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KANSAS WATER OFFICE and the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

Sediment Deposition and Trends and Transport of Phosphorus and Other Chemical Constituents, Cheney Reservoir Watershed, South-Central Kansas

Water-Resources Investigations Report 01–4085

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

Cover photographs: Control tower and shoreline northeast of dam, Cheney Reservoir, south-central Kansas.

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By DAVID P. MAU

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Lawrence, Kansas
2001

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CONVERSION FACTORS, ABBREVIATIONS, AND DEFINITIONS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
acre-foot per year per square mile [(acre-ft/yr)/mi^2]	476.1	cubic meter per year per square kilometer
cubic foot (ft^3)	0.02832	cubic meter
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
inch per year (in/yr)	2.54	centimeter per year
liter (L)	0.2642	gallon
microgram per gram (μg/g)	1.0000×10^{-6}	ounce per ounce
microgram per kilogram (μg/kg)	1.000×10^{-3}	ounce per ounce
microgram per liter (μg/L)	1.0	part per billion
mile (mi)	1.609	kilometer
milligram (mg)	0.0000353	ounce
milligram per kilogram (mg/kg)	1.0×10^{-6}	ounce per ounce
milligram per liter (mg/L)	1.0	part per million
millimeter (mm)	0.03937	inch
picocurie per gram (pCi/g)	0.03527	picocurie per ounce
pound (lb)	453.6	gram
pound per acre (lb/acre)	1.121	kilogram per hectare
pound per acre-foot (lb/acre-ft)	0.3679	gram per cubic meter
pound per year per acre [(lb/yr)/acre]	1.121	kilogram per year per hectare
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
pound per year (lb/yr)	453.6	gram per year
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
ton	0.9072	megagram

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

$$°C = 5/9\ (°F - 32)$$

$$°F = 9/5\ (°C) + 32.$$

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

Water year: In this report, "water year" is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends. Thus, the year ending September 30, 1998, is called "1998 water year."

Sediment Deposition and Trends and Transport of Phosphorus and Other Chemical Constituents, Cheney Reservoir Watershed, South-Central Kansas

By David P. Mau

Abstract

Sediment deposition, water-quality trends, and mass transport of phosphorus, nitrogen, selected trace elements, and selected pesticides within the Cheney Reservoir watershed in south-central Kansas were investigated using bathymetric survey data and reservoir bottom-sediment cores. Sediment loads in the reservoir were investigated by comparing 1964 topographic data to 1998 bathymetric survey data. Approximately 7,100 acre-feet of sediment deposition occurred in Cheney Reservoir from 1965 through 1998. As of 1998, sediment had filled 27 percent of the reservoir's inactive conservation storage pool, which is less than the design estimate of 34 percent. Mean annual sediment deposition was 209 acre-feet per year, or 0.22 acre-feet per year per square mile, and the mean annual sediment load was 453 million pounds per year. During the 3-year period from 1997 through 1999, 23 sediment cores were collected from the reservoir, and subsamples were analyzed for nutrients (phosphorus and nitrogen species), selected trace elements, and selected organic pesticides.

Mean concentrations of total phosphorus in reservoir bottom sediment ranged from 94 milligrams per kilogram at the upstream end of the reservoir to 710 milligrams per kilogram farther downstream near the reservoir dam. The mean concentration for all sites was 480 milligrams per kilogram. Total phosphorus concentrations were greatest when more silt- and clay-sized particles were present. The implications are that if anoxic conditions (inadequate oxygen) occur near the dam, phosphorus could be released from the sediment and affect the drinking-water supply. Analysis of selected cores also indicates that total phosphorus concentrations in the reservoir sediment increased over time and were probably the result of nonpoint-source activities in the watershed, such as increased fertilizer use and livestock production.

Mean annual phosphorus loading to Cheney Reservoir was estimated to be 226,000 pounds per year on the basis of calculations from deposited sediment in the reservoir. Mean total phosphorus concentration in the surface-water inflow to Cheney Reservoir was 0.76 milligram per liter, mean annual phosphorus yield of the watershed was estimated to be 0.38 pound per year per acre, and both are based on sediment deposition in the reservoir. A comparison of the Cheney Reservoir watershed to the Webster Reservoir, Tuttle Creek Lake, and Hillsdale Lake watersheds showed that phosphorus yields were smallest in the Webster Reservoir watershed where precipitation was less than in the other watersheds.

Mean concentrations of total ammonia plus organic nitrogen in bottom sediment from Cheney Reservoir ranged from 1,200 to 2,400 milligrams per kilogram as nitrogen. A regression analysis between total ammonia plus organic nitrogen as nitrogen and sediment particle size showed a strong relation between the two variables and suggests, as with phosphorus, that total ammonia plus

organic nitrogen as nitrogen adsorbs to the silt- and clay-sized particles that are transported to the deeper parts of the reservoir. An analysis of trends with depth of total ammonia plus organic nitrogen as nitrogen did not indicate a strong relation between the two variables despite the increase in fertilizer use in the watershed during the past 40 years.

Selected cores were analyzed for trace elements. Concentrations of arsenic, chromium, copper, and nickel at many sites exceeded levels where adverse effects on aquatic organisms sometimes occur. Larger concentrations of these elements also occurred in sediment closer to the reservoir dam where there is a larger percentage of silt and clay in the bottom sediment than farther upstream. However, the lack of industrial or commercial land use in the watershed suggests that these concentrations may be the result of natural conditions.

Organochlorine insecticides were detected in the reservoir-bottom sediment in Cheney Reservoir. DDT and its degradation products DDD and DDE were detected in analyzed samples but at concentrations that were less than the U.S. Environmental Protection Agency's recommended guidelines for these compounds. Similarly, selected organophosphate insecticides and acetanilide, chlorophenoxy-acid, and triazine herbicides were analyzed in reservoir sediment samples; however, only small concentrations of the acetanilide herbicide metolachlor were detected.

The reservoir sediment investigation at Cheney Reservoir was used to reconstruct historical trends in water quality and can be used to measure the effectiveness of best-management practices that have been implemented throughout the reservoir watershed. With the addition of bathymetric surveys and the inclusion of additional reservoir watersheds, sediment investigations also can be used to estimate historical loading of phosphorus and other constituents in future water-quality assessments throughout Kansas.

INTRODUCTION

The effects of land use on water quality is an environmental issue that has gained increased public awareness. Activities within a watershed, such as point-source discharges to streams from municipal wastewater-treatment facilities and nonpoint-source discharges from crop and livestock production, may help transport potential contaminants to surface and ground water and ultimately to downstream reservoirs.

Reservoirs in Kansas are affected by a variety of constituents that include suspended sediment, nutrients (phosphorus and nitrogen species), trace elements, and agricultural pesticides. Many of these constituents adhere to sediment particles and are deposited in reservoirs, which act as sinks for storage of these constituents. The large sediment concentrations common in Kansas reservoirs also are responsible for turbidity levels that can reduce the euphotic zone (that part of a water body in which there is sufficient light penetration to support photosynthesis) from several feet to a fraction of a foot. Large turbidity levels in combination with the presence of nutrients and pesticides can have harmful effects on both humans and aquatic organisms and can reduce the recreational value of the reservoir. One reservoir currently under investigation to determine the effects of these constituents, Cheney Reservoir, is located in south-central Kansas (fig. 1) and serves as both a drinking-water supply for the more than 300,000 people in the city of Wichita and as a regional recreational resource.

Cheney Reservoir is a multipurpose impoundment located on the North Fork Ninnescah River. The reservoir was constructed between 1962 and 1965 by the Bureau of Reclamation (BOR), U.S. Department of the Interior, to provide downstream flood control, to serve as a public water-supply source, to allow recreational activities, and to provide wildlife benefits. Because of the reservoir's importance to the area, there is considerable interest in maintaining acceptable water quality by mitigating contamination and preventing long-term detrimental effects to the aquatic ecosystem.

Previous Investigations

In 1996, the U.S. Geological Survey (USGS) entered into a cooperative study with the city of Wichita, Kansas, to define the water quality of the Cheney Reservoir watershed. Synoptic water-quality sampling

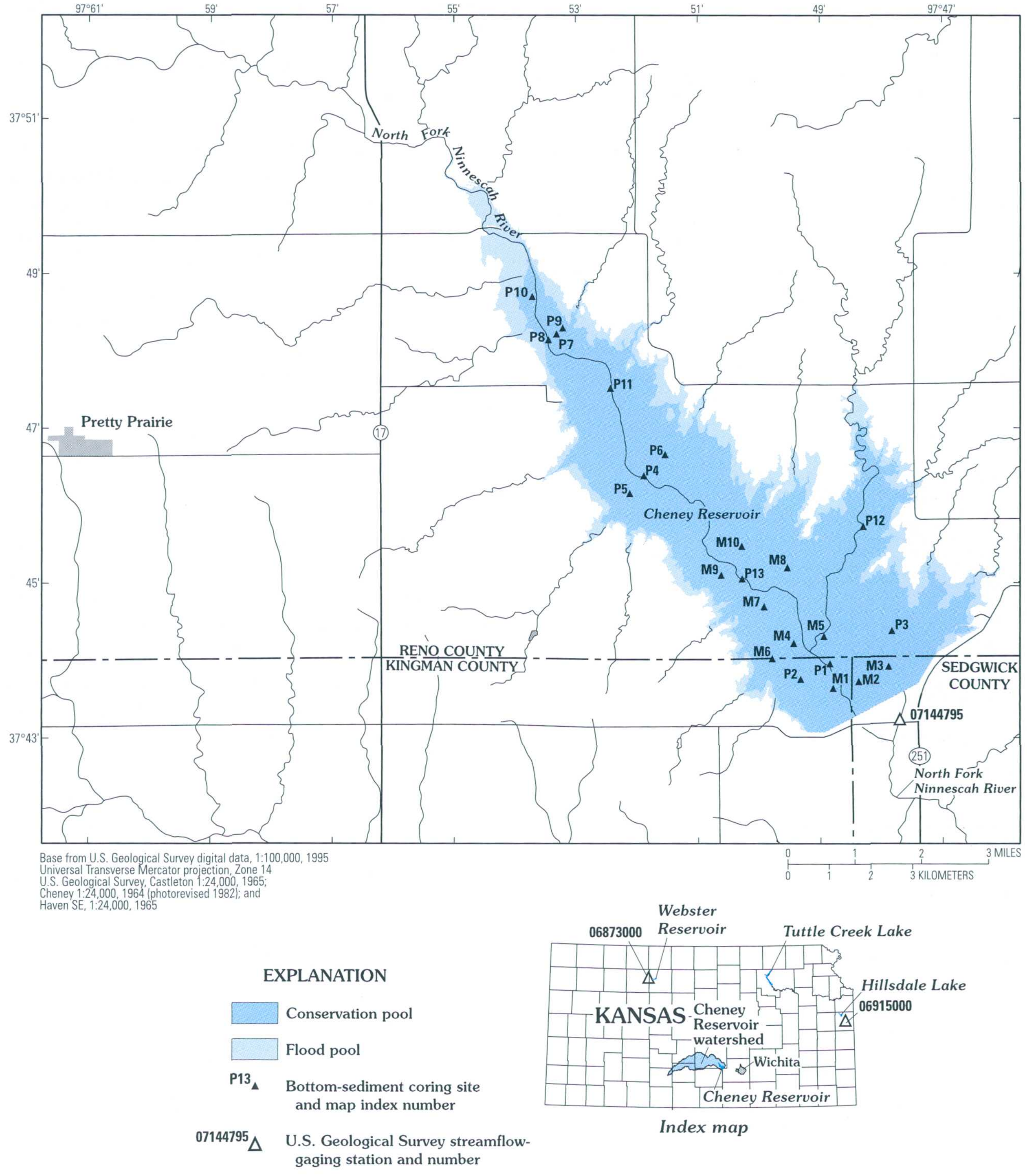


Figure 1. Location of Cheney Reservoir watershed in south-central Kansas and bottom-sediment coring sites in Cheney Reservoir.

was conducted during two low-flow periods in 1996 to determine spatial variability of various chemical constituents (Christensen and Pope, 1997). The sampling was done at many locations over a short time period to evaluate nonrunoff-affected water-quality conditions in a broad geographical area. Results from the study suggested a potential for water-quality problems that was based on a comparison of constituent concentrations to water-quality criteria. Total phosphorus concentrations in water commonly exceeded the U.S. Environmental Protection Agency (1986) recommended goal of 0.1 mg/L.

A preliminary assessment of Cheney Reservoir bottom sediment was done in 1997 by the USGS in cooperation with the city of Wichita and with technical assistance provided by the Bureau of Reclamation (Pope, 1998). Sediment cores from 13 locations throughout the reservoir were analyzed for nutrients, trace elements, and selected organic constituents. The study indicated an increasing trend in total phosphorus concentrations that may be related to an increase in fertilizer sales in the area between 1965–96 and to livestock production. Few organochlorine compounds were detected in the sediment cores, and only the acetanilide herbicide metolachlor was detected in small concentrations. However, calculations of sediment and chemical mass transport to the reservoir were not possible from this preliminary assessment because sediment volume in the reservoir was not determined.

Current Investigation

In 1998, the USGS began a cooperative investigation with the Kansas Water Office and the Kansas Department of Health and Environment, and funded in part through the State Water Plan Fund. One of the objectives of the current investigation described in this report was to identify trends in concentrations of selected water-quality constituents. Through chemical analysis and dating of sediment cores, both baseline conditions and trends in water-quality constituents were determined. Results will help further the understanding of the effects of land use on receiving water bodies and the effectiveness of land-management practices.

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

Additional objectives of the investigation included determination of the volume of accumulated sediment in Cheney Reservoir since completion of the dam and determination of the mass loading of selected water-quality constituents from the watershed to the reservoir bed. Some of these constituents may be toxic to aquatic organisms or possibly could bioaccumulate in the food chain.

The lack of long-term water-quality data for the Cheney Reservoir watershed makes interpretation of any trends in the watershed difficult. However, many water-quality constituents attach to suspended sediment and are transported and deposited in the reservoir. Therefore, an examination of reservoir bottom sediment is one method of determining trends in water-quality constituents. The purposes of this report are to: (1) document the volume of sediment deposition in Cheney Reservoir, (2) describe trends in phosphorus, nitrogen, selected trace elements, and selected pesticides, and (3) describe mass transport of selected water-quality constituents.

The results of this investigation will provide estimates of the rate of sedimentation and loading of selected chemical constituents to the reservoir. Results also will help understand contaminant sources and provide a baseline to evaluate future progress made toward cleaner water. These results will support Federal, State, and local goals toward implementing watershed strategies to improve water quality. The results also may be used by resource-management agencies to evaluate the effects of various contaminant sources on TMDLs and to evaluate nonpoint-source pollution-management practices in the watershed. Without these data, it would be difficult to determine the degree of success obtained through the current and future implementation of best-management practices (BMPs).

DESCRIPTION OF CHENEY RESERVOIR WATERSHED

Cheney Reservoir has a surface area of about 15 mi^2, a mean depth of about 16 ft, a conservation-pool storage of about 152,000 acre-ft, and an additional flood-control pool capacity of about 81,000 acre-ft. The study area encompasses a contributing-drainage area of 933 mi^2 (597,000 acres) and includes the North Fork Ninnescah River and associated tributary streams (fig. 1).

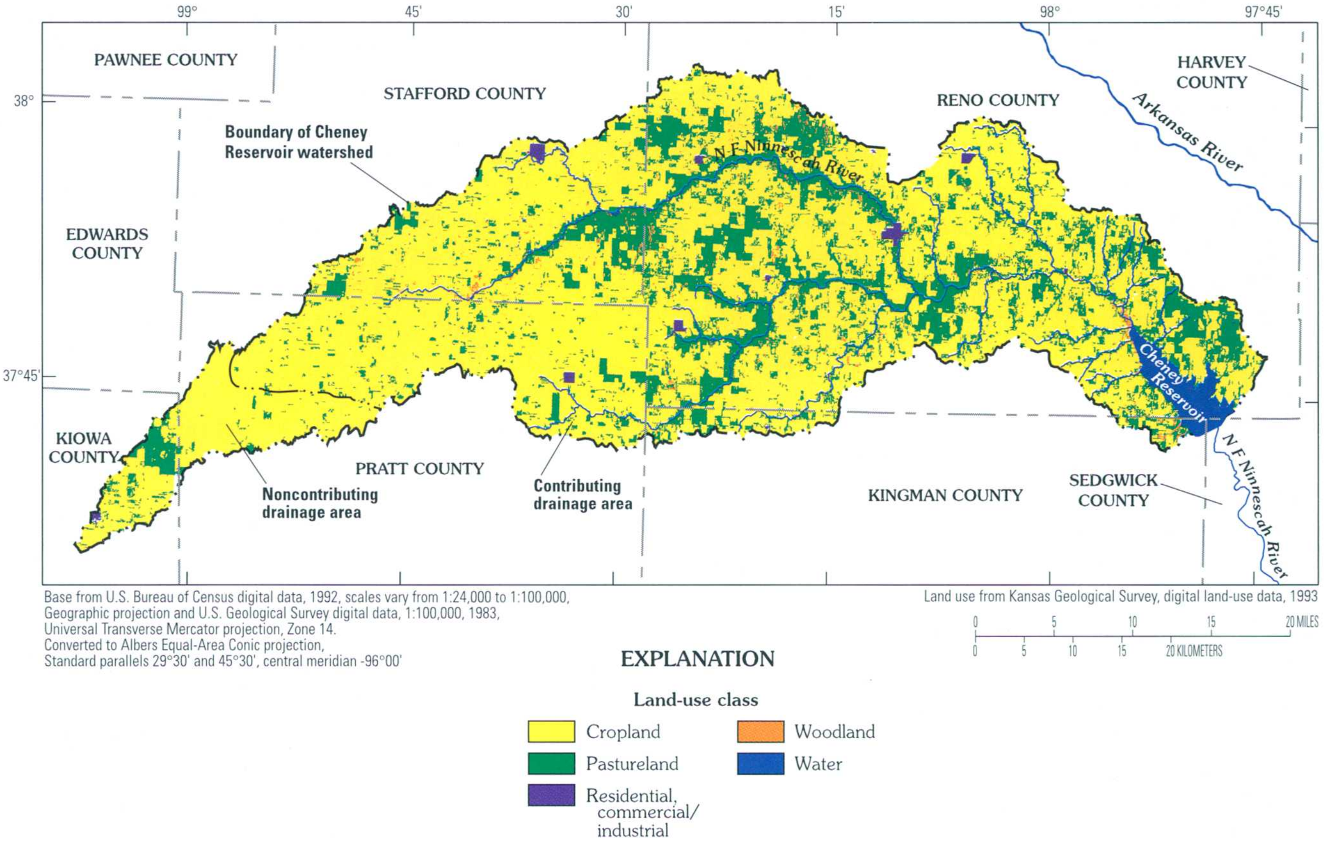
There are less than 4,000 people in the watershed, most of whom live on the approximately 1,000 farms in the area (Cheney Reservoir Watershed Task Force Committee, written commun., 1996). The six largest towns in the watershed range in population from less than 200 to slightly more than 1,200 people (Helyar, 1994).

The mean annual temperature in south-central Kansas is 56 °F, with a mean monthly range of 30.7 °F in January to 81.3 °F in July (Kansas Department of Agriculture and U.S. Department of Agriculture, 1997, p. 8). Mean annual precipitation (1961–90) is about 27 in., which occurs primarily during the growing season from April through September (National Oceanic and Atmospheric Administration, 1966–98).

The North Fork Ninnescah River Valley and the surrounding plains are underlain by consolidated rocks of Permian age (230 to 280 million years old) and covered by unconsolidated fluvial and windblown deposits of Pleistocene age (Zeller, 1968). The thickness of the unconsolidated deposits ranges from 0 to 40 ft and is commonly about 20 ft (Zeller, 1968). Soils in the Cheney Reservoir watershed generally are classified as clayey loam on the uplands to sand or sandy loam on low-lying areas or where slopes are less than 3 percent. Many of the soils in the watershed are subject to erosion by wind and rainfall runoff (Rockers and others, 1966).

Land use in the Cheney Reservoir watershed is predominantly agricultural (fig. 2) as previously described in other recent reports (Christensen and Pope, 1997; Pope, 1998). Crop production has fluctuated between 46 and 57 percent of the land use from 1964 to 1994, with a long-term mean of 52 percent (Kansas State Board of Agriculture and U.S. Department of Agriculture, 1964–94; Kansas Department of Agriculture and U.S. Department of Agriculture, 1995–97). The primary crop raised in the area is wheat, comprising about 63 percent of the crop production, followed by sorghum (24 percent), corn (10 percent), and soybeans (3 percent).

Irrigated crop production in the Cheney Reservoir watershed increased significantly after 1970 (Kansas State Board of Agriculture and U.S. Department of Agriculture, 1964–94; Kansas Department of



Base from U.S. Bureau of Census digital data, 1992, scales vary from 1:24,000 to 1:100,000,
Geographic projection and U.S. Geological Survey digital data, 1:100,000, 1983,
Universal Transverse Mercator projection, Zone 14.
Converted to Albers Equal-Area Conic projection,
Standard parallels 29°30' and 45°30', central meridian -96°00'

Land use from Kansas Geological Survey, digital land-use data, 1993

Figure 2. Land use in the Cheney Reservoir watershed, 1993.

Agriculture and U.S. Department of Agriculture, 1995–97). There was a nine-fold increase in irrigated crop production between 1970 and 1982 (from 0.63 to 6.0 percent). Since 1982, irrigated crop production has remained relatively constant at about 6 percent (Pope, 1998, p. 5).

Livestock production is a large and vital part of the economy in the Cheney Reservoir watershed. The mean annual number of cattle and calves in the watershed between 1964 and 1996 was 64,000 head, fluctuating between a low of 55,000 in 1976 to a high of 75,000 in 1996 (Kansas Department of Agriculture and U.S. Department of Agriculture, 1995–97). Annual inventories of hogs and sheep were considerably less than for cattle and averaged about 18,000 head for hogs and pigs and about 9,400 head for sheep and lambs for 1964–96.

METHODS

Meeting the objectives of the investigation described in this report required knowledge of reservoir sedimentation (depth and volume) relative to preimpoundment topography, density of sediment, and vertical variability in sediment chemical composition. A bathymetric survey, or mapping of the reservoir bottom, provided the sedimentation information for calculation of mean sediment depth and volume. Sediment-core samples collected at selected sites throughout the reservoir provided sediment density and chemical information to determine historical trends and mass transport of sediment and selected water-quality constituents.

Bathymetric Survey

A bathymetric survey was done by the USGS at Cheney Reservoir in 1998 using a Starlink differential global positioning system (GPS) and Innerspace Technology thermal depth-sounder recording fathometer. Both of these instruments were connected to a portable laptop computer, and the data collected from the instruments were filtered and manipulated through the Coastal Oceanographics HYPACK computer software package. The GPS measured spatial position in latitude and longitude with an accuracy of 5 ft; horizontal control points were established at the beginning of the survey each day to maintain accuracy. The survey fathometer measured depth with an accuracy of 0.1 ft; the fathometer was calibrated at the start of each day to maintain accuracy. The HYPACK computer software package was used for survey planning, survey execution, and storage and editing of data. The software package also was used to generate a preliminary contour map of the reservoir bottom that was exported to ARCINFO, a geographic information systems (GIS) software program, where final editing and curve smoothing of the contour lines were completed.

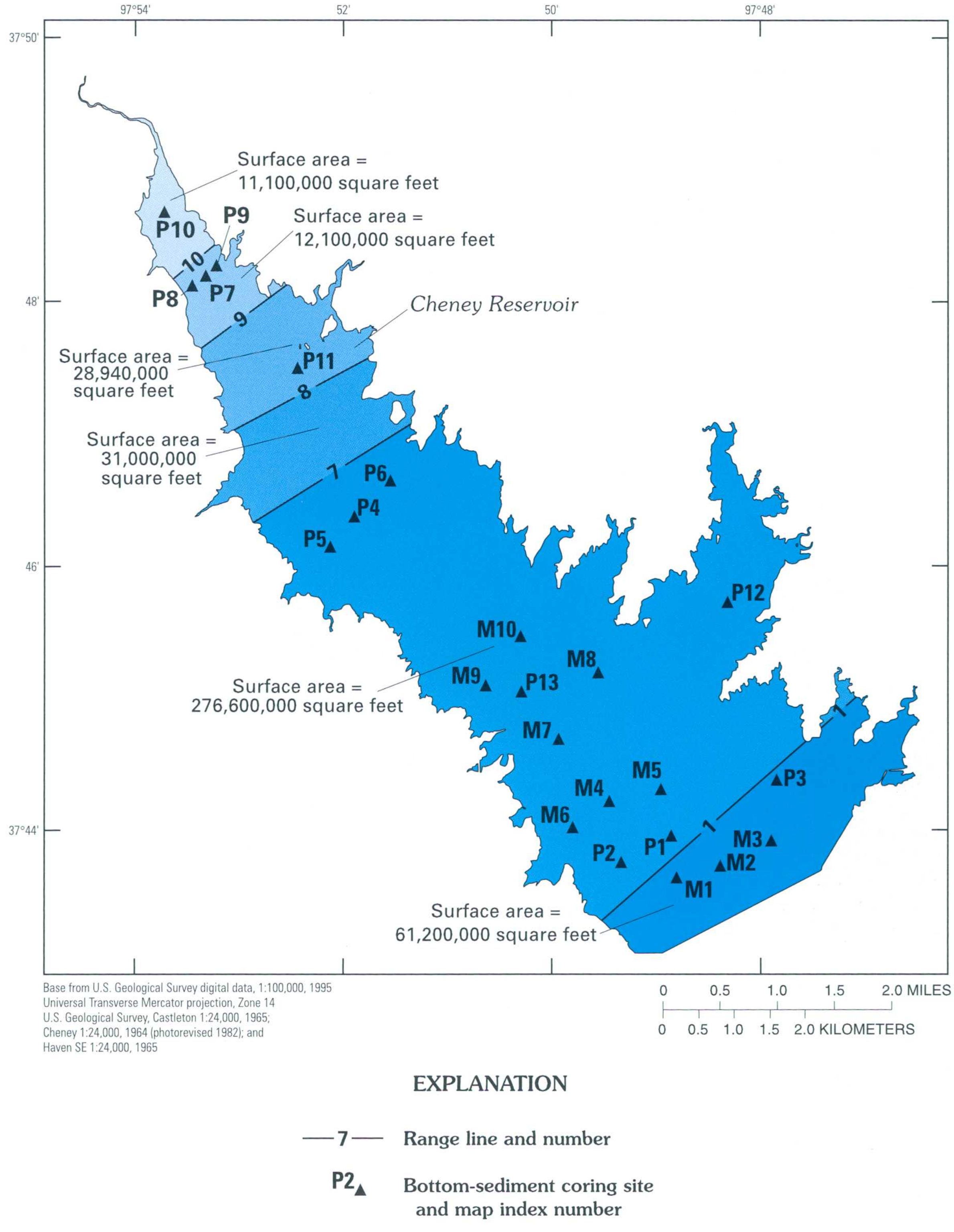
The bathymetric survey of Cheney Reservoir was done using a pontoon boat to which the GPS and fathometer were mounted. Range lines were established by the BOR in 1964 and used in the initial design of Cheney Reservoir (fig. 3) (Bureau of Reclamation, U.S. Department of Interior, written commun., 1993). These range lines were resurveyed during the current investigation, and the data from each range line compared to the 1964 range-line data (figs. 13–17 in "Supplemental Information" section at the back of this report). Information on any range lines that may have been established by the BOR in 1964 between range lines 1 and 7 was not available during this investigation. Therefore, no historical data were available in that area to compare to the 1998 bathymetric data.

Estimation of Bottom-Sediment Depth and Volume

To calculate bottom-sediment volume from Cheney Reservoir, area and depth of sediment deposition were required. The area was determined from GIS ARCINFO map coverage of the reservoir, and sediment depth was determined from the 1964 and 1998 bathymetric range-line data.

Cheney Reservoir was divided into six segments and each segment was defined by range lines (fig. 3). Each segment was separated further into an in-channel and out-of-channel subsegment because of differences in sediment depth in these areas.

In-channel areas were determined by calculating the mean of the two in-channel widths from the 1964 range lines (prior to any sediment deposition) that defined each segment. The mean in-channel width for each segment then was multiplied by the in-channel length in each segment to determine the in-channel area. Mean in-channel depth of sedimentation for each reservoir segment was calculated as the average of the mean differences between reservoir-bottom elevations determined by the 1964 and 1998 surveys for the in-channel parts of the range lines that bracket the



Base from U.S. Geological Survey digital data, 1:100,000, 1995
Universal Transverse Mercator projection, Zone 14
U.S. Geological Survey, Castleton 1:24,000, 1965;
Cheney 1:24,000, 1964 (photorevised 1982); and
Haven SE 1:24,000, 1965

Figure 3. Location of range lines and coring sites at Cheney Reservoir, 1997–98, and estimated surface area of reservoir segments.

reservoir segment (figs. 13–17 in "Supplemental Information" section at the back of this report). A corresponding procedure was used to determine the mean out-of-channel depths.

The segments closest to the dam and farthest upstream from the dam were defined by range lines on one side only (range lines 1 and 10). The dam and upstream shoreline represented the other boundary side of these two segments, respectively. Depth of sedimentation for these two segments was determined using the depth of sedimentation calculated from range lines 1 and 10, respectively, and applying the depth to the entire segment. Finally, the in-channel and out-of-channel results from the product of area and depth for all segments were summed to provide an estimate of total sediment volume in the reservoir.

Reservoir Sediment-Core Collection, Processing, and Analysis

Collection and analysis of reservoir bottom-sediment cores can provide a detailed history of water quality in a watershed. The depth of bottom material can be an indicator of sediment loading to the reservoir and future loss of water-storage capacity. Estimates of sediment mass in conjunction with chemical analysis of the bottom-sediment cores can be used to gain insight into mass loading of chemical constituents into the reservoir as well as chemical trends in the watershed.

Sediment mass (in pounds) is a product of sediment volume (cubic feet) and sediment bulk density (pounds per cubic foot). Sediment bulk density was determined at selected locations in the reservoir between August 1997 and May 1999. A gravity corer was used to collect sediment cores from 13 in- and out-of-channel sites in 1997 (sites P1 through P13) and 10 out-of-channel sites (sites M1 through M10) in 1998–99 (table 1, fig. 3). The liner used in the corer was cellulose acetate butyrate transparent tubing with a 2.88-in. outside diameter and a 2.63-in. inside diameter. Depending upon the types of analyses, one to three sediment cores were collected at each site to provide sufficient material.

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

Table 1. Location of bottom-sediment coring sites in Cheney Reservoir, south-central Kansas, 1997–99

Coring site (fig. 1)	U.S. Geological Survey site identification number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)
1997 coring sites			
P1	374357097484900	37°43'56.80"	97°48'48.97"
P2	374344097491800	37°43'44.83"	97°49'18.00"
P3	374422097474800	37°44'22.31"	97°47'48.34"
P4	374623097515200	37°46'22.58"	97°51'51.85"
P5	374608097520500	37°46'08.88"	97°52'05.70"
P6	374638097513100	37°46'38.86"	97°51'31.10"
P7	374812097531800	37°48'12.31"	97°53'17.70"
P8	374808097532500	37°48'08.03"	97°53'25.66"
P9	374817097531100	37°48'17.20"	97°53'11.68"
P10	374841097534100	37°48'41.53"	97°53'41.78"
P11	374730097522400	37°47'30.40"	97°52'24.68"
P12	374543097481600	37°45'43.27"	97°48'16.52"
P13	374502097501500	37°45'02.82"	97°50'15.42
1998–99 coring sites			
M1	374326097484300	37°43'26.00"	97°48'43.00"
M2	374332097481600	37°43'32.00"	97°48'16.00"
M3	374345097474400	37°43'45.00"	97°47'44.00"
M4	374406097492400	37°44'06.00"	97°49'24.00"
M5	374412097485200	37°44'12.00"	97°48'52.00"
M6	374401097494200	37°44'01.00"	97°49'42.00"
M7	374438097495500	37°44'38.00"	97°49'55.00"
M8	374512097493000	37°45'12.00"	97°49'30.00"
M9	374506097504000	37°45'06.00"	97°50'40.00"
M10	374531097501800	37°45'31.00"	97°50'18.00"

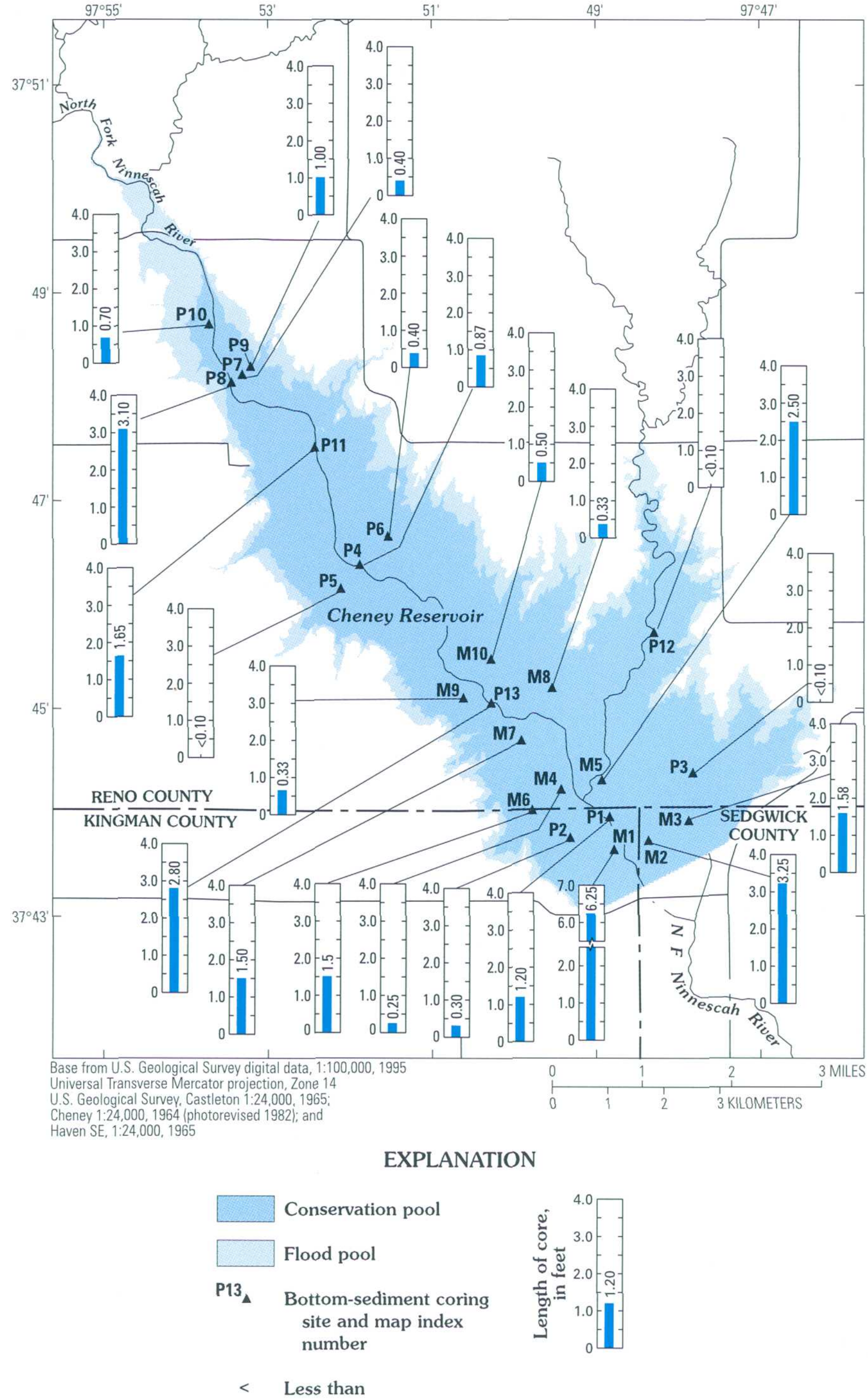
The sediment cores were processed at the USGS laboratory in Lawrence, Kansas. The plastic liners were cut longitudinally in two places and 180° apart. The cuts were partially completed using a rotary handsaw and finished with a retractable razor knife set at a depth to minimize penetration of the sediment core. The cores were split in half by pulling a tightly held nylon string through the length of the two cuts and allowing the halves to separate. Depending upon the type of analysis as well as available bottom material in each core, the cores then were subsectioned into equal length intervals, and sediment samples from each interval were removed for physical and chemical determinations. Analyses of selected bottom-sediment cores included mean concentrations for the entire core. In these instances, equal volumes of sediment from each interval were removed from the sediment core, placed in a mixing bowl, and mechanically homogenized. A sample of the homogenized mass then was sent to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado, for chemical analysis.

Sediment bulk densities were determined for selected sediment cores. These sediment cores were subsectioned, weighed, and oven dried to remove all moisture. Each dried subsectioned core was reweighed, and the weight divided by the respective subsection volume to determine bulk density. The mean bulk density for the entire sediment core was determined from the subsectioned bulk densities. Sediment-core mean bulk densities were used to calculate an average bulk density for each reservoir segment (fig. 3). Sediment cores were not collected for the reservoir segment located between range lines 7 and 8 (fig. 3). Mean bulk densities from upstream and downstream sediment cores closest to the segment were averaged to determine bulk densities.

Subsections of some of the cores collected during the investigation (sites P1–P13) were analyzed for bulk density and percentage of sand and silt and (or) clay at the USGS laboratory in Lawrence, Kansas, according to methods presented in Guy (1969). Subsections of other cores collected during the investigation (sites M1–M10) were analyzed for percentage of sand and silt and (or) clay at the USGS sediment laboratory in Iowa City, Iowa, according to methods presented in Guy (1969). Core subsections from selected sites (M1–M10) were analyzed at the NWQL for total phosphorus and nitrogen and selected trace elements according to methods presented in Fishman (1993) (tables 13–14, in "Supplemental Information" section at the back of this report). In addition, organophosphate insecticides, chlorophenoxy-acid herbicides, organochlorine insecticides, and triazine and acetanilide pesticides were analyzed from selected core subsections according to procedures in Foreman and others (1994) (table 15, in "Supplemental Information" section at the back of this report).

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

Reservoir bottom sediment can undergo mixing during storms or periods of flooding. This mixing can create difficulties in the analysis of trends in water-quality constituents. To determine whether bottom sediment had been disturbed, selected sediment cores (sites P4, P13, M5) (fig. 3) were analyzed for cesium-137 by Quantera Laboratory in Denver, Colorado (table 16, in "Supplemental Information" section at the back of this report). Cesium-137, a by-product of the thermonuclear-weapons testing era of the 1950s and early 1960s, was widely dispersed by atmospheric deposition and potentially sorbed to soil particles (primarily clay). Detectable cesium-137 concentrations in sediment began about 1952 and peaked in 1963–64, followed by a steady decline in concentrations (Holmes, 1998). Identifiable peaks other than the 1963–64 peak in cesium-137 concentrations from the bottom-sediment core profile may be indicative of turbulence and resuspension of sediment. Analysis of sediment for chemical trends would not be appropriate under these conditions.



Base from U.S. Geological Survey digital data, 1:100,000, 1995
Universal Transverse Mercator projection, Zone 14
U.S. Geological Survey, Castleton 1:24,000, 1965;
Cheney 1:24,000, 1964 (photorevised 1982); and
Haven SE, 1:24,000, 1965

Figure 4. Length of bottom-sediment cores collected from Cheney Reservoir, 1997–99.

A chemical marker (consisting of calcium carbonate and barium sulfate) was placed over a 30-ft by 30-ft area on the Cheney Reservoir bottom in 1998. The intent was to deposit this minimally degradable material as a layer on top of the reservoir bottom sediment and return several years later to this location and remove a sediment core. The calcium carbonate and barium sulfate would be identified by distinct layering in the sediment core, and any sediment above the marker attributed to sediment deposition since 1998.

Quality Control

Multiple cores were collected at various sites in the reservoir to provide sufficient sediment for both physical and chemical analyses. Therefore, it was important to evaluate "within-site" variability between core samples as well as analytical precision and reproducibility from the laboratories.

Within-site variability was evaluated through the collection and analysis of sequential replicate samples collected at coring sites P1 and P2 (fig. 3; Pope, 1998). Two replicate samples at coring site P1 were subsectioned into 0.2-ft intervals for a total of six subsample pairs. The two replicate samples at coring site P2 were not subsectioned because there was insufficient sediment (Pope, 1998). Each core subsection was homogenized and subsequently analyzed for total phosphorus concentration. Relative percentage differences between replicate concentrations were calculated as the absolute value of the quotient of the difference in replicate concentrations divided by the summation of replicate concentrations, multiplied by 100.

The range in relative percentage differences in total phosphorus concentrations from coring sites P1 and P2 was small, with median values of 2.3 and 1.3 percent, respectively. The results indicated that within-site variability in the quality of deposited sediment is small in Cheney Reservoir and probably not a concern (Pope, 1998).

The analytical precision and reproducibility of analytical results from bottom-sediment cores were determined by analyzing split replicate samples. Split samples were prepared by homogenizing like core subsections, then splitting each homogenized subsection into two samples. By homogenizing the sample and then splitting it into two samples, both samples should have been chemically equivalent, and any differences could be attributed to variability within the laboratory procedure.

Analysis of split replicate samples from coring sites M2 and M3 showed little or no variability among the nutrients and trace elements analyzed (table 2), with median relative percentage differences of 1.7 (coring site M2) and 3.1 percent (coring site M3). The relative percentage difference in total phosphorus was 6.0 percent in the sediment core from coring site M2 and 14 percent in the core from coring site M3. Split replicate samples analyzed for total phosphorus in 1997 showed similar relative percentage differences that varied from 0.1 to 6.4 percent (Pope, 1998).

SEDIMENT DEPOSITION IN CHENEY RESERVOIR

One of the purposes of determining volume and mass of sediment deposition was to evaluate reservoir storage capacity and changes in capacity since reservoir impoundment in 1965. Decreases in reservoir storage capacity from sediment deposition can affect reservoir allocations used for flood control, drinking-water supplies, recreation, and wildlife habitat. Estimates of sediment mass also provide information that can be used with chemical concentrations to determine watershed loads (mass transported during a specified time period) and yields (loads per unit area of watershed) of chemical constituents to the reservoir.

Calculation of Bottom-Sediment Volume and Mass

Total sediment volume deposited in Cheney Reservoir from 1965 through 1998, was approximately 7,100 acre-ft, not including sediment removed from the reservoir through the outlet works at the dam (tables 3 and 4). Of this amount, 1,075 acre-ft, or 15 percent, were attributed to in-channel sedimentation, and 5,990 acre-ft, or 85 percent, were attributed to out-of-channel sediment deposition. The mean annual sediment deposition rate for 1965 through 1998 (34 years), calculated on the basis of 7,100 acre-ft of total sediment deposition, was 209 acre-ft/yr, or 0.22 (acre-ft/yr)/mi^2 of watershed, when divided by the 933 mi^2 of contributing-drainage area in the Cheney watershed.

The total mass of reservoir bottom-sediment material was determined by multiplying the bottom-sediment volume (tables 3 and 4) by the mean sediment bulk density for each range-line segment (tables 5 and 6). Separate calculations were done for the in-channel sediment and the out-of-channel sediment. Mean bulk densities for both in-channel and out-of-channel subsegments were greater in the upstream part of the reservoir where larger sediment particles tended to settle out faster than the finer sediment material found in the downstream part of the reservoir. Mean bulk densities ranged from 24.0 to 52.0 lb/ft^3 (1.0 to 2.3 million lb/acre-ft) for in-channel reservoir subsegments, and from 20.0 to 104.0 lb/ft^3 (900,000 to 4.5 million lb/acre-ft) for out-of-channel subsegments (table 6). The area-weighted mean bulk densities for both the in-channel and out-of-channel subsegments (table 6), calculated to account for areal differences of the various segments, were 1.6 and 2.7 million lb/acre-ft, respectively (table 6). Area-weighted mean bulk densities (table 6) were calculated as the sum of the products of bulk density (table 5) times surface area (table 4) for the individual reservoir segments, divided by the sum of surface areas (table 4). Area-weighted mean bulk densities were calculated separately for the in-channel and out-of-channel areas.

The total mass of in-channel bottom-sediment material was estimated to be about 1.63 billion lb by summing the masses of the six reservoir segments (table 6). Similarly, the total mass of out-of-channel bottom-sediment material was estimated to be about 13.8 billion lb. The total estimated mass of bottom sediment in the reservoir, the sum of all the in-channel and out-of-channel subsegments, was about 15.4 billion lb. Total estimated mass of bottom sediment, 15.4 billion lb, when divided by the 34 years of sedimentation, resulted in 453 million lb of bottom-sediment deposition per year, known as the mean annual sediment load.

These results indicate that 11 percent of the deposited sediment mass was located in the submerged river channel and that about 89 percent of the sediment mass was located in the out-of-channel area. Negative values for bottom-sediment volume and bottom-sediment mass (tables 4 and 6) indicate uplake areas of

Table 2. Analytical results and relative percentage differences for selected nutrients and trace elements for split replicate samples of bottom sediment from coring sites M2 and M3, Cheney Reservoir, south-central Kansas, 1998–99

[R, replicate sample; mg/kg, milligram per kilogram; µg/g, microgram per gram; µg/kg, microgram per kilogram; <, less than]

Constituent and unit of measurement	Coring site (fig. 1)			Coring site (fig. 1)		
	M2	M2R	Relative percentage difference	M3	M3R	Relative percentage difference
			Nutrients			
Ammonia plus organic nitrogen as nitrogen, mg/kg	2,300	2,300	0	2,000	1,700	8.1
Phosphorus, mg/kg	710	630	6.0	520	690	14
			Trace elements			
Aluminum, percent	8.9	8.6	1.7	8.3	7.9	2.5
Antimony, µg/g	.82	.85	1.8	.80	.82	1.2
Arsenic, µg/g	12	12	0	10	10	0
Barium, µg/g	540	550	.92	550	500	4.8
Beryllium, µg/g	3.0	3.1	1.6	3.0	2.6	7.1
Bismuth, µg/g	<1	<1	0	<1	<1	0
Cadmium, µg/g	.32	.34	3.0	.33	.31	3.1
Calcium, percent	1.8	1.8	0	1.9	1.9	0
Cerium, µg/g	79	77	1.3	77	72	3.4
Chromium, mg/g	89	86	1.7	89	75	8.5
Cobalt, mg/g	14	15	3.4	14	15	3.4
Copper, mg/g	20	22	4.8	20	22	4.8
Eropium, µg/g	1.5	1.5	0	1.5	1.5	0
Gallium, µg/g	22	22	0	21	20	2.4
Gold, µg/g	<1	<1	0	<1	<1	0
Holmium, µg/g	1.0	1.2	9.1	1.0	1.0	0
Iron, percent	4.6	4.8	2.1	4.4	4.5	1.1
Lanthanum, µg/g	43	41	2.4	41	39	2.5
Lead, µg/g	24	23	2.1	24	22	4.4
Lithium, µg/g	69	68	.73	68	64	3.0
Magnesium, percent	2.2	2.2	0	2.2	2.0	4.8
Manganese, µg/g	840	890	2.9	700	740	2.8
Molybdenum, µg/g	.64	.64	0	.59	.65	4.8
Neodymium, µg/g	39	38	1.3	38	37	1.3
Nickel, µg/g	38	42	5.0	38	41	3.8
Niobium, µg/g	14	14	0	12	14	7.7
Potassium, percent	2.8	2.9	1.7	2.9	2.8	1.7
Scandium, µg/g	15	15	0	15	15	0
Silver, µg/g	<1.0	<1.0	0	<1.0	<1.0	0
Sodium, percent	.40	.41	1.2	.44	.40	4.8

Table 2. Analytical results and relative percentage differences for selected nutrients and trace elements for split replicate samples of bottom sediment from coring sites M2 and M3, Cheney Reservoir, south-central Kansas, 1998–99—Continued

Constituent and unit of measurement	Coring site (fig. 1)			Coring site (fig. 1)		
	M2	M2R	Relative percentage difference	M3	M3R	Relative percentage difference
			Trace elements—Continued			
Strontium, µg/g	110	110	0	110	110	0
Tantalum, µg/g	2.1	1.9	5.0	1.4	1.6	6.7
Thorium, µg/g	13	13	0	13	12	4.0
Tin, µg/g	3.6	3.6	0	3.4	3.6	2.9
Titanium, percent	.36	.39	4.0	.39	.35	5.4
Uranium, µg/g	2.2	2.2	0	2.3	2.2	2.2
Vanadium, µg/g	110	100	4.8	110	98	5.8
Ytterbium, µg/g	3.0	3.40	6.2	2.8	2.7	1.8
Yttrium, µg/g	24	25	2.0	24	25	2.0
Zinc, µg/g	100	110	4.8	100	110	4.8
Median relative percentage difference			**1.7**			**3.1**

Table 3. Estimated mean sediment deposition along range lines for both in-channel and out-of-channel subsegments in Cheney Reservoir, south-central Kansas, 1965–98

Range-line number (fig. 3)	Mean sediment deposition (feet)	
	In-channel subsegment	Out-of-channel subsegment
1	6.75	1.06
7	2.82	.31
8	1.78	.12
9	6.18	.77
10	3.10	-.90

the reservoir where erosion of the original 1964 topography was evident (fig. 17, in "Supplemental Information" section at the back of this report). It is possible that the reservoir bottom was scoured during periods of intense inflow, and original bottom sediment was transported farther into the reservoir. The estimated bottom-sediment mass for these out-of-channel areas (rangelines 9 and 10), therefore, was subtracted from the total mass of sediment deposition in the reservoir.

Changes in Reservoir Storage Capacity

Cheney Reservoir was designed to include storage for flood control, an active conservation storage that can be varied depending on climatic conditions, and inactive conservation storage; each storage volume is defined by different elevations in the reservoir (fig. 5) (Bureau of Reclamation, 2000). The inactive conservation storage pool (between elevations 1,378 and 1,393 ft above sea level) is the volume of water located below the active conservation storage pool and normally is not used by reservoir managers except during prolonged periods of extreme drought (Morris and Fan, 1998, p. 3.8). Frequently, a part of the inactive conservation storage pool of a reservoir is allocated for sediment deposition.

The area designated for the inactive conservation storage pool at Cheney Reservoir extends from the dam to about midway between range lines 1 and 7 (fig. 3). An estimate of total sediment deposition in the inactive conservation storage pool can be determined if it is assumed that sediment is deposited evenly throughout the segment between range lines 1 and 7. If true, then one-half of the deposited sediment between these two range lines would be located in the inactive conservation storage pool, in addition to the deposited sediment located between the dam and range line 1. On the basis of these assumptions, the total volume of sediment deposited is about 4,100 acre-ft and represents 27 percent of the approximately 15,300 acre-ft of inactive conservation storage pool volume from Cheney Reservoir.

Table 4. Estimated mean in-channel and out-of-channel sediment depth, surface area, and sediment volume deposited between 1965 and 1998, Cheney Reservoir, south-central Kansas

[RL, range line; ft^2, square feet; ft, feet; acre-ft, acre-feet; --, not applicable]

Reservoir segment (fig. 3)	In-channel surface area (ft^2)	Out-of-channel surface area (ft^2)	Mean in-channel sediment depth (ft)	Mean out-of-channel sediment depth (ft)	In-channel bottom sediment volume (acre-ft)	Out-of-channel bottom sediment volume (acre-ft)
Dam–RL1	800,000	60,400,000	6.75	1.06	124	1,470
RL1–RL7	5,600,000	271,000,000	4.78	.69	615	4,290
RL7–RL8	800,000	30,200,000	2.30	.22	42	152
RL8–RL9	1,040,000	27,900,000	3.98	.45	95	288
RL9–RL10	800,000	11,300,000	4.64	-.07	85	-18
RL10–lake boundary	1,600,000	9,500,000	3.10	-.90	114	-196
Total	**10,640,000**	**410,300,000**	--	--	**1,075**	**5,990**

Table 5. Estimated mean sediment bulk density in both in-channel and out-of-channel reservoir subsegments, Cheney Reservoir, south-central Kansas, 1998

[RL, range line; lb/ft^3, pounds per cubic foot]

Reservoir segment (fig. 3)	Coring sites (fig. 3)	Mean bulk density (lb/ft^3)
	In-channel subsegments	
Dam–RL1	P1	24.0
RL1–RL7	P1, P4, P13	30.0
RL7–RL8	P4, P11	41.0
RL8–RL9	P11	42.0
RL9–RL10	P8	52.0
RL10–lake boundary	P8	52.0
	Out-of-channel subsegments	
Dam–RL1	P2	20.0
RL1–RL7	P2, P6	62.0
RL7–RL8	P6	104.0
RL8–RL9	P6, P7, P9	91.0
RL9–RL10	P7, P9	84.0
RL10–lake boundary	P10	104.0

The inactive conservation storage pool commonly is designed to provide storage for 100 years of sediment deposition (Morris and Fan, 1998, p. 2.13). As of 1998, 34 years of sediment deposition had occurred, which equates to 34 percent of the design life of the reservoir. Total sediment deposited during the 34-year period (27 percent of available capacity) is less than the current volume allocated (34 percent). Therefore, design-life specifications for the reservoir are being met provided that the design-life specifications were used in the design of the reservoir.

Comparison to Sediment Deposition in Other Reservoirs in Kansas

A comparison of Cheney Reservoir and three other reservoirs in Kansas—Webster Reservoir, Tuttle Creek Lake, and Hillsdale Lake—was made by the USGS, and sediment deposition rates were calculated (Mau and Christensen, 2000). Calculated mean annual sediment deposition was about 34.5 acre-ft for Webster Reservoir, 3,000 acre-ft for Tuttle Creek Lake, and 140 acre-ft for Hillsdale Lake. Calculated mean annual sediment deposition for Cheney Reservoir was 209 acre-ft. When the comparison was made on the basis of sediment yield (mean annual sediment deposition divided by the contributing-drainage area), the Hillsdale Lake watershed was the largest contributor of sediment, followed by the Tuttle Creek, Cheney, and Webster watersheds (table 7) (Mau and Christensen, 2000).

The amount of runoff (water yield) from a watershed can be an important factor in explaining site-to-site variability in chemical or sediment loading characteristics. A previous investigation of the Cheney Reservoir watershed (Pope and Milligan, 2000) evaluated relations between annual phosphorus yields and annual water yields from three reservoir watersheds in Kansas. Additional factors were noted that also may affect variability in phosphorus yields

Table 6. Estimated bottom-sediment volume, mean bulk density, and bottom-sediment mass in both in-channel and out-of-channel subsegments, Cheney Reservoir, south-central Kansas, 1998

[RL, range line; acre-ft, acre-feet; lb/ft^3, pounds per cubic foot; million lb/acre-ft, million pounds per acre-foot; million lb, million pounds; --, not applicable]

Reservoir segment (fig. 3)	Bottom-sediment volume (acre-ft)	Mean bulk density (lb/ft^3)	Mean bulk density (million lb/acre-ft)	Bottom-sediment mass[1] (million lb)
	In-channel subsegments			
Dam–RL1	124	24.0	1.0	124
RL1–RL7	615	30.0	1.3	800
RL7–RL8	42	41.0	1.8	76
RL8–RL9	95	42.0	1.8	171
RL9–RL10	85	52.0	2.3	196
RL10–lake boundary	114	52.0	2.3	262
Subtotal	**1,075**	--	--	**1,630[1]**
Area-weighted mean	--	--	**1.6**	
	Out-of-channel subsegments			
Dam–RL1	1,470	20.0	0.9	1,320
RL1–RL7	4,290	62.0	2.7	11,600
RL7–RL8	152	104.0	4.5	684
RL8–RL9	288	91.0	4.0	1,150
RL9–RL10	-18	84.0	4.0	-72
RL10–lake boundary	-196	104.0	4.5	-882
Subtotal	**5,990**	--	--	**13,800**
Area-weighted mean	--	--	**2.7**	
Total estimated bottom-sediment mass for Cheney Reservoir				**15,400**

[1] Values rounded to three significant figures.

among watersheds. These factors included differences in precipitation, soil composition and structure, topography, land use, and land-management practices. Similar factors also may affect variability in sediment yields among watersheds.

The calculated mean annual water yield for 1999 from the Hillsdale Lake watershed, 530 (acre-ft/yr)/mi^2, was almost three times larger than from the Tuttle Creek Lake watershed, 181 (acre-ft/yr)/mi^2, followed by Cheney and Webster Reservoir watersheds with 115 and 38 (acre-ft/yr)/mi^2, respectively (table 8). Sediment yield in the Hillsdale Lake watershed was three times larger than for the Tuttle Creek Lake watershed, followed by Cheney and Webster Reservoir watersheds, which suggests a close relation exists between sediment yield and water yield.

Webster Reservoir is located in northwestern Kansas (fig. 1), and although long-term mean annual precipitation in the watershed (24 in/yr) (National Oceanic and Atmospheric Administration, 1998) is similar to that for the Cheney Reservoir watershed (approximately 27 in/yr), the topography and land-use practices vary between the two watersheds. The topography of the Webster Reservoir watershed is gently sloping, and land use includes more than 800 small farm ponds that are water and sediment traps for the reservoir (Bureau of Reclamation, 1984, p. 37). The ponds serve to reduce peak streamflows and volume of suspended sediment transported into the reservoir. The number of small farm ponds in the other watersheds was unknown at the time of publication of this report (2001). Small watershed impoundments may have a substantial effect on the transport of sediment to other reservoirs as well.

The contributing-drainage area for Tuttle Creek Lake is the largest of the four reservoirs investigated (9,600 mi^2), and it receives an average of about 32 in. of precipitation annually (National Oceanic and Atmospheric Administration, 1998). Approximately 75 percent of the contributing-drainage area to Tuttle Creek Lake is located in southeast Nebraska and the remainder in northeast Kansas. Land use in the watershed includes about 72 percent cropland, 16 percent pastureland, 10 percent woodland, and about 2 percent urban area (Nebraska Natural Resources Commission, 1983; Kansas Geological Survey, 1993). Although cropland in the watershed is substantial, mean annual sediment deposition on a per-square-mile basis of watershed is only slightly greater than for Cheney Reservoir watershed, 0.31 and 0.22 acre-ft/mi^2, respectively (table 7) (Mau and Christensen, 2000). The topographic similarities between the smooth plains of the Nebraska section of the Tuttle Creek Lake watershed and the flat to gently rolling topography of the Cheney Reservoir watershed, in conjunction with slight differences in precipitation, may provide a partial explanation for the similarities in sediment deposition.

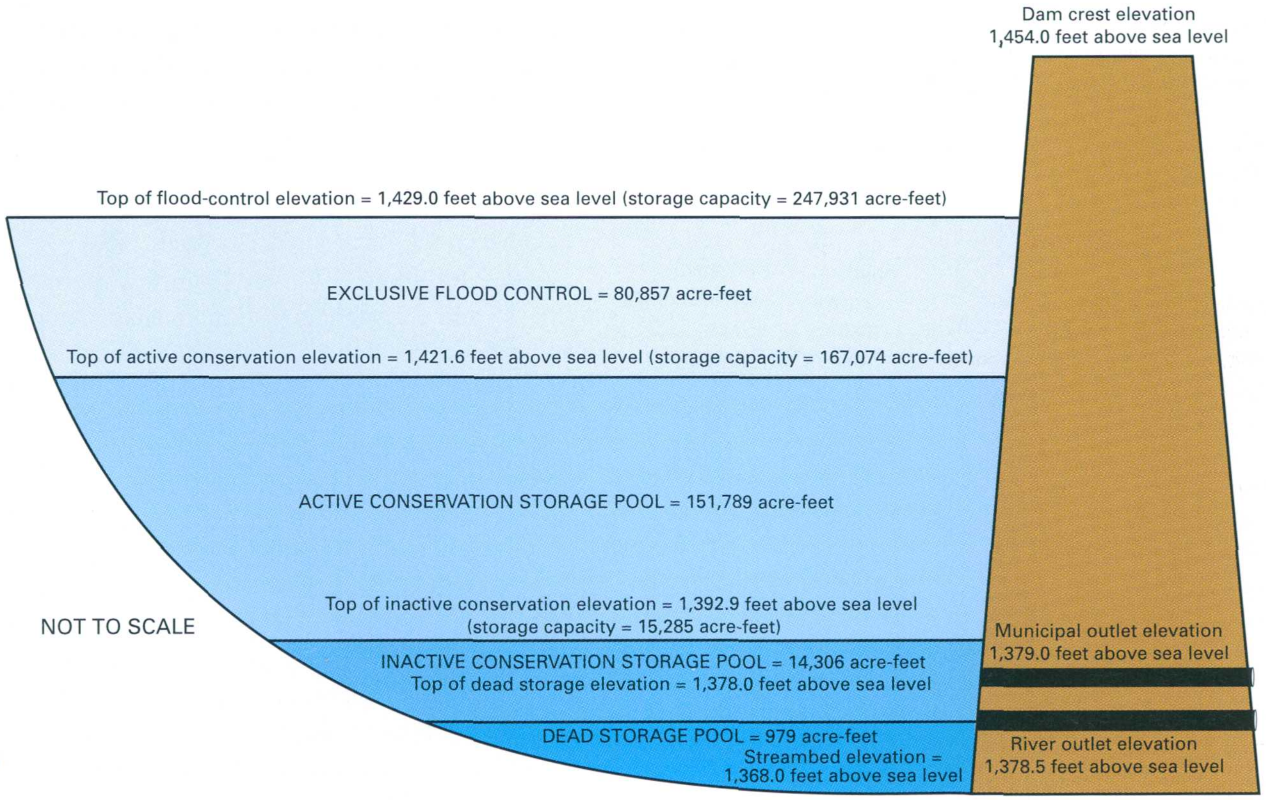


Figure 5. Storage capacities in Cheney Reservoir (modified from Bureau of Reclamation, 2000).

The Hillsdale Lake watershed, located in eastern Kansas (fig. 1), receives an average of about 41 in. of precipitation annually (Juracek, 1997), 42 percent more than the Webster Reservoir watershed and 34 percent more than the Cheney Reservoir watershed. Approximately 40 percent of the Hillsdale Lake watershed is cultivated, 20 percent is undeveloped woodland, and 40 percent is pastureland, feedlots, and residential and urban development (Juracek, 1997). The combination of precipitation and cultivated land increases the potential for erosion that probably is a significant source of sediment deposition in Hillsdale Lake. About 56 percent of the total volume of bottom sediment in Hillsdale Lake in northeastern Kansas occurs in the in-channel area (Juracek, 1997). Differences in watershed topology, including but not limited to precipitation, land use, soil types, channel dimensions, and landslope between Hillsdale Lake and Cheney Reservoir, may account for the variation in sediment deposition (Juracek, 1997; Pope, 1998).

In a typical Kansas watershed, storm runoff increases streamflow that ultimately leads to the transport of more sediment to a downstream reservoir. Annual sediment deposition in Hillsdale Lake, on a per-square-mile of watershed basis, was more than four times greater than deposition in Cheney Reservoir, 0.97 and 0.22 (acre-ft/yr)/mi^2, respectively (table 7) (Mau and Christensen, 2000). Mean annual sediment load deposited in Cheney Reservoir was calculated to be about 453 million lb/yr. Annual sediment load per acre of contributing-drainage area, when divided by the 597,000 acres representing the contributing-drainage area of the reservoir, was calculated to be about 759 (lb/yr)/acre).

Large differences in sediment deposition in the four reservoirs cannot be attributed solely to differences in precipitation. Other factors such as topography, contributing-drainage area of the watershed, and differing soil types also affect the rate of sediment deposition. In an effort to reduce sediment deposition and increase the storage capacity and water quality of Cheney Reservoir, BMPs have been implemented, such as terracing, no-till practices, and the creation of buffer zones near contributing streams to the reservoir (Cheney Reservoir Watershed Task Force Committee, written commun., 1996).

Table 7. Estimated total sediment deposition and sediment yield since impoundment of Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake, Kansas

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

Reservoir or lake (fig. 1)	Year of impoundment	Total sediment deposition (acre-ft)	Contributing-drainage area (mi^2)	Mean annual sediment yield[1] [(acre-ft/yr)/mi^2)
Webster Reservoir	1956	1,330	1,150	0.03
Cheney Reservoir	1965	[2]7,100	933	[2].22
Tuttle Creek Lake	1962	114,000	9,600	.31
Hillsdale Lake	1981	2,100	144	.97

[1] Mau and Christensen (2000).

[2] Values updated from previous publications.

Table 8. Mean annual water yield from Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake watersheds, Kansas, 1999

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

Reservoir or lake (fig. 1)	Annual runoff[1] (acre-ft)	Gaged drainage area (mi^2)	Yield [(acre-ft/yr)/mi^2]
Webster Reservoir	39,350	1,040	38
Cheney Reservoir	107,800	933	115
Tuttle Creek Lake	1,538,500	8,511	181
Hillsdale Lake	76,340	144	530

[1] Putnam and others (2000).

WATER-QUALITY TRENDS AND MASS TRANSPORT

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

Phosphorus

Phosphorus is a nutrient essential for the growth and reproduction of plants. It is used as an energy source in the cells of plants and animals and can have a direct effect on the production of phytoplankton populations, an important component of the food chain. Phosphorus availability is also a critical factor in the eutrophication (nutrient enrichment) of water bodies because typically phosphorus is the nutrient in shortest supply and because the limiting nutrient controls biological production rates (Hem, 1985, p. 128). Excessive phosphorus in water bodies, where nitrogen is not a limiting factor, can accelerate eutrophication and is characterized by extensive algal growth (algal blooms) that may reduce the aesthetic and recreational value of water and, in severe cases, stress or kill aquatic organisms as a result of dissolved-oxygen depletion when algal blooms die.

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

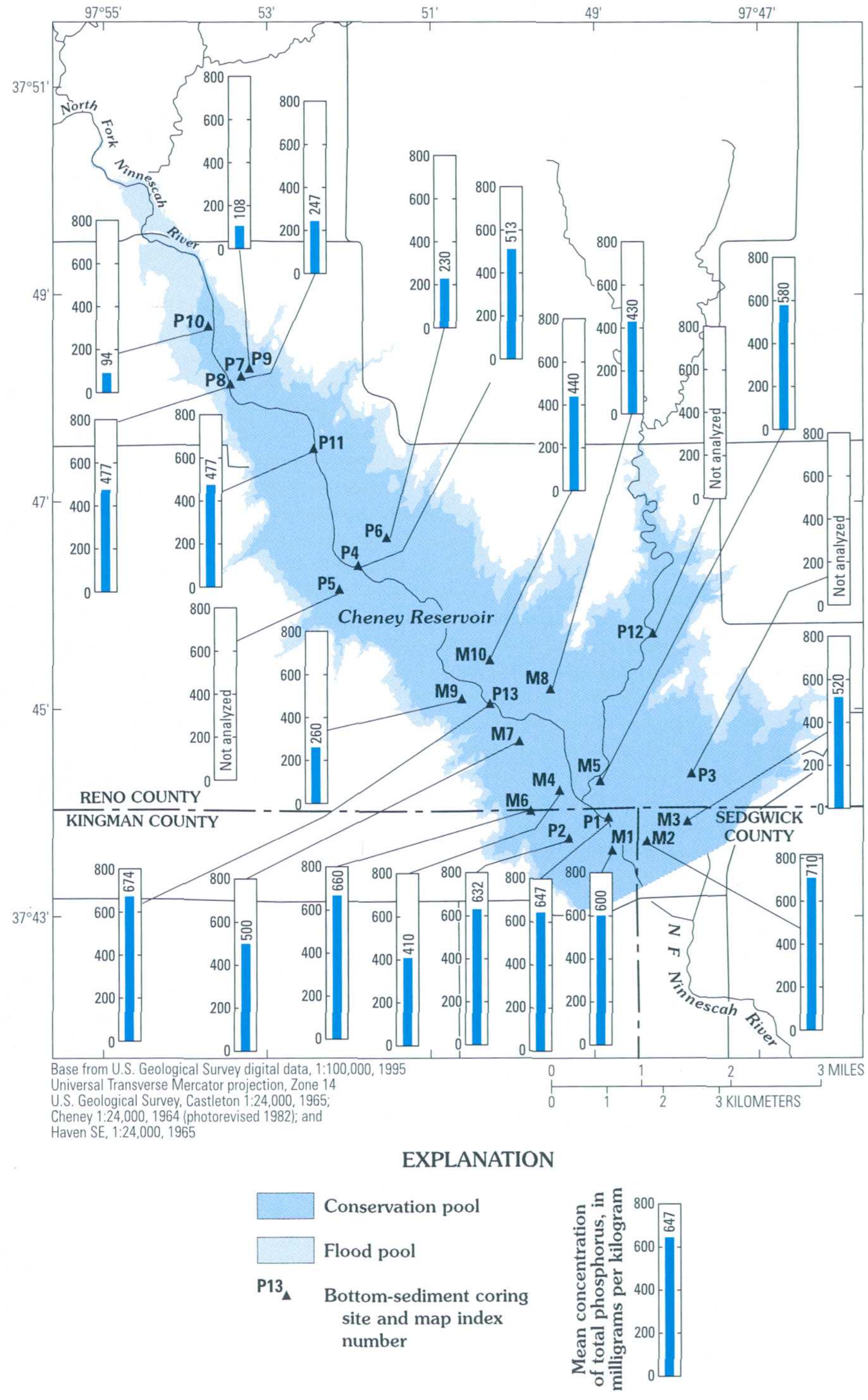
Phosphorus may be associated with sediment loads that are transported to reservoirs. Found primarily with the finer sediment fractions, the incorporation of phosphorus into sediment effectively removes phosphorus from the water column, and the reservoir sediment becomes the primary sink for phosphorus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

Phosphorus Concentrations in Reservoir Bottom Sediment

Reservoir sediment may contain large quantities of deposited phosphorus from sediment transport into reservoirs in both particulate and dissolved forms. Analysis of the sediment may assist in determining the extent of phosphorus deposition and whether historical trends can be identified.

Mean concentrations of total phosphorus in bottom-sediment cores from in-channel sites in Cheney Reservoir ranged from 477 mg/kg in cores from coring sites P8 and P11 to 674 mg/kg in a core from coring site P13 (fig. 6). Mean concentrations of total phosphorus in bottom-sediment cores from the out-of-channel sites in Cheney Reservoir ranged from 94 mg/kg in a core from coring site P10 at the upstream end of the reservoir to 710 mg/kg in a core from coring site M2 near the reservoir dam (fig. 6). The implications of this are that if anoxic conditions (inadequate oxygen) occur near the dam, phosphorus releases into the water column could affect the drinking-water supply. The mean phosphorus concentration in cores from all sites was 480 mg/kg. The mean in-channel phosphorus concentration was 630 mg/kg, and the mean out-of-channel concentration was 430 mg/kg.

The 1997 sediment investigation at Cheney Reservoir showed a strong linear relation between bottom-sediment particle size and total phosphorus concentration (Pope, 1998). Additional data collected during 1998–99 was added to the 1997 data in an effort to further define the relation. The regression analysis done by Pope (1998) was repeated in this investigation.



Base from U.S. Geological Survey digital data, 1:100,000, 1995
Universal Transverse Mercator projection, Zone 14
U.S. Geological Survey, Castleton 1:24,000, 1965;
Cheney 1:24,000, 1964 (photorevised 1982); and
Haven SE, 1:24,000, 1965

Figure 6. Mean concentrations of total phosphorus in bottom-sediment cores collected from Cheney Reservoir, 1997–99.

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

The additional data collected during 1998–99 (coring sites M1–M10, figs. 6 and 7) were used with the 1997 data to develop a curvilinear regression to represent the data. The resulting curvilinear equation (fig. 8) decreased the correlation coefficient slightly to $r=0.94$ ($y=111.51e^{0.017x}$, p less than 0.001) in relation to the 1997 data, but still showed a strong relation between particle-size distribution and total phosphorus concentration. The term 'e' is an irrational number resulting from an infinite series, and it cannot be expressed in exact decimal or fractional form; it is approximately equal to 2.71828. The term 'e' is used when a quantity increases at a rate proportional to its value. Explained another way, e is related to how much more money one would earn under compound interest than under simple interest (University of Toronto Mathematics Network, 1997).

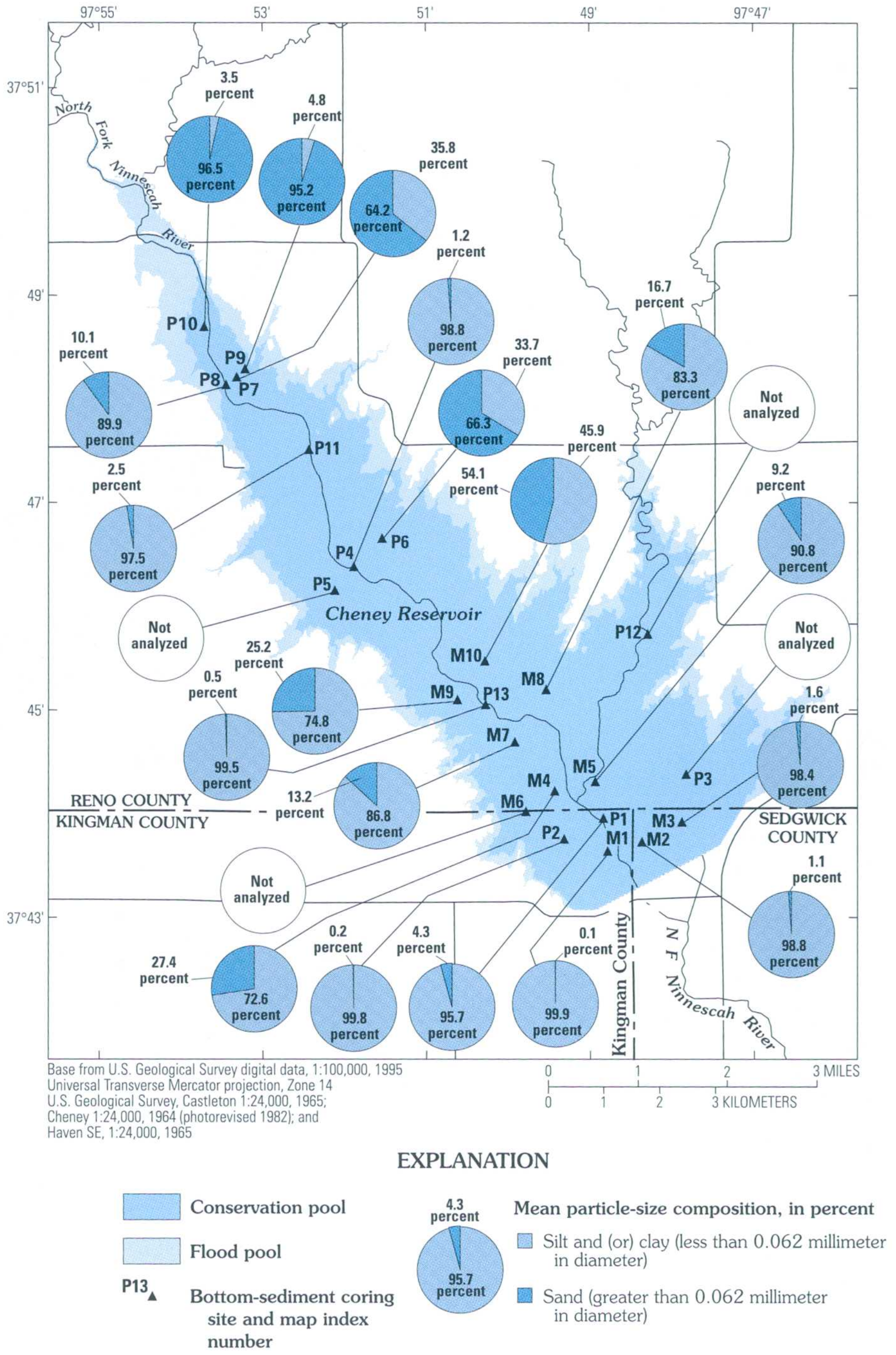


Figure 7. Mean particle-size composition of bottom-sediment cores from Cheney Reservoir, 1997–99.

The relation between bottom-sediment particle size and total phosphorus concentration suggests that phosphorus in bottom sediment is adsorbed to the smaller (silt- and clay-sized) particles. The silt- and clay-sized particles have large surface areas relative to their mass and, therefore, settle out of the water column much slower than sand-sized or larger material (Morris and Fan, 1998). These small particles are transported farther into the reservoir and settle out from the water column into bottom sediment in calm-water areas where the reservoir hydrodynamics are minimal. Typically, the calm, low-energy water areas are found in the deeper parts of the reservoir, especially near the dam. The bottom-sediment cores collected near the dam contained not only the largest volume of bottom-sediment material but also represented some of the largest percentages of sediment particles less than 0.062 mm in diameter (silt- and clay-sized particles) (fig. 7) and, not surprisingly, the largest phosphorus concentrations (fig. 6).

Total phosphorus concentrations in bottom-sediment cores from Cheney Reservoir generally showed an increasing trend from the older deposited sediment to the newer sediment near the top of the

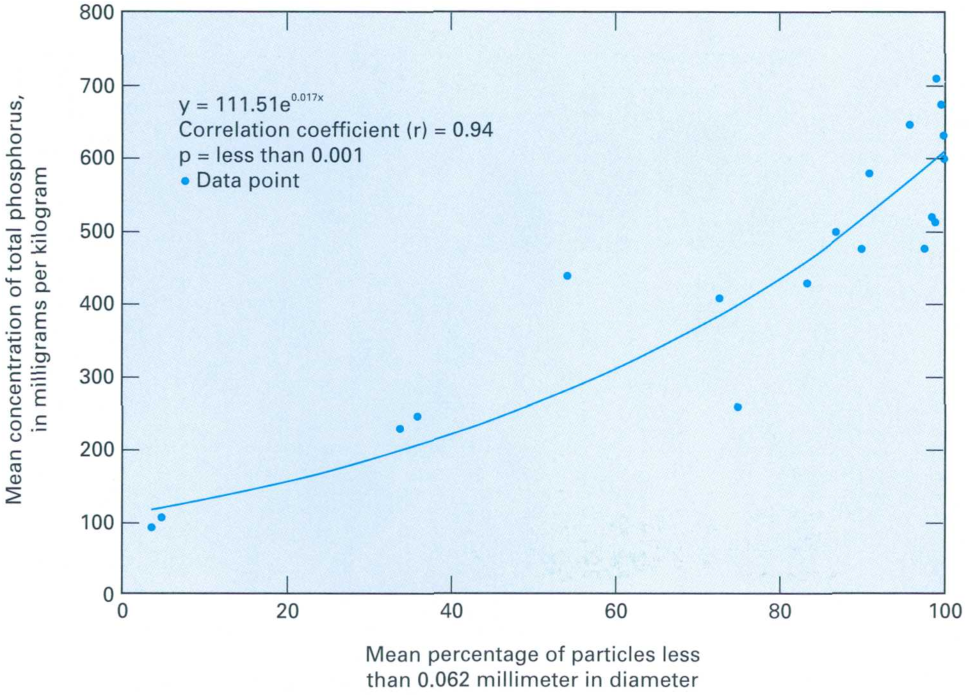


Figure 8. Relation between mean percentage of bottom-sediment particles less than 0.062 millimeter in diameter and mean concentrations of total phosphorus in bottom-sediment samples, Cheney Reservoir, 1997–99.

core (fig. 9) (Pope, 1998). This suggests that the transport of total phosphorus into Cheney Reservoir has been increasing over time. Natural sources of phosphorus would be expected to result in a fairly constant concentration over time. On the basis of a previous water-quality investigation of streams in the Cheney Reservoir watershed, the increase probably is not a result of point-source discharges (Christensen and Pope, 1997).

Information on land-use characteristics in the Cheney Reservoir watershed indicates that the increase in total phosphorus in reservoir bottom sediment probably is of nonpoint-source origin and related to agricultural activities such as fertilizer and manure application to croplands or livestock production. Between 1965 and 1996, the total amount of fertilizer sold in Kansas more than doubled from 835,000 to 1,710,000 tons (Kansas State Board of Agriculture and U.S. Department of Agriculture, 1986, p. 5; Kansas Department of Agriculture and U.S. Department of Agriculture, 1997, p. 5). A similar increasing trend in fertilizer sales and application could be expected in the Cheney Reservoir watershed. Therefore, in developing a management strategy for mitigating the transport of phosphorus to Cheney Reservoir, it would be important to address the human-related sources of phosphoru and (or) to implement management practices that would restrict the movement of phosphorus from areas of application.

The depositional trend of phosphorus in the reservoir was supported by cesium-137 data. Cesium-137 data in bottom sediment from coring sites P4, P13, and M5 showed a general decline in cesium-137 concentrations from a maximum of about 1.4 pCi/g (site M5) in the older and deeper sediment to 0.3 to 0.6 pCi/g determined from sediment cores collected from more recent deposition (fig. 10). This is consistent with the known peak cesium-137 atmospheric concentrations that occurred in 1964 and the continual decrease in concentrations since that time. The cesium data in the sediment cores indicate that substantial disturbance of sediment layers has not occurred in Cheney Reservoir and, therefore, would not affect time-trend analysis.

Estimates of Total Phosphorus Concentrations in Surface-Water Inflow

Total phosphorus concentrations in reservoir bottom sediment are important, but equally important are the phosphorus concentrations in the water column. The contribution of total phosphorus to the reservoir is of substantial concern because the reservoir is used as a drinking-water supply, a recreational area, and wildlife resource. In an effort to reduce accelerated eutrophication and excessive algal growth, the U.S. Environmental Protection Agency has recommended a nonenforceable total phosphorus concentration goal of 0.1 mg/L in flowing surface water (U.S. Environmental Protection Agency, 1986).

An estimate of the historical mean total phosphorus concentration in surface water from the Cheney Reservoir watershed was calculated for comparison to the nonenforceable goal of 0.1 mg/L. A previous investigation in 1997–98 analyzed phosphorus concentrations in surface water from five sampling sites upstream from Cheney Reservoir, and concentrations ranged from 0.02 to 2.37 mg/L (Pope and Milligan, 2000). However, there was some uncertainty of the representativeness of the watershed water yield during the 2-year period; therefore, phosphorus concentrations in surface water were calculated using phosphorus concentrations from Cheney Reservoir bottom sediment.

Concentration calculations require knowledge of mass and volume, and both were calculated for the inflow water from the Cheney Reservoir watershed. Mass and volume were determined on the basis of total sediment deposition estimated from the 1964 topographic and 1998 bathymetric surveys of the reservoir and bulk-density determinations at selected coring sites in the reservoir. The sum of the in-channel and out-of-channel sediment deposition, 15.4 billion lb (table 6) was multiplied by the sediment volume-weighted mean phosphorus concentration in bottom sediment for the reservoir. The sediment volume-weighted mean phosphorus concentration (498 mg/kg) was calculated as the sum of the products of sediment volume times mean total phosphorus concentration (table 9) divided by total reservoir sediment volume for both the in-channel and out-of-channel subsegments in each reservoir segment (table 4). Total phosphorus mass, 7.7 million lb, was calculated by multiplying the total sediment deposition, 15.4 billion lb, by the sediment volume-weighted mean phosphorus concentration, 498 mg/kg, and dividing by a conversion factor of approximately 1.0 million. The mean annual phosphorus load, 226,000 lb/yr, was determined by dividing the total phosphorus mass by 34 years, the number of years since dam impoundment.

The total volume of net inflow water to the reservoir from the water-

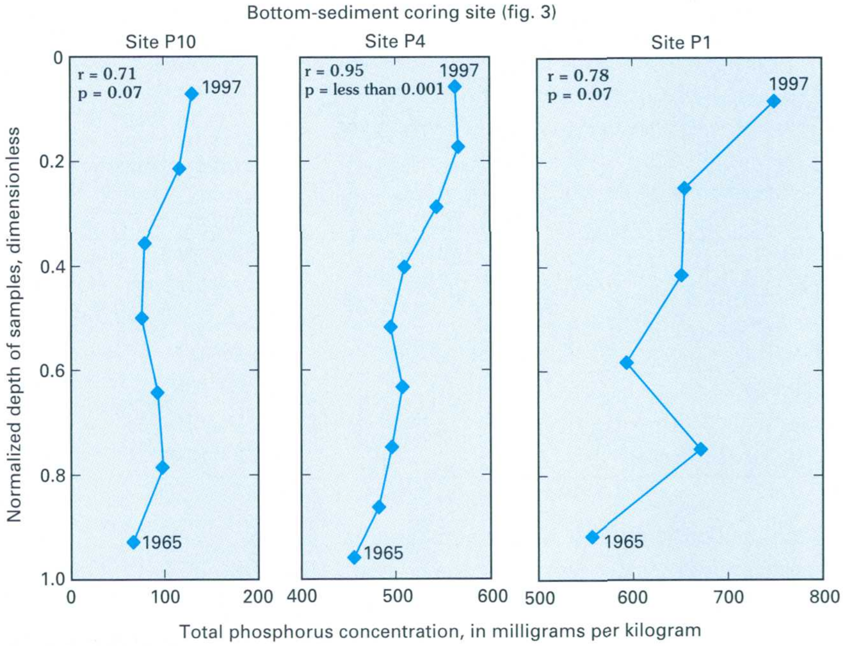


Figure 9. Relation between total phosphorus concentrations in bottom-sediment core sample and normalized depth of sample from selected coring sites in Cheney Reservoir, 1965–97 (modified from Pope, 1998, fig. 10). Sediment cores were collected in August 1997.

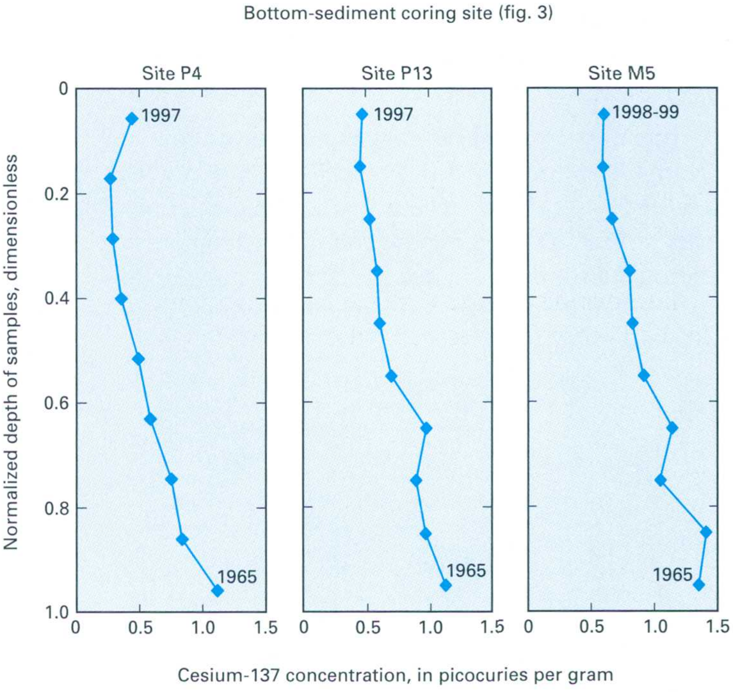


Figure 10. Relation between concentrations of radioactive cesium-137 and normalized depth of bottom-sediment core samples from selected coring sites in Cheney Reservoir, 1965–99. Sediment cores were collected from 1997–99.

Table 9. Estimated mean in-channel and out-of-channel concentrations of total phosphorus in reservoir bottom sediment by reservoir segment, Cheney Reservoir, south-central Kansas, 1999

[RL, range line; mg/kg, milligram per kilogram]

Reservoir segment (fig. 3)	In-channel coring sites (fig. 3)	Out-of-channel coring sites (fig. 3)	In-channel mean phosphorus concentration (mg/kg)	Out-of-channel mean phosphorus concentration (mg/kg)
Dam–RL1	P1	M1, M2, M3	647	610
RL1–RL7	P1, P4, P13	P2, P6, M4, M5 M6, M7, M8, M9, M10	611	460
RL7–RL8	P4, P11	P7, P9	495	178
RL8–RL9	P11	P7, P9	477	178
RL9–RL10	P8	P7, P9, P10	477	150
RL10–lake boundary	P8	P7, P9, P10	477	150

shed was determined from a water-budget analysis done for Cheney Reservoir for water years 1966–98. Hydrologic data commonly are evaluated by the USGS on a water-year basis, which represents the time period from October 1 to September 30. For example, water year 1966 would include October 1, 1965, to September 30, 1966. The following hydrologic components for each water year were added or subtracted to determine the water budget:

$$\begin{gathered}\text{stream inflow} + \text{precipitation} - \text{evaporation} - \\ \text{discharge from reservoir} - \text{city of Wichita withdrawals} \pm \\ \text{ground-water inflow or outflow} = \text{change in reservoir storage}\,. \end{gathered}\tag{1}$$

Equation 1 can be rearranged and solved for stream inflow, precipitation, ground-water inflow/outflow, and evaporation. These four hydrologic components represent the net inflow volume and can be determined from the change in reservoir storage, discharge from the reservoir, and water withdrawals by the city of Wichita:

$$\begin{gathered}\text{stream inflow} + \text{precipitation} - \text{evaporation} \pm \\ \text{ground-water inflow or outflow} = \\ \text{change in reservoir storage} + \text{discharge from reservoir} + \\ \text{city of Wichita withdrawals}\end{gathered}\tag{2}$$

The change in reservoir storage was measured as the difference in monthly reservoir storage capacity and summed to determine the value for the water year (table 10). Discharge from the reservoir was measured at the USGS streamflow-gaging station on the North Fork Ninnescah River at Cheney Dam (station 07144795, fig. 1; data on file with USGS, Lawrence, Kansas). Withdrawals from the reservoir by the city of Wichita to supplement its drinking-water supplies were measured at the Cheney Reservoir pump station (data on file with Kansas Department of Agriculture, Division of Water Resources, Topeka, Kansas).

Water budgets were determined annually using available data from water years 1966–98 and then summed (table 10). The total net inflow volume of water to the reservoir from the watershed (3.71 million acre-ft) was converted to liters (4.6 x 10^{12} L) and used to calculate the total phosphorus concentration in water for water years 1966–98 from the Cheney Reservoir watershed on the basis of total phosphorus deposited in reservoir bottom sediment. The mass of total phosphorus deposited in the reservoir bottom sediment from 1965–98, 7.7 million lb (3.5 x 10^{12} mg) was divided by the net inflow volume of water to the reservoir, 4.6 x 10^{12} L, and the result was a mean total phosphorus concentration (that is based on reservoir bottom sediment) of 0.76 mg/L in the surface-water inflow to Cheney Reservoir.

Estimates of Phosphorus Yields in Cheney Reservoir Watershed

Phosphorus yields in the Cheney Reservoir watershed can be calculated on the basis of total phosphorus mass (7.7 million lb) previously determined. Dividing the total phosphorus mass by the contributing-drainage area in the watershed, 597,000 acres, and by the 34 years of sedimentation, results in 0.38 (lb/yr)/acre, the phosphorus yield in the Cheney Reservoir watershed. The results of the sediment-based phosphorus yield were compared to estimates of phosphorus yield from a 1997–98 study in the Cheney Reservoir watershed (Pope and Milligan, 2000). The mean annual phosphorus yield for water years 1997 and 1998 was estimated to be 0.20 lb/acre (Pope and Milligan, 2000). Data from six gaged streamflow sampling sites plus two additional ungaged areas were used in that analysis.

Table 10. Annual water budgets for Cheney Reservoir, south-central Kansas, 1966–98

[all values are in acre-feet and rounded to three significant figures]

Water year	Change in reservoir storage[1]	Discharge from reservoir[1]	Water withdrawals by city of Wichita[2]	Net inflow volume
1966	20,500	455	11,400	32,400
1967	22,800	3,260	10,400	36,500
1968	18,100	232	10,200	28,500
1969	22,900	77,600	14,000	114,000
1970	-11,300	73,100	12,800	74,600
1971	3,500	50,400	11,700	65,600
1972	-54,000	51,600	11,300	8,900
1973	48,900	94,600	11,100	155,000
1974	14,900	252,000	12,300	279,000
1975	-8,270	119,000	16,800	127,000
1976	-640	58,600	15,700	73,700
1977	33,800	118,000	15,900	168,000
1978	-39,900	93,000	15,700	68,800
1979	10,700	59,900	23,000	93,600
1980	-8,750	233,000	24,100	248,000
1981	5,950	21,200	18,000	45,100
1982	2,040	109,000	23,200	134,000
1983	-7,350	75,400	21,700	89,700
1984	-2,560	85,500	22,900	106,000
1985	13,400	56,700	18,300	88,400
1986	-1,520	144,000	24,600	167,000
1987	2,200	269,000	24,600	296,000
1988	-13,100	57,100	30,700	74,700
1989	13,400	59,500	26,100	99,000
1990	-20,100	63,300	29,100	72,300
1991	-3,170	25,300	28,600	50,700
1992	19,400	18,400	20,900	58,700
1993	-2,850	294,000	22,100	313,000
1994	-12,700	25,500	26,500	39,300
1995	14,400	157,000	28,500	200,000
1996	-3,040	17,800	33,100	47,900
1997	5,610	89,800	34,100	129,000
1998	-19,000	104,000	44,200	129,000
Total	**64,000**	**2,960,000**	**694,000**	**3,710,000**

[1] Data on file with U.S. Geological Survey in Lawrence, Kansas.

[2] Data on file with Kansas Department of Agriculture, Division of Water Resources, in Topeka, Kansas.

Results of the current investigation indicated that annual mean phosphorus yields in Cheney Reservoir are 90 percent larger than the 0.20-(lb/yr)/acre estimate presented in Pope and Milligan (2000) that was based on streamflow sampling in the watershed. The difference probably can be attributed to the fact that the estimate using streamflow sampling was based on a 2-year data set (Pope and Milligan, 2000), whereas the estimate in the current investigation was based on sediment data that were integrated over 34 years of the life of the reservoir (1965 through 1998).

Recent studies of phosphorus transported to Webster Reservoir, Tuttle Creek Lake, and Hillsdale Lake enable comparisons with the estimates of phosphorus transported into Cheney Reservoir. On the basis of phosphorus deposited in reservoir sediment, the mean annual phosphorus yield was estimated at 0.04 (lb/yr)/acre from the Webster Reservoir watershed (V. Christensen, U.S. Geological Survey, written commun., 1999), 0.41 (lb/yr)/acre from the Tuttle Creek Lake watershed (data on file with USGS, Lawrence, Kansas), and 1.8 (lb/yr)/acre from the Hillsdale Lake watershed (Juracek, 1997).

Nitrogen

The presence of nitrogen, along with phosphorus, is essential for plant growth. However, nitrogen also is important because it is used to synthesize proteins and, along with carbohydrates and fats, constitutes the major part of living substances (Reid and Wood, 1976). Nitrogen differs from phosphorus in that nitrogen is very mobile and not highly adsorbed to soil, with the exception of ammonia (NH_3), which tends to adsorb to clay or organic particles (Morris and Fan, 1998).

There are many sources of nitrogen in the Cheney Reservoir watershed, including municipal waste discharges from the several small towns as well as from agricultural and atmospheric sources. The application of fertilizer (the application of synthetic fertilizers in Kansas has increased about 10-fold in the past 40 years; Kansas Department of Agriculture and U.S. Department of Agriculture, 1996) and livestock wastes are probable sources in an agricultural watershed. The presence of nitrogen compounds along with phosphorus contributions to water bodies can lead to excessive algal growth, which may cause taste-and-odor problems in drinking water, stress aquatic organisms, and decrease the aesthetic and recreational value of the water body.

Atmospheric nitrogen also is a source of nitrogen in the watershed. Natural cyclic processes exist where atmospheric nitrogen enters the soil and becomes part of living organisms before returning to the atmosphere. Atmospheric nitrogen, representing 79 percent of the atmosphere, can be converted to ammonia and nitrate using cosmic radiation to effect the conversion, and subsequently deposited on soil through precipitation (Manahan, 1994, p. 160).

The nitrogen associated with finer sediment particles and organic matter may be transported into reservoirs as part of the sediment load. Concentrations of mean total ammonia plus organic nitrogen as nitrogen (N) in homogenized bottom-sediment cores collected from eight out-of-channel sites in Cheney Reservoir ranged from 1,200 to 2,400 mg/kg as N, with a median out-of-channel concentration of 1,850 mg/kg as N (table 11). These values are similar to concentrations of mean total ammonia plus organic nitrogen analyzed in bottom-sediment cores collected in 1998 from Kirwin and Webster Reservoirs and Waconda Lake (Christensen, 1999). The ranges in mean concentrations of total ammonia plus organic nitrogen as N in sediment cores were 1,200 to 1,980 mg/kg for Kirwin Reservoir, 30.0 to 1,910 mg/kg for Webster Reservoir, and 704 to 3,210 mg/kg for Waconda Lake.

An evaluation of the concentrations of total ammonia plus organic nitrogen as N in relation to the particle-size composition of bottom-sediment cores from Cheney Reservoir suggests a statistically significant relation between total ammonia plus organic nitrogen as N and percentage of silt- and (or) clay-sized particles in the sediment cores ($r = 0.90$, $p=0.002$) (fig. 11). The relation suggests, as with phosphorus, that ammonia and organic nitrogen adsorb to the smallest sediment particles, which are the silt- and clay-sized particles. These particles are transported farther into the reservoir and deposited in bottom sediment in calm-water areas.

A sediment core from site M5 at Cheney Reservoir was divided into 10 equal core subsections, and each subsection was analyzed for total ammonia plus organic nitrogen as N. A regression analysis of depth versus concentration of total ammonia plus organic nitrogen as N did not indicate a statistically significant relation between the two variables. However,

Table 11. Concentrations of total ammonia plus organic nitrogen as nitrogen (N) in Cheney Reservoir bottom sediment, south-central Kansas, 1999

[mg/kg, milligram per kilogram; --, not determined]

Coring site (fig. 3)	Total ammonia plus organic nitrogen as N (mg/kg)
M1	2,400
M2	2,300
M3	2,000
M4	1,200
M5	1,800
M6	--
M7	1,900
M8	1,400
M9	1,600
M10	--

synthetic fertilizer use has increased throughout the State and probably in the Cheney Reservoir watershed as well. Therefore, it is unlikely that nitrogen use is decreasing over time in the watershed.

Trace Elements

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

Several bottom-sediment cores from Cheney Reservoir were analyzed for trace elements (table 12). Many trace element concentrations were larger in sediment cores located farther downstream in the reservoir and may be associated with the increased percentage of silt and clay particles found farther downstream. Clay-sized particles probably contain larger concentrations of trace elements incorporated into the mineral matrix or adsorbed to the particles because of their larger surface area compared to sand- and silt-sized particles (Pope, 1998). The clay particles also tend to settle in the deeper parts of the reservoir (near the dam) where there is less disturbance to the particles from wind and wave action.

The U.S. Environmental Protection Agency (1998) has established sediment-quality guidelines for selected trace elements, and two sets of guidelines

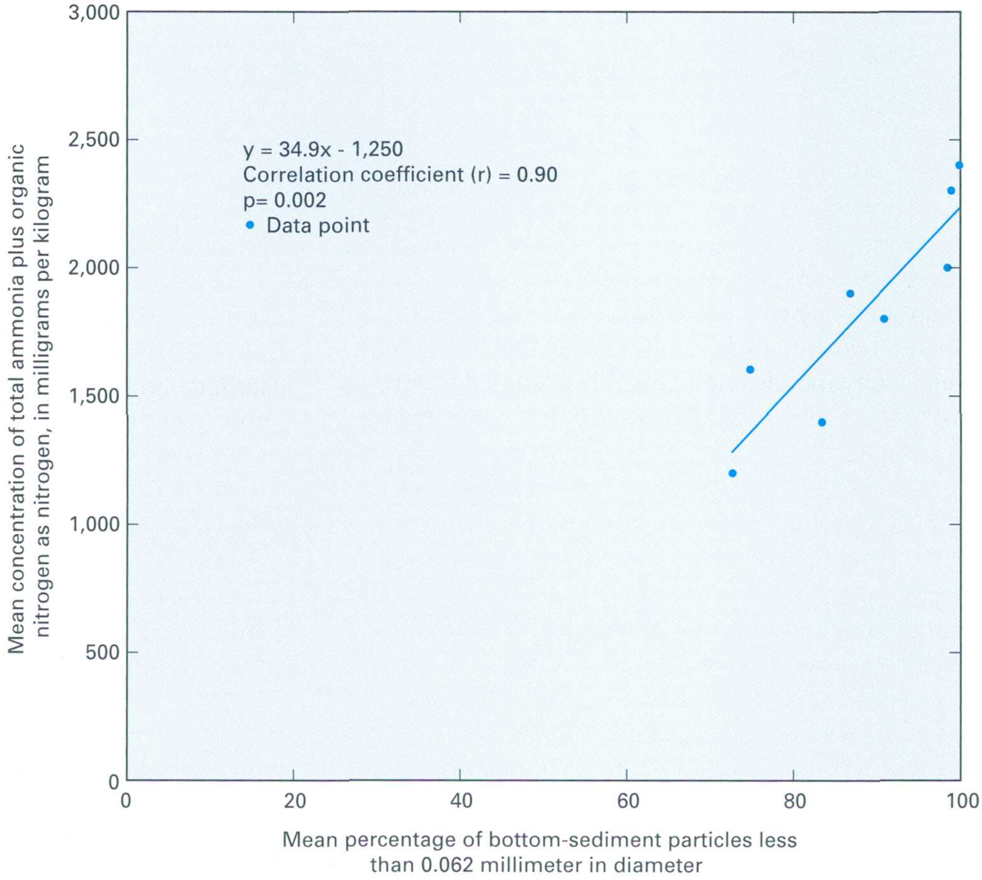


Figure 11. Relation between mean percentage of bottom-sediment particles less than 0.062 millimeter in diameter and mean concentrations of total ammonia plus organic nitrogen as nitrogen in bottom-sediment samples, Cheney Reservoir, 1997–99.

Table 12. Summary of mean concentrations and comparisons to sediment-quality guidelines for selected trace elements in 13 bottom-sediment samples from Cheney Reservoir, south-central Kansas, 1997–99

[all values in micrograms per gram; --, not determined; <, less than]

Coring site (fig. 3)	Arsenic	Cadmium	Chromium	Cobalt	Copper	Lead	Mercury	Molybdenum	Nickel	Selenium	Strontium	Zinc
M1	12	0.37	89	15	24	26	0.05	0.64	43	0.52	100	120
M2	12	.32	89	14	20	24	.05	.64	38	.48	110	100
M3	10	.33	86	14	20	24	.04	.59	38	.50	110	100
M4	7.6	.29	55	11	17	19	.04	.50	26	.36	110	66
M5	11	.32	74	15	23	22	--	.65	34	--	120	97
M6	10	.35	71	13	19	20	.03	.57	36	.39	120	97
M7	8.0	.30	60	11	16	18	.04	.50	28	.43	120	71
M8	8.0	.27	64	11	17	19	.04	.50	29	.40	120	71
M9	6.1	.26	42	8.5	13	16	.03	.50	18	.31	130	47
M10	7.4	.24	61	10	15	17	.04	.50	25	.38	120	67
P4	7.5	.40	61	13	14	16	--	<2.0	26	--	150	74
P8	5.9	.37	55	10	12	14	--	<2.0	19	--	170	58
P13	10	.37	100	17	18	23	--	<2.0	37	--	130	110
Sediment-quality guidelines												
TEL[1]	7.2	.68	52	--	19	30	.13	--	16	--	--	120
PEL[1]	42	4.2	160	--	110	110	.70	--	43	--	--	270

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

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

Mean concentrations of most trace elements in the Cheney Reservoir bottom sediment were generally less than the TELs and considerably less than the respective PELs (table 12). However, arsenic, chromium, copper, and nickel exceeded the TELs at several coring sites.

Mean concentrations of arsenic from 11 of 13 coring sites in Cheney Reservoir exceeded 7.2 μg/g, the TEL for arsenic (table 12). Mean concentrations of arsenic in sediment ranged from 5.9 to 12 μg/g. Arsenic has been used extensively as a pesticide, herbicide, and soil sterilant in agricultural soils in this country but has only a moderate bioaccumulation effect because it is not very mobile (Pais and Jones, 1997, p. 86).

Chromium concentrations exceeded the TEL in all cores except from site M9. Concentrations were about 75 percent larger in the core from in-channel site P13 compared to the mean chromium concentrations in cores from nearby out-of-channel sites M7 through M10 (fig. 3). The source of chromium is not well understood, but what is not of natural origin may be a by-product of agricultural fertilizer application (Pais and Jones, 1997).

Mean concentrations of copper in reservoir bottom sediment exceeded the TEL at four coring sites.

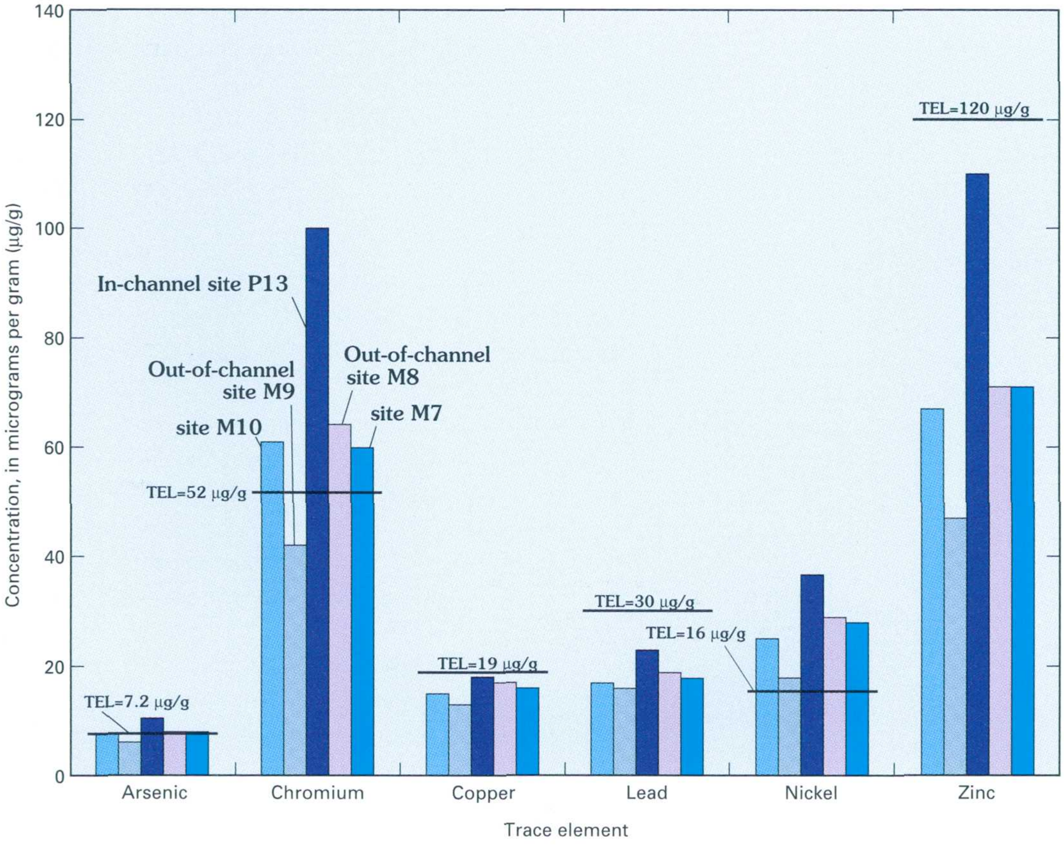


Figure 12. Comparison of selected trace element mean concentrations in bottom-sediment cores from in-channel and out-of-channel coring sites to Threshold Effects Level (TELs) (U.S. Environmental Protection Agency, 1998), Cheney Reservoir, 1997–99. Location of coring sites shown in figure 3.

Copper is an essential micronutrient for plants and commonly is found in soils (Pais and Jones, 1997, p. 100). The PEL for copper is 110 µg/g, more than 4.5 times larger than the largest mean copper concentrations detected in sediment in Cheney Reservoir.

The typical nickel concentration in uncontaminated soil is 25 µg/g although concentrations in soil can range from 1 to 200 µg/g (Kabata-Pendias and Pendias, 1994; Pais and Jones, 1997, p. 124). Concentrations of nickel in bottom-sediment samples from Cheney Reservoir were greater than the TEL of 16 µg/g at all coring sites but were less than or equal to the PEL of 43 µg/g. With no apparent industrial nickel source in the watershed, it may be that phytoplankton, which are known to bioaccumulate certain trace elements including nickel, are ingesting trace amounts of nickel from the water column and subsequently depositing and concentrating the nickel in the reservoir bottom sediment. Recent research suggests that nickel is an essential micronutrient for both plants and animals; however, in large concentrations it can be toxic (Pais and Jones, 1997, p. 125).

A comparison of concentrations of selected trace elements in the sediment core from in-channel site P13 with the sediment cores from nearby out-of-channel sites M7 through M10 (fig. 12) shows larger concentrations of all trace elements in the in-channel sediment core (coring site P13). As stated previously, the in-channel sites are located in the deepest parts of the reservoir where wave action is minimal, and these sites accumulate larger amounts of silt and clay than their respective out-of-channel sites. Concentrations of constituents that adsorb to clay particles, such as phosphorus and selected trace elements, generally are larger where silt and clay percentages are large (table 12, fig. 7).

An examination of subsectioned bottom-sediment cores from coring site M5 for trends in selected trace elements was inconclusive (fig. 18 in "Supplemental Information" section at the back of this report). Arsenic, chromium, copper, and nickel concentrations varied with depth with no apparent increasing or decreasing trend. The Cheney Reservoir watershed is primarily agricultural, supporting very little commercial or industrial use. It is possible that trace element concentrations that exceeded TELs or PELs are the result of natural contributions from the sediment and not related to either point- or nonpoint-source contributions within the watershed. The Cheney Reservoir watershed does not have large urban areas, an industrial base, or large population centers; therefore, the opportunity to contribute significant trace element concentrations is limited.

Selected Pesticides

During August 1997, seven bottom-sediment core samples from four coring sites (P1, P4, P8, P13) were collected from Cheney Reservoir and analyzed for selected pesticides, including organochlorine and organophosphate insecticides, and acetanilide, chlorophenoxy-acid, and triazine herbicides (Pope, 1998). Core samples collected during 1998 and 1999 were not analyzed for pesticides.

Organochlorine insecticides can be found in reservoir bottom sediment in watersheds where these compounds are used extensively to control insect damage to crops such as corn, wheat, and sorghum. These compounds also are used to control insects such as ants, termites, beetles, fleas, lice, mites, and mosquitos. The organophosphate insecticides have uses similar to organochlorine insecticides, may be used on human food crops such as fruits and vegetables, and are more water soluble and less persistent than organochlorine compounds. The organochlorine and organophosphate insecticides, and acetanilide, chlorophenoxy-acid, and triazine herbicides are used in weed and grass control for, among other things, crops such as corn, sorghum, and soybeans.

Few organochlorine insecticides were detected in bottom-sediment samples collected from Cheney Reservoir during August 1997 (Pope, 1998). DDT was detected in one core sample (1.0 μg/kg, site P4), and its degradation products, DDD and DDE, were detected in small concentrations in core samples analyzed for pesticides. There was one detection of DDD at a concentration of 0.65 μg/kg in the sediment core from sampling site P8, and DDE was detected in all seven core samples at concentrations ranging from 0.31 to 1.3 μg/kg. A comparison of the TEL and PEL guidelines to concentrations of organochlorine insecticides indicate that all concentrations in Cheney Reservoir bottom sediment were considerably less than guideline concentrations. No organophosphate insectides were detected in the August 1997 sediment-core samples.

The acetanilide herbicide metolachlor was the only acetanilide, chlorophenoxy-acid, or triazine herbicide detected among the 23 pesticides analyzed in bottom-sediment samples from Cheney Reservoir. Concentrations of metolachlor ranged from 0.62 to 1.0 μg/L (Pope, 1998).

SUMMARY AND CONCLUSIONS

This report describes sediment deposition, water-quality trends, and mass transport within the Cheney Reservoir watershed in south-central Kansas using bathymetric survey data and bottom-sediment cores. Bathymetric data were collected during 1998 by the U.S. Geological Survey (USGS) and compared to 1964 topographic data collected by the Bureau of Reclamation to provide an estimate of total sediment deposition in the reservoir since dam closure (1965). Thirteen bottom-sediment cores were collected from the reservoir and analyzed for selected inorganic and organic constituents in 1997. The results from the effort showed that phosphorus, nitrogen, selected trace elements, and some organic pesticides were present in the reservoir bottom sediment. Ten additional out-of-channel bottom-sediment cores collected during 1998–99 showed that the percentage of finer grained sediment (silt and clay) was largest in in-channel coring sites and reservoir areas closest to the dam. Silt and clay provides the adsorption mechanism for many constituents, such as phosphorus and many trace elements.

Estimated sediment deposition, using bathymetric survey data and bottom-sediment cores collected during this investigation, was about 7,100 acre-ft since dam closure. Mean annual sediment deposition was 209 acre-ft/yr, or 0.22 (acre-ft/yr)/mi^2, and the mean annual sediment load was 453 million lb/yr. As of 1998, sediment deposition has filled 27 percent of the inactive conservation storage pool since dam closure, less than the design estimate of 34 percent. This estimate provides information on the useful life of the reservoir and on the capacity of the reservoir for future public supply.

Data collected during this investigation indicate that the silt/clay sediment fraction is deposited in larger quantities closer to the dam than farther upstream in the reservoir. As a consequence, phosphorus concentrations are larger near the dam than farther upstream. Mean concentrations of total phosphorus ranged from 94 mg/kg upstream to 710 mg/kg downstream near the dam. Mean total phosphorus concentration from all coring sites was 480 mg/kg. The implications of this are that if anoxic conditions occur near the dam, phosphorus releases into the water column could affect the drinking-water supply. If phosphorus usage in the watershed continues to increase, there probably will be additional increases in phosphorus concentrations near the dam. Selected cores also indicated increasing phosphorus concentrations in reservoir sediment over time that probably are a result of nonpoint-source activities in the watershed, such as increased fertilizer use and livestock production.

Mean annual phosphorus loading to Cheney Reservoir was estimated to be 226,000 lb/yr on the basis of calculations from deposited sediment in the reservoir. The mean total phosphorus concentration in the surface-water inflow to Cheney Reservoir, calculated on the basis of reservoir bottom sediment, was 0.76 mg/L. Mean annual phosphorus yield in the Cheney Reservoir watershed from sediment deposition was estimated to be 0.38 (lb/yr)/acre, 90 percent larger than the mean annual phosphorus yield calculated from streamflow sampling during 1997–98. The difference was attributed to the short duration of streamflow sampling data and uncertainties of the representativeness of the watershed water yield compared with reservoir bottom-sediment data that were integrated over the life of the reservoir.

Land use has considerable effect on sediment loading in a reservoir. Intense agricultural use in the watershed, with limited or ineffective erosion prevention methods, can contribute large loads of sediment along with constituents (such as phosphorus) to downstream reservoirs. A comparison of the Cheney Reservoir watershed to the Webster Reservoir, Tuttle Creek Lake, and Hillsdale Lake watersheds showed that phosphorus yields were smallest in the Webster watershed [0.04 (lb/yr)/acre], and largest in the Hillsdale Lake watershed [1.8 (lb/yr)/acre].

Total ammonia plus organic nitrogen as nitrogen in bottom-sediment cores from Cheney Reservoir showed mean concentrations ranging from 1,200 to 2,400 mg/kg as nitrogen. A regression analysis between total ammonia plus organic nitrogen as nitrogen and sediment particle size indicated that total ammonia plus organic nitrogen as nitrogen adsorbs to the silt- and clay-sized particles that are transported to the deeper parts of the reservoir. However, an analysis of trends with depth of total ammonia plus organic nitrogen as nitrogen in bottom sediment did not indicate a strong relation between the two variables despite the increase in fertilizer use in the watershed during the past 40 years.

Concentrations in Cheney Reservoir bottom sediment of several trace elements from many coring sites exceeded both nationwide background concentrations and U.S. Environmental Protection Agency Threshold Effects Levels (TELs) for aquatic organisms. Nickel concentrations exceeded the TEL guideline in sediment cores from 13 in-channel and out-of-channel coring sites and equaled the Probable Effects Level (PEL) in a core sample collected close to the dam.

Implications of large trace element concentrations are uncertain because the U.S. Environmental Protection Agency guidelines are nonenforceable; however, it is assumed that toxic effects frequently occur when trace element concentrations exceed the PEL guidelines. Larger concentrations of these elements also occurred in sediment closer to the reservoir dam where there is a larger percentage of silt and clay in the bottom sediment than farther upstream. However, the lack of industrial or commercial land use in the watershed suggests that larger concentrations may be the result of natural conditions. It would be beneficial to monitor trace element concentrations in reservoir sediment every few years to determine whether there is a trend and if concentrations are increasing or decreasing.

Reservoir bottom-sediment samples collected in 1997 were analyzed for selected pesticides, including organochlorine and organophosphate insecticides, and acetanilide, chlorophenoxy-acid, and triazine herbicides. The most frequently detected organochlorine insecticide in reservoir bottom sediment from Cheney Reservoir was DDE, but DDT and DDD also were detected. However, the concentrations were all less than the sediment-quality guidelines established by the U.S. Environmental Protection Agency for these compounds. The acetanilide herbicide metolachlor was detected in small concentrations.

The reservoir sediment investigation of Cheney Reservoir was used to reconstruct historical trends in water quality. With the addition of bathymetric surveys and the inclusion of additional reservoirs, sediment investigations can be used for estimating historical loading of phosphorus and other constituents in future water-quality assessments throughout Kansas.

REFERENCES

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.

Bureau of Reclamation, 1984, Solomon River Basin water management study, Kansas: U.S. Department of the Interior, Special Report, April 1984, 88 p.

———2000, Cheney Reservoir allocations: accessed December 18, 2000, at URL http://www.gp.usbr.gov/aop/resaloc/cheneyra.htm

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 Investigation Report 99–4230, 46 p.

Christensen, V.G., and Pope, L.M., 1997, Occurrence of dissolved solids, nutrients, atrazine, and fecal coliform bacteria during low flow in the Cheney Reservoir watershed, south-central Kansas, 1996: U.S. Geological Survey Water-Resources Investigations Report 97–4153, 13 p.

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

Fishman, M.J., 1993, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—methods for the determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 94–140, 78 p.

Foreman, W.T., Connor, B.F., Furlong, E.T., Vaught, D.G., and Merten, L.M., 1994, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory—determination of organochlorine insecticides and polychlorinated biphenyls in bottom sediments: U.S. Geological Survey Open-File Report 94–140, 78 p.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p.

Helyar, Thelma, ed., 1994, Kansas statistical abstract 1992–93: Lawrence, University of Kansas Institute for Public Policy and Business Research, 420 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3rd ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Holmes, C.W., 1998, Short-lived isotopic chronometers—a means of measuring decadal sedimentary dynamics: U.S. Geological Survey Fact Sheet 073–98, 2 p.

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

Horowitz, A.J., Robbins, J.A., Elrick, K.A., and Cook, R.B., 1996, Bed sediment-trace element geochemistry of Terrace Reservoir, near Summitville, southwestern Colorado: U.S. Geological Survey Open-File Report 96–344, 41 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.

Kabata-Pendias, A., and Pendias, H., 1994, Trace elements in soils and plants: Boca Raton, Florida, CRC Press, 413 p.

Kansas Department of Agriculture and U.S. Department of Agriculture, 1995–97, Kansas farm facts: Topeka, Kansas, published annually.

Kansas Geological Survey, 1993, Landcover metadata: accessed April 9, 2001, at URL: http://gisdasc.kgs.ukans.edu/dasc/meta_info/landcov.html

Kansas State Board of Agriculture and U.S. Department of Agriculture, 1964–94, Kansas farm facts: Topeka, Kansas, published annually.

Manahan, S.E., 1994, Environmental chemistry: Boca Raton, Florida, Lewis Publ., p. 160.

Mau, D.P., and Christensen, V.G., 2000, Comparison of sediment deposition in reservoirs of four Kansas watersheds: U.S. Geological Survey Fact Sheet 102–00, 4 p.

Morris, L.M., and Fan, J., 1998, Reservoir sedimentation handbook: New York, McGraw-Hill, p. 4.17.

National Oceanic and Atmospheric Administration, 1966–98, Climatological data annual summary—south-central Kansas: Asheville, North Carolina, National Weather Service Climate Center, published monthly.

Nebraska Natural Resources Commission, 1983, Digitized landuse by county: accessed April 9, 2001, at URL http://www.nrc.state.ne.us/databank/spat.html

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

Pope, L.M., 1998, Watershed trend analysis and water-quality assessment using bottom-sediment cores from Cheney Reservoir, south-central Kansas: U.S. Geological Survey Water-Resources Investigations Report 98–4227, 24 p.

Pope, L.M., and Milligan, C.R., 2000, Preliminary assessment of phosphorus transport in the Cheney Reservoir watershed, south-central Kansas, 1997–98: U.S. Geological Survey Water-Resources Investigations Report 00–4023, 29 p.

Putnam, J.E., Lacock, D.L., Schneider, D.R., Carlson, M.D., 2000, Water resources data Kansas water year 1999: U.S. Geological Survey Water-Data Report KS–99–1, 466 p.

Reid, G.K., and Wood, R.D., 1976, Ecology of inland water and estuaries: New York, D. Van Nostrand Co., 485 p.

Rockers, J.J., Ratcliff, Ivan, Doed, L.W., and Bouse, E.F., 1966, Soil survey of Reno County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, 72 p.

University of Toronto Mathematics Network, 1997, accessed January 31, 2001, at URL http://www.math.toronto.edu/mathnet/answers/ereal.html

U.S. Environmental Protection Agency, 1986, Quality criteria for water, 1986: U.S. Environmental Protection Agency Report 440/5–86–001, unnumbered pages.

———1998, The incidence and severity of sediment contamination in surface waters of the United States, volume 1—national sediment survey: U.S. Environmental Protection Agency Report 823–R–97–006, various pagination.

Zeller, D.E., ed., 1968, The stratigraphic succession in Kansas: Kansas Geological Survey Bulletin 189, 81 p.

Supplemental Information

Table 13. Nutrients analyzed in reservoir bottom sediment from Cheney Reservoir, south-central Kansas

[mg/kg, milligrams per kilogram]

Constituent	Method reporting limit	Units of measurement
Nitrogen, organic	20	mg/kg
Phosphorus	40	mg/kg

Table 14. Selected trace elements and miscellaneous constituents analyzed in reservoir bottom sediment from Cheney Reservoir, south-central Kansas

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

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

Table 15. Selected organic constituents analyzed in reservoir bottom sediment from Cheney Reservoir, south-central Kansas

[µg/kg, micrograms per kilogram; <, less than]

Constituent	Method reporting limit	Units of measure-ment	Constituent	Method reporting limit	Units of measure-ment
Organochlorine insecticides			**Acetanilide herbicides**		
Aldrin	<0.20	µg/kg	Acetochlor	<0.20	µg/kg
Chlordane	3.0	µg/kg	Alachlor	<.20	µg/kg
P,P'-DDD	<.50	µg/kg	Metolachlor	<.20	µg/kg
P,P'-DDE	<.20	µg/kg	Propachlor	<.20	µg/kg
P,P'-DDT	<.50	µg/kg	**Chlorophenoxy-acid herbicides**		
Dieldrin	<.20	µg/kg	2,4-D	<.10	µg/kg
Endosulfan	<.20	µg/kg	2,4-DP	<.10	µg/kg
Endrin	<.20	µg/kg	2,4,5-T	<.10	µg/kg
Ethion	<.20	µg/kg	Silvex	<.10	µg/kg
Heptachlor	<.20	µg/kg	**Triazine herbicides**		
Heptachlor epoxide	<.20	µg/kg	Ametryn	<.20	µg/kg
Lindane	<.20	µg/kg	Atrazine	<.20	µg/kg
Methoxychlor	<2.5	µg/kg	Cyanazine	<.20	µg/kg
Mirex	<.20	µg/kg	Cyanazine amide	<.20	µg/kg
Toxaphene	<50	µg/kg	Deethylatrazine	<.20	µg/kg
Organophosphate insecticides			Deisopropylatrazine	<.20	µg/kg
Diazinon	<.20	µg/kg	Metribuzin	<.20	µg/kg
Malathion	<.20	µg/kg	Prometon	<.20	µg/kg
Methylparathion	<.20	µg/kg	Prometryn	<.20	µg/kg
Parathion	<.20	µg/kg	Simazine	<.20	µg/kg
			Terbutryn	<.20	µg/kg
			Polychlorinated biphenyls (PCBs)		
			PCBs, gross	<5.0	µg/kg

Table 16. Radiochemicals analyzed in reservoir bottom sediment for age dating, Cheney Reservoir, south-central Kansas

[pCi/g, picocuries per gram]

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

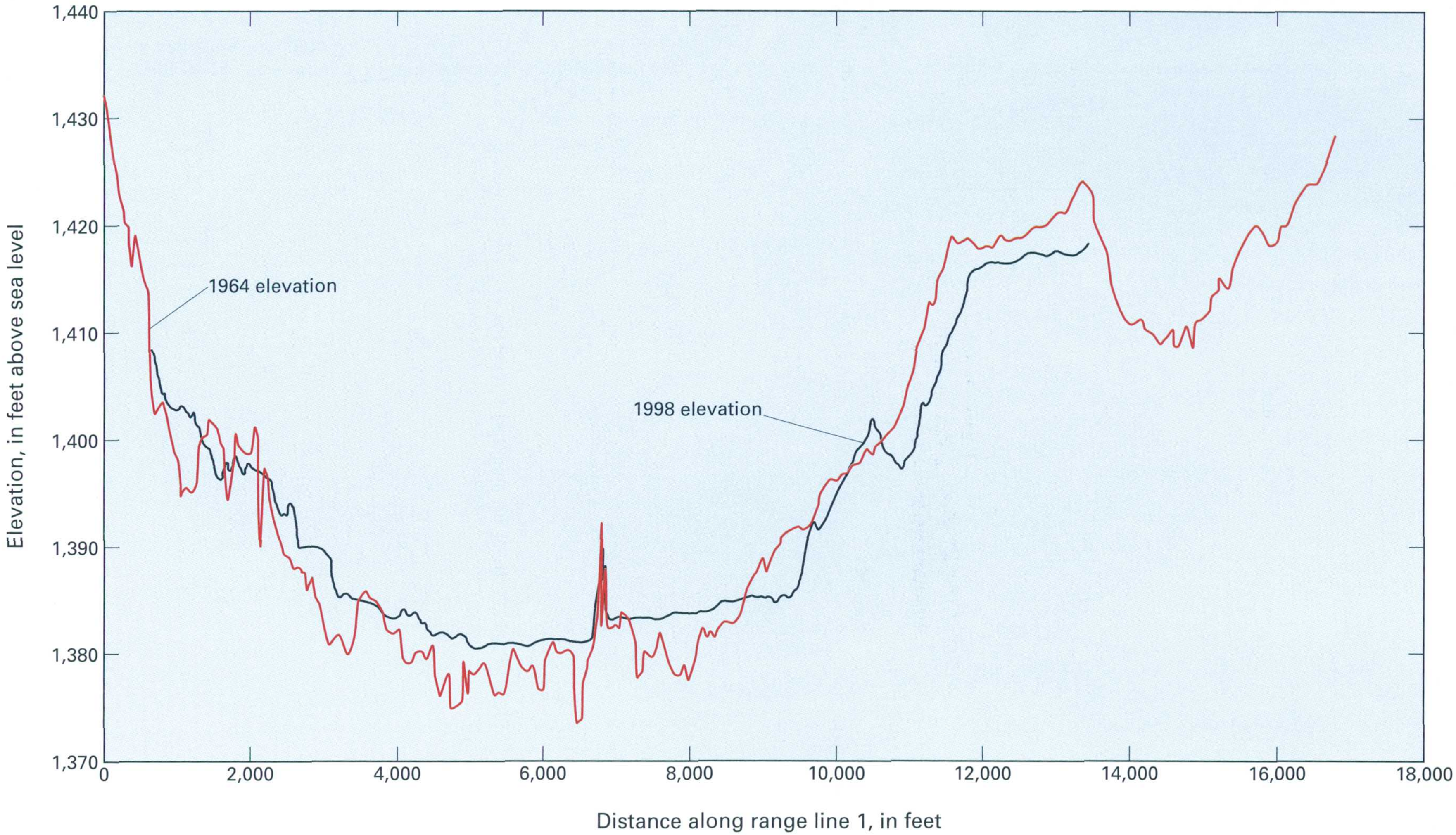


Figure 13. Comparison of 1964 Bureau of Reclamation topographic data and 1998 U.S. Geological Survey bathymetric data for Cheney Reservoir, range line 1. Location of range line shown in figure 3.

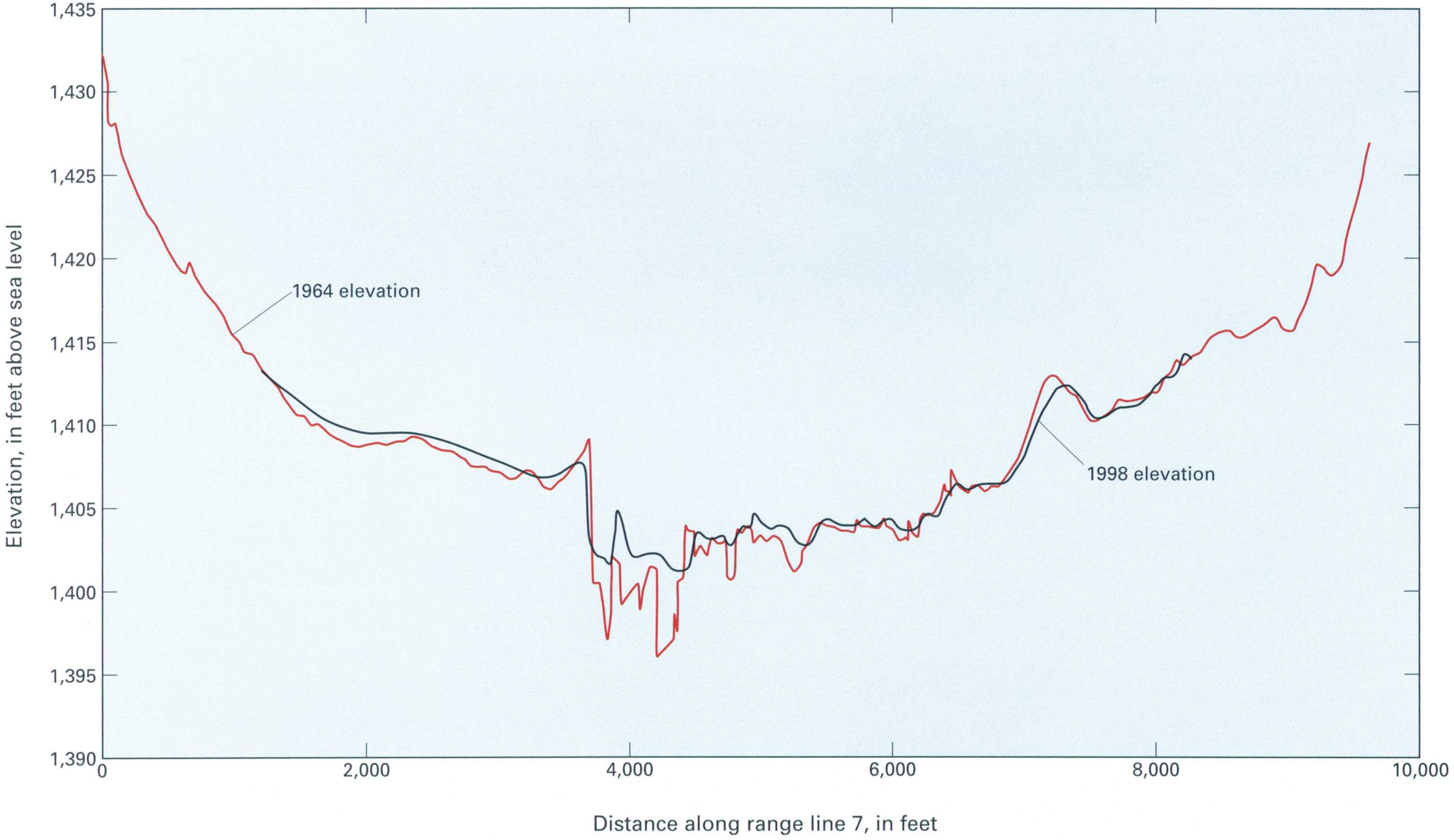


Figure 14. Comparison of 1964 Bureau of Reclamation topographic data and 1998 U.S. Geological Survey bathymetric data for Cheney Reservoir, range line 7. Location of range line shown in figure 3.

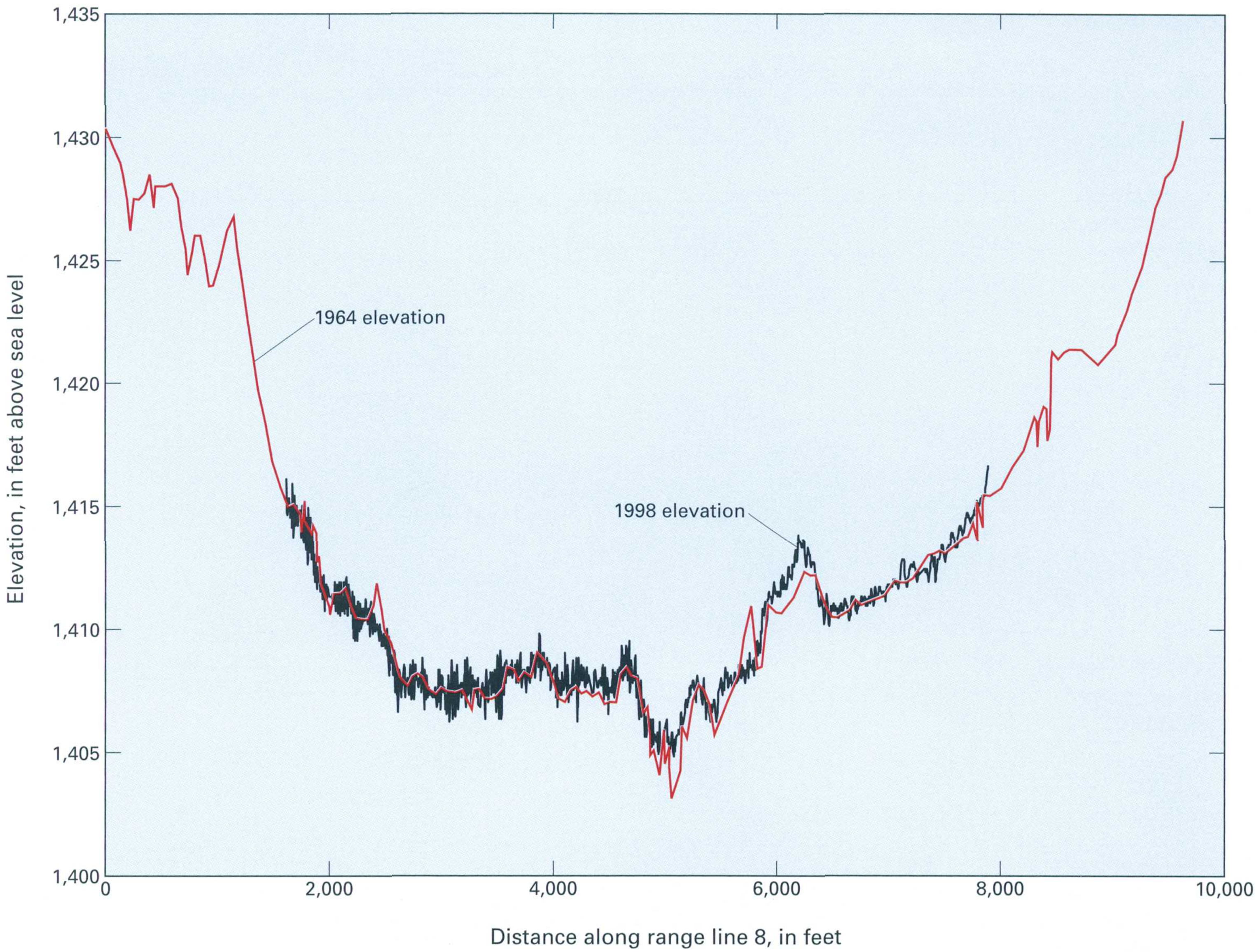


Figure 15. Comparison of 1964 Bureau of Reclamation topographic data and 1998 U.S. Geological Survey bathymetric data for Cheney Reservoir, range line 8. Location of range line shown in figure 3.

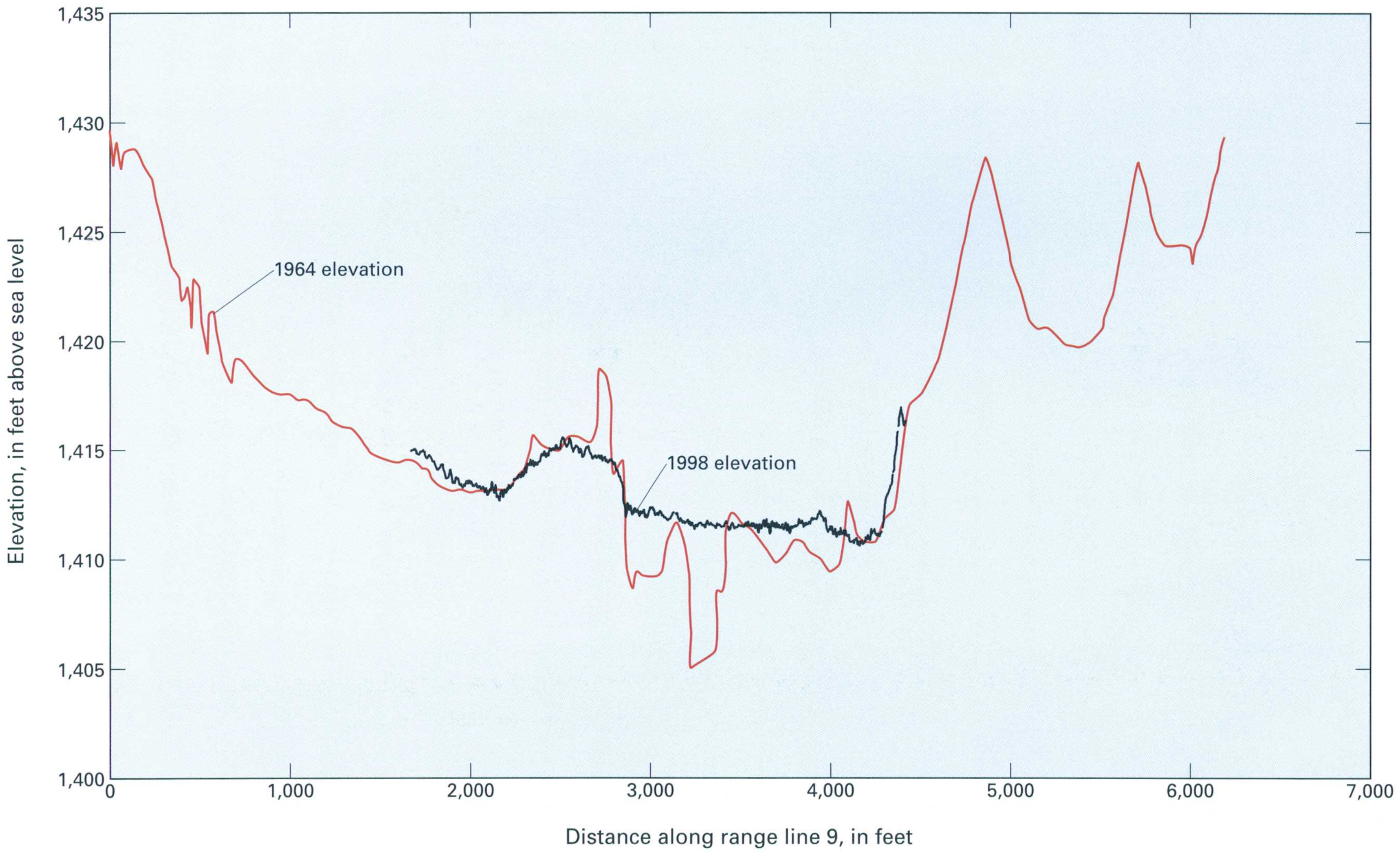


Figure 16. Comparison of 1964 Bureau of Reclamation topographic data and 1998 U.S. Geological Survey bathymetric data for Cheney Reservoir, range line 9. Location of range line shown in figure 3.

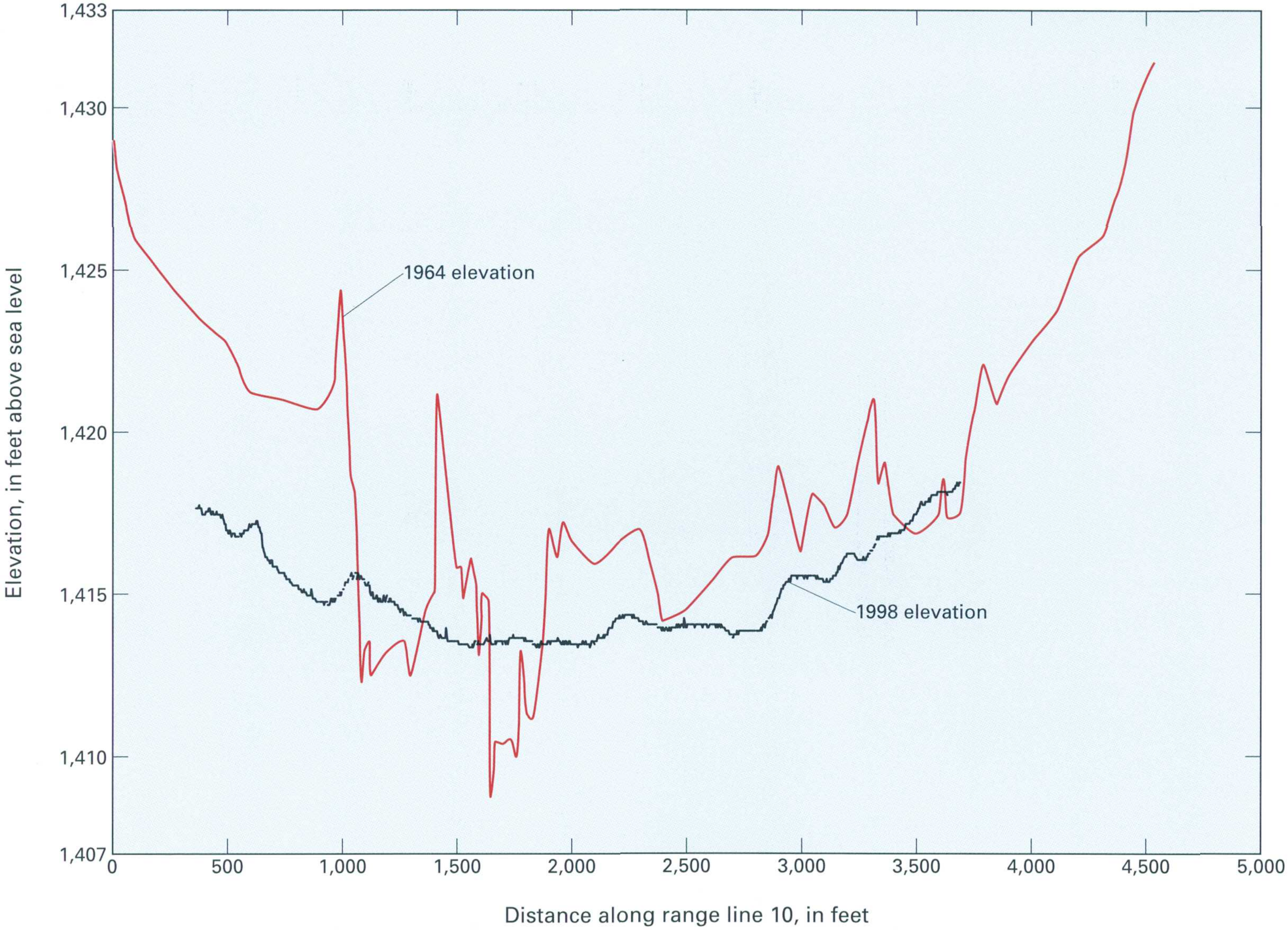


Figure 17. Comparison of 1964 Bureau of Reclamation topographic data and 1998 U.S. Geological Survey bathymetric data for Cheney Reservoir, range line 10. Location of range line shown in figure 3.

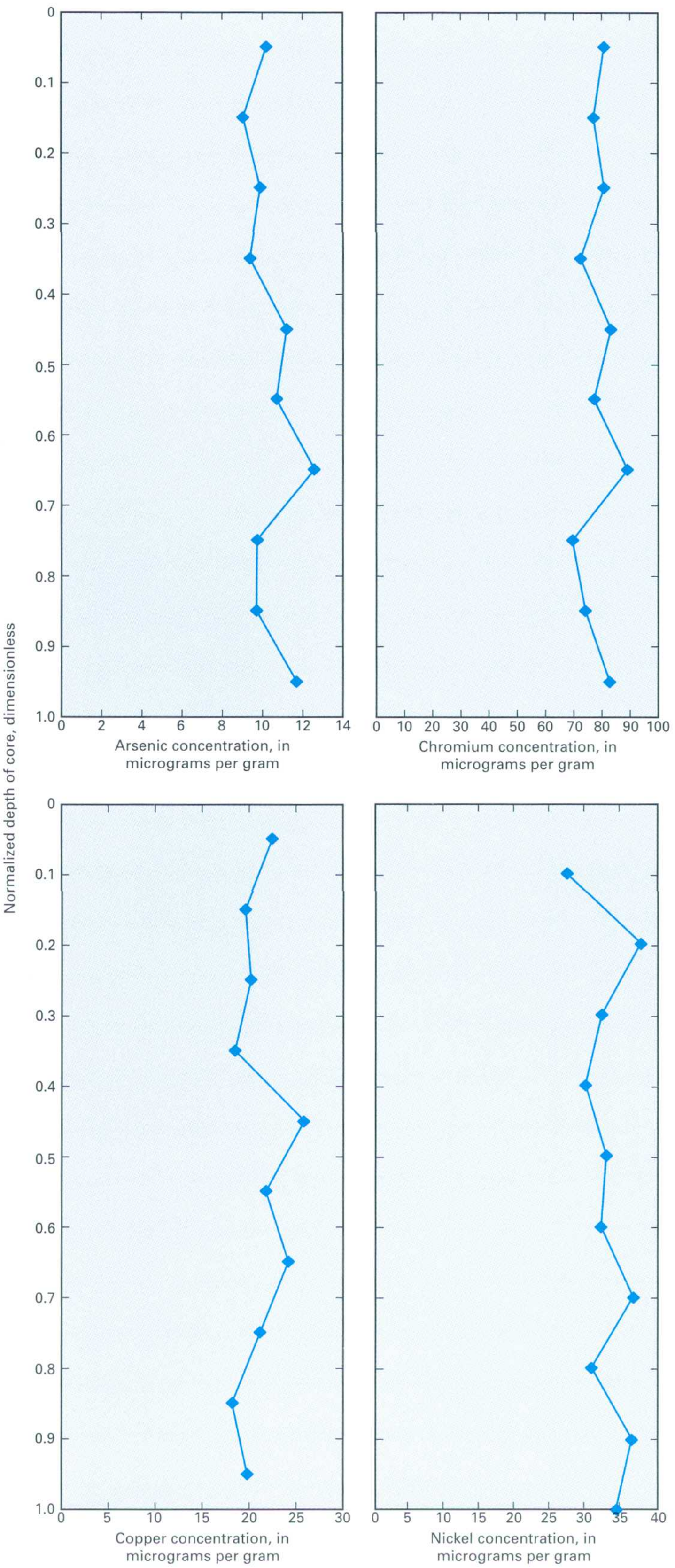


Figure 18. Relation between arsenic, chromium, copper, and nickel concentrations in bottom-sediment sample and normalized depth of sample at coring site M5, Cheney Reservoir, 1999. Location of coring site shown in figure 3.

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Back cover photograph: North Fork Ninnescah River above Cheney Reservoir, south-central Kansas (photograph by Chad Milligan, U.S. Geological Survey, Wichita, Kansas).

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