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Watershed Trend Analysis and Water-Quality Assessment Using Bottom-Sediment Cores From Cheney Reservoir, South-Central Kansas

Water-Resources Investigations Report 98–4227

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

Cover photograph: Outlet-control structure at Cheney Reservoir, south-central Kansas.

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By LARRY M. POPE

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Lawrence, Kansas
1998

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CONVERSION FACTORS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot	1,233	cubic meter
foot	0.3048	meter
inch	25.4	millimeter
microgram per gram	1.0	part per million
microgram per kilogram	1.0	part per billion
mile	1.609	kilometer
milligram per kilogram	1.0	part per million
square mile	2.590	square kilometer
ton (short)	0.9072	megagram
	907.2	kilogram

Temperature can be converted to degrees Celsius (^{o}C) or degrees Fahrenheit (^{o}F) by the equations:

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

Watershed Trend Analysis and Water-Quality Assessment Using Bottom-Sediment Cores From Cheney Reservoir, South-Central Kansas

By Larry M. Pope

Abstract

An examination of Cheney Reservoir bottom sediment was conducted in August 1997 to describe long-term trends and document the occurrence of selected constituents at concentrations that may be detrimental to aquatic organisms. Average concentrations of total phosphorus in bottom-sediment cores ranged from 94 to 674 milligrams per kilogram and were statistically related to silt- and (or) clay-size particles. Results from selected sampling sites in Cheney Reservoir indicate an increasing trend in total phosphorus concentrations. This trend is probably of nonpoint-source origin and may be related to an increase in fertilizer sales in the area, which more than doubled between 1965 and 1996, and to livestock production.

Few organochlorine compounds were detected in bottom-sediment samples from Cheney Reservoir. DDT, its degradation products DDD and DDE, and dieldrin had detectable concentrations in the seven samples that were analyzed. DDT and DDD were each detected in one sample at concentrations of 1.0 and 0.65 microgram per kilogram, respectively. By far, the most frequently detected organochlorine insecticide was DDE, which was detected in all seven samples, ranging in concentration from 0.31 to 1.3 micrograms per kilogram. A decreasing trend in DDE concentrations was evident in sediment-core data from one sampling site. Dieldrin was detected in one sample from each of two sampling sites at concentrations of 0.21 and 0.22 micrograms per kilogram. Polychlorinated biphenyls were not detected in any bottom-sediment sample analyzed.

Selected organophosphate, chlorophenoxy-acid, triazine, and acetanilide pesticides were analyzed in 18 bottom-sediment samples. Of the 23 pesticides analyzed, only the acetanilide herbicide metolachlor was detected (in 22 percent of the samples).

Seven bottom-sediment samples were analyzed for major metals and trace elements. The median and maximum concentrations of arsenic and chromium, the maximum concentration of copper, and all concentrations of nickel in the seven samples were in the range where adverse effects to aquatic organisms occasionally occur. No time trends in trace elements were discernable in the August 1997 data.

INTRODUCTION

Land use and human activities within a watershed can have considerable effects on the water quality in a downstream reservoir. Of particular concern in south-central Kansas are the effects of point-source discharges from municipal wastewater-treatment plants and nonpoint-source runoff from areas used for crop and livestock production. Suspended sediment, nutrients (species of nitrogen and phosphorus), pesticides, and major metals and trace elements may have detrimental effects on reservoir water quality through increased sedimentation, accelerated eutrophication, reduced light penetration, potentially harmful effects to human health and aquatic organisms, and a general decrease in recreational value. One such downstream reservoir in south-central Kansas is Cheney Reservoir, which serves as a public-water supply for more than 300,000 people in the city of Wichita and surrounding area.

Cheney Reservoir is a multipurpose impoundment located on the North Fork Ninnescah River in south-central Kansas (fig. 1). The reservoir was constructed between 1962 and 1965 by the Bureau of Reclamation, U.S. Department of the Interior, to serve as a public water-supply source, to provide downstream flood control, 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 and potability by mitigating contamination and preventing long-term detrimental effects to the aquatic ecosystem.

In 1996, the U.S. Geological Survey (USGS) entered into a cooperative study with the city of Wichita, with technical assistance provided by the Bureau of Reclamation, to define the water quality of the Cheney Reservoir watershed. One of the objectives of this study was to determine historical trends in concentrations of selected water-quality constituents. Such trends can help identify the effects of land use on receiving water bodies and the effectiveness of environmental regulations and land-conservation and management practices.

Traditionally, trend analysis consists of a statistical evaluation of long-term water-quality data. Unfortunately, no long-term, comprehensive water-quality records exist for the Cheney Reservoir watershed. However, because many water-quality constituents are transported attached to suspended sediment, which ultimately can be deposited in a downstream reservoir, an examination of reservoir bottom sediment may provide a record of trends for those constituents. The purposes of this report are to: (1) present the results from an analysis of bottom-sediment cores collected at 13 sites in Cheney Reservoir to provide information on historical changes in water quality and (2) evaluate concentrations of selected water-quality constituents in reservoir bottom sediment in relation to guidelines for protection against adverse biological effects.

Setting

Cheney Reservoir has a surface area of about 15 square miles, a mean depth of about 16 feet, a conservation pool storage of 151,800 acre-feet, and an additional flood-control pool capacity of 80,860 acre-feet. The contributing drainage area of about 933 square miles (597,000 acres) is predominately agricultural (fig. 2) and used mainly for crop and livestock production.

Human population in the watershed is less than 4,000, much of which is associated with the approximately 1,000 farms in the watershed (Cheney Reservoir Watershed Task Force Committee, written commun., 1996). Populations of the six largest towns in the watershed range from less than 200 to slightly more than 1,200 people (Helyar, 1994).

In south-central Kansas, precipitation and temperature vary considerably throughout the year. The average annual (1961–90) precipitation is about 27 inches, most of which occurs during the growing season (April through September). The average annual temperature is 56.6 °F, with an average 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).

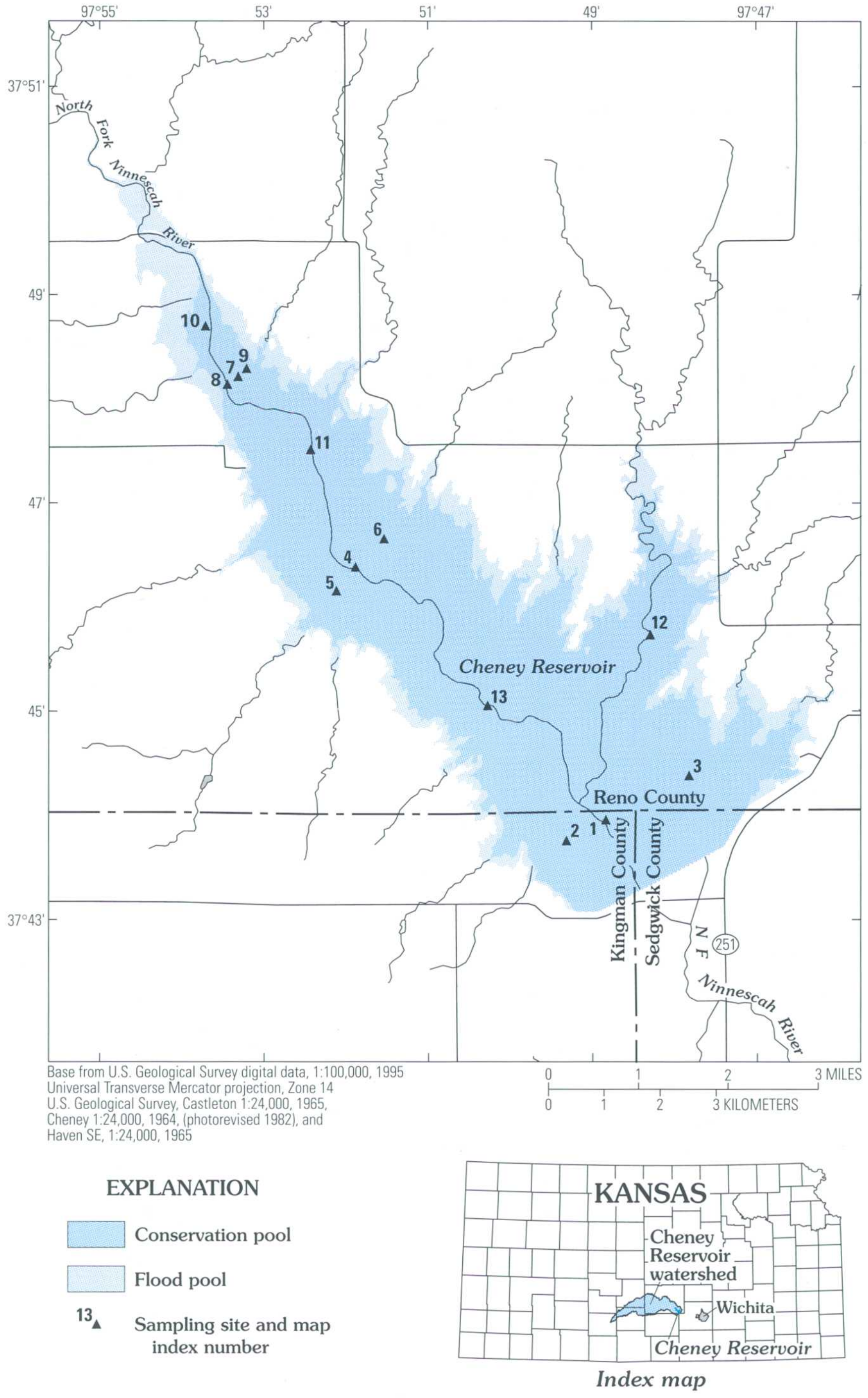
The North Fork Ninnescah River Valley and the surrounding plains are underlain by consolidated rocks of Permian age (230 to 280 million years old) covered by unconsolidated fluvial and windblown deposits of Pleistocene age (less than 1.5 million years old) (Zeller, 1968). Soils in the Cheney Reservoir 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 about 3 percent. Many of the soils in the watershed are subject to erosion by wind and rainfall runoff (Rockers and others, 1966).

Topography in the Cheney Reservoir watershed generally consists of flat to gently sloping hills. Total topographic relief is about 550 feet, with maximum local relief (within 1 mile) of about 50 feet.

Cheney Reservoir is considered eutrophic (nutrient enriched) because of large nutrient inputs from the watershed. Algal blooms during the summer months have created taste and odor problems in treated drinking water for the city of Wichita (Cheney Reservoir Watershed Task Force Committee, written commun., 1996).

Agricultural Production

Land use in a watershed can have substantial effects on water quality (Omernik, 1976; Polls and Lanyon, 1980; Kashner and Hunter, 1983; Helgesen

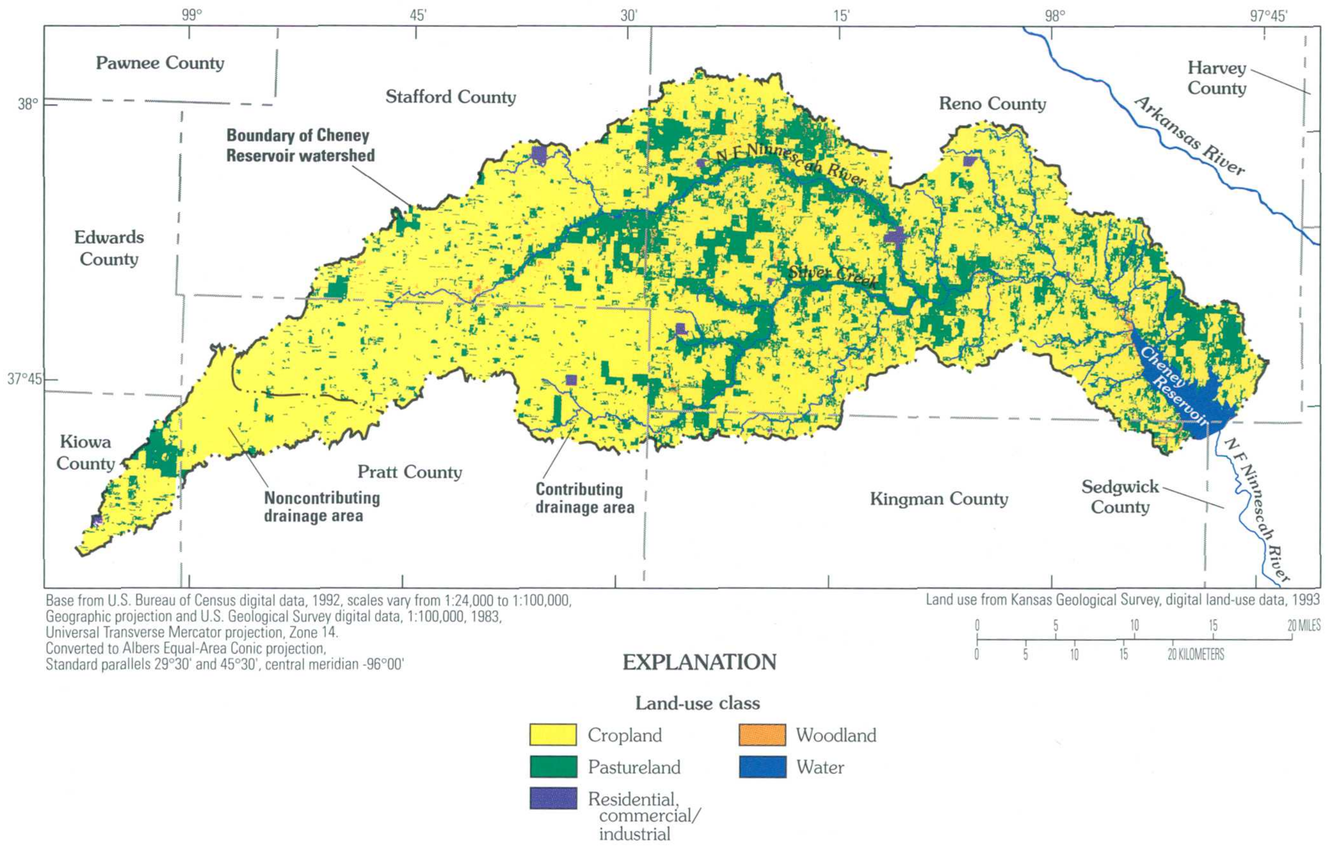


Base from U.S. Geological Survey digital data, 1:100,000, 1995
Universal Transverse Mercator projection, Zone 14
U.S. Geological Survey, Castleton 1:24,000, 1965,
Cheney 1:24,000, 1964, (photorevised 1982), and
Haven SE, 1:24,000, 1965

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

and others, 1993). These effects may be the result of many diverse activities that include urbanization (industrial, commercial, and residential areas), mining of minerals and metal ore, oil and gas production, and agricultural production. The Cheney Reservoir watershed is almost exclusively devoted to agriculture (fig. 2); therefore, the general (nonlocal) effects of other land-use activities probably are minimal.

Agricultural activities have been shown to affect instream concentrations of constituents such as suspended sediment (Johnson and others, 1979; Schwab and others, 1980), nutrients (Johnson and others, 1979;



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.

Beaulac and Reckhow, 1982), and pesticides (Wauchope, 1978; Pope and others, 1997). The transport of these constituents to downstream reservoirs can create water-quality problems or accelerate eutrophication (Bachman, 1980). Agricultural effects on water quality may be the result of crop production (Wendt and Corey, 1980; Baker, 1985), irrigation associated with crop production (Balsters and Anderson, 1979; Berg and Carter, 1980), and livestock production (Terry and others, 1981; Hollon and others, 1982; Dixon and others, 1983). Therefore, an examination of the extent to which these activities occur in the Cheney Reservoir watershed is necessary to establish or indicate possible cause-and-effect relationships with water-quality constituents determined in Cheney Reservoir bottom-sediment samples.

Estimates for crop production, irrigated acreage, and livestock production in the Cheney Reservoir watershed were calculated by multiplying the annual county crop production, irrigated acreage, and livestock inventory values provided by the Kansas State Board of Agriculture and U.S. Department of Agriculture (1964–94) and the Kansas Department of Agriculture and U.S. Department of Agriculture (1995–97) by the percentage of each county in the watershed and totalling these products.

Much of the Cheney Reservoir watershed is used for crop production (fig. 2) that has a substantial economic value. For example, the value of the four major crops (corn, sorghum, soybeans, and wheat) produced in Reno County (fig. 1) in 1996 was about $74,000,000 (Kansas Department of Agriculture and U.S. Department of Agriculture, 1997).

Since 1964, the percentage of the watershed used for crop production has fluctuated between 46 and 57 percent (fig. 3), with a long-term (1964–96) annual average of 52 percent. Fluctuations may be due to unstable market conditions, weather patterns, or government programs such as the Conservation Reserve Program that removed highly erodible cropland from production. No clear trend in the percentage of the Cheney Reservoir watershed devoted to crop production is indicated in figure 3.

The majority of the major crop area in the Cheney Reservoir watershed is used for the production of wheat. For example, of the estimated 327,000 acres

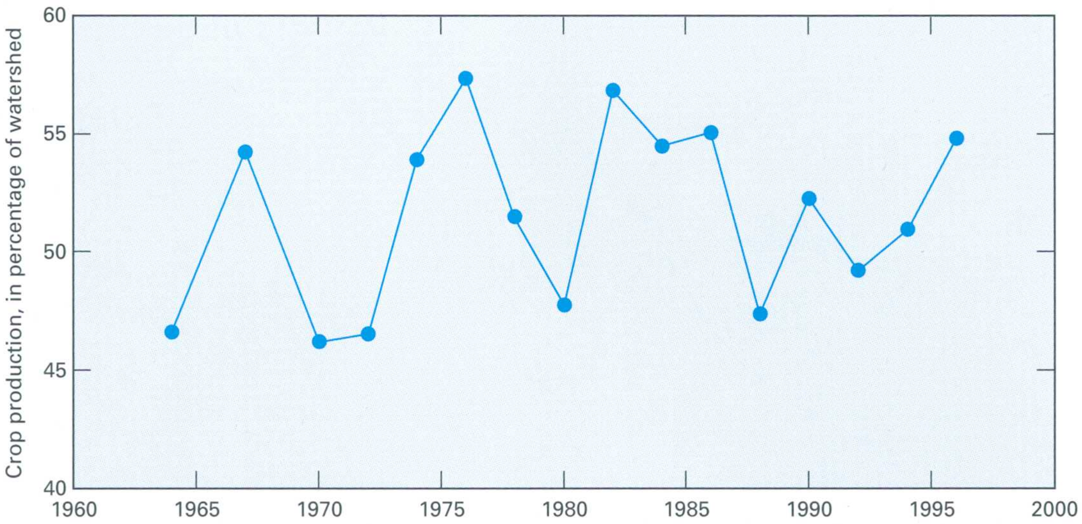


Figure 3. Percentage of Cheney Reservoir watershed in the production of corn, sorghum, soybeans, and wheat for selected years between 1964 and 1996 (source of data: Kansas State Board of Agriculture and U.S. Department of Agriculture, 1964–94; Kansas Department of Agriculture and U.S. Department of Agriculture, 1995–97).

used in 1996 for the production of corn, sorghum, soybeans, and wheat in the watershed, 63 percent was planted in wheat, about 10 percent in corn, 24 percent in sorghum, and 3 percent in soybeans.

The percentage of the Cheney Reservoir watershed devoted to irrigated crop production (corn, sorghum, and wheat) has increased considerably since 1970 (fig. 4). Between 1970 and 1982, irrigated crop production increased about nine times (from 0.63 to 6.0 percent). Since 1982, irrigated production has remained fairly constant at about 6 percent except for the late 1980's when the number of irrigated acres decreased presumably in response to economic conditions.

Livestock production is a large part of the economy in the Cheney Reservoir watershed. For example, in 1996 the total value of livestock and poultry (includes meat animals, chickens, eggs, turkeys, wool, and milk) in Reno County (fig. 1) was more than $41,000,000, ranking it 16th of the State's 105 counties (Kansas Department of Agriculture and U.S. Department of Agriculture, 1997). Much of this value is associated with the production of cattle, hogs, and sheep.

Between 1964 and 1996, the average annual inventory of cattle and calves in the Cheney Reservoir watershed was 64,000. Annual inventory fluctuations (fig. 5) around this average presumably are in response to fluctuations in market conditions. No clear long-term (1964–96) trend in annual cattle inventory is apparent in figure 5; however, a slight upward trend is evident since 1976 when inventories were at minimum values (55,000). The cattle and calf inventory for 1996 was about 20,000 greater than the 1976 minimum.

Historical annual inventories of hogs and sheep have been considerably less than those for cattle (fig. 5). Long-term (1964–96) average annual inventories were about 18,000 for hogs and pigs and about 9,400 for sheep and lambs. Although no historical trend in hogs and pigs is evident in figure 5, a downward trend in annual inventories of sheep and lambs has been occurring since at least 1964. This downward trend may be the result of depressed market conditions and (or) an effort by producers to shift production to cattle and hogs.

METHODS

Bottom-sediment cores were collected at 13 sampling sites (fig. 1, table 1) in Cheney Reservoir on August 19 and 20, 1997. Bottom-sediment sampling sites were selected to define spatial variability in depth of sediment and variability in particle-size and chemical composition relative to reservoir features such as proximity to the original river channel and longitudinal location.

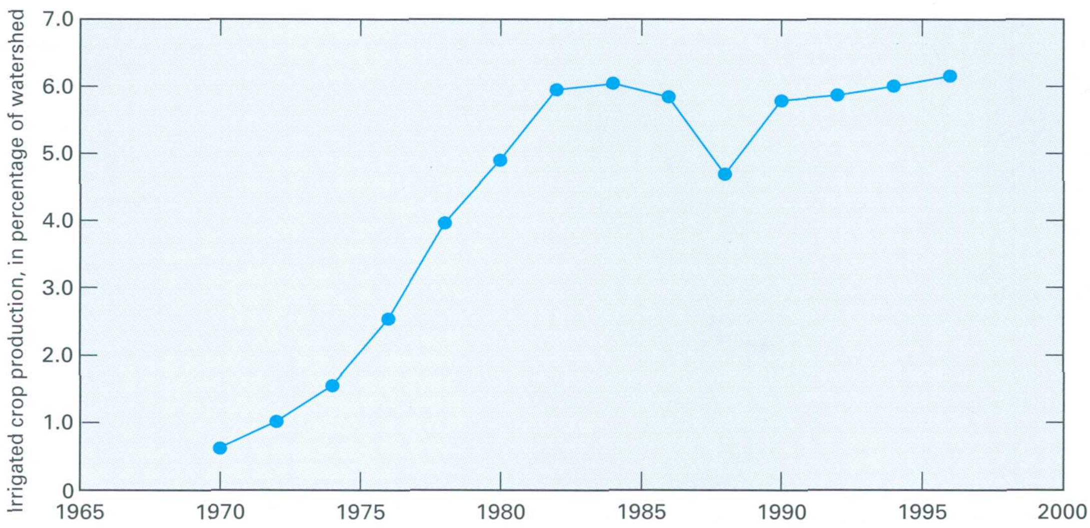


Figure 4. Percentage of Cheney Reservoir watershed in irrigated production of corn, sorghum, and wheat for selected years between 1970 and 1996 (source of data: Kansas State Board of Agriculture and U.S. Department of Agriculture, 1970–94; Kansas Department of Agriculture and U.S. Department of Agriculture, 1995–97).

Sediment-Core Collection, Processing, and Analysis

Bottom-sediment cores were collected with a gravity corer using round transparent plastic liners of cellulose acetate butyrate construction with a 2.625-inch inside diameter. One to three cores were collected at each site to provide a sufficient quantity of material for the intended analyses.

All of the bottom-sediment cores collected penetrated into pre-reservoir material. This was determined by a change in physical appearance of the sediment, change in particle-size composition, or the presence of pre-reservoir soil-surface organic matter such as small sticks, plant material, or roots or root hairs. The presence of pre-reservoir material ensured that a complete sedimentation record was represented by each core sample.

Processing of core samples was conducted at the USGS laboratory in Lawrence, Kansas. The plastic liners were cut longitudinally in two places 180 degrees apart. The cuts were partially completed with a 1/8-inch hand-held rotary saw 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. Each core then was segmented into equal intervals that ranged from 0.1 to about 0.3 foot depending on the length of core and the amount of bottom material required for the planned physical and chemical determinations.

All core segments were analyzed for percentage moisture, 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). Core segments from selected sites were analyzed at the USGS National Water-Quality Laboratory in Arvada, Colorado, for total phosphorus, organophosphate, and chlorophenoxy-acid pesticides, and major metals and trace elements according to methods presented in Fishman (1993) and for organochlorine compounds according to procedures in Foreman and others (1994). Selected core segments also were analyzed for triazine and acetanilide pesticides at the USGS laboratory in Lawrence, Kansas, according to methods presented in Mills and Thurman (1992). Analytical results for all sediment-core samples collected during this study are on file at the USGS office in Lawrence, Kansas.

Quality Control

At selected sampling sites during this study, multiple bottom-core samples were collected to provide the required amount of material for planned physical and chemical determinations. As a result, it was necessary to evaluate “within-site” variability (sediment-quality variability between core samples). Within-site variability was evaluated through the collection and analysis of

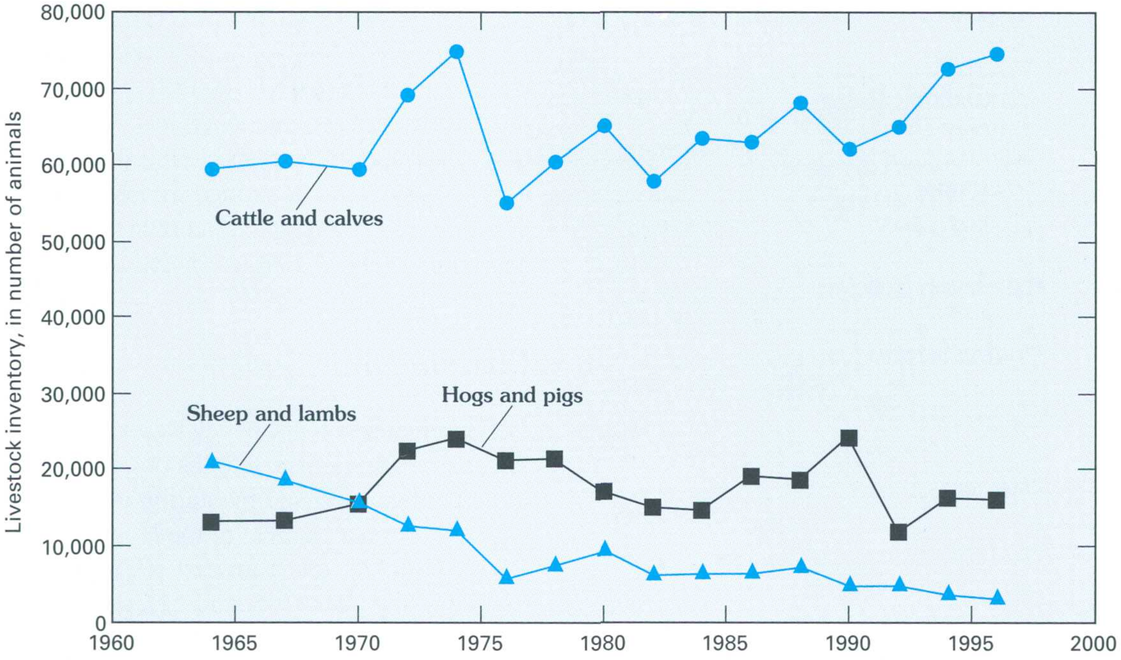


Figure 5. Livestock inventories in the Cheney Reservoir watershed for selected years between 1964 and 1996 (source of data: Kansas State Board of Agriculture and U.S. Department of Agriculture, 1964–94; Kansas Department of Agriculture and U.S. Department of Agriculture, 1995–97).

sequential replicate samples collected at sampling sites 1 and 2 (fig. 1). The two replicate samples collected at site 1 each were segmented into 0.2-foot intervals for a total of six subsample pairs. Because of little sediment deposition at site 2 (0.30 foot), the two replicate samples collected at this site were not segmented. Each core segment or length was homogenized and subsequently analyzed for total phosphorus concentration. Relative percent differences between replicate total phosphorus 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 percent differences in total phosphorus concentrations for the six core segments from sampling site 1 was 0.5 to 8.5 percent, with a median value of 2.3 percent. The relative percent difference in sequential replicates collected at sampling site 2 was 1.3 percent. These results indicate that within-site variability in the quality of deposited sediment is small in Cheney Reservoir and probably not a concern when multiple-core samples were needed to provide sufficient bottom material for physical and chemical determinations.

Analytical quality control (analytical precision and reproducibility) consisted of analyses of split replicate samples of bottom sediment. Split replicate samples were prepared by homogenizing core segments and splitting each segment into two samples. The homogenization process was designed to ensure that both split samples were chemically equivalent and that analytical differences were the result of inherent laboratory variability in procedures or methodologies.

Analytical results for concentrations of total phosphorus in split replicate samples were evaluated for a total of 18 core segments collected at sampling sites 1 (6 segments), 4 (9 segments), and 13 (3 segments). Relative percent differences in split replicate samples for total phosphorus among the 18 core segments ranged from 0.1 to 6.4 percent, with a median value of 1.4 percent. These results indicate that variability in analytical precision and reproducibility for total phosphorus were small and probably not a concern during this study.

One split replicate sample pair from sampling site 4 was prepared and analyzed for selected major metals and trace elements. Analytical results and relative percent differences of these replicate samples are presented in table 2. All relative percent differences listed in table 2 are less than 5.0 percent with the exception of mercury, which is 20 percent. The relatively large percent difference for mercury is due mainly to the extremely small mercury concentrations in the replicate samples and the fact that the reporting units were to the nearest 0.01 µg/g (microgram per gram) and,

Table 1. Location of bottom-sediment sampling sites in Cheney Reservoir

Map index number (fig. 1)	U.S. Geological Survey site identification number	Latitude (lat.) and longitude (long.)
1	374357097484900	lat. 37°43'56.80" long. 97°48'48.97"
2	374344097491800	lat. 37°43'44.83" long. 97°49'18.00"
3	374422097474800	lat. 37°44'22.31" long. 97°47'48.34"
4	374623097515200	lat. 37°46'22.58" long. 97°51'51.85"
5	374608097520500	lat. 37°46'08.88" long. 97°52'05.70"
6	374638097513100	lat. 37°46'38.86" long. 97°51'31.10"
7	374812097531800	lat. 37°48'12.31" long. 97°53'17.70"
8	374808097532500	lat. 37°48'08.03" long. 97°53'25.66"
9	374817097531100	lat. 37°48'17.20" long. 97°53'11.68"
10	374841097534100	lat. 37°48'41.53" long. 97°53'41.78"
11	374730097522400	lat. 37°47'30.40" long. 97°52'24.68"
12	374543097481600	lat. 37°45'43.27" long. 97°48'16.52"
13	374502097501500	lat. 37°45'02.82" long. 97°50'15.42"

therefore, any analytical difference between the two values would represent a large percentage. Relative percent differences were not calculated for constituents with nondetected values (less-than values). The results in table 2 indicate that laboratory precision and reproducibility are excellent in the analyses of major metals and trace elements in reservoir bottom sediment for this study.

EVALUATION OF BOTTOM-SEDIMENT CORE ANALYSES

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 study 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.

Distribution of Sediment

Sedimentation in Cheney Reservoir is not uniform. An examination of the lengths of core samples (fig. 6) indicates that most sedimentation is occurring in or near the original channel of the North Fork Ninnescah River and in the upstream part of the reservoir. At several sampling sites (3, 5, and 12), sedimentation was too little to process samples for physical or chemical determinations.

The length of core samples shown in figure 6 should not be considered an indication of sedimentation depth. Research at Hillsdale Lake in northeast Kansas documented a phenomenon referred to as "core shortening" when samples are collected with a gravity corer (Juracek, 1997). As explained by 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 after penetration, but before retrieval from the sediment." Emery and Hulsemann (1964) and Blomqvist and Bostrom (1987) attribute the core-shortening phenomenon to friction of the sediment against the inner wall of the plastic liner. The friction causes the core sample to underrepresent 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).

The core-shortening phenomenon can be substantial. Core shortening of 50 percent of the original depth of sediment has been reported (Emery and Hulsemann, 1964; Hongve and Erlandsen, 1979). Core shortening was observed during the collection of the Cheney Reservoir samples, some of which approached the 50-percent reduction documented by other researchers. However, core shortening is not a consideration for concentrations and trend results presented in this report because a complete sedimentation record was represented in each core sample and possible thinning of

Table 2. Analytical results and relative percent differences for selected major metals and trace elements for split replicate samples of bottom sediment from sampling site 4 in Cheney Reservoir, August 1997

[μg/g, micrograms per gram; <, less than; --, not calculated]

Constituent and unit of measurement	Replicate sample concentration A	Replicate sample concentration B	Relative percent difference
Aluminum, percent	6.2	6.7	3.9
Antimony, μg/g	.74	.74	0
Arsenic, μg/g	7.5	7.5	0
Barium, μg/g	520	570	4.6
Beryllium, μg/g	2	2	0
Bismuth, μg/g	<10	<10	--
Cadmium, μg/g	.40	.40	0
Calcium, percent	3.0	3.2	3.2
Cerium, μg/g	78	77	.6
Chromium, μg/g	62	60	1.6
Cobalt, μg/g	14	13	3.7
Copper, μg/g	15	14	3.4
Eropium, μg/g	<2.0	<2.0	--
Gallium, μg/g	16	15	3.2
Gold, μg/g	<8.0	<8.0	--
Holmium, μg/g	<4.0	<4.0	--
Iron, percent	2.9	3.0	1.7
Lanthanum, μg/g	41	40	1.2
Lead, μg/g	16	17	1.9
Lithium, μg/g	44	48	4.3
Magnesium, percent	1.4	1.4	0
Manganese, μg/g	530	540	.9
Mercury, μg/g	.03	.02	20
Molybdenum, μg/g	<2.0	<2.0	--
Neodymium, μg/g	37	36	1.4
Nickel, μg/g	26	26	0
Niobium, μg/g	14	13	3.7
Potassium, percent	2.1	2.2	2.3
Scandium, μg/g	10	10	0
Selenium, μg/g	.47	.48	1.1
Silver, μg/g	.10	.10	0
Sodium, percent	.71	.77	4.1
Strontium, μg/g	150	150	0
Sulfur, μg/g	.13	.13	0
Tantalum, μg/g	<40	<40	--
Thorium, μg/g	13.2	14.0	2.9
Tin, μg/g	<5.0	<5.0	--
Titanium, percent	.33	.33	0
Uranium, μg/g	2.60	2.41	3.8
Vanadium, μg/g	83	85	1.2
Ytterbium, μg/g	2	2	0
Yttrium, μg/g	23	23	0
Zinc, μg/g	73	75	1.4

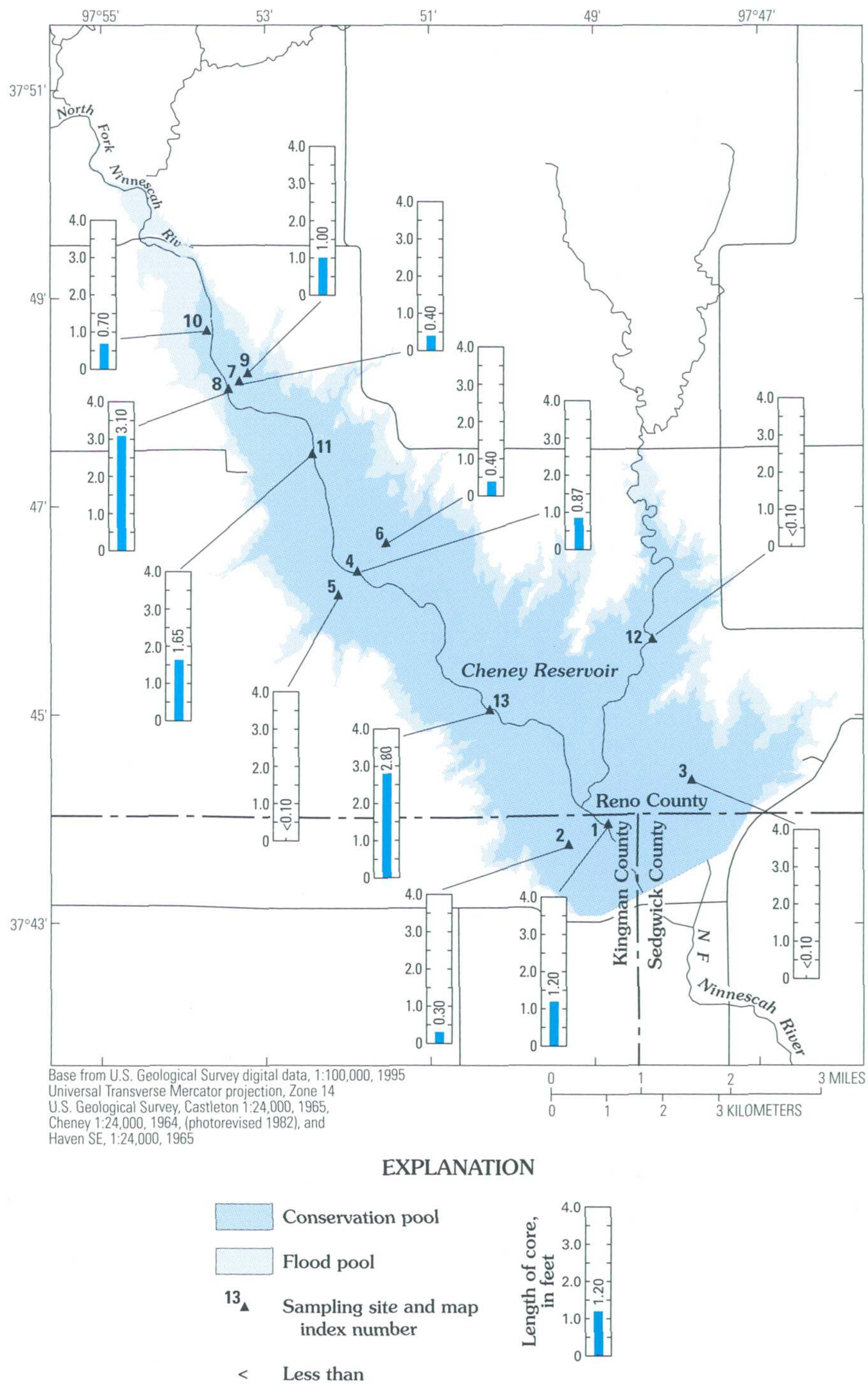
sediment layers during sampler penetration would not affect concentration distribution in the sediment profile.

As with sediment in general, the distribution of sediment particle sizes is not uniform in Cheney Reservoir (fig. 7). Most all sand-size particles (greater than 0.062 millimeter in diameter) have been deposited in the upstream part of the reservoir, whereas sediment in the remainder of the reservoir consists mainly of silt- and (or) clay-size particles (less than 0.062 millimeter in diameter). The sand probably is transported into the reservoir during high flow in the North Fork Ninnescah River as either suspended particles or as bed load. Upon entering the relatively calm water of the reservoir (the upstream part of the reservoir), the sand particles in the river water are lost from suspension. The finer silt- and (or) clay-size particles, on the other hand, may remain in suspension longer and be distributed more widely throughout the reservoir. Additionally, these finer particles may be resuspended by wind and wave action (Laenen and LeTourneau, 1995) and redeposited in the deeper parts (old river channel) of the reservoir where they may be less affected by wind and waves. This resuspension and redeposition may explain why such little sediment deposition was found at sampling sites removed from the main river channel (fig. 6).

Phosphorus

Phosphorus is a macronutrient required by plants for growth and reproduction. It is present in soils in organic forms and as inorganic iron, manganese, aluminum, and calcium phosphates. Phosphorus is necessary in cellular reactions involving photosynthesis, respiration, energy storage and transfer, and cell division, growth, and genetic coding (Sine, 1993, p. B46). Ecologically, phosphorus is the single most-controlling factor in maintaining biogeochemical cycles because of its role in energy-transfer systems and its normally short supply (Reid and Wood, 1976, p. 236). Phosphorus availability is a critical factor in the eutrophication of water bodies because the nutrient in shortest supply controls biological production rates (Hem, 1985, p. 128).

Phosphorus often is added to agricultural soils to stimulate plant growth and increase crop yields. It is applied as an inorganic phosphate or as a component of manure from confined feeding operations or human sewage disposal. However, the use of phosphorus as a fertilizer has detrimental effects on water bodies



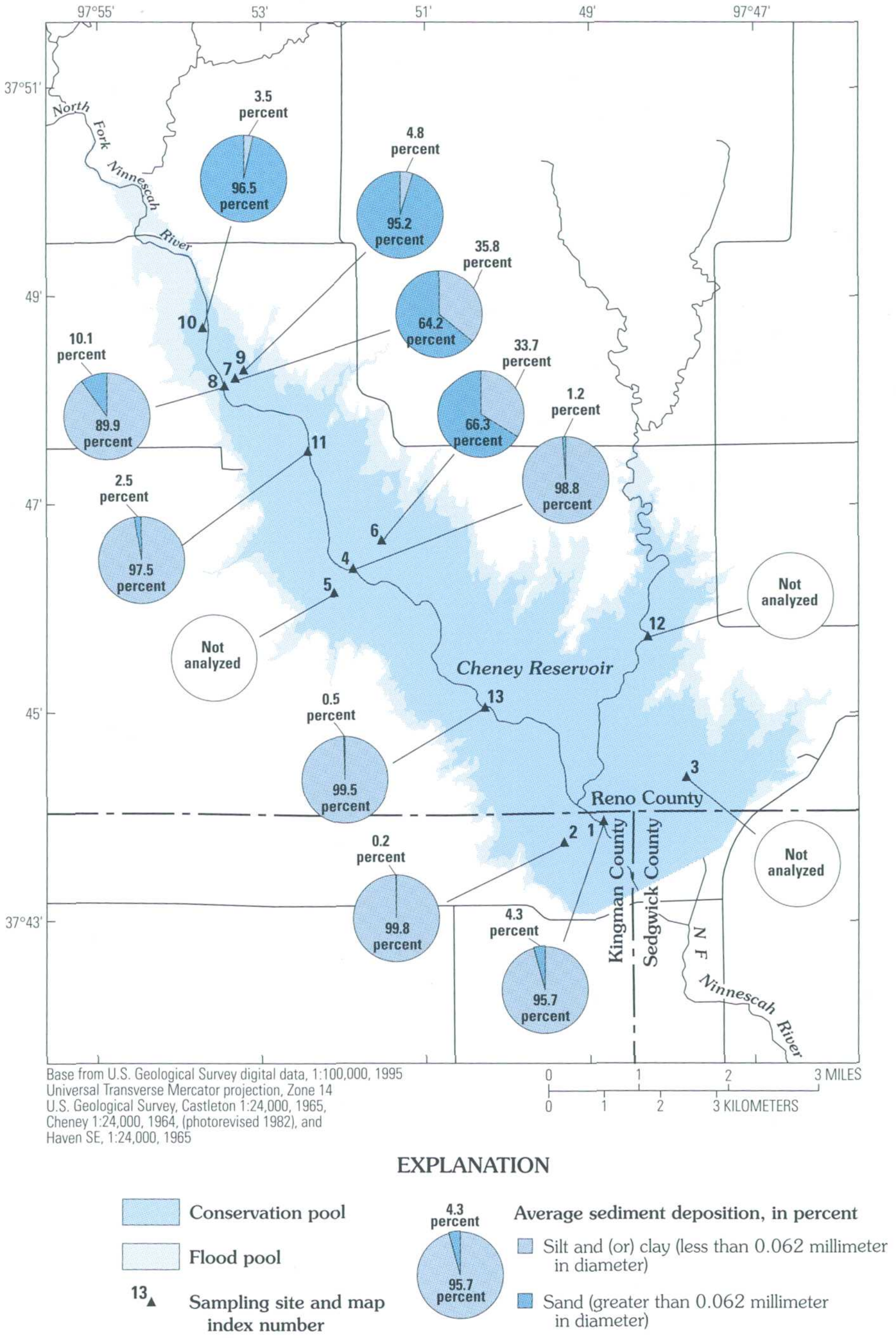
Base from U.S. Geological Survey digital data, 1:100,000, 1995
Universal Transverse Mercator projection, Zone 14
U.S. Geological Survey, Castleton 1:24,000, 1965,
Cheney 1:24,000, 1964, (photorevised 1982), and
Haven SE, 1:24,000, 1965

Figure 6. Length of bottom-sediment core samples collected during August 1997.

receiving runoff from source areas when excessive concentrations of phosphorus promote algal growth (create algal blooms), which can produce taste and odor problems in treated drinking water.

Reservoir sediment may contain large quantities of phosphorus deposited as a result of inflow transport of particulate forms and of dissolved forms, which ultimately may be used during in-lake microbial cellular processes with subsequent bottom deposition upon death of the organisms. Examination of reservoir bottom sediment may reveal the extent and historical trend of phosphorus deposition.

The average concentration of total phosphorus in bottom-sediment core samples varied considerably

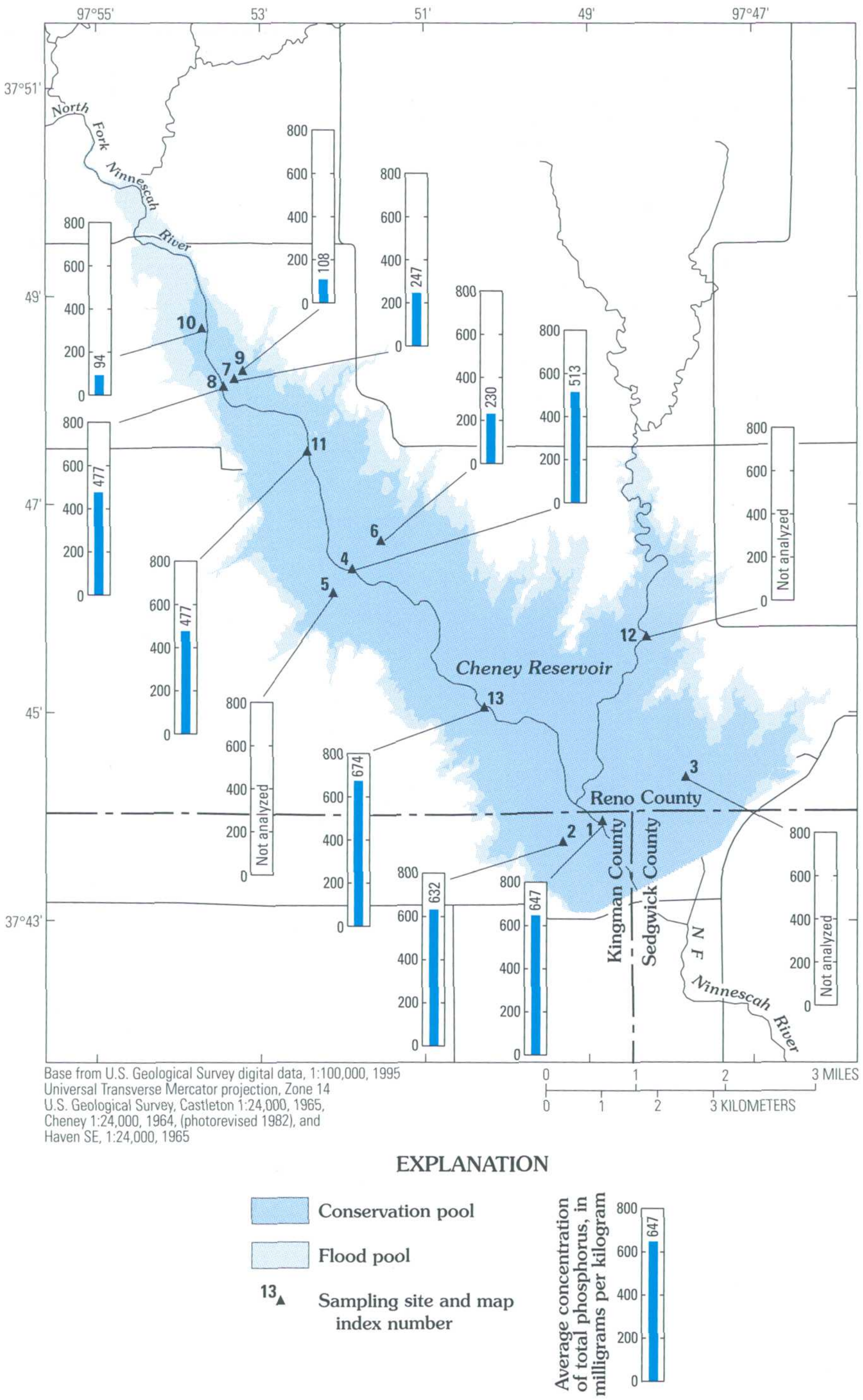


Base from U.S. Geological Survey digital data, 1:100,000, 1995
Universal Transverse Mercator projection, Zone 14
U.S. Geological Survey, Castleton 1:24,000, 1965,
Cheney 1:24,000, 1964, (photorevised 1982), and
Haven SE, 1:24,000, 1965

Figure 7. Average particle-size composition of bottom-sediment cores collected during August 1997.

among the 10 sampling sites in Cheney Reservoir with sufficient sediment deposition to sample (fig. 8). Average concentrations ranged from 94 mg/kg (milligrams per kilogram, equivalent to parts per million) at sampling site 10 in the extreme upstream part of the reservoir to 674 mg/kg at sampling site 13. The mean of the average total phosphorus concentration in the 10 sampled cores was 410 mg/kg.

A comparison of the results presented in figure 8 with those in figure 7 appears to indicate a direct relationship between total phosphorus concentrations and percentage of silt- and (or) clay-size particles in the sediment cores. In fact, upon more detailed examination, a statistically significant relation (correlation coefficient = 0.96, p value = less than 0.001) exists (fig. 9). The correlation coefficient (r) is a measure of



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 8. Average concentrations of total phosphorus in bottom-sediment core samples from Cheney Reservoir, August 1997.

the strength of the relationship between two variables, and its range is 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 (Blalock, 1979). The p value is a measure of the statistical significance of a relationship—the smaller the p value, the stronger the statistical significance of the correlation.

The regression analysis presented in figure 9 indicates that, in Cheney Reservoir, phosphorus in bottom sediment is sorbed mostly to silt- and (or) clay-size

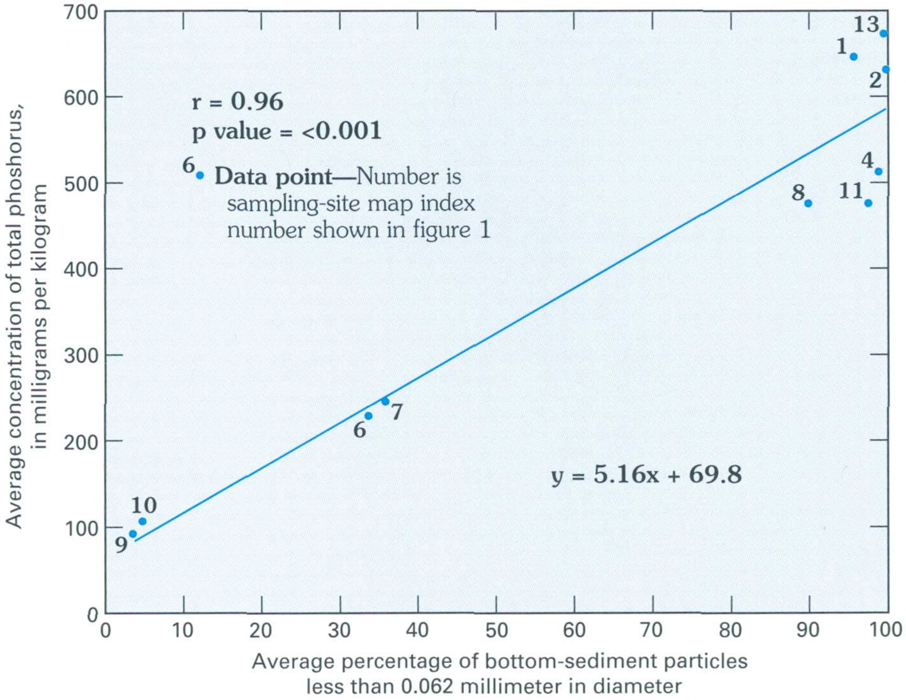


Figure 9. Relation between average percentage of bottom-sediment particles less than 0.062 millimeter in diameter (silt and clay) and average concentrations of total phosphorus in bottom-sediment core samples from 10 sampling sites in Cheney Reservoir, August 1997.

particles. The implication of this observation for watershed management is that, to mitigate the transport of phosphorus into Cheney Reservoir, it would be necessary either to reduce the annual distribution of phosphorus in the watershed or to control the movement of silt- and (or) clay-size particles from the watershed.

Historical trends in total phosphorus loadings into Cheney Reservoir were examined at four sampling sites (1, 4, 10, and 13) located in or near the original North Fork Ninnescah River channel. These sampling sites were selected to represent main sediment-deposition areas and sites at which sediment-particle size was nearly homogeneous. Uniformity in particle size limited variability in total phosphorus concentrations associated with particle size (fig. 9). Therefore, variability in total phosphorus concentrations at these sites represent historical trends and not variability caused by variation in particle sizes. Sedimentation at sampling sites 1, 4, and 13 consisted of mostly silt- and (or) clay-size particles, whereas sedimentation at sampling site 10 consisted of mostly sand-size particles.

To make direct site-to-site comparisons, variability in depth of sedimentation at the sampling sites (fig. 6) was normalized by dividing the mid-interval depth of each sampled core segment by the total depth of sediment (core length). This produced dimensionless normalized depths with a theoretical range from 0 to 1.0 for each sediment-core segment collected at the four sampling sites (fig. 10).

Results from sampling sites 1, 4, and 10 (fig. 10) indicate increasing trends over time in total phosphorus concentrations. The most-recent sediment (approaching zero normalized depth) had concentrations considerably larger than the oldest sediment (approaching 1.0 normalized depth). These data were statistically evaluated to correlate total phosphorus concentrations with sediment depth. Correlation coefficients (r) between sampling sites 1, 4, and 10 ranged from 0.71 to 0.95, with p values of less than 0.07. Results from sampling site 4 indicated a very significant correlation ($r = 0.95$, p value = less than 0.001) between total phosphorus concentration and sediment depth. In contrast to these results, correlation results from sampling site 13 indicate a decreasing trend in total phosphorus; although the correlation coefficient was not as high ($r = -0.61$), the relation was significant at a reasonable level (p value = 0.06). The reason for the apparent reversal in trend at sampling site 13 is not known.

The mixing of sediment layers under certain conditions, such as extreme floods or substantial

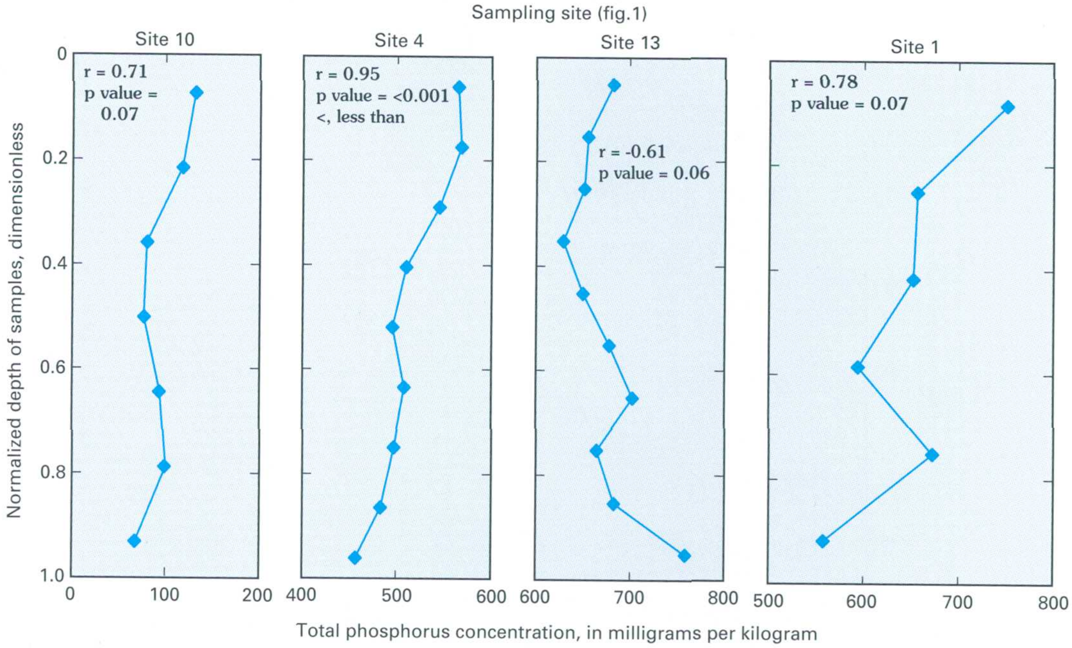


Figure 10. Relation between total phosphorus concentrations in bottom-sediment core samples and normalized depth of samples from selected sampling sites in Cheney Reservoir, August 1997 (sites arranged in downstream order).

resuspension and redeposition from wind and wave action, may complicate the identification of trends. Although not evident from the graphs presented in figure 10, this possibility was examined at sampling sites 4 and 13 using the radioactive isotope cesium-137.

Cesium-137 is one of the long-lived (half-life of 30.2 years) by-products of thermonuclear-weapons testing and is widely dispersed by atmospheric deposition as a result of above-ground testing in the early 1950's. Atmospheric concentrations peaked about 1964. Because of its wide dispersal, subsequent deposition on land, and eventual erosion and fluvial transport sorbed to soil particles (mostly clay), the sedimentation of cesium-137 in reservoirs can serve as a method of age-dating sediment layers (McHenry and Ritchie, 1981; Ritchie and McHenry, 1990; Callender, 1993). A characteristic cesium-137 concentration curve in reservoir sediment is presented in Van Metre and others (1996). Detectable cesium-137 concentrations begin at a time assumed to be 1952 and peak about 1964, followed by a general decline in concentrations.

Cesium-137 concentration curves in bottom sediment from sampling sites 4 and 13 (fig. 11) generally indicate a rather uniform and constant decline in concentrations from largest values of about 1.2 picocuries per gram in the oldest sediment layers (approaching 1.0 normalized depth) to about 0.3 to 0.5 picocurie per gram in the most-recent deposition (approaching zero normalized depth). Because substantial impoundment of water in Cheney Reservoir did not begin until 1965, after the time of peak atmospheric cesium-137 concentration in 1964, only the decline side of the cesium-137 concentration curve is documented in sediment from Cheney Reservoir. The generally consistent decline in concentrations in bottom-sediment samples from sites 4 and 13 indicate that substantial mixing of sediment layers is not a concern in Cheney Reservoir and, therefore, would not obscure time-trend analysis.

The evidence presented in figures 10 and 11 for sampling sites 1, 4, and 10 indicate that, since 1965, concentrations of total phosphorus transported from the Cheney Reservoir watershed have been increasing. The fact that there is a definite trend would indicate that the increasing phosphorus concentrations are not due to natural sources. Natural sources of input would result in fairly constant concentrations over time. Also, the trend probably is not due to point-source discharges because substantial municipal or industrial wastewater discharges are lacking in the watershed. A previous water-quality investigation by Christensen and Pope (1997) of streams in the Cheney Reservoir watershed during low-flow (nonrunoff) conditions identified no

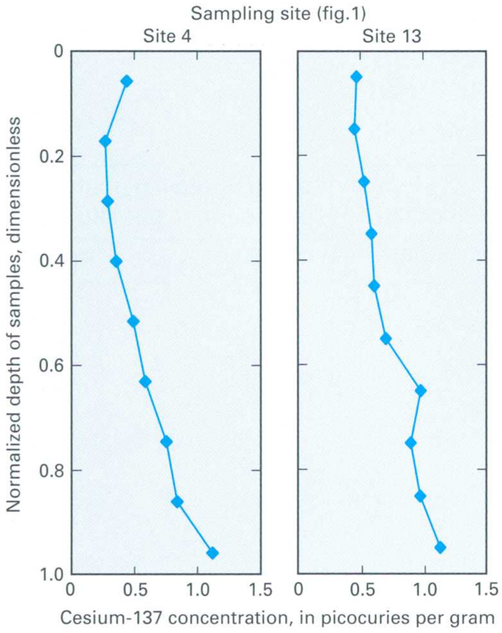


Figure 11. Relation between concentrations of radioactive celsium-137 and normalized depth of bottom-sediment core samples from selected sampling sites in Cheney Reservoir, August 1997.

substantial point sources of total phosphorus in the watershed.

The generally increasing trend of total phosphorus in bottom sediment of Cheney Reservoir probably is of nonpoint-source origin. Because of land-use characteristics of the watershed, this nonpoint-source origin is likely related to agricultural activities such as the application of commercial fertilizers or manure to croplands and the pasturing and confined feeding of livestock (fig. 5). Between 1965 and 1996, the total amount of fertilizer sold in Kansas more than doubled from 834,816 to 1,707,025 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). It is reasonable to assume that this statewide trend in fertilizer sales also occurred in the Cheney Reservoir watershed. Failed domestic septic systems also may be a nonpoint source of phosphorus to Cheney Reservoir although the occurrence and extent of these failed systems would be difficult to document.

Organochlorine Compounds

For most of the 20th century, organochlorine compounds have been manufactured and used extensively in both urban and agricultural environments as insecticides, and industrial chemicals such as polychlorinated biphenyls (PCBs). Most of the organochlorine insecticides, mainly because of their persistence and toxicity, have been exceptionally effective in controlling targeted organisms. However, these two qualities and the fact that these compounds may bioaccumulate in the food chain eventually generated concerns for human health and adverse effects on nontarget organisms. Because of these concerns, many of the organochlorine compounds, beginning in the late 1960's, were deregistered for certain uses or banned from use in the United States.

Organochlorine insecticides commonly are found in streambed and reservoir-bottom sediments in areas where the compounds have been used extensively (Elder and Mattraw, 1984; Smith and others, 1987; Gilliom and Clifton, 1990; Kalkhoff and Van Metre, 1997). These compounds have been used to control insect damage to crops as diverse as corn and pineapple, and tobacco and sugarcane, and to control nuisance insects such as ants, termites, beetles, fleas, flies, lice, mites, and mosquitoes.

PCBs have been used for almost 70 years as industrial chemicals in the manufacture of electrical transformers, cutting and lubricating oils, paints, printing inks, sealants, adhesives, plasticizers, and many other products. Worldwide, more than 1 million metric tons of PCBs have been produced (Schwarzenbach and others, 1993, p. 36). Generally, PCBs are nonreactive and very stable in the environment. They are resistant to chemical oxidation, photodegradation, hydrolysis, and are poorly metabolized by biological systems.

Bottom-sediment core samples were collected at sampling sites 4, 8, and 13 for the analysis of organochlorine insecticides and PCBs, and the cores from sites 8 and 13 were divided into three equal-length segments. Because of its relatively short length (0.87 foot, fig. 6), the core from sampling site 4 was not segmented. Each core segment was homogenized before shipment to the laboratory.

Few organochlorine compounds were detected in bottom-sediment samples from Cheney Reservoir. Only DDT, its degradation products DDD and DDE, and dieldrin had detectable concentrations among the seven samples analyzed for organochlorine compounds (table 3). DDT was detected only in the sample from site 4 at a concentration of 1.0 μg/kg (micrograms per kilogram; equivalent to parts per billion). DDD was detected at a concentration of 0.65 μg/kg in the deepest

Table 3. Statistical summary of concentrations and comparison to sediment-quality guidelines for organochlorine insecticides and polychlorinated biphenyls (PCBs) in seven bottom-sediment samples from Cheney Reservoir sampling sites 4, 8, and 13, August 1997

[TEL, threshold-effects level; PEL, probable-effects level; <, less than; --, no value assigned]

	Concentration (micrograms per kilogram)			Sediment-quality guidelines[1] (micrograms per kilogram)	
Constituents	**Minimum**	**Median**	**Maximum**	**TEL**	**PEL**
Aldrin	<0.20	<0.20	<0.20	--	--
Chlordane	<3.0	<3.0	<3.0	2.26	4.79
P, P'-DDD	<.50	<.50	.65	1.22	7.81
P, P'-DDE	.31	.66	1.3	2.07	374
P, P'-DDT	<.50	<.50	1.0	1.19	4.77
Dieldrin	<.20	<.20	.22	.715	4.30
Endosulfan	<.20	<.20	<.20	--	--
Endrin	<.20	<.20	<.20	--	--
Ethion	<.20	<.20	<.20	--	--
Heptachlor	<.20	<.20	<.20	--	--
Heptachlor epoxide	<.20	<.20	<.20	--	--
Lindane	<.20	<.20	<.20	--	--
Methoxychlor	<2.5	<2.5	<2.5	--	--
Mirex	<.20	<.20	<.20	--	--
Toxaphene	<50.0	<50.0	<50.0	--	--
PCBs, gross	<5.0	<5.0	<5.0	21.6	189

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

sediment-core segment from sampling site 8. The most frequently detected organochlorine insecticide was DDE, which was detected in all seven samples ranging in concentration from 0.31 to 1.3 µg/kg. The smallest DDE concentration was associated with the sediment-core segment containing the most-recent sediment deposition at both sampling sites 8 and 13. Because DDT was used in the watershed before it was banned from use in 1972, a trend in DDT or one of its degradation products might be detectable in reservoir sediment cores. In fact, a decreasing trend in DDE concentrations is evident in data from sampling site 8 (fig. 12). This trend indicates that, although DDT no longer occurs at detectable concentrations in Cheney Reservoir, its toxic and very persistent (between 2 and 15 years half-life) degradation product, DDE, is still transported from the watershed, albeit in small quantities.

Dieldrin was detected in one sample each from sampling sites 8 and 13 at concentrations (0.21 and 0.22 µg/kg, respectively) slightly larger than the detection level (0.20 µg/kg). These small concentrations and the lack of detections in samples containing the most-recent sediment deposition may indicate that dieldrin transport from the Cheney Reservoir watershed has not been or is not currently a substantial water-quality problem.

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

The U.S. Environmental Protection Agency (USEPA) has presented sediment-quality guidelines in the form of level-of-concern concentrations for several organochlorine compounds (U.S. Environmental Protection Agency, 1998). These level-of-concern concentrations were derived from biological-effects correlations made on the basis of paired field and laboratory data to relate incidence of adverse biological effects to dry-weight sediment concentrations. Two such level-of-concern concentrations presented by USEPA are referred to as the threshold-effects level (TEL) and the probable-effects level (PEL). The smaller of the two guidelines (the TEL) is assumed to

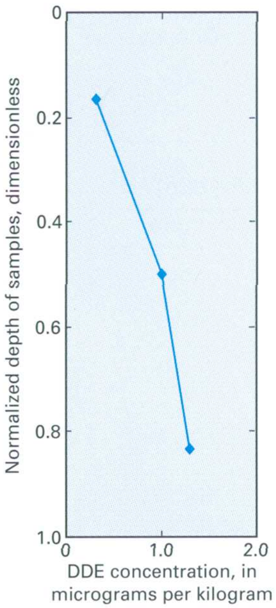


Figure 12. Relation between concentrations of DDE in bottom-sediment core samples and normalized depth of samples from sampling site 8 in Cheney Reservoir, August 1997.

represent the concentration below which toxic effects rarely occur. In the range of concentrations between the TEL and PEL, adverse effects occasionally occur. Toxic effects usually or frequently occur at concentrations above the larger guideline (the PEL).

The USEPA (1998) cautions that the TEL and PEL are guidelines used as screening tools for possible hazardous levels of chemicals and are not intended as regulatory criteria. 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. In fact, 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.

A comparison of the TEL and PEL level-of-concern guidelines to concentrations of several organochlorine compounds (table 3) indicate that all detectable concentrations in Cheney Reservoir bottom sediment were considerably less than guideline concentrations. These comparisons indicate that concentrations of DDT, its degradation products DDD and DDE, and dieldrin in Cheney Reservoir bottom sediment are at levels less than those calculated to produce direct adverse effects on organisms associated with the sediment. However, this does not negate the possibility of bioaccumulation of these compounds in the food chain to a concentration that may produce adverse effects in some higher order predatory organism.

Organophosphate, Chlorophenoxy-Acid, Triazine, and Acetanilide Pesticides

In addition to the organochlorine insecticides previously discussed, other classes of pesticides were analyzed in selected Cheney Reservoir bottom-sediment samples. The seven bottom-sediment samples analyzed for organochlorine compounds (sampling sites 4, 8, and 13) also were analyzed for organophosphate insecticides and chlorophenoxy-acid herbicides. Eighteen bottom-sediment core segments from sampling sites 1 (6 segments), 4 (9 segments), and 13 (3 segments) were analyzed for triazine and acetanilide herbicides.

The organophosphate insecticides have many of the same uses as the organochlorine insecticides and may be used on human food crops such as fruits and vegetables. The organophosphates insecticides are more water soluble and less persistent than the organochlorine insecticides. For instance, the organochlorine compounds DDT, DDD, and DDE are almost insoluble in water and have half-lives of between 2 and 15 years, whereas the organophosphate insecticide diazinon has a water solubility of 40 mg/L (milligrams per liter) and a half-life in soil of a few days (U.S. Environmental Protection Agency, 1989).

The chlorophenoxy-acid, triazine, and acetanilide herbicides have a wide range of uses in both urban and agricultural environments for the control of broadleaf weeds and annual grasses. The chlorophenoxy-acid herbicides are broadleaf weed and brush killers and are or have been used extensively on turf grasses in urbanized areas and on grain crops and rangeland in rural areas. The triazine and acetanilide herbicides represent some of the most extensively applied herbicides in the United States (U.S. Environmental Protection Agency, 1989) for control of annual weeds and grasses in crops such as corn, sorghum, and soybeans. Some of these herbicides are used alone, but many are used in combination with other compounds to increase weed-control effectiveness.

The acetanilide herbicide metolachlor was the only organophosphate, chlorophenoxy-acid, triazine, or acetanilide pesticide detected among the 23 analyzed in samples of Cheney Reservoir bottom sediment from selected sampling sites (table 4). Metolachlor was detected in one bottom-core segment each from sampling sites 1 and 4 and in two bottom-core segments

Table 4. Statistical summary of concentrations of selected organophosphate insecticides and chlorophenoxy-acid, triazine, and acetanilide herbicides in bottom-sediment samples from Cheney Reservoir sampling sites 1, 4, 8, and 13, August 1997

[<, less than]

Constituents	Number of analyses	Concentration (micrograms per kilogram)		
		Minimum	Median	Maximum
Organophosphate insecticides				
Diazinon	7	<0.20	<0.20	<0.20
Malathion	7	<.20	<.20	<.20
Methylparathion	7	<.20	<.20	<.20
Parathion	7	<.20	<.20	<.20
Chlorophenoxy-acid herbicides				
2,4-D	7	<.10	<.10	<.10
2,4-DP	7	<.10	<.10	<.10
2,4,5,-T	7	<.10	<.10	<.10
Silvex	7	<.10	<.10	<.10
Triazine herbicides				
Ametryn	18	<.20	<.20	<.20
Atrazine	18	<.20	<.20	<.20
Cyanazine	18	<.20	<.20	<.20
Cyanazine amide	18	<.20	<.20	<.20
Deethylatrazine	18	<.20	<.20	<.20
Deisopropylatrazine	18	<.20	<.20	<.20
Metribuzin	18	<.20	<.20	<.20
Prometon	18	<.20	<.20	<.20
Prometryn	18	<.20	<.20	<.20
Simazine	18	<.20	<.20	<.20
Terbutryn	18	<.20	<.20	<.20
Acetanilide herbicides				
Acetochlor	18	<.20	<.20	<.20
Alachlor	18	<.20	<.20	<.20
Metolachlor	18	<.20	<.20	1.0
Propachlor	18	<.20	<.20	<.20

from sampling site 13. This represents a detection rate of 22 percent of the samples analyzed. These detections ranged from 0.62 µg/kg in the bottom-core segment from sampling site 4 to 1.0 µg/kg in a segment from sampling site 13. The USEPA has not proposed TEL or PEL guideline concentrations in bottom sediment for metolachlor or any of the organophosphate, chlorophenoxy-acid, triazine, or acetanilide pesticides.

The low incidence of detections of the organophosphate, chlorophenoxy-acid, triazine, and acetanilide pesticides probably is related to their large solubility and rapid degradation relative to the organochlorine compounds even though some of these compounds may have been or currently (1998) are used extensively in the Cheney Reservoir watershed. The results presented in table 4 indicate that these four classes of pesticides, as groups, probably have little long-term, water-quality implications for aquatic organisms in Cheney Reservoir as a result of chemical storage in bottom sediment. However, the short-term implications, as a result of the occurrence of these pesticides in surface water, may be significant and is intended to be examined in subsequent phases of this cooperative assessment of water quality in the Cheney Reservoir watershed.

Major Metals and Trace Elements

Major metals and trace elements form the matrix core of or can be sorbed to sediment particles and ultimately deposited in reservoirs. Resuspension or desorption of these elements may create water-quality problems for humans or aquatic organisms using reservoirs as water-supply sources. Major metals are among the most abundant elements in the Earth's crust and include aluminum, calcium, iron, magnesium, potassium, sodium, and titanium. Trace elements are much rarer and generally occur at concentrations of a few hundred micrograms per gram or less. Many of these trace elements are essential nutrients for plants and animals in small concentrations but in larger concentrations may be toxic. Most of the major metals and trace elements occur naturally in bottom sediment and are a reflection of the chemistry of soil types within a watershed. However, human activities in a watershed may cause sediment enrichment of major metals and trace elements, particularly those activities associated with industrial or commercial areas (Wilber and Hunter, 1979; Hopke and others, 1980; Pope and Bevans, 1987; Pope and Putnam, 1997). Reservoir bottom sediment, therefore, can serve as a watershed integrator or sink for major metals and trace elements, and trend analysis can be used to examine possible effects of changes in land use in a watershed.

The seven bottom-sediment samples collected at sampling sites 4, 8, and 13 and analyzed for organochlorine compounds also were analyzed for major metals and trace elements. A statistical summary of those analytical results is presented in table 5 along with TEL and PEL sediment-quality guidelines for several elements (U.S. Environmental Protection Agency, 1998).

Several of the constituents listed in table 5 have large ranges in concentrations relative to other constituents. These relatively large ranges probably indicate site-to-site variability more than within-site variability. Average concentrations of several trace elements at the three sampling sites show considerable site-to-site variation (fig. 13). Generally, average concentrations increased the farther downstream in the reservoir the sampling sites were located (fig. 1). These differences may be due, in part, to between-site differences in percentage of sand- and silt- and (or) clay-size particles in the bottom sediment (fig. 7) but, more specifically, may be related to the percentage of clay-size particles (though not determined) in the silt- and (or) clay-size fraction. Clay-size particles probably contain larger concentrations of major metals and trace elements either incorporated in the mineral matrix or sorbed to the particles because of the greater surface area provided by the finer particles relative to silt- and sand-size particles. Also, it is likely that the percentage of clay-size particles in bottom sediment increases in the reservoir in a downstream direction, corresponding to deeper areas of the reservoir that are less susceptible to sediment resuspension from wind and wave action. In effect, the deeper areas of the reservoir may serve as a final depository for a large percentage of the load of clay-size sediment entering the reservoir.

Sediment-quality guidelines were exceeded by four of the trace elements listed in table 5. The median and maximum concentrations of arsenic and chromium and all concentrations of nickel in the seven bottom-sediment samples analyzed for major metals and trace elements exceeded the respective TEL, but most were considerably less than the respective PEL. According to USEPA (U.S. Environmental Protection Agency, 1998), this places these values in the range where toxic effects occasionally occur. Additionally, the maximum concentration of copper exceeded the TEL.

The actual environmental significance of concentrations of arsenic, chromium, copper, and nickel that exceed guidelines is not known nor can it be evaluated with the data currently available. Furthermore, the degree of uncertainty inherent in these guidelines may make such an evaluation impractical. To reiterate from a previous section of this report, USEPA has presented these guideline values (the TEL and PEL) as screening tools. They are not intended for regulatory purposes, and the reader is cautioned that for any particular site they may be over- or underprotective. Therefore, to assign toxicological significance to arsenic, chromium, copper, and nickel concentrations on the basis of these guidelines would be inappropriate at the present time.

A certain degree of speculative comment may be appropriate because of knowledge of land use and human activities within the Cheney Reservoir watershed. It is believed that the concentrations of trace elements that exceed guidelines probably are the result of natural-source contributions and do not indicate enrichment from either point- or nonpoint-source contamination. This belief is based on the fact that the watershed has no significant point-source discharges, no large urban areas, no large population, no industry, and no large commercial areas. Therefore, the opportunity for trace-element contamination is greatly reduced relative to a watershed that may have many of these land uses or activities.

Trace-element concentrations in bottom-sediment samples from Cheney Reservoir were evaluated for evidence of time trends. On the basis of data collected during this investigation, there were few, if any, indications of trends in trace elements. This conclusion may be because there simply are no trends or that existing trends are so subtle that data currently (1998) available are insufficient to define them.

Table 5. Statistical summary of concentrations and comparison to sediment-quality guidelines for selected major metals and trace elements in seven bottom-sediment samples from Cheney Reservoir sampling sites 4, 8, and 13, August 1997

[μg/g, micrograms per gram; TEL, threshold-effects level; PEL, probable-effects level; <, less than; --, no value assigned]

Constituent and unit of measurement	Concentration			Sediment-quality guidelines[1]	
	Minimum	Median	Maximum	TEL	PEL
Aluminum, percent	5.2	6.2	8.4	--	--
Antimony, μg/g	.55	.74	.93	--	--
Arsenic, μg/g	5.1	7.5	11	7.24	41.6
Barium, μg/g	520	560	650	--	--
Beryllium, μg/g	1	2	2	--	--
Bismuth, μg/g	<10	<10	<10	--	--
Cadmium, μg/g	.30	.40	.40	.676	4.21
Calcium, percent	2.0	2.8	3.8	--	--
Cerium, μg/g	64	78	94	--	--
Chromium, μg/g	54	62	110	52.3	160
Cobalt, μg/g	9.0	14	18	--	--
Copper, μg/g	10	15	19	18.7	108
Eropium, μg/g	<2.0	<2.0	<2.0	--	--
Gallium, μg/g	11	16	23	--	--
Gold, μg/g	<8.0	<8.0	<8.0	--	--
Holmium, μg/g	<4.0	<4.0	<4.0	--	--
Iron, percent	2.0	2.9	4.5	--	--
Lanthanum, μg/g	32	42	49	--	--
Lead, μg/g	10	16	26	30.2	112
Lithium, μg/g	29	44	67	--	--
Magnesium, percent	.81	1.4	2.1	--	--
Manganese, μg/g	390	570	1,000	--	--
Mercury, μg/g	<.02	.02	.04	.13	.696
Molybdenum, μg/g	<2.0	<2.0	<2.0	--	--
Neodymium, μg/g	30	37	45	--	--
Nickel, μg/g	17	26	38	15.9	42.8
Niobium, μg/g	11	16	17	--	--
Potassium, percent	2.0	2.1	2.6	--	--
Scandium, μg/g	7	10	15	--	--
Selenium, μg/g	.42	.54	.59	--	--
Silver, μg/g	.10	.10	.10	.733	1.77
Sodium, percent	.43	.71	.86	--	--
Strontium, μg/g	120	150	180	--	--
Sulfur, μg/g	.08	.11	.15	--	--
Tantalum, μg/g	<40	<40	<40	--	--
Thorium, μg/g	10.3	13.2	16.1	--	--
Tin, μg/g	<5.0	<5.0	<5.0	--	--
Titanium, percent	.25	.33	.40	--	--
Uranium, μg/g	2.25	2.52	2.6	--	--
Vanadium, μg/g	58	83	120	--	--
Ytterbium, μg/g	2	2	3	--	--
Yttrium, μg/g	19	23	29	--	--
Zinc, μg/g	48	73	110	124	271

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

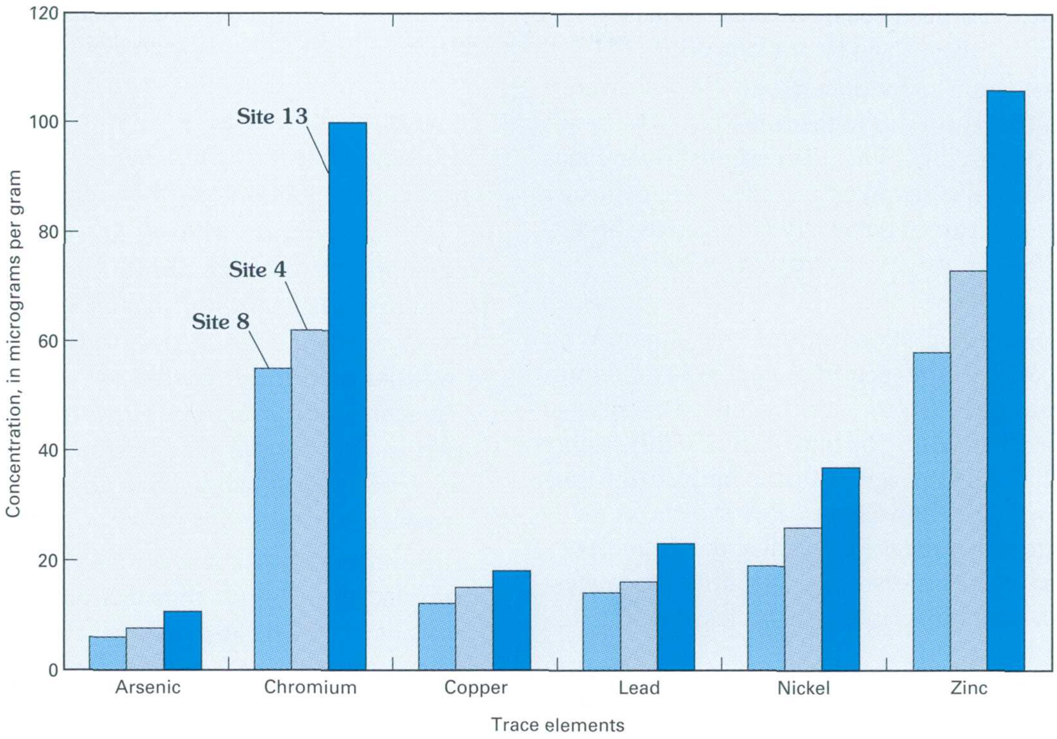


Figure 13. Comparison of average concentrations of selected trace elements in bottom-sediment core samples from sampling sites 4, 8, and 13 in Cheney Reservoir, August 1997 (arranged in downstream order).

Increases in extent of irrigated land in other areas of the United States has produced increases in surface- and shallow ground-water concentrations of trace elements such as arsenic, selenium, and uranium (Hoffman and others, 1990; Mueller and others, 1991; Engberg and Sylvester, 1993). Although the percentage of the Cheney Reservoir watershed in irrigated cropland has increased substantially since construction of the reservoir in 1965 (fig. 4), the percentage has remained about 6 percent since about 1980, which is a relatively small percentage of the watershed. Water-quality effects, if any, from this increased irrigation are not discernible from an analysis of trace-element concentrations in reservoir bottom-sediment samples, at least not with the August 1997 data.

SUMMARY

Land use and human activities can have considerable effects on the water quality in a downstream reservoir. Constituents such as suspended sediment, nutrients (species of nitrogen and phosphorus), pesticides, and major metals and trace elements may have detrimental effects on reservoir water quality through increased sedimentation, accelerated eutrophication, reduced light penetration, potentially harmful effects to human health and aquatic organisms, and a general decrease in recreational value. Of particular concern in south-central Kansas is the long-term quality of water in Cheney Reservoir, which serves as a water-supply source for more than 300,000 people.

In 1996, the U.S. Geological Survey entered into a cooperative study with the city of Wichita, Kansas, with technical assistance provided by the Bureau of Reclamation, U.S. Department of the Interior, to define the water quality in the mostly agricultural, 933-square-mile Cheney Reservoir watershed. An examination of Cheney Reservoir bottom sediment was conducted as part of this study to describe long-term trends and document the occurrence of selected constituent concentrations that may be detrimental to aquatic organisms.

Bottom-sediment cores were collected at 13 sampling sites in Cheney Reservoir in August 1997. These cores were segmented into equal-length intervals, with most segments analyzed for percentage moisture, bulk density, percentage of sand and silt and (or) clay, and total phosphorus. At selected sites, core segments also were analyzed for pesticides, polychlorinated biphenyls, and major metals and trace elements.

Sedimentation and sediment-particle sizes were not uniformly distributed in the reservoir. Most sedimentation occurred in or near the original river channel. Most sand-size sediment particles were deposited in the upstream part of the reservoir, whereas the silt- and (or) clay-size particles were more widely distributed.

Average concentrations of total phosphorus in bottom-sediment cores ranged from 94 to 674 milligrams per kilogram and were statistically related to silt- and (or) clay-size particles. The implication of this relation for watershed management is that to mitigate the transport of phosphorus into Cheney Reservoir it would be necessary to either reduce the annual distribution of phosphorus in the watershed or to control the movement of silt- and (or) clay-size particles from the watershed.

Results from selected sampling sites in Cheney Reservoir indicate an increasing trend in total phosphorus concentrations. This trend is probably of non-point-source origin and may be related to an increase in fertilizer sales in the area, which more than doubled between 1965 and 1996, and to livestock production.

Few organochlorine compounds were detected in bottom-sediment samples from Cheney Reservoir. Only DDT, its degradation products DDD and DDE, and dieldrin had detectable concentrations among seven samples analyzed. DDT and DDD were each detected in one sample at concentrations of 1.0 and 0.65 microgram per kilogram, respectively. By far, the most frequently detected organochlorine insecticide was DDE, which was detected in all seven samples ranging in concentrations from 0.31 to 1.3 micrograms per kilogram. A decreasing trend in DDE concentrations was evident in data from one sampling site. Dieldrin was detected in one sample from each of two sampling sites at concentrations of 0.21 and 0.22 microgram per kilogram. Polychlorinated biphenyls were not detected in any bottom-sediment sample analyzed.

A comparison of several organochlorine compounds to U.S. Environmental Protection Agency sediment-quality screening guidelines indicates that all detectable concentrations in Cheney Reservoir bottom sediment were considerably less than guideline values. This probably indicates that concentrations of DDT, its degradation products DDD and DDE, and dieldrin in Cheney Reservoir bottom sediment are less than those concentrations calculated to produce direct adverse effects on organisms associated with the sediment. However, this does not negate the possibility of bioaccumulation of these insecticides in the food chain to a concentration that may produce adverse effects on some higher order predatory organism.

Beside the organochlorine insecticides, selected organophosphate, chlorophenoxy-acid, triazine, and acetanilide pesticides were analyzed in 18 bottom-sediment samples. Of the 23 pesticides analyzed, only the acetanilide herbicide metolachlor was detected (in 22 percent of the samples). These results indicate that these last four classes of pesticides probably have little long-term, water-quality implications for aquatic organisms in Cheney Reservoir.

Seven bottom-sediment samples were analyzed for major metals and trace elements, and the results were compared to sediment-quality guidelines. The median and maximum concentrations of arsenic and chromium, the maximum concentration of copper, and all concentrations of nickel in the seven samples were in the range where adverse effects to aquatic organisms occasionally occur. However, because of the uncertainty associated with these guidelines, the actual environmental significance of these concentrations is not known. No time trends in trace elements were discernible with the August 1997 data.

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