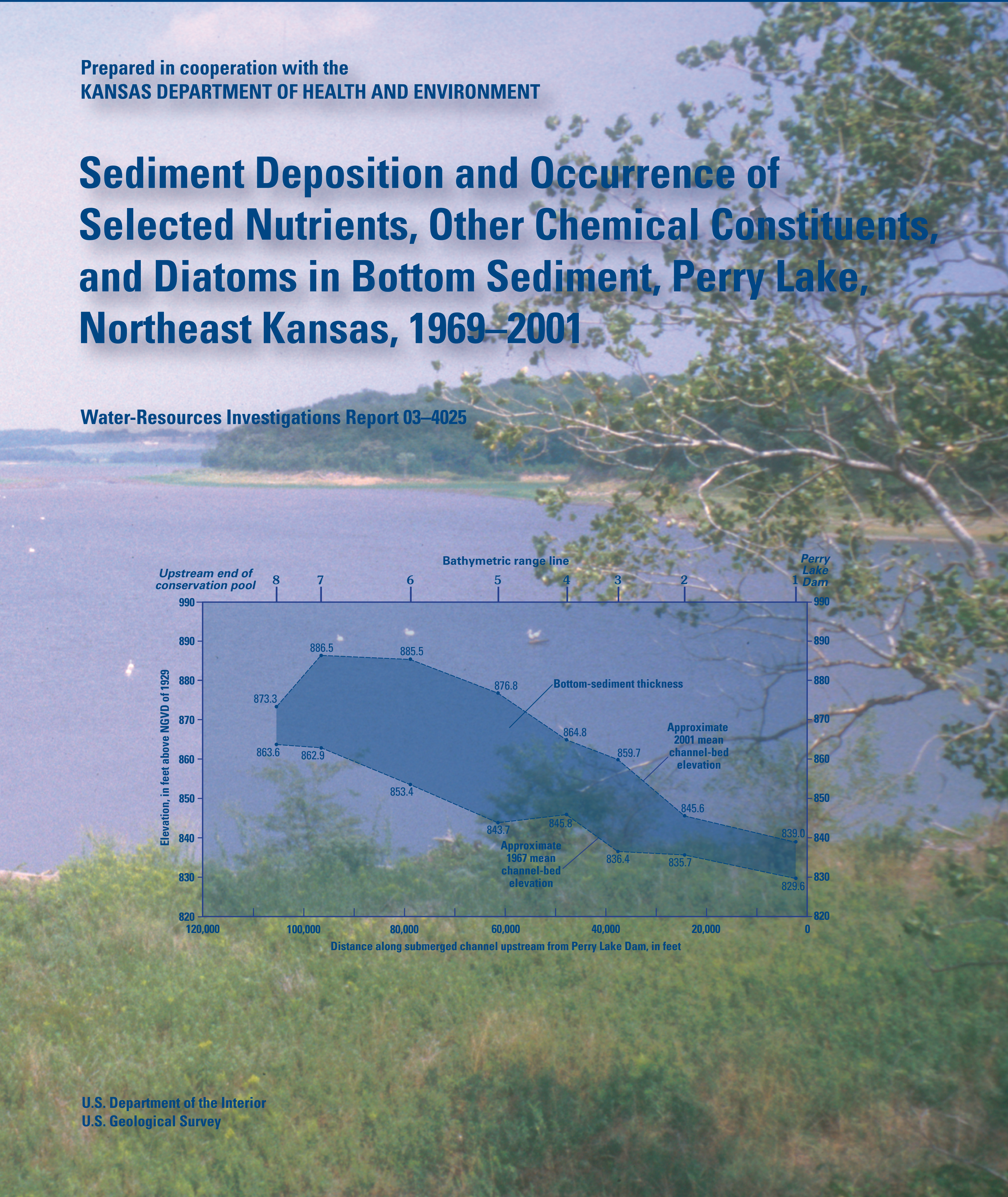
USGS
science for a changing world

Prepared in cooperation with the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

Sediment Deposition and Occurrence of Selected Nutrients, Other Chemical Constituents, and Diatoms in Bottom Sediment, Perry Lake, Northeast Kansas, 1969–2001

Water-Resources Investigations Report 03–4025



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

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

Sediment Deposition and Occurrence of Selected Nutrients, Other Chemical Constituents, and Diatoms in Bottom Sediment, Perry Lake, Northeast Kansas, 1969–2001

By KYLE E. JURACEK

Water-Resources Investigations Report 03–4025

Prepared in cooperation with the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

Lawrence, Kansas
2003

U.S. Department of the Interior

Gale A. Norton, Secretary

U.S. Geological Survey

Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
4821 Quail Crest Place
Lawrence, KS 66049–3839

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Building 810
Box 25286, Federal Center
Denver, CO 80225–0286

CONTENTS

Abstract 1
Introduction 2
    Previous Investigations 2
    Current Study 3
    Description of Perry Lake Basin 4
    Acknowledgments 6
Methods 6
    Bathymetric Survey 7
    Estimation of Bottom-Sediment Volume, Mass, Mean Annual Net Deposition, and Mean Annual Yield 7
    Sediment-Core Collection, Processing, and Analysis 9
    Quality Control 12
    Trend Analysis 12
Sediment Deposition in Perry Lake 14
Occurrence of, and Trends in, Selected Chemical Constituents and Diatoms 16
    Nutrients and Total Organic Carbon 17
    Metals and Trace Elements 18
    Organochlorine Compounds 21
    Diatoms 24
Comparison of Depositional Trends to Streamflow and Human Activity 30
Summary and Conclusions 37
References 41
Supplemental Information 45

FIGURES

1–4. Maps showing:
    1. Location of Delaware River Basin, streamflow-gaging station, and Perry Lake, northeast Kansas 3
    2. Location of bathymetric range lines and bottom-sediment coring sites in Perry Lake 5
    3. Depth-weighted, mean soil permeability in Delaware River Basin 6
    4. Land use in Delaware River Basin, 1988–90 7
5–8. Graph showing:
    5. Variation in cesium–137 activity with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001, and from coring site TIC–2 in Tuttle Creek Lake, September 1999 11
    6. Estimated bottom-sediment thickness in submerged Delaware River channel of Perry Lake, 2001 17
    7. Estimated bottom-sediment thickness on submerged Delaware River flood plain in Perry Lake, 2001 18
    8. Variation in total nitrogen and total phosphorus concentrations with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001 25
9. Map showing mean concentrations of total nitrogen and total phosphorus in bottom-sediment cores collected from Perry Lake, July and August 2001 26
10. Graph showing variation in total organic carbon concentrations with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001 30
11. Map showing mean concentrations of total organic carbon in bottom-sediment cores collected from Perry Lake, July and August 2001 31
12. Graphs showing variation in arsenic and manganese concentrations with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001 32
13. Graphs showing variation in concentrations of beryllium, chromium, titanium, and vanadium with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001 33

FIGURES—Continued

14. Maps showing mean concentrations of arsenic, chromium, copper, and nickel in bottom-sediment cores collected from Perry Lake, July and August 2001 34

15–17. Graphs showing variation in diatom occurrence with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, September 2001, for:

  15. *Aulacoseira islandica* 36
  16. *Cyclotella radiosa* 36
  17. *Stephanodiscus niagarae* 37

18–20. Graphs showing:

  18. Estimated population in Atchison, Brown, Jackson, Jefferson, and Nemaha Counties, Kansas, 1960–2000.. 37
  19. Approximate total number of acres harvested in Atchison, Brown, Jackson, Jefferson, and Nemaha Counties, Kansas, 1965–2000, for alfalfa, grain corn, grain sorghum, soybeans, and wheat 38
  20. Approximate number of cattle and hogs in Atchison, Brown, Jackson, Jefferson, and Nemaha Counties, Kansas, 1965–2000 39

21–33. Graphs showing comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake:

  21. Range line 1 50
  22. Range line 2 50
  23. Range line 3 51
  24. Range line 4 51
  25. Range line 5 52
  26. Range line 6 52
  27. Range line 7 53
  28. Range line 8 53
  29. Range line 24 54
  30. Range line 25 54
  31. Range line 26 55
  32. Range line 28 55
  33. Range line 29 56

TABLES

1. Chemical analyses performed on bottom-sediment samples from Perry Lake, northeast Kansas 10
2. Relative percentage differences for constituent concentrations in sequential replicate and split replicate samples of bottom sediment from coring site PIC–1 in Perry Lake, northeast Kansas, July 2001 13
3. Estimated channel length, mean channel width, mean bottom-sediment thickness, and computed bottom-sediment volume in submerged in-channel components of Perry Lake, northeast Kansas, July 2001 15
4. Estimated surface area, mean bottom-sediment thickness, and computed bottom-sediment volume in submerged out-of-channel components of Perry Lake, northeast Kansas, July 2001 16
5. Estimated mean bulk density of bottom sediment at in- and out-of-channel coring sites in Perry Lake, northeast Kansas, July and August 2001 19
6. Estimated bottom-sediment volume, representative bulk density, and computed bottom-sediment mass in submerged in-channel components of Perry Lake, northeast Kansas, July and August 2001 20
7. Estimated bottom-sediment volume, representative bulk density, and computed bottom-sediment mass in submerged out-of-channel components of Perry Lake, northeast Kansas, July and August 2001 20
8. Estimated total sediment deposition and mean annual net sediment yield for Perry Lake, Hillsdale Lake, Cedar Lake, Lake Olathe, Tuttle Creek Lake, Cheney Reservoir, and Webster Reservoir, Kansas 21
9. Statistical summary of concentrations and comparison to sediment-quality guidelines for selected constituents in bottom-sediment samples from Perry Lake, northeast Kansas, July and August 2001 22
10. Results of trend tests on concentrations of selected constituents in bottom-sediment samples collected from coring site PIC–1 in Perry Lake, northeast Kansas, July 2001 24

TABLES—Continued

11. Estimated mean annual net loads and mean annual yields of constituents deposited in bottom sediment of Perry Lake, northeast Kansas, and associated bioaccumulation index 28
12. Estimated mean annual net total phosphorus yields for Perry Lake, Cedar Lake, Hillsdale Lake, Lake Olathe, Tuttle Creek Lake, Cheney Reservoir, and Webster Reservoir, Kansas 29
13. Occurrence, relative percentage abundance, and trends of diatom species in bottom-sediment samples collected from coring site PIC–1 in Perry Lake, northeast Kansas, September 2001.................... 35
14. Latitude and longitude coordinates for end points of U.S. Army Corps of Engineers range lines used in bathymetric surveys of Perry Lake, northeast Kansas.................... 46
15. Latitude and longitude coordinates for bottom-sediment coring sites in Perry Lake, northeast Kansas 46
16. Diatom species, relative percentage abundance, and total number of valves per gram of material in bottom-sediment samples collected from coring site PIC–1 in Perry Lake, northeast Kansas, September 2001 47

CONVERSION FACTORS, ABBREVIATIONS, AND DATUMS

Multiply	By	To obtain
acre	0.4047	hectare (ha)
acre-foot (acre-ft)	43,560	cubic foot (ft^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]
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot (ft^3)	2.296×10^{-5}	acre-foot (acre-ft)
foot (ft)	0.3048	meter (m)
gram (g)	0.03527	ounce (oz)
hectare (ha)	2.471	acre
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)
kilogram per year (kg/yr)	2.205	pound per year (lb/yr)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer (km)
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)
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)
pound per square mile per year [(lb/mi^2)/yr]	0.001751	kilogram per hectare per year [(kg/ha)/yr]
pound per square mile per year [(lb/mi^2)/yr]	0.001562	pound per acre per year [(lb/acre)/yr]
pound per year (lb/yr)	0.4536	kilogram per year (kg/yr)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
ton	907.2	kilogram (kg)

Temperature can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$^{o}C = 5/9\ (^{o}F - 32)$$
$$^{o}F = 9/5\ (^{o}C) + 32\ .$$

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

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

Sediment Deposition and Occurrence of Selected Nutrients, Other Chemical Constituents, and Diatoms in Bottom Sediment, Perry Lake, Northeast Kansas, 1969–2001

By Kyle E. Juracek

Abstract

A combination of bathymetric surveying and bottom-sediment coring was used to investigate sediment deposition and the occurrence of selected nutrients (total nitrogen and total phosphorus), organic and total carbon, 26 metals and trace elements, 15 organochlorine compounds, 1 radionuclide, and diatoms in bottom sediment of Perry Lake, northeast Kansas. The total estimated volume and mass of bottom sediment deposited from 1969 through 2001 in the original conservation-pool area of the lake was 2,470 million cubic feet (56,700 acre-feet) and 97,200 million pounds (44,100 million kilograms), respectively. The estimated sediment volume occupied about 23 percent of the original conservation-pool, water-storage capacity of the lake. Mean annual net sediment deposition since 1969 was estimated to be 3,040 million pounds (1,379 million kilograms). Mean annual sediment yield from the Perry Lake Basin was estimated to be 2,740,000 pounds per square mile (4,798 kilograms per hectare).

The estimated mean annual net loads of total nitrogen and total phosphorus deposited in the bottom sediment of Perry Lake were 7,610,000 pounds per year (3,450,000 kilograms per year) and 3,350,000 pounds per year (1,520,000 kilograms per year), respectively. The estimated mean annual yields of total nitrogen and total phosphorus from the Perry Lake Basin were 6,850 pounds per square mile per year (12.0 kilograms per hectare per year) and 3,020 pounds per square mile per year (5.29 kilograms per hectare per year), respectively. A statistically significant positive trend for total nitrogen deposition in the bottom sediment of Perry Lake was indicated. However, the trend may be due solely to analytical variance. No statistically significant trend for total phosphorus deposition was indicated. Overall, the transport and deposition of these constituents have been relatively uniform throughout the history of Perry Lake.

On the basis of nonenforceable sediment-quality guidelines established by the U.S. Environmental Protection Agency, concentrations of arsenic, chromium, copper, and nickel in the bottom sediment of Perry Lake typically exceeded the threshold-effects levels, which represent the concentrations above which toxic biological effects occasionally occur. Most nickel concentrations also exceeded the probable-effects level, which represents the concentration above which toxic biological effects usually or frequently occur. Sediment concentrations of metals and trace elements were relatively uniform over time. Statistically significant positive depositional trends for arsenic and manganese and statistically significant negative depositional trends for beryllium, chromium, titanium, and vanadium were indicated. However, the trends may be due solely to analytical variance. Organochlorine compounds either were not detected or were detected at concentrations less than the threshold-effects levels. Evidence of a negative depositional trend for DDE (degradation product of DDT) was

consistent with the history of DDT use. Other organochlorine compounds detected were DDD and dieldrin.

Diatom occurrence in the bottom sediment of Perry Lake was dominated by species that are indicators of eutrophic (nutrient-rich) conditions. Thus, it was concluded that eutrophic conditions have existed during much of the history of Perry Lake. However, an increase in the relative percentage abundance of the oligotrophic (nutrient-poor) species, combined with the significant positive depositional trends for two oligotrophic species (*Aulacoseira islandica* and *Cyclotella radiosa*) and the significant negative depositional trend for one eutrophic species (*Stephanodiscus niagarae*), indicated that conditions in Perry Lake may have become less eutrophic in recent years.

Notable changes in human activity within the basin included a substantial decrease in alfalfa production and a substantial increase in soybean production from 1965 to 2000. These and other changes in human activity may have had some effect on the deposition of chemical constituents and diatoms in the bottom sediment of Perry Lake. It is uncertain whether changes in human actitivity may account, in part, for the possibility of Perry Lake becoming less eutrophic over time as indicated by trends in the deposition of several diatom species in the lake-bed sediment.

INTRODUCTION

In addition to their importance for flood control, reservoirs in Kansas are a valuable resource as a water supply for various human uses, for recreation, and as habitat for fish and wildlife. Effective reservoir management requires several types of information including water quality, sedimentation, and sediment quality.

Water-quality information is important for determining the suitability of the water in a reservoir in 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 a warning of potential future water-quality problems.

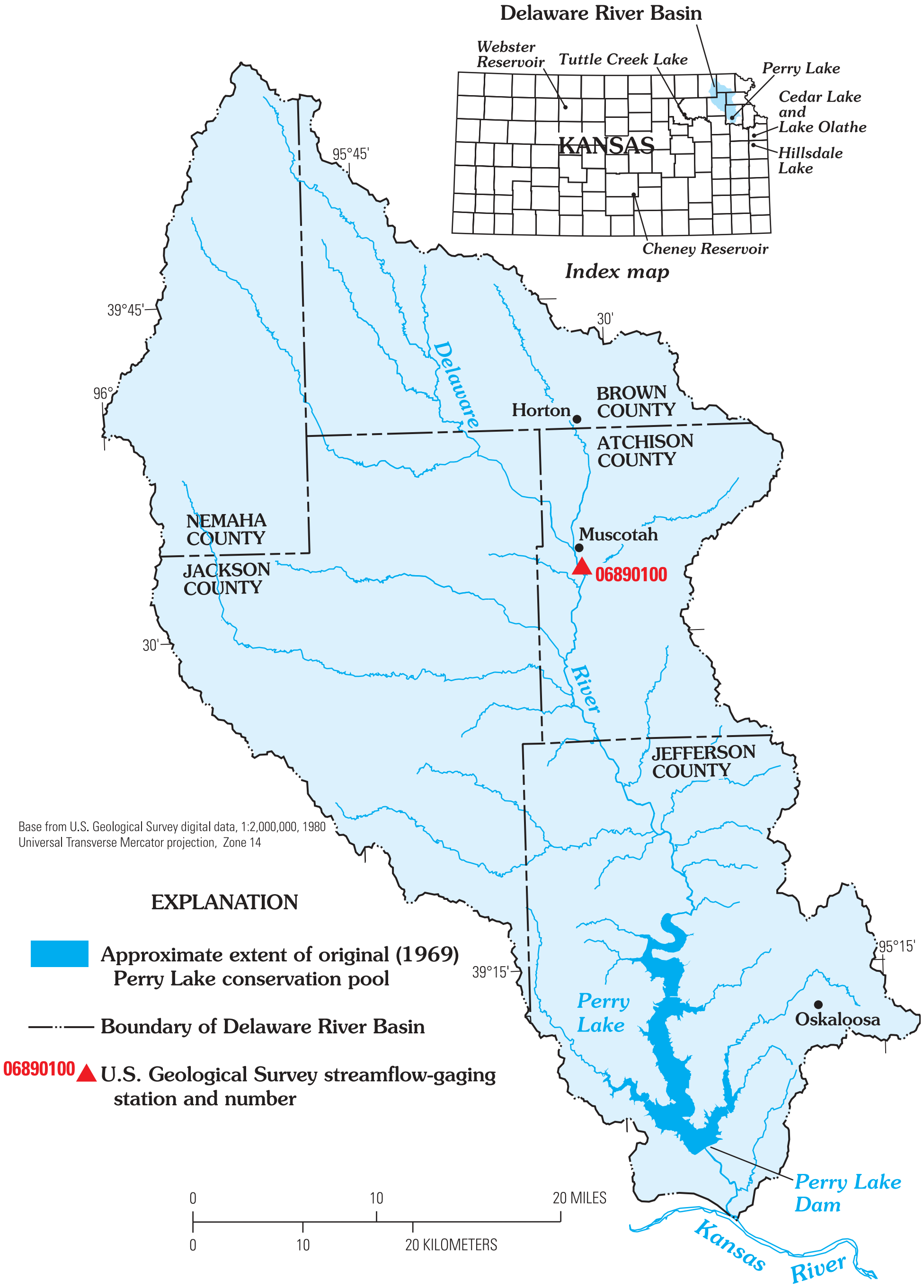
The volume and quality of sediment deposited in a reservoir also are important. Sedimentation affects both the useful life and the aesthetic quality of a reservoir. Sediment quality is an important environmental concern because sediment may act as a sink for some water-quality constituents and as a source of constituents to the overlying water column and biota (Baudo and others, 1990; Zoumis and others, 2001). Once in the food chain, sediment-derived constituents may pose an even greater concern due to bioaccumulation. 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 water-quality records and to determine a present-day baseline with which to evaluate long-term changes in reservoir water and sediment quality, which then may be related to changes in human activity in the basin.

Perry Lake is a Federal impoundment on the Delaware River in Jefferson County, northeast Kansas (fig. 1). Completed in 1969 by the U.S. Army Corps of Engineers (USCOE), the reservoir is used for flood control, water supply, recreation, fish and wildlife habitat, water-quality control, and navigation supplementation. The original design life for Perry Lake was 100 years (Frank Funk, U.S. Army Corps of Engineers, oral commun., 2002).

Perry Lake is listed under Section 303(d) of the Federal Clean Water Act of 1972 on the basis of eutrophication (Tom Stiles, Kansas Department of Health and Environment, written commun., 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).

Previous Investigations

During 1996–2000, the water in Perry Lake was sampled several times a year by USCOE personnel



Base from U.S. Geological Survey digital data, 1:2,000,000, 1980
Universal Transverse Mercator projection, Zone 14

Figure 1. Location of Delaware River Basin, streamflow-gaging station, and Perry Lake, northeast Kansas.

and analyzed for nutrients and herbicides (U.S. Army Corps of Engineers, 2001). The Kansas Department of Health and Environment (KDHE), as part of its Lake and Wetland Monitoring Program, sampled the water in Perry Lake in 1977, 1980, 1982, 1985, 1988, 1991, 1994, 1996–98, and 2000 for a variety of organisms and constituents including nutrients, metals, pesticides, algal abundance and composition, chlorophyll-a, and selected bacteria (Ed Carney, Kansas Department of Health and Environment, written commun., 2002). The results of these analyses are available from the agencies.

In 1992, the Delaware River Basin was classified as a pesticide management area by the Kansas Department of Agriculture. The goal of the pesticide management area is to limit the input of atrazine into surface water in the basin. The U.S. Geological Survey (USGS) completed a study in 1996 to determine atrazine loads and yields from the entire basin as well as 10 subbasins (Pope and others, 1997).

Some historical water-quality information for Perry Lake is available from USCOE (U.S. Army Corps of Engineers, 1975). Additional historical information on water quality and (or) sediment quality in Perry Lake and (or) the Delaware River Basin is available from several sources including Tanner and others (1990), Fallon and McChesney (1993), Fallon (1994), Scribner and others (1994), Stamer and Zelt (1994), and Jordan and Stamer (1995).

Current Study

A 2-year study by the USGS, in cooperation with KDHE, was begun in 2001 to estimate sedimentation in Perry Lake as well as the deposition of, and trends in, various chemical constituents and diatoms. The specific study objectives were to:

(1) Estimate the volume and mass of bottom sediment deposited in the reservoir as well as the mean annual net deposition and mean annual yield since 1969;

(2) Determine the occurrence and mass of, as well as trends in, selected chemical constituents in the bottom sediment;

(3) Determine the mean annual net load and mean annual yield for selected chemical constituents in the bottom sediment;

(4) Determine the occurrence of, as well as trends in, diatoms in the bottom sediment;

(5) Relate, to the extent possible, any observed constituent and diatom trends in the bottom sediment to documented historical changes in streamflow and human activity in the basin; and

(6) 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 basin.

The purpose of this report is to present the results of the USGS study to estimate sedimentation and to determine the occurrence of, and trends in, selected chemical constituents and diatoms in the bottom sediment of Perry Lake. Results presented in this report will assist KDHE in evaluating the implementation of existing TMDLs and in developing new TMDLs for constituents found to contribute to water-quality impairment in Perry Lake. From a national perspective, the methods and results presented in this report provide guidance and perspective for future reservoir studies concerned with the issues of sedimentation and water quality.

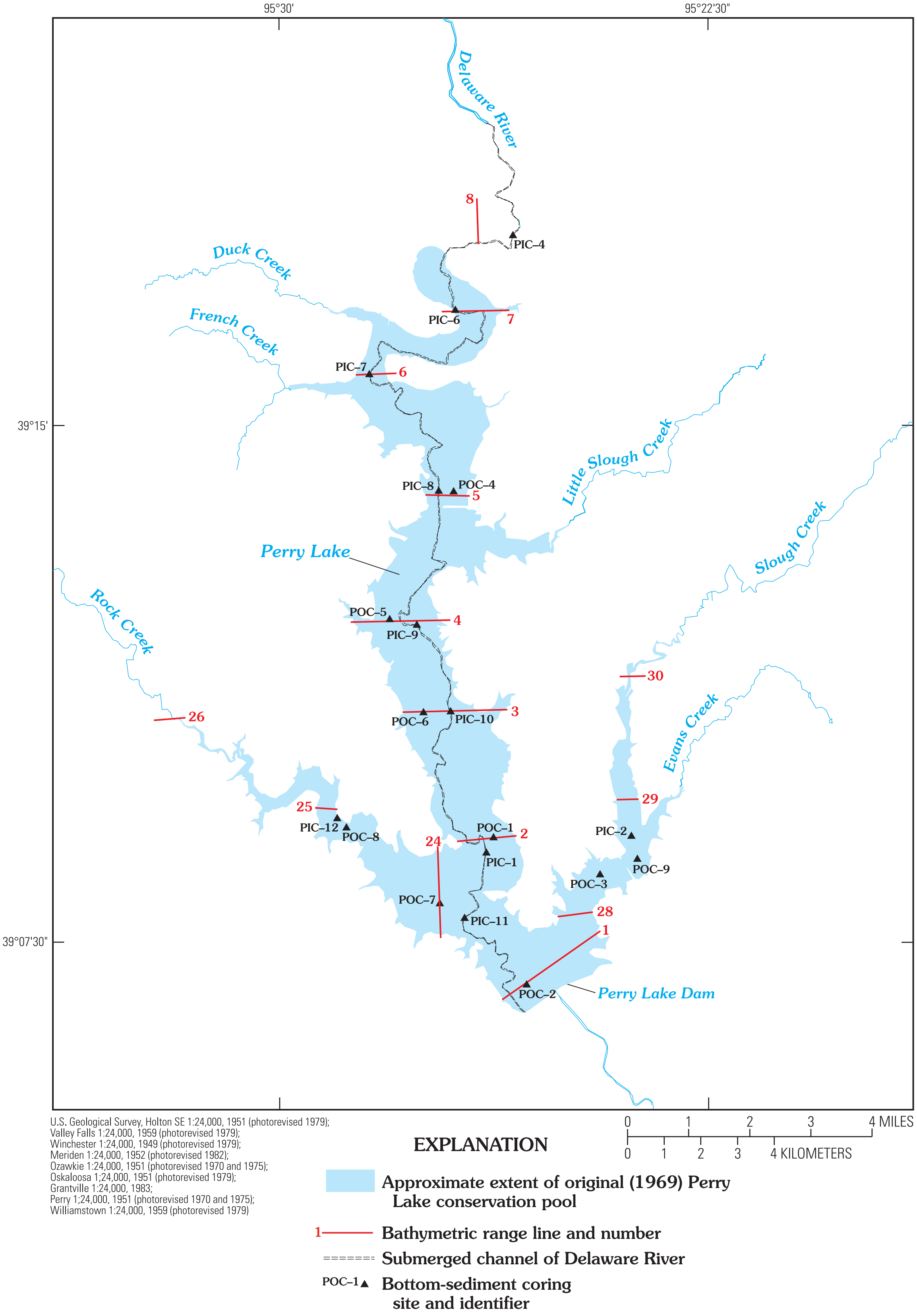
Description of Perry Lake Basin

The Perry Lake Basin, which is essentially synonymous with the Delaware River Basin (except for the small area located downstream from Perry Lake Dam), is an area of 1,117 mi^2 that drains part of northeast Kansas (fig. 1). In 1990, the lake had a surface area of about 11,150 acres and a water-storage capacity of about 209,500 acre-ft at the conservation-pool elevation of 891.5 ft above the NGVD of 1929 (Frank Funk, U.S. Army Corps of Engineers, oral commun., 2001). According to USCOE, the lake had an original surface area of about 12,200 acres and a water-storage capacity of about 243,200 acre-ft at the conservation-pool elevation (U.S. Army Corps of Engineers, 1973). In this study, the original conservation-pool surface area, derived from USGS 1:24,000-scale topographic quadrangles, was determined to be 12,256 acres. The decreases in surface area and storage capacity are due to the effects of ongoing sedimentation. At the flood-control pool elevation of 920.6 ft above the NGVD of 1929, the lake has a surface area of about 25,300 acres and a 1990 water-storage capacity of about 725,300 acre-ft (Frank Funk, U.S. Army Corps of Engineers, oral commun., 2001). In addition to the Delaware River, small tributaries that contribute flow directly to Perry Lake include Duck Creek, Evans Creek, French Creek, Little Slough Creek, Rock Creek, and Slough Creek (fig. 2).

Physiographically, the Delaware River Basin can be characterized with reference to physical divisions as defined by Fenneman (1946). The basin is located within the Dissected Till Plains Section of the Central Lowland Province. This section is 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). Maximum local relief is about 200 ft. Slopes in the basin range from nearly level to gently sloping on the flood plains and from gently sloping to steep in the uplands. Generally, slopes are less than 10 percent but may locally be as steep as 25 to 40 percent (U.S. Department of Agriculture, Soil Conservation Service, 1960, 1977, 1979, 1982, 1984). Slope, along with soil permeability and land use (discussed in the following paragraphs), are important determinants of storm runoff in a basin.

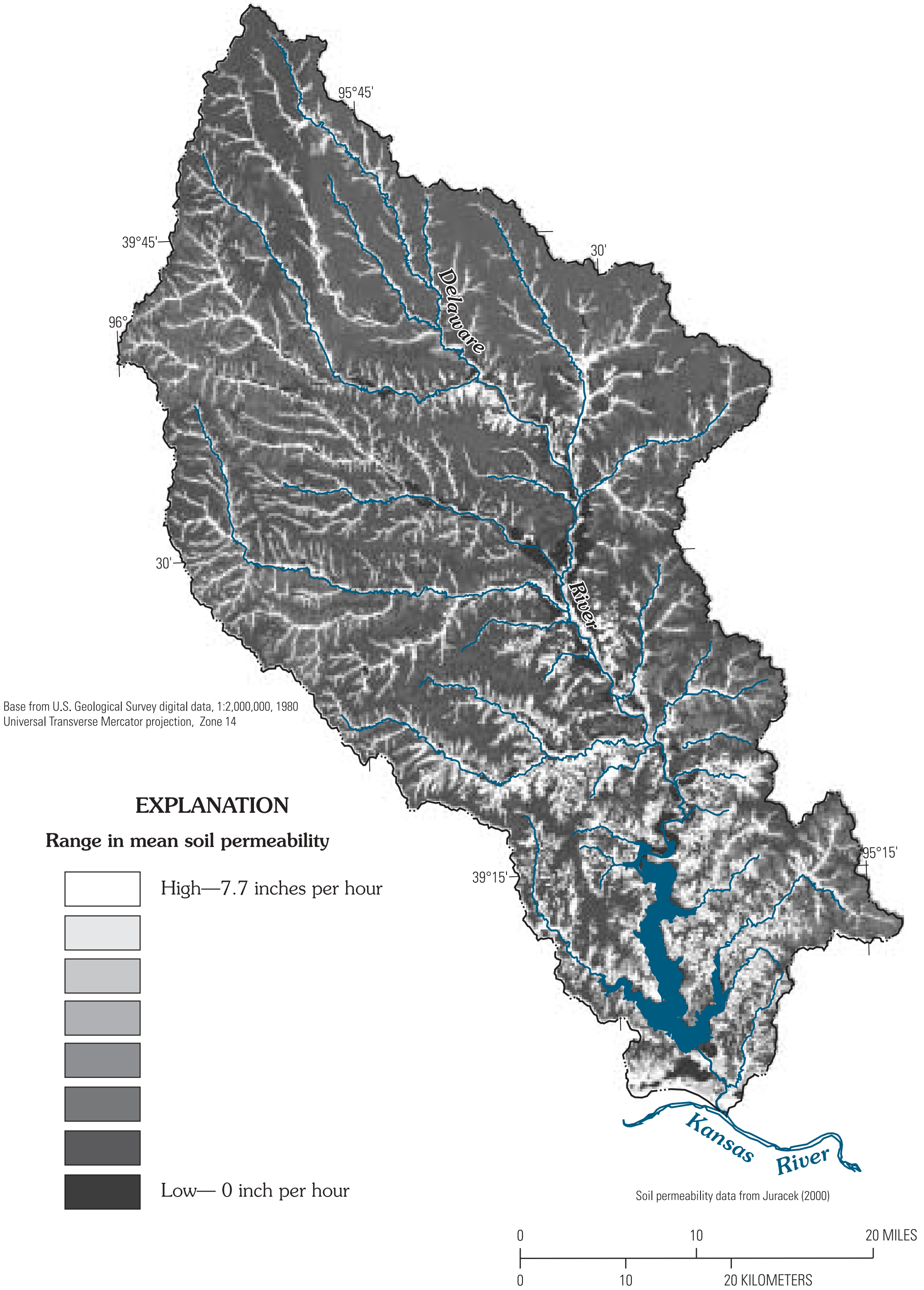
Typically, there is an inverse relation between soil permeability and runoff; that is, as soil permeability decreases, the potential for runoff increases. In the Delaware River Basin depth-weighted, mean soil permeability ranges from 0 to about 7.7 in/h with a mean of about 0.5 in/h. In general, soil permeability is less in the uplands (typically 0.4 in/h or less) and greater in the flood plains of the principal rivers and streams (typically 1.1 to 1.3 in/h). An isolated small area with much greater soil permeability (about 7.7 in/h) is located at the confluence of the Delaware River with the Kansas River (fig. 3) (Juracek, 2000). Soil erodibility is relatively uniform throughout the basin (U.S. Department of Agriculture, 1994).

Long-term, mean annual precipitation in the Delaware River Basin ranges from about 35 in. at Horton, Kansas (period of record 1900–2000), in the northern part of the basin, to about 39 in. at Oskaloosa, Kansas (period of record 1958–2000), in the south (High



U.S. Geological Survey, Holton SE 1:24,000, 1951 (photorevised 1979);
Valley Falls 1:24,000, 1959 (photorevised 1979);
Winchester 1:24,000, 1949 (photorevised 1979);
Meriden 1:24,000, 1952 (photorevised 1982);
Ozawkie 1:24,000, 1951 (photorevised 1970 and 1975);
Oskaloosa 1;24,000, 1951 (photorevised 1979);
Grantville 1:24,000, 1983;
Perry 1;24,000, 1951 (photorevised 1970 and 1975);
Williamstown 1:24,000, 1959 (photorevised 1979)

Figure 2. Location of bathymetric range lines and bottom-sediment coring sites in Perry Lake.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1980
Universal Transverse Mercator projection, Zone 14

Soil permeability data from Juracek (2000)

Figure 3. Depth-weighted, mean soil permeability in Delaware River Basin (source of data: Juracek, 2000).

Plains Regional Climate Center, 2000) (fig. 1). Most of the annual precipitation is received during the growing season (generally April–September).

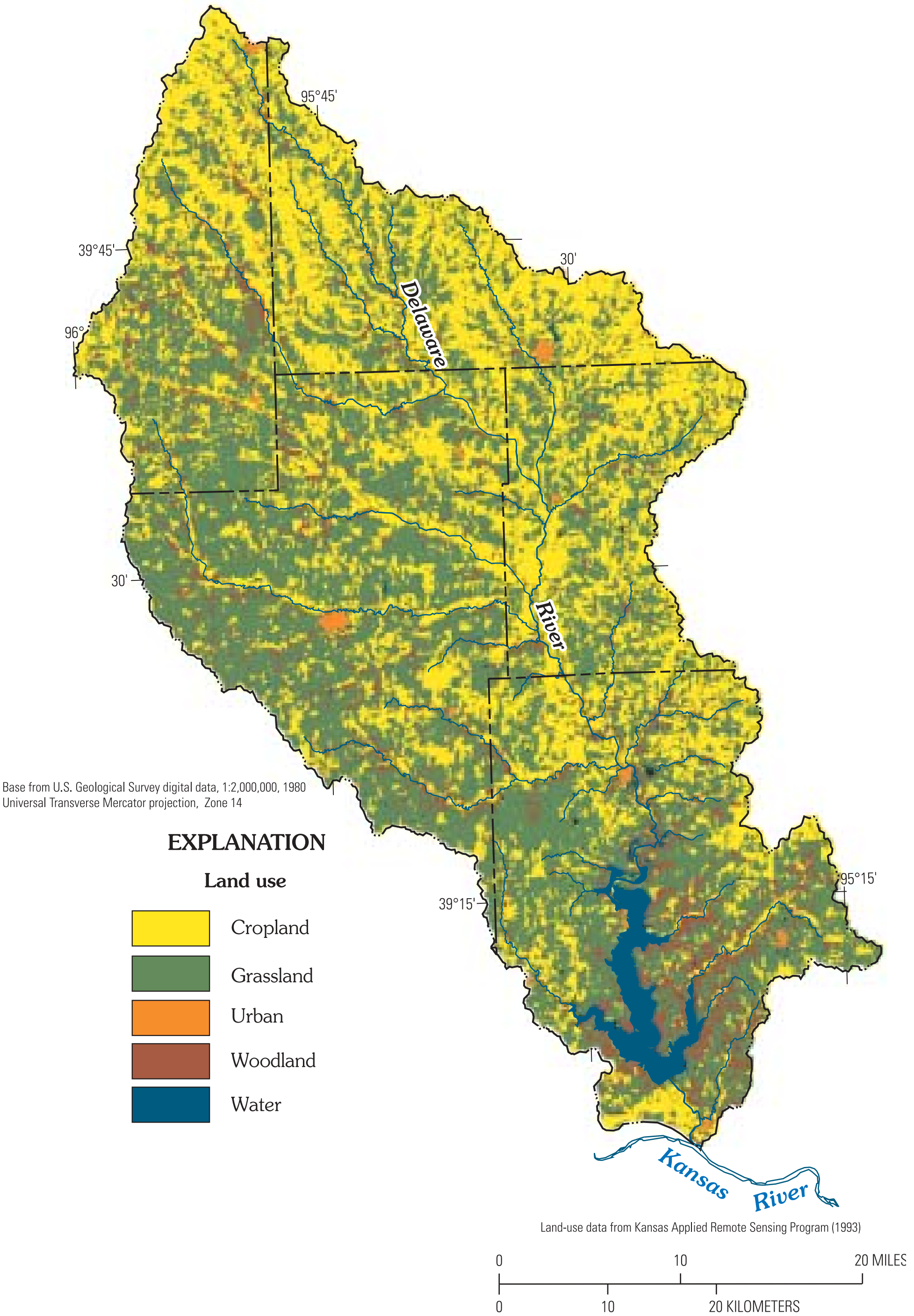
Land use (1988–90) in the Delaware River Basin is mostly agricultural with grassland and cropland accounting for about 50 and 40 percent of the basin, respectively. Woodland accounts for about 7 percent of the basin. Urban land use occupies less than 1 percent of the basin (fig. 4) (Kansas Applied Remote Sensing Program, 1993).

Acknowledgments

This study was made possible in part by support from the Kansas State Water Plan Fund and the U.S. Environmental Protection Agency. The author gratefully acknowledges the topographic and bathymetric information provided by USCOE.

METHODS

The objectives of the study described in this report were accomplished using available and newly collected information. Available information included USCOE 1967 topographic and bathymetric information for the lake and USGS 1:24,000-scale topographic quadrangles that were used as base maps. New information was obtained through additional bathymetric surveying and the collection and analysis of bottom-sediment cores.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1980
Universal Transverse Mercator projection, Zone 14

Land-use data from Kansas Applied Remote Sensing Program (1993)

Figure 4. Land use in Delaware River Basin, 1988–90 (source of data: Kansas Applied Remote Sensing Program, 1993).

Bathymetric Survey

To provide the additional information necessary for estimating the volume of bottom sediment in Perry Lake, a bathymetric (lake-bed elevation) survey was performed by the USGS during July 2001. 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 13 range lines (1–8, 24–26, 28, 29) that were established by USCOE in 1967 (fig. 2; see also figs. 21–33 in the “Supplemental Information” section at the back of this report). The latitude and longitude coordinates for the end points of the USCOE range lines are provided in table 14 in the “Supplemental Information” section. The upstream limits of the original conservation-pool surface area of the lake were defined approximately by range lines 8, 26, and 30 (fig. 2).

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

Total bottom-sediment volume (sediment plus water and gases) in Perry Lake was estimated using a partitioning approach in which the original conservation-pool surface area of the lake (12,256 acres) was divided into segments as determined by the locations where the bathymetric range lines crossed the lake (fig. 2). These segments were divided further into in-channel and out-of-channel components to improve the precision of the bottom-sediment volume estimates. Bottom-sediment volume was computed separately for all components as the total surface area multiplied by the mean thickness of the bottom sediment.

The total conservation-pool surface area for each segment was determined by digitizing the lake boundary and range lines using USGS 1:24,000-scale topographic quadrangles as the source maps. Mean channel widths of the Delaware River, Rock Creek, and Slough Creek were estimated using the USCOE 1967 and USGS 2001 bathymetric information. The channel width at each range-line site was estimated only for the sediment-filled part of the channel rather than the entire bankfull channel. With three exceptions, the mean channel width for each segment was computed as the average of the channel widths determined using the two range lines that defined the segment. The exceptions were the segments from the dam to range line 1, from range line 24 to the confluence with the submerged Delaware River channel, and from range line 28 to the confluence with the submerged Delaware River channel (fig. 2), for which the respective channel widths determined for range lines 1, 24, and 28 were used. The main channel length for each segment was estimated by measuring the channel centerline on USGS 1:24,000-scale topographic quadrangles. The surface area for each in-channel component was computed (mean channel width multiplied by channel length) and subtracted from the total surface area for each segment to determine the surface area for each out-of-channel component.

For each range line surveyed, the mean thickness of the bottom sediment was computed as the difference between the 2001 and 1967 lake-bed elevations (figs. 21–33 at the back of this report). With four exceptions, the mean sediment thickness was computed for each in- and out-of-channel component as the average of the sediment thicknesses determined using the range lines that defined the segment. The three in-channel exceptions were the components from the dam to range line 1, from range line 24 to the confluence with the submerged Delaware River channel, and from range line 28 to the confluence with the submerged Delaware River channel (fig. 2), for which the respective in-channel sediment thicknesses determined for range lines 1, 24, and 28 were used. The out-of-channel exception was the component from the dam to range line 1, for which the out-of-channel sediment thickness determined for range line 1 was used. Also, because range line 30 was not accessible by boat, the in-channel sediment thickness for that site was estimated on the basis of a streamside estimate of the 2001 channel-bed elevation in combination with 1967, 1979, and 1989 USCOE bathymetric information. The component results then were combined to provide an estimate of the total volume of bottom sediment in the lake.

The total mass (dry weight) of bottom sediment in the lake was estimated using the same in- and out-of-channel components as described previously. For each component, a representative bulk density was computed using the bulk densities that were determined from sediment cores (see discussion in following section). Bottom-sediment mass then was computed for each component as bottom-sediment volume multiplied by the representative bulk density. The component results then were combined to provide an estimate of the total mass of bottom sediment in the lake.

To the extent possible, the representative bulk density for each component was computed as the average of the bulk densities determined for the coring sites located along or near the range lines that defined the reservoir segments. Limited information dictated that the representative bulk density for several components was the value for the nearest coring site for which a bulk density value was available. Overall, the approach taken was to assign a bulk density value to each component, using available values outright or averaged, to provide what was believed to be the most representative value in the absence of more complete information. Typically, the bulk densities of reservoir sediment tend to be lowest downstream near the dam where the fine sediment (silt and clay) is deposited and highest in the upstream part of the lake where the coarse delta deposits (for example, sand) are located (Morris and Fan, 1998).

Because it was not feasible to accurately distinguish annual layers of sediment deposition in the lake, mean annual net sediment deposition was estimated by dividing the total mass of bottom sediment by the number of years of deposition. Given that water storage at Perry Lake began on January 15, 1969, about 32 years of sediment deposition had occurred in the lake at the time the new bathymetric survey was completed in July 2001. Therefore, mean annual net sediment deposition was estimated as the total mass of bottom sediment divided by 32.

The mean annual sediment load that exits Perry Lake was estimated using available USGS and USCOE data on suspended-sediment concentrations in the lake outflow and available USGS data on the volume of flow. The flow-weighted, mean suspended-sediment concentration and the mean annual discharge were determined and multiplied to provide an estimate of the instantaneous sediment load exiting the lake, which then was converted to a mean annual sediment load.

The mean annual sediment yield from the Perry Lake Basin was estimated by dividing the total amount of sediment transported to the lake (that is, the mean annual amount of sediment deposited in the lake plus the mean annual amount of sediment that exits the lake) by the area of the basin (1,117 mi^2).

Sediment-Core Collection, Processing, and Analysis

To determine the occurrence and mass of, as well as trends in, selected chemical constituents, bottom-sediment cores were collected in July, August, and September of 2001 at 19 sites (fig. 2) within Perry Lake. One core also was analyzed to determine the occurrence of, and trends in, diatoms. The cores were collected using a gravity corer. The liner used in the corer was cellulose acetate butyrate transparent tubing with a 2.625-in. inside diameter. The coring sites were located to provide a spatially representative sample of bottom sediment both in and outside of the submerged river and stream channels. A total of 10 in-channel and 9 out-of-channel sites were cored. In most cases, the cores were collected on or near the range lines used in the bathymetric survey (fig. 2). One to three cores were collected at each site to provide sufficient sediment material for laboratory analyses. The latitude and longitude for each coring site, obtained using GPS technology, are provided in table 15 in the “Supplemental Information” section at the back of this report.

When using a gravity corer, a phenomenon referred to as “core shortening” occurs that results in a recovered sediment core that may be only about one-half of the actual thickness of sediment penetrated (Emery and Hulsemann, 1964). Core shortening is caused by the friction of the sediment against the inner wall of the 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 at Perry Lake, which is characterized by uniform texture with decreasing water content at depth, core shortening results in a core sample that provides a thinned but complete representation of all of the sediment layers that were penetrated (Emery and Hulsemann, 1964; Hongve and Erlandsen, 1979). The use of a gravity corer may or may not result in the complete 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 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 60 percent.

The sediment cores were refrigerated (at about 4 ^{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 lake-bottom sediment 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.

Due to the substantial thickness of the bottom sediment in Perry Lake, penetration of the entire thickness of sediment was not achieved for all cores. Of the 10 in-channel sites that were cored, complete penetration of the sediment was achieved for five sites (PIC–1, PIC–6, PIC–7, PIC–10, and PIC–11) (fig. 2). For the nine out-of-channel sites, complete penetration was achieved for every site except POC–4 (fig. 2).

The number of samples extracted from each core was dependent on the length of the core, the intended use of the core, and the amount of material required for chemical analyses. For composite sampling purposes, an approximately uniform volume of sediment (defined as the space occupied by the sediment particles, water, and gases as measured in cubic units) was extracted from the entire length of the core, homogenized, and sampled. For trend analyses, a core was divided into 8 to 11 intervals of equal length. From each interval, an approximately equal volume of sediment was extracted lengthwise from both halves and combined. The combined sediment volume for each interval was homogenized and sampled for subsequent chemical analyses.

The sediment samples were analyzed for nutrients (total nitrogen and total phosphorus), organic and total carbon, 26 metals and trace elements, 15 organochlorine compounds, 1 radionuclide, and diatoms. In-channel cores collected at site PIC–1 (fig. 2) were used for trend analyses. One core was divided into 11 intervals for the analysis of nutrients, organic and total carbon, and metals and trace elements. A second core was divided into 11 intervals for the analysis of the radionuclide cesium–137 (^{137}Cs) (discussed in a following paragraph). A third core was divided into 8 intervals for the analysis of organochlorine compounds. A fourth core was divided into 10 intervals for the analysis of diatoms. Additionally, composite samples for the analysis of nutrients, organic and total carbon, metals and trace elements, and organochlorine compounds were collected from sites PIC–1, PIC–2, PIC–8, PIC–12, POC–1, and POC–4 (fig. 2). A total of 19 sediment samples were analyzed for nutrients, organic and total carbon, and metals and trace elements. A total of 16 sediment samples were analyzed for organochlorine compounds. A complete list of the chemical constituents for which analyses were performed is provided in table 1.

Constituent analyses of sediment samples were performed at the USGS National Water-Quality Laboratory in Denver, Colorado, and the USGS Sediment Trace Element Partitioning Laboratory in Atlanta, Georgia. Analyses of sediment samples for total nitrogen and carbon concentrations were performed using the methods described by Horowitz and others (2001). Analyses for total phosphorus, metals, 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). Diatom analyses were performed by BSA Environmental Services, Inc., Beachwood, Ohio. Analyses for diatoms were performed using equipment and methods described by Patrick and Reimer (1966, 1975), Battarbee (1973), Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b), and Stoermer and others (1995).

Mean annual net load was computed for each constituent that was detected with a sufficient frequency (that is, in at least 50 percent of the samples analyzed) to determine a representative median value for the concentration of that constituent in the bottom sediment of

Table 1. Chemical analyses performed on bottom-sediment samples from Perry Lake, northeast Kansas

	Nutrients		
Total nitrogen	Total phosphorus		
	Carbon		
Carbon, organic (TOC)	Carbon, total		
	Metals and trace elements		
Aluminum	Cobalt	Molybdenum	Tin
Antimony	Copper	Nickel	Titanium
Arsenic	Iron	Selenium	Uranium
Barium	Lead	Silver	Vanadium
Beryllium	Lithium	Strontium	Zinc
Cadmium	Manganese	Sulfur	
Chromium	Mercury	Thallium	
	Organochlorine compounds		
Aldrin	DDT	Gross polychlorinated biphenyls (PCBs)	Methoxychlor
Chlordane	Dieldrin	Heptachlor	Mirex
DDD	Endosulfan	Heptachlor epoxide	Toxaphene
DDE	Endrin	Lindane	
	Radionuclide		
Cesium–137			

Perry Lake. For each constituent, mean annual net load was computed as the median concentration multiplied by the mean annual mass of sediment deposited in the lake. For all constituents for which a mean annual net load was computed, the mean annual yield was estimated by dividing the total mean annual load transported to the lake by the area of the basin.

Age dating of the bottom sediment from coring site PIC–1 was accomplished by determining the activity of ^{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 if a generally uniform, exponential decrease in ^{137}Cs concentrations follows the 1963–64 peak. As shown in figure 5 (which includes the ^{137}Cs profile for a sediment core collected from Tuttle Creek Lake that includes the 1963–64 peak), the ^{137}Cs profile for coring site PIC–1, which represents the decrease following the 1963–64 peak, indicated that the sediment is relatively undisturbed. Thus, trend analyses performed for this site can be considered meaningful.

The sediment cores also were analyzed to determine bulk density. For this purpose, each core was divided into five intervals of equal length. From the second and fourth intervals, a 1-in. thick sediment sample was extracted, 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 core sample was computed as:

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

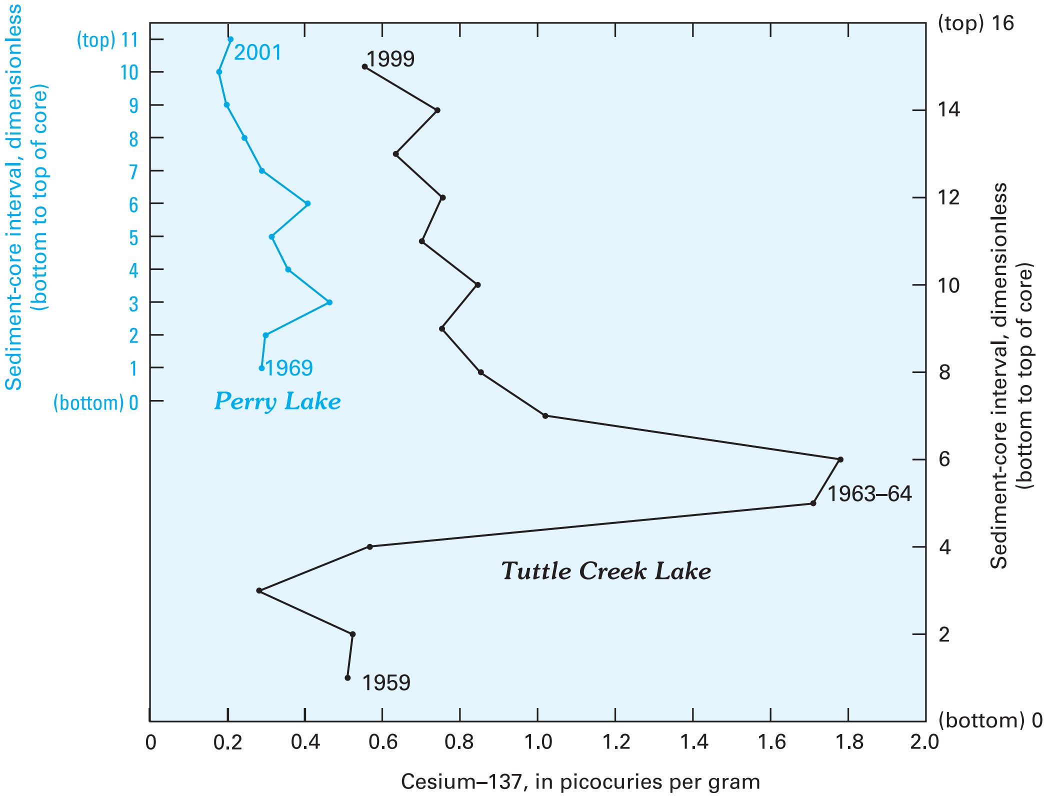


Figure 5. Variation in cesium–137 activity with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001, and from coring site TIC–2 in Tuttle Creek Lake, September 1999. Location of coring site PIC–1 shown in figure 2. Cesium–137 activity in Tuttle Creek Lake sediment from Juracek and Mau (2002).

where v is the volume of the core sample (in cubic centimeters), h is the height (length) of the core sample (in centimeters), and d is the diameter of the core sample (in centimeters) (Gordon and others, 1992). Results for the two 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. Analyses of sediment samples for bulk density were performed at the USGS laboratory in Lawrence, Kansas.

A particle-size analysis was performed to determine the percentage of sand (that is, particles larger than 0.063 mm in diameter) and silt and (or) clay (that is, particles smaller than 0.063 mm in diameter) in the sediment cores. The particle-size analyses were completed at the USGS Sediment Trace Element Partitioning Laboratory in Atlanta, Georgia, according to the methods presented in Grosbois and others (2001).

Quality Control

For quality control, the reliability of the fathometer used in the bathymetric survey 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.

Quality control for the chemical analysis of sediment samples was provided by an evaluation of within-site and analytical variability. At in-channel coring site PIC–1, multiple sediment cores were collected to provide the required amount of material for physical and 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 site PIC–1 (fig. 2). For each core a composite sample was prepared, as described previously, and analyzed for the various constituents. For the 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 2. With the exception of mercury, molybdenum, tin, zinc, and DDE, within-site variability was minimal with relative percentage differences of less than 4 percent (table 2). Mercury, molybdenum, tin, zinc, and DDE had relative percentage differences of 11.1, 33.3, 25.0, 8.3, and 33.3 percent, respectively.

Analytical variability was evaluated through the collection and analysis of split replicate samples from an individual core collected from in-channel site PIC–1 (fig. 2). Two composite samples were prepared for the core and analyzed for the various constituents. The relative percentage differences between the split replicate sample concentrations were computed as previously described.

The relative percentage differences computed for all constituents detected in the split replicate samples also are provided in table 2. With the exception of total nitrogen, antimony, cadmium, tin, and DDE, analytical variability was minimal with relative percentage differences generally less than 4 percent. Total nitrogen, antimony, cadmium, tin, and DDE had relative percentage differences of 20.0, 7.7, 11.1, 25.0, and 16.9 percent, respectively. On the basis of these results, most of the within-site variability determined for tin and DDE may be due to analytical variability.

Trend Analysis

Sediment cores collected at in-channel site PIC–1 (fig. 2), which were divided into 8 to 11 sample intervals, were used for the purpose of trend analyses. Site PIC–1 was selected because it is in relatively deep water near the dam where the sediment is mostly fine grained (and thus more likely to contain measurable constituent concentrations) and least likely to be disturbed. Trends in constituent concentration and diatom occurrence 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 or diatom occurrence increased toward the top of the sediment core) or negative (constituent concentration or diatom occurrence 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 or

Table 2. Relative percentage differences for constituent concentrations in sequential replicate and split replicate samples of bottom sediment from coring site PIC–1 in Perry Lake, northeast Kansas, July 2001

Table
samples
[--, not calculated]

Constituent	Relative percentage difference	
	Sequential replicate samples	Split replicate samples
Nutrients		
Total nitrogen	0	20.0
Total phosphorus	0	0
Carbon		
Carbon, organic (TOC)	0	2.6
Carbon, total	2.3	2.3
Metals and trace elements		
Aluminum	.5	.5
Antimony	0	7.7
Arsenic	0	2.7
Barium	.7	1.4
Beryllium	0	1.8
Cadmium	0	11.1
Chromium	.5	.5
Cobalt	0	2.9
Copper	0	0
Iron	1.0	1.0
Lead	1.8	0
Lithium	1.4	0
Manganese	0	3.4
Mercury	11.1	0
Molybdenum	33.3	0
Nickel	1.0	2.0
Selenium	0	0
Silver	--	--
Strontium	0	0
Sulfur	--	--
Thallium	--	--
Tin	25.0	25.0
Titanium	1.1	1.1
Uranium	--	--
Vanadium	3.2	3.2
Zinc	8.3	4.0
Organochlorine compounds		
Aldrin	--	--
Chlordane	--	--
DDD	--	--

Table 2. Relative percentage differences for constituent concentrations in sequential replicate and split replicate samples of bottom sediment from coring site PIC–1 in Perry Lake, northeast Kansas, July 2001—Continued

Constituent	Relative percentage difference	
	Sequential replicate samples	Split replicate samples
Organochlorine compounds—Continued		
DDE	33.3	16.9
DDT	--	--
Dieldrin	--	--
Endosulfan	--	--
Endrin	--	--
Gross polychlorinated biphenyls (PCBs)	--	--
Heptachlor	--	--
Heptachlor epoxide	--	--
Lindane	--	--
Methoxychlor	--	--
Mirex	--	--
Toxaphene	--	--

diatom having four or more sample intervals with no detection.

Because constituent concentrations for the bottom interval of the core collected at in-channel site PIC–1 were typically substantially smaller than (about one-half) the concentrations for the remainder of the core, the bottom interval was excluded from the trend analysis. The bottom interval was excluded because the anomalous concentrations may be due to locally derived sediment (deposited during the initial filling of the reservoir), which may be chemically different from and not representative of sediment originating elsewhere in the basin.

SEDIMENT DEPOSITION IN PERRY LAKE

The total volume of bottom sediment in Perry Lake was estimated by partitioning the original conservation-pool surface area of the lake into in- and out-of-channel components (as segmented by the bathymetric range lines), computing bottom-sediment volume separately for each component, and then summing all component results. The total in- and out-of-channel bottom-sediment volumes were 360 million and 2,110 million ft^3, respectively. Therefore, the total estimated volume of bottom sediment in the original conservation-pool area of the lake was 2,470 million ft^3 or about 56,700 acre-ft. In comparison, the USCOE bathymetry-based estimate of the total volume of bottom sediment in 1993 was 36,500 acre-ft (Edith Reynolds, U.S. Army Corps of Engineers, written commun., 2002). The 56,700 acre-ft of sediment occupies about 23 percent of the lake's original water-storage capacity of 243,200 acre-ft at conservation pool. Table 3 provides the estimated channel length, mean channel width, mean bottom-sediment thickness, and computed bottom-sediment volume for each in-channel component. Table 4 provides the estimated surface area, mean bottom-sediment thickness, and computed bottom-sediment volume for each out-of-channel component. A longitudinal view of in-channel and out-of-channel sediment deposition in Perry Lake is provided in figures 6 and 7, respectively.

Bottom-sediment mass was estimated as the computed bottom-sediment volume multiplied by the representative bulk density of the sediment. Bulk densities were estimated at 10 in-channel and 8 out-of-channel sites in the lake (table 5, fig. 2). Estimated bulk densities ranged from a mean of 18.4 lb/ft^3 for core samples from site POC–2 (out-of-channel site) to 59.9 lb/ft^3 for core samples from site PIC–8 (in-channel site) with an overall mean of 34.8 lb/ft^3. The particle-size composition of the bottom sediment in Perry Lake was very uniform. At every site and sampling depth, the silt and (or) clay content of the sediment was 98 percent or greater.

Table 3. Estimated channel length, mean channel width, mean bottom-sediment thickness, and computed bottom-sediment volume in submerged in-channel components of Perry Lake, northeast Kansas, July 2001

[all values have been rounded to two or three significant figures]

In-channel lake component (fig. 2)	Estimated channel length (feet)	Mean channel width (feet)	Mean bottom-sediment thickness (feet)	Computed bottom-sediment volume[1] (cubic feet)
Delaware River				
Dam to range line 1	2,190	125	9.4	2,570,000
Range lines 1 to 2	22,100	125	9.6	26,500,000
Range lines 2 to 3	13,400	140	16.6	31,100,000
Range lines 3 to 4	9,850	150	21.2	31,300,000
Range lines 4 to 5	13,800	145	26.1	52,200,000
Range lines 5 to 6	17,300	150	32.6	84,600,000
Range lines 6 to 7	18,000	150	27.9	75,300,000
Range lines 7 to 8	8,530	115	16.6	16,300,000
Rock Creek				
Confluence with Delaware River to range line 24	5,500	45	10.8	2,670,000
Range lines 24 to 25	15,300	50	12.2	9,330,000
Range lines 25 to 26	23,100	50	6.8	7,850,000
Slough Creek				
Confluence with Delaware River to range line 28	11,800	40	8.0	3,780,000
Range lines 28 to 29	20,000	40	11.1	8,880,000
Range lines 29 to 30	14,600	45	12.3	8,080,000
Total for lake				**360,000,000**

[1] Bottom-sediment volume is computed as estimated channel length multiplied by mean channel width multiplied by mean bottom-sediment thickness.

The total in-channel mass of bottom sediment in the lake, estimated as the sum of the sediment mass computed for the individual channel components (fig. 2), was 15,400 million lb. Total out-of-channel bottom-sediment mass, estimated as the sum of the sediment mass computed for the individual out-of-channel components (fig. 2), was 81,800 million lb. Therefore, the total estimated mass of bottom sediment in the original conservation-pool surface area of the lake was 97,200 million lb or about 44,100 million kg. Tables 6 and 7 detail the bottom-sediment mass estimated for the in- and out-of-channel lake components, respectively.

Annual net sediment deposition was estimated by dividing the total mass of bottom sediment in the lake by the number of years of deposition (that is, 32). The mean annual net sediment deposition was estimated to be 3,040 million lb (1,379 million kg). The mean annual amount of sediment that exits the lake through the outflow was estimated to be 23 million lb (10.4 million kg). Thus, the total mean annual amount of sediment transported to the lake was estimated to be 3,063 million lb (1,389 million kg), of which about 99 percent is deposited on the lake bed. Mean annual sediment yield from the Perry Lake Basin, computed as the total mean annual amount of sediment transported to the lake divided by the basin area (1,117 mi^2), was estimated to be 2,740,000 (lb/mi^2)/yr [4,798 (kg/ha)/yr].

A comparison of sediment deposition in Perry Lake with six other reservoirs in Kansas (Cedar Lake, Cheney Reservoir, Hillsdale Lake, Lake Olathe, Tuttle Creek Lake, and Webster Reservoir) (fig. 1) is provided in table 8. To account for differences in reservoir age and size of contributing-drainage area, the reservoirs were compared on the basis of mean annual net sediment yield, which was computed in acre-feet per square mile of contributing-drainage area.

Results of the comparison indicated that decreases in water-storage capacity due to sedimentation ranged

Table 4. Estimated surface area, mean bottom-sediment thickness, and computed bottom-sediment volume in submerged out-of-channel components of Perry Lake, northeast Kansas, July 2001

[all values have been rounded to two or three significant figures]

Out-of-channel lake component (fig. 2)	Estimated surface area (square feet)	Mean bottom-sediment thickness (feet)	Computed bottom-sediment volume[1] (cubic feet)
	Delaware River		
Dam to range line 1	19,300,000	0.7	13,500,000
Range lines 1 to 2, 24 to 28	85,400,000	.5	42,700,000
Range lines 2 to 3	71,500,000	2.5	179,000,000
Range lines 3 to 4	41,700,000	3.8	158,000,000
Range lines 4 to 5	70,100,000	7.9	554,000,000
Range lines 5 to 6	72,000,000	10.4	749,000,000
Range lines 6 to 7	32,800,000	6.0	197,000,000
Range lines 7 to 8	14,400,000	3.6	51,800,000
	Rock Creek		
Range lines 24 to 25	45,800,000	1.3	59,500,000
Range lines 25 to 26	16,500,000	2.2	36,300,000
	Slough Creek		
Range lines 28 to 29	34,800,000	1.2	41,800,000
Range lines 29 to 30	11,100,000	2.3	25,500,000
Total for lake			**2,110,000,000**

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

from less than 5 percent at Hillsdale Lake in northeast Kansas and Webster Reservoir in north-central Kansas to about 50 percent at Cedar Lake, a small impoundment in northeast Kansas. Decreases in capacity at Cheney Reservoir (south-central Kansas), Perry Lake (northeast Kansas), and Tuttle Creek Lake (northeast Kansas) were in the range of 20 to 35 percent. Sedimentation has decreased the capacity of the five large Federal reservoirs (Cheney Reservoir, Hillsdale Lake, Perry Lake, Tuttle Creek Lake, Webster Reservoir) at an average annual rate of less than 1 percent. Mean annual net sediment yield ranged from 0.03 (acre-ft/mi^2)/yr for Webster Reservoir to 1.59 (acre-ft/mi^2)/yr for Perry Lake. In general, reservoir sedimentation decreases east to west across Kansas and reflects the decrease in mean annual precipitation.

OCCURRENCE OF, AND TRENDS IN, SELECTED CHEMICAL CONSTITUENTS AND DIATOMS

The U.S. Environmental Protection Agency (USEPA) has established nonenforceable sediment-quality guidelines in the form of level-of-concern concentrations for several metals, 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 established by USEPA are referred to as the threshold-effects level (TEL) and the probable-effects level (PEL). The TEL is assumed to represent the concentration below which toxic biological effects rarely occur. In the range of concentrations between the TEL and PEL, toxic effects occasionally occur. Toxic effects usually or frequently occur at concentrations above the PEL.

The 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

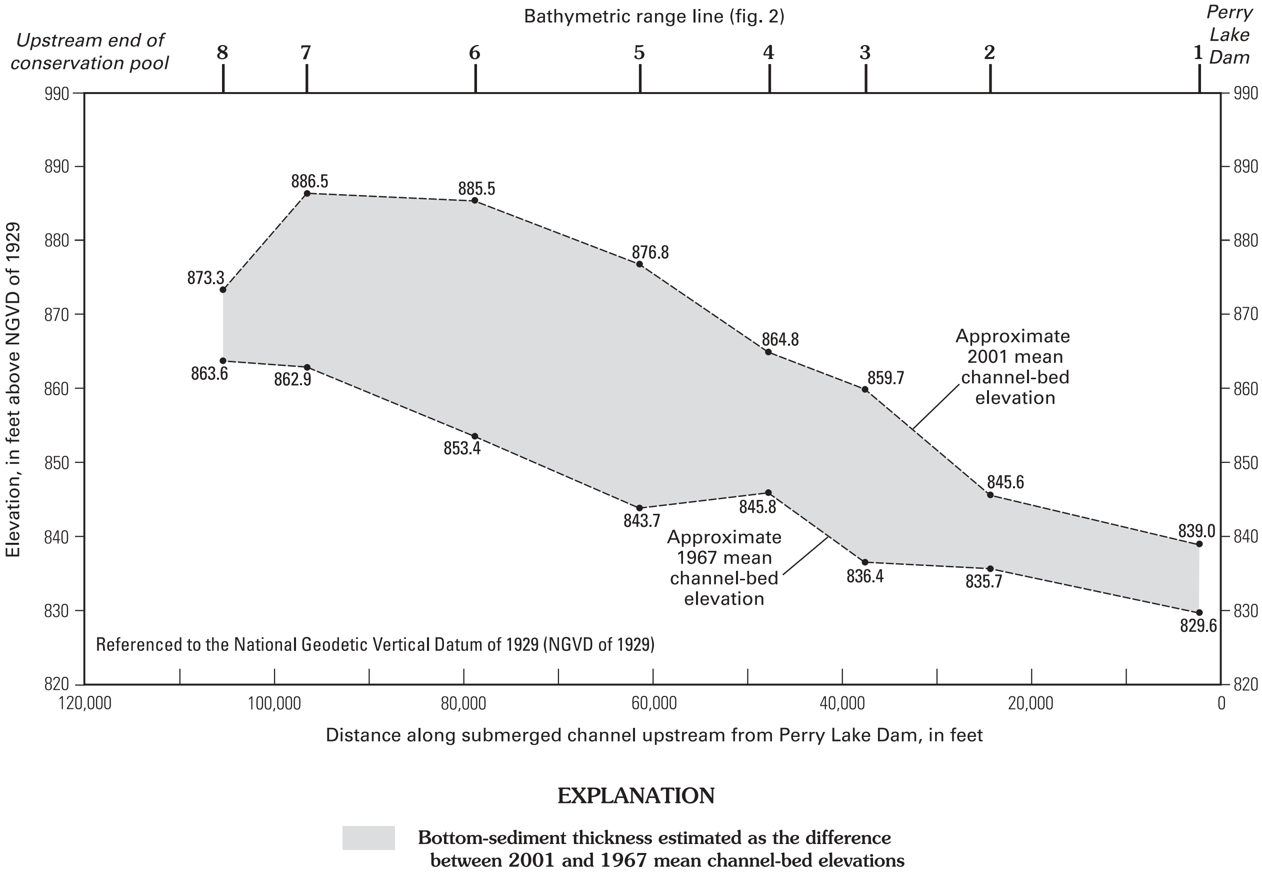


Figure 6. Estimated bottom-sediment thickness in submerged Delaware River channel of Perry Lake, 2001.

procedure may not demonstrate that a particular chemical is solely responsible. In fact, biological-effects correlations may not indicate direct cause-and-effect relationships because coring sites may contain a mixture of chemicals that contribute to the adverse effects to 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.

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 effluent. The USEPA has not established sediment-quality guidelines for nitrogen or phosphorus.

Total nitrogen concentrations in the bottom sediment of Perry Lake ranged from 1,300 to 2,800 mg/kg with a median concentration of 2,500 mg/kg (table 9). A statistically significant positive depositional trend for total nitrogen was indicated (that is, total nitrogen concentrations increased toward the top of the sediment core) (table 10, fig. 8*A*). However, despite the statistical significance, this trend may not be representative of an actual trend due to analytical variance (defined here as the mean total nitrogen concentration in the sediment core, excluding the bottom interval, plus or minus 10 percent). This conclusion was based on the fact that all of the concentrations used in the trend analysis were within 10 percent of the mean total nitrogen concentration.

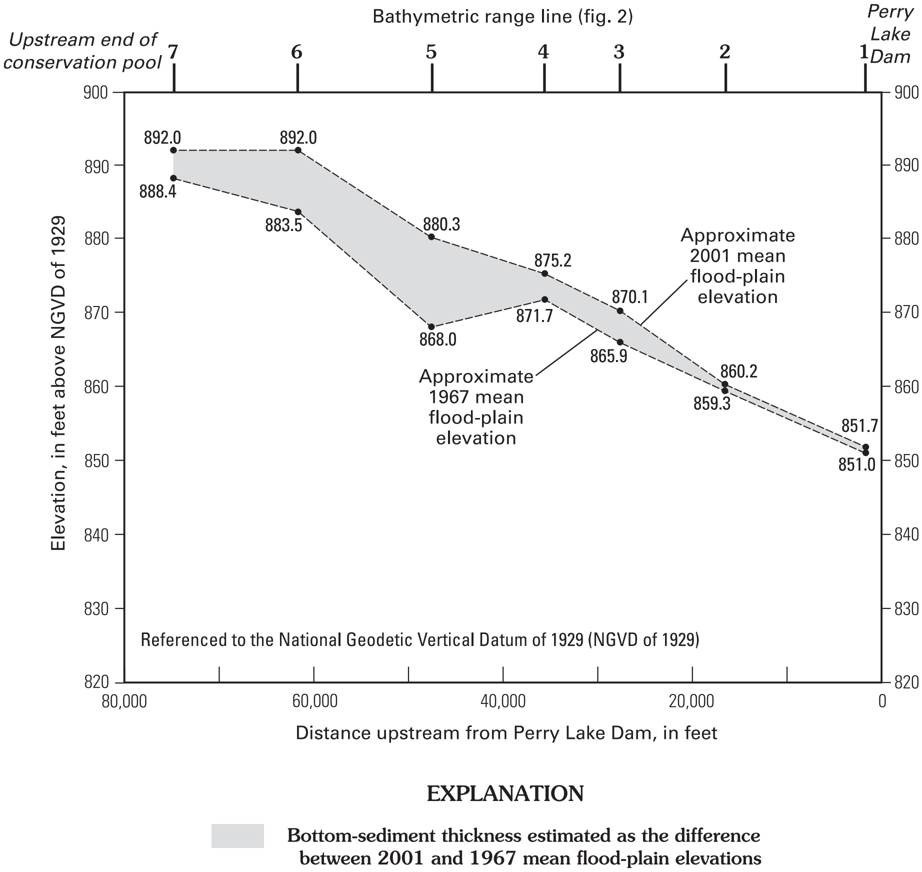


Figure 7. Estimated bottom-sediment thickness on submerged Delaware River flood plain in Perry Lake, 2001.

Mean concentrations of total nitrogen in bottom-sediment cores collected from Perry Lake are shown in figure 9*A*. For figures 9, 11, and 14, mean concentrations are based on data from composite samples collected from the coring sites. The estimated mean annual net load of total nitrogen deposited in the bottom sediment was 7,610,000 lb/yr (3,450,000 kg/yr). The estimated mean annual yield of total nitrogen from the Perry Lake Basin was 6,850 (lb/mi^2)/yr [12.0 (kg/ha)/yr] (table 11).

Total phosphorus concentrations ranged from 630 to 1,300 mg/kg with a median concentration of 1,100 mg/kg (table 9). No statistically significant trend in total phosphorus deposition was indicated (table 10, fig. 8*B*). Mean concentrations of total phosphorus in bottom-sediment cores collected from Perry Lake are shown in figure 9*B*. The estimated mean annual net load of total phosphorus deposited in the bottom sediment was 3,350,000 lb/yr (1,520,000 kg/yr). The estimated mean annual yield of total phosphorus from the Perry Lake Basin was 3,020 (lb/mi^2)/yr [5.29 (kg/ha)/yr] (table 11).

A comparison of the mean annual net total phosphorus yield (that is, not accounting for the phosphorus exiting in the reservoir outflow) from the Perry Lake Basin with six other reservoir basins in Kansas is provided in table 12. Mean annual net total phosphorus yields, which paralleled the sediment yields (table 8), ranged from 26 (lb/mi^2)/yr for Webster Reservoir to 3,000 (lb/mi^2)/yr for Perry Lake.

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 metal solubilities (Hem, 1992). 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 established by the USEPA.

TOC concentrations ranged from 1.0 to 2.1 percent with a median concentration of 1.9 percent (table 9). No statistically significant trend in TOC deposition was indicated (table 10, fig. 10). Mean concentrations of TOC in bottom-sediment cores collected from Perry Lake are shown in figure 11. The estimated mean annual net load of TOC deposited in the bottom sediment was 57,800,000 lb/yr (26,200,000 kg/yr). The estimated mean annual yield of TOC from the Perry Lake Basin was 52,100 (lb/mi^2)/yr [91.2 (kg/ha)/yr] (table 11).

Metals and Trace Elements

Metals and trace elements, especially the latter, are important determinants of sediment quality because of

Table 5. Estimated mean bulk density of bottom sediment at in- and out-of-channel coring sites in Perry Lake, northeast Kansas, July and August 2001

[bulk-density values rounded to three significant figures; --, not determined]

Site number (fig. 2)	Mean bulk density (pounds per cubic foot)
In-channel sites	
PIC–1	25.4
PIC–2	35.2
PIC–4	58.7
PIC–6	53.1
PIC–7	44.6
PIC–8	59.9
PIC–9	30.8
PIC–10	28.5
PIC–11	28.8
PIC–12	34.9
Out-of-channel sites	
POC–1	26.1
POC–2	18.4
[1]POC–3	--
POC–4	46.3
POC–5	28.4
POC–6	26.0
POC–7	18.8
POC–8	32.7
POC–9	30.7
Mean	**34.8**

[1] Bulk density was not determined at this site due to insufficient sediment volume.

their potential toxicity to living organisms (Forstner and Wittmann, 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 aluminum and iron (Adriano, 1986).

Metals and trace elements in sediment originate naturally from the rock and soils within the basin. Also, sediment enrichment of certain metals and 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 Wittmann, 1981; Adriano, 1986).

The health of living organisms is dependent on a sufficient intake of various metals and 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 metal or trace element in the environment, and its potential to bioaccumulate once in the food chain. The daily intake of metals and trace elements by animals and humans may be classified as deficient, optimal, or toxic. Most, if not all, metals and trace elements may be toxic to animals and humans if the concentrations are sufficiently large (Pais and Jones, 1997). Information on the bioaccumulation index for most of the metals and trace elements that were analyzed in this study is provided in table 11.

Of the 26 metals and trace elements analyzed, 22 were detected in all or virtually all of the sediment samples analyzed and at all coring sites for which the analyses were performed (sites PIC–1, PIC–2, PIC–8, PIC–12, POC–1, and POC–4; fig. 2). The exceptions were silver, thallium, and uranium, which were not detected in any of the 19 sediment samples analyzed. Sulfur was detected in 5 of 19 samples analyzed (table 9).

Trend analyses, with a significance level of 0.05, indicated a statistically significant positive depositional trend (constituent concentration increased toward the top of the sediment core) for arsenic and manganese (table 10, fig. 12). A statistically significant negative depositional trend (constituent concentration decreased toward the top of the sediment core) was indicated for beryllium, chromium, titanium, and vanadium (table 10, fig. 13). However, despite the statistical significance, these trends may not be representative of actual trends due to analytical variance (defined here as the mean element concentration for the core, excluding the bottom interval, plus or minus 10 percent). This conclusion was based on the fact that, for the elements for which a trend was indicated, most or all of the concentrations used

Table 6. Estimated bottom-sediment volume, representative bulk density, and computed bottom-sediment mass in submerged in-channel components of Perry Lake, northeast Kansas, July and August 2001

[all values rounded to three significant figures]

In-channel lake component (fig. 2)	Estimated bottom-sediment volume (cubic feet)	Representative bulk density (pounds per cubic foot)	Computed bottom-sediment mass[1] (pounds)
Delaware River			
Dam to range line 1	2,570,000	28.8	74,000,000
Range lines 1 to 2	26,500,000	27.1	718,000,000
Range lines 2 to 3	31,100,000	27.0	840,000,000
Range lines 3 to 4	31,300,000	29.7	930,000,000
Range lines 4 to 5	52,200,000	45.4	2,370,000,000
Range lines 5 to 6	84,600,000	52.3	4,420,000,000
Range lines 6 to 7	75,300,000	48.9	3,680,000,000
Range lines 7 to 8	16,300,000	55.9	911,000,000
Rock Creek			
Confluence with Delaware River to range line 24	2,670,000	34.9	93,200,000
Range lines 24 to 25	9,330,000	34.9	326,000,000
Range lines 25 to 26	7,850,000	34.9	274,000,000
Slough Creek			
Confluence with Delaware River to range line 28	3,780,000	35.2	133,000,000
Range lines 28 to 29	8,880,000	35.2	313,000,000
Range lines 29 to 30	8,080,000	35.2	284,000,000
Total for lake			**15,400,000,000**

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

Table 7. Estimated bottom-sediment volume, representative bulk density, and computed bottom-sediment mass in submerged out-of-channel components of Perry Lake, northeast Kansas, July and August 2001

[all values rounded to three significant figures]

Out-of-channel lake component (fig. 2)	Estimated bottom-sediment volume (cubic feet)	Representative bulk density (pounds per cubic foot)	Computed bottom-sediment mass[1] (pounds)
Delaware River			
Dam to range line 1	13,500,000	18.4	248,000,000
Range lines 1 to 2, 24 to 28	42,700,000	21.1	901,000,000
Range lines 2 to 3	179,000,000	26.1	4,670,000,000
Range lines 3 to 4	158,000,000	27.2	4,300,000,000
Range lines 4 to 5	554,000,000	37.4	20,700,000,000
Range lines 5 to 6	749,000,000	46.3	34,700,000,000
Range lines 6 to 7	197,000,000	46.3	9,120,000,000
Range lines 7 to 8	51,800,000	46.3	2,400,000,000
Rock Creek			
Range lines 24 to 25	59,500,000	25.8	1,540,000,000
Range lines 25 to 26	36,300,000	32.7	1,190,000,000
Slough Creek			
Range lines 28 to 29	41,800,000	30.7	1,280,000,000
Range lines 29 to 30	25,500,000	30.7	783,000,000
Total for lake			**81,800,000,000**

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

Table 8. Estimated total sediment deposition and mean annual net sediment yield for Perry Lake, Hillsdale Lake, Cedar Lake, Lake Olathe, Tuttle Creek Lake, Cheney Reservoir, and Webster Reservoir, Kansas

[mi^2, square miles; acre-ft, acre-feet; (acre-ft/mi^2)/yr, acre-feet per square mile per year]

Reservoir (fig. 1)	Drainage area (mi^2)	Number of years since dam closure	Estimated total sediment deposition (acre-ft)	Mean annual net sediment yield [(acre-ft/mi^2)/yr]	Approximate decrease in water-storage capacity[1] (percent)
Perry Lake	1,117	32	56,700	1.59	23
Hillsdale Lake[2]	144	15	2,100	.97	3
Cedar Lake[3]	6.14	62	338	.89	50
Lake Olathe[3]	16.6	45	317	.42	10
Tuttle Creek Lake[4]	9,628	37	142,000	.40	33
Cheney Reservoir[5]	933	33	7,100	.22	27
Webster Reservoir[6]	1,150	40	1,267	.03	2

[1] Approximate decrease in water-storage capacity is based on a comparison to the original conservation-pool storage capacity for Cheney Reservoir, Hillsdale Lake, Perry Lake, Tuttle Creek Lake, and Webster Reservoir and to the original design storage capacity for Cedar Lake and Lake Olathe.

[2] Juracek (1997).

[3] Mau (2002). Lake Olathe is located downstream from Cedar Lake within the same basin.

[4] Juracek and Mau (2002).

[5] Mau (2001).

[6] Christensen (1999).

in the trend analysis were within 10 percent of the mean element concentration.

Sediment-quality guidelines have been established by USEPA for the elements arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. For cadmium, lead, mercury, and silver, the measured concentrations were all less than the respective TELs (table 9).

Arsenic concentrations in the bottom sediment of Perry Lake ranged from 8 to 25 µg/g with a median concentration of 19 µg/g (table 9). In all cases, the concentrations exceeded the TEL (7.24 µg/g) but were less than the PEL (41.6 µg/g). Mean concentrations of arsenic in bottom-sediment cores collected from Perry Lake are shown in figure 14*A*.

Chromium concentrations ranged from 59 to 100 µg/g with a median concentration of 99 µg/g (table 9). In all cases, the concentrations exceeded the TEL (52.3 µg/g) but were less than the PEL (160 µg/g). Mean concentrations of chromium in bottom-sediment cores collected from Perry Lake are shown in figure 14*B*.

Copper concentrations ranged from 18 to 35 µg/g with a median concentration of 33 µg/g (table 9). With one exception (18 µg/g), all detections exceeded the TEL (18.7 µg/g) but were less than the PEL (108 µg/g). Mean concentrations of copper in bottom-sediment cores collected from Perry Lake are shown in figure 14*C*.

Nickel concentrations ranged from 22 to 54 µg/g with a median concentration of 50 µg/g (table 9). All detections exceeded the TEL (15.9 µg/g) and 16 of 19 detections exceeded the PEL (42.8 µg/g). Figure 14*D* shows the mean concentrations of nickel in bottom-sediment cores collected from Perry Lake.

Zinc concentrations ranged from 58 to 140 µg/g with a median concentration of 120 µg/g (table 9). Of the 19 detections, 13 were less than the TEL (124 µg/g) and 6 exceeded the TEL but were less than the PEL (271 µg/g).

The USEPA has not established sediment-quality guidelines for selenium. However, 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). Selenium concentrations ranged from 0.4 to 1.0 µg/g with a median concentration of 0.9 µg/g (table 9).

The estimated mean annual net loads and mean annual yields for most of the metals and trace elements are provided in table 11.

Organochlorine Compounds

Historically, organochlorine compounds have been manufactured and used extensively for a variety of

Table 9. Statistical summary of concentrations and comparison to sediment-quality guidelines for selected constituents in bottom-sediment samples from Perry Lake, northeast Kansas, July and August 2001

[mg/kg, milligrams per kilogram; %, percent; µg/g, micrograms per gram; µg/kg, micrograms per kilogram; TEL, threshold-effects level; PEL, probable-effects level; <, less than; --, no value assigned]

samp

Constituent and unit of measurement	Number of detections/number of analyses[1]	Concentration			Sediment-quality guidelines[2]	
		Minimum	Median	Maximum	TEL	PEL
Nutrients						
Total nitrogen, mg/kg	19/19	1,300	2,500	2,800	--	--
Total phosphorus, mg/kg	19/19	630	1,100	1,300	--	--
Carbon						
Carbon (organic, TOC), %	19/19	1.0	1.9	2.1	--	--
Carbon (total), %	19/19	1.0	2.1	2.3	--	--
Metals and trace elements						
Aluminum, %	19/19	6	9.6	12	--	--
Antimony, µg/g	19/19	.9	1.3	1.8	--	--
Arsenic, µg/g	19/19	8	19	25	7.24	41.6
Barium, µg/g	19/19	640	710	770	--	--
Beryllium, µg/g	19/19	1.7	2.8	3.0	--	--
Cadmium, µg/g	19/19	.2	.5	.6	.676	4.21
Chromium, µg/g	19/19	59	99	100	52.3	160
Cobalt, µg/g	19/19	10	17	19	--	--
Copper, µg/g	19/19	18	33	35	18.7	108
Iron, %	19/19	2.6	5.3	5.5	--	--
Lead, µg/g	19/19	18	28	30	30.2	112
Lithium, µg/g	19/19	35	69	74	--	--
Manganese, µg/g	19/19	580	1,400	1,700	--	--
Mercury, µg/g	19/19	.01	.05	.07	.13	.696
Molybdenum, µg/g	18/19	.5	1	2	--	--
					--	--
Nickel, µg/g	19/19	22	50	54	15.9	42.8
Selenium, µg/g	19/19	.4	.9	1.0	--	--
Silver, µg/g	0/19	<.5	<.5	<.5	.733	1.77
Strontium, µg/g	19/19	120	130	160	--	--
Sulfur, %	5/19	<.1	<.1	.3	--	--
					--	--
Thallium, µg/g	0/19	<50	<50	<50	--	--
Tin, µg/g	19/19	1	3	5	--	--
Titanium, %	19/19	.41	.44	.47	--	--
Uranium, µg/g	0/19	<50	<50	<50	--	--
Vanadium, µg/g	19/19	88	160	160	--	--
Zinc, µg/g	19/19	58	120	140	124	271
Organochlorine compounds						
Aldrin, µg/kg	0/16	<.2	<.2	<.2	--	--
Chlordane, µg/kg	0/16	<3	<3	<3	2.26	4.79
DDD, µg/kg	1/16	<.50	<.50	.55	1.22	7.81
DDE, µg/kg	7/16	<.20	<.20	.80	2.07	374

Table 9. Statistical summary of concentrations and comparison to sediment-quality guidelines for selected constituents in bottom-sediment samples from Perry Lake, northeast Kansas, July and August 2001—Continued

Constituent and unit of measurement	Number of detections/number of analyses[1]	Concentration			Sediment-quality guidelines[2]	
		Minimum	Median	Maximum	TEL	PEL
Organochlorine compounds—Continued						
DDT, µg/kg	0/16	<0.5	<0.5	<0.5	1.19	4.77
Dieldrin, µg/kg	3/16	<.20	<.20	.24	.715	4.3
Endosulfan, µg/kg	0/16	<.2	<.2	<.2	--	--
Endrin, µg/kg	0/16	<.2	<.2	<.2	--	--
Gross polychlorinated biphenyls (PCBs), µg/kg	0/16	<5	<5	<5	21.6	189
Heptachlor, µg/kg	0/16	<.2	<.2	<.2	--	--
Heptachlor epoxide, µg/kg	0/16	<.2	<.2	<.2	--	--
Lindane, µg/kg	0/16	<.2	<.2	<.2	--	--
Methoxychlor, µg/kg	0/16	<2.5	<2.5	<2.5	--	--
Mirex, µg/kg	0/16	<.2	<.2	<.2	--	--
Toxaphene, µg/kg	0/16	<50	<50	<50	--	--

[1] Number of analyses includes multiple core-interval samples from site PIC–1 and composite samples from sites PIC–1, PIC–2, PIC–8, PIC–12, POC–1, and POC–4.

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

urban, agricultural, and industrial applications. The use of organochlorine insecticides in agriculture in the United States started 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 of the 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 on 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.

Of the 15 organochlorine compounds analyzed in this study (14 insecticides and PCBs), only 3 were detected in the bottom sediment of Perry Lake. Dieldrin was detected in 3 of 16 sediment samples analyzed (table 9). The three detections, with concentrations of 0.20, 0.20, and 0.24 µg/kg, were from coring sites PIC–8, POC–4, and PIC–1, respectively (fig. 2). All three detections of dieldrin were less than the TEL of 0.715 µg/kg.

DDT was not detected in any of the 16 sediment samples analyzed. However, its degradation products DDD and DDE were detected. DDD was detected in 1 of 16 sediment samples analyzed (table 9). The single detection, with a concentration of 0.55 µg/kg, was from the bottom of the core collected for trend analysis at site PIC–1 (fig. 2). The DDD detection was less than the TEL of 1.22 µg/kg.

DDE was detected in 7 of 16 sediment samples analyzed (table 9) and at 2 of 6 coring sites for which the analysis was performed (sites PIC–1 and PIC–2; fig. 2). Concentrations of DDE ranged from less than the detection limit of 0.20 to 0.80 µg/kg. Because only four of eight intervals from the core collected for trend analysis at site PIC-1 (fig. 2) had detectable concentrations of DDE, a trend analysis was not performed. However, the available information did provide some indication of a negative depositional trend over time. The concentration of DDE steadily decreased from

Table 10. Results of trend tests on concentrations of selected constituents in bottom-sediment samples collected from coring site PIC–1 in Perry Lake, northeast Kansas, July 2001

[--, not calculated]

Constituent	Spearman's rho[1]	Trend test at a 0.05 level of significance[1]
Nutrients		
Total nitrogen	0.69	positive trend
Total phosphorus	.20	no trend
Carbon		
Carbon (organic, TOC)	.40	no trend
Carbon (total)	.46	no trend
Metals and trace elements		
Aluminum	- .05	no trend
Antimony	- .45	no trend
Arsenic	.66	positive trend
Barium	- .40	no trend
Beryllium	- .87	negative trend
Cadmium	.24	no trend
Chromium	- .76	negative trend
Cobalt	- .24	no trend
Copper	- .20	no trend
Iron	.09	no trend
Lead	- .29	no trend
Lithium	.27	no trend
Manganese	.64	positive trend
Mercury	- .48	no trend
Molybdenum	.36	no trend
Nickel	- .34	no trend
Selenium	- .15	no trend
Silver	--	--
Strontium	- 0.29	no trend
Metals and trace elements—Continued		
Sulfur	--	--
Thallium	--	--
Tin	- .14	no trend
Titanium	- .82	negative trend
Uranium	--	--
Vanadium	- .70	negative trend
Zinc	- .38	no trend
Organochlorine compounds		
Aldrin	--	--
Chlordane	--	--
DDD	--	--
DDE	--	--
DDT	--	--
Dieldrin	--	--
Endosulfan	--	--
Endrin	--	--
Gross polychlorinated biphenyls (PCBs)	--	--
Heptachlor	--	--
Heptachlor epoxide	--	--
Lindane	--	--
Methoxychlor	--	--
Mirex	--	--
Toxaphene	--	--

[1] Computed with interval 1 (bottom of sediment core) excluded.

0.80 µg/kg for the bottom sample interval of the core to successive concentrations of 0.60, 0.49, and 0.22 µg/kg for the overlying intervals. The four uppermost sample intervals in the core all had DDE concentrations less than the detection limit. The detectable concentrations of DDE were less than the TEL of 2.07 µg/kg. The pattern of DDE deposition was consistent with the history of DDT usage. DDT was used extensively in agriculture during the 1950s and 1960s. Then, with the ban of DDT in 1972, its use declined (Manahan, 2000).

PCBs were not detected in any of the 16 sediment samples analyzed. Because PCBs are associated with industrial or commercial activities such as those related to intensively urbanized areas, PCBs generally would not be expected in reservoir bottom sediment from a predominantly agricultural basin.

Diatoms

Diatoms are microscopic algae that occur in almost all aquatic environments. They have a siliceous shell, or frustule, consisting of two valves (halves), that is preserved in sediment. Because many diatom species are sensitive to changes in environmental conditions (for example, pH, light, temperature, and

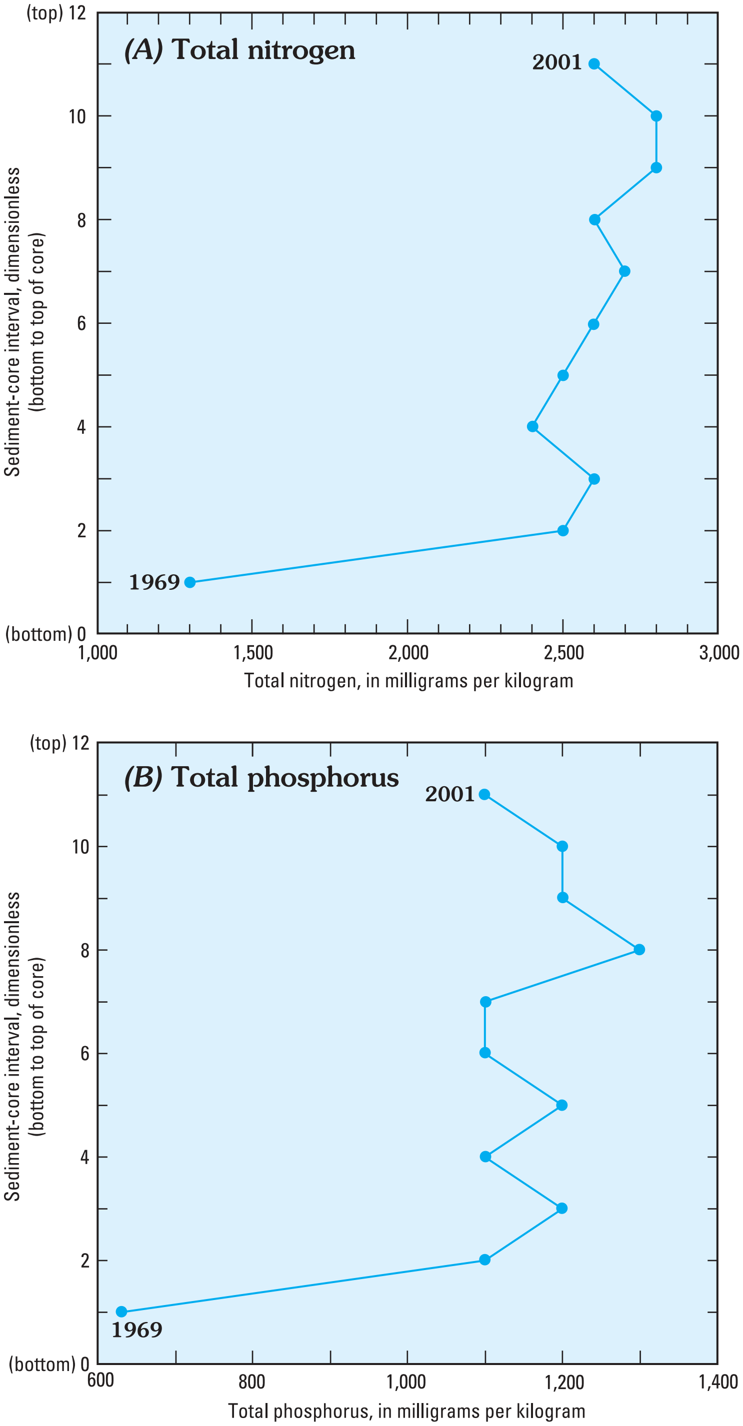


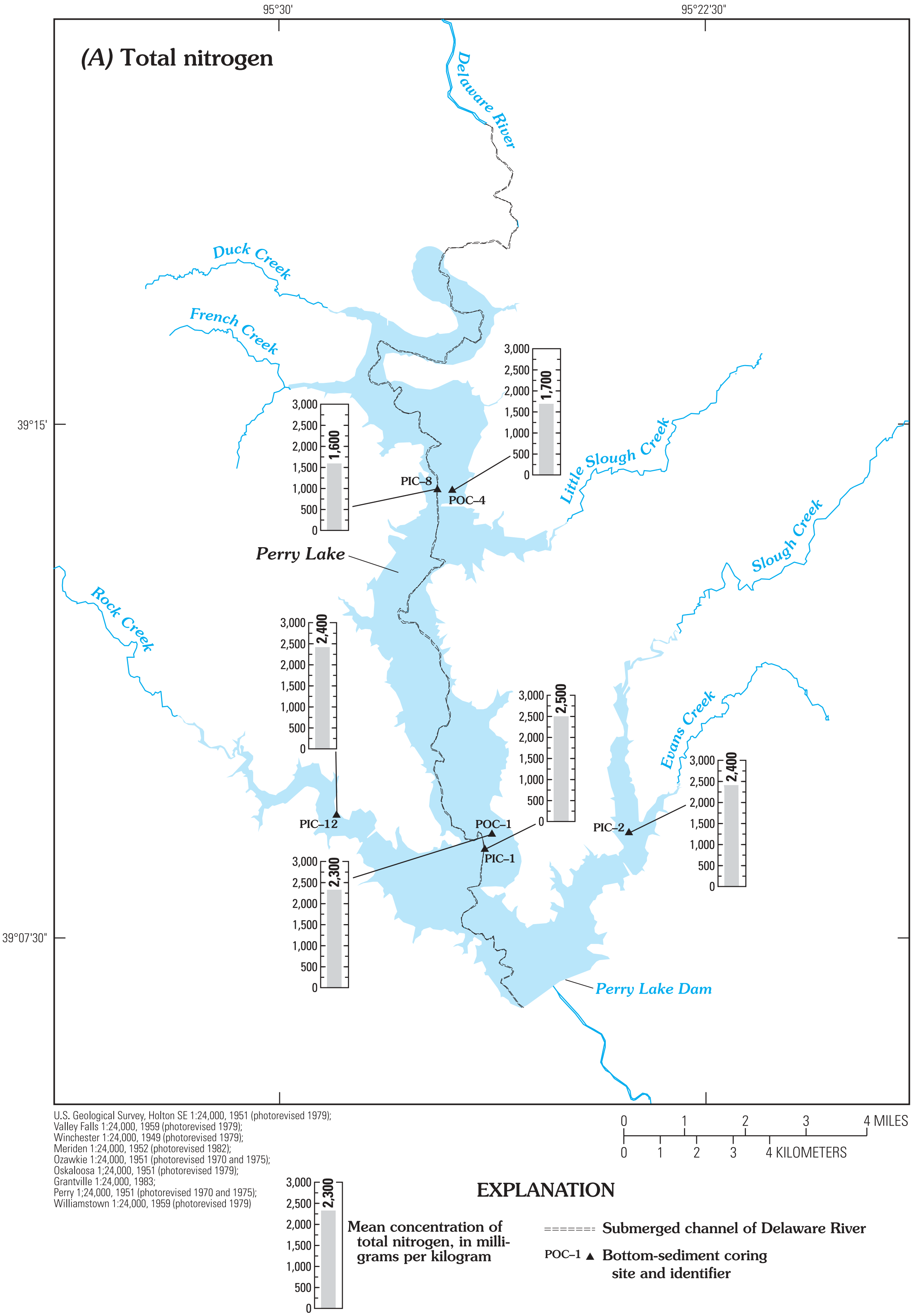
Figure 8. Variation in *(A)* total nitrogen and *(B)* total phosphorus concentrations with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001. Location of coring site shown in figure 2.

concentrations of nutrients, trace elements, and pesticides), changes in diatom species composition and abundance can be used as indicators of environmental changes (Dixit and others, 1992; Stoermer and Smol, 1999).

A total of 25 different diatom species (table 13) were identified in a bottom-sediment core collected at site PIC–1 in Perry Lake (fig. 2). Within each sample interval of the core, the number of diatom species identified ranged from 6 to 16. For 16 of the 25 diatom species, occurrence was limited to 3 or fewer of the 10 sample intervals with a relative percentage abundance of 1.3 percent or less (table 13). Six diatom species occurred in eight or more of the sample intervals with relative percentage abundances ranging from less than 1.0 to 65.0 percent (table 13). Complete information on the occurrence and abundance of diatom species in each sample interval is provided in table 16 in the “Supplemental Information” section at the back of this report.

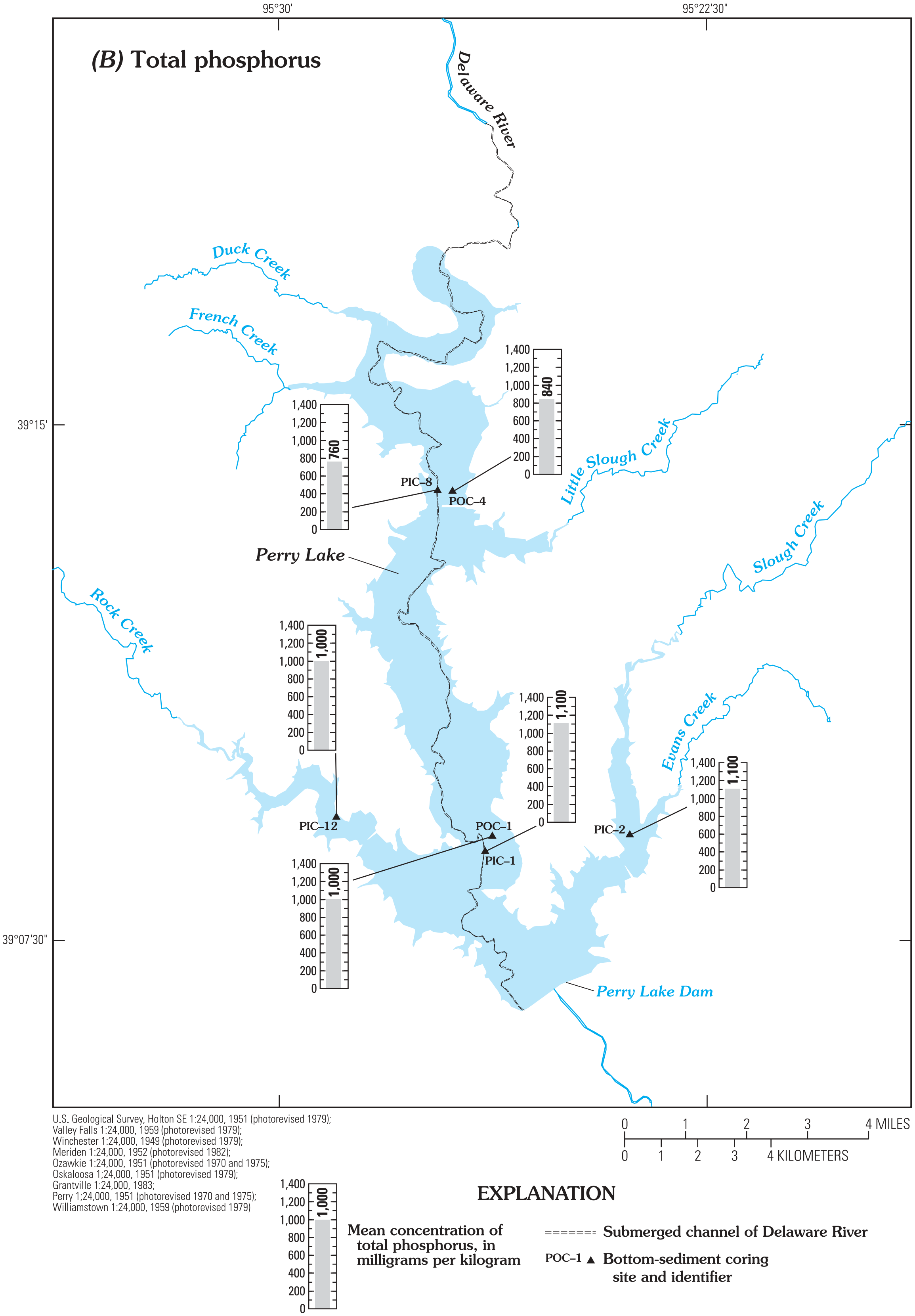
Trend analyses, with a significance level of 0.05, indicated a statistically significant positive depositional trend (diatom occurrence increased toward the top of the sediment core) for *Aulacoseira islandica* (fig. 15) and *Cyclotella radiosa* (fig. 16). A statistically significant negative depositional trend (diatom occurrence decreased toward the top of the sediment core) was indicated for *Stephanodiscus niagarae* (fig. 17) (table 13). Because concentrations of total nitrogen and total phos-phorus were relatively uniform with depth in a bottom-sediment core collected at site PIC–1 (with the exception of the bottom (oldest) sample interval for which concentrations were anomalously small) (fig. 8), the trends in diatom occurrence do not appear to be related to changes in nutrient concentrations in the sediment.

Diatoms are useful for assessing the trophic condition and history of a lake. For example, a lake may be characterized as eutrophic (nutrient rich, high primary productivity) or oligotrophic (nutrient poor, low primary productivity) (Horne and Goldman, 1994). Generally, in eutrophic water, the diatom community will be dominated by a few abundant species tolerant of nutrient and organic enrichment. In contrast, diatom communities in uncontaminated water (free of sewage or other organic enrichment due to waste discharge) consist of a greater number of more equally



U.S. Geological Survey, Holton SE 1:24,000, 1951 (photorevised 1979);
Valley Falls 1:24,000, 1959 (photorevised 1979);
Winchester 1:24,000, 1949 (photorevised 1979);
Meriden 1:24,000, 1952 (photorevised 1982);
Ozawkie 1:24,000, 1951 (photorevised 1970 and 1975);
Oskaloosa 1;24,000, 1951 (photorevised 1979);
Grantville 1:24,000, 1983;
Perry 1;24,000, 1951 (photorevised 1970 and 1975);
Williamstown 1:24,000, 1959 (photorevised 1979)

Figure 9. Mean concentrations of *(A)* total nitrogen and *(B)* total phosphorus in bottom-sediment cores collected from Perry Lake, July and August 2001.



U.S. Geological Survey, Holton SE 1:24,000, 1951 (photorevised 1979);
Valley Falls 1:24,000, 1959 (photorevised 1979);
Winchester 1:24,000, 1949 (photorevised 1979);
Meriden 1:24,000, 1952 (photorevised 1982);
Ozawkie 1:24,000, 1951 (photorevised 1970 and 1975);
Oskaloosa 1;24,000, 1951 (photorevised 1979);
Grantville 1:24,000, 1983;
Perry 1;24,000, 1951 (photorevised 1970 and 1975);
Williamstown 1:24,000, 1959 (photorevised 1979)

EXPLANATION

Mean concentration of total phosphorus, in milligrams per kilogram

======= Submerged channel of Delaware River

POC–1 ▲ Bottom-sediment coring site and identifier

Figure 9. Mean concentrations of *(A)* total nitrogen and *(B)* total phosphorus in bottom-sediment cores collected from Perry Lake, July and August 2001—Continued.

Table 11. Estimated mean annual net loads and mean annual yields of constituents deposited in bottom sediment of Perry Lake, northeast Kansas, and associated bioaccumulation index

[Mean annual net loads and yields have been rounded to three significant figures. mg/kg, milligrams per kilogram; kg/yr, kilograms per year; lb/yr, pounds per year; (kg/ha)/yr, kilograms per hectare per year; (lb/mi^2)/yr, pounds per square mile per year; <, less than; --, not calculated or not available]

Kansas, and associate

Constituent	Median concentration (mg/kg)	Mean annual net load[1]		Mean annual yield[2]		Bioaccumulation index[3]
		(kg/yr)	(lb/yr)	[(kg/ha)/yr]	[(lb/mi^2)/yr]	
Nutrients						
Total nitrogen	2,500	3,450,000	7,610,000	12.0	6,850	--
Total phosphorus	1,100	1,520,000	3,350,000	5.29	3,020	--
Carbon						
Carbon (organic, TOC)	19,000	26,200,000	57,800,000	91.2	52,100	--
Carbon (total)	21,000	29,000,000	63,900,000	101	57,700	--
Metals and trace elements						
Aluminum	96,000	132,000,000	291,000,000	460	263,000	--
Antimony	1.3	1,790	3,950	.006	3.43	moderate
Arsenic	19	26,200	57,800	.09	51.4	moderate
Barium	710	980,000	2,160,000	3.41	1,950	low
Beryllium	2.8	3,860	8,510	.01	5.71	low
Cadmium	.5	690	1,520	.002	1.14	moderate
Chromium	99	137,000	302,000	.48	274	moderate
Cobalt	17	23,500	51,800	.08	45.7	high
Copper	33	45,500	100,000	.16	91.4	high
Iron	53,000	73,100,000	161,000,000	254	145,000	low
Lead	28	38,600	85,100	.13	74.2	moderate
Lithium	69	95,200	210,000	.33	188	slight
Manganese	1,400	1,930,000	4,260,000	6.71	3,830	low
Mercury	.05	69	152	.0002	.114	high
Molybdenum	1	1,380	3,040	.005	2.86	high
Nickel	50	69,000	152,000	.24	137	moderate
Selenium	.9	1,240	2,730	.004	2.28	high
Silver	<.5	--	--	--	--	moderate
Strontium	130	179,000	395,000	.63	360	moderate
Sulfur	<1,000	--	--	--	--	--
Thallium	<50	--	--	--	--	low
Tin	3	4,140	9,130	.01	5.71	--
Titanium	4,400	6,070,000	13,400,000	21.1	12,000	moderate
Uranium	<50	--	--	--	--	--
Vanadium	160	221,000	487,000	.77	440	low
Zinc	120	166,000	366,000	.58	331	high
Organochlorine compounds						
Aldrin	<.0002	--	--	--	--	--
Chlordane	<.003	--	--	--	--	--
DDD	<.0005	--	--	--	--	--
DDE	<.0002	--	--	--	--	--
DDT	<.0005	--	--	--	--	--

Table 11. Estimated mean annual net loads and mean annual yields of constituents deposited in bottom sediment of Perry Lake, northeast Kansas, and associated bioaccumulation index—Continued

Constituent	Median concentration (mg/kg)	Mean annual net load[1] (kg/yr)	Mean annual net load[1] (lb/yr)	Mean annual yield[2] [(kg/ha)/yr]	Mean annual yield[2] [(lb/mi^2)/yr]	Bioaccumulation index[3]
Organochlorine compounds—Continued						
Dieldrin	<0.0002	--	--	--	--	--
Endosulfan	<.0002	--	--	--	--	--
Endrin	<.0002	--	--	--	--	--
Gross polychlorinated biphenyls (PCBs)	<.005	--	--	--	--	--
Heptachlor	<.0002	--	--	--	--	--
Heptachlor epoxide	<.0002	--	--	--	--	--
Lindane	<.0002	--	--	--	--	--
Methoxychlor	<.0025	--	--	--	--	--
Mirex	<.0002	--	--	--	--	--
Toxaphene	<.05	--	--	--	--	--

[1] Mean annual net load in kilograms per year was computed as median concentration multiplied by the mean annual sediment load deposited in Perry Lake (1,380 million kilograms), divided by 1 million. Mean annual net load in pounds per year was computed as mean annual net load in kilograms per year multiplied by 2.205.

[2] Mean annual yield in kilograms per hectare per year was computed as the total mean annual load divided by the area of the Perry Lake Basin (289,303 hectares). Mean annual yield in pounds per square mile per year was computed as the mean annual yield in kilograms per hectare per year multiplied by 571.09.

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

abundant species (U.S. Environmental Protection Agency, 1977).

Several diatom species are indicators of eutrophic conditions including *Aulacoseira granulata*, *Cyclotella meneghiniana*, *Stephanodiscus hantzschii*, and *Stephanodiscus niagarae* (Sabater and Haworth, 1995; Stoermer and Smol, 1999; Blais and others, 2000; Dixit and others, 2000). In the core collected at site PIC–1 in Perry Lake, *Aulacoseira granulata* was found in every sample interval with relative percentage abundances ranging from 17.7 to 53.3 percent. *Cyclotella meneghiniana* was found in only two sample intervals with relative percentage abundances of 0.4 and 1.3 percent. *Stephanodiscus hantzschii* was found in eight sample intervals with a range in relative percentage abundance of 0.3 to 5.8 percent. *Stephanodiscus niagarae* was found in all 10 sample intervals with relative percentage abundances ranging from 18.3 to 65.0 percent (table 13). The statistically significant negative depositional trend determined for *Stephanodiscus niagarae* (fig. 17) indicated that environmental conditions in the lake may have changed in some way that has contributed to a steady decline in the abundance of this species.

Diatom species indicative of oligotrophic conditions include *Aulacoseira distans*, *Aulacoseira islandica*, *Cyclotella comensis*, *Cyclotella ocellata*, *Cyclotella radiosa*, and *Cyclotella stelligera* (Yang and others, 1993; Sabater and Haworth, 1995; Stoermer and Smol, 1999; Clerk and others, 2000). In the core collected at site PIC–1 in Perry Lake, *Aulacoseira distans* and *Cyclotella ocellata* were detected in two and three sample intervals, respectively, with relative percentage abundances of 1.2 percent or less. *Aulacoseira islandica* was found in 9 of 10 sample intervals with relative percentage abundances ranging from 0.4 to 21.9 percent. *Cyclotella radiosa* was found in all

Table 12. Estimated mean annual net total phosphorus yields for Perry Lake, Cedar Lake, Hillsdale Lake, Lake Olathe, Tuttle Creek Lake, Cheney Reservoir, and Webster Reservoir, Kansas

[mi^2, square miles; (lb/mi^2)/yr, pounds per square mile per year]

Reservoir (fig. 1)	Drainage area (mi^2)	Estimated mean annual net total phosphorus yield [(lb/mi^2)/yr]
Perry Lake	1,117	3,000
Cedar Lake	6.14	2,390
Hillsdale Lake	144	949
Lake Olathe	16.6	582
Tuttle Creek Lake	9,628	348
Cheney Reservoir	933	243
Webster Reservoir	1,150	26

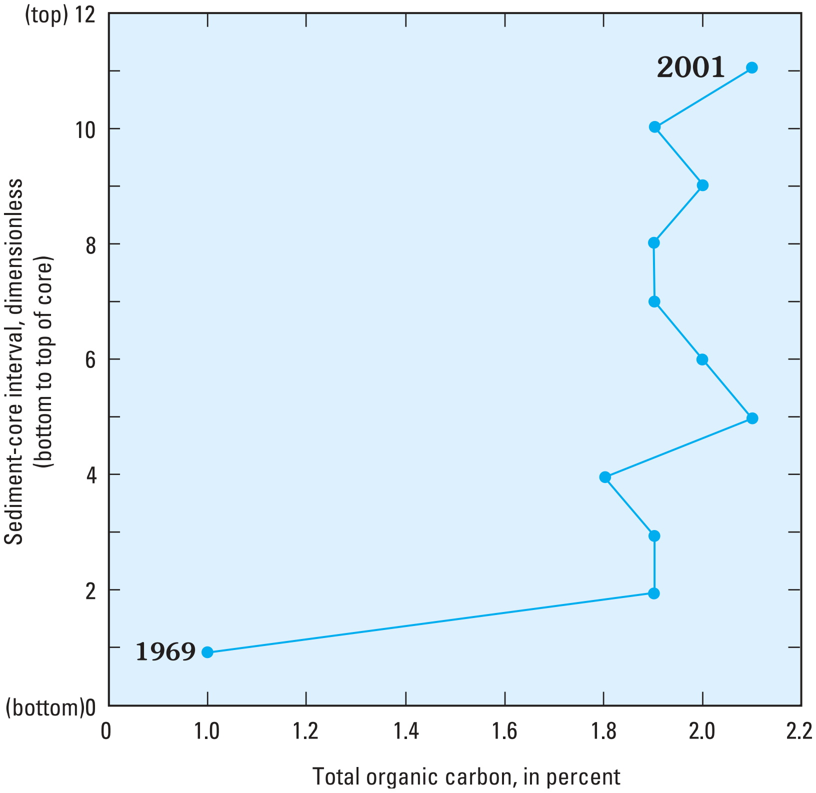


Figure 10. Variation in total organic carbon concentrations with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001. Location of coring site shown in figure 2.

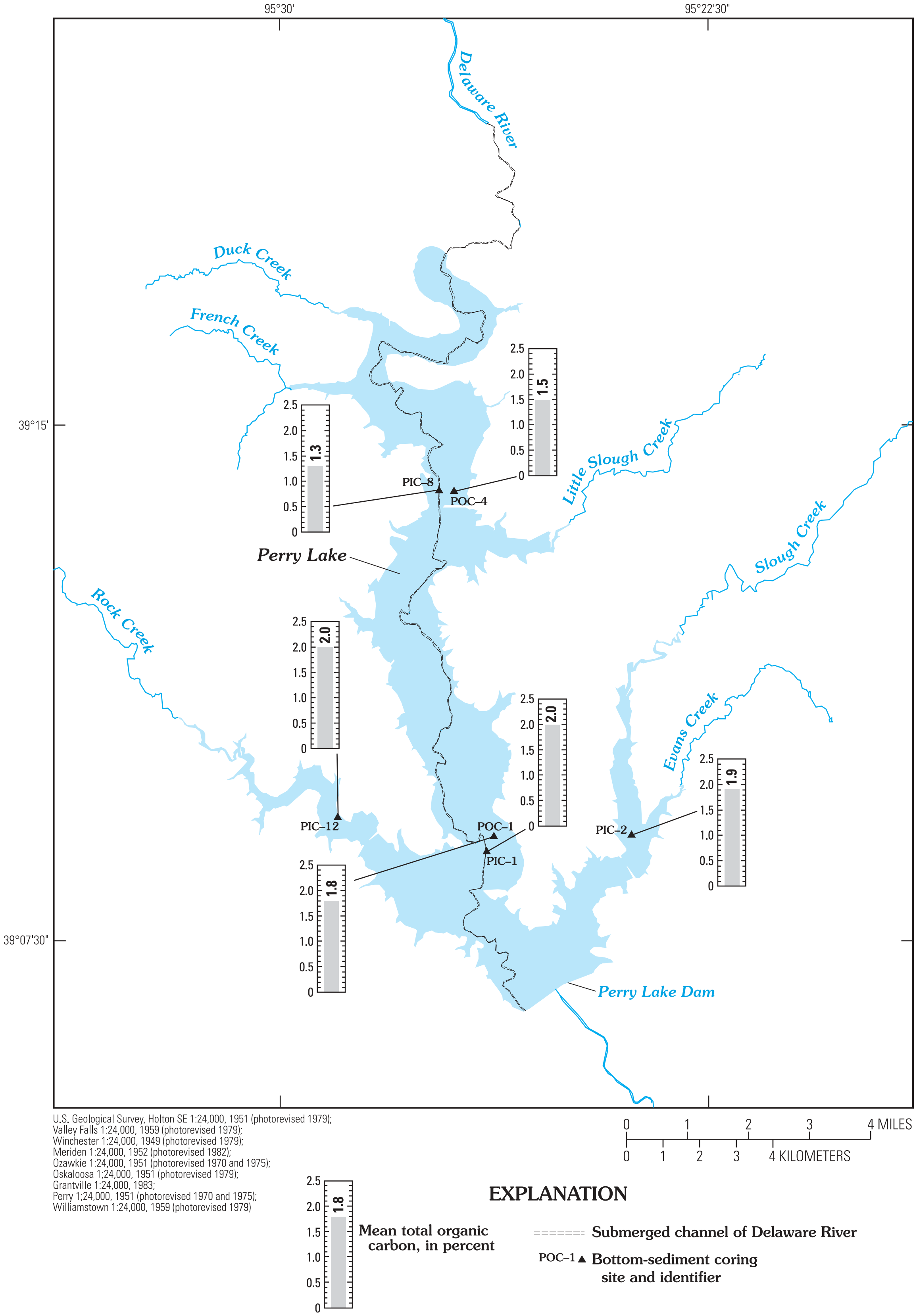
10 sample intervals with relative percentage abundances ranging from 0.8 to 10.2 percent. *Cyclotella comensis* and *Cyclotella stelligera* were found in 6 of 10 sample intervals with relative percentage abundances less than 3 percent (table 13). The positive depositional trends determined for *Aulacoseira islandica* and *Cyclotella radiosa* indicated that environmental conditions in the lake may have changed in some way that is more favorable for these two species.

A comparison of the combined relative percentage abundances of the eutrophic indicator species (*Aulacoseira granulata*, *Cyclotella meneghiniana*, *Stephanodiscus hantzschii*, and *Stephanodiscus niagarae*) with the oligotrophic indicator species (*Aulacoseira distans*, *Aulacoseira islandica*, *Cyclotella comensis*, *Cyclotella ocellata*, *Cyclotella radiosa*, and *Cyclotella stelligera*) indicated that the eutrophic species have been dominant throughout the history of Perry Lake. In the bottom (oldest) six sample intervals, the eutrophic and oligotrophic species had mean combined relative percentage abundances of 85.2 and 4.4 percent, respectively. In the top (youngest) four sample intervals, the eutrophic and oligotrophic species had mean combined relative percentage abundances of 65.8 and 21.8 percent, respectively. The dominance of the eutrophic indicator species throughout the core suggests that eutrophic conditions have existed during much of the history of Perry Lake. However, the increase in the relative percentage abundance of the oligotrophic species, combined with the significant positive depositional trends for two oligotrophic species (*Aulacoseira islandica* and *Cyclotella radiosa*) and the significant negative depositional trend for one eutrophic species (*Stephanodiscus niagarae*), indicated that conditions at Perry Lake may have become less eutrophic in recent years.

As part of its Lake and Wetland Monitoring Program, KDHE periodically samples the water in Perry Lake for chlorophyll-a as a surrogate indicator of eutrophication. The samples were collected in a relatively deep part of the lake where algal abundance would be expected to be lowest. For 1985, 1988, 1991, 1994, and 1996, mean chlorophyll-a concentrations ranged from about 5 to 12 parts per billion. For 1997, 1998, and 2000, mean chlorophyll-a concentrations ranged from about 18 to 20 parts per billion. KDHE classifies a lake with chlorophyll-a concentrations of 7.21 to 12.00 parts per billion as slightly eutrophic and a lake with chlorophyll-a concentrations of 12.01 to 20.00 parts per billion as eutrophic (Ed Carney, Kansas Department of Health and Environment, written commun., 2002).

COMPARISON OF DEPOSITIONAL TRENDS TO STREAMFLOW AND HUMAN ACTIVITY

In this study, trend analyses indicated a significant positive depositional trend over time for total nitrogen, arsenic, manganese, and the oligotrophic diatom species *Aulacoseira islandica* and *Cyclotella radiosa*. A significant negative depositional trend over time was indicated for beryllium, chromium, titanium, vanadium, and the eutrophic diatom species *Stephanodis-*



U.S. Geological Survey, Holton SE 1:24,000, 1951 (photorevised 1979);
Valley Falls 1:24,000, 1959 (photorevised 1979);
Winchester 1:24,000, 1949 (photorevised 1979);
Meriden 1:24,000, 1952 (photorevised 1982);
Ozawkie 1:24,000, 1951 (photorevised 1970 and 1975);
Oskaloosa 1;24,000, 1951 (photorevised 1979);
Grantville 1:24,000, 1983;
Perry 1;24,000, 1951 (photorevised 1970 and 1975);
Williamstown 1:24,000, 1959 (photorevised 1979)

Figure 11. **Mean concentrations of total organic carbon in bottom-sediment cores collected from Perry Lake, July and August 2001.**

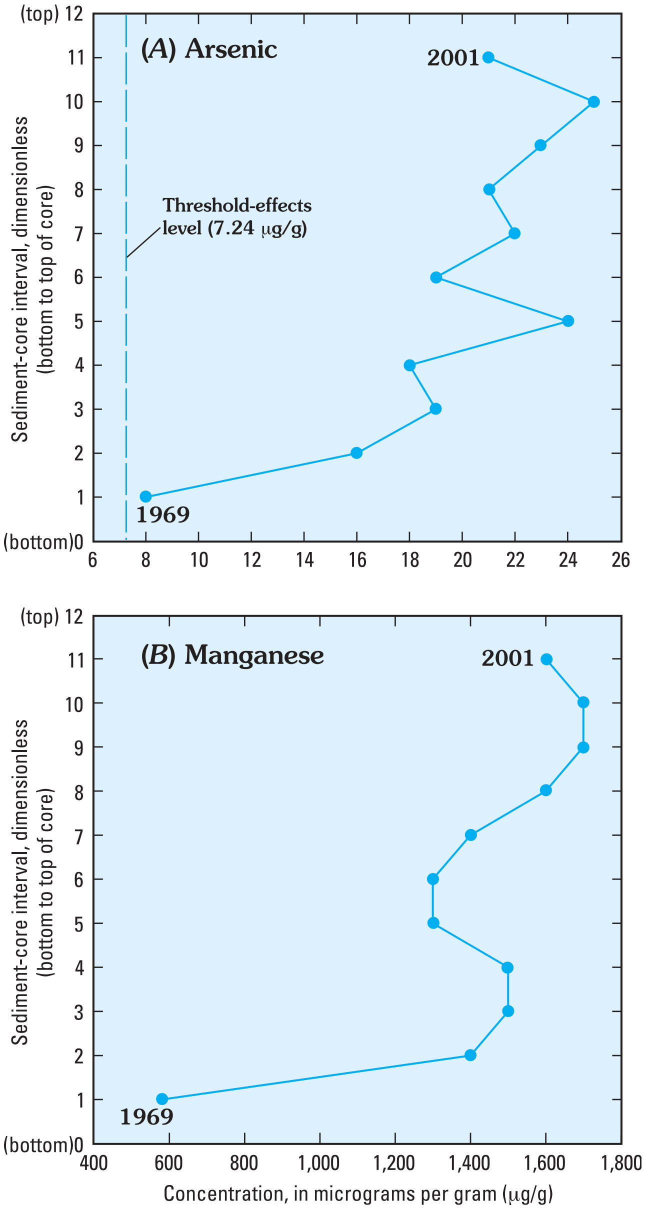


Figure 12. Variation in *(A)* arsenic and *(B)* manganese concentrations with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001. Location of coring site shown in figure 2. Threshold-effects level from U.S. Environmental Protection Agency (1997).

cus niagarae. However, due to analytical variance, the trends may or may not be representative of actual trends for the chemical constituents. For DDE, the available information (which was insufficient for statistical analysis) indicated a negative depositional trend. In general, differences in the deposition of nutrients, metals, trace elements, and organochlorine compounds over time may be due, in part, to several factors including changes in the particle size and composition of the sediment, redox conditions (oxidation/reduction potential of the environment), precipitation, streamflow, land use, irrigation (source of water and method of application), and land-management practices. Differences in the deposition of diatoms over time may be due, in part, to several factors including changes in pH, light, temperature, and concentrations of nutrients, trace elements, and pesticides.

To describe conditions for the mostly agricultural Delaware River Basin that may affect the deposition of chemical constituents and diatoms in Perry Lake sediment, the factors streamflow, population, crop production, irrigation, and livestock production were investigated. The time period of interest was 1965 through 2000.

Streamflow, specifically mean annual discharge for the period of record, was examined for the USGS streamflow-gaging station located on the Delaware River near Muscotah, Kansas (station 06890100, period of record 1970–2000) (fig. 1). This gaging station monitors streamflow for about 39 percent (431 mi^2) of the Perry Lake Basin. Results indicated year-to-year variability in mean annual discharge. No statistically significant trend in streamflow was determined.

County-level data were used to assess changes in population, crop production, irrigation, and livestock production. The Delaware River Basin covers parts of Atchison, Brown, Jackson, Jefferson, and Nemaha Counties in northeast Kansas (fig. 1). About half of Jackson and Jefferson Counties are located in the basin, whereas less than half of Atchison, Brown, and Nemaha Counties are located in the basin (fig. 1).

Population changes over time can provide a general indication of human activity and the associated potential for environmental pollution. For the Delaware River Basin, population estimates for the years 1960, 1970, 1980, 1990, and 2000 were compiled. Overall, the total population for the five counties was relatively stable from 1960 to 2000. However, for Jackson and Jefferson Counties, the net population increased from 1960 to 2000 by 23 and 64 percent, respectively. In comparison, respective net population decreases of 20, 19, and 17 percent were indicated from 1960 to 2000 for Atchison, Brown, and Nemaha Counties (U.S. Census Bureau, 2001) (fig. 18).

Crop production can have a substantial effect on water and sediment quality in a basin due to repeated disturbance of the land surface, application of pesti-

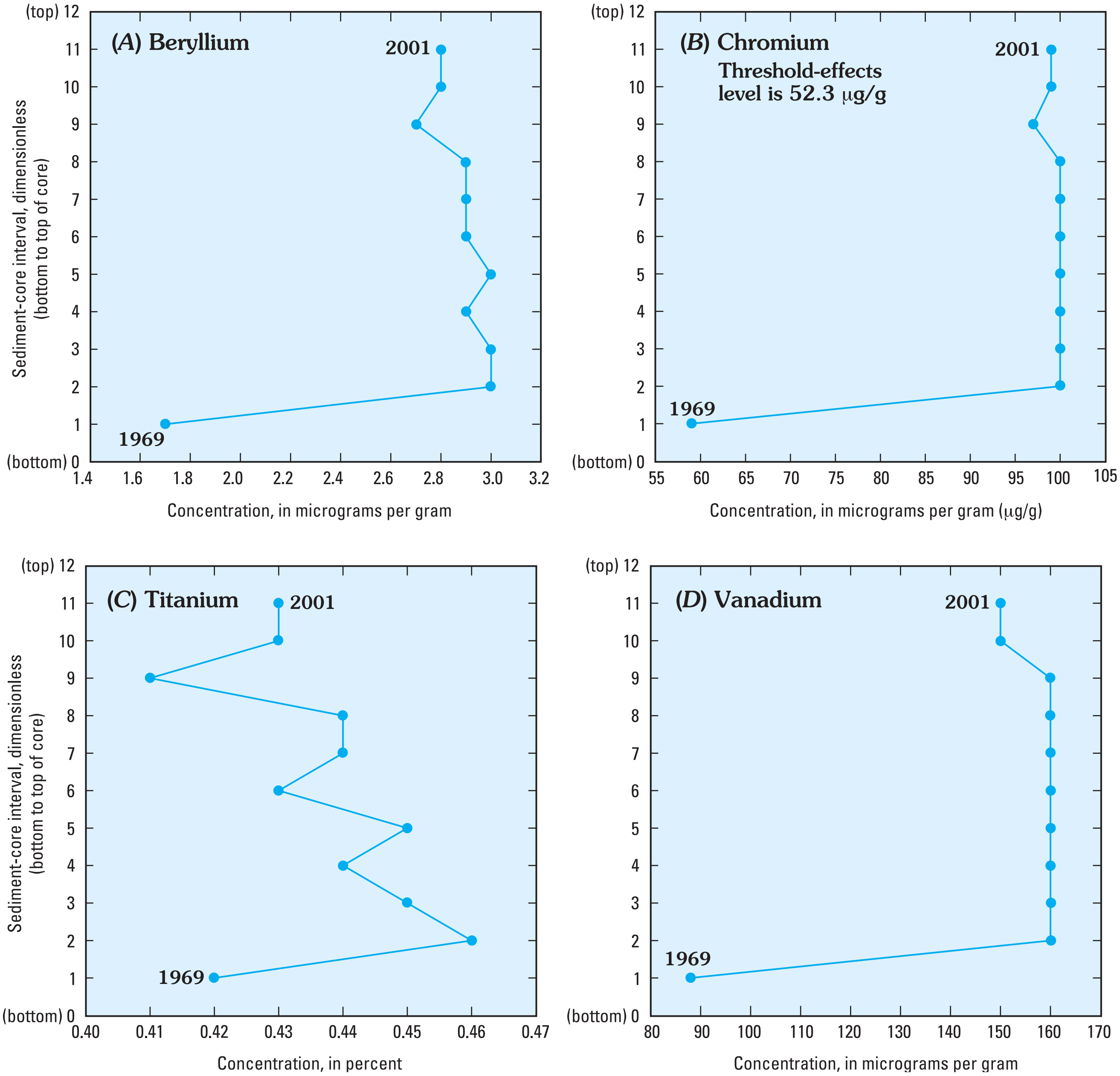
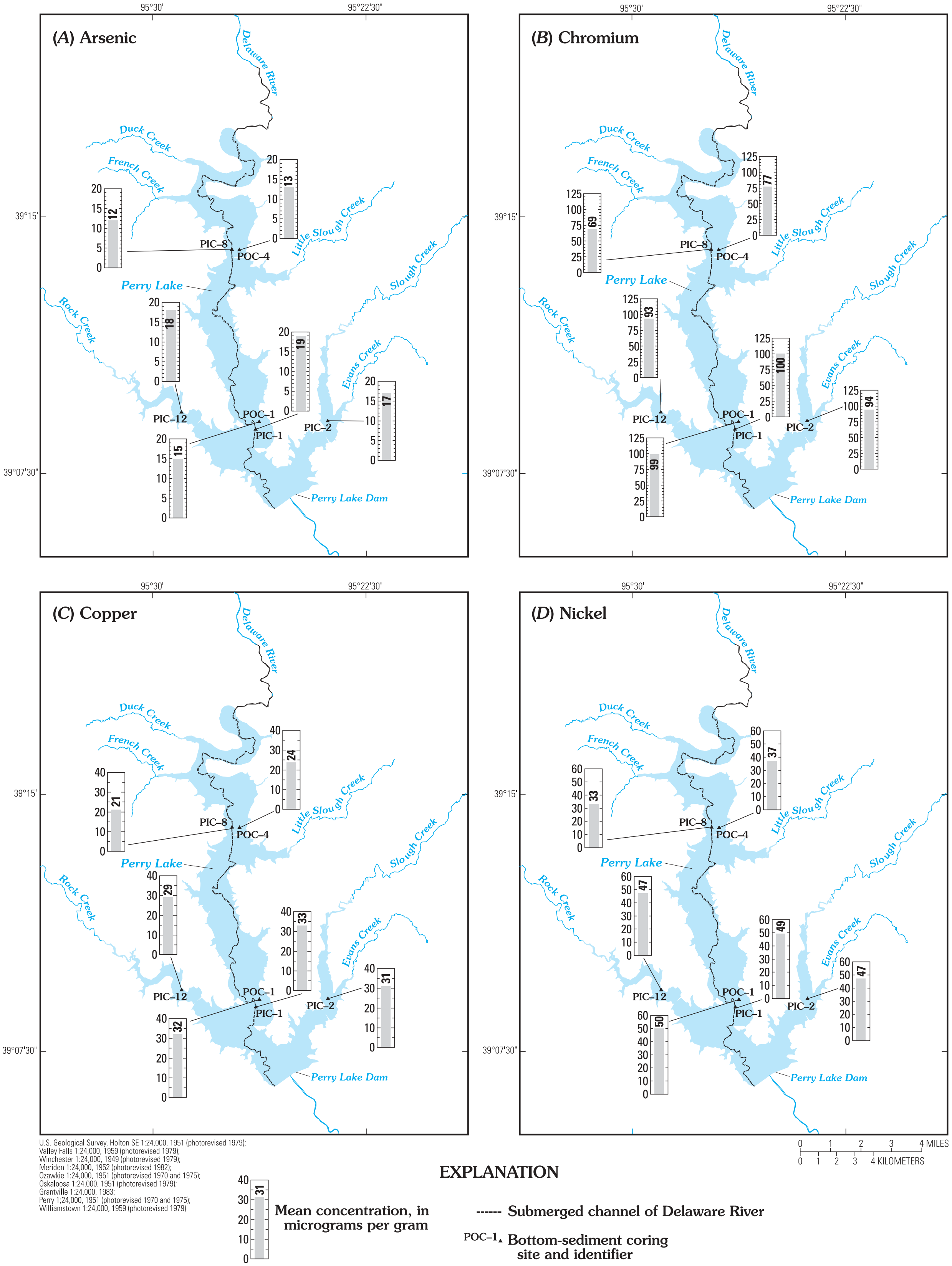


Figure 13. Variation in concentrations of *(A)* beryllium, *(B)* chromium, *(C)* titanium, and *(D)* vanadium with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, July 2001. Location of coring site shown in figure 2. Threshold-effects level from U.S. Environmental Protection Agency (1997).

cides and fertilizers, and irrigation. Cropland is typified by higher runoff volumes and sediment yields than grassland and woodland (Novotny and Chesters, 1981; Novotny, 1995; Morris and Fan, 1998). Increased runoff from cropland can be attributed to several factors, including the removal of native vegetation and soil compaction, which decrease surface permeability.

Pesticides and fertilizers are potential sources of nutrient, metal, and trace-element pollution. Pesticides may contain arsenic, copper, mercury, lead, manganese, and zinc (Alloway and Ayres, 1997). Nitrogen and phosphorus are significant components of fertilizers, and impurities in fertilizers may include cadmium, chromium, lead, molybdenum, uranium, vanadium, and zinc (Alloway and Ayres, 1997). 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. From 1990–91 to 2000–01, total annual fertilizer sold increased from about 1,500,000 to



U.S. Geological Survey, Holton SE 1:24,000, 1951 (photorevised 1979);
Valley Falls 1:24,000, 1959 (photorevised 1979);
Winchester 1:24,000, 1949 (photorevised 1979);
Meriden 1:24,000, 1952 (photorevised 1982);
Ozawkie 1:24,000, 1951 (photorevised 1970 and 1975);
Oskaloosa 1:24,000, 1951 (photorevised 1979);
Grantville 1:24,000, 1983;
Perry 1:24,000, 1951 (photorevised 1970 and 1975);
Williamstown 1:24,000, 1959 (photorevised 1979)

Figure 14. Mean concentrations of *(A)* arsenic, *(B)* chromium, *(C)* copper, and *(D)* nickel in bottom-sediment cores collected from Perry Lake, July and August 2001.

Table 13. Occurrence, relative percentage abundance, and trends of diatom species in bottom-sediment samples collected from coring site PIC–1 in Perry Lake, northeast Kansas, September 2001

[E, eutrophic indicator species; O, oligotrophic indicator species; --, not computed]

Diatom species (indicator of eutrophic or oligotrophic conditions)[1]	Number of detections/number of analyses	Relative percentage abundance		Spearman's rho[2]	Trend test at a 0.05 level of significance[2]
		Minimum	Maximum		
Achnanthidium sp. 1	3/10	0.4	0.8	--	--
Aulacoseira distans (O)	2/10	.4	1.2	--	--
Aulacoseira granulata (E)	10/10	17.7	53.3	0.12	no trend
Aulacoseira islandica (O)	9/10	.4	21.9	.78	positive trend
Aulacoseira c.f. nygaardii	10/10	5.0	15.1	- .07	no trend
Caloneis bacillum	1/10	.4	.4	--	--
Craticula cuspidata	2/10	.3	.4	--	--
Cyclotella comensis (O)	6/10	.4	2.6	--	--
Cyclotella meneghiniana (E)	2/10	.4	1.3	--	--
Cyclotella ocellata (O)	3/10	.4	1.1	--	--
Cyclotella radiosa (O)	10/10	.8	10.2	.67	positive trend
Cyclotella sp. 1	2/10	.4	.8	--	--
Cyclotella stelligera (O)	6/10	.2	1.2	--	--
Fragilaria capucina var. mesolepta	2/10	.4	.6	--	--
Fragilaria sp. 1	1/10	.4	.4	--	--
Hantzschia amphioxys	1/10	.4	.4	--	--
Navicula sp. 1	1/10	.2	.2	--	--
Navicula sp. 2 (canted)	1/10	.4	.4	--	--
Nitzschia dissipata	2/10	.2	.2	--	--
Nitzschia subacicularis	1/10	.2	.2	--	--
Pinnularia borealis	1/10	.4	.4	--	--
Stephanodiscus hantzschii (E)	8/10	.3	5.8	- .05	no trend
Stephanodiscus niagarae (E)	10/10	18.3	65.0	- .78	negative trend
Stephanodiscus sp. 1	3/10	.2	.6	--	--
Stephanodiscus sp. 2	6/10	.4	1.3	--	--

[1] Information on diatoms as indicators of eutrophic or oligotrophic conditions from Yang and others (1993), Sabater and Haworth (1995), Stoermer and Smol (1999), Blais and others (2000), Clerk and others (2000), and Dixit and others (2000).

[2] Not computed for species with four or more nondetections.

2,700,000 tons (Kansas Department of Agriculture, 2002).

Irrigation can degrade water and sediment quality through the mobilization, transport, and deposition of various constituents. For example, nutrients, metals, and trace elements often are redistributed by irrigated agriculture. Also, the use of ground water for irrigation may provide an additional source of metals and trace elements. In the Delaware River Basin, crops generally are not irrigated (U.S. Department of Agriculture, 2001). Thus, irrigation is not considered to be a likely cause of changes in water and sediment quality in the basin.

Crop-production data were compiled for the five counties that contain the Delaware River Basin—Atchison, Brown, Jackson, Jefferson, and Nemaha (fig. 1). The data were compiled at 5-year intervals for five principal crops in the basin—alfalfa, grain corn, grain sorghum, soybeans, and wheat. In 1965, the combined harvested acres for the five principal crops

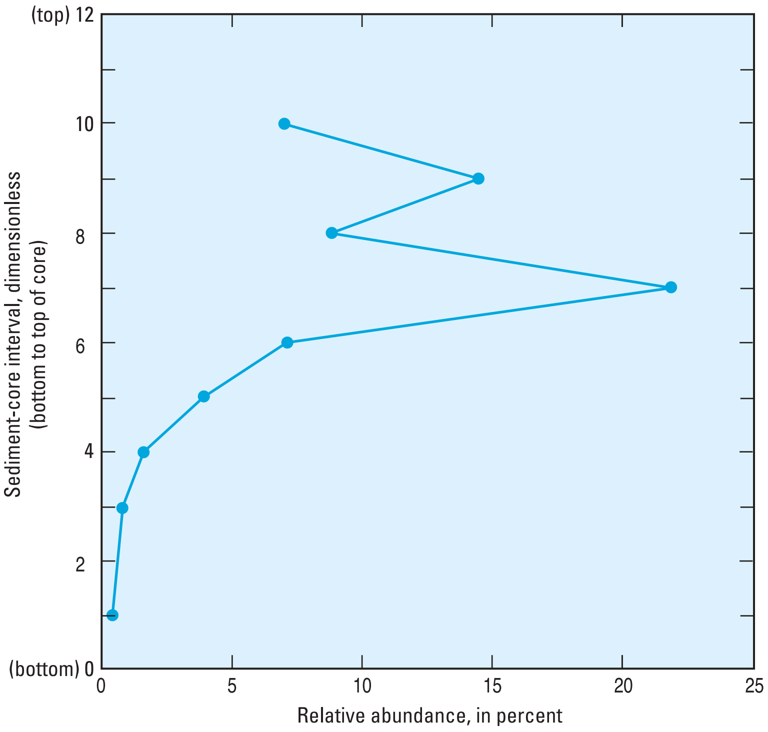


Figure 15. Variation in occurrence of *Aulacoseira islandica* with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, September 2001. Location of coring site shown in figure 2.

was about 627,000 acres. From 1970 to 2000, the annual combined harvested acres fluctuated within about ±4 percent of the mean of 717,000 acres.

Alfalfa production steadily declined from about 84,200 acres harvested in 1965 to about 19,900 acres harvested in 2000 (fig. 19*A*). (U.S. Department of Agriculture, 2001). Following a modest increase from 1965 to 1970, grain corn production decreased from about 227,000 acres harvested in 1970 to about 110,000 acres harvested in 1980. From 1980 to 1995, production was relatively stable. Then, production increased substantially to about 249,000 acres harvested in 2000 (fig. 19*B*) (U.S. Department of Agriculture, 2001). Grain sorghum production increased from about 152,000 acres harvested in 1965 to about 235,000 acres harvested in 1980 and 1985. Subsequently, production varied with about 146,000 acres harvested in 1990, about 165,000 acres harvested in 1995, and about 77,200 acres harvested in 2000 (fig. 19*C*). Soybean production increased from about 103,000 acres harvested in 1965 to about 322,000 acres harvested in 2000 (fig. 19*D*) (U.S. Department of Agriculture, 2001). Wheat production increased from about 85,000 acres harvested in 1965 to about 178,000 acres harvested in 1975. From 1975 to 1995, production was relatively stable in the range of about 154,000 to 192,000 acres harvested before decreasing substantially to about 62,000 acres harvested in 2000 (fig. 19*E*) (U.S. Department of Agriculture, 2001).

Livestock-production data were compiled for the same five counties. The data were compiled at 5-year intervals for cattle and hogs. Cattle production was relatively stable at about 300,000 animals from 1965 to 1975. From 1975 to 1990, production decreased to about 202,000 animals. Production from 1990 to 2000 was relatively stable in the range of about 202,000 to 212,000 animals (fig. 20*A*) (U.S. Department of Agriculture, 2001).

With the exception of a peak of about 214,000 animals in 1970, hog production was relatively stable from 1965 to 1995 in the range of about 151,000 to 178,000 animals. Production decreased to about 132,000 animals in 2000. Overall, production from 1965 to 2000

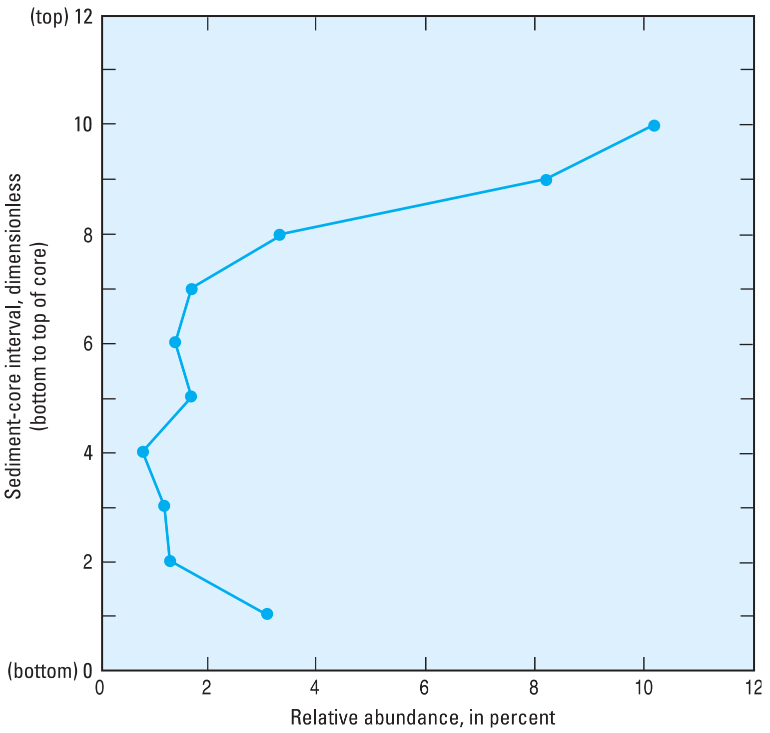


Figure 16. Variation in occurrence of *Cyclotella radiosa* with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, September 2001. Location of coring site shown in figure 2.

decreased in Atchison, Brown, Jackson, and Jefferson Counties but increased in Nemaha County (fig. 20*B*) (U.S. Department of Agriculture, 2001). Most hog production in Nemaha County is outside of the Delaware River Basin. Wastes from hog production may include arsenic, cadmium, copper, lead, nickel, and zinc, which are residues of feed additives (Harrison, 1996; Alloway and Ayres, 1997). Both cattle and hog wastes contain large amounts of nitrogen and phosphorus.

It appears that changes in human activity in the Delaware River Basin may have had some effect on the deposition of chemical constituents in the bottom sediment of Perry Lake. For example, the possible positive depositional trend for total nitrogen (fig. 8*A*) may be related to a statewide increase in fertilizer sales from 1990–91 to 2000–2001. It is uncertain whether changes in human activity may account, in part, for the possibility of Perry Lake becoming less eutrophic over time as indicated by trends in the deposition of several diatom species in the lake-bed sediment.

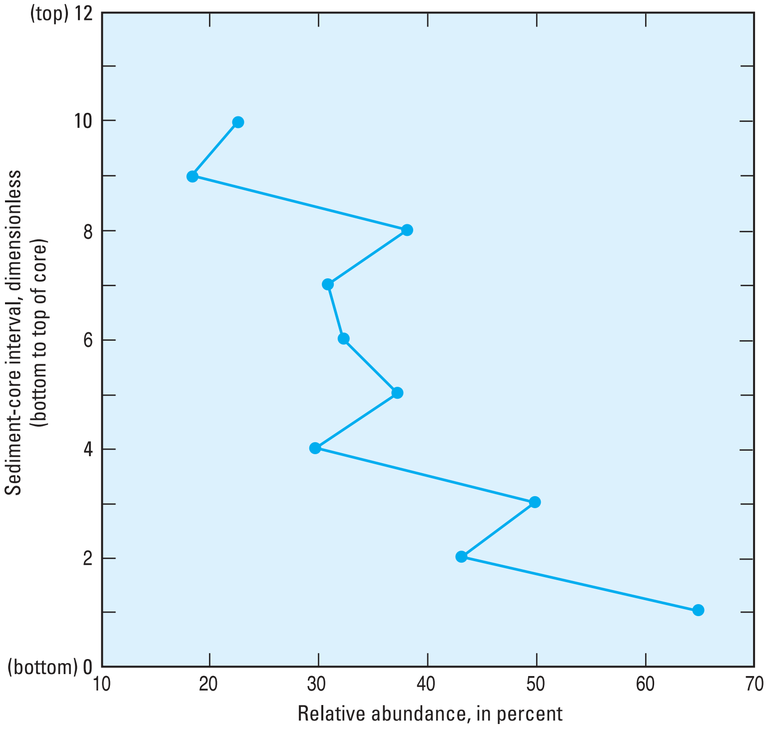


Figure 17. Variation in occurrence of ***Stephanodiscus niagarae*** with depth of bottom-sediment samples collected from coring site PIC–1 in Perry Lake, September 2001. Location of coring site shown in figure 2.

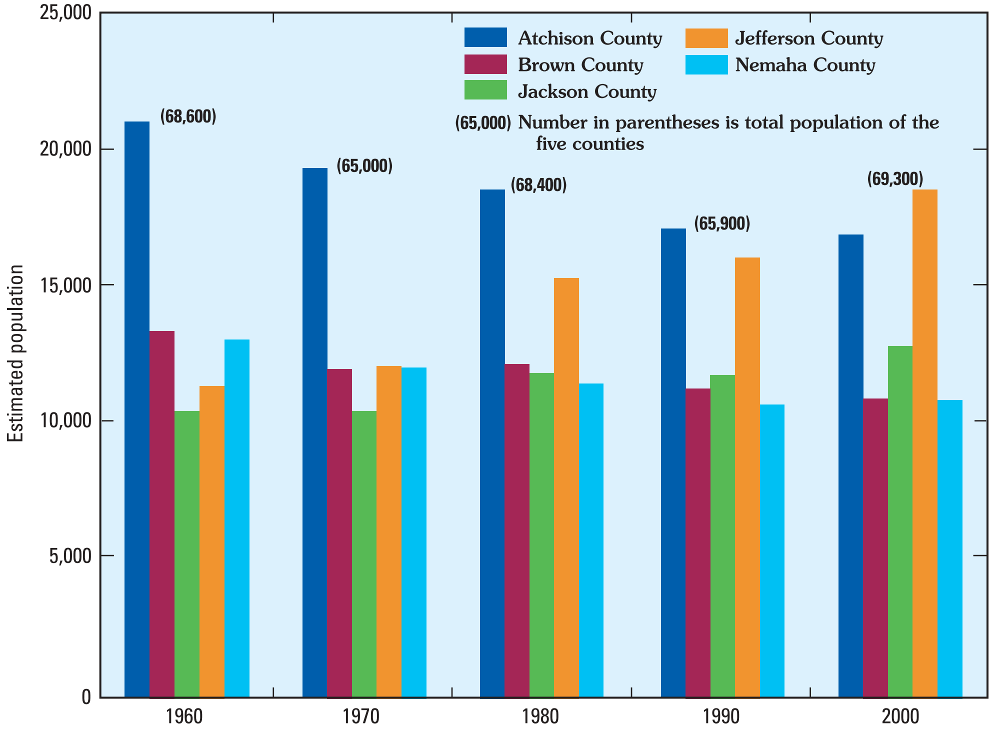


Figure 18. Estimated population of Atchison, Brown, Jackson, Jefferson, and Nemaha Counties, Kansas, 1960–2000 (source of data: U.S. Census Bureau, 2001).

SUMMARY AND CONCLUSIONS

A combination of bathymetric surveying and bottom-sediment coring was used to investigate sediment deposition and the occurrence of selected nutrients (total nitrogen and total phosphorus), organic and total carbon, 26 metals and trace elements, 15 organochlorine compounds, 1 radionuclide, and diatoms in bottom sediment of Perry Lake, northeast Kansas. The total estimated volume of bottom sediment in the original (1969) conservation-pool area of the lake was 2,470 million ft^3 (56,700 acre-ft). The volume of sediment

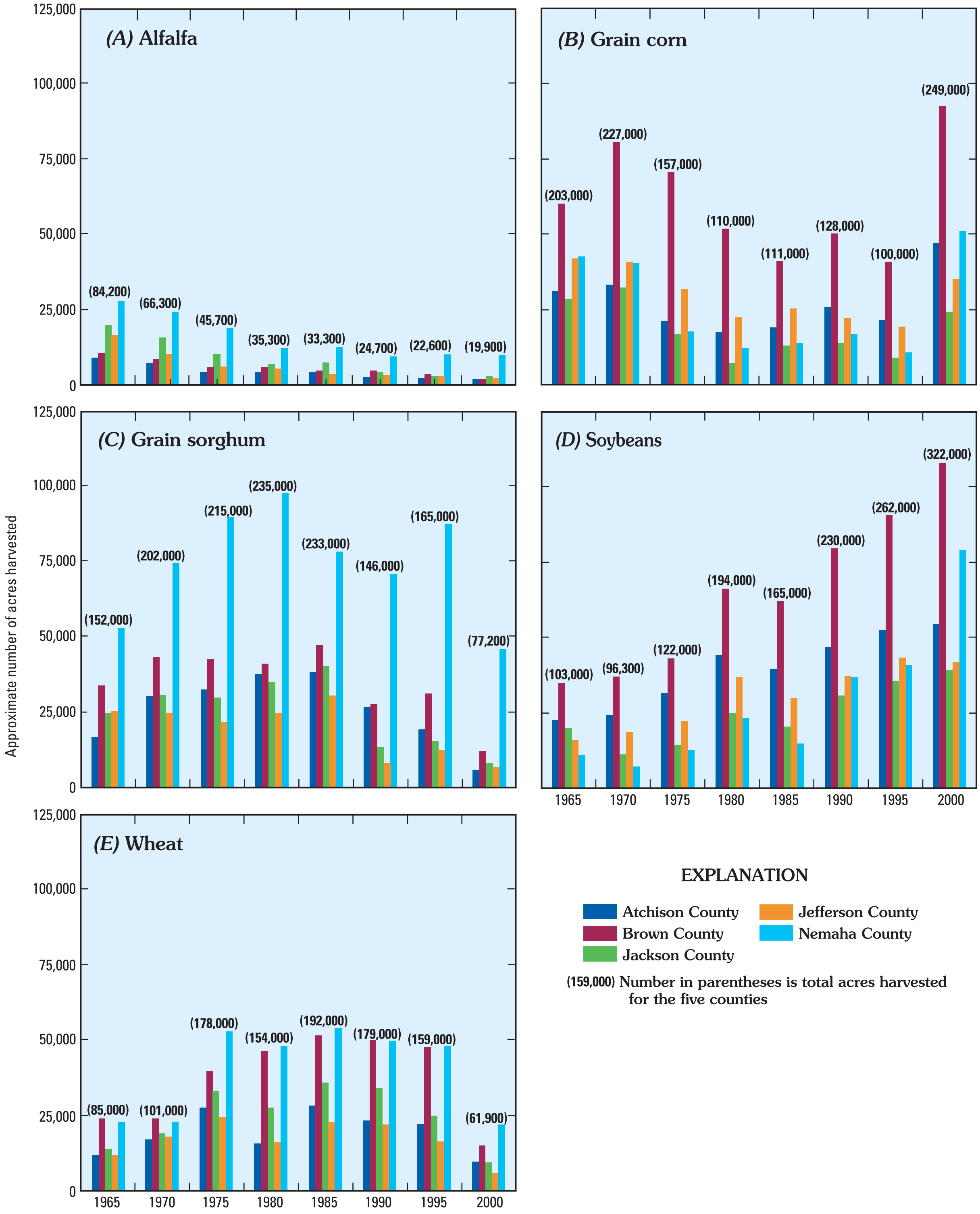


Figure 19. Approximate total number of acres harvested in Atchison, Brown, Jackson, Jefferson, and Nemaha Counties, Kansas, 1965–2000, for *(A)* alfalfa, *(B)* grain corn, *(C)* grain sorghum, *(D)* soybeans, and *(E)* wheat (data compiled from U.S. Department of Agriculture, 2001).

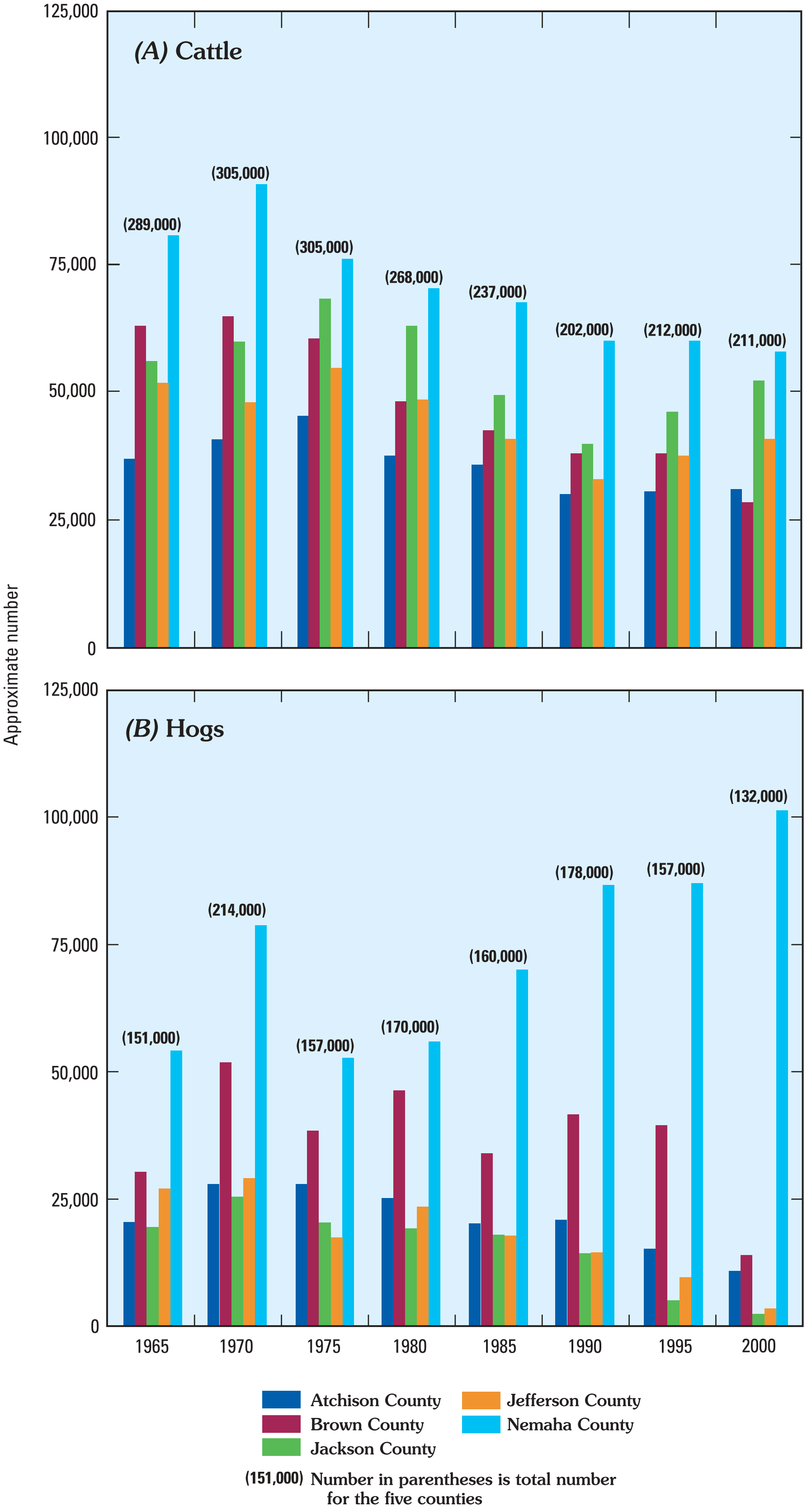


Figure 20. Approximate number of *(A)* cattle and *(B)* hogs in Atchison, Brown, Jackson, Jefferson, and Nemaha Counties, Kansas, 1965–2000 (data compiled from U.S. Department of Agriculture, 2001).

occupies about 23 percent of the original conservation-pool, water-storage capacity of the lake. The total estimated mass of bottom sediment in the original conservation-pool area of the lake was 97,200 million lb (44,100 million kg). Mean annual net sediment deposition since 1969 was estimated to be 3,040 million lb (1,379 million kg). Mean annual sediment yield from the Perry Lake Basin was estimated to be 2,740,000 lb/mi^2 (4,798 kg/ha).

The estimated mean annual net loads of total nitrogen and total phosphorus deposited in the bottom sediment of Perry Lake were 7,610,000 lb/yr (3,450,000 kg/yr) and 3,350,000 lb/yr (1,520,000 kg/yr), respectively. The estimated mean annual yields of total nitrogen and total phosphorus from the Perry Lake Basin were 6,850 (lb/mi^2)/yr [12.0 (kg/ha)/yr] and 3,020 (lb/mi^2)/yr [5.29 (kg/ha)/yr], respectively.

Trend analysis indicated no statistically significant trend for total phosphorus deposition in the bottom sediment of Perry Lake. A statistically significant positive depositional trend (constituent concentration increased toward the top of the sediment core) was indicated for total nitrogen, arsenic, and manganese. A statistically significant negative depositional trend (constituent concentration decreased toward the top of the sediment core) was indicated for beryllium, chromium, titanium, and vanadium. However, due to analytical variance, the trends may not be representative of actual trends. Available information (which was insufficient for statistical analysis) indicated a negative depositional trend for the DDT degradate DDE, which was consistent with the history of DDT use.

On the basis of nonenforceable sediment-quality guidelines, concentrations of arsenic, chromium, copper, and nickel in the bottom sediment of Perry Lake typically exceeded the threshold-effects levels (TELs), which represent the concentrations above which toxic biological effects occasionally occur in aquatic organisms. For arsenic and chromium, all of the sediment samples analyzed had concentrations that exceeded the TELs but were less than the probable-effects levels (PELs), which represent the concentrations above which toxic biological effects usually or frequently occur. For copper, all but one of the sediment samples analyzed had concentrations that exceeded the TEL but were less than the PEL. For nickel, all of the sediment samples analyzed had concentrations that exceeded the TEL, and most also exceeded the PEL. For zinc, most of the sediment samples analyzed had concentrations that were less than the TEL. Cadmium, lead, mercury, and silver were all detected at concentrations that were less than the TELs. Organochlorine compounds either were not detected or were detected at concentrations that were less than the TELs. Of the three organochlorine compounds detected, DDE was detected in about half the sediment samples analyzed, whereas DDD and dieldrin were detected infrequently.

The concentrations of nutrients, metals, and trace elements determined for the bottom sediment in Perry Lake in part reflect the natural concentrations of these constituents in the rock and soils of the basin. Human activity may cause sediment enrichment through the increased mobilization of naturally occurring nutrients, metals, and trace elements in the soils (for example, by irrigation) as well as the addition of human-related sources of nutrients, metals, and trace elements. Organochlorine compounds in the bottom sediment of Perry Lake are of human origin.

Diatoms provide an indication of historical environmental conditions. The dominance of eutrophic indicator species in the bottom sediment indicated that eutrophic conditions have existed during much of the history of Perry Lake. However, an increase in the relative percentage abundance of the oligotrophic species, combined with the significant positive depositional trends for two oligotrophic species (*Aulacoseira islandica* and *Cyclotella radiosa*) and the significant negative depositional trend for one eutrophic species (*Stephanodiscus niagarae*), indicated that conditions in Perry Lake may have become less eutrophic in recent years.

Notable changes in human activity within the basin included a substantial decrease in alfalfa production and a substantial increase in soybean production from 1965 to 2000. Following steady increases, the production of grain sorghum and wheat declined substantially from 1985 to 2000. Grain corn production decreased from 1970 to 1980, was relatively stable from 1980 to 1995, then increased substantially in 2000. Statewide, total fertilizer sales increased substantially from 1990–91 to 2000–01. Cattle production in the basin was relatively stable from 1965 to 1975, decreased substantially from 1975 to 1990, and then was relatively stable from 1990 to 2000.

The changes in human activity in the Delaware River Basin may have had some effect on the deposition of chemical constituents in the bottom sediment of Perry Lake. For example, the possible positive depositional trend for total nitrogen may be related to the statewide increase in fertilizer sales. It is uncertain whether changes in human activity may account, in part, for the possibility of Perry Lake becoming less eutrophic over time as indicated by trends in the deposition of several diatom species in the lake-bed sediment.

Information in this report may be used to partly reconstruct historical water-quality records, to provide a present-day baseline with which to evaluate long-term changes in reservoir water and sediment quality that may reflect changes in human activity in the basin, and to assist in the development and evaluation of total maximum daily loads for chemical constituents that contribute to the water and sediment quality of Perry Lake. Also, information from this and other reservoir studies may be used in a comparative analysis to determine which basin characteristics (for example, topography, soils, land use) are the most important determinants of the sediment (and associated chemical constituent) yield from basins. The results of such comparative analyses will have widespread applicability for reservoir and basin management.

Changes in human activity in a large basin may not have a substantial effect on the deposition of chemical constituents in the reservoir bottom sediment in part because a relatively small percentage of the basin may have been affected by the changes. Additional investigation, focused on small impoundments throughout the Perry Lake Basin, may improve understanding of the effects of changes in human activity on water and sediment quality.

REFERENCES

Adriano, D.C., 1986, Trace elements in the terrestrial environment: New York, Springer-Verlag, 533 p.

Alloway, B.J., and Ayres, D.C., 1997, Chemical principles of environmental pollution (2d ed.): New York, Blackie Academic & Professional, 395 p.

American Society for Testing and Materials (ASTM), 2000, Standard practice for high-resolution gamma-ray spectrometry of water, *in* Annual book of ASTM standards, section 11, water and environmental technology: West Conshohocken, Pennsylvania, ASTM, v. 11.02, D 3649–98a, p. 294–304.

Arbogast, B.F., 1996, Analytical methods manual for the Mineral Resource Surveys Program: U.S. Geological Survey Open-File Report 96–525, 248 p.

Battarbee, R.W., 1973, A new method for the estimation of absolute microfossil numbers, with reference especially to diatoms: Limnology and Oceanography, v. 18, p. 647–653.

Baudo, Renato, Giesy, J.P., and Muntau, Herbert, eds., 1990, Sediments—chemistry and toxicity of in-place pollutants: Ann Arbor, Michigan, Lewis Publ., Inc., 405 p.

Blais, J.M., Duff, K.E., Schindler, D.W., Smol, J.P., Leavitt, P.R., and Agbeti, Michael, 2000, Recent eutrophication histories in Lac Ste. Anne and Lake Isle, Alberta, Canada, inferred using paleolimnological methods: Lake and Reservoir Management, v. 16, no. 4, p. 292–304.

Blomqvist, Sven, 1985, Reliability of core sampling of soft bottom sediment—an in situ study: Sedimentology, v. 32, p. 605–612.

Blomqvist, Sven, and Bostrom, Kurt, 1987, Improved sampling of soft bottom sediments by combined box and piston coring: Sedimentology, v. 34, p. 715–719.

Briggs, P.H., and Meier, A.L., 1999, The determination of forty two elements in geological materials by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 99–166, 15 p.

Christensen, V.G., 1999, Deposition of selenium and other constituents in reservoir bottom sediment of the Solomon River Basin, north-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 99–4230, 46 p.

Clerk, Saloni, Hall, Roland, Quinlan, Roberto, and Smol, J.P., 2000, Quantitative inferences of past hypolimnetic anoxia and nutrient levels from a Canadian Precambrian Shield lake: Journal of Paleolimnology, v. 23, p. 319–336.

Cole, G.A., 1994, Textbook of limnology (4th ed.): Prospect Heights, Illinois, Waveland Press, Inc., 412 p.

Crusius, John, and Anderson, R.F., 1991, Core compression and surficial sediment loss of lake sediments of high porosity caused by gravity coring: Limnology and Oceanography, v. 36, no. 5, p. 1021–1031.

Dixit, A.S., Hall, R.I., Leavitt, P.R., Quinlan, R., and Smol, J.P., 2000, Effects of sequential depositional basins on lake response to urban and agricultural pollution—a palaeoecological analysis of the Qu’ Appelle Valley, Saskatchewan, Canada: Freshwater Biology, v. 43, no. 3, p. 319–337.

Dixit, S.S., Smol, J.P., Kingston, J.C., and Charles, D.F., 1992, Diatoms—powerful indicators of environmental change: Environmental Science and Technology, v. 26, no. 1, p. 23–33.

Emery, K.O., and Hulsemann, J., 1964, Shortening of sediment cores collected in open barrel gravity corers: Sedimentology, v. 3, p. 144–154.

Fallon, J.D., 1994, Determining the three-dimensional distribution, transport, and relative age of atrazine and selected metabolites in Perry Lake, Kansas: Lawrence, Kansas, University of Kansas, master’s thesis, 191 p.

Fallon, J.D., and McChesney, J.A., 1993, Surface-water-quality assessment of the lower Kansas River Basin, Kansas and Nebraska—project data, November 1986 through April 1990: U.S. Geological Survey Open-File Report 93–51, 594 p.

Fenneman, N.M., 1946, Physical divisions of the United States: U.S. Geological Survey special map, scale 1:7,000,000, 1 sheet.

Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Forstner, Ulrich, and Wittmann, G.T.W., 1981, Metal pollution in the aquatic environment: New York, Springer-Verlag, 486 p.

Gordon, N.D., McMahon, T.A., and Finlayson, B.L., 1992, Stream hydrology—an introduction for ecologists: New York, John Wiley & Sons, 526 p.

Grosbois, C., Horowitz, A.J., Smith, J.J., and Elrick, K.A., 2001, The effect of mining and related activities on the sediment-trace element geochemistry of Lake Coeur d’Alene, Idaho, USA, part III. Downstream effects—the Spokane River Basin: Hydrological Processes, v. 15, p. 855–875.

Hakanson, L., and Jansson, M., 1983, Principles of lake sedimentology: New York, Springer-Verlag, 316 p.

Harrison, R.M., ed., 1996, Pollution—causes, effects and control (3rd ed.): Cambridge, The Royal Society of Chemistry, 480 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Amsterdam, Elsevier Science Publ., 529 p.

Hem, J.D., 1992, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

High Plains Regional Climate Center, 2000, Historical data summaries: Information available on the World Wide Web, accessed December 6, 2000, at URL http://www.hprcc.unl.edu/

Hongve, Dag, and Erlandsen, A.H., 1979, Shortening of surface sediment cores during sampling: Hydrobiologia, v. 65, no. 3, p. 283–287.

Horne, A.J., and Goldman, C.R., 1994, Limnology (2d ed.): New York, McGraw-Hill, Inc., 576 p.

Horowitz, A.J., Elrick, K.A., and Smith, J.J., 2001, Estimating suspended sediment and trace element fluxes in large river basins—methodological considerations as applied to the NASQAN Program: Hydrological Processes, v. 15, p. 1107–1132.

Jordan, P.R., and Stamer, J.K., eds.,1995, Surface-water-quality assessment of the lower Kansas River Basin, Kansas and Nebraska—analysis of available data through 1986: U.S. Geological Survey Water-Supply Paper 2352–B, 161 p.

Juracek, K.E., 1997, Analysis of bottom sediment to estimate nonpoint-source phosphorus loads for 1981–96 in Hillsdale Lake, northeast Kansas: U.S. Geological Survey Water-Resources Investigations Report 97–4235, 55 p.

———2000, Depth-weighted, mean soil permeability in Kansas: U.S. Geological Survey Open-File Report 00–252, available as digital spatial data from the Kansas Data Access and Support Center in Lawrence, Kansas (http://gisdasc.kgs.ukans.edu/).

Juracek, K.E., and Mau, D.P., 2002, Sediment deposition and occurrence of selected nutrients and other chemical constituents in bottom sediment, Tuttle Creek Lake, northeast Kansas, 1962–99: U.S. Geological Survey Water-Resources Investigations Report 02–4048, 73 p.

Kansas Applied Remote Sensing Program, 1993, Kansas land cover data base, 1:100,000 scale: Lawrence, Kansas, Data Access and Support Center, available on CD.

Kansas Department of Agriculture, 2002, Kansas Agricultural Statistics Service: Information available on the World Wide Web, accessed November 4, 2002, at URL http://www.nass.usda.gov/ks

Karickhoff, S.W., 1984, Organic pollutant sorption in aquatic systems: Journal of Hydraulic Engineering, v. 110, no. 6, p. 707–735.

Krammer, K., and Lange-Bertalot, H., 1986, Bacillariophyceae, 1. Teil—Naviculaceae: Jena, Germany, VEB Gustav Fisher Verlag, 876 p.

———1988, Bacillariophyceae, 2. Teil—Epithemiaceae, bacillariaceae, surirellaceae: Jena, Germany, VEB Gustav Fisher Verlag, 596 p.

———1991a, Bacillariophyceae, 3. Teil—Centrales, fragilariaceae, eunotiaceae, achnanthaceae: Jena, Germany, VEB Gustav Fisher Verlag, 576 p.

———1991b, Bacillariophyceae, 1. Teil—Achnanthaceae, kritische erganzungen zu navicula (lineolatae) und gomphonema: Jena, Germany, VEB Gustav Fisher Verlag, 437 p.

Lemly, D.A., and Smith, G.J., 1987, Aquatic cycling of selenium—implications for fish and wildlife: U.S. Fish and Wildlife Service, Fish and Wildlife Leaflet 12, 10 p.

Lide, D.R., ed., 1993, CRC handbook of chemistry and physics (74th ed.): Boca Raton, Florida, CRC Press, various pagination.

Manahan, S.E., 2000, Environmental chemistry (7th ed.): Boca Raton, Florida, Lewis Publ., 898 p.

Mau, D.P., 2001, Sediment deposition and trends and transport of phosphorus and other chemical constituents, Cheney Reservoir watershed, south-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 01–4085, 40 p.

———2002, Sediment deposition and selected water-quality characteristics in Cedar Lake and Lake Olathe, northeast Kansas, 2000: U.S. Geological Survey Water-Resources Investigations Report 02–4073, 71 p.

Morris, G.L., and Fan, Jiahua, 1998, Reservoir sedimentation handbook: New York, McGraw-Hill, various pagination.

Novotny, Vladimir, ed., 1995, Nonpoint pollution and urban stormwater management: Lancaster, Pennsylvania, Technomic Publ., 434 p.

Novotny, Vladimir, and Chesters, Gordon, eds., 1981, Handbook of nonpoint pollution—sources and management: New York, Van Nostrand Reinhold, 555 p.

Nowell, L.H., Capel, P.D., and Dileanis, P.D., 1999, Pesticides in stream sediment and aquatic biota—distribution, trends, and governing factors: Boca Raton, Florida, Lewis Publ., 1001 p.

Pais, Istvan, and Jones, J.B., Jr., 1997, The handbook of trace elements: Boca Raton, Florida, St. Lucie Press, 223 p.

Patrick, R., and Reimer, C.W., 1966, The diatoms of the United States, volume 1: Monographs of the Academy of Natural Sciences of Philadelphia, no. 13, 688 p.

———1975, The diatoms of the United States, volume 2, part 1: Monographs of the Academy of Natural Sciences of Philadelphia, no. 13, 213 p.

Pope, L.M., Brewer, L.D., Foley, G.A., and Morgan, S.C., 1997, Concentrations and transport of atrazine in surface water of the Delaware River-Perry Lake system, northeast Kansas, July 1992 through September 1995: U.S. Geological Survey Water-Supply Paper 2489, 43 p.

Sabater, Sergi, and Haworth, E.Y., 1995, An assessment of recent trophic changes in Windermere South Basin (England) based on diatom remains and fossil pigments: Journal of Paleolimnology, v. 14, p. 151–163.

Scribner, E.A., Goolsby, D.A., Thurman, E.M., Meyer, M.T., and Pomes, M.L., 1994, Concentrations of selected herbicides, two triazine metabolites, and nutrients in storm runoff from nine stream basins in the midwestern United States, 1990–92: U.S. Geological Survey Open-File Report 94–396, 144 p.

Stamer, J.K., and Zelt, R.B., 1994, Organonitrogen herbicides in the lower Kansas River Basin: Journal American Water Works Association, v. 86, January 1994, p. 93–104.

Stoermer, E.F., Edlund, M.B., Pilskaln, C.H., and Schelske, C.L., 1995, Siliceous microfossil distribution in the surficial sediments of Lake Baikal: Journal of Paleolimnology, v. 14, p. 69–82.

Stoermer, E.F., and Smol, J.P., eds., 1999, The diatoms—applications for the environmental and earth sciences: New York, Cambridge University Press, 469 p.

Tanner, D.Q., Sanzolone, R.F., and Zelt, R.B., 1990, Surface water-quality assessment of the lower Kansas River Basin, Kansas and Nebraska—concentrations of major metals and trace elements in streambed sediments, 1987: U.S. Geological Survey Open-File Report 90–581, 73 p.

U.S. Army Corps of Engineers, 1973, Lower Kansas River Basin lake regulation manual, volume 3, Perry Lake: Kansas City, Missouri, U.S. Army Corps of Engineers, Kansas City District, July 1973, various pagination.

———1975, Final environmental statement, operation and maintenance, Perry Lake, Kansas: Kansas City, Missouri, U.S. Army Corps of Engineers, Kansas City District, January 1975, various pagination.

———2001, Perry Lake: Information available on the World Wide Web, accessed July 6, 2001, at URL http://www.nwk.usace.army.mil/perry/perry_home.htm

U.S. Census Bureau, 2001, County population census counts: Information available on the World Wide Web, accessed March 19, 2001, at URL http://www.census.gov/

U.S. Department of Agriculture, 1994, State soil geographic data base—U.S. coverage by States including Puerto Rico: U.S. Department of Agriculture, Soil Conservation Service, October 1994, CD-ROM digital data.

———2001, National Agricultural Statistics Service, published estimates data base: Information available on the World Wide Web, accessed January 29, 2002, at URL http://www.nass.usda.gov:81/ipedb/

U.S. Department of Agriculture, Soil Conservation Service, 1960, Soil survey of Brown County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, 32 p.

———1977, Soil survey of Jefferson County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, 67 p.

———1979, Soil survey of Jackson County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, 86 p.

———1982, Soil survey of Nemaha County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, 89 p.

———1984, Soil survey of Atchison County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, 105 p.

U.S. Environmental Protection Agency, 1977, Algae and water pollution: Municipal Environmental Research Laboratory, Office of Research and Development, Report 600–77–036, 122 p.

———1991, Guidance of water quality-based decisions—the TMDL process: Washington, D.C., Office of Water, Report EPA440/4–91–001, 59 p.

———1997, The incidence and severity of sediment contamination in surface waters of the United States, volume 1—national sediment quality survey: U.S. Environmental Protection Agency Report 823–R–97–006, September 1997, various pagination.

Van Metre, P.C., Callender, Edward, and Fuller, C.C., 1997, Historical trends in organochlorine compounds in river basins identified using sediment cores from reservoirs: Environmental Science and Technology, v. 31, no. 8, p. 2339–2344.

Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., eds., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 80 p.

Yang, J.R., Duthie, H.C., and Delorme, L.D., 1993, Reconstruction of the recent environmental history of Hamilton Harbour (Lake Ontario, Canada) from analysis of siliceous microfossils: Journal of Great Lakes Research, v. 19, no. 1, p. 55–71.

Zoumis, Theofanis, Schmidt, Astrid, Grigorova, Lidia, and Calmano, Wolfgang, 2001, Contaminants in sediments—remobilisation and demobilisation: The Science of the Total Environment, v. 266, p. 195–202.

SUPPLEMENTAL INFORMATION

Table 14. Latitude and longitude coordinates for end points of U.S. Army Corps of Engineers range lines used in bathymetric surveys of Perry Lake, northeast Kansas

[Horizontal datum is North American Datum of 1983]

	Left end point[1]		Right end point[1]	
Range line (fig. 2)	Latitude (decimal degrees)	Longitude (decimal degrees)	Latitude (decimal degrees)	Longitude (decimal degrees)
1	39.1276	95.4120	39.1124	95.4421
2	39.1505	95.4362	39.1497	95.4541
3	39.1801	95.4378	39.1803	95.4693
4	39.2014	95.4541	39.2016	95.4840
5	39.2303	95.4472	39.2308	95.4604
6	39.2595	95.4680	39.2594	95.4803
7	39.2734	95.4334	39.2734	95.4457
8	39.2891	95.4423	39.2998	95.4423
24	39.1486	95.4601	39.1272	95.4599
25	39.1580	95.4897	39.1585	95.4965
26	39.1804	95.5346	39.1801	95.5441
28	39.1322	95.4141	39.1314	95.4247
29	39.1582	95.3992	39.1583	95.4058
30	39.1869	95.3959	39.1869	95.4038

[1] Left and right end points designated looking in the downstream direction.

Table 15. Latitude and longitude coordinates for bottom-sediment coring sites in Perry Lake, northeast Kansas

[Horizontal datum is North American Datum of 1983]

Coring site (fig. 2)	Latitude (decimal degrees)	Longitude (decimal degrees)
	In-channel sites	
PIC–1	39.1468	95.4454
PIC–2	39.1497	95.4018
PIC–4	39.2910	95.4318
PIC–6	39.2738	95.4497
PIC–7	39.2595	95.4772
PIC–8	39.2316	95.4564
PIC–9	39.2007	95.4642
PIC–10	39.1801	95.4548
PIC–11	39.1316	95.4525
PIC–12	39.1559	95.4899
	Out-of-channel sites	
POC–1	39.1503	95.4433
POC–2	39.1157	95.4344
POC–3	39.1408	95.4115
POC–4	39.2315	95.4519
POC–5	39.2018	95.4724
POC–6	39.1801	95.4632
POC–7	39.1353	95.4599
POC–8	39.1537	95.4873
POC–9	39.1442	95.4002

Table 16. Diatom species, relative percentage abundance, and total number of valves per gram of material in bottom-sediment samples collected from coring site PIC–1 in Perry Lake, northeast Kansas, September 2001

Depth of sample (feet)	Species	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
0 – 0.79	*Aulacoseira granulata*	217	40.9	4,970,000
	Aulacoseira islandica	37	7.0	848,000
	Aulacoseira c.f. nygaardii	41	7.7	940,000
	Cyclotella comensis	5	.9	115,000
	Cyclotella meneghiniana	7	1.3	160,000
	Cyclotella ocellata	6	1.1	137,000
	Cyclotella radiosa	54	10.2	1,240,000
	Cyclotella stelligera	5	.9	115,000
	Fragilaria capucina var. mesolepta	3	.6	68,800
	Navicula sp. 1	1	.2	22,900
	Nitzschia dissipata	1	.2	22,900
	Nitzschia subacicularis	1	.2	22,900
	Stephanodiscus hantzschii	23	4.3	527,000
	Stephanodiscus niagarae	120	22.6	2,750,000
	Stephanodiscus sp.1	2	.4	45,800
	Stephanodiscus sp. 2	7	1.3	160,000
Total		**530**	**100[1]**	**12,100,000**
0.79–1.58	*Aulacoseira distans*	6	1.2	159,000
	Aulacoseira granulata	235	46.8	6,230,000
	Aulacoseira islandica	73	14.5	1,930,000
	Aulacoseira c.f. nygaardii	25	5.0	662,000
	Cyclotella comensis	3	.6	79,500
	Cyclotella meneghiniana	2	.4	53,000
	Cyclotella ocellata	2	.4	53,000
	Cyclotella radiosa	41	8.2	1,090,000
	Cyclotella stelligera	6	1.2	159,000
	Hantzschia amphioxys	2	.4	53,000
	Nitzschia dissipata	1	.2	26,500
	Stephanodiscus hantzschii	9	1.8	238,000
	Stephanodiscus niagarae	92	18.3	2,440,000
	Stephanodiscus sp. 1	3	0.6	79,500
	Stephanodiscus sp. 2	2	.4	53,000
Total		**502**	**100[1]**	**13,300,000**
1.58–2.38	*Aulacoseira distans*	2	.4	33,600
	Aulacoseira granulata	146	29.1	2,450,000
	Aulacoseira islandica	44	8.8	739,000
	Aulacoseira c.f. nygaardii	69	13.8	1,160,000
	Cyclotella comensis	13	2.6	218,000

Table 16. Diatom species, relative percentage abundance, and total number of valves per gram of material in bottom-sediment samples collected from coring site PIC–1 in Perry Lake, northeast Kansas, September 2001—Continued

Depth of sample (feet)	Species	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
1.58–2.38	*Cyclotella radiosa*	17	3.4	285,000
	Cyclotella sp. 1	4	.8	67,200
	Fragilaria sp. 1	2	.4	33,600
	Stephanodiscus hantzschii	6	1.2	101,000
	Stephanodiscus niagarae	191	38.1	3,210,000
	Stephanodiscus sp. 1	1	.2	16,800
	Stephanodiscus sp. 2	6	1.2	101,000
Total		**501**	**100[1]**	**8,420,000**
2.38–3.17	*Aulacoseira granulata*	133	25.7	3,900,000
	Aulacoseira islandica	113	21.9	3,310,000
	Aulacoseira c.f. nygaardii	78	15.1	2,290,000
	Cyclotella comensis	7	1.4	205,000
	Cyclotella ocellata	3	.6	87,900
	Cyclotella radiosa	9	1.7	264,000
	Cyclotella stelligera	1	.2	29,300
	Stephanodiscus hantzschii	9	1.7	264,000
	Stephanodiscus niagarae	159	30.8	4,660,000
	Stephanodiscus sp. 2	5	1.0	146,000
Total		**517**	**100[1]**	**15,200,000**
3.17–3.96	*Aulacoseira granulata*	242	47.8	2,700,000
	Aulacoseira islandica	36	7.1	401,000
	Aulacoseira c.f. nygaardii	41	8.1	457,000
	Cyclotella comensis	4	.8	44,600
	Cyclotella radiosa	7	1.4	78,000
	Cyclotella stelligera	2	.4	22,300
	Fragilaria capucina var. mesolepta	2	.4	22,300
	Stephanodiscus hantzschii	4	.8	44,600
	Stephanodiscus niagarae	163	32.2	1,820,000
	Stephanodiscus sp. 2	5	1.0	55,700
Total		**506**	**100[1]**	**5,650,000**
3.96 – 4.75	*Achnanthidium sp. 1*	1	.4	18,100
	Aulacoseira granulata	108	46.8	1,950,000
	Aulacoseira islandica	9	3.9	163,000
	Aulacoseira c.f. nygaardii	19	8.2	344,000
	Cyclotella radiosa	4	1.7	72,300
	Cyclotella stelligera	2	.9	36,200
	Stephanodiscus niagarae	86	37.2	1,550,000
	Stephanodiscus sp. 2	2	.9	36,200
Total		**231**	**100[1]**	**4,170,000**

Table 16. Diatom species, relative percentage abundance, and total number of valves per gram of material in bottom-sediment samples collected from coring site PIC–1 in Perry Lake, northeast Kansas, September 2001—Continued

Depth of sample (feet)	Species	Number of valves counted	Relative percentage abundance	Valves per gram of material[1]
4.75–5.54	*Aulacoseira granulata*	194	53.3	3,610,000
	Aulacoseira islandica	6	1.6	112,000
	Aulacoseira c.f. nygaardii	50	13.7	930,000
	Craticula cuspidata	1	.3	18,600
	Cyclotella radiosa	3	.8	55,800
	Cyclotella stelligera	1	.3	18,600
	Stephanodiscus hantzschii	1	.3	18,600
	Stephanodiscus niagarae	108	29.7	2,010,000
Total		**364**	**100[1]**	**6,770,000**
5.54 – 6.33	*Achnanthidium sp. 1*	2	.8	37,000
	Aulacoseira granulata	90	35.9	1,660,000
	Aulacoseira islandica	2	.8	37,000
	Aulacoseira c.f. nygaardii	29	11.6	536,000
	Cyclotella radiosa	3	1.2	55,500
	Stephanodiscus niagarae	125	49.8	2,310,000
Total		**251**	**100[1]**	**4,640,000**
6.33–7.13	*Aulacoseira granulata*	101	42.3	1,840,000
	Aulacoseira c.f. nygaardii	22	9.2	402,000
	Cyclotella radiosa	3	1.3	54,800
	Cyclotella sp. 1	1	.4	18,300
	Stephanodiscus hantzschii	9	3.8	164,000
	Stephanodiscus niagarae	103	43.1	1,880,000
Total		**239**	**100[1]**	**4,360,000**
7.13–7.92	*Achnanthidium sp. 1*	1	.4	16,000
	Aulacoseira granulata	40	17.7	639,000
	Aulacoseira islandica	1	.4	16,000
	Aulacoseira c.f. nygaardii	12	5.3	192,000
	Caloneis bacillum	1	.4	16,000
	Craticula cuspidata	1	.4	16,000
	Cyclotella comensis	1	.4	16,000
	Cyclotella radiosa	7	3.1	112,000
	Navicula sp. 2 (canted)	1	.4	16,000
	Pinnularia borealis	1	.4	16,000
	Stephanodiscus hantzschii	13	5.8	208,000
	Stephanodiscus niagarae	147	65.0	2,350,000
Total		**226**	**100[1]**	**3,610,000**

[1] Numbers have been rounded to two or three significant figures.

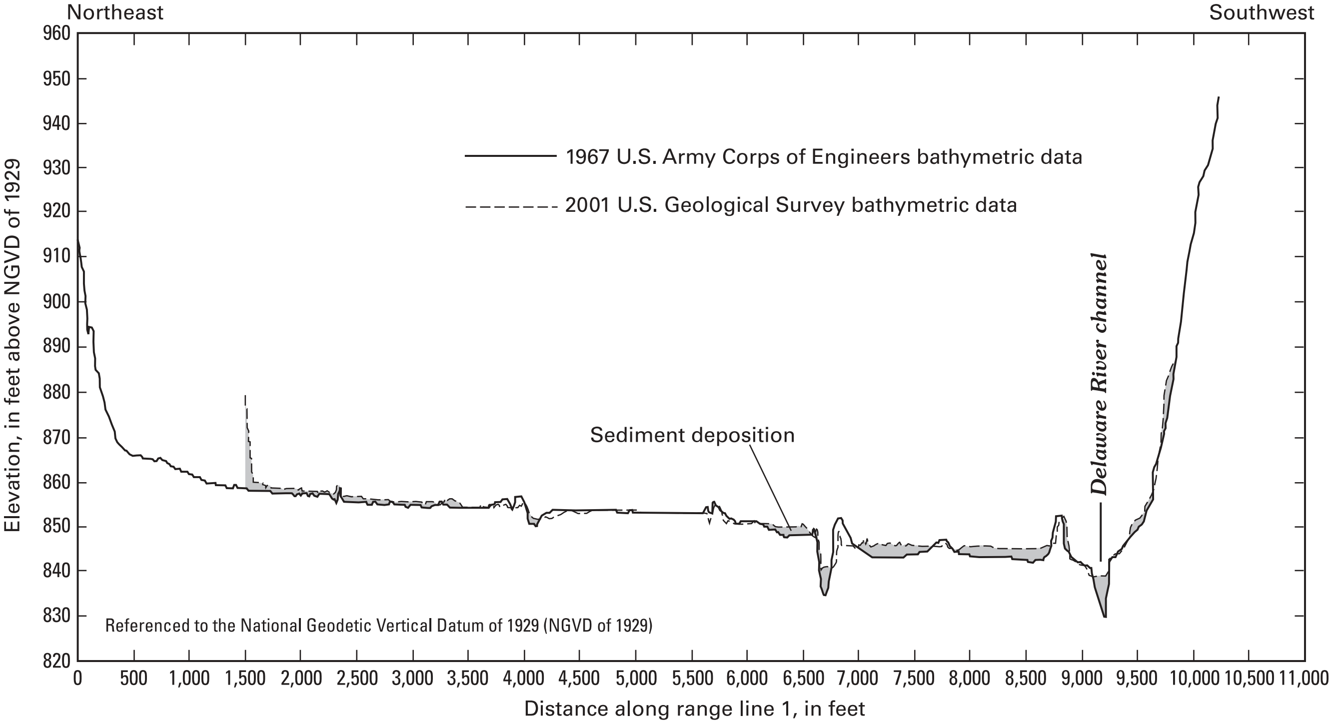


Figure 21. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 1. Location of range line shown in figure 2.

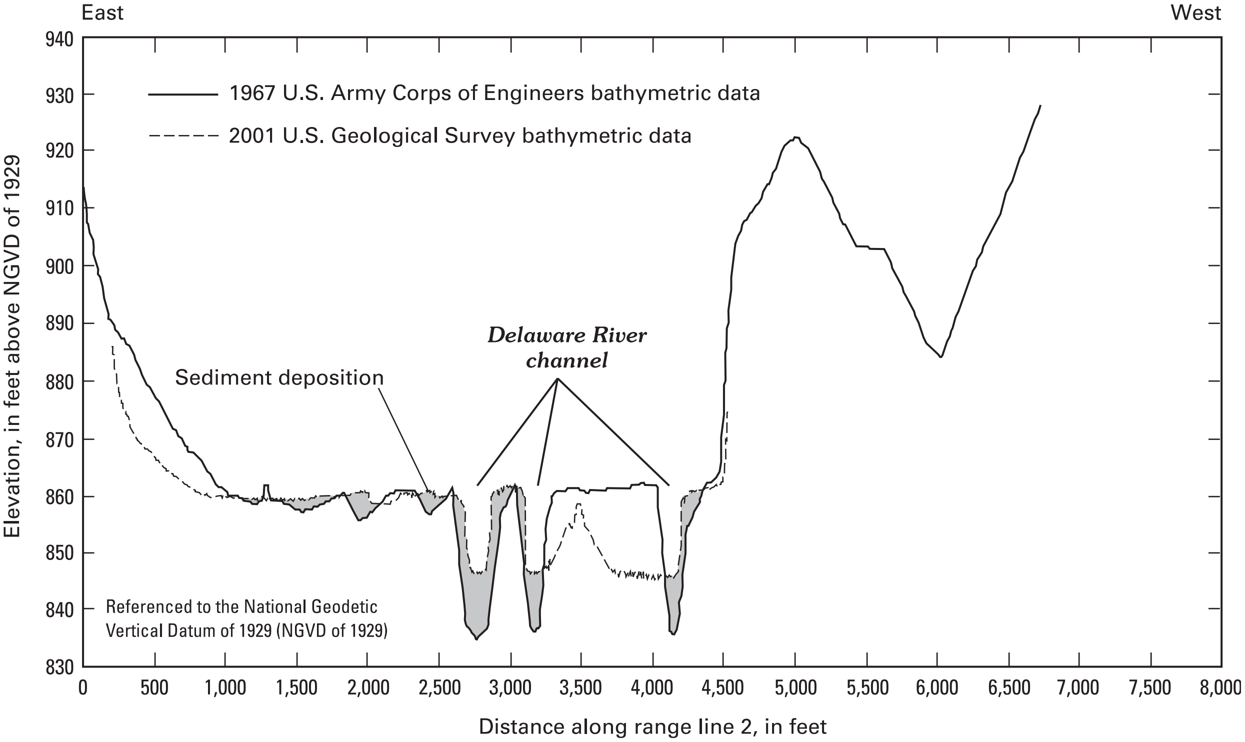


Figure 22. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 2. Location of range line shown in figure 2.

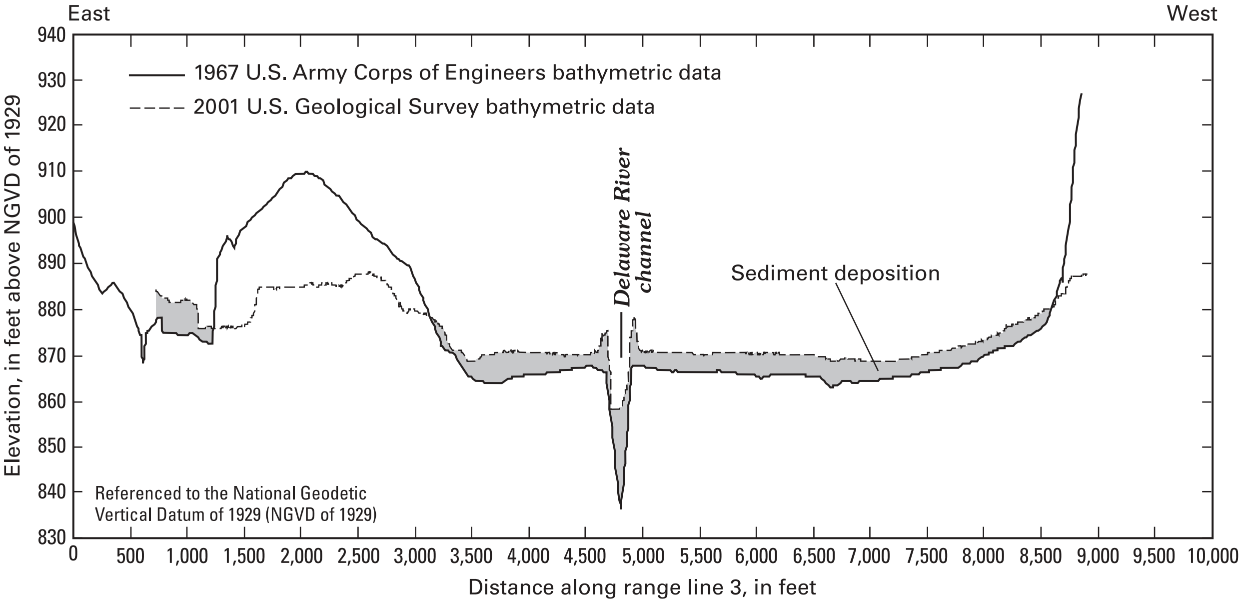


Figure 23. **Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 3. Location of range line shown in figure 2.**

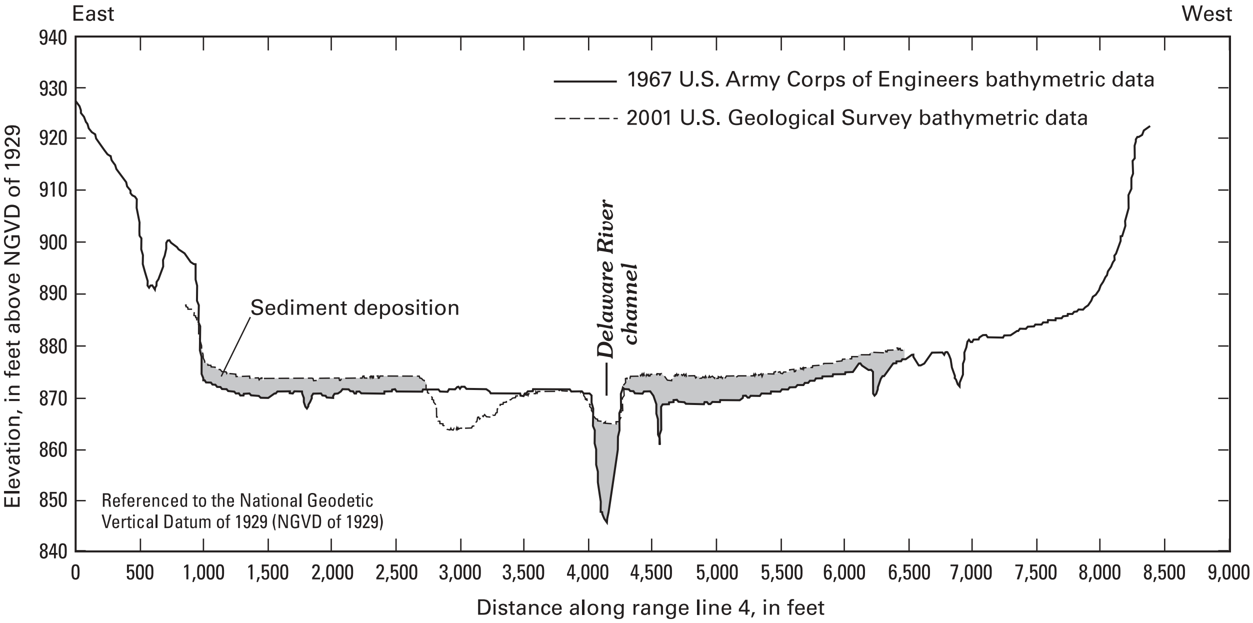


Figure 24. **Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 4. Location of range line shown in figure 2.**

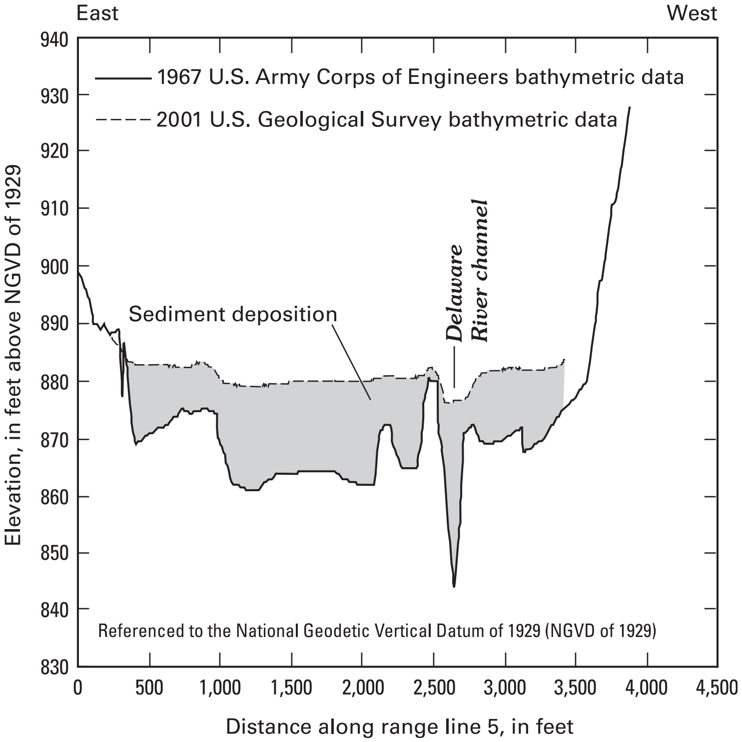


Figure 25. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 5. Location of range line shown in figure 2.

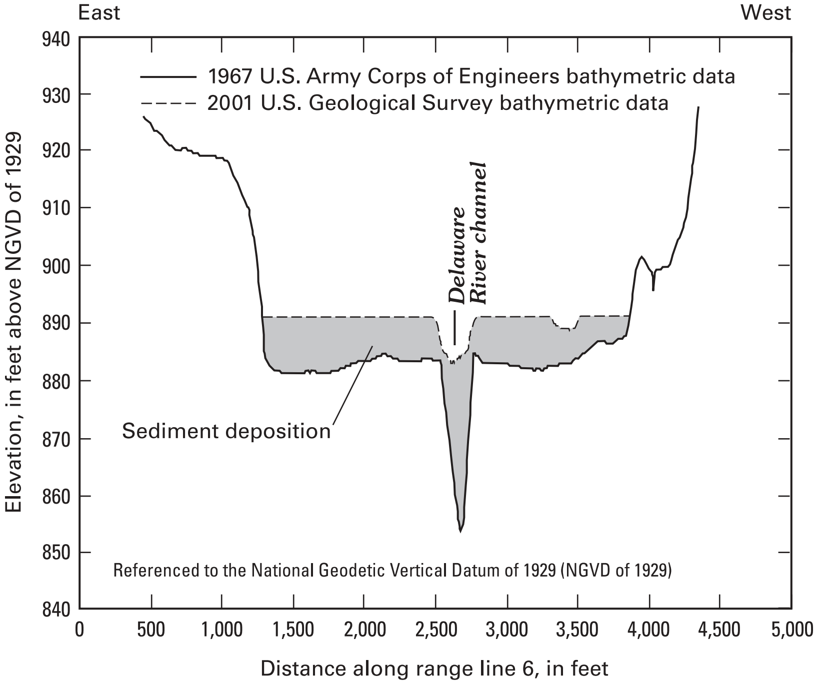


Figure 26. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 6. Location of range line shown in figure 2.

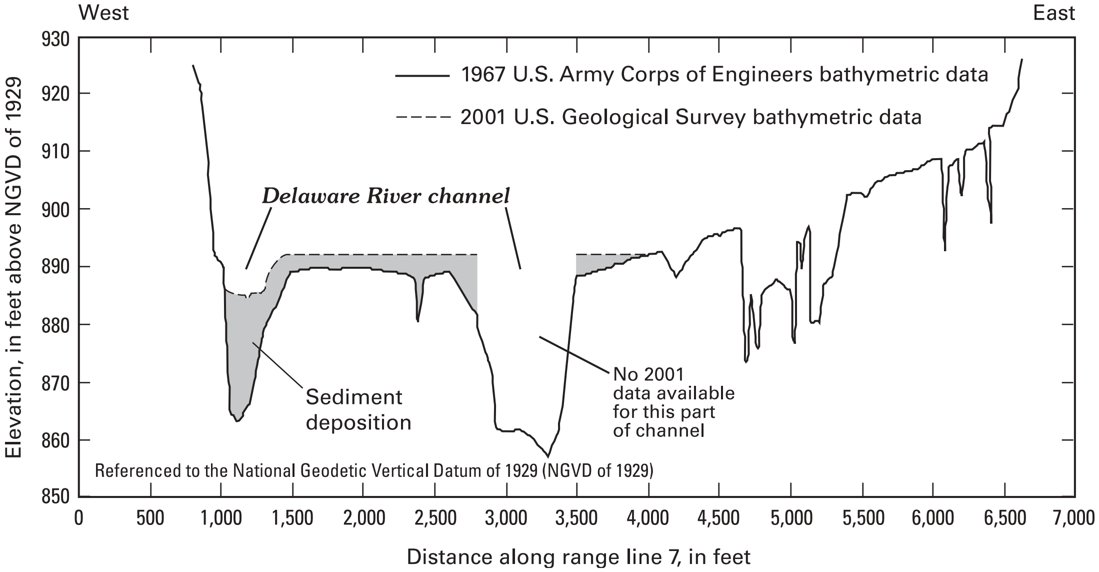


Figure 27. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 7. Location of range line shown in figure 2.

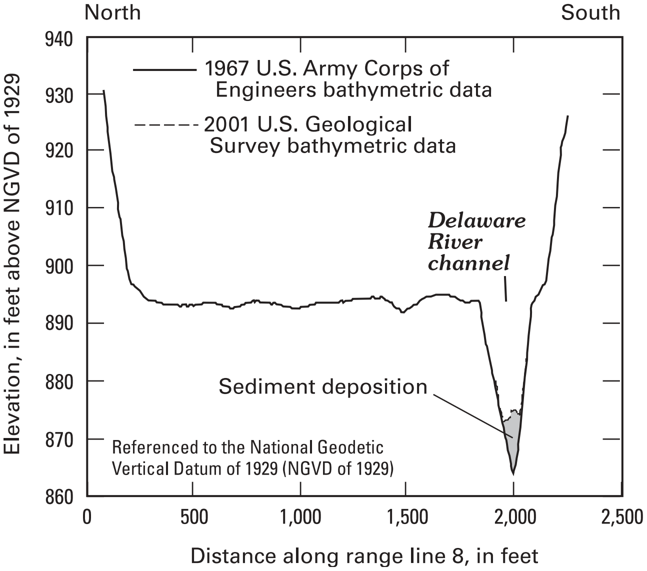


Figure 28. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 8. Location of range line shown in figure 2.

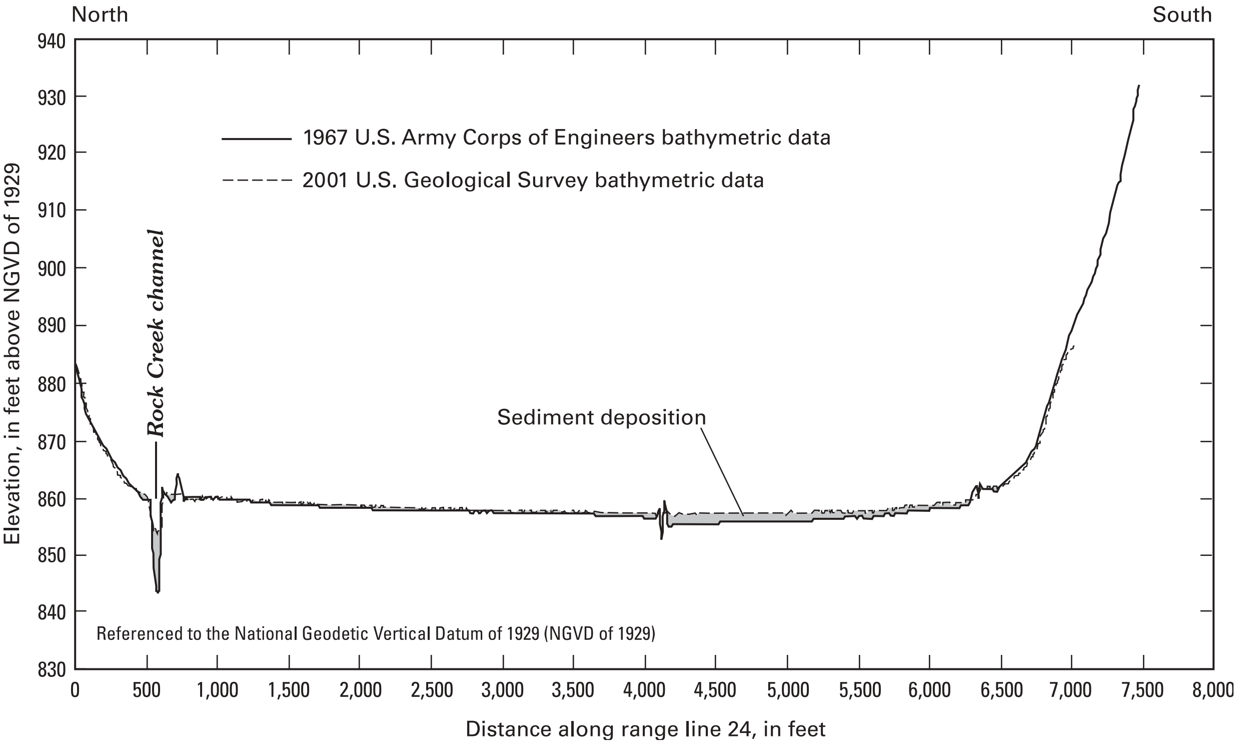


Figure 29. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 24. Location of range line shown in figure 2.

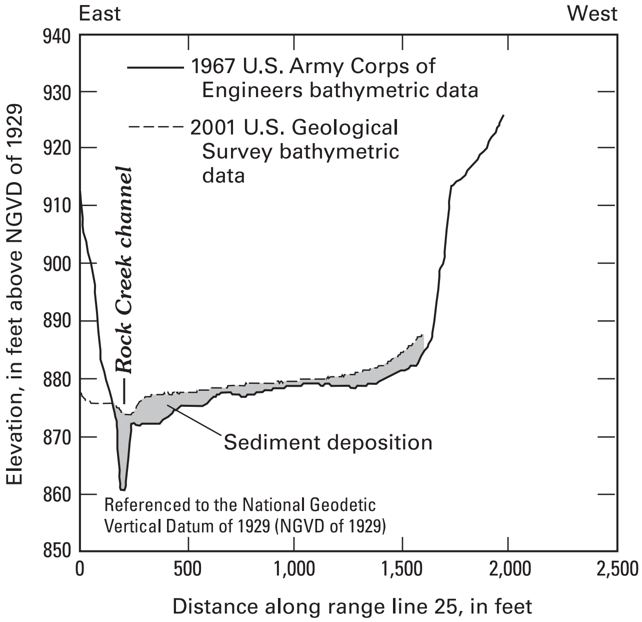


Figure 30. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 25. Location of range line shown in figure 2.

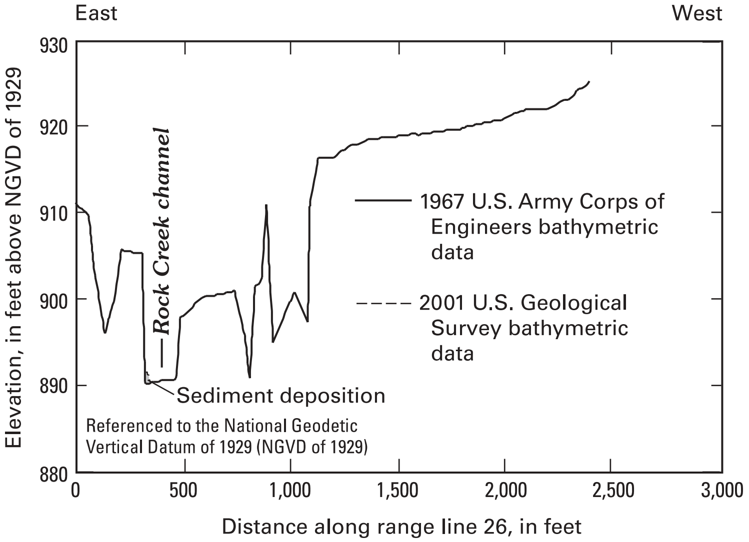


Figure 31. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 26. Location of range line shown in figure 2.

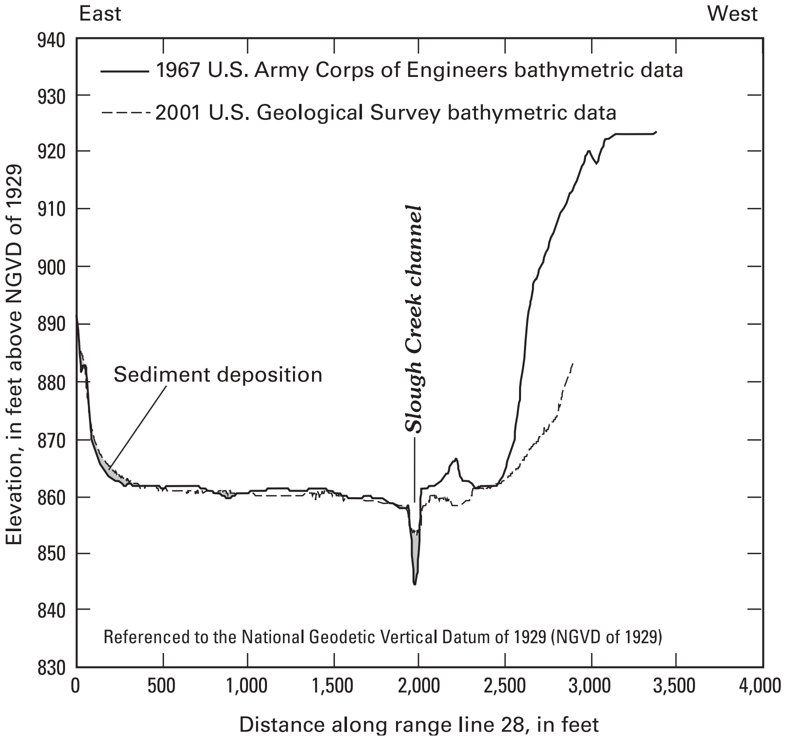


Figure 32. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 28. Location of range line shown in figure 2.

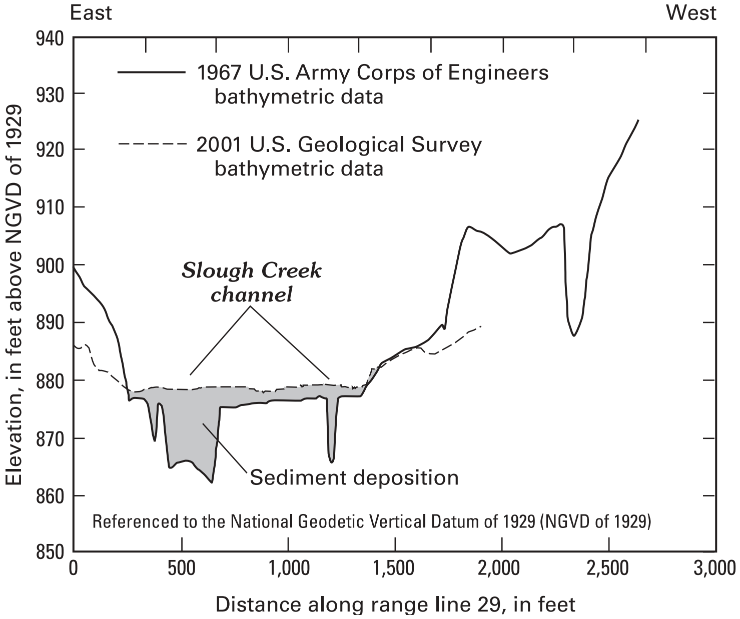


Figure 33. Comparison of 1967 U.S. Army Corps of Engineers bathymetric data and 2001 U.S. Geological Survey bathymetric data for Perry Lake, range line 29. Location of range line shown in figure 2.