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KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

# Sedimentation and Occurrence and Trends of Selected Chemical Constituents in Bottom Sediment of 10 Small Reservoirs, Eastern Kansas

Scientific Investigations Report 2004–5228

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

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By Kyle E. Juracek

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# Conversion Factors, Abbreviations, and Datum

| Multiply | By | To obtain |
|---|---|---|
| acre | 0.4047 | hectare (ha) |
| acre | 43,560 | square foot ($ft^2$) |
| acre | 4,047 | square meter ($m^2$) |
| acre | 0.001562 | square mile ($mi^2$) |
| acre-foot (acre-ft) | 43,560 | cubic foot ($ft^3$) |
| acre-foot (acre-ft) | 1,233 | cubic meter ($m^3$) |
| acre-foot per square mile per year [(acre-ft/$mi^2$)/yr] | 476.1 | cubic meter per square kilometer per year [($m^3$/$km^2$)/yr] |
| centimeter (cm) | 0.3937 | inch (in.) |
| cubic centimeter ($cm^3$) | 0.06102 | cubic inch ($in^3$) |
| cubic foot ($ft^3$) | 0.02832 | cubic meter ($m^3$) |
| cubic foot ($ft^3$) | $2.296 \times 10^{-5}$ | acre-foot (acre-ft) |
| foot (ft) | 0.3048 | meter (m) |
| gram (g) | 0.03527 | ounce (oz) |
| gram per cubic centimeter (g/$cm^3$) | 62.43 | pound per cubic foot (lb/$ft^3$) |
| inch (in.) | 2.54 | centimeter (cm) |
| inch per hour (in/h) | 2.54 | centimeter per hour (cm/h) |
| kilogram (kg) | 2.205 | pound (lb) |
| kilogram per cubic meter (kg/$m^3$) | 0.06243 | pound per cubic foot (lb/$ft^3$) |
| kilogram per hectare (kg/ha) | 571.1 | pound per square mile (lb/$mi^2$) |
| meter (m) | 3.281 | foot (ft) |
| microgram per gram (µg/g) | 1.0 | milligram per kilogram (mg/kg) |
| microgram per gram (µg/g) | 1.0 | part per million (ppm) |
| microgram per kilogram (µg/kg) | 0.001 | milligram per kilogram (mg/kg) |
| microgram per kilogram (µg/kg) | 1.0 | part per billion (ppb) |
| mile (mi) | 1.609 | kilometer (km) |
| milligram per kilogram (mg/kg) | 1.0 | part per million (ppm) |
| millimeter (mm) | 0.03937 | inch (in.) |
| percent concentration | 10,000 | milligram per kilogram (mg/kg) |
| pound (lb) | 0.4536 | kilogram (kg) |
| pound per cubic foot (lb/$ft^3$) | 16.02 | kilogram per cubic meter (kg/$m^3$) |
| pound per square mile (lb/$mi^2$) | 0.001751 | kilogram per hectare (kg/ha) |
| square mile ($mi^2$) | 259.0 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| ton (short) | 0.9072 | megagram (Mg) |

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

$$°F = (1.8 \times °C) + 32$$

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

$$°C = (°F - 32) / 1.8$$

# Datum

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

# Sedimentation and Occurrence and Trends of Selected Chemical Constituents in Bottom Sediment of 10 Small Reservoirs, Eastern Kansas

By Kyle E. Juracek

## Abstract

Many municipalities in Kansas rely on small reservoirs as a source of drinking water and for recreational activities. Because of their significance to the community, management of the reservoirs and the associated basins is important to protect the reservoirs from degradation. Effective reservoir management requires information about water quality, sedimentation, and sediment quality.

A combination of bathymetric surveying and bottom-sediment coring during 2002 and 2003 was used to investigate sediment deposition and the occurrence of selected nutrients (total nitrogen and total phosphorus), organic and total carbon, 26 trace elements, 15 organochlorine compounds, and 1 radionuclide in the bottom sediment of 10 small reservoirs in eastern Kansas. Original reservoir water-storage capacities ranged from 23 to 5,845 acre-feet. The mostly agricultural reservoir basins range in area from 0.6 to 14 square miles.

The mean annual net volume of deposited sediment, estimated separately for several of the reservoirs, ranged from about 43,600 to about 531,000 cubic feet. The estimated mean annual net mass of deposited sediment ranged from about 1,360,000 to about 23,300,000 pounds. The estimated mean annual net sediment yields from the reservoir basins ranged from about 964,000 to about 2,710,000 pounds per square mile. Compared to sediment yield estimates provided by a statewide study published in 1965, the estimates determined in this study differed substantially and were typically smaller. A statistically significant positive correlation was determined for the relation between sediment yield and mean annual precipitation.

Nutrient concentrations in the bottom sediment varied substantially among the 10 reservoirs. Median total nitrogen concentrations ranged from 1,400 to 3,700 milligrams per kilogram. Median total phosphorus concentrations ranged from 550 to 1,300 milligrams per kilogram. A statistically significant positive trend (that is, nutrient concentration increased toward the top of the sediment core) was indicated in one reservoir for total nitrogen and in two reservoirs for total phosphorus. Also, a possible positive trend for total nitrogen was indicated in two other reservoirs. These trends in nutrient concentrations may be related to a statewide increase in fertilizer use. Alternatively, the trends may be indicative of diagenesis (that is, postdepositional changes in the sediment caused by various processes including decomposition).

Nutrient loads and yields also varied substantially among the five reservoirs for which loads and yields were estimated. Estimated mean annual net loads of total nitrogen deposited in the bottom sediment ranged from 4,080 to 49,100 pounds. Estimated mean annual net loads of total phosphorus deposited in the bottom sediment ranged from 1,120 to 20,800 pounds. Estimated mean annual net yields of total nitrogen from the basins ranged from 2,210 to 6,800 pounds per square mile. Estimated mean annual net yields of total phosphorus from the basins ranged from 598 to 2,420 pounds per square mile.

Compared to nonenforceable sediment-quality guidelines adopted by the U.S. Environmental Protection Agency, bottom-sediment concentrations of arsenic, chromium, copper, and nickel in samples from all 10 reservoirs typically exceeded the threshold-effects levels (TELs) but were less than the probable-effects levels (PELs). TELs represent the concentrations above which toxic biological effects occasionally occur in aquatic organisms, whereas PELs represent the concentrations above which toxic biological effects usually or frequently occur. Concentrations of cadmium, lead, and zinc exceeded the TELs but were less than the PELs in sediment samples from about one-half of the reservoirs and were less than the TELs in samples from the remaining reservoirs. Mercury concentrations were less than the TEL (information only available for four reservoirs). Silver was not detected in the bottom sediment from any of the 10 reservoirs sampled. Trace element concentrations at the bottom of the sediment core for the oldest reservoir indicated the possibility that, for certain constituents in certain areas, baseline concentrations may equal or exceed the TELs prior to the effects of human activity.

With few exceptions, organochlorine compounds typically either were not detected or were detected at concentrations that were less than the TELs in the most recently deposited bottom sediments. Compounds detected included chlordane, DDD, DDE, dieldrin, and polychlorinated biphenyls (PCBs).

Exceptions included the chlordane detections, which exceeded the TEL in a sediment sample from one reservoir and exceeded the PEL in sediment samples from another reservoir. Also, the DDE detection in a sediment sample from one reservoir exceeded the TEL but was less than the PEL.

With one possible exception, the effects of human activity are evident in the bottom sediment of each reservoir. Evidence includes possible positive trends in nutrient deposition, elevated concentrations and trends of certain trace elements (for example, copper, lead, and zinc), and detectable concentrations of organochlorine compounds.

# Introduction

Many municipalities in Kansas rely on small reservoirs as a source of drinking water and for recreational activities. Because of their significance to the community, management of the reservoirs and the associated basins is important to protect the reservoirs from degradation. Effective reservoir management requires information about water quality, sedimentation, and sediment quality. Water-quality information is important for determining the suitability of the water in a reservoir for meeting various needs. Also, water-quality trends may be used to describe the overall effect of human activity in a reservoir basin, to indicate the effectiveness of regulatory decisions and changes in land-management practices, and to provide advanced notice of potential future water-quality problems.

The volume and quality of sediment deposited in a reservoir also are important. Sedimentation affects the useful life and the aesthetic quality of a reservoir. Sediment quality is an important environmental concern because sediment may act as a sink for water-quality constituents and, under certain conditions, as a source of constituents to the overlying water column and biota (Baudo and others, 1990; Zoumis and others, 2001). Once in the food chain, sediment-derived constituents may pose an even greater concern because of bioaccumulation. An analysis of reservoir bottom sediment can provide historical information on sediment deposition as well as the occurrence of sediment-bound constituents. Such information may be used to partly reconstruct historical sediment-quality and water-quality records and to determine a present-day baseline with which to evaluate long-term changes in reservoir sediment and water quality that may be related to changes in human activity in the basin (Charles and Hites, 1987; Van Metre and Callender, 1996; Van Metre and Mahler, 2004).

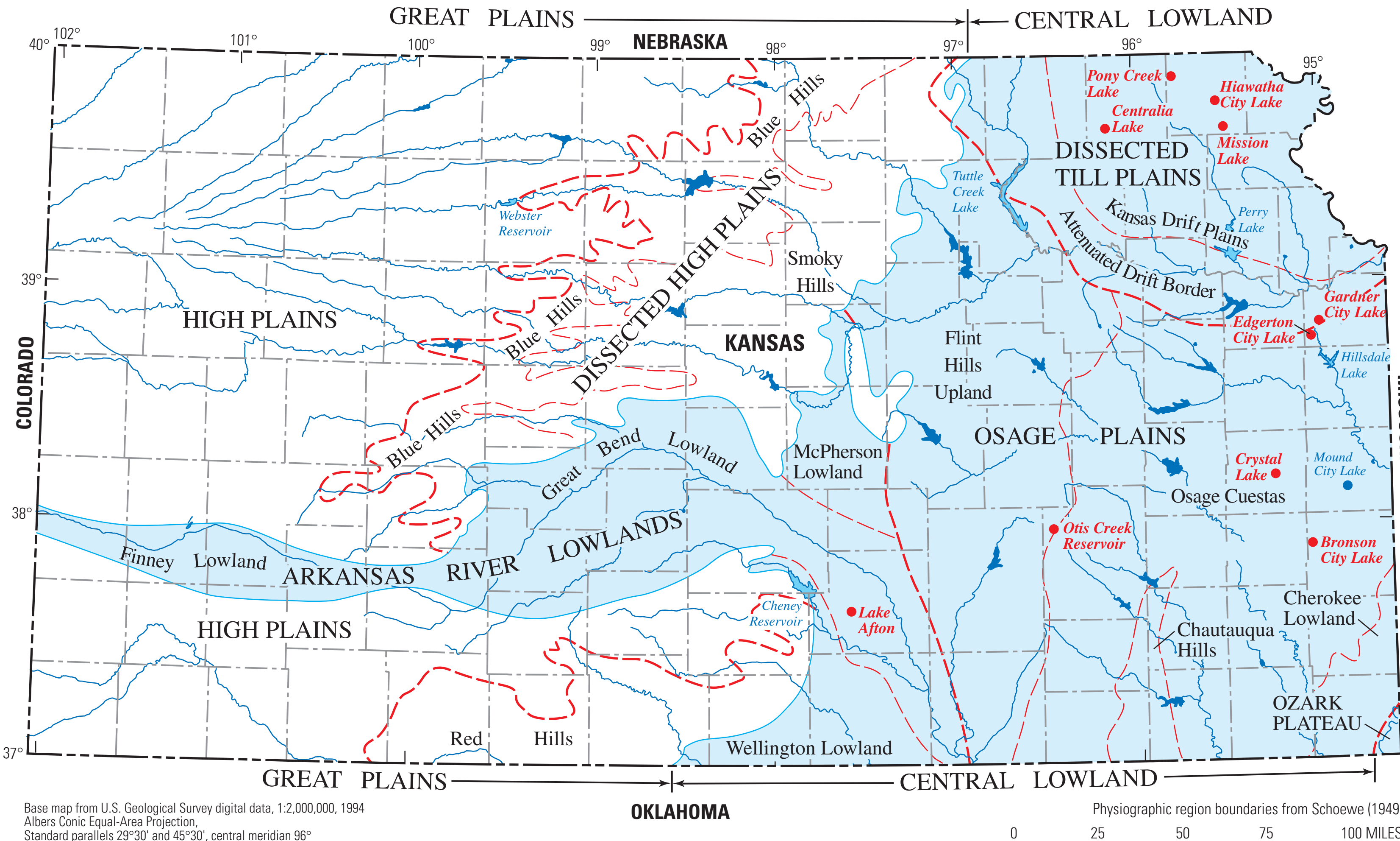
## Purpose and Scope

This report describes a 2-year study by the U.S. Geological Survey (USGS), done in cooperation with the Kansas Department of Health and Environment (KDHE). The study was begun in 2002 to estimate sedimentation in 10 small reservoirs in eastern Kansas as well as the deposition of various chemical constituents. The specific study objectives for each reservoir were to:

1. Estimate the total volume and mass of bottom sediment;
2. Determine the occurrence, mass, and trends of selected chemical constituents in the bottom sediment;
3. Determine the mean annual net load and yield of sediment, total nitrogen, total phosphorus, and other selected constituents;
4. Determine, to the extent possible, the relation between sedimentation rates, sediment quality, and basin characteristics; and
5. Provide a baseline of information on reservoir conditions with which to compare future conditions that may represent a response to changes in human activity in the associated basins.

The 10 small reservoirs selected for the study were Bronson City Lake, Centralia Lake, Crystal Lake, Edgerton City Lake, Gardner City Lake, Hiawatha City Lake, Lake Afton, Mission Lake, Otis Creek Reservoir, and Pony Creek Lake (fig. 1). Each of these reservoirs is used as a public water supply and (or) for recreation. All but Otis Creek Reservoir were listed under Section 303(d) of the Federal Clean Water Act of 1972 for eutrophication (Kansas Department of Health and Environment, 2002). A eutrophic lake contains nutrient-rich water and supports high biotic productivity (Cole, 1994). The 303(d) list is a priority list that identifies water bodies that do not meet water-quality standards that are based on the use of the water bodies. For each impaired water body on the 303(d) list, a State is required by the Clean Water Act to develop a total maximum daily load (TMDL), which is an estimate of the maximum pollutant load (material transported during a specified time period) from point and nonpoint sources that a receiving water can accept without exceeding water-quality standards (U.S. Environmental Protection Agency, 1991). Otis Creek Reservoir, which was not on the 303(d) list, was included in the study for the purpose of comparison. Otis Creek Reservoir also was studied as part of a national investigation of PL566 reservoirs in cooperation with the U.S. Department of Agriculture's Natural Resources Conservation Service.

This report presents estimates of sedimentation as well as the occurrence of, and trends in, selected chemical constituents in the bottom sediment of the 10 small reservoirs. Data were collected during 2002 and 2003. Information in this report may be used to partly reconstruct historical sediment-quality and water-quality records and to provide a present-day baseline with which to evaluate long-term changes in reservoir sediment and water quality that may reflect changes in human activity in the basins. Also, the information in this report may be used to assist in the development, implementation, evaluation, and revision of TMDLs for sediment and associated chemical constituents that contribute to the water-quality impairment of the reservoirs. From a national perspective, the methods and results presented provide guidance and perspective for future reservoir




**EXPLANATION**

Physiographic boundary

*Lake Afton* ● Location and name of small reservoir described in this report

**Figure 1.** Physiography of Kansas and location of small reservoirs selected for study.

studies concerned with the issues of sedimentation and water quality.

## Description of Reservoir Basins

The small reservoirs included in this study have completion dates ranging from 1879 (Crystal Lake) to 1993 (Pony Creek Lake). The reservoir basins range in area from less than 1 $mi^2$ (Bronson City Lake, Crystal Lake, Hiawatha City Lake) to 14.0 $mi^2$ (Otis Creek Reservoir), with most of the basins less than 10 $mi^2$ in area. The original water-storage capacities for the reservoirs range from 23 acre-ft (Edgerton City Lake) to 5,845 acre-ft (Otis Creek Reservoir). The current (2004) water-storage capacities are smaller because of ongoing sedimentation. With two exceptions, it is believed that the reservoirs have not been dredged. The exceptions are Edgerton City Lake (dredged in the 1930s, 1967, and 1976) and Hiawatha City Lake (dredged in 1988). Table 1 provides the year completed, approximate basin area, original water-storage capacity, and the dredging history for each of the small reservoirs.

Physiographically, the reservoir basins can be characterized with reference to physical divisions as defined by Fenneman (1946) and Schoewe (1949) (fig. 1). All of the basins are located within the Central Lowland Province of the Interior Plains (Fenneman, 1946). Within the Central Lowland Province, the basins are located within three separate sections—the Dissected Till Plains, the Osage Plains, and the Arkansas River Lowlands (Schoewe, 1949).

The reservoir basins located in the Dissected Till Plains Section of northeast Kansas include Centralia Lake, Gardner City Lake, Hiawatha City Lake, Mission Lake, and Pony Creek Lake (fig. 1). The Dissected Till Plains are characterized by dissected deposits of glacial till that consist of silt, clay, sand, gravel, and boulders that overlie bedrock of primarily shale and limestone, with some sandstone (Jordan and Stamer, 1995). Slopes in the reservoir basins in this physiographic section typically are less than 10 percent (U.S. Department of Agriculture, Soil Conservation Service, 1960, 1979a, 1982b). However, in the Gardner City Lake Basin, slopes near the streams may be as much as 20 percent (U.S. Department of Agriculture, Soil Conservation Service, 1979a).

The Osage Plains Section, which covers much of east-central and southeast Kansas, includes four of the reservoir basins. Within the Osage Plains, Bronson City Lake, Crystal Lake, and Edgerton City Lake are located in the Osage Cuestas physiographic division, whereas Otis Creek Reservoir is located in the Flint Hills Upland (fig. 1). The Osage Cuestas generally consist of a series of irregular northeast-southwest trending escarpments between which are flat to gently rolling plains. The topography of the Flint Hills Upland is

**Table 1.** Year completed, approximate basin area, original water-storage capacity, and dredging history for 10 small reservoirs in eastern Kansas.

[$mi^2$, square miles; --, not available or not determined]

| Reservoir (fig. 1) | Year completed | Approximate basin area ($mi^2$) | Original water-storage capacity (acre-feet) | Years dredged |
|---|---|---|---|---|
| Bronson City Lake | 1956 | 0.8 | -- | None |
| Centralia Lake | 1990 | 12.5 | [1]4,769 | None |
| Crystal Lake | 1879 | .6 | [2]229 | None |
| Edgerton City Lake | 1900 | 4.9 | [3]23 | 1930s, 1967, 1976 |
| Gardner City Lake | 1940 | 5.5 | [2]2,301 | None |
| Hiawatha City Lake | 1933 | .8 | [4]60 | 1988 |
| Lake Afton | 1942 | 10.4 | [5]3,264 | None |
| Mission Lake | 1924 | 8.6 | [2]1,866 | None |
| Otis Creek Reservoir | 1971 | 14.0 | [6]5,845 | None |
| Pony Creek Lake | 1993 | 6.6 | [2]2,367 | None |

[1] Original water-storage capacity for Centralia Lake from original as-built plans on file at the Upper Black Vermillion Watershed Joint District No. 37 office in Centralia, Kansas.

[2] Original water-storage capacities for Crystal Lake, Gardner City Lake, Mission Lake, and Pony Creek Lake from Kansas Water Authority (2001).

[3] Original water-storage capacity for Edgerton City Lake from Green & Burns Architects & Engineers (1975).

[4] Original water-storage capacity for Hiawatha City Lake from original plans on file at city hall in Hiawatha, Kansas.

[5] Original water-storage capacity for Lake Afton from Sedgwick County Department of Public Works and Department of Environmental Resources (1984).

[6] Original water-storage capacity for Otis Creek Reservoir from original plans on file at the U.S. Department of Agriculture's Natural Resources Conservation Service office in Eureka, Kansas.

characterized as gently rolling. Throughout the Osage Plains, the underlying bedrock is primarily limestone and shale (Schoewe, 1949). Slopes in the Bronson City Lake, Crystal Lake, and Edgerton City Lake Basins are generally less than 5 percent (U.S. Department of Agriculture, Soil Conservation Service, 1977, 1979a, 1981). In the Otis Creek Reservoir Basin, slopes are generally 5 to 20 percent (U.S. Department of Agriculture, Soil Conservation Service, 1982a).

Lake Afton, in south-central Kansas, is located in the Great Bend Lowland physiographic division of the Arkansas River Lowlands Section (fig. 1). In this area, the topography is generally flat with little relief. Typically, slopes in the basin are 3 percent or less (U.S. Department of Agriculture, Soil Conservation Service, 1979b). Surface materials are mostly sand and gravel (Schoewe, 1949).

Soil permeability, which is the rate at which water moves down through the soil, is an important determinant of storm runoff in a basin (other important determinants are slope and land use). Typically, there is an inverse relation between soil permeability and runoff; that is, as soil permeability decreases, the potential for runoff increases. With two exceptions, the site-specific, depth-weighted, mean soil permeability in the 10 reservoir basins ranges from 0 to about 1.3 in/hr. One exception is the Hiawatha City Lake Basin in which soil permeability ranges from 0 to about 0.3 in/hr. The other exception is along a tributary to Lake Afton where soil permeability ranges up to 4.0 to 7.5 in/hr. Table 2 provides the depth-weighted, mean soil permeability as an average value for each reservoir basin. Typically, soil permeability in Kansas is less in the uplands and greater in the flood plains of the major rivers and streams (Juracek, 2000).

Soil erodibility, defined as the susceptibility of soil to erosion by water, typically is moderate for the soils in the reservoir basins. In general, the basins are comparable in terms of mean soil erodibility (U.S. Department of Agriculture, Soil Conservation Service, 1960, 1977, 1979a, 1979b, 1981, 1982a, 1982b).

Long-term mean annual precipitation ranges from about 30 in. for the Lake Afton Basin to about 40 in. for the Bronson City Lake and Crystal Lake Basins (table 2) (High Plains Regional Climate Center, 2002). Most of the annual precipitation is received during the growing season (generally April–September).

Land use (1988–90) in the basins is a mostly agricultural mix of cropland and grassland (table 2). Cropland is the dominant land use in the Bronson City Lake, Centralia Lake, Edgerton City Lake, Hiawatha City Lake, Lake Afton, Mission Lake, and Pony Creek Lake Basins. Grassland is the dominant land use in the Crystal Lake and Otis Creek Reservoir Basins. The Gardner City Lake Basin is characterized by a mix of cropland, grassland, and urban land uses. Substantial urban land use also is present in the Crystal Lake Basin (table 2).

## Acknowledgments

This study was made possible in part by support from the Kansas State Water Plan Fund, the U.S. Environmental Protection Agency, the U.S. Department of Agriculture's Natural Resources Conservation Service, and the Fall River Watershed Joint District No. 21.

**Table 2.** Depth-weighted mean soil permeability, mean annual precipitation, and land use for 10 small reservoir basins in eastern Kansas.

[Soil permeability data from Juracek (2000). Precipitation data from High Plains Regional Climate Center (2002). Land-use data from Kansas Applied Remote Sensing Program (1993)]

| Reservoir (fig. 1) | Depth-weighted mean soil permeability[1] (inches per hour) | Mean annual precipitation (inches) | Land use, in percentage of basin | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Cropland | Grassland | Woodland | Urban | Water | Other |
| Bronson City Lake | 0.6 | 40 | 61.0 | 29.5 | 6.5 | 0 | 3.0 | 0 |
| Centralia Lake | .4 | 35 | 77.1 | 17.6 | 2.1 | 0 | 3.0 | .1 |
| Crystal Lake | .8 | 40 | 10.7 | 65.3 | .7 | 18.0 | 5.3 | 0 |
| Edgerton City Lake | .2 | 39 | 58.7 | 31.5 | 4.3 | 3.9 | .8 | .9 |
| Gardner City Lake | .3 | 39 | 30.8 | 43.0 | 3.4 | 17.3 | 4.3 | 1.1 |
| Hiawatha City Lake | .3 | 37 | 78.0 | 18.7 | 2.3 | 0 | .9 | 0 |
| Lake Afton | 1.0 | 30 | 81.0 | 14.3 | .9 | 0 | 3.5 | .3 |
| Mission Lake | .3 | 35 | 69.9 | 25.0 | 1.4 | .5 | 3.1 | .1 |
| Otis Creek Reservoir | .4 | 33 | .1 | 96.4 | .1 | 0 | 3.4 | 0 |
| Pony Creek Lake | .5 | 34 | 52.8 | 32.8 | 3.5 | 5.6 | 5.2 | .1 |

[1] Depth-weighted mean soil permeability is an average value for each reservoir basin.

# Methods

The objectives of this study were accomplished using available and newly collected information. Available information included water-storage capacity data (estimated by bathymetric survey) from the Kansas Water Authority (2001) and historical information from the cities that use the reservoirs. New information was obtained through bathymetric surveying (Otis Creek Reservoir only) and the collection and analysis of bottom-sediment cores for all 10 reservoirs.

## Bathymetric Survey

To provide the information necessary for estimating the current water-storage capacity for Otis Creek Reservoir, a bathymetric (lake-bed elevation) survey was performed by the USGS during August 2002. The bathymetric survey involved the use of global-positioning-system (GPS) technology to record the geographic location of the boat on the lake and a fathometer system to determine the depth to the sediment-water interface (top of lake bed). The GPS and fathometer data were recorded digitally using a data-logging unit.

The bathymetric survey was conducted along a series of transects, spaced 250 ft apart, both parallel and perpendicular to the axis of the dam. The reliability of the fathometer was verified at the start and end of each day (weather conditions permitting) by suspending a metal plate at known depths directly below the transducer. A total of 54 transects were surveyed. The transect data were used to estimate the 2002 water-storage capacity of the reservoir. Transect data are on file with the USGS in Lawrence, Kansas.

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

The total bottom-sediment volume (sediment plus water and gases) for Crystal Lake, Gardner City Lake, Lake Afton, Mission Lake, and Otis Creek Reservoir was estimated by subtracting the updated water-storage capacity from the original water-storage capacity. For these five reservoirs the mean annual volume of sediment deposited was estimated by dividing the total sediment volume by the number of years of deposition. Estimates of total sediment volume were not possible for Bronson City Lake, Centralia Lake, Edgerton City Lake, Hiawatha City Lake, and Pony Creek Lake because of a lack of information.

The total bottom-sediment mass for Crystal Lake, Gardner City Lake, Lake Afton, Mission Lake, and Otis Creek Reservoir was estimated by multiplying the total bottom-sediment volume by the representative bulk density. The representative bulk density for each reservoir was computed as the average of the bulk densities that were determined from two or three sediment cores (see discussion in “Physical Analyses” section). Because bulk density varies with location and the representative bulk density only accounts for two or three sites in each reservoir, the estimated total bottom-sediment mass for each reservoir has a potential error of unknown magnitude.

The mean annual mass of sediment (dry weight) deposited was computed as the total sediment mass divided by the number of years of deposition. Mean annual sediment yield from each reservoir basin was estimated by dividing the mean annual mass of sediment deposited by the area of the basin. Because sediment losses are not accounted for (for example, due to reservoir outflow), the computed mean annual sediment deposition and yield represent net, rather than total, values.

## Sediment-Core Collection and Processing

For planned physical and chemical analyses, bottom-sediment cores were collected either in the fall of 2002 or the spring of 2003 at two or three sites within each reservoir. With three exceptions, the cores for chemical analyses (constituents and age dating) were collected from a site located in the downstream one-third of the reservoir relatively close to the dam. The near-dam site was selected because it is in relatively deep water where the sediment was least likely to be disturbed. The exceptions were Edgerton City Lake, Hiawatha City Lake, and Otis Creek Reservoir. At Edgerton and Hiawatha City Lakes, the cores were collected from the upstream one-third of the reservoir to avoid downstream areas that had been disturbed by dredging. At Otis Creek Reservoir, the cores were collected from the middle of the reservoir because of the need to obtain a representative sample of relatively thin sediment deposits using a box corer.

At each coring site, one to four cores were collected to provide sufficient sediment material for laboratory analyses. The latitude and longitude for each coring site, obtained using GPS technology, are provided in table 28 in the “Supplemental Information” section of this report. Maps showing the location of coring sites in each reservoir and land use in the reservoir basins are provided in figures 22–31 in the “Supplemental Information” section.

The method of sediment coring varied depending on boat access, sediment thickness, and water depth at each reservoir. At Edgerton and Hiawatha City Lakes, restricted boat access and shallow water depths necessitated that cellulose acetate butyrate transparent tubes (with a 2.625-in. inside diameter) were hand-driven into the bottom sediment and removed. At Otis Creek Reservoir, restricted boat access and relatively thin sediment deposits dictated the use of a box corer. The inside dimensions of the transparent plastic liner used in the box corer were 5.5 in. long by 5.5 in. wide by 8.0 in. deep. At the remaining reservoirs, the cores were collected using a gravity corer mounted on a pontoon boat. The liner used in the gravity corer was the same transparent tubing as previously described.

When using a gravity corer, a phenomenon referred to as “core shortening” occurs that results in a recovered sediment core that may be only about one-half of the actual thickness of sediment penetrated (Emery and Hulsemann, 1964). Core shortening is caused by the friction of the sediment against the inner wall of the sample tube as the corer penetrates the sediment (Emery and Hulsemann, 1964; Hongve and Erlandsen, 1979; Blomqvist, 1985; Blomqvist and Bostrom, 1987). In “normal” lake-bottom sediment, which is characterized by uniform texture with decreasing water content at depth, core shortening results in a core that provides a thinned but complete representation of all of the sediment layers that were penetrated (Emery and Hulsemann, 1964; Hongve and Erlandsen, 1979). However, there is some evidence to suggest that the use of a gravity corer may or may not result in the loss of some of the uppermost soft surficial sediment on the lake bed (Crusius and Anderson, 1991). In this study, a comparison of the length of core recovered by gravity coring to the thickness of sediment penetrated (for all sites that penetration of the entire sediment thickness was achieved) indicated that core recovery was typically in the range of 50 to 75 percent. Estimated sediment thickness, length of core recovered, and estimated recovery percentage for the coring sites are provided in table 28 at the back of this report.

Penetration of the entire thickness of sediment was not achieved for Edgerton and Hiawatha City Lakes because of the substantial thickness of the bottom sediment coupled with the need to hand-drive the cores. Also, when lakes are drained the bottom sediment dries out, compacts, and becomes more difficult to penetrate. Edgerton City Lake was partially drained when the reservoir was dredged in 1976 (Rita Moore, city of Edgerton, oral commun., 2002). Hiawatha City Lake was drained and left dry for about 9 to 12 months in 1987–88 (for dredging) and for about 3 to 4 months in 1994 (to repair the spillway) (Dave Grimm, city of Hiawatha, oral commun., 2002).

Sediment samples for Otis Creek Reservoir were removed onsite directly from the box corer. The sediment cores collected from the other reservoirs were stored vertically, refrigerated (at 4–5 $^{o}$C), and processed within 1 week after collection at the USGS laboratory in Lawrence, Kansas. The core liners were cut lengthwise in two places 180 degrees apart. The cuts were completed with a 4-in. hand-held circular saw with its blade set at a depth to minimize penetration of the sediment cores. The cores were split in half by pulling a tightly held nylon string through the length of the cores and allowing the halves to separate. Once split, the relatively undisturbed inner parts of the cores were exposed for examination and sampling.

On the basis of differences in moisture content, texture, and organic matter content (for example, root hairs, sticks, seed pods, leaves), the boundary between the sediment deposited in the reservoir and the underlying original (pre-reservoir) land-surface (or channel-bed) material was determined. Typically, the bottom sediment was characterized by higher moisture content, finer texture, and little if any visible organic matter as compared to the original material.

For each reservoir, constituent analyses were performed on sediment samples collected from one site, and bulk-density analyses were performed on sediment samples collected from all sites. The number of samples removed from each core was dependent on the length of the core, the intended use of the core, and the amount of material required for analyses. Typically, two or three cores were used for the purposes of constituent analyses and age dating.

For Edgerton City Lake, Gardner City Lake, Hiawatha City Lake, Lake Afton, and Mission Lake, one core was used for constituent analyses (nutrients, carbon, and trace elements) and age dating. The core was split longitudinally, and the two halves were used for different purposes. One-half was divided into five intervals of equal length which were used for constituent analyses. The other half was divided into 10 intervals of equal length which were used for age dating. From each interval, a representative volume of sediment (defined as the space occupied by the sediment particles, water, and gases as measured in cubic units) was removed, homogenized, and sampled for subsequent analyses. A second core was divided into five intervals of equal length and sampled for the analysis of organochlorine compounds (top interval only).

For Bronson City Lake, separate cores were used for constituent analyses (three intervals) and organochlorine compounds (top one-third of core only). Due to an insufficient amount of material, age dating of the sediment was not performed for Bronson City Lake. For Centralia and Pony Creek Lakes, a single core was used for constituent analyses (three intervals) and organochlorine compounds (top one-third of core only). Age dating was not performed for the sediment in Centralia and Pony Creek Lakes because the reservoirs were too young for a meaningful analysis. For Crystal Lake, separate cores were used for constituent analyses (10 intervals), age dating (15 intervals), and organochlorine compounds (top one-fifth of core only). For Otis Creek Reservoir, separate cores were used for constituent analyses (five intervals), age dating (five intervals), and organochlorine compounds (top one-third of core only).

## Physical Analyses

Physical analyses included bulk-density determinations and particle-size analyses. A sediment core from all sites at each reservoir was analyzed to determine bulk density. The bulk densities of reservoir sediment tend to be lowest downstream near the dam where the fine sediment is deposited and highest in the upstream part of the reservoir where the coarse delta deposits are located (Morris and Fan, 1998). Typically, at each reservoir, one core for bulk density analysis was collected in the downstream one-third of the reservoir and the other core was collected in the upstream one-third of the reservoir to provide a representative sample of reservoir conditions. However, onsite conditions (that is, thin sediment deposits) and sampling considerations (that is, use of a box corer) at Otis Creek Reservoir dictated that both cores be collected from the middle of the reservoir. At Hiawatha City Lake, all cores were collected in the middle and upstream one-thirds of the reservoir to avoid the previously dredged part of the reservoir near the dam.

Typically, each core was divided into three or five intervals of equal length. From each interval, a 1-in. thick volume of sediment was removed using a putty knife, weighed to the nearest 0.10 g, oven dried at about 45 °C for 96 hours, and reweighed. Oven drying of the sample continued as it was reweighed on a daily basis until no additional moisture loss was observed. Bulk density was computed as follows:

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

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

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

where $v$ is the volume of the sample (in cubic centimeters), $h$ is the height (length) of the sample (in centimeters), and $d$ is the diameter of the sample (in centimeters) (Gordon and others, 1992).

Results for all sampled intervals were averaged to determine the mean bulk density for the core. The bulk densities then were converted to pounds per cubic foot for use in subsequent computations. Results for the cores were averaged to determine the representative bulk density for each reservoir. Analyses of sediment samples for bulk density were performed at the USGS laboratory in Lawrence, Kansas.

Particle-size analysis was performed to determine the percentage of sand (that is, particles larger than 0.063 mm in diameter) and silt and (or) clay (that is, particles smaller than 0.063 mm in diameter) in the sediment cores. For all reservoirs, the core used for constituent analyses (that is, nutrients, organic and total carbon, and trace elements) also was used for particle-size analyses. The particle-size analyses were completed at the USGS Sediment Trace Element Partitioning Laboratory in Atlanta, Georgia, according to the methods presented in Guy (1969) and Grosbois and others (2001).

## Chemical Analyses, Quality Control, and Age Dating

The sediment samples were analyzed for nutrients (total nitrogen and total phosphorus), organic and total carbon, 26 trace elements, 15 organochlorine compounds, and 1 radionuclide. A complete list of the constituents for which analyses were performed is provided in table 3. Constituent analyses of bottom-sediment samples were performed at the USGS

**Table 3.** Chemical analyses performed on bottom-sediment core samples from 10 small reservoirs in eastern Kansas.

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

| | | | |
|---|---|---|---|
| | | Nutrients | |
| Total nitrogen (1,000 mg/kg) | Total phosphorus (50 mg/kg) | | |
| | | Carbon | |
| Carbon, total organic (TOC) (0.1%) | Carbon, total (0.1%) | | |
| | | Trace elements | |
| Aluminum (0.1%) | Cobalt (1.0 µg/g) | Molybdenum (1.0 µg/g) | Tin (1.0 µg/g) |
| Antimony (0.1 µg/g) | Copper(1.0 µg/g) | Nickel (1.0 µg/g) | Titanium (0.01%) |
| Arsenic (0.1 µg/g) | Iron (0.1%) | Selenium (0.1 µg/g) | Uranium (50 µg/g) |
| Barium (1.0 µg/g) | Lead (1.0 µg/g) | Silver (0.5 µg/g) | Vanadium (1.0 µg/g) |
| Beryllium (0.1 µg/g) | Lithium (1.0 µg/g) | Strontium (1.0 µg/g) | Zinc (1.0 µg/g) |
| Cadmium (0.1 µg/g) | Manganese (10.0 µg/g) | Sulfur (0.1%) | |
| Chromium (1.0 µg/g) | Mercury (0.01 µg/g) | Thallium (50 µg/g) | |
| | | Organochlorine compounds | |
| Aldrin (0.2 µg/kg) | DDT (0.5 µg/kg) | Gross polychlorinated biphenyls (PCBs) (5.0 µg/kg) | Methoxychlor (2.5 µg/kg) |
| Chlordane (3.0 µg/kg) | Dieldrin (0.2 µg/kg) | Heptachlor (0.2 µg/kg) | Mirex (0.2 µg/kg) |
| DDD (0.5 µg/kg) | Endosulfan (0.2 µg/kg) | Heptachlor epoxide (0.2 µg/kg) | Toxaphene (50 µg/kg) |
| DDE (0.2 µg/kg) | Endrin (0.2 µg/kg) | Lindane (0.2 µg/kg) | |
| | | Radionuclide | |
| Cesium-137 (0.05 pCi/g)[1] | | | |

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

National Water-Quality Laboratory in Denver, Colorado, and the USGS Sediment Trace Element Partitioning Laboratory in Atlanta, Georgia. Analyses of sediment samples for total nitrogen and carbon concentrations were performed using the methods described by Horowitz and others (2001). Analyses for total phosphorus and trace elements were performed using the methods described by Fishman and Friedman (1989), Arbogast (1996), and Briggs and Meier (1999). Analyses for organochlorine compounds were performed using the methods described by Wershaw and others (1987).

Quality control for the chemical analyses of sediment samples was provided by an evaluation of within-site and analytical variability. At each reservoir, multiple sediment cores were collected to provide the required amount of material for planned chemical determinations. As a result, it was necessary to evaluate "within-site" variability (sediment-quality variability among cores). Within-site variability was evaluated through the collection and analysis of sequential replicate sediment cores at one site for Centralia Lake, Edgerton City Lake, and Gardner City Lake (fig. 1). Each core was divided into three or five intervals of equal length, and a sample from the top interval was prepared, as described previously, and analyzed for the various constituents. For each pair of cores, the relative percentage difference between the replicate sample concentrations was computed as:

$$D_{rp} = [|C1 - C2| / (C1 + C2)] * 100, \qquad (3)$$

where $D_{rp}$ is the relative percentage difference, $C1$ is the first replicate sample concentration, and $C2$ is the second replicate sample concentration.

The relative percentage differences computed for the constituents detected in the sequential replicate cores are provided in table 4. With the exception of cadmium, selenium, tin, chlordane, and dieldrin, within-site variability was minimal with relative percentage differences less than 5 percent. Cadmium, selenium, tin, chlordane, and dieldrin had relative percentage differences of 7.3, 5.9, 22.5, 7.3, and 13.6 percent, respectively.

Analytical variability was evaluated through the analysis of split replicate samples from an individual core collected at Gardner City Lake (fig. 1). The core was divided into five intervals of equal length. A representative volume of sediment was removed from the top interval, homogenized, and sampled twice. Both samples were analyzed for the various constituents. The relative percentage differences between the split replicate sample concentrations were computed as previously described. With the exception of cadmium, tin, and chlordane, analytical variability was minimal with relative percentage differences generally 3 percent or less. Cadmium, tin, and chlordane had relative percentage differences of 14.3, 14.3, and 16.9 percent, respectively (table 4). On the basis of these results, most of the within-site variability determined for cadmium, tin, and chlordane may be due to analytical variability.

To assess the effect of cold storage (at 4–5 $^{o}$C) on constituent concentrations in a sediment core, archived cores from Mission Lake and Lake Afton were analyzed. The assessment was done to determine whether or not archived cores provide representative information on constituent concentrations in sediment. The period of time in cold storage for the Mission Lake and Lake Afton cores was 7 and 18 months, respectively. Results for the comparison of the archived cores with the original cores are presented in separate sections for Mission Lake and Lake Afton in the "Occurrence of, and Trends in, Selected Chemical Constituents" section.

Age dating of the bottom sediment at each reservoir was accomplished by determining the activity of cesium-137 ($^{137}$Cs) by gamma-ray spectrometry (American Society for Testing and Materials, 2000). $^{137}$Cs is a radioactive isotope that is a by-product of nuclear weapons testing. Measurable concentrations of this isotope first appeared in the atmosphere in about 1952, peaked during 1963–64, and have since declined. $^{137}$Cs is an effective marker for age dating bottom sediment in reservoirs constructed before 1963–64 (Van Metre and others, 1997). It also can be used to demonstrate that the sediment is relatively undisturbed if the 1963–64 peak is well-defined and a generally uniform, exponential decrease in $^{137}$Cs activity follows the 1963–64 peak. Age dating of sediment using $^{137}$Cs was attempted for Crystal Lake, Edgerton City Lake, Gardner City Lake, Hiawatha City Lake, Lake Afton, and Mission Lake because these reservoirs were completed before the 1963–64 $^{137}$Cs peak. For unknown reasons, $^{137}$Cs was not detected in the bottom sediment of Edgerton City Lake. Age dating for Bronson City Lake was not attempted due to insufficient sediment for analysis. Age dating for Centralia Lake, Otis Creek Reservoir, and Pony Creek Lake was not done because these three reservoirs were completed after the 1963–64 peak.

## Determination of Constituent Loads and Yields

Mean annual load was computed for each constituent that was detected with a sufficient frequency (that is, in the majority of the core intervals analyzed) to determine a representative median value for the concentration of that constituent in the bottom sediment of each reservoir. For each constituent, mean annual load was computed as the median concentration multiplied by the mean annual mass of sediment deposited in the reservoir. For comparison, mean annual load also was computed as the top-interval (most-recent) concentration multiplied by the mean annual mass of sediment deposited in the reservoir.

For all constituents for which a mean annual load was computed, the mean annual yield was estimated by dividing the mean annual load by the area of the reservoir basin. Because sediment losses are not accounted for (for example, due to reservoir outflow), the computed loads and yields represent net, rather than total, values.

## Trend Analysis

A sediment core collected from Crystal Lake and analyzed for nutrients, carbon, and trace elements (10 core intervals) was used for trend analyses. Also, a sediment core collected from

**Table 4.** Relative percentage differences for constituent concentrations in sequential replicate and split replicate samples of bottom sediment from selected small reservoirs in eastern Kansas, fall 2002 and spring 2003.

[--, not calculated]

| Constituent | Relative percentage difference[1] | |
|---|---|---|
| | Sequential replicate samples | Split replicate samples |
| | Nutrients | |
| Total nitrogen | 3.8 | 1.5 |
| Total phosphorus | 2.8 | 0 |
| | Carbon | |
| Carbon (total organic, TOC) | 1.8 | 0 |
| Carbon (total) | 2.8 | 0 |
| | Trace elements | |
| Aluminum | 2.6 | .6 |
| Antimony | 3.3 | 0 |
| Arsenic | 2.0 | 0 |
| Barium | 1.8 | .7 |
| Beryllium | 2.3 | 2.1 |
| Cadmium | 7.3 | 14.3 |
| Chromium | 3.3 | .6 |
| Cobalt | 1.4 | 0 |
| Copper | 2.6 | 0 |
| Iron | 2.4 | 0 |
| Lead | 1.3 | 0 |
| Lithium | 2.7 | 0 |
| Manganese | 2.6 | 0 |
| Mercury | -- | -- |
| Molybdenum[2] | 0 | 0 |
| Nickel | 2.9 | 0 |
| Selenium | 5.9 | 3.0 |
| Silver | -- | -- |
| Strontium | 1.4 | 0 |
| Sulfur[3] | 0 | 0 |
| Thallium | -- | -- |
| Tin | 22.5 | 14.3 |
| Titanium | 2.6 | 1.2 |
| Uranium | -- | -- |
| Vanadium | 2.7 | 0 |
| Zinc | 4.7 | 3.0 |
| | Organochlorine compounds | |
| Aldrin | -- | -- |
| Chlordane[4] | 7.3 | 16.9 |
| DDD | -- | -- |

**Table 4.** Relative percentage differences for constituent concentrations in sequential replicate and split replicate samples of bottom sediment from selected small reservoirs in eastern Kansas, fall 2002 and spring 2003.—Continued

[--, not calculated]

| Constituent | Relative percentage difference[1] | |
|---|---|---|
| | Sequential replicate samples | Split replicate samples |
| Organochlorine compounds—Continued | | |
| DDE | 2.7 | -- |
| DDT | -- | -- |
| Dieldrin[4] | 13.6 | -- |
| Endosulfan | -- | -- |
| Endrin | -- | -- |
| Gross polychlorinated biphenyls (PCBs) | -- | -- |
| Heptachlor | -- | -- |
| Heptachlor epoxide | -- | -- |
| Lindane | -- | -- |
| Methoxychlor | -- | -- |
| Mirex | -- | -- |
| Toxaphene | -- | -- |

[1]Sequential replicate samples (two per reservoir) collected from Centralia Lake, Edgerton City Lake, and Gardner City Lake. Split replicate samples (two per reservoir) collected from Gardner City Lake. Unless otherwise noted, the relative percentage difference reported for the sequential replicate samples is computed as the mean (n=3) of the results for the three reservoirs for which sequential replicate samples were analyzed.

[2]Mean relative percentage difference for the sequential replicate samples was computed using only data from Gardner City Lake due to nondetections for molybdenum in the sediment samples collected from Centralia Lake and Edgerton City Lake.

[3]Mean relative percentage difference for the sequential replicate samples was computed using only data from Centralia Lake and Gardner City Lake due to nondetections for sulfur in the sediment samples collected from Edgerton City Lake.

[4]Mean relative percentage difference for the sequential replicate samples was computed using only data from Gardner City Lake due to nondetections for chlordane and dieldrin in the sediment samples collected from Centralia Lake and Edgerton City Lake.

Mission Lake and analyzed for nutrients (10 core intervals) was used for trend analyses. Trends in constituent concentrations were examined by computing a nonparametric Spearman's rho correlation coefficient. An advantage of Spearman's rho is that, because it is based on ranks, it is more resistant to outlier effects than the more commonly used Pearson's r correlation coefficient (Helsel and Hirsch, 1992). Trends were considered to be significantly positive (constituent concentration increased toward the top of the sediment core) or negative (constituent concentration decreased toward the top of the sediment core) if the probability (two-sided p-value) of rejecting a correct hypothesis (in this case, no trend) was less than or equal to 0.05. Rho was not computed for any constituent having four or more core intervals with no detections.

Because an insufficient number of core intervals (typically three or five per core) were analyzed for the remaining reservoirs, a statistical test for trends was not appropriate. Thus, possible trends for these reservoirs are discussed in relative, rather than statistical, terms. In the results, a possible trend will be considered meaningful only if the change in constituent concentration is beyond the variability that could be explained by analytical variance (defined here as the mean constituent concentration in the sediment core plus or minus 10 percent).

# Sedimentation

The mean annual net volume of sediment deposited in each small reservoir was estimated by dividing the total sediment volume by the number of years of deposition. Total sediment volume was estimated as the difference between the original and updated water-storage capacities (table 5) for the reservoirs. The estimated mean annual net volume of deposited sediment ranged from about 43,600 $ft^3$ for Crystal Lake to about 531,000 $ft^3$ for Mission Lake (table 5). Estimates of mean annual net sediment deposition for Bronson, Edgerton, and Hiawatha City Lakes were not possible because the original and updated water-storage capacities were unavailable for Bronson City Lake, and the updated storage capacities were unavailable for Edgerton and Hiawatha City Lakes.

**Table 5.** Original and updated water-storage capacity, estimated mean annual net decrease in water-storage capacity, and estimated mean annual net volume of sediment deposited in 10 small reservoirs in eastern Kansas.

[Estimated mean annual net volume of sediment deposited rounded to three significant figures. --, not available or not determined]

| Reservoir (fig. 1) | Original water-storage capacity[1], in acre-feet (year) | Updated water-storage capacity, in acre-feet (year) | Estimated mean annual net decrease in water-storage capacity (acre-feet) | Estimated mean annual net decrease in water-storage capacity (percent) | Estimated mean annual net volume of sediment deposited[2] (cubic feet) |
|---|---|---|---|---|---|
| Bronson City Lake | -- | -- | -- | -- | -- |
| Centralia Lake | 4,769 (1990) | -- | [3]11.8 | -- | -- |
| Crystal Lake | 229 (1879) | [4]104 (2000) | 1.0 | 0.44 | 43,600 |
| Edgerton City Lake | 23 (1900) | -- | -- | -- | -- |
| Gardner City Lake | 2,301 (1940) | [4]2,020 (2000) | 4.7 | .20 | 205,000 |
| Hiawatha City Lake | 60 (1933) | -- | -- | -- | -- |
| Lake Afton | 3,264 (1942) | [5]2,981 (1983) | 6.9 | .21 | 301,000 |
| Mission Lake | 1,866 (1924) | [4]940 (2000) | 12.2 | .65 | 531,000 |
| Otis Creek Reservoir | [6]5,590 (1971) | [7]5,280 (2002) | 10.0 | .18 | 436,000 |
| Pony Creek Lake | 2,367 (1993) | -- | [3]5.3 | -- | -- |

[1] See footnotes in table 1.

[2]Mean annual net sediment volume, in cubic feet, estimated as mean annual net decrease in water-storage capacity, in acre-feet, multiplied by 43,560.

[3] Annual decrease in water-storage capacity due to sedimentation, projected at time of reservoir completion, from Kansas Water Authority (2001).

[4] Kansas Water Authority (2001).

[5] Sedgwick County Department of Public Works and Department of Environmental Resources (1984).

[6]Water-storage capacity was revised from original (5,845 acre-feet at water-surface elevation of 1,038 feet) by interpolation to provide an original capacity for the same water-surface elevation (1,037 feet) as at the time of the August 2002 bathymetric survey. Vertical datum unknown.

[7] Determined from bathymetric survey conducted by U.S. Geological Survey, August 2002 (data on file with U.S. Geological Survey, Lawrence, Kansas).

The mean annual net mass of sediment deposited in the small reservoirs was estimated as the mean annual net volume of deposited sediment multiplied by the representative bulk density of the sediment. Table 6 provides the bulk densities of sediment estimated for each reservoir. The estimated mean annual net mass of deposited sediment ranged from 1,360,000 lb in Crystal Lake to 23,300,000 lb in Mission Lake (table 7). For Centralia and Pony Creek Lakes, the mean annual net mass of sediment deposited was not computed because only projected values of uncertain quality were available for the mean annual net decrease in water-storage capacity due to sedimentation (table 5).

With two exceptions, the particle-size composition of the bottom sediment in the reservoirs was very uniform. For Bronson City Lake, Crystal Lake, Gardner City Lake, Lake Afton, Mission Lake, Otis Creek Reservoir, and Pony Creek Lake, the silt and (or) clay content of the sediment was 99 percent or greater at every sampling depth. For Centralia Lake, the silt and (or) clay content of the sediment was 98 percent or greater at every sampling depth. The two exceptions were Edgerton and Hiawatha City Lakes. At Edgerton City Lake, the silt and (or) clay content of the sediment ranged from 78 to 99 percent (five sampling depths) with a mean of 91 percent. At Hiawatha City Lake, the silt and (or) clay content of the sediment ranged from

**Table 6.** Estimated mean bulk density of bottom sediment at coring sites in 10 small reservoirs in eastern Kansas.

[Bulk-density values rounded to three significant figures.]

| Reservoir (fig. 1) | Estimated mean bulk density (pounds per cubic foot) | |
|---|---|---|
| | Downstream site (figs. 22–31) | Upstream site(s) (figs. 22–31) |
| Bronson City Lake | 16.0 | 24.0 |
| Centralia Lake | 29.7 | 32.8, 35.6 |
| Crystal Lake | 31.1 | 31.3 |
| Edgerton City Lake[1] | 55.5 | 65.6 |
| Gardner City Lake | 27.5 | 36.5 |
| Hiawatha City Lake [1,2] | 68.3 | 75.1 |
| Lake Afton | 30.1 | 47.3 |
| Mission Lake | 34.6 | 53.2 |
| Otis Creek Reservoir[3] | 29.0 | 32.9 |
| Pony Creek Lake | 25.0 | 29.5 |

[1]Bulk densities may not be representative since entire thickness of sediment was not penetrated during coring. Also, the reservoir was drained on at least one occasion which resulted in drying and compaction of the bottom sediment.

[2]Due to downstream dredging, cores were collected from the middle and upstream parts of the reservoir only.

[3]Both cores were collected from the middle of the reservoir.

73 to 89 percent (five sampling depths) with a mean of 80 percent. The differences in sand content for the sediment in Edgerton and Hiawatha City Lakes likely are related to the location within the reservoir. In both cases, the core used for particle-size analysis was collected from the upstream one-third of the reservoir (unlike the other reservoirs) in an attempt to avoid downstream areas that were previously affected by dredging. The larger sand content in the sediment samples analyzed for Edgerton and Hiawatha City Lakes is consistent with the fact that reservoir sediment typically becomes more coarse with distance upstream from the dam (Morris and Fan, 1998).

Mean annual net sediment yields from the reservoir basins, estimated as the mean annual net mass of deposited sediment divided by the basin area, ranged from 964,000 lb/mi$^2$ for Otis Creek Reservoir to 2,710,000 lb/mi$^2$ for Mission Lake (table 7). For Centralia and Pony Creek Lakes, the mean annual net sediment yield was not computed because only projected values of uncertain quality were available for the mean annual net decrease in water-storage capacity due to sedimentation (table 5).

Collins (1965) produced a generalized map of sediment yield in Kansas. The map was created using available information on areal geology, topography, soil characteristics, precipitation, runoff, reservoir sedimentation, and measured suspended-sediment loads in streams. In the Collins map, mean annual sediment yield ranges from less than 100,000 lb/mi$^2$ in part of southwestern and south-central Kansas to more than 10,000,000 lb/mi$^2$ in the extreme northeastern part of the State. A comparison of the basin-specific sediment yields estimated in this study with the regional estimates provided by Collins (1965) indicated that only Otis Creek Reservoir had a sediment yield that was within the range provided by Collins. The sediment yield for Crystal Lake was greater than the Collins' estimate, whereas the sediment yields for Gardner City Lake, Lake Afton, and Mission Lake were less than the Collins' estimates. The same comparison for three large reservoirs (Cheney Reservoir, Hillsdale Lake, and Perry Lake) also indicated differences (table 8, fig. 1).

Several possible explanations may account, in part, for the differences between the basin-specific sediment yields estimated in this study and the regional estimates provided by Collins (1965). First, the sediment-yield map produced by Collins is highly generalized because most of the suspended-sediment data used were for main-stem streams and rivers and thus represent an integrated composite for the upstream drainage basins. Therefore, the estimated mean sediment yields for a particular region may not be representative of subareas within that region. Second, in cases where bulk-density data for reservoir sediments were lacking, Collins used an assumed value of 60 lb/ft$^3$. This value is substantially larger than the bulk densities estimated for the bottom sediment of the undisturbed small reservoirs in the present study (see table 6). Use of the assumed value would potentially result in an overestimation of sediment yield. Third, implemented conservation practices may reduce sediment yields to less than the minimum value estimated by Collins for a particular region. Collins (1965) acknowledged the first and third limitations in his report. A final consideration is that the sediment yields in the present study are net values (that is, sediment losses due to reservoir outflow were not accounted for) which are less than the total sediment yields.

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

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

**Table 7.** Estimated mean annual net volume of sediment deposited, representative bulk density, estimated mean annual net mass of sediment deposited, and estimated mean annual net sediment yield for selected small reservoirs in eastern Kansas.

[$mi^2$, square miles; --, not available or not determined; all sediment and bulk density values have been rounded to three significant figures]

| Reservoir (fig. 1) | Approximate basin area ($mi^2$) | Estimated mean annual net volume of sediment deposited[1] (cubic feet) | Representative bulk density [2] (pounds per cubic foot) | Estimated mean annual net mass of sediment deposited[3] (pounds) | Estimated mean annual net sediment yield[4] (pounds per square mile) |
|---|---|---|---|---|---|
| Bronson City Lake[5] | 0.8 | -- | -- | -- | -- |
| Centralia Lake[6] | 12.5 | -- | -- | -- | -- |
| Crystal Lake | .6 | 43,600 | 31.2 | 1,360,000 | 2,270,000 |
| Edgerton City Lake[5] | 4.9 | -- | -- | -- | -- |
| Gardner City Lake | 5.5 | 205,000 | 32.0 | 6,560,000 | 1,190,000 |
| Hiawatha City Lake[5] | .8 | -- | -- | -- | -- |
| Lake Afton | 10.4 | 301,000 | 38.7 | 11,600,000 | 1,120,000 |
| Mission Lake | 8.6 | 531,000 | 43.9 | 23,300,000 | 2,710,000 |
| Otis Creek Reservoir | 14.0 | 436,000 | 31.0 | 13,500,000 | 964,000 |
| Pony Creek Lake[6] | 6.6 | -- | -- | -- | -- |

[1] Mean annual net sediment volume, in cubic feet, was estimated as mean annual net decrease in water-storage capacity (table 5), in acre-feet, multiplied by 43,560.

[2]Representative bulk density is the average of the mean bulk densities estimated for the bottom-sediment coring sites in each reservoir.

[3] Mean annual net mass of deposited sediment was estimated as mean annual net volume of deposited sediment multiplied by representative bulk density.

[4] Mean annual net sediment yield was estimated as mean annual net mass of deposited sediment divided by basin area.

[5] Mean annual net volume of sediment deposited, mass of sediment deposited, and sediment yield were not estimated for Bronson, Edgerton, and Hiawatha City Lakes because the original and updated water-storage capacities were not available for Bronson City Lake, and the updated storage capacities were not available for Edgerton and Hiawatha City Lakes.

[6] Mean annual net volume of sediment deposited, mass of sediment deposited, and sediment yield were not estimated for Centralia Lake and Pony Creek Lake because of the uncertain quality of the projected values for the mean annual net decrease in water-storage capacity (table 5) available for these two reservoirs.

Toxic effects usually or frequently occur at concentrations above the PEL.

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

In this report, discussion of constituent concentrations with respect to sediment-quality guidelines is limited to the nine trace elements and six organochlorine compounds for which guidelines are available. Although sediment-quality guidelines for selenium have not been adopted by USEPA, concentrations equal to or greater than 4.0 μg/g in sediment are a concern for fish and wildlife because of the potential for bioaccumulation (Lemly and Smith, 1987).

## Nutrients and Total Organic Carbon

Nutrients, such as nitrogen and phosphorus, are necessary for growth and reproduction of plants. In most freshwater environments, phosphorus is the principal limiting factor for primary production (Hakanson and Jansson, 1983). If phosphorus concentrations are too large, algal growth may become excessive and cause taste-and-odor problems for water suppliers. Additionally, excessive algal growth may be detrimental to aquatic life in, as well as discourage recreational use of, a lake. Major human-related sources of nutrients include fertilizer application, livestock production, and sewage-treatment plants. USEPA has not adopted sediment-quality guidelines for nitrogen or phosphorus.

**Table 8.** Comparison of basin-specific sediment yields computed in this study with regional estimates of sediment yield provided by Collins (1965).

[<, less than]

| Reservoir basin | U.S. Geological Survey sediment-yield estimate (pounds per square mile) | Collins (1965) sediment-yield estimate[1] (pounds per square mile) |
|---|---|---|
| Small reservoir basins | | |
| Crystal Lake | 2,270,000 | 600,000–1,500,000 |
| Gardner City Lake | 1,190,000 | 4,000,000–10,000,000 |
| Lake Afton | 1,120,000 | 1,500,000–4,000,000 |
| Mission Lake | 2,710,000 | 4,000,000–10,000,000 |
| Otis Creek Reservoir | 964,000 | 600,000–1,500,000 |
| Large reservoir basins | | |
| Cheney Reservoir[2] | 486,000 | <100,000–4,000,000 |
| Hillsdale Lake[3] | 1,840,000 | 4,000,000–10,000,000 |
| Perry Lake[4] | 2,740,000 | 4,000,000–10,000,000 |

[1] Sediment-yield estimates converted from tons per square mile to pounds per square mile.

[2] Mau (2001).

[3] Juracek (1997).

[4] Juracek (2003).

Total organic carbon (TOC), an approximate determination of total organic material in a sediment sample, is important because various organic solutes can form complexes, which in turn affect trace element solubilities (Hem, 1989). The organic carbon content of sediment also is important because many contaminants (for example, organochlorine compounds) specifically sorb to the organic material in sediment (Karickhoff, 1984). Sediment-quality guidelines for TOC have not been adopted by USEPA.

## Trace Elements

Trace elements are important determinants of sediment quality because of their potential toxicity to living organisms (Forstner and Wittman, 1981). Trace elements may be defined as elements that are found in the environment in relatively low (less than 0.1 percent) concentrations (Adriano, 1986; Pais and Jones, 1997). Using this definition, the majority of the elements analyzed in this study may be considered trace elements. Exceptions, which are some of the abundant rock-forming elements, include the metals aluminum and iron (Adriano, 1986).

Trace elements in sediment originate naturally from the rock and soil within the basin. Also, sediment enrichment of certain trace elements may be attributable to several human-related sources including fertilizers, liming materials, pesticides, irrigation water, animal and human wastes, coal combustion residues, leaching from landfills, metal-smelting industries, and automobile emissions (Forstner and Wittman, 1981; Adriano, 1986).

The health of living organisms is dependent on a sufficient intake of various trace elements. Many elements, such as cobalt, copper, iron, manganese, and zinc, are essential for plants, animals, and humans. Other elements, such as arsenic and chromium, are required by animals and humans but are not essential for plants. Nonessential elements for plants, animals, and humans include cadmium, mercury, and lead (Adriano, 1986; Lide, 1993; Pais and Jones, 1997).

Toxicity is a function of several factors including the type of organism, availability of a trace element in the environment, and its potential to bioaccumulate once in the food chain. The daily intake of trace elements by animals and humans may be classified as deficient, optimal, or toxic. Most, if not all, trace elements may be toxic in animals and humans if the concentrations are sufficiently large (Pais and Jones, 1997).

Nonenforceable sediment-quality guidelines have been adopted by USEPA for arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc and are provided in a number of tables beginning with table 9. Information on the bioaccumulation index (Pais and Jones, 1997) for most of the trace elements is provided in a number of tables beginning with table 12.

## Organochlorine Compounds

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

Polychlorinated biphenyls (PCBs), organochlorine compounds that were first produced industrially in 1929, were used for a variety of applications including ink and paint additives, plasticizers, and coolant-insulation fluids in transformers and capacitors (Alloway and Ayres, 1997; Manahan, 2000). PCBs were identified as environmental pollutants in 1966 with toxic effects similar to those of DDT. By 1977, worldwide production of PCBs had practically ceased (Alloway and Ayres, 1997). However, because of their persistence, PCBs remain widespread in the environment. Nonenforceable sediment-quality guidelines have been adopted by USEPA for chlordane, DDD, DDE, DDT, dieldrin, and PCBs and are provided in several tables beginning with table 9.

# Occurrence of, and Trends in, Selected Chemical Constituents

This section describes the occurrence of, and trends in, selected chemical constituents in bottom-sediment samples collected from 10 small reservoirs in eastern Kansas. Land use in the reservoir basins and the location of coring sites for each reservoir are shown in figures 22–31 at the back of this report.

## Bronson City Lake

Bronson City Lake was completed in 1956. Because of the limited thickness of the bottom sediment in the reservoir (less than 1 ft near the dam where the sediment cores for constituent analyses were collected), the recovered sediment core was divided into only three intervals for constituent analyses. A possible positive trend (constituent concentrations increased toward the top of the sediment core) for total nitrogen and TOC concentrations was indicated in the bottom sediment. No trend was indicated for total phosphorus concentrations (table 9). Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for total nitrogen, total phosphorus, and TOC were not determined for Bronson City Lake.

In the bottom sediment of Bronson City Lake, arsenic, cadmium, chromium, lead, nickel, and zinc concentrations all exceeded the TELs but were less than the PELs. Silver concentrations were less than the TEL. Copper concentrations exceeded the PEL (table 9). The elevated concentrations of copper likely are due to the historical application of copper sulfate to control algal blooms in the reservoir (Ellen Harper, city of Bronson, oral commun., 2003). With the exception of a possible negative trend for lead, no trends in trace element concentrations (beyond the variability that could be attributed to analytical variance) were evident in the core samples. Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for the trace elements were not determined for Bronson City Lake.

Two organochlorine compounds were detected in the bottom sediment from the top of a Bronson City Lake core. DDE was detected at a concentration of 0.52 μg/kg, which was less that the TEL (2.07 μg/kg). Dieldrin was detected at a concentration of 0.54 μg/kg, which was less than the TEL (0.715 μg/kg).

## Centralia Lake

For Centralia Lake (completed in 1990), the recovered sediment core was divided into three intervals for constituent analyses. In the bottom sediment of Centralia Lake, no depositional trends for nutrients or TOC were indicated (table 10). Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for total nitrogen, total phosphorus, and TOC were not determined for Centralia Lake.

Arsenic, cadmium, chromium, copper, and nickel concentrations in the bottom sediment of Centralia Lake all exceeded the TELs but were less than the PELs (table 10). All lead, silver, and zinc concentrations were less than the TELs. With the exception of a possible positive trend for manganese, no trends in trace element concentrations (beyond the variability that could be attributed to analytical variance) were indicated. Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for the trace elements were not determined for Centralia Lake.

The only organochlorine compound detected in the bottom sediment from the top of a Centralia Lake core was DDE with a concentration of 0.27 μg/kg. This detection was less than the TEL (2.07 μg/kg).

## Crystal Lake

Crystal Lake was completed in 1879. The recovered sediment core was divided into 10 intervals for constituent analyses. In the bottom-sediment samples collected from Crystal Lake, total nitrogen concentrations ranged from 2,600 to 4,300 mg/kg (table 11) with a median concentration of 3,000 mg/kg (table 12). The estimated mean annual net load of total nitrogen deposited in the bottom sediment was 4,080 lb. The estimated mean annual net yield of total nitrogen from the Crystal Lake Basin was 6,800 lb/mi$^2$ (table 12).

Total phosphorus concentrations ranged from 690 to 1,300 mg/kg (table 11) with a median concentration of 825 mg/kg (table 12). The estimated mean annual net load of total phosphorus was 1,120 lb. The estimated mean annual net yield of total phosphorus was 1,870 lb/mi$^2$ (table 12).

TOC concentrations ranged from 2.6 to 3.9 percent with a median concentration of 2.9 percent (table 11). The estimated mean annual net load and yield of TOC were 39,500 lb and 65,800 lb/mi$^2$, respectively (table 12).

A comparison of the constituent loads and yields estimated using the median constituent concentration for the sediment core with those estimated using the interval-10 (most-recent) constituent concentration (table 12) indicated substantial differences (greater than 10 percent) for nutrients, TOC, total carbon, and several trace elements.

Trend analyses, with a significance level of 0.05, indicated a statistically significant positive trend (constituent concentration increased toward the top of the sediment core) for total nitrogen (fig. 2*A*), total phosphorus (fig. 2*B*), and total carbon (fig. 3) (table 13). For TOC, a positive trend was significant at the 0.06 level (fig. 3). Because the $^{137}Cs$ activity has a well-defined 1963–64 peak followed by a uniform, exponential decrease (fig. 4), it was concluded that the bottom sediment in Crystal Lake is relatively undisturbed, and the trends may be considered meaningful. In all four cases, inspection of the vertical profile indicated relatively uniform concentrations in the bottom (oldest) two-thirds of the core and a positive trend in the top one-third of the core. For total nitrogen, the indicated positive trend does not appear to be due to analytical variance

**Table 9.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 22) in Bronson City Lake, April 2003.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 (middle of core) | Interval 3 (top of core) | TEL | PEL |
| Percentage of silt and clay | >99 | >99 | >99 | -- | -- |
| **Nutrients** | | | | | |
| Total nitrogen, mg/kg | 3,400 | 3,700 | 4,200 | -- | -- |
| Total phosphorus, mg/kg | 1,100 | 1,000 | 1,200 | -- | -- |
| **Carbon** | | | | | |
| Carbon (total organic, TOC), % | 3.4 | 3.6 | 4.1 | -- | -- |
| Carbon (total), % | 3.6 | 3.9 | 4.5 | -- | -- |
| **Trace elements** | | | | | |
| Aluminum, % | 8.6 | 8.3 | 8.0 | -- | -- |
| Antimony, µg/g | 1.1 | .9 | .9 | -- | -- |
| Arsenic, µg/g | 15 | 16 | 15 | 7.24 | 41.6 |
| Barium, µg/g | 660 | 620 | 610 | -- | -- |
| Beryllium, µg/g | 2.4 | 2.2 | 2.1 | -- | -- |
| Cadmium, µg/g | 1.0 | .7 | .7 | .676 | 4.21 |
| Chromium, µg/g | 82 | 74 | 74 | 52.3 | 160 |
| Cobalt, µg/g | 13 | 11 | 11 | -- | -- |
| Copper, µg/g | 220 | 200 | 180 | 18.7 | 108 |
| Iron, % | 4.1 | 4.0 | 3.8 | -- | -- |
| Lead, µg/g | 38 | 34 | 32 | 30.2 | 112 |
| Lithium, µg/g | 51 | 51 | 49 | -- | -- |
| Manganese, µg/g | 960 | 1,000 | 930 | -- | -- |
| Mercury, µg/g | -- | -- | -- | .13 | .696 |
| Molybdenum, µg/g | 1 | 1 | 1 | -- | -- |
| Nickel, µg/g | 40 | 37 | 36 | 15.9 | 42.8 |
| Selenium, µg/g | 1.0 | .9 | 1.0 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 110 | 110 | 120 | -- | -- |
| Sulfur, % | .2 | .3 | .3 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 2 | 2 | 2 | -- | -- |
| Titanium, % | .48 | .45 | .43 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 130 | 120 | 120 | -- | -- |
| Zinc, µg/g | 170 | 150 | 150 | 124 | 271 |

**Table 9.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 22) in Bronson City Lake, April 2003.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 (middle of core) | Interval 3 (top of core) | TEL | PEL |
| | | Organochlorine compounds | | | |
| Aldrin, µg/kg | -- | -- | <0.2 | -- | -- |
| Chlordane, µg/kg | -- | -- | <3 | 2.26 | 4.79 |
| DDD, µg/kg | -- | -- | <.5 | 1.22 | 7.81 |
| DDE, µg/kg | -- | -- | .52 | 2.07 | 374 |
| DDT, µg/kg | -- | -- | <.5 | 1.19 | 4.77 |
| Dieldrin, µg/kg | -- | -- | .54 | .715 | 4.3 |
| Endosulfan, µg/kg | -- | -- | <.2 | -- | -- |
| Endrin, µg/kg | -- | -- | <.2 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | -- | -- | <5 | 21.6 | 189 |
| Heptachlor, µg/kg | -- | -- | <.2 | -- | -- |
| Heptachlor epoxide, µg/kg | -- | -- | <.2 | -- | -- |
| Lindane, µg/kg | -- | -- | <.2 | -- | -- |
| Methoxychlor, µg/kg | -- | -- | <2.5 | -- | -- |
| Mirex, µg/kg | -- | -- | <.2 | -- | -- |
| Toxaphene, µg/kg | -- | -- | <50 | -- | -- |

[1]Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

**Table 10.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 23) in Centralia Lake, May 2003.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 (middle of core) | Interval 3 (top of core) | TEL | PEL |
| Percentage of silt and clay | 99 | 98 | >99 | -- | -- |
| | | Nutrients | | | |
| Total nitrogen, mg/kg | 2,400 | 2,500 | 2,300 | -- | -- |
| Total phosphorus, mg/kg | 1,200 | 1,400 | 1,300 | -- | -- |
| | | Carbon | | | |
| Carbon (total organic, TOC), % | 2.8 | 2.6 | 2.7 | -- | -- |
| Carbon (total), % | 2.7 | 2.6 | 2.8 | -- | -- |
| | | Trace elements | | | |
| Aluminum, % | 8.8 | 8.4 | 8.5 | -- | -- |
| Antimony, µg/g | 1.1 | 1.1 | 1.1 | -- | -- |
| Arsenic, µg/g | 17 | 19 | 18 | 7.24 | 41.6 |
| Barium, µg/g | 650 | 660 | 660 | -- | -- |
| Beryllium, µg/g | 2.4 | 2.3 | 2.3 | -- | -- |
| Cadmium, µg/g | .9 | .8 | .7 | .676 | 4.21 |
| Chromium, µg/g | 81 | 75 | 77 | 52.3 | 160 |
| Cobalt, µg/g | 13 | 14 | 13 | -- | -- |
| Copper, µg/g | 31 | 30 | 29 | 18.7 | 108 |
| Iron, % | 4.7 | 4.5 | 4.4 | -- | -- |
| Lead, µg/g | 17 | 19 | 19 | 30.2 | 112 |
| Lithium, µg/g | 56 | 53 | 52 | -- | -- |
| Manganese, µg/g | 1,000 | 1,300 | 1,600 | -- | -- |
| Mercury, µg/g | -- | -- | -- | .13 | .696 |
| Molybdenum, µg/g | 1 | 1 | <1 | -- | -- |
| Nickel, µg/g | 41 | 40 | 40 | 15.9 | 42.8 |
| Selenium, µg/g | .8 | .8 | .8 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 110 | 110 | 110 | -- | -- |
| Sulfur, % | .1 | .1 | .1 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 2 | 3 | 3 | -- | -- |
| Titanium, % | .36 | .35 | .36 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 150 | 140 | 150 | -- | -- |
| Zinc, µg/g | 120 | 110 | 110 | 124 | 271 |

**Table 10.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 23) in Centralia Lake, May 2003.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 (middle of core) | Interval 3 (top of core) | TEL | PEL |
| Organochlorine compounds | | | | | |
| Aldrin, µg/kg | -- | -- | <0.2 | -- | -- |
| Chlordane, µg/kg | -- | -- | <3 | 2.26 | 4.79 |
| DDD, µg/kg | -- | -- | <.5 | 1.22 | 7.81 |
| DDE, µg/kg | -- | -- | .27 | 2.07 | 374 |
| DDT, µg/kg | -- | -- | <.5 | 1.19 | 4.77 |
| Dieldrin, µg/kg | -- | -- | <.4 | .715 | 4.3 |
| Endosulfan, µg/kg | -- | -- | <.2 | -- | -- |
| Endrin, µg/kg | -- | -- | <.2 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | -- | -- | <5 | 21.6 | 189 |
| Heptachlor, µg/kg | -- | -- | <.2 | -- | -- |
| Heptachlor epoxide, µg/kg | -- | -- | <.2 | -- | -- |
| Lindane, µg/kg | -- | -- | <.2 | -- | -- |
| Methoxychlor, µg/kg | -- | -- | <2.5 | -- | -- |
| Mirex, µg/kg | -- | -- | <.2 | -- | -- |
| Toxaphene, µg/kg | -- | -- | <50 | -- | -- |

[1]Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

**Table 11.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 24) in Crystal Lake, April 2003.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | |
|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 | Interval 6 |
| Percentage of silt and clay | >99 | >99 | >99 | >99 | >99 | >99 |
| | | | Nutrients | | | |
| Total nitrogen, mg/kg | 3,100 | 2,800 | 2,600 | 2,700 | 2,700 | 3,100 |
| Total phosphorus, mg/kg | 770 | 700 | 690 | 800 | 820 | 830 |
| | | | Carbon | | | |
| Carbon (total organic, TOC), % | 3.1 | 2.8 | 2.6 | 2.8 | 2.7 | 3.0 |
| Carbon (total), % | 3.0 | 2.8 | 2.8 | 2.9 | 2.7 | 3.2 |
| | | | Trace elements | | | |
| Aluminum, % | 9.2 | 8.2 | 7.5 | 8.7 | 8.8 | 8.5 |
| Antimony, µg/g | .8 | .8 | .8 | .9 | 1.0 | 1.5 |
| Arsenic, µg/g | 16 | 15 | 15 | 16 | 17 | 21 |
| Barium, µg/g | 730 | 660 | 670 | 680 | 670 | 660 |
| Beryllium, µg/g | 2.6 | 2.3 | 2.1 | 2.4 | 2.5 | 2.4 |
| Cadmium, µg/g | .5 | .5 | .5 | 1.0 | 1.4 | 1.3 |
| Chromium, µg/g | 85 | 76 | 70 | 81 | 82 | 76 |
| Cobalt, µg/g | 15 | 12 | 10 | 12 | 13 | 12 |
| Copper, µg/g | 29 | 25 | 25 | 28 | 34 | 430 |
| Iron, % | 4.4 | 3.8 | 3.6 | 4.4 | 4.5 | 4.3 |
| Lead, µg/g | 28 | 32 | 31 | 36 | 46 | 64 |
| Lithium, µg/g | 56 | 48 | 43 | 53 | 55 | 51 |
| Manganese, µg/g | 750 | 980 | 780 | 1,000 | 900 | 800 |
| Mercury, µg/g | -- | -- | -- | -- | -- | -- |
| Molybdenum, µg/g | <1 | <1 | <1 | <1 | <1 | <1 |
| Nickel, µg/g | 43 | 36 | 32 | 39 | 43 | 42 |
| Selenium, µg/g | .9 | .8 | .9 | 1.0 | .9 | 1.2 |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| Strontium, µg/g | 110 | 110 | 100 | 110 | 110 | 120 |
| Sulfur, % | .1 | .1 | .1 | .1 | .2 | .3 |
| Thallium, µg/g | <50 | <50 | <50 | <50 | <50 | <50 |
| Tin, µg/g | 2 | 2 | 2 | 3 | 3 | 3 |
| Titanium, % | .46 | .45 | .44 | .46 | .44 | .43 |
| Uranium, µg/g | <50 | <50 | <50 | <50 | <50 | <50 |
| Vanadium, µg/g | 130 | 100 | 110 | 120 | 120 | 120 |
| Zinc, µg/g | 140 | 130 | 130 | 170 | 220 | 250 |

**Table 11.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 24) in Crystal Lake, April 2003.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|
| | Interval 7 | Interval 8 | Interval 9 | Interval 10 (top of core) | TEL | PEL |
| Percentage of silt and clay | >99 | >99 | >99 | >99 | -- | -- |
| Nutrients | | | | | | |
| Total nitrogen, mg/kg | 2,900 | 3,500 | 3,800 | 4,300 | -- | -- |
| Total phosphorus, mg/kg | 900 | 840 | 1,000 | 1,300 | -- | -- |
| Carbon | | | | | | |
| Carbon (total organic, TOC), % | 2.8 | 3.5 | 3.7 | 3.9 | -- | -- |
| Carbon (total), % | 3.3 | 5.0 | 5.5 | 6.1 | -- | -- |
| Trace elements | | | | | | |
| Aluminum, % | 8.7 | 7.5 | 7.3 | 6.7 | -- | -- |
| Antimony, µg/g | 1.1 | 1.1 | 1.0 | .9 | -- | -- |
| Arsenic, µg/g | 21 | 20 | 17 | 14 | 7.24 | 41.6 |
| Barium, µg/g | 670 | 590 | 570 | 530 | -- | -- |
| Beryllium, µg/g | 2.4 | 2.0 | 2.0 | 1.7 | -- | -- |
| Cadmium, µg/g | .9 | .9 | .9 | .8 | .676 | 4.21 |
| Chromium, µg/g | 93 | 87 | 72 | 67 | 52.3 | 160 |
| Cobalt, µg/g | 13 | 12 | 12 | 11 | -- | -- |
| Copper, µg/g | 880 | 210 | 1,500 | 1,600 | 18.7 | 108 |
| Iron, % | 4.5 | 3.9 | 3.8 | 3.7 | -- | -- |
| Lead, µg/g | 62 | 65 | 59 | 51 | 30.2 | 112 |
| Lithium, µg/g | 55 | 49 | 49 | 44 | -- | -- |
| Manganese, µg/g | 770 | 760 | 810 | 1,200 | -- | -- |
| Mercury, µg/g | -- | -- | -- | -- | .13 | .696 |
| Molybdenum, µg/g | <1 | <1 | <1 | <1 | -- | -- |
| Nickel, µg/g | 41 | 37 | 36 | 33 | 15.9 | 42.8 |
| Selenium, µg/g | .8 | 1.2 | 1.1 | 1.1 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 130 | 180 | 210 | 230 | -- | -- |
| Sulfur, % | .4 | .5 | .3 | .2 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 4 | 4 | 3 | 3 | -- | -- |
| Titanium, % | .43 | .36 | .34 | .31 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 120 | 100 | 98 | 87 | -- | -- |
| Zinc, µg/g | 220 | 220 | 250 | 250 | 124 | 271 |

**Table 11.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 24) in Crystal Lake, April 2003.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | Sediment-quality guidelines[1] | |
|---|---|---|---|
| | | TEL | PEL |
| | Organochlorine compounds[2] | | |
| Aldrin, µg/kg | <0.2 | -- | -- |
| Chlordane, µg/kg | <3 | 2.26 | 4.79 |
| DDD, µg/kg | <.5 | 1.22 | 7.81 |
| DDE, µg/kg | 4.76 | 2.07 | 374 |
| DDT, µg/kg | <.5 | 1.19 | 4.77 |
| Dieldrin, µg/kg | <.2 | .715 | 4.3 |
| Endosulfan, µg/kg | <.2 | -- | -- |
| Endrin, µg/kg | <.2 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | <5 | 21.6 | 189 |
| Heptachlor, µg/kg | <.2 | -- | -- |
| Heptachlor epoxide, µg/kg | <.2 | -- | -- |
| Lindane, µg/kg | <.2 | -- | -- |
| Methoxychlor, µg/kg | <2.5 | -- | -- |
| Mirex, µg/kg | <.2 | -- | -- |
| Toxaphene, µg/kg | <50 | -- | -- |

[1] Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

[2] The top (most-recent) one-fifth of the core was sampled for organochlorine compounds.

**Table 12.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Crystal Lake, eastern Kansas, and associated bioaccumulation index.

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi$^2$, pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-10 constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using median constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using interval-10 constituent concentration | Bio-accumulation index[3] |
|---|---|---|---|---|---|---|
| Nutrients | | | | | | |
| Total nitrogen | 3,000 | 4,080 | 5,850 | 6,800 | 9,750 | -- |
| Total phosphorus | 825 | 1,120 | 1,770 | 1,870 | 2,950 | -- |
| Carbon | | | | | | |
| Carbon (total organic, TOC) | 29,000 | 39,500 | 53,100 | 65,800 | 88,500 | -- |
| Carbon (total) | 31,000 | 42,200 | 83,000 | 70,300 | 138,000 | -- |
| Trace elements | | | | | | |
| Aluminum | 84,000 | 114,000 | 91,200 | 190,000 | 152,000 | -- |
| Antimony | 1.0 | 1.4 | 1.2 | 2.3 | 2.0 | moderate |
| Arsenic | 17 | 23 | 19 | 38.3 | 31.7 | moderate |
| Barium | 665 | 905 | 721 | 1,510 | 1,200 | low |
| Beryllium | 2.4 | 3.3 | 2.3 | 5.5 | 3.8 | low |
| Cadmium | .9 | 1.2 | 1.1 | 2.0 | 1.8 | moderate |
| Chromium | 79 | 107 | 91 | 178 | 152 | moderate |
| Cobalt | 12 | 16 | 15 | 26.7 | 25.0 | high |
| Copper[4] | 28 | 38 | -- | 63.3 | -- | high |
| Iron | 41,000 | 55,800 | 50,300 | 93,000 | 83,800 | low |
| Lead | 49 | 67 | 69 | 112 | 115 | moderate |
| Lithium | 50 | 68 | 60 | 113 | 100 | slight |
| Manganese | 805 | 1,100 | 1,630 | 1,830 | 2,720 | low |
| Mercury | -- | -- | -- | -- | -- | high |
| Molybdenum | <1 | -- | -- | -- | -- | high |
| Nickel | 38 | 52 | 45 | 86.7 | 75.0 | moderate |
| Selenium | 1.0 | 1.4 | 1.5 | 2.3 | 2.5 | high |
| Silver | <.5 | -- | -- | -- | -- | moderate |
| Strontium | 115 | 156 | 313 | 260 | 522 | moderate |
| Sulfur | 2,000 | 2,720 | 2,720 | 4,530 | 4,530 | -- |
| Thallium | <50 | -- | -- | -- | -- | low |
| Tin | 3.0 | 4.1 | 4.1 | 6.8 | 6.8 | -- |
| Titanium | 4,400 | 5,990 | 4,220 | 9,980 | 7,030 | moderate |
| Uranium | <50 | -- | -- | -- | -- | -- |
| Vanadium | 115 | 156 | 118 | 260 | 197 | low |
| Zinc | 220 | 299 | 340 | 498 | 567 | high |

**Table 12.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Crystal Lake, eastern Kansas, and associated bioaccumulation index.—Continued

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi$^2$, pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-10 constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using median constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using interval-10 constituent concentration | Bio-accumulation index[3] |
|---|---|---|---|---|---|---|
| Organochlorine compounds | | | | | | |
| Aldrin | -- | -- | -- | -- | -- | -- |
| Chlordane | -- | -- | -- | -- | -- | -- |
| DDD | -- | -- | -- | -- | -- | -- |
| DDE | -- | -- | 0.0065 | -- | 0.011 | -- |
| DDT | -- | -- | -- | -- | -- | -- |
| Dieldrin | -- | -- | -- | -- | -- | -- |
| Endosulfan | -- | -- | -- | -- | -- | -- |
| Endrin | -- | -- | -- | -- | -- | -- |
| Gross polychlorinated biphenyls (PCBs) | -- | -- | -- | -- | -- | -- |
| Heptachlor | -- | -- | -- | -- | -- | -- |
| Heptachlor epoxide | -- | -- | -- | -- | -- | -- |
| Lindane | -- | -- | -- | -- | -- | -- |
| Methoxychlor | -- | -- | -- | -- | -- | -- |
| Mirex | -- | -- | -- | -- | -- | -- |
| Toxaphene | -- | -- | -- | -- | -- | -- |

[1]Mean annual net load in pounds was computed as the mean annual net load in kilograms multiplied by 2.205. Mean annual net load in kilograms was computed as median or top-interval concentration multiplied by the mean annual net sediment load deposited in Crystal Lake (617,000 kilograms), divided by 1 million.

[2]Mean annual net yield in pounds per square mile was computed as the mean annual net load in pounds divided by the area of the Crystal Lake Basin (0.6 mi$^2$).

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

[4]Because the top five (most-recent) core intervals contain elevated concentrations of copper (table 11) most likely caused by the artificial application of copper sulfate to the lake, these five intervals were not considered to be representative of copper loads and yields from the basin. Therefore, the median of the bottom five intervals was used to compute mean annual copper loads and yields from the basin.

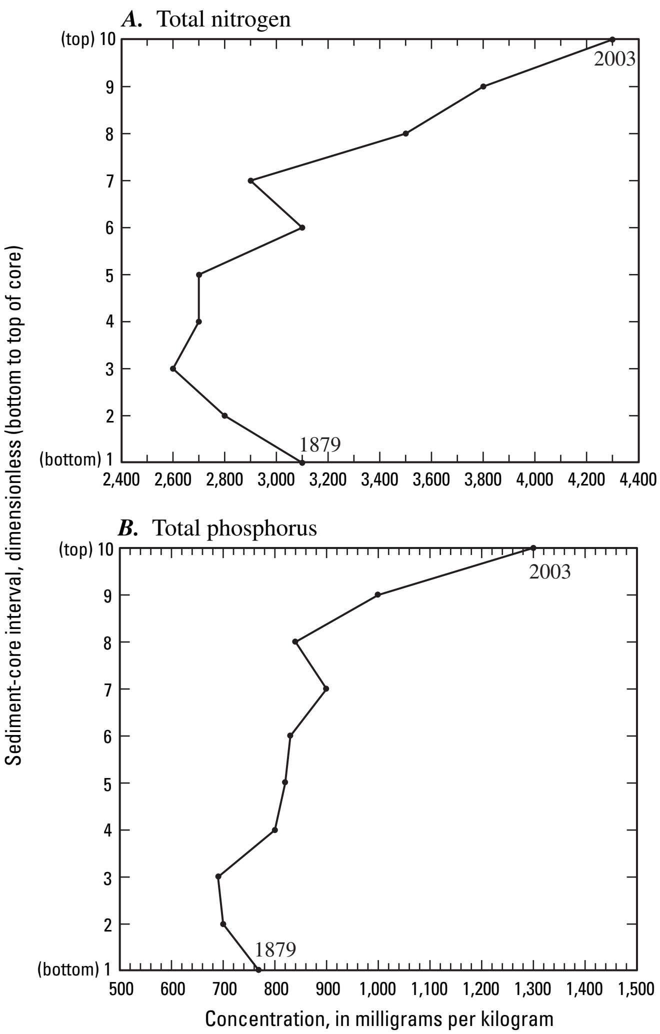



**Figure 2.** Variation in *(A)* total nitrogen and *(B)* total phosphorus concentrations with depth of bottom-sediment samples collected from downstream coring site (site 1) in Crystal Lake, April 2003. Location of Crystal Lake shown in figure 1, and location of coring site shown in figure 24 at the back of this report.

(defined here as the mean concentration for the core, plus or minus 10 percent) as only three intervals were within 10 percent of the mean concentration. For total phosphorus, the indicated positive trend does not appear to be due to analytical variance as only the middle five intervals were within 10 percent of the mean concentration. Thus, the indicated positive trends for total nitrogen and total phosphorus may be representative of actual trends. Because Crystal Lake was completed in 1879, the nutrient concentrations at the bottom of the sediment core likely provide an indication of baseline concentrations.

Likewise, the indicated positive trends for total organic carbon and total carbon (fig. 3) do not appear to be due to analytical variance as only five intervals and one interval, respectively, were within 10 percent of the mean concentration. The increase in total carbon in the upper part of the core may have been caused by the introduction of crushed limestone into the Crystal Lake Basin. In the 1960s, a crushed limestone access road was constructed just south of the reservoir. Then, in the mid-1990s, additional crushed limestone was introduced with the construction of fishing piers along the south shore of the reservoir (Rick Doran, city of Garnett, oral commun., 2003). The limestone provides a source of inorganic carbon that likely has contributed to the increase in the total carbon concentration in the bottom sediment.

In the bottom sediment of Crystal Lake, arsenic, chromium, and zinc concentrations all exceeded the TELs but were less than the PELs (table 11). Cadmium concentrations for the top (most-recent) seven core intervals exceeded the TEL but were less than the PEL. For the bottom (oldest) three intervals, cadmium concentrations were less than the TEL. Copper concentrations exceeded the TEL for all intervals. For the top five intervals, copper concentrations also exceeded the PEL. The elevated concentrations of copper in the upper half of the core likely are a result of the historical application of copper sulfate to control algal blooms in the reservoir (Rick Doran, city of Garnett, oral commun., 2003). With the exception of the bottom (oldest) interval, which was less than the TEL, lead concentrations exceeded the TEL but were less than the PEL. All nickel concentrations were greater than the TEL, and concentrations in two intervals (1 and 5) were slightly greater than the PEL. All silver concentrations were less than the TEL (table 11). The estimated mean annual net loads and yields for most of the trace elements are provided in table 12.

Trend analyses, with a significance level of 0.05, indicated a statistically significant positive trend (constituent concentration increased toward the top of the sediment core) for copper (fig. 5*A*), lead (fig. 5*B*), strontium (fig. 5*C*), sulfur, tin, and zinc (fig. 5*D*) (table 13). Also, positive trends for antimony and selenium were significant at the 0.06 and 0.09 levels, respectively.

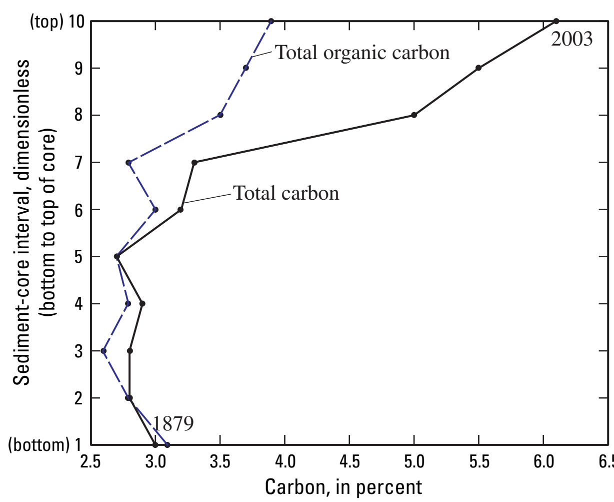



**Figure 3.** Variation in total organic carbon and total carbon concentrations with depth of bottom-sediment samples collected from downstream coring site (site 1) in Crystal Lake, April 2003. Location of Crystal Lake shown in figure 1, and location of coring site shown in figure 24 at the back of this report.

**Table 13.** Results of trend tests on concentrations of selected constituents in bottom-sediment core samples collected from downstream coring site (site 1, fig. 24) in Crystal Lake, eastern Kansas, April 2003.

[--, not computed or not available]

| Constituent | Spearman's rho | Trend test at a 0.05 level of significance |
|---|---|---|
| | Nutrients | |
| Total nitrogen | 0.69 | positive trend |
| Total phosphorus | .94 | positive trend |
| | Carbon | |
| Carbon (total organic, TOC) | .62 | no trend |
| Carbon (total) | .80 | positive trend |
| | Trace elements | |
| Aluminum | - .64 | negative trend |
| Antimony | .63 | no trend |
| Arsenic | .26 | no trend |
| Barium | - .78 | negative trend |
| Beryllium | - .66 | negative trend |
| Cadmium | .37 | no trend |
| Chromium | - .18 | no trend |
| Cobalt | - .29 | no trend |
| Copper | .89 | positive trend |
| Iron | - .17 | no trend |
| Lead | .78 | positive trend |
| Lithium | - .26 | no trend |
| Manganese | .22 | no trend |
| Mercury | -- | -- |
| Molybdenum | -- | -- |
| Nickel | - .28 | no trend |
| Selenium | .58 | no trend |
| Strontium | .91 | positive trend |
| Sulfur | .76 | positive trend |
| Tin | .74 | positive trend |
| Titanium | - .94 | negative trend |
| Vanadium | - .62 | no trend |
| Zinc | .86 | positive trend |

The indicated positive trends for copper, lead, strontium, and zinc do not appear to be caused by analytical variance as the majority of the concentrations were not within 10 percent of the mean concentration. Thus, the indicated positive trends for these constituents may be representative of actual trends. For antimony, selenium, sulfur, and tin, visual inspection of the data (table 11) indicated that the trends were negligible.

A statistically significant negative trend (constituent concentration decreased toward the top of the sediment core) was indicated for aluminum, barium, beryllium, and titanium (table 13). Also, a negative trend for vanadium was significant at the 0.06 level. With the exception of titanium, the indicated negative trends may be due to analytical variance as the majority of the concentrations were within 10 percent of the mean concentration.

The indicated positive trends may be due to human activity in and near the Crystal Lake Basin. The elevated concentrations of copper in the upper half of the sediment core (fig. 5*A*) likely

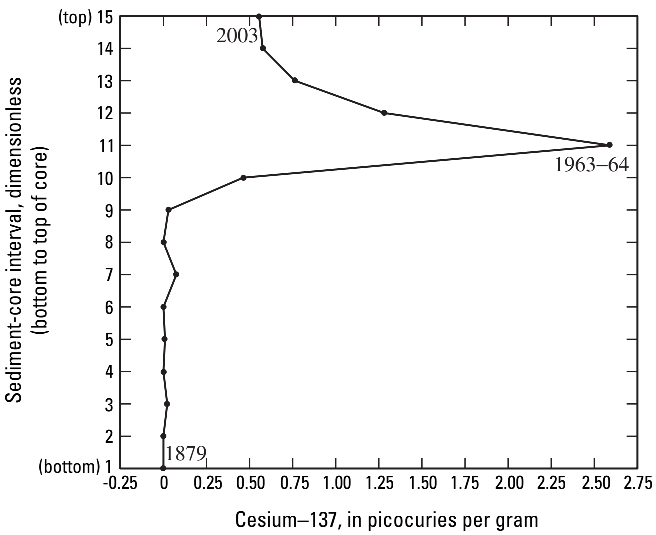



**Figure 4.** Variation in cesium-137 activity with depth of bottom-sediment samples collected from downstream coring site (site 1) in Crystal Lake, April 2003. Location of Crystal Lake shown in figure 1, and location of coring site shown in figure 24 at the back of this report.

are caused by historical applications of copper sulfate to control algal blooms in the reservoir (Rick Doran, city of Garnett, oral commun., 2003). The increase in strontium (fig. 5*C*) may have been caused by the introduction of crushed limestone into the basin in the 1960s (construction of access road just south of the reservoir) and the 1990s (construction of fishing piers along the south shore of the reservoir) (Rick Doran, city of Garnett, oral commun., 2003). Increased lead (fig. 5*B*) and zinc (fig. 5*D*) may be attributed to a general increase in human-related contamination over time.

For lead, there was a statistically significant positive trend over the life of the reservoir. However, inspection of figure 5*B* indicates that the initial positive trend leveled off and became a negative trend at the top of the core. This profile is consistent with the history of particulate lead emissions from leaded gasoline usage in the United States. Leaded gasoline was introduced in the 1920s and quickly became standard (Davies, 1990). Use of leaded gasoline increased until its phase out, legislated by the Clean Air Act of 1970, began in the 1970s. From 1970 to 1990, total national lead emissions from vehicles decreased an estimated 99.8 percent (U.S. Environmental Protection Agency, 2000).

Because Crystal Lake was completed in 1879, the trace element concentrations at the bottom of the sediment core likely provide an indication of baseline concentrations. Evidence in support of this interpretation is provided by the substantially smaller and relatively uniform concentrations of lead and zinc in the bottom three core intervals (table 11).

For arsenic, chromium, copper, lead, nickel, and zinc, the baseline concentrations (likely represented by the bottom three core intervals) are either similar to, or substantially larger than, the respective TELs (table 11). This finding indicates the possibility that, for certain constituents in certain areas, baseline concentrations may equal or exceed the TELs prior to the effects of human activity.

The only organochlorine compound detected in the bottom sediment from the top of a Crystal Lake core was DDE with a concentration of 4.76 µg/kg. This concentration was greater than the TEL (2.07 µg/kg) but less than the PEL (374 µg/kg).

## Edgerton City Lake

For Edgerton City Lake (completed in 1900), the recovered sediment core was divided into five intervals for constituent analyses. Total nitrogen concentrations in the bottom-sediment samples collected from Edgerton City Lake ranged from 1,000 to 2,200 mg/kg with a median concentration of 1,800 mg/kg. Total phosphorus concentrations ranged from 480 to 610 mg/kg with a median concentration of 550 mg/kg. TOC concentrations ranged from 0.7 to 2.1 percent with a median concentration of 1.8 percent (table 14). No obvious trends for nutrients or TOC were evident. Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for total nitrogen, total phosphorus, and TOC were not determined for Edgerton City Lake.

Arsenic and nickel concentrations in the bottom sediment of Edgerton City Lake all exceeded the TELs but were less than the PELs. For chromium, the deepest (oldest) interval had a concentration that was less than the TEL, whereas the four more recently deposited intervals had concentrations greater than the TEL but less than the PEL. For copper, the two oldest intervals had concentrations that were less than the TEL, whereas the three youngest intervals had concentrations that were either slightly less than or slightly more than the TEL. All cadmium, lead, silver, and zinc concentrations were less than the TELs (table 14). With the exception of a possible positive trend for strontium, no trends for trace elements were indicated. Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for the trace elements were not determined for Edgerton City Lake.

The only organochlorine compound detected in the bottom sediment from the top of an Edgerton City Lake core was DDE with a concentration of 0.22 µg/kg. This detection was less than the TEL (2.07 µg/kg).

## Gardner City Lake

Gardner City Lake was completed in 1940. The recovered sediment core was divided into five intervals for constituent analyses. In the bottom-sediment samples collected from Gardner City Lake, total nitrogen concentrations ranged from 1,600 to 3,100 mg/kg (table 15) with a median concentration of 3,000 mg/kg (table 16). The estimated mean annual net load of total nitrogen deposited in the bottom sediment was 19,700 lb. The estimated mean annual net yield of total nitrogen from the Gardner City Lake Basin was 3,580 lb/mi$^2$ (table 16).

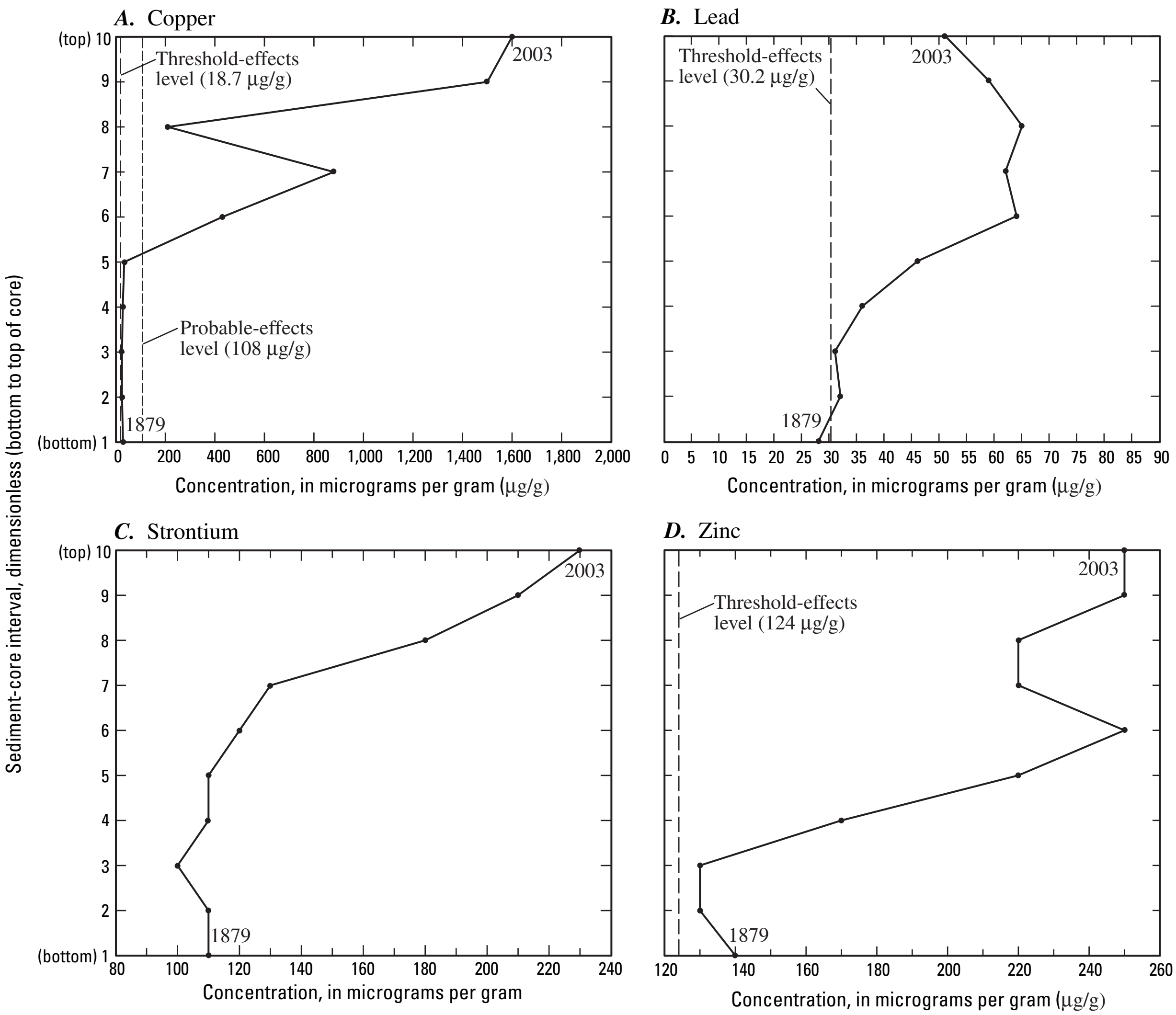



**Figure 5.** Variation in *(A)* copper, *(B)* lead, *(C)* strontium, and *(D)* zinc concentrations with depth of bottom-sediment core samples collected from Crystal Lake, April 2003. Location of Crystal Lake shown in figure 1. Threshold-effects levels from U.S. Environmental Protection Agency (1997).

Total phosphorus concentrations ranged from 1,100 to 1,300 mg/kg (table 15) with a median concentration of 1,200 mg/kg (table 16). The estimated mean annual net load of total phosphorus was 7,890 lb. The estimated mean annual net yield of total phosphorus was 1,430 lb/mi$^2$ (table 16).

TOC concentrations ranged from 3.2 to 3.4 percent with a median concentration of 3.3 percent (table 15). The estimated mean annual net load and yield of TOC were 217,000 lb and 39,500 lb/mi$^2$, respectively (table 16). No trends for nutrients or TOC were indicated in the core from Gardner City Lake. With the exception of total carbon and mercury, a comparison of the constituent loads and yields estimated using the median constituent concentration for the sediment core with those estimated using the interval-5 (most-recent) constituent concentration (table 16) indicated no substantial (greater than 10 percent) differences.

In the bottom sediment of Gardner City Lake, arsenic, chromium, lead, and zinc concentrations all exceeded the TELs but were less than the PELs. Cadmium concentrations were either slightly less than or slightly more than the TEL. Nickel concentrations exceeded the TEL, and four of five concentrations also exceeded the PEL. For mercury and silver, all concentrations were less than the TELs (table 15).

All copper concentrations exceeded the TEL, and the top (most-recent) two intervals of the core had concentrations that also exceeded the PEL. Throughout the life of the reservoir, a positive trend in copper concentrations is evident in the bottom sediment (table 15). The positive trend is likely caused by frequent applications of copper sulfate (since the 1970s) to control algal blooms in the reservoir (Mike Howard, city of Gardner, written commun., 2003). A possible negative trend was indicated for barium. The concentration profile for lead is consistent with the history of particulate lead emissions from leaded gasoline usage in the United States. Because the $^{137}Cs$ activity has a well-defined 1963–64 peak followed by a uniform, exponential decrease (fig. 6), it was concluded that the bottom sediment in

**Table 14.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from upstream coring site (site 1, fig. 25) in Edgerton City Lake, November 2002.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| Percentage of silt and clay | 78 | 83 | 98 | 99 | 97 | -- | -- |
| | | | Nutrients | | | | |
| Total nitrogen, mg/kg | 1,000 | 1,500 | 2,200 | 1,800 | 1,800 | -- | -- |
| Total phosphorus, mg/kg | 520 | 610 | 590 | 480 | 550 | -- | -- |
| | | | Carbon | | | | |
| Carbon (total organic, TOC), % | .7 | 1.4 | 2.1 | 1.8 | 2.0 | -- | -- |
| Carbon (total), % | .6 | 1.3 | 2.0 | 1.7 | 1.9 | -- | -- |
| | | | Trace elements | | | | |
| Aluminum, % | 4.1 | 4.9 | 6.0 | 5.9 | 6.0 | -- | -- |
| Antimony, µg/g | .8 | .9 | 1.1 | 1.0 | 1.0 | -- | -- |
| Arsenic, µg/g | 7.3 | 11 | 15 | 11 | 10 | 7.24 | 41.6 |
| Barium, µg/g | 490 | 570 | 670 | 670 | 650 | -- | -- |
| Beryllium, µg/g | 1.4 | 1.6 | 1.9 | 1.8 | 1.8 | -- | -- |
| Cadmium, µg/g | .2 | .2 | .2 | .1 | .4 | .676 | 4.21 |
| Chromium, µg/g | 48 | 56 | 59 | 61 | 60 | 52.3 | 160 |
| Cobalt, µg/g | 11 | 12 | 8 | 8 | 10 | -- | -- |
| Copper, µg/g | 14 | 17 | 19 | 18 | 19 | 18.7 | 108 |
| Iron, % | 1.8 | 2.1 | 2.4 | 2.2 | 2.3 | -- | -- |
| Lead, µg/g | 21 | 23 | 24 | 21 | 24 | 30.2 | 112 |
| Lithium, µg/g | 21 | 25 | 30 | 28 | 29 | -- | -- |
| Manganese, µg/g | 270 | 580 | 550 | 450 | 470 | -- | -- |
| Mercury, µg/g | -- | -- | -- | -- | -- | .13 | .696 |
| Molybdenum, µg/g | <1 | <1 | <1 | <1 | <1 | -- | -- |
| Nickel, µg/g | 19 | 24 | 22 | 21 | 23 | 15.9 | 42.8 |
| Selenium, µg/g | .7 | 1.0 | 1.0 | 1.0 | 1.1 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 92 | 100 | 110 | 120 | 120 | -- | -- |
| Sulfur, % | <.1 | <.1 | <.1 | <.1 | <.1 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 1 | 1 | 2 | 1 | 2 | -- | -- |
| Titanium, % | .31 | .36 | .41 | .42 | .41 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 64 | 78 | 88 | 86 | 88 | -- | -- |
| Zinc, µg/g | 58 | 72 | 74 | 66 | 76 | 124 | 271 |

**Table 14.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from upstream coring site (site 1, fig. 25) in Edgerton City Lake, November 2002.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| | Organochlorine compounds | | | | | | |
| Aldrin, µg/kg | -- | -- | -- | -- | <0.2 | -- | -- |
| Chlordane, µg/kg | -- | -- | -- | -- | <3 | 2.26 | 4.79 |
| DDD, µg/kg | -- | -- | -- | -- | <.5 | 1.22 | 7.81 |
| DDE, µg/kg | -- | -- | -- | -- | .22 | 2.07 | 374 |
| DDT, µg/kg | -- | -- | -- | -- | <.5 | 1.19 | 4.77 |
| Dieldrin, µg/kg | -- | -- | -- | -- | <.2 | .715 | 4.3 |
| Endosulfan, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Endrin, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | -- | -- | -- | -- | <5 | 21.6 | 189 |
| Heptachlor, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Heptachlor epoxide, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Lindane, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Methoxychlor, µg/kg | -- | -- | -- | -- | <2.5 | -- | -- |
| Mirex, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Toxaphene, µg/kg | -- | -- | -- | -- | <50 | -- | -- |

[1]Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

**Table 15.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 26) in Gardner City Lake, October 2002.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| Percentage of silt and clay | >99 | >99 | 99 | 99 | 99 | | |
| Nutrients | | | | | | | |
| Total nitrogen, mg/kg | 3,000 | 2,100 | 1,600 | 3,000 | 3,100 | -- | -- |
| Total phosphorus, mg/kg | 1,200 | 1,100 | 1,200 | 1,200 | 1,300 | -- | -- |
| Carbon | | | | | | | |
| Carbon (total organic, TOC), % | 3.2 | 3.4 | 3.3 | 3.4 | 3.3 | -- | -- |
| Carbon (total), % | 3.0 | 3.5 | 3.6 | 3.2 | 3.9 | -- | -- |
| Trace elements | | | | | | | |
| Aluminum, % | 11.0 | 9.0 | 8.3 | 8.7 | 8.4 | -- | -- |
| Antimony, µg/g | 1.7 | 1.6 | 1.5 | 1.5 | 1.4 | -- | -- |
| Arsenic, µg/g | 20 | 18 | 18 | 18 | 18 | 7.24 | 41.6 |
| Barium, µg/g | 1,000 | 810 | 750 | 730 | 710 | -- | -- |
| Beryllium, µg/g | 3.2 | 2.6 | 2.4 | 2.4 | 2.3 | -- | -- |
| Cadmium, µg/g | .6 | .6 | .8 | .7 | .6 | .676 | 4.21 |
| Chromium, µg/g | 110 | 93 | 84 | 87 | 83 | 52.3 | 160 |
| Cobalt, µg/g | 13 | 13 | 12 | 12 | 11 | -- | -- |
| Copper, µg/g | 39 | 44 | 77 | 120 | 210 | 18.7 | 108 |
| Iron, % | 5.5 | 4.6 | 4.3 | 4.4 | 4.3 | -- | -- |
| Lead, µg/g | 39 | 42 | 49 | 50 | 40 | 30.2 | 112 |
| Lithium, µg/g | 63 | 50 | 47 | 51 | 48 | -- | -- |
| Manganese, µg/g | 1,300 | 1,400 | 1,600 | 1,500 | 1,400 | -- | -- |
| Mercury, µg/g | .05 | .07 | .06 | .06 | .05 | .13 | .696 |
| Molybdenum, µg/g | 2 | 2 | 2 | 2 | 2 | -- | -- |
| Nickel, µg/g | 48 | 48 | 43 | 43 | 40 | 15.9 | 42.8 |
| Selenium, µg/g | 1.5 | 1.6 | 1.3 | 1.5 | 1.5 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 150 | 130 | 130 | 140 | 150 | -- | -- |
| Sulfur, % | .1 | .2 | .2 | .2 | .2 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 3 | 3 | 3 | 3 | 3 | -- | -- |
| Titanium, % | .56 | .44 | .41 | .42 | .39 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 170 | 150 | 140 | 140 | 140 | -- | -- |
| Zinc, µg/g | 190 | 180 | 160 | 160 | 160 | 124 | 271 |

**Table 15.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 26) in Gardner City Lake, October 2002.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| | Organochlorine compounds | | | | | | |
| Aldrin, µg/kg | -- | -- | -- | -- | <0.5 | -- | -- |
| Chlordane, µg/kg | -- | -- | -- | -- | 10.3 | 2.26 | 4.79 |
| DDD, µg/kg | -- | -- | -- | -- | <.5 | 1.22 | 7.81 |
| DDE, µg/kg | -- | -- | -- | -- | .46 | 2.07 | 374 |
| DDT, µg/kg | -- | -- | -- | -- | <.5 | 1.19 | 4.77 |
| Dieldrin, µg/kg | -- | -- | -- | -- | .46 | .715 | 4.3 |
| Endosulfan, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Endrin, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | -- | -- | -- | -- | 5 | 21.6 | 189 |
| Heptachlor, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Heptachlor epoxide, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Lindane, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Methoxychlor, µg/kg | -- | -- | -- | -- | <2.5 | -- | -- |
| Mirex, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Toxaphene, µg/kg | -- | -- | -- | -- | <50 | -- | -- |

[1]Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

**Table 16.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Gardner City Lake, eastern Kansas, and associated bioaccumulation index.

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi$^2$, pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-5 constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using median constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using interval-5 constituent concentration | Bioaccumulation index[3] |
|---|---|---|---|---|---|---|
| Nutrients | | | | | | |
| Total nitrogen | 3,000 | 19,700 | 20,400 | 3,580 | 3,710 | -- |
| Total phosphorus | 1,200 | 7,890 | 8,540 | 1,430 | 1,550 | -- |
| Carbon | | | | | | |
| Carbon (total organic, TOC) | 33,000 | 217,000 | 217,000 | 39,500 | 39,500 | -- |
| Carbon (total) | 35,000 | 230,000 | 256,000 | 41,800 | 46,500 | -- |
| Trace elements | | | | | | |
| Aluminum | 87,000 | 572,000 | 552,000 | 104,000 | 100,000 | -- |
| Antimony | 1.5 | 9.9 | 9.2 | 1.8 | 1.7 | moderate |
| Arsenic | 18 | 118 | 118 | 21.5 | 21.5 | moderate |
| Barium | 750 | 4,930 | 4,670 | 896 | 849 | low |
| Beryllium | 2.4 | 15.8 | 15.1 | 2.9 | 2.7 | low |
| Cadmium | .6 | 3.9 | 3.9 | .71 | .71 | moderate |
| Chromium | 87 | 572 | 545 | 104 | 99.1 | moderate |
| Cobalt | 12 | 79 | 72 | 14.4 | 13.1 | high |
| Copper[4] | 42 | 276 | -- | 50.2 | -- | high |
| Iron | 44,000 | 289,000 | 283,000 | 52,500 | 51,500 | low |
| Lead | 42 | 276 | 263 | 50.2 | 47.8 | moderate |
| Lithium | 50 | 329 | 315 | 59.8 | 57.3 | slight |
| Manganese | 1,400 | 9,200 | 9,200 | 1,670 | 1,670 | low |
| Mercury | .06 | .39 | .33 | .07 | .06 | high |
| Molybdenum | 2 | 13 | 13 | 2.4 | 2.4 | high |
| Nickel | 43 | 283 | 263 | 51.5 | 47.8 | moderate |
| Selenium | 1.5 | 9.9 | 9.9 | 1.8 | 1.8 | high |
| Silver | <.5 | -- | -- | -- | -- | moderate |
| Strontium | 140 | 920 | 986 | 167 | 179 | moderate |
| Sulfur | 2,000 | 13,100 | 13,100 | 2,380 | 2,380 | -- |
| Thallium | <50 | -- | -- | -- | -- | low |
| Tin | 3 | 20 | 20 | 3.6 | 3.6 | -- |
| Titanium | 4,200 | 27,600 | 25,600 | 5,020 | 4,650 | moderate |
| Uranium | <50 | -- | -- | -- | -- | -- |
| Vanadium | 140 | 920 | 920 | 167 | 167 | low |
| Zinc | 160 | 1,050 | 1,050 | 191 | 191 | high |

**Table 16.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Gardner City Lake, eastern Kansas, and associated bioaccumulation index.—Continued

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi$^2$, pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-5 constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using median constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using interval-5 constituent concentration | Bioaccumu-lation index[3] |
|---|---|---|---|---|---|---|
| | | | Organochlorine compounds | | | |
| Aldrin | -- | -- | -- | -- | -- | -- |
| Chlordane | -- | -- | 0.68 | -- | 0.12 | -- |
| DDD | -- | -- | -- | -- | -- | -- |
| DDE | -- | -- | .0030 | -- | .00055 | -- |
| DDT | -- | -- | -- | -- | -- | -- |
| Dieldrin | -- | -- | .0030 | -- | .00055 | -- |
| Endosulfan | -- | -- | -- | -- | -- | -- |
| Endrin | -- | -- | -- | -- | -- | -- |
| Gross polychlorinated biphenyls (PCBs) | -- | -- | .033 | -- | .0060 | -- |
| Heptachlor | -- | -- | -- | -- | -- | -- |
| Heptachlor epoxide | -- | -- | -- | -- | -- | -- |
| Lindane | -- | -- | -- | -- | -- | -- |
| Methoxychlor | -- | -- | -- | -- | -- | -- |
| Mirex | -- | -- | -- | -- | -- | -- |
| Toxaphene | -- | -- | -- | -- | -- | -- |

[1]Mean annual net load in pounds was computed as the mean annual net load in kilograms multiplied by 2.205. Mean annual net load in kilograms was computed as median or top-interval concentration multiplied by the mean annual net sediment load deposited in Gardner City Lake (2,980,000 kilograms), divided by 1 million.

[2]Mean annual net yield in pounds per square mile was computed as the mean annual net load in pounds divided by the area of the Gardner City Lake Basin (5.5 mi$^2$).

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

[4]Because the top three (most-recent) core intervals contain elevated concentrations of copper (table 15) most likely caused by the artificial application of copper sulfate to the lake, these three intervals were not considered to be representative of copper loads and yields from the basin. Therefore, the mean of the bottom two intervals was used to compute mean annual copper loads and yields from the basin.

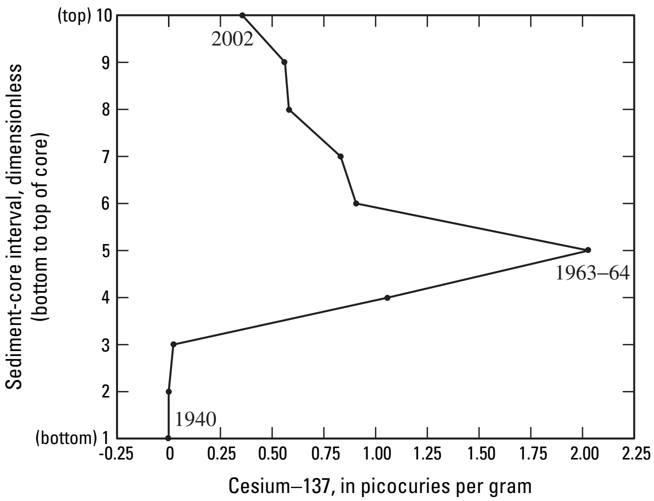



**Figure 6.** Variation in cesium-137 activity with depth of bottom-sediment samples collected from downstream coring site (site 1) in Gardner City Lake, October 2002. Location of Gardner City Lake shown in figure 1, and location of coring site shown in figure 26 at the back of this report.

Gardner City Lake is relatively undisturbed, and the trends may be considered meaningful. The estimated mean annual net loads and yields for most of the trace elements are provided in table 16.

Several organochlorine compounds were detected in the bottom sediment from the top of a Gardner City Lake core. Chlordane was detected at a concentration (10.3 µg/kg) that exceeded the PEL (4.79 µg/kg). Both DDE and dieldrin were detected at a concentration of 0.46 µg/kg. This concentration was less than the respective TELs for DDE (2.07 µg/kg) and dieldrin (0.715 µg/kg). PCBs were detected at a concentration of 5 µg/kg, which was less than the TEL (21.6 µg/kg).

## Hiawatha City Lake

For Hiawatha City Lake (completed in 1933), the recovered sediment core was divided into five intervals for constituent analyses. Total nitrogen concentrations in the bottom-sediment samples collected from Hiawatha City Lake ranged from 1,000 to 1,700 mg/kg with a median concentration of 1,400 mg/kg. Total phosphorus concentrations ranged from 400 to 680 mg/kg with a median concentration of 550 mg/kg (table 17). Throughout the life of the reservoir, possible positive trends in total nitrogen and total phosphorus concentrations are evident in the bottom sediment. However, because the $^{137}Cs$ activity has a poorly defined 1963–64 peak (fig. 7), it was concluded that the bottom sediment in Hiawatha City Lake has been disturbed, and the trends may or may not be meaningful. TOC concentrations ranged from 1.1 to 2.4 percent with a median concentration of 2.2 percent (table 17). Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for total nitrogen, total phosphorus, and TOC were not determined for Hiawatha City Lake.

All arsenic and nickel concentrations in the bottom sediment of Hiawatha City Lake exceeded the TELs but were less than the PELs. Cadmium concentrations were either slightly less than or slightly more than the TEL. For chromium, the four oldest (deepest) intervals had concentrations that were less than the TEL, whereas the most recently deposited interval had a concentration slightly more than the TEL. For copper, the three oldest intervals had concentrations that were less than the TEL, whereas the two youngest intervals had concentrations that were slightly more than the TEL. For lead, the two oldest intervals and the youngest interval had concentrations that were less than the TEL, whereas the intermediate intervals had concentrations that exceeded the TEL but were less than the PEL. The concentration profile for lead is consistent with the history of particulate lead emissions from leaded gasoline usage in the United States. For zinc, the second youngest interval had a concentration that exceeded the TEL but was less than the PEL. Zinc concentrations for the remaining intervals were all less than the TEL. All mercury and silver concentrations were less than the TELs (table 17). Possible positive trends were indicated for arsenic, copper, iron, and manganese. Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for the trace elements were not determined for Hiawatha City Lake.

Several organochlorine compounds were detected in the bottom sediment from the top of a Hiawatha City Lake core. Chlordane was detected at a concentration (3.66 µg/kg) that exceeded the TEL (2.26 µg/kg) but was less than the PEL (4.79 µg/kg). DDD (1.19 µg/kg), DDE (1.99 µg/kg), dieldrin (0.34 µg/kg), and PCBs (6 µg/kg) all were detected at concentrations that were less than the respective TELs (table 17).

## Lake Afton

Lake Afton was completed in 1942. The recovered sediment core was divided into five intervals for constituent analyses. In the bottom-sediment samples collected from Lake Afton, total nitrogen concentrations ranged from 2,200 to 2,600 mg/kg with a median concentration of 2,300 mg/kg. The estimated mean annual net load of total nitrogen deposited in the bottom sediment was 26,700 lb. The estimated mean annual net yield of total nitrogen from the Lake Afton Basin was 2,570 lb/$mi^2$ (tables 18 and 19).

Total phosphorus concentrations ranged from 740 to 840 mg/kg with a median concentration of 810 mg/kg. The estimated mean annual net load of total phosphorus was 9,390 lb. The estimated mean annual net yield of total phosphorus was 903 lb/$mi^2$ (tables 18 and 19).

TOC concentrations ranged from 1.9 to 2.4 percent with a median concentration of 2.3 percent. The estimated mean annual net load and yield of TOC were 267,000 lb and 25,700 lb/$mi^2$, respectively (tables 18 and 19). No trends for nutrients or TOC were evident in the core from Lake Afton.

**Table 17.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from upstream coring site (site 1, fig. 27) in Hiawatha City Lake, October 2002.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| Percentage of silt and clay | 75 | 82 | 81 | 73 | 89 | -- | -- |
| Nutrients | | | | | | | |
| Total nitrogen, mg/kg | 1,000 | 1,200 | 1,400 | 1,600 | 1,700 | -- | -- |
| Total phosphorus, mg/kg | 400 | 420 | 550 | 680 | 610 | -- | -- |
| Carbon | | | | | | | |
| Carbon (total organic, TOC), % | 1.1 | 1.5 | 2.3 | 2.4 | 2.2 | -- | -- |
| Carbon (total), % | 1.2 | 1.5 | 2.1 | 2.6 | 2.2 | -- | -- |
| Trace elements | | | | | | | |
| Aluminum, % | 5.0 | 5.2 | 5.1 | 5.1 | 5.9 | -- | -- |
| Antimony, µg/g | 1.0 | 1.0 | 1.1 | 1.3 | 1.1 | -- | -- |
| Arsenic, µg/g | 8.2 | 8.4 | 8.8 | 12 | 11 | 7.24 | 41.6 |
| Barium, µg/g | 710 | 730 | 710 | 740 | 730 | -- | -- |
| Beryllium, µg/g | 1.4 | 1.4 | 1.4 | 1.5 | 1.6 | -- | -- |
| Cadmium, µg/g | .5 | .5 | .7 | .9 | .6 | .676 | 4.21 |
| Chromium, µg/g | 43 | 44 | 44 | 45 | 53 | 52.3 | 160 |
| Cobalt, µg/g | 9 | 10 | 9 | 10 | 8 | -- | -- |
| Copper, µg/g | 14 | 15 | 17 | 20 | 19 | 18.7 | 108 |
| Iron, % | 1.9 | 1.9 | 2.1 | 2.3 | 2.6 | -- | -- |
| Lead, µg/g | 21 | 23 | 49 | 58 | 29 | 30.2 | 112 |
| Lithium, µg/g | 20 | 22 | 21 | 23 | 28 | -- | -- |
| Manganese, µg/g | 390 | 330 | 580 | 570 | 650 | -- | -- |
| Mercury, µg/g | .01 | .01 | .04 | .06 | .04 | .13 | .696 |
| Molybdenum, µg/g | 2 | 2 | 2 | 2 | 1 | -- | -- |
| Nickel, µg/g | 21 | 22 | 22 | 26 | 24 | 15.9 | 42.8 |
| Selenium, µg/g | .4 | .5 | .5 | .5 | .6 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 140 | 140 | 150 | 150 | 150 | -- | -- |
| Sulfur, % | <.1 | <.1 | <.1 | <.1 | <.1 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 2 | 2 | 6 | 4 | 2 | -- | -- |
| Titanium, % | .36 | .37 | .36 | .33 | .38 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 77 | 77 | 76 | 74 | 85 | -- | -- |
| Zinc, µg/g | 58 | 63 | 110 | 250 | 88 | 124 | 271 |

**Table 17.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from upstream coring site (site 1, fig. 27) in Hiawatha City Lake, October 2002.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| | | | Organochlorine compounds | | | | |
| Aldrin, µg/kg | -- | -- | -- | -- | <0.2 | -- | -- |
| Chlordane, µg/kg | -- | -- | -- | -- | 3.66 | 2.26 | 4.79 |
| DDD, µg/kg | -- | -- | -- | -- | 1.19 | 1.22 | 7.81 |
| DDE, µg/kg | -- | -- | -- | -- | 1.99 | 2.07 | 374 |
| DDT, µg/kg | -- | -- | -- | -- | <.5 | 1.19 | 4.77 |
| Dieldrin, µg/kg | -- | -- | -- | -- | .34 | .715 | 4.3 |
| Endosulfan, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Endrin, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | -- | -- | -- | -- | 6 | 21.6 | 189 |
| Heptachlor, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Heptachlor epoxide, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Lindane, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Methoxychlor, µg/kg | -- | -- | -- | -- | <2.5 | -- | -- |
| Mirex, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Toxaphene, µg/kg | -- | -- | -- | -- | <50 | -- | -- |

[1]Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

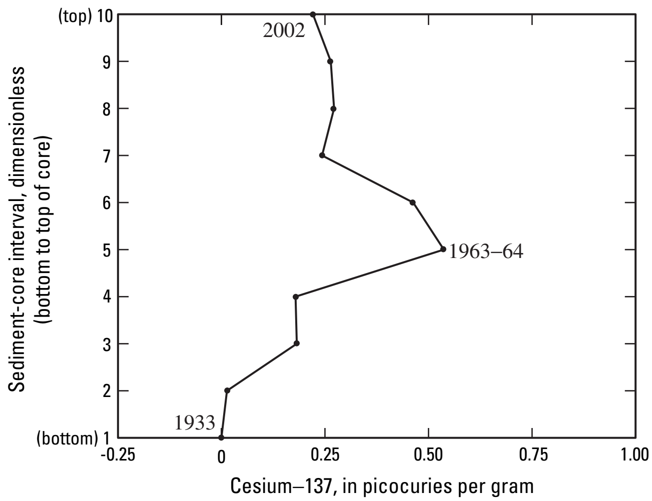



**Figure 7.** Variation in cesium-137 activity with depth of bottom-sediment samples collected from upstream coring site (site 1) in Hiawatha City Lake, October 2002. Location of Hiawatha City Lake shown in figure 1, and location of coring site shown in figure 27 at the back of this report.

A comparison of the constituent loads and yields estimated using the median constituent concentration for the sediment core with those estimated using the interval-5 (most-recent) constituent concentration (table 19) indicated similar results for nutrients, TOC, total carbon, and most of the trace elements. Substantial differences (greater than 10 percent) were indicated for arsenic, lead, mercury, and sulfur.

To assess the effect of 18 months of cold storage (at 4–5 °C) on constituent concentrations in a sediment core, an archived core from Lake Afton was divided into 10 intervals. From each interval, sediment was removed, homogenized, and sampled. These samples were analyzed for all of the constituents listed in table 3 (except the organochlorine compounds and cesium-137). Results for the archived core are provided in table 20. A comparison of the same intervals for the original and archived cores was made on the basis of relative percentage differences (as computed previously). Because the original core was divided into five intervals and the archived core was divided into 10 intervals, successive sets of two intervals were averaged for the archived core to enable comparison with the original core.

With five exceptions, the relative percentage differences were less than 8.0 percent. The exceptions were antimony, cadmium, manganese, molybdenum, and tin, with respective relative percentage differences of 19.1, 50.3, 16.4, 29.5, and 10.1 percent. The relative percentage difference for total phosphorus was 7.8 percent. For paired samples, differences of as much as 20 percent may be considered to be within analytical error. Differences in constituent concentrations may be due, in part, to several causes including spatial differences in sediment chemistry within the reservoir, diagenesis (that is, postdepositional changes in the sediment caused by various processes including decomposition), and analytical variability. In the case of antimony, cadmium, molybdenum, and tin, the concentrations are close to the detection limit, and this may account for some of the variability. With the possible exception of the five trace elements noted above, 18 months of cold storage apparently had minimal effect on constituent concentrations in the sediment. Thus, in general, these results indicated that an archived core held in cold storage (at 4–5 °C) for as long as 18 months can provide representative information on constituent concentrations in sediment.

In the bottom sediment of Lake Afton, arsenic, chromium, copper, lead, and nickel concentrations all exceeded the TELs but were less than the PELs. In general, cadmium and zinc concentrations were either slightly less than or slightly more than the TELs. Mercury and silver concentrations were less than the TELs (table 18). The concentration profile for lead is consistent with the history of particulate lead emissions from leaded gasoline usage in the United States. Because the $^{137}Cs$ activity has a well-defined 1963–64 peak followed by a uniform, exponential decrease (fig. 8), it was concluded that the bottom sediment in Lake Afton is relatively undisturbed and the concentration profile may be considered meaningful. The estimated mean annual net loads and yields for most of the trace elements are provided in table 19.

The only organochlorine compound detected in the bottom sediment from the top of a Lake Afton core was DDE with a concentration of 0.22 µg/kg. This concentration was less than the TEL (2.07 µg/kg).

## Mission Lake

For Mission Lake (completed in 1924), the originally recovered sediment core (in October 2002) was divided into five intervals for constituent analyses. Total nitrogen concentrations in the bottom-sediment samples ranged from 1,900 to 2,400 mg/kg with a median concentration of 2,100 mg/kg. Total phosphorus concentrations in the original core ranged from 670 to 1,200 mg/kg with a median concentration of 890 mg/kg. Possible positive trends in total nitrogen and total phosphorus concentrations were evident in the bottom sediment (table 21).

To allow for a statistical determination of whether or not total nitrogen and total phosphorus concentrations have increased over time, a new sediment core was collected from Mission Lake in May 2003 near the original coring site and divided into 10 intervals for analysis. No statistically significant trend (Spearman's rho = -0.17) was indicated for total nitrogen (fig. 9*A*). However, a statistically significant positive trend (Spearman's rho = 0.77) was indicated for total phosphorus (fig. 9*B*). The positive trend for total phosphorus does not appear to be the result of analytical variance (defined here as the mean total phosphorus concentration in the sediment core plus or minus 10 percent). This conclusion was based on the fact that only two intervals in the core had total phosphorus concentrations within 10 percent of the mean total phosphorus concentration. Thus, this trend is likely representative of an actual trend. Also, because the $^{137}Cs$ activity has a well-defined 1963–64

**Table 18.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 28) in Lake Afton, October 2002.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| Percentage of silt and clay | 99 | 99 | 99 | 99 | 99 | -- | -- |
| Nutrients | | | | | | | |
| Total nitrogen, mg/kg | 2,600 | 2,200 | 2,300 | 2,500 | 2,200 | -- | -- |
| Total phosphorus, mg/kg | 740 | 810 | 810 | 790 | 840 | -- | -- |
| Carbon | | | | | | | |
| Carbon (total organic, TOC), % | 2.3 | 1.9 | 2.2 | 2.3 | 2.4 | -- | -- |
| Carbon (total), % | 2.5 | 2.1 | 2.2 | 2.3 | 2.0 | -- | -- |
| Trace elements | | | | | | | |
| Aluminum, % | 9.3 | 9.6 | 9.6 | 9.1 | 8.9 | -- | -- |
| Antimony, µg/g | 1.1 | 1.3 | 1.3 | 1.2 | 1.2 | -- | -- |
| Arsenic, µg/g | 12 | 15 | 14 | 11 | 9.9 | 7.24 | 41.6 |
| Barium, µg/g | 700 | 680 | 670 | 660 | 660 | -- | -- |
| Beryllium, µg/g | 2.8 | 2.9 | 2.9 | 2.7 | 2.7 | -- | -- |
| Cadmium, µg/g | .6 | .6 | .7 | .8 | .7 | .676 | 4.21 |
| Chromium, µg/g | 71 | 72 | 74 | 70 | 69 | 52.3 | 160 |
| Cobalt, µg/g | 14 | 14 | 13 | 12 | 12 | -- | -- |
| Copper, µg/g | 32 | 33 | 35 | 33 | 33 | 18.7 | 108 |
| Iron, % | 4.3 | 4.5 | 4.6 | 4.3 | 4.2 | -- | -- |
| Lead, µg/g | 34 | 45 | 54 | 53 | 39 | 30.2 | 112 |
| Lithium, µg/g | 54 | 57 | 58 | 54 | 54 | -- | -- |
| Manganese, µg/g | 780 | 1,000 | 850 | 690 | 770 | -- | -- |
| Mercury, µg/g | .03 | .04 | .04 | .04 | .03 | .13 | .696 |
| Molybdenum, µg/g | 2 | 2 | 2 | 2 | 2 | -- | -- |
| Nickel, µg/g | 38 | 40 | 40 | 38 | 37 | 15.9 | 42.8 |
| Selenium, µg/g | .7 | .7 | .7 | .7 | .7 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 100 | 99 | 99 | 100 | 110 | -- | -- |
| Sulfur, % | .1 | .1 | .1 | .2 | .2 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 3 | 3 | 4 | 3 | 3 | -- | -- |
| Titanium, % | .45 | .44 | .43 | .42 | .42 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 130 | 130 | 130 | 130 | 120 | -- | -- |
| Zinc, µg/g | 120 | 130 | 140 | 130 | 120 | 124 | 271 |

**Table 18.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 28) in Lake Afton, October 2002.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| | Organochlorine compounds | | | | | | |
| Aldrin, µg/kg | -- | -- | -- | -- | <0.5 | -- | -- |
| Chlordane, µg/kg | -- | -- | -- | -- | <7.5 | 2.26 | 4.79 |
| DDD, µg/kg | -- | -- | -- | -- | <1.25 | 1.22 | 7.81 |
| DDE, µg/kg | -- | -- | -- | -- | .22 | 2.07 | 374 |
| DDT, µg/kg | -- | -- | -- | -- | <1.25 | 1.19 | 4.77 |
| Dieldrin, µg/kg | -- | -- | -- | -- | <.5 | .715 | 4.3 |
| Endosulfan, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Endrin, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | -- | -- | -- | -- | <12.5 | 21.6 | 189 |
| Heptachlor, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Heptachlor epoxide, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Lindane, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Methoxychlor, µg/kg | -- | -- | -- | -- | <6.25 | -- | -- |
| Mirex, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Toxaphene, µg/kg | -- | -- | -- | -- | <125 | -- | -- |

[1]Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

**Table 19.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Lake Afton, eastern Kansas, and associated bioaccumulation index.

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi$^2$, pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-5 constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using median constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using interval-5 constituent concentration | Bioaccumulation index[3] |
|---|---|---|---|---|---|---|
| **Nutrients** | | | | | | |
| Total nitrogen | 2,300 | 26,700 | 25,500 | 2,570 | 2,450 | -- |
| Total phosphorus | 810 | 9,390 | 9,740 | 903 | 937 | -- |
| **Carbon** | | | | | | |
| Carbon (total organic, TOC) | 23,000 | 267,000 | 278,000 | 25,700 | 26,700 | -- |
| Carbon (total) | 22,000 | 255,000 | 232,000 | 24,500 | 22,300 | -- |
| **Trace elements** | | | | | | |
| Aluminum | 93,000 | 1,080,000 | 1,030,000 | 104,000 | 99,000 | -- |
| Antimony | 1.2 | 13.9 | 13.9 | 1.3 | 1.3 | moderate |
| Arsenic | 12 | 139 | 115 | 13.4 | 11.1 | moderate |
| Barium | 670 | 7,770 | 7,650 | 747 | 736 | low |
| Beryllium | 2.8 | 32.5 | 31.3 | 3.1 | 3.0 | low |
| Cadmium | .7 | 8.1 | 8.1 | .78 | .78 | moderate |
| Chromium | 71 | 823 | 800 | 79.1 | 76.9 | moderate |
| Cobalt | 13 | 151 | 139 | 14.5 | 13.4 | high |
| Copper | 33 | 383 | 383 | 36.8 | 36.8 | high |
| Iron | 43,000 | 499,000 | 487,000 | 48,000 | 46,800 | low |
| Lead | 45 | 522 | 452 | 50.2 | 43.5 | moderate |
| Lithium | 54 | 626 | 626 | 60.2 | 60.2 | slight |
| Manganese | 780 | 9,050 | 8,930 | 870 | 859 | low |
| Mercury | .04 | .46 | .35 | .04 | .03 | high |
| Molybdenum | 2 | 23 | 23 | 2.2 | 2.2 | high |
| Nickel | 38 | 441 | 429 | 42.4 | 41.3 | moderate |
| Selenium | .7 | 8.1 | 8.1 | .78 | .78 | high |
| Silver | <.5 | -- | -- | -- | -- | moderate |
| Strontium | 100 | 1,160 | 1,280 | 112 | 123 | moderate |
| Sulfur | 1,000 | 11,600 | 23,200 | 1,120 | 2,230 | -- |
| Thallium | <50 | -- | -- | -- | -- | low |
| Tin | 3 | 35 | 35 | 3.4 | 3.4 | -- |
| Titanium | 4,300 | 49,900 | 48,700 | 4,800 | 4,680 | moderate |
| Uranium | <50 | -- | -- | -- | -- | -- |
| Vanadium | 130 | 1,510 | 1,390 | 145 | 134 | low |
| Zinc | 130 | 1,510 | 1,390 | 145 | 134 | high |

**Table 19.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Lake Afton, eastern Kansas, and associated bioaccumulation index.—Continued

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi$^2$, pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-5 constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using median constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using interval-5 constituent concentration | Bioaccumulation index[3] |
|---|---|---|---|---|---|---|
| | | | Organochlorine compounds | | | |
| Aldrin | -- | -- | -- | -- | -- | -- |
| Chlordane | -- | -- | -- | -- | -- | -- |
| DDD | -- | -- | -- | -- | -- | -- |
| DDE | -- | -- | 0.0026 | -- | 0.00025 | -- |
| DDT | -- | -- | -- | -- | -- | -- |
| Dieldrin | -- | -- | -- | -- | -- | -- |
| Endosulfan | -- | -- | -- | -- | -- | -- |
| Endrin | -- | -- | -- | -- | -- | -- |
| Gross polychlorinated biphenyls (PCBs) | -- | -- | -- | -- | -- | -- |
| Heptachlor | -- | -- | -- | -- | -- | -- |
| Heptachlor epoxide | -- | -- | -- | -- | -- | -- |
| Lindane | -- | -- | -- | -- | -- | -- |
| Methoxychlor | -- | -- | -- | -- | -- | -- |
| Mirex | -- | -- | -- | -- | -- | -- |
| Toxaphene | -- | -- | -- | -- | -- | -- |

[1] Mean annual net load in pounds was computed as the mean annual net load in kilograms multiplied by 2.205. Mean annual net load in kilograms was computed as median or top-interval concentration multiplied by the mean annual net sediment load deposited in Lake Afton (5,260,000 kilograms), divided by 1 million.

[2] Mean annual net yield in pounds per square mile was computed as the mean annual net load in pounds divided by the area of the Lake Afton Basin (10.4 mi$^2$).

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

**Table 20.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from archived core collected from downstream coring site (site 1, fig. 28) in Lake Afton, October 2002.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | |
|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 | Interval 6 |
| Percentage of silt and clay | >99 | >99 | >99 | >99 | >99 | >99 |
| | | | Nutrients | | | |
| Total nitrogen, mg/kg | 2,300 | 2,500 | 2,200 | 2,300 | 2,400 | 2,300 |
| Total phosphorus, mg/kg | 610 | 690 | 670 | 720 | 710 | 670 |
| | | | Carbon | | | |
| Carbon (total organic, TOC), % | 2.0 | 2.3 | 2.2 | 2.1 | 2.1 | 2.1 |
| Carbon (total), % | 2.2 | 2.3 | 2.2 | 2.1 | 2.1 | 2.1 |
| | | | Trace elements | | | |
| Aluminum, % | 8.3 | 9.0 | 8.7 | 9.2 | 10.0 | 9.2 |
| Antimony, µg/g | .6 | .8 | .8 | 1.8 | .8 | .8 |
| Arsenic, µg/g | 12 | 13 | 14 | 15 | 15 | 16 |
| Barium, µg/g | 630 | 660 | 640 | 640 | 650 | 600 |
| Beryllium, µg/g | 2.6 | 2.7 | 2.6 | 2.8 | 3.0 | 2.7 |
| Cadmium, µg/g | .2 | .2 | .2 | .4 | .3 | .4 |
| Chromium, µg/g | 68 | 73 | 70 | 74 | 80 | 74 |
| Cobalt, µg/g | 13 | 14 | 13 | 14 | 14 | 13 |
| Copper, µg/g | 33 | 33 | 33 | 34 | 36 | 37 |
| Iron, % | 3.8 | 4.1 | 4.1 | 4.2 | 4.4 | 4.3 |
| Lead, µg/g | 28 | 31 | 36 | 43 | 50 | 55 |
| Lithium, µg/g | 48 | 51 | 50 | 54 | 58 | 53 |
| Manganese, µg/g | 660 | 690 | 910 | 800 | 820 | 520 |
| Mercury, µg/g | -- | -- | -- | -- | -- | -- |
| Molybdenum, µg/g | 1 | 1 | 1 | 1 | 1 | 1 |
| Nickel, µg/g | 35 | 38 | 38 | 38 | 41 | 38 |
| Selenium, µg/g | .6 | .8 | .7 | .7 | .3 | .7 |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| Strontium, µg/g | 110 | 110 | 100 | 100 | 100 | 100 |
| Sulfur, % | .1 | .1 | .1 | .1 | .1 | .2 |
| Thallium, µg/g | <50 | <50 | <50 | <50 | <50 | <50 |
| Tin, µg/g | 3 | 4 | 4 | 4 | 3 | 3 |
| Titanium, % | .44 | .46 | .45 | .46 | .47 | .44 |
| Uranium, µg/g | <50 | <50 | <50 | <50 | <50 | <50 |
| Vanadium, µg/g | 110 | 120 | 110 | 120 | 130 | 120 |
| Zinc, µg/g | 120 | 130 | 120 | 140 | 160 | 140 |

**Table 20.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from archived core collected from downstream coring site (site 1, fig. 28) in Lake Afton, October 2002.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|
| | Interval 7 | Interval 8 | Interval 9 | Interval 10 (top of core) | TEL | PEL |
| Percentage of silt and clay | >99 | >99 | >99 | >99 | -- | -- |
| | | Nutrients | | | | |
| Total nitrogen, mg/kg | 2,600 | 2,200 | 2,800 | 2,900 | -- | -- |
| Total phosphorus, mg/kg | 650 | 650 | 670 | 780 | -- | -- |
| | | Carbon | | | | |
| Carbon (total organic, TOC), % | 2.3 | 2.3 | 2.3 | 2.4 | -- | -- |
| Carbon (total), % | 2.4 | 2.3 | 2.5 | 2.5 | -- | -- |
| | | Trace elements | | | | |
| Aluminum, % | 8.8 | 8.7 | 8.5 | 8.6 | -- | -- |
| Antimony, µg/g | .8 | .7 | .7 | .7 | -- | -- |
| Arsenic, µg/g | 12 | 11 | 10 | 11 | 7.24 | 41.6 |
| Barium, µg/g | 600 | 600 | 620 | 610 | -- | -- |
| Beryllium, µg/g | 2.7 | 2.6 | 2.6 | 2.6 | -- | -- |
| Cadmium, µg/g | .2 | .2 | .1 | .1 | .676 | 4.21 |
| Chromium, µg/g | 72 | 71 | 70 | 70 | 52.3 | 160 |
| Cobalt, µg/g | 12 | 12 | 12 | 12 | -- | -- |
| Copper, µg/g | 35 | 34 | 34 | 33 | 18.7 | 108 |
| Iron, % | 4.1 | 4.1 | 4.0 | 4.1 | -- | -- |
| Lead, µg/g | 55 | 43 | 35 | 34 | 30.2 | 112 |
| Lithium, µg/g | 51 | 51 | 50 | 50 | -- | -- |
| Manganese, µg/g | 380 | 360 | 360 | 560 | -- | -- |
| Mercury, µg/g | -- | -- | -- | -- | .13 | .696 |
| Molybdenum, µg/g | 1 | 1 | 1 | 2 | -- | -- |
| Nickel, µg/g | 37 | 37 | 36 | 36 | 15.9 | 42.8 |
| Selenium, µg/g | .6 | .6 | .6 | .5 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 110 | 110 | 110 | 110 | -- | -- |
| Sulfur, % | .2 | .2 | .2 | .1 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 4 | 4 | 3 | 3 | -- | -- |
| Titanium, % | .45 | .44 | .44 | .44 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 120 | 110 | 110 | 110 | -- | -- |
| Zinc, µg/g | 140 | 130 | 120 | 130 | 124 | 271 |

[1]Guidelines from U.S. Environmental Protection Agency (1997).

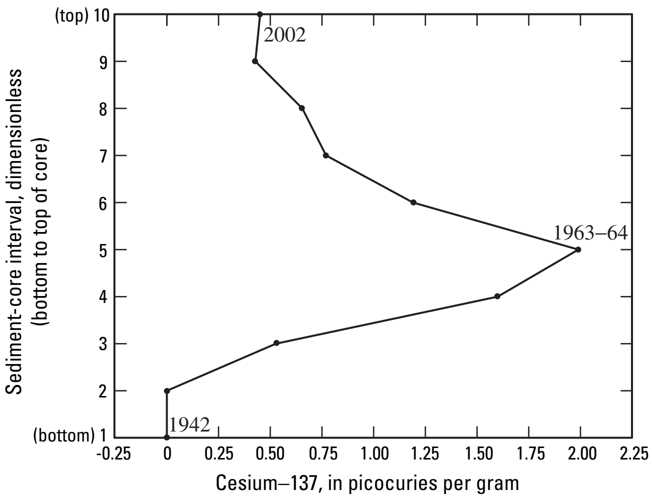



**Figure 8.** Variation in cesium-137 activity with depth of bottom-sediment samples collected from downstream coring site (site 1) in Lake Afton, October 2002. Location of Lake Afton shown in figure 1, and location of coring site shown in figure 28 at the back of this report.

peak followed by a uniform, exponential decrease (fig. 10), it was concluded that the bottom sediment in Mission Lake is relatively undisturbed and the trend may be considered meaningful.

To assess the effect of cold storage (at 4–5 °C) on nutrient and carbon concentrations in a sediment core, an archived core (collected in October 2002) was compared to the new core. The archived core was divided into 10 intervals, and sediment was removed, homogenized, and sampled for the first (most-recent), third, fifth, seventh, and ninth intervals. These samples were analyzed for total nitrogen, total phosphorus, TOC, and total carbon. A comparison of the same intervals for the archived and new cores was made on the basis of relative percentage differences (as computed previously). The respective relative percentage differences for total nitrogen, total phosphorus, TOC, and total carbon were 2.2, 4.0, 3.0, and 3.5 percent. Thus, 7 months of cold storage apparently had little, if any, effect on the nutrient and carbon concentrations in the sediment. These results indicated that, for the four constituents analyzed, an archived core held in cold storage (at 4–5 °C) for as long as 7 months can provide representative information on constituent concentrations in sediment.

The estimated mean annual net loads of total nitrogen and total phosphorus deposited in the bottom sediment were 49,100 and 20,800 lb, respectively. The estimated mean annual net yields of total nitrogen and total phosphorus from the Mission Lake Basin were 5,710 and 2,420 lb/mi$^2$, respectively (table 22).

TOC concentrations in the original core ranged from 2.1 to 2.6 percent with a median concentration of 2.4 percent (table 21). No obvious trend for TOC was evident in the core. The estimated mean annual net load and yield of TOC from the Mission Lake Basin were 561,000 lb and 65,200 lb/mi$^2$, respectively (table 22). With five exceptions (total nitrogen, total phosphorus, cobalt, manganese, and molybdenum), a comparison of the constituent loads and yields estimated using the median constituent concentration for the sediment core with those estimated using the interval-5 (most-recent) constituent concentration (table 22) indicated no substantial (greater than 10 percent) differences.

Arsenic, chromium, and copper concentrations in the bottom sediment of Mission Lake all exceeded the TELs but were less than the PELs. For lead, the two oldest intervals had concentrations that were less than the TEL, whereas the remaining intervals had concentrations that were either slightly less than or slightly more than the TEL. The concentration profile for lead subtly reflects the history of particulate lead emissions associated with the use of leaded gasoline in the United States. All nickel concentrations exceeded the TEL, and the concentration for the top (most-recent) interval also exceeded the PEL. For zinc, the two oldest intervals had concentrations that were slightly less than the TEL, whereas the remaining intervals had concentrations that exceeded the TEL but were less than the PEL. All cadmium, mercury, and silver concentrations were less than the TELs (table 21). A possible positive trend was indicated for manganese. The estimated mean annual net loads and yields for most of the trace elements are provided in table 22.

The only organochlorine compound detected in the bottom sediment from the top of a Mission Lake core was DDE with a concentration of 1.86 µg/kg. This concentration was less than the TEL (2.07 µg/kg).

## Otis Creek Reservoir

Otis Creek Reservoir was completed in 1971. The recovered sediment core was divided into five intervals for constituent analyses. In the bottom-sediment samples collected from Otis Creek Reservoir, total nitrogen concentrations ranged from 2,200 to 2,400 mg/kg with a median concentration of 2,300 mg/kg. The estimated mean annual net load of total nitrogen deposited in the bottom sediment was 31,000 lb. The estimated mean annual net yield of total nitrogen from the Otis Creek Reservoir Basin was 2,210 lb/mi$^2$ (tables 23 and 24).

Total phosphorus concentrations ranged from 600 to 640 mg/kg with a median concentration of 620 mg/kg. The estimated mean annual net load of total phosphorus was 8,370 lb. The estimated mean annual net yield of total phosphorus was 598 lb/mi$^2$ (tables 23 and 24).

TOC concentrations ranged from 2.0 to 2.3 percent with a median concentration of 2.1 percent. The estimated mean annual net load and yield of TOC were 283,000 lb and 20,200 lb/mi$^2$, respectively (tables 23 and 24). No trends for nutrients or TOC were evident in the core from Otis Creek Reservoir. With the exception of arsenic and manganese, a comparison of the constituent loads and yields estimated using the median constituent concentration for the sediment core with those estimated using the interval-5 (most-recent) constituent

**Table 21.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 29) in Mission Lake, October 2002.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| Percentage of silt and clay | >99 | >99 | >99 | >99 | >99 | -- | -- |
| **Nutrients** | | | | | | | |
| Total nitrogen, mg/kg | 2,000 | 1,900 | 2,100 | 2,200 | 2,400 | -- | -- |
| Total phosphorus, mg/kg | 750 | 670 | 890 | 1,000 | 1,200 | -- | -- |
| **Carbon** | | | | | | | |
| Carbon (total organic, TOC), % | 2.4 | 2.1 | 2.4 | 2.5 | 2.6 | -- | -- |
| Carbon (total), % | 2.0 | 1.9 | 2.1 | 2.2 | 2.3 | -- | -- |
| **Trace elements** | | | | | | | |
| Aluminum, % | 8.6 | 8.4 | 9.4 | 9.4 | 9.4 | -- | -- |
| Antimony, µg/g | 1.3 | 1.2 | 1.3 | 1.4 | 1.3 | -- | -- |
| Arsenic, µg/g | 13 | 12 | 15 | 16 | 15 | 7.24 | 41.6 |
| Barium, µg/g | 870 | 850 | 860 | 850 | 870 | -- | -- |
| Beryllium, µg/g | 2.5 | 2.4 | 2.6 | 2.6 | 2.6 | -- | -- |
| Cadmium, µg/g | .3 | .3 | .3 | .3 | .3 | .676 | 4.21 |
| Chromium, µg/g | 76 | 74 | 83 | 83 | 84 | 52.3 | 160 |
| Cobalt, µg/g | 12 | 12 | 13 | 12 | 14 | -- | -- |
| Copper, µg/g | 29 | 28 | 32 | 33 | 35 | 18.7 | 108 |
| Iron, % | 4.1 | 3.9 | 4.6 | 4.7 | 4.8 | -- | -- |
| Lead, µg/g | 25 | 24 | 31 | 30 | 29 | 30.2 | 112 |
| Lithium, µg/g | 46 | 45 | 55 | 53 | 56 | -- | -- |
| Manganese, µg/g | 840 | 660 | 960 | 1,100 | 1,300 | -- | -- |
| Mercury, µg/g | .02 | .02 | .04 | .04 | .04 | .13 | .696 |
| Molybdenum, µg/g | 2 | 2 | 2 | 1 | 1 | -- | -- |
| Nickel, µg/g | 38 | 37 | 41 | 41 | 44 | 15.9 | 42.8 |
| Selenium, µg/g | .8 | .8 | .9 | .9 | .9 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 130 | 130 | 120 | 120 | 120 | -- | -- |
| Sulfur, % | <.1 | <.1 | <.1 | <.1 | .1 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 3 | 2 | 3 | 3 | 3 | -- | -- |
| Titanium, % | .46 | .44 | .46 | .45 | .46 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 140 | 130 | 150 | 150 | 150 | -- | -- |
| Zinc, µg/g | 120 | 120 | 140 | 140 | 140 | 124 | 271 |

**Table 21.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 29) in Mission Lake, October 2002.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| **Organochlorine compounds** | | | | | | | |
| Aldrin, µg/kg | -- | -- | -- | -- | <0.5 | -- | -- |
| Chlordane, µg/kg | -- | -- | -- | -- | <3 | 2.26 | 4.79 |
| DDD, µg/kg | -- | -- | -- | -- | <.5 | 1.22 | 7.81 |
| DDE, µg/kg | -- | -- | -- | -- | 1.86 | 2.07 | 374 |
| DDT, µg/kg | -- | -- | -- | -- | <.5 | 1.19 | 4.77 |
| Dieldrin, µg/kg | -- | -- | -- | -- | <.2 | .715 | 4.3 |
| Endosulfan, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Endrin, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | -- | -- | -- | -- | <12.5 | 21.6 | 189 |
| Heptachlor, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Heptachlor epoxide, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Lindane, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Methoxychlor, µg/kg | -- | -- | -- | -- | <2.5 | -- | -- |
| Mirex, µg/kg | -- | -- | -- | -- | <.5 | -- | -- |
| Toxaphene, µg/kg | -- | -- | -- | -- | <50 | -- | -- |

[1]Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

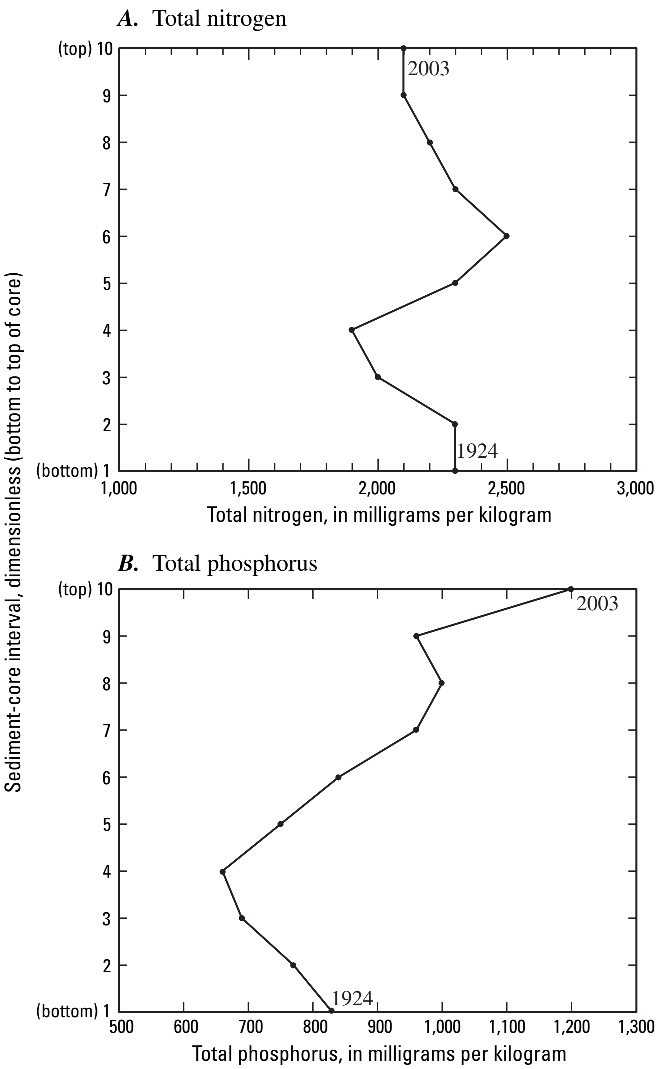



**Figure 9.** Variation in *(A)* total nitrogen and *(B)* total phosphorus concentrations with depth of bottom-sediment samples collected from downstream coring site (site 1) in Mission Lake, May 2003. Location of Mission Lake shown in figure 1, and location of coring site shown in figure 29 at the back of this report.

concentration (table 24) indicated no substantial (greater than 10 percent) differences.

In the bottom sediment of Otis Creek Reservoir, arsenic, chromium, copper, and nickel concentrations all exceeded the TELs but were less than the PELs. For cadmium, lead, silver, and zinc, all concentrations were less than the TELs (table 23). No trends for trace elements were indicated in the core. The estimated mean annual net loads and yields for most of the trace elements are provided in table 24. No organochlorine compounds were detected in the bottom sediment from the top of an Otis Creek Reservoir core.

## Pony Creek Lake

For Pony Creek Lake (completed in 1993), the recovered sediment core was divided into three intervals for constituent analyses. Total nitrogen, total phosphorus, and TOC concentrations in the bottom sediment of Pony Creek Lake were relatively uniform with depth (table 25). Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for total nitrogen, total phosphorus, and TOC were not determined for Pony Creek Lake.

Arsenic, chromium, copper, and nickel concentrations in the bottom sediment of Pony Creek Lake all exceeded the TELs but were less than the PELs. All cadmium, lead, silver, and zinc concentrations were less than the TELs (table 25). No trends for trace elements were evident in the core. Because an estimate of mean annual sediment deposition was not possible, estimates of mean annual net loads and yields for the trace elements were not determined for Pony Creek Lake.

The only organochlorine compound detected in the bottom sediment from the top of a Pony Creek Lake core was DDE with a concentration of 0.20 µg/kg. This concentration was less than the TEL (2.07 µg/kg).

## Interlake Comparison

### Nutrients and Total Organic Carbon

Median total nitrogen concentrations in the reservoir bottom sediment ranged from 1,400 mg/kg for Hiawatha City Lake to 3,700 mg/kg for Bronson City Lake. Of the 10 reservoirs, 4 (Bronson City Lake, Crystal Lake, Gardner City Lake, and

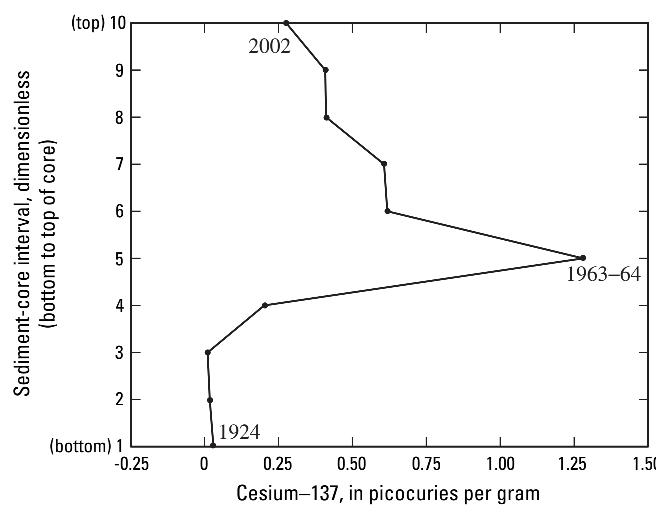



**Figure 10.** Variation in cesium-137 activity with depth of bottom-sediment samples collected from downstream coring site (site 1) in Mission Lake, October 2002. Location of Mission Lake shown in figure 1, and location of coring site shown in figure 29 at the back of this report.

**Table 22.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Mission Lake, eastern Kansas, and associated bioaccumulation index.

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi$^2$, pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-5 constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using median constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using interval-5 constituent concentration | Bioaccumulation index[3] |
|---|---|---|---|---|---|---|
| **Nutrients** | | | | | | |
| Total nitrogen | 2,100 | 49,100 | 56,100 | 5,710 | 6,520 | -- |
| Total phosphorus | 890 | 20,800 | 28,000 | 2,420 | 3,260 | -- |
| **Carbon** | | | | | | |
| Carbon (total organic, TOC) | 24,000 | 561,000 | 608,000 | 65,200 | 70,700 | -- |
| Carbon (total) | 21,000 | 491,000 | 538,000 | 57,100 | 62,600 | -- |
| **Trace elements** | | | | | | |
| Aluminum | 94,000 | 2,200,000 | 2,200,000 | 256,000 | 256,000 | -- |
| Antimony | 1.3 | 30.4 | 30.4 | 3.5 | 3.5 | moderate |
| Arsenic | 15 | 351 | 351 | 40.8 | 40.8 | moderate |
| Barium | 860 | 20,100 | 20,300 | 2,340 | 2,360 | low |
| Beryllium | 2.6 | 60.8 | 60.8 | 7.1 | 7.1 | low |
| Cadmium | .3 | 7.0 | 7.0 | .81 | .81 | moderate |
| Chromium | 83 | 1,940 | 1,960 | 226 | 228 | moderate |
| Cobalt | 12 | 280 | 327 | 32.6 | 38.0 | high |
| Copper | 32 | 748 | 818 | 87.0 | 95.1 | high |
| Iron | 46,000 | 1,080,000 | 1,120,000 | 126,000 | 130,000 | low |
| Lead | 29 | 678 | 678 | 78.8 | 78.8 | moderate |
| Lithium | 53 | 1,240 | 1,310 | 144 | 152 | slight |
| Manganese | 960 | 22,400 | 30,400 | 2,600 | 3,530 | low |
| Mercury | .04 | .93 | .93 | .11 | .11 | high |
| Molybdenum | 2 | 47 | 23 | 5.5 | 2.7 | high |
| Nickel | 41 | 958 | 1,030 | 111 | 120 | moderate |
| Selenium | .9 | 21.0 | 21.0 | 2.4 | 2.4 | high |
| Silver | <.5 | -- | -- | -- | -- | moderate |
| Strontium | 120 | 2,800 | 2,800 | 326 | 326 | moderate |
| Sulfur | <1,000 | -- | -- | -- | -- | -- |
| Thallium | <50 | -- | -- | -- | -- | low |
| Tin | 3 | 70 | 70 | 8.1 | 8.1 | -- |
| Titanium | 4,600 | 108,000 | 108,000 | 12,600 | 12,600 | moderate |
| Uranium | <50 | -- | -- | -- | -- | -- |
| Vanadium | 150 | 3,510 | 3,510 | 408 | 408 | low |
| Zinc | 140 | 3,270 | 3,270 | 380 | 380 | high |

**Table 22.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Mission Lake, eastern Kansas, and associated bioaccumulation index.—Continued

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi$^2$, pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-5 constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using median constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using interval-5 constituent concentration | Bioaccumulation index[3] |
|---|---|---|---|---|---|---|
| | | | Organochlorine compounds | | | |
| Aldrin | -- | -- | -- | -- | -- | -- |
| Chlordane | -- | -- | -- | -- | -- | -- |
| DDD | -- | -- | -- | -- | -- | -- |
| DDE | -- | -- | 0.044 | -- | 0.0051 | -- |
| DDT | -- | -- | | -- | -- | -- |
| Dieldrin | -- | -- | -- | -- | -- | -- |
| Endosulfan | -- | -- | -- | -- | -- | -- |
| Endrin | -- | -- | -- | -- | -- | -- |
| Gross polychlorinated biphenyls (PCBs) | -- | -- | -- | -- | -- | -- |
| Heptachlor | -- | -- | -- | -- | -- | -- |
| Heptachlor epoxide | -- | -- | -- | -- | -- | -- |
| Lindane | -- | -- | -- | -- | -- | -- |
| Methoxychlor | -- | -- | -- | -- | -- | -- |
| Mirex | -- | -- | -- | -- | -- | -- |
| Toxaphene | -- | -- | -- | -- | -- | -- |

[1] Mean annual net load in pounds was computed as the mean annual net load in kilograms multiplied by 2.205. Mean annual net load in kilograms was computed as median or top-interval concentration multiplied by the mean annual net sediment load deposited in Mission Lake (10,600,000 kilograms), divided by 1 million.

[2] Mean annual net yield in pounds per square mile was computed as the mean annual net load in pounds divided by the area of the Mission Lake Basin (8.6 mi$^2$).

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

**Table 23.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from middle coring site (site 1, fig. 30) in Otis Creek Reservoir, September 2002.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| Percentage of silt and clay | >99 | >99 | >99 | >99 | >99 | -- | -- |
| Nutrients | | | | | | | |
| Total nitrogen, mg/kg | 2,300 | 2,200 | 2,200 | 2,300 | 2,400 | -- | -- |
| Total phosphorus, mg/kg | 640 | 620 | 620 | 600 | 640 | -- | -- |
| Carbon | | | | | | | |
| Carbon (total organic, TOC), % | 2.0 | 2.1 | 2.1 | 2.1 | 2.3 | -- | -- |
| Carbon (total), % | 3.5 | 3.6 | 3.6 | 3.7 | 3.7 | -- | -- |
| Trace elements | | | | | | | |
| Aluminum, % | 7.3 | 6.9 | 6.9 | 6.8 | 7.1 | -- | -- |
| Antimony, µg/g | 1.0 | 1.0 | .9 | .9 | 1.0 | -- | -- |
| Arsenic, µg/g | 11 | 10 | 11 | 11 | 13 | 7.24 | 41.6 |
| Barium, µg/g | 500 | 480 | 490 | 470 | 490 | -- | -- |
| Beryllium, µg/g | 2.2 | 2.2 | 2.1 | 2.0 | 2.2 | -- | -- |
| Cadmium, µg/g | .6 | .5 | .4 | .5 | .5 | .676 | 4.21 |
| Chromium, µg/g | 82 | 76 | 78 | 78 | 80 | 52.3 | 160 |
| Cobalt, µg/g | 14 | 14 | 14 | 13 | 15 | -- | -- |
| Copper, µg/g | 22 | 21 | 21 | 21 | 22 | 18.7 | 108 |
| Iron, % | 3.6 | 3.4 | 3.5 | 3.4 | 3.7 | -- | -- |
| Lead, µg/g | 24 | 23 | 23 | 23 | 23 | 30.2 | 112 |
| Lithium, µg/g | 61 | 59 | 61 | 60 | 61 | -- | -- |
| Manganese, µg/g | 730 | 730 | 740 | 760 | 1,100 | -- | -- |
| Mercury, µg/g | -- | -- | -- | -- | -- | .13 | .696 |
| Molybdenum, µg/g | <1 | <1 | <1 | <1 | <1 | -- | -- |
| Nickel, µg/g | 39 | 36 | 36 | 35 | 37 | 15.9 | 42.8 |
| Selenium, µg/g | 1.1 | 1.0 | 1.0 | 1.2 | 1.2 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 200 | 200 | 200 | 200 | 200 | -- | -- |
| Sulfur, % | .1 | <.1 | <.1 | <.1 | <.1 | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 4 | 3 | 4 | 3 | 4 | -- | -- |
| Titanium, % | .40 | .38 | .37 | .35 | .38 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 100 | 96 | 96 | 93 | 99 | -- | -- |
| Zinc, µg/g | 74 | 68 | 67 | 66 | 67 | 124 | 271 |

**Table 23.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from middle coring site (site 1, fig. 30) in Otis Creek Reservoir, September 2002.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 | Interval 4 | Interval 5 (top of core) | TEL | PEL |
| | Organochlorine compounds[2] | | | | | | |
| Aldrin, µg/kg | -- | -- | -- | -- | <0.2 | -- | -- |
| Chlordane, µg/kg | -- | -- | -- | -- | <3 | 2.26 | 4.79 |
| DDD, µg/kg | -- | -- | -- | -- | <.5 | 1.22 | 7.81 |
| DDE, µg/kg | -- | -- | -- | -- | <.2 | 2.07 | 374 |
| DDT, µg/kg | -- | -- | -- | -- | <.5 | 1.19 | 4.77 |
| Dieldrin, µg/kg | -- | -- | -- | -- | <.2 | .715 | 4.3 |
| Endosulfan, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Endrin, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | -- | -- | -- | -- | <5 | 21.6 | 189 |
| Heptachlor, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Heptachlor epoxide, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Lindane, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Methoxychlor, µg/kg | -- | -- | -- | -- | <2.5 | -- | -- |
| Mirex, µg/kg | -- | -- | -- | -- | <.2 | -- | -- |
| Toxaphene, µg/kg | -- | -- | -- | -- | <50 | -- | -- |

[1] Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

[2] For organochlorine compounds, the top one-third of the sediment core was analyzed.

**Table 24.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Otis Creek Reservoir, eastern Kansas, and associated bioaccumulation index.

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi$^2$, pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-5 constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using median constituent concentration | Mean annual net yield[2] (lb/mi$^2$) computed using interval-5 constituent concentration | Bioaccumulation index[3] |
|---|---|---|---|---|---|---|
| Nutrients | | | | | | |
| Total nitrogen | 2,300 | 31,000 | 32,400 | 2,210 | 2,310 | -- |
| Total phosphorus | 620 | 8,370 | 8,640 | 598 | 617 | -- |
| Carbon | | | | | | |
| Carbon (total organic, TOC) | 21,000 | 283,000 | 310,000 | 20,200 | 22,100 | -- |
| Carbon (total) | 36,000 | 486,000 | 499,000 | 34,700 | 35,600 | -- |
| Trace elements | | | | | | |
| Aluminum | 69,000 | 931,000 | 958,000 | 66,500 | 68,400 | -- |
| Antimony | 1.0 | 13.5 | 13.5 | .96 | .96 | moderate |
| Arsenic | 11 | 148 | 175 | 10.6 | 12.5 | moderate |
| Barium | 490 | 6,610 | 6,610 | 472 | 472 | low |
| Beryllium | 2.2 | 29.7 | 29.7 | 2.1 | 2.1 | low |
| Cadmium | .5 | 6.7 | 6.7 | .48 | .48 | moderate |
| Chromium | 78 | 1,050 | 1,080 | 75.0 | 77.1 | moderate |
| Cobalt | 14 | 189 | 202 | 13.5 | 14.4 | high |
| Copper | 21 | 283 | 297 | 20.2 | 21.2 | high |
| Iron | 35,000 | 472,000 | 499,000 | 33,700 | 35,600 | low |
| Lead | 23 | 310 | 310 | 22.1 | 22.1 | moderate |
| Lithium | 61 | 823 | 823 | 58.8 | 58.8 | slight |
| Manganese | 740 | 9,990 | 14,800 | 714 | 1,060 | low |
| Mercury | -- | -- | -- | -- | -- | high |
| Molybdenum | <1 | -- | -- | -- | -- | high |
| Nickel | 36 | 486 | 499 | 34.7 | 35.6 | moderate |
| Selenium | 1.1 | 14.8 | 16.2 | 1.1 | 1.2 | high |
| Silver | <.5 | -- | -- | -- | -- | moderate |
| Strontium | 200 | 2,700 | 2,700 | 193 | 193 | moderate |
| Sulfur | <1,000 | -- | -- | -- | -- | -- |
| Thallium | <50 | -- | -- | -- | -- | low |
| Tin | 4 | 54 | 54 | 3.9 | 3.9 | -- |
| Titanium | 3,800 | 51,300 | 51,300 | 3,660 | 3,660 | moderate |
| Uranium | <50 | -- | -- | -- | -- | -- |
| Vanadium | 96 | 1,300 | 1,340 | 92.9 | 95.7 | low |
| Zinc | 67 | 904 | 904 | 64.6 | 64.6 | high |

**Table 24.** Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Otis Creek Reservoir, eastern Kansas, and associated bioaccumulation index.—Continued

[Mean annual net loads and yields have been rounded to two or three significant figures. mg/kg, milligrams per kilogram; lb, pounds; lb/mi², pounds per square mile; <, less than; --, not computed or not available]

| Constituent | Median concentration (mg/kg) | Mean annual net load[1] (lb) computed using median constituent concentration | Mean annual net load[1] (lb) computed using interval-5 constituent concentration | Mean annual net yield[2] (lb/mi²) computed using median constituent concentration | Mean annual net yield[2] (lb/mi²) computed using interval-5 constituent concentration | Bioaccumulation index[3] |
|---|---|---|---|---|---|---|
| | | | Organochlorine compounds | | | |
| Aldrin | -- | -- | -- | -- | -- | -- |
| Chlordane | -- | -- | -- | -- | -- | -- |
| DDD | -- | -- | -- | -- | -- | -- |
| DDE | -- | -- | -- | -- | -- | -- |
| DDT | -- | -- | -- | -- | -- | -- |
| Dieldrin | -- | -- | -- | -- | -- | -- |
| Endosulfan | -- | -- | -- | -- | -- | -- |
| Endrin | -- | -- | -- | -- | -- | -- |
| Gross polychlorinated biphenyls (PCBs) | -- | -- | -- | -- | -- | -- |
| Heptachlor | -- | -- | -- | -- | -- | -- |
| Heptachlor epoxide | -- | -- | -- | -- | -- | -- |
| Lindane | -- | -- | -- | -- | -- | -- |
| Methoxychlor | -- | -- | -- | -- | -- | -- |
| Mirex | -- | -- | -- | -- | -- | -- |
| Toxaphene | -- | -- | -- | -- | -- | -- |

[1] Mean annual net load in pounds was computed as the mean annual net load in kilograms multiplied by 2.205. Mean annual net load in kilograms was computed as median or top-interval concentration multiplied by the mean annual net sediment load deposited in Otis Creek Reservoir (6,120,000 kilograms), divided by 1 million.

[2] Mean annual net yield in pounds per square mile was computed as the mean annual net load in pounds divided by the area of the Otis Creek Reservoir Basin (14.0 mi²).

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

**Table 25.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 31) in Pony Creek Lake, May 2003.

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 (top of core) | TEL | PEL |
| Percentage of silt and clay | >99 | >99 | >99 | -- | -- |
| | | Nutrients | | | |
| Total nitrogen, mg/kg | 3,000 | 3,400 | 3,400 | -- | -- |
| Total phosphorus, mg/kg | 1,200 | 1,200 | 1,100 | -- | -- |
| | | Carbon | | | |
| Carbon (total organic, TOC), % | 2.6 | 2.6 | 2.8 | -- | -- |
| Carbon (total), % | 3.2 | 3.8 | 3.9 | -- | -- |
| | | Trace elements | | | |
| Aluminum, % | 7.9 | 7.3 | 7.1 | -- | -- |
| Antimony, µg/g | 1.1 | 1.1 | 1.1 | -- | -- |
| Arsenic, µg/g | 17 | 14 | 13 | 7.24 | 41.6 |
| Barium, µg/g | 650 | 620 | 630 | -- | -- |
| Beryllium, µg/g | 2.0 | 1.9 | 1.8 | -- | -- |
| Cadmium, µg/g | .4 | .5 | .5 | .676 | 4.21 |
| Chromium, µg/g | 77 | 72 | 70 | 52.3 | 160 |
| Cobalt, µg/g | 14 | 13 | 13 | -- | -- |
| Copper, µg/g | 29 | 26 | 26 | 18.7 | 108 |
| Iron, % | 4.0 | 3.7 | 3.6 | -- | -- |
| Lead, µg/g | 25 | 24 | 25 | 30.2 | 112 |
| Lithium, µg/g | 58 | 55 | 53 | -- | -- |
| Manganese, µg/g | 1,100 | 1,200 | 1,400 | -- | -- |
| Mercury, µg/g | -- | -- | -- | .13 | .696 |
| Molybdenum, µg/g | 2 | 2 | 2 | -- | -- |
| Nickel, µg/g | 38 | 37 | 35 | 15.9 | 42.8 |
| Selenium, µg/g | .8 | .8 | .9 | -- | -- |
| Silver, µg/g | <.5 | <.5 | <.5 | .733 | 1.77 |
| Strontium, µg/g | 170 | 200 | 190 | -- | -- |
| Sulfur, % | -- | -- | -- | -- | -- |
| Thallium, µg/g | <50 | <50 | <50 | -- | -- |
| Tin, µg/g | 3 | 3 | 3 | -- | -- |
| Titanium, % | .35 | .34 | .34 | -- | -- |
| Uranium, µg/g | <50 | <50 | <50 | -- | -- |
| Vanadium, µg/g | 120 | 110 | 110 | -- | -- |
| Zinc, µg/g | 120 | 110 | 110 | 124 | 271 |

**Table 25.** Percentage of silt and clay, constituent concentrations, and comparison to sediment-quality guidelines for bottom-sediment samples from downstream coring site (site 1, fig. 31) in Pony Creek Lake, May 2003.—Continued

[Highlighted values are greater than or equal to the respective threshold-effects level (TEL) or probable-effects level (PEL). mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; >, greater than; <, less than; --, no value assigned or not available]

| Constituent and unit of measurement | Constituent concentration | | | Sediment-quality guidelines[1] | |
|---|---|---|---|---|---|
| | Interval 1 (bottom of core) | Interval 2 | Interval 3 (top of core) | TEL | PEL |
| Organochlorine compounds | | | | | |
| Aldrin, µg/kg | -- | -- | <0.2 | -- | -- |
| Chlordane, µg/kg | -- | -- | <3 | 2.26 | 4.79 |
| DDD, µg/kg | -- | -- | <.5 | 1.22 | 7.81 |
| DDE, µg/kg | -- | -- | .20 | 2.07 | 374 |
| DDT, µg/kg | -- | -- | <.5 | 1.19 | 4.77 |
| Dieldrin, µg/kg | -- | -- | <.2 | .715 | 4.3 |
| Endosulfan, µg/kg | -- | -- | <.2 | -- | -- |
| Endrin, µg/kg | -- | -- | <.2 | -- | -- |
| Gross polychlorinated biphenyls (PCBs), µg/kg | -- | -- | <5 | 21.6 | 189 |
| Heptachlor, µg/kg | -- | -- | <.2 | -- | -- |
| Heptachlor epoxide, µg/kg | -- | -- | <.2 | -- | -- |
| Lindane, µg/kg | -- | -- | <.2 | -- | -- |
| Methoxychlor, µg/kg | -- | -- | <2.5 | -- | -- |
| Mirex, µg/kg | -- | -- | <.2 | -- | -- |
| Toxaphene, µg/kg | -- | -- | <50 | -- | -- |

[1]Guidelines from U.S. Environmental Protection Agency (1997). TEL and PEL values for organochlorine compounds converted from milligrams per kilogram to micrograms per kilogram.

Pony Creek Lake) had median total nitrogen concentrations of 3,000 mg/kg or more, 4 (Centralia Lake, Lake Afton, Mission Lake, and Otis Creek Reservoir) had median total nitrogen concentrations of between 2,000 and 2,500 mg/kg, and 2 (Edgerton and Hiawatha City Lakes) had median total nitrogen concentrations of less than 2,000 mg/kg (fig. 11*A*). Due to the larger percentage of sand in some of the bottom-sediment samples analyzed, the nutrient concentrations for Edgerton and Hiawatha City Lakes may be somewhat underrepresented.

Mean annual net loads of total nitrogen ranged from 4,080 lb for Crystal Lake to 49,100 lb for Mission Lake. Mean annual net yields of total nitrogen ranged from 2,210 lb/mi$^2$ for Otis Creek Reservoir to 6,800 lb/mi$^2$ for Crystal Lake (fig. 12*A*). In the "Interlake Comparison" section of this report, the comparison of loads and yields for all constituents is based on the constituent loads and yields estimated using the median constituent concentrations.

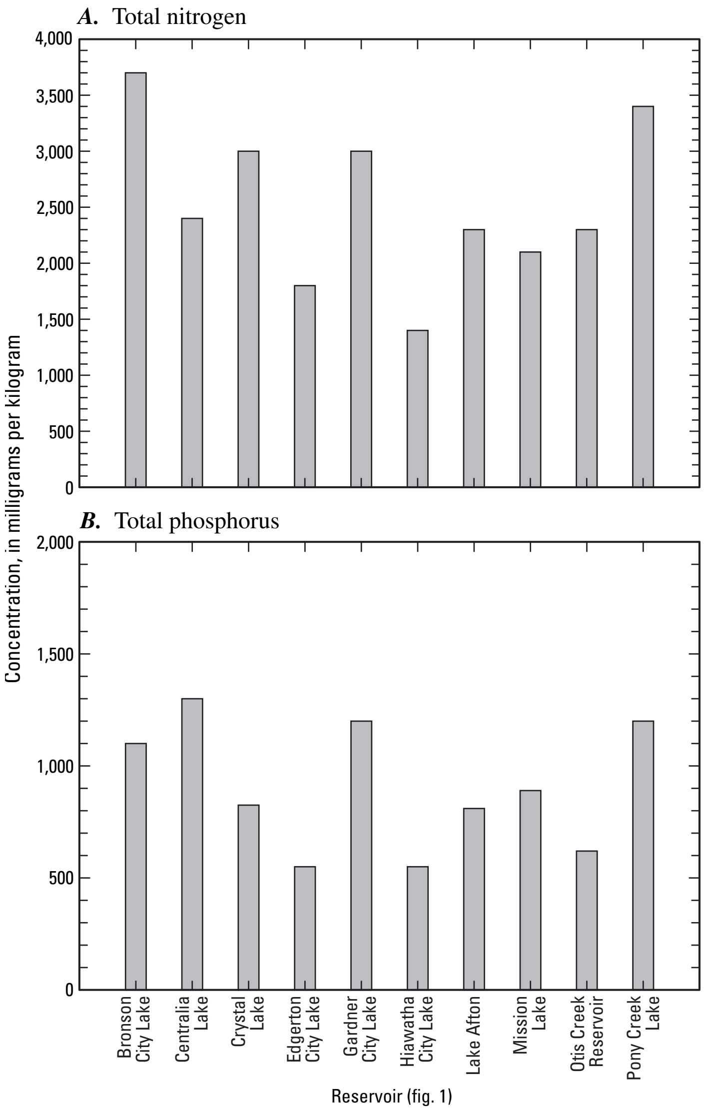



**Figure 11.** Median concentrations of *(A)* total nitrogen and *(B)* total phosphorus in bottom-sediment samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1.

Median total phosphorus concentrations ranged from 550 mg/kg at Edgerton and Hiawatha City Lakes to 1,300 mg/kg at Centralia Lake. Of the 10 reservoirs, 4 (Bronson City Lake, Centralia Lake, Gardner City Lake, and Pony Creek Lake) had median total phosphorus concentrations larger than 1,000 mg/kg, and 6 (Crystal Lake, Edgerton City Lake, Hiawatha City Lake, Lake Afton, Mission Lake, and Otis Creek Reservoir) had median total phosphorus concentrations between 500 and 900 mg/kg (fig. 11*B*).

Mean annual net loads of total phosphorus ranged from 1,120 lb for Crystal Lake to 20,800 lb for Mission Lake. Mean annual net yields of total phosphorus ranged from 598 lb/mi$^2$ for Otis Creek Reservoir to 2,420 lb/mi$^2$ for Mission Lake (fig. 12*B*).

The range of median TOC concentrations was from 1.8 percent at Edgerton City Lake to 3.6 percent at Bronson City Lake. Of the 10 reservoirs, 2 (Bronson and Gardner City Lakes) had median TOC concentrations larger than 3 percent, 7 (Centralia Lake, Crystal Lake, Hiawatha City Lake, Lake Afton, Mission Lake, Otis Creek Reservoir, and Pony Creek Lake) had median TOC concentrations between 2 and 3 percent, and 1 (Edgerton City Lake) had a median TOC concentration less than 2 percent (fig. 13).

## Trace Elements

The interlake comparison for trace elements is limited to the nine trace elements for which sediment-quality guidelines are available. Information on mercury concentrations in bottom sediment was only available for Gardner City Lake, Hiawatha City Lake, Lake Afton, and Mission Lake. At all sampling depths in each of these four reservoirs, mercury concentrations were less than the TEL (0.13 µg/g). Silver was not detected in the bottom sediment from any of the 10 reservoirs sampled.

Median arsenic concentrations ranged from 8.8 µg/g in sediment samples from Hiawatha City Lake to 18 µg/g in sediment samples from Centralia Lake and Gardner City Lake. For all reservoirs, the median arsenic concentration exceeded the TEL (7.24 µg/g) but was less than the PEL (41.6 µg/g) (fig. 14). Mean annual net loads of arsenic ranged from 23 lb for Crystal Lake to 351 lb for Mission Lake. Mean annual net yields of arsenic ranged from 10.6 lb/mi$^2$ for Otis Creek Reservoir to 40.8 lb/mi$^2$ for Mission Lake (tables 12, 16, 19, 22, and 24).

The core-interval specific, trace element concentrations reported for Edgerton and Hiawatha City Lakes (tables 14 and 17) may not be directly comparable with sediment concentrations reported for the other reservoirs because of differences in particle size. At Edgerton City Lake, core intervals 3 through 5 had a silt and (or) clay content of 97 percent or greater, whereas intervals 1 and 2 had a respective silt and (or) clay content of 78 and 83 percent. At Hiawatha City Lake, the respective silt and (or) clay contents for the five core intervals (bottom to top) were 75, 82, 81, 73, and 89 percent. In contrast, the sediment

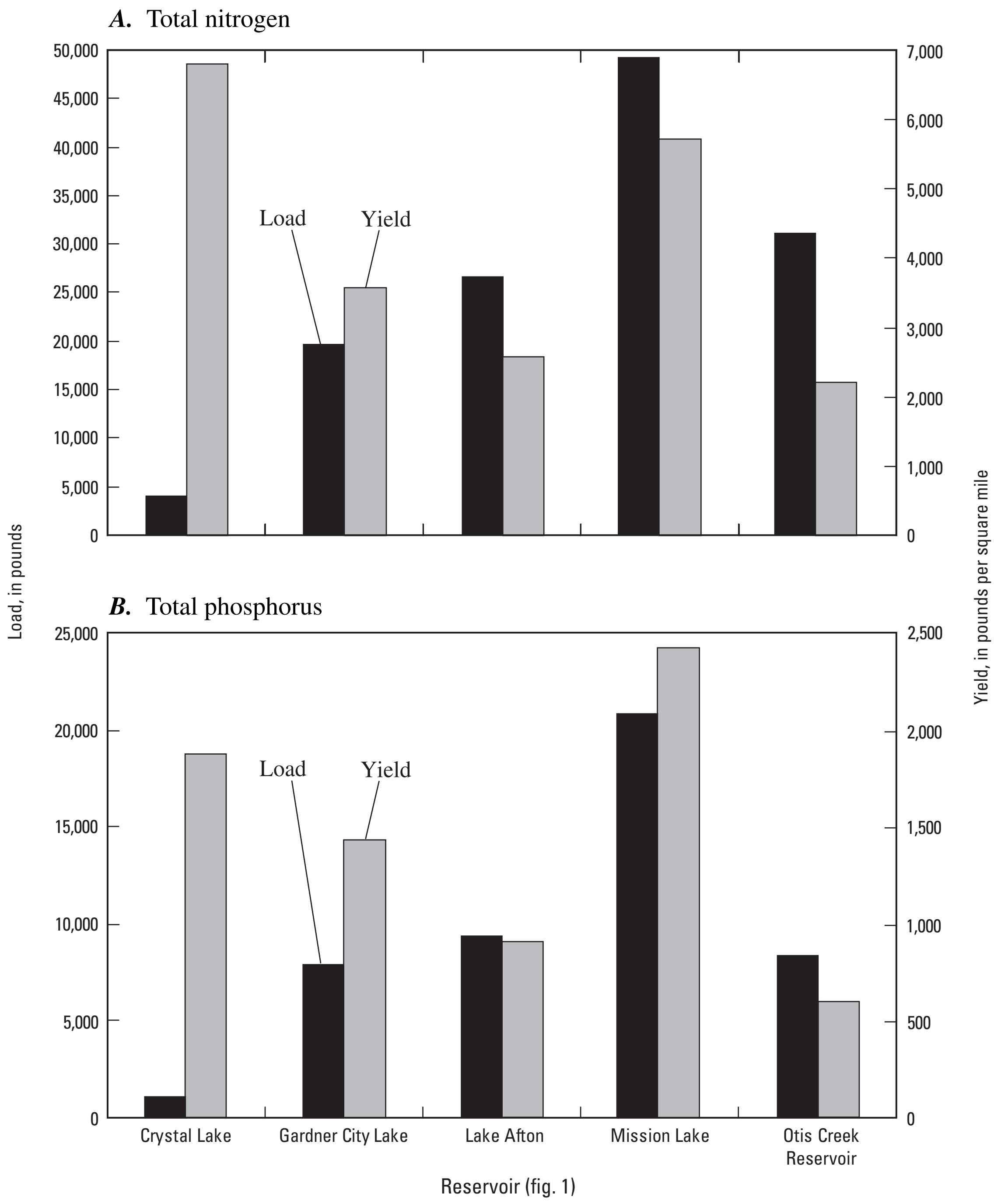



**Figure 12.** Mean annual net *(A)* total nitrogen and *(B)* total phosphorus loads and yields estimated for five small reservoirs in eastern Kansas. Location of reservoirs shown in figure 1.

samples analyzed for trace elements for the other reservoirs had uniform silt and (or) clay content of 98 percent or greater. Because trace element concentrations in stream sediment are inversely related to particle size (Horowitz and Elrick, 1987), the trace element concentrations determined for the core intervals with relatively small silt and (or) clay content (and relatively large sand content) may be somewhat underrepresented.

Median cadmium concentrations ranged from 0.2 µg/g in sediment samples from Edgerton City Lake to 0.9 µg/g in sediment samples from Crystal Lake. For four reservoirs (Bronson City Lake, Centralia Lake, Crystal Lake, and Lake Afton), median cadmium concentrations exceeded the TEL (0.676 µg/g) but were less than the PEL (4.21 µg/g). Sediment samples from the remaining reservoirs had median cadmium concentrations that were less than the TEL (fig. 15). Mean annual net loads of cadmium ranged from 1.2 lb for Crystal Lake to 8.1 lb for Lake Afton. Mean annual net yields of

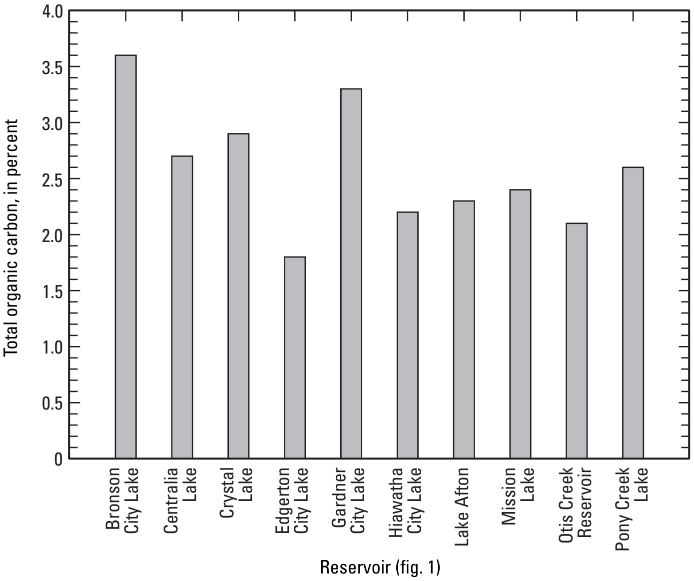



**Figure 13.** Median concentrations of total organic carbon for bottom-sediment core samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1.

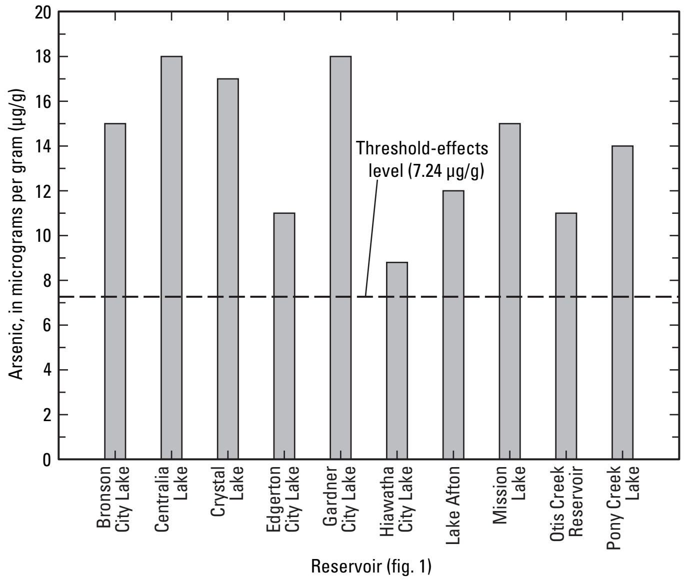



**Figure 14.** Median arsenic concentrations in bottom-sediment core samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1. Threshold-effects level from U.S. Environmental Protection Agency (1997).

cadmium ranged from 0.48 lb/mi$^2$ for Otis Creek Reservoir to 2.0 lb/mi$^2$ for Crystal Lake (tables 12, 16, 19, 22, and 24).

Median chromium concentrations ranged from 44 µg/g in sediment samples from Hiawatha City Lake to 87 µg/g in sediment samples from Gardner City Lake. With one exception, median chromium concentrations in sediment samples from all reservoirs exceeded the TEL (52.3 µg/g) but were less than the PEL (160 µg/g). The exception was Hiawatha City Lake for which the median chromium concentration was less than the TEL. Other than Edgerton and Hiawatha City Lakes, the median chromium concentrations for the reservoir-sediment samples were relatively uniform (fig. 16). Mean annual net loads of chromium ranged from 107 lb for Crystal Lake to 1,940 lb for Mission Lake. Mean annual net yields of chromium ranged from 75.0 lb/mi$^2$ for Otis Creek Reservoir to 226 lb/mi$^2$ for Mission Lake (tables 12, 16, 19, 22, and 24).

Median copper concentrations ranged from 17 µg/g in sediment samples from Hiawatha City Lake to 42 µg/g in sediment samples from Gardner City Lake. For seven reservoirs (Centralia Lake, Crystal Lake, Gardner City Lake, Lake Afton, Mission Lake, Otis Creek Reservoir, and Pony Creek Lake), median copper concentrations exceeded the TEL (18.7 µg/g) but were less than the PEL (108 µg/g). For Edgerton and Hiawatha City Lakes, median copper concentrations were less than the TEL (fig. 17). A representative median copper concentration for sediment in Bronson City Lake (that is, representative of the copper originating from the basin) was not available because of the historical application of copper sulfate to control algal blooms in the reservoir (Ellen Harper, city of Bronson, oral commun., 2003). The magnitude of the copper concentrations (table 9) indicated that copper sulfate likely has been applied throughout most of the life of Bronson City Lake. Mean annual net loads of copper ranged from 38 lb for Crystal Lake to 748 lb for Mission Lake. Mean annual net yields of copper ranged from 20.2 lb/mi$^2$ for Otis Creek Reservoir to 87.0 lb/mi$^2$ for Mission Lake (tables 12, 16, 19, 22, and 24).

Median lead concentrations ranged from 19 µg/g in sediment samples from Centralia Lake to 49 µg/g in sediment samples from Crystal Lake. For four reservoirs (Bronson City Lake, Crystal Lake, Gardner City Lake, and Lake Afton), median lead concentrations exceeded the TEL (30.2 µg/g) but were less than the PEL (112 µg/g). Median lead concentrations for the remaining reservoirs were less than the TEL (fig. 18). Mean annual net loads of lead ranged from 67 lb for Crystal Lake to 678 lb for Mission Lake. Mean annual net yields of lead ranged from 22.1 lb/mi$^2$ for Otis Creek Reservoir to 112 lb/mi$^2$ for Crystal Lake (tables 12, 16, 19, 22, and 24).

Median nickel concentrations ranged from 22 µg/g in sediment samples from Edgerton and Hiawatha City Lakes to 43 µg/g in sediment samples from Gardner City Lake. With one exception, median nickel concentrations for all reservoirs exceeded the TEL (15.9 µg/g) but were less than the PEL (42.8 µg/g). The exception was Gardner City Lake for which the median nickel concentration was slightly more than the PEL. Other than Edgerton and Hiawatha City Lakes, median nickel concentrations for the reservoirs were relatively uniform (fig. 19). Mean annual net loads of nickel ranged from 52 lb for Crystal Lake to 958 lb for Mission Lake. Mean annual net yields of nickel ranged from 34.7 lb/mi$^2$ for Otis Creek Reservoir to 111 lb/mi$^2$ for Mission Lake (tables 12, 16, 19, 22, and 24).

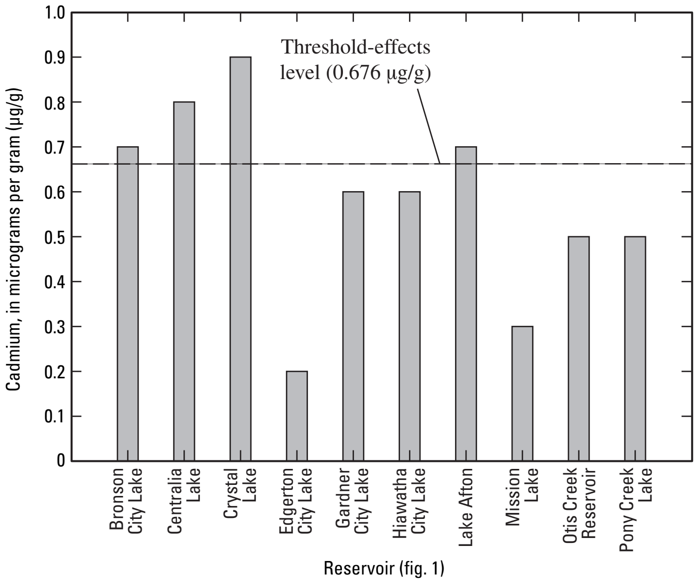



**Figure 15.** Median cadmium concentrations in bottom-sediment core samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1. Threshold-effects level from U.S. Environmental Protection Agency (1997).

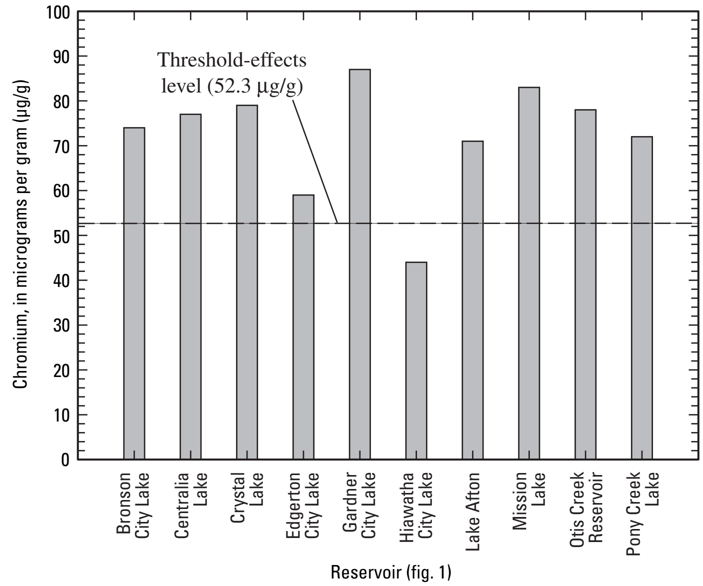



**Figure 16.** Median chromium concentrations in bottom-sediment core samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1. Threshold-effects level from U.S. Environmental Protection Agency (1997).

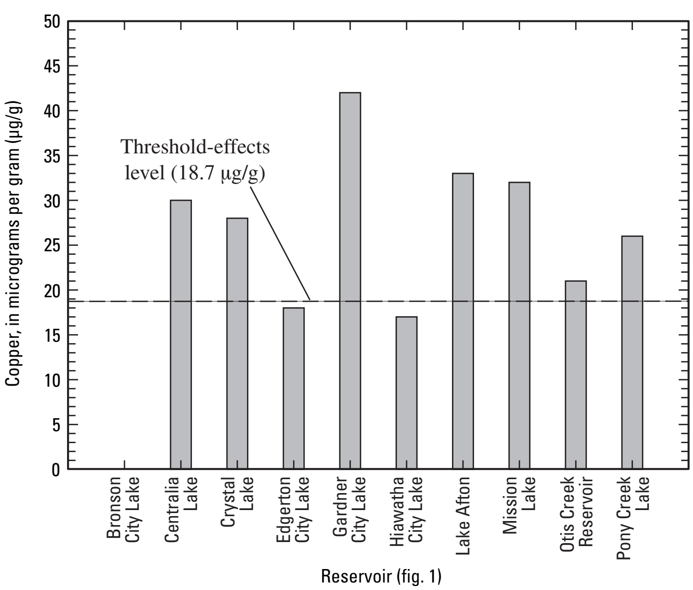



**Figure 17.** Median copper concentrations in bottom-sediment core samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1. Threshold-effects level from U.S. Environmental Protection Agency (1997).

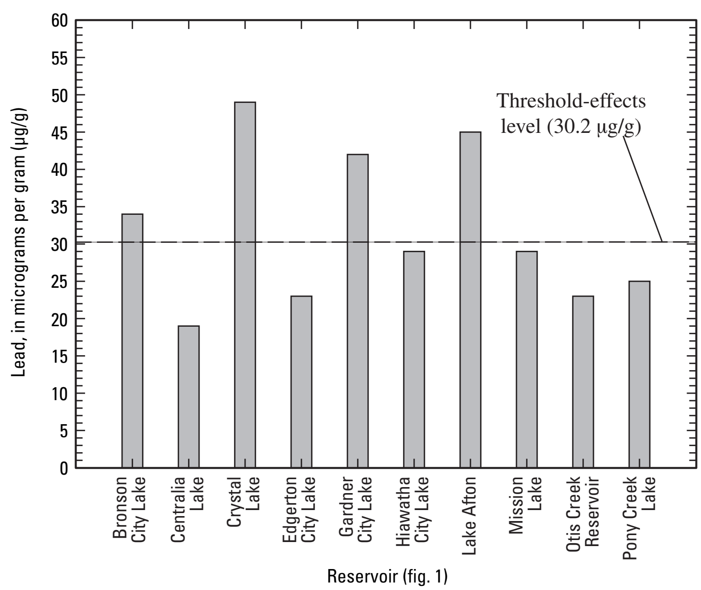



**Figure 18.** Median lead concentrations in bottom-sediment core samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1. Threshold-effects level from U.S. Environmental Protection Agency (1997).

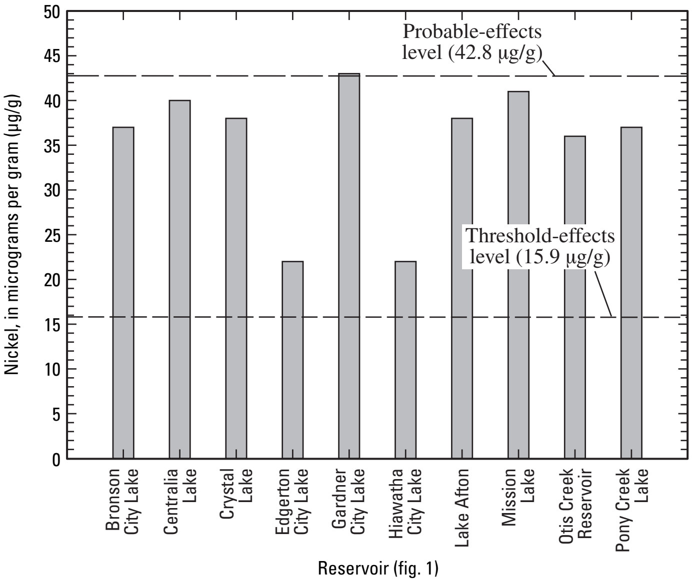



**Figure 19.** Median nickel concentrations in bottom-sediment core samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1. Threshold-effects and probable-effects levels from U.S. Environmental Protection Agency (1997).

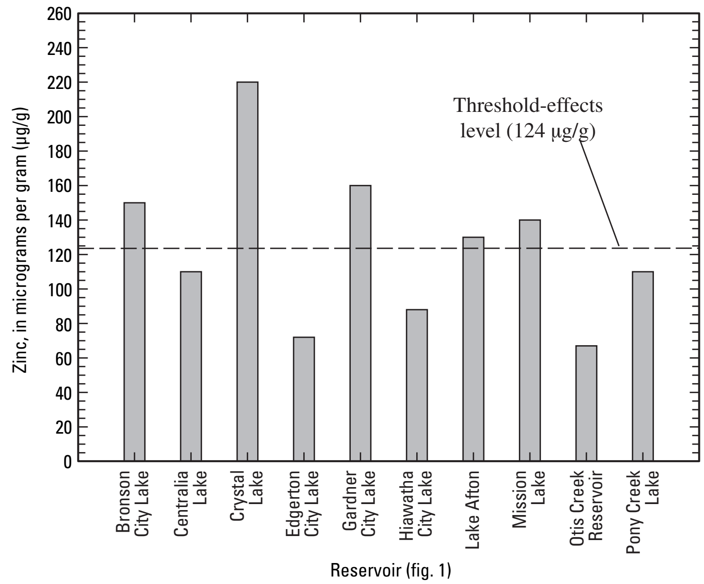



**Figure 20.** Median zinc concentrations in bottom-sediment core samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1. Threshold-effects level from U.S. Environmental Protection Agency (1997).

Median zinc concentrations ranged from 67 µg/g in sediment samples from Otis Creek Reservoir to 220 µg/g in sediment samples from Crystal Lake. For five reservoirs (Bronson City Lake, Crystal Lake, Gardner City Lake, Lake Afton, and Mission Lake), median zinc concentrations exceeded the TEL (124 µg/g) but were less than the PEL (271 µg/g). For the remaining reservoirs, median zinc concentrations were less than the TEL (fig. 20). Mean annual net loads of zinc ranged from 299 lb for Crystal Lake to 3,270 lb for Mission Lake. Mean annual net yields of zinc ranged from 64.6 lb/mi$^2$ for Otis Creek Reservoir to 498 lb/mi$^2$ for Crystal Lake (tables 12, 16, 19, 22, and 24).

## Organochlorine Compounds

Of the 15 organochlorine compounds analyzed in this study (14 insecticides and PCBs), 5 were detected. Chlordane was detected in the bottom sediment from Gardner City Lake (10.3 µg/kg) and Hiawatha City Lake (3.66 µg/kg). In both cases, the chlordane detections exceeded the TEL (2.26 µg/kg). For Gardner City Lake, the detection also exceeded the PEL (4.79 µg/kg). Dieldrin was detected at concentrations less than the TEL (0.715 µg/kg) in the bottom sediment from Bronson City Lake (0.54 µg/kg), Gardner City Lake (0.46 µg/kg), and Hiawatha City Lake (0.34 µg/kg). PCBs were detected at concentrations less than the TEL (21.6 µg/kg) in the bottom sediment from Gardner City Lake (5 µg/kg) and Hiawatha City Lake (6 µg/kg).

DDT was not detected in any of the bottom-sediment samples analyzed for the 10 reservoirs. However, its degradation products DDD and DDE were detected. DDD was detected only in a sediment sample from Hiawatha City Lake at a concentration (1.19 µg/kg) that was less than the TEL (1.22 µg/kg). With the exception of Otis Creek Reservoir, DDE was detected in the sediment samples analyzed for all of the reservoirs. DDE concentrations ranged from 0.20 µg/kg in the sediment sample from Pony Creek Lake to 4.76 µg/kg in the sediment sample from Crystal Lake (fig. 21). With the exception of Crystal Lake, DDE concentrations were less than the TEL (2.07 µg/kg).

Overall, the number of organochlorine compounds detected in bottom-sediment samples ranged from none for Otis Creek Reservoir to five for Hiawatha City Lake. Multiple organochlorine compounds were detected in samples from Bronson City Lake (DDE, dieldrin), Gardner City Lake (chlordane, DDE, dieldrin, PCBs), and Hiawatha City Lake (chlordane, DDD, DDE, dieldrin, PCBs).

# Natural and Human Effects on Sediment and Constituent Deposition

Sediment yield varies substantially among reservoir basins in Kansas. In an attempt to partially explain the differences, the estimated sediment yields for several small and large reservoirs were compared to factors that affect soil erosion. Specifically, the factors included were precipitation, soil permeability, slope, and land use (table 26). Statistical analysis, with a significance level of 0.05, indicated a significant positive correlation (significant at the 0.001 level) between sediment yield and mean

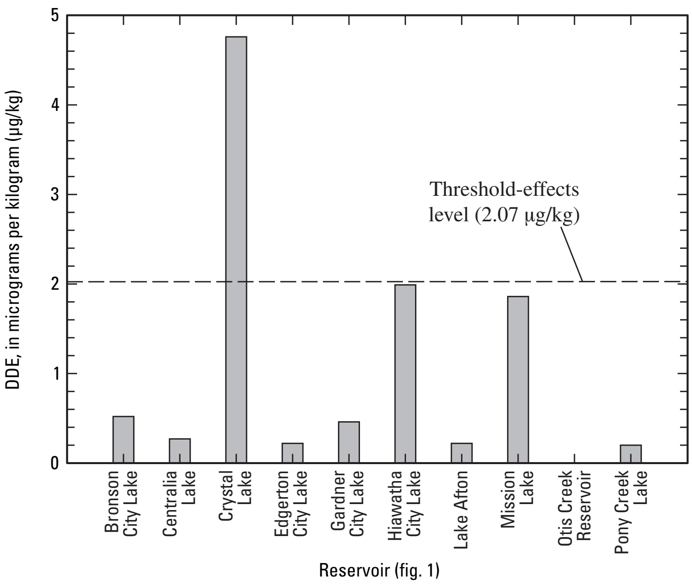



**Figure 21.** DDE concentrations in bottom-sediment core samples collected from 10 small reservoirs in eastern Kansas, fall 2002 and spring 2003. Location of reservoirs shown in figure 1. Threshold-effects level from U.S. Environmental Protection Agency (1997).

annual precipitation (Spearman's rho = 0.86). No statistically significant correlation (at the 0.05 level) was determined for the relation between sediment yield and mean depth-weighted soil permeability, mean basin slope, percentage of cropland, and percentage of grassland and woodland. Thus, for the 11 reservoirs included in this analysis, mean annual precipitation was the best predictor of sediment yield.

In the discussion that follows, it should be kept in mind that the chemical results for Edgerton and Hiawatha City Lakes may not be directly comparable with the other reservoirs because of differences in the particle-size composition of the sediment. Specifically, some (but not all) of the bottom-sediment samples analyzed for these two reservoirs contained a somewhat greater percentage of sand. Typically, the concentrations of nutrients (figs. 11*A* and 11*B*) and selected trace elements (figs. 14–20) in the bottom-sediment samples from these two reservoirs were small in comparison to samples from the other reservoirs. A possible interpretation is that the constituent concentrations may be somewhat underrepresented due to the greater percentage of sand in the sediment (Horowitz and Elrick, 1987).

Nutrient concentrations in the bottom sediment varied substantially among the 10 small reservoirs sampled for this study. Variability of nutrient concentrations in sediment is due partly to the variability in natural sources (that is, soils and bedrock) among basins and also to the effects of human activity (for example, septic systems, crop and livestock production). A comparison of median nutrient concentrations with land use in the basins is provided in table 27. Statistical analysis, with a significance level of 0.05, indicated no significant correlations between median total nitrogen or total phosphorus concentrations in bottom sediment and any of the land-use categories (that is, cropland, grassland, woodland, and urban). Likewise, no significant correlations (at the 0.05 level of significance) were indicated between the top-interval (most-recent) total nitrogen and total phosphorus concentrations and any of the land-use categories. Thus, the variability of nutrient concentrations in sediment may be due, in part, to factors for which information is not readily available. Such information includes background nutrient availability from the soils and bedrock in the basins, historical land-management practices, historical application of fertilizers, historical livestock production, and in-reservoir biological processes. A comparison of nutrient yields with land use for the five reservoirs for which nutrient yields were estimated also indicated no discernible relation.

A positive trend in nutrient concentration was indicated for four of the reservoirs. For Crystal Lake, statistically significant positive trends (that is, nutrient concentration increased toward the top of the sediment core) were indicated for both total nitrogen and total phosphorus. For Mission Lake, a statistically significant positive trend was indicated for total phosphorus. For Bronson and Hiawatha City Lakes, possible positive trends for total nitrogen were indicated. However, because the respective cores for these two reservoirs were sampled only for three and five intervals, respectively, an analysis to determine the statistical significance of the trends was not appropriate. These positive trends in nutrient concentration may be related, in part, to changes in human activity in the basins. For example, fertilizer use in Kansas has increased in recent years. Statewide, total annual fertilizer sold by State fiscal year (July 1 through June 30) fluctuated in the range of about 1,300,000 to 1,600,000 tons from 1979–80 to 1989–90. Then, from 1990–91 to 2000–01, total annual fertilizer sold increased from about 1,500,000 to 2,700,000 tons (Kansas Department of Agriculture, 2002). It also is possible that the trends in nutrient concentration may be caused, in part, by diagenesis (that is, postdepositional changes in the sediment caused by various processes including decomposition) (Fitzpatrick and others, 2003).

A comparison of the reservoirs in terms of the relative concentration of selected trace elements in the bottom sediment indicated probable human-related effects. Typically, Crystal Lake and Gardner City Lake were among the reservoirs with the largest median sediment concentrations for the seven trace elements considered (that is, arsenic, cadmium, chromium, copper, lead, nickel, and zinc) (figs. 14–20). Crystal Lake had the largest median concentrations for cadmium, lead, and zinc. Gardner City Lake had the largest median concentrations for arsenic (along with Centralia Lake), chromium, and copper. Crystal Lake and Gardner City Lake are the only two reservoirs with a substantial percentage of urban land use in their basins (table 2).

Trace element yields were compared to land use for the five reservoirs for which yields were estimated. For the seven trace elements considered, Crystal and Mission Lakes had the largest yields. Specifically, Crystal Lake had the largest yields for cadmium, lead, and zinc. Mission Lake had the largest yields for arsenic, chromium, copper, and nickel. The trace element

**Table 26.** Sediment yield, precipitation, soil permeability, slope, and land use for selected reservoir basins in Kansas.

[Reservoir basins are ordered from largest to smallest in sediment yield. Location of reservoirs shown in figure 1]

| Reservoir basin | Sediment yield[1] (acre-feet per square mile per year) | Mean annual precipitation[2] (inches) | Mean depth-weighted soil permeability[3] (inches per hour) | Mean basin slope[4] (percent) | Land use | |
|---|---|---|---|---|---|---|
| | | | | | Cropland[5] (percent) | Grassland and woodland[5] (percent) |
| **Small reservoir basins** | | | | | | |
| Mound City Lake | 2.03 | 40 | 0.9 | 4.1 | 16.3 | 79.5 |
| Crystal Lake | 1.72 | 40 | .8 | 2.7 | 10.7 | 66.0 |
| Mission Lake | 1.42 | 35 | .3 | 3.8 | 69.9 | 26.4 |
| Gardner City Lake | .85 | 39 | .3 | 2.4 | 30.8 | 46.4 |
| Otis Creek Reservoir | .71 | 33 | .4 | 5.2 | .1 | 96.5 |
| Lake Afton | .66 | 30 | 1.0 | 3.4 | 81.0 | 15.2 |
| **Large reservoir basins** | | | | | | |
| Perry Lake | 1.59 | 37 | .5 | 5.3 | 40.0 | 57.0 |
| Hillsdale Lake | .97 | 41 | .6 | 3.6 | 35.4 | 57.3 |
| Tuttle Creek Lake | .40 | 30 | .9 | 3.1 | 66.0 | 32.0 |
| Cheney Reservoir | .22 | 27 | 5.0 | 1.1 | 72.7 | 25.4 |
| Webster Reservoir | .03 | 21 | 1.6 | 3.7 | 61.1 | 38.3 |

[1]Sediment volume information for Mound City Lake from Kansas Water Authority (2001). Sediment volume information for large reservoirs from Juracek (1997, 2003), Christensen (1999), Mau (2001), and Juracek and Mau (2002).

[2]High Plains Regional Climate Center (2002).

[3]Juracek (2000).

[4]Mean basin slope computed using 30-meter digital elevation model (DEM) data available from the U.S. Geological Survey (2003).

[5]Kansas Applied Remote Sensing Program (1993) and U.S. Geological Survey (2000).

yields for Gardner City Lake and Lake Afton were intermediate. Otis Creek Reservoir had the smallest yields for all seven trace elements. Other than the fact that the smallest trace element yields were for a reservoir with a basin that contained virtually no cropland and no urban land use (Otis Creek Reservoir), the relation between trace element yields and land use for the reservoirs was not readily apparent.

The history of leaded gasoline usage apparently was documented by lead deposition in the bottom sediment of Crystal Lake (table 11, fig. 5*B*), Gardner City Lake (table 15), Hiawatha City Lake (table 17), Lake Afton (table 18), and, to a lesser degree, Mission Lake (table 21). That is, the reversal from an initial positive trend to a negative trend reflects the historical increase in consumption of leaded gasoline from the 1920s until the late 1970s when the phase out of lead from gasoline began (Callender and Van Metre, 1997; Callender and Rice, 2000). The fact that the largest median lead concentration was measured in the bottom sediment of Crystal Lake likely is because of the presence of the well-traveled U.S. Highway 59, which is located within the Crystal Lake Basin less than 100 ft upstream from the reservoir shore. In contrast, lead deposition in the bottom sediment of Otis Creek Reservoir was uniform through time (table 23). The lack of trend at this location may be attributable to the remote location of the Otis Creek Reservoir Basin, which is several miles from the nearest highway in every direction.

The variability of zinc concentrations in the bottom sediment of the reservoirs also likely was affected by human activity. A significant source of zinc is vehicular tire wear. Callender and Rice (2000) determined that increased zinc concentrations in sediment are related to increased vehicular traffic. The fact that the largest median zinc concentration was measured in the bottom sediment from Crystal Lake likely was because of its proximity to U.S. Highway 59. The fact that the smallest median zinc concentration was measured in the bottom sediment from Otis Creek Reservoir likely was because of the relative absence of vehicular traffic in and near its basin.

With one exception, organochlorine compounds typically were not detected in the most recently deposited bottom sediment of the reservoirs. The exception was DDE, a degradation product of DDT. DDE was detected in the bottom sediment of every reservoir except Otis Creek Reservoir, which has a basin that is virtually without cropland (table 2). Statistical analysis, with a significance level of 0.05, indicated no significant correlations between DDE concentrations in bottom sediment and

**Table 27.** Median total nitrogen and total phosphorus concentrations in bottom sediment and basin land use for 10 small reservoirs in eastern Kansas.

[N, median total nitrogen concentration; P, median total phosphorus concentration; mg/kg, milligrams per kilogram. Land-use data from Kansas Applied Remote Sensing Program (1993). Location of reservoirs shown in figure 1]

| Reservoir | N (mg/kg) | P (mg/kg) | Basin land use (percent) | | | |
|---|---|---|---|---|---|---|
| | | | Cropland | Grassland | Woodland | Urban |
| Bronson City Lake | 3,700 | 1,100 | 61.0 | 29.5 | 6.5 | 0 |
| Centralia Lake | 2,400 | 1,300 | 77.1 | 17.6 | 2.1 | 0 |
| Crystal Lake | 3,000 | 825 | 10.7 | 65.3 | .7 | 18.0 |
| Edgerton City Lake | 1,800 | 550 | 58.7 | 31.5 | 4.3 | 3.9 |
| Gardner City Lake | 3,000 | 1,200 | 30.8 | 43.0 | 3.4 | 17.3 |
| Hiawatha City Lake | 1,400 | 550 | 78.0 | 18.7 | 2.3 | 0 |
| Lake Afton | 2,300 | 810 | 81.0 | 14.3 | .9 | 0 |
| Mission Lake | 2,100 | 890 | 69.9 | 25.0 | 1.4 | .5 |
| Otis Creek Reservoir | 2,300 | 620 | .1 | 96.4 | .1 | 0 |
| Pony Creek Lake | 3,400 | 1,200 | 52.8 | 32.8 | 3.5 | 5.6 |

land use (that is, cropland and urban) in the basins. The detection of DDE in the bottom sediment of the nine reservoirs indicated that the historical use of DDT was widespread in eastern Kansas. Moreover, it indicated that the basins continue to be a source of DDE to the reservoirs more than 30 years after the use of DDT was banned.

Otis Creek Reservoir was included in this study for the purpose of comparison. Because of its relatively remote location and the fact that land use in its basin is almost exclusively grassland (table 2), Otis Creek Reservoir provided an opportunity to assess human-related effects on the deposition of chemical constituents in the bottom sediment of the other reservoirs. For total nitrogen, total phosphorus, arsenic, cadmium, copper, lead, and zinc, the bottom-sediment concentrations in samples from Otis Creek Reservoir were typically among the smallest measured (figs. 11*A*, 11*B*, 14–20). For chromium and nickel, the bottom-sediment concentrations in samples from Otis Creek Reservoir were comparable to samples from the other reservoirs (with the exception of Edgerton and Hiawatha City Lakes for which the chromium and nickel concentrations were relatively small and possibly underrepresented). Among the five reservoir basins for which yields were computed, Otis Creek Reservoir Basin had the smallest mean annual net yield for sediment, total nitrogen, total phosphorus, and most of the trace elements. Otis Creek Reservoir was the only reservoir for which no organochlorine compounds were detected in the bottom sediment.

# Summary and Conclusions

Many municipalities in Kansas rely on small reservoirs as a source of drinking water and for recreational activities. Because of their significance to the community, management of the reservoirs and the associated basins is important to protect the reservoirs from degradation. Effective reservoir management requires information about water quality, sedimentation, and sediment quality. A 2-year study by the U.S. Geological Survey, in cooperation with the Kansas Department of Health and Environment, was begun in 2002 to estimate sedimentation and the deposition of various chemical constituents in 10 small reservoirs in eastern Kansas.

A combination of bathymetric surveying and bottom-sediment coring during 2002 and 2003 was used to investigate sediment deposition and the occurrence of selected nutrients (total nitrogen and total phosphorus), organic and total carbon, 26 trace elements, 15 organochlorine compounds, and 1 radionuclide in the bottom sediment of the 10 small reservoirs. Original water-storage capacities of the reservoirs ranged from 23 acre-ft for Edgerton City Lake to 5,845 acre-ft for Otis Creek Reservoir. Reservoir basin areas ranged from 0.6 $mi^2$ for Crystal Lake to 14.0 $mi^2$ for Otis Creek Reservoir.

The estimated mean annual net volume of deposited sediment ranged from about 43,600 $ft^3$ in Crystal Lake to about 531,000 $ft^3$ in Mission Lake. The estimated mean annual net mass of deposited sediment ranged from 1,360,000 lb in Crystal Lake to 23,300,000 lb in Mission Lake. Mean annual net sediment yields from the reservoir basins ranged from 964,000 lb/$mi^2$ for Otis Creek Reservoir to 2,710,000 lb/$mi^2$ for Mission Lake. Compared to sediment yield estimates provided in a statewide study by Collins (1965), the estimates determined in this study differed substantially and were typically smaller. A statistically significant positive correlation was determined for the relation between sediment yield and mean annual precipitation.

Nutrient concentrations in the bottom sediment varied substantially among the reservoirs. Median total nitrogen concentrations ranged from 1,400 mg/kg in sediment samples from Hiawatha City Lake to 3,700 mg/kg in samples from Bronson City Lake. Median total phosphorus concentrations ranged from 550 mg/kg in sediment samples from Edgerton and Hiawatha City Lakes to 1,300 mg/kg in samples from Centralia Lake. For Crystal Lake, statistically significant positive trends (that is, nutrient concentration increased toward the top of the sediment core) were indicated for both total nitrogen and total phosphorus. For Mission Lake, a statistically significant positive trend was indicated for total phosphorus. For Bronson and Hiawatha City Lakes, a possible positive trend for total nitrogen was indicated. These possible positive trends in nutrient concentration may be related to a statewide increase in fertilizer use. Alternatively, the trends may be indicative of diagenesis (that is, postdepositional changes in the sediment caused by various processes including decomposition).

Nutrient loads and yields also varied substantially among the reservoirs. Estimated mean annual net loads of total nitrogen deposited in the bottom sediment ranged from 4,080 lb for Crystal Lake to 49,100 lb for Mission Lake. Estimated mean annual net loads of total phosphorus deposited in the bottom sediment ranged from 1,120 lb for Crystal Lake to 20,800 lb for Mission Lake. Estimated mean annual net yields of total nitrogen from the basins ranged from 2,210 lb/mi$^2$ for Otis Creek Reservoir to 6,800 lb/mi$^2$ for Crystal Lake. Estimated mean annual net yields of total phosphorus from the basins ranged from 598 lb/mi$^2$ for Otis Creek Reservoir to 2,420 lb/mi$^2$ for Mission Lake.

Compared to nonenforceable sediment-quality guidelines adopted by the U.S. Environmental Protection Agency, bottom-sediment concentrations of arsenic, chromium, copper, and nickel in samples from all 10 reservoirs typically exceeded the threshold-effects levels (TELs) but were less than the probable-effects levels (PELs). TELs represent the concentrations above which toxic biological effects occasionally occur in aquatic organisms, whereas PELs represent the concentrations above which toxic biological effects usually or frequently occur. Concentrations of cadmium, lead, and zinc exceeded the TELs but were less than the PELs in sediment samples from about one-half of the reservoirs with the concentrations for these three trace elements being less than the TELs in samples from the remaining reservoirs. Mercury concentrations were less than the TEL (information only available for four reservoirs). Silver was not detected in the bottom sediment from any of the 10 reservoirs sampled. Trace element concentrations at the bottom of the sediment core for Crystal Lake indicated the possibility that, for certain constituents in certain areas, baseline concentrations may equal or exceed the TELs prior to the effects of human activity.

With few exceptions, organochlorine compounds typically either were not detected or were detected at concentrations that were less than the TELs. Compounds detected included chlordane (Gardner and Hiawatha City Lakes), DDD (Hiawatha City Lake), DDE (every reservoir except Otis Creek Reservoir), dieldrin (Bronson, Gardner, and Hiawatha City Lakes), and PCBs (Gardner and Hiawatha City Lakes). The exceptions included chlordane detections, which exceeded the TEL in a sediment sample from Hiawatha City Lake and exceeded the PEL in samples from Gardner City Lake. Also, the DDE detection in a sediment sample from Crystal Lake exceeded the TEL but was less than the PEL.

The effects of human activity are evident in the bottom sediment of all 10 reservoirs with the possible exception of Otis Creek Reservoir. Evidence includes possible positive trends in nutrient deposition, elevated concentrations and trends of certain trace elements (for example, copper, lead, and zinc), and detectable concentrations of organochlorine compounds.

Information in this report may be used to partly reconstruct historical sediment-quality and water-quality records and to provide a present-day baseline with which to evaluate long-term changes in reservoir sediment and water quality that may reflect changes in human activity in the basins. Also, the information in this report may be used to assist in the development, implementation, evaluation, and revision of total maximum daily loads for sediment and associated chemical constituents that contribute to the water quality of the reservoirs.

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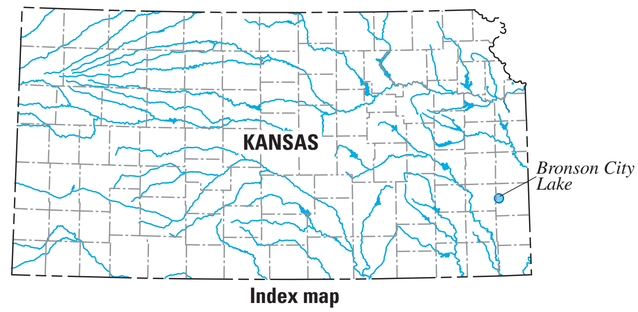
# Supplemental Information

**Table 28.** Latitude and longitude coordinates, water depth, estimated sediment thickness, length of recovered core, and estimated recovery percentage for bottom-sediment coring sites at 10 small reservoirs in eastern Kansas.

[--, not determined]

| Reservoir (fig. 1) | Date cored (month/day/year) | Coring site number (figs. 22–31) | Latitude (decimal degrees) | Longitude (decimal degrees) | Water depth (feet) | Estimated sediment thickness[1] (inches) | Length of recovered core (inches) | Estimated recovery percentage |
|---|---|---|---|---|---|---|---|---|
| Bronson City Lake | 04/03/03 | 1 | 37.8866 | 95.0329 | 23 | -- | 11 | -- |
| | | 2 | 37.8876 | 95.0355 | 12 | -- | 14 | -- |
| Centralia Lake | 05/02/03 | 1 | 39.7025 | 96.1574 | 26 | 78 | 40 | 51 |
| | | 2 | 39.6933 | 96.1500 | 13.5 | 54 | 27 | 50 |
| | | 3 | 39.7040 | 96.1418 | 16 | 66 | 32 | 48 |
| Crystal Lake | 04/10/03 | 1 | 38.2677 | 95.2456 | 11 | 84 | 63 | 75 |
| | | 2 | 38.2688 | 95.2474 | 4.5 | 48 | 27 | 56 |
| Edgerton City Lake | 11/12/02 | 1 | 38.7629 | 95.0047 | 4.5 | -- | 50 | -- |
| | | 2 | 38.7638 | 95.0039 | 4.5 | -- | 37 | -- |
| Gardner City Lake | 10/21/02 | 1 | 38.8520 | 94.9295 | 35 | 108 | 66 | 61 |
| | | 2 | 38.8443 | 94.9240 | 16 | 66 | 47 | 71 |
| Hiawatha City Lake | 10/02/02 | 1 | 39.8257 | 95.5304 | 1.2 | -- | 35 | -- |
| | | 2 | 39.8257 | 95.5298 | 1.8 | -- | 33 | -- |
| Lake Afton | 10/17/02 | 1 | 37.6095 | 97.6274 | 22 | 120 | 96 | 80 |
| | | 2 | 37.6150 | 97.6295 | 14 | -- | 49 | -- |
| Mission Lake | 10/23/02 | 1 | 39.6758 | 95.5153 | 11 | 120 | 88 | 73 |
| | | 2 | 39.6818 | 95.5190 | 7 | -- | 77 | -- |
| Otis Creek Reservoir | 09/10/02 | 1 | 37.9401 | 96.4654 | 27 | -- | 8 | -- |
| | | 2 | 37.9433 | 96.4648 | 27 | -- | 7 | -- |
| Pony Creek Lake | 05/21/03 | 1 | 39.9451 | 95.7782 | 31 | 48 | 36 | 75 |
| | | 2 | 39.9404 | 95.7825 | 18 | -- | 20 | -- |

[1] Sediment thickness estimated as depth of penetration of gravity corer for sites at which the entire thickness of bottom sediment was penetrated.



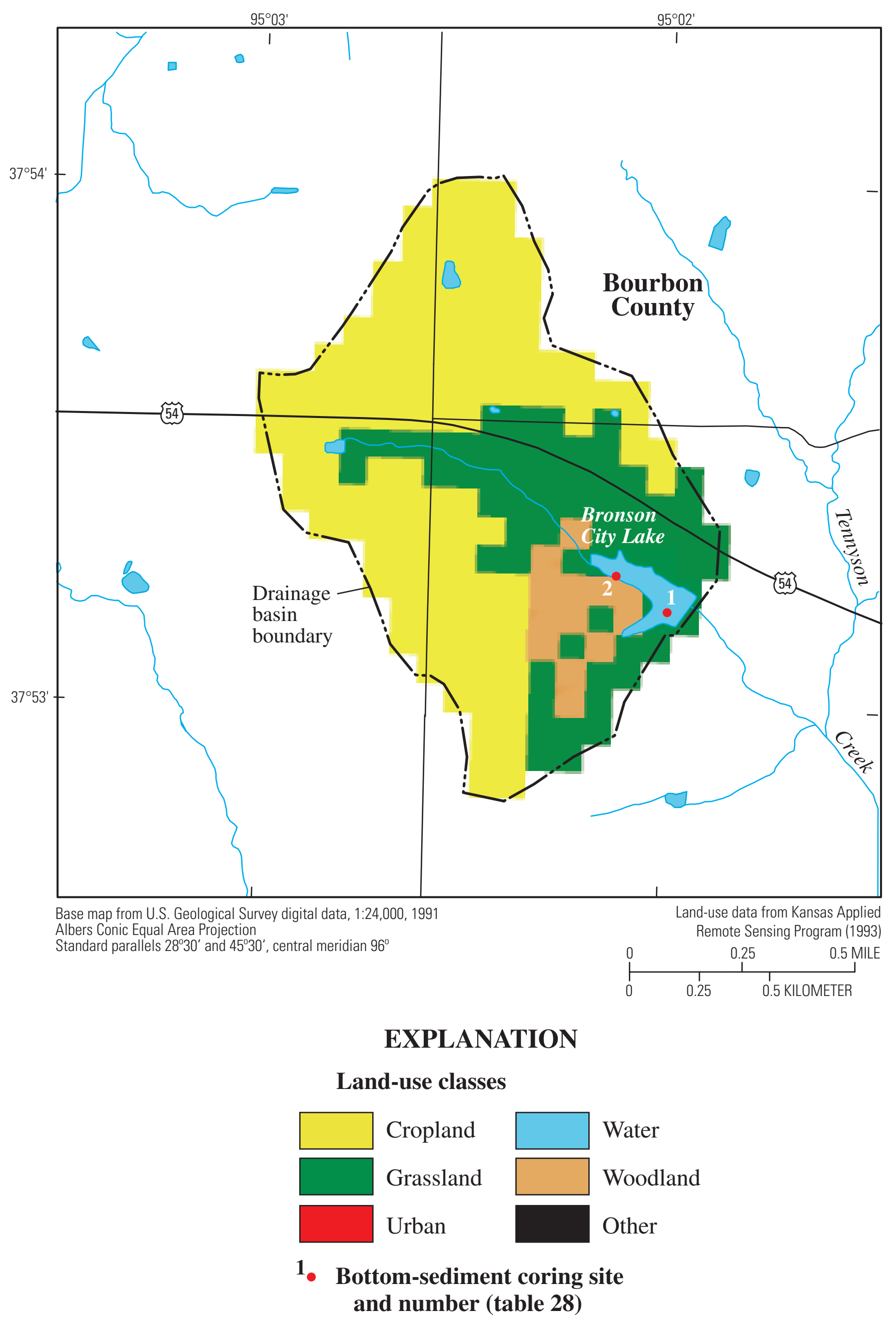




**Figure 22.** Land use in reservoir basin and location of bottom-sediment coring sites in Bronson City Lake.

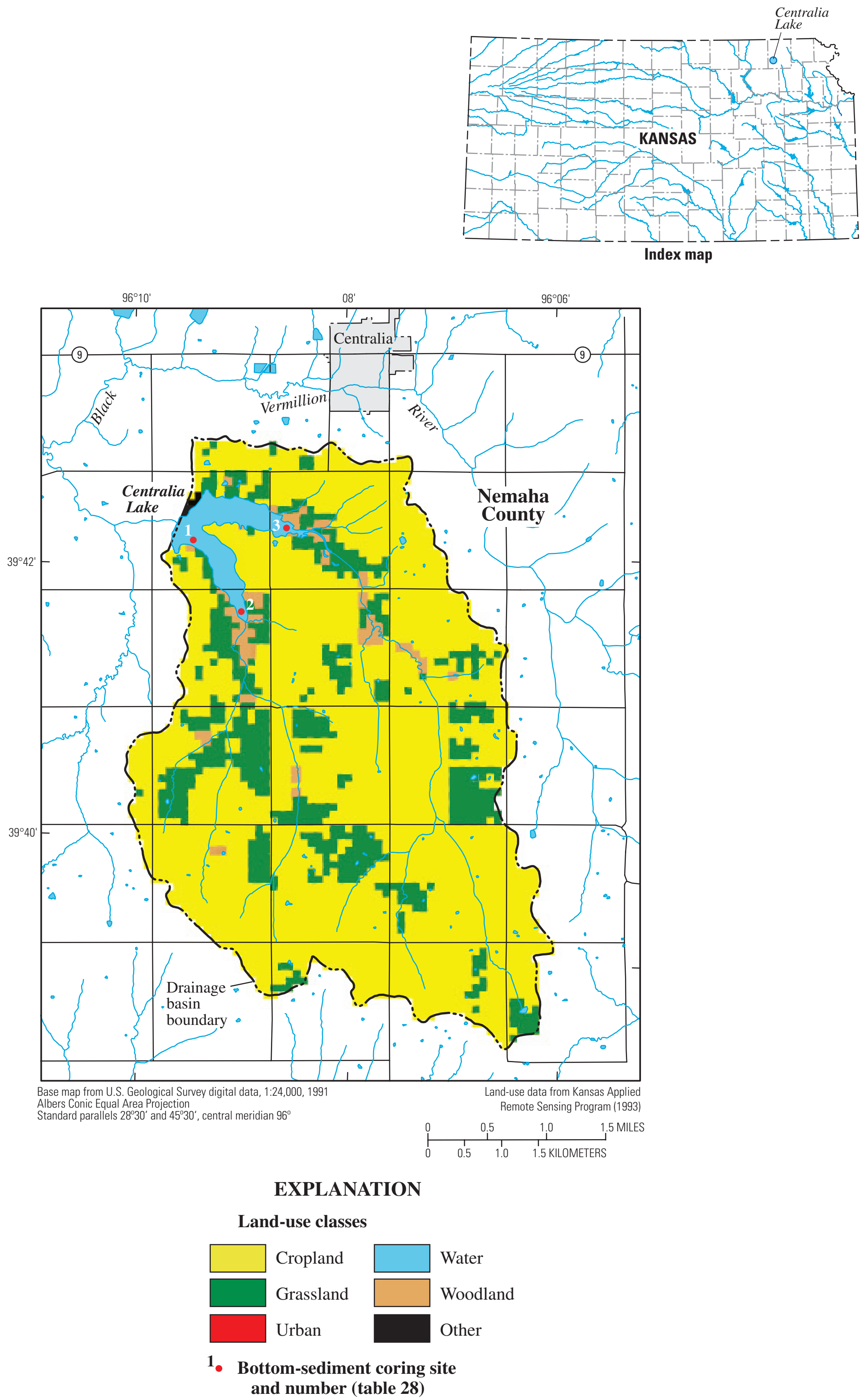
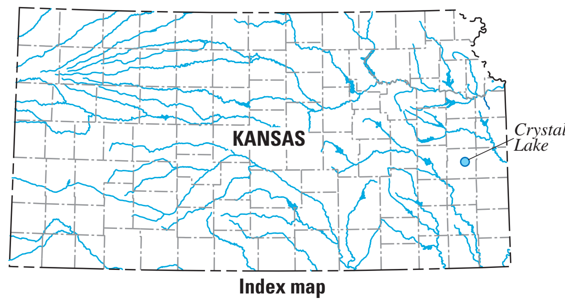



**Figure 23.** Land use in reservoir basin and location of bottom-sediment coring sites in Centralia Lake.



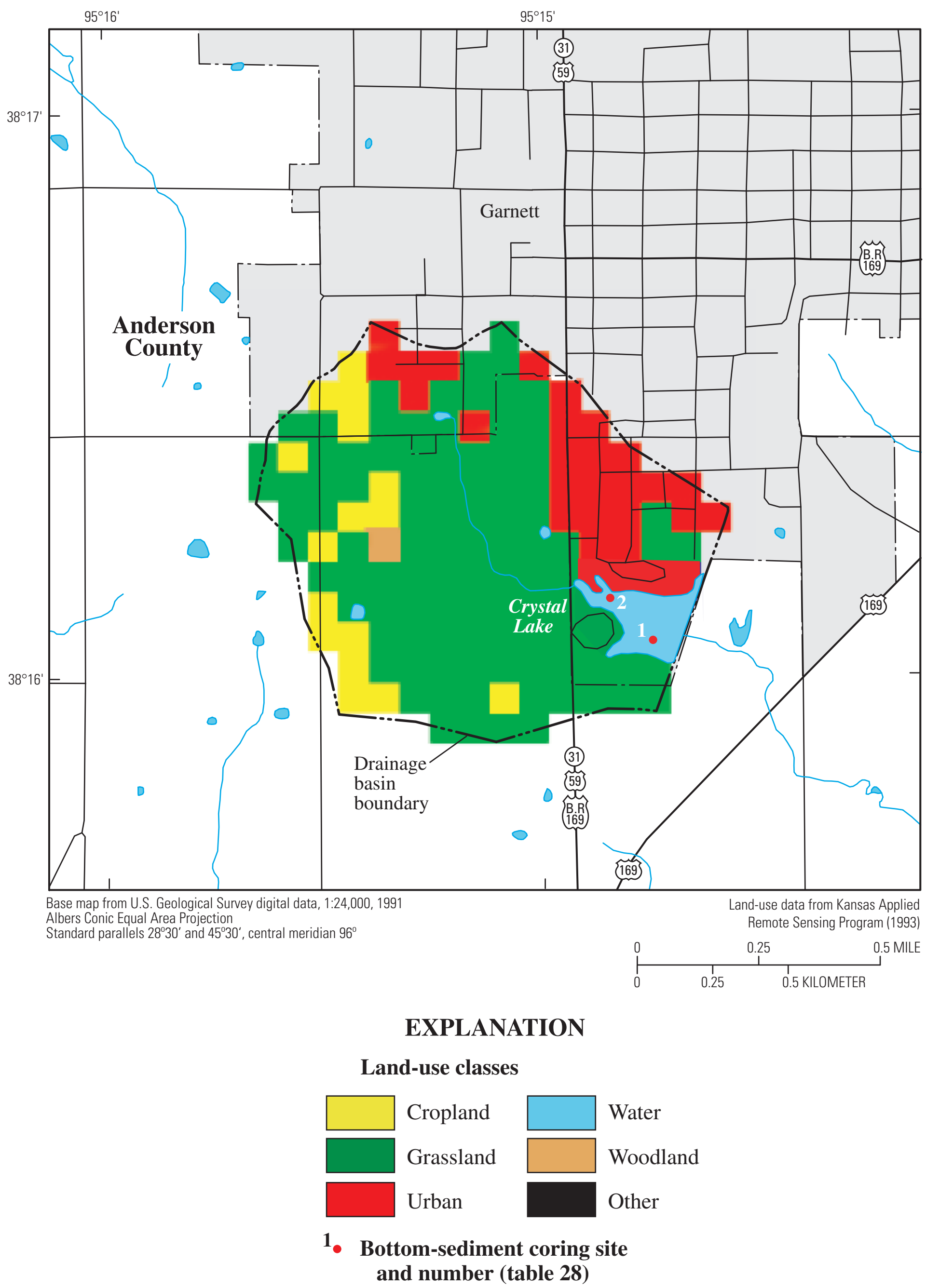




**Figure 24.** Land use in reservoir basin and location of bottom-sediment coring sites in Crystal Lake.

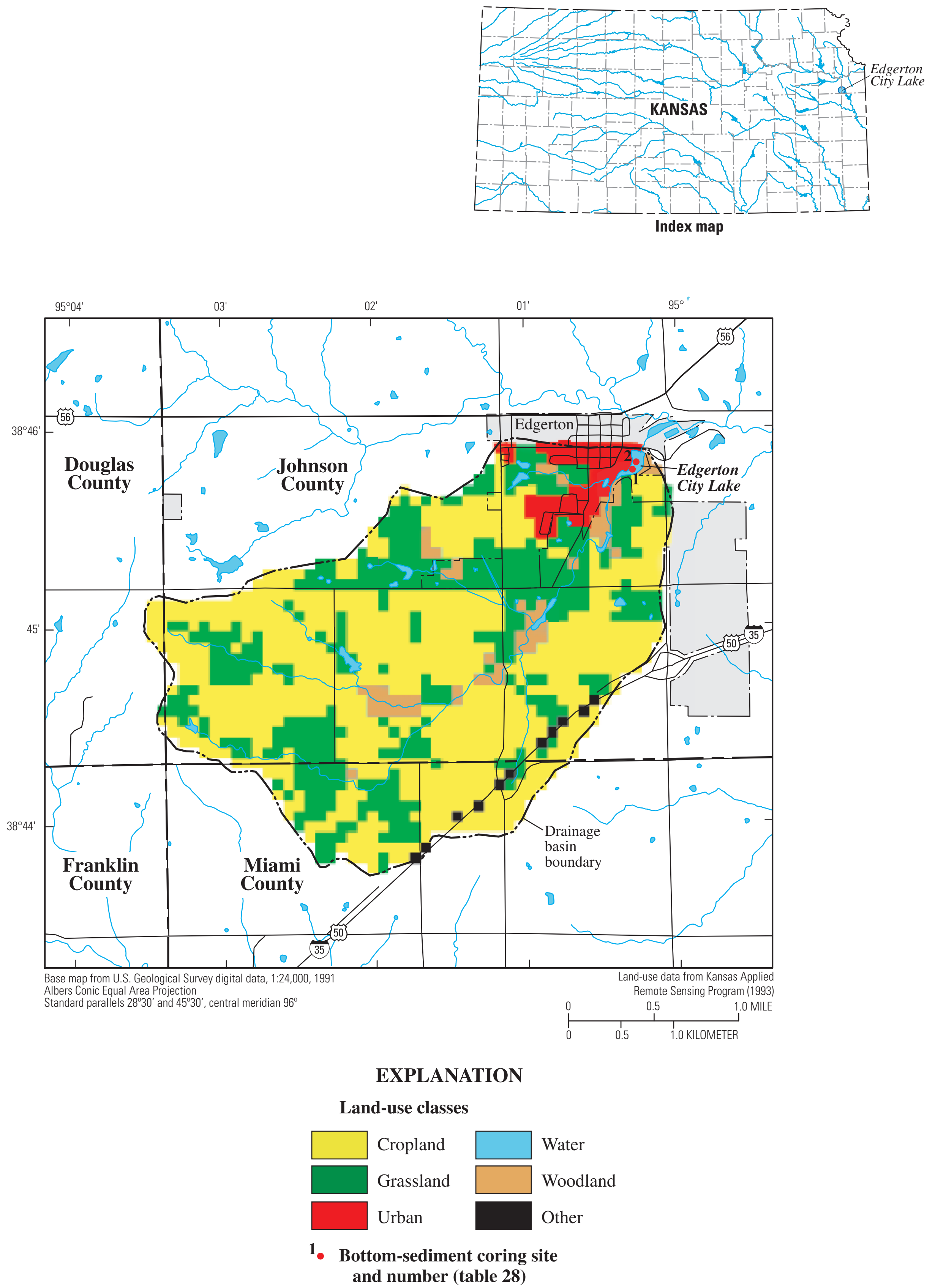
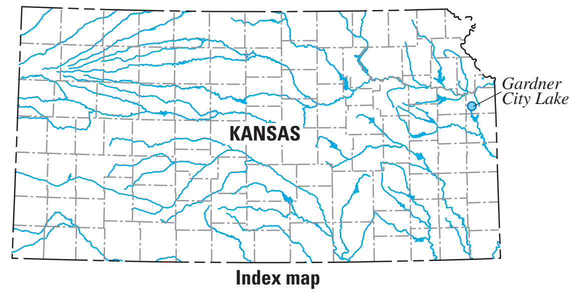



**Figure 25.** Land use in reservoir basin and location of bottom-sediment coring sites in Edgerton City Lake.



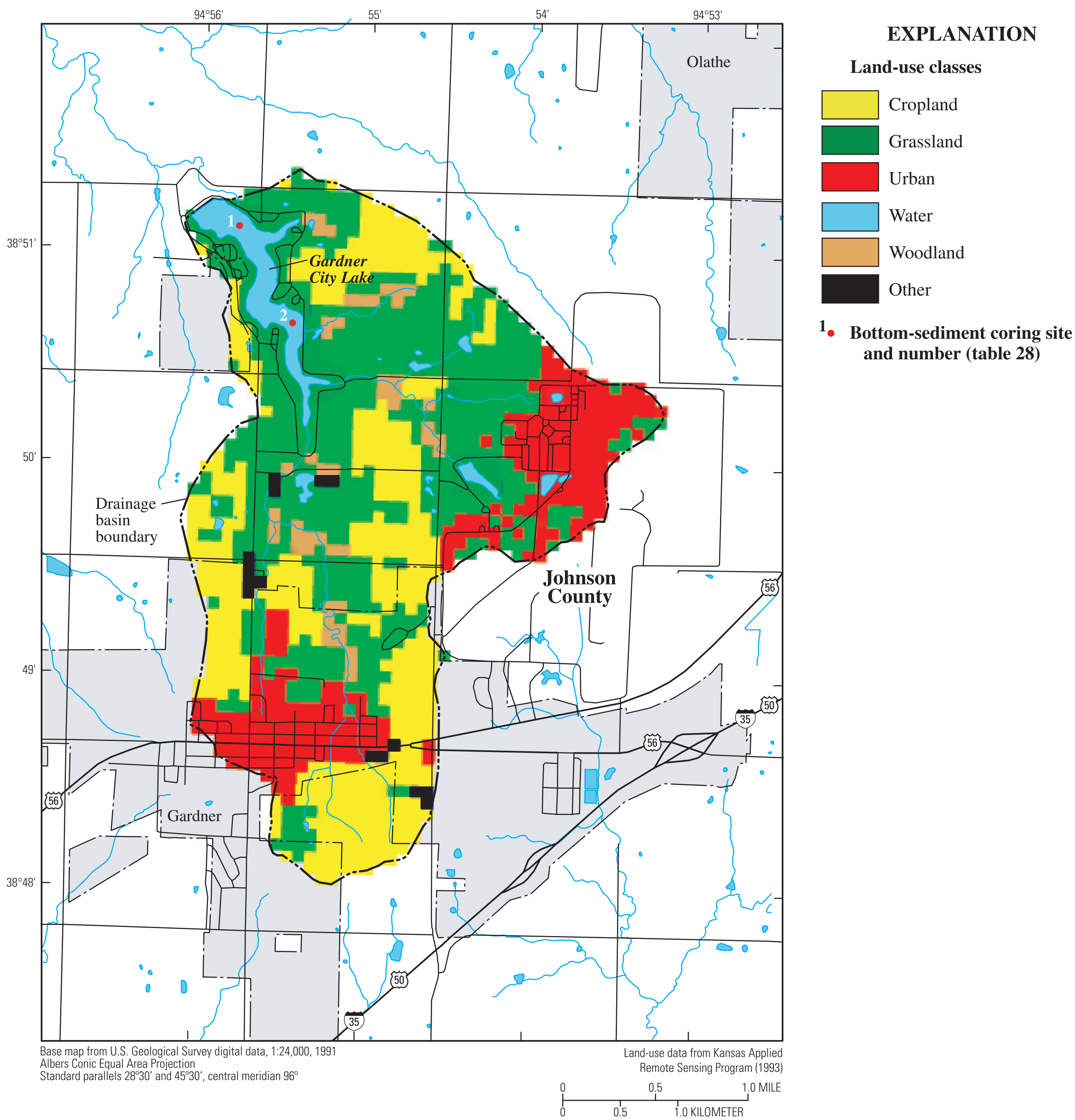




**Figure 26.** Land use in reservoir basin and location of bottom-sediment coring sites in Gardner City Lake.

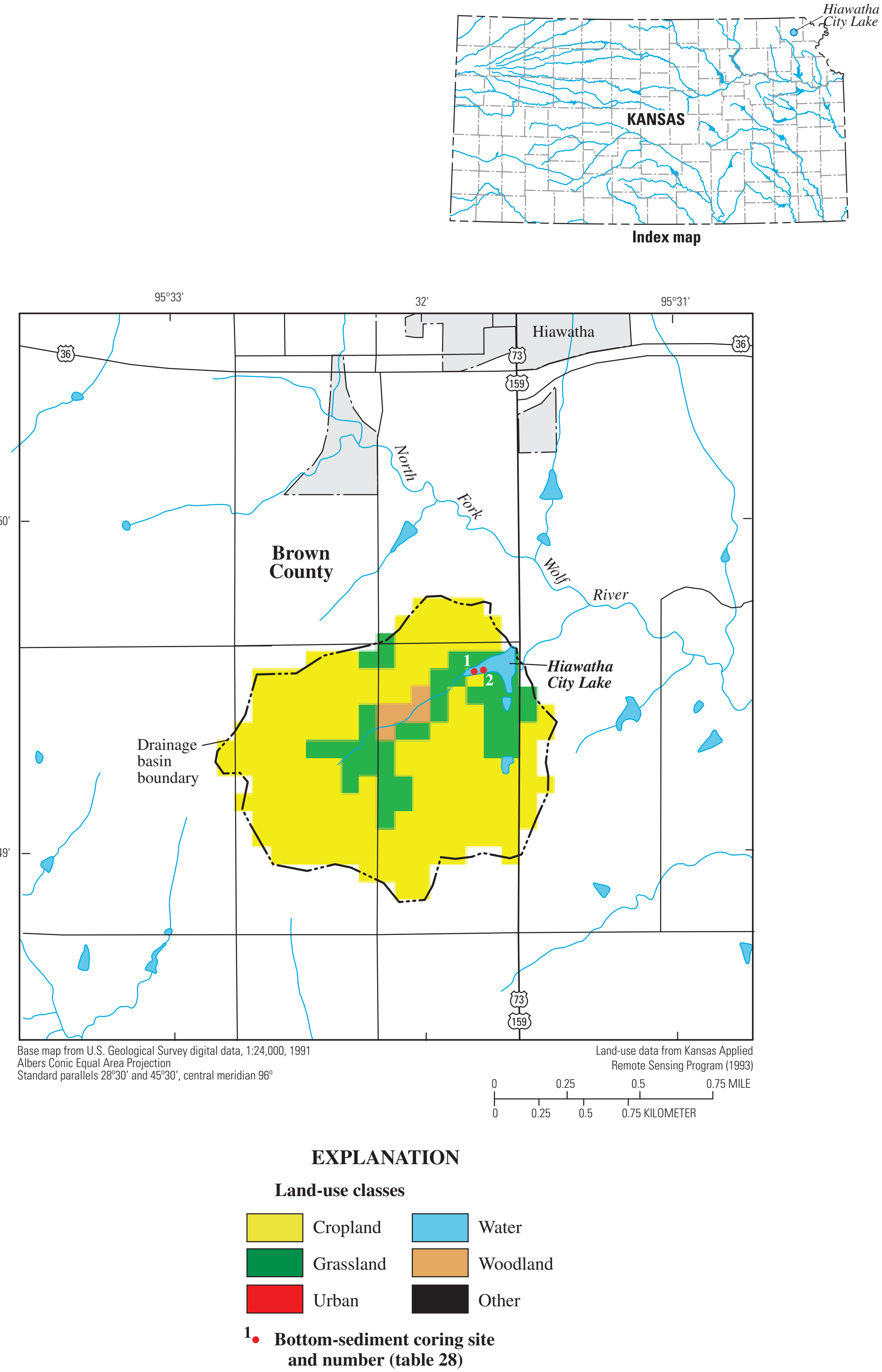
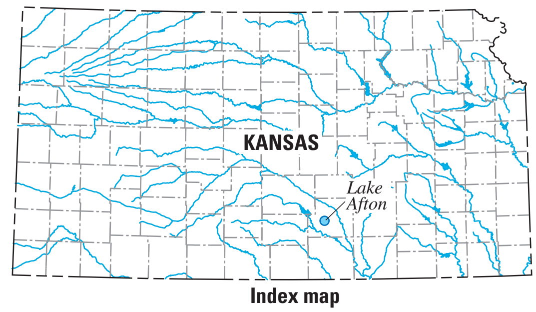



**Figure 27.** Land use in reservoir basin and location of bottom-sediment coring sites in Hiawatha City Lake.



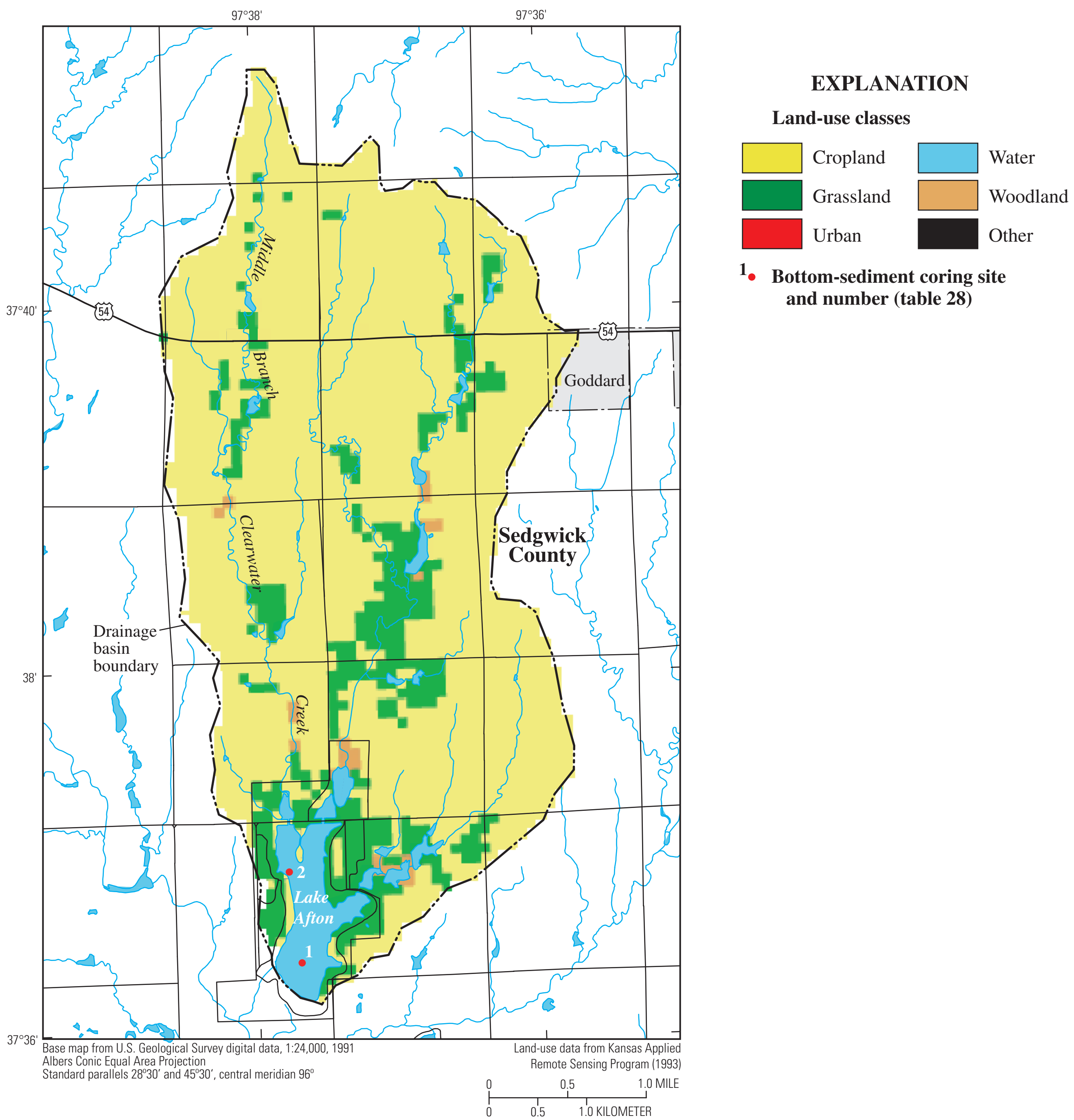
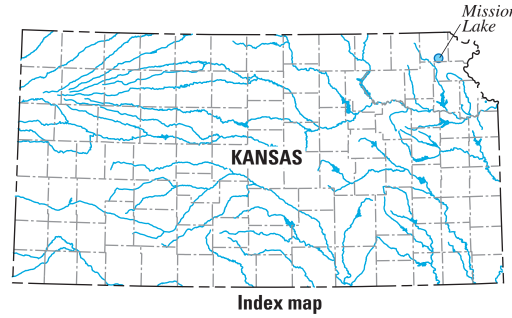




**Figure 28.** Land use in reservoir basin and location of bottom-sediment coring sites in Lake Afton.



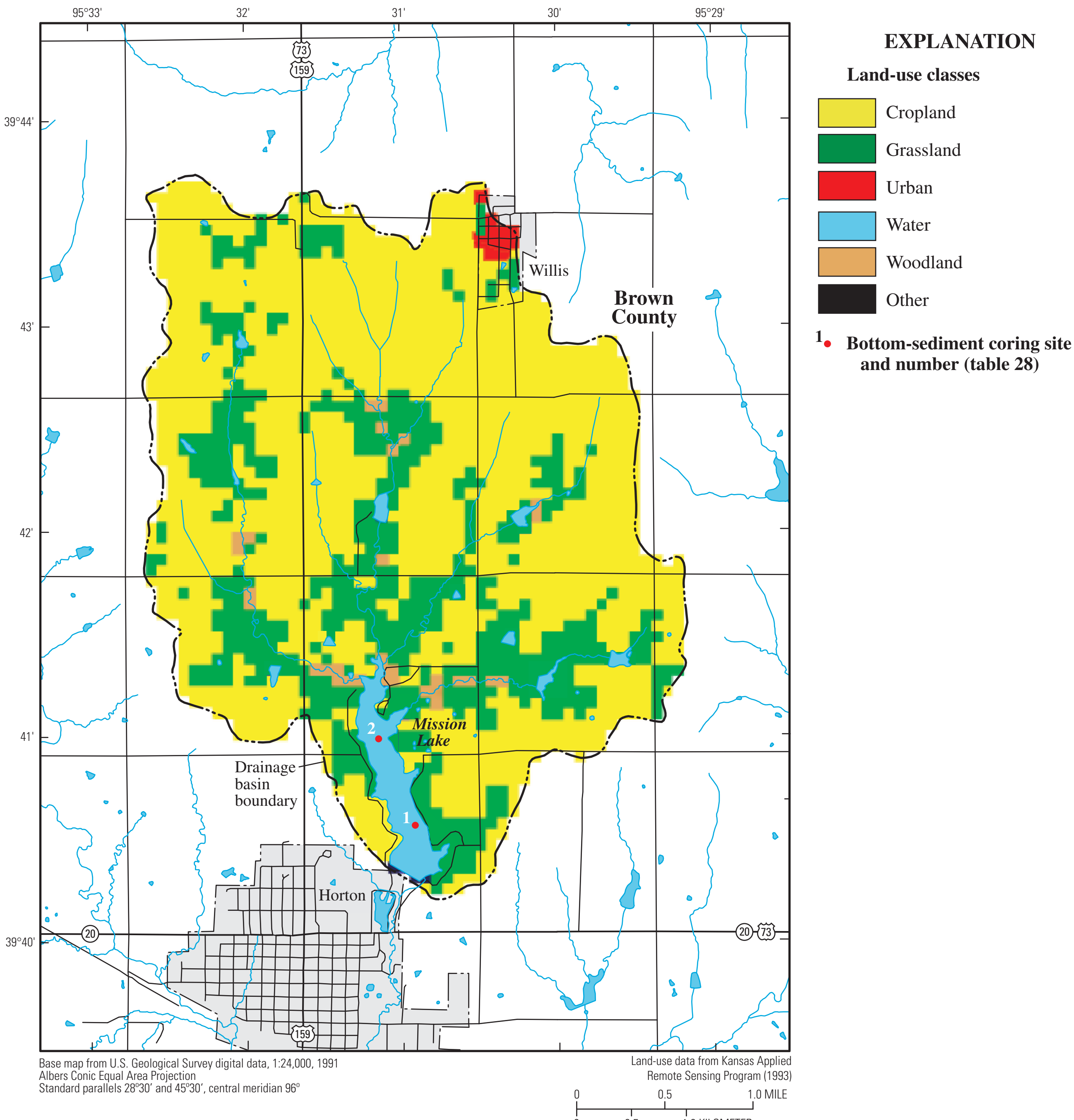




**Figure 29.** Land use in reservoir basin and location of bottom-sediment coring sites in Mission Lake.

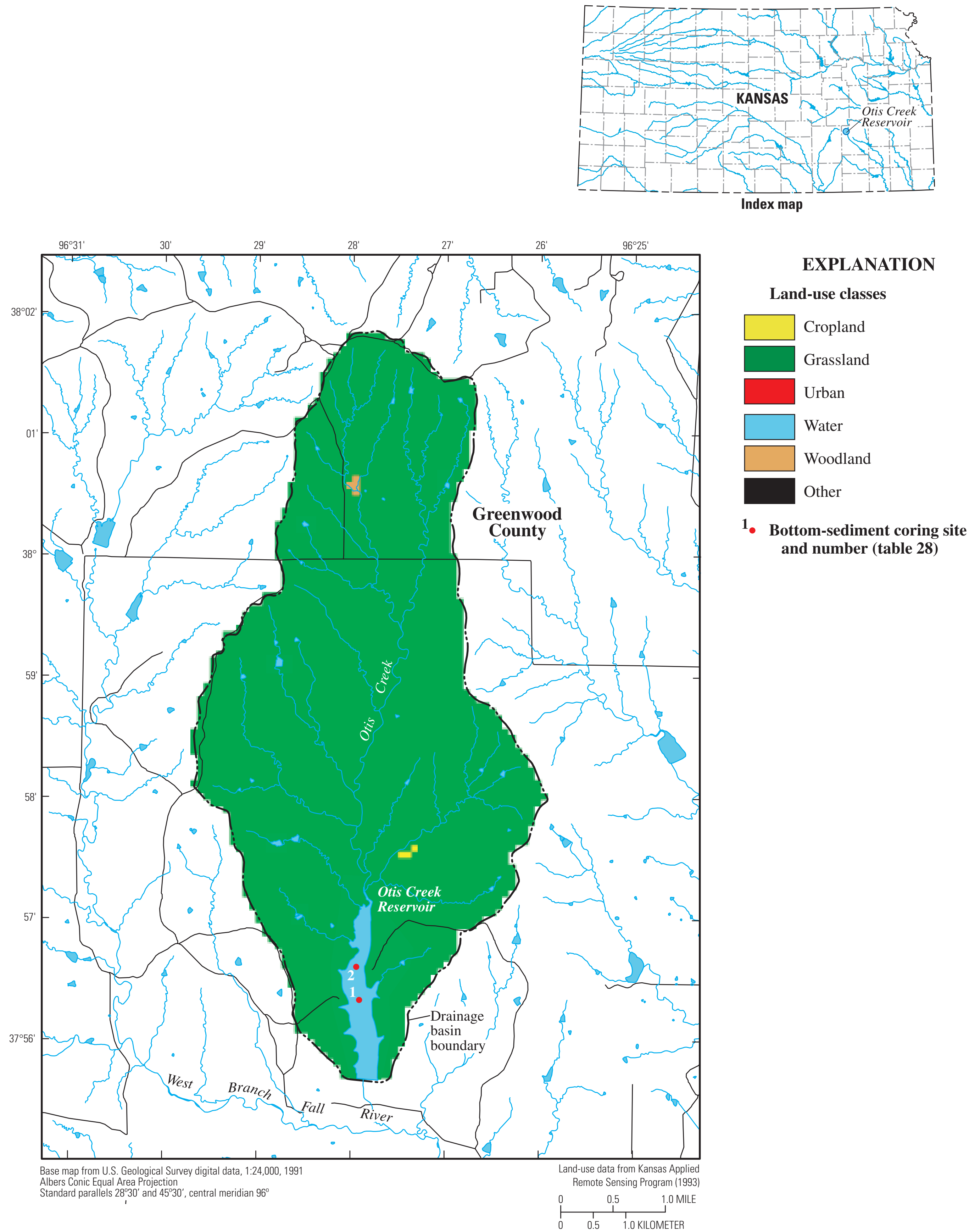



**Figure 30.** Land use in reservoir basin and location of bottom-sediment coring sites in Otis Creek Reservoir.

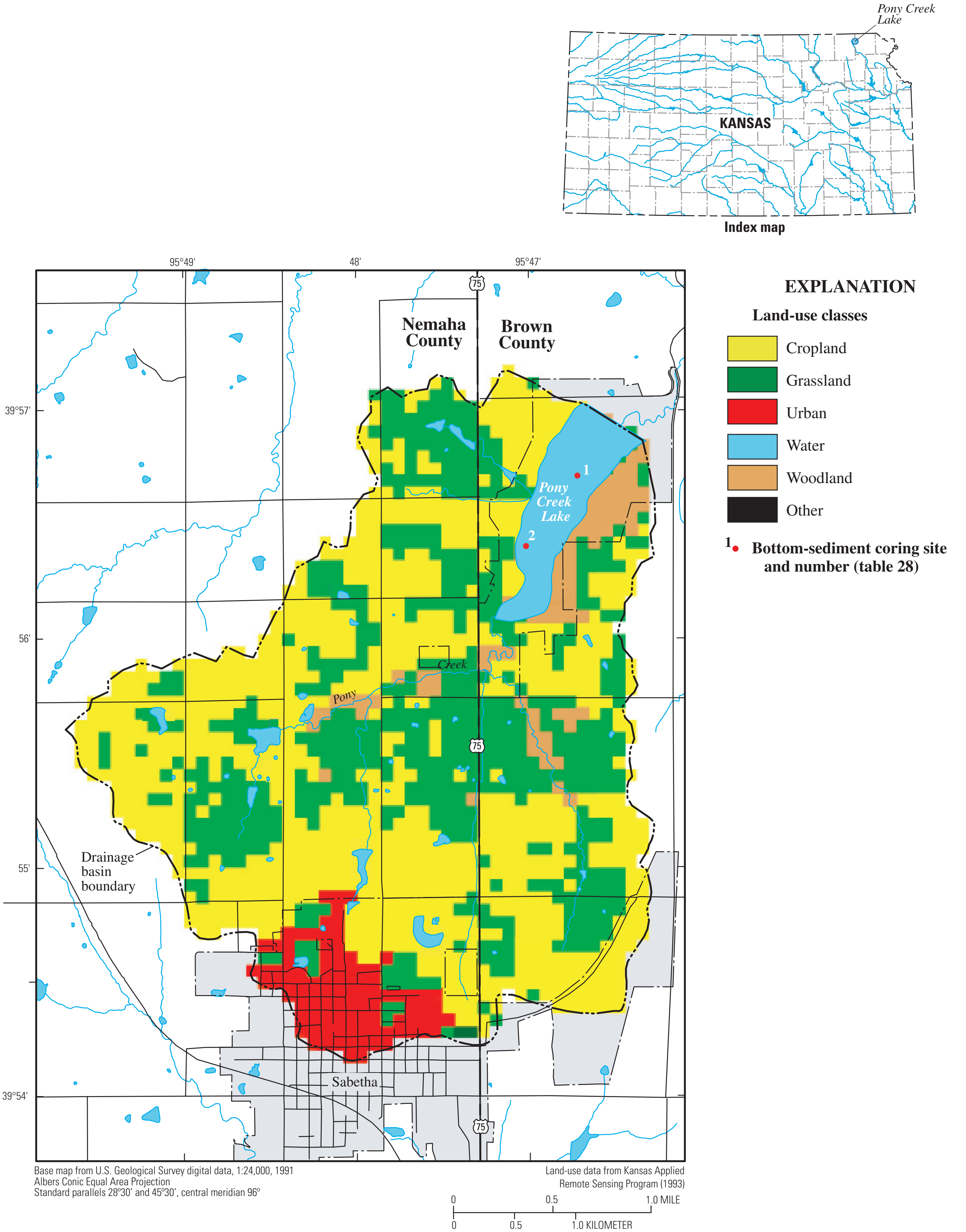



**Figure 31.** Land use in reservoir basin and location of bottom-sediment coring sites in Pony Creek Lake.