathe coring site 5	16	.33	90	35	34	.06	37	142
Sediment-quality guidelines								
TEL[1]	7.2	.68	52	19	30	.13	16	120
PEL[1]	42	4.2	160	110	110	.70	43	270

[1]TEL, Threshold Effects Level; PEL, Probable Effects Level (U.S. Environmental Protection Agency, 1998).

essential micronutrient for plants and commonly is found in soil, and although the TEL concentration guidelines were exceeded by 84 percent in bottom-sediment samples from both Cedar Lake and Lake Olathe, the mean concentrations were substantially less than the PEL for copper (table 7).

Lead is a metal introduced primarily into the atmosphere through volatilization and combustion of leaded gasoline (Pais and Jones, 1997). Lead also can be introduced to the environment through agricultural fertilizer use; the lead content of fertilizers frequently ranges between 2 and 225 μg/g (Pais and Jones, 1997). Lead is not very mobile in soils or soluble in water. Mean lead concentrations exceeded the TEL guideline of 30 μg/g in bottom-sediment samples from both Cedar Lake and Lake Olathe by 10 and 13 percent, respectively, but were substantially less than the PEL guideline of 110 μg/g for lead (table 7).

Lead concentrations in bottom-sediment samples from Cedar Lake varied little with depth in the sediment profile (fig. 13), which may be related to the possible sediment disturbance from dam repair work in 1995. In contrast, the sediment profile from bottom sediment in Lake Olathe showed a slight decrease in lead concentrations from sediment in the bottom of the core to the water/sediment interface (fig. 14). The decrease in lead concentrations may be a result of the discontinued use of leaded gasoline in the early 1970s.

The typical total nickel content in uncontaminated soil is 25 μg/g, although concentrations in soil can range from 1 to 200 μg/g (Kabata-Pendias and Pendias, 1994; Pais and Jones, 1997, p. 124). Recent research suggests that nickel is an essential micronutrient for both plants and animals; however, in large concentrations it can be toxic (Pais and Jones, 1997, p. 125). Mean concentrations of nickel in bottom-sediment samples from both Cedar Lake and Lake Olathe were more than double the TEL guideline for nickel and slightly less than the PEL (table 7, figs. 13–14). With no apparent industrial source of nickel in the watershed, it may be that seepage from residential septic systems and surface runoff are contributing and concentrating nickel in the reservoir bottom sediment (Sedlack and others, 1997).

Zinc is an essential micronutrient for both plants and animals and is fairly uniformly distributed in soils (Pais and Jones, 1997, p. 147). Toxicity can occur from elevated zinc levels in industrial wastes or sewage sludge that can contain zinc at concentrations in excess of 1,700 μg/g (Pais and Jones, 1997, p. 148). Zinc also can be released to the atmosphere by electric-utility coal-burning operations as well as from the burning of industrial wastes (U.S. Public Health Service, 1994). The lack of industrial sources in the Lake Olathe watershed suggests that seepage from leaking septic systems may be a possible source of zinc in the reservoir bottom sediment. Concentrations of zinc in bottom-sediment samples from both Cedar Lake and Lake Olathe exceeded the TEL guideline for zinc by 30 percent and 18 percent, respectively, but were substantially less than the PEL guideline of 270 μg/g (table 7, figs. 13–14).

An examination of the subsectioned bottom-sediment cores from Lake Olathe for trends in five of the six selected trace elements was inconclusive (fig. 14). Arsenic, chromium, copper, nickel, and zinc fluctuated with depth with no apparent increasing or decreasing trend. The concentrations of these trace elements that exceed the TEL guidelines may be related more to natural conditions than to point or nonpoint sources. The Lake Olathe watershed does not have any large urban areas, an industrial base, or large population centers; therefore, any significant contributions from these sources would be limited.

Selected Pesticides

Pesticides are used in the United States to control weeds, insects, and other organisms. About 80 percent of pesticide application is used on agricultural land, and although crop production has been enhanced, the use of pesticides has raised concerns about potential adverse effects on human health and the environment (Nowell and others, 1999). This investigation analyzed the occurrence of 70 pesticides in reservoir bottom sediment from both Cedar Lake and Lake Olathe that could pose a current (2001) or future risk.

Bottom-sediment cores from both Cedar Lake and Lake Olathe were collected and analyzed for selected pesticides including organochlorine insecticides, organophosphate insecticides, acetanilide herbicides, and triazine herbicides (table 8). Organochlorine insecticides can be found in reservoir bottom sediment in watersheds where these compounds are used extensively to control insect damage to crops such as corn, wheat, and sorghum (Elder and Mattraw, 1984; Smith and others, 1987; Kalkhoff and Van Metre, 1997). These compounds also are used to control insects such as ants, termites, beetles, fleas, lice, mites, and mosquitos. The organophosphate insecticides have uses similar to organochlorine insecticides, may be used on human food crops such as fruits and vegetables, and are more

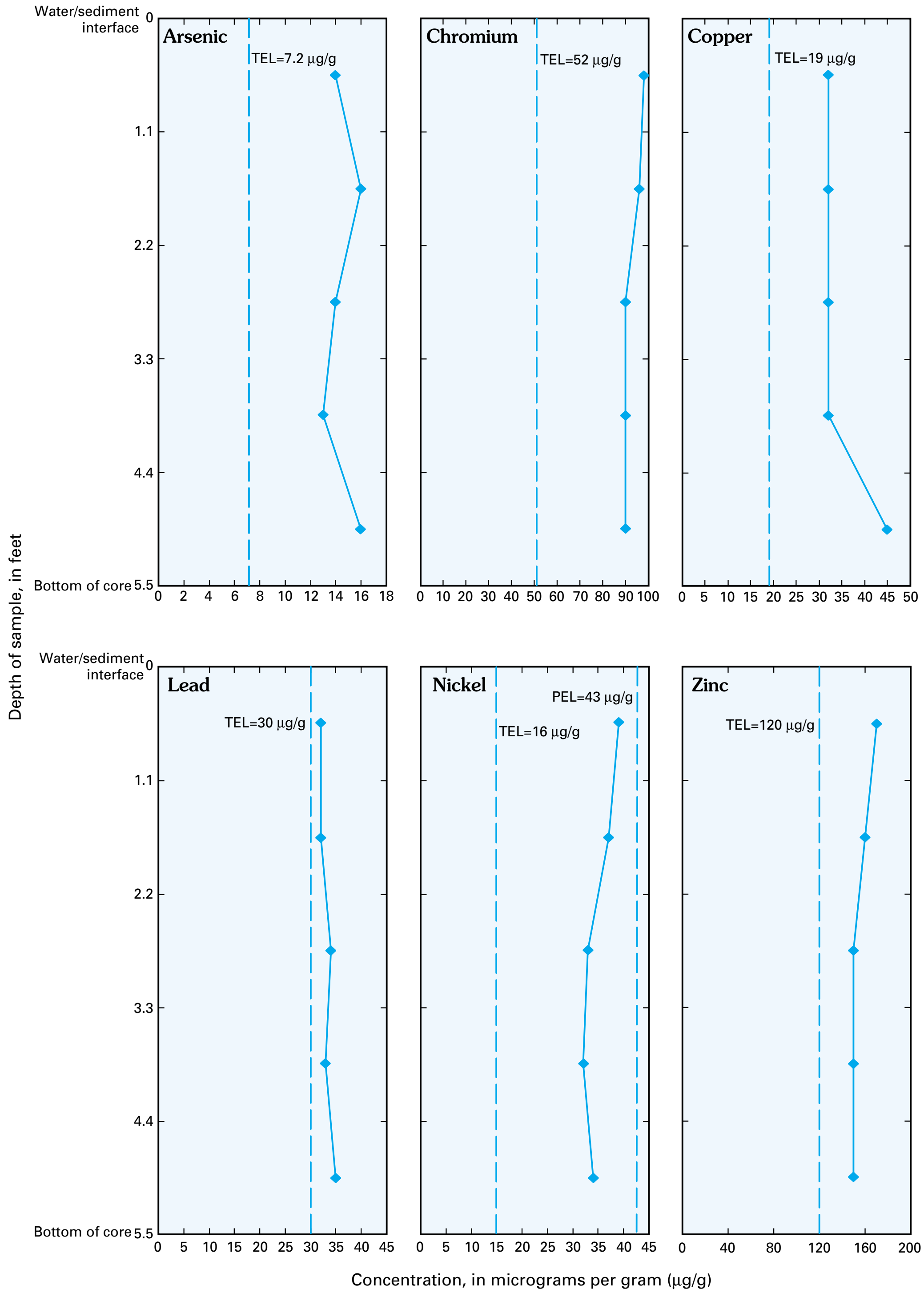

Figure 13. Relation between selected trace element concentrations in bottom-sediment samples and depths of samples from coring site 3 in Cedar Lake, 2000. Location of coring site shown in figure 1. Sediment-quality guidelines from U.S. Environmental Protection Agency (1998) (TEL, Threshold Effects Level; PEL, Probable Effects Level).

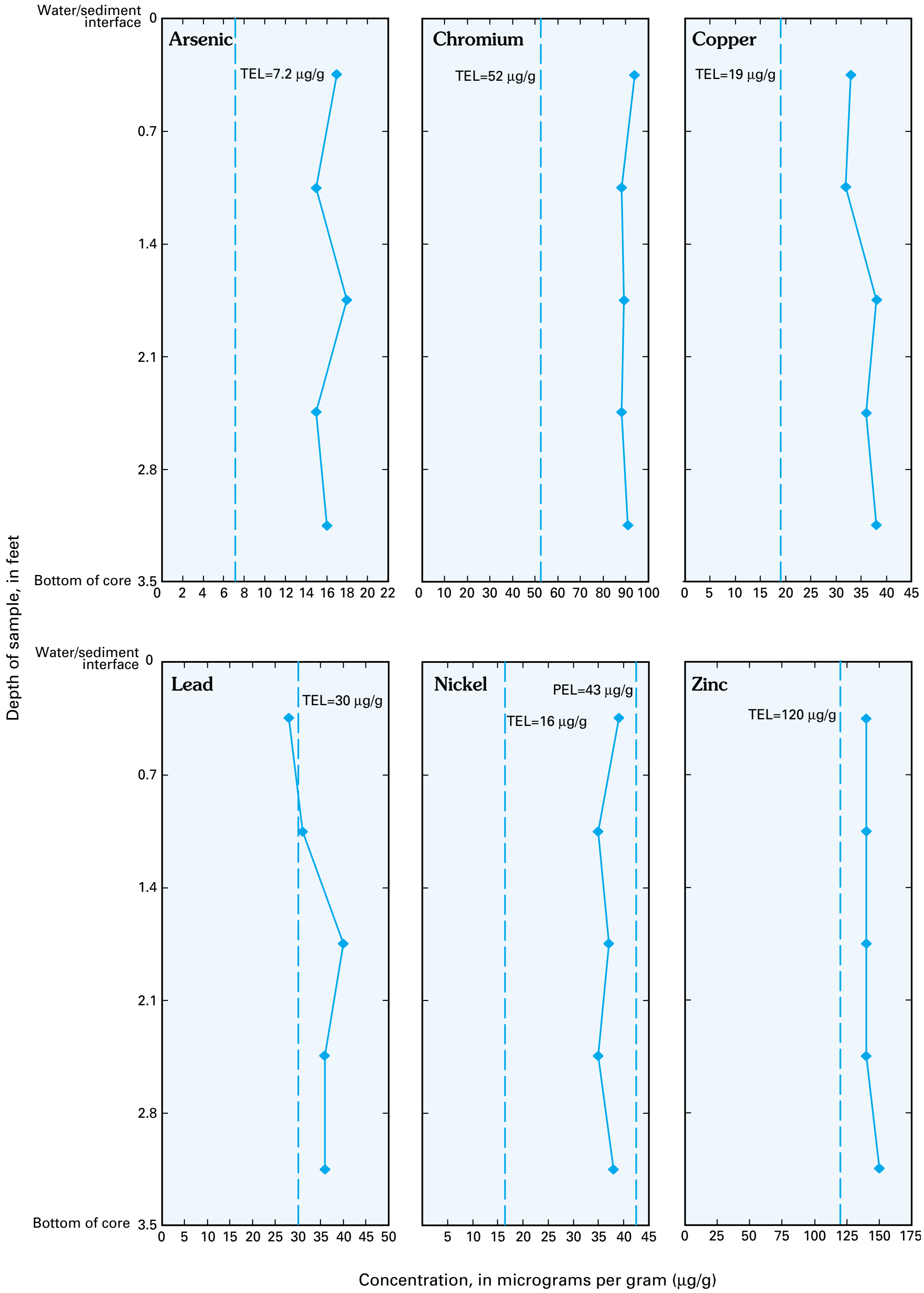

Figure 14. Relation between selected trace element concentrations in bottom-sediment samples and depths of samples from coring site 5 in Lake Olathe, 2000. Location of coring site shown in figure 1. Sediment-quality guidelines from U.S. Environmental Protection Agency (1998) (TEL, Threshold Effects Level; PEL, Probable Effects Level).

water soluble and less persistent than organochlorine compounds (U.S. Environmental Protection Agency, 1989). The acetanilide and triazine herbicides are used for weed and grass control on crops such as corn, sorghum, and soybeans and along roadways and railroad rights-of-way (U.S. Environmental Protection Agency, 1989).

There were no detections of selected organochlorine or organo-phosphate insecticides in bottom-sediment samples from Cedar Lake or Lake Olathe (table 8). This is surprising because of their widespread use and prevalence in the environment. During the past 30 years, more than 400 scientific studies including five national programs have looked for pesticides in stream sediment or aquatic biota. Most of the compounds detected in these studies were organochlorine insecticides or their degradation products, which were detected in about 92 percent of the studies (Nowell and others, 1999). The results of these studies are a reflection of the hydrophobic nature and persistence of these compounds, and the fact that most of the monitoring programs analyzed for organochlorine compounds.

Some acetanilide and triazine herbicides were detected at low concentrations in bottom-sediment samples from Cedar Lake and Lake Olathe

Table 8. Mean concentrations of selected pesticides in bottom-sediment samples from Cedar Lake and Lake Olathe, northeast Kansas, 2000

[µg/kg, micrograms per kilogram; <, less than indicated method reporting limit]

Pesticide	Method reporting limit (µg/kg)	Cedar Lake		Lake Olathe	
		Number of analyses	Mean concentration[1] (µg/kg)	Number of analyses	Mean concentration[1] (µg/kg)
Organochlorine insecticides					
Alpha-HCH	<0.20	5	<0.20	7	<0.20
Beta-HCH	<.20	5	<.20	7	<.20
Delta-HCH	<.20	5	<.20	7	<.20
Lindane	<.20	5	<.20	7	<.20
Heptachlor	<.20	5	<.20	7	<.20
Aldrin	<.20	5	<.20	7	<.20
Heptachlor epoxide	<.20	5	<.20	7	<.20
Chlordane	<.20	5	<.20	7	<.20
Endosulfan I	<.20	5	<.20	7	<.20
Dieldrin	<.20	5	<.20	7	<.20
pp-DDE	<.20	5	<.20	7	<.20
Endrin	<.20	5	<.20	7	<.20
Endosulfan II	<.20	5	<.20	7	<.20
pp-DDD	<.20	5	<.20	7	<.20
Endrin aldehyde	<.20	5	<.20	7	<.20
Endosulfan sulfate	<.20	5	<.20	7	<.20
pp-DDT	<.20	5	<.20	7	<.20
Methoxychlor I	<.20	5	<.20	7	<.20
Methoxychlor II	<.20	5	<.20	7	<.20
Organophosphate insecticides					
Azinfos ethyl	<.20	5	<.20	5	<.20
Carbophenothion	<.20	5	<.20	5	<.20
Chlorfenvinfos	<.20	5	<.20	5	<.20
Chlorpyrifos	<.20	5	<.20	5	<.20
Chlorpyrifos methyl	<.20	5	<.20	5	<.20
Coumafos	<.20	5	<.20	5	<.20
Diazinon	<.20	5	<.20	5	<.20
Dichlorvos	<.20	5	<.20	5	<.20
Dicrotofos	<.20	5	<.20	5	<.20
Ethion	<.20	5	<.20	5	<.20
Ethoprop	<.20	5	<.20	5	<.20
Fenchlorfos	<.20	5	<.20	5	<.20
Fenitrothion	<.20	5	<.20	5	<.20
Fensulfothion	<.20	5	<.20	5	<.20
Fonofos	<.20	5	<.20	5	<.20

Table 8. Mean concentrations of selected pesticides in bottom-sediment samples from Cedar Lake and Lake Olathe, northeast Kansas, 2000—Continued

Pesticide	Method reporting limit (µg/kg)	Cedar Lake: Number of analyses	Cedar Lake: Mean concentration[1] (µg/kg)	Lake Olathe: Number of analyses	Lake Olathe: Mean concentration[1] (µg/kg)
Organophosphate insecticides—Continued					
Leptofos	<0.20	5	<0.20	5	<0.20
Malathion	<.20	5	<.20	5	<.20
Methidiathion	<.20	5	<.20	5	<.20
Methyl parathion	<.20	5	<.20	5	<.20
Mevinphos	<.20	5	<.20	5	<.20
Monocrotofos	<.20	5	<.20	5	<.20
Oxydemeton methyl	<.20	5	<.20	5	<.20
Parathion	<.20	5	<.20	5	<.20
Stirofos	<.20	5	<.20	5	<.20
Sulfotepp	<.20	5	<.20	5	<.20
Sulprofos	<.20	5	<.20	5	<.20
Thionazin	<.20	5	<.20	5	<.20
Tokuthion	<.20	5	<.20	5	<.20
Tribufos	<.20	5	<.20	5	<.20
Tributyl phosphate	<.20	5	<.20	5	<.20
Trichlornate	<.20	5	<.20	5	<.20
Acetanilide herbicides					
Acetochlor	<.20	5	<.20	7	<.20
Alachlor	<.20	5	4.3	7	14
Metolachlor	<.20	5	.57	7	.60
Propachlor	<.20	5	<.20	7	<.20
Trifluralin	<.20	5	<.20	7	.80
Triazine herbicides					
Ametryn	<.20	5	2.0	7	6.0
Atrazine	<.20	5	1.3	7	1.6
Cyanazine	<.20	5	<.20	7	<.20
Cyanazine amide	<.20	5	<.20	7	<.20
Deethylatrazine	<.20	5	<.20	7	<.20
Deisopropylatrazine	<.20	5	<.20	7	<.20
Dimethenamid	<.20	5	<.20	7	<.20
Flufenacet	<.20	5	<.20	7	<.20
Metribuzin	<.20	5	<.20	7	<.20
Pendamethalin	<.20	5	<.20	7	<.20
Prometon	<.20	5	<.20	7	<.20
Prometryn	<.20	5	<.20	7	<.20
Propazine	<.20	5	<.20	7	<.20
Simazine	<.20	5	<.20	7	.35
Terbutryn	<.20	5	<.20	7	.25

[1]Mean concentration reported as <0.20 µg/kg when all analyses were less than the method reporting limit.

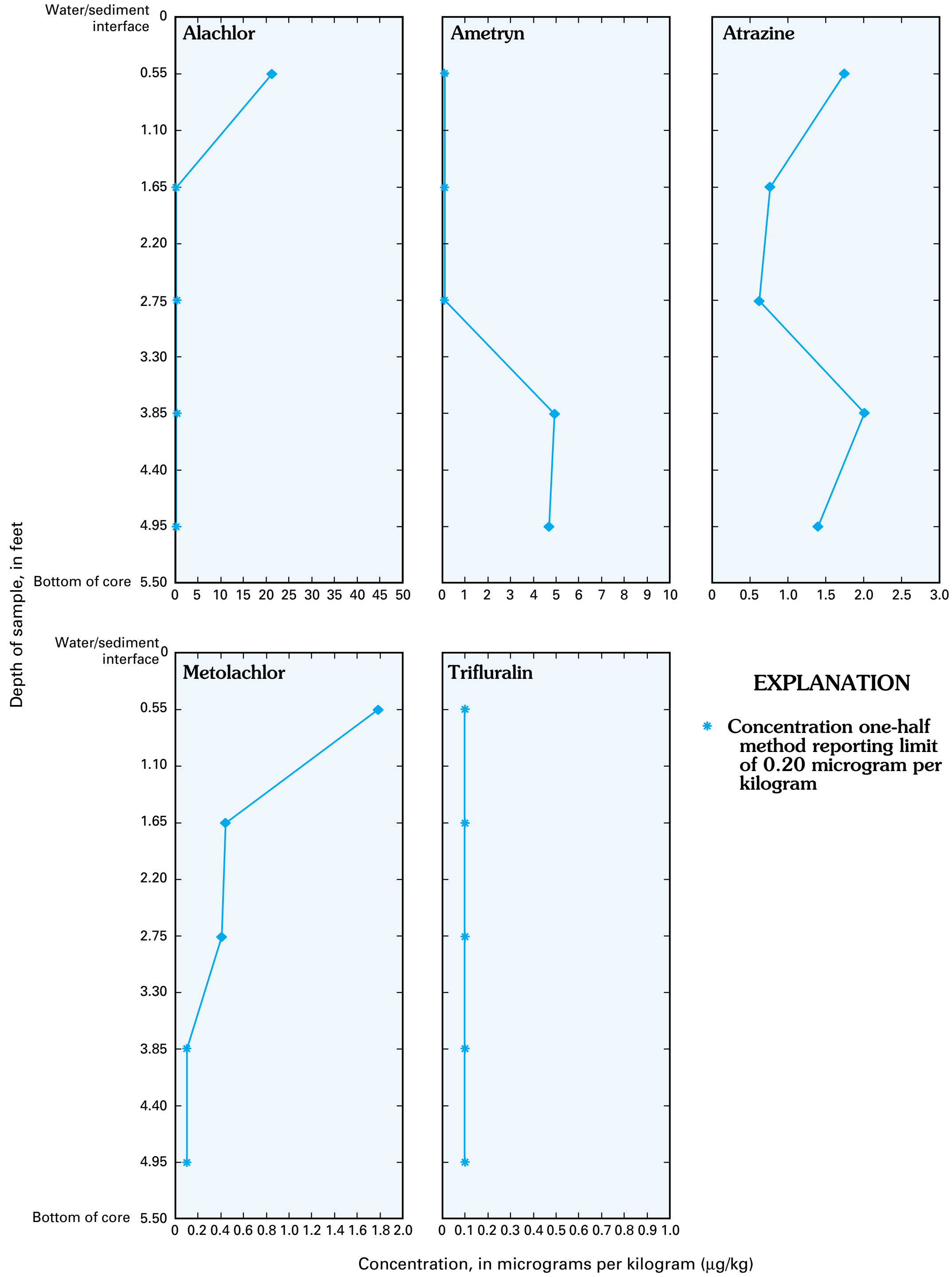

Figure 15. Relation between selected pesticide concentrations in bottom-sediment samples and depths of samples from coring site 3 in Cedar Lake, 2000. Location of coring site shown in figure 1.

(table 8) (figs. 15–16). Trends in concentrations of pesticides in bottom sediment from Cedar Lake will not be compared to concentrations of pesticides in bottom sediment from Lake Olathe because of the uncertainty associated with the sediment data from Cedar Lake previously discussed.

Concentrations of alachlor in bottom sediment from Cedar Lake were higher in subsamples from the upper one-third of the sediment core (from 0.55 to

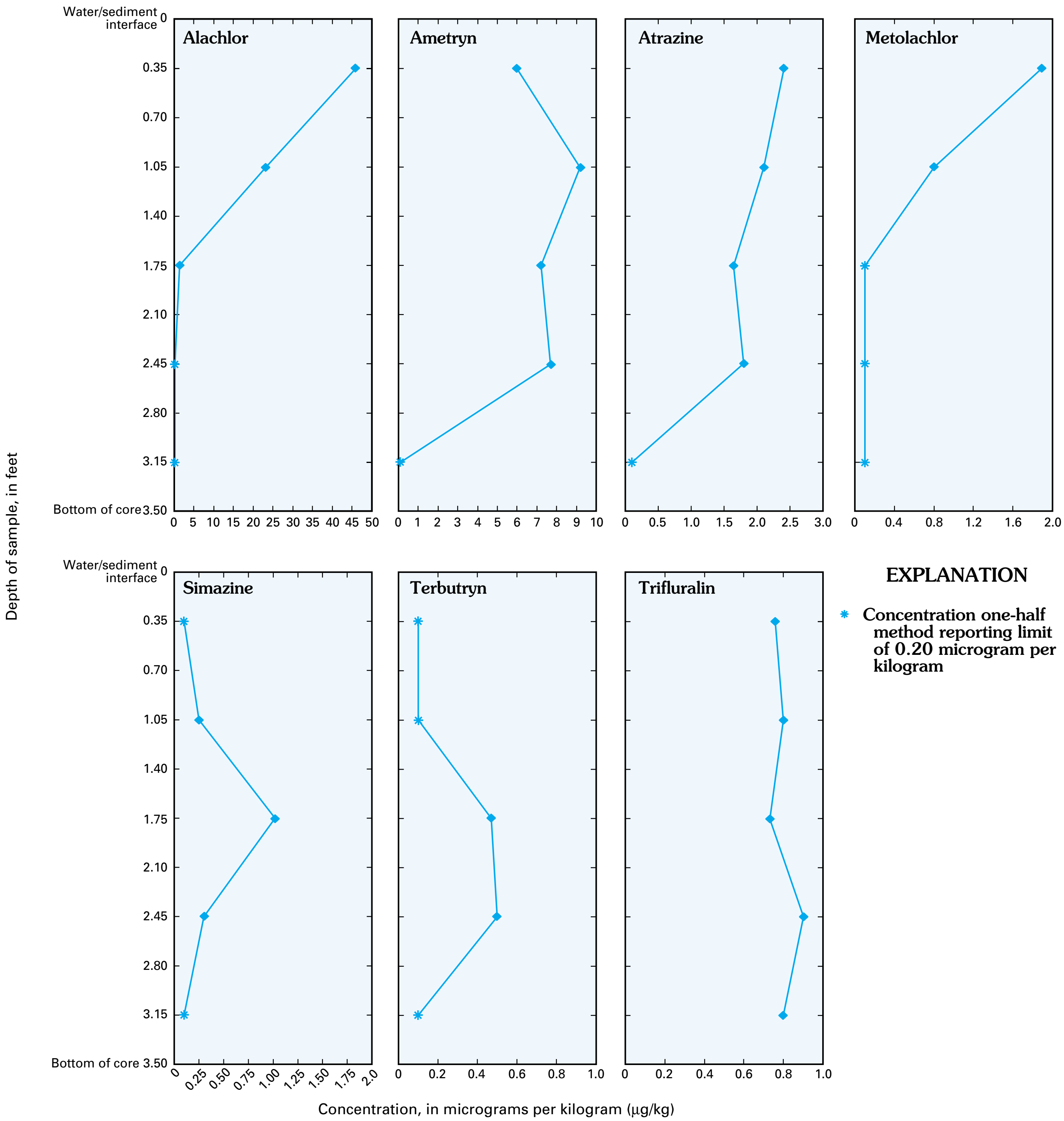

Figure 16. Relation between selected pesticide concentrations in bottom-sediment samples and depths of samples from coring site 5 in Lake Olathe, 2000. Location of coring site shown in figure 1.

1.65 ft below the water/sediment interface) and, in bottom sediment from Lake Olathe, were higher in subsamples from the upper one-half of the sediment core (from 0.35 to 1.75 ft below the water/sediment interface). Concentrations of alachlor in Cedar Lake bottom sediment increased from less than 0.20 to 21 µg/kg as the water/sediment interface was approached (fig. 15). Similarly, concentrations of alachlor in Lake Olathe bottom sediment increased from 1.3 to 46 µg/kg as the water/sediment interface was approached (fig. 16). Alachlor was commercially introduced to the United States in 1969 for weed control (Ahrens, 1994).

Concentrations of metolachlor in bottom sediment from Cedar Lake were higher in subsamples from the upper one-third of the sediment core (from 0.55 to 1.65 ft below the water/sediment interface) and in Lake Olathe were higher in subsamples from the upper one-half of the sediment core (from 0.35 to 1.75 ft below the water/sediment interface). Concentrations of metolachlor in Cedar Lake sediment increased from less than 0.20 to 1.8 µg/kg as the water/sediment interface was approached (fig. 15). Concentrations of metolachlor in bottom sediment from Lake Olathe increased from less than 0.20 to 1.9 µg/kg in subsamples from the upper one-half of the sediment core as the water/sediment interface was approached (fig. 16). Metolachlor was commercially introduced to the United States in 1977 for weed control (Ahrens, 1994). The presence of metolachlor above detection levels in the bottom-sediment profile suggests that about one-half (2.75 ft) of the total sediment deposition to Lake Olathe has occurred sometime since the introduction of metolachlor in 1977.

Bottom-sediment samples from Cedar Lake and Lake Olathe also showed detections of the triazine herbicide atrazine. Concentrations of atrazine in Cedar Lake sediment ranged from 1.4 µg/kg, near the bottom of the sediment core farthest from the water/sediment interface, to 1.8 µg/kg, near the water/sediment interface (fig. 15). Concentrations of atrazine in Lake Olathe ranged from less than 0.20 µg/kg, near the bottom of the sediment core farthest from the water/sediment interface, to 2.4 µg/kg near the water/sediment interface (fig. 16). Atrazine became commercially available in the United States in 1958, 2 years after dam impoundment of Lake Olathe, and its continued and increased usage in the watershed is indicated in the bottom-sediment profile. However, the detection of atrazine in Cedar Lake at the bottom of the sediment core suggests that the sediment was disturbed because atrazine was not commercially available in 1938 when the dam was constructed.

Although the detected herbicides have large solubilities, they degrade rapidly (1 to 2 months), and probably have little long-term water-quality implications for aquatic organisms in either lake as a result of chemical storage in bottom sediment. However, there may be degradation compounds from the detected herbicides in the sediment that are toxic to aquatic organisms. Some, but not all, of the degradation compounds were analyzed. The USEPA has not proposed TEL or PEL guideline concentrations in bottom sediment for any of the organochlorine, organophosphate, acetanilide, or triazine pesticides.

DIATOMS AS INDICATORS OF LAKE EUTROPHICATION

Lake eutrophication is the most widespread form of lake pollution on a global scale, can negatively affect aquatic ecosystems (Harper, 1992), and is a costly economic problem. Excessive algal growth, in response to eutrophication, can increase water-treatment costs and sometimes cause treatment facilities to malfunction (Vaughn, 1961; Hayes and Greene, 1984). In addition, algal blooms (including diatom blooms) can create taste-and-odor problems (Mason, 1991).

Diatoms are microscopic algae that occur in freshwater and marine environments. They have a siliceous shell, or frustule, consisting of two valves (halves), that generally is preserved well in sediment (Pyle and others, 1998). Diatoms occur in a variety of habitats including open water, on plants and macroalgae, and on sediment. Diatoms are abundant and diverse in freshwater lakes and may play an important role in the aquatic food chain (Round and others, 1990). Therefore, the response of diatoms to lake eutrophication may have implications for other components in the aquatic ecosystem. Diatoms are ideal for lake eutrophication studies because individual species are sensitive to environmental changes such as changes in nutrient concentrations and, therefore, can quantify environmental changes that accompany eutrophication (Stoermer and Smol, 1999).

Diatom species were identified and counted in subsections of bottom-sediment cores from both Cedar Lake and Lake Olathe. The number of diatom species identified in the subsections ranged from12 to 41 in the sediment core collected from Cedar Lake and from 27 to 50 in the sediment core collected from Lake Olathe (fig. 17) (tables 18–19 in “Supplemental Information” section of this report). However, the p-values were much greater than 0.05, suggesting no significance to the relation between depth and number of diatom species in the bottom sediment.

Estimates of the number of diatom valves per gram of sediment, a measurement of diatom density in sediment, ranged from 1.8 million to about 65 million valves per gram of material in bottom-sediment

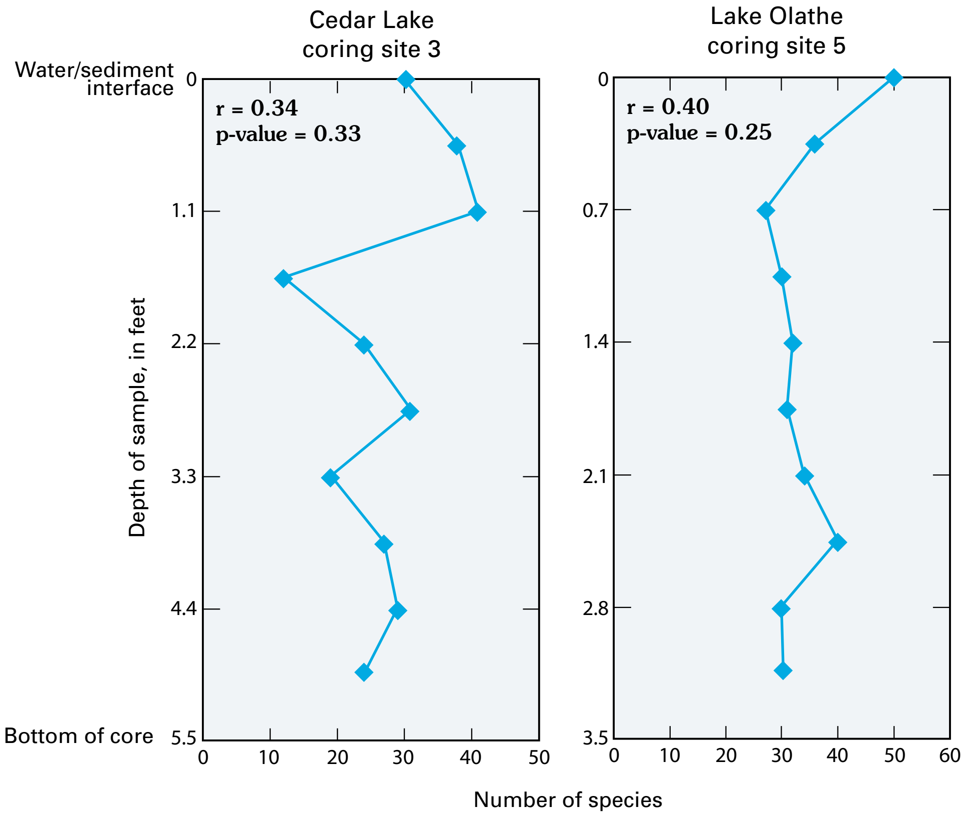

Figure 17. Relation between total number of identified diatom species in bottom-sediment samples and depths of samples from coring site 3 in Cedar Lake, 1938–2000, and coring site 5 in Lake Olathe, 1956–2000. Location of coring sites shown in figure 1.

samples from Cedar Lake and from about 5.3 million to 26 million valves per gram of material in samples from Lake Olathe (fig. 18). Bottom-sediment samples from both lakes showed a general increase in diatom densities closer to the water/sediment interface compared to the bottom of the sediment core, especially at Lake Olathe, which had a correlation coefficient, r, of 0.72 and a p-value equal to 0.02. This trend may reflect an increase in the productivity of the diatom community over the time period represented by the sediment cores. However, some or all of the changes may be a result of other factors, such as variable sedimentation rates or preservation of the valves in the sediment (Pyle and others, 1998). At slower sedimentation rates, for example, there may be more valves per gram of material for the same rate of diatom productivity because there is less sediment to “dilute” the density of the valves.

Generally, in eutrophic water, the diatom community will be dominated by a few abundant species tolerant to nutrient and organic enrichment. In contrast, diatom communities in uncontaminated water (free of sewage or other organic enrichment due to waste discharge) consist of a greater number of more equally abundant species (U.S. Environmental Protection Agency, 1977). The abundance of diatom valves per gram of material, represented by the six most-prevalent diatom species from each lake, accounted for relative percentage abundances ranging from 37 to 89 percent (median; 74 percent) of the total diatoms in the bottom-sediment sample from Cedar Lake and from 51 to 87 percent (median; 77 percent) in the sample from Lake Olathe (tables 9–11). These data indicate that, on the basis of a general definition of eutrophic water using diatom densities, both Cedar Lake and Lake Olathe probably have experienced eutrophic conditions throughout their history. However, diatom concentrations and the diversity of diatom species also can be affected by other factors such as turbidity, temperature, and solar intensity.

Selected diatom species in reservoir bottom sediment were compared to nutrient concentrations to determine whether a relation existed between the two variables. Six diatom species were selected that had the largest relative percentage abundance and that were found in most sediment-core subsections. Diatom abundances were compared to the total phosphorus concentrations, total ammonia plus organic nitrogen as nitrogen (N) concentrations, and sample depths from the sediment profile (table 10). Descriptions of each of the six diatom species and the environmental conditions that promote their growth are presented in table 11.

An analysis for trends using Kendall’s tau did not indicate any trend in bottom-sediment samples from Cedar Lake between total valves per gram of material for the six diatom species and concentrations of total phosphorus or total ammonia plus organic nitrogen as nitrogen (N) (table 10). The lack of any trend in samples from Cedar Lake may indicate that the diatom species are independent of nutrient concentrations or that the lake has historically been eutrophic. The dam repair work at Cedar Lake in 1995 also may have disturbed the deposition of bottom sediment and diatoms, and masked the occurrence of any possible trends. The presence of *Cyclotella bodanica* suggests water-quality conditions free of organic enrichment, whereas the presence of *Aulacoseira cf alpigena* and *Cyclotella meneghiniana* suggests just the opposite—a water body enriched with organic material. The apparent discrepancy may be related to seasonal water-quality variations in the lake. Water may be low in organic material part of the year, indicating perhaps less eutrophic conditions that encourage the growth of *Cyclotella bodanica*, and higher in organic material during other times of the year, encouraging the growth of *Aulacoseira cf alpigena* and *Cyclotella meneghiniana.* The genus *Aulacoseira* is a heavily silicified diatom that requires turbulence to maintain its presence in the water column. Increased turbulence along with increased nutrient concentrations during low lake stage can favor this genus over other planktonic species (Stoermer and Smol, 1999, p.188). Both *Cyclotella bodanica* and *Cyclotella meneghiniana* showed a negative correlation to total phosphorus concentration in Lake Olathe, indicating that the densities of both species decreased in the presence of total phosphorus concentrations (table 10). However, *Cyclotella meneghiniana* typically increases in the presence of phosphorus and organic-enriched material. This factor, in addition to the lack of a trend in total phosphorus concentration in the bottom-sediment profile, indicate that the Kendall's tau trend test may be inaccurate in this situation, possibly because of very little variability in abundance of *Cyclotella meneghiniana* in the bottom sediment of Lake Olathe.

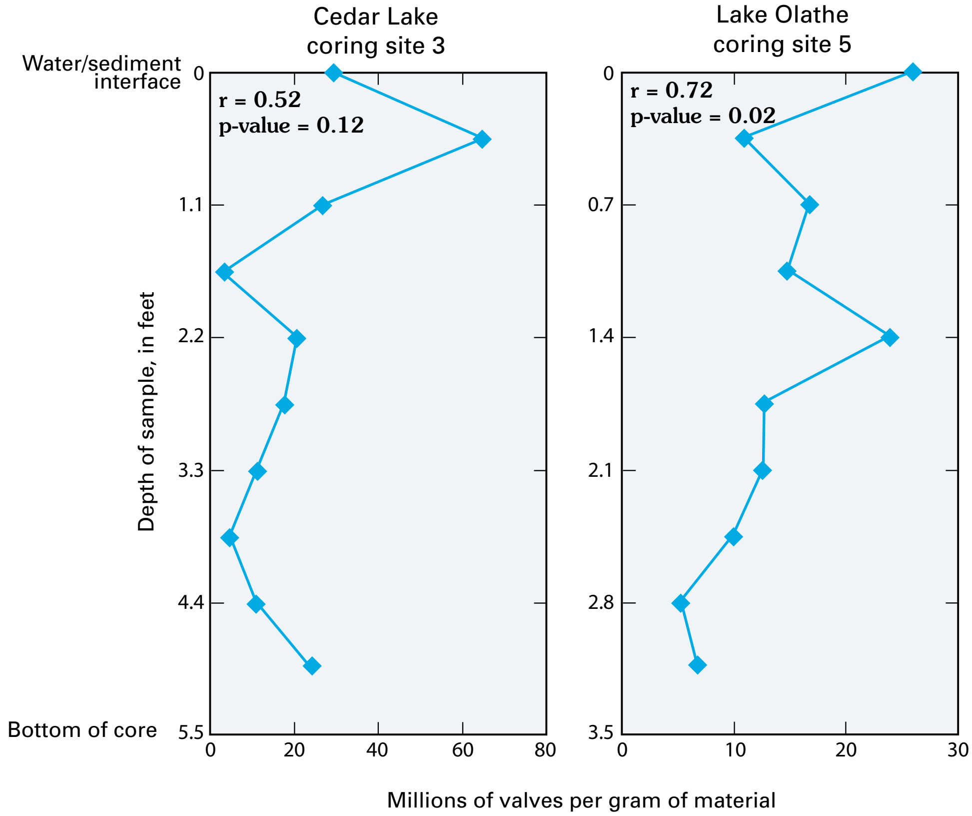

Figure 18. Relation between total number of valves of identified diatom species per gram of material in bottom-sediment samples and depths of samples from coring site 3 in Cedar Lake, 1938–2000, and coring site 5 in Lake Olathe, 1956–2000. Location of coring sites shown in figure 1.

An analysis of trends of the diatom species *Stephanodiscus nigarae* in bottom-sediment samples from Lake Olathe indicated a relation between total valves per gram of material of the species and total ammonia plus organic nitrogen as nitrogen (N) (table 10). *Stephanodiscus nigarae* is present in eutrophic water and is noted for imparting unacceptable taste to water (U.S. Environmental Protection Agency, 1977). *Stephanodiscus nigarae* was not present in each sediment-core subsection and had a low relative percentage abundance.

Diatom concentrations of *Aulacoseira cf alpigena*, *Cyclotella meneghiniana*, and *Cyclotella striata* correlated well with depths of sediment samples from Cedar Lake (table 10). Concentrations of *Aulacoseira cf alpigena* and *Stephanodiscus nigarae* in bottom-sediment samples from Lake Olathe similarly correlated well with depths of samples. Concentrations of these four diatoms were largest at the water/sediment interface (more recent deposition) and smallest at the bottom of the cores (older sediment). The presence of the diatom species *Aulacoseira cf alpigena* in bottom sediment from Cedar Lake suggests degrading water-

Table 9. Relative percentage abundance of six most-prevalent diatom species in bottom-sediment samples from Cedar Lake, 1938–2000, and Lake Olathe, 1956–2000, northeast Kansas

	Cedar Lake coring site 3 (fig. 1)		Lake Olathe coring site 5 (fig. 1)	
	Depth (feet)	Relative percentage abundance	Depth (feet)	Relative percentage abundance
Water/sediment interface	0.55	89	0.35	73
	1.10	87	.70	51
	1.65	77	1.05	62
	2.20	66	1.40	86
	2.75	76	1.75	82
	3.30	70	2.10	78
	3.85	81	2.45	76
	4.40	73	2.80	79
	4.95	72	3.15	87
Bottom of core	5.50	37	3.50	73
Median		**75**		**77**

Table 10. Relation between relative abundance of selected species of diatoms and concentrations of total phosphorus, total ammonia plus organic nitrogen as nitrogen (N), and depths of samples from selected bottom-sediment cores from Cedar Lake and Lake Olathe, northeast Kansas, 2000

[--, incomplete data set]

		Total phosphorus concentration		Total ammonia plus organic nitrogen as N		Depths of samples	
Diatom species	Reservoir	Kendall's tau	Trend test at 0.05 level of significance	Kendall's tau	Trend test at 0.05 level of significance	Kendall's tau	Trend test at 0.05 level of significance
Aulacoseira cf alpigena	Cedar Lake	-0.178	no	-0.267	no	-0.622	yes
	Lake Olathe	-.333	no	-.311	no	-.600	yes
Aulacoseira granulata	Cedar Lake	.044	no	-.200	no	-.244	no
	Lake Olathe	-.067	no	.133	no	-.067	no
Cyclotella bodanica	Cedar Lake	--	--	--	--	--	--
	Lake Olathe	-.511	yes	-.178	no	-.289	no
Cyclotella meneghiniana	Cedar Lake	-.044	no	-.289	no	-.422	yes
	Lake Olathe	-.444	yes	-.111	no	-.356	no
Cyclotella striata	Cedar Lake	-.244	no	-.156	no	-.556	yes
	Lake Olathe	--	--	--	--	--	--
Stephanodiscus nigarae	Cedar Lake	--	--	--	--	--	--
	Lake Olathe	-.200	no	.600	yes	-.644	yes

Table 11. Selected diatom species and their presence under various water-quality conditions

[Source of information: U.S. Environmental Protection Agency, 1977]

Diatom species	Type of diatom	Water-quality conditions
Aulacoseira cf alpigena	Freshwater planktonic	Present in mesotrophic and eutrophic water.
Aulacoseira granulata	Freshwater planktonic	Reliable indicator of eutrophic conditions; can clog water-treatment filters and screens.
Cyclotella bodanica	Freshwater planktonic	Uncontaminated water indicator; water free of sewage or other organic enrichment due to waste discharge.
Cyclotella meneghiniana	Freshwater planktonic	Indicator of contamination; can clog water-treatment filters and screens. Present in water containing treated or untreated domestic sewage and related organic wastes.
Cyclotella striata	Freshwater planktonic	None specified.
Stephanodiscus nigarae	Freshwater planktonic	Indicator of taste problems; can impart vegetable to oily taste to water; abundant in shallow eutrophic lakes of southwestern Minnesota.

quality conditions in the lake. However, because sediment in the lake may have been disturbed during dam repair work, trend analysis may be invalid for this lake, and water quality in Cedar Lake may or may not be degrading. The increased concentration of the eutrophic-indicator diatom species from the bottom of the cores to the water/sediment interface suggests that over time these lakes are eutrophic more often or eutrophic for longer periods.

SUMMARY AND CONCLUSIONS

This report describes sediment deposition, water-quality trends, transport (loads and yields) of nutrients (phosphorus and nitrogen species), selected trace elements, selected pesticides, and diatoms as indicators of water-quality conditions within the Lake Olathe watershed in northeast Kansas. Bathymetric survey data from both Cedar Lake and Lake Olathe were collected during 2000 by the U.S. Geological Survey and compared to the available historic topographic data for each lake provided by the city of Olathe. The information was used to estimate total sediment deposition in each lake since dam closure.

Three bottom-sediment cores were collected from Cedar Lake, and five bottom-sediment cores were collected from Lake Olathe in 2000 and analyzed for selected inorganic and organic constituents and diatoms. The results showed that phosphorus, total ammonia plus organic nitrogen as nitrogen, selected trace elements, and a few organic pesticides were present in the bottom sediment of each lake. The percentage of finer grained sediment (silt and clay) was fairly uniform throughout each lake and represented more than 97 percent of the sediment particle-size distribution. Silt and clay provide more efficient adsorption sites for many water-quality constituents, such as phosphorus and many trace elements.

The total estimated sediment deposition since dam closure, calculated on the basis of bathymetric data and bottom-sediment cores, was 338 acre-ft for Cedar Lake and 317 acre-ft for Lake Olathe. Mean annual sediment deposition was 5.45 acre-ft/yr [0.89 acre-ft/yr)/mi^2] for Cedar Lake and 7.0 acre-ft/yr [0.42 (acre-ft/yr)/mi^2] for Lake Olathe. Mean annual sediment loads for the two lakes were 9.6 million lb/yr for Cedar Lake and 12.6 million lb/yr for Lake Olathe.

Although the percentage of finer grained material in both lakes was fairly uniform, the concentration of total phosphorus in bottom sediment increased from upstream to downstream in the lakes. In sediment samples from Cedar Lake, mean concentrations of total phosphorus ranged from 1,370 mg/kg upstream to 1,810 mg/kg near the dam. Mean concentrations of total phosphorus in samples from Lake Olathe ranged from 588 mg/kg upstream to 1,030 mg/kg near the dam. The implications of large total phosphorus concentrations in bottom-sediment samples from Cedar Lake are that adverse water-quality conditions in Cedar Lake could easily affect the quality of the Lake Olathe drinking-water supply through discharge of water from Cedar Lake to Lake Olathe via Cedar Creek.

On the basis of calculations of deposited sediment in each lake, the mean annual phosphorus load transported to Cedar Lake was estimated to be 14,700 lb/yr and was estimated to be 9,720 lb/yr to Lake Olathe. The mean annual phosphorus yield to Cedar Lake calculated from sediment deposition was 3.74 (lb/acre)/yr and was 0.91 (lb/acre)/yr to Lake Olathe. The difference may be attributed to different historical agricultural and residential practices in the respective subwatersheds.

Land use can have a considerable effect on sediment loading to a lake. Intense agricultural use in a watershed can be a source of sediment loading, and chemical constituents such as phosphorus can be transported with the sediment to downstream lakes. Comparisons of phosphorus yields from the Lake Olathe watershed [0.91 (lb/acre)/yr] to the Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake watersheds showed that the Webster Reservoir watershed had the smallest yield [0.04 (lb/acre)/yr] and that the Cedar Lake watershed had the largest [3.74 (lb/acre)/yr].

Mean concentrations of total ammonia plus organic nitrogen as nitrogen (N) ranged from 2,000 to 2,700 mg/kg in bottom-sediment samples from Cedar Lake and from 1,300 to 2,700 mg/kg in samples from Lake Olathe. The relation between total ammonia plus organic nitrogen as nitrogen (N) and bottom-sediment particle size was inconclusive for sediment samples from both Cedar Lake and Lake Olathe. Concentrations of total ammonia plus organic nitrogen as nitrogen (N) in samples from both lakes increased from upstream to downstream, although there was no trend in sediment particle-size distribution. Even though fertilizer application in Kansas has increased substantially during the past 40 years, a regression analysis between total ammonia plus organic nitrogen as nitrogen (N) and bottom-sediment particle size showed no discernible trend for the sediment profile from Cedar Lake, but a slight increasing trend was seen for the sediment profile from Lake Olathe.

Mean concentrations of six trace elements in bottom-sediment samples from Cedar Lake and Lake Olathe exceeded the U.S. Environmental Protection Agency (USEPA) Threshold Effects Levels (TELs) sediment-quality guidelines for aquatic organisms. Those trace elements exceeding TEL guidelines were arsenic, chromium, copper, lead, nickel, and zinc. Probable Effects Levels (PELs) for trace elements were not exceeded in samples from either lake.

Implications of large trace element concentrations are uncertain because the USEPA guidelines are nonenforceable; however, it is assumed that toxic effects frequently occur when trace elements exceed the PEL guidelines. A program to monitor trace element concentrations in lake sediment every few years would facilitate a better understanding of temporal trends in trace element concentrations.

Reservoir bottom-sediment samples collected in 2000 were analyzed for selected pesticides, including organochlorine and organophosphate insecticides, and acetanilide and triazine herbicides. There were no detections of the organochlorine and organophosphate insecticides, but the acetanilide herbicides alachlor and metolachlor were detected in sediment from both lakes with larger concentrations corresponding to the more recent deposition. The USEPA has not proposed TEL or PEL guideline concentrations in bottom sediment for any of the organochlorine, organophosphate, acetanilide, or triazine compounds.

Diatom species in reservoir bottom-sediment samples were identified and used as indicators of lake eutrophication. The diatom *Cyclotella bodanica,* an indicator of low organic-enriched water, and *Aulacoseira cf alpigena* and *Cyclotella meneghiniana,* indicators of organic-enriched water, were identified in sediment from Lake Olathe. The presence of these diatoms suggests varying periods of low and high eutrophication in Lake Olathe from 1956 to 2000. The concentration of two species in bottom sediment from Cedar Lake, *Aulacoseira cf alpigena* and *Cyclotella meneghiniana,* as well as two species in sediment from Lake Olathe, *Aulacoseira cf alpigena* and *Stephanodiscus nigarae*, increased in sediment cores from the older bottom material to the more recent deposition near the top of the sediment core. These diatoms indicate eutrophic conditions, and the increased concentration of these eutrophic diatom species from the bottom of the cores to the sediment/water interface suggests that historically these lakes have been and continue to be eutrophic at times.

Trends in water-quality characteristics can be used by the Lake Olathe watershed managers to document historical changes in the watershed such as changes in land use, the suspension of the use of chlorinated insecticides, such as DDT and chlordane, and the use of hydrophobic fertilizers. The investigation described in this report provides a baseline of water-quality information to compare future changes in water quality or other watershed activities. With the addition of bathymetric surveys and the inclusion of additional reservoirs, reservoir sediment investigations can be used to estimate historical transport of phosphorus and other constituents in future water-quality assessments throughout Kansas.

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Supplemental Information

Table 12. Laboratory analysis methods for reservoir bottom-sediment constituents

[USGS, U.S. Geological Survey; GC/MS, gas chromatography/mass spectrometry]

Constituent or constituent group	Analysis method	Method reference
Nutrients	Various methods	Fishman (1993)
Trace elements (USGS schedule 2420)	Inductively coupled plasma-mass spectrometry	Fishman (1993)
Cesium-137 (USGS laboratory code 2307)	Gamma counting	American Society for Testing and Materials (2000)
Pesticides	GC/MS liquid extraction with methanol and water	Mills and Thurman (1992)

Table 13. Nutrients analyzed in bottom sediment from Cedar Lake and Lake Olathe, northeast Kansas, 2000

[mg/kg, milligrams per kilogram]

Nutrient	Method reporting limit	Units of measurement
Total ammonia plus organic nitrogen as nitrogen	20	mg/kg
Phosphorus	40	mg/kg

Table 14. Selected metals and trace elements analyzed in bottom sediment from Cedar Lake and Lake Olathe, northeast Kansas, 2000

[LRL, laboratory reporting level; pct, percent; µg/g, micrograms per gram]

Metal or trace element	LRL	Unit of measurement	Metal or trace element	LRL	Unit of measurement
Aluminum	0.005	pct	Mercury	0.02	µg/g
Antimony	.1	µg/g	Molybdenum	2	µg/g
Arsenic	.1	µg/g	Neodymium	1	µg/g
Barium	1	µg/g	Nickel	2	µg/g
Beryllium	.1	µg/g	Niobium	4	µg/g
Bismuth	1	µg/g	Potassium	.005	pct
Cadmium	.1	µg/g	Scandium	2	µg/g
Calcium	.005	pct	Selenium	.1	µg/g
Cerium	1	µg/g	Silver	.1	µg/g
Chromium	1	µg/g	Sodium	.005	pct
Cobalt	1	µg/g	Strontium	2	µg/g
Copper	1	µg/g	Sulfur	.05	pct
Europium	1	µg/g	Tantalum	1	µg/g
Gallium	1	µg/g	Thallium	1	µg/g
Gold	1	µg/g	Thorium	1	µg/g
Holmium	1	µg/g	Tin	1	µg/g
Iron	.005	pct	Titanium	.005	pct
Lanthanum	1	µg/g	Uranium	.1	µg/g
Lead	4	µg/g	Vanadium	2	µg/g
Lithium	1	µg/g	Ytterbium	1	µg/g
Magnesium	.005	pct	Yttrium	1	µg/g
Manganese	4	µg/g	Zinc	4	µg/g

Table 15. Radiochemical analyzed for age dating bottom sediment from Cedar Lake and Lake Olathe, northeast Kansas, 2000

[pCi/g, picocuries per gram]

Radiochemical	Method reporting limit	Units of measurement
Cesium-137	0.05	pCi/g

Table 16. Statistical summary of concentrations and comparison to sediment-quality guidelines for selected metals and trace elements in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000

[µg/g, micrograms per gram; TEL, Threshold Effects Level; PEL, Probable Effects Level; <, less than; --, no value assigned]

Metal or trace element and unit of measurement	Concentration			Sediment-quality guidelines[1]	
	Minimum	Median	Maximum	TEL	PEL
Aluminum, percent	8	8.1	8.4	--	--
Antimony, µg/g	1	1.1	1.1	--	--
Arsenic, µg/g	13	14	16	7.2	42
Barium, µg/g	730	760	800	--	--
Beryllium, µg/g	2.1	2.3	2.7	--	--
Bismuth, µg/g	<1.0	.5	<1.0	--	--
Cadmium, µg/g	.23	.31	.36	.68	4.2
Calcium, percent	1	1.1	1.9	--	--
Cerium, µg/g	83	84	87	--	--
Chromium, µg/g	90	90	98	52	160
Cobalt, µg/g	9.5	11	11	--	--
Copper, µg/g	32	32	45	19	110
Europium, µg/g	1.4	1.5	1.6	--	--
Gallium, µg/g	19	20	20	--	--
Gold, µg/g	<1.0	.5	<1.0	--	--
Holmium, µg/g	1.2	1.2	1.3	--	--
Iron, percent	4.1	4.2	4.4	--	--
Lanthanum, µg/g	48	50	51	--	--
Lead, µg/g	32	33	35	30	110
Lithium, µg/g	44	45	49	--	--
Magnesium, percent	.75	.77	.83	--	--
Manganese, µg/g	760	800	980	--	--
Mercury, µg/g	.05	.05	.14	.13	.70
Molybdenum, µg/g	.92	1	1.2	--	--
Neodymium, µg/g	40	42	43	--	--
Nickel, µg/g	32	34	39	16	43
Niobium, µg/g	20	21	21	--	--
Potassium, percent	1.6	1.6	1.7	--	--
Scandium, µg/g	14	14	14	--	--
Selenium, µg/g	.86	.99	1.1	--	--
Silver, µg/g	.2	.21	.24	--	--
Sodium, percent	.3	.35	.35	--	--
Strontium, µg/g	130	140	160	--	--
Sulfur, percent	.07	.09	.14	--	--
Tantalum, µg/g	1.5	1.5	1.5	--	--
Thorium, µg/g	15	15	16	--	--
Thallium, µg/g	<1.0	1	1	--	--

Table 16. Statistical summary of concentrations and comparison to sediment-quality guidelines for selected metals and trace elements in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Metal or trace element and unit of measurement	Concentration			Sediment-quality guidelines[1]	
	Minimum	Median	Maximum	TEL	PEL
Tin, µg/g	3.2	3.2	3.4	--	--
Titanium, percent	.38	.39	.39	--	--
Uranium, µg/g	4	4.4	4.8	--	--
Vanadium, µg/g	130	130	140	--	--
Ytterbium, µg/g	2.8	2.9	3	--	--
Yttrium, µg/g	30	31	32	--	--
Zinc, µg/g	150	150	170	120	270

[1]Guidelines from U.S. Environmental Protection Agency (1998).

Table 17. Statistical summary of concentrations and comparison to sediment-quality guidelines for selected metals and trace elements in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000

[µg/g, micrograms per gram; TEL, Threshold Effects Level; PEL, Probable Effects Level; <, less than; --, no value assigned]

Metal or trace element and unit of measurement	Concentration			Sediment-quality guidelines[1]	
	Minimum	Median	Maximum	TEL	PEL
Aluminum, percent	8.5	8.7	9.0	--	--
Antimony, µg/g	1.1	1.2	1.4	--	--
Arsenic, µg/g	15	16	18	7.2	42
Barium, µg/g	710	760	780	--	--
Beryllium, µg/g	2	2.3	2.6	--	--
Bismuth, µg/g	<1.0	<1.0	<1.0	--	--
Cadmium, µg/g	.27	.33	.41	.68	4.2
Calcium, percent	1.1	1.3	2.6	--	--
Cerium, µg/g	88	91	93	--	--
Chromium,	88	89	94	52	160
Cobalt, µg/g	10	11	12	--	--
Copper, µg/g	32	36	38	19	110
Europium, µg/g	1.4	1.4	1.5	--	--
Gallium, µg/g	20	21	21	--	--
Gold, µg/g	<1.0	<1.0	<1.0	--	--
Holmium, µg/g	1.1	1.1	1.2	--	--
Iron, percent	4	4.1	4.2	--	--
Lanthanum, µg/g	54	56	58	--	--
Lead, µg/g	28	36	40	30	110
Lithium, µg/g	44	45	48	--	--
Magnesium, percent	.79	.84	.86	--	--
Manganese, µg/g	890	1,000	1,200	--	--
Mercury, µg/g	.05	.05	.07	.13	.70
Molybdenum, µg/g	.93	1.0	1.1	--	--
Neodymium, µg/g	40	43	44	--	--
Nickel, µg/g	35	37	39	16	43
Niobium, µg/g	20	21	21	--	--
Potassium, percent	1.8	1.8	1.9	--	--
Scandium, µg/g	15	15	15	--	--
Selenium, µg/g	.95	.99	1.2	--	--
Silver, µg/g	.43	.44	.48	--	--
Sodium, percent	.33	.36	.39	--	--
Strontium, µg/g	130	140	170	--	--
Sulfur, percent	.07	.11	.16	--	--
Tantalum, µg/g	1.7	1.8	1.9	--	--
Thorium, µg/g	14	15	16	--	--
Thallium, µg/g	<1.0	.5	1.0	--	--

Table 17. Statistical summary of concentrations and comparison to sediment-quality guidelines for selected metals and trace elements in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Metal or trace element and unit of measurement	Concentration			Sediment-quality guidelines[1]	
	Minimum	Median	Maximum	TEL	PEL
Tin, µg/g	3.2	3.2	3.4	--	--
Titanium, percent	.5	.52	.53	--	--
Uranium, µg/g	3.7	4	4.3	--	--
Vanadium, µg/g	130	130	140	--	--
Ytterbium, µg/g	2.7	2.8	3	--	--
Yttrium, µg/g	28	30	30	--	--
Zinc, µg/g	140	140	150	120	270

[1]Guidelines from U.S. Environmental Protection Agency (1998).

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
0.55	*Achnanthidium minutissimum*	2	0.6	176,000
	Amphora inariensis	2	.6	176,000
	Aulacoseira cf alpigena	159	48.0	14,000,000
	Aulacoseira granulata	101	30.5	8,910,000
	Brachysira vitrea	1	.3	88,200
	Cocconeis placentula	2	.6	176,000
	Cyclotella sp. 1 (small)	1	.3	88,200
	Cyclotella meneghiniana	17	5.1	1,500,000
	Cyclotella ocellata	1	.3	88,200
	Cyclotella striata	17	5.1	1,500,000
	Gomphonema gracile	1	.3	88,200
	Gomphonema grovei	1	.3	88,200
	Gomphonema parvulum	1	.3	88,200
	Mastogloia smithii	1	.3	88,200
	Navicula cryptotenella	1	.3	88,200
	Navicula cryptocephala	1	.3	88,200
	Navicula geoppertiana	1	.3	88,200
	Navicula gregaria	2	.6	176,000
	Navicula tripunctata	1	.3	88,200
	Navicula trivialis	1	.3	88,200
	Neidium affine	2	.6	176,000
	Nitzschia acicularis	1	.3	88,200
	Nitzschia inconspicua	2	.6	176,000
	Nitzschia subacicularis	1	.3	88,200
	Pinnularia interrupta	2	.6	176,000
	Stephanodiscus nigarae	4	1.2	353,000
	Surirella angusta	2	.6	176,000
	Surirella brebissonii	1	.3	88,200
	Synedra delicatissima	1	.3	88,200
	Synedra ulna	1	.3	88,200
Total		**331**	**100[1]**	**29,200,000**

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
1.10	*Achnanthes bioreti*	1	0.2	101,000
	Achnanthes deflexa	2	.3	203,000
	Achnanthes exigua	8	1.3	812,000
	Achnanthidium minutissimum	4	.6	406,000
	Aulacoseira cf alpigena	383	59.9	38,900,000
	Aulacoseira granulata	128	20.0	13,000,000
	Bacillaria paradoxa	1	.2	101,000
	Cocconeis placentula	2	.3	203,000
	Cyclotella sp. 1 (small)	1	.2	101,000
	Cyclotella cf stelligera	4	.6	406,000
	Cyclotella meneghiniana	27	4.2	2,740,000
	Cyclotella ocellata	2	.3	203,000
	Cyclotella striata	21	3.3	2,130,000
	Denticula kuetzingii	2	.3	203,000
	Gomphonema angustum	1	.2	101,000
	Gomphonema minutum	4	.6	406,000
	Gomphonema parvulum	1	.2	101,000
	Gomphonema sp.	2	.3	203,000
	Gomphonema sp. (heterovalvie)	3	.5	305,000
	Melosira sp.	3	.5	305,000
	Melosira varians	3	.5	305,000
	Navicula absoluta	1	.2	101,000
	Navicula cincta	1	.2	101,000
	Navicula cryptocephala	3	.5	305,000
	Navicula geoppertiana	1	.2	101,000
	Navicula halophila	1	.2	101,000
	Navicula miniscula	2	.3	203,000
	Navicula ordinaria	1	.2	101,000
	Navicula striata	1	.2	101,000
	Nitzschia acicularis	4	.6	406,000
	Nitzschia dissipatta	2	.3	203,000
	Nitzschia inconspicua	2	.3	203,000
	Nitzschia linearis	2	.3	203,000
	Nitzschia palea	7	1.1	711,000
	Nitzschia recta	2	.3	203,000
	Nitzschia subacicularis	1	.2	101,000
	Stephanodiscus nigarae	4	.6	406,000
	Synedra delicatissima	1	.2	101,000
Total		**639**	**100[1]**	**64,900,000**

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
1.65	*Achnanthes deflexa*	2	0.3	89,800
	Achnanthes exigua	4	.7	180,000
	Achnanthes spp.	8	1.3	359,000
	Achnanthidium minutissimum	4	.7	180,000
	Amphora montana	2	.3	89,800
	Aulacoseira cf alpigena	272	45.5	12,200,000
	Aulacoseira granulata	106	17.7	4,760,000
	Cocconeis placentula	2	.3	89,800
	Cyclotella sp. 1 (small)	8	1.3	359,000
	Cyclotella cf stelligera	2	.3	89,800
	Cyclotella meneghiniana	50	8.4	2,240,000
	Cyclotella ocellata	6	1.0	269,000
	Cyclotella striata	32	5.4	1,440,000
	Denticula kuetzingii	6	1.0	269,000
	Encyonema minutum	4	.7	180,000
	Fragilaria capucina	6	1.0	269,000
	Gomphoneis sp.	4	.7	180,000
	Gomphonema minutum	2	.3	89,800
	Gomphonema sp.	2	.3	89,800
	Melosira varians	26	4.4	1,170,000
	Navicula capitata	2	.3	89,800
	Navicula cryptocephala	2	.3	89,800
	Navicula geoppertiana	2	.3	89,800
	Navicula gregaria	2	.3	89,800
	Navicula halophila	4	.7	180,000
	Navicula lanceolata	2	.3	89,800
	Navicula miniscula	2	.3	89,800
	Navicula cf salinarium	3	.5	135,000
	Navicula trivialis	2	.3	89,800
	Nitzschia amphibia	5	.8	224,000
	Nitzschia clausii	3	.5	135,000
	Nitzschia dissipatta	3	.5	135,000
	Nitzschia inconspicua	2	.3	89,800
	Nitzschia littoralis	2	.3	89,800
	Nitzschia palea	2	.3	89,800
	Nitzschia perminuta	6	1.0	269,000
	Planothidium lanceolatum	2	.3	89,800
	Surirella angusta	1	.2	44,900
	Surirella brebissonii	1	.2	44,900
	Surirella ovalis	1	.2	44,900
	Synedra delicatissima	1	.2	44,900
Total		**598**	**100[1]**	**26,800,000**

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
2.20	*Achnanthidium minutissimum*	8	6.0	107,000
	Aulacoseira cf alpigena	8	6.0	107,000
	Aulacoseira ambigua	4	3.0	53,300
	Aulacoseira granulata	52	39.1	694,000
	Aulacoseira lirata	8	6.0	107,000
	Bacillaria paradoxa	1	.8	13,300
	Cyclotella meneghiniana	8	6.0	107,000
	Cyclotella ocellata	8	6.0	107,000
	Cyclotella striata	20	15.0	267,000
	Melosira varians	8	6.0	107,000
	Navicula cincta	4	3.0	53,300
	Planothidium lanceolatum	4	3.0	53,300
Total		**133**	**100[1]**	**1,780,000**

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
2.75	*Achnanthes bioreti*	1	0.2	36,000
	Achnanthes deflexa	3	.5	108,000
	Achnanthes spp.	1	.2	36,000
	Achnanthidium minutissimum	6	1.0	216,000
	Amphora montana	6	1.0	216,000
	Amphora ovalis	6	1.0	216,000
	Aulacoseira cf alpigena	31	5.4	1,120,000
	Aulacoseira distans	6	1.0	216,000
	Aulacoseira granulata	350	60.8	12,600,000
	Cyclotella sp. 1 (small)	30	5.2	1,080,000
	Cyclotella meneghiniana	8	8.3	1,730,000
	Cyclotella striata	12	2.1	432,000
	Denticula kuetzingii	8	1.4	288,000
	Denticula tenuis	6	1.0	216,000
	Encyonema lange-bertalotii	3	.5	108,000
	Encyonema silesiacum	3	.5	108,000
	Fragilaria capucina	3	.5	108,000
	Navicula geoppertiana	9	1.6	324,000
	Planothidium lanceolatum	3	.5	108,000
	Stephanodiscus sp. 1	25	4.3	899,000
	Stephanodiscus nigarae	3	.5	108,000
	Synedra delicatissima	4	.7	144,000
	Synedra ulna	9	1.6	324,000
Total		**576**	**100[1]**	**20,700,000**

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
3.30	*Achnanthes bioreti*	1	0.2	34,900
	Achnanthes deflexa	1	.2	34,900
	Achnanthidium minutissimum	12	2.4	419,000
	Amphora ovalis	9	1.8	314,000
	Aulacoseira distans	21	4.2	733,000
	Aulacoseira granulata	219	43.5	7,640,000
	Bacillaria paradoxa	3	.6	105,000
	Coscinodiscus sp.	3	.6	105,000
	Craticula cuspidata	3	.6	105,000
	Cyclotella sp. 1 (small)	21	4.2	733,000
	Cyclotella cf stelligera	9	1.8	314,000
	Cyclotella meneghiniana	42	8.3	1,470,000
	Cyclotella ocellata	3	.6	105,000
	Cyclotella striata	93	18.5	3,250,000
	Cymbella delicatula	3	.6	105,000
	Denticula kuetzingii	3	.6	105,000
	Diploneis oblongella	3	.6	105,000
	Diploneis pupula	3	.6	105,000
	Fragilaria sp.	6	1.2	209,000
	Gomphonema sp. (heterovalvie)	7	1.4	244,000
	Gyrosigma obtusatum	3	.6	105,000
	Hantzschia amphioxys	3	.6	105,000
	Melosira varians	4	.8	140,000
	Nitzschia dissipatta	2	.4	69,800
	Nitzschia linearis	2	.4	69,800
	Planothidium lanceolatum	1	.2	34,900
	Stephanodiscus sp. 1	9	1.8	314,000
	Stephanodiscus nigarae	6	1.2	209,000
	Surirella brebissonii	3	.6	105,000
	Synedra delicatissima	2	.4	69,800
	Synedra ulna	3	.6	105,000
Total		**503**	**100**[1]	**17,600,000**

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
3.85	*Achnanthes bioreti*	1	0.2	26,900
	Achnanthidium minutissimum	4	1.0	108,000
	Amphipleura pellucida	1	.2	26,900
	Aulacoseira cf alpigena	60	14.6	1,620,000
	Aulacoseira ambigua	12	2.9	323,000
	Aulacoseira distans	8	1.9	215,000
	Aulacoseira granulata	228	55.3	6,140,000
	Bacillaria paradoxa	4	1.0	108,000
	Cocconeis placentula	4	1.0	108,000
	Cyclotella cf areolata	4	1.0	108,000
	Cyclotella meneghiniana	32	7.8	862,000
	Cyclotella ocellata	4	1.0	108,000
	Cyclotella striata	16	3.9	431,000
	Navicula geoppertiana	4	1.0	108,000
	Stephanodiscus sp. 1	1	.2	26,900
	Stephanodiscus nigarae	20	4.9	539,000
	Surirella sp.	1	.2	26,900
	Synedra delicatissima	8	1.9	215,000
Total		**412**	**100[1]**	**11,100,000**

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
4.40	*Achnanthes spp.*	8	2.3	108,000
	Achnanthidium minutissimum	8	2.3	108,000
	Aulacoseira cf alpigena	32	9.2	431,000
	Aulacoseira distans	28	8.0	377,000
	Aulacoseira granulata	218	62.6	2,940,000
	Bacillaria paradoxa	4	1.1	53,900
	Cocconeis pediculus	2	.6	26,900
	Cocconeis placentula	4	1.1	53,900
	Cyclostephanos cf dubius	2	.6	26,900
	Cyclotella meneghiniana	4	1.1	53,900
	Cyclotella striata	2	.6	26,900
	Cymbella delicatula	2	.6	26,900
	Encyonema gracile	2	.6	26,900
	Fragilaria capucina	2	.6	26,900
	Gomphonema parvulum	2	.6	26,900
	Gyrosigma spencerii	6	1.7	80,800
	Hantzschia amphioxys	2	.6	26,900
	Navicula geoppertiana	2	.6	26,900
	Navicula placentula	2	.6	26,900
	Navicula rhynchocephala	2	.6	26,900
	Nitzschia littoralis	2	.6	26,900
	Pinnularia borealis	2	.6	26,900
	Rhoicosphenia curvata	2	.6	26,900
	Sellaphora pupula	2	.6	26,900
	Stephanodiscus nigarae	2	.6	26,900
	Synedra delicatissima	2	.6	26,900
	Synedra ulna	2	.6	26,900
Total		**348**	**100[1]**	**4,690,000**

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
4.95	*Achnanthes bioreti*	3	0.6	64,600
	Achnanthes deflexa	2	.4	43,100
	Achnanthes sp.	5	1.0	108,000
	Achnanthidium minutissimum	10	2.0	215,000
	Amphipleura pellucida	3	.6	64,600
	Amphora montana	3	.6	64,600
	Aulacoseira distans	27	5.4	582,000
	Aulacoseira granulata	358	71.2	7,710,000
	Bacillaria paradoxa	13	2.6	280,000
	Cyclotella bodanica	5	1.0	108,000
	Cyclotella meneghiniana	8	1.6	172,000
	Cyclotella striata	1	.2	21,500
	Encyonema lange-bertalotii	3	.6	64,600
	Encyonema minutum	3	.6	64,600
	Fragilaria capucina	8	1.6	172,000
	Fragilaria cf zeilleri	3	.6	64,600
	Gomphoneis sp.	5	1.0	108,000
	Hantzschia amphioxys	5	1.0	108,000
	Melosira sp.	5	1.0	108,000
	Navicula geoppertiana	10	2.0	215,000
	Navicula mutica	5	1.0	108,000
	Navicula rhynchocephala	2	.4	43,100
	Nitzschia amphibia	2	.4	43,100
	Nitzschia capitellata	0	0	0
	Pinnularia borealis	2	.4	43,100
	Planothidium lanceolatum	2	.4	43,100
	Stephanodiscus nigarae	3	.6	64,600
	Synedra delicatissima	2	.4	43,100
	Synedra ulna	5	1.0	108,000
Total		**503**	**100[1]**	**10,800,000**

Table 18. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Cedar Lake coring site 3, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
5.50	*Achnanthes bioreti*	10	2.4	442,000
	Achnanthidium minutissimum	40	9.5	1,770,000
	Aulacoseira distans	155	36.6	6,850,000
	Aulacoseira granulata	125	29.6	5,520,000
	Aulacoseira lirata	30	7.1	1,330,000
	Cocconeis pediculus	1	.2	44,200
	Cocconeis placentula	1	.2	44,200
	Cyclotella cf areolata	25	5.9	1,100,000
	Cyclotella bodanica	1	.2	44,200
	Cyclotella meneghiniana	30	7.1	1,330,000
	Cyclotella ocellata	5	1.2	221,000
	Diadesmis contenta	15	3.5	663,000
	Fragilaria capucina	15	3.5	663,000
	Frustulia rhomboides	5	1.2	221,000
	Gyrosigma spencerii	5	1.2	221,000
	Hantzschia amphioxys	3	.7	133,000
	Navicula cryptotenella	5	1.2	221,000
	Navicula geoppertiana	10	2.4	442,000
	Nitzschia dissipatta	1	.2	44,200
	Nitzschia linearis	10	2.4	442,000
	Nitzschia palea	5	1.2	221,000
	Sellaphora pupula	10	2.4	442,000
	Stephanodiscus sp. 1	5	1.2	221,000
	Stephanodiscus nigarae	30	7.1	1,330,000
Total		**423**	**100[1]**	**23,900,000**

[1]Numbers are rounded to three significant figures.

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
0.35	*Achnanthes bioreti*	4	0.4	109,000
	Achnanthidium minutissimum	16	1.7	436,000
	Asterinella formosa	30	3.1	818,000
	Aulacoseira cf alpigena	446	46.8	12,200,000
	Aulacoseira granulata	32	3.4	873,000
	Bacillaria paradoxa	4	.4	109,000
	Caloneis limosa	8	.8	218,000
	Cocconeis pediculus	2	.2	54,500
	Cyclostephanos cf dubius	12	1.3	327,000
	Cyclotella bodanica	58	6.1	1,580,000
	Cyclotella cf fottii	6	.6	164,000
	Cyclotella cf stelligera	12	1.3	327,000
	Cyclotella meneghiniana	116	12.2	3,160,000
	Cyclotella ocellata	6	.6	164,000
	Cymatopleura solea	2	.2	54,500
	Denticula kuetzingii	2	.2	54,500
	Diadesmis contenta	4	.4	109,000
	Diploneis pupula	2	.2	54,500
	Encyonema silesiacum	2	.2	54,500
	Fragilaria capucina	4	.4	109,000
	Fragilaria nanana	12	1.3	327,000
	Gomphonema olivaceum	4	.4	109,000
	Gomphonema parvulum	2	.2	54,500
	Hantzschia amphioxys	4	.4	109,000
	Navicula cryptotenella	14	1.5	382,000
	Navicula gregaria	4	.4	109,000
	Navicula subrhynchocephala	2	.2	54,500
	Navicula tripunctata	2	.2	54,500
	Navicula trivialis	2	.2	54,500
	Nitzschia acicularis	8	.8	218,000
	Nitzschia amphibia	6	.6	164,000
	Nitzschia dissipatta	16	1.7	436,000
	Nitzschia dubia	2	.2	54,500
	Nitzschia inconspicua	4	.4	109,000
	Nitzschia linearis	6	.6	164,000
	Nitzschia littoralis	2	.2	54,500
	Nitzschia palea	2	.2	54,500
	Nitzschia perminuta	2	.2	54,500

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
0.35	*Nitzschia subacicularis*	8	0.8	218,000
	Reimeria sinuata	2	.2	54,500
	Stephanodiscus cf neoastraea	4	.4	109,000
	Stephanodiscus nigarae	48	5.0	1,310,000
	Stephanodiscus sp. 1	4	.4	109,000
	Stephanodiscus sp. 2	4	.4	109,000
	Surirella brebissonii	4	.4	109,000
	Surirella minuta	2	.2	54,500
	Surirella ovalis	2	.2	54,500
	Surirella sp.	4	.4	109,000
	Synedra delicatissima	2	.2	54,500
	Synedra ulna	6	.6	164,000
Total		**952**	**100[1]**	**26,000,000**

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
0.70	*Achnanthes bioreti*	8	2.0	217,000
	Achnanthidium minutissimum	12	3.0	325,000
	Asterinella formosa	38	9.5	1,030,000
	Aulacoseira cf alpigena	42	10.5	1,140,000
	Aulacoseira distans	2	.5	54,200
	Aulacoseira granulata	26	6.5	704,000
	Caloneis bacillum	2	.5	54,200
	Cyclostephanos cf dubius	14	3.5	379,000
	Cyclotella bodanica	36	9.0	975,000
	Cyclotella cf stelligera	4	1.0	108,000
	Cyclotella meneghiniana	60	15.0	1,630,000
	Cyclotella ocellata	26	6.5	704,000
	Cymbella tumida	2	.5	54,200
	Denticula tenuis	2	.5	54,200
	Encyonema lange-bertalotii	2	.5	54,200
	Fragilaria capucina	16	4.0	434,000
	Gomphonema sp. (heterovalvie)	2	.5	54,200
	Hantzschia amphioxys	2	.5	54,200
	Navicula cryptotenella	4	1.0	108,000
	Navicula geoppertiana	2	.5	54,200
	Navicula halophila	2	.5	54,200
	Navicula trivialis	2	.5	54,200
	Nitzschia acicularis	2	.5	54,200
	Nitzschia capitellata	4	1.0	108,000
	Nitzschia constricta	2	.5	54,200
	Nitzschia dissipatta	2	.5	54,200
	Nitzschia inconspicua	2	.5	54,200
	Nitzschia linearis	4	1.0	108,000
	Nitzschia palea	2	.5	54,200
	Nitzschia perminuta	4	1.0	108,000
	Sellaphora pupula	4	1.0	108,000
	Stephanodiscus nigarae	40	10.0	1,080,000
	Stephanodiscus sp. 1	2	.5	54,200
	Stephanodiscus sp. 2	2	.5	54,200
	Surirella minuta	2	.5	54,200
	Synedra delicatissima	22	5.5	596,000
Total		**400**	**100[1]**	**10,800,000**

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
1.05	*Achnanthidium minutissimum*	2	1.7	282,000
	Asterinella formosa	70	11.8	1,980,000
	Aulacoseira cf alpigena	134	22.6	3,780,000
	Aulacoseira distans	6	1.0	169,000
	Aulacoseira granulata	110	18.5	3,110,000
	Caloneis bacillum	4	.7	113,000
	Cyclostephanos cf dubius	4	.7	113,000
	Cyclotella bodanica	52	8.8	1,470,000
	Cyclotella cf fottii	4	.7	113,000
	Cyclotella cf stelligera	4	.7	113,000
	Cyclotella meneghiniana	46	7.8	1,300,000
	Cyclotella ocellata	54	9.1	1,520,000
	Encyonema prostrata	2	.3	56,500
	Encyonema silesiacum	2	.3	56,500
	Fragilaria capucina	16	2.7	452,000
	Hantzschia amphioxys	2	.3	56,500
	Navicula cryptotenella	2	.3	56,500
	Navicula gregaria	2	.3	56,500
	Navicula rhynchocephala	4	.7	113,000
	Navicula tripunctata	2	.3	56,500
	Nitzschia dissipatta	2	.3	56,500
	Nitzschia linearis	2	.3	56,500
	Stephanodiscus nigarae	26	4.4	734,000
	Stephanodiscus sp. 1	2	.3	56,500
	Surirella minuta	2	.3	56,500
	Synedra delicatissima	28	4.7	790,000
	Synedra ulna	1	.2	28,200
Total		**593**	**100[1]**	**16,700,000**

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
1.40	*Achnanthes bioreti*	2	0.4	54,800
	Achnanthidium minutissimum	8	1.5	219,000
	Aulacoseira cf alpigena	168	31.1	4,600,000
	Aulacoseira distans	4	.7	110,000
	Aulacoseira granulata	254	47.0	6,960,000
	Bacillaria paradoxa	4	.7	110,000
	Caloneis bacillum	4	.7	110,000
	Cyclostephanos cf dubius	6	1.1	164,000
	Cyclotella bodanica	12	2.2	329,000
	Cyclotella meneghiniana	6	1.1	164,000
	Cyclotella ocellata	2	.4	54,800
	Cymatopleura solea	2	.4	54,800
	Diploneis pupula	2	.4	54,800
	Encyonema prostrata	2	.4	54,800
	Fragilaria capucina	4	.7	110,000
	Gomphonema angustum	2	.4	54,800
	Gomphonema minutum	2	.4	54,800
	Gomphonema pavulum	2	.4	54,800
	Gomphonema sp.	6	1.1	164,000
	Gomphonema sp. (heterovalvie)	2	.4	54,800
	Navicula clementis	2	.4	54,800
	Navicula cryptotenella	2	.4	54,800
	Nitzschia commutata	2	.4	54,800
	Nitzschia linearis	2	.4	54,800
	Nitzschia perminuta	4	.7	110,000
	Stephanodiscus cf neoastraea	2	.4	54,800
	Stephanodiscus nigarae	24	4.4	657,000
	Stephanodiscus sp. 1	2	.4	54,800
	Stephanodiscus sp. 2	2	.4	54,800
	Synedra ulna	4	.7	110,000
Total		**540**	**100[1]**	**14,800,000**

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
1.75	*Achnanthes bioreti*	6	0.7	165,000
	Achnanthidium minutissimum	28	3.2	768,000
	Amphipleura pellucida	2	.2	54,800
	Asterinella formosa	8	.9	219,000
	Aulacoseira cf alpigena	406	46.7	11,100,000
	Aulacoseira granulata	118	13.6	3,240,000
	Aulacoseira italica	12	1.4	329,000
	Cyclostephanos cf dubius	14	1.6	384,000
	Cyclotella bodanica	78	9.0	2,140,000
	Cyclotella cf stelligera	4	.5	110,000
	Cyclotella meneghiniana	72	8.3	1,970,000
	Eunotia musicola	8	.9	219,000
	Fragilaria capucina	2	.2	54,800
	Gomphonema parvulum	2	.2	54,800
	Melosira varians	8	.9	219,000
	Navicula clementis	2	.2	54,800
	Navicula decussis	2	.2	54,800
	Navicula mutica	8	.9	219,000
	Navicula rhynchocephala	2	.2	54,800
	Navicula tripunctata	2	.2	54,800
	Navicula viridula	4	.5	110,000
	Nitzschia dissipatta	4	.5	110,000
	Nitzschia dubia	2	.2	54,800
	Nitzschia filaformis	2	.2	54,800
	Nitzschia perminuta	4	.5	110,000
	Sellaphora pupula	2	.2	54,800
	Stephanodiscus cf neoastraea	4	.5	110,000
	Stephanodiscus nigarae	40	4.6	1,100,000
	Stephanodiscus sp. 1	4	.5	110,000
	Stephanodiscus sp. 2	2	.2	54,800
	Synedra delicatissima	16	1.8	439,000
	Synedra ulna	2	.2	54,800
Total		**870**	**100[1]**	**23,900,000**

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
2.10	*Achnanthes bioreti*	1	0.2	27,800
	Achnanthidium minutissimum	6	1.3	167,000
	Amphipleura pellucida	1	.2	27,800
	Asterinella formosa	10	2.2	278,000
	Aulacoseira cf alpigena	62	13.6	1,730,000
	Aulacoseira granulata	225	49.3	6,260,000
	Aulacoseira italica	2	.4	55,700
	Caloneis limosa	2	.4	55,700
	Cyclostephanos cf dubius	7	1.5	195,000
	Cyclotella bodanica	11	2.4	306,000
	Cyclotella meneghiniana	17	3.7	473,000
	Cyclotella ocellata	2	.4	55,700
	Diadesmis contenta	2	.4	55,700
	Diatoma vulgare	2	.4	55,700
	Encyonema silesiacum	1	.2	27,800
	Fragilaria capucina	1	.2	27,800
	Navicula cryptocephala	2	.4	55,700
	Navicula cryptotenella	1	.2	27,800
	Navicula geoppertiana	3	.7	83,500
	Navicula mutica	17	3.7	473,000
	Navicula trivialis	2	.4	55,700
	Navicula viridula	1	.2	27,800
	Nitzschia acicularis	1	.2	27,800
	Nitzschia dissipatta	5	1.1	139,000
	Nitzschia linearis	4	.9	111,000
	Planothidium lanceolatum	1	.2	27,800
	Stephanodiscus cf neoastraea	8	1.8	223,000
	Stephanodiscus nigarae	40	8.8	1,110,000
	Stephanodiscus sp. 1	3	.7	83,500
	Synedra delicatissima	11	2.4	306,000
	Synedra ulna	5	1.1	139,000
Total		**456**	**100[1]**	**12,700,000**

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
2.45	*Achnanthes bioreti*	6	1.3	159,000
	Achnanthidium minutissimum	12	2.5	318,000
	Amphora inariensis	1	.2	26,500
	Amphora ovalis	1	.2	26,500
	Asterinella formosa	4	.8	106,000
	Aulacoseira cf alpigena	207	43.4	5,480,000
	Aulacoseira granulata	100	21.0	2,650,000
	Aulacoseira italica	20	4.2	529,000
	Bacillaria paradoxa	2	.4	52,900
	Cyclostephanos cf dubius	10	2.1	26,500
	Cyclotella bodanica	11	2.3	291,000
	Cyclotella meneghiniana	20	4.2	529,000
	Cyclotella ocellata	2	.4	52,900
	Encyonmea caespitosa	1	.2	26,500
	Fragilaria capucina	4	.8	106,000
	Gomphonema parvulum	1	.2	26,500
	Gyrosigma obtusatum	2	.4	52,900
	Gyrosigma spencerii	1	.2	26,500
	Hantzschia amphioxys	3	.6	79,400
	Hantzschia rhaetica	1	.2	26,500
	Navicula geoppertiana	2	.4	52,900
	Navicula rhynchocephala	1	.2	26,500
	Navicula viridula	1	.2	26,500
	Nitzschia clausii	1	.2	26,500
	Nitzschia linearis	3	.6	79,400
	Planothidium lanceolatum	2	.4	52,900
	Stauroneis anceps	1	.2	26,500
	Stephanodiscus nigarae	25	5.2	662,000
	Stephanodiscus sp. 1	3	.6	79,400
	Stephanodiscus sp. 2	1	.2	26,500
	Synedra delicatissima	21	4.4	556,000
	Synedra parasitica	1	.2	26,500
	Synedra ulna	4	.8	106,000
	Thalassiosira cf weissflogii	2	.4	52,900
Total		**477**	**100**[1]	**12,600,000**

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
2.80	*Achnanthes bioreti*	4	0.6	56,200
	Achnanthes sp.	10	1.4	140,000
	Achnanthidium minutissimum	16	2.3	225,000
	Amphora inariensis	2	.3	28,100
	Asterinella formosa	4	.6	56,200
	Aulacoseira cf alpigena	76	10.7	1,070,000
	Aulacoseira granulata	296	41.8	4,160,000
	Caloneis limosa	4	.6	56,200
	Cyclostephanos cf dubius	2	.3	28,100
	Cyclotella bodanica	50	7.1	702,000
	Cyclotella cf fottii	4	.6	56,200
	Cyclotella cf stelligera	16	2.3	225,000
	Cyclotella meneghiniana	100	14.1	1,400,000
	Cyclotella ocellata	4	.6	56,200
	Cymbella tumida	2	.3	28,100
	Denticula tenuis	2	.3	28,100
	Diadesmis contenta	4	.6	56,200
	Diploneis pupula	2	.3	28,100
	Eunotia curvata	2	.3	28,100
	Eunotia musicola	4	.6	56,200
	Fragilaria capucina	4	.6	56,200
	Gomphonema parvulum	2	.3	28,100
	Gyrosigma spencerii	4	.6	56,200
	Hantzschia amphioxys	4	.6	56,200
	Hantzschia rhaetica	2	.3	28,100
	Meridion circulare	2	.3	28,100
	Navicula capitata	2	.3	28,100
	Navicula cryptotenella	6	.8	84,200
	Navicula mutica	4	.6	56,200
	Navicula tripunctata	2	.3	28,100
	Nitzschia dissipatta	2	.3	28,100
	Nitzschia linearis	2	.3	28,100
	Pinnularia microstauron	6	.8	84,200
	Planothidium lanceolatum	6	.8	84,200
	Stephanodiscus nigarae	40	5.6	562,000
	Stephanodiscus sp. 1	8	1.1	112,000
	Stephanodiscus sp. 2	2	.3	28,100
	Surirella brebissonii	2	.3	28,100
	Synedra delicatissima	2	.3	28,100
	Synedra ulna	2	.3	28,100
Total		**708**	**100[1]**	**9,940,000**

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
3.15	*Achnanthes bioreti*	2	0.5	28,300
	Achnanthidium minutissimum	8	2.1	113,000
	Amphipleura pellucida	1	.3	14,100
	Amphora inariensis	2	.5	28,300
	Aulacoseira cf alpigena	88	23.6	1,240,000
	Aulacoseira distans	2	.5	28,300
	Aulacoseira granulata	76	20.4	1,070,000
	Aulacoseira italica	1	.3	14,100
	Cyclotella bodanica	50	13.4	707,000
	Cyclotella cf fottii	1	.3	14,100
	Cyclotella cf stelligera	5	1.3	70,700
	Cyclotella meneghiniana	75	20.1	1,060,000
	Cyclotella ocellata	1	.3	14,100
	Diadesmis contenta	1	.3	14,100
	Diploneis pupula	1	.3	14,100
	Fragilaria capucina	2	.5	28,300
	Gomphonema parvulum	1	.3	14,100
	Gomphonema sp.	1	.3	14,100
	Hantzschia amphioxys	1	.3	14,100
	Navicula cryptotenella	4	1.1	56,500
	Navicula gregaria	1	.3	14,100
	Nitzschia acicularis	1	.3	14,100
	Nitzschia clausii	1	.3	14,100
	Nitzschia littoralis	3	.8	42,400
	Pinnularia borealis	3	.8	42,400
	Stephanodiscus nigarae	36	9.7	509,000
	Stephanodiscus sp. 1	2	.5	28,300
	Stephanodiscus sp. 2	1	.3	14,100
	Synedra delicatissima	1	.3	14,100
	Synedra ulna	1	.3	14,100
Total		**373**	**100[1]**	**5,270,000**

Table 19. Diatom taxa, relative percentage abundance, and total number of valves per gram of material in bottom-sediment sample from Lake Olathe coring site 5, northeast Kansas, 2000—Continued

Depth of sample (feet)	Taxa	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
3.50	*Achnanthes bioreti*	5	1.0	70,400
	Achnanthidium minutissimum	34	7.1	479,000
	Amphora inariensis	3	.6	42,300
	Aulacoseira cf alpigena	97	20.3	1,370,000
	Aulacoseira granulata	160	33.4	2,250,000
	Aulacoseira italica	27	5.6	380,000
	Caloneis limosa	4	.8	56,300
	Cyclostephanos cf dubius	1	.2	14,100
	Cyclotella bodanica	30	6.3	423,000
	Cyclotella cf fottii	1	.2	14,100
	Cyclotella meneghiniana	35	7.3	493,000
	Cyclotella ocellata	2	.4	28,200
	Diploneis pupula	1	.2	14,100
	Gomphonema parvulum	1	.2	14,100
	Hantzschia amphioxys	3	.6	42,300
	Meridion circulare	2	.4	28,200
	Navicula cf lapidosa	1	.2	14,100
	Navicula cryptotenella	4	.8	56,300
	Navicula trivialis	2	.4	28,200
	Nitzschia inconspicua	22	4.6	310,000
	Nitzschia linearis	1	.2	14,100
	Nitzschia palea	1	.2	14,100
	Pinnularia borealis	5	1.0	70,400
	Pinnularia microstauron	1	.2	14,100
	Planothidium lanceolatum	1	.2	14,100
	Stephanodiscus nigarae	29	6.1	408,000
	Stephanodiscus sp. 1	1	.2	14,100
	Stephanodiscus sp. 2	2	.4	28,200
	Surirella minuta	2	.4	28,200
	Synedra ulna	1	.2	14,100
Total		**479**	**100[1]**	**6,750,000**

[1]Numbers are rounded to three significant figures.